Zambia, Madagascar, Mozambique,
Cambodia, Laos

Data Collection Survey on the Monitoring for Environmentally Friendly Mining Development

Final Report

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Japan International Cooperation Agency (JICA)

Sumiko Resources Exploration & Development Co., Ltd.
Mitsubishi Materials Techno Co.

Abbreviation

AI	Artificial Intelligence
AIST	National Institute of Advanced Industrial Science and Technology, JAPAN
ALOS	Advanced Land Observing Satellite
ArcGIS	ArcGIS for Desktop Basic (software name)
ASEAN	Association of South-East Asian Nations
ASM	Artisanal Small-scale Mining
ASGM	Artisanal Small-scale Gold Mining
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVNIR	Advanced Visible and Near Infrared Radiometer
CIA	Central Intelligence Agency, USA
CCOP	Coordinating Committee for Geoscience Programmes in East and Southeast ASIA
DB	Database
DEM	Digital Elevation Model
EIA	Environmental Impact Assessment
ESA	European Space Agency
ESIA	Environment and Social Impact Assessment
GDP	Gross Domestic Product
GIS	Geographic Information System
GSJ	Geological Survey of Japan
HISUI	Hyperspectral Imager Suite
JEITA	Japan Electronics and Information Technology Industries Association
JICA	Japan International Cooperation Agency
JMEC	Japan Mining Engineering & Training Center
JOGMEC	Japan Organization for Metals and Energy Security
JORC	Australian Joint Ore Reserves Committee
J/V	Joint Venture
LMI	London Metal Exchange
MEDD	Ministère de l'Environnement et du Développement Durable
MEM	Ministry of Energy and Mines
MGEE	Ministry of Green Economy and Environment
MINETEC	International Institute for Mining Technology, JMEC, JAPAN
MME	Ministry of Mines and Energy
MMMD	Ministry of Mines and Minerals Development
MMRE	Ministry of Mineral Resources and Energy

MMRS	Ministry of Mines and Strategic Resources
MMTEC	Mitsubishi Materials Techno Co.
MNDWI	Modified Normalized Difference Water Index
MoE	Ministry of Environment
MoNRE	Ministry of Natural Resources and Environment
MTA	Ministry of Land and Environment
NDSI	Normalized Difference Soil Index
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PGM	Platinum Group Metals
REE	Rare Earth Element
RGB	Red Green Blue
SEA	Strategic Environmental Assessment
SMM	Sumitomo Metal Mining Co., Ltd.
SRED	Sumiko Resources Exploration & Development Co., Ltd.
SRTM	Shuttle Radar Topography Mission
SWIR	Short Wave Infrared
UN	United Nations
USGS	United States Geological Survey
VIS	Visible
VSW	Vegetation Soil Water
WB	World Bank
WVS CLN	Water-Vegetation-Soil Classification

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1. Study Overview

1.1 Background of the Study

For developing countries possessing useful mineral resources, mineral resources development is a powerful national growth strategy. In general, mining development produces results in a shorter period of time compared to the development of other industries, and has a very large impact on the society and economy of those countries not only developing mines merely, but also contributing to the development of social and life infrastructure, regional development in remote areas, and human resource development for engineers and technicians in various fields. Therefore, while developing countries seek to develop mineral resources for economic development, many developing countries are lacking in funds, technology, government experience and structure for mineral resources development.

In mining development, it is important to understand and monitor the status of mine development based on the granting of development rights. It will contribute to tax collection and securing royalties on the national finance side, and to preventing air pollution, loss of biodiversity, groundwater contamination, health hazards to neighboring residents, etc. due to mining on the environmental preservation side. In developing countries, there are a certain percentage of artisanal small-scale (ASM) mining sites, where ores are mined by hand using simple tools. These small-scale mining sites are often unauthorized (illegal), and as mentioned above, appropriate actions to ASM are required in terms of proper mining claim management and environmental measures. In Japan, as JEITA (Japan Electronics and Information Technology Industries Association) established the Responsible Minerals Trade Working Group in 2012 and there is growing social momentum to achieve responsible minerals sourcing, mine development based on appropriate management and monitoring has been required from this point of view. On the other hand, mining development areas are often remote and spread out over a vast area, and the governments of developing countries, which lack funds, human resources and systems, are unable to manage mining development sufficiently since management and monitor of mines are not easy.

Considering these circumstances, monitoring of mine development status using satellite imagery is expected. In recent years, satellite launch costs have fallen, and satellites, cameras, and radars have become smaller and more sophisticated, it becomes easier to acquire various types of satellite data.

As satellite can grasp the ground surface condition of a wide area at once, the understanding of mine development in remote areas, where it used to be difficult, can be realized accurately and inexpensively by use of satellite data.

1.2 Objectives of the Study

This study aims to understand the mine development status by analyzing satellite images as desk research in Japan, to collect and organize information related to the mining industry in general, and to organize the technical, institutional, and financial issues for the introduction of monitoring method using satellite images. Also, the possibility of cooperation with Japan in the mining sector using the information obtained from the monitoring method will be confirmed.

In order to make future cooperation more strategic, the mining potential and the interest of Japanese companies in the surveyed countries will also be organized.

1.3 Countries to be Studied

Five countries in which the study is conducted are as follows; Republic of Zambia, Republic of Madagascar; Republic of Mozambique, Kingdom of Cambodia, and Lao People's Democratic Republic. These countries location is shown in Figure 1-1.

These countries have high potential of mining and many undeveloped mineral resources. Japanese companies and government have a high interest in the mining sector in each country.

In Japanese governmental organizations, JICA (Japan International Cooperation Agency) has had projects and Kizuna program in the mining sector, and JOGMEC (Japan Organization for Metals and Energy Security) has had mineral exploration projects and GSJ (Geological Survey of Japan) have conducted geological and mineral exploration survey.

1.4 Implementation policy of the Study

Developing countries possessing mineral resource potential often make mineral resource development one of pillars in their growth strategies in their national development plans and policies. This is because the ore mined in the country itself not only becomes a powerful primary product, but also has the potential to develop peripheral industries that will lead to the industrial development in the future. On the other hand, the lack of compliance on mining, environmental, and security laws, as well as the lack of proper mining operations and treatment of ore, waste rock, and wastewater, has resulted in various environmental problems, such as water and air pollution, dust and noise problems, ecosystem impacts, deforestation, heavy metal contamination, land erosion, and collapse of abandoned stone piles, and others. It is also noted that there are many governance problems to achieve sustainable development while ensuring transparency.

The mining sector's share of GDP in the five countries is 4.6% in Laos, 1.4% in Cambodia, 4.5% in Madagascar, 7.8% in Mozambique, and 10% in Zambia. For reference, in Botswana, which has achieved significant growth by mining development, the share is about 25% (88% of foreign currency earnings), and in Namibia it is 10% (51% of foreign currency earnings). (JOGMEC, 2021)

Based on the above background, the implementation policy of this study will contribute to “appropriate monitoring of mining development and operation status” and “sustainable development of the mining sector”. Specific implementation policies are described in a later chapter.

Source: WB(2020)

Figure 1-1 Five countries studied

1.5 Items and Outlines of the Study

(1) Collection, organization and analysis of information

- Collection of mining-related general information (including ASM), particularly information on mining development and operations, and geological and mineral resources information
- Confirmation of mining areas (operating, abandoned) and mining potential areas (resources exploration, resources indication)
- Selection of target areas for satellite image analysis based on mining information and mining potential information

- Collection of information on the development potential and development status of major minerals, development policies and mining policies
- Collection of information on Japan's involvement in the mining sector (investment, development, exploration, etc.)
- Survey of interests and trends of Japanese companies
- Selection of two countries to be visited again for the purpose of confirming the mine development status in more detail
- Collection of more detailed mining operations data on the two countries

(2) Satellite imagery analysis

- Selection of appropriate satellite imagery, and search and acquisition of satellite imagery
- Satellite imagery analysis: Confirmation of time-series changes, extraction of change areas, automatic extraction of mine areas (AI learning)
- Confirmation of mining development status based on satellite image analysis results
- Study of monitoring method of mine development status by satellite image analysis

(3) Country visits

- Visit all five countries: Sharing and explaining the study results to the government of each country, hearing and exchanging opinions, requesting and obtaining information
- Visit two countries selected: Explaining the study results, hearing and exchanging opinions, holding feedback seminar on study results

(4) Comprehensive review and summary

- Confirmation of more detailed mining development status based on satellite image analysis and its results
- Based on the above, organization of analytical procedures, consideration of issues, and organization of countermeasures and improvement measures
- Organization of technical, institutional and financial issues in monitoring methods and consideration of solutions and countermeasures
- Organization of the above collected information and construction of GIS data in the five countries

1.6 Person in charge of the Study

The Joint Venture of Sumiko Resources Exploration & Development Co., Ltd. (Hereinafter, SRED) and Mitsubishi Materials Techno Co., Ltd. (Hereinafter, MMTEC) implements this Study.

The study team is composed of six persons shown in Table 1-1, in which their name and their area of responsibility are shown.

Table 1-1 Person in charge

Area of responsibility	Name	Affiliation
Leader／Satellite image analysis (1)	ONUMA Takumi	SRED
Sub leader／Satellite image analysis (2)	MATSUO Shigeaki	MMTEC
Analysis of mining development and operation status	NEGISHI Yoshimitsu	MMTEC
Analysis of mining potential	ISHIKAWA Hiromasa	SRED
GIS (1)	NAKASATO Yoshio	SRED
GIS (2)	OSAWA Kota	MMTEC

1.7 Schedule of the Study

The study schedule is shown in Table 1-2. Three times of country visits are planned; the first trip to two Asian countries in early to mid-September, then to the three African countries in early to mid-October, and the last trip to two countries in late November to early December.

Table 1-2 Study schedule

Period / Study item	2023							2024	
	6	7	8	9	10	11	12	1	2
Information collection	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	
Acquisition of satellite imagery	- - -	- - -	- - -	- - -	- - -	- - -			
Analysis of satellite imagery	- - -	- - -	- - -	- - -	- - -	- - -	- - -	-	
Analysis of information collected	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	
Country visits (3 times)				▭	▭	▭			
Summary				- - -	- - -	- - -	- - -	- - -	
Report	△		△					△	

1.8 Country visits

In this study, the two phases of country visits are planned. The first phase of country visits is to visit all five countries, firstly two Asian countries of Cambodia and Laos, then secondly three African countries of Zambia, Madagascar and Mozambique. The second phase of country visits is to visit two countries selected from five countries.

1.8.1 The first phase of country visits

(1) Two Asian countries
The study team plans to travel to Laos and Cambodia in that order from the 5th of September to the 15th of September.

(2) Three African countries

The study team plans to travel to Zambia, Madagascar and Mozambique in that order from the 8th of October to the 27th of October.

1.8.2 The second phase of country visits

According to the study results of first phase of country visits, the study team selected three countries from five countries to visit again in the second phase of country visits. The travel date was from the 7th of January to the 18th of January, 2024.

2. Contents of the Study Implementation

2.1 Information gathering

2.2 Basic information

As general basic information in each country, natural environment, social environment, geography, vegetation, infrastructure, environmental reserve area, geology and mining were summarized concisely. These information were obtained from websites of government agencies and information dissemination service sites in each country, the World Bank, Japanese government agencies, and various information provision sites.

2.2.1 Mineral resources

The target commodities for information gathering in the five countries are as follows.

- Zambia: Copper, cobalt, nickel, tin, lead, zinc, PGM (platinum group minerals)
- Madagascar: Nickel, chrome, cobalt, graphite
- Mozambique: Graphite, REE (rare earth elements)
- Cambodia: Gold, silver, bauxite
- Laos: Gold, copper, tin, lead, zinc

Papers, books, published materials, survey reports of mineral exploration, and GIS data on geology and mineral resources related to target commodities in each country, were mainly obtained from the following organizations websites. Then, location of mineral resources (development sites, exploration areas, mineral showings), ore deposit type, related geology and structure were organized.

- USGS (United States Geological Survey): Possessing a wealth of information on global geology and mineral resources
- JOGMEC, GSJ, JICA in Japan: Conducting and possessing geological survey results and information gathering survey in developing countries
- CCOP (Coordinating Committee for Geoscience Programs in East and Southeast ASIA) : Managing geoscience data in Southeast ASIA
- Geological survey in Europe, World Bank: Providing global geology, mineral resources and mining information
- Mining related online websites: Displaying free data related to mining
- Ministries in charge of mining and geology in the five countries: Possessing information related to geology, mineral resources, mineral resources exploration and mining claims and others
- Private and state mining companies in the five countries: Operating mines and possessing mine operation and production status, exploration situation and others

2.2.2 Status of mining and mine development

The following information related to target commodities was collected and organized.

- Production and import/export data related to national mining
- Mining claim, status of mining rights, status of ASM
- Basic information on operating and closed mines (owner, year of operation, location, scale, commodity, production volume, etc.)
- Social and environmental issues related to mining
- World metal prices, supply and demand trends, production statistics, etc. on the target commodities

The following information on mine development status (including ASM) as detailed information was collected as much as possible.

- Owner, mine location, mining method/scale, mineral commodity, mining claim, production volume
- Operation history and status (start of development, start of production, suspension or termination)
- Mine facilities (waste dumps, tailing pits, water storage, thickener, mineral processing plant, smelter, etc.)

The representative organizations of each country for information gathering through country visits are shown in Table 2-1. Using these organizations as contact points, further information from other related organizations will be collected.

Table 2-1 Representative organizations for information gathering through country visits

Country	Organization
Zambia	Ministry of Mines and Minerals Development (MMMD) Geological Survey Department, MMMD
Madagascar	Ministry of Mines and Strategic Resources
Mozambique	Ministry of Mineral Resources and Energy (MIREME)
Cambodia	Ministry of Mines and Energy, General Department of Mineral Resources
Laos	Ministry of Natural Resources and Environment, Department of Geology and Mineral Resources Ministry of Energy and Mines, Department of Mines

2.2.3 Policy and legal system related to mining

National policy, development plans and related laws and legislation related to mining were concisely summarized and the following information were collected and organized.

- Mining budget, mining sector management system, mine safety
- Procedures related to exploration and mine development, mining claim management
- Economic growth, mining sector growth, industrial/economic structure, treatment of foreign capital

2.2.4 Policy and legal system related to environment

National policy, development plans and related laws and legislation related to environment were concisely summarized and the following information were collected and organized.

- Environmental reserves, nature reserves, national parks (including Figures)
- Characteristics of ecosystems, natural conditions, natural disasters, climate change
- Environment-related issues, social issues, infrastructure status and problems

2.2.5 Achievements of research, development and investment by Japan side

Achievements of surveys and development and investment related to mining by Japanese government agencies and companies were summarized referring to websites of JICA, JOGMEC, GSJ, JETRO and others.

2.3 Settlement of satellite image analysis area and mining area

2.3.1 Settlement of satellite image analysis area

Based on information of geology, mineral resources and mining development in each country, the target areas for satellite image analysis were selected in the following instructions. The area of the target area is about 40,000 square kilometers (equivalent to 200km x 200km).

Since the status of mining development and mine operations are analyzed using satellite imagery, the target area for satellite imagery analysis should include many operating or developing mines and should be an area with high potential of geological mineral resources. In addition, the area is desirable to have diverse geological units, mineral resources of important and strategic mineral types for the target country, and a high diversity of topography, vegetation, and land use.

Information on geology, mineral resources, and mining that is necessary for selecting appropriate target areas as described above were mainly obtained from the websites of USGS, CCOP, JOGMEC, the World Bank, government agencies and companies of mining sector in each country. As location of mines, ore deposits and mineral showings related to the target commodities in each country were plotted on GIS, the satellite image analysis areas were selected by prioritizing areas with geologically high potential for mineral resources. The satellite image analysis areas in each country are shown in Figure 2-1.

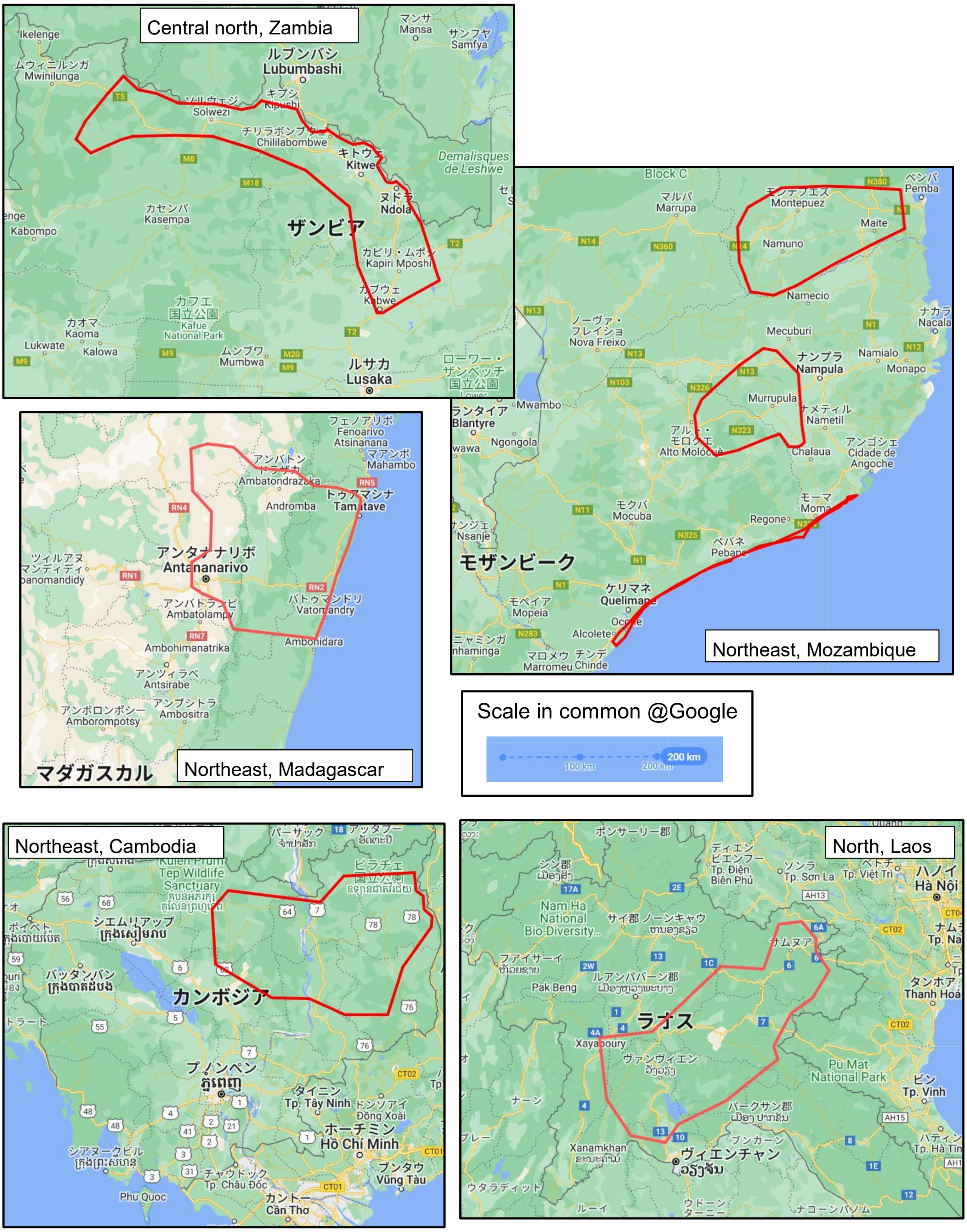


Figure 2-1 Satellite image analysis areas in five countries

Main mines and mineral resources existing in the satellite image analysis area of each country and nature characteristics are shown in Table 2-2.

Table 2-2 Mineral resources and nature environment in satellite image analysis area

Country/Area	Main mines, mineral resources, geology	Nature environmental characteristics
Zambia Central north	・Called as copper-belt, Cu-Co mines such as Lumwana, Konkola, Lubambe, Chambishi, and Kawako Ni mine and Sable Pb mine ・ASM (gem stone) ・Mostly metamorphosed sedimentary rocks of Eocene, partly granite age	・Highland, forest and farmland, wetland, provincial city ・Elevation: 1,100~1,550m ・Gentle terrain overall
Mozambique Northeast	・Balama graphite mine, pegmatite Li mine ・ASM (gold, gem stone) ・Proterozoic gneiss, migmatite, hornblendite	・High plateau, farmland and partly forest, linear undulating land ・Elevation: 150~700m ・Gentle terrain overall
Madagascar Northeast	・Ambatovy Ni-Co mine, Graphmada graphitemine, Andriamena Cr mine ・ASM (gem stone) ・Proterozoic gneiss, migmatite, gabbro	・Forest and farmland ・From the Indian Ocean coast in East to the inland plateau in West. Eastern half is slope. ・Elevation: 0~1,700m
Cambodia Northeast	・Okvau Au mine, Cu, Au, Mo deposits ・ASM (gold) ・Cenozoic basalt, Paleozoic sedimentary rocks and volcanic sedimentary rocks, Proterozoic metamorphic rocks	・Mekong river basin plains and mountainous area, ・Farmland and forest ・Elevation: 20~800m ・Gentle terrain in plains
Laos North	・Phu Kham and Ban Houayxai Cu-Au mine, Phu Ngeune Pb mine, Phu Loi Au mine ・ASM (gold) ・Paleozoic to Mesozoic sedimentary rocks, granitoids	・Mountainous forest area, partly farmland, large dum lake ・Elevation: 170~2,800m ・Rich in mountains and valleys

2.3.2 Selection of mining area

There are several mines in the satellite image analysis area of approximately 40,000 square kilometers, but each mine development area is only a few tens to a few hundred square kilometers. Since the satellite images that are practically necessary for monitoring mining development is the extent of each mine's development, the mining areas for actual satellite image analysis were selected with the confirmation of the extent of mine development by satellite images (basically Google Earth image). In setting this mining area, the extent of potential environmental impacts, including mine-related facilities, mining sites, tailings deposition sites, and connecting roads was considered with topographical feature. Therefore, the area and shape of the mining area varies depending on the size and topography of the mine.

Mining areas in each country are shown in the Chapter of each country's study results. The example of Madagascar is shown in Figure 2-2.

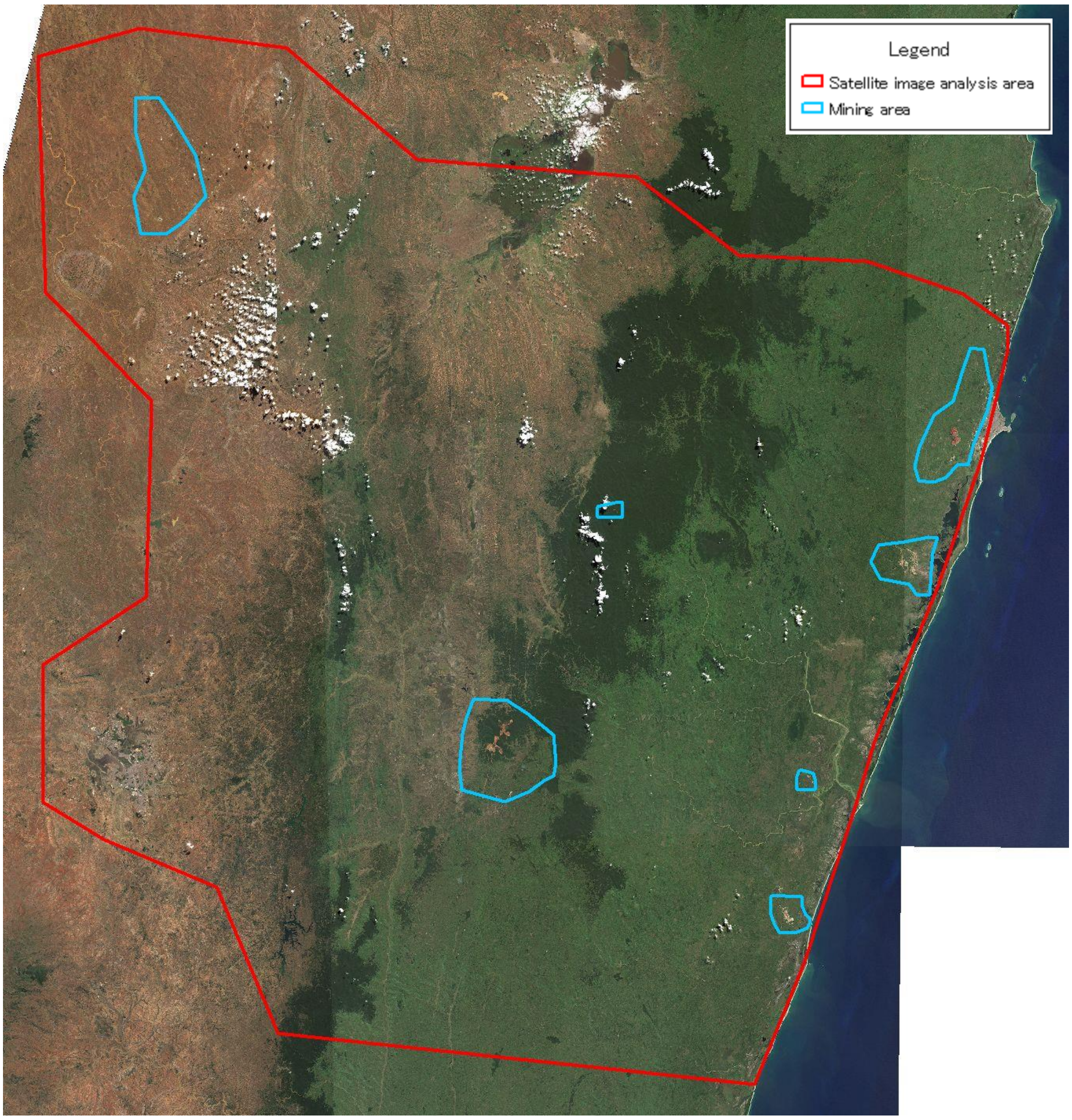


Figure 2-2 Mining areas in Madagascar

2.4 Analysis of mining development status

Mining-related information related to the target commodities presented in Section 2.1 was collected, and based on this information the status of mining development was analyzed and organized. In particular, as far as possible, the following detailed information was collected and organized for the mines subject to analysis of mine development status using satellite images.

- Basic information of mines: Owner, mine location, commodity, statistical data of production, mining claim, mining rights
- Operation history and status: Start of development, start of production, suspension or termination
- Mine facilities: Waste dumps, tailing pits, water storage, thickener, mineral processing plant, smelter
- Detail information of mine operation: Mining method, beneficiation and smelting methods, tailings and waste rock treatment methods
- Data of production status: Production volume, tailings volume, waste rock volume, assumed mine life
- Information of environment: Environmental monitoring method and its measurement data, past disasters, etc.
- Ore grade and ore reserves: "Exploration Results, Mineral Resources, Ore Reserves" based on the JORC code

2.5 Satellite data analysis

Satellite image parameters, image analysis methods, and examples of image analysis results in satellite image analysis is described in this section. Analysis results of each country are described in detail in Chapter 3 and thereafter.

2.5.1 Kind of satellite data

The policy for selecting satellite images suitable for monitoring is as follows.

- Assuming continuous monitoring by satellite images in the future, the satellite images used in this study should be available free of charge via websites.
- In order to analyze and interpret mining development status and mine operation by satellite images, the ground resolution shall be higher.
- Since the mine development monitoring is implemented by image analysis and interpretation, multiband satellite images of optical sensor with different wavelength regions (bands) are used.
- The image acquisition in the future is expected to be continued.
- Satellite imagery acquisition intervals are short and the archive data is abundant.

The satellite images of optical sensors that fit the objectives of this study are Sentinel-2, ASTER and Landsat-7/8. The most suitable satellite is Sentinel-2. Although Sentinel-2 has only images after 2015, Sentinel-2 satellite data was decided to be used for monitoring analysis because it provides images of sufficient period to understand the mining development status and to study monitoring methods. If images before 2015 are necessary in case, ASTER or Landsat-4/5/7 images were used.

2.5.2 Acquisition of satellite data

(1) Sentinel-2

Sentinel-2 image data were searched and downloaded from the following ESA website (Copernicus Open Access Hub). User registration in the site is necessary to obtain the image data.

https://scihub.copernicus.eu/dhus/#/home

Instructions on how to use this site is found in the website below.

https://scihub.copernicus.eu/userguide/WebHome

This site provides a large number of Sentinel-2 images with different time periods, and it is relatively easy to identify and obtain image data with low cloud cover. The five countries have distinct seasonal changes, a rainy and dry season. Therefore, in order to accurately capture changes over time while eliminating the effects of vegetation changes as much as possible, images during the same season (late dry season) were collected as much as possible. However, if it is not possible to obtain high-quality images due to the influence of cloud cover, the season does not matter.

(2) ASTER, Landsat

ASTER and Landsat-4/5/7 image data were searched and downloaded from the following USGS website (Earth Explorer). User registration in the site is necessary to obtain the image data.

https://earthexplorer.usgs.gov/

2.5.3 Specification of Sentinel-2 satellite data

ESA's Sentinel-2 mission is operated by two satellites of the same specifications, Sentinel-2A and Sentinel-2B. Since the revisit time of both satellites is 10 days, the two-satellite conFiguration means that observations of the same location are conducted practically every 5 days. Sentinel-2A was launched on 23rd June 2015, and Sentinel-2B on 7th March 2017. In this study, the two satellites are referred to simply as Sentinel-2 unless it is specifically necessary to distinguish between them.
Sentinel-2 has 13 bands with different ground resolutions in the visible to near-infrared to short-wave infrared wavelength regions, and the relationship between Sentinel-2 bands, wavelength bands, and ground resolutions is shown in Table 2-3. The product type of Sentinel-2 is Level 1C from 2015 to 2019

and Level 2A from 2020 to the present, both of which are geometrically corrected reflectance data.
The Sentinel-2 data set, obtained from the ESA website, consists of data files of 13 bands in JPEG2000 format and related files. The observation width of Sentinel-2 is 290 km. Each data set consists of a tile grid, with each tile being a square tile with 100 km on a side. The data range of each tile overlaps with adjacent tiles in four directions (east, west, south, and north) by a width of approximately 5 km. The data volume of a single data set varies by year and location, but ranges from 500 to 1,000 MB. The data volume for each band is approximately 30 to 150 MB.
As shown in Table 2-3, since the ground resolution varies from band to band, band 11 and band 12 with a resolution of 20 m was resampled to 10 m resolution for analysis.

Table 2-3 Bands specification of Sentinel-2

Band No.	Sentinel-2A		Sentinel-2B		Resolution	Observation	Wavelength (wl.)
	Central wl.	Width	Central wl.	Width			
Band 1	442.7 nm	21 nm	442.2 nm	21 nm	60 m	Aerosol	Ultra blue
Band 2	492.4 nm	66 nm	492.1 nm	66 nm	10 m		Blue
Band 3	559.8 nm	36 nm	559.0 nm	36 nm	10 m	Land information	Green
Band 4	664.6 nm	31 nm	664.9 nm	31 nm	10 m		Red
Band 5	704.1 nm	15 nm	703.8 nm	16 nm	20 m		VNIR
Band 6	740.5 nm	15 nm	739.1 nm	15 nm	20 m		VNIR
Band 7	782.8 nm	20 nm	779.7 nm	20 nm	20 m		VNIR
Band 8	832.8 nm	106 nm	832.9 nm	106 nm	10 m	Land info. / Vapor correction	VNIR
Band 8A	864.7 nm	21 nm	864.0 nm	22 nm	20 m		VNIR
Band 9	945.1 nm	20 nm	943.2 nm	21 nm	60 m	Water vapor	SWIR
Band 10	1373.5 nm	31 nm	1376.9 nm	30 nm	60 m	Cirrus	SWIR
Band 11	1613.7 nm	91 nm	1610.4 nm	94 nm	20 m	Land info. / Aerosol	SWIR
Band 12	2202.4 nm	175 nm	2185.7 nm	185 nm	20 m		SWIR

2.5.4 Analysis method of Sentinel-2 satellite data

(1) Data preprocessing
The six bands of Sentinel-2 used in this study were Band 2, Band 3, Band 4, Band 8, Band 11, and Band 12. Of these, Band 11 and Band 12 have a ground resolution of 20 m, then these two bands data were resampled to 10 m to match the ground resolution of the other four bands.
In case a single mining area spanned multiple tiles (located on tile boundaries), mosaic processing (integration of tiled data) was performed as needed.
Each band data was clipped according to the mining area (see Figure 2-2). If color images described below were created without clipping, the data volume of a single image file becomes several hundred MB. When multi-year and multi-type files in multiple mining areas are loaded into GIS software, the operation of the

software becomes slow and the workability becomes very poor. Therefore, by clipping data by each mining area, the size of each file is reduced and the work in the GIS software becomes more efficient.

(2) Color image creation (basic analysis)

The following four basic types of images were created using software dedicated to satellite image analysis in order to understand the status of mining development. In color composite images of satellite imagery, the notation RGB usually refers to a color image created by assigning three different band images to Red, Green, and Blue respectively.

(I) True color image (TCI)

RGB = Band4, Band3, Band2

This band assignment results in an image as seen by human eyes.

(II) False color composite image (FCC)

RGB = Band12, Band4, Band2

As clay minerals are shown in magenta color, etc., this image is effective to identify lithology, etc.

(III) Band ratio composite image (BRC)

RGB = Band11/Band12, Band12/Band4, Band4/Band2

This image is useful to distinguish between vegetation, water bodies, soils, etc.

(IV) Normalized Difference Vegetation Index image (NDVI)

Gray scale image (value is 0 to 1)

Calculation formula: (Band4-Band3)/ (Band4+Band3)

This represents the activity level of vegetation and can distinguish between vegetated and non-vegetated areas. The value of non-vegetated areas is near zero with black color.

[Example of basic analysis]

Figure 2-3 shows the above four types of images analyzed for Sentinel-2 data (taken on 20th May 2023). The image area is the development area of the Ambatovy laterite nickel mine located in northeastern Madagascar. The length of the white line in the lower right in the upper left true color image corresponds to 2 km.

In the true color image, the forested areas are dark green and the mine operation areas are brownish and they can be clearly distinguished. In the normalized difference vegetation index image, the mine operation areas and roads are non-vegetated areas and are clearly distinguishable with black color. In the false color composite image, there is a wide variety of color tones within the mine operation area, ranging from brown to yellow to blue to green to magenta. This suggests that the rocks and soils on the surface are composed of different minerals. In the band ratio composite image, as in the other images, the mining operation areas can be clearly distinguished from the vegetated areas, and the water areas (here mainly water storage ponds) are identified by dark color.

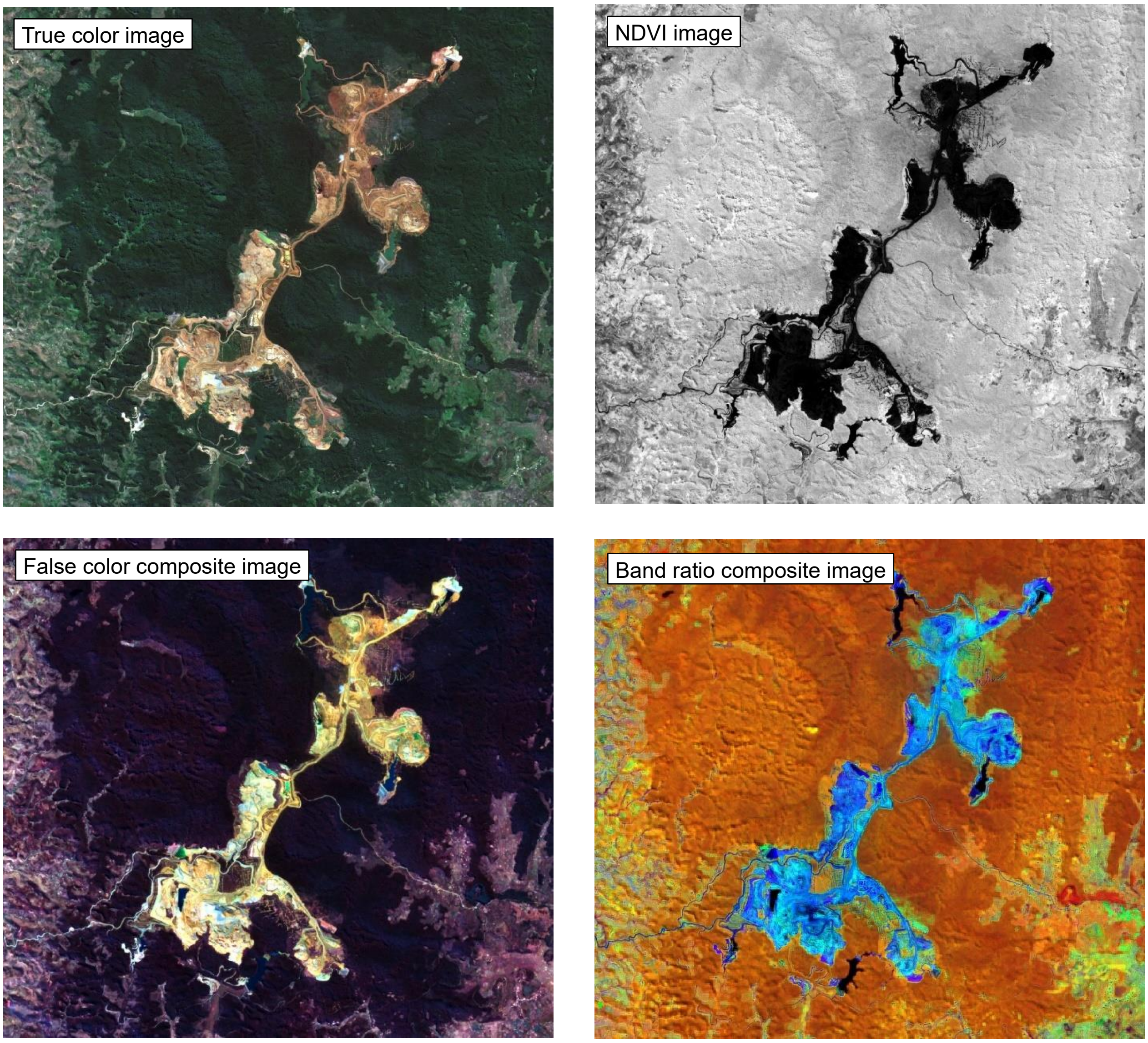


Figure 2-3 Examples of images created in basic analysis for Sentinel-2 images

(3) Advanced analysis

In addition to the four types of image analysis described above, the following advanced analyses were performed as necessary for mines that are unique in terms of geology, ore deposits, topography, and distribution.

- Multivariate statistical analysis: Classification of surface materials (vegetation, soil, artifacts, etc.), land use classification
- Change areas extraction by comparing time-series images (see Figure 2-4)
- Automatic extraction of mining areas (AI machine learning or deep learning)
- Elevation data analysis: Results can be used as environmental data to understand topography, water systems, and other geographical features and watershed classifications

[Example of advanced analysis]

Figure 2-4 shows two images with different years of observation and an image representing the change area of both images. The upper left image is a false color image of ASTER data taken on 5th September 2013, the upper right image is a false color image of ASTER data taken on 27th November 2020, and the lower center image represents the change area of both ASTER images. The image area is almost the same as Figure 2-3, the development area of Ambatovy laterite nickel mine. The ASTER images in the upper row is false color images with RGB=Band3, Band2, Band1, and the vegetation areas present red color. The image of the change area is a grayscale image, with areas of greater change exhibiting white color, and areas of less change exhibiting dark color.

The two false color images show that the mine operation site is located in the center of the image It is confirmed that the lower left side of the image was developed before 2013 and the development area has extended to the upper right side of the image in 2020. The change areas extracted in both images are shown as white color in the grayscale image. It should be noted here that the clouds and their shadows are present in about five sites in the 2020 image, and these sites were extracted as change areas. In addition to this, sites of deforestation and farmland development were also extracted as change areas. When analyzing image changes during the two periods, it should be noted that many areas of change are extracted outside of the mining area.

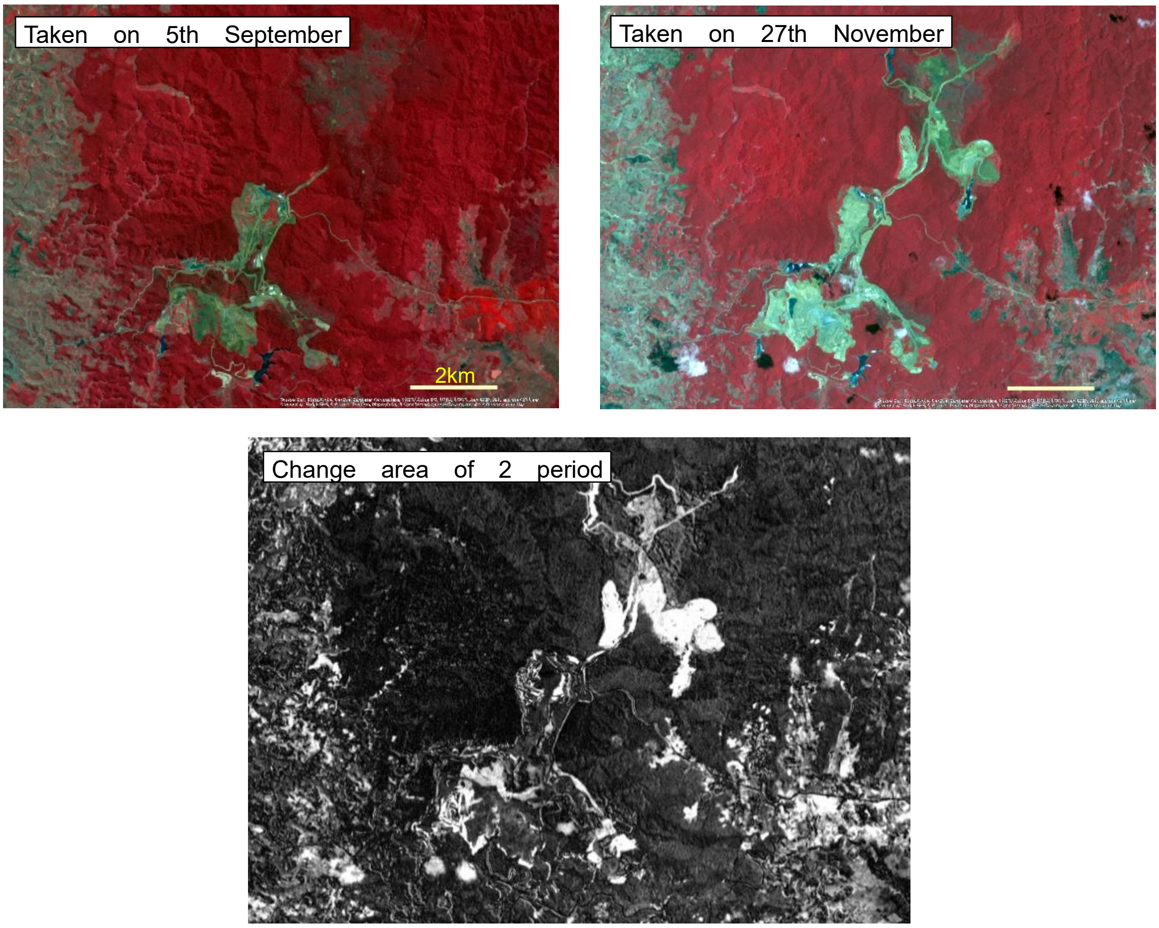


Figure 2-4 Examples of images created in advanced analysis for Sentinel-2 images

2.5.5 Interpretation of analysis imagery of Sentinel-2 satellite data

From the four types of analyzed images mentioned above, the mine operation sites were extracted by visually interpreting the true color image (I) on the GIS software. Images (II) to (IV) and Google Earth images were used as references for interpretation, as necessary.

Specific tasks in the GIS software are to trace manually the boundaries of mine operation sites for creating polygons and also to trace the roads associated with mine operations for creating polylines (continuous line segments).

[Example of image interpretation]

Figure 2-5 shows the results of interpreting a true-color image in 2023 (same as Figure 2-3). In the interpretation map of Figure 2-5, the background image is the true color image and the areas surrounded by red lines are the mine operation sites, and black lines are roads.

The right image in Figure 2-5 is an enlarged image of the yellow-bordered area in the left image, showing some of the interpretable mining facilities, etc. (see section 2.4.6).

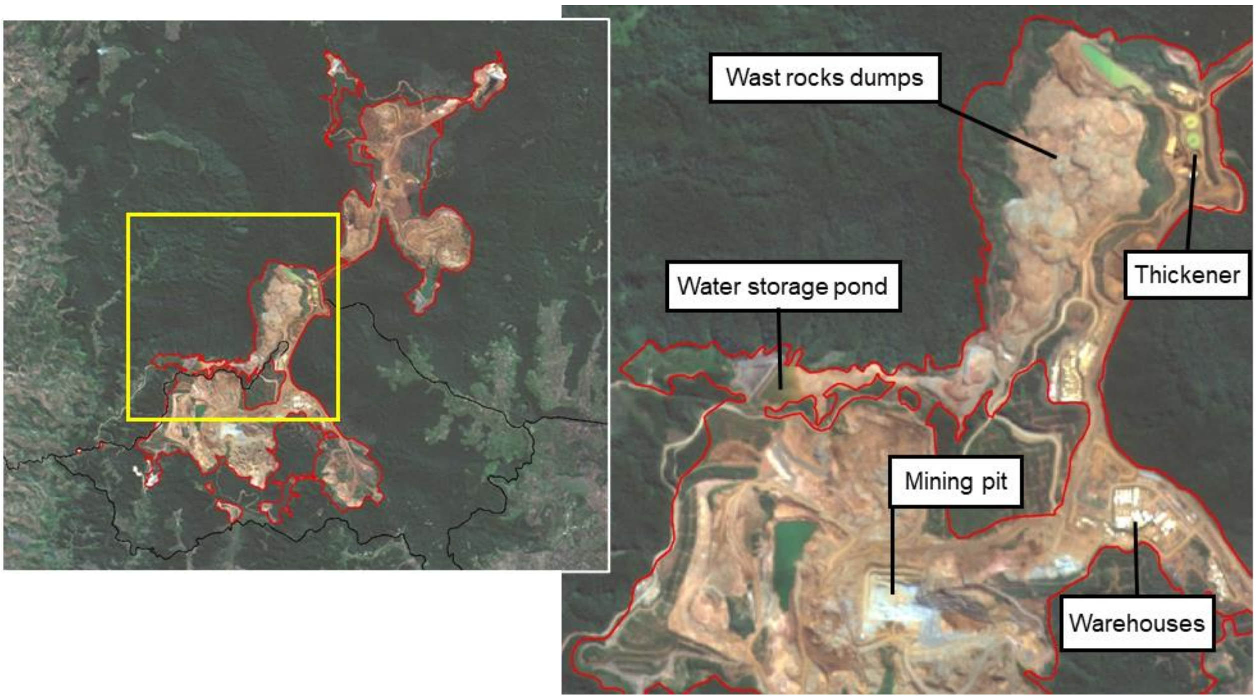
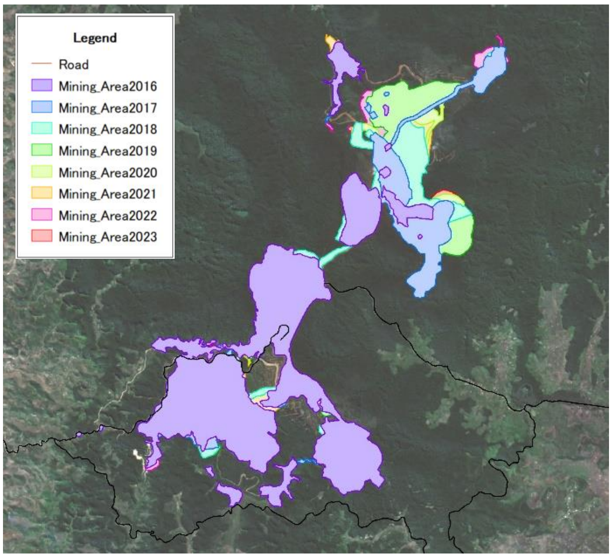


Figure 2-5 Example of mine operation sites interpreted by Sentinel-2 analyzed images

Sentinel-2 images of each year from 2015 to 2023 were interpreted in the same manner to create polygon and polyline data in each year image. Figure 2-6 shows the polygons of each year as a different color of different layer. In which, the polygon of the most recent year, 2023, is set in the bottom of layers, and the polygon of the older year in upper layer in sequence. However, in this mining area, all Sentinel-2 images of 2015 are widely covered with clouds, and no analytical images and interpretation map for images of 2015 were produced. By creating a time-series change diagram in mine operation sites (overlaid by year),

as shown in Figure 2-6, it is possible to determine where the mine was developed from, and in which direction and to what extent the development area has progressed.
The left Figure in Figure 2-6 shows polygons filled with color, while the right Figure shows only colored borders without filling.



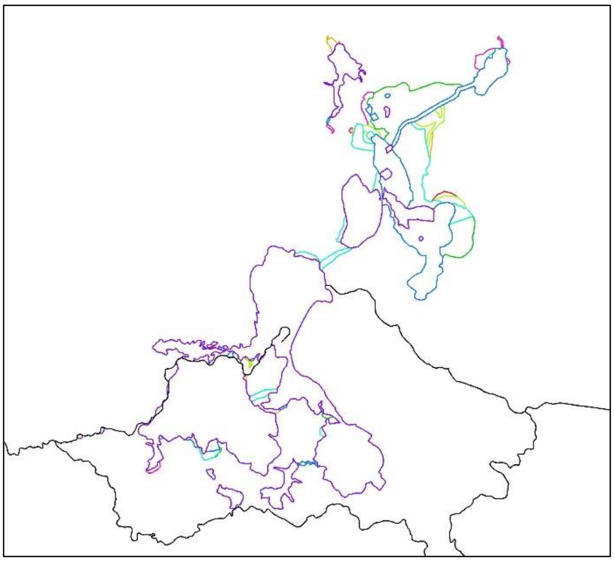


Figure 2-6 Example of time-series change diagram interpreted by Sentinel-2 analyzed images

2.5.6 Mine operation information grasped from Sentinel-2 satellite data analysis

The information on the ground surface that can be obtained from satellite images depends on the ground resolution of the image. In general, one meter ground resolution can detect the presence of a car, three meters ground resolution can detect the presence of a large airplane, and ten meters ground resolution can detect the presence of a building or other large structure.
As the ground resolution of the true color image of Sentinel-2 satellite data is 10 m, it allows a rough understanding of the following information distributed on a certain scale. However, the accuracy of determination will vary depending on the scale of the mine, mining method, ore type, geology, topography, vegetation, and other details.

- Mining facilities: large buildings, thickeners, ore dressing plants, smelters
- Surface mining sites: open pits (mortar-shaped areas mined deep underground), relatively flat areas mined shallow underground
- Ore management sites: ore storage sites, waste rock deposition sites, tailings deposition sites (sedimentation dams), and water reservoirs
- Roads: roads from public roads to mines, and roads connecting mine facilities and mining sites

On the other hand, it is sometimes difficult to distinguish between the following categories

- Plane mining sites / storage areas / waste rock deposition sites / bare ground
- Roads within the mining area / mining area / bare ground

- Reservoirs with shallow water or much algae blooms / soils / sparsely vegetated areas
- Pits submerged due to mining suspension / reservoirs

2.5.7 Monitoring method of mining development by satellite data analysis

The procedures and methods for analyzing satellite data to monitor the status of mining development are described below.

(1) Types of satellite data and its acquisition
Sentinel-2 data should be used for monitoring because Sentinel-2 currently has the highest ground resolution of 10 m among the satellite images available at free, and archived data has been available since 2015, and future observation are expected to continue.
Sentinel-2 data is obtained by searching and downloading from the ESA website.
In order to assess the applicability of monitoring of mining development by understanding basic time-series changes, one data set for each year from 2015 to 2023 were obtained and analyzed in this study. If the data is to be used for future monitoring, it is necessary to retrieve and analyze the data at any time (about once a month) to understand time-series changes.

(2) Analysis of satellite data
Following four basic types of images are created (see Figure 2-3).
(I) True color image (TCI)
RGB = Band4, Band3, Band2
(II) False color composite image (FCC)
RGB = Band12, Band4, Band2
(III) Band ratio composite image (BRC)
RGB = Band11/Band12, Band12/Band4, Band4/Band2
(IV) Normalized Difference Vegetation Index image (NDVI)
Calculation formula: (Band4-Band3) / (Band4+Band3)

(3) Interpretation of satellite images
Basically, the interpretation map for mine operation sites is created by visually interpreting the true color image (I). Images (II) to (IV) and Google Earth images are used as references for interpretation, as necessary.

(4) Monitoring
By superimposing the time-series interpretation map on the GIS software (see Figure 2-6), time-series changes in the mine operation sites can be determined and monitored. The contents of the changes will be determined from the true-color images.

2.5.8 Issues

(1) Quality of satellite data
At this time, there are very few images that are not suitable for analysis due to widespread cloud cover over the targeting mining areas. This is nothing other than selecting data during the dry season when there are few clouds in each year. Assuming future monitoring in practice, since all five target countries have rainy and dry seasons, it is expected that data for a certain period of time especially during the rainy season cannot be used for monitoring because of higher cloud coverage in the images. This is the greatest weakness of satellite imagery of optical sensors.

(2) Hardware and software necessary for monitoring
An Internet connection is required to search and download satellite data. The latest Sentinel-2 data set is approximately 1 GB in size. It takes about 5 minutes to download depending on the connection speed. Since the Internet connection in the target countries institutions is often WiFi connection, more time is expected, and there may be some instability in the connection that interrupts the downloading process. It is necessary to work with the assumption that it will take some time to obtain satellite data by download.
As for software required for satellite data analysis, ESRI's ArcGIS or the open source software QGIS can be used for (I) through (IV) images abovementioned. By using these GIS software, it is not difficult to display, and interpret Sentinel-2 analysis images, and draw shapefiles.

2.6 Analysis of mining potential

2.6.1 Analysis of mineral resources potential

Based on the collected information (geology, geological structure, deposit type, mineralization, mineral indications, alteration, reserves, ore grade, chemical analysis results, etc.), mineral resources potential for each target commodity was analyzed. Furthermore, the following information was collected to analyze issues in the mining sector, and finally analyze the mining potential for each target commodity.

- Global market and supply/demand trends for major minerals, metal price trends
- Mining policy and related laws, mining budget, mining sector management system, mine safety
- Environmental policies and related laws, environmental reserves, nature reserves, characteristics of ecosystems, environment-related issues
- Development/growth plans, economic growth, mining sector growth, industrial/economic structure, treatment of foreign capital
- Social issues, infrastructure status and problems, natural conditions, natural disasters, climate change

2.6.2 Analysis of mining potential

In the analysis of mining potential, in addition to the information presented in Section 2.5.1, the following information was collected, organized, and analyzed by commodity, which may lead to investment by Japanese companies and other foreign capitals.

- Locations of mineral resources (development sites, exploration areas, mineral showings), deposit types, associated geology and geological structures
- “Exploration Results, Mineral Resources, Ore Reserves” based on the JORC code, ore grade
- Global metal price trends (fluctuations, future outlook), supply and demand trends, market size

2.7 Interests and trends of Japanese companies

Hearing to Japanese mining companies, trading companies, and mineral resource-related organizations will be conducted, for exploration, acquisition of mining concessions, mine development and investment in the five countries, such as their interests, their interesting commodity, their past activities and their future activity plans and possibility. , what kind of information they would like to be provided and whether they are interested in other than the target mineral commodities. In addition, hearing to satellite imaging service companies and drone development and operation companies will also be conducted regarding their interests in providing mine management and operation services.
The following companies are currently engaged in mining-related activities in the five target countries.

- Madagascar: Sumitomo Corporation (Operation of Ambatovy laterite nickel mine)
- Cambodia: Nittetsu Mining Co., Ltd. (exploration, application for exploration rights), JOGMEC (mineral resources exploration)
- Zambia: JOGMEC (joint exploration with a Canadian company)

2.8 GIS data creation

The analyzed images and interpretation maps of satellite data obtained in this survey, as well as the mineral resources maps collected and compiled, were compiled into a GIS database by country. The GIS software used was ESRI's ArcGIS, and the GIS database consists of the following items.

- Satellite image data: Geotiff files
- Satellite image analysis areas, mining areas: ESRI Shapefiles
- Mine operation sites: Zambia: ESRI Shapefiles
- Mineral resources maps, geological maps, other maps: ESRI Shapefiles, Geotiff files
- Map display application file: ArcMap files (extension is mxd)

2.9 Study by country visits

In this study, the first and second rounds of field surveys were conducted. The first field survey targeting five countries consisted of two trips: one trip to two Asian countries (Laos and Cambodia) and another trip to three African countries (Zambia, Madagascar, and Mozambique). Based on the results of the first field survey and satellite image analysis of each country, three countries (Laos, Cambodia, and Mozambique) were selected from the five countries and the second field survey was conducted.
The schedule of the three field surveys is shown in Table 2-4 to Table 2-6.

Table 2-4 Schedule of the first round of the first field survey

Date	Organization visited
Sep. 5	Move from Japan to Laos
Sep. 6	JICA Laos office Department of Mining Management, Ministry of Energy and Mines Department of Geology and Mineral, Ministry of Energy and Mines
Sep. 7	Department of Mining Management, Ministry of Energy and Mines Residence of the Japanese Ambassador in Laos
Sep. 8	Department of Planning and Finance, Ministry of Natural Resources and Environment JICA Laos office
Sep. 9-10	Move from Laos to Cambodia
Sep. 11	JICA Cambodia office General Department of Mineral Resources, Ministry of Mines and Energy Department of Mineral Operational Inspection, Ministry of Mines and Energy Department of Mineral Geology, Ministry of Mines and Energy Department of Industrial Mining, Ministry of Mines and Energy
Sep. 12	General Directorate of Environmental Protection, Ministry of Environment
Sep. 13	General Department of Mineral Resources, Ministry of Mines and Energy JICA Cambodia office
Sep. 14-15	Move from Cambodia to Japan

Table 2-5 Schedule of the second round of the first field survey

Date	Organization visited
Oct. 8-10	Move from Japan to Zambia
Oct. 11	Geological Survey Department, Ministry of Mines and Minerals Development Mining Cadastre Department, Ministry of Mines and Minerals Development Mines Development Department, Ministry of Mines and Minerals Development
Oct. 12	Zambia Environment Management Agency, Ministry of Green Economy and Environment
Oct. 13	JICA Zambia office
Oct. 14-15	Move from Zambia to Madagascar
Oct. 16	Direction Generale des Mines, Ministry of Mines and Strategic Resources JICA Madagascar office
Oct. 17	General Direction of Environmental Governance, Ministère de l'Environnement et du Développement Durable Conservation International
Oct. 18	Office des Mines Nationales et des Industries Stratégique
Oct. 19	ASM site visit near Antsirabe (stay at Antsirabe)
Oct. 20	Move from Antsirabe to Antananarivo JICA Madagascar office
Oct. 21-22	Move from Madagascar to Mozambique
Oct. 23	JICA Mozambique office National Directorate of Geology and Mines, Ministry of Mineral Resources and Energy National Institute of Mines, Ministry of Mineral Resources and Energy
Oct. 24	National Directorate of Environment, Ministry of Land and Environment National Directorate of Forestry, Ministry of Land and Environment
Oct. 25	National Museum of Geology, Ministry of Mineral Resources and Energy JICA Mozambique office
Oct. 26-27	Move from Mozambique to Japan

Table 2-6 Schedule of the second field survey

Date	Organization visited
Jan. 7	Move from Japan to Laos
Jan. 8	Department of Mining Management, Ministry of Energy and Mines
Jan. 9	Department of Planning and Finance, Ministry of Natural Resources and Environment Embassy of Japan in the Lao PDR JICA Laos office
Jan. 10	Move from Laos to Cambodia
Jan. 11	General Department of Mineral Resources, Ministry of Mines and Energy
Jan. 12	General Directorate of Environmental Protection, Ministry of Environment
Jan. 13-14	Move from Cambodia to Mozambique
Jan. 15	National Institute of Mines, Ministry of Mineral Resources and Energy
Jan. 16	National Directorate of Environment, Ministry of Land and Environment JICA Mozambique office
Jan. 17-18	Move from Mozambique to Japan

2.9.1 First field survey：five countries (Laos, Cambodia, Zambia, Madagascar, Mozambique)

An each visited organization, the survey team explained the areas of satellite image analysis in each country, the specifications and availability of Sentinel-2 satellite images, and the methods and examples of analysis of satellite image. In addition, we requested information on mining and environment-related issues in each country and confirmed the counterpart organizations' willingness to cooperate with Japan.

(1) Laos PDR
・Department of Mining Management (DMM), Ministry of Energy and Mines (MEM)
・Department of Geology and Mineral (DGM), MEM
・Department of Planning and Finance (DPF), Ministry of Natural Resources and Environment (MoNRE)

(2) Cambodia
・General Department of Mineral Resources (GDMR), Ministry of Mines and Energy (MME)
・Department of Mineral Operational Inspection, MME
・Department of Mineral Geology (DMG), MME
・Department of Industrial Mining (DIM), MME
・General Directorate of Environmental Protection (GDEP), Ministry of Environment (MoE)

(3) Zambia
・Geological Survey Department, Ministry of Mines and Minerals Development (MMMD)
・Cadastre Department, MMMD
・Mines Development Department, MMMD

・Zambia Environment Management Agency (ZEMA), Ministry of Green Economy and Environment (MGEE)

(4) Madagascar
・Direction Generale des Mines (DGM), Ministry of Mines and Strategic Resources (MMRS)
・General Direction of Environmental Governance, Ministère de l'Environnement et du Développement Durable (MEDD)
・Conservation International (CI)
・Office des Mines Nationales et des Industries Stratégique (OMNIS)

(5) Mozambique
・National Directorate of Geology and Mines (DNGM), Ministry of Mineral Resources and Energy (MIREME)
・National Institute of Mines (INAMI), MIREME
・National Directorate of Environment, Ministry of Land and Environment (MTA)
・National Museum of Geology, MIREME

2.9.2 Second field survey: three countries (Laos, Cambodia, Mozambique)

Based on the information collected during the first field survey, the results of interviews and satellite image analysis, JICA selected three countries for the second field survey: Laos, Cambodia and Mozambique.
At each visited organization, the survey team gave an explanation for the retrieval, data acquisition, and image processing of Sentinel-2 satellite image, giving a demonstration on Web. Also, the survey team reported the results of satellite image analysis at open-pit mines and ASM areas in each country. In addition, we interviewed the counterpart organizations for issues related to mining and environment in each country, and confirmed the request of the counterpart organizations for the cooperation with Japan.
The organizations visited in each country were as follows.

(1) Laos PDR
・Department of Mining Management (DMM), Ministry of Energy and Mines (MEM)
・Department of Planning and Finance (DPF), Ministry of Natural Resources and Environment (MoNRE)

(2) Cambodia
・General Department of Mineral Resources (GDMR), Ministry of Mines and Energy (MME)
・General Directorate of Environmental Protection (GDEP), Ministry of Environment (MoE)

(3) Mozambique
・National Institute of Mines (INAMI), MIREME
・National Directorate of Environment, Ministry of Land and Environment (MTA)

3. Study result: Zambia

3.1 Basic information

3.1.1 Natural and social environment

Geographical map of Zambia is shown in Figure 3-1.

Reference: United Nations (2004)

Figure 3-1 Geographical map of Zambia

The Republic of Zambia (hereinafter called Zambia) is an inland country located in southern Africa and was formerly British Northern Rhodesia. The capital is Lusaka. Zambia borders the Republic of Angola (hereinafter called Angola) to the northwest and west, to the north is the Democratic Republic of the Congo (hereinafter called DR Congo), to the northeast is the United Republic of Tanzania (hereinafter called Tanzania), and to the east is the Republic of Malawi (hereinafter called Malawi). From east to southeast is the Republic of Mozambique (hereafter called Mozambique), to the south is the Republic of Zimbabwe (hereafter called Zimbabwe), and from south to southwest is the Republic of Namibia (hereafter called Namibia). The total land area is 752,610 km^2 (about twice the size of Japan), and the total population is 19.47 million (2021).

Most of Zambia, including the capital Lusaka, belongs to the Monsoon influenced humid subtropical climate (Cwa) in the Köppen climate classification, with a mild rainy season (December to April), a cool dry season (May to August), and a hot dry season. It is divided into three seasons (September to November). The average annual rainfall is about 1,000 mm, more than 1,300 mm in the north and less than 800 mm in the south. The average annual temperature is 18-24°C.

Christianity is the main religion in Zambia, accounting for about 80%, followed by Hinduism, Islam, and traditional religions. There are 73 ethnic groups (Tongan, Nyanja, Bemba, Lunda). Languages are English (official), Bemba, Nyanja and Tongan.

Zambia's major industries are mining (copper, cobalt, and etc.), agriculture (corn, cotton, tobacco, soybeans) and tourism, with a GDP of US$22.1 billion (World Bank, 2021). Total trade is US$11.141 billion in exports and US$7.096 billion in imports (WTO, 2021), of which exports include copper, cobalt, cement and tobacco, and imports include chemicals, petroleum products and medical agents. Export counterparts are Switzerland (44.3%), China (18.7%) and DR Congo (12.4%). On the other hand, import counterparts are South Africa (33.2%), China (16.8%) and UAE (8.8%) (WTO, 2020).

As an economic overview, Zambia has become a monoculture economy dependent on copper production (copper accounts for about 60% of the export value), and the behavior of copper production amounts and international prices have had a major impact on the Zambian economy. For this reason, the highest priority issues in Zambia's current policies are the promotion of foreign investment and industrial structural reforms for the agriculture and tourism.

3.1.2 Topography

Zambia is geographically located between 8° and 18° of south latitude, and most of the land consists of highland peneplains with altitudes between 700 m and 2,000 m. Among them, the altitude of the capital Lusaka is about 1,200m. The highest point is in the highlands at an altitude of about 2,300m near Malawi border.

The major rivers are the Zambezi and Kafue rivers. Of these, the Zambezi River has a total length of over 2,000 km, and this length is comparable to the second largest river in Africa after the Nile and Congo River. The source of the Zambezi River is the mountains in northern Zambia, and the flow of the river once flows southward through Angola, then enters Zambia again and flows southward. After that, it flows east to northeast from near the Namibian border to near the Zimbabwe border, enters Mozambique, and finally flows into the Indian Ocean. There are world-class scenic spots such as Victoria Falls and Lake Kariba at the border with Zimbabwe in the Zambezi River. Among these, Lake Kariba is a dammed lake with a length of over 200 km, an area of just under 6,000 km2, and a reservoir capacity of over 180 km3. This scale corresponds to the world's largest water storage volume.

On the other hand, the Kafue River, which is a tributary of the Zambezi River, is the second largest river in Zambia after the Zambezi River, with a total length of over 1,500 km. The source of the Kafue River is in the highlands near the border with the DR Congo in the Copperbelt in northern Zambia, and the river flows southwest to southeast from the area to the south of Lusaka, the capital, before joining the Zambezi River. This water basin includes Kafue National Park and the Lukanga Wetlands as natural parks.

3.1.3 Vegetation

The average annual rainfall in Zambia is about 1,000 mm, which is not much amounts, and the dry season lasts nearly half a year, so the growth of vegetation is generally poor. The vegetation is divided into three categories: forest consisting of shrubs, woodland consisting of groves, and grassland consisting of sparse shrubs and trees.

3.1.4 Infrastructure

Zambia's economic infrastructure, such as transportation networks and electricity, is fragile, and its social infrastructures, such as education, medical care, and water supply and sanitation facilities, are underdeveloped. In Zambia, an inland country, the most important infrastructure for trade is the transportation network that serves as the trunk line for transportation. Important corridors are the Tazara Corridor (Zambia to Dar es Salaam Port in Tanzania), the Mtwara Corridor (Zambia to Malawi to Mtwara Port in Tanzania) and the Nacala Corridor (Zambia to Malawi to Nacala Port in Mozambique), the North-South Corridor (Zambia-Zimbabwe or Botswana-Durban Port in South Africa), and the Lobito Corridor (Zambia-Lobito Port in Angola).

Domestic electricity depends on the hydropower, and the proportion of hydropower in the electricity reaches more than 75%. Of these, the largest source of hydropower is the Kariba Dam, which has the world's largest water storage. On the other hand, power outages have occurred frequently in recent years due to reduced power generation capacity due to droughts in the country, and the 8th National Development Plan of Zambia announced in 2022 will expand power sources such as solar, winds, and biogas.

Other railways include the Tanzania-Zambia Railway (TAZARA) and the Zambia Railway. TAZARA operates approximately 1,800km between the port town of Dar es Salaam in eastern Tanzania and Kapiri Mposhi at the north of Lusaka in Zambia. Zambia Railways operates the Kitwe-Lusaka-Livingstone route within Zambia. During the colonial era, the Zambia Railway used to connect Angola, DR Congo, Zambia, Zimbabwe, and Durban in South Africa for the purpose of transporting copper ores in the copperbelt, etc., but now it only operates at some sections in the Railway.

3.1.5 Environmental reserve area

Zambia has 20 national parks and 23 game reserves. Of these, Victoria Falls on the Zimbabwe border in southern Zambia is adjacent to Mosi-oa-Tunya National Park. Kafue National Park, one of the largest in Africa, is located along the Kafue River which is a tributary of the Zambezi River in central Zambia.

In addition, there are South Luangwa National Park in the northeastern part of Zambia and Lochinvar National Park in the southwest of Lusaka, the capital of Zambia. These national parks are world-famous treasure troves and sacred places for wild animals including rare animals.

3.1.6 Geology

The geology of Zambia is characterized by the formation of the Katanga Basin as a mobile zone after the Pan-African orogeny in the late Proterozoic and the subsequent formation of the Karoo Rift Valley between the Congo Craton in the north side and the Kalahari Craton in the south side.

Basement rocks consist of early Proterozoic gneisses, schists, quartzites, granites, etc., and are mainly distributed in eastern to northeastern Zambia. These rock bodies are unconformably overlain by low-level metamorphic rocks such as metasedimentary rocks and metavolcanic rocks of the Muva Supergroup of the Middle Proterozoic. The period of unconformity with basement rocks is thought to be about 1 billion years. Intrusive rocks in the Muva Supergroup include many types of rocks which comprise granitoids, granite porphyries, granodiorites, syenites, dolerites, norites, lamprophyres, carbonatites, pegmatites, gabbros, mafic volcanic rocks and ultramafic rocks.

The basement complex and Muva Supergroup are overlain by conglomerates, shales, quartzites, arkosic sandstones, greywackes, aeolian sandstones, phyllites and dolomites of the late Proterozoic to Cambrian Katanga Supergroup. Intrusive rocks in the Katanga Supergroup consist of granitoids, adameritic rocks, lamprophyres, dolerites, gabbros and ultramafic rocks. The Katanga Supergroup is divided into the Rowan Group, the Mwasha Group and the Kundelungu Group. The Rowan Group consists of shales, sandstones, dolomites and quartzites, which corresponds to host rocks for copper mineralizations within the Copperbelt. The Mwasha Group consists of carbonate shales, claystones and quartzites. The Kundelungu Group consists of conglomerates, dolomites, limestones and carbonate shales of glacial sediments origin in the lower part and sandstones, quartzites and shales in the upper part, which unconformably covers the Mwasha Group.

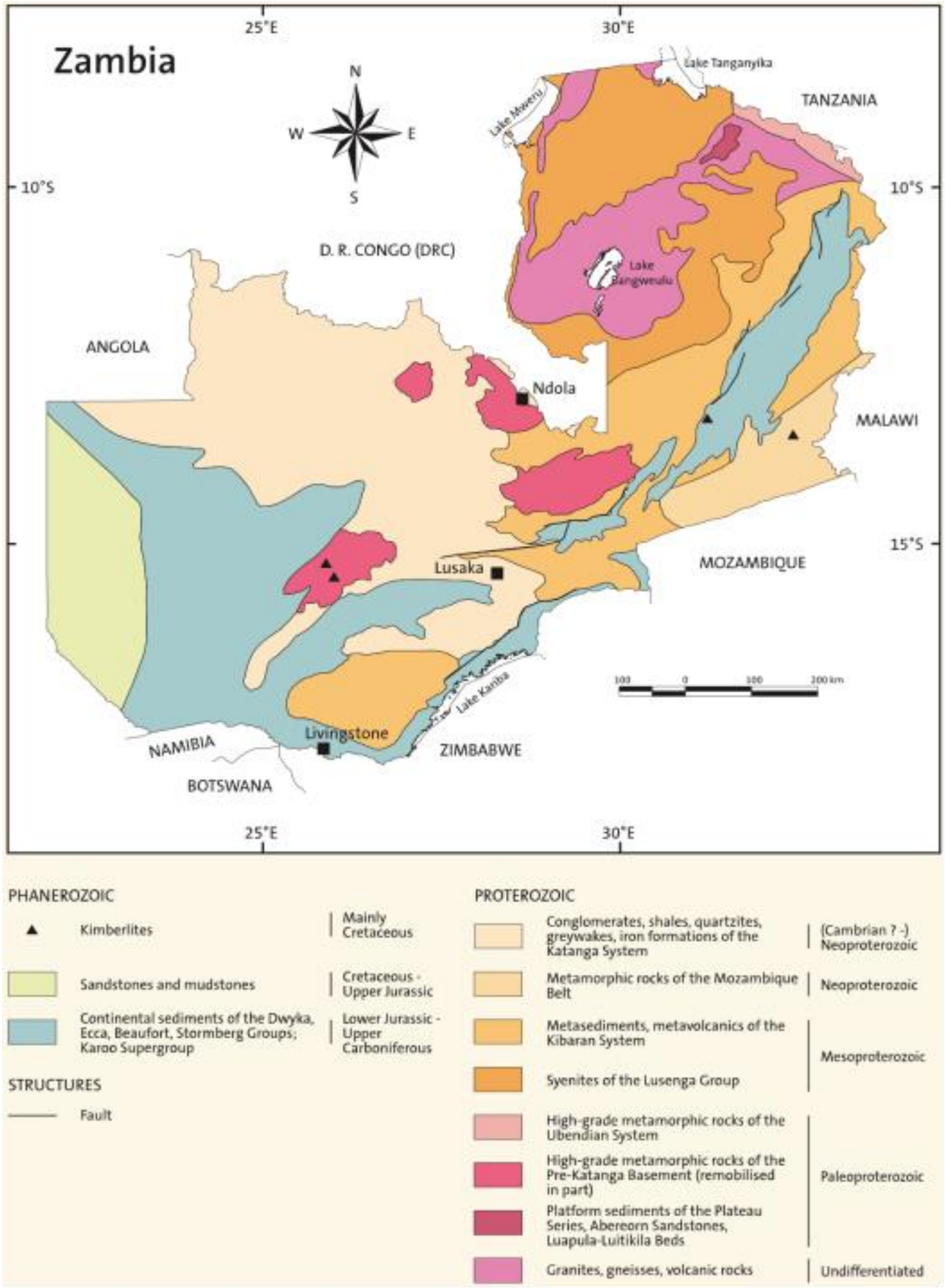
The Early Carboniferous-Jurassic Karoo Supergroup is deposited within a rift valley-like structure extending northeastward in eastern-southern Zambia. The rift valleys include the Zambezi Valley in the Lake Kariba region and the Luangwa Valley in the east. The main lithofacies of the Karoo Supergroup are mudstones, shales and sandstones. The lithofacies of the lowest part comprise tillites and gradually changes to sandstones. This same horizon includes the Gwembe coal bed. Part of the upper part consists of Jurassic basalt lavas distributed around Livingstone and Victoria Falls. Other intrusive rocks in the Karoo Supergroup slightly include carbonatites and kimberlites.

Late Jurassic to Cretaceous Kalahari Group occupies most of the Western Province of Zambia. The group consists of sandstones and mudstones. A part of the sandstones of this group becomes aeolian sediments. These sediments are distributed in the central and southern states as well as the western state. These deposits are recognized as a part of the Kalahari Desert that were formed in the Tertiary to Pleistocene.

The major tectonic provinces and geological structures in Zambia are the Bangweulu Block, the Ubendian Belt, the Irumide Belt, the Kibaran Belt, the Mozambique Belt, the Zambezi Belt, the Lufilian Arc, the Katanga Basin, the Mwembeshi Shear Zone and the Karoo Rift Basin. Among them, the Bangweulu Block occupies a large area of northern Zambia as a Proterozoic craton. The Ubendian belt extends in the northwest-southeast direction and is estimated to have been formed in the Early Proterozoic. The Irumide and Kibaran belts extend northeast-southwest, and their formation age shows 1.1 Ga in the Middle Proterozoic. The Mozambique belt is located in the southern part of the tectonic belt continuous from Ethiopia and cuts through the Irumide belt in southern Zambia. The geological period of formation of the tectonic zone is considered to be the Middle Proterozoic. The Zambezi belt is probably the southern extension of the Mozambique belt.

The formation of the Lufilian Arc and the Mwembeshi Shear Zone corresponds to the Pan-African Orogeny. Among them, the Lufilian Arc extends on an arched line from Angola to DR Congo to Zambia and the area of arc forms the Copperbelt. The formative period of the arc is thought to be from 840 Ma (Late Proterozoic) to 465 Ma (Ordovician), which corresponds to the deposition period of the Katanga Supergroup and the formative period of the Katanga Basin. The Katanga Basin was formed as a main part of Zambia's geological body by the tectonic movement during this period. On the other hand, the Mwembeshi shear zone is a ductile tectonic zone with a left-lateral strike-slip component extending from northeast to southwest in southern Zambia. The active period is about 550 Ma (Late Proterozoic), and this activity led to the formation of Karoo rift basins such as the Luangwa Valley, the Zambezi Valley, and the Luano-Lukasashi Valley.

Geological map of Zambia is shown in Figure 3-2



Reference: Schlüter, T. (2006)

Figure 3-2 Geological map of Zambia

3.1.7 Mining

The largest operations in Zambia's mining industry are the mining and production of copper in the Northern and Northwestern Copperbelt and Northwestern Provinces. Zambia's copper production (smelted copper) in 2019 was approximately 640,000 tons, accounting for 4% of the world's production and ranking seventh in the world. The region has over a dozen copper mines and smelters, including Lumwana, Kansanshi and Chingola. Cobalt, nickel, gold and platinum are also included as by-products of copper production. Of this, the 2019 metal production of cobalt from this region is about 1,500 ton. Gold is produced only at the Kansansi mine. Other base metals produced are lead and copper at the Kabwe mine north of Lusaka at the southern end of the Copperbelt. Mining of ore at the Kabwe mine has been completed, but the smelting is being carried out after receiving ore purchases from abroad. Other metal resources of medium to small scale operations include the Maunali nickel mine at Kafue, south of Lusaka, and the Mansa manganese mine at northeast of the Copperbelt. The Maunari mine is the country's first nickel mine. Manganese is currently under development, and production is expected to increase in the future.

A major non-metallic resource operation is the mining and production of precious stones such as emeralds, aquamarines and garnets in pegmatite basement rocks within the Copperbelt Province. Among them, the emerald production in 2019 was 15,400 kg, and Zambia's emerald production in 2019 is said to account for about 20% of the world's production. Mining and production of precious stones is dominated by small-scale operators, but the country's leading producers are the Kagem and Mbuva-Chibolele mines. Among them, the output of beryls and emeralds at the Kagem mine in 2019 is said to be 6,600 kg. In addition, the mining of talcs and limestones as stone materials in Ndola, the coal mining from the lower part of the Karoo Group, etc. are being carried out.

The location of mine and mineral occurrences in Zambia is shown in Figure 3-3, and the location of mine and mineral occurrences in this study is shown in Figure 3-4. Table 3-1 shows the operational status of mining in Zambia, and Table 3-2 shows the status of facilities. Information on mines, prospects, mining related facilities and mining projects are based on USGS (2023) and JOGMEC (2021).

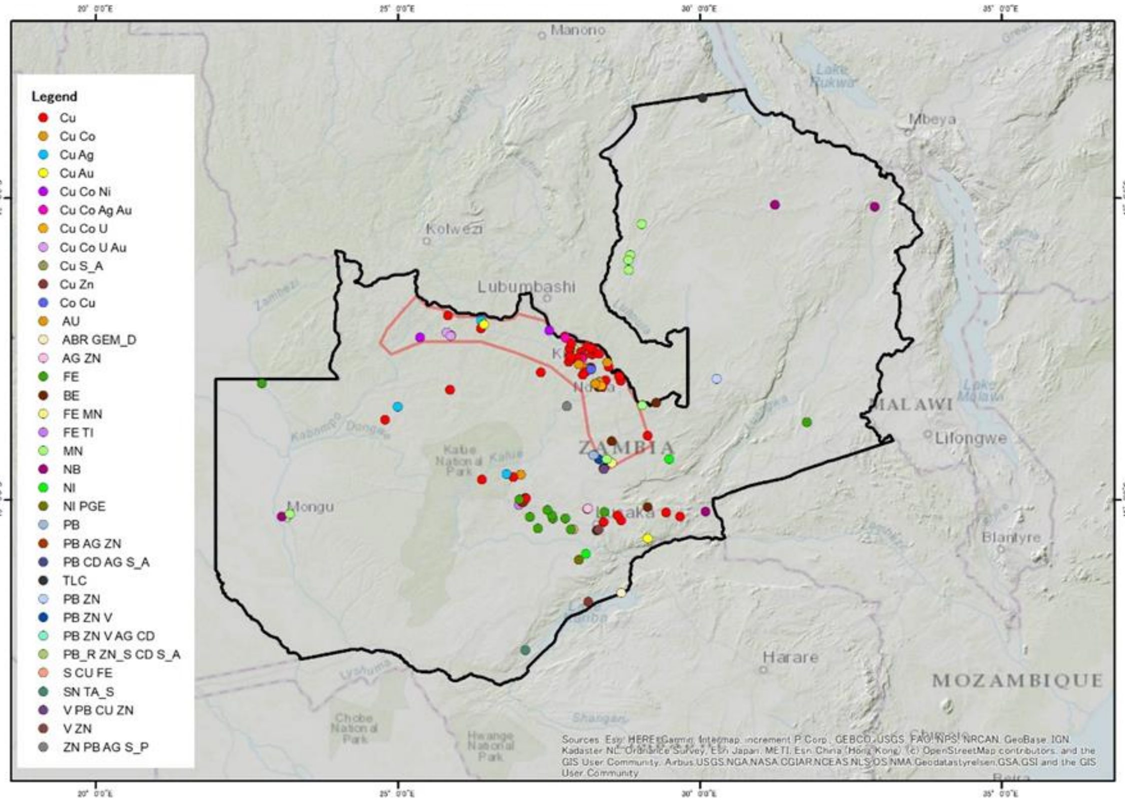


Figure 3-3 Location map of mines and mineral occurrences in Zambia

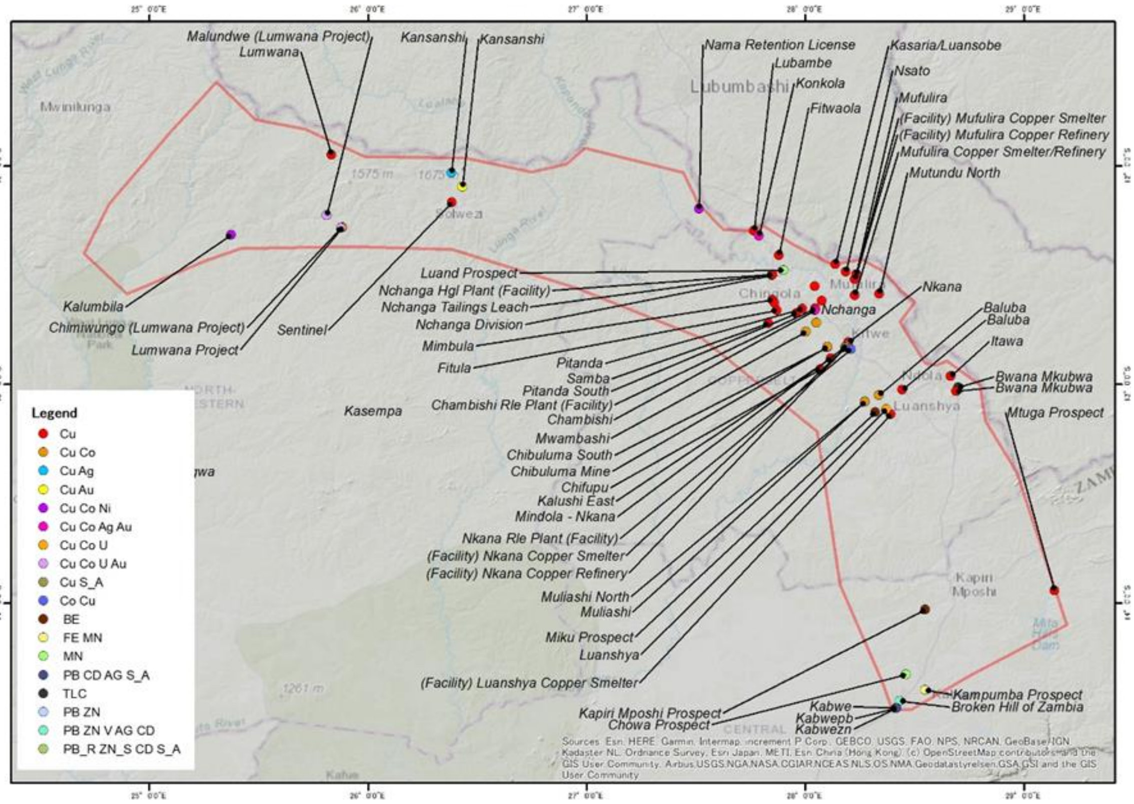


Figure 3-4 Location map of mines and mineral occurrences in satellite image analysis area

Table 3-1 List of operating mines of mineral resources in Zambia (1/3)

Copper, cobalt, gold and silver					
Mine Name	Com-modity	Province	Company	Production	Remarks
Kansanshi	Cu, Au	North-western	Kansanshi Mining plc [First Quantum Minerals Ltd.,80%; Zambia Consoli-dated Copper Mines In-vestments Holdings plc (ZCCM–IH),20%]	Cu 221.5 kt Au 128.4 koz	ore capacity sulfide:12 Mt oxide:8.8 Mt mixed:8.6 Mt
Sentinel (Trident)	Cu	North-western	Kalumbila Minerals Ltd. [First Quantum Minerals Ltd.,100%]	Cu 251.2 kt	
Lumwana	Cu	North-western	Lumwana Mining Company Ltd. [Barrick Gold Corp.,100%]	Cu 125.2 kt	ore capacity: 21 Mt
Mufulira Mine	Cu	Copper-belt	Mopani Copper Mines plc [Glencore plc,73.1%; First Quantum Minerals Ltd.,16.9%; Zambia Consolidated Copper Mines Investments Holdings plc (ZCCM–IH),10%]	Cu 41.5 kt	ore capacity: 2.5 Mt
Nkana Mine	Cu	Copper-belt	ditto	unk.	ore capacity: 5.5 Mt
Konkola	Cu, Co, Ag, Au	Copper-belt	Konkola Copper Mines plc (KCM) [Vedanta Resources plc.,79.4%; Zambia Consolidated Copper Mines Investments Holdings plc (ZCCM–IH),20.6%]	unk.	ore capacity: 2.4 Mt
Nchanga	Cu, Co	Copper-belt	ditto	Cu 65.5 kt Co 1.3 kt	ore capacity: 2.8 Mt underground
Muliashi North	Cu, Co	Copper-belt	CNMC Luanshya Copper Mines plc [NFC Africa Mining plc,80%; Zambia Consolidated Copper Mines Investments Holdings plc (ZCCM–IH),20%]	Cu 43.0 kt	ore capacity: 4.5 Mt
Chambishi	Cu, Co, Ag, Au	Copper-belt	NFC Africa Mining plc [China Nonferrous Metal Mining (Group) Co. Ltd.,85%; Zambia Consolidated Copper Mines Investments Holdings plc (ZCCM–IH),15%]	Cu 40.2 kt	ore capacity: 2.145 Mt
Baluba	Cu, Co	Copper-belt	CNMC Luanshya Copper Mines plc [NFC Africa Mining plc,80%; Zambia Consolidated Copper Mines Investments Holdings plc (ZCCM–IH),20%]	Cu 13.6 kt	ore capacity: 1.5 Mt underground
Lubambe		Copper-belt	Lubambe Copper Mine Ltd. [African Rainbow Minerals Ltd.,40%; Vale S.A.,40%; Zambia Consolidated Copper Mines Investments Holdings plc (ZCCM–IH),20%]	Cu 43.7 kt	ore capacity: 2.5 Mt concentrate capacity: Cu 45 kt
Mimbula	Cu	Copper-belt	Moxico Resources plc,85%; Unnamed owner, 15%	unk.	concentrate capacity: Cu 20 kt
Chibuluma South	Cu	Copper-belt	Chibuluma Mines plc [Metorex Ltd. (Jinchuan Group International Resources Co. Ltd.,100%),85%; Zambia Consolidated Copper Mines Investments Holdings plc (ZCCM–IH),15%]	Cu 8.0 kt	ore capacity: 0.6 Mt concentrate capacity: Cu 19 kt

Table 3-1 List of operating mines of mineral resources in Zambia (2/3)

Mine Name	Com-modity	Province	Company	Production	Remarks
Gold					
Kansanshi	Au	North-western	Kansanshi Mining plc [First Quantum Minerals Ltd.,80%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),20%]	unk.	capacity: Au content 5,300 kg
Nickel					
Munali	Ni	Lusaka	Consolidated Nickel Mines Ltd.	unk.	ore capacity: 4 kt
Manganese					
Mine in Mansa area	Mn	Luapula	Green Core Enterprises	unk.	ore capacity: 240 kt
Mines in Mansa and Mkushi area	Mn	Luapula and Central	Small scale miners	unk.	ore capacity: 120 kt
Gemstone					
Various locations	Amethyst	Various locations	Artisanal miners	unk.	-
Kariba	Amethyst	Southern	Kariba Minerals Ltd. [Gemfields PLC,50%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),50%]	1,100 kg	-
Various locations	Beryl and emerald	Various locations	Artisanal miners	unk.	-
Lufwanyama	Beryl and emerald	Copper-belt	Grizzly Mining Ltd.	unk.	-
Mbuva-Chibolele	Beryl and emerald	Copper-belt	Kagem Mining Ltd. [Hagura Mining Ltd. (Gemfields PLC,100%),75%; Government of Zambia,25%]	unk.	-
Kagem	Beryl and emerald	Copper-belt	Kagem Mining Ltd. [Hagura Mining Ltd. (Gemfields PLC,100%),75%; Government of Zambia,25%]	6,600 kg	-
Various locations	Tourmaline	Various locations	Artisanal miners	unk.	-
Limestone					
Quarry in Ndola	Limestone	Copper-belt	Dangote Quarries (Zambia) Ltd.	unk.	-
Sulfur					
Nampundwe	Pyrite	Lusaka	Konkola Copper Mines plc [Vedanta Resources plc,79.4%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),20.6%]	unk.	capacity: 300 kt

Table 3-1 List of operating mines of mineral resources in Zambia (3/3)

Coal					
Mine Name	Com-modity	Province	Company	Production	Remarks
Siankondobo coalfield	Coal	Southern	Maamba Collieries Ltd. [Nava Bharat consortium,65%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),35%]	unk.	capacity: 400 kt
Kandabwe	Coal	Southern	Nkandabwe Coal Mine Ltd. [Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),100%]	unk.	capacity: 240 kt

Table 3-2 List of facilities related to mineral resources in Zambia (1/3)

Copper and cobalt					
Mine Name	Com-modity	Province	Company	Production	Remarks
Kansanshi copper smelter	Cu	North-western	Kansanshi Mining plc [First Quantum Minerals Ltd., 80%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),20%]	unk.	capacity: Cu cathode 340 kt
Chambishi copper smelter near Kitwe	Cu	Copper-belt	Chambishi Copper Smelter Company, Ltd. [China Nonferrous Metal Mining (Group) Co. Ltd., 60%; Yunnan Copper Industry (Group) Co. Ltd.,40%]	unk.	capacity: Cu anode 250 kt
Chambishi near Kitwe	Cu	Copper-belt	Sino-Metals Leach Zambia Ltd. [China Nonferrous Metals Mining (Group) Co. Ltd., Sino-Africa Mining Investments Ltd., NFC Africa Mining plc, and China Hainan Construction Co. Ltd.]	unk.	capacity: Cu cathode 8 kt
Chambishi cobalt plant	Cu, Co	Copper-belt	Chambishi Metals plc [Eurasian Resources Group, S.a.r.l.(ERG),90%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),10%]	unk.	capacity: Cu cathode 27 kt Co metal 5.5 kt Crude ore are from D.R.Congo
Nchanga copper smelter at Chingola	Cu, Cu-Co	Copper-belt	Konkola Copper Mines plc [Vedanta Resources plc,79.4%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),20.6%]	unk.	capacity: Cu anode 311 kt Cu-Co alloy 3 kt
Nchanga tailings leach plant at Chingola	Cu	Copper-belt	ditto	unk.	capacity: Cu cathode 80 kt
Mufulira refinery	Cu	Copper-belt	Mopani Copper Mines plc [Glencore plc,73.1%; First Quantum Minerals Ltd.,16.9%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),10%]	unk.	capacity: Cu cathode 275 kt
Mufulira smelter	Cu	Copper-belt	ditto	unk.	capacity: Cu anode 200 kt

Table 3-2 List of facilities related to mineral resources in Zambia (2/3)

Copper and cobalt					
Mine Name	Com-modity	Province	Company	Production	Remarks
Mufulira West heap-leach facility	Cu	Copper-belt	ditto	unk.	unk.
Nkana solvent extraction plant	Cu	Copper-belt	ditto	unk.	capacity: Cu cathode 15 kt
Nkana cobalt plant	Co	Copper-belt	ditto	unk.	capacity: Co metal 2.8 kt
Nkana copper refinery	Cu	Copper-belt	Konkola Copper Mines plc [Vedanta Resources plc, 79.4%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),20.6%]	unk.	Cu cathode 300 kt
Bwana Mkubwa solvent extraction-electrowinning plant	Cu	Copper-belt	First Quantum Mining and Operations Ltd. (First Quantum Minerals Ltd.,100%)	unk.	capacity: Cu cathode 52 kt
Muliashi leach plant	Cu	Copper-belt	CNMC Luanshya Copper Mines Plc (NFC Africa Mining plc,100%)	unk.	capacity: Cu cathode 40 kt
Luanshya slag recovery from tailings	Cu	Copper-belt	CNMC Luanshya Copper Mines Plc [NFC Africa Mining plc, 80%, and Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),20%]	unk.	capacity: 500,000 slag, which yeilds 3,500 Cu in concentrate
Reprocessing material from tailings dams in Chingola, Nchanga, and so on	Cu	Copper-belt	Konkola Copper Mines plc (KCM) [Vedanta Resources Plc.,80%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),20%]	unk.	unk.
Sable copper leach and electrowinning plant at Kabwe	Cu, Co	Central	Jubilee Metals Group Plc.	unk.	capacity: Cu cathode 14 kt Co carbonate 0.6 kt
Mkushi heap leach facility	Cu	Central	Mkushi Copper Joint Venture Ltd. (Seringa Mining Ltd.,51%; Katanga Resources Ltd.,49%)	unk.	unk.
Lead					
Mine Name	Com-modity	Province	Company	Production	Remarks
Recycling facility in Lusaka	Pb, other metals	Lusaka	Pagrik Zambia Ltd.	unk.	capacity: Pb and other metals 1 kt
Sulfur					
Mine Name	Com-modity	Province	Company	Production	Remarks
Nchanga acid plant in Chingola	Sulfuric acid	Copper-belt	Konkola Copper Mines Plc [Vedanta Resources plc, 79.4%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),20.6%]	unk.	capacity: 675 kt

Table 3-2 List of facilities related to mineral resources in Zambia (3/3)

Mine Name	Com-modity	Province	Company	Production	Remarks
Sulfur					
Chambishi copper smelter	Sulfuric acid	Copper-belt	Chambishi Copper Smelter Company, Ltd. [China Nonferrous Metal Mining (Group) Co. Ltd., 60%; Yunnan Copper Industry (Group) Co. Ltd.,40%]	unk.	capacity: 600 kt
Kansanshi smelter	Sulfuric acid	North-western	Kansanshi Mining plc [First Quantum Minerals Ltd.,80%; Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),20%]	unk.	capacity: 1,000 kt

Mine Name	Com-modity	Province	Company	Production	Remarks
Cement					
Plant in Ndola	Cement	Copper-belt	Dangote Industries (Zambia) Ltd. (Dangote Cement Plc,100%)	unk.	capacity: 1,500 kt
Plant in Ndola	Cement	Copper-belt	Lafarge Zambia Plc (LafargeHolcim Ltd.)	unk.	capacity: 550 kt
Plant in Ndola	Cement	Copper-belt	Zambezi Portland Cement Ltd.	unk.	capacity: 800 kt
Chilanga I and II plants	Cement	Copper-belt	Lafarge Zambia Plc (LafargeHolcim Ltd.)	unk.	capacity: 950 kt
Plant in Lusaka	Cement	Lusaka	Scirocco Enterprises Ltd.	unk.	capacity: 100 kt
Plant in Chongwe	Cement	Eastern	Sinoma Mpande Limestone Ltd. (China National Building Materials Co. Ltd.)	unk.	capacity: 1,000 kt

Mine Name	Com-modity	Province	Company	Production	Remarks
Lime and quicklime					
Plant in Ndola	Lime, quicklime	Copper-belt	Ndola Lime Company Ltd. [Zambia Consolidated Copper Mines Investments Holdings Plc (ZCCM–IH),100%]	unk.	capacity: 300 kt
unk.	Lime, quicklime	unk.	Neelkanth Lime Ltd.	unk.	capacity: 144 kt

Mine Name	Com-modity	Province	Company	Production	Remarks
Iron, steel, and crude steel					
Steel factory in Kafue	Iron and steel, crude steel	Copper-belt	Universal Mining and Chemical Industries Ltd. (Trade Kings Group)	unk.	capacity: 100 kt

Mine Name	Com-modity	Province	Company	Production	Remarks
Rifined petroleum					
Indeni refinery at Ndola	Rifined petroleum	Copper-belt	Indeni Petroleum Refinery Ltd. (Government, 100%)	unk.	capacity: 10 M barrels

3.2 Mineral resources

3.2.1 Metallic mineral resources

The major metal mineral resource in Zambia is copper. The copper-bearing strata are the Lower Roan Group in the Late Proterozoic to Cambrian Katanga Supergroup during the Pan-African Orogeny within the Copperbelt in northern to northwestern Zambia. The type of copper deposits is the sediment-hosted stratabound copper deposit. Ore minerals are mainly composed of chalcopyrite, bornites and chalcocite, and these copper minerals are zoned parallel or obliquely to the bedding plane. The host rock is formed in the sedimentary basin mainly composed of siliceous sandstones, dolomite rocks and shales. Red formations and evaporites are also contained within the sedimentary basin, and the mineralization is believed to have progressed under the influence of pressure and diagenetic fluids in the sedimentary basin. Cobalt, nickel, gold and platinum are also associated with copper ores. The morphology of the current deposits is controlled by the structure of the Lufilian Arc, and the current mining targets extend from the surface to more than 5,000m underground.

There are two types of nickel deposits in the Cooperbelt. Main type is produced as a by-product in sediment-hosted copper deposits and the other type is the ortho magmatic deposits with PGM mineralization in ultramafic rocks as host rocks. Of these, the Maunari deposit, Zambia's first nickel mine, is considered to be the latter ortho magmatic deposit.

The lead-zinc deposits is located at the Kabue mine at the southern end of the Copperbelt, but is currently not mined. Mineralization is observed within the Roan Group as well as sediment-hosted copper deposits in the Copperbelt, with lead-zinc-silver-bearing dolomite. The deposit type is believed to be skarn, but the existence of related igneous rocks has not been confirmed.

3.2.2 Past surveys

Regarding the current mineral resources survey in Zambia, explorations and surveys by foreign companies for copper and cobalt, especially in the Copperbelt, is progressing well. On the other hand, the mineral resources potential of the entire country as a national infrastructure information has not been fully understood because explorations and surveys for the resources other than copper have not progressed as much as expected, and the creation of geological maps of the entire country is only about 70% complete.

Regarding past international support for explorations and researches, there is support of the preparation of quadrangle geological maps and mineral resources potential studies by UK in the late 1950s-1970s, World Bank and EU in the 1990s. Support by Japanese governments as an intergovernmental aid for mineral resources terrains was provided from the 1980s to the 2000s and includes the following projects.

1984-1986: Reconnaissance surveys of silver, copper, lead, and zinc in the Karenda area through the mineral exploration project (geological and geochemical survey, geophysical exploration, and boring survey).

1989-1990: A follow-up survey of zinc deposits in the Kabwe West area (boring survey of approx. 4,000m in total depth) through the mineral exploration project as a regional development planning survey.

1993-1995: Reconnaissance surveys of copper in the Chambishi Southeast area (reviews of existing data, boring survey of approx. 10,000m in total depth, and mineral resources assessments).

2006-2009: Data arrangements of information on geology and mineral resources in whole lands and the northeastern region through a study to arrange the information on geology and mineral resources to promote investments in the mining sector.

3.2.3 Products of mining and industry

The major mineral products in the Zambian mining industry are copper and cobalt. Production of these metals in recent years has been as follows.

Table 3-3 Production of Major Metallic Ores

Mineral Type	2018	2019	2020	Global Share (%)	World Rank
Copper (thousand tons)	854.1	789.9	861.1	9.0	7

Reference: JOGMEC (2021)
(Data are based on World Metal Statistics Yearbook 2021)

Table 3-4 Metal Production

Mineral Type	2018	2019	2020	Global Share (%)	World Rank
Copper (thousand tons)	1038.7	782.9	896.6	-	-
Cobalt (thousand tons)	1.6	1.3	0.4	0.3	13

Reference: JOGMEC (2021)
(Data are based on ICSG Copper Bulletin, August 2021, and World Metal Statistics Yearbook 2021)

Mineral products account for 77% of Zambia's exports, of which copper, a major export, accounts for about 60%. Copper exports in recent years have been as follows.

Table 3-5 Copper Export Amount

Mineral Types	2018	2019	2020	Main Export Destinations
Copper ore (thousand tons)	4.0	2.3	47.0	Switzerland, DR Congo, China
Copper ingot (thousand tons) (blister and anode)	654.9	615.6	674.7	Switzerland, China, Singapore
Copper ingot (thousand tons) (refined)	318.3	189.4	232.7	Switzerland, Singapore, China

Reference: JOGMEC (2021)
(Data are based on ICSG Copper Bulletin, August 2021, and International Trade Centre)

3.2.4 Metal prices of the world

The current situation of prices for the metals covered in this study is as follows.

Copper: Prices remained low at US$2,000/t until 2003, but reached around US$3,000/t in 2004, then exceeded US$5,000/t. Prices temporarily reached around US$10,000/t in 2011, and are currently around US$8,000/t. Prices basically fluctuate according to the demand situation in China, the largest importer, and the operating conditions in Chile, Peru, and other countries that are the largest producers.

Cobalt: Prices were around US$10/kg until the early 2000s and rose to around US$40/kg after 2004. After reaching a temporary peak of about US$110/kg in 2008, it further reached about US$90/kg in 2018 and US$80/kg in 2022 as a temporary peak, and the price is currently at about US$30/kg. The productions of DR Congo and Zambia account for more than half of the global share, and price fluctuations are influenced by political conditions in the producing countries, temporary growth in demands as a battery metal, and inventory adjustments.

Nickel: The price was around US$6,000/t until the early 2000s, rising after 2004, and then surged to a temporary peak of about US$37,000/t in 2007, followed by a temporary peak of about US$25,000/t in 2022, while remaining at US$15,000 to 20,000/t up to now. The largest producer is Indonesia and the production volume accounts for more than half of the global share, including the Philippines and Russia. Price fluctuations are influenced by temporary growth in demands as a battery metal and inventory adjustments.

Tin: The price once fell from the upper US$10,000/t to just over US$5,000/t in the mid-1980s, and remained at around US$5,000/t until the early 2000s, after which it began to rise again, reaching a temporary peak of around US$30,000/t in 2011 and US$32,000/t in 2021. The price is still at about US$25,000/t, and the price fluctuates widely but remains at a high level. China is the largest producer, accounting for about half of global production.

Lead and zinc: The prices of lead and zinc, which are used for lead batteries and plating materials, have been stable in the past compared to base metals such as copper and other rare metals. Since 2007, the prices have been around US$2,000/t for lead and US$2,000/t for zinc. China is the largest producer, with more than half of the world's share, including production in Peru and Australia.

PGM: The price of platinum, which is the most widely produced of the PGM, was around US$500/oz until the first half of 2000, and has been around US$800/oz since 2004, temporarily at US$1,700/oz in 2011, and around US$1,000/oz since 2015. The price of palladium reached a high of about US$2,900/oz in 2021 and is currently around US$2,000/oz. South Africa is the largest producer of platinum group elements, accounting for about 70% of the world market share, while Russia accounts for less than half of the world market share for palladium.

3.3 Mineral resources potential of target minerals

3.3.1 Copper

Copper deposits were formed within the Katanga Basin during the Lufilian Arc activity during the Pan-African Orogeny in the Late Proterozoic to the Cambrian period, and the deposits are distributed in the Copperbelt across Zambia and DR Congo.

The deposit type is sediment-hosted stratiform copper deposits, and the host rocks are siliceous sandstones, dolomites, and shales of the Roan Group of the Katanga Supergroup within the Katanga Basin. The depositional environment of the host rock is estimated to be a shallow-water basin or lagoon. Copper mineralization are thought to have occurred after deposition of the host rocks and to have progressed under the influence of temperature and pressure of thermal fluids related to the formation of an arc and diagenetic processes within the Katanga Basin.

The distribution of copper deposits and their potential areas are shown in Figure 3-5.

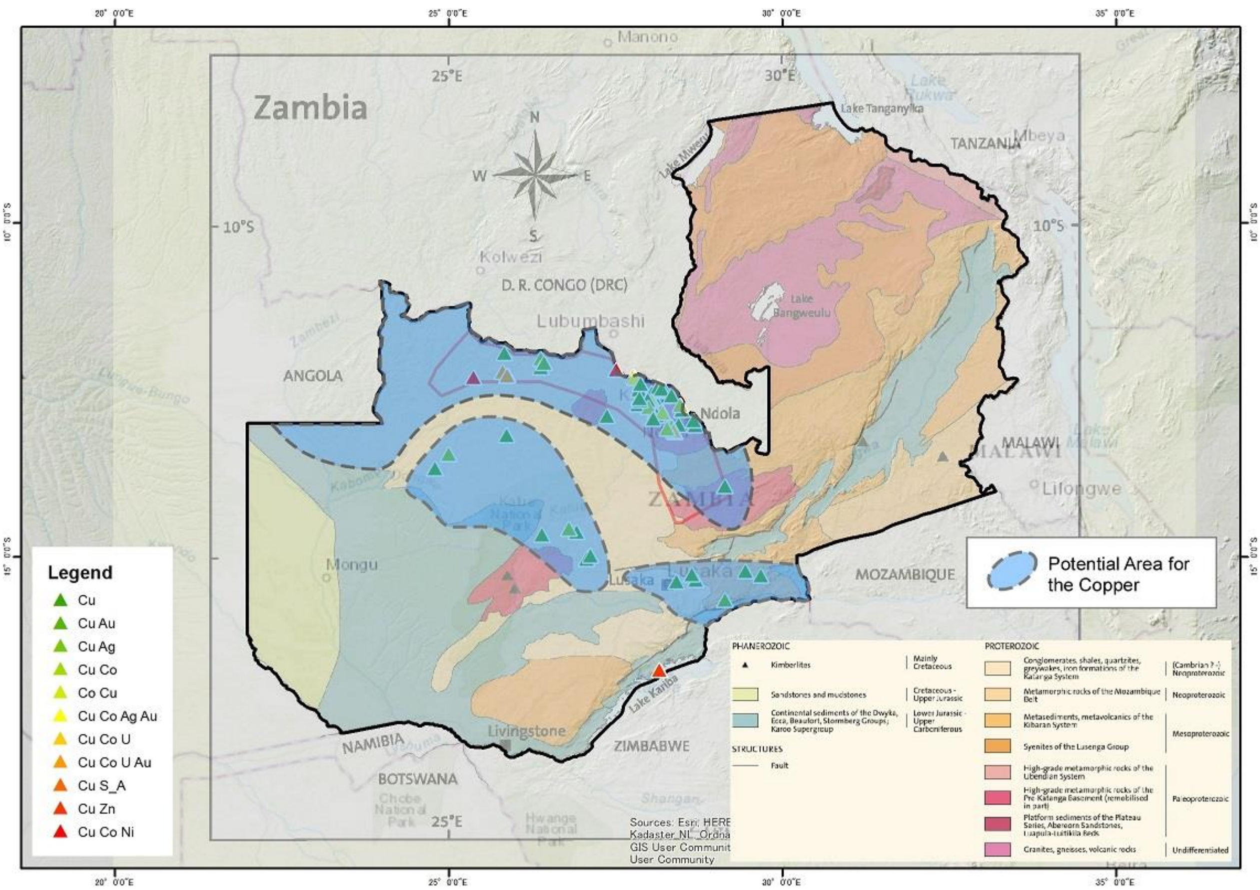


Figure 3-5 Distribution of copper deposits (mines and deposits) and potential areas

The main copper deposits in Zambia are located within the Copperbelt, and the potential areas are also distributed in the Copperbelt.

3.3.2 Cobalt

Cobalt deposits in Zambia occur concomitantly as cobalt ore in copper ores in the Copperbelt. Currently, there are no mines where cobalt ore is the main mining target.

The distribution of cobalt-bearing deposits within copper deposits and their potential areas are shown in Figure 3-6.

The distribution of the cobalt deposits is limited within the Copperbelt and all deposits are associated with copper ore within the copper deposits. Therefore, the cobalt potential areas are similar to those of copper deposits within the Copperbelt.

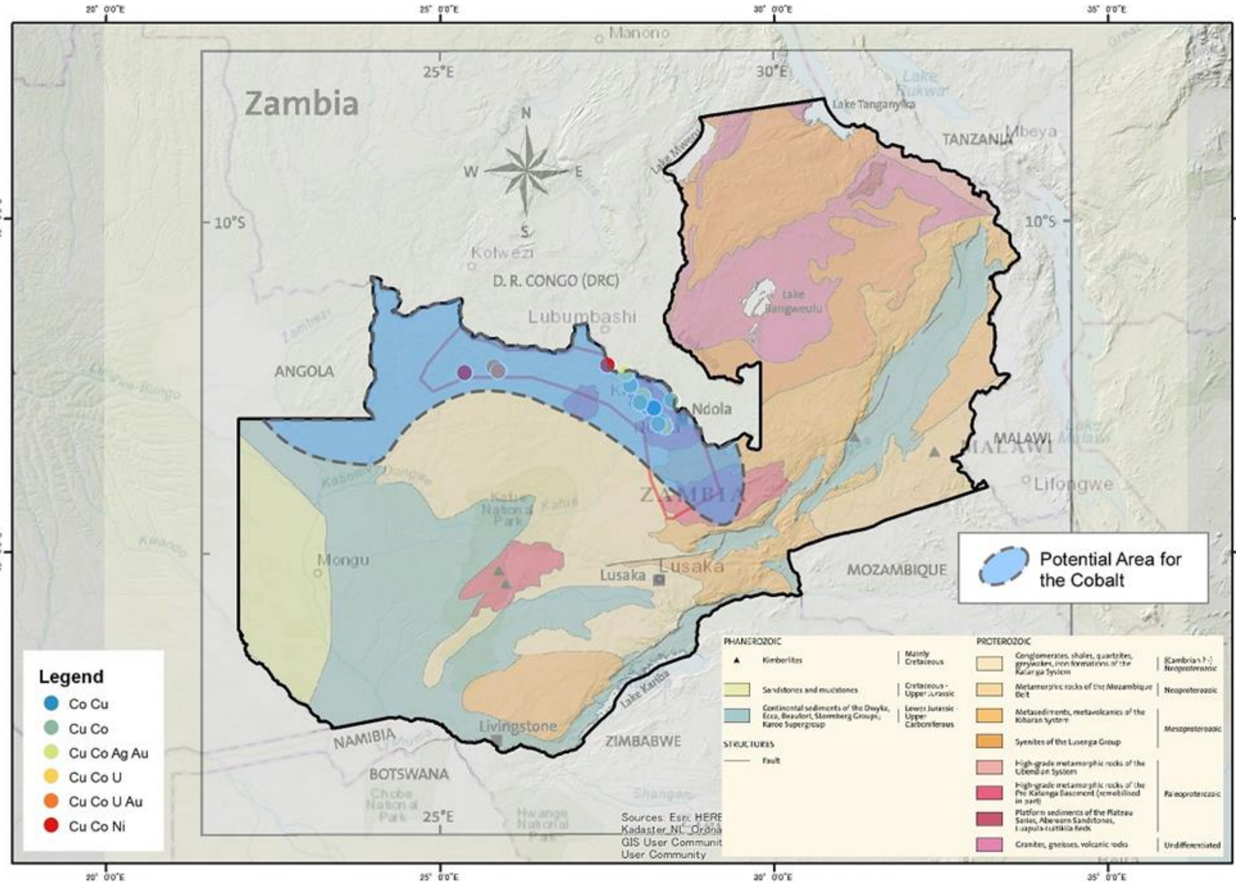


Figure 3-6 Distribution of cobalt deposits (mines and deposits) and potential areas

3.3.3 Nickel

Two types of nickel deposits are recognized in Zambia. One of these types is that occurs as an nickel deposit within sediment-hosted stratiform copper deposits in the Copperbelt, and another type is that occurs as orthomagmatic sulfide deposits which also produce PGM as the main elements of nickel ore. The latter type of orthomagmatic sulfide deposit is contained within basic plutonic complexes that were formed in the Zambezi Supercrustal Sequence (ZSS) of the Zambezi Belt during the Pan-African Orogeny. The age of the complex body is late Proterozoic.

The distribution of nickel deposits and their potential areas are shown in Figure 3-7.
The potential areas for nickel deposits are the same as the distribution areas of sediment-hosted stratiform copper deposits within the Copperbelt and the distribution areas of basic complexes as the host rock of orthomagmatic sulfide deposits of the Late Proterozoic within the Zambezi Belt.

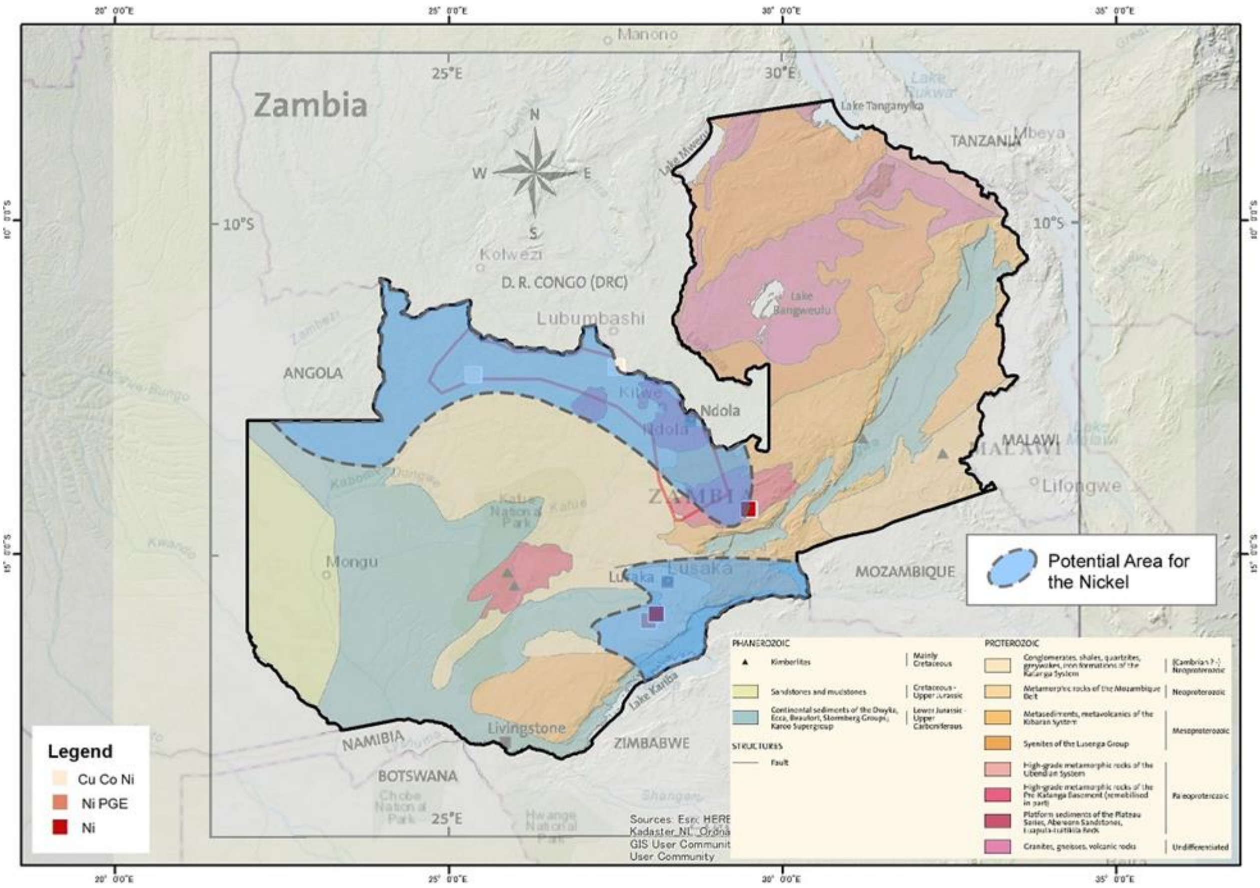


Figure 3-7 Distribution of nickel deposits (mines and deposits) and potential areas

3.3.4 Tin

There are no known mineral features or mines for tin in Zambia. On the other hand, in neighboring Zimbabwe, the xenothermal type tin deposits with pegmatite occur within the Zambezi Belt of the Pan-African Orogeny, and geological bodies contrasting with the host rocks and related igneous rocks of the deposit are also distributed in Zambia. In DR Congo, there are also large- scale pegmatite deposits such as the Bisie tin deposit and the Manono lithium-tin deposit within the Kirbaran belt during the Pan-African Orogeny. Therefore, it is possible that tin deposits may also exist within Zambia. In addition to tin, the pegmatites contain tungsten, tantalum, lithium, mica, and beryl, and are important as a deposit containing rare metals.
Potential areas for tin deposits in Zambia, based on the situation in neighboring countries where tin deposits exist, are the Zambezi belt, which is continuous from neighboring Zimbabwe, and the Copperbelt in the north and the Irumide belt in the east, which are interrupted from within DR Congo.

The potential areas of tin are shown in Figure 3-8.

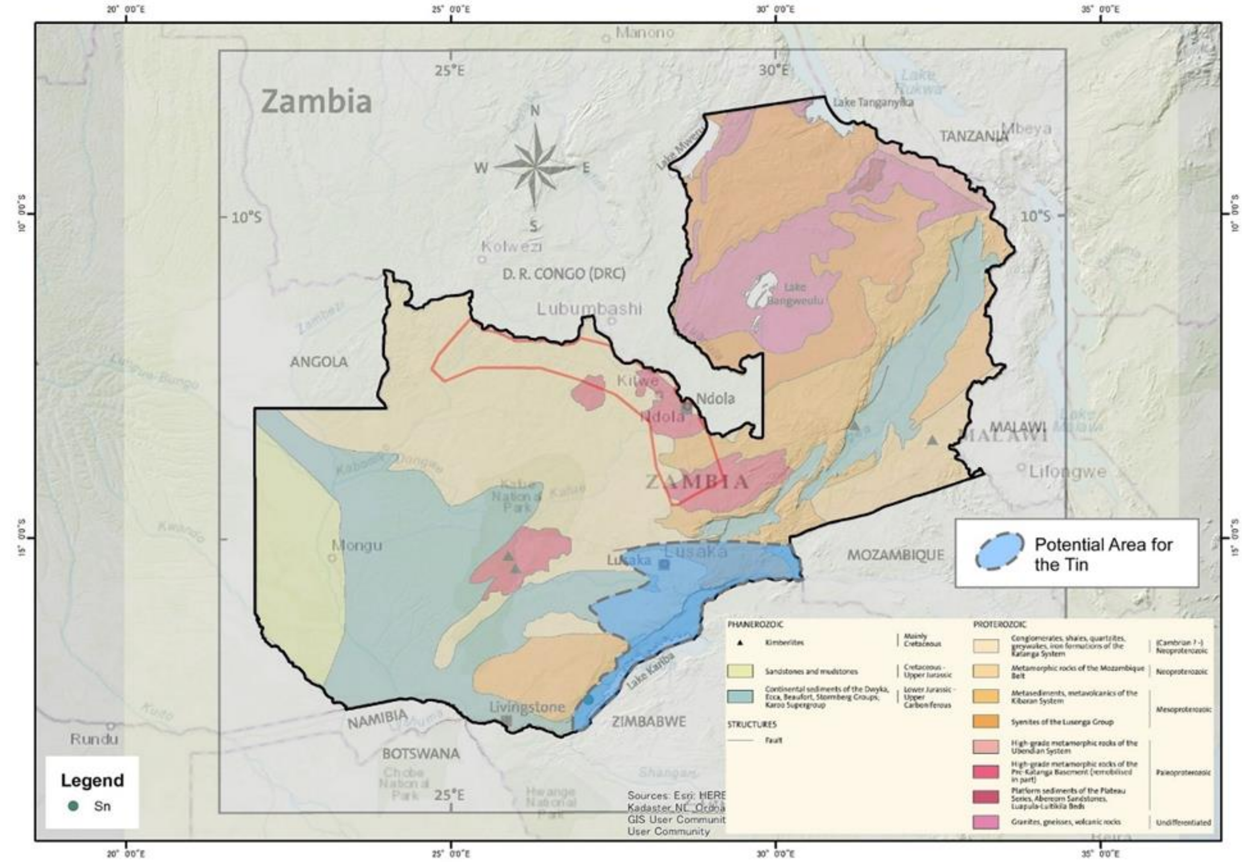


Figure 3-8 Potential area of tin

3.3.5 Led

The lead mineralization and ore deposits in Zambia are distributed in the southern part of the Copperbelt in central Zambia. A deposit that has been mined so far is the Kabwe deposit, which is hosted by dolomite within the Roan Formation as well as sediment-hosted copper deposits in the Copperbelt, and the deposit is considered to be of skarn type, although the igneous rocks involved are not known.

The distribution of lead (including zinc, etc.) deposits and their potential areas are shown in Figure 3-9..

The potential area for lead mineralization is essentially within the Copperbelt, in the same of the distribution area of dolomite and igneous rock thought to have been formed contemporaneously with the sediment-hosted copper deposits within the Roan Formation.

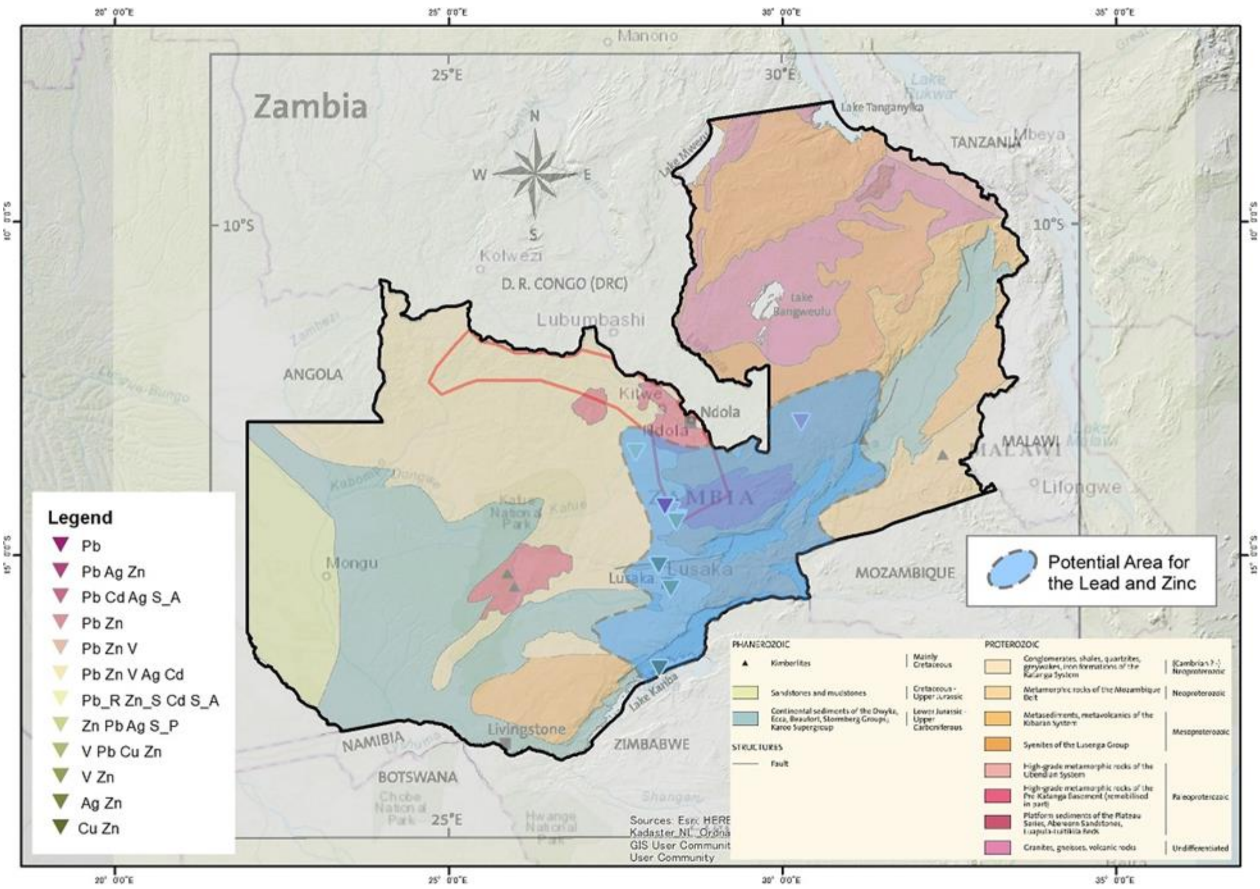


Figure 3-9 Distribution of lead and zinc deposits (mines and deposits) and potential areas

3.3.6 Zinc

The zinc mineralization and deposits in Zambia are distributed in the area from the southern Copperbelt in central Zambia to the Zambezi belt in southern Zambia. A deposit that has been mined so far is the Kabwe deposit, which, like the lead deposit mentioned above, is hosted by dolomite in the Roan Formation of the southern Copperbelt, and is considered to be of skarn type, although the igneous rocks involved are not yet known. On the other hand, deposits recognized within the Zambezi Belt in southern Zambia are associated with gold, silver, copper, and vanadium, and the types of these deposits are considered to be sedimentary or vein type based on the timing of formation of the deposits and geological environments.

The zinc potential area is similar to that of lead, and the area basically overlaps the distribution area of dolomite within the Roan Group in the Copperbelt and the related igneous rocks thought to have formed at the same time.

The distribution of zinc (including lead, etc.) deposits and their potential areas are shown in the lead section above (Figure 3-9).

3.3.7 PGM

PGM in Zambia occurs in the orthomagmatic sulfide deposit which is mainly nickel ore with associated PGM. The deposits are hosted in basic complexes placed within the Zambezi Supracrustal Sequence (ZSS) of the Zambezi Belt, which were formed during the Pan-African Orogeny, and the age of the complexes are Late Proterozoic.

The PGM potential area is the same as the distribution area of basic complex that is located within or contemporaneously with the Zambezi Supracrustal Sequence (ZSS) of the Zambezi Belt.

The distribution of PGM (including nickel, copper, and cobalt) deposits and their potential areas are shown in Figure 3-10.

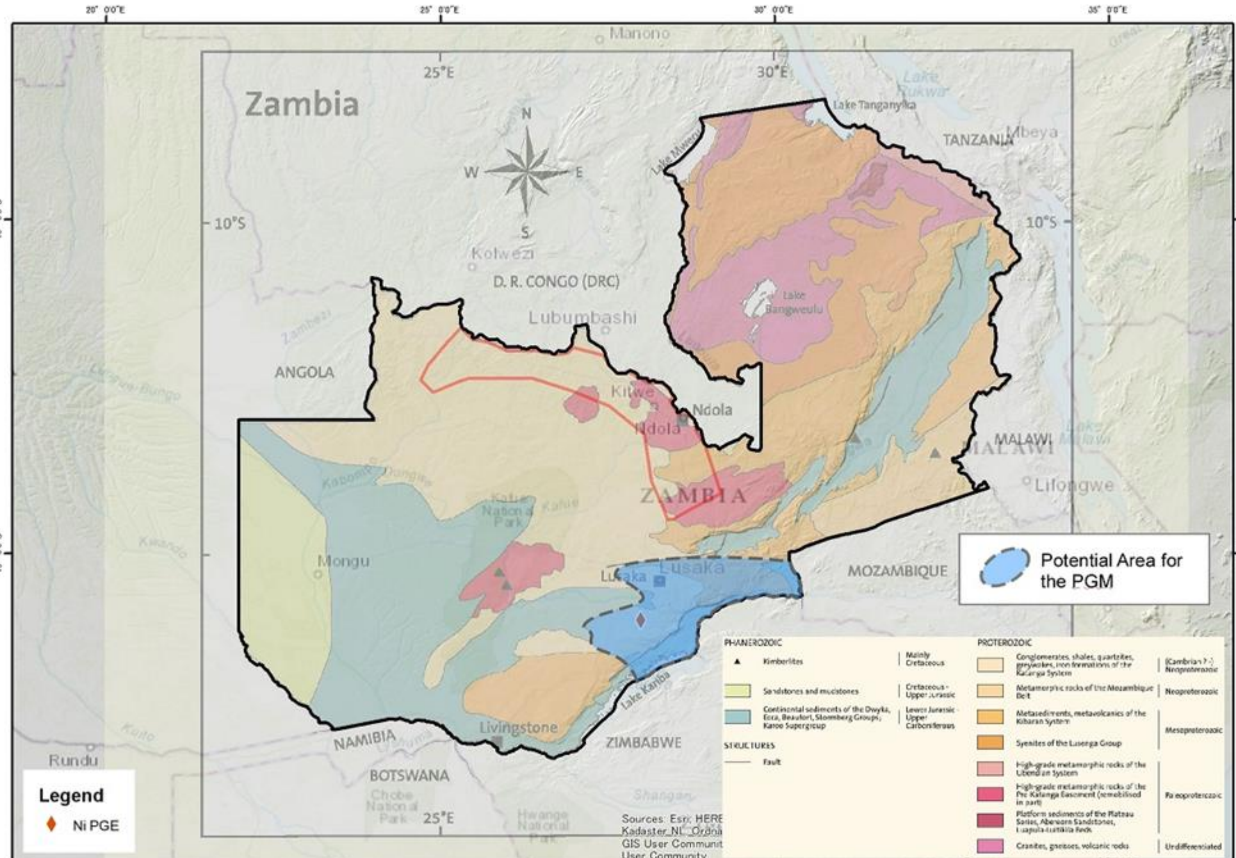


Figure 3-10 Distribution of PGM deposits (mines and placer deposits) and potential areas

3.4 Mining administration

3.4.1 Mining policy

Zambia has become a monoculture economy dependent on copper production in the Copperbelt, with copper exports accounting for approximately 60% of Zambia's total exports. In terms of total mining production, the mining sector also accounts for 17.5% of Zambia's GDP, 77% of exports, 70% of the foreign currency revenue, about 28% of the tax revenue, and 2.4% of the working population (2019-2021 results). As a result, the Zambian economy is highly sensitive to fluctuations in the copper production and international prices, especially in the mining industry. In this context, prior to the first half of 2014, the copper production was also increasing, influenced by the rise in international copper prices since the mid-2000s, and the economic growth reached around 6% per year. On the other hand, from the second half of 2014 onward, international copper prices turned downward, production volume stagnated, the local currency weakened, and planned power outages occurred due to insufficient rainfall. Due to these effects, the Zambian economy took a turn for the worse. Furthermore, in November 2020, Zambia failed to meet its Eurobond interest payments, making it the first African country to default on its debt since the COVID-19 pandemic. Currently, Zambia has a policy that puts the highest priority on reforming the industrial structures through the promoting foreign investments and the forwarding agriculture and tourism. This will led to build economic infrastructures without relying on the copper industry.

Based on the above economic situation in Zambia in recent years, the important issues about mining policy are a revision of laws and regulations to stabilize the copper industry, a creation of added value, a development of related infrastructures (roads, railways, water, energy, etc.), and a security and strengthening environmental measures. In addition, against the background of large-scale power outages due to power shortages in recent years, the utilization of renewable energy such as solar powers is cited as an alternative energy source to hydroelectric power generation, which currently accounts for 85% of the total power generation. Zambia's installed power capacity is approximately 2,800 MW, but due to the effects of recent frequent dry weather, the actual power generation capacity is just over 1,300 MW.

Regarding the revision of laws and regulations among the important matters in the mining policy, in 2019, taxes related to the mining industry, such as royalties and import and export taxes, were revised to increase. On the other hand, regarding the utilization of renewable energy for infrastructure developments for stable mining operations, the copper mines owned by First Quantum Minerals (FMQ) in the Copperbelt are powered by solar power.

3.4.2 Law and regulation related to mining

The relevant law is the Mines and Minerals Development Act (enacted in 2015). This law is comparable to revisions of the Mining Act (1970) and the Mines and Minerals Development Act (2008), which established the guidelines related exploration and operating. The guideline includes the large- and small-scale mining licenses, export/import authorizations, mining rights, safety, health, environmental protection and mineral trade licenses.

In relation to the mine safety, this was enacted as the Mines Regulations (enacted in 1973), and is now included in the Mines and Minerals Development Act.

The Mines and Minerals Development Act consists of the Mining Regulations (enacted in 1995), the Mines and Minerals (Environmental) Regulations (enacting in 1997), the Mining (Environmental Protection Fund) Regulations (enacting in 1998), the Mining and Mineral Resources Development (Uranium and Other Survey of Radioactive Mineral Resources, and Mining) Regulations (enforced in 2008).

The laws and regulations related to the mine environment are the Environmental Management Act (enacted in 2011). This is a revised version of the Environmental Protection and Pollution Control Act (1990).

The Environmental Management Act consists of the Hazardous Waste Management Regulations (enforced in 2001), Environmental Impact Assessment Regulations (enforced in 1997), Air Pollution Control Regulations (enforced in 1997), and the Water Environmental Conservation Regulations (enforced in 1993). The standards for the drinking water are used according to WHO standards.

Regarding the mining taxes system, the government announced that changes the tax system in 2018, and then implemented a new tax system in 2019. Of these, the royalties from copper productions increased by 1.5% and the royalties from cobalt productions increased by 3% from before 2018. In addition, a new import duty of 5% on copper and cobalt concentrates and an export duty of 15% on precious metals and gemstones has been applied.

3.4.3 National budget of mining sector

In relation to the budget for the mining sector, the copper production and exports are a major part of Zambia's GDP, foreign exchange earnings, and tax revenues. Therefore, the budget for basic operations of the sector has been secured. On the other hand, there does not appear to be any independent budgeting for the human resource capacity building, which is currently largely supported by international cooperation agencies of other countries.

The largest share of the budget is for items related to the management of mining concessions and items related to mine safety, occupational health, and the mine environment. The latter includes measures to address the artisanal and small-scale mining (ASM), such as raising awareness of health and safety among small-scale miners, inspections, and risk assessments.

3.4.4 Management system of mining sector

The mining authority is the Ministry of Mines and Mining Development (MMMD). The Mines Development Department (MDD) under the ministry is responsible for managing and supervising the operation of mines, including a management of mining areas and a supervision of mining. Permits for mining areas will be issued by the Department. This permits premise that the Environmental Impact Assessment (EIA) has been approved by the Zambian Environmental Management Agency (ZEMA) under the Ministry of Green Economy and Environment (MGEE). Supervision of the actual mining is carried out every three months by engineers from the MDD, who audit whether the mining methods of operating mines are appropriate. The authorities are not involved in the EIA approval, which is premised on acquiring mining properties.

The Mines Safety Department (MSD) supervises activities related to the mine environment and safety for the operating mines. The actual supervisions are carried out by inspectors of the Department through monitoring and auditing of the mine environment and safety conditions in the operating mines. The agency's audits are conducted in collaboration with ZEMA.

The Geological Survey Department (GSD), as a survey and research organization for regional geology, natural resources, and applied geology, manages this information and conducts surveys and research projects related to geology and mineral resources in the country.

In addition, there is ZCCM Investment Holdings Plc (ZCCM-IH) as a mining corporation under the government. The ZCCM-IH has a share of the operating mines and participates in the operation and production as a state-owned company.

3.4.5 Issues

The following is a summary of issues related to the mining sector, based on information gathered and the results of interviews with relevant departments of the MMMD.

(1) Current Status of the Mining Sector

Mining sector in Zambia is a major sector of the Zambian economy and accounts for about 70% of Zambia's total exports and 10% of GDP. Therefore, the Ministry of Mines and Minerals Development, which oversees the mining activities in the country, plays an important role in managing mineral resources and export of mineral products. Full-scale development of copper as a major mineral product began in the 1940s with UK and US capitals, and Zambia is still ranked among the top 10 countries in the world, second only to its neighbor, the DR Congo. As a result, operations are still large-scale, and many of the mines have smelters. The scope of supervision by the government covers a wide range of areas, including mining, ore processing, smelting, mine environment, and security. In addition, since the majority of operators are still foreign-owned, the government need to be managed and supervised in accordance with international standards. The Zambian government's Vision 2030 for the mining sector includes the promoting mining development through private investment, the improving regulations, the implementing mining laws, the managing investors, and the strengthening the monitoring and control system for mining volumes. In accordance with this vision, the new Mining Law of 2008 was revised in 2015, updating the mining management in terms of investment, security, and mining rights.

In Zambia, where there are many large-scale mines and smelting-related facilities, both within African countries and globally, the impact of mining activities on the surrounding environment, residents, and society has become a major social concern. The impact of lead dispersion and runoff from the Kabwe lead mine, north of Lusaka, on the surrounding residents and lands was once reported by the Blacksmith Institute (current Pure Earth) as one of the world's ten most polluted places in the environment. The impact of sulfurous acid gas emissions from copper smelters such as Mufulira in the Kitwe region of the Copperbelt has also been improved, but the effects of past pollution are still a concern today. The MSD under MMMD manages and supervises the overall mining environment at operating mines. The department is located in Kitwe, capital city of the Copperbelt province, where there is a concentration of large mines.

Regarding the geological and mineral resources information, approximately 60% of the national geological and mineral resources map (1:100,000 scale) has been prepared for the Copperbelt, but the northeastern and southwestern areas of Zambia, which are also remote areas, remain blank. On the other hand, the exploration and development activities in the Copperbelt by foreign capital companies are ongoing, mainly for copper, cobalt, and nickel, and new deposits are still being discovered. Therefore, the updated geological and mineral resources information in recent years is mainly detailed information on exploration and development by foreign companies in the existing areas.

(2) Support from other national institutions, etc.

There are recent support for mining sector administration by foreign organizations. One support is the World Bank's Zambia Mining Environmental Remediation and Improvement Project (ZMERIP) (2017-2024), which targets lead contamination at the Kabwe mine. Another support is the Zambia Copperbelt Environment Project (CEP) (2003-2011), which targets mine environmental investigation measures within the Copperbelt. In addition, China provided a bilateral government support for the creation of 1:100,000 scale geological map of northeastern Zambia from 2013 to 2015.

As part of a support from Japan for the mining sector, JOGMEC has been holding mining-related seminars and remote sensing training for mineral resource exploration in southern African countries since the opening of the Botswana Geological Remote Sensing Center in 2008 by JOGMEC. JICA conducted the " Geological mapping and mineral information service project for promotion of mining industry in the republic of Zambia" (2007-2010), followed by the dispatch of relevant short-term experts in 2010-2011 to conduct a geological survey of four regions in northeastern Zambia, including the creation of a 1:100,000 scale geological map of the region. The project also provided technical transfers and capacity buildings to the Geological Survey of Zambia through the development of GIS for geological and mineral resources information throughout the country, including the preparation of map widths at a scale of 1:100,000 for four regions in the northeastern part of Zambia. In addition, "The Kizuna Program", which began in 2014, has so far welcomed numerous international students from the mining sector and universities to Japan. In addition, JICA/Japan Science and Technology Agency (JST) has implemented the " Visualization of Impact of Chronic/Latent Chemical Hazard and Geo-Ecological Remediation " (2015-2021) under the Science and Technology Research Partnership for Sustainable Development (SATREPS), and Hokkaido University and University of Zambia, with the aim of eliminating lead contamination at the Kabwe Mine, as well as conducting the comprehensive research involving the three sectors of agriculture, livestock, mining, and the environment.

(3) Issues

Regarding concerns surrounding the mining sector, especially Zambia, mining operators are concerned with ensuring stable and safe operations to secure production. On the other hand, government is concerned with managements and supervisions of mineral resources. Furthermore, inhabitants and societies are concerned with employments, working environments, natural environments and social impacts. In monitoring mining activities, an important issue for the mining administration is to confirm and supervise whether operations and production are being conducted properly in accordance with mining and environmental laws and regulations, as well as security and other regulations. The MDD, MCD and MSD, which are responsible for this task, have established guidelines and systems for the supervision, and the verification and supervision are conducted in accordance with these procedures. In addition, the MDD and MCD stores information on mining licenses and periodic reports on operations from mining concessionaires in the cloud, which is not open to the public but is managed online within the department. On the other hand, the implementation of verification and supervision is labor intensive, given the large number of mines in Zambia, including large-scale mines. Currently, the number of mining licenses is approximately 120 large scale (up to 25,000 ha), 500 small scale (up to 400 ha), and 300 ASM (up to 6.6 ha), and including inspections once or twice per year/site. In addition, there are illegal ASMs without licenses, especially in northern Zambia. The managements and supervisions for these activities are also a major labor.

Once a problem arises in relation to the above activities, the media, NGOs, and others often raise major concerns about the employments and labor environments and environmental and social considerations. Therefore, the identifying and handling of the mining pollution, which has a particularly large environmental and social impact, has become a major issue for the mining sector. The MMMD provides guidance and recommendations to mining operators regarding the mining pollutions, but the pollutions that is currently recognized and addressed are events that are obvious to the naked eye, such as sulfurous acid gas emissions from smelters. As discussed below in the section of environmental sector, the MMMD is aware of the widespread soil and river pollutions caused by past mining activities, but has yet to confirm or implement specific measures.

Regarding the development of geological and resources information, approximately 40% of the quadrangle geological map and mineral resources map in the country have not yet been developed. As a world-class mining country, Zambia is required to disseminate its potential information about mineral resources both domestically and internationally, and the GSD needs to conduct the research and development works of this information as soon as possible.

Based on the above, the challenges in the mining sector can be summarized as follows

- The related organizations are required to ensure the reliable and efficient implementation of verification and supervision of mining activities, and to develop and build a management and monitoring system for the implementation of the verification and supervision of mining activities.
- The budgets for securing the professional human resources, and the infrastructure development and maintenance for the research and development of geological and mineral resources information are required.

3.5 Environment administration

3.5.1 Environment policy

The Ministry of Green Economy and Environment (MGEE) is responsible for the environmental administration in Zambia. The scope of environment-related activities in the ministry is wide, including wildlife, forest uses, land uses, mining origins, health care origins, and so on. After the enactment of the Environmental Protection and Pollution Control Act, Zambia formulated a National Environmental Action Plan, which mandates the implementation of EIA for development projects in all sectors.

Regarding the mining industry in the environmental field, the Zambia Environmental Management Agency (ZAMA), which belongs to the MGEE, is in charge of EIA approvals and approvals for mining activities, and subsequent EIA monitoring of the mining environment at operating mines. The department in charge of ZEMA is the EIA Unit. The base of mine environmental supervision is the North Regional Office in Ndola, Copperbelt Province. The office conducts irregular audits of operating mine facilities such as pits, storages and smelters in the surrounding area of Kitwe in collaboration with the MSD of the MMMD.

3.5.2 Law and regulation related to environment

The relevant law is the Environmental Management Act (enacted in 2013). This is a revision of the Environmental Protection and Pollution Prevention Act (enacted in 1990) and the Environmental Management Act (enacted in 2011).

The Environmental Management Act consists of the Hazardous Waste Management Regulations (enforced in 2001), Environmental Impact Assessment Regulations (enforced in 1997), Air Pollution Control Regulations (enforced in 1997), and the Water Environmental Conservation Regulations (enforced in 1993). The standards for the drinking water are used according to WHO standards.

3.5.3 National park and reserve

Natural parks in Zambia include 20 national park areas and 23 animal reserves. Of these, Victoria Falls on the Zimbabwean border in southern Zambia is adjacent to Mosi-oa-Tunya National Park. Kafue National Park, one of the largest park in Africa, is located along the Kafue River, a tributary of the Zambezi River, in central Zambia.

Recently, as part of nature conservation, the eradication of illegal trade in wild animals and plants in natural parks has been identified as an urgent global issue. One example is the animal protection activities through the " Monitoring the Illegal Killing of Elephants (MIKE) " project in the Lower Zambezi National Park. This activity is conducted in accordance with the Washington Convention.

3.5.4 Environmental survey related to mineral resources development

Mine pollutions of environmental concern in Zambia are the lead contaminations at the Kabwe lead-zinc mine in the Copperbelt, which has been closed. Waste slags and tailings around the mine generated by activities of mining and smelting during operation are diffused by floods, and this, the residues polluted the soil. In addition, the slags are still piled up on hills around the mine, and the wind and rain continue to spread it around and the diffused slags are still polluting the soil.

For other pollutions, the sulfurous acid gas emissions from smelters and soil-groundwater contaminations around mines in the cooperbelt have been observed in some locations within the Copperbelt.

3.5.5 Issues

The following summary of issues related to the environmental sector is based on information gathered and the results of interviews with the Ministry of Green Economy and Environment (MGEE) and the Zambia Environmental Management Agency (ZEMA).

(1) Current status of the environmental sector related to mining activities

The environmental sector administration is responsible for implementing the national environmental protection measures, assessing and monitoring the environmental impact of land and natural changes, and formulating and implementing the environmental policies. In Zambia, the " National Environment Action Plan (NEAP) " was formulated in 1994 and the National Policy on Environment in 2007. The activities include the preservation of a favorable environment for residents, natural resources management by residents and business operators, and the implementation of environmental impact assessments for major development projects in all sectors.

With respect to mining activities, Zambia has many large-scale developments, and under the Environmental Management Act of 2011, ZEMA oversees all development projects to ensure that environmental and social considerations are properly addressed. ZEMA is responsible for assessing the environmental impact of the development projects based on the submitted reports and supervising projects that raise concerns about the surrounding communities and nature. ZEMA is responsible for the supervision of the development projects that are of concern to local residents and nature. The MSD of the MMMD, conducts inspections in accordance with the inspection guidelines. However, ZEMA does not have its own guidelines for mining activities.

ZEMA is responsible for the environmental impact assessments and the oversight of areas of public concern, such as a lead contamination at the Kabwe Lead Mine and the sulfurous acid gas emission from a copper smelter such as Mufulira. ZEMA also conduct inspections in conjunction with the MSD under above situations. On the other hand, environmental concerns at large mines can have far-reaching effects on neighboring communities and the natural environments, and in some cases, information about these concerns can be disseminated nationally and internationally through the news and NGOs. Therefore, the response is not limited to ZEMA and the MSD, but may require a government response.

(2) Support from other national institutions, etc.

As for assistance related to the environment in general, the World Bank established an environment support program around the time of the enactment of the Environmental Protection and Pollution Control Law in 1990, and since then, environmental management initiatives have been undertaken. The support for environmental impacts of mining activities includes the " Zambia Copperbelt Environment Project (CEP) " (2003-2011) and the " Zambia Mining Environmental Remediation and Improvement Project (ZMER) ", as previously mentioned in the " Mining Sector section. Improvement Project (ZMERIP) " (2020-2024). The MGEE and ZEMA are participating in these projects, but the MMMD is the lead agency and not the main actor.

Major assistance to the MGEE and ZEMA has focused on environmental impacts such as the climate change, nature and wildlife, etc., and has included financial assistances from the World Bank, UN, and European countries, as well as bilateral government assistances from the Netherlands, Sweden, and others.

(3) Issues related to mining activities

An important part of the environmental administration's role in monitoring mining activities is to confirm and supervise that the environmental plan prepared by the operator is being followed after operation in accordance with the regulations. On-site inspections by ZEMA are conducted once or twice a year in collaboration with the MSD of the MMMD. As mentioned above, Zambia has many large-scale mines, and the number of environmental impact assessment sites and the content of the assessments are large. Furthermore, once a problem arises, the social impact of the problem becomes significant, and it is difficult for ZEMA and the relevant organizations of the MMMD alone to deal with the problem.

A major challenge for mining activities in the environmental sector, as in the mining sector, is to identify and deal with mining pollutions. As in the mining sector, the mining pollutions that are currently recognized and addressed are events that are obvious to the naked eye, such as sulfurous acid gas emissions from smelters. On the other hand, soil and river water pollutions that are not recognized as mining pollutions are not subject to confirmation or supervision by the current MDD or MSD, because most of the pollutions are caused by past mining activities, and the corresponding agency is the MGEE and ZEMA. The actual status of soil and river pollutions related to mining activities are still unclear in many respects, but the Kabwe lead contamination, which is recognized as a global contamination, and soil and crop contaminations in mine around Kitwe in the Copperbelt have been reported (Etter et al., 2012, Kribek et al., 2012, etc.). The dump of contaminations in soil, crops, and flora and fauna has become a major concern with eventual effects on the surrounding population, and the government is required to confirm and address the contaminations. In addition, it is reported that mercury is still being used in some places for illegal ASM, especially for gold, and there is great concern about an environmental pollution, but the actual situation is not clear.

The issues related to mining activities in the environmental sector can be summarized as follows.

・Environmental government side needs to secure specialized personnels and a budget for the identification and supervision of environmental impacts of mining activities and mine-related pollutions.

・Efficient implementation for the verification and supervision of various environmental impacts of mining activities based on the related guidelines, which should be arranged, are required.

・The status of various types of pollution, including illegal ASM, related to mining activities must be confirmed and monitored, and the countermeasures must be implemented or a policy for countermeasures must be formulated.

3.6 Satellite image analysis

3.6.1 Mining area

Satellite imagery was analyzed by selecting districts with clear mining activity on the imagery. In Zambia, five districts (mines) were selected from within the Copperbelt. The selected mines are Sentinel (Kalumbila) copper mine, Lumwana copper mine, Kansanshi copper-(gold) mine, Chambishi copper-(cobalt-gold-silver) mine, and Baluba copper-(cobalt) mine. The location of the district is shown in Figure 3-11.

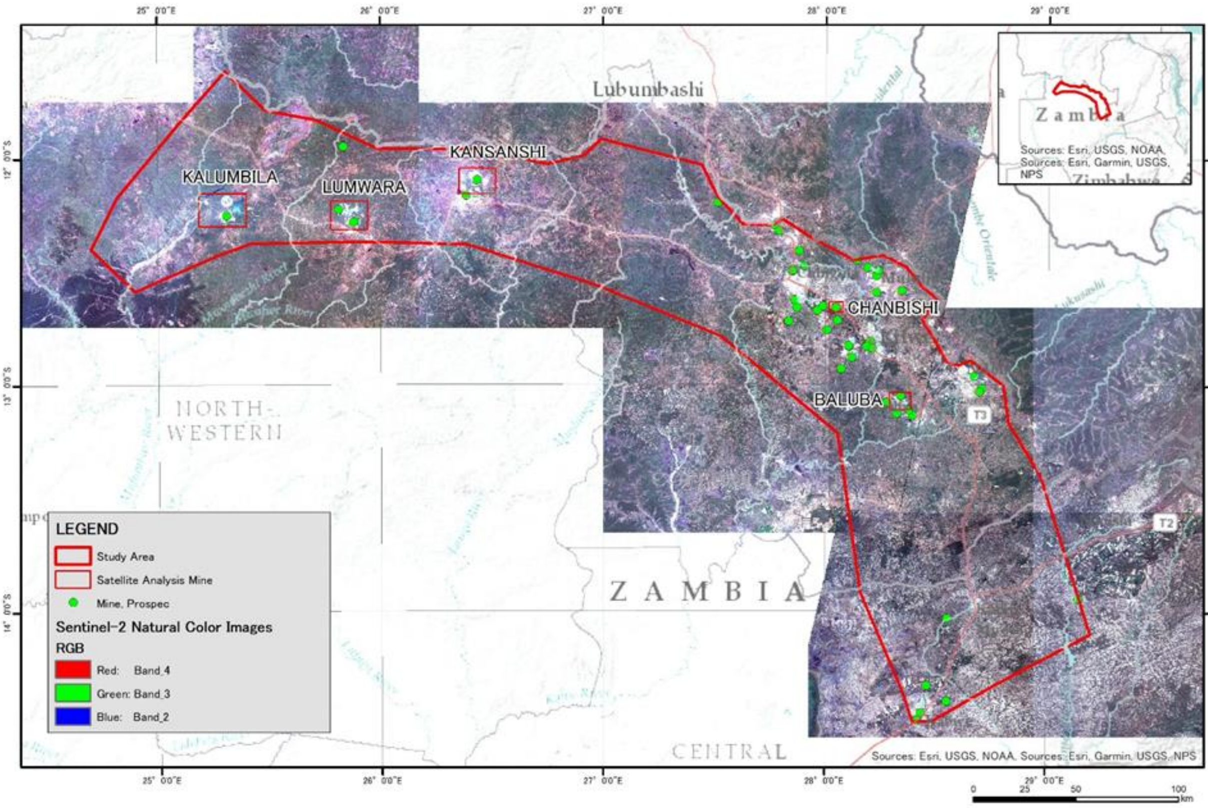


Figure 3-11 Study area for interpretation of mining activities in Zambia

3.6.2 Time series change

Regarding the mining activities in the selected areas, we confirmed how the activities were captured on the images and how the captured situations of activities changed in time series using the actual satellite imagery. The confirmed period is from 2015 to 2023 for each area. The used satellite image is Sentinel-2. True color images of each area are shown in Figure 3-12 to Figure 3-16.

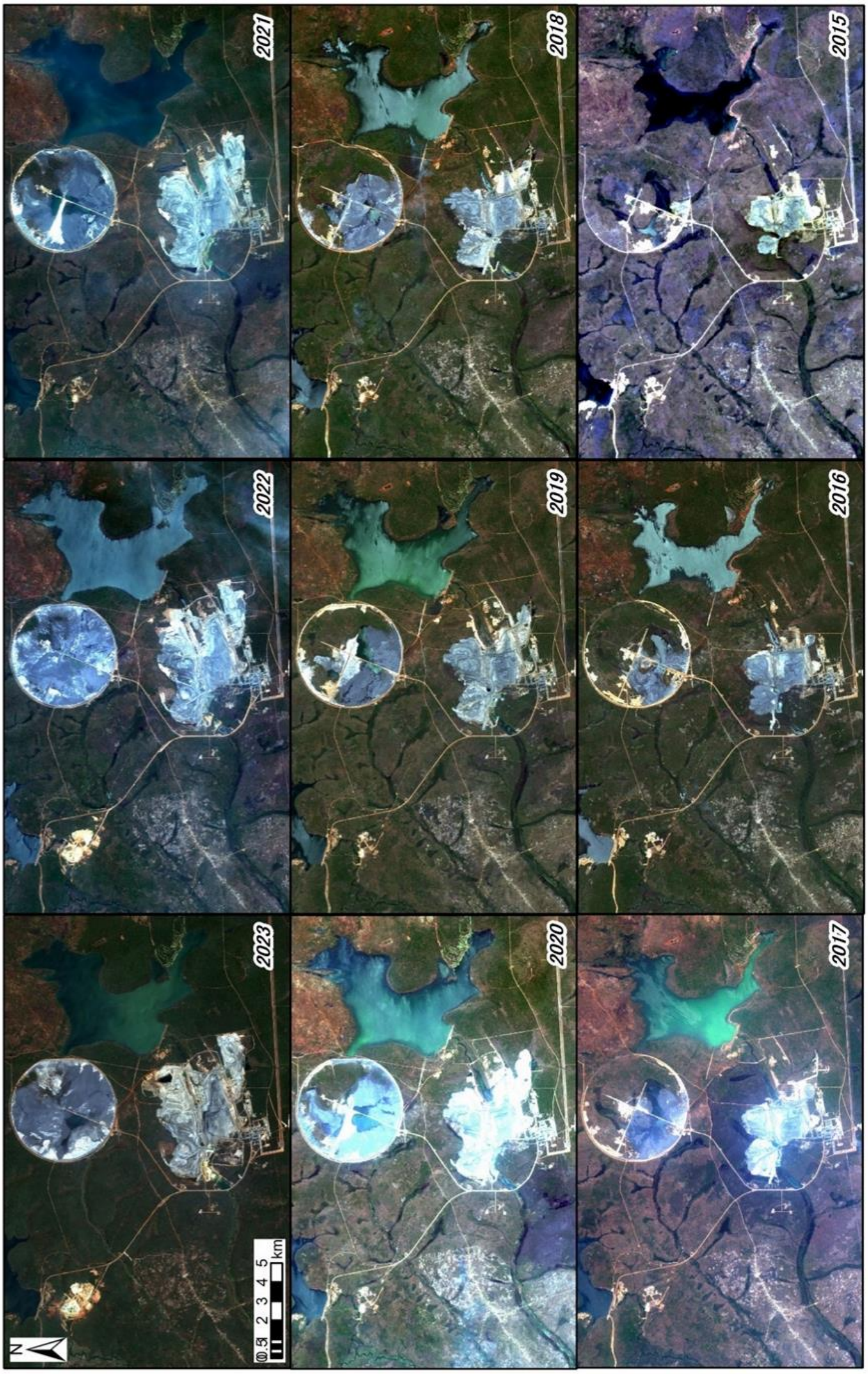


Figure 3-12 Time series change of Sentinel (Kalumbila) Cu Mine (2015-2023)

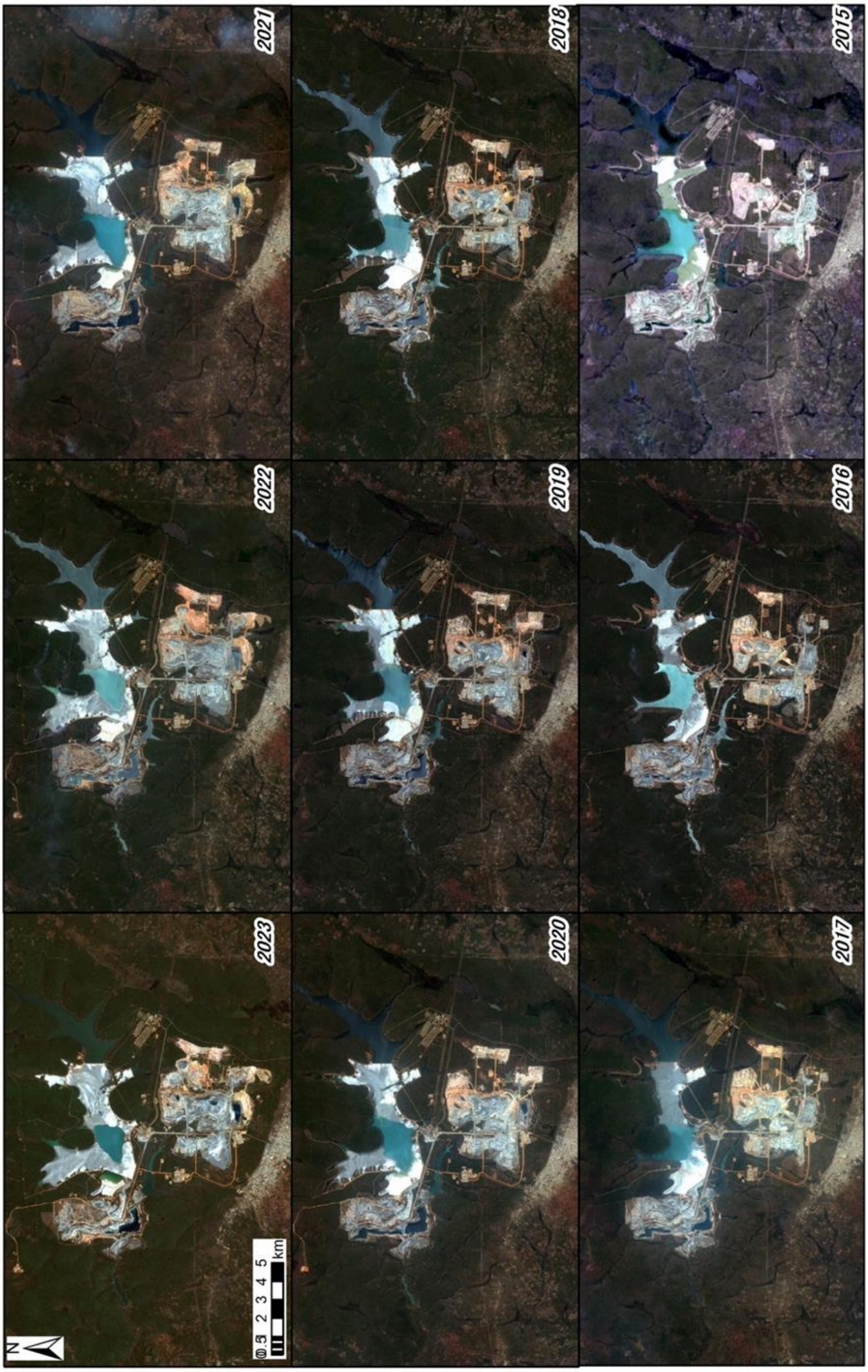


Figure 3-13 Time series change of Lumwana Cu Mine (2015-2023)

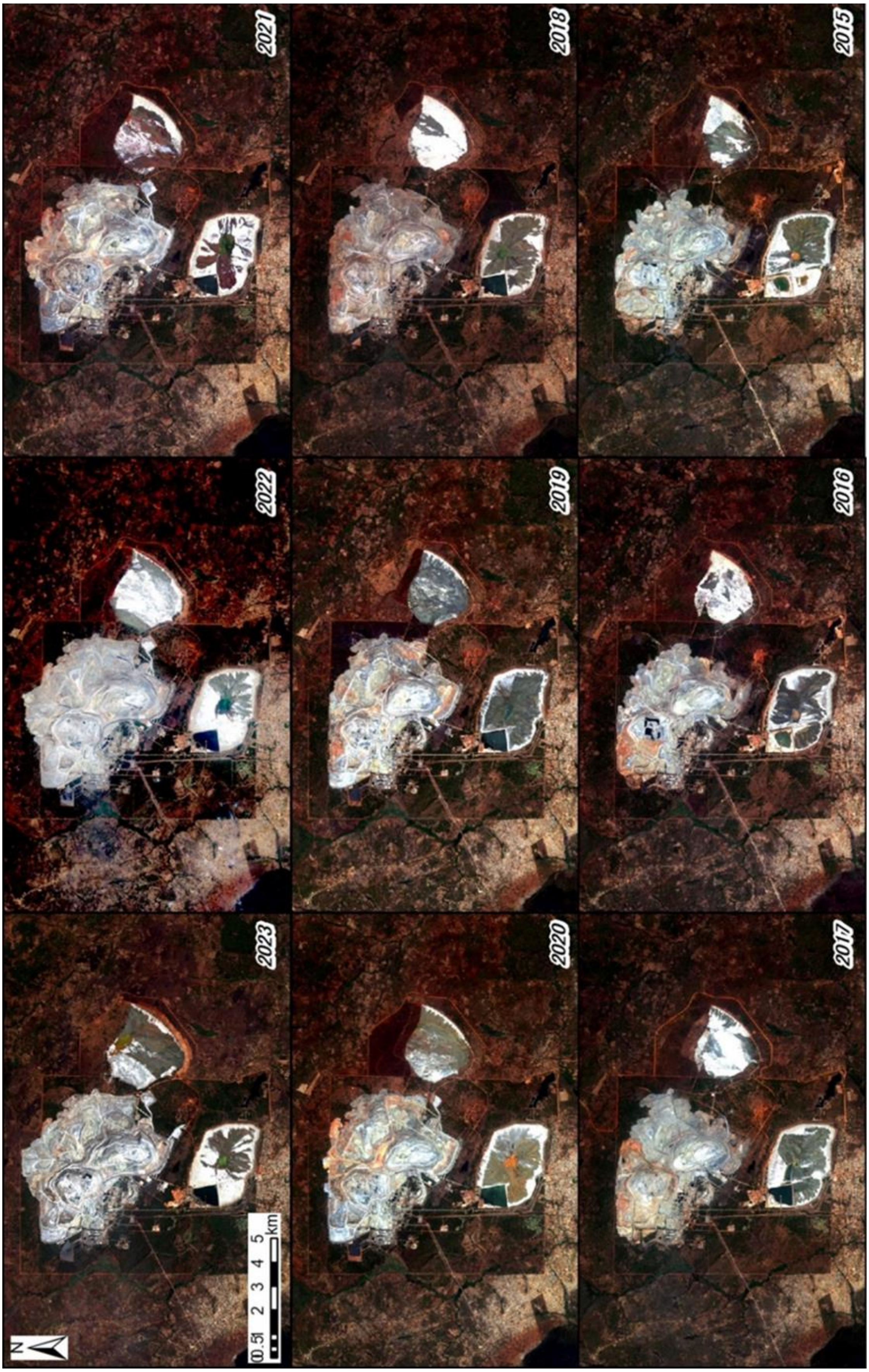


Figure 3-14 Time series change of Kansanshi Cu-(Au) Mine (2015-2023)

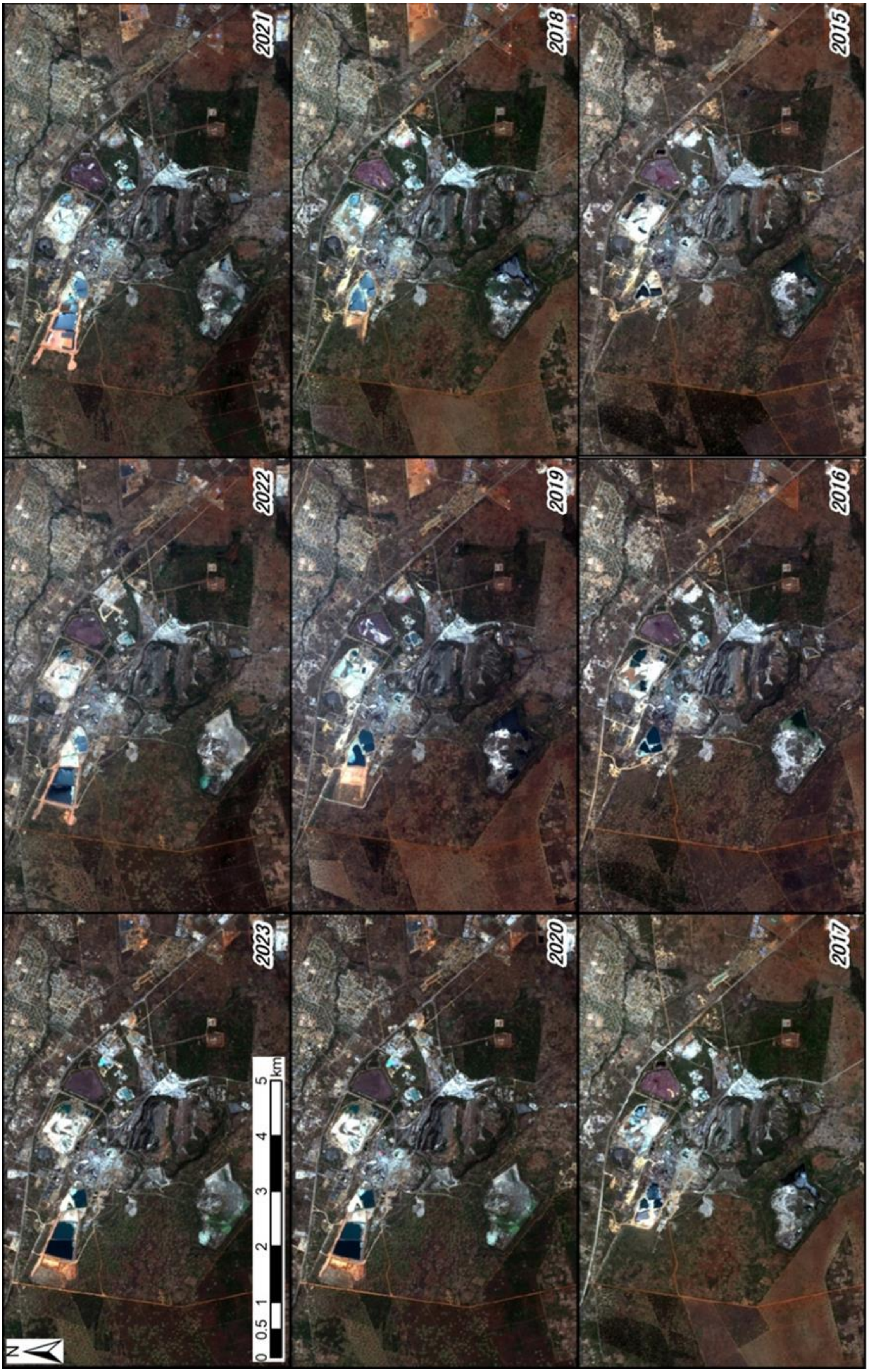


Figure 3-15 Time series change of Chambishi Cu-(Co-Au-Ag) Mine (2015-2023)

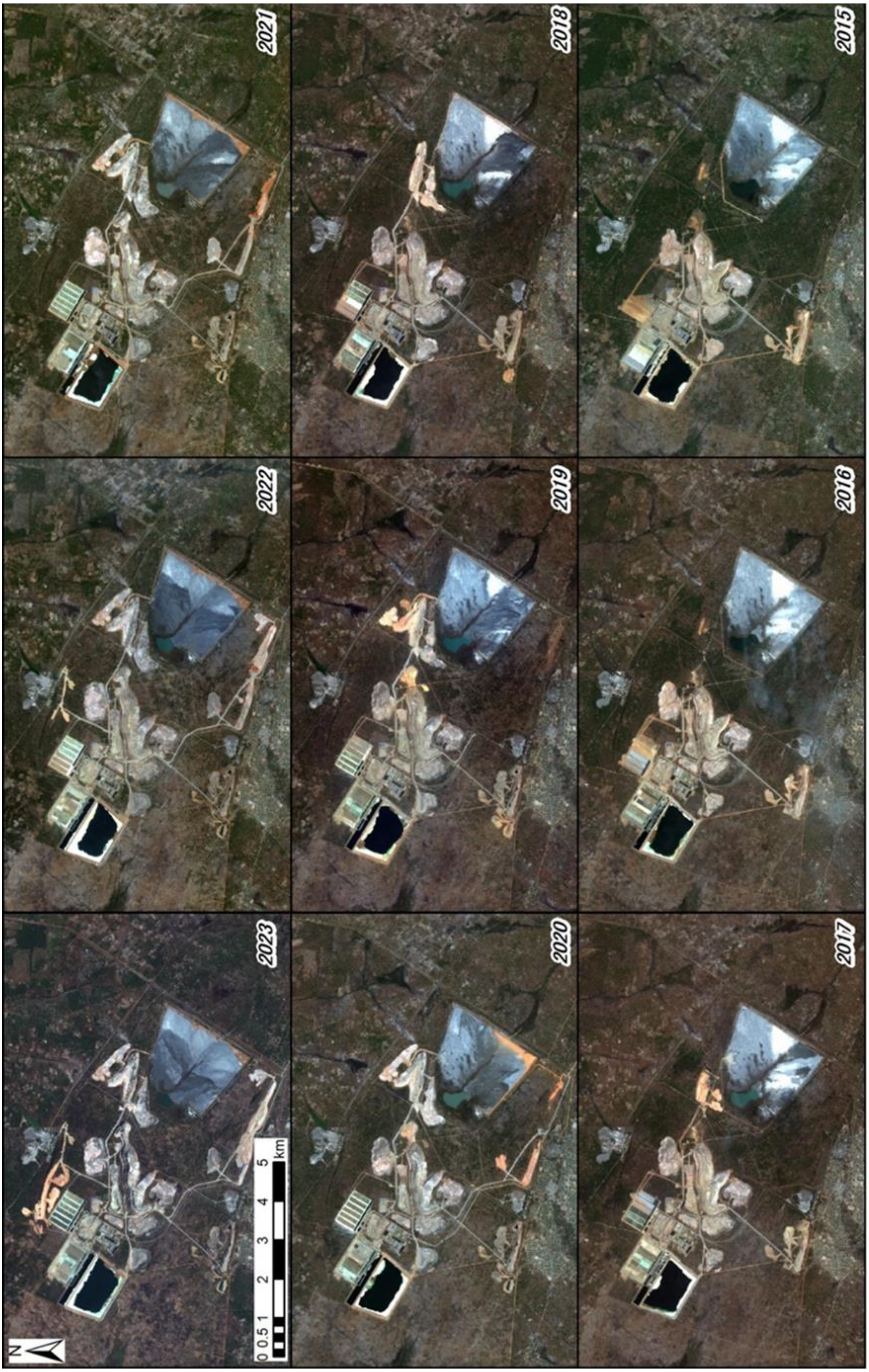


Figure 3-16 Time series change of Baluba Cu-(Co) Mine (2015-2023)

3.6.3 Analysis result

(1) Sentinel Copper Mine

Sentinel Copper mine was granted mining concession in April 2011. Figure 3-17 shows the time-series change diagram of Sentinel mine activity as interpreted from the Sentinel-2 images. The Sentinel-2 true-color image identifies open pits, waste rock dump sites, and possible process plants on the southern part of the mine, and a large circular tailing pond (approximately 5 km in diameter) on the north side. The open pit is vast, with a long diameter of approximately 3 km. It can be interpreted that the pit and the waste rock dump are expanding to the east every year from 2016 to 2023. Similarly, the tailing site shows an expanding area of deposit. There are new activities northwest of the mine after 2022.

Figure 3-18 shows the ratio image and normalized difference vegetation index (NDVI) images of the Sentinel mine. The ratio image was processed to emphasize the presence of clay minerals and iron hydroxide. The active area in the eastern part of the mine is relatively recent and is presumed to be rich in iron hydroxide due to its strong blue. Some areas are presumed to be rich in clay minerals because of their green to yellow coloration, but the overall darkness of the pits and other areas suggests that relatively less altered rock may be exposed. The NDVI image shows a low vegetation activity in the operational area, and it is in high contrast with the area around the mine. There is no evidence of changes in vegetation activity around the mine.

(2) Lumwana Copper Mine

The Lumwana copper mine was granted mining concession in January 2004. Figure 3-19 shows the time-series change diagram of Lumwana mine activity as interpreted from the Sentinel-2 images. An open pit and waste rock dump area, as well as structures presumed to be plant-related facilities, are identified in the southern part of the mine, while a large tailings deposition area extending 6 km east to west is located in the northern part of the mine, with activity to the west of this area. Looking at changes over time, the area of activity continues to expand, albeit gradually, from 2016 to 2023. The expansion is particularly recognizable in the eastern part of the area, which has a characteristic yellowish-brown coloration. At the tailings deposition site, the area of tailings distribution can be seen to expand toward the north. The eastern side of the tailings deposition site is bordered by a dam or embankment.

Figure 3-20 shows the ratio image and NDVI image of the Lumwana mine. The ratio-calculated image was processed to emphasize the presence of clay minerals and iron hydroxide. The active area in the eastern part of the mine is strongly yellow in color and yellowish brown in the true color image, suggesting that it is rich in clay minerals and iron hydroxide at the same time. The NDVI image shows a low vegetation index in the active area and a high contrast around the mine. There is no evidence of a change in vegetation activity around the mine.

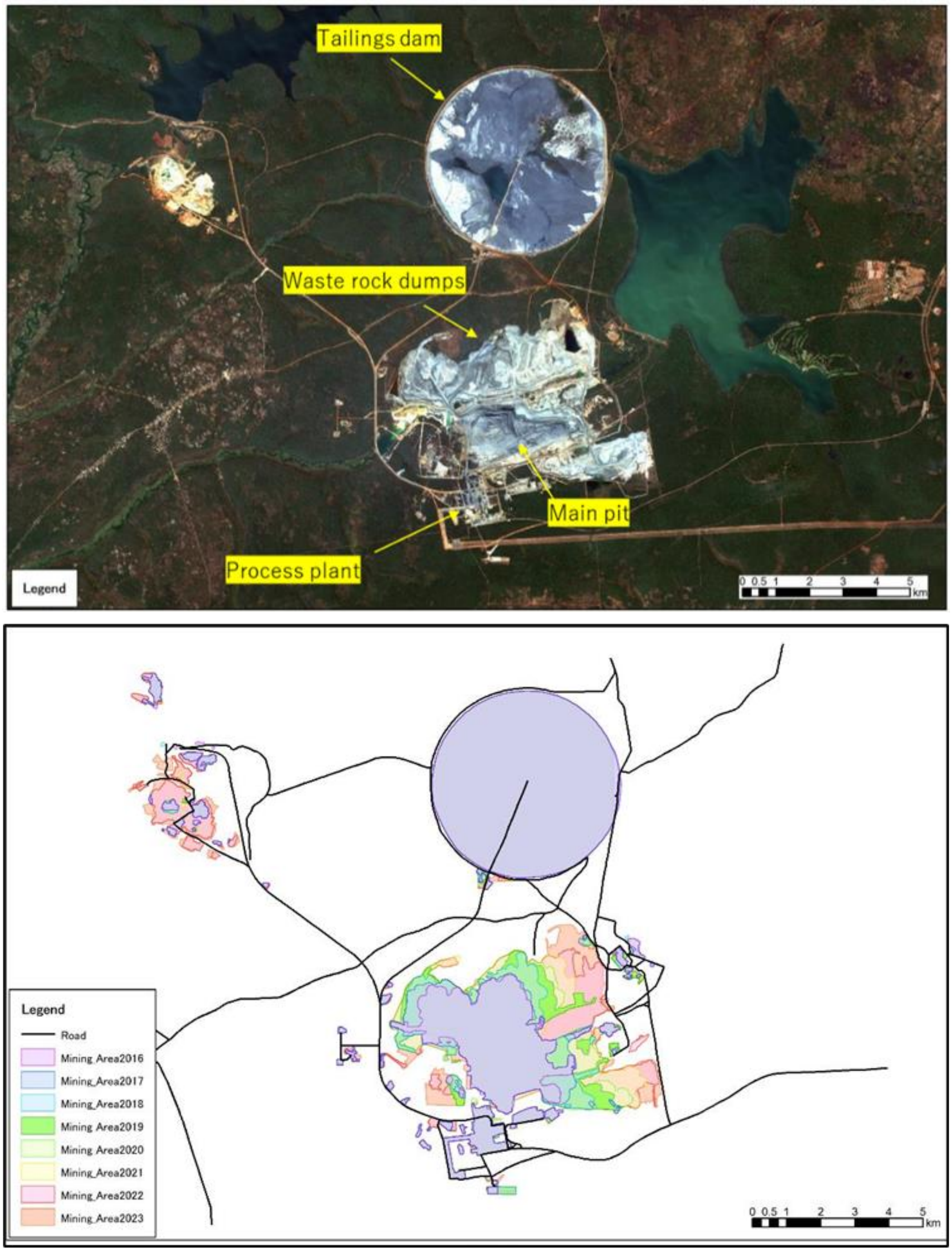


Figure 3-17 Time-series change diagram Sentinel mining operation site from 2015 to 2023

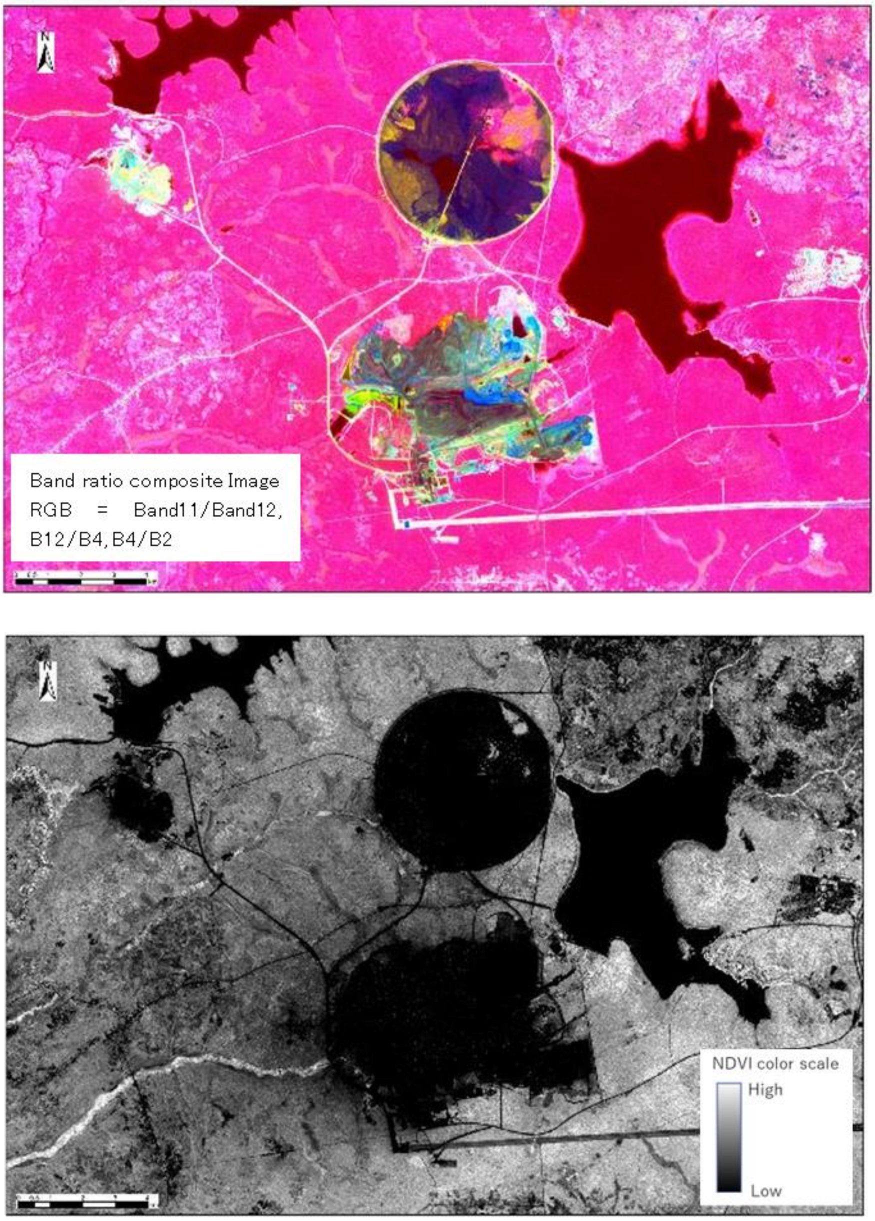


Figure 3-18 Ratio image (top) and NDVI image (bottom) of the Sentinel mine of 2023

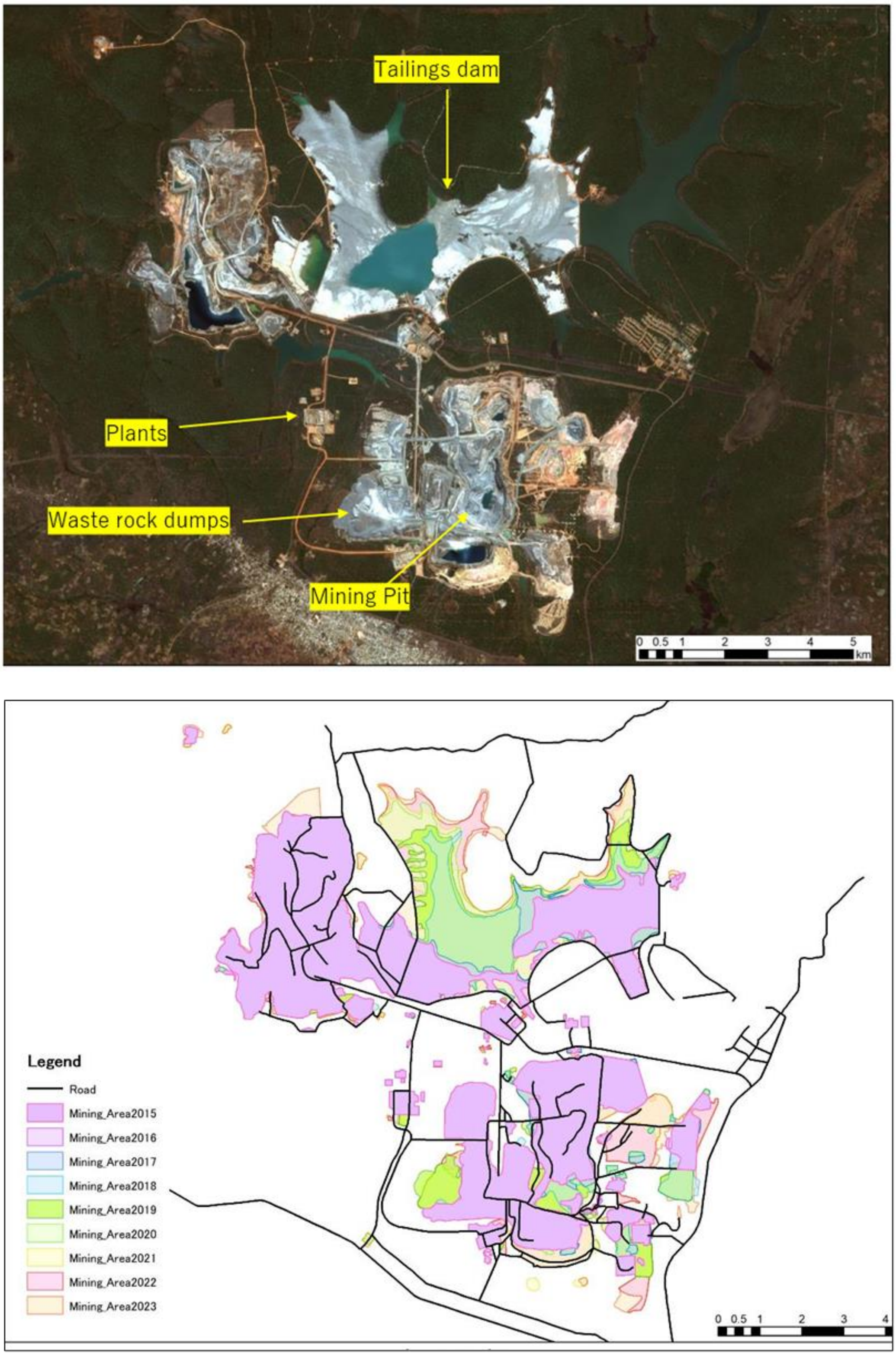
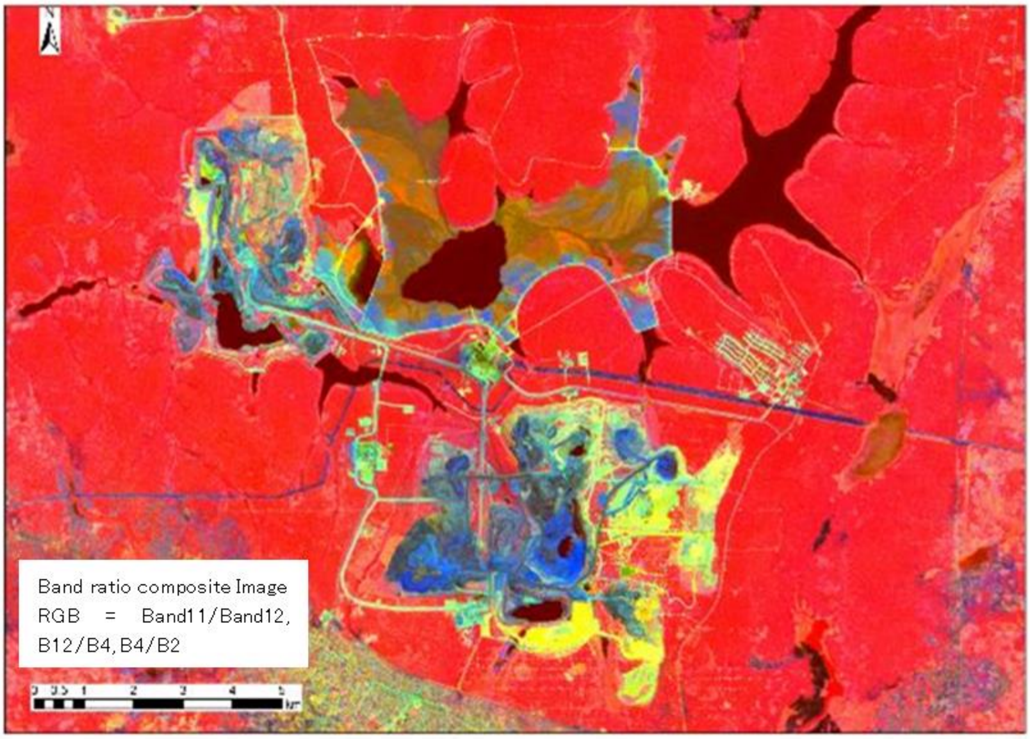


Figure 3-19 Time-series change diagram Lumuwana mining operation site from 2015 to 2023



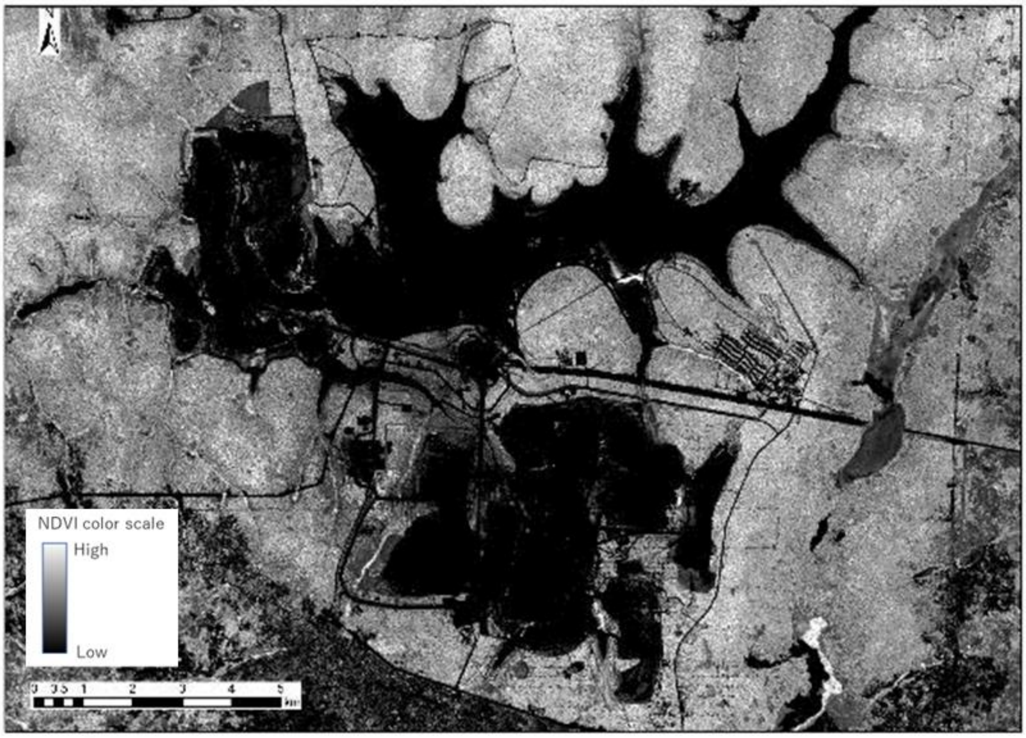


Figure 3-20 Ratio image (top) and NDVI image (bottom) of the Lumuwana mine of 2023

(3) Kansanshi Copper Mine

The Kansanshi copper mine was acquired in March 1997. Figure 3-21 Two large open pits exist in the center of the mine, extending 4 km. A waste rock dump area can be identified to the north and east of the pits, and a number of structures, including plant facilities, can be identified to the southwest of the pits. A large tailings deposition area extends to the south and east. Changes over time show a marked expansion of the waste rock dump area, expanding to the east from 2015 to 2019 and to the north since 2016. The eastern tailings deposition area has gradually expanded in area since 2018.

Figure 3-22 shows the ratio image and normalized vegetation index (NDVI) images of the Kansanshi mine. The ratio-calculated image was processed to emphasize the presence of clay minerals and iron hydroxide. The ratio-computed image shows complex variations throughout the mine, from green to blue in the open pit and waste rock dump areas, and from yellow to red in the tailings deposition areas. The waste rock dump areas are separated by green or blue coloration within a certain coherent area; the NDVI image shows low vegetation index in the operation area and high distinct contrast around the mine. There is no evidence of a change in vegetation activity around the mine.

(4) Chambishi Copper Mine

The Chambishi copper mine was acquired in June 1998. Figure 3-23 shows the chronological evolution of the mine operation area, as read from Sentinel-2 imagery. An open pit and waste rock dump area are located in the southern part of the mine, but no signs of mining progress have been observed since 2015. On the other hand, the tailings deposition area in the northwestern part of the mine has been under construction since 2017 and extended to the west. Other tailings deposition sites are located to the south and north of the mine, but no expansion has been observed since 2015. In the center of the mine, structures that appear to be ore dressing facilities can be identified, including a circular water storage facility (diameter less than 100 m).

Figure 3-24 shows the ratio-calculated and normalized vegetation index (NDVI) images of the Chambishi mine. The ratio-calculated images were processed to emphasize the presence of clay minerals and iron hydroxide. Although no evidence of activity was observed in the visible images for the open pit and the waste rock dump area, the high NDVI of the remaining wall of the open pit and the slope of the waste rock dump area can be interpreted as evidence of inactivity there, if we focus on the NDVI of this area. In the ratio-computed image, the area around the tailings dump area and the ore dressing facility is colored mainly green.

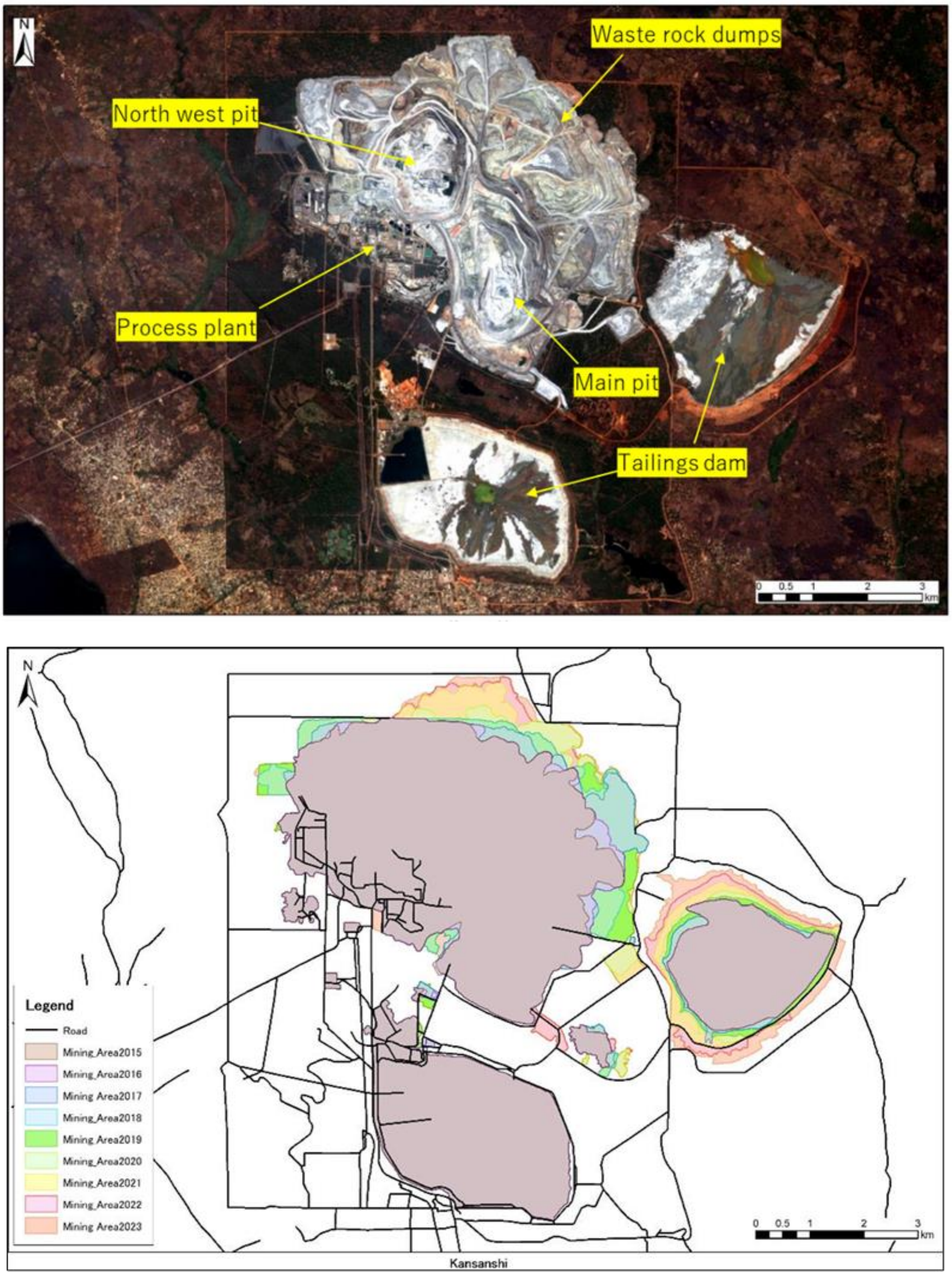
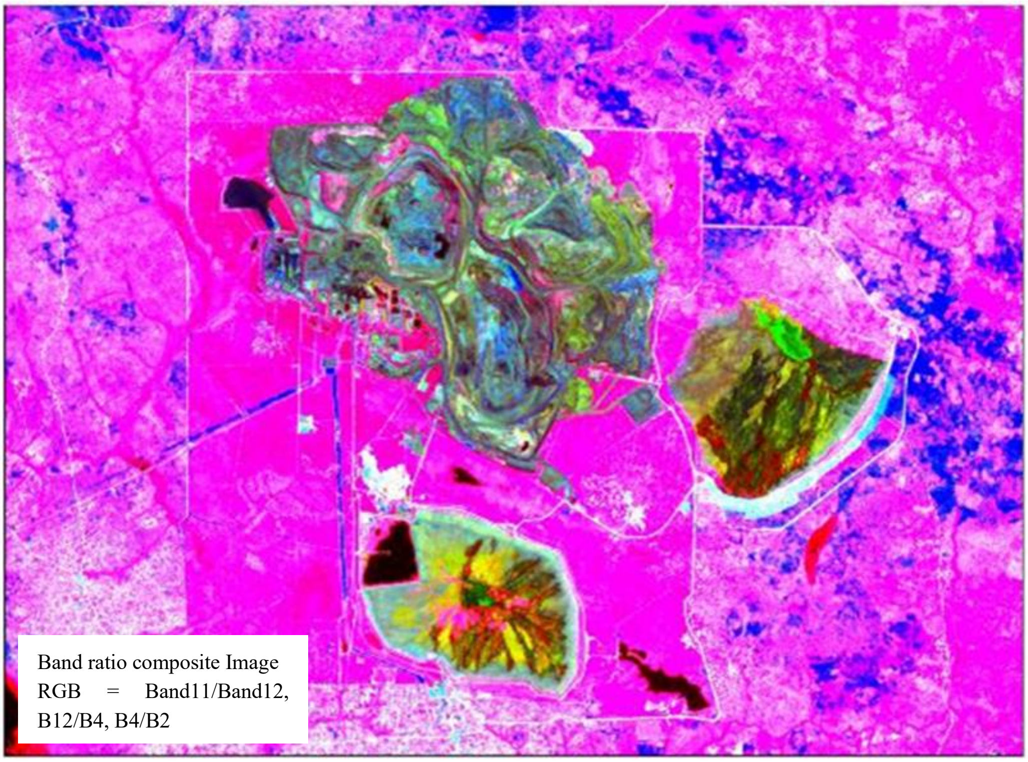


Figure 3-21 Time-series change diagram Kansanshi mining operation site from 2015 to 2023



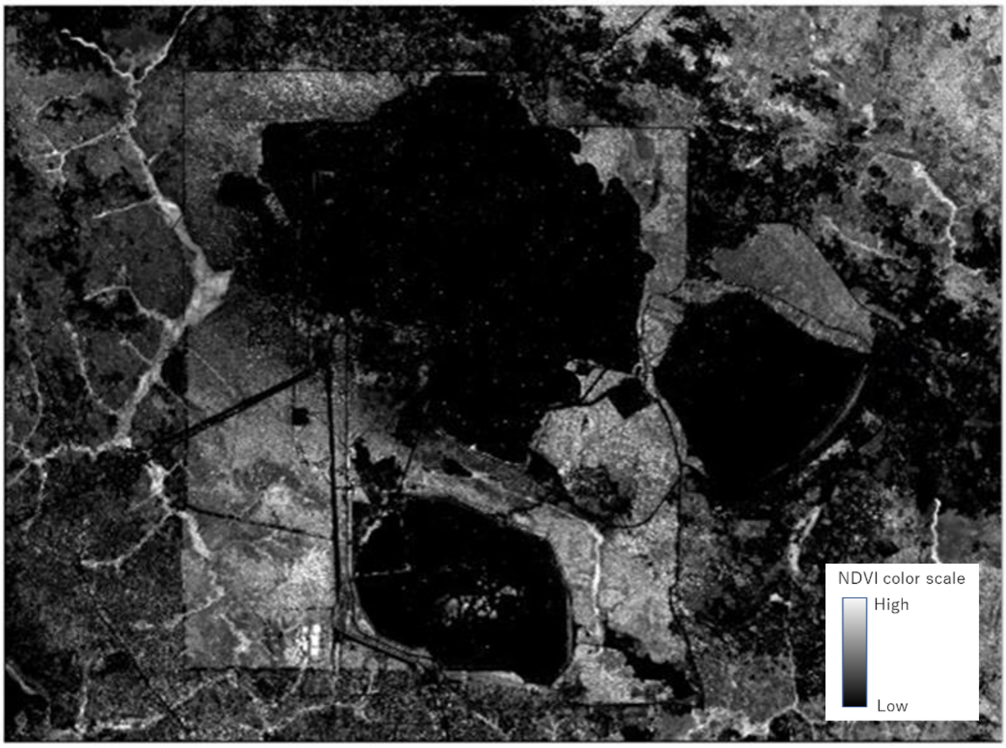


Figure 3-22 Ratio image (top) and NDVI image (bottom) of the Kansanshi mine of 2023

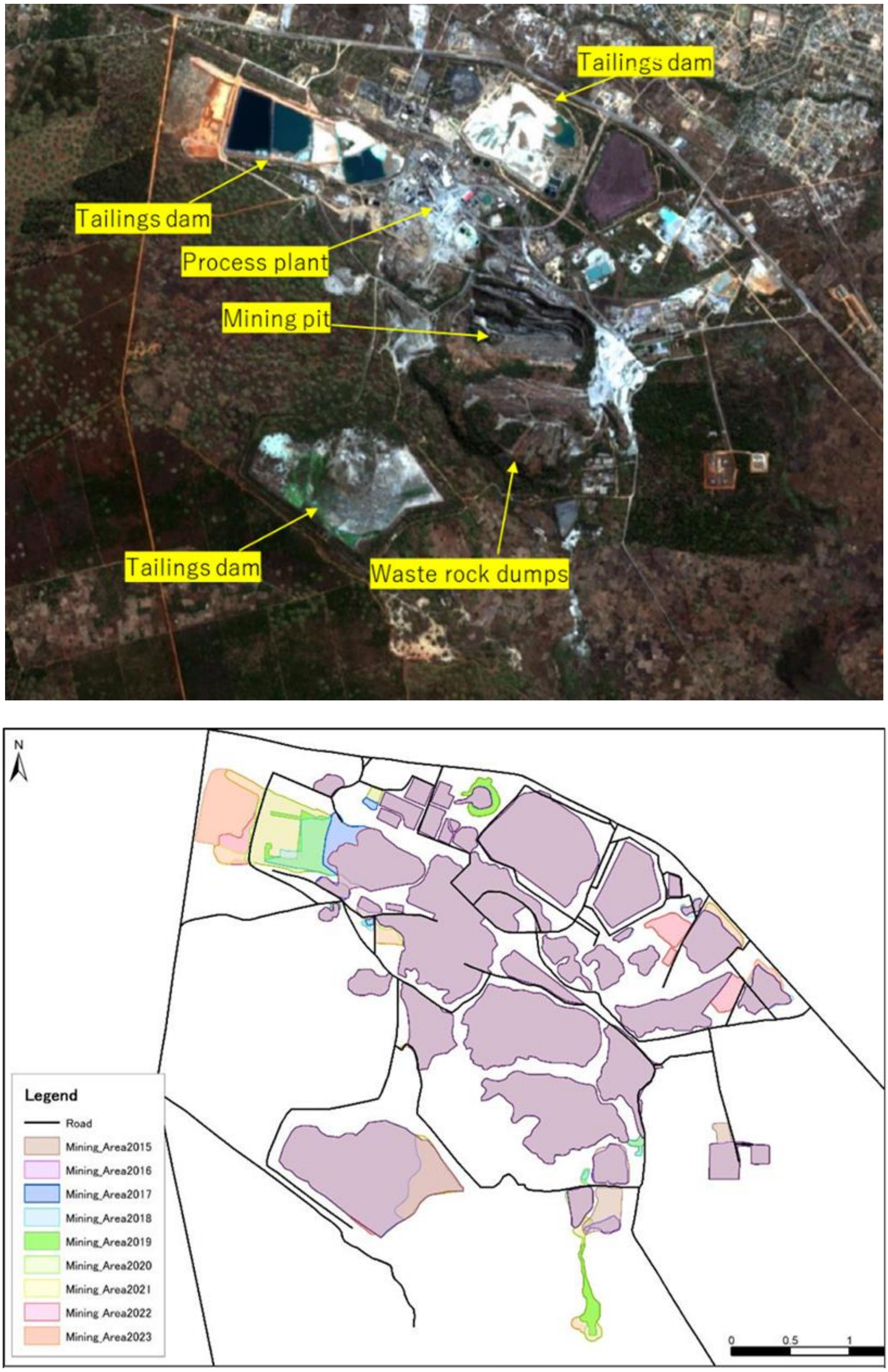


Figure 3-23 Time-series change diagram Chambishi mining operation site from 2015 to 2023

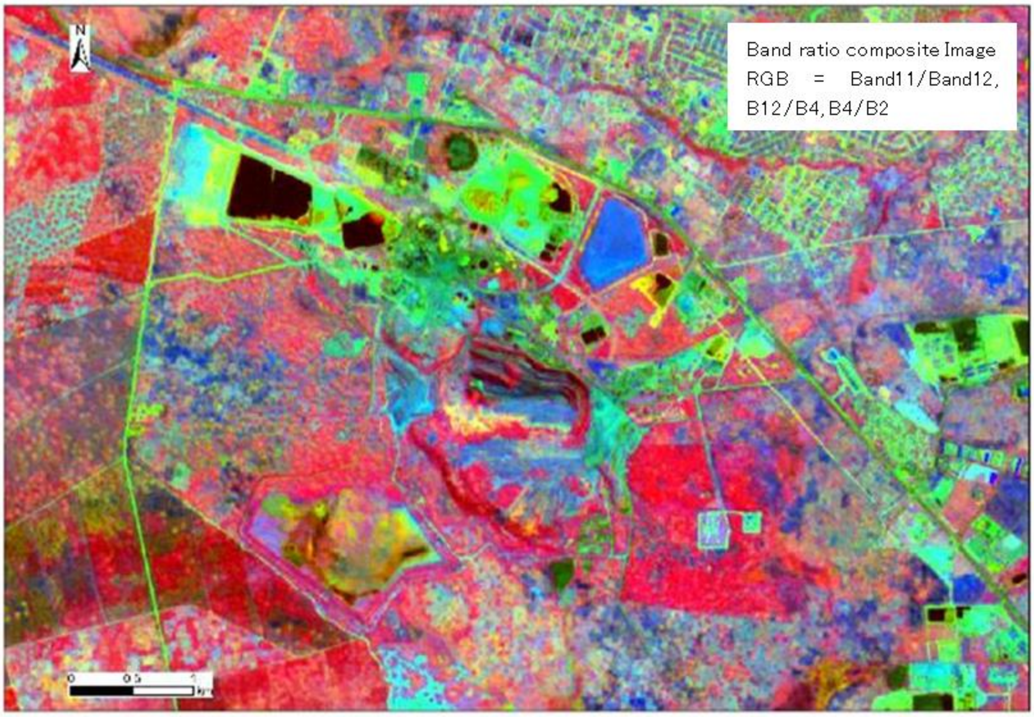


Figure 3-24 Ratio image (top) and NDVI image (bottom) of Chambishi mine of 2023

(5) Baluba Mine

The Baluba copper mine was acquired in January 2004.Figure 3-25 shows the temporal change of the mine operation location as deciphered from Sentinel-2 imagery. Several pits are located along the boundary between the central part of the mine and the southern urban area, all of which are in the form of elongated trenches. The main pit in the center has been mined since 2015, but no changes have been observed since 2022. The western pit in the southern part of the site shows no change after 2019, although the area of waste rock around it can be discerned to expand as mining progresses from year to year between 2015 and 2019. To the east of the pit, new pit excavation began in 2020, and the expansion of the pit and the adjacent waste rock dump area can be discerned until 2023. To the north of the eastern tailings dump area, pit development began in 2017, and in the north-central area, new pit excavation began in 2022. The color tone of the visible image changes over time: the pits and their waste rock immediately after excavation are yellowish brown due to the exposure of topsoil and weathered zone rocks, whereas the image after one year shows a more grayish coloration.

A tailing dam extends across the eastern part of the mine, and a reservoir is located in the western part. On the east side of the reservoir in the center of the mine is a structure that appears to be a ore dressing facility, and a rectangular facility is adjacent to the north side of the reservoir, but its use is unknown.

Figure 3-26 shows the ratio image and normalized vegetation index (NDVI) images for the Baluba mine. The ratio-calculated image was processed to emphasize the presence of clay minerals and iron hydroxide. In the ratio-calculated image, the relatively newly developed open pit and waste rock dump area develop a green to yellowish-green color, which changes to blue over time. While the band combinations in the ratio images emphasize the presence of clay minerals and iron hydroxide,

The NDVI image shows low vegetation index in the operation area and high distinct contrast around the mine. There is no evidence of a change in vegetation activity around the mine.

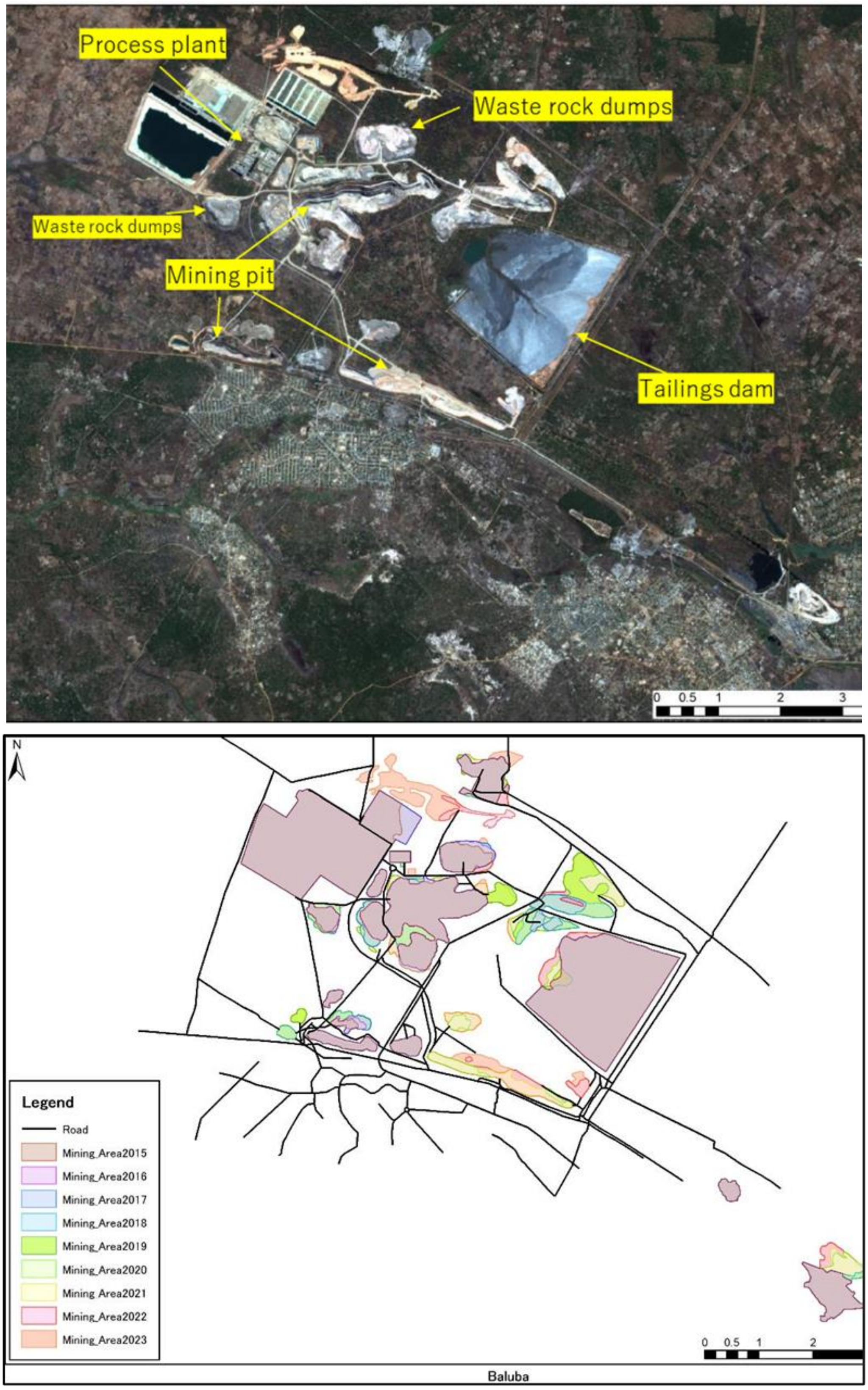
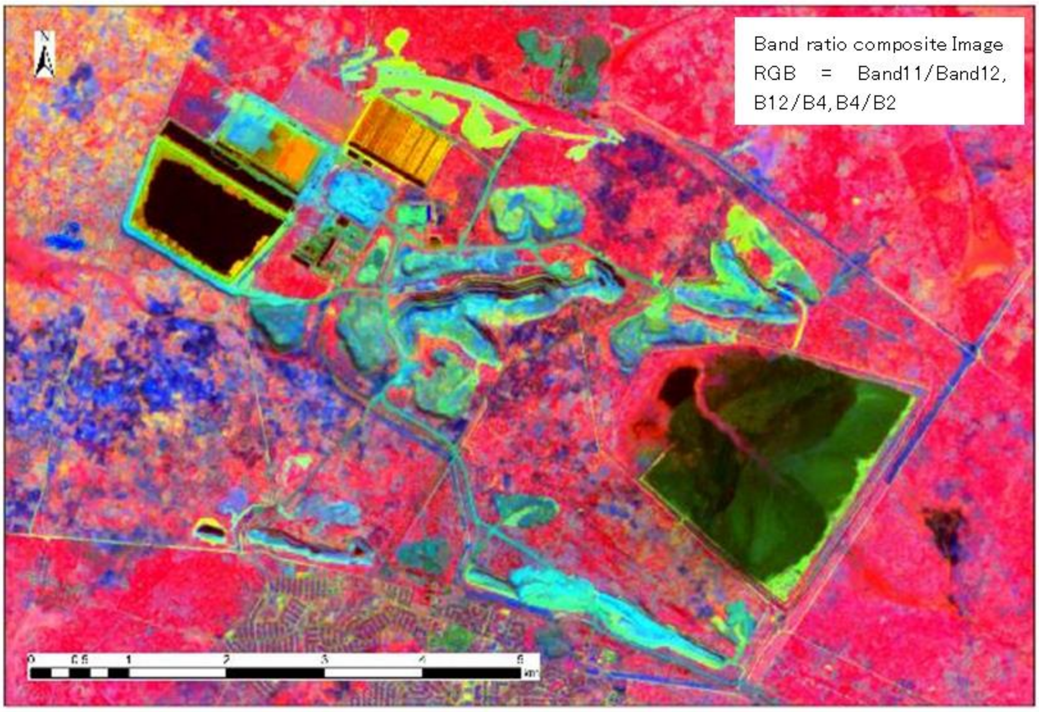


Figure 3-25 Time-series change diagram Baluba mining operation site from 2015 to 2023



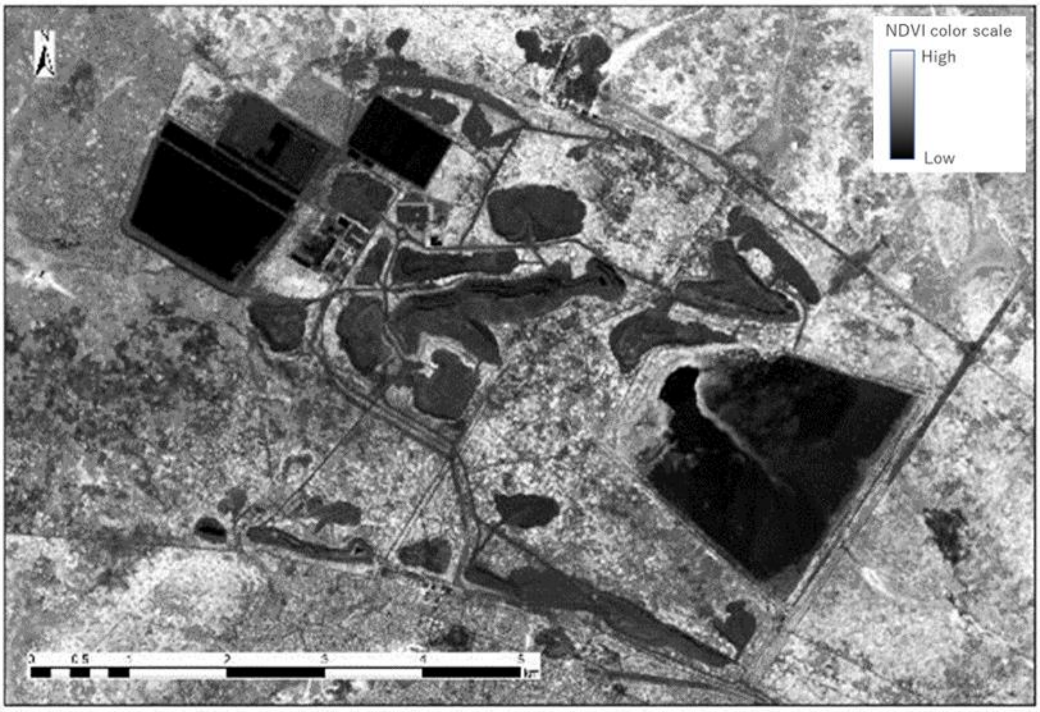


Figure 3-26 Ratio image (top) and NDVI image (bottom) of Baluba mine of 2023

3.6.4 Details of Mining Development Status Assessed

The development status identified from the 2023 Sentinel-2 images for each mine is summarized below.

(1) Sentinel Mine

Open pits, waste rock dump areas, and other above-ground facilities will be located in an approximately 5 km square area.

Mining facilities: ore dressing plant and large buildings, wastewater treatment facilities and reservoirs for wastewater treatment

Surface mining location: Open pit

Ore management sites: Waste rock deposition sites, tailings deposition sites (sedimentation dams), reservoirs (dams)

Roads: access roads to the mine. Roads within the mine.

Others: Power line route (mowing site)

(2) Lumwana Mine

Open pits, waste rock dump areas, and other above-ground facilities will be located in an approximately 5 km square area.

Mining facility: large building

Surface mining location: Open pit

Ore management sites: Waste rock deposition sites, tailings deposition sites (sedimentation dams), reservoirs (dams)

Roads: access roads to the mine. Roads within the mine.

(3) Kansanshi Mine

Open pits, waste rock dump areas, and other aboveground facilities will be located within an approximately 4 km square area.

Mining facilities: ore dressing plant and large building

Surface mining location: Open pit

Ore management sites: Waste rock deposition sites, tailings deposition sites (sedimentation dams), reservoirs

Roads: access roads to and within the mine

(4) Chambishi Mine

Open pits, waste rock dump areas, and other aboveground facilities will be located within an approximately 7 km square area.

Mining facilities: ore dressing plant and large building, wastewater treatment plant (Thickener)

Surface mining location: Open pit (dormant)

Ore management sites: Waste rock deposition sites, tailings deposition sites (sedimentation dams), reservoirs

Roads: access roads to and within the mine

(5) Baluba Mine

Open pits, waste rock dump areas, and other aboveground facilities will be located within an approximately 7 km square area.

Mining facilities: ore dressing plant and large building, wastewater treatment plant (Thickener)

Surface mining location: Open pit

Ore management sites: waste rock deposition sites, tailings deposition sites (sedimentation dams), reservoirs, and demarcated tailings or waste rock storage areas.

Roads: access roads to and within the mine

3.6.5 Monitoring plan of mining development status

Based on the image decipherment and analysis conducted using Sentinel-2 satellite data, the possible monitoring targets and image processing contents can be summarized as shown in Table 3-6.

Table 3-6 Monitoring Details of Mining Development Status

Objects of monitoring	Images to be used (Sentinel-2)	Details of analysis
Confirmation of mining and operation area	- True color images (red: band 4, green: band 3, blue: band 2)	- Visual interpretation (monitoring of operation areas in time series)
Confirmation of the extent of ore processing and other facilities and piling areas within the operation site	- Rationing images (red: Band 11/Band 12, green: Band 12/Band 4, blue: Band 4/Band 2)	- Visual interpretation (monitoring of operation areas in time series)
Characterization of soils, tailings, and piles in the operation site	- Rationing images (red: Band 11/Band 12, green: Band 12/Band 4, blue: Band 4/Band 2) - Index combination images (red: iron hydroxide indicator (Band 4/Band 3), green: water index (MNDWI), blue: vegetation index (NDVI))	- Visual interpretation (monitoring of differences in soil and other properties in time series) - Visual interpretation (monitoring of changes in each index in time series)
Confirmation of the range of environmental impact of soil, water quality, and vegetation inside and outside the operation site	- Rationing images (red: Band 11/Band 12, green: Band 12/Band 4, blue: Band 4/Band 2) - Index combination images (red: iron hydroxide indicator (Band 4/Band 3), green: water indicator (MNDWI), blue: vegetation indicator (NDVI))	- Visual interpretation (time series monitoring of the possibility of dispersal and spillage of tailings, etc. from operation sites) - Visual interpretation (time series monitoring of the possibility of dispersal and spillage from the operation site according to changes in each index)

The actual acquisition, processing, and analysis of image data for monitoring should be considered based on the capacity of each sector in terms of human resources, infrastructure, etc. However, at present, this can be done free of charge, including GIS analysis, with an ordinary PC and an internet connection in offices of the sector.

3.6.6 Issues

The challenges for the mining industries and environmental administrations in the monitoring of mining activities using satellite image data can be summarized as follows.

・The technical personnel of the mining and environmental sector in the government do not have experience in processing and analyzing satellite data in the case of monitoring mining activities, and therefore they require the training specific to the objects of the monitoring and the target of the extraction.

・However, to perform monitoring systematically, data management based on GIS is required, so it is necessary to establish a system including a monitoring system within the office in the sector.

3.7 Mining development potential

Mineral types with high potential for mining development in Zambia consist of copper, cobalt, and nickel, and the potential areas are in the Copperbelt. In addition, exploration activities for rare metals such as manganese and vanadium have been conducted, but to a limited extent.
Although the activity area of exploration and development has shifted from central part to the western part of the Copperbelt, once development begins in the western part, the availability of existing smelters and other facilities in the central Copperbelt and the availability of extended power infrastructure mean that once water is secured, operations in the western part of Copperbelt can be completed in a relatively short period of time.

3.8 Study by country visit

3.8.1 Collection of information during the first field survey

During the second round of the first field study, the following relevant organizations in the capital Lusaka were visited from 11 to 13 October 2023 to collect information and conduct interviews.

・Geological Survey Department, Ministry of Mines and Minerals Development (MMMD)
・Cadastre Department, MMMD
・Mines Development Department, MMMD
・Zambia Environment Management Agency (ZEMA), Ministry of Green Economy and Environment (MGEE)

Information obtained in Zambia were as follows.

① Cooperation with JICA projects

Both Ministry of Mines and Mineral Development (MMMD) and Ministry of Green Economy and Environment (MGEE) expressed a high level of interest in the project contents, especially in monitoring through satellite image, and mentioned that they would cooperate with us in providing information.

When asked about the benefits of providing information from MMMD, we responded that JICA would provide, in the present project, the technologies of satellite data analysis and mine monitoring methodology. The counterpart expected us to provide training in the project, but we confirmed that it would be offered in a separate program. Zambia Environmental Management Agency (ZEMA) said that an official letter from JICA was required to provide information.

Due to the almost complete absence of mining-related JICA projects to date (background of sufficient development in the mining industry), JICA's presence in the mining sector seemed low.

② Mine management

MMMD itself manages the mine, Geological Survey Department (GSD) manages the exploration license, and Mining Cadastre Department (MCD) manages the mining license

The number of mining licenses is approximately 120 of large scale (maximum area of 25,000 ha), 500 of small scale (maximum area of 400 ha), and 300 ASMs (maximum area of 6.6 ha). Each license has a different expiration date and number of extensions. The expiration date and number of extensions for exploration licenses in each category are also different. The licenses are managed in cloud data, and data can be uploaded and checked online. These license data are not open to the public.

Periodic activity reports (annual or quarterly) submitted by the mineral rights holder are also stored in the same cloud as the licenses.

③ Monitoring status of mining activities

GSD inspects the areas of exploration licenses and MCD inspects the areas of mining licenses. Both are visiting directly the site to check the current situation. GPS is used to check the extent of licenses (there was a comment that it would be very effective if the extent of activities could be monitored by satellite image). Mine Safety Department (MSD) is conducting inspection for safety.

ZEMA conducts environmental inspections. Normally, inspections are conducted once or twice a year, but inspections are conducted more frequently for mines that are causing environmental problems (Problematic). As for ASM, it also conducts inspection of transboundary mining out of the license area.

④ Status of the use of satellite data and utilization technology

GSD uses ASTER data for mineral resource exploration to extract information concerning structure, lithology, alteration, etc. Many of the technicians were sent to the training at Remote Sensing Center of JOGMEC Botswana and many of them have knowledge of remote sensing (Note: The Center invites several southern African countries each year for remote sensing training. Other departments of MMMD do not seem to use satellite data on a daily basis.

At ZEMA, IT department is using it, but the details are unknown.

⑤ Drone

MMMD does not use drones. However, MCD has a plan to use them.
ZEMA uses drones in order to check changes of the color in river water, and transboundary crossings, etc.

⑥ Status of ASM (artisanal/small-scale *mining*)

MMMD administers exploration and mining licenses of ASM. There is a large amount of (illegal) manganese ASMs in northern Zambia. MMMD recognizes the importance of ASM (including its potential) and has begun to take measures to manage it for the national interest through legal control and education of relevant personnel.
ZEMA is concerned about illegal ASM mining and environmental pollution. In particular, ZEMA is aware of the use of mercury by ASM for gold mining, which is causing environmental problems.

⑦ Mining-related work by Ministry of the Environment

ZEMA reviews EIA prior to granting mining licenses. ZEMA conducts periodic environmental inspections after the start of mining operations, and conducts a timely inspection in the event of environmental pollution or other problems at the mine.

⑧ Status of assistance from other countries

The British Geological Survey is providing assistance of geological mapping to MMMD.
The training sites are mostly in China, and also in the Netherlands, and Sweden.

3.9 Conclusion and proposal

This chapter has summarized information on the general situation in relation to the mining activities in Zambia, the situation of the relevant organizations of the MMMD and the MGEE, which are responsible for the management and supervision of mining activities, and the possibility of monitoring of mining activities.

Based on the confirmation results, the following issues were identified for each sector related to the mining activities and the implementation of satellite image analysis for the monitoring.

1) Issues in the relevant organizations of the MMMD

- The organizations are required to ensure reliable and efficient implementation of the verification and supervision in the mining activities, and to develop and build a management system for the implementation.
- The budgets for securing the professional human resources and the infrastructure development and preservation for the research and development of geological and mineral resources information are required.

2) Issues in the relevant departments of the MGEE

・Environmental government side needs to secure specialized personnels and a budget for the identification and supervision of environmental impacts of mining activities and mine-related pollutions.
・Efficient implementation for the verification and supervision of various environmental impacts of mining activities based on the related guidelines, which should be arranged, are required.
・The status of various types of pollution, including illegal ASM, related to mining activities must be confirmed and monitored, and the countermeasures must be implemented or a policy for countermeasures must be formulated.

3) Issues in processing and analyzing satellite image data for the monitoring mining activities
・The technicians of the mining and environmental sector in the government do not have experiences in the processing and analyzing data using satellite image data in the case of monitoring for the mining activities, so relevant technicians need to be trained specifically for the monitoring purposes and extraction targets.
・By using Sentinel-2 for the monitoring using satellite images, special materials and equipment for the data processing and analysis are not required. However, the data management system including a monitoring system based on GIS is required to perform monitoring systematically.

Based on the above situations, the recommended support is as follows.

a) Project name: " Support for the identification of environmental and social impacts from mining activities and the capacity building for the administrative management "

Target institutions: relevant departments of the MMMD and the ZEMA

Outline of support: The support will address mining-related pollution in Zambia, which is still unclear, by identifying contaminated areas that have a particularly large impact on the environment and society, clarifying the scope and scale of the pollution, and developing future countermeasures. Furthermore, it will consider remote monitoring methods for contaminated areas and build management / monitoring methods and systems to contribute to reducing the occurrence and spread of new contamination in the future. At the same time, this will lead to strengthening of the reliable and efficient management capabilities in the administrative agencies.

Contents: i) Review of the relevant information on mining-derived pollutions, ii) identification of the pollution affecting the environment and society around the operation sites such as soils, rivers, peoples and livestock, etc., iii) implementation of the environmental impact assessments and countermeasure studies in the test areas, iv) considerations of the remote monitoring methods using satellite data for pollutions and other impacts caused by the mining activities, v) considerations and establishment of the image processing, analysis procedures and methods of site inspection in relation to the remote monitoring of the pollutions, vi) considerations and establishment of a system for the coordination and division of activities among the mining-related department and the environment-related department for pollution monitoring and control, and vii) implementation of the related training programs.

b) Project Name: " Support for the establishment of an efficient management and supervision system for the mining activities "

Target institutions: relevant departments of the MMMD and the ZEMA

Outline of Support: To ensure an efficient and reliable management and supervision of the mining activities covering hundreds of large-scale to small-scale mining operations, the project will support the establishment of an efficient management and supervision system by linking the remote monitoring using satellite data and site inspections. Remote monitoring using satellite data will also cover pollution monitoring, and the system will be a management and supervision system that coordinates the mining and environmental sectors.

Contents: i) Review of the management and supervision items and contents, ii) review and establishment of the image processing and analysis procedures for the monitoring of mining activities, iii) review and establishment of the monitoring and site inspection procedures related to the control and supervision, iv) implementation of the site inspection and supervision according to the developed procedures, and v) implementation of related training programs.

4. Study result: Madagascar

4.1 Basic information

4.1.1 Natural and social environment

Madagascar consists of the island of Madagascar, the world's fourth largest island, and its surrounding islands in the Indian Ocean, southeast of the African continent. Madagascar is long from north to south, measuring approximately 1,600 km from north to south and 570 km from east to west. The total land area is 587,041 km^2, the total population is approximately 30.6 million, and the official languages are Madagascan and French. The capital is Antananarivo, located almost in the center of the island. The natural resources are rich and unique, and the country is famous for its many endemic species of flora and fauna. As for mineral resources, it produces nickel, chromium, cobalt, ilmenite, graphite, and gemstones.

Figure 4-1 Map of Madagascar

The main industries are agriculture, forestry, fisheries, mining, and tourism. The share of major industries in GDP is about 23% for agriculture, forestry, and fisheries, 4.8% for mining, and 7% for tourism. Major trading partners include France, USA, Germany, China, and the Netherlands for exports, and China, India, France, the United Arab Emirates, and South Africa for imports. Major donors are USA, France, Germany, Japan, and Norway. (Website; World Bank)

Since gaining independence from France in 1960, the political situation has not always been stable, with turmoil occurring with each presidential election. In March 2009, rebels seized power with the support of the military, forming an interim government that did not follow the law. Foreign countries did not approve it and immediately suspended economic aid and investment, and the membership of AU (African Union) and SADC (Southern African Development Community) was also suspended, resulting in continued economic turmoil and stagnation. After democratically elected president assumed the office in 2014, IMF support began in 2016, and support from other countries resumed.

The Madagascan people are believed to have their roots in the Malay people of East Asia, and this indigenous population accounts for about 90% of the current population, with its strong influences remaining in various cultures. The staple food is rice, and per capita rice consumption is about twice that of the Japanese. As for religion, about 58% of the population is said to be Christian, about 39% traditional religion, and about 2% Muslim.

4.1.2 Topography

The topography of Madagascar can be divided into three areas: the Central Highlands, a plateau extending from south to north, and the lowlands on the east and west sides of the plateau. The Central Highlands is roughly equivalent to a range of 800 to 1,800 meters above sea level, with some mountains reaching over 2,000 meters, the highest peak being the 2,876-meter-high Mount Maromokotro in the northernmost part of the island. Antananarivo, the capital, is located in the center of the Central Highlands at an elevation of 1,280 meters.

The watershed is located on the eastern side of the Central Highlands, extending from south to north. Therefore, rivers flowing into the Indian Ocean on the east side are short and have steep slopes. On the other hand, rivers flowing into the Mozambique Channel on the west side are long and have gentle slopes.

The eastern coastline is straight, while the western coastline is uneven. In the Indian Ocean on the east side, the water depth immediately deepens from the coast, reaching a depth of 5,000 m.

Figure 4-2 Sentinel-2 satellite image of Madagascar

The volcanic islands of Reunion and Mauritius are located 700 km offshore to the east. The Mozambique Channel at the west is also deep, reaching depths of 2,000 to 4,000 meters. The narrowest part of the Mozambique Channel is about 400 km wide.

4.1.3 Vegetation

Madagascar is considered a biodiversity hotspot, famous for its rich diversity of flora and fauna, as well as its large number of endemic species. This is deeply related to geology and plate tectonics (see below for details). Madagascar island was separated from the African continent and the Indian subcontinent about 70 million years ago, and has remained an isolated island up to now. As a result, organisms evolved independently on the island without continental influence, resulting in a large number of endemic species. It is estimated that more than 80% of Madagascar's plant species are endemic species that cannot be found outside of Madagascar.

As for climate classification, the coastal lowlands on the east and west sides of the island are tropical, the Central Highlands is temperate, and the coastal lowlands in the southwest are arid. The vegetation corresponds to these climatic divisions. In the arid zone in the southwestern part of the island, unique plants adapted to the arid climate grow. The Central Highlands and the western coastal lowlands are savannas, consisting of sparse forests, shrubs, and grasslands. The eastern escarpment of the Central Highlands and the eastern coastal lowlands (the green zone of the eastern part in Figure 4-2) consist of tropical rainforest. Mangrove forests are present along the western coastline. The baobab tree, which has become synonymous with Madagascar, is found in the western, southern, and northern regions of the island. 11 species of baobab have been identified worldwide, 8 of which are endemic to Madagascar alone. The tropical rainforests in the northern part of the island are home to ebony and rosewood, which are high-grade timbers, and are designated as endangered species, and their logging is prohibited. The island produces the largest amount of vanilla in the world, with a share of about 44%.

The total forest area is 124,000 km^2, accounting for 21.3% of the total land area. The island used to be almost completely forested, but the deforestation due to slash-and-burn agriculture and charcoal burning has resulted in the loss of a large area of forest, especially in the Central Highlands, which has had a significant impact on the ecosystem and has become an environmental problem.

4.1.4 Infrastructure

Madagascar has two separate rail lines (northern line and southern line) with a total length of 855 km. Both lines run from major cities on the Central Highlands to port cities on the east coast. The northern line consists of a main line from Antsirabe, the third largest city (south of Antananarivo) to Toamasina, a port city on the east coast, via Antananarivo, and a branch line from Moramanga to Ambatondrazaka. The northern line is operated by Madarail and consists of freight and passenger traffic. The southern line connects Fianarantsoa, the fifth largest city in the southern part of the Central Highlands, with the port city of Manakara on the east coast and is used for passenger traffic. These were built in the 1920s and 1930s and are extremely deteriorated. For the logistics in Madagascar, road transport is predominant.

The road network covers the entire country, but there are no high-standard roads. There are about 60 national roads, about half of which are paved roads with one lane on each side, and the rest are unpaved. The roads in the Central Highlands are full of ups and downs and curves, making travel surprisingly time-consuming.

The only international airport is Ivato International Airport, located in the capital, with direct flights to France, South Africa, Kenya, Ethiopia, Mauritius, and Reunion. There are 10 routes of domestic flights, based at Ivato International Airport.

Major ports with container terminals are located in Toamasina on the central east coast, Toliara and Tolanaro in the south, and Mahajanga and Antilanana in the north. Toamasina is a hub for international port logistics due to its proximity to the capital city, but the other ports are underutilized due to land access problems. JICA is supporting the development of a port in Toamasina.

4.1.5 Environmentally Protected Areas

Madagascar has three types of environmental reserves: Special Reserves, Strict Nature Reserves, and National Parks, with respectively 13, 2, and 25 sites. In addition, there are five Ramsar Convention sites, five Biosphere Reserves, and 12 UNESCO World Heritage sites (some of which overlap with national parks). The country is also actively promoting environmental activities to preserve the ecosystem by protecting the endemic flora, fauna, and natural landscapes that are unique to Madagascar.

It is estimated that Madagascar was first inhabited about 2,300 years ago, and more than 90% of the primary forests have been lost since then. Despite recent efforts by the government, the forests continue to decline. Deforestation caused by human activities not only affects the ecosystem, but also increases the risk of disasters due to gully erosion and soil runoff at several sites caused by deforestation, which has become a further environmental problem.

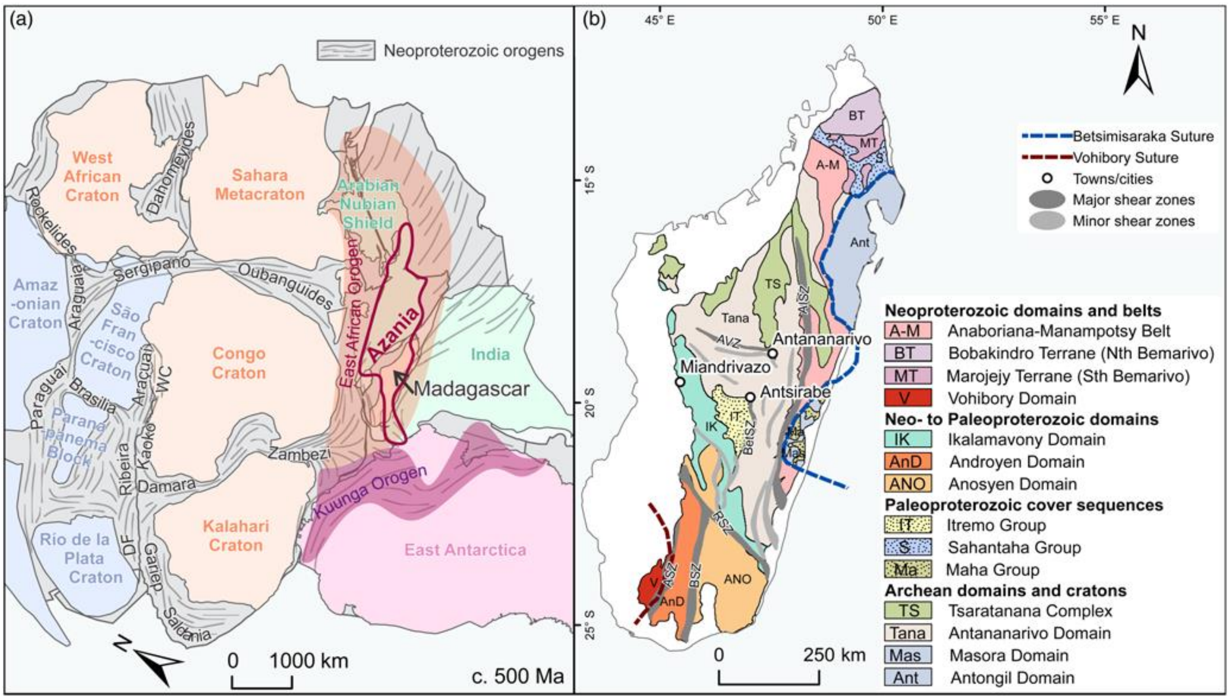
4.1.6 Geology

Systematic research on geology and mineral deposits in Madagascar dates back to the French occupation in the 1960s. Since then, with the accumulation of research results based on a new understanding of the earth, such as plate tectonics, which was not recognized at that time, and the results of chemical analysis using advanced technology, Madagascar is now attracting worldwide attention as a region that holds the key to the evolutionary process of the Gondwanan continent.

In the Paleozoic era, Gondwana was a huge continent that included the present-day continents of Africa, South America, Indian subcontinent, Antarctica, Australia, Arabian Peninsula, and Madagascar. The island of Madagascar is believed to have been located at the center of this Gondwana continent. After the Late Coal Era, about 300 million years ago, the Gondwanan continent began to break up, which led to the formation of sedimentary basins on the western side of the island as the widened sea area between the island and the African continent. On the other hand, the separation from India on the eastern side of the island is thought to have occurred later, around the middle Cretaceous period (about 70 million years ago).

In the eastern two-thirds of Madagascar, are widely exposed crystalline basement rocks such as granitoids, metamorphic rocks, and basic igneous rocks formed during the Precambrian era (Archaean and Proterozoic era), approximately 3 billion to 500 million years ago. During the late Proterozoic and early Paleozoic era (approximately 650 to 500 million years ago), the East African orogenic movement, which was accompanied by high-temperature, high-pressure, and intense metamorphism, was active on a continent-wide scale in Gondwana, and even in Madagascar, rocks formed before that time have undergone extensive re-metamorphism. Especially, in southern Madagascar, high-temperature and high-pressure metamorphic zones (granulite facies, etc.) from this period are widely distributed and have attracted scientific attention.

A tectonic map of the continent of Gondwana 500 million years ago and a geologic tectonic classification map of present-day Madagascar are shown in Figure 4-3.



Source：Sheree A., et.al. (2020)

Figure 4-3 Structural map of Gondwana continent and the geological tectonic zone of Madagascar

Structural zone of Precambrian crystalline basement rocks in Madagascar can be divided into the following two main categories.

① Composed of gneisses, metasedimentary rocks, and granitoids of Mesoarchaean to Paleoproterozoic era (about 3.1 to 1.6 billion years ago) and the more recent granitoids (about 800 million years ago) that intrude them.
② Composed of metamorphic rocks of Neoproterozoic to Early Palaeozoic era (about 650 to 500 million years ago) of sedimentary origin.

In the northern part of the island, Archaean to Paleoproterozoic greenstone (TS in the right side of Figure 4-3) is distributed, where metallic mineral resources such as chromium, cobalt, nickel, and copper occur.
One third of the western part of the island consists of thick sedimentary rocks dating from Palaeozoic to Cenozoic, 350 million years ago. Limestones of Mesozoic and Tertiary era are distributed along the western edge of the island. Part of this area, known as Twingee, is a World Heritage Site and is designated as a Strict Nature Reserve. Ammonites are found in the Triassic sedimentary rocks.
Flood basalts and other rocks formed during large-scale igneous activity that occurred 90 to 80 million years ago during the Mesozoic Cretaceous era, before Madagascar was separated from the Indian subcontinent, are distributed in a form of ring around the present-day eastern and northwestern coastlines of the island. Contemporaneous flood basalts are also widely distributed in India.
Most of the Precambrian system has undergone lateritization, a process that proceeds with tropical climatization, and the average thickness of the laterite is 10 to 20 meters. Lateritization has resulted in the formation of nickel deposits and bauxite deposits.

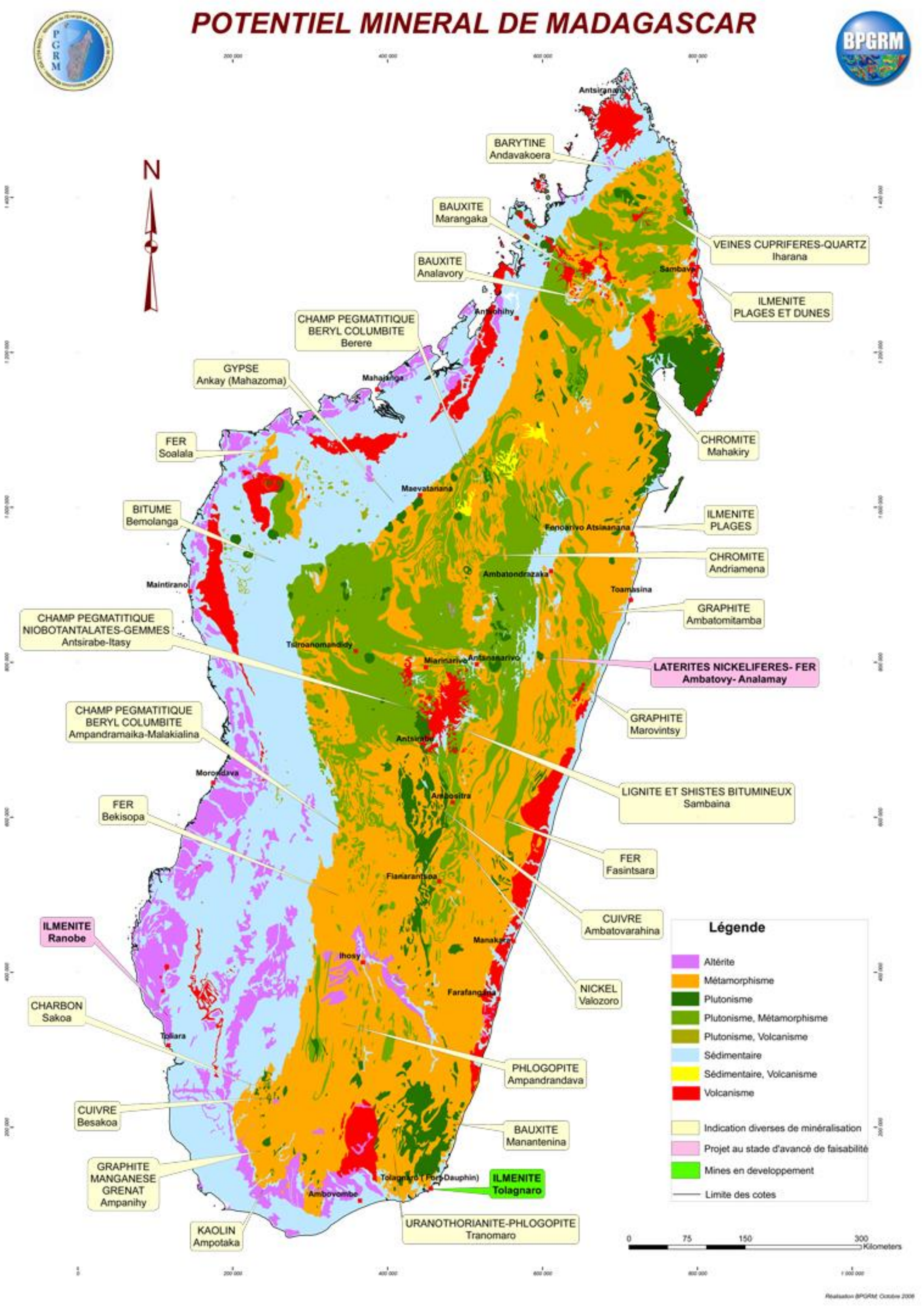
4.1.7 Mining

Most of the mineral resources in Madagascar are associated with Precambrian crystalline basement rocks. Table 4-1 shows information on the mode of occurrence of the main mineral resources, and Figure 4-4 shows the distribution map.
Mineralization actions and mineral resources can be largely classified into the following five categories

(i) Associated with basic and ultrabasic rocks (chromite, platinum group elements, base metals, etc.)
(ii) Associated with hydrothermal veins and pegmatites (emeralds, rare metals, gold, precious stones, etc.)
(iii) Associated with metamorphic rocks (sapphires, rubies, iron, etc.)
(vi) Weathered remnant deposits (bauxite, nickel, etc.)
(v) Drift deposits (gemstones, gold, etc.)

Table 4-1 Mode of occurrence and distribution of Madagascar's mineral resources

	Ore type	Mode of occurrence	Main distribution area
Mineral & Metal Resources	Gold (ASM)	Quartz veins, drifting sand deposits	North central region Tsaratanana、Southwestern region Davolava, and other locations
	Chromium	Associated with ultrabasic rocks	Tsaratanana sheet (North western region Andriamena and other locations)
	Nickel	Weathered residual deposits of ultrabasic rock (accompanied by cobalt)	Central eastern region Ambatovy Mine, Northern Nickel Valley, Central southern region Valorozo
	Iron	Magnetite-bearing quartzite in striated iron formation	Central western region Soalala, Central southern region Fasintsara
	Bauxite	Weathered deposits of white gneiss and basalt	Southern and northern coastal areas (Manantenina, Farafangana)
	Copper	Quartz veins, mineralized, skarn	Northern region Iharana, Southern region Besakoa, Central southern region Ambatovarahina
	Platinum group elements	Associated with ultrabasic, drifting sand deposits	Central northern region Andranomiely
	Uranium Thorium	Associated with pyroxenite, pegmatite	Southern region Toranomaro (Uranothorianite)
	Ilmenite, Zircon, Monazite	Beach sand	Southern region QMM mine (Tolanaro), Southwestern region Toliara
Industrial raw material resources	Graphite	In paragneiss (partially associated with some phlogopite)	Betsimisaraka, Antananarivo Various locations of both units (Central eastern region Marovintsy, and other locations)
	Phlogopite	In gneiss, pegmatite (in Androyen Unit)	Southern region Ampandrandava mine (operation suspended)
	Sapphire, ruby (ASM)	Associated with Permian to Cretaceous sandstones, ultrabasic rocks, drifting sand deposits	Southwestern region Ilakaka, Southern region Ejeda- Fotadrevo
	Emerald (ASM)	Pegmatite associated replacement deposit	Eastern region Mananjary



Source：JICA (2012)

Figure 4-4 Mineral Resources of Madagascar

Madagascar is considered to have a diverse resource potential, but not enough resources have been developed, and the mining industry is still at the stage of development. Resources produced before 2000 included chromium, graphite and mica, gemstones, and stone. More recently, nickel, cobalt, and ilmenite have been produced. Other resources with proven potential include gold, copper, lead, zinc, manganese, platinum group metals, rare earth elements (REEs), iron, bauxite, uranium, coal, and oil, etc. Figure 4-4 shows a Figure of Madagascar's mineral resource potential.
Major mines currently in operation include Ambatovy nickel mine (Sumitomo Corporation/KOMIR), QMM ilmenite mine (Rio Tinto/Government of Madagascar), KRAOMA chrome mine (KRAOMA), Antsirakambo and Marovintsy graphite mines (Ets. Gallos), and Molo graphite mine (NextSource). In addition, gold and gemstones are mined by small-scale mines and private miners, but the actual situation is unknown.

(1) Nickel, cobalt
In northern and eastern Madagascar, basic igneous bodies are widely distributed, and there exist the deposits of nickel, cobalt, and chromium. The Ambatovy lateritic nickel deposit, located in east-central Madagascar, was explored in the 1960s, initial FS was completed in the 1990s, construction began in 2007, and production started in 2012. After Phelps Dodge obtained the mining rights in 1995, several companies joined and left. Currently, Sumitomo Corporation (approximately 54%) and Korea's KOMIR hold concessions. The slurry ore is transported by pipeline to a smelter in the port city of Toamasina, 220 km from the mining and beneficiation facilities at the mine's base. Production in 2022 is estimated at 36 thousand tons of nickel and 3.4 thousand tons of cobalt (Ambatovy, 2022). The mine has a very significant role in Madagascar's economy (tax revenues and employment).

(2) Chromium
KRAOMA, Madagascar's only state-owned mining company, has several mines in the north of the island that produce chrome ore. In 2018, KRAOMA produced 185 thousand tons of chromite ore at five mines with a chromite grade of 47% (Website;KRAOMA). Total chromite production in 2021 was the 18th largest in the world (USGS, 2021).

(3) Graphite
Deposits of graphite are abundant in the eastern, central, and southwestern parts of the island. On the east coast, there are three mines, Antsirakambo, Marovintsy, and Ambalafotaka, owned by Etablissements Gallois, and Sahamamy mine, owned by Tirupati Graphite. In the southwestern part of the country, there exists Molo mine, owned by NextSource Materials. In 2021, Madagascar was the third largest producer of graphite in the world with 70 thousand tons (USGS, 2021).

(4) Titanium
Sand deposited on the coast of Madagascar contains heavy minerals (ilmenite, rutile, zircon, and monazite), and ilmenite deposits have been identified at various locations, making it a rich titanium resource.

QMM (Rio Tinto 80%, Government of Madagascar 20%) has been producing ilmenite, rutile, and zircon since 2009 at the Tolagnaro deposit on the southeast coast. In 2017, production of QMM was 403 thousand tons of ilmenite and 28 thousand tons of zircon. In 2020, QMM ranks 9th in the world in total titanium production (USGS, 2021).

(5) Mica

Deposits of gold mica occur in southern Madagascar. Ampandrandava mine began operations in 1938 and is the oldest tunnel-mined gold mica mine in Madagascar. In recent years, SOMIDA operated the mine, but ceased operations in 2010. Total gold mica production in 2017 was 23.5 thousand tons, which came from ASM in the southeast region (USGS, 2021).

(6) Gold

Although many gold deposits are known throughout Madagascar, no large-scale deposits have been discovered, and most are mined by ASM. As a result, the actual situation, including the amount of production, is unclear. The government reports that 900 kg were exported in the first four months of 2017 (USGS, 2021).

(7) Gemstones and quartz

Madagascar is famous for the production of a wide variety of gemstones and precious stones. These include emerald, ruby, sapphire, tourmaline, aquamarine, garnet, citrine, jasper, amazonite, celestite, and quartz. Quartz of commercial value includes quartz, amethyst, yellow quartz, red quartz, smoke quartz, and industrial quartz.

Emeralds are found near Mananjary on the east coast, rubies at Andilamena and Didy in the northeast and at Vatomandry on the east coast, sapphires at Ilakaka, Manombe and Sakara in the southwest and at Marosely in the north. Annual production of beryl in quartz was 30 tons in 1998, 12 tons in 2005, and 12 tons in 2009.

Gemstones are generally mined by private miners, and the actual production volume and other details are often unclear. Before being cut and polished, most of the gemstones are exported to Thailand, the United States, and other countries.

Norcross Madagascar Group (USA) produces amazonite, apatite, jasper, red iron ore, red quartz, purple quartz, labradorite, silicified wood, and ammonite.

(8) Stone material

Labradorite is a type of feldspar that has a unique color of play, called the labradorescence, and is used as a building material and jewelry material. Good quality labradorite is produced in Madagascar, Norway, and Canada. EUROMAD (Italy), MAGRAMA (Italy), SQNY (India), and NMG (USA) produce labradorite in plagioclase intrusive bodies, around Lanapera and Maniry in southern Madagascar. In addition, limestone and marble are also produced.

4.2 Mineral resources

4.2.1 Metallic and Mineral Resources

In addition to many gem minerals, Madagascar has rich deposits of many important minerals including nickel, chromium, cobalt, graphite, ilmenite, etc. The Ambatovy mine, one of the largest lateritic nickel mines in the world, is particularly famous for its nickel and cobalt production. As for graphite, the country is the world's fifth largest producer, and several junior companies (NexSource Materials of Canada, Greenwing Resources of Australia, Tirupati Graphite of UK, etc.) are developing and producing graphite. Figure 4-5 shows the distribution of metal and mineral resources (mines, prospects, etc.) for nickel, chromium, cobalt, and graphite. Data were collected primarily from USGS website. These minerals tend to be concentrated in the areas of Archaean gneiss, migmatite, and gabbro, especially in central to northeastern Madagascar.

A detailed description of the geology of Madagascar can be found in Mellos et al. (2005) and Moine et al. (2014). The geology of Madagascar is largely divided into Precambrian metamorphic rocks, sedimentary rocks, igneous rocks, and weathering residues. Among these rocks, the Precambrian metamorphic rocks are classified into several domains, including Antongil domain, Antananarivo domain, Tsaratanana domain, Betsimisaraka domain, Bemarivo domain, and Itremo domain (Figure 4-6), and have the potential for mineral resources such as nickel, chromium, cobalt, and graphite. For example, the largest Antananarivo domain, which occupies central Madagascar, is basically composed of Neo-Archaean orthogneiss and Proterozoic metasedimentary rocks, but Cretaceous intrusive bodies such as the Antampombato - Ambatovy complex intrusive body are also recognized. Among these bodies, the Ambatovy and Analamay bodies are composed of ultrabasic rocks and are the source rocks of the nickel- and cobalt-producing Ambatovy deposit. Also, Tsaratanana domain is an allochthonous greenstone body thrusting through Antananarivo domain in north-central Madagascar. Multiple chromite mineralization (especially chromite) is recognized in the ultrabasic rocks in this Tsaratanana domain. Moreover, Betsimisaraka domain, interpreted to be part of a marine suture zone, consists of muddy meta-gneiss and basic to ultrabasic rocks, and has the mineralization of chromium and graphite. Also, in southern Madagascar, graphite mineralization is observed for more than 300 km along shear zones including Ampanihy shear zone, in a metamorphic area of sedimentary source rocks.

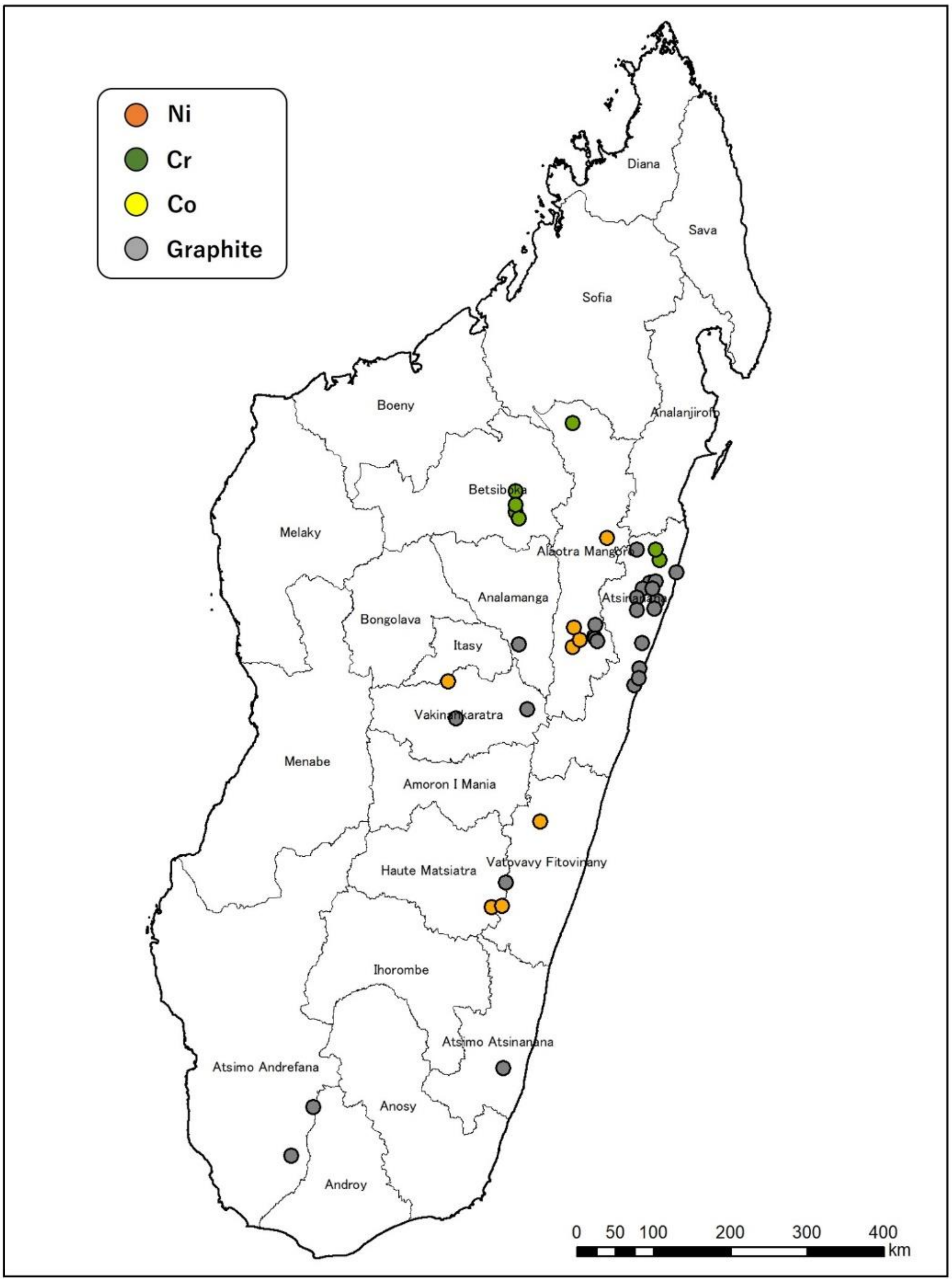


Figure 4-5 Distribution of metal and mineral resources in Madagascar
(only for the target ore types)

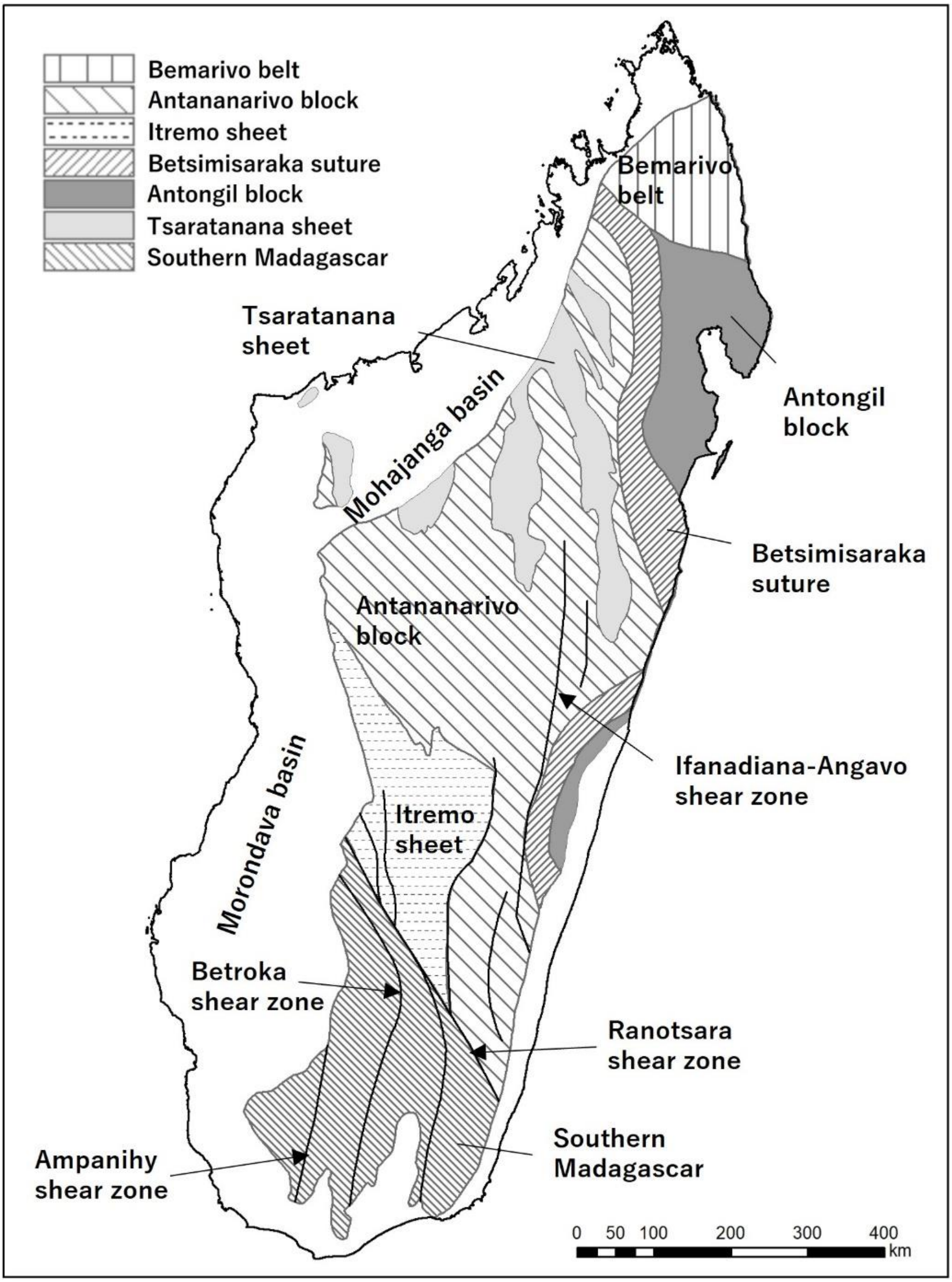


Figure 4-6 Regional geology of Madagascar (Adapted from Moine et al.,2014)

4.2.2 Past surveys

The survey of mineral resources in Madagascar includes the "Overseas Geological Survey" conducted in central Madagascar by Metal Mining Agency of Japan in 1974, and the "Basic Survey for Cooperation in Natural Resources Development" conducted in southern Madagascar from 1991 to 1993 by Japan International Cooperation Agency (JICA) and Metal Mining Agency of Japan. Since the 2000s, Metal Mining Agency of Japan has compiled a survey of mineral resources throughout Madagascar under the title "Resource Development Environment Survey," and Japan International Cooperation Agency conducted a "Survey on Geological and Mineral Resource Information Development for the Promotion of Mining in Madagascar".

The major exploration projects in Madagascar (only for target ore types) are summarized in Table 4-2. The Ambatovy mine, producing nickel and cobalt, is well known in Madagascar, but in recent years, exploration for graphite has been active due to the demand for batteries for electric vehicles (EVs). Incidentally, graphite production in China in 2022 was 850,000 tons, accounting for more than 60% of the world's production, but graphite exploration activities are expected to become even more active in the future, partly because the Chinese government has begun export controls on graphite and related items since December 2023. For example, POSCO International of Korea visited Madagascar in August and September 2023 and concluded a business agreement on graphite supply chain establishment (MOU) with NextSource, a Canadian mining company, in order to secure graphite. As a result, it is reported that the company expects to be able to procure scaled or globular graphite produced at the Molo mine for 10 years.

Table 4-2 Major Exploration Projects in Madagascar (Only for target mineral types)

Project	Concession holder	Major ore types
Valozoro	DFR Gold Inc.	Nickel
Toamasina	DNI Metals Inc.	Graphite
Maniry	Evion Group NL	Graphite
Madagascar	Avana Resources Ltd.	Graphite
Green Giant	NextSource Materials Inc.	Graphite

4.2.3 Mining and Industrial Production

The operating mines in Madagascar (only for target ore types) are summarized in Table 4-3. The Ambatovy mine, one of the world's largest lateritic nickel mines, is particularly famous for its nickel and cobalt production. Sumitomo Corporation (SC) holds a 54.17% interest and Korean Mine Rehabilitation and Resources Corporation (KOMIR) holds a 45.82% interest. Annual production (capacity) is estimated to be 60,000 tons of nickel and 5,600 tons of cobalt, although production in 2020 was significantly reduced to 8,676 t of nickel and 746 t of cobalt following the suspension of operation in March 2020 due to the coronavirus pandemic. In 2021, production has recovered to 30,367 t of nickel and 2,720 t of cobalt (JOGMEC, 2022). Despite concerns about the environmental impact of development, a Bangor University study indicates that the project is expected to achieve an overall no-net loss by minimizing deforestation due to the small-scale agriculture occurring in the surrounding area (Devenish et al., 2022).

Table 4-3 Operating mines in Madagascar (only for target ore types)

Project	Concession holder	Ore types
Ambatovy	Sumitomo Corporation（54.17）, Kores（45.82）	Ni, Co
Andriamena	Office Militaire National pour les Industries Strategiques	Cr
Graphmada	Greenwing Resources	Graphite
Molo	NextSource Material	Graphite
Sahamamy	Tirupati	Graphite
Vatomina	Tirupati and others	Graphite

4.2.4 World Metal Prices

Nickel: The price was around US$6,000/t until the early 2000s, rising after 2004, and then surged to a temporary peak of about US$37,000/t in 2007, followed by a temporary peak of about US$25,000/t in 2022, while remaining at US$15,000 to 20,000/t up to now. The largest producer is Indonesia and the production volume accounts for more than half of the global share, including the Philippines and Russia. Price fluctuations are influenced by temporary growth in demands as a battery metal and inventory adjustments.

Chromium: There is no international pricing mechanism for chromium. The CIF prices from the journal “Metals Week” are generally used as a price indicator. Chromium has a relatively low unit price per weight and therefore there is no such strong speculative factor to change the price drastically for the metal. In general, it is largely influenced by supply and demand trends in South Africa, the largest producer, and China, the largest consumer. Most recently, it exceeded US$200/Lb from April to May 2022, but it has generally remained around US$150/Lb.

Cobalt: Prices were around US$10/kg until the early 2000s and rose to around US$40/kg after 2004. After reaching a temporary peak of about US$110/kg in 2008, it further reached about US$90/kg in 2018 and US$80/kg in 2022 as a temporary peak, and the price is currently at about US$30/kg. The productions of DR Congo and Zambia account for more than half of the global share, and price fluctuations are influenced by political conditions in the producing countries, temporary growth in demands as a battery metal, and inventory adjustments.

Graphite: The price of natural graphite was stable at around US$1,000/t until the 2000s, but has risen since the late 2000s and is currently traded at around US$2,000/t. China holds an oligopoly in production, accounting for approximately 70% of global production, but this situation may improve if new production from Mozambique and other countries starts in the future.

4.3 Mineral Resource Potential of Target Minerals

There are relatively well-organized studies on the metal mineral resource potential of Madagascar, including Melluso et al. (2005) and Moine et al. (2014). Here, focusing on the results of these studies, this section describes mineral resource potential of nickel-chromium, cobalt and graphite in Madagascar.

4.3.1 Nickel

Figure 4-7 shows the distribution of nickel (Ni) mineral resources (mine, mineralized area) in Madagascar. In general, ultrabasic rocks and serpentinites contain a traces of nickel minerals, and nickel is often concentrated in residual weathered soil (laterite) that are derived from these source rocks. Ambatovy deposit consists of two lateritic ore bodies (ore bodies of Ambatovy and Analamay) that were formed from two large weathered ultrabasic rocks within the Gabbro-Syenite Complex, among the rock bodies recognized within the largest Antananarivo domain, which occupies central Madagascar (Figure 4-8). Ambatovy and Anaramay ore bodies germinate over a wide area of approximately 3 km by 2.4 km (Ambatovy) and approximately 4 km by 2.8 km (Anaramay), and the thickness of the deposit is very thick compared to other lateritic nickel deposits, averaging approximately 40 m and a maximum of approximately 100 m. According to Technical Report published in 2018, the amount of resources is 52.6Mt (0.98% nickel grade) for the category classified as measured resources, while it is 129.7Mt (0.91% nickel grade) for the category classified as indicated resources, and 69Mt (0.85% nickel grade) for the category classified as inferred resources (Table 4-4). Similarly, a reasonable amount of reserves is also reported (Table 4-5), which makes it one of the largest nickel mines in the world. Furthermore, these deposit potentials are said to extend to the vicinity of the eastern coast. On a smaller scale, Valozoro and Bemainty in the south-central region have reported mineral resources of 3.7 million tons at a nickel grade of 1.75% (Valozoro) and 1.6 million tons at a nickel grade of 1.3% (Bermainty).

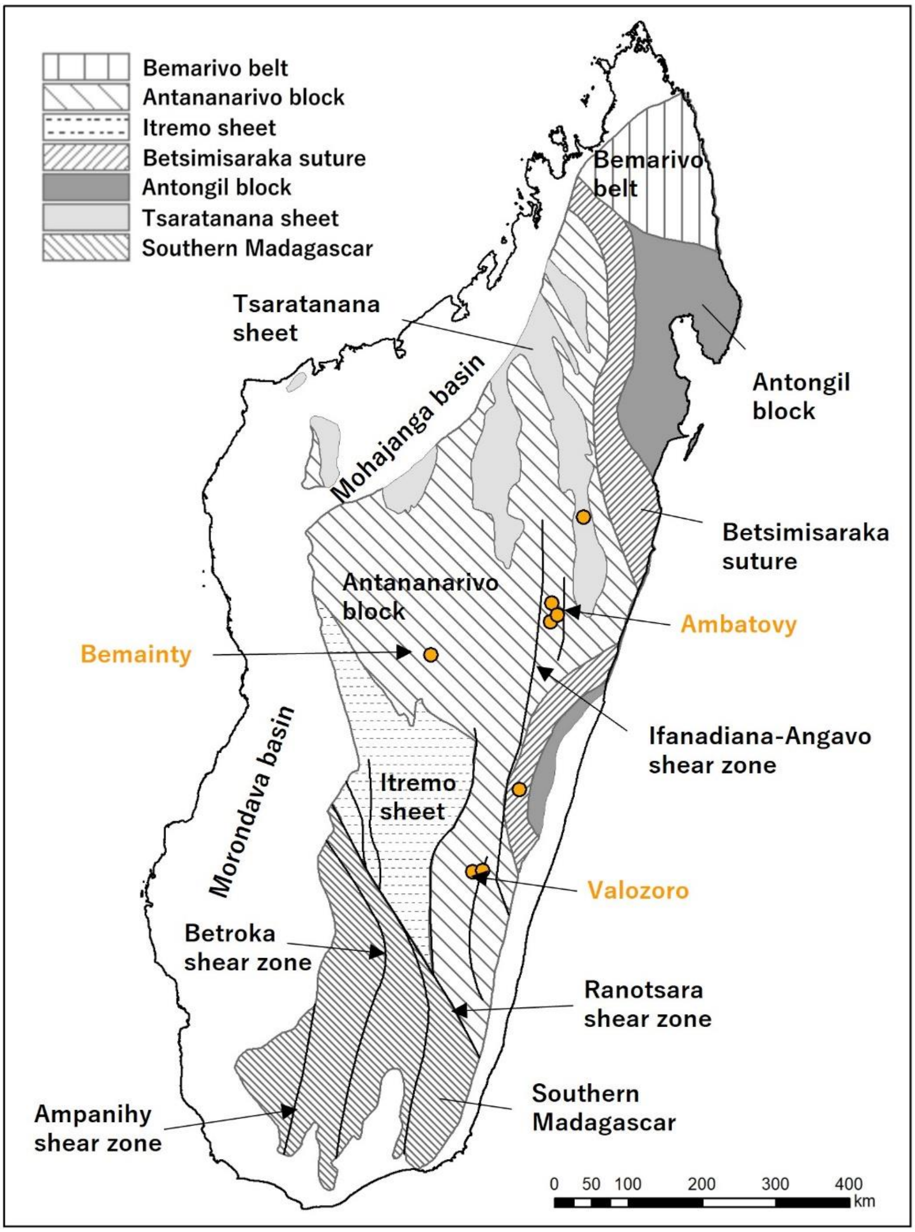


Figure 4-7 Distribution of Ni mineral resources in Madagascar

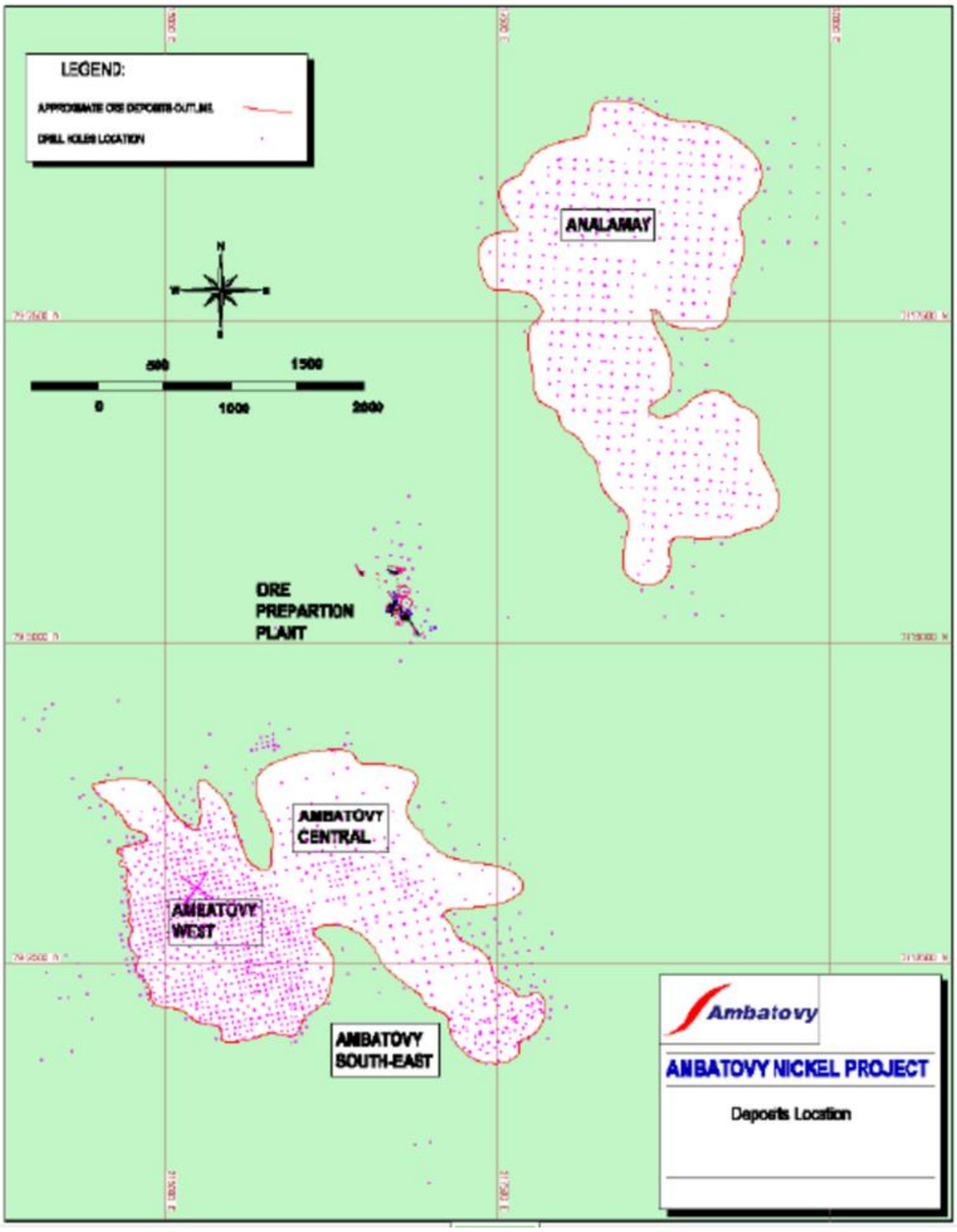


Figure 4-8 Locations of the deposits in the Ambatovy（Sherritt International Cooperation, 2018）

Table 4-4 Mineral Resources for the Ambatovy（Sherritt International Cooperation, 2018）

Deposit	Classification	Tonnage (Mt)	Ni (%)	Co (%)
Ambatovy	Measured	43.1	1.02	0.08
	Indicated	66.3	0.90	0.07
	Measured+Indicated	109.4	0.95	0.08
	Inferred	27.8	0.80	0.07
Analamay	Measured	9.5	0.81	0.08
	Indicated	63.4	0.93	0.09
	Measured+Indicated	72.9	0.91	0.08
	Inferred	41.2	0.88	0.09
ALL DEPOSITS	**Measured**	**52.6**	**0.98**	**0.08**
	Indicated	**129.7**	**0.91**	**0.08**
	Measured+Indicated	**182.3**	**0.93**	**0.08**
	Inferred	**69.0**	**0.85**	**0.08**
Stockpiles	**Measured**	**10.7**	**0.81**	**0.06**

Table 4-5 Mineral Reserves for the Ambatovy（Sherritt International Cooperation, 2018）

Deposit	Classification	Tonnage (Mt)	Ni (%)	Co (%)	Al (%)	Mg (%)	Ni metal (kt)	Co metal (kt)
Ambatovy	Proven	31.5	0.96	0.08	4.70	1.21	303.0	26.2
	Probable	39.8	0.85	0.07	4.76	1.55	338.9	29.5
	Proven+Probable	**71.3**	**0.90**	**0.08**	**4.74**	**1.40**	**641.8**	**55.8**
Analamay	Proven	7.5	0.77	0.08	4.07	1.00	58.0	6.1
	Probable	47.8	0.88	0.09	3.92	1.39	421.2	41.4
	Proven+Probable	**55.3**	**0.87**	**0.09**	**3.94**	**1.33**	**479.2**	**47.5**
All Deposits	Proven	39.0	0.93	0.08	4.58	1.17	361.0	32.3
	Probable	87.6	0.87	0.08	4.30	1.46	760.1	71.0
Mineral Reserve (ROP)	Proven+Probable	126.6	0.89	0.08	4.39	1.37	1,121.1	103.3
Stockpiles	Proven	4.0	0.77	0.06	6.63	2.52	31.2	2.4
Total Mineral Reserve (ROP)	Proven+Probable	130.6	0.89	0.08	4.46	1.41	1,152.3	105.7

4.3.2 Chromium

The distribution of chromium (Cr) mineral resources in Madagascar (mines, mineralized areas, etc.) is shown in Figure 4-9. The geological bodies that host chromium deposits are generally limited to basic to ultrabasic rocks. In Madagascar, multiple chromium mineralization (especially chromite) is observed in the ultrabasic rocks of Tsaratanana domain, especially in Andriamana and Bemanevika, where layered ore bodies have been identified. Tsaratanana domain is an allochthonous greenstone body that thrusts through Antananarivo domain in north-central Madagascar. Other chromium mineralization is also recognized in Betsimisaraka domain, which is interpreted to be part of a marine suture zone and is composed of muddy meta-gneiss and basic to ultrabasic rocks.

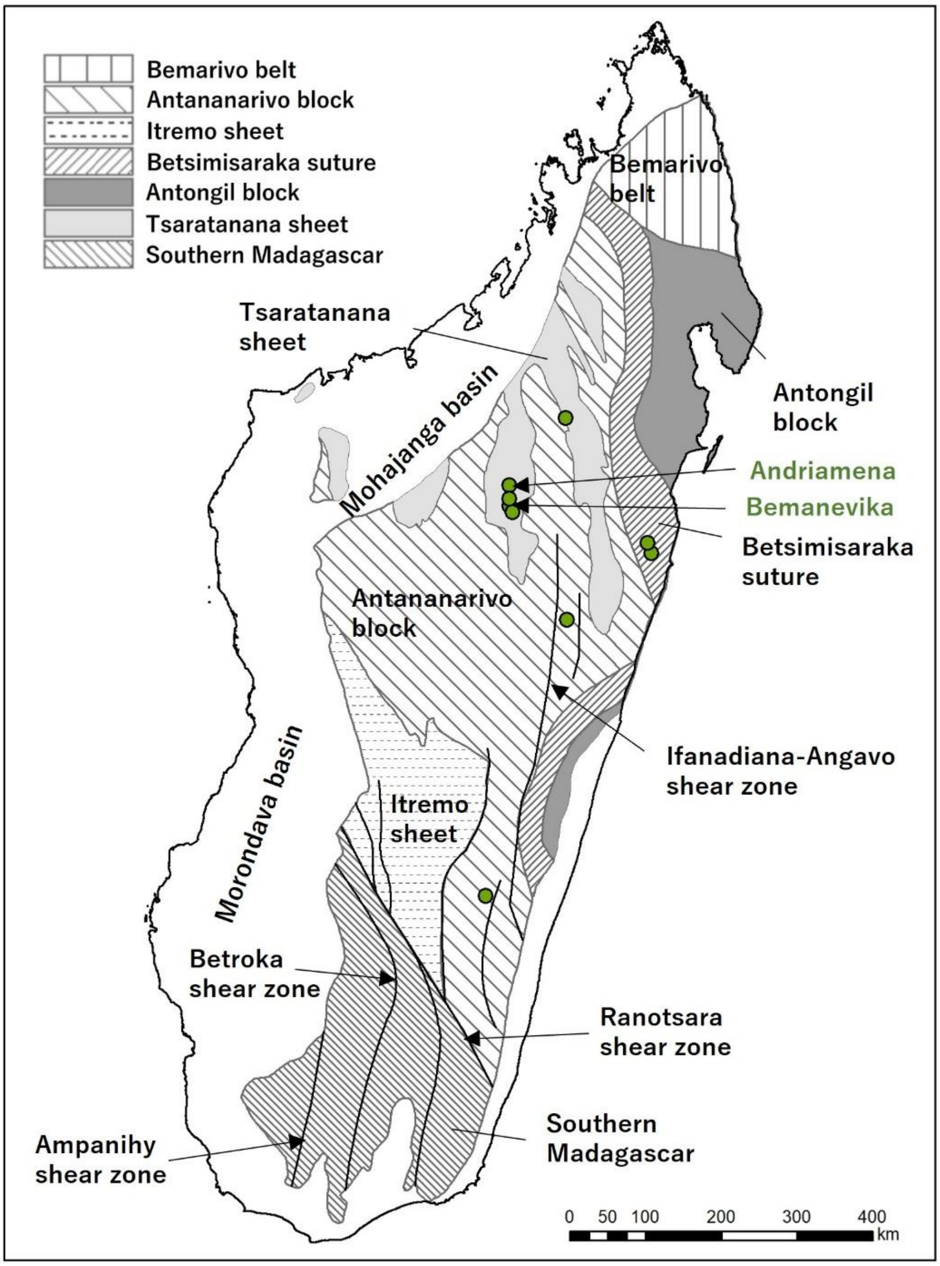


Figure 4-9 Distribution of Cr mineral resources in Madagascar

4.3.3 Cobalt

The distribution of cobalt (Co) resources (mines, mineralized areas, etc.) in Madagascar is shown in Figure 4-10. In general, ultrabasic rocks and serpentinites contain a trace of nickel minerals, which are often accompanied by cobalt. In Madagascar, cobalt is produced as a by-product in the Ambatovy deposit, a lateritic nickel deposit. This deposit has a nickel grade of 1.11% and cobalt grade of 0.1%, with total reported resources of 168 million tons.

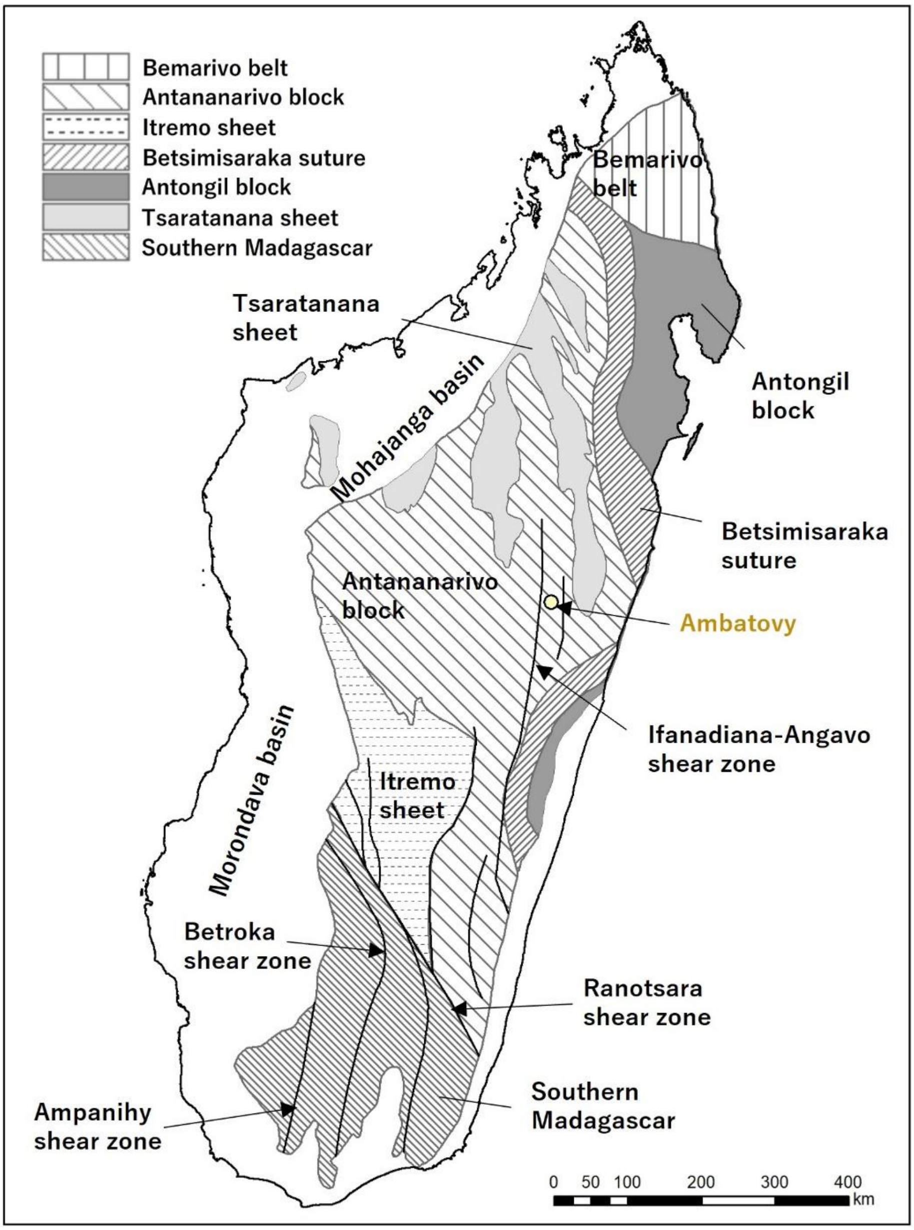


Figure 4-10 Distribution of Co mineral resources in Madagascar

4.3.4 Graphite

The distribution of graphite resources (mines, mineralized areas, etc.) in Madagascar is shown in Figure 4-11. In general, graphite deposits occur in Precambrian gneisses, schists, and crystalline calcareous rocks that have undergone extensive metamorphism, and also in pegmatitic aplites that have intruded into these rocks. The graphite of Madagascar is found, in the ancient times, in Betsimisaraka domain of muddy meta-gneisses, such as Tamatave in the northeast, and in gneisses in Antananarivo domain. However, in the southern areas of Molo and Maniry, graphite mineralization is observed over 300 km around a metamorphic zone where sedimentary rocks are the source rocks. Among others, Molo deposit, discovered by NextSource in 2011, is located in Ampanihy shear zone corresponding to the border between Vohivory and Androyen domains, and is associated with metamorphosed siltstones, mudstones, or sandstones (Figure 4-12). This deposit is large by global standards, and it is reported that, according to NI43-101 (a standard to be followed by companies listed on Canadian stock exchanges when disclosing technical information on mineral resource projects), it has a resource of 23.62Mt (graphite grade of 6.32%), classified as measured resources. Also it has resources of 76.75Mt (graphite grade of 6.25%), classified as Indicated resources, and those of 40.91Mt (graphite grade of 5.78%), classified as Inferred resources. The Feasibility Study in 2019 identified a reasonable amount of graphite reserves (Table 4-6). In response to this, the company plans to begin production of "SuperFlake graphite", high-purity graphite, for battery in June 2023, and to increase annual production to a maximum of 17,000 tons by July 2024. The potential of this deposit is still expected to be large, and according to the company, it is aiming for an annual production volume of 150 thousand tons in the next phase.

In Madagascar, exploration activities for graphite are active not only at Molo deposit, but also at Toamasina, Vatomina, Graphmada, and others, against the background of growing demand for batteries for electric vehicles (EVs). Another factor is the impact of China, the largest producer of graphite, which has initiated graphite export restrictions starting in December 2023. As a result, each country and company, including the world's automakers, are seeking graphite procurement sources other than China, which is also a factor pushing up investment in Madagascar, a country with high graphite resource potential.

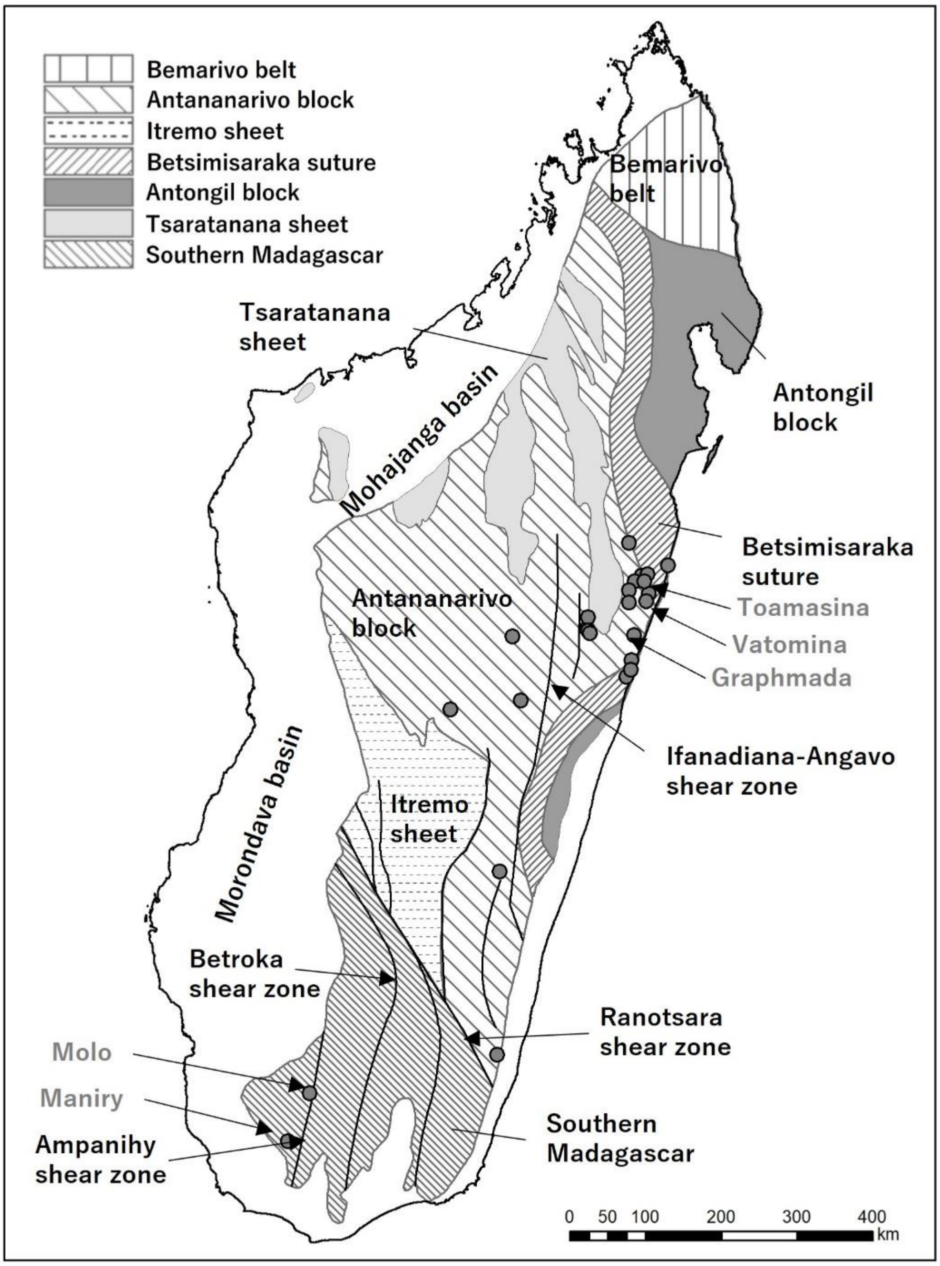


Figure 4-11 Distribution of Graphite Mineral Resources in Madagascar

Table 4-6 Graphite reserves at Molo deposit (NextSource Materials, 2019)

Category	Tonnage	C Grade (%)
Proven	14 169 741	7.00
Probable	8 266 944	7.04
Proven and Probable	22 436 685	7.02

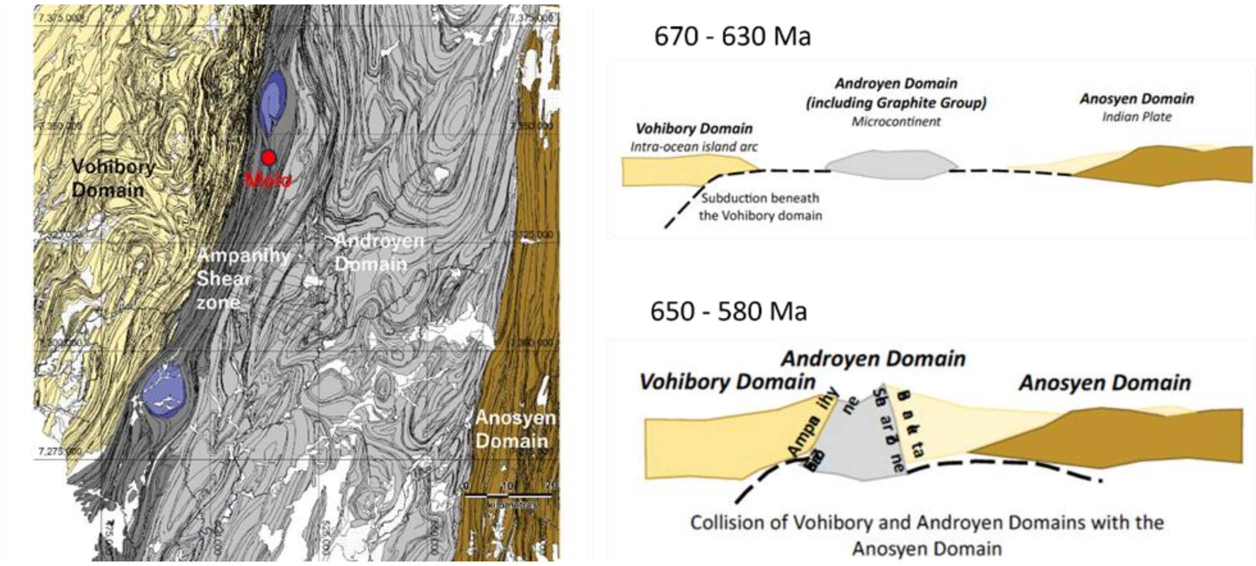


Figure 4-12 Molo Mine and Ampanihy Shear zone

4.4 Mining administration

4.4.1 Mining policy

Madagascar shared the vision with the African Heads of States and Government during the adoption of the Africa Mining Vision (AMV) in 2009. This framework optimizes the revenues from the resource-based industrialization and promotes the structural transformation in different levels. The policy documents highlight the shift from raw commodity export dependency to the industrialization through local beneficiation and value addition of minerals. The main goal of the Vision is to create: Transparent, equitable and optimal exploitation of mineral resources to underpin broad-based sustainable growth and socio-economic development. The AMV envisions more integrated approach on resource-based development and industrialization strategies in synergy with human and institutional capacity building, local beneficiation, mining and infrastructure investment and access on geological and mining information.
At national level, since his ascension to the Presidency in 2019, the President Andry Nirina Rajoelina has promoted an aggressive national plan, Madagascar Emergence Plan (PEM), and worked collaboratively with international partners to address the country's most pressing needs. The foundation of the PEM encompasses the human capital development, inclusive and sustainable economic growth, and sustainable natural resource management along with access to water and electricity.
The governance of the mining sector has been deeply disrupted following numerous crises that the country has experienced periodically from 1972 to 2009. Nevertheless, the government of Madagascar has collaborated with various partners national and internationals to put forward into a concrete action of the pledge (Velirano) strategic priority No.10 and to achieve the sustainable Development Goals.
Perceived that the outcomes of the previous mining code dated 1999, modified in 2005, remain below the expectations of the State, local authorities, the population and mining operators, the Malagasy government adopted new code to all mining project in 2023. This new inclusive mining code identifies the pledges

(Velirano) strategic priority No.10 of the President of the Republic which advocates sustainable management and conservation of natural resources, valorization of natural resources while preserving the environment and providing for the benefit of future generations.

4.4.2 Law and regulation related to mining industry

Madagascar's mining and quarrying sector was governed by the two main Mining Code and their implementing decrees.

Text of the Common Law especially the Law 99-022 dated 19 August 1999 on the Mining Code, amended by Law 2005-021 dated 17 October 2005, and revised by Law 2023-007 dated 25 July 2023. This Mining Code organizes the mining sector in Madagascar. It sets out mining permits, the regime for certain particular substances (gold, fossils, etc.), the relationship between land owners and mining permit holders, the obligations of permit holders, the use of mining products (detention, transport, processing, marketing), the stability of investments, sanctions for offenses and shortcomings as well as consultation bodies between stakeholders operating in mines.

-Text relating to the Special Regimes for the large-scale investments exceeding 50 billion Ariary (~25million USD):

Decree 2003-784 dated 8 January 2003 implementing the Law on Large Scale Mining Investments in Madagascar (LGIM) ;

Law 2005-022 dated 17 October 2005 amending Law 2001-031 dated 8 October 2002 ;

Law No. 98-002 dated 26 January 1998, agreement for the establishment of the Ilménite Project: promulgated in the Official Journal on March 2, 1998. This agreement specifically governs the activities of QMM-Rio Tinto in the Anosy region.

The actual government made a reform of on mining sector by starting the full revision of the Mining Code. If the previous mining code Common Law 99-022 of August 19, 1999, modified by Law No. 2005-021 of October 17, 2005, was characterized by reassuring measures regarding the transparency of the management of mining activities and the incentive to the arrival of new investors, the axes of the newly revised mining code refer to the following orientations :

1- strengthening the role of the State and Decentralized Territorial Communities in sector governance;
2- consideration of Strategic Mining Substances;
3- securing mining rights and investments;
4- bringing mining projects into harmony with local communities;
5- the redefinition of the mining permit regime and the quarry regime;
6- the reorganization and formalization of the gold sector through the responsible gold supply chain;
7- the reorganization of the precious stones and fine stones sector;
8- the establishment of a fair mining tax regime;
9- the professionalization of artisanal mining by nationals;
10- the financial valuation of operations relating to the granted mining rights;
11-the reformulation of the link between mining law and environmental and social standards;
12-incentivizing the development of mining research, the basis for the future development of large-scale

mining activities;
13-the fight against negative speculation in mining;
14-management of rushes through the Artisanal Mining Authorization;
15-promotion of local content;
16-the establishment of a Mining Social and Community Investment Fund;
17-matching sanctions for mining offenses to the challenges represented by resources;
18-restructuring of the institutional framework.

(1) Mining Permit
In accordance with Mining Code, mining permit issued by the BCMM are mandatory for those who carry out research, exploration and/exploitation. The main principle for those through competition is the ‘first come, first served' approach. The renewal of a mining permit is granted under the same conditions as the granting. The mining permits are classified as follows:
- Research Permit or PR, which confers on its holder the exclusive right to carry out prospecting and research within the defined perimeter;
- Exploitation Permit or PE, which confers on its holder the exclusive right to undertake exploitation, prospecting, and research within the defined perimeter;
- Permit Reserved for Artisanal Operators or PREA, which gives its holder the right to undertake prospecting, research, and exploitation within the defined perimeter.

4.4.3 Budget related of mining sector

(1) Taxation and Royalties
The Mining Code distinguishes two types of mining royalties: “readvances” which amount to 3% of the price of the mineral commodity, the quarry or the fossils; and “ristournes” which amount to 2% of the price of the mineral commodity.
In addition to the two categories of taxes, the BCMM charges a fee corresponding to the category and the number of years of possession of the permit. The value of this levy is fixed by interministerial order while its recovery is affected by the antennas of BCMM in provincial capitals.
There is also a duty which governs especially in the mining sector. These are the Excise Duty (DA) and the Special Duty on Mining Transactions (DSTM). This DA is a duty levied on harvested products, extracted, manufactured, or imported in Madagascar. In the case of mineral substances, this duty applies to precious stones and semi-precious stones, precious metals, i.e. luxury products, as well as certain industrial stones necessary for the high-tech industry. The DSTM is a fee withheld in advance and non-refundable and often qualified as a mining parafiscal tax.

(2) Tax Incentive
The Law 005-022 dated 17 October 2005 amending Law 2001-031 dated 8 October 2002 introduces a specific incentive regime for large-scale investment projects in the Malagasy mining sector (LGIM) involving an investment of more 25million USD and over. The duty will be 5% of the amount of an investment in the case of the sale or purchase of a company or company shares, changes to a company’s

name or its shareholders, or transfers by inheritance; and 10% of the value of the right affected in the case of farm-outs, pledges, and partnering operations.

(3) Revenue distribution

Mining is one of the main contributors to economic growth and social development in resource-rich countries like Madagascar. According to EITI report in 2022, the accounted for 4.6% of GDP, 4.4% of total government revenues, and 28% of total exports. The country is also considered to be a new frontier for oil and gas prospecting, but oil exploration remains limited.

- "Redevances" royalties are distributed as follows:
  -65% to the central government's general budget
  -15% to the Gold Agency
  -10% to the registration office and control/inspection entities
  -10% to the National Mining Committee.
- "Ristournes" royalties are distributed as follows:
  -10% to the National Equalization Fund;
  -90% to local government units, of which 10% are allocated to provinces, 30% to regions and 60% to municipalities.
- Royalties from the oil sector are distributed as follows:
  -50% to OMNIS;
  -50% to the central government and local government authorities, however the exact distribution is not specified.

4.4.4 Management system of mining sector

The management in mining sector is stipulated in the decree No.2021-688 dated 30 June 2021 and well categorized in EITI report 2022. The extractive industry is regulated by the Ministry of Mines and Strategic Resources, which develops state policies in the mining sector and ensures compliance with these policies. The Ministry of Economy and Finance, which includes the Revenue Authority and the Customs Authority, oversees the implementation and application of the tax policy.

Standard permits are issued by the Minister in charge of Mines who may delegate his authority according to article 42 of the Mining Code to the Regional and Municipal levels and only Malagasy registered entities can own mining rights. The granting, renewal, transfer of mining permit and other related activities were suspended since 2010.

The main actors in the management of the extractive sector are as follows:

- Ministry of Mine and Strategic Resources (MMRS), Branch of Government: Define the strategy for the realization of the Initiative Emergence of Madagascar (IEM) of the Madagascar President and develop policies and regulations.

- General Directorate of Mine (DGM), Directorate within the MMRS: Coordinate, supervise, and monitor of the mining activities.
- General Directorate of the Strategic Resources (DGRS), Directorate within the MMRS: Coordinate, supervise, and monitor of upstream oil and gas activities,
- Directorate of Mining Police (DPM), Directorate within the MMRS: Establish and is in charge of repression in case of mining infractions.

Organizations under supervision or attached are:

- Mining Registration Office of Madagascar (BCMM), under the authority of the Ministry of Economy, Finance and Budget: Manage the mining authorizations and permits, and all related procedures. This establishment is under the authority of the Ministry of Economy, Finance and Budget.
- National Gold Agency (ANOR), under the authority of the MMRS: Manage the gold sector (monitoring of artisanal or industrial mining, processing, collection and marketing activities), and grant cards for gold miners, collectors and gold counters.
- Office of National Mines and Strategic Industries (OMNIS), under the authority of the Prime Minister: Manage develop and promote oil and mineral resources in Madagascar.
- Bureau of Geology and Gemmology of Madagascar (BGGM), Directorate within the MMRS: Support for the implementation of the MMRS policy; Improve of the gem market in Madagascar and provide training in gemmology, mining Promotion of mining product processing work.
- National Laboratory of the Extractive Industries (LNIE): In charge of analyses, quality assessment of mining products, oil and gas products; grant gold smelting authorizations and certificates of authenticity for raw or cut stones.
- EITI Madagascar, attached organization: Improve the transparency and promoting of good governance and accountability in the management and use of revenues from mining and petroleum resources.
- National Committee of Mines (CNM): Joint body for dialogue, consultation and collaboration between the different stakeholders in the mining sector.

4.4.5 Issues

Although Madagascar's mining industry has the potential to benefit, the sector is facing various issues. Among the recurring prevailing issues are the following.

(1) Administration level

- Blockages or delays of the mining data and information due to the staff reshuffles within the administration following changes in government
- Failures in terms of local governance (Ministry, Mining Police)
- Lack of traceability in the marketing of products, leading to the lack of economic benefits on the municipalities of origin of the minerals

- Insufficient financial resources for the management-The non-receipt of the templates from certain entities (company and financial management) constitutes a limit not only for the completeness of the data but also the reliability of the analysis results.
- Lack of transparency on management and fees
- Lack of communication between state institutions, the poor distribution of roles between institutions, the practice of exploiting gold outside of authorized locations and counterfeiting in the gold sector

(2) Technical

- Lack of reliable information on mineral production
- Lack of basic geological data concerning Madagascar

(3) Economy and infrastructure

- High levels of corruption in different levels, illegal exploitation of natural resources and gold laundering, fraud and tax evasion, money laundering mainly in gold sector
- Low contribution by the mining industry to the local community
- Lack of human and material resources to support the industry
- Lack of highway, port, energy and rail infrastructure

(4) Human right

- Human rights violations
- Practice of employing children in mining.

(5) Environment

- Lack of provisions for enforcement of the MECIE order, specifying standards and procedures to be adopted in the industry.
- Land disputes between the project owner and the local community

4.5 Environment administration

4.5.1 Environment policy

The Malagasy environmental and forest policy require the Environmental Impact Assessment (EIA) and the Environmental Commitment Program (PREE) for all investment projects, which has been implemented through successive decrees and regulations on compatibility of investments with the environment known as “MECIE”.

The extractive sector in Madagascar is also subject to environmental regulations. In accordance with the mining code and the oil code, mineral research and exploitation activities that harms the environment must be the subject of an impact study and must obtain a favorable opinion from the environmental authority (art.8 of the Mining Code 2023); and upstream petroleum activities must consider environmental requirements (art.10 and art.28 of the Petroleum Code).

4.5.2 Law and regulation related to environment protection

At regional level, Madagascar has ratified most of the major international environmental conventions including the Algiers Convention on the Conservation of Nature and Natural resources (Law No.70 004 of 23 Sept.1970), the Convention on Biological Diversity (Law No.95-013), the International Convention on Trade in Endangered Species (CITES) (Law No.75-014), the Ramsar Convention on Wetlands of International Importance (Law No.98-004), the World Heritage Convention (ratified 9/12/82), the UN Convention on the Law of the Sea (ratified in October 2000) and the Climate Change Convention (Law No.98-020).

At national level, the Malagasy environmental and forest policy is based on four laws, namely ①the National Environmental Charter (Law 90-033 of 21 December 1990), ②GELOSE (Gestion Locale Sécurisée) (Law 95-025 of 30 September 1996 - the local management of renewable natural resources), ③the Forest Law (Law 97-017 of 8 August 1997) and ④the Protected Areas Code (Law 2015-005 of 26 February 2015). In addition, Law 96-025 AGAR law is supposed to organize the transfer of the management of state-renewable resources to local communities or resident riparian forest areas.

The Environmental Charter, Law No. 90-033 of December 21, 1990 defines the environment by a set of natural and artificial environments including human environments and social and cultural factors which are of interest to development. It defines the principles of environmental management. Thus, the principle of the citizen's right to information, the right to participate in environmental management are the innovative concepts established by the Charter. In its article 10, it states that “public or private investment projects, whether or not subject to authorization or approval by an administrative authority, likely to harm the environment must be subject to an impact study, taking into account the technical nature and scale of said projects as well as the sensitivity of the implementation environment.

The Environmental and social impact assessment for mining activities follows both international conventions and national laws and decrees. According to the Chapter II of the Mining Code 2005 and 2023 and articles 10 and 28 of the Petroleum Code, a mining permit must be always be accompanied by an authorization or environmental permit to motivate the establishment and the start of the operating work of the project. This authorization or environmental permit is issued by the National Office for the Environment (ONE) or by a competent and mandated public power.

4.5.3 National park

Madagascar National Parks (MNP), formerly known as ANGAP (National Protected Areas Management Association), is the institution created in 1991 with the mandate to develop and manage the national protected areas network under powers delegated under forestry legislation.

The protected area network in Madagascar, which is known as the Système des Aires Protégées de Madagascar, covers approximately 6.9 million hectares including 2.4 million hectares of national parks managed by Madagascar National Parks (MNP) and 4.5 million hectares of new protected areas that are being developed predominantly by NGOs (including Conservation International, Wildlife Conservation Society and WWF) on behalf of the Ministry of Environment and Forests. Landscapes or corridors covering 2.6 million hectares have also obtained formal temporary protection status from the Government. There are currently 144 protected areas covering 12 percent of the Madagascar territory.

The National Environmental Action Plan (NEAP) as defined in the Charter for the Environment and subsequent texts and as manifested by the three five-year phases (EP1 1992-1996, EP2 1997-2002, and EP3 2003-2007) constitutes the principal current environmental program in Madagascar. The program is coordinated by the National Environment Office (ONE) under the aegis of the Ministry for Environment.

Under the decree No. 2005-848, the classification of Protected Areas in the Protected Areas Code (COAP) had been reviewed/reclassified to bring them more in line with IUCN protected area categories. These include:

(a) Natural Park (Le Parc Naturel)
(b) Natural Monument (Le Monument Naturel)
(c) Landscape (or Heritage) Protected Area (Paysage Harmonieux Protégé)
(d) Natural Resources Reserve (Réserve des Ressources Naturelles)

4.5.4 Environmental survey related to mineral resources development

According to the Mining Code, the Petroleum Code, the Environmental Charter and subsequent texts, the different types of contracts and licenses which govern the exploration and exploitation activities of oil, gas and minerals are as follows.

- Artisanal Mining Authorization (AMEA)
- Research permit (PR)
- Exploitation permit (PE)
- Permit Reserved for Artisanal Operators (PREA)
- Gold prospector card
- Quarry

The decree of MECIE (Mise en Compatibilité des Investissements avec l'Environnement) n°99-954 of 15 December 1999 is applicable to all investments, including mining. This decree concerning environmental compatibility of investments sets out the rules and procedures to be followed in order to make investments compatible with the environment and specifies the nature, respective powers and degree of authority of the institutions or bodies authorized for this purpose.

4.5.5 Issues

Despite of the regulatory framework and existing systems of integrated Environmental Management System (SIGE) adopted by the Ministry of Mine in connection with the National Office of Environment, many issues are not taken into consideration, and some remain recurrent problems in Environmental and social Impact Assessment practice Among the prevailing issues are:

(1) Administration

- Inconsistency in the process timeline for awarding mining permits and non-compliance with the timeframes imposed for signing permits
- The insufficient resources of the National Office of Environment (ONE) lead to the dependence of this institution on the financing provided by promoters (TI-MG, 2020). The risk is that the ONE's dependence on funding provided by promoters will lead to the loss of objectivity of the teams involved in environmental assessments.
- Lack of institutional capacity: inadequate management resources, necessity of training and institutional support of ministry and agency personnel
- Power conflicts at the Ministry of the Environment: Minister in charge of the environment may, by virtue of his own power, issue the environmental permit. The minister has the power to override the unfavorable technical opinion of the ONE.
- The ministerial authority in charge of granting environmental permits has the power to override the technical opinion of Office National of Environment (ONE).

(2) Local community

- The low level of education of the community facilitates manipulation by opinion leaders or companies
- Lack of understanding of the content of the EIS can lead to corruption if community members do not know whether the issues raised have been considered by the developer. Opinion leaders may interpret the content in their own way to serve their own interests.
- The public is not involved during the preparation of Environmental Impact Assessment report: According to the survey by Nikiema et al., 2023 (see p. 15), the public was consulted only after the submission of the Environmental Impact Assessment report to Government by the promoter, which is against the mining permit procedure.

(3) Environment

- Conflicts between Mines and the Environment: Even the granted mining title has fixed coordinates, there is possible overlap of the sites for mining activities and the protected areas. There is no similar precise delimitation for protected areas

Non-compliance of the rule of Environmental law and the submitted and planned Environmental Impact Assessment and the restoration management

4.6 Satellite image analysis

4.6.1 Mining area

The locations of the survey area (described above in section 2.2.1) and the seven mining areas are shown in Figure 4-13. The background is a true color image of Sentinel-2, with the red box representing the area of satellite image analysis and the blue box representing the mining area. The target ore types in Madagascar are nickel, chromium, cobalt, and graphite, and the satellite image analysis includes mines of all ore types.

The five mining areas where satellite image analysis was carried out were Ambatovy nickel-cobalt mine, Marovintsy graphite mine, Tamatauw graphite mine, Didy ASM and Maladialina ASM.

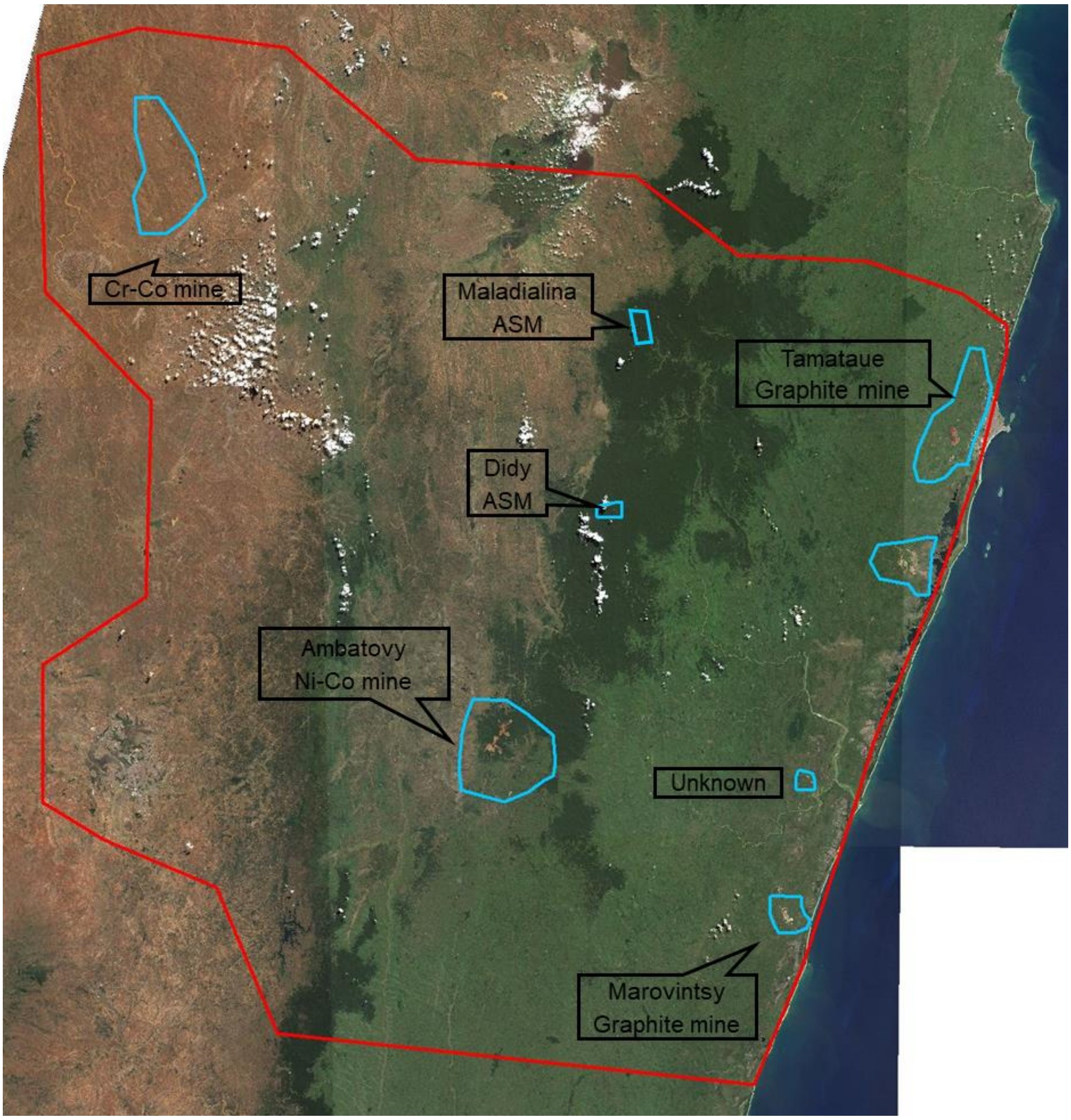


Figure 4-13 Mining areas in Madagascar

4.6.2 Time series change

(1) Ambatovy nickel and cobalt mine

A time series of Sentinel-2 true color images of Ambatovy nickel-cobalt mine for each year from 2015 to 2023 is shown in Figure 4-14. Image of 2015 show a great deal of cloud cover, but this is the image of the least amount of clouds in the data for that year.

The images from 2016 onward show little change in the central to southwest operating area, while the northeast area began to develop in 2017 and is still recognized as developing in a northeastern direction.

(2) Marovintsy graphite mine

Sentinel-2 true color images of Marovintsy graphite mine for each year from 2015 to 2023 are shown in time series in Figure 4-15. Image of 2015 has cloud cover, but this is the best quality data for that year.

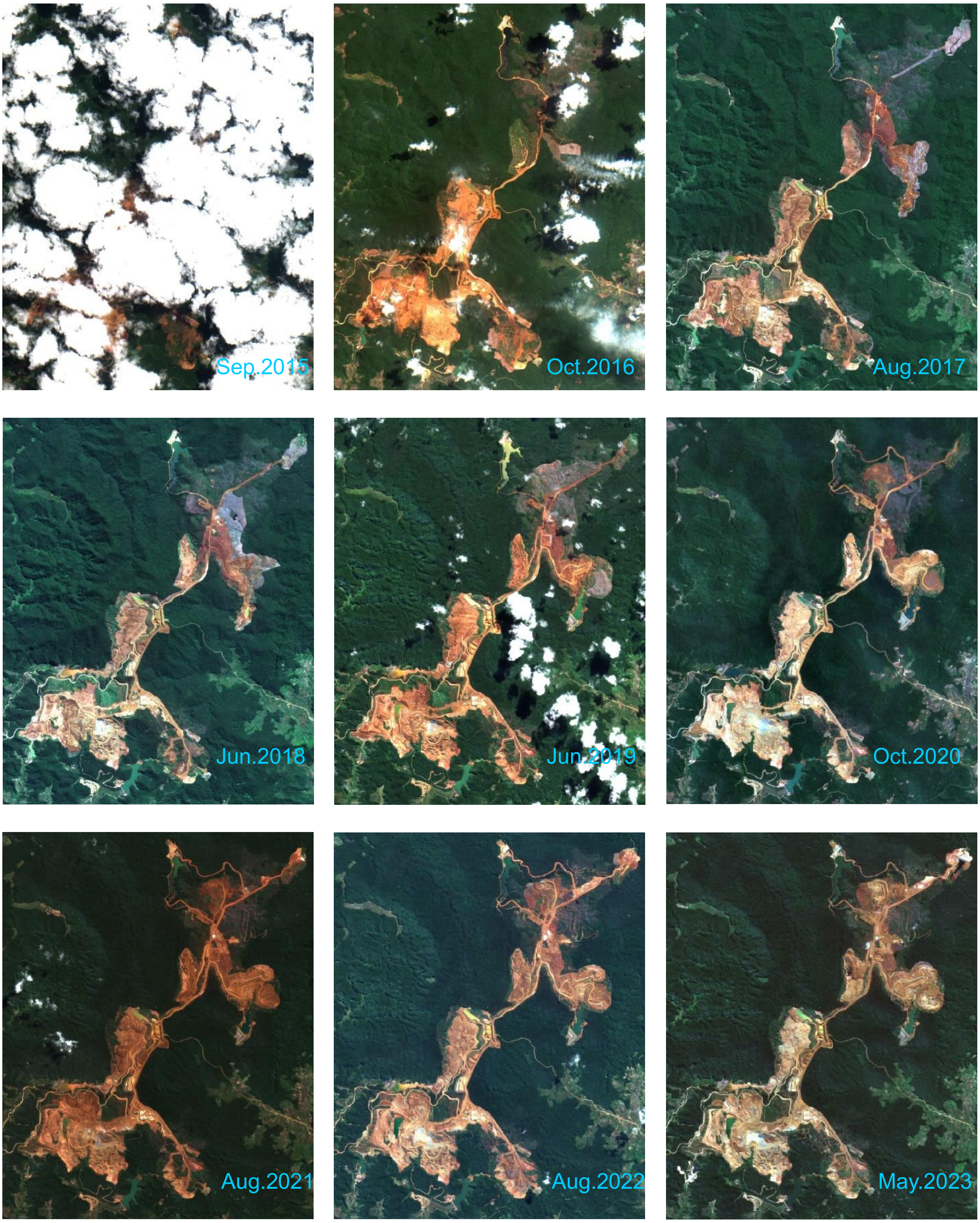
In the images from 2016 onward, it is recognized that the northern area of operation has not changed much, while the southern area began to develop in 2018 and the central-western area began to develop in 2019.

(3) Tamataue graphite mine

Sentinel-2 true color images of Tamataue graphite mine for each year from 2015 to 2023 are shown in time series in Figure 4-16. Image of 2015 has cloud cover, but this is the best quality data for that year.

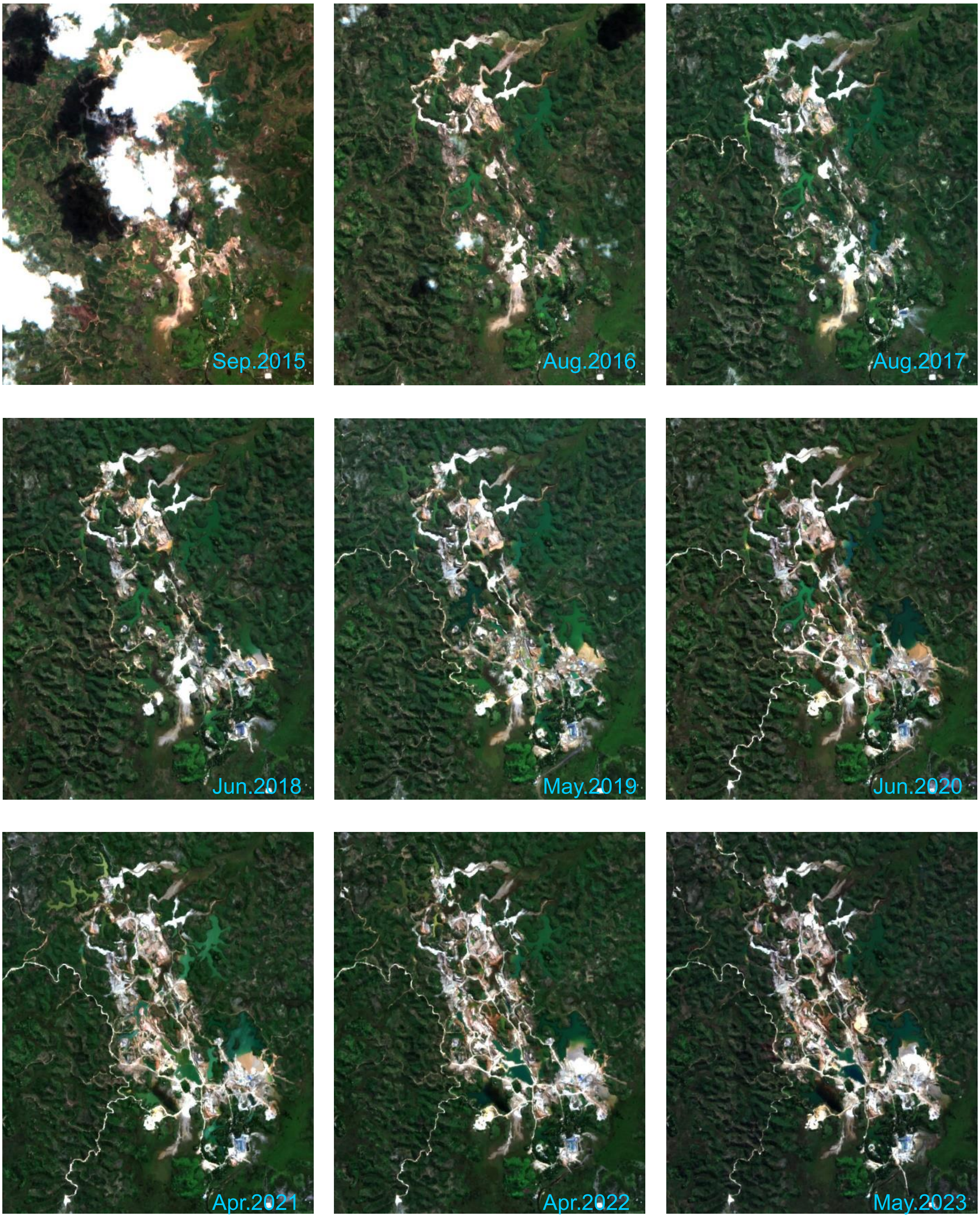
The red area seen in the northeast is a dammed lake constructed by mining development. Past satellite image shows that the dam construction began in 2011.

Images from 2016 onward show the development around the dammed lake and in the central-west area, while the southeastern operating area appears to have been rehabilitated (restored to its original condition) by around 2022.



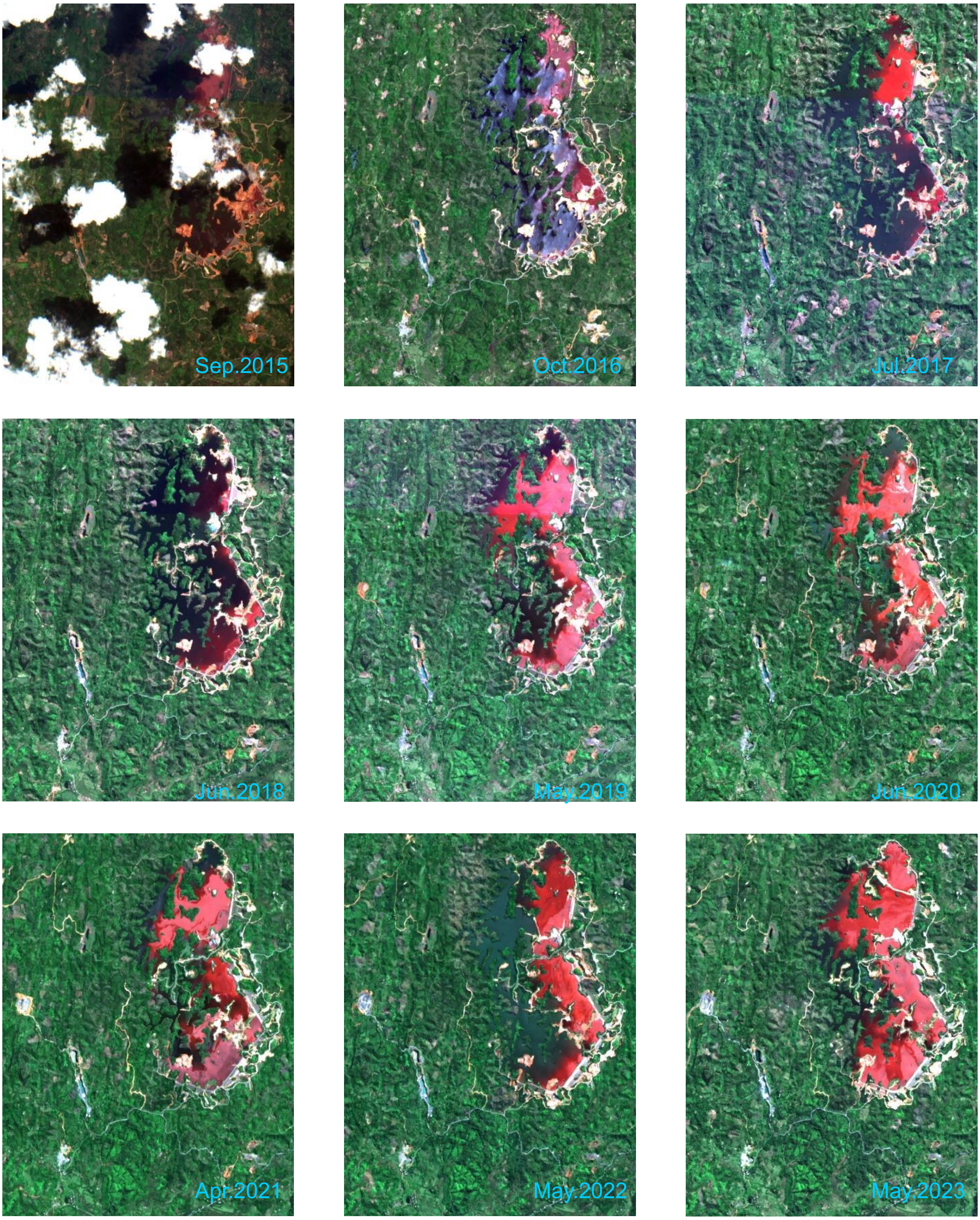
Note: The annuals are newer from top left to right, middle left to right, and bottom left to right, in that order.

Figure 4-14 True color images of Ambatovy mining area from 2015 to 2023



Note: The annuals are newer from top left to right, middle left to right, and bottom left to right, in that order.

Figure 4-15 True color images of Marovintsy mining area from 2015 to 2023



Note: The annuals are newer from top left to right, middle left to right, and bottom left to right, in that order.

Figure 4-16 True color images of Tamataue mining area from 2015 to 2023

(4) Didy ASM

Sentinel-2 true color images of Didy ASM (ruby mining) site in 2016, 2018, 2021 and 2023 are shown side by side in Figure 4-17. It is recognized that the existing data indicate that the gemstone mining rush in this district occurred in 2012, and that the rush was over by 2016. However, the image of 2023 shows a larger area of the distribution of soil (deforestation) in the western part of the district, which suggests that there may have been new ASM activity.

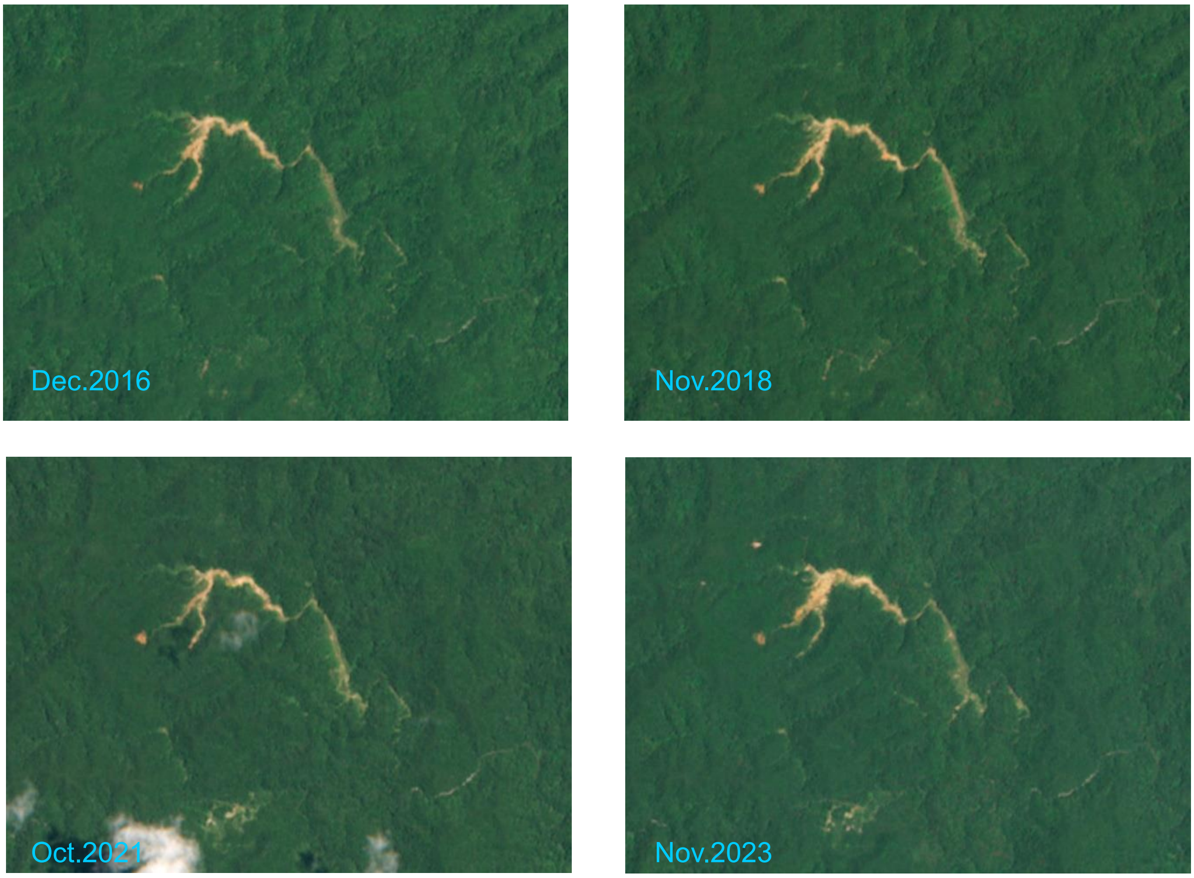


Figure 4-17 True color images of Didy ASM area from 2016, 2018, 2021, and 2023

(5) Maladialina ASM

Sentinel-2 true color images of Maladialina ASM (sapphire mining) site for each year from 2016 to 2020 and 2023 are shown in time series in Figure 4-18.

According to existing data, the rush of gemstone mining in this district is considered to be from late 2016 to 2017, and according to the image of 2017 is recognized a wider soil distribution area (light brown area in the image) along the river. However, the image of 2019 is not much different from the image of 2016, which suggests that this rush ended after about two years.

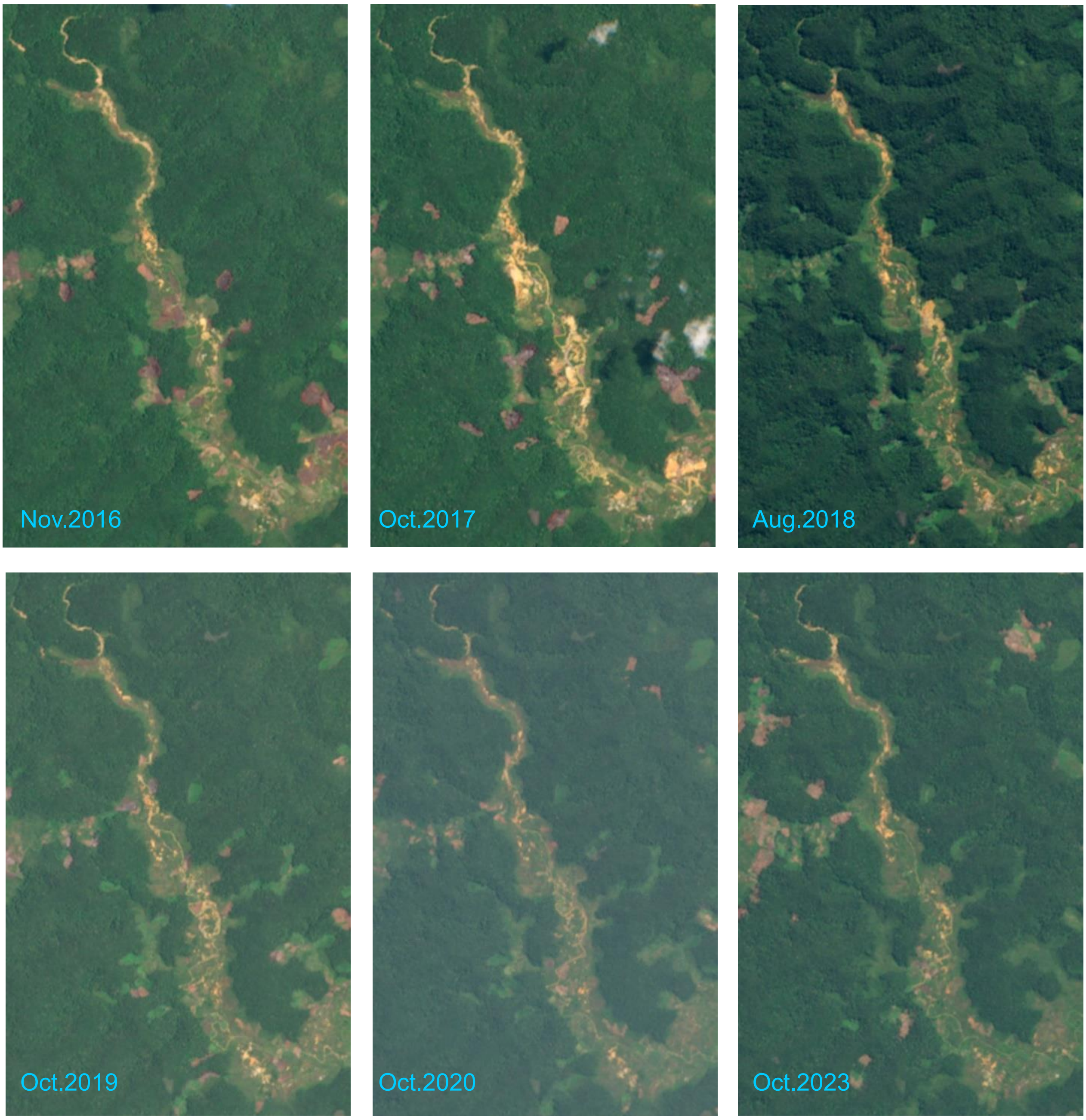


Figure 4-18 True color images of Maladialina ASM area from 2016-2020 and of 2023

4.6.3 Analysis result

(1) Ambatovy nickel-cobalt mine

Ambatovy mine began production in 2012. Figure 4-19 shows the operating areas for each year from 2016 to 2023 in Figure 4-14 were deciphered and drawn in GIS, with the polygon for the most recent year, 2023, at the bottom, and the polygons for the older years in turn overlaid with different colors.

In Figure 4-19, it is readable that the area from the center to the southwest was developed first, and that the development on the northeast side had already begun in 2016, with the operation area expanding to the northeast after 2017.

The main access road to the mine is from the west, and its route can be seen on the southwest side of Figure 4-19. On the other hand, there is also a road extending to the east, which is the route with a pipeline that was laid to transport ore in slurry from the mine.

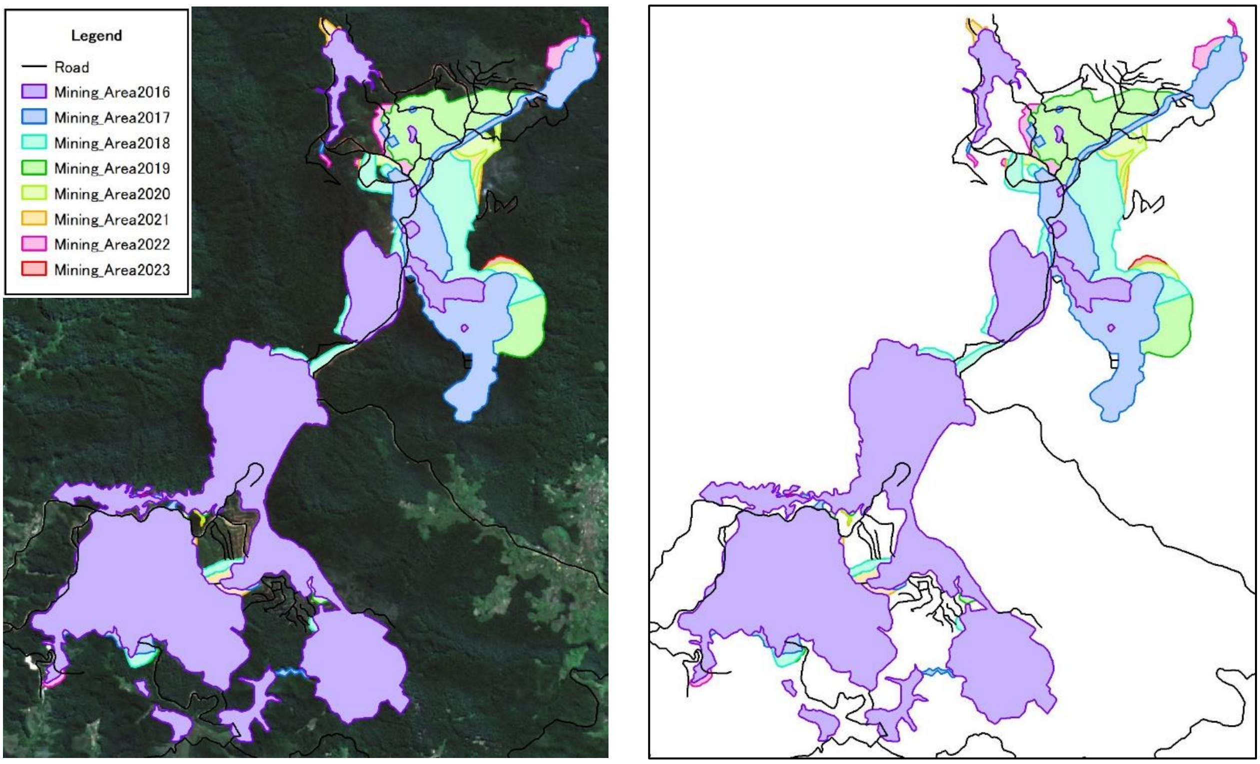


Figure 4-19 Changes in times series of operating locations at Ambatovy mine (2016 to 2023)

The most recent (taken as of December 26, 2023) Sentinel-2 image showing the location of the core mining facilities of Ambatovy Mine is shown in Figure 4-20. From this figure, opencut pit (operational, abandoned, and submerged), waist rock deposition site, mine building, thickener, water storage dam, and reservoir can be deciphered. The location and degree of progress of the restoration to original condition (afforestation/revegetation) can be deciphered from the data of changes over time (Figure 4-14). In addition, the pit on the west side in Figure 4-20 already submerged in the image of June 2019, which indicates that the pit had been terminated by this time.

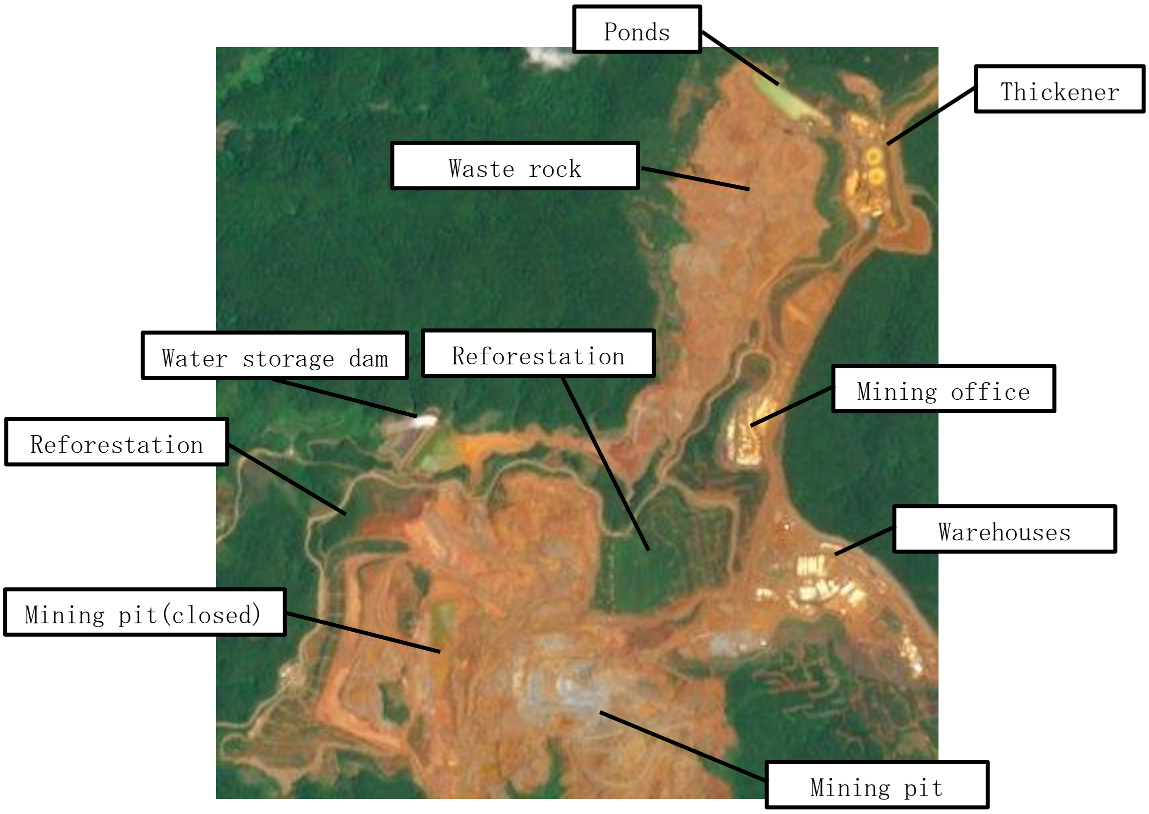


Figure 4-20 Decipherment of Ambatovy mining facilities

Ambatovy mine was developed by clearing native forest, so the mining operation area is located within a forested area. For this reason, the image of vegetation index analysis shows the mining area very clearly. Figure 4-21 shows the true color image and the normalized vegetation index (NDVI) image side by side.

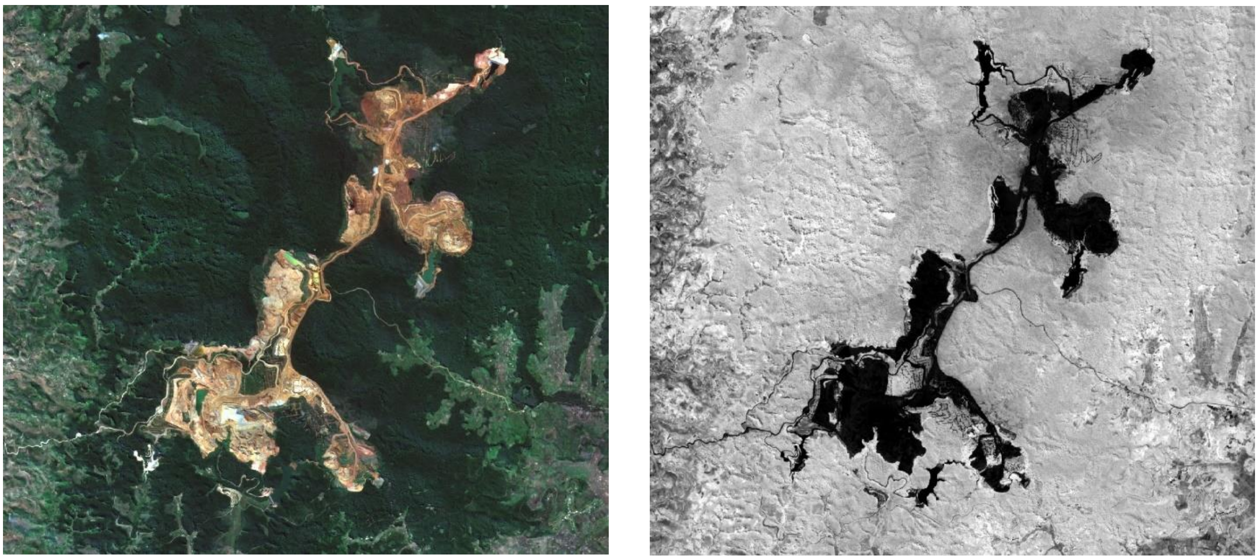
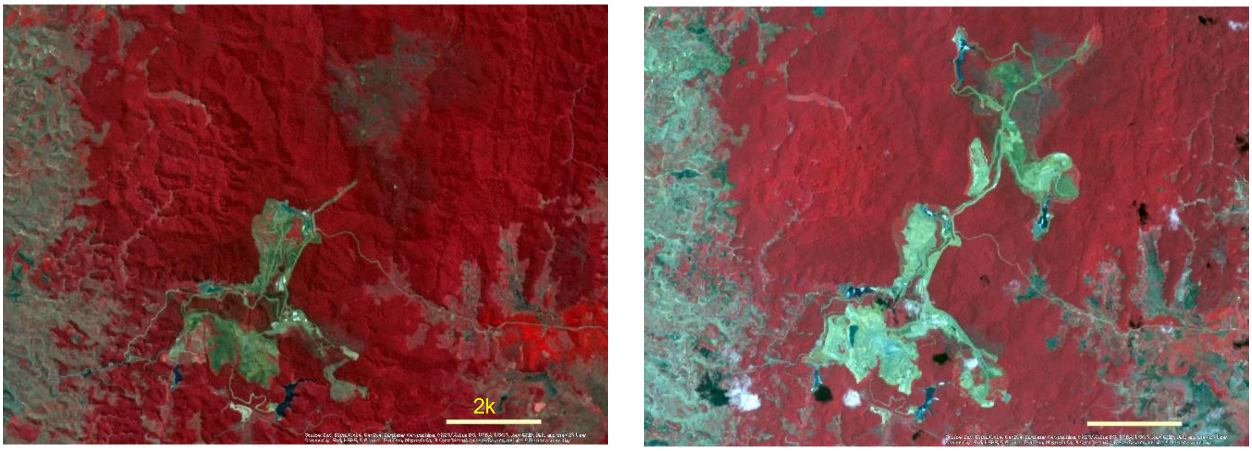


Figure 4-21 True color images and vegetation index images of Ambatovy mine area

In NDVI image, areas with no vegetation are black and areas with highly active vegetation are white. Since no vegetation is present in mine pits, waist rock deposition sites, and water bodies, NDVI image in Figure 4-21 clearly shows the operational areas in black.

Using images for the two periods of Ambatovy mine, an analysis was attempted to extract differences between the images. Here, images acquired by the Japanese satellite sensor ASTER were used. Figure 4-22 shows the ASTER images of September 2013 and November 2020. In both ASTER band composite color images (RGB=Band 3, Band 2, Band 1), the red areas represent vegetation, indicating that the northeast side of the mine was not yet developed in 2013, while it was developed in 2020.

Figure 4-23 shows the results of the change extraction analysis for both color images. This figure is a grayscale image with 256 shades, and the whiter the image, the greater the change between the two images, and the blacker the image, the smaller the change.



Left image: September 5, 2013; Right image: November 27, 2020

Figure 4-22 Comparison of images of two periods of Ambatovy Mine

Figure 4-23 Results of the change extraction analysis for images of two periods of Ambatovy Mine

The figure shows that the newly developed area on the northeast side of the mine is well extracted, and the expanded area is also extracted with good accuracy in the central developed area. Therefore, it can be seen that this type of analysis method is effective for monitoring mining development. It should be noted, however, that extracted changes include not only changes in mining operation areas and water areas related to mining, but also events such as new road construction, agricultural land development, and forest loss, as well as clouds and cloud shadows.

In the image comparison in Figure 4-22, it is easily recognized that agricultural lands have been developed in the western edge and southeastern parts of the image, and they are also clearly identified as white to gray color in Figure 4-23. Therefore, such image analysis is useful not only in the mining sector but also in other fields.

(2) Marovintsy graphite mine

Figure 4-24 shows the changes in time series of Marovintsy mine from 2015 to 2023. From the same figure, it can be read that the development in the southern to southeastern and central areas of the mine has progressed since 2017.

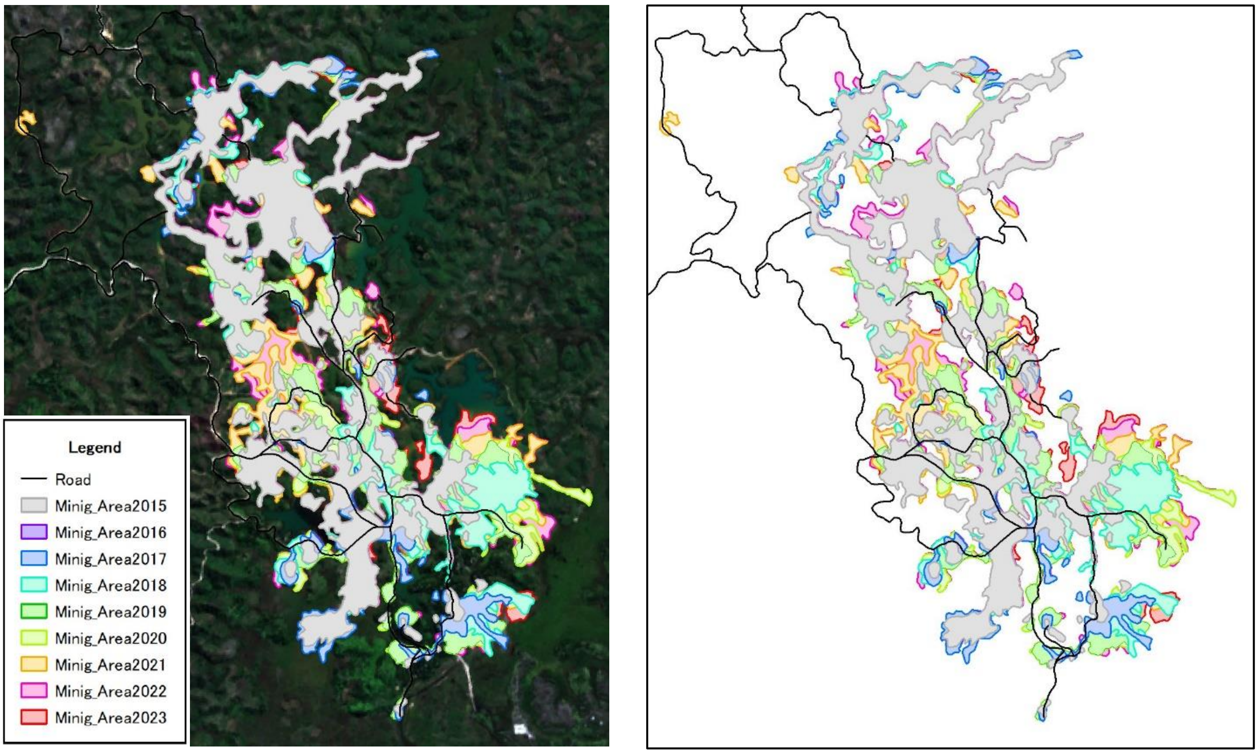


Figure 4-24 Changes in time series of Marovintsy mine operating locations (from 2015 to 2023)

In each year's image of Marovintsy mine, are observed environmental impacts in the form of the runoff of soil and sand from the mine operation area into the river system. Among these images, image of 2017 shows a relatively large impact, and the impacted area is shown in Figure 4-25. In this figure, the image on the left includes the entire mine area, and the enlarged images for the areas inside light blue frames of these two locations in the north and south are shown on the right. The areas inside the red frame in the right image can be read as the areas where sand and soil were discharged into the river due to mining operations. This is a good example of how satellite image can be effectively used for environmental monitoring of mines.

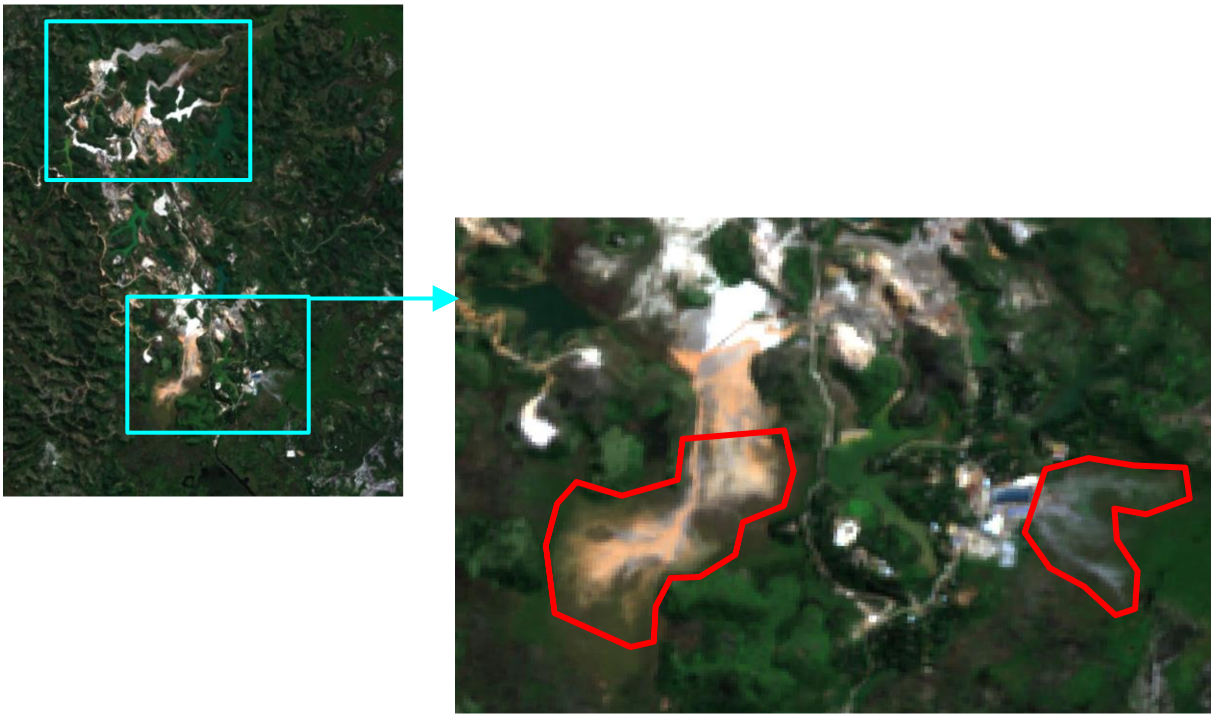


Figure 4-25 Discharge of sand and soil from Marovintsy mine operation area into the river

(3) Tamataue graphite mine

The changes in time series from 2015 to 2023 for Tamataue Mine is shown in Figure 4-26. From this figure, it can be read that the development has expanded gradually around the dammed lake since 2016. In the leftmost center of the image, one can read the presence of a pit where mining began in 2020.

The dammed lake at the mine has a very strange red color, but this is because the brightness of the image has been adjusted, and it is actually brownish brown. Lateritic soil seems to have developed in this area, and it is assumed that the iron oxide contained in the soil is deposited in the dammed lake, giving it a brownish color.

The presence of this dammed lake may be the reason why Tamataue mine has not experienced the runoff of soil and sand, seen at Marovintsy mine mentioned above.

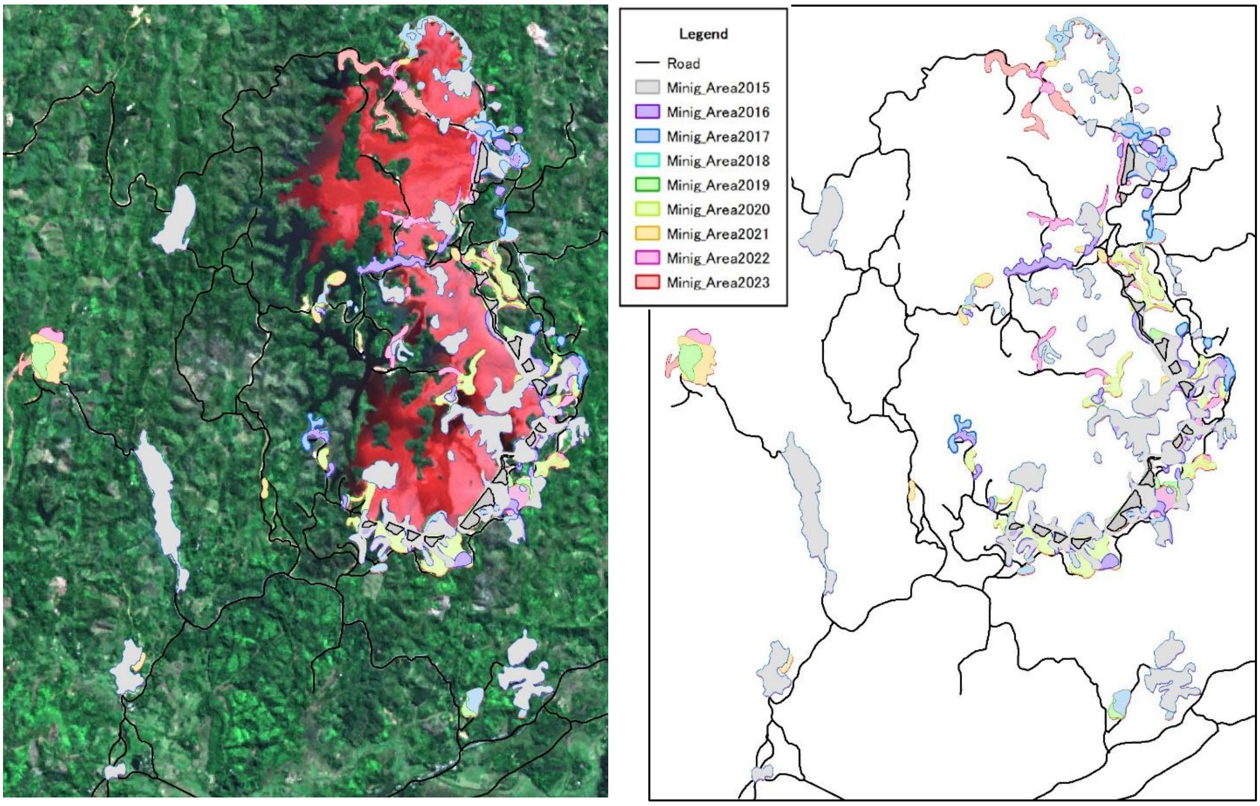
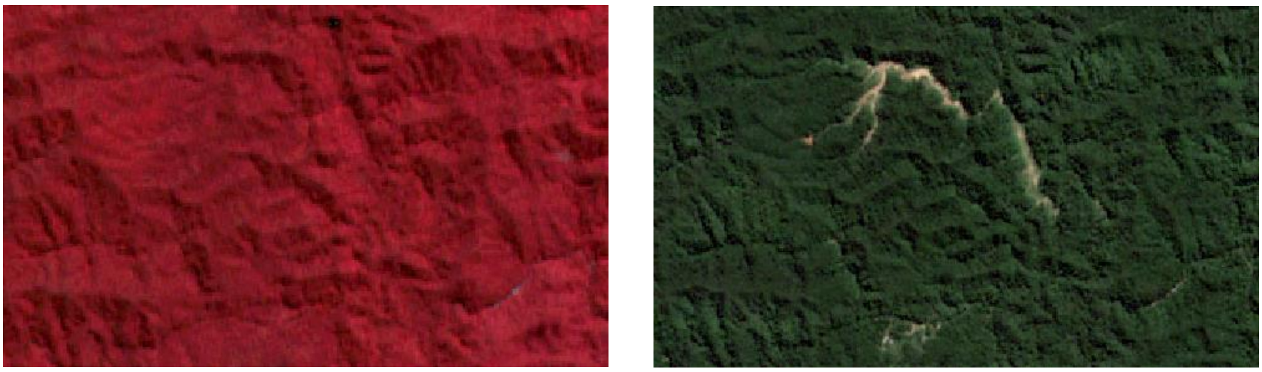


Figure 4-26 Changes in time series of Tamataue mine operating locations (from 2015 to 2023)

(4) Didy ASM (ruby mining)

The above time series change diagram was not created because little change or transition was observed in the Sentinel-2 images for each year of the change in time series described above. Since the rush of gemstone mining in this district is considered to be in 2012, ASTER images were retrieved and obtained as satellite images before that year. Figure 4-27 shows side by side the ASTER image taken on May 30, 2009 and the Sentinel-2 image taken on May 30, 2021 for the same area. It is evident that the forest has been cleared along the river. A photograph of the mining scene taken at the same location is shown in Figure 4-28. It shows the mining work in progress, with many people panning.



Left image: May 30, 2009; Right image: May 30, 2021

Figure 4-27 Comparison of the images of two periods of Didy ASM site

Source：V.Pardieu（2012）

Figure 4-28 Gemstone mining scene at Didy ASM site

(5) Maladialina ASM (sapphire mining)

The time series change diagram as mentioned above was not created because not much change/transition was observed in the Sentinel-2 images for each year of the change in time series.

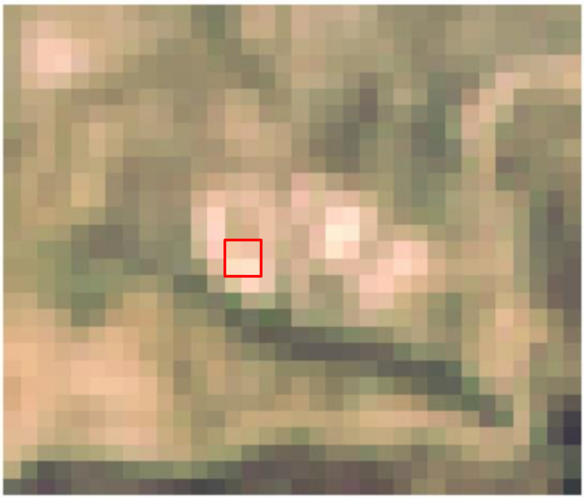
4.6.4 Field survey of quarry ASM site

As previously mentioned, this project includes image analysis of ASM sites, although its main focus is satellite image analysis of large-scale mines. However, since ASM sites generally operate on a small scale, it is often difficult to identify the location of operations using Sentinel-2 image with a resolution of 10 to 20 m. In addition, ASM sites are generally located in remote areas and are often difficult to access.

In Madagascar, visited secondly among the three African countries in the second round of field survey, we considered conducting a field survey of ASM sites close to the capital city, since we had a little more leeway in terms of schedule compared to the other countries. As a result of a careful review of existing literature and Google images, we were able to confirm the existence of numerous small mining sites in an area (5 km x 10 km square) approximately 10 km southeast of Antirabe, which is 120 km south of the capital, Antananarivo. Since Anchirabe is the fifth largest city in Madagascar and the area where these small mining sites are located is a rural area near the city, it was judged to be safe and a visit to the site was planned. In fact, the site visit was planned to take two days and one night, as it was expected to take nearly five hours by car from the capital city to the site.

The Sentinel-2 image and Google image of the survey site are shown side by side in Figure 4-29. The Sentinel-2 image was taken on October 17, 2023, and the Google image was taken on April 25, 2023. The field survey was conducted on October 19, 2023, which is almost the same time as the Sentinel-2 image.

A square red frame is shown in the center of both images in Figure 4-29. It corresponds to a 20m x 20m area, or 2 x 2 pixels in the Sentinel-2 image. In the enlarged Sentinel-2 image, where the pixels are clearer, the presence of a road and the distribution of vegetation can be recognized, but it is difficult to determine what exists inside the red frame. There is no vegetation in the area and it is impossible to decipher the presence of a mining pit here, even though the distribution of rocks and soil can be inferred.



Left image: October 17, 2023; Right image: April 25, 2023

Figure 4-29 Images of Sentinel-2 and Google for Antsirabe ASM site

The photos taken at the site are shown in Figure 4-30. Google images and descriptions of the photos in the figure are provided as captions above the figure titles.

Since the discovery of numerous mining sites in this area in Google image in Figure 4-29, we had assumed that these were the remains of mining for gemstones contained in pegmatite. However, upon visiting the site, it turned out to be the remains of stone mining. In developed countries, large-scale opencut mining is common when it comes to quarrying, while in developing countries, this type of mining (these are also a type of ASM) is widely practiced by people with equipment as small as hammers in a cottage industry manner. However, the most commonly seen mining is done at the foot of exposed rocky areas of large mountain bodies or under cliffs, and it is rare to see it done in the rolling plains as those of this area. It is considered that stone mining is actively conducted in the area due to the geological distribution of high-quality rocks suitable for stone and its proximity to the large city of Anchirabe.

In any case, for the ASM site, it proved to be extremely difficult to decipher the location and status of the operation from Sentinel-2 image alone, unless there was information on the location and ore type. In addition, the importance of ground truth was reaffirmed for the satellite image analysis. In this sense as well, the field survey was meaningful.

・Google image at upper right: Red arrows indicate mining sites, light blue dotted ovals indicate mining sites in the upper left photo, and magenta dotted arrows indicate the location and direction of the lower right photo.

・Top left photo: The mining site, about 10 meters deep, indicated by the light blue dotted oval in the upper right Google image. A mother and two children were engaged in the work. A cubic rock block product of about 20 cm per side can be seen in the upper right of the photo.

・Lower right photo: The photo was taken in the direction of the arrow from the point of the magenta dotted arrow in the upper right Google image. The red arrow in the photo indicates the same point as in the upper right Google image.

・Lower left photo: 2- to 3-cm-sized stone product made from rock blocks that have been mined and broken into smaller pieces with a hammer. A contractor is coming to buy the product.

Figure 4-30 Field photo of Antsirabe ASM site

4.6.5 Decipherment of mining development status

As mentioned above, analysis and interpretation of Sentinel-2 image generally deciphers the mining development status of relatively large mines such as Ambatovy mine, including opencut mining pits (operational, abandoned, or submerged), waist rock deposition site, various mine buildings, thickeners, storage dams, reservoirs, and work roads. In addition, the environmental status of the discharge of soil and sand, and the location and progress of restoration (afforestation/revegetation) may also be deciphered.
On the other hand, as for small-scale mining activities such as ASM, conditions of deforestation and soil exposure, etc. can be deciphered, but it is impossible to recognize more detailed information.

4.6.6 Monitoring policy of mining development status

If satellite image monitoring is to be implemented in the future, Sentinel-2 data, free of charge, available via the Web, and having a high imaging frequency, would be the only option.
The method of monitoring mining development status, using Sentinel-2 image, is summarized below. Normally, good quality cloud-free image is only available during the dry season, but since Sentinel-2 data is acquired every 5 days, it is required to check the Copernicus website at least once a month to check the image. Weekly checks are especially required if environmental impacts are to be monitored.

(1) Identification of operation area

- Used image 1: True color image (RGB=Band 4, Band 3, Band 2)
- Decipherment 1: Locations of mining sites, waist rock deposition sites, various mining facilities, etc., are identified to determine the operation area.
- Used image 2: Normalized vegetation index (NDVI) image (formula = (Band4-Band3)/(Band4+Band3))
- Decipherment 2 : Since there is usually no vegetation in the operation area, the area with a vegetation index of zero is determined to be the operation area.

(2) Identification of mining sites and waist rock deposition sites

- Used image 1: True color image (RGB=Band 4, Band 3, Band 2)
- Decipherment 1: Distribution of mining sites and waist rock deposition sites are identified.
- Used image 2: False color image (RGB=Band12, Band4, Band2)
- Decipherment 2 ： Distribution of rock and soil is determined by color tone.

(3) Identification of reservoirs and tailings disposal sites

- Used image 1: True color image (RGB=Band 4, Band 3, Band 2)
- Decipherment 1: Distribution of reservoirs and tailings disposal sites are identified.
- Used image 2: Band ratio calculation image (RGB=Band11/Band12, Band12/Band4, Band4/Band2)
- Decipherment 2 : Vegetation, water bodies, and soils are distinguishable, and the distribution of water bodies and waist rock deposition sites is determined by color tone.

(4) Environmental impacts such as soil runoff and others

・Used image 1: False color image (RGB=Band 12, Band 4, Band 2)

・Decipherment 1: Distribution of rock and soil is determined by color tone.

・Frequency: As often as possible to capture the changes over time

(5) Environmental impacts against vegetation

・Used image 1: Normalized vegetation index (NDVI) image (formula = (Band4-Band3)/(Band4+Band3))

・Decipherment 1: This index indicates the distribution and activity of vegetation and thus determines the impact on vegetation.

・Frequency: As often as possible to capture the changes over time

(6) Identification of ASM site

・Used image 1: True color image (RGB=Band 4, Band 3, Band 2)

・Decipherment 1: Location of mining sites is identified.

・Used image 2: Band ratio calculation image (RGB=MNDWI, NDVI,(Band11+Band8)/ (Band11+Band8)). Here MNDWI is Modified Normalized Difference Water Index and the formula is (Band3-Band12)/(Band3+Band12).

・Decipherment 2 : Usually, water areas are represented by red tones, vegetated areas by green tones, and soil areas by blue tones. In ASMs, since large amounts of water is used, ponds are often created. Identifying the dense distribution of ponds and rivers by this image may be useful in determining the location of ASM activities.

4.6.7 Various problems related to the use of satellite data

The challenges for government agencies involved in the mining industry and the environment to use Sentinel-2 satellite data in order to monitor mining activities can be summarized as follows.

(1) Human resources

There are few engineers who fully understand the theories and techniques related to satellite data handling and data analysis. There are no engineers who analyze satellite data on a daily basis.

(2) Training for satellite data analysis

It cannot be assumed that engineers with some data analysis skills and experience can provide technical guidance to others within their organizations. Therefore, technical training by outside experts is necessary. In fact, training was requested during the interviews at the target organizations.

The contents of training include satellite data theory, data analysis methods, deciphering and interpretation of analyzed images, database construction, introduction of analysis cases, analysis of actual data and field verification surveys of analysis results, and monitoring methods, etc.

(3) Field survey

Information that can be deciphered and monitored only by satellite data analysis needs to be verified even if periodically (once a year, at the same time as mine inspections, is acceptable). However, due to the budget and human resource constraints, it is unlikely that many such opportunities will be available.

(4) Organizational structure

When it comes to the monitoring of mining activities, the department the most related to the mining industry should be in charge, but it will also be necessary to collaborate with the departments that manage licenses and environmental management. It is necessary to establish a system that allows various data to be shared among multiple departments.

4.7 Potential of mining development

Mineral types with high potential for mining development include nickel in laterite and cobalt as a byproduct, chromium in ultrabasic rocks, and graphite in metasedimentary rocks. There is still much room for exploration and development of all of these ore types. In particular, the importance of Madagascar as a producer of graphite is likely to increase in the future, given the current oligopoly of China as a producer, in addition to the increasing demand for batteries used in electric vehicles (EVs).

Potential areas for these ore types are concentrated in the central to eastern and coastal areas of Madagascar, but graphite has potential especially in the southern part of the country. In addition to the development of each mining corridor and port infrastructure, the development of human resources, particularly in the mining industry, which is in short supply in Madagascar, is expected to contribute to the promotion of the country.

4.8 Field survey

4.8.1 Collection of information during the first field survey

During the second round of the first field survey, we visited the following organizations in the capital, Antananarivo, from October 16 to 20, 2023, to gather information and conduct interviews.

- Direction Generale des Mines (DGM), Ministry of Mines and Strategic Resources (MMRS)
- General Direction of Environmental Governance, Ministère de l'Environnement et du Développement Durable (MEDD)
- Conservation International (CI)
- Office des Mines Nationales et des Industries Stratégique (OMNIS)

On October 19, during the second phase of the first field survey, a field verification survey of satellite image was conducted by visiting ASM quarry site, located approximately 5 hours by car from the capital Antananarivo. Its details are previously described in Section 4.6.4.

Information obtained in Madagascar were as follows.

① Cooperation with JICA projects

Ministry of Mines and Strategic Resources (MMRS) was highly interested in the project contents, especially in monitoring through satellite image, and recognized its effectiveness. They mentioned that they could cooperate with us in providing information in the future. Ministry of Environment and Sustainable Development (MEDD) was similarly interested in JICA project.

The local office of JICA Madagascar expressed interest in the project. In particular, they are interested in the mining industry in general and ASM in particular, since a Japanese company operates the Ambatovy mine and has provided assistance in port development, etc.

② Mine management

MMRS administers mining licenses. The inspection department conducts inspections of operating mines. However, due to the recent political changes, political turmoil, and suspension of foreign aid, inspections are not conducted very often due to the shortages of budget and staff. As for our satellite images and their analysis results, the counterpart commented that they were effective and efficient for inspections.

③ Monitoring status of mining activities

MMRS inspections are conducted at random in the dry season, but actually they are not frequent. Normally, inspections are conducted once a year, but the Ambatovy Mine has only been inspected once in 12 years since it began operation. The mine submits periodic reports, so the inspections are done through checking these reports.

MMRS also has a department for the environment, which conducts inspections related to the mine's environment. MMRS conducts inspections of the mine's operations, environment, and safe work practices. Whenever there are complaints from residents living near the mines, MMRS visits the mines to check the problems.

MEDD is in charge of EIA (Environmental Impact Assessment) for the mine and conducts biannual inspections of the Ambatovy mine in accordance with the environmental agreement. The mine requires an application for new logging of trees.

④ Status of the use of satellite data and utilization technology

MMRS has used Landsat and ASTER data for geological and mineral confirmation, but never for monitoring. This is due to the fact that many of the participants have experience as training participants at the Remote Sensing Center of JOGMEC Botswana. Many of them are familiar with satellite images and can handle ENVI (a specialized software for satellite data analysis). In the past JICA projects, satellite images have been handled, and seminars on analysis methods have been conducted. Although they have never used the Sentinel-2 data used in this project, if they can handle Landsat and ASTER, they should be able to use it without any problems.

MEDD uses U.S. MODIS satellite data for forest management, especially for monitoring forest fires. In the forest protected areas, MEDD uses the data to understand the forest, vegetation, biodiversity, fauna, and soil, etc. Under the mining policy, deforestation in protected areas is subject to court proceedings.

⑤ Drone

MMRS and MEDD do not carry out the work using drones.

⑥ Status of ASM (artisanal/small-scale *mining*)

MMRS has a database of ASMs (only for location information). However, many of them are illegal and there is no detailed information.

MEDD is aware of ASMs, but does not specifically target them for management, etc.

⑦ Status of the assistance from other countries

Foreign support was suspended in 2009 due to the political upheaval. A new MMRS minister was appointed in 2022.

Foreign assistance in the field of geology and mineral resources has been provided by the World Bank (European countries and the United States), France, Japan, Korea, and China. Iran began support in 2022.

In 2014, MMRS signed an MOU with Geology and Remote Sensing Center of JOGMEC Botswana and agreed to promote lithium resource exploration and human resource development. SATREPS (JST/JICA) is considering a geological and environmental project on soil degradation in gold mining.

In MEDD, there is assistance from China and France.

⑧ Activity of OMNIS (Office des Mines Nationales et des Industries Stratégiques)

OMNIS is a state-owned company under MMRS that explores and develops mineral and petroleum resources and has an analytical laboratory. It is currently conducting an exploration of graphite and gold and co-manages the Ilmenite Mine (QMM). Petroleum exploration has been in place for more than 40 years, and the company is currently exploring six mining areas. Only one borehole is in production. Exploration of lithium is under planning. There are no activities concerning ASM.

OMNIS uses Landsat and ASTER data in its exploration activities. Several engineers have participated in JICA's KCCP training and Kizuna Program. They have shown high interest in this JICA project, but would like to cooperate with projects related to mineral resource exploration.

⑨ Activity of Conservation International（CI）

CI is an environmental NGO with offices in 58 locations in 31 countries and is currently implementing programs in five countries in Africa. In Madagascar, CI is working with MEDD to manage environmental conservation (conservation, restoration, establishment of protected areas, education of the residents, etc.) in three sites.

As an offset conservation, the Ambatovy mine has established a protected area of the same size as the mine development area. Here, the aim is not only to conserve the area of forest cleared by the mine development, but also to restore the ecosystems that have been lost and to conserve more sufficiently the environment.

We are aware of illegal ASM activities for jewelry and gold within the forest protected area, but CI is unable to take any action.

CI has a contract with a system (Fire Cast Alert) that automatically detects forest fires, wildfires, etc., and it may be contacted whenever a forest fire occurs.

⑩ Visit of ASM site

Based on existing literature, we assumed that a small group of pits located about 10 km east of Antsirabe was ASM of gem, and planned a field survey of this site. According to the information from a Madagascan university's professor who accompanied us, the gem mining site was located about 50 km further east in the mountains, and we thought it might be a new gem mining site. However, when we actually visited the site, it turned out to be a stone (building material) mining site. Although we realized the significance and necessity of the field survey (Ground truth), we believe that we have acquired results in image interpretation.

Mining at one location was done by two to three persons, who used large hammers to cut out the rock blocks and break them into smaller pieces. The products were cubic blocks of 10 to 20 cm on a side and small pieces of 2 to 3 cm in diameter.

4.9 Summary and recommendations

4.9.1 Summary

(1) Mineral Resources

As chromium and mica have long been developed, and graphite, nickel-cobalt, and ilmenite have been developed in recent years, Madagascar is considered to have high potential for mineral resources. ASM of gemstones is taking place in many parts of the country, and mining rushes are frequent. The share of mining in GDP is estimated at 4.8%.

(2) Management of mining development

Ministry of Mines and Strategic Resources (MMRS) fulfills properly the role of managing mining licenses and inspecting safety aspects, while Ministry of Environment and Sustainable Development (MEDD) approves EIAs for mining development and inspects environmental aspects. However, the reality is that few mine inspections are conducted.

(3) Monitoring mining development with satellite image

Although the relevant ministries and agencies have experience in using satellite image, it has not been used for monitoring mining development. The relevant agencies have shown a much interest in the satellite image analysis and other activities in this project, and have come to recognize their effectiveness.

(4) ASM

Most of ASMs are illegal, and MMRS does not have detailed information. MEDD does not specifically target them for management. Looking at the existing data, it seems impossible to control the rush to mine gemstones.

(5) Cooperation with Japan

All of the ministries showed a great interest in the use of satellite image, and they are looking forward to JICA's support and cooperation.

(6) Japanese Involvement

A Japanese company owns and operates Ambatovy nickel mine with an interest of more than 50%.

JICA is providing assistance in the mining sector. Madagascar is a recipient of the Kizuna program and its students are admitted to Japanese universities.

4.9.2 Issue

(1) Social conditions

There was a political upheaval in 2009 and economic stagnation due to the suspension of foreign aid. A democratically elected president was inaugurated in 2014, and support from other countries resumed after 2016.

There was a period of suspension of mining operations due to COVIT-19, but operations have now resumed.

(2) Mining development

Development of existing mineral resources is continuing, and future mining development is expected. In particular, graphite is attracting attention as a critical energy mineral, and abundant resources in Madagascar are under development. On the other hand, investment in resource exploration and mine development has not increased significantly due to the problems such as access to mines and underdeveloped port facilities for export.

(3) ASM

As for ASM, gemstone mining is the most common, which brings about environmental impacts such as deforestation, landform destruction, soil runoff, and water pollution. These are illegal mining operations, but the reality is that there isn’t any sufficient circumstances and conditions to crack down on them.

(4) Natural environment

Madagascar has attracted worldwide attention for its unique natural environment and ecosystem. Therefore, although mining companies are focusing on environmental conservation, the impact of resource development on the ecosystem has especially become a concern.

(5) Human resources

Although the organizations concerned showed great interest in satellite image analysis and monitoring, in reality there is a lack of technology, know-how, and human resources, and adequate support is needed to improve, maintain, and sustain the development of the technology.

4.9.3 Support measures

(1) Establishment of a system for mine inspections and human resource development

Since mine inspections are rarely conducted, a system for mine inspections should be established and support should be provided so that adequate inspections can be conducted in terms of safety and environment. Training and human resource development related to the following items should be conducted. The relevant departments of Ministry of Environment may be included.

1) Establishment of inspection method
   - Creation of safety check sheet
   - Creation of environmental check sheets
   - Establishment of procedures and methods for implementation

2) Implementation of Inspections
   - Inspection is carried out twice a year during the rainy season and dry season
   - Observation by drone during inspection
   - Creation of programming for drone operation and automatic flight
   - Monitoring using Sentinel-2 satellite images

(2) Data compilation and exploration of mineral resources

Madagascar is considered to have high mineral resource potential, and extensive surveys were conducted by the World Bank in the 2000s. However, no new mines have been developed for mineral types other than graphite. There is not much public information or updates on mineral resources. If we expect future investment in the field of resources, it is necessary to collect, organize, and compile a database of new geological and mineral resource information once again. The use and analysis of Sentinel-2 satellite data used in this study would be beneficial in this process.

Based on the compilation of such data and the evaluation of mineral resources, it is also necessary to support in a long-term perspective the resource exploration targeting mineral resources that are interesting and suitable for our needs.

If the government expects future investment in the mineral resource field, it is necessary to collect and organize new geological and mineral resources information, to create its database, and then to evaluate mineral resources properly. In this case, it is also useful to use and analyze the Sentinel-2 satellite data used in this study.

The support from a broader perspective such as collecting and organizing the latest data and utilizing satellite data is also proposed.

(3) Human resource development for satellite data analysis

Training and human resource development for the following items using Sentinel-2 satellite data on the Copernicus website will be conducted. The website allows free data analysis through data processing programming.

- How to use the Copernicus website
- Script programming for data analysis on the Copernicus website
- Data analysis methods for resource exploration
- Monitoring of mining operations and the environment
- Monitoring of land alteration
- Development of method to detect ASM activities

For the above analyses, on-site verification surveys at key sites will be carried out. Based on the results of the field verification surveys, programming improvements and new analysis methods will be developed. In the field verification survey, a drone will be used to compare and verify the results with the results of satellite data analysis.

5. Study result: Mozambique

5.1 Basic information

5.1.1 Natural and social environment

Geographical map of Mozambique is shown in Figure 5-1.

Reference: United Nations (2020)

Figure 5-1 Geographical map of Mozambique

The Republic of Mozambique (hereinafter called Mozambique) is located in the southeastern part of Africa. The capital is Maputo. Mozambique borders South Africa to the south, Kingdom of Eswatini (hereinafter called Madagascar) to the southwest, Zimbabwe to the west, Zambia and Malawi to the northwest, and Tanzania to the north. To the east is the Indian Ocean, with the Republic of Madagascar (hereinafter called Madagascar), the Comoros Islands, and uninhabited islands in the Mozambique Strait and on the opposite shore. The total land area is 799,000 km^2 (approximately double that of Japan), and the total population is 30.83 million (Mozambique Statistics Agency, 2021).

According to the Köppen climate classification, the northern and coastal areas of Mozambique have a tropical savanna climate (60% of the total), while the central inlands and southern intermediate tablelands have a dry tropical savanna climate (28% of the total). A part of the southern inland area located in Limpopo River is classified as a desert climate (2% of the total), and a part of the central inland area and the northern inland area is classified as a humid temperate climate (10% of the total). The season is divided into a rainy season (around October to March) and a dry season (around April to September), with hot and humid days continuing in the rainy season and relatively cool days in the dry season. The average annual rainfall is around 800mm and tends to decrease from north to south and from coastal to inland areas. The highest rainfall is in the highlands of the northern Zambezia Province, where there are areas with an annual rainfall of more than 2,500 mm. On the other hand, the area with the least rainfall is the upper reaches of the Limpopo River at the southwestern tip, with an annual rainfall of about 300mm. The temperature increases toward the north and inland, and the average annual temperature is 23°C on the southern coast, 26°C on the northern coast, and 25°C on the inland. The temperature drops to around 20°C in the Manica and Lichinga where correspond to a high altitude inland. The average annual temperature in the country is 18-24°C.

Religions in Mozambique are Christianity (about 40%), Islam (about 20%), and traditional religions. The ethnic group consists of about 40 tribes such as Makua and Romwe. Languages are Portuguese and local languages (Bantu languages).

Main industries of the Mozambique are an agriculture and a forestry (corn, sugar, cashew nuts, cottons, tobacco, sugar, woods, etc.), a fishing (shrimps, etc.), and an industrial mining (aluminum, coal, natural gas, etc.), with a GDP of US$ 16 billion (IMF, 2022). The total trade in the country is US$4.71 billion in exports and US$6.79 billion in imports (The Bank of Mozambique, 2019), of which exports include coal, aluminum, natural gas, heavy sands, tobacco and precious metals, while imports include diesel fuel and petroleum, alumina steel, construction materials, automobiles and automobile products, and so on. Export counterparts are South Africa (18.8%), India (17%) and China (6.8%), import counterparts are South Africa (28.4%), China (11.5%) and the United Arab Emirates (8.1%) (The Bank of Mozambique, 2019).

As for the economic situation, Mozambique achieved that an economic growth of around 6% per every year was established in the late 1990s following the consolidation of peace after the civil war. At the same time, investments from South Africa and other countries are also active, and large-scale projects such as the aluminum smelting in Maputo, the Maputo Corridor project , and the Beira Corridor project are being implemented. Mozambique's economy is temporarily depressed due to falling resource prices and the existence of undisclosed government debts. It is one of the countries where the willingness to invest is high and stable growth is expected in the future.

5.1.2 Topography

Mozambique is geographically located between 10° and 26° south latitude. The terrain is divided into coastal plains, middle plateaus, and higher plateaus and high lands. Of these, the coastal plains are widely distributed in the coastal areas south of the Save River and downstream of the Zambezi River system, accounting for 44% of land area in the country. The middle plateaus consist of terrains with an altitude of 200m to 1,000m, mainly distributed south of the Zambezi River and occupies 29% of the country. Higher plateaus and highlands consist of terrains with an altitude of about 1,000 m, mainly distributed north of the Zambezi River and occupying 27% of the national land. The highest location of the Mozambique is the Mount Binga at 2,436 m in the Chimanimani massif, near the border with Zimbabwe. The mountain is located in the west of Chimoio which is the capital of Manica Province.

Major rivers of Mozambique basically flow across the country from west to east. The major rivers, from north to south, are the Lurio, Licungo, Zambezi and Limpopo Rivers, all of which are international rivers. The largest river is the Zambezi, which originates at the Zambia-Angola border.

The topography of Mozambique is divided by the Zambezi River into two major regions. The northern side of the Zambezi River consists of hills and low plateaus with a gentle coastline leading inland. To the west consist of steep plateaus such as the Niassa and Namuri Highlands (Shire Highlands) covered by the Miombo Woodlands, and the Angonia Highlands, the Tete Highlands and the Maconde Plateau. The south side is a wide lowland, and the southernmost part consists of the Mashonaland Plateau and the Lembo Mountains.

The major lakes are Lake Niaasa (or Lake Malawi), Lake Chiuta and Lake Chilwa, all located in the north of the country.

5.1.3 Vegetation

Since Mozambique has a subtropical climate in coastal areas, the coastal vegetation is dominated by mangrove forests and palm-based forests. On the other hand, the inland area has a semi-arid climate, so it is grassland mainly composed of sparse forests such as baobabs and cashew nuts, and grasslands.

5.1.4 Infrastructure

Mozambique is actively involved in the infrastructure developments and projects related to powers, transportations, harbors, etc., against the backdrop of abundant domestic coal and natural gas reserves. As of 2020, approximate 80% of power sources will be hydroelectric power and the 15% will be natural gas. The main source of hydropower is the large Cahora Bassa Dam (240km long, 30km wide at its widest) upstream of the Tete on Zambezi Rivers, which has the fourth largest capacity in Africa. The electricity generated by the areas is also transmitted to South Africa. Furthermore, according to the expected increase in power generation demands in the future, there are several projects such as the Nphanda Nkuwa in Zambezi River (Tete Province), Tsate in Revue River (Manica Province), Boroma in Zambezi River (Tete

Province) and Lupata in Zambezi River (Sofala Province) are planned to develop new hydropower plants. Furthermore, in 2020, Mozambique will launch the PROLER (Developing Power Production from Renewable Energies) through the French Development Cooperation Agency (AFD) to consider and introduce the solar and wind power generations as diversification of low-cost electricity energy sources. Development has started and about 10 projects are already underway.

Economic traffic routes including railways and roads that are important for transport and port infrastructure are the Maputo Corridor and Beira Corridor in the south of Mozambique and the Nacala Corridor in the north. Of these, the developments of the Maputo Corridor (Johannesburg to Maputo Port) and the Beira Corridor (Maputo to Central Beira) have resulted in post-conflict reconstruction and social development along the corridors. The Nacala Corridor (Malawi-Nacala Port) project is still underway, and it is being developed with the main purpose of coal transportation in conjunction with the coal development in Tete.

5.1.5 Environmental reserve area

Mozambique has 16 national parks and reserves, with particular emphasis on the wildlife protection within parks and areas. The largest of these is the Niassa Reserve in northern Mozambique, with an area of 42,200 km^2. The reserve connects to the Lukwika-Lumesule Game Reserve of Tanzania to the north. The second largest area is the Primeiras and Segundas Environmental Protection Area in the central coastal zone of Mozambique, with an area of 10,409 km^2, which is the largest coastal marine protected area in Africa.

In addition to the above, there are Maputo National Park (Maputo Special Reserve) in southern Mozambique, Gorongosa National Park in central Mozambique, and Chimanimani National Park in western Mozambique, all of which have diverse wildlife. In addition to being a habitat for the tropical savannah climate, it has a magnificent landscape of tropical rainforests and grasslands.

5.1.6 Geology

The geology of Mozambique is shaped by the formation of cratons and basement rocks before the Pan African orogeny and the formation of the Karoo Group and sedimentary basins toward the Indian Ocean after the orogeny. Of these, the strata before the Pan African orogenic movements are distributed along the border between Zimbabwe and Malawi in central to western Mozambique and central to northern Mozambique. On the other hand, strata during and after the Pan African orogeny are widely distributed in the central, northern and eastern coastal areas of Mozambique, as well as in the central and southern coastal areas.

The oldest stratum in Mozambique is the Zimbabwe Craton, which is distributed near the border with Zimbabwe in the west, and consists mainly of gneisses, granites, and granite-greenstone belts. The rock complexes of the Zimbabwe Craton are divided into Mudzi metamorphic complex in the north and Mavonde complex in the south. The geological age is considered to be 3,000 to 2,500 Ma (Late Archean).

In addition, the basement rocks before Pan African orogeny are distributed closely with the tectonic belt extending to the northwestern part of Mozambique, and are distributed within the Irumide Belt. The strata distributed in Mozambique are the Middle Proterozoic Umkondo, Gairezi and Manica Groups, which are composed of various granitic rocks, metamorphic rocks and metasedimentary rocks. The geological age is considered to be 1,800 to 1,350 Ma (middle Proterozoic).

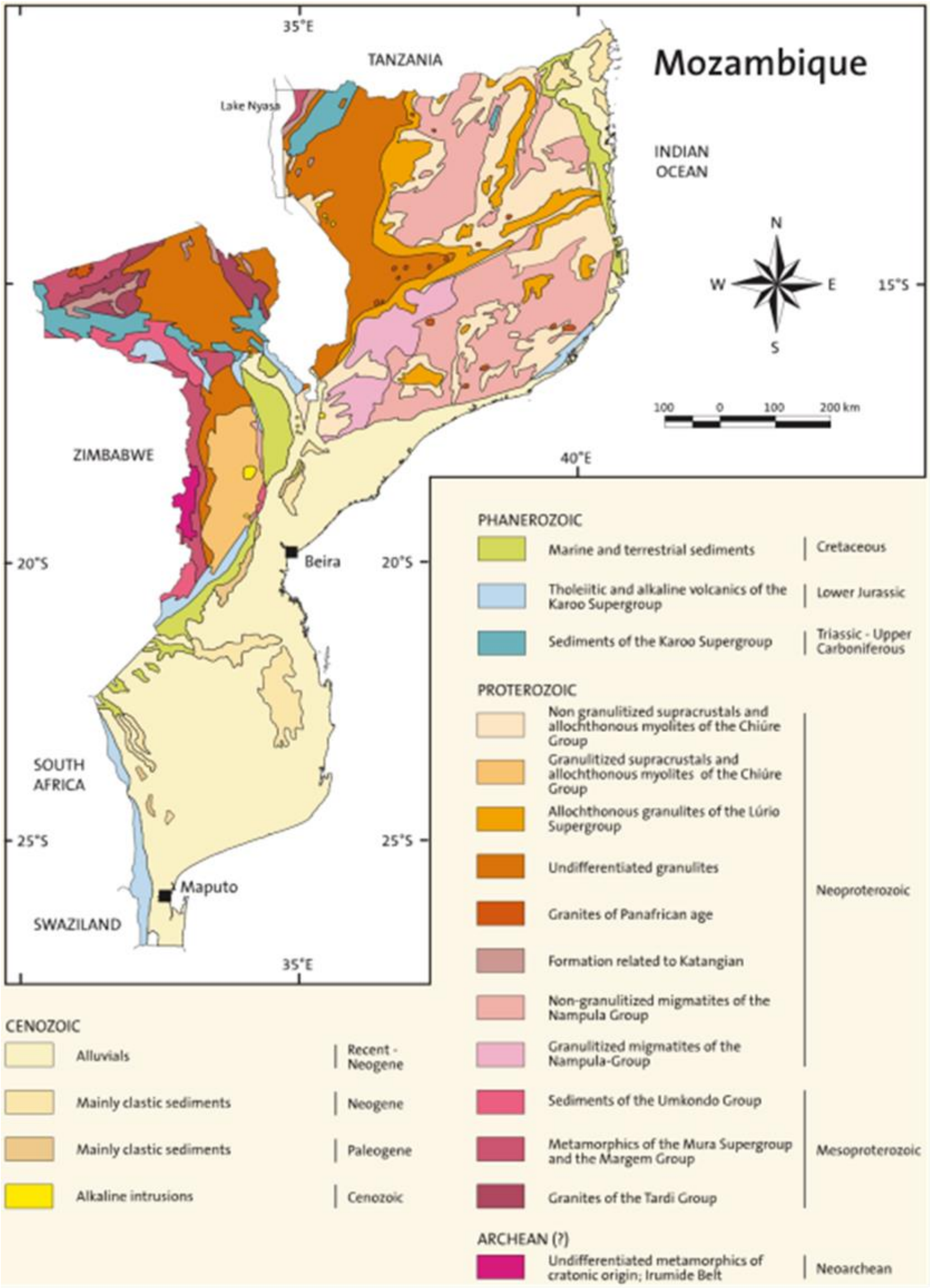
The strata during Pan African orogeny are distributed within the Mozambique Belt. The Mozambique Belt is divided into three tectonic provinces, the Mozambique province, the Niassa province and the Central Zambezi province, and is distributed over most of central to northern Mozambique. Among them, the strata of Mozambique province are divided into the Mecuburi and Muaguibe Groups, and Nampula, Chiure and Lurio Supergroups. The geological ages are 800 to 500 Ma (Late Proterozoic to Cambrian), and the strata are believed to have been formed during the Pan African orogeny. Rocks consist of granulites and charnockites on the eastern shore of Lake Nyassa in northwestern Mozambique, and quartzites, marbles, schists, gneisses, migmatites, and granite-charnockite complexes in the northeastern part of Mozambique. Intrusions of alkaline rocks and carbonatite complexes are recognized in some areas. Among them, the strata of Niassa province distribute from the north side of the Zambezi River to both sides of Lake Niassa in western Mozambique and divided into the Meponde, Zambue, Luia, Tete, Angonia and Fingoe Groups, and the Pre-Fingoe granites. The rocks consist of quartzites, mica schists and marbles, which are intruded by gneisses, granites, syenites, dolerites, gabbros and anorthosites. The strata of the Central Zambezi province are distributed between the eastern edge of the Irumide Belt and the Zambezi graben, and consist of the Rushinga, Nhamatanda and Madzuire Groups, and the Barue complexes. The rocks of these strata consist of schists, quartzites, migmatites and gneisses.

In addition to the above, there is the Katangula Group as a stratum formed during the Pan African orogeny. The distribution is limited to the western Mozambique near the border with Zimbabwe and Zambia. This Group is contrasted with the Katanga Supergroup, which is distributed in the Copperbelt of Zambia and the DR Congo, and contains several host rocks of copper deposits.

The Karoo Supergroup, which is widely distributed in southern Africa after the Pan African orogeny, is distributed in the northwestern, northern, southwestern and a part of northeastern coasts of Mozambique on a small scale. The geological ages of these strata show Permian to Late Jurassic. Three basins have formed after the Pan African orogeny, which consist of the Alt Zambezi, Rio Lunho and Rio Lugenda basins. The stratum are composed of mainly terrestrial sedimentary layers, with intercalated coal beds and red mudstones. The stratigraphic features of the strata are almost the same in all basins, but in the Alt Zambezi basin, rhyolitic to basaltic volcanic rocks and molasse-like sedimentary rocks originating from these volcanic rocks are included in the upper part of the strata. The coal beds are also distributed in the Alt Zambezi basin, which include a high-quality coal resources.

After the formation of the Karoo Supergroup, terrestrial and marine sediments are widely deposited in the central, eastern and southern Mozambique after Jurassic era, and formed the Ruvuma, Mozambique, Save/Limpopo and Baixa Zambezi basins. The depositional facies of these strata transition from terrestrial to marine sediments with time. The marine sediments are mainly composed of limestones and sandstones, intercalated with conglomerates.

Geological map of Mozambique is shown in Figure 5-2.



Reference: Schlüter, T. (2006)

Figure 5-2 Geological map of Mozambique

5.1.7 Mining

Large-scale operations in the mining industry of Mozambique are the coal mining and production in Tete Province in northwestern Mozambique, the gas mining and production at the Pande-Temane gas fields in the central Mozambique sedimentary basin, the ilmenite and zirconium mining and production along the coastal area in Nampula to Zambezi Provinces, the tantalum and niobium mining and production in the northeastern to central Nampula to Zambezia Provinces, and the aluminum smelting in Lusaka. Recently, the mining and production of graphite in Cabo Delgado and Nampula Provinces have also increased.

Of the above, The Moatize mine as a largest coal mine, produced 7 million tons of coal in 2017 before the COVID-19 pandemic, and 200 million tons of steam coal. Regarding ilmenite, the ilmenite productions in Mozambique is the fourth largest in the world, accounting for 11% of the world production. The largest titanium mine in country is the Moma mine, which produced just under 1 million tons in 2017. Zirconium and rutile are also mined and produced at the Moma mine at the same time. Other heavy sand projects include the Mutamba and Moebase-Naburi projects as an exploration or FS stage by Rio Tinto and other companies. Minings and productions of tantalum and niobium continue at the Marropino and Muiane mines, but the current production volume is not large at several tens to hundreds of tons per year.

In addition to the above, the mining and development of graphite has recently become active, and there are the Balama graphite mine operated by the Australia's Syrah Resources Ltd. and the Montepuez project operated by the Battery Minerals Ltd.. The graphite production at the Barama mine began in 2018, with a production capacity of 2 million tons/year and a production capacity of 350,000 tons in 2020. This has made Mozambique one of the world's leading graphite producers, along with Brazil, Canada, China and India.

Rare earth projects currently underway include Monte Muamba project operated by Altona Rare Earths Plc in Tete Province.

There are several medium to small-scale operations in country, such as the alluvial gold mining at the central inland in Manica Province, the ruby, garnet and tourmaline mining at the northeastern coastal areas in Cabo Delgado Province, the bauxite mining in Manica Provice. All of these have been practiced in Mozambique for a long time and have become important industries for the region. In addition, there are medium to small-scale miners around the mining and production areas of tantalum, niobium, ilmenite, and zirconium, which are already in large-scale operations.

In addition to the above, major cement factories such as Cimentos are located in coastal ports such as Maputo, Nacala and Beira with a total production capacity of 4.25 million tons/year. There is also a lead smelter operated by the Indian company in Maputo with a production capacity of 4,500 tons/year.

The location of mine and mineral occurrences in Mozambique is shown in Figure 5-3, and the location of mine and mineral occurrences in this study is shown in Figure 5-4. Table 5-1shows the operational status of mining in Mozambique, and Table 5-2 shows the status of facilities. Information on mines, prospects, mining related facilities and mining projects are based on USGS (2022) and JOGMEC (2021).

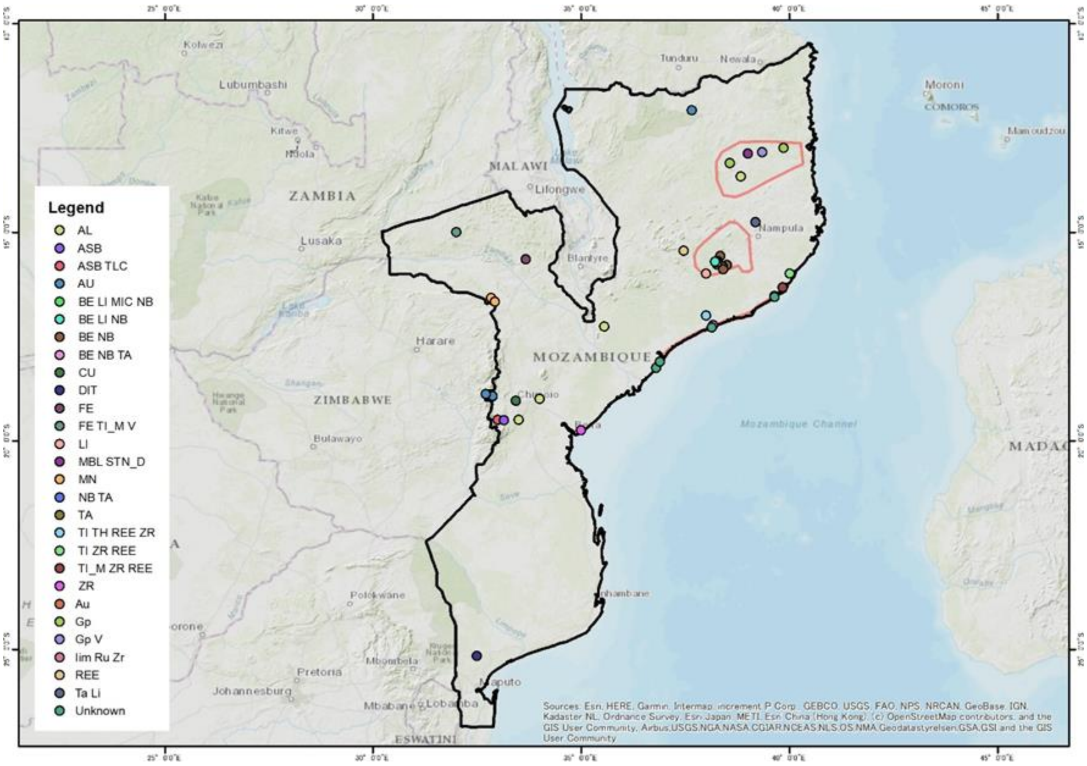


Figure 5-3 Location map of mines and mineral occurrences in Mozambique

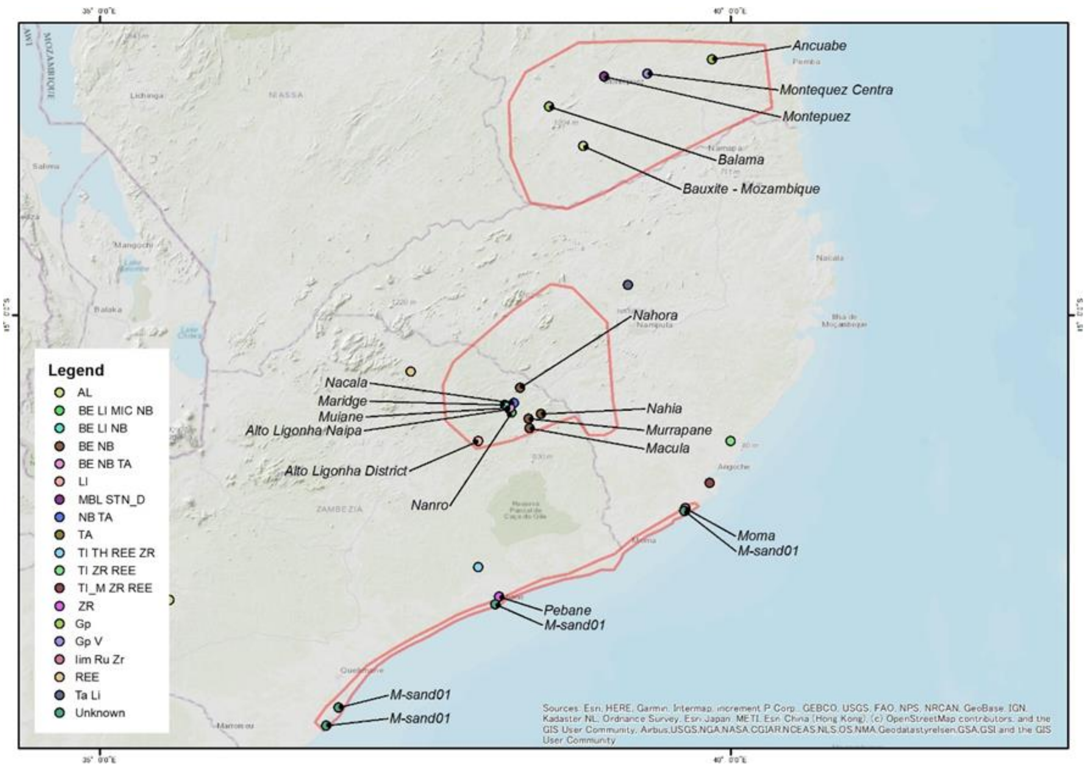


Figure 5-4 Location map of mines and mineral occurrences in satellite image analysis area

Table 5-1 List of operating mines of mineral resources in Mozambique (1/2)

Titanium mineral concentrates, zirconium, zircon					
Mine Name	Com-modity	Province	Company	Production	Remarks
Moma	Ilm, Rut Zr	Nampula	Kenmare Resources plt	Ilm 756 kt Rut 6 kt Zr 43.3 kt	-
Sangage	Ilm Zr	Manica	Haiyu (Mozambique) Mining Company Lda.	Ilm 80 kt Zr 14 kt	estimated
Tantalum, niobium (columbium)					
Mine Name	Com-modity	Province	Company	Production	Remarks
Marropino	Ta, Nb	Zambezia	Noventa Ltd.	Ta_2O_5 370t	-
Muiane	Ta, Li	Zambezia	Novak Holding Ltd.	unk.	-
Muiane	Ta, Nb, Li	Zambezia	Artisanal miners	Ta_2O_5 34t	-
Gold					
Mine Name	Com-modity	Province	Company	Production	Remarks
Manica alluvium	Au	Manica	Xtract Resources Plc	Au 2,200 oz	-
Manica alluvium	Au	Manica	Artisanal miners	Au 600 kg	etimated
Bauxite					
Mine Name	Com-modity	Province	Company	Production	Remarks
Mina Alumina	Bx	Manica	Mina Alumina Lda.	12 kt	estimated
Graphite, vanadium					
Mine Name	Com-modity	Province	Company	Production	Remarks
Ancuabe	Gp	Cabo Delgado	GK Ancuabe Graphite Mine SA. (Graphit Kropfmühl GmbH,90%; Empresa Moçambicana de Exploração Mineira, S.A. (EMEM),10%)	unk.	capacity: 9 kt
Balama	Gp	Cabo Delgado	Syrah Resources Ltd. (Twigg Exploration and Mining Limitada,100%)	unk.	capacity: 350 kt
Montequez Central	Gp, V	Cabo Delgado	Battery Minerals Ltd.	-	under construction
Gemstones					
Mine Name	Com-modity	Province	Company	Production	Remarks
Mavuco (location)	Aquamarine	Zambezia	Mozambique Gems Ltd.	3,600 kg	estimated
Cuamba (location)	Garnet	Niassa	Sociedade Vision 2000 Lda.	8,000 kg	gem quality
Various locations	Garnet	unk.	Artisanal miners	unk.	-
Montepuez	Ruby	Cabo Delgado	Montepuez Ruby Mining Lda. (Gemfields plc,75%; Mwiriti Lda.,25%)	1,600 kg	estimated
Montepuez (project)	Ruby	Cabo Delgado	Mustang Resources Ltd.	40 kg	estimated
Various mines	Ruby	Niassa	Artisanal miners	unk.	-
Various mines in Barue district	Tourmaline	Manica	Artisanal miners	unk.	-
Beryl					
Mine Name	Com-modity	Province	Company	Production	Remarks
Mine in Zambezia	Be	Zambezia	African Rare Gemwood	unk.	-

Table 5-1 List of operating mines of mineral resources in Mozambique (2/2)

Coal					
Mine Name	Com-modity	Province	Company	Production	Remarks
Moatize	Coal	Tete	Vale Moçambique, Lda (Vale S.A., 80.75%;Mitsui & Co., Ltd.,14.25%; Empresa Moçambicana de Exploração Mineira S.A. (EMEM),5%)	16,000 kt	capacity: 22,000 kt Vale and Mitsui sold the rights to Vulcan Minerals
Benga	Coal	Tete	International Coal Ventures Private Ltd.,65%; Tata Steel Ltd.,35%	unk.	capacity: 2,400 kt
Chirodzi	Coal	Tete	Jindal Steel & Power Ltd.,100%	unk.	capacity: 3,000 kt
Minas Moatize	Coal	Tete	Beacon Hill Resources plc (BHR),100%	unk.	capacity: 880 kt
Natural gas					
Mine Name	Com-modity	Province	Company	Production	Remarks
Pande-Temane	Gas	Inhambane	Sasol Ltd.,70%, and Empresa Nacional de Hidrocarbonetos, E.P.,30%	unk.	capacity: 5,100 Mm^3
Clay, bentonite					
Mine Name	Com-modity	Province	Company	Production	Remarks
Mufiane	Clay, bentonite	unk.	Minerais Industriais de Moçambique Lda.	unk.	capacity: 30 kt
Diatomite					
Mine Name	Com-modity	Province	Company	Production	Remarks
Diana quarry	Diatomite	Manica	Diatomites de Moçambique Lda.	unk.	capacity: 4.8 kt

Table 5-2 List of operating mines of mineral resources in Mozambique

Aluminum					
Name	Com-modity	Province	Company	Production	Remarks
Mozal smelter	Aluminum	Maputo	Mozambique Aluminum SARL (South32 Ltd.,47.1%; Mitsubishi Corp.,25%; Industrial Development Corp. of South Africa Ltd.,24%; Government,3.9%)	unk.	capacity: 561 kt
Lead					
Mine Name	Com-modity	Province	Company	Production	Remarks
Plant at Maputo	Pb	Maputo	Gravita Mozambique Lda. (Gravita India Ltd.,100%)	umk.	capacity: 4.5 kt
Cement					
Mine Name	Com-modity	Province	Company	Production	Remarks
Plant at Dondo, Matola and Nacala	Cement	Sofala, Maputo and Nampula	Cimentos de Moçambique SARL (Cimentos de Portugal, SGPS, SA (Cimpor),82.46%)	umk.	capacity: 3,100 kt
Plant at Nacala	Cement	Nampula	Cimentos de Nacala S.A. (Cimentos de Portugal, SGPS, SA (Cimpor),100%)	umk.	capacity: 350 kt
Plant at Beira	Cement	Sofala	Cimentos de Beira (Ambrian plc, 100%)	umk.	capacity: 800 kt
Plant near Maputo	Cement	Maputo	Limak Holding	umk.	capacity: 700 kt
Cement					
Mine Name	Com-modity	Province	Company	Production	Remarks
Plant at Dondo	Cement	Sofala	Austral Cimentos Sofala S.A. (Heidelberg Cement, 100%)	umk.	capacity: 400 kt
Plant at Maputo	Cement	Maputo	Cimento Nacional Lda.	umk.	capacity: 325 kt
Plant in Metuge District	Cement	Cabo Delgado	Fabrica Cimentos de Cabo Delgado	umk.	capacity: 250 kt
Plant at Matola	Cement	Maputo	S & S Cimentos	umk.	capacity: 210 kt
Plant at Maputo	Cement	Maputo	Maputo Cement and Steel	umk.	capacity: 130 kt
Plant at Tchumene	Cement	Maputo	Adil Cimentos	umk.	capacity: 120 kt

5.2 Mineral resources

5.2.1 Metallic mineral resources

Metal mineral resources produced in Mozambique include gold, copper, tin, tantalum/niobium, rare earths, ilmenite, zirconium, and bauxite. In addition, although it is a non-metallic mineral, graphite is produced as an important mineral in Mozambique.

Gold and copper are found in the Zimbabwe Craton and Greenstone Belt of the Late Archean period, and in the basement rocks of the Middle to Late Proterozoic, which are distributed in the Manica and Tete Provinces in northwestern to midwestern Mozambique. Copper mineralization is observed in the Katangian Group, which contrasts with the Rowan Group in the Katanga Supergroup, which is the copper-bearing horizon of the Copperbelt in Zambia and DR Congo, and the deposit type is sediment-hosted Cu deposits same as them. However, the amount of copper resources is limited in Mozambique, and copper has not yet been mined or developed so far. The gold occurs within the Late Archean Manica Greenstone Belt as vein type deposits or alluvial deposits in surrounding areas.

Tantalum and niobium occur as tantalum and pegmatite deposits in late Proterozoic basement rocks distributed in Nampula and Zambezia Provinces in northeastern to central Mozambique, and the deposits sometimes accompany tin minerals as pneumatolytic deposits. It is also produced as alluvial deposits in the surrounding areas of deposits.

Rare earths are produced as carbonatite deposits in the basement rocks of the late Proterozoic to early Cambrian periods in Tete and Nampula Provinces, but they have not yet been produced.
Ilmenite and zirconium are produced as heavy sand deposits in the sand dunes and beach sands of the coastal areas, with the basement rocks of Nampula and Zambezia Provinces in the northeastern to central coastal areas as hinterlands.

Bauxite occurs as a weathered residual deposit within the Late Archean Zimbabwe Craton near the border with Zimbabwe in Manica Province.

Graphite is found in graphite ore deposits generated during the regional metamorphism during the formation of late Proterozoic gneisses and schists distributed in the Gabo Delgado and Nampula Provinces.

5.2.2 Past surveys

Recent mineral resource surveys in Mozambique have been conducted since the end of the civil war in the early 1990s. First, in the 2000s, the aeromagnetic, geological, and geochemical surveys supported by World Bank were conducted, which led to the revision of a 1:1,000,000 scale mineral resources map covering the entire country. At the same time, the presence of coal in Tete Province, central part of Mozambique, and rare earths and rare metals in Zambezia and Nampula Province, northeastern part of Mozambique, have attracted attention, and the exploration and development projects have been carried out by private foreign investors such as Australian. Recently, while coal developments have slowed down due to global trends toward the decarbonization, the explorations and developments of graphite, which is used as a battery electrode material, has been booming, especially in Cabo Delgado region, northeastern part of Mozambique. These projects have led to the operation of the Moma ilmenite-zircon mine, the Muiane tantalum-lithium mine, and the Balama graphite mine.
There are no large scale projects by Japan for the exploration and development of metal resources, but there is the Xixano JV project for nickel and PGE by JOGMEC in Cabo Delgado during the 2010s.
There is a recent international cooperation project, which is " Mining and Gas Technical Assistance Project (MAGTAP) " supported by World Bank. This project was carried out from 2013 to 2022, and the project resulted in the creation of 1:50,000 and 1:250,000 scale geological maps of the Nampula Province. The actual implementation of the project was carried out by the International Geoscience Services (IGS) of the United Kingdom and the Bureau de Recherches Géologiques et Minières (BRGM) of France.

5.2.3 Products of mining and industry

The main mineral product of the mining industry in Mozambique is coal, which accounts for about 70% of ore exports in the country. Other products include ilmenite and zirconium from heavy sand and, more recently, graphite, which has been started in full production since 2018. All of these metals have a high global market share, with graphite production in particular currently the second largest in the world. Aluminum is also smelted as an ingot. The production volumes of these metals are as follows.

Table 5-3 Production of major metal ores

Mineral Type	2018	2019	2020	Global Share (%)	World Rank
Graphite (thousand tons)	104	107	120	10.9	2
Zirconium (thousand tons)	48	100	125	8.9	4
Ilmenite (thousand tons)	575	590	600	7.9	5

Reference: JOGMEC (2021)
(Data are based on Mineral Commodity Summaries 2020, 2021)

Table 5-4 Production of Major Metals

Mineral Type	2018	2019	2020	Global Share (%)	World Rank
Aluminum (thousand tons)	571.1	564.8	571.1	0.9	17

Reference: JOGMEC (2021)
(Data are based on World Metal Statistics Yearbook 2021)

The following table shows the export volume of mineral products related to metals as a percentage of exports in Mozambique.

Table 5-5 Export Volume of Major Metals

Mineral Types	2018	2019	2020	Main Export Destinations
Titanium ore (thousand tons)	1,090.2	1,096.0	1,119.2	China, Spain, Malaysia
Zirconium ore (thousand tons)	654.9	615.6	674.7	China, Italy, France

Reference: JOGMEC (2021)
(Data are based on International Trade Centre)

5.2.4 Metal prices of the world

The price situation for the metals covered in this study is as follows.

Graphite: The price of natural graphite was stable at around US$1,000/t until the 2000s, but has risen since the late 2000s and is currently traded at around US$2,000/t. China holds an oligopoly in production, accounting for approximately 70% of global production, but this situation may improve if new production from Mozambique and other countries starts in the future.

Rare earth metals: The average import price of rare earth metals was around US$10/kg until the 2000s, but temporarily rose sharply to less than US$150/kg during the rare earth shock caused by the Chinese trade embargo policy in 2011, and has remained at around US$30/kg since 2013 to present. The Chinese oligopoly is expected to continue to the dominate production in the future.

Rare metals: Among rare metals, the average import price of ilmenite, the raw material for titanium, has remained constant at around US$200/t since the 2000s, US$800/t for non-ilmenite such as rutile, and is currently around US$1,000/t. The largest producers are China for ilmenite and Australia for rutile. Among rare metals, the average import price of lithium as lithium carbonates or lithium hydroxides has been stable at around US$10/kg, while the average price of metallic lithium has remained at around US$80/kg. Chile and Australia are the two largest producers, accounting for more than 70% of the world market share.

5.3 Mineral resources potential of target minerals

5.3.1 Graphite

The graphite deposit is formed by a widespread metamorphism during the Pan-African Orogeny phase during the formation of Late Proterozoic gneisses and schists in Gabo Delgado to Nampula Province in the northeastern part of Mozambique, and the target of mining is graphite gneisses containing scale-like graphites. The operating mines are Balama, Ancuabe and Montepuez, located in Gabo Delgado Province, and the mines have been in operation since 2017. The graphite content (grade) in the raw gneiss is around 10% in all cases.
The distribution of graphite deposits and their potential areas are shown in Figure 5-5.

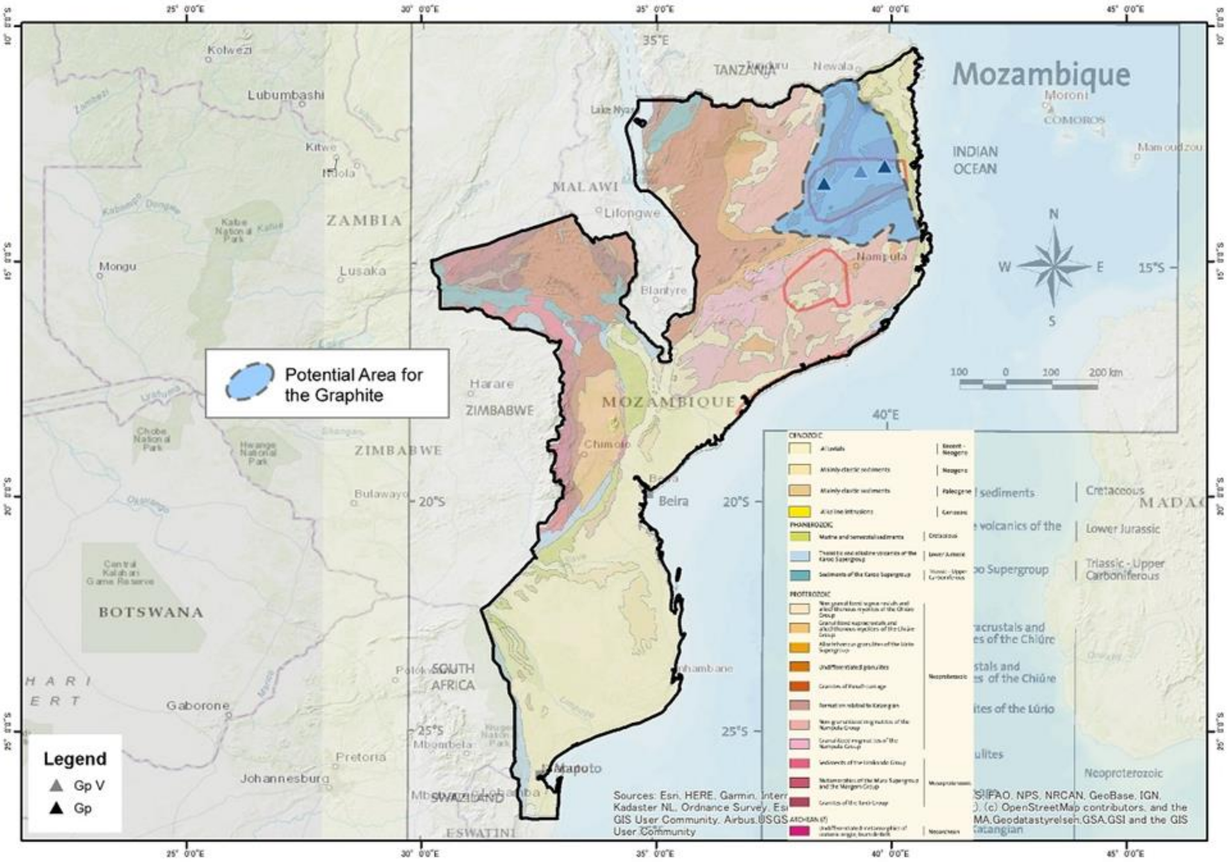


Figure 5-5 Distribution of graphite deposits (mines and deposits) and potential areas

The graphite potential area is the currently mined area of graphitic gneisses that underwent widespread metamorphism during the Late Proterozoic in northeastern Mozambique, particularly in Gabo Delgado Province.

5.3.2 REE

There are two types of REE deposits in Mozambique. One type is hosted as phosphate ores within carbonatite deposits which formed during the Late Proterozoic to Early Cambrian periods. Another type is contain REE minerals as a placer within heavy sand deposits targeting ilmenite and zircon. The project of former type includes Muiane and Marropino, although no rare-earth production is currently underway. Pabane and Congolone are the deposits of latter type that contain rare earth minerals.

The distribution of rare earth deposits and their potential areas are shown in Figure 5-6.

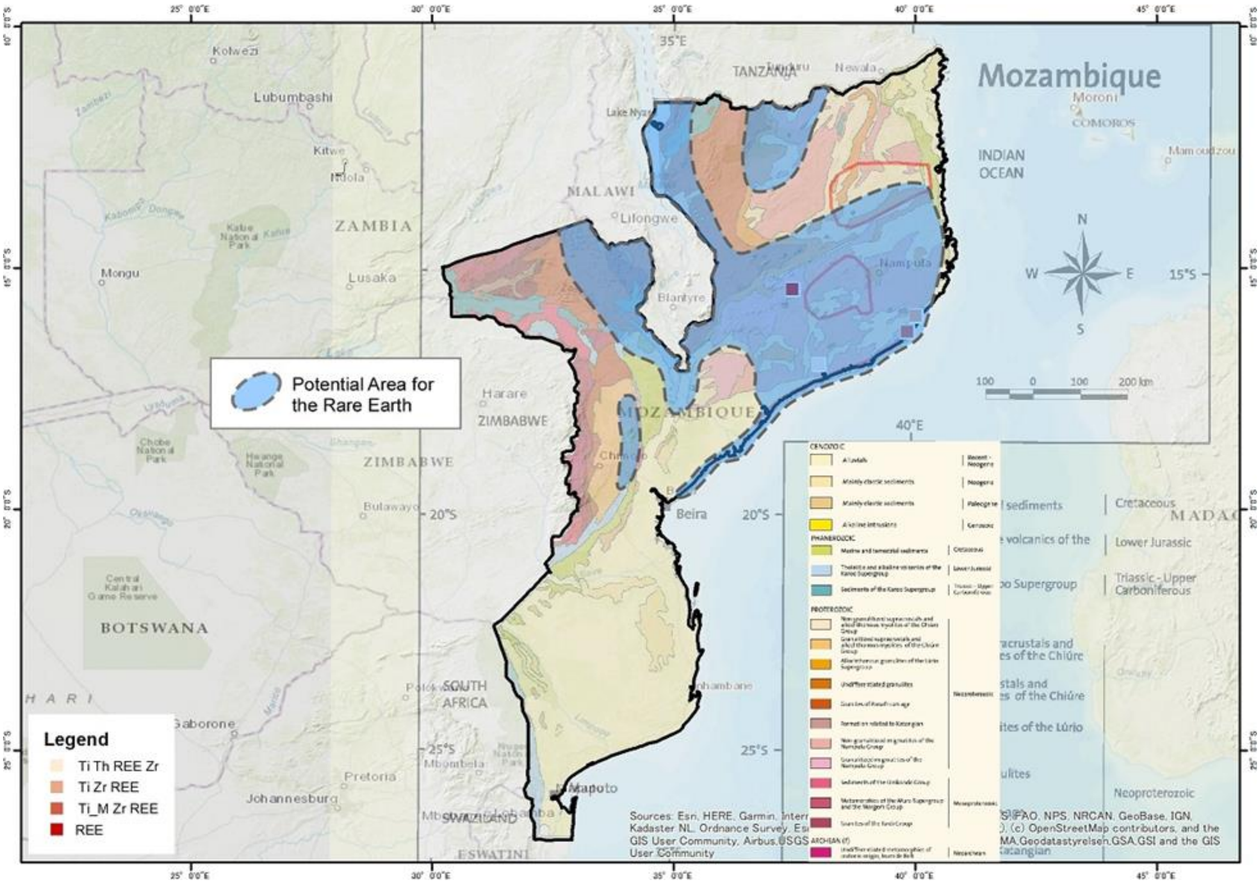


Figure 5-6 Distribution of rare earth deposits and potential areas

Potential areas for rare earth deposits are the carbonatite distribution area associated with alkaline rocks and the heavy sand in the surrounding and coastal areas, which are mostly in the area from Nampula Province to Tete Province in the northeastern part to central part of the country.

5.3.3 Rare metals

There are two types of rare metals to be mined in Mozambique. One type is that the deposit contains particles of ilmenite and zircon in heavy sands including rare earths. Another type is pegmatites in the Late Proterozoic, which include ores of niobium, tantalum, and lithium. Among these two types of mines, the largest mines targeting ilmenite and zircon in heavy sands are the Moma Mine in Nampula Province and the Sangage Mine in Manica Province. On the other hand, the Muiane Mine in Nampula Province targets niobium, tantalum, and lithium in pegmatites.

The distribution of the two types of rare metal deposits targeting heavy sand and their potential areas are shown in Figure 5-7.

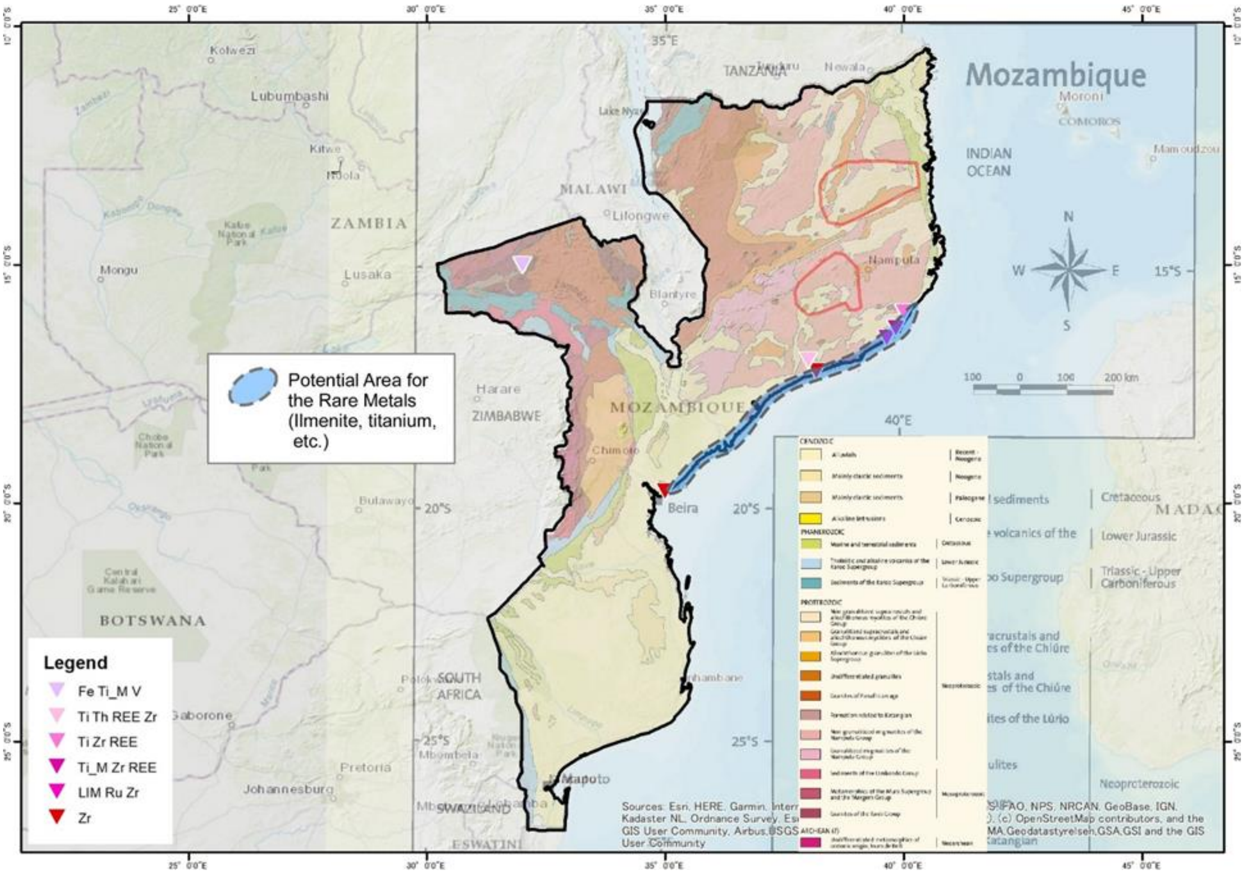


Figure 5-7 Distribution of rare metal deposits (titanium, zircon, etc.) and potential areas

Potential areas for ilmenite, zircon, etc. in heavy sands are the coastal areas in the central part to northern part of Mozambique, where operating mines such as the Moma Mine are located.

The distribution of the two types of rare metal deposits targeting pegmatites and their potential areas are shown in Figure 5-8.

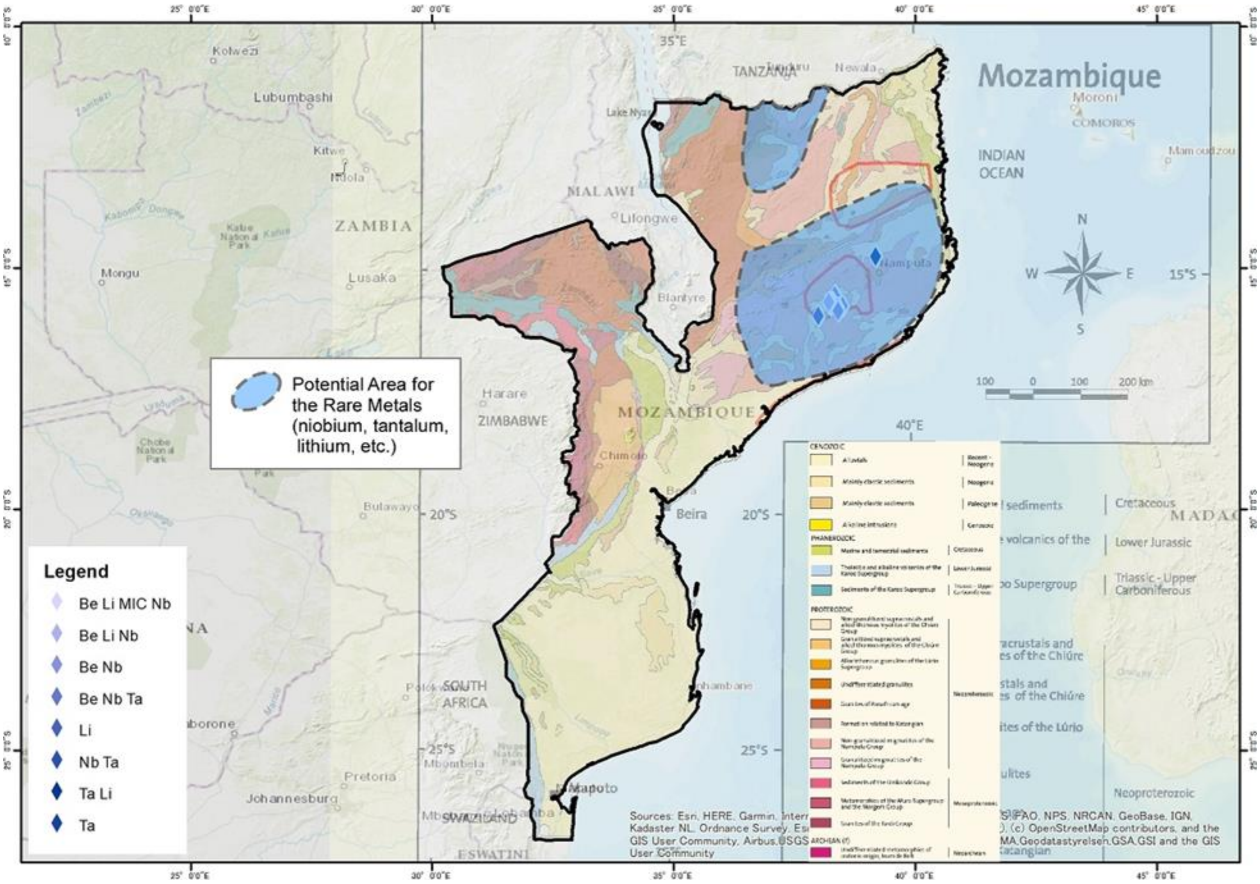


Figure 5-8 Distribution of rare metal deposits (niobium, tantalum, lithium, etc.) and potential areas

Potential areas for occurrences of the niobium, tantalum, lithium, etc. are distributed in pegmatites of the Late Proterozoic located in the interior of northeastern part of Mozambique.

5.4 Mining administration

5.4.1 Mining policy

In Mozambique, natural resources have been the engine of economic growth in Mozambique. Of these, coal and natural gas resources have been actively developed since the latter half of the 2000s, and even in the global decarbonization movement that began around 2020, an appetite for investments by private sectors is still high. As of 2017, exports from Mozambique are coal (36%), aluminum (22%), natural gas (8%), heavy sand (4%), and precious minerals (2%). This accounts for about 70% of all exports from Mozambique are natural resources. In addition, full-scale production of graphite has commenced since 2018, and the share of mineral resources in exports is expected to increase further.

Under these circumstances, Mozambique has taken specific measures to link the promotion of natural resource development with economic growth. The actual measures are the creation of legal environments and additional values for mineral resources, the development of infrastructures such as traffics, ports and

energies, and the forwarding of partnerships between domestic private companies and the mining sectors. Among these, regarding the development of laws and regulations, the revised Mining Law of 2002 and the revised Mining Regulations enacted in 2003 were clarified the detail, and a new Mining Law was enacted in 2014.
In relation to the infrastructure development, Nacala and Beira Corridors are being developed traffics, ports and so on to link with the natural resources development such as the coal mining and productions in Tete. Furthermore, hydroelectric facilities are also being developed in several locations that are effective in supplying electricity based on the demand.
In addition, another development projects are underway to introduce the solar and wind power generations for the use of renewable energy associated with decarbonization in the future.

5.4.2 Law and regulation related to mining

The relevant law is the New Mining Law (enacted in 2014). This law includes guidelines and procedures to clarify the contents of the existing Mining Law (enacted in 2002), Environmental Regulations (enacted in 2004) concerning mining activities, and Mine Safety Regulations (enacted in 2006).

5.4.3 National budget of mining sector

In terms of the budget for the administration of the mining sector, the budget for basic operations of the relevant agencies has been secured. On the other hand, there is no budget for the development and preservation of technical infrastructures for the management and operation of GIS, etc. Securing such a budget is an issue for an effective management through the use of various mining-related data, which will become necessary in the future. In addition, as in other developing countries, there is no budget for a capacity building of human resources, where international support from the other countries is significant.
On the other hand, the management of the artisanal and small-scale mining (ASM) is considered a challenge in Mozambique, and the budget for this management have been secured.

5.4.4 Management system of mining sector

The mining authority is the Ministry of Mineral Resources and Energy (MIREME). The National Directorate of Mines (INAMI) under the ministry is responsible for the licensing and management of rights such as the exploration rights and mining rights based on the Mining Law. Based on this responsibility, they have been implementing a supervision of mine operations and mine safety, an audit and a monitoring of mine environment, and an approval of EIA (collaboration with the ministry). Furthermore, they are also responsible for an economic analysis related to the mineral resources policy in country, etc. So, their scope is wide.
The National Directorate of Geology and Mines (DNGM), as a survey and research institute for regional geology, natural resources, and applied geology, manages information and conducts the survey and research projects related to geologies and mineral resources.

In addition, the department related to mine environment is the Environment Department, and the department related to mine safety is the General Inspection of Mines. These departments work in collaboration with the Ministry of Environment, Ministry of Labor, and Ministry of Health.

5.4.5 Issues

The following is a summary of issues related to the mining sector, based on information gathered and the results of interviews with relevant departments of the MIREME.

(1) Current Status of the Mining Sector

The main responsibilities of the administration of the mining sector are the management of mineral resources in the country and the formulation and implementation of related measures, etc. The main responsibilities of management are the monitoring of mining activities based on laws and regulations, and the development and investigation of geological and mineral resource information. Among these, management related to laws and regulations has been implemented since the enactment of the new Mining Law in 2014 as the management and supervision of mining rights applied for in connection with mining activities. This has made it easier for foreign companies to enter Mozambique. In particular, in addition to coal, which has been developed and produced by above situations in advance. Furthermore, in recent years, these situations have led to the development and expansion of production of rare metals such as graphite and rare earth deposits. As a result, Mozambique is becoming one of the countries with a presence within the global supply chain as an important resource-rich country for the SDGs.

On the other hand, basic geological and mineral resources information are based on surveys conducted prior to the civil war and has not been updated to cover the entire country. The development of national geological and mineral resources information is the responsibility of the DNGM in the mining sector, but the recent updates of these information are the result of assistances from other countries based on the collection and compilation of basic information by the World Bank and other organizations, as well as explorations and developments by foreign companies. Therefore, the mining sector, led by the DNGM, has not yet proactively developed this information and disseminated it domestically and internationally to induce foreign investments into the country. Mineral resources potential in Mozambique is considered to be high, but the country is still in the process of identifying its potential based on the latest information. It will be important to identify this potential through researches and developments of relevant information throughout the country.

In addition to the above, production of gold and gem stones by ASM has increased with the rise in prices since the mid-2000s (IGC, 2021), and the management and supervision of ASM is also potentially problematic due to the environmental impacts through land alterations by illegal mining and wastewater by processing. These situations of ASM are becoming more important as production increases in Mozambique (OECD, 2017).

(2) Support from other national institutions, etc.

In the mining sector, support for the mineral resources sector by other countries and organizations has recently been provided as part of the World Bank-supported Mozambique " Mining and Gas Technical Assistance Project (MAGTAP) " (2013-2022), which includes a geological mapping project in the Nampula Province. Other coal-related training programs include training at Jindal, Indian coal company, and geology and mining-related training (including master's and doctoral programs) by Australia.

As part of Japan's support for the mining sector, JOGMEC has been holding mining-related seminars and training programs for southern African countries since the opening of the Botswana Geological Remote Sensing Center in 2008. Mozambique is one of the target countries, and many staff members of the government in the sector have participated in the seminars and training programs. JICA also implemented the " Project on Capacity Development in Mineral Resource Sector " project (2014-2019) to strengthen the capacity and systems of domestic engineers and researchers in the mining sector. In addition, the " Kizuna Program " which began in 2014, has welcomed many international students from the mining sector and universities from Mozambique to Japan.

(3) Issues

The most important responsibility of the mining sector administration is the management and supervision of mining activities in accordance with the Mining Law, which has been steadily implemented by the INAMI since the enactment of the new Mining Law in 2014. On the other hand, the current budget for maintaining the infrastructure and human resources for those operations is not sufficient, and there are concerns about its reliable implementation in the event that mining activities become more active in the future. If the implementation of mining-related procedures and supervision stagnates, it will lead to the stagnation of active mining activities, and therefore, the efficient and effective implementation should be considered and the budgetary considerations should be taken into account.

Another important responsibilities are the developments and researches of geological and mineral resources information. This information is important to promote the mineral potential in Mozambique domestically and internationally, and is being handled by the DNGM, but systematic and continuous surveys and researches have not yet been conducted. Therefore, although mineral resources potential in Mozambique is currently considered to be high, the actual understanding of this potential is limited to only a portion of the land area in the country. One of the reasons for the slow implementation of verification is the lack of sufficient human resources and technical capacities, as well as a small budget for the implementation. Additionally, the budget for implementing infrastructure development for the surveys and researches is low. Under the above circumstances, a major challenge for mining administration is securing engineers and budget in conjunction with the formulation of concrete medium- to long-term plans for the basic information development in relation to the mineral resources.

In addition to the above, apart from the management of medium- to large-scale mining activities, the mining sector administration places emphasis on the understanding, management, and supervision of the artisanal and small-scal gold mining (ASGM), which have been increasing in recent years. While the local governments and the regional offices of the MIREME in each province have a basic jurisdiction over small-scale mining, and the control and supervision of production activities based on normal laws and regulations are carried out without problems. However, when environmental or occupational safety concerns are raised, the local administration alone is not effective in dealing with them due to the lack of professional personnel working in the local area. Therefore, it is recognized that cooperative responses with the management and supervisory personnel and specialized personnel from central governments in the sector, as well as technical and social support for small-scale mining companies, will become increasingly important issues in the future.

Based on the above, the issues in the MIREME can be summarized as follows.

- The related organizations are required to secure professional human resources and budgets for the management and supervision of mining activities.
- The budgets for the development and maintenance of management systems and other infrastructure related to the management and supervision of mining activities must be secured in preparation for the increase in mining activities, and efficient management and supervision must be implemented in the future.
- The budgets for securing professional human resources and infrastructure development and maintenance for research and development of geological and mineral resources information are required.

5.5 Environment administration

5.5.1 Environment policy

Management and supervision of the mine environment are carried out by the National Environmental Impact Assessment Agency under the Ministry of the Environment and the Environment Department of the National Directorate of Mines under the Ministry of Mineral Resources and Energy. Both departments are in charge of the auditing and monitoring of mine environments and the approval of EIA licenses, which the two departments work together. These activities have been implemented by the National Directorate of Environmental Impact Assessment since 1998 after the enactment of the Environmental Law, and by the Environment Department of the National Directorate of Mines since 2004 after the Environmental Law was revised. Implementation is coordinated by the National Directorate of Mines, Department of Labor and Department of Health.

5.5.2 Law and regulation related to environment

The laws and regulations related to mine environments are the Environmental Law (enacted in 1997, revised in 2004), Environmental Impact Assessment Regulations (enacted in 2004), and Environmental Quality and Wastewater Emission Standards (enacted in 2004). The standards for effluent are used on their own standards. On the other hand, Guidelines, procedures, etc. accompanying these related laws and regulations have not been developed.
In addition, the Ministry of Health sets standards for groundwater qualities (well water).

5.5.3 National park and reserve

Mozambique has 16 national parks and national reserves. The largest of these is the Niassa Reserve in northern part of Mozambique, which covers an area of 42,200 km^2. The reserve is connected to the Lukwika-Lumesule Game Reserve in Tanzania to the north. The second largest area is the Primeiras and Segundas Environmental Protection Area along the coastal zone in the central part of Mozambique, with an area of 10,409 km^2. This protected area is the largest coastal marine protected area in Africa.
In addition to the above, there is Maputo National Park (Maputo Special Reserve) in southern part of Mozambique, Gorongosa National Park in central part of Mozambique, and Chimanimani National Park in the western part of Mozambique.

5.5.4 Environmental survey related to mineral resources development

There is a case of mine pollution related to environmental concerns in Mozambique, which is a washout of the tailings dam at the Moma ilmenite and zircon mine in Nampula Province. The failure happened in 2011. In addition, as a mine pollution that is a concern even now, there is a disposal of waste at the Maboos uranium abandoned mine in Tete Province. The waste including radioactive materials is left behind at the site.
As other concerns, mercury contaminations and land modifications due to the illegal alluvial gold mining in Manica are observed.

5.5.5 Issues

The following is a summary of issues related to the environmental sector, based on information gathered and the results of interviews with relevant organizations in the Ministry of Land and Environment (MTA).

(1) Current status of the environmental sector related to mining activities
The environmental sector administration is responsible for the implementation and specific monitoring of national environmental conservation measures and the formulation and implementation of environmental policies. The environmental protection items to be addressed in mining activities include wastes, pollutions, and natural environments, while monitoring and measures for conservation include forests, rivers, wastes, and chemical substances. The MTA, which has jurisdiction over the environmental sector, is responsible for reviewing environmental impact assessment reports submitted by mining operators and providing guidance.
Regarding the actual monitoring of mining activities by the MTA, site inspections are not conducted on a regular basis, but rather when environmental problems occur within the mining area. These inspections are conducted in cooperation with the MIREME, which supervises mining operators.
One of the most recent major responsibilities of the MTA in mining activities has been operations related to the " Minamata Convention on Mercury ". The main source of mercury emissions in Mozambique is considered to be ASGM, and activities have recently been initiated by the MTA to eliminate the use of

mercury in these mining industries. The Convention requires Parties to notify the Secretariat of the Convention if the Party cannot ignore ASGM in the country, to develop and implement an action plan, to submit the plan to the Secretariat within three years, and to update the plan every three years. The plan must be developed and implemented with the participation of aboriginal peoples, local communities, and stakeholders. The MTA is currently preparing to identify the contaminated sites and to prepare an inventory of identified ASGM in order to determine the actual status of ASGM, which will then be used to manage ASGM.

(2) Support from other national institutions, etc.

Regarding support for the environmental sector by other countries and organizations, the World Bank has provided financial support for environmental conservation, climate change, and environmental impact assessment projects, and Germany has provided bilateral assistance in the environmental sector in general. In addition, as an intermittent environment-related project since the 2000s, Mozambique and neighboring Zimbabwe have conducted joint studies on the river management in the Pungwe, Buzi, and Save Rivers. The project has been partially supported by the Sida of Sweden. As part of this project, MTA conducted a joint investigation with Zimbabwe to address concerns about water pollution caused by illegal placer gold mining in the Pungwe River, Manica province. On the other hand, MTA has not received any support for actual environmental conservation and countermeasures in relation to mining activities in the mining sector. Therefore, the inventory creation of ASGM for the Minamata Convention, including planning and implementation of the task, is being carried out independently by the MTA.

(3) Issues related to mining activities

A current major environmental monitoring issue in the MTA related to mining activities is the response to ASGM, which is one of the issues stipulated in the Minamata Convention on Mercury. The MTA is required to prepare an action plan and periodically update the plan after implementation (every three years). As mentioned above, as a specific response by the MTA, it has first started to prepare an inventory of ASGM throughout the country. However, the inventory should include not only the location of the ASGM but also the actual activities at the site, and since it is expected to take time and effort to identify ASGM that have not been systematically identified, an efficient response is required. In addition, the response also includes matters for ASGM operators in the mining sector, such as a concrete education and training on mining and beneficiation to reduce the environmental impact of gold mining. Therefore, the items to be addressed are more diverse than those of the environmental impact studies on ASGM that have been conducted in the past by the environmental sector with the support of other countries, etc. At the same time, in order to achieve the items stipulated in the Convention, it is not the responsibility of the current MTA alone to address these issues, but also to coordinate with local governments, the MIREME and the health sector, that have jurisdiction over ASGM. In this regard, the MTA recognizes the need for collaboration with other organizations, but collaboration requires the coordination of cross-ministry roles and cost sharing, and so far, collaboration has not yet been achieved.

Based on the above, the issues related to mining activities in the MTA can be summarized as follows.

- Efficient implementation of the action plan for ASGM within the " Minamata Convention on Mercury " and formulation / updating of the plan based on the status of activities are required.
- The " Minamata Convention on Mercury " requires cooperation with the mining sector and other related sectors in activities related to the mining, such as ASGM.
- It is necessary to secure specialized human resources and related budgets for environmental conservation and countermeasures related to mining activities.

5.6 Satellite image analysis

5.6.1 Mining area

The analysis of the satellite images was conducted by selecting areas where the conditions of mining activities are clear on the images. In Mozambique, six areas (mines) were selected from within the inlands and coastal areas. The selected mines are the Balama graphite mine, the Montepuez Central graphite mine, the Montepuez gem mine, the Muiane tantalum-(niobium-lithium) mine, the Nanro gem mine, and the Moma titanium mine. The location of the areas is shown in Figure 5-9.

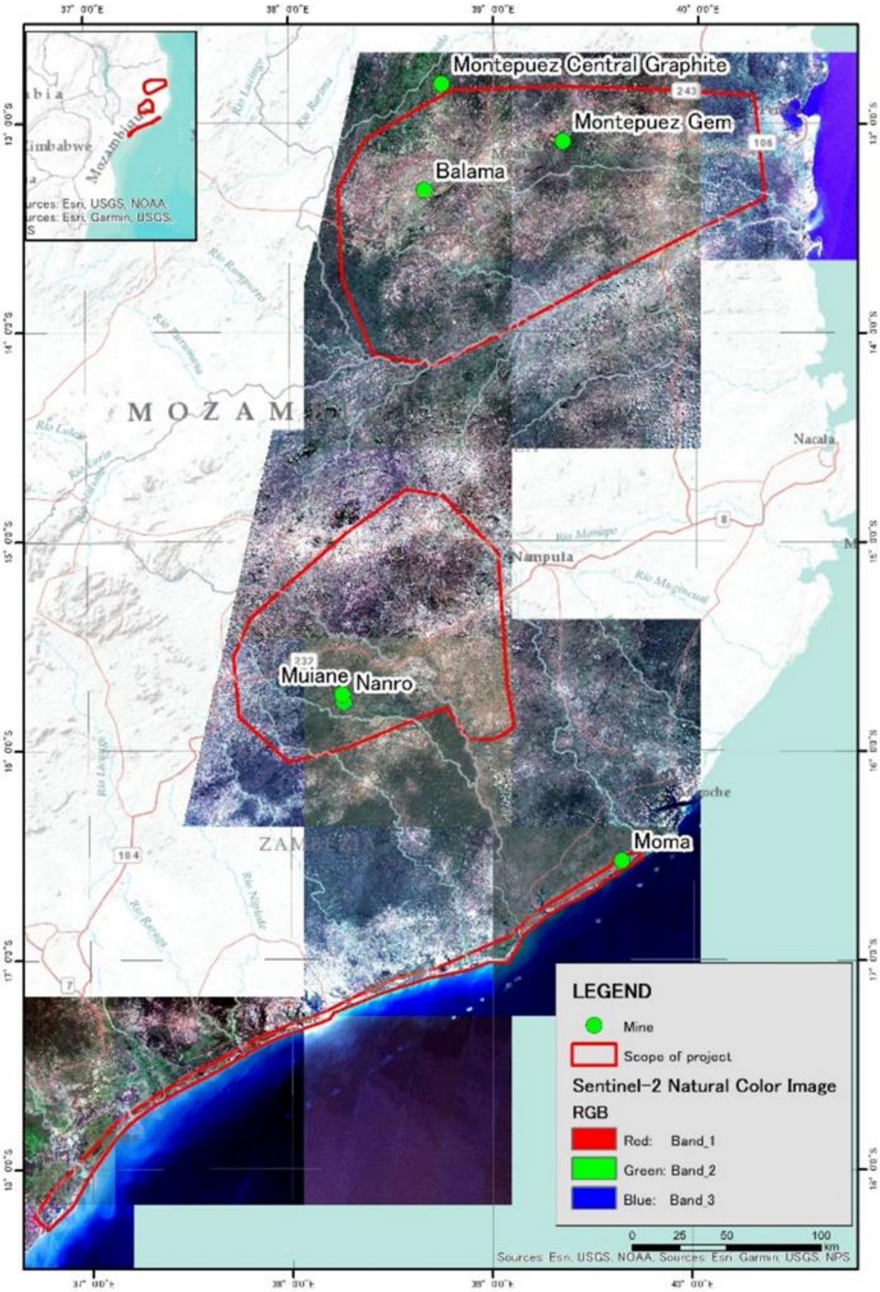


Figure 5-9 Location map of mines and mineral occurrences in satellite image analysis area

5.6.2 Time series change

Regarding the mining activities in the selected areas, we confirmed how the activities were captured on the images and how the captured situations of activities changed in time series using the actual satellite imagery. The confirmed period is from 2015 to 2023 for each area. The used satellite image is Sentinel-2.

True color images of each area are shown in Figure 5-10 to Figure 5-15.

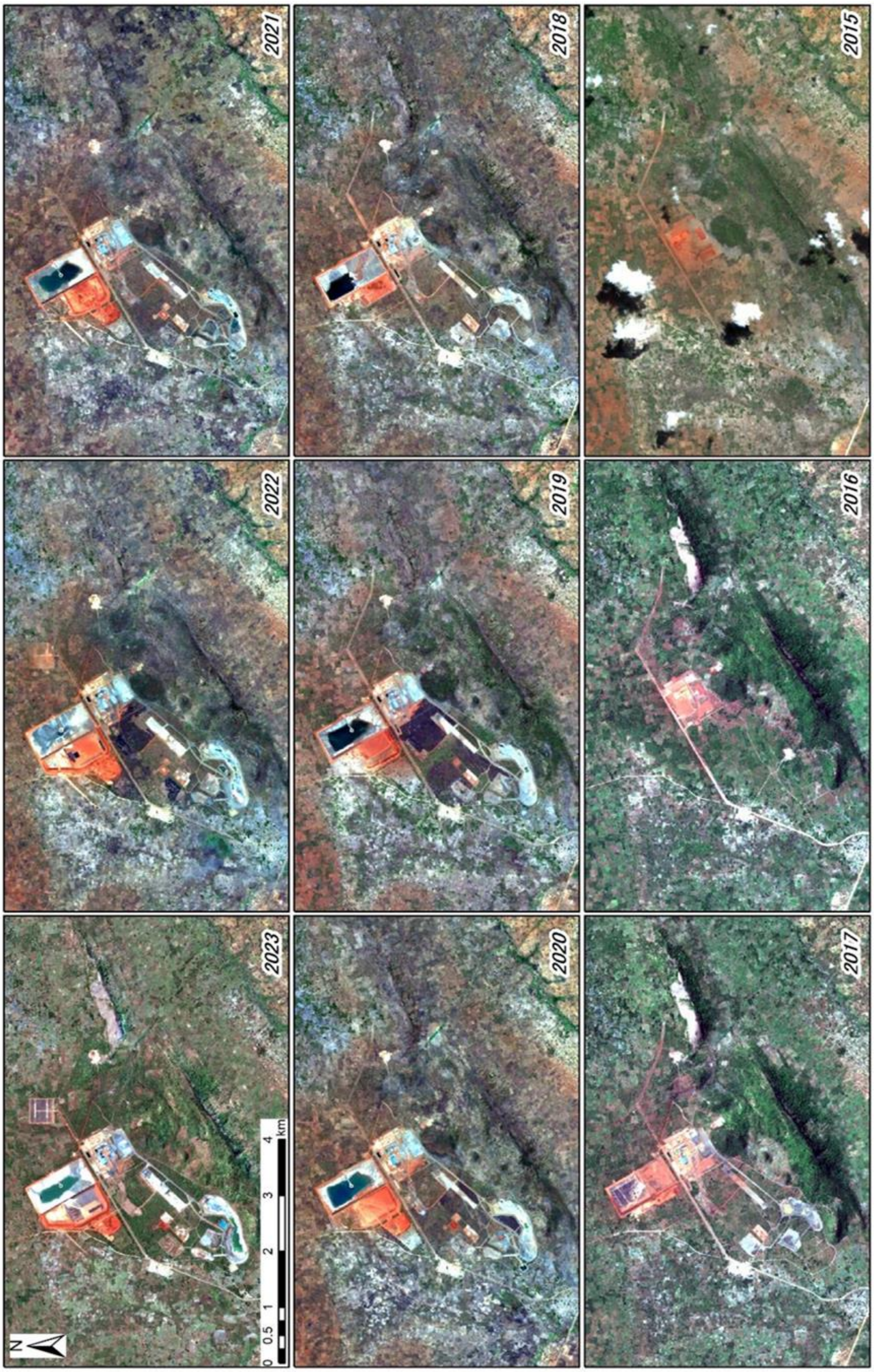


Figure 5-10 Time series change of Balama graphite Mine (2015-2023)

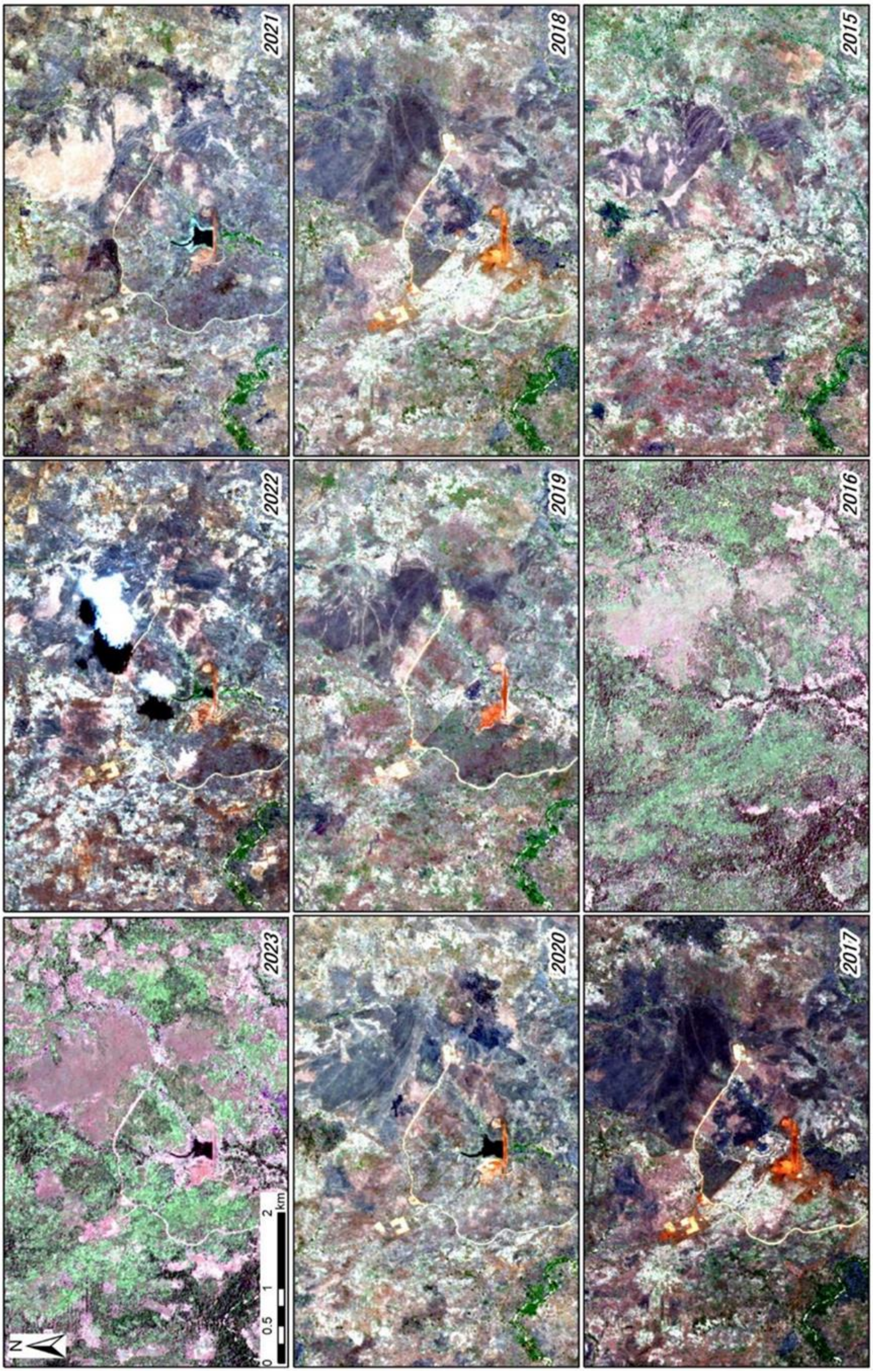


Figure 5-11 Time series change of Montepuez Central graphite Mine (2015-2023)

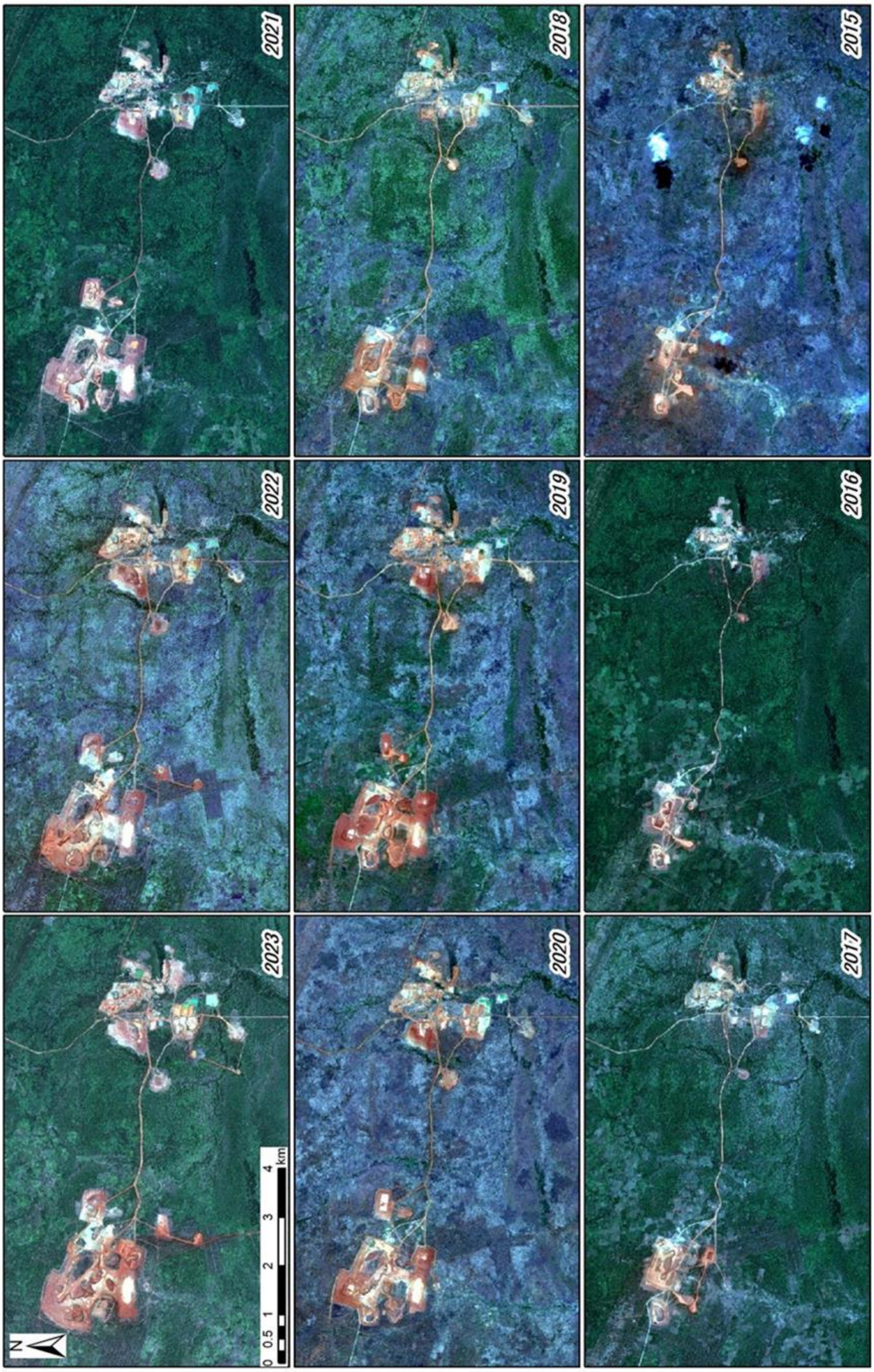


Figure 5-12 Time series change of Montepuez Gem Mine (2015-2023)

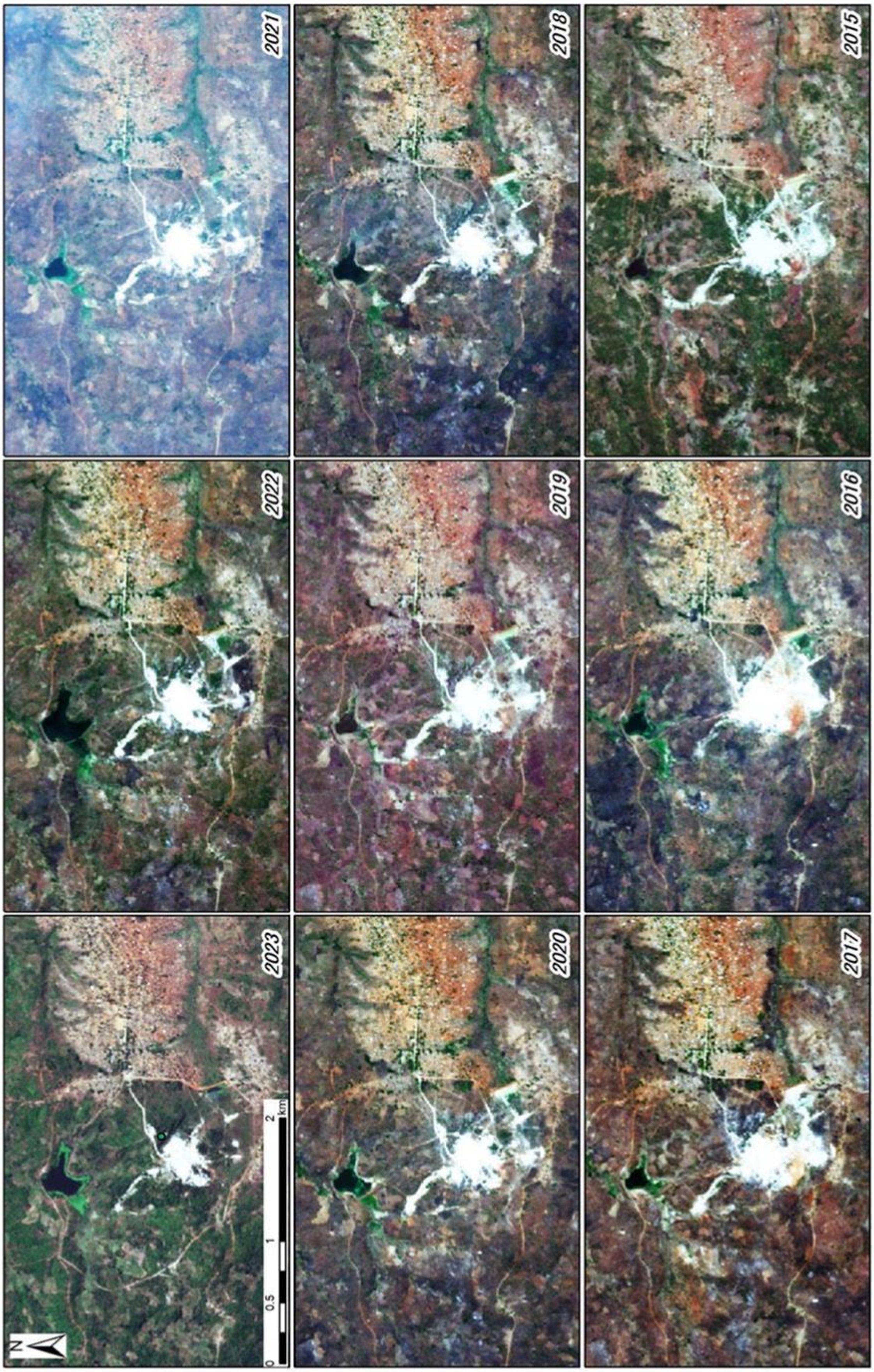


Figure 5-13 Time series change of Muiane Ta-(Nb-Li) Mine (2015-2023)

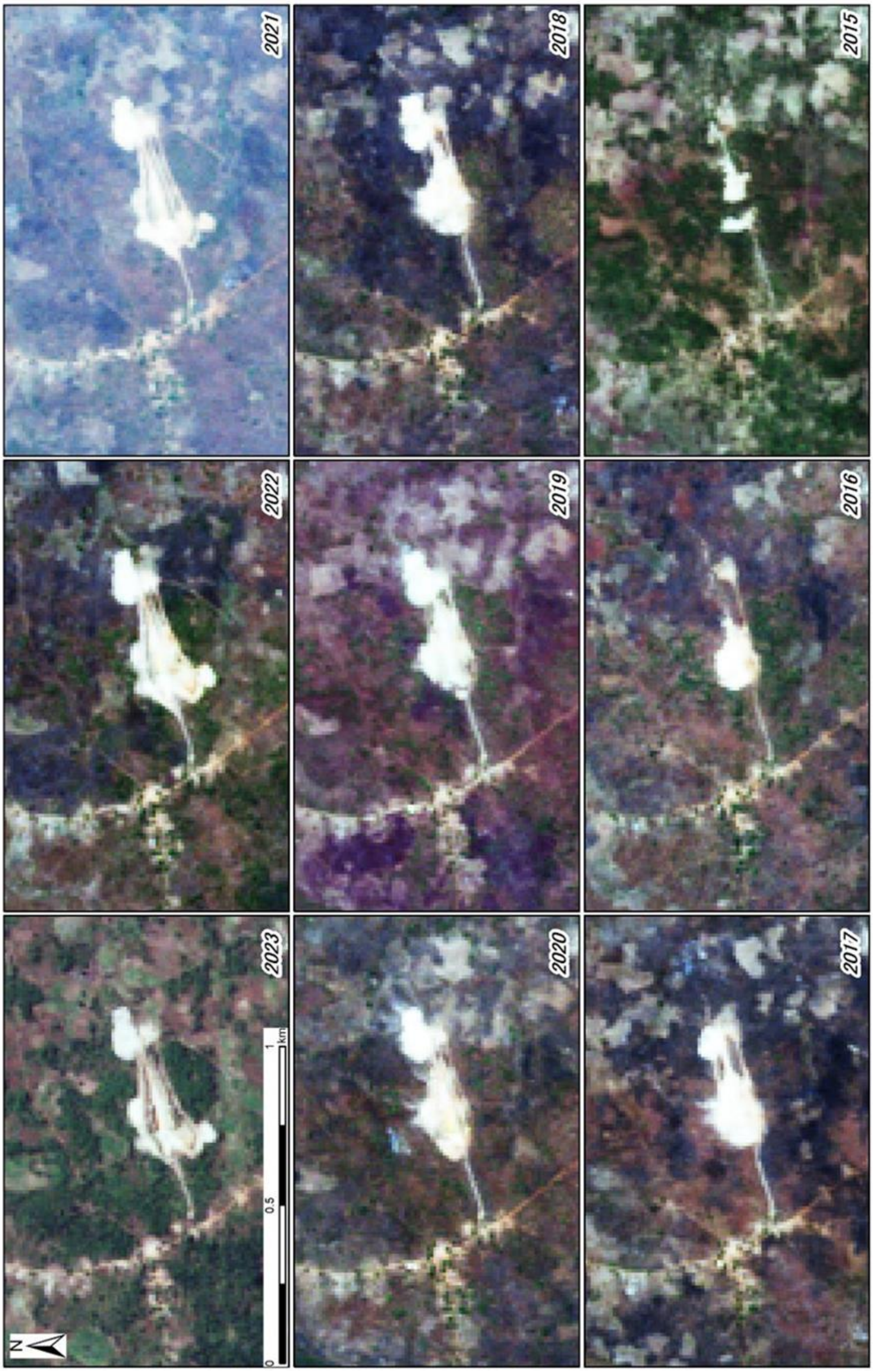


Figure 5-14 Time series change of Nanro Ta-(Li-Nb) Mine (2015-2023)

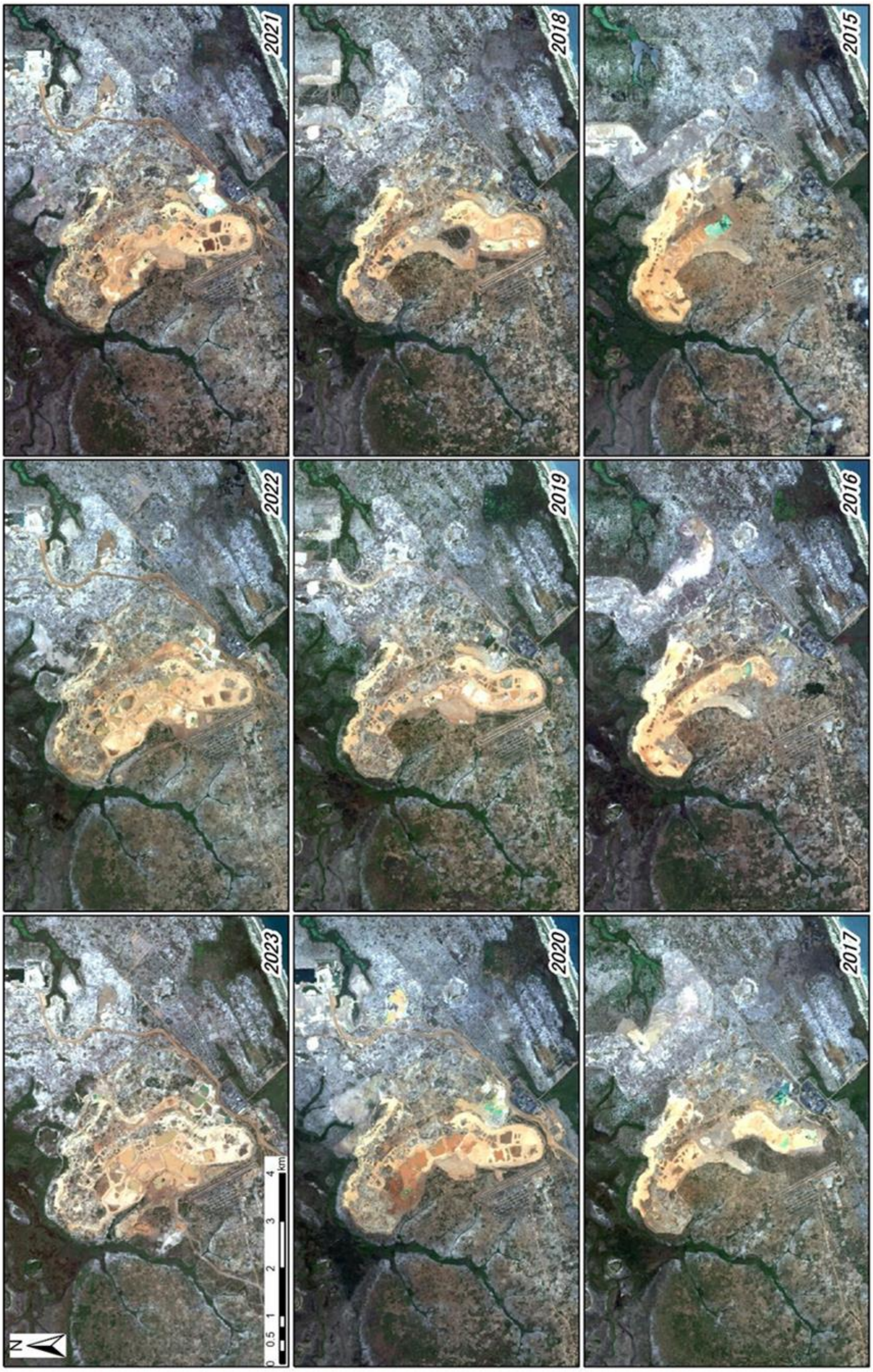


Figure 5-15 Time series change of Moma Ti Mine (2015-2023)

5.6.3 Analysis result

(1) Balama Graphite Mine

The Balama graphite mine was acquired in 2013. Figure 5-16 shows a diagram of the mine operation location over time, as read from Sentinel-2 imagery. The mine is identifiable from Sentinel-2 true-color imagery by the condition of the pits, tailings deposition area, and other mine facilities. Looking at the changes over time, it can be read that as of 2015, the site was still being developed, and in 2017, open excavation began in the southwestern open pit and the tailings deposition area was being developed, which is consistent with the information that graphite production began in 2017. Thereafter, the open pit and expansion of the facility is evident until 2013. New activity is also evident in the 2023 image, including the clearing of vegetation in the eastern part of the mine.
Figure 5-17 shows a ratio-calculated image and a normalized vegetation index (NDVI) image of the Balama mine. The ratio-computed image has been processed to emphasize the presence of clay minerals and iron hydroxide, but the mine site is expected to have a relatively uniform component due to the overall green coloration; the NDVI image shows a low vegetation index in the operational area and an obvious contrast with the mine perimeter, but no evidence of vegetation activity changes around the mine. activity level around the mine, although the contrast with the mine perimeter is evident.

(2) Montequez Gem Mine
The Montepuez gemstone mine was acquired in 2011 and mines rubies and aquamarines. The Montepuez mine is the largest gemstone mine in the region, with two operating areas, one in the east and one in the west, each with a diameter of about 2 km. Figure 5-18 The Sentinel-2 true-color image shows a relatively well-defined waste rock dump area and a reservoir, but the mining area is not clearly defined. The lack of clarity in the mining area is thought to be due to the fact that the excavation of deep open pits was not conducted. In addition, the mine buildings and other facilities are small and difficult to identify from the image. The change over time shows clearly how the mine has been expanded year by year from 2015 to 2013.
Figure 5-19 shows a ratio-calculated image and a normalized vegetation index (NDVI) image of the Montequez mine. The NDVI image shows a low vegetation index in the operation area and a clear contrast with the area surrounding the mine, but there is no evidence of a change in the level of vegetation activity around the mine. There is no evidence of a change in the level of vegetation activity around the mine.

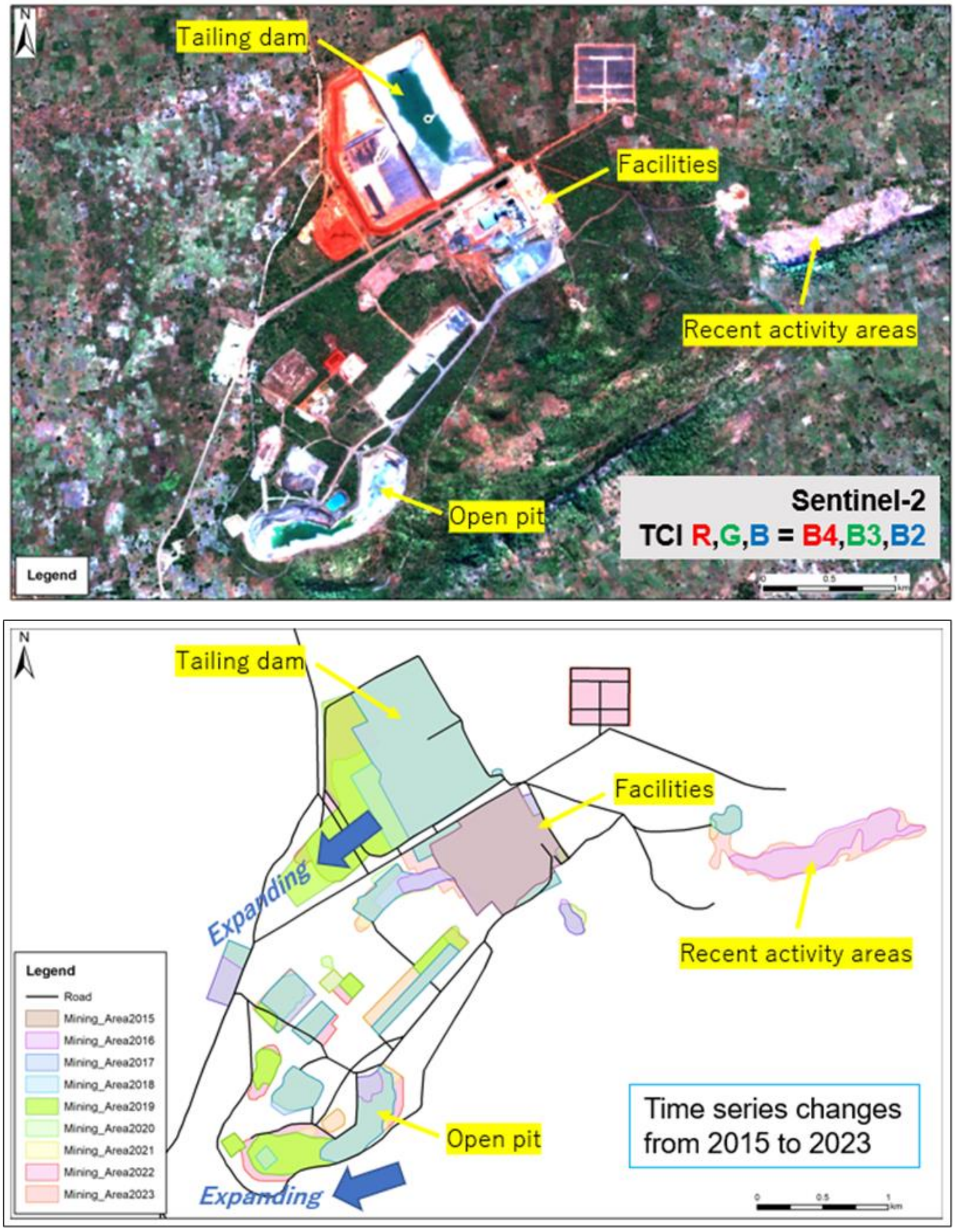


Figure 5-16 Time-series change diagram Balama mining operation site from 2015 to 2023

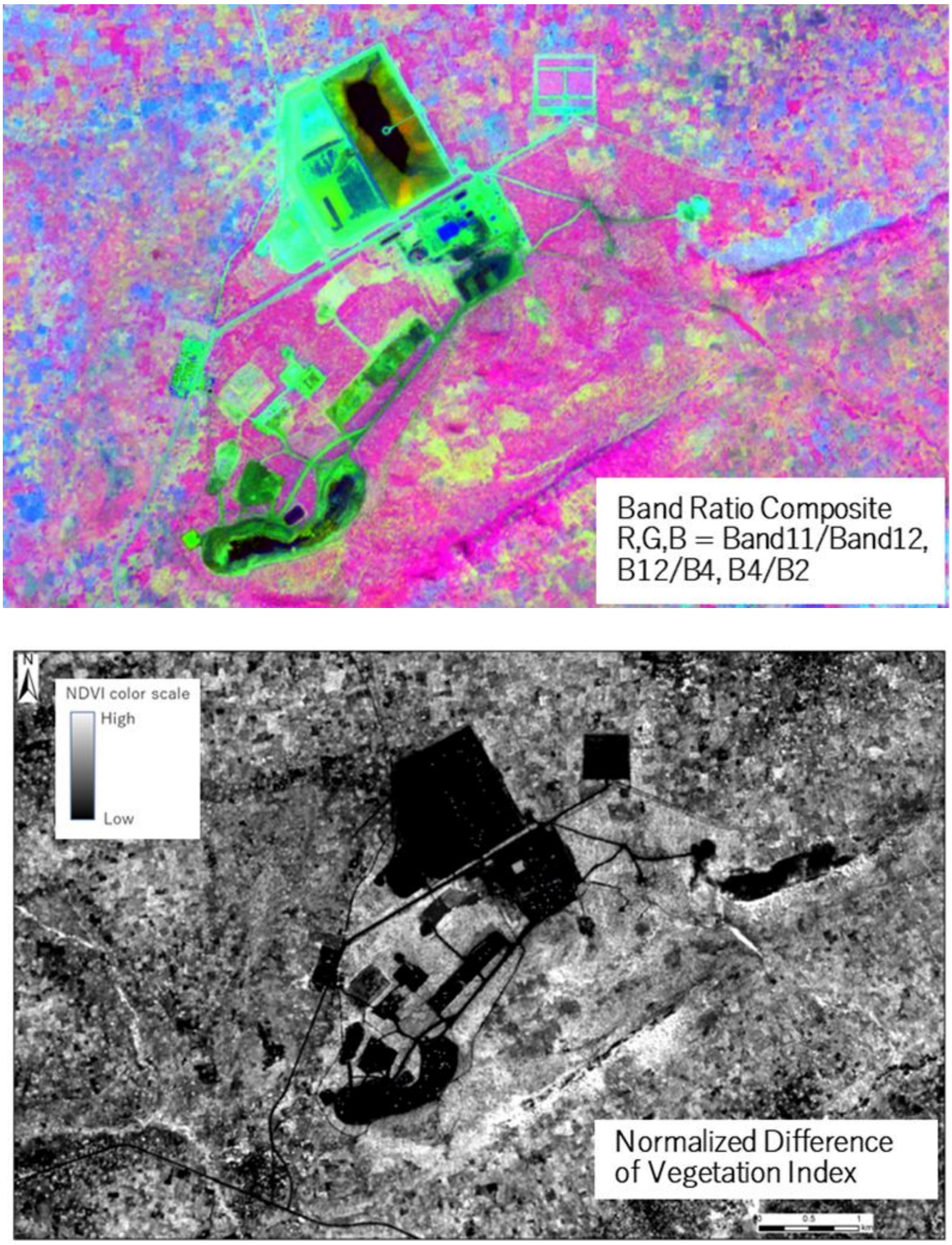


Figure 5-17 Ratio image (top) and NDVI image (bottom) of Balama mine of 2023

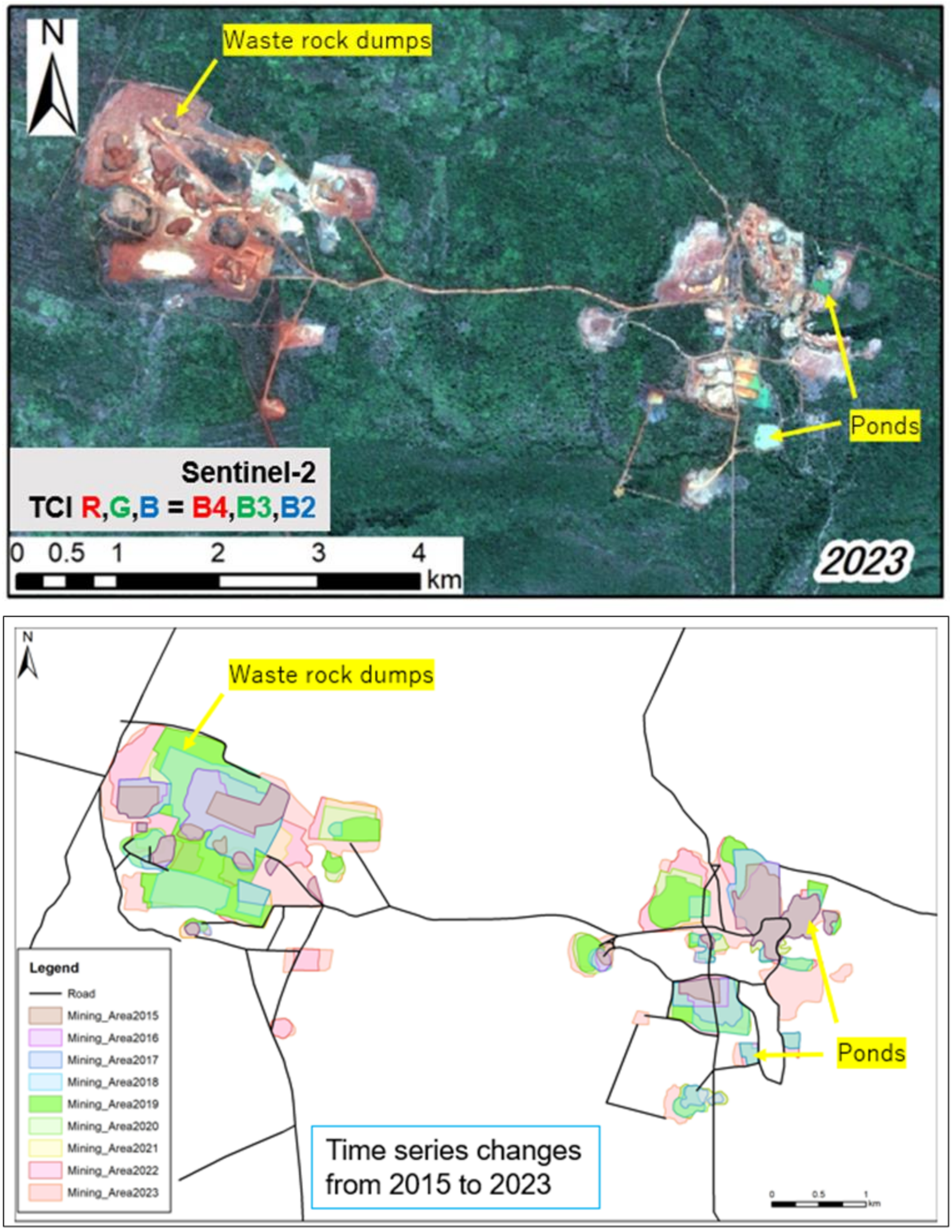


Figure 5-18 Time-series change diagram Montepuez gem mining operation site from 2015 to 2023

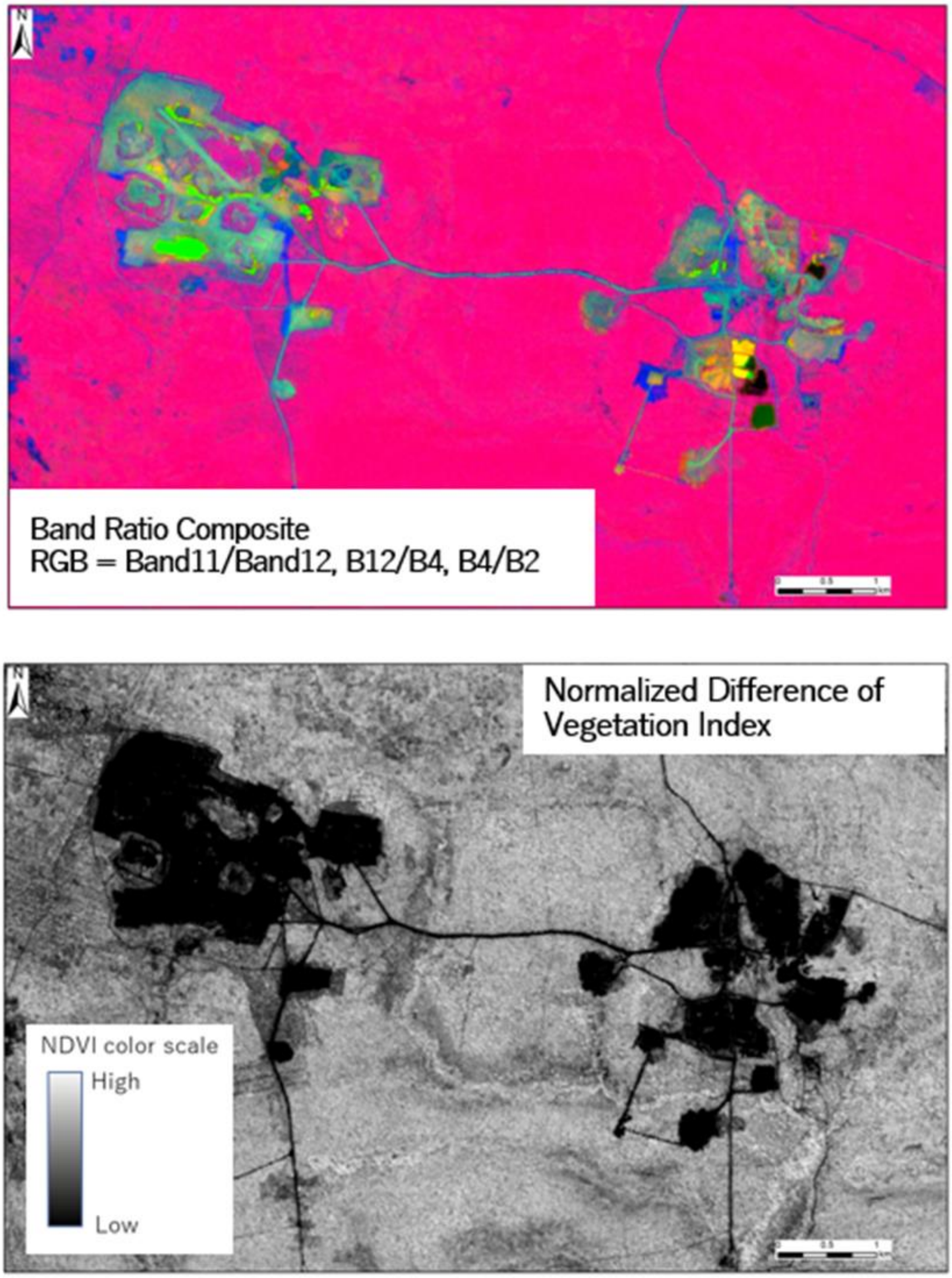


Figure 5-19 Ratio image (top) and NDVI image (bottom) of Montepuez gem mine of 2023

(3) Montepuez Central Graphite Mine

Montepuez Central graphite mine acquired mining rights in February 2018. Figure 5-12 in the time-series chart shows that construction of roads and reservoir dams began in 2017, but there is no indication that the mine has been in operation since then until 2023.

(4) Muiane Tantalum Mine

The Muiane Mine has been mining tantalum since 2001. The mine is located at the top of a small hill with a diameter of about 1 km (the difference in elevation from the surrounding area is about 150 m. The temporal change of the mine operation area, as deciphered from Sentinel-2 images, is shown in Figure 5-20. In the Sentinel-2 true-color image, the active mining area is small (about 400 m) and the ground surface is highly reflective, making it impossible to read the details. There are no clear changes over time, and although the mine is located at the top of a small hill, there is no indication of expansion.

Figure 5-21 shows the ratio-calculated and normalized vegetation index (NDVI) images of the Muiane mine. The NDVI image shows a low vegetation index in the operation area and an obvious contrast with the area surrounding the mine, but no evidence of a change in vegetation activity around the mine. The NDVI image shows a low vegetation index in the operation area and an obvious contrast with the mine perimeter, but no evidence of changes in vegetation activity around the mine.

(5) Nanro Gemstone Mine

The status of the Nanro mine is unknown. The gemstones are believed to be aquamarine and beryl, and a diagram of the mine operation location over time, as deciphered from Sentinel-2 imagery, is shown in Figure 5-22 shows a diagram of the mine operation location over time as deciphered from Sentinel-2 imagery. The mine site shows strong white reflections in the Sentinel-2 true-color image. Changes over time indicate that the site expanded between 2015 and 2021, but the details of this expansion are not legible.

Figure 5-23 shows a ratio-calculated image and a normalized vegetation index (NDVI) image of the Nanro mine. The NDVI image shows a low vegetation index in the operation area and a clear contrast with the mine surroundings, but no evidence of a change in vegetation activity around the mine.

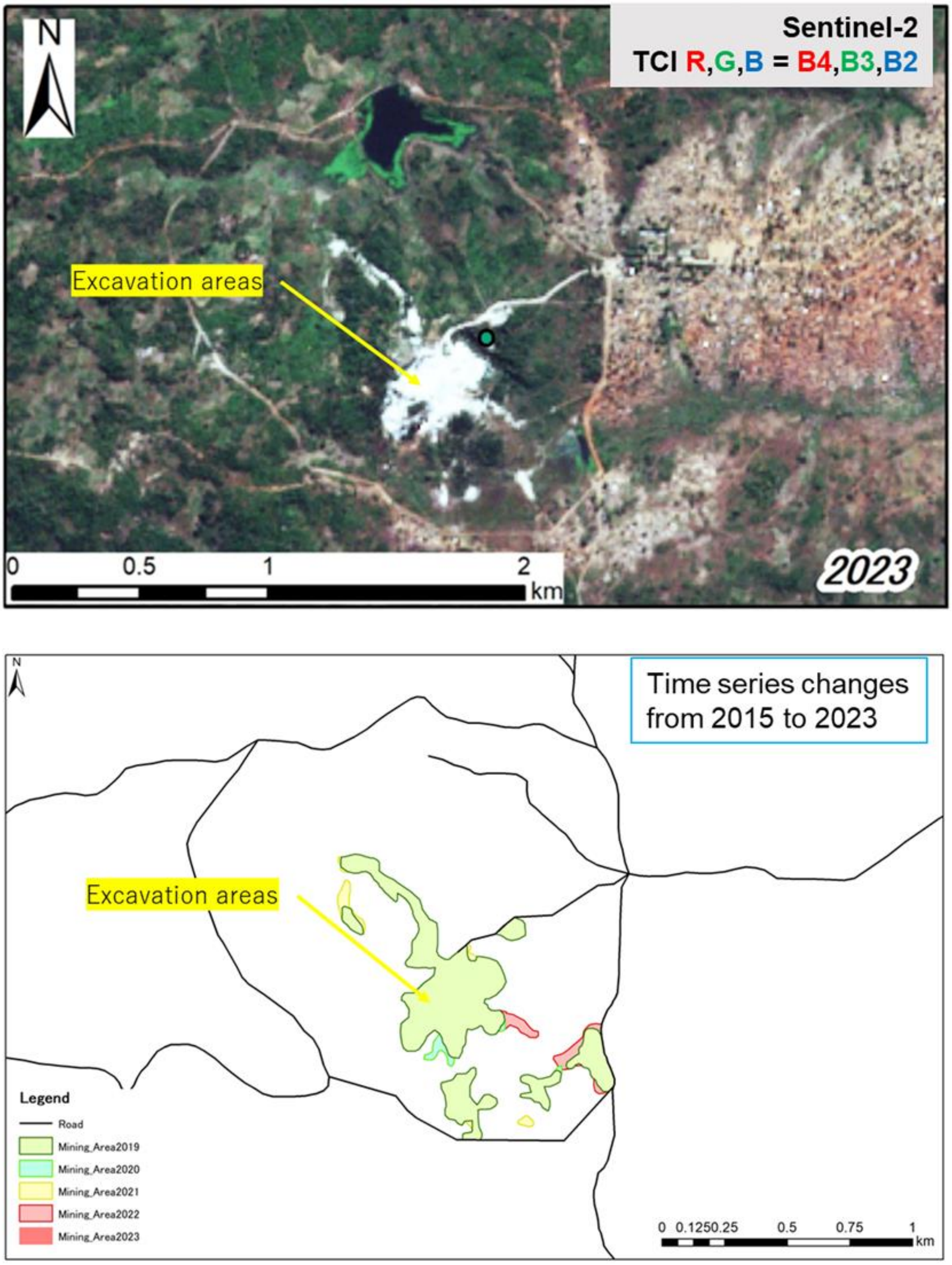
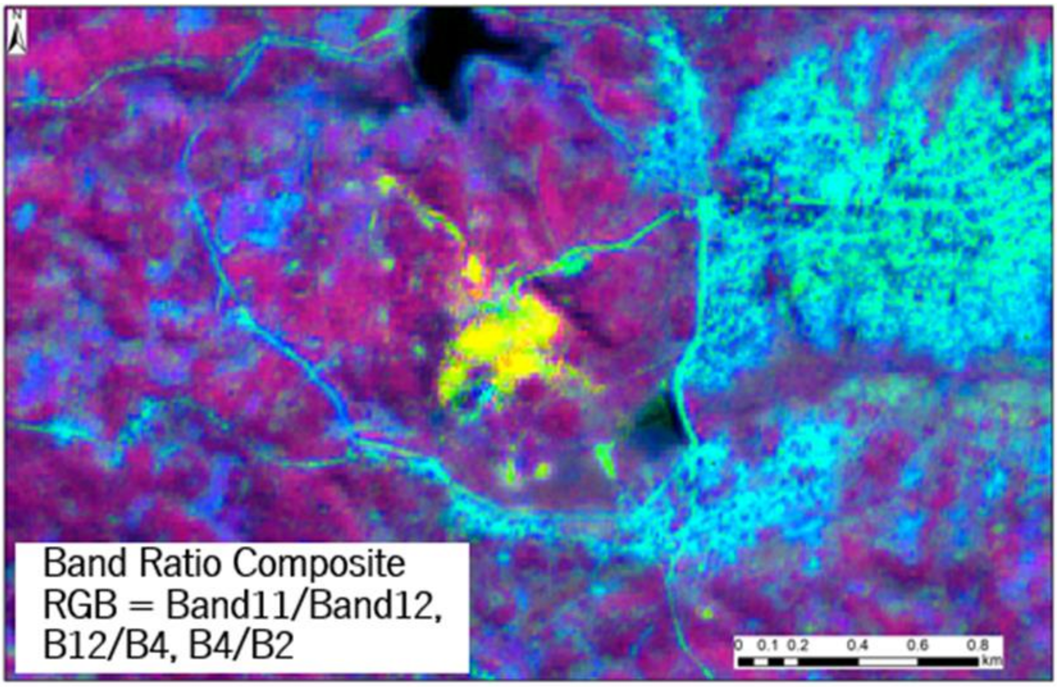


Figure 5-20 Time-series change diagram Muiane mining operation site from 2015 to 2023



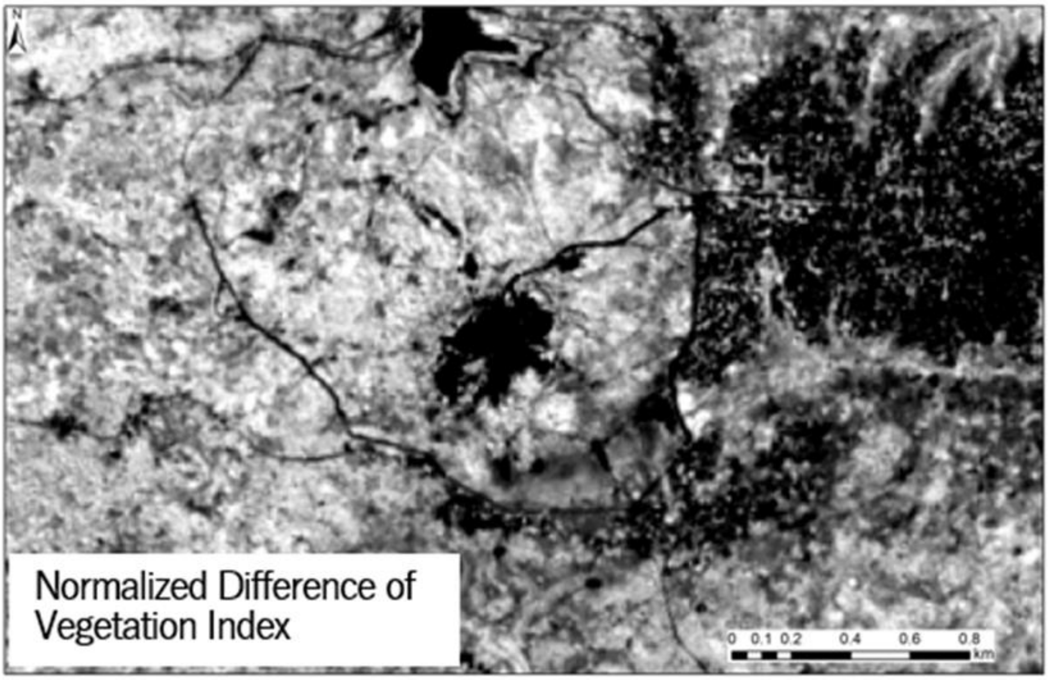


Figure 5-21 Ratio image (top) and NDVI image (bottom) of Muiane mine of 2023

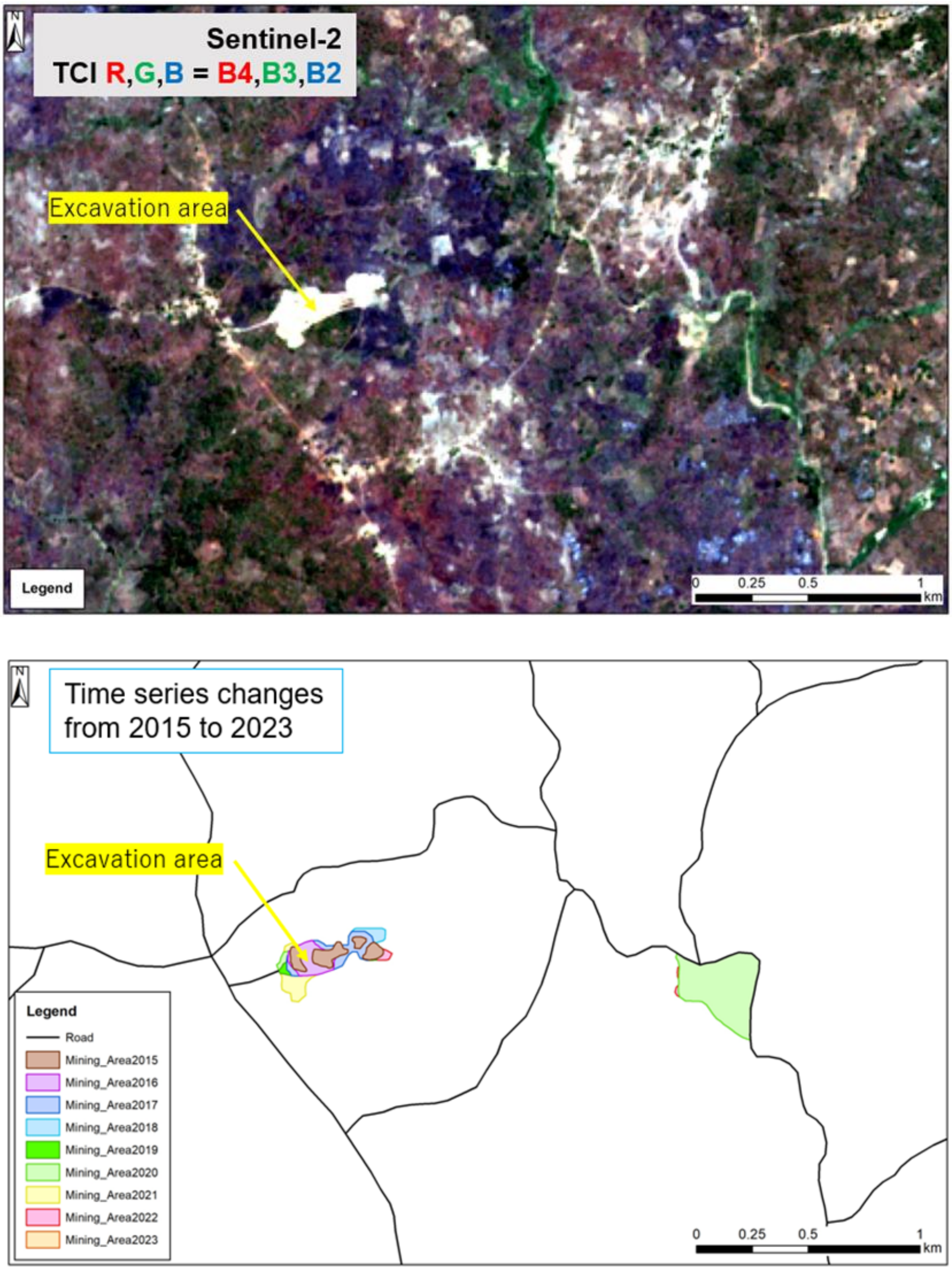
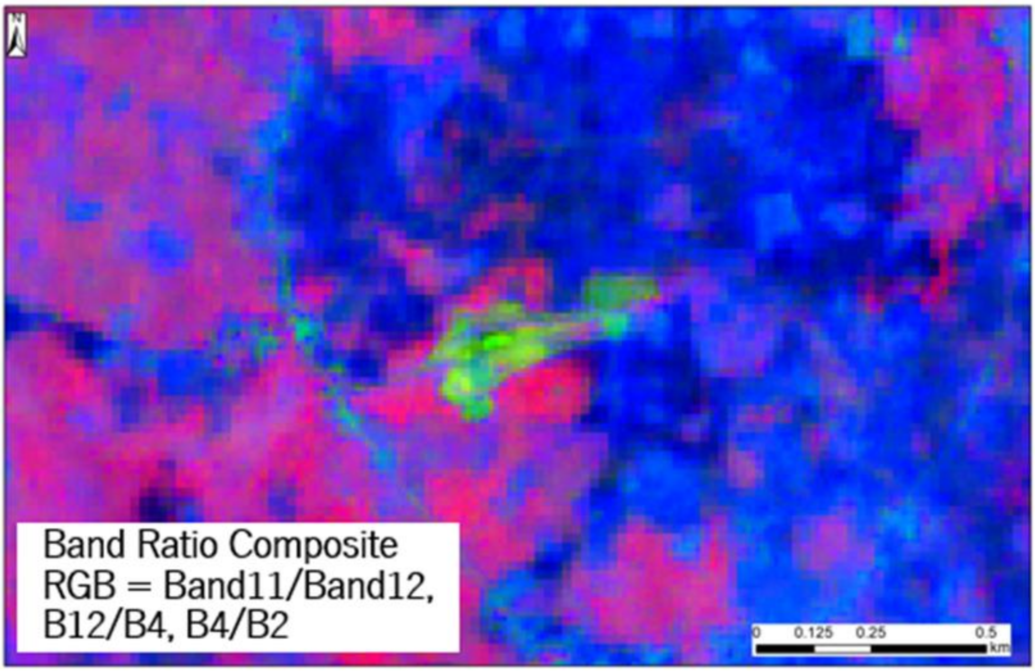


Figure 5-22 Time-series change diagram Nanro mining operation site from 2015 to 2023



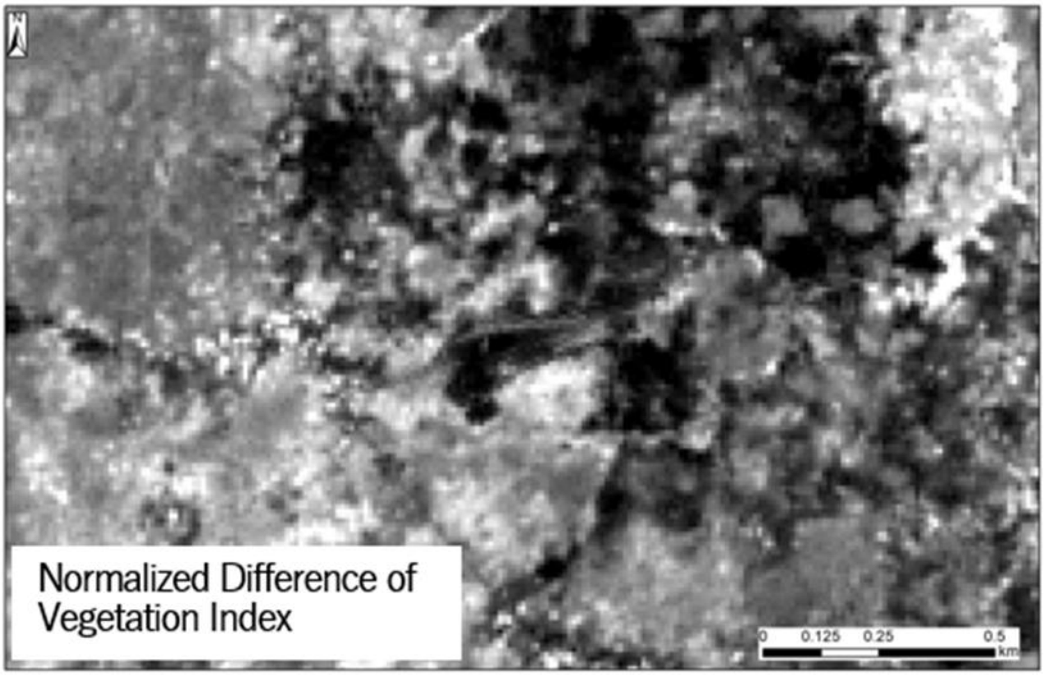


Figure 5-23 Ratio image (top) and NDVI image (bottom) of Nanro mine of 2023

(6) Moma Titanium Mine

The Moma mine was acquired in 2004 and produces titanium and other metals from heavy sand. Figure 5-24 The western part of the mine expanded southward and the eastern part expanded northeastward between 2015 and 2023. In the western part of the mine, a number of reservoir-like facilities with diameters ranging from several hundred to 500 m can be seen expanding, which are presumed to be heavy sand mining sites. The eastern part of the mine, which appears as a mottled white color in the true color image, is an area with low vegetation density according to the NDVI image described below, and is presumably being cleared as a new heavy sand extraction area.

Figure 5-25 shows a ratio-calculated image and a normalized vegetation index (NDVI) image of the Nanro mine. In the ratio-calculated image, the entire area is colored green, with some areas colored yellow to orange, and the NDVI image shows heterogeneity, but its details cannot be determined. Heterogeneity is present but its details cannot be discerned; in the NDVI image the vegetation index is low in the operation area and the contrast with the mine perimeter is obvious. There is no evidence of a change in vegetation activity around the mine.

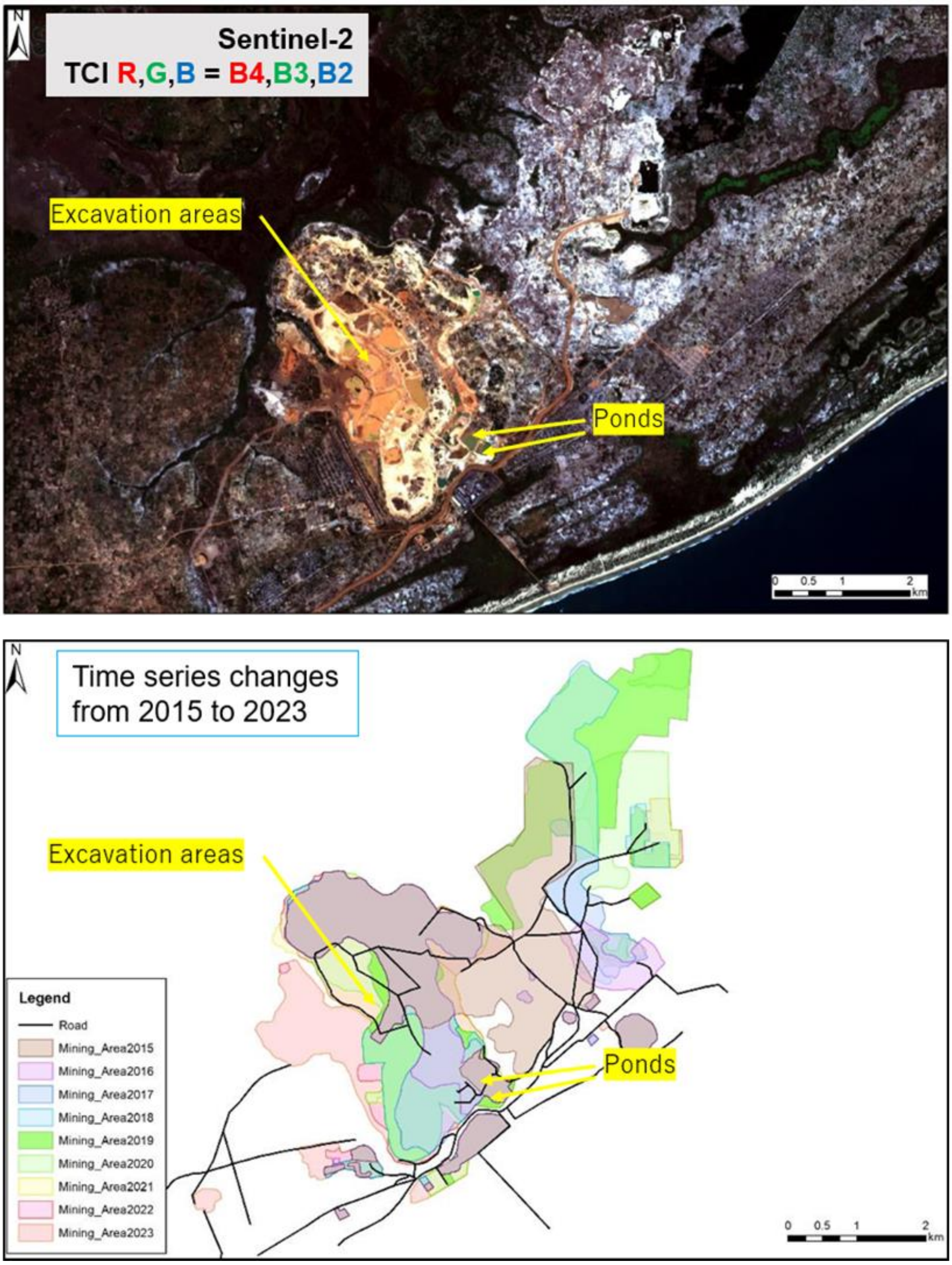
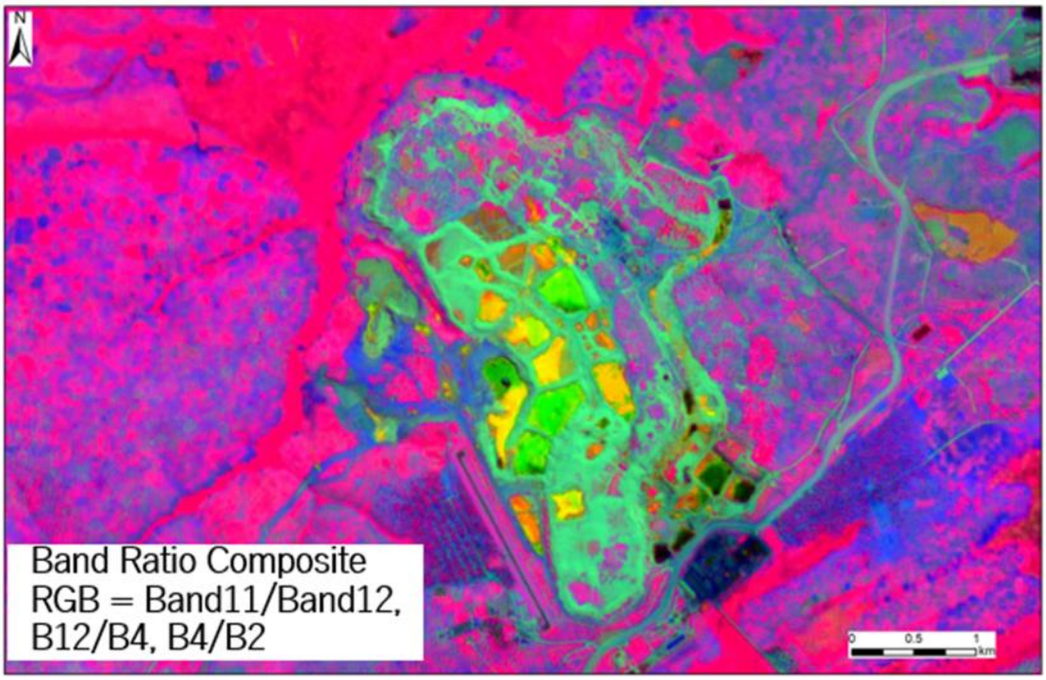


Figure 5-24 Time-series change diagram Moma mining operation site from 2015 to 2023



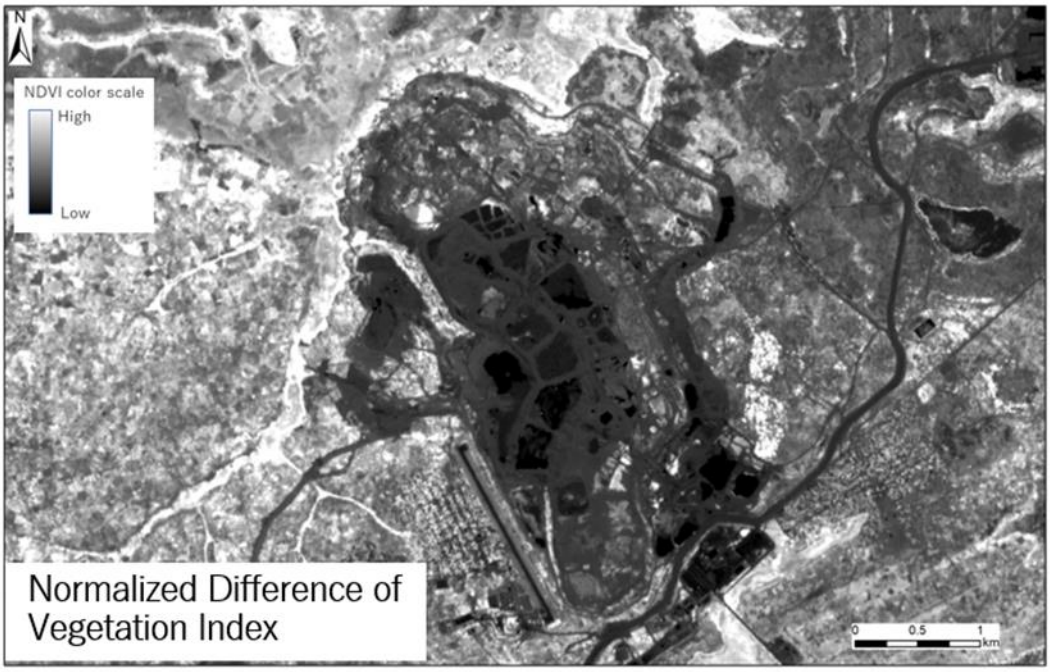


Figure 5-25 Ratio image (top) and NDVI image (bottom) of Moma mine of 2023

5.6.4 Details of Mining Development Status Assessed

The development status identified from the 2023 Sentinel-2 images for each mine is summarized below.

(1) Balama Mine

Open pits, waste rock dump areas, and other above-ground facilities will be located in an approximately 3 km square area.

Mining facilities: ore dressing plant and large building

Surface mining location: Open pit

Ore management sites: Waste rock deposition sites, tailings deposition sites (sedimentation dams), reservoirs (dams)

Roads: access roads to and within the mine

Others: Photovoltaic power generation facilities (450m square, confirmed by Google Earth)

(2) Montepuez Gemstone Mine

The mine activity area is placed within a 2 km square, and the mine equipment legible from Sentinel-2 imagery includes the following

Mining Facilities: Reservoir

Location of surface mining: Unidentified (Google Earth confirmed the existence of shallow pits that strip the surface layer).

Ore management site: Waste rock deposition site

Roads: access roads to the mine. Roads within the mine.

(3) Montepuez Central Graphite Mine

Before operation, the reservoir (dam) and access road can be seen.

(4) Muiane Tantalum Mine

The active area of the mine is within a 400 m square; the Sentinel-2 image does not show any discernible activity; Google Earth shows progressive collapse and runoff of sediment.

(5) Nanro Gemstone Mine

Mine activity is within 500 m x 200 m. Sentinel-2 imagery cannot discern activity; Google Earth shows a trench-like mining area, an abandoned stone pit, and a small building.

(6) Moma Mine

The sand extraction site and extensive sedimentation basin extend over an area of 1.5 km x 3.5 km.

Mining facilities: ore dressing plant and large building

Surface mining location: Sand extraction location

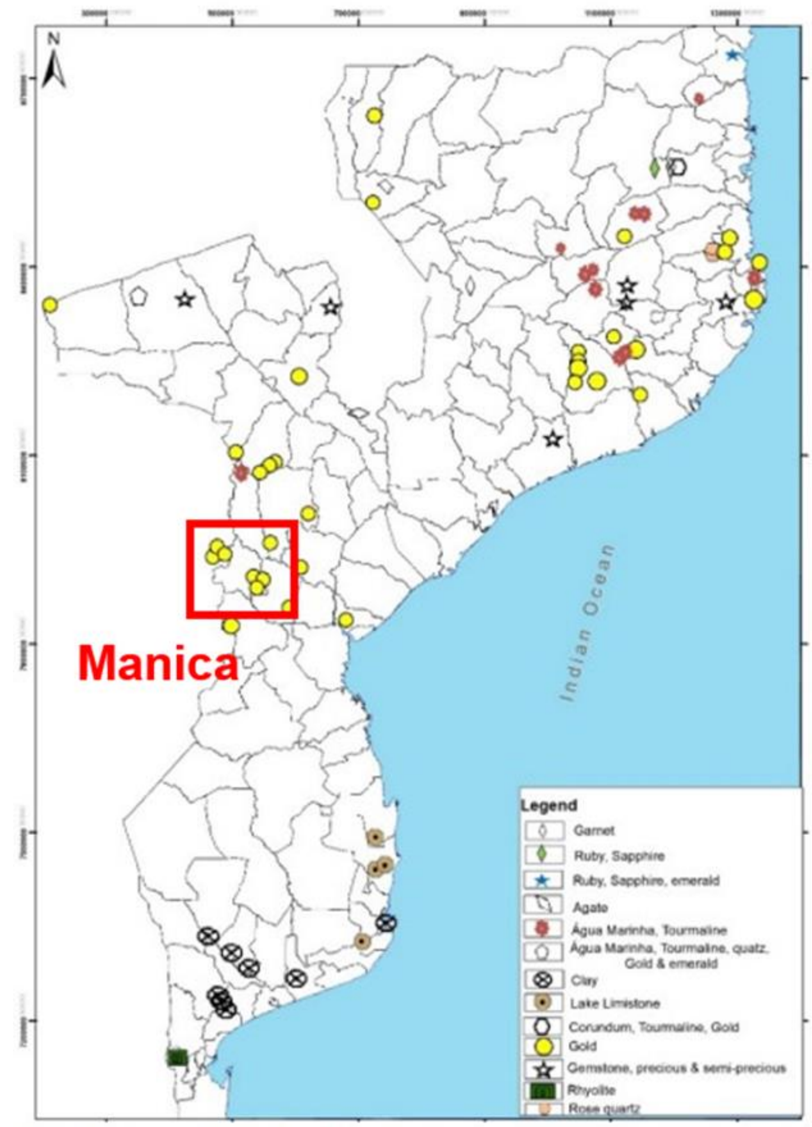
Ore management site: Sedimentation pond

Roads: Roads around the mine

5.6.5 Activities of small-scale mining mines in the Manica region

The distribution map of ASM in Mozambique is shown in Figure 5-26. In central Mozambique, gold ASM is abundant; in Zambezia, gold and gemstone; and in the south Mozambique, ASM for industrial materials such as clay. In this study, the Manica region is focused on, where gold ASM activity is relatively large, and attempted to extract ASM from satellite images. The Manica region is in central Mozambique near the border with Zimbabwe (Figure 5-26).

The satellite images used were Sentinel-2 images acquired in 2016 and 2023. First, we compared the ASM activity in the two images, extracted areas considered to be ASM using the 2023 image, and then devised and applied a method to extract ASM-specific features from the image for representative ASMs.



(Hilson et al., 2021)

Figure 5-26 Distribution of ASM in Mozambique

(1) Distribution of ASM in the Manica Region

Figure 5-27 shows true color images of the Manica region in 2016 and 2023. In the 2023, surface disturbance is observed along the river in the center of the image. ASM is distributed in this vicinity.

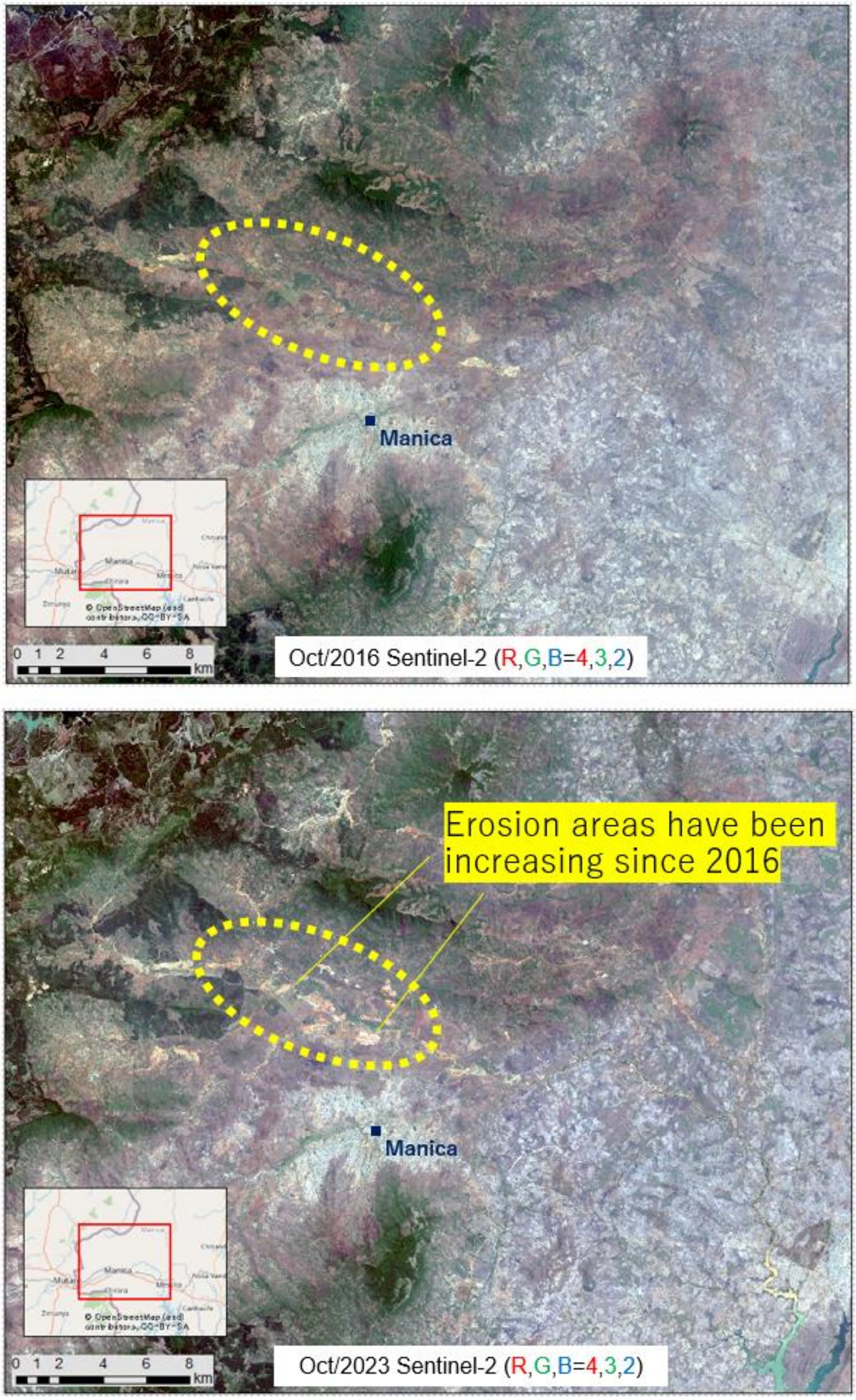


Figure 5-27 Change over time in Sentinel-2 true-color images of the Manica region (2016 top, 2023 bottom).

Sentinel-2 image were used to interpret the potential of ASM distribution. The results of interpretation are shown in Figure 5-28. The potential ASM areas are concentrated along major rivers. This may be because the mineral type targeted for ASM is gold, which is extracted from alluvial sediments. The status of mining concessions in Manica area is shown in Figure 5-29. In most of the target areas, mining rights have been acquired with gold.

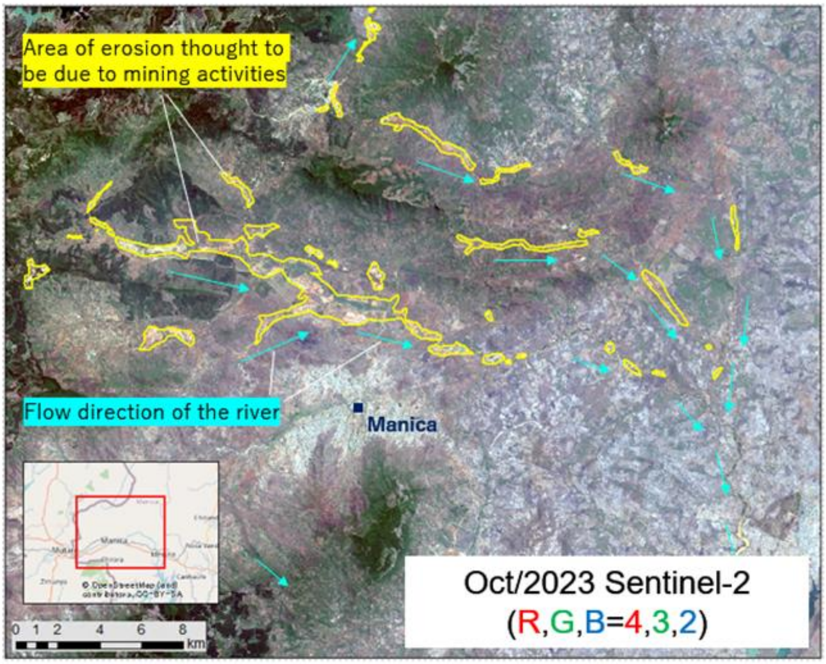


Figure 5-28 Image interpretation of possible ASM areas in Manica

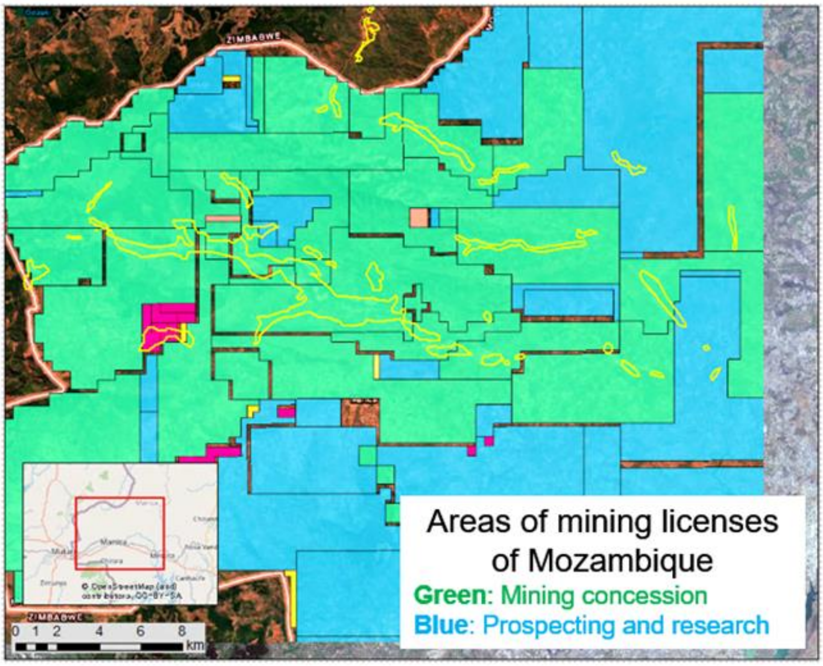


Figure 5-29 Status of mining concession of Manica

(2) ASM Features

Magnified images of typical ASM are shown in Figure 5-30. ASM are characterized by a lighter yellowish-brown than its surroundings and are along rivers. In detail, bare lands and reservoirs that have been cleared of vegetation and created within an area of less than several hundred meters in diameter are distributed in patches or in a string of beads. This feature differs significantly from that of a typical large-scale mine. The green area in image B of Figure 5-30 are presumed to be ponds. In image A of Figure 5 30, a brown halo is identified around the built-up area, presumably the area of dust and other dispersal. On the other hand, no facilities related to mining can be identified. In general, gold ASM uses large amounts of water for mining, so water is secured in ponds, and ponds are also used to deposit washed-out sediment. Therefore, an adequate water source is also needed in the vicinity, and in the case of this area, it is assumed that river water is used. If the polluted wastewater cannot be treated sufficiently, the environmental impact on the river would be a concern.

(3) Image processing method for ASM extraction

The characteristics of ASMs interpreted from these satellite images can be attributed to the exposure of sediment due to land surface disturbance and the presence of large amounts of water, such as in ponds. Therefore, if it is possible to spectroscopically detect water bodies and lands with high water content from satellite images, it will lead to the identification of ASMs. In particular, the presence of water in a pond with low pollution would most likely indicate that the ASM is in operation. Therefore, in this study, we selected indicators of ASM characteristics in satellite imagery and applied them to the Sentinel-2 data. The selected ASM indices are shown in Table 5-6. The three indicators are the Modified Normalized Difference Water Index (MNDWI) (Xu, 2006), which is used to determine surface water content, the iron hydroxide indicator, which is an indicator of sediment and host rock exposure due to surface excavation, and the Normalized Vegetation Index (NDVI). The MNDWI is based on the property of water molecules to absorb electromagnetic waves in the short-wavelength infrared (SWIR) region. It can be estimated from the relationship between Band 12, which is affected by water absorption, and Band 3, which is less affected by visible light, in the case of Sentinel-2, as shown in the Earth observation satellite bandwidths in Figure 5-31.

Table 5-6 Indicators for ASM Extraction

Indicators	Sentinel-2 band arithmetic formula	Features of ASM
Modified normalized difference water index (MNDWI) Indicates the moisture content at the ground surface.	$MNDWI = \frac{(band3 - band12)}{(band3 + band12)}$	The presence of ponds, for the use of large amounts of water. High water content on the ground surface due to washing.
Iron hydroxide indicator Enhance spectral features of iron hydroxide, which is abundant in soils and rocks.	band4/band3	Exposure of soil and sediment due to surface excavation. Sediment discharge and pollution of river water due to mining.
Normalized difference vegetation index (NDVI) Indicates the level of activity of the vegetation.	$NDVI = \frac{(band8 - band4)}{(band8 + band4)}$	Decrease in vegetation due to deforestation, alteration of agricultural lands, etc.

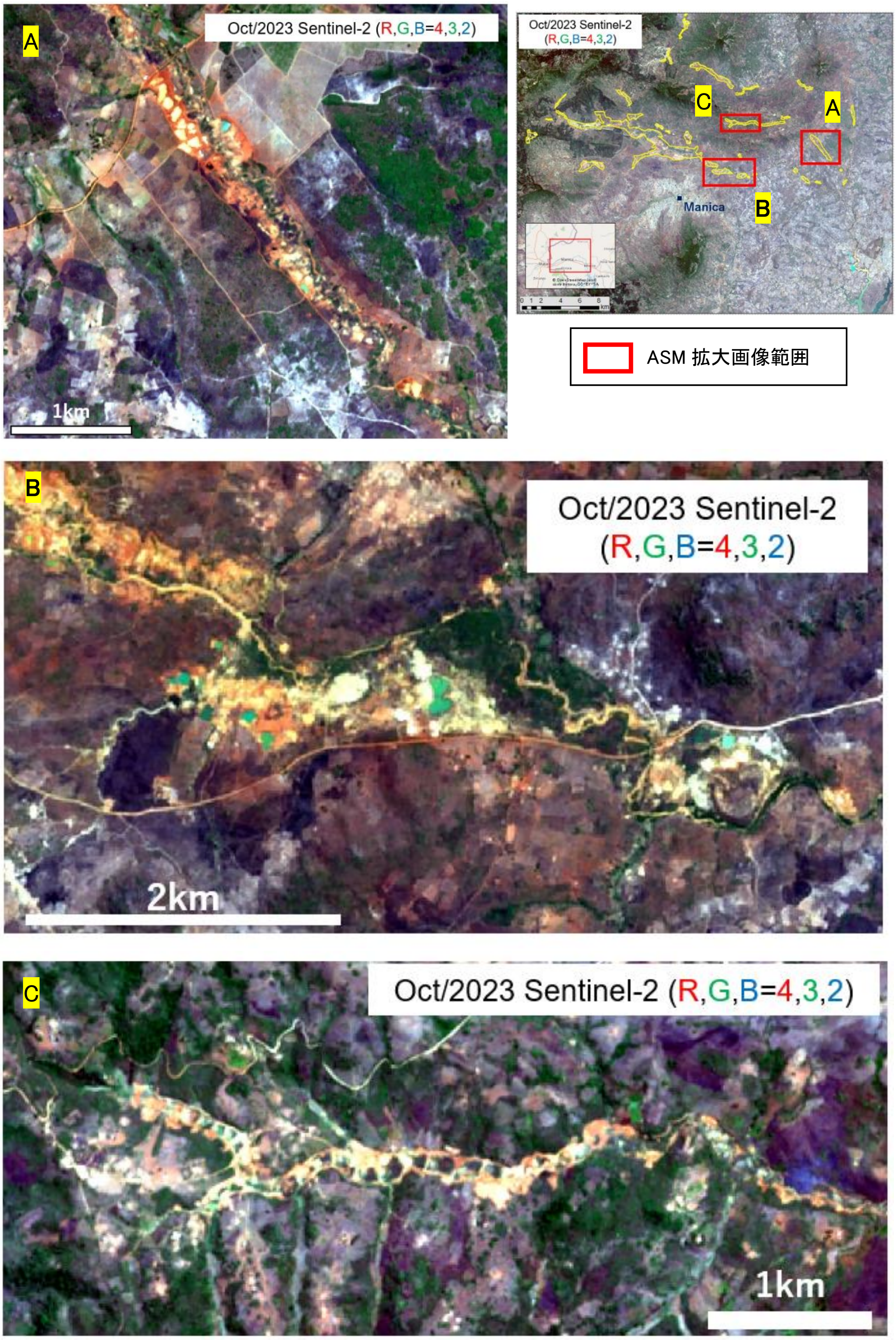


Figure 5-30 Enlarged image of the ASM area

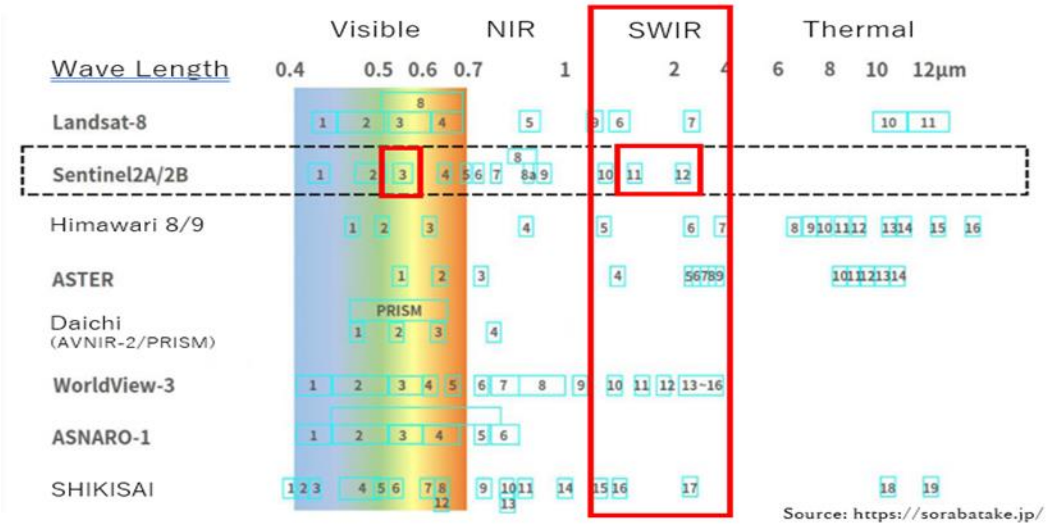


Figure 5-31 Wavelength Range of Major Earth Observation Satellites

(4) Results of ASM evaluation by index composite image

Figure 5-32 shows a comparison between the index composite image created from the three indices examined in the previous section and the visible image.

For the index composite image, band4/band3 values, an index of iron hydroxide, were assigned to red, MNDWI to green, and NDVI to blue. The brighter the color tone, the higher the index. The characteristics of the images can be interpreted as follows.

[Area of ASM]

The ASM is generally bright red in color. This reflects the exposure of iron hydroxide-rich soil (laterite) and weathered host rock, which in turn suggests that the excavation was shallow and there is no or very little exposure of fresh rock. The area surrounding the ASM also shows relatively strong red, which may be due to the predominance of soil information from the low vegetation density.

[Reservoir].

The areas identified as ponds in the visible image have a high MNDWI (green), which confirms the presence of water. In addition, some adjacent areas that could not be read as ponds in the visible image also show a high MNDWI, which clearly indicates the presence of a pond.

On the other hand, yellow places are recognized while showing similar morphology to these. The yellow color is a mixture of red and green, which is a strong indicator of both iron hydroxide and water, meaning that this condition could indicate the presence of water turbid with sediment or sediment with high water content.

[Vegetation]

Because the image was acquired during the dry season, the NDVI tends to be low throughout the region. The light blue along the rivers suggests that vegetation is growing due to the abundance of groundwater.

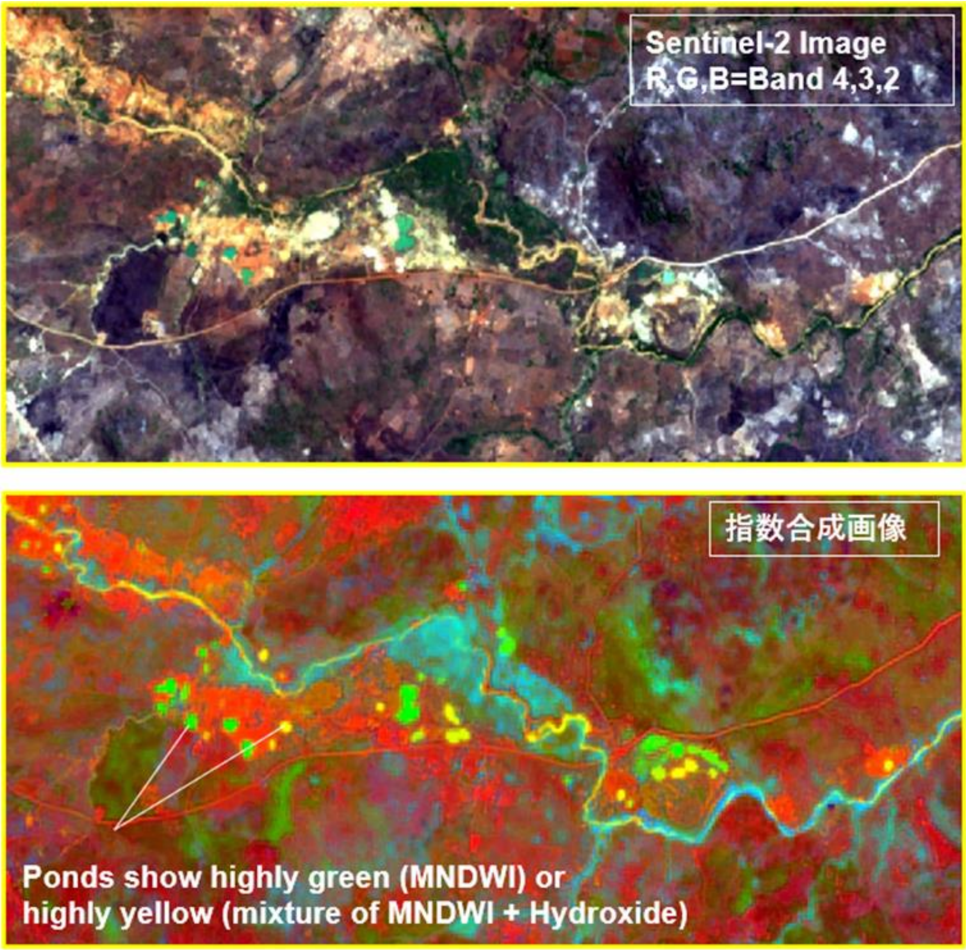


Figure 5-32 Extraction of pond in AMS using index composite image

(5) Impact on river water quality

As mentioned in the previous section, ASMs are distributed along rivers, and Nhantumbo et al. (2020) clarified that the river water quality in the target area is polluted by ASM activities. Figure 5-33 shows the surveyed sites of river water and Table 5 7 shows the results of water quality analysis of river water, respectively. According to the results, a wide area exceeded drinking water quality standards (Diploma Ministerial no. 180/2004 de 15 de Setembro) for pH, turbidity, arsenic, copper, iron, manganese, hexavalent chromium, zinc, and sulfate ions. In particular, turbidity was 56,000 NTU compared to the standard value of 5 NTU, arsenic was 15 mg/L compared to the standard value of 0.01 mg/L, and hexavalent chromium was 4.95 compared to the standard value of 0.05 mg/L.

To confirm the situation of the river in the target area, a satellite image of a representative site is shown in Figure 5-34. the Sentinel-2 index composite image shows that the river is strongly colored yellow, a mixture of the colors indicating the presence of water (green) and iron hydroxide (red), suggesting a high turbidity condition. The river flows east from Manica and then turns to south, flowing into the dam lake finally (A in Figure 5-34). In the enlarged image of the dam lake, the river water, which is polluted and yellow in color, can be seen merging into the dam lake, which is green in color (clear water).

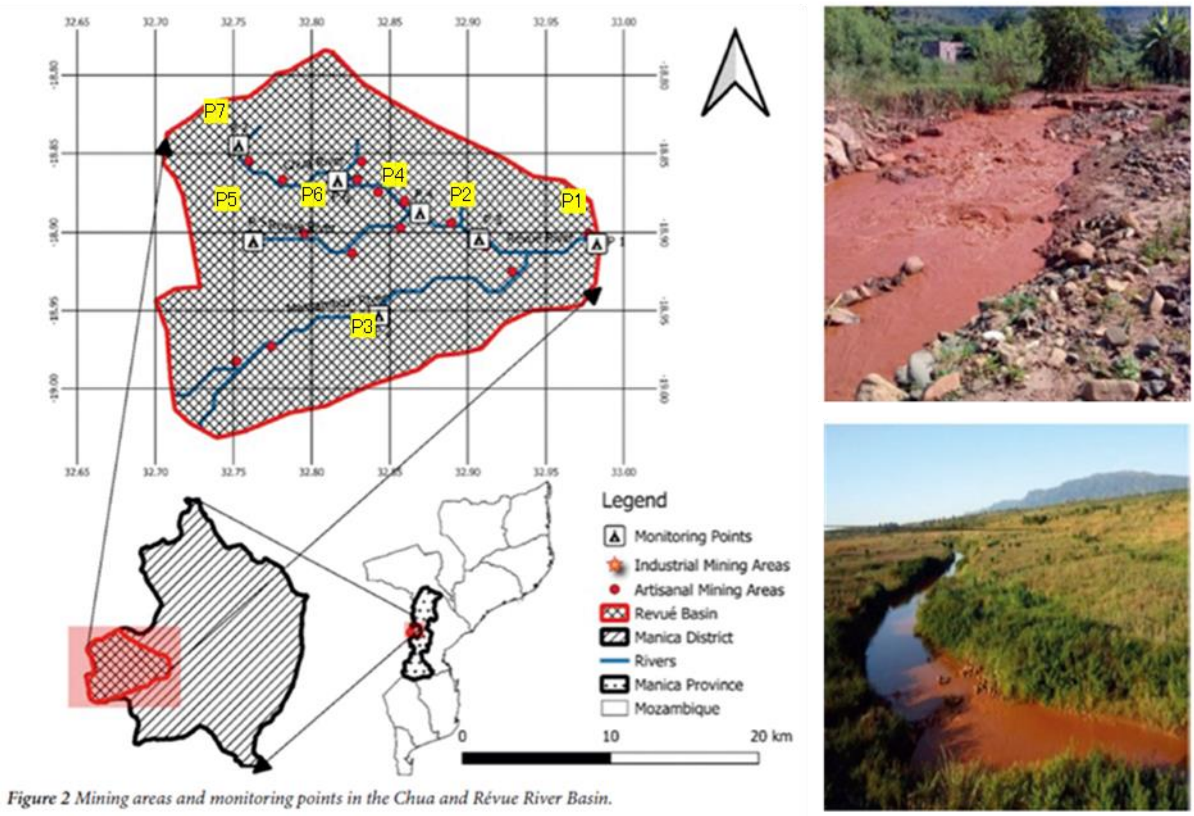


Figure 2 *Mining areas and monitoring points in the Chua and Révue River Basin.*

Figure 5-33 Photographs of river water sampling points and river pollution in the Manica region

Table 5-7 Results of water quality analysis of river water in the Manica region

Table 2 *Results of chemical analysis in Chua and Revué rivers, and standard values. P1, P2, P3, P4, P5, P6 and P7 are monitoring points indicated in Figure 2.*

		Monitoring points							
Parameter	Units	P7	P6	P5	P4	P3	P2	P1	Standard*
pH	-	7.63	5.94	7.78	6.79	6.47	6.91	6.50	6.5 - 8.5
EC	µS/cm	896	659.3	941	760.3	749	148.6	837	50 – 2000
TDS	mg/L	423	378	545	362	358	705	407	1000
Alkalinity	mg/L	35	25.4	33	29.51	29.96	-	28.63	-
Turbidity	NTU	6	5600	5.27	734	669	197	338	5
As	mg/L	0	15	0	1.5	0.5	0	0.01	0.01
Cu	mg/L	0.001	1.6	0.006	0.9	0.3	0	0.27	1.0
Fe	mg/L	1.46	6	1.52	3.68	1.28	2.23	0.73	0.3
Mn	mg/L	0.003	165	0.03	29	30	18	8	0.1
Cr^{6+}	mg/L	0.15	4.95	0.11	1.27	0.96	0.69	0.83	0.05
Zn	mg/L	2.9	24.2	4.8	10.6	8	7.2	4.9	3.0
SO_4^{2-}	mg/L	11.0	56.0	21.0	34.0	25.0	22.0	20.0	25.0
S^{2-}	mg/L	0.21	4.18	0.11	1.50	1.16		0.73	-

(grey) Values that exceed the standard

(box) Values that do not exceed the standards

* Mozambican Legislation, extracted from "Diploma Ministerial no. 180/2004 de 15 de Setembro"

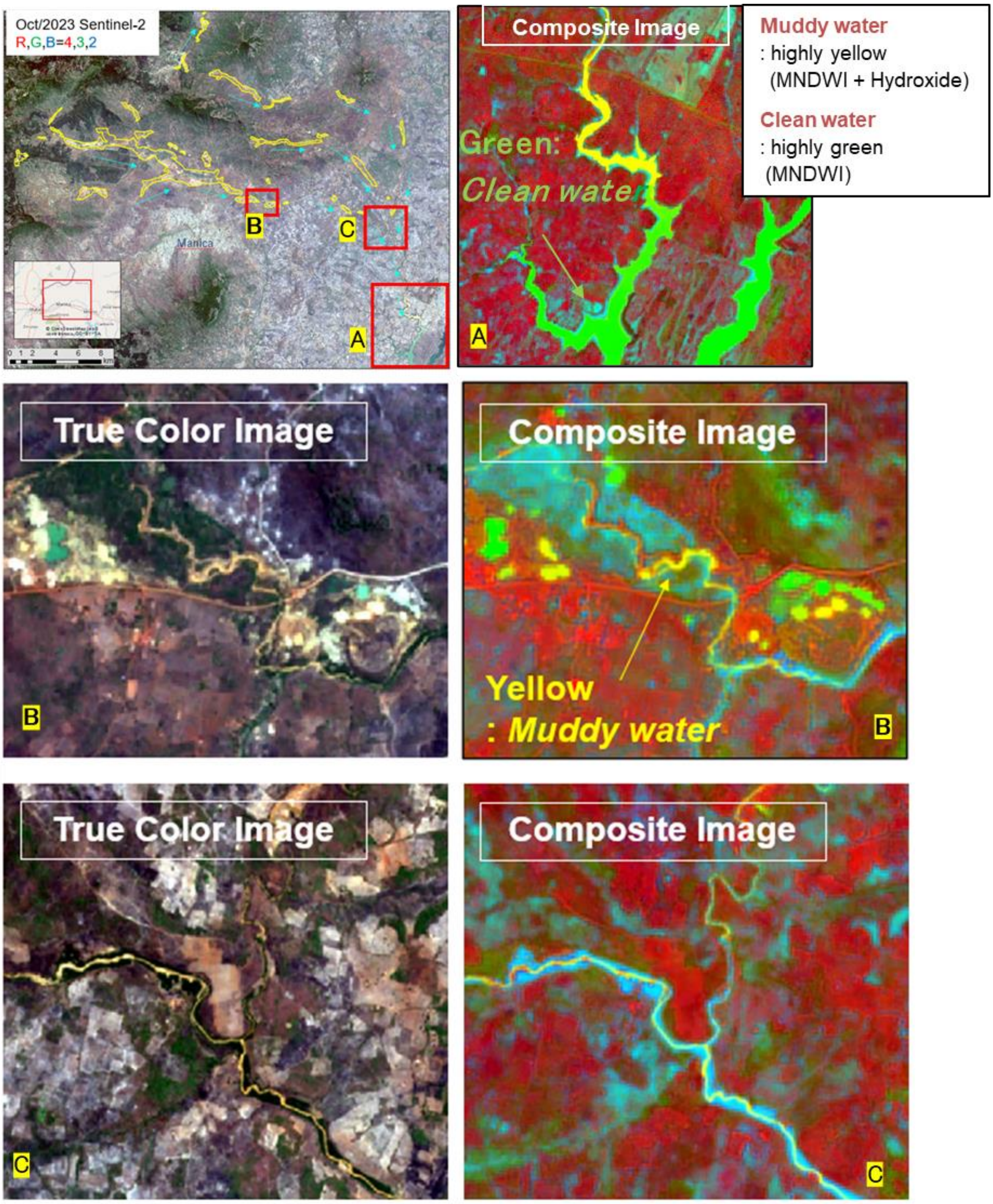


Figure 5-34 Pollution of river water

(6) Proposed image analysis method for ASM extraction

The above results show that the use of Sentinel-2 images can effectively extract not only the ASM activity but also the pollution of the surrounding environment by using spectral indices such as MNDW. The flow of the image analysis method for ASM extraction is shown in Figure 5-35.

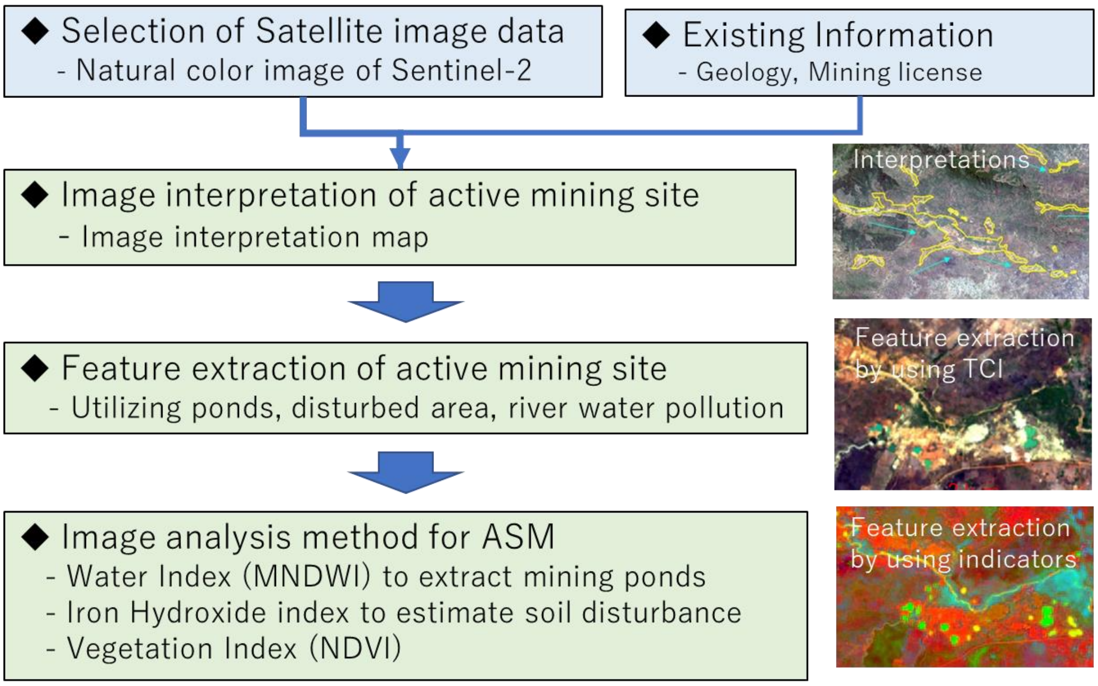


Figure 5-35 Flow of image analysis method for ASM extraction

5.6.6 Monitoring plan of mining development status

Based on the image decipherment and analysis conducted using Sentinel-2 satellite data, the possible monitoring targets and image processing contents can be summarized as shown in Table 5-8.

Table 5-8 Mining Development Status Monitoring Details

Objects of monitoring	Images to be used (Sentinel-2)	Details of analysis
Confirmation of mining and operation area	- True color images (red: band 4, green: band 3, blue: band 2)	- Visual interpretation (monitoring of operation areas in time series)
Confirmation of the extent of ore processing and other facilities and piling areas within the operation site	- Rationing images (red: Band 11/Band 12, green: Band 12/Band 4, blue: Band 4/Band 2)	- Visual interpretation (monitoring of operation areas in time series)
Characterization of soils, tailings, and piles in the operation site	- Rationing images (red: Band 11/Band 12, green: Band 12/Band 4, blue: Band 4/Band 2) - Index combination images (red: iron hydroxide indicator (Band 4/Band 3), green: water index (MNDWI), blue: vegetation index (NDVI))	- Visual interpretation (monitoring of differences in soil and other properties in time series) - Visual interpretation (monitoring of changes in each index in time series)
Confirmation of the range of environmental impact of soil, water quality, and vegetation inside and outside the operation site	- Rationing images (red: Band 11/Band 12, green: Band 12/Band 4, blue: Band 4/Band 2) - Index combination images (red: iron hydroxide indicator (Band 4/Band 3), green: water indicator (MNDWI), blue: vegetation indicator (NDVI))	- Visual interpretation (time series monitoring of the possibility of dispersal and spillage of tailings, etc. from operation sites) - Visual interpretation (time series monitoring of the possibility of dispersal and spillage from the operation site according to changes in each index)

The actual acquisition, processing, and analysis of image data for monitoring should be considered based on the capacity of each sector in terms of human resources, infrastructure, etc. However, at present, this can be done free of charge, including GIS analysis, with an ordinary PC and an internet connection in offices of the sector.

5.6.7 Issues

The challenges for the mining and environmental administrations in monitoring of the mining activities using satellite imagery data can be summarized as follows.

- The engineers in both sectors do not have experiences in processing and analyzing the satellite data, so they will need to be trained specifically on the monitoring objectives and extraction targets in relation to mining activities.
- However, because GIS-based data management is required for systematic monitoring, it is necessary to establish a monitoring system including an administrative structure within the institute.

5.7 Mining development potential

Mineral resources with high potential for actual mining development are graphite as a strategic mineral, rare earths in carbonatites including heavy rare earths, rare metals such as ilmenite in heavy sands and pegmatites including niobium and lithium. There are still much promising areas for exploration and development of all types of minerals in Mozambique, and an importance of Mozambique as a producer of graphite and rare earths is likely to increase in the future, especially since China currently holds an oligopoly in these minerals.

The potential areas for these types of minerals are in the central, northern, and coastal regions of Mozambique, and it is expected that promoting mining development along with the development of corridors and port infrastructure will lead to the promotion of the entire region.

5.8 Study by country visit

5.8.1 Collection of information during the first field survey

During the second round of the first field survey, we visited the following organizations in the capital, Maputo, from October 23 to 25, 2023, to gather information and conduct interviews.

- National Directorate of Geology and Mines (DNGM), Ministry of Mineral Resources and Energy (MIREME)
- National Institute of Mines (INAMI), MIREME
- National Directorate of Environment, Ministry of Land and Environment (MTA)
- National Museum of Geology, MIREME

Information obtained in Mozambique were as follows.

① Cooperation with JICA projects

Ministry of Mineral Resources and Energy (MIREME) showed great interest in the project contents, especially in monitoring through satellite images, and recognized its effectiveness. In addition, they expressed a strong interest in future cooperation, with concrete proposals regarding ASM and possession of the database (to be provided in the future). An official letter from JICA is required for data provision.

Ministry of Land and Environment (MTA) was also highly interested in satellite image monitoring and recognized its effectiveness. Although it was outside the scope of this project, the survey team presented Sentinel-2 image of the Manica area, where ASM of gold is active, and it was confirmed that monitoring is possible and Sentinel-2 image can be utilized.

JICA's Mozambique local office showed interest in the project contents, starting with accompanying visit to MIREME, and showed strong interest not only in supporting this project but also in its future development. Effectively, there had never been a project related to the mining industry before, and that also seemed to be a source of interest. The Deputy Director attended the last meeting and exchanged views on the future formation of the project.

② Mine management

MIREME manages the mining licenses (2,160). This includes all licenses including coal, metal resources, graphite, gemstones, industrial raw material resources, ASM (of which about 100), etc. A database (EXCEL data) of mining activities, locations, ore types, etc. has been created (and appears to be maintained, so to speak). National Mining Institute (INAMI) under MIREME has all information concerning the mines (and will be the contact point for the future).

It appears that, among all the mines, they would like to monitor and manage 12 large mines (various ore types).

③ Monitoring status of mining activities

In principle, inspections by MIREME (activity status, safety, environment, etc.) are conducted twice a year. The counterpart commented that inspections have not been conducted as scheduled due to the lack of budget, but that this method using satellite images can be appreciated in terms of low-cost and low manpower.

MTA is involved in EIA prior to mine operations. When environmental issues occur (e.g., reports from the mine and residents, etc.), MTA conducts field investigations on its own or in cooperation with MIREME.

④ Status of the use of satellite data and utilization technology

MIREME uses Landsat and ASTER data, and many of its technicians have received training at the Remote Sensing Center of JOGMEC Botswana. The main departments own QGIS (free), ArcGIS, ENVI, and MultiSpec (free) as relevant software. Many technicians can operate these software programs.

MTA is supposed to be using satellite data, but this has not been confirmed. Recently, there was a workshop on satellite data detection of methane emissions in coal mining areas. Forest and vegetation classification maps for the prefectures of Cabo Delgado and Gaza have been produced under a JICA project (2016).

⑤ Drone
Neither MIREME nor MTA owns a drone.

⑥ Status of ASM (artisanal/small-scale *mining*)
MIREME is aware of mercury contamination by ASM of gold and aims to manage ASM including other ore types, beginning with resident education, and to conserve the environment.
MTA is concerned about mercury contamination (water quality, soil, vegetation, and damage of resident health) from ASM of gold in the Manica district. However, no analysis has been actually conducted and the present state of contamination is not known. Most of ASM in this district is illegal mining. A survey of the district will begin in 2024 if the budget is approved under the Minamata Convention on Mercury by the United Nations. They believe that the control of ASM by law is essential. In some cases, ASM has started in mines that have ceased operations, so there is a need for such a management.

⑦ Status of the assistance from other countries
MIREME currently has no support from other donors. There was previously support from the German Geotechnical Consultancy (GAF-BGR), but this has been terminated. In DNGM, there is a room on which the mark of BGR is put.
In MTA, currently, there is neither any support from other donors.

5.8.2 Collection of Information during the second survey

During the second field survey, we visited the following relevant organizations in the capital city of Maputo on January 15 and 16, 2024, to report the results of satellite data analysis, and collect information and conduct interviews.

・National Institute of Mines (INAMI), MIREME
・National Directorate of Environment, Ministry of Land and Environment (MTA)

Information obtained in Mozambique were as follows.

① Comments on the report of the survey team
Almost the same comments from MIREME and MTA
・The counterparts were interested in satellite image analysis; it is very effective and useful in managing the mining industry and understanding the environmental impact.
・They think it would be especially useful for ASGM monitoring in Manica district; it would also be useful for ASGM inventorying (activities under the Minamata Convention).

・They expect training and equipment support for such image analysis.
・They look forward to and cooperate with JICA's support.
＊ Comments on PPT contents
・In satellite image analysis, it is necessary to pay attention to the seasonal change of wet and dry seasons. ASGM may not be able to extract water bodies such as ponds because water is not used during the dry season and water is scarce. Some idea may be needed to cope with this problem.
・The counterpart thinks it is very important to understand and monitor the operation status by combining satellite image analysis and mine location information such as existing data.
・Is the location extracted as ASM by the analysis at Manica 100% correct? Answer: We believe that the accuracy is high, but a field survey is necessary to confirm it. It is useful to be able to extract the information by preliminary analysis.

② Mining license
・MIREME (INAMI) manages the mining licenses (2,160). These include coal, metal resources, graphite, gemstones, industrial raw material resources, and ASM (about 100).
・Licenses are classified as large, small, and human-powered micro. Licenses are managed by QGIS software and have a portal site.

③ Inspection and monitoring
・MIREME conducts inspections related to mining operations, while MTA conducts inspections related to the environment.
・MIREME is supposed to conduct inspections twice a year, but due to the budget shortage, not many inspections are actually conducted.
・MTA conducts monitoring in accordance with EIA. If some environmental problems occur, MTA conducts on-site inspections in cooperation with MIREME.

④ ASM/ASGM
・INAMI of MIREME and DNGM cooperate with each other to supervise ASM (document checking and inspection).
・Some ASMs have licenses, but there are many illegal ASMs (several hundreds).
・MIREME and MTA recognize the need for ASM management and maintenance. They are particularly concerned about mercury contamination by ASGM (mostly illegal) in Manica.

⑤ Minamata Convention on Mercury
・In this activity, an inventory of ASMs was initiated. This includes details of ASM workers and training for these workers on mining and beneficiation methods. Reports are submitted annually.
・MTA is teaming up with Ministry of Health to control illegal ASGM in Manica district. This district has problems such as water pollution by chemicals, mercury contamination, and water contamination by soil particles.

⑥ Problems, systems, etc.

- In MIREME, the budget for mine management is not sufficient and there is a lack of human resources. Many of them have an experience of training on satellite image analysis at JOGMEC's Remote Sensing Center in Botswana. They also have analysis software.
- MTA has never participated in JICA training programs, so they would like to participate in them. In particular, they would like to participate in a training course that combines image analysis and field survey, since the satellite image analysis presented here can be useful for future field surveys.
- Since there is little support from other countries, they look forward to JICA's future support, starting with the present survey.
- Once the ASM inventory is completed, it will be possible for MIREME and MTA to conduct joint field surveys based on the results of image analysis and monitoring, as in the present JICA project. They expect the assistance for organization and support of such a project.

5.9 Conclusion and proposal

This chapter has summarized information on the general situation related to mining in Mozambique, the situation of the relevant offices of the MIREME and the MTA, which are responsible for the management and supervision of mining activities, and the possible monitoring method related to the mining activities. Based on the confirmation results, the following issues were identified for each organization related to the mining activities and the implementation of satellite image analysis for the monitoring.

(1) Issues in the relevant organizations of the MIREME

- The related organizations are required to secure professional human resources and budgets for the management and supervision of mining activities.
- The budgets for the development and maintenance of management systems and other infrastructure related to the management and supervision of mining activities must be secured in preparation for the increase in mining activities, and efficient management and supervision must be implemented in the future.
- The budgets for securing professional human resources and infrastructure development and maintenance for research and development of geological and mineral resources information are required.

(2) Issues at the relevant bureaus of the MTA

- Efficient implementation of the action plan for ASGM within the " Minamata Convention on Mercury " and formulation / updating of the plan based on the status of activities are required.
- The " Minamata Convention on Mercury " requires cooperation with the mining sector and other related sectors in activities related to the mining, such as ASGM.
- It is necessary to secure specialized human resources and related budgets for environmental conservation and countermeasures related to mining activities.

(3) Issues in processing and analyzing satellite image data for monitoring mining activities

- The engineers of the two ministries do not have experiences in processing and analyzing satellite data, so they need to be trained specifically for the monitoring purpose and the target to be extracted through the monitoring.
- By using Sentinel-2 for the monitoring using satellite images, special materials and equipment for the data processing and analysis are not required. However, the data management system including a monitoring system based on GIS is required to perform monitoring systematically.

Based on the above situations, the recommended support is as follows.

a) Project name: "Support for the establishment of efficient management and supervision system for mining activities”

Target organizations: relevant departments and regional offices of the MIREME and departments in charge of local government

Outline of support: To support the establishment of an efficient management and supervision system for the management and supervision of mining rights and mining activities, which are expected to become more active in the future, by linking remote monitoring using satellite data and site inspections.

Contents: i) Review of management and supervision items and contents, ii) consideration and establishment of image processing and analysis procedures for monitoring of mining activities, iii) consideration and establishment of monitoring and site inspection procedures related to managemant and supervision, iv) implementation of site inspection and supervision according to the prepared procedures and establishment of a system in this project, v) implementation of related training programs

b) Project name: " Support for improving administrative capacity related to the monitoring of mining activities targeting ASGM ".

Target organizations: relevant departments of the MTA and the MIREME, and regional offices of both ministries and relevant local government departments.

Outline of support: The MTA is currently leading the implementation of the mining industry-related (ASGM-related) contents stipulated in the " Minamata Convention on Mercury ", and the Ministry has begun to implement the Convention. This support will include the efficient implementation of inventory creation of ASGM, which will serve as the basic data for the monitoring initiated by the Ministry, and the study and construction of remote monitoring and monitoring methods using satellite data as part of efforts to improve efficiency. This will ensure the implementation of the action plan required by the Minamata Convention, and will ultimately lead to enhance the administrative responses and structures for the management and supervision of ASGM, which requires coordination between ministries and agencies.

Contents: i) Review of ASGM information related to inventory creation, ii) review and establish efficient methods for the preparation and updating of the inventory, including remote monitoring of ASGM activities using satellite data and site inspections, iii) role-sharing arrangement in relation to this collaborative activities with related ministries and agencies, iv) review and establish the contents of remote monitoring and implementation of ASGM activities in the Convention Action Plan, v) study and establishment of image processing / analysis procedures and site inspection contents related to ASGM activity monitoring, and vi) Site survey of ASGM activities based on the prepared inventory and image processing / analysis results, vii) implementation of related training programs.

6. Study result: Cambodia

6.1 Basic information

6.1.1 Natural and social environment

Cambodia is located in Southeast Asia, with the southern part facing the South China Sea, and borders with Thailand, Laos, and Vietnam. The total land area is 181,035 km^2 and the total population is approximately 16.9 million. Phnom Penh, the capital, is located in the south-central part of the country. Although the country has mineral resource potential such as bauxite, iron, manganese, gold, and copper, there has been little production activity due to the long civil war and political turmoil, but gold mines have been developed in recent years.

Figure 6-1 Map of Cambodia

6.1.2 Topography

In the central part of the country, the lowlands, basins of the Tonle Sap River and Mekong River, are widely distributed, accounting for 75% of the country's land area, and are less than 200 m above sea level. The Mekong River flows into the country from Laos in the north and flows south across the country, entering Vietnam and reaching the South China Sea. The Tonle Sap Lake, the largest lake in Southeast Asia, is located in the western central part of the country. The maximum depth of the lake is as shallow as 12 meters, and its area varies greatly between the wet and dry seasons, with the maximum area in the wet season being six times larger than the minimum area in the dry season.
Parts of the northern and northeastern border areas are mountainous with elevations exceeding 500 meters. The southwestern mountains are the most extensive, with the highest elevation at 1,810 meters.

6.1.3 Vegetation

Most of the country has a tropical savanna climate, and about 48% of the land is covered with forests. However, since 2000, deforestation has been progressing rapidly due to the development of agricultural land and infrastructure, and it is estimated that about one-third of the forest area has been lost over the past 40 years. The central lowlands have been developed as rice paddies, and forests are extremely scarce, but forests still remain in the mountainous areas. Mangroves have developed along the coastline and along the shores of Tonle Sap Lake.

6.1.4 Infrastructure

Road transportation is the primary mode of travel and transport in Cambodia. However, there are no high-standard roads, and paved roads are limited to some national and provincial roads.
There are two railroad lines. One runs toward northwest from Phnom Penh, the capital, to Poipet on the Thai border, connecting with the Thai railroad. The other runs toward south from the capital Phnom Penh to the coastal city of Sihanoukville. The former is for cargo only, while the latter is for cargo and passenger transport.
As for commercial ports, Sihanoukville is the only international port. In recent years, cargo traffic has been increasing, and new construction of this port facility is underway.
There are three international airports: Phnom Penh (the capital), Siem Reap (near the World Heritage Site of Angkor Wat), and Sihanoukville (a coastal tourist destination).

6.1.5 Environmental reserve area

Eight types of nature reserves have been defined in Cambodia: natural parks, wildlife reserves, landscape reserves, multi-purpose management areas, biosphere reserves, natural heritage sites, marine parks, and Ramsar Convention sites. There are seven nature parks, eight wildlife reserves, five Ramsar Convention sites, and eight forest reserves. Mining development in some of the forest reserves has become a problem.

The high percentage of forested area in the country makes it rich in natural resources and biodiversity.

6.1.6 Geology

The geology of Cambodia consists of Precambrian metamorphic rocks, Mesozoic weakly metamorphosed sedimentary rocks, and igneous rocks. Most of the country consists of Mesozoic marine formations. As a result, the mineral resource potential is low compared to neighboring countries.
A nationwide geological map was created in the 1960s with the support of the United Nations and France. Since then, some geological maps have been updated with individual support.

6.1.7 Mining Industry

The mining industry is not well developed, with mining accounting for only 1.4% of GDP. The mineral types produced are limestone, river sand and gravel, construction stone, gemstones, and gold. Gold was first produced commercially in the country in 2021. Until then, and to date, gold has been mined by ASM, details of which are unknown.
The following three mines are currently operating in Cambodia under gold mining licenses. Satellite image analysis of these three mining areas is being conducted in this study.
Okvau gold mine obtained an exploration license in 2007, filed an EIA in 2016. With EIA approved in 2017, mining license in 2018, mine construction started in 2020, and gold production began in August 2022.
Late Cheng mine received its mining license in 2022. Pilot gold production was planned for 2023.
Delcom mine received an exploration license in 1996, filed an ESIA in 2011, and began pilot gold production in 2022.

6.2 Mineral resources

6.2.1 Metallic mineral resources

Due to the long civil war and political turmoil, many of Cambodia's mineral resources are undeveloped, with some exceptions of construction materials such as crushed stone, sand, gravel and limestone. However, as represented by the start of gold production in June 2021 in the Okvau deposit in the eastern part of Cambodia, the potential of mineral resources such as gold, copper, and bauxite has been reviewed in recent years. In particular, foreign companies are starting to actively explore gold and copper. Figure 6-2 shows the distribution of gold, copper, and bauxite mineral resources (mines, mineral occurrences, etc.).

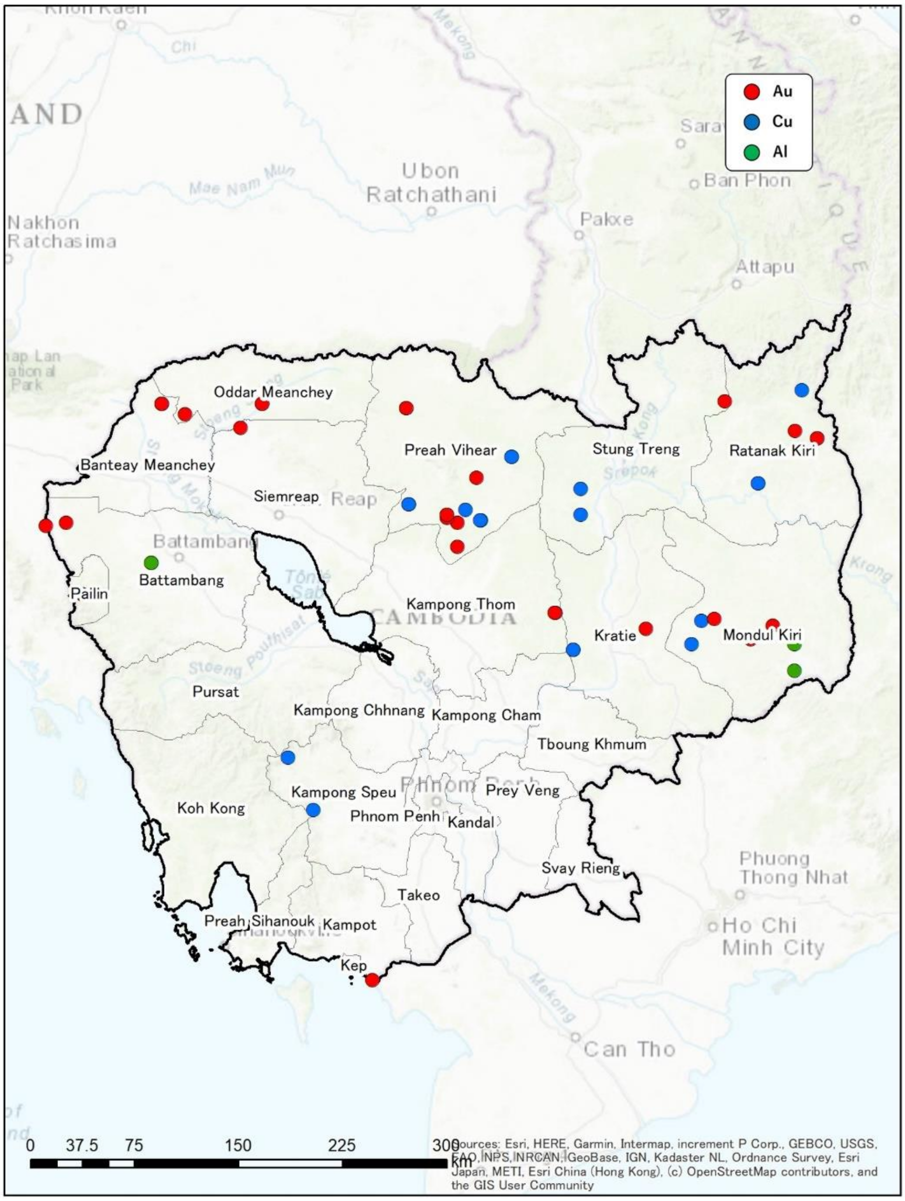


Figure 6-2 Distribution of metallic mineral resources in Cambodia (only target minerals)

Sirisokha (2019), Khin Zaw et al. (2014), and Wang et al. (2023) provide detailed explanations of the geology and mineralization of the Indochina Peninsula, including Cambodia. Based on these recent research results, the distribution of metallic mineral resources in Cambodia is reviewed here.The geology of the Indochina Peninsula consists of the South China, Indochina, and Sibumasu blocks that collided and re-aggregated from the Permian to the Triassic after separating from the Gondwana continent from the Devonian to the Permian (e.g., Ueno and Hisada, 1999). There are multiple fold belts such as Loei belt and Truongsong belt in between the blocks. Most of Cambodia's land lies in the Loei fold belt that developed to the west of the Indochina massif, surrounded by the Khorat Plateau, which corresponds to the center of the Indochina massif. surrounded by the Dalat–Kratie, Chanthaburi, and Truongson fold belts (Figure 6-3). The Loei fold belt which was formed during the Permian to Triassic period during the eastward subduction of Paleo-Tethys oceanic crust into the Indochina massif. has a high potential of metal mineral resources related to hydrothermal activity associated with magmatic activity during subduction (Figure 6-4). Specifically, calc-alkaline I-type granites (quartz diorite, granodiorite, quartz monzonite, etc.) associated with the subduction relates to porphyry-type, skarn-type, and epithermal vein-type mineralization. Along the northern extension of the Loei fold belt to Thailand, many hydrothermal deposits such as porphyry-skarn type Phu Lon deposit (Pisutha-Arnond et al., 1993), the Putep deposit (Kamvong et al., 2014), and epithermal vein type Chatree gold deposit (James and Cumming, 2007), which all are associated with calc-alkaline magmatism. Similar deposits of porphyry type, skarn type, epithermal vein type are also expected in Cambodia. In addition, since basic volcanic rocks that are thought to have been formed in the back-arc basin are also distributed in the Loei fold belt, there is a possibility that volcanic massive sulfide deposits exist (e.g., Panjasawatwong et al., 2006). Thus, the Loei Belt is one of the areas with the largest potential for metal mineral resources, although it is still undeveloped in Cambodia. On the other hand, the Dalat–Kratie fold belt, which occupies part of the southeastern part of Cambodia, is also a geological zone formed in association with the collision of crusts. Gold mineralization associated with intrusive rocks from the Jurassic to Cretaceous periods has recently been recognized within Dalat–Kratie fold belt. The Okvau Mine, which is the first gold mine in Cambodia, is also considered to be an intrusive-related gold deposit in the Dalat–Kratie fold belt. (Sirisokha, 2019; Khin Zaw et al., 2014) although it appears to be located in the Loei belt in the Figure.

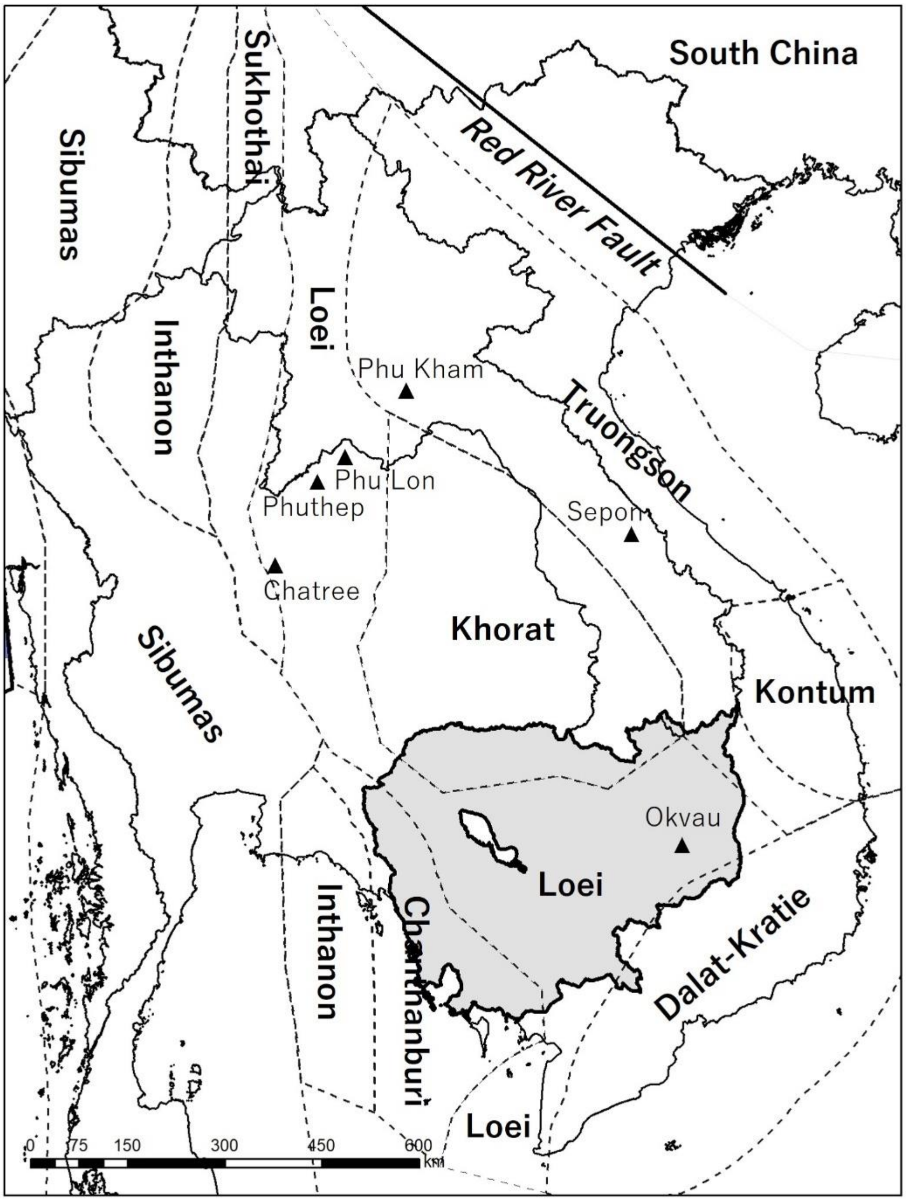


Figure 6-3 Regional tectonic map around Cambodia (Adapted from Khin Zaw et al., 2014)

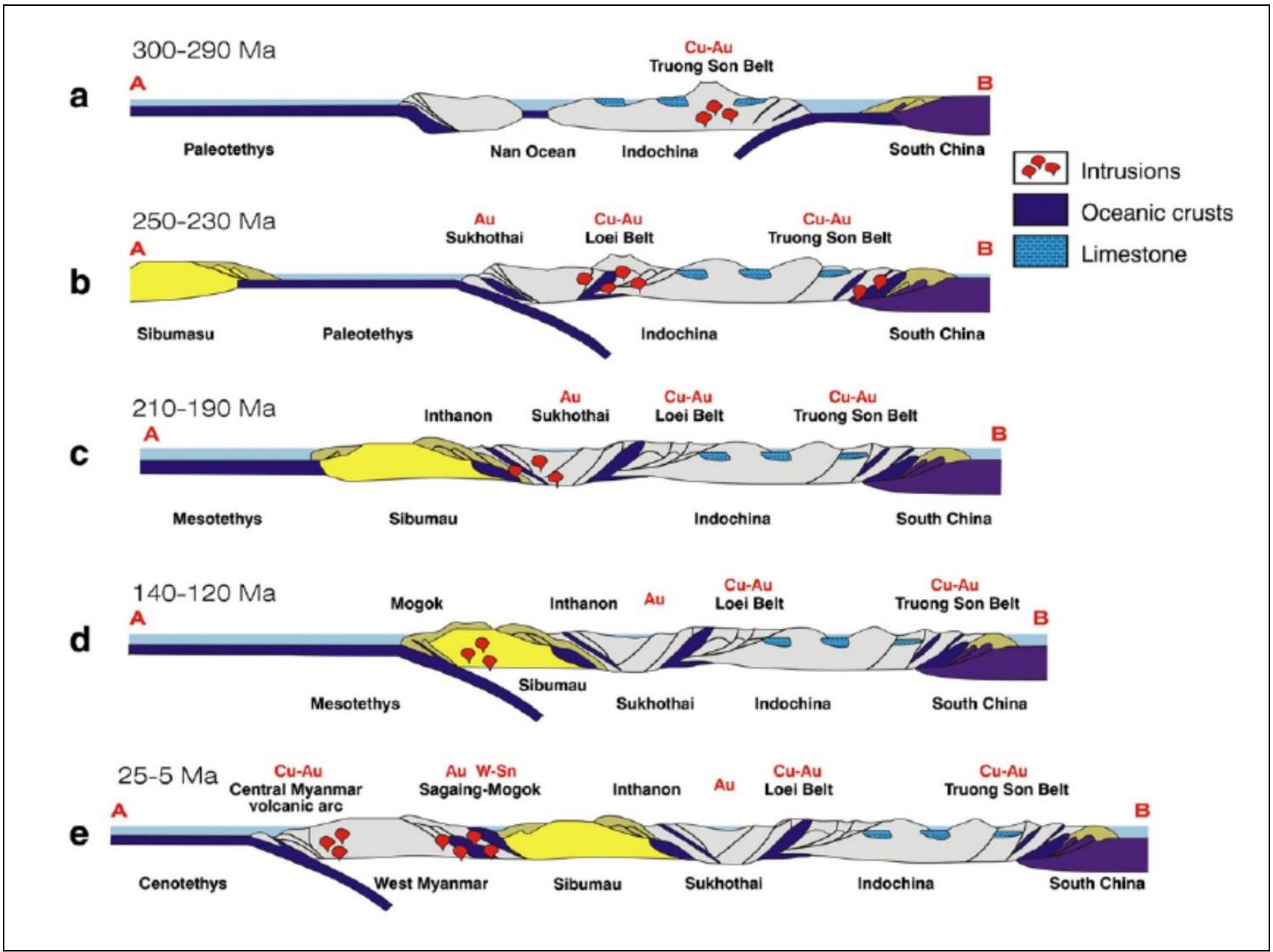


Figure 6-4 Schematic diagrams of tectonic and metallogenic evolution of SE Asia including Cambodia (Adapted from Khin Zaw et al., 2014)

6.2.2 Past surveys

Comprehensive survey for mineral resources has not been conducted in Cambodia since the ESCAP (1993) report. Meanwhile, JOGMEC was conducting geological surveys from 2014 jointly with the Ministry of Mines and Energy of the Kingdom of Cambodia. In 2018, JOGMEC discovered skarn-type and vein-type copper and zinc mineralization in Stung Treng province in the north of the country. After the discovery, JOGMEC handed their position over to Japanese private mining company Nittetsu Mining in 2019. JOGMEC also started to work with Angkor Resources Corp. for the copper, gold, and molybdenum exploration project in Oyadao south, Ratanakkiri province. Major exploration projects in Cambodia are shown in Table 6-1.

Table 6-1 Major exploration projects in Cambodia (only target minerals)

Project name	Project owner	minerals
Andong Meas	Angkor Resources Corp.	Gold, silver, molybdenum, copper
Antrong	Riversgold Ltd.	Gold
Banlung	Angkor Resources Corp.	Gold, silver, copper, molybdenum
Kang Roland South	Riversgold Ltd.	Gold
Koan Nheak	Angkor Resources Corp.	Gold
Kou Sa	Geopacific Resources Ltd. 85% Royal Group 15%	Copper, gold, zinc, silver
Kratie North	Emerald Resources NL 70% Santana Minerals Ltd. 15% Southern Gold Ltd. 15%	Gold
Kratie South	Mekong Minerals Ltd. 85% Southern Gold Ltd. 15%	Gold, copper, zinc, lead, silver
Memot	Emerald Resources NL	Gold, copper, silver, zinc, lead

6.2.3 Products of mining and industry

Active mines (only for target minerals) in Cambodia are listed in Table 6-5. Due to the long-lasting civil war and political turmoil in Cambodia, the production of non-ferrous metal mineral resources has not been in statistics until recently. Okvau gold mine started operation in June 2021 has accounted for the production of metal mineral resources for the first time in the country.

Okvau Mine (Mondulkiri Province), which is operated by Renaissance Minerals, a subsidiary of Emerald Resources NL, is the first large-scale modern open pit mine in Cambodia. It produced 108,866 ounces of gold from July 2022 to June 2023 (Table 6-2) and expects to produce 100,000 oz in 2024 as well.

Emerald Resources NL released the Definitive Feasibility Study (DFS) of Okvau deposit in May 2017 and subsequently updated in November 2019. The DFS delivered a updated maiden JORC compliant mineral resource (measured, indicated and inferred) estimate of 17,150,000 tonnes at 1.91 g/t for 1,056,000 ounces (Table 6-3) and ore reserve (proved and probable) estimate of 13,480,000 tonnes at 1.88 g/t for 816,000 ounces (Table 6-4).

Table 6-2 Okvau production and costs (Adapted from Emerald Resources NL, 2023)

Operating Physicals for the Quarter		**Sep 22**	**Dec 22**	**Mar 23**	**Jun 23**
Ore mined	'000 BCM	213	220	261	**277**
Waste mined	'000 BCM	1,207	1,215	1,146	**1,175**
Stripping ratio	w:o	5.65	5.51	4.39	**4.24**
Ore mined	'000 t	692	528	911	**888**
Ore milled	'000 t	446	532	515	**511**
Head grade milled	g/t	2.03	2.14	2.16	**2.13**
Recovery	%	80%	80%	80%	**78%**
Gold production	**oz**	**23,217**	**29,640**	**28,764**	**27,245**
Mining	$m	13.5	13.6	13.2	**13.4**
Milling	$m	8.5	9.2	9.3	**8.6**
Administration	$m	1.4	1.7	1.6	**1.7**
Change in inventory	$m	(6.8)	(4.6)	(4.6)	**(5.4)**
Total Cash Costs	**$m**	**16.6**	**19.9**	**19.5**	**18.3**
Royalties	$m	1.8	2.4	2.5	**2.5**
Refining and by-product	$m	0.1	0.1	0.1	**0.1**
Rehabilitation	$m	-	0.5	-	**-**
Sustaining capital	$m	-	0.4	0.3	**0.1**
Corporate overheads	$m	0.6	0.3	0.4	**0.5**
All-in sustaining costs	**$m**	**19.1**	**23.6**	**22.8**	**21.5**
All-in sustaining costs	US$/oz	824	795	793	**789**

Table 6-3 Okvau mineral resource estimate (Adapted from Emerald Resources NL, 2023)

Okvau March 2022 Mineral Resource Estimate											
Measured Resources(i)			**Indicated Resources(ii)**			**Inferred Resources(ii)**			**Total Resources**		
Tonnage (Mt)	Grade (g/t Au)	Contained Au (Koz)	Tonnage (Mt)	Grade (g/t Au)	Contained Au (Koz)	Tonnage (Mt)	Grade (g/t Au)	Contained Au (Koz)	Tonnage (Mt)	Grade (g/t Au)	Contained Au (Koz)
1.67	0.94	51	12.93	2.10	872	2.55	1.62	133	**17.15**	**1.91**	**1,056**

(i) Oxide stockpiles are reported at > 0.4g/t Au, Fresh stockpiles are reported at >0.5g/t Au
(ii) Mineral Resource is reported at >0.7g/t Au

Table 6-4 Okvau ore reserve estimate (Adapted from Emerald Resources NL, 2023)

Okvau March 2022 Ore Reserve Estimate	Tonnage (Mt)	Grade (g/t Au)	Contained Au (Koz)
Proven Ore Reserve	1.67Mt	0.94g/t Au	51koz
Probable Ore Reserve	11.80Mt	2.02g/t Au	765koz
Total Ore Reserve	**13.48Mt**	**1.88g/t Au**	**816koz**

Starting with the opening of the Okvau mine, several locations in Cambodia have started or are planning to start gold production. In the northeastern state of Ratanakkiri, Mesco Gold, a subsidiary of Indian steel company Mesco Steel, owns the Phum Syarung mine. Tthe construction for production is progressing although the start of production, originally scheduled for 2020, has been delayed due to the impact of the pandemic. In the province of Preah Vihear, Delcom Campuchea started a trial operation in August 2022, producing around 20kg of gold. It is planned to produce approximately 340kg of gold per year and is expected to generate annual royalties of $600,000. In the southern Kratie province, Xing Yuan Kanng Yeak reportedly started gold production in the Sambor area from October 2022.

Table 6-5 Active mines in Cambodia (only target minerals)

Mine site	Mine owner	minerals	production
Okvau	Emerald Resources NL (Renaissance Minerals)	Gold	108,866 oz (July 2022 to June 2023)
Phum Syarung	Mesco Gold	Gold	Unknown
-	Delcom Campuchea	Gold	20kg (August 2022)
-	Xing Yuan Kanng Yeak	Gold	8kg or more (October 2022)

6.2.4 Metal prices of the world

Gold: Gold price remained low at US$500/oz for nearly 20 years from the 1980s to the 1990s. However, in the 2000s, there was an upward trend due to geopolitical risks such as the September 11 terrorist attacks and the Iraq War. After that, the price rose further due to the development of the pandemic and the Russia-Ukraine war, and in 2020, the price exceeded US$ 2,000 / oz for the first time in history. Since then, the price has remained high at around US$ 2,000 / oz, although there have been some fluctuations.

Copper: Prices remained low at US$2,000/t until 2003, but reached around US$3,000/t in 2004, then exceeded US$5,000/t. Prices temporarily reached around US$10,000/t in 2011, and are currently around US$8,000/t. Prices basically fluctuate according to the demand situation in China, the largest importer, and the operating conditions in Chile, Peru, and other countries that are the largest producers.

Aluminum: Aluminum price generally remained within US$1,800/t until the 1990s, but since the mid-2000s they have often exceeded US$2,000/t. The production of aluminum requires a large amount of electricity, and the electricity cost burden is the heaviest among non-ferrous metals. Therefore, a sharp rise in the price of energy such as natural gas is likely to lead to concerns about the supply of aluminum. In addition, prices have increased significantly in recent years due to the Russia-Ukraine war, and in March 2022, they exceeded US$4,000/t for the first time in history.

6.3 Mineral resources potential of target minerals

Although many of Cambodia’s metal mineral resources are undeveloped, Khin Zaw et al. (2014) and Wang et al. (2023) reported metal mineral resource potential of Cambodia comprehensively as well as Japanese journals such as Sudo et al. (1996) and JICA (2008). Here, we will discuss the potential of Cambodia's gold, copper, and bauxite mineral resources.

6.3.1 Gold (Au)

The distribution of gold (Au) mineral resources (mines, mineral occurrences, etc.) in Cambodia is shown in Figure 6-5. In addition to the known mineral distribution, the potential area of gold (Au) mineral resources considering the geology and geological structure is shown in Figure 6-6.

The primary gold deposits in Cambodia consisted primarily of those formed during the Pre-Carboniferous period prior to the Indochinese orogeny, and those formed with intrusive rocks of the Mesozoic Era. There are also secondary alluvial deposits. Mineralization in the Pre-Carboniferous period is limited in exposure, but small-scale gold mineralization are recognized in the area of granite, crystalline schist, and gneiss in Ratanakiri province (Kontum massif distribution area) in the northeast, Pailin province in the west, and Kampot province in the southwest, mostly accompanied by placer gold. In addition to the recently discovered Phum Syarung deposit, Ratanakiri province also has a JV exploration project for copper, gold and molybdenum being pursued by JOGMEC with Canadian junior Angkor Gold. Intrusive rocks from the Jurassic to Cretaceous periods are found in this area, and hydrothermal alteration zones are widely distributed around it, so the potential for porphyry-type mineralization is expected. On the other hand, the Mesozoic mineralization is widespread from Oddar Meanchey province in the northwest (Thailand border) to Preah Vihear in the north (Thai-Laos border), but most of them are small-scale at present. Most of them are reticulated quartz veins, mostly accompanied by some alluvial deposits nearby. Quartz veins near Rovieng are accompanied by bismuth and tellurium minerals. In the eastern province of Mondulkiri, Okvau Mine started gold production for the first time in Cambodia in June 2021. The Okvau Mine is considered to be an intrusive-related gold deposit in the Dalat–Kratie fold belt. (Sirisokha, 2019; Khin Zaw et al., 2014) although it appears to be located in the Loei belt in the Figure.

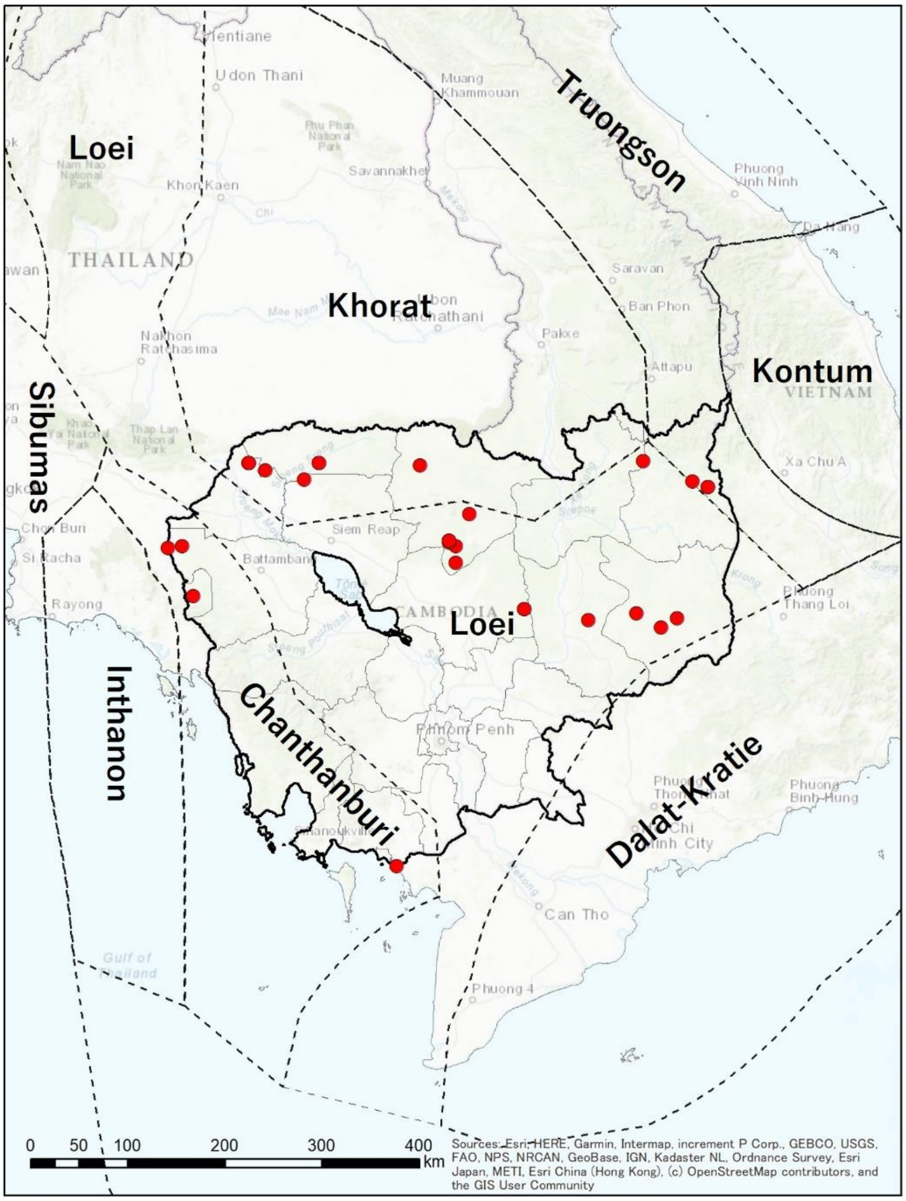


Figure 6-5 Distribution of gold (Au) mineral resources in Cambodia

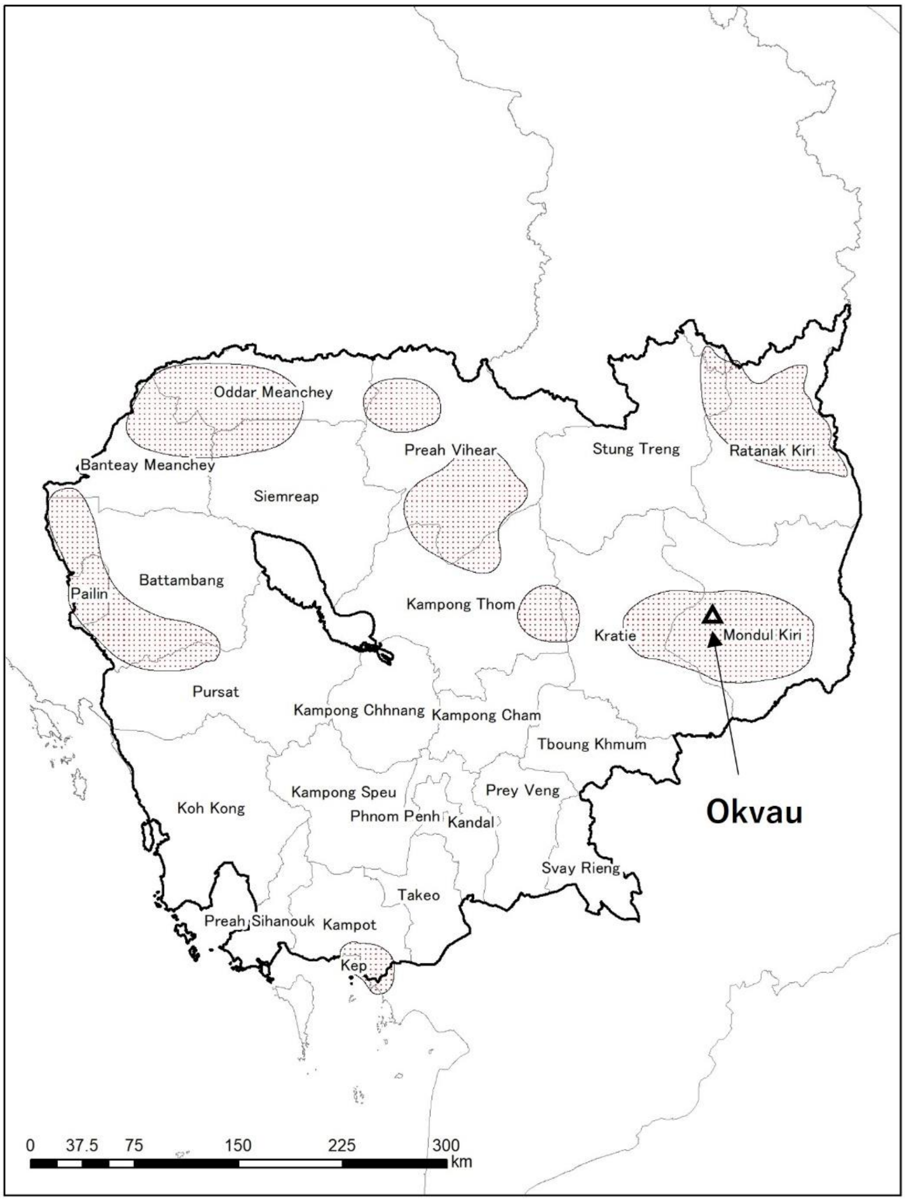


Figure 6-6 Potential area of gold (Au) mineral resources in Cambodia

6.3.2 Copper (Cu)

The distribution of copper (Cu) mineral resources (mines, mineral occurrences, etc.) in Cambodia is shown in Figure 6-7. In addition to the known mineral distribution, the potential area of copper (Cu) mineral resources considering the geology and geological structure is shown in Figure 6-8.

Copper in Cambodia is mostly distributed in the northern province of Preah Vihear (the border between Thailand and Laos), and most of them are skarn-type deposits. In the Rovieng-Chhep district of the province, small amounts of malachite are recognized in schist and sandstone with Triassic marble at Pnom Ke and Phnom Sekahm, indicating skarnization caused by granite intrusion. In the southwest of the country, the Cu-Pb-Zn mineral occurrences such as chalcopyrite have been recognized near the Knong Ay granite in Knong Ay in Kompong Speu province. For example, chalcopyrite-sphalerite-galena veins are recognized at Daun Penh, and chalcopyrite dissemination are found in diorite veins west of Kdam Ngoeut (JICA, 2008). At Sam Rong, also in Kompong Speu province, copper-bearing lead-zinc vein-type mineralization is known on the hills of Kchol massif., which is Jurassic to Cretaceous granitic rocks that intruded into Triassic sandstone (JICA, 2008). In addition, Cambodia has potential for porphyry copper deposits. For example, the Pnom Basset granite in Kandal Province, about 20 km northwest of Phnom Penh, contains molybdenum, which is characteristic of porphyry copper deposits. Moreover, around Rovieng in Preah Vihear province, there are sedimentary or metasomatic magnetite and hematite mineralization, as well as copper oxide and alluvial gold occurrences, indicating that Iron Oxide Copper-Gold Deposit (IOCG deposit) might also be another potential in Cambodia.

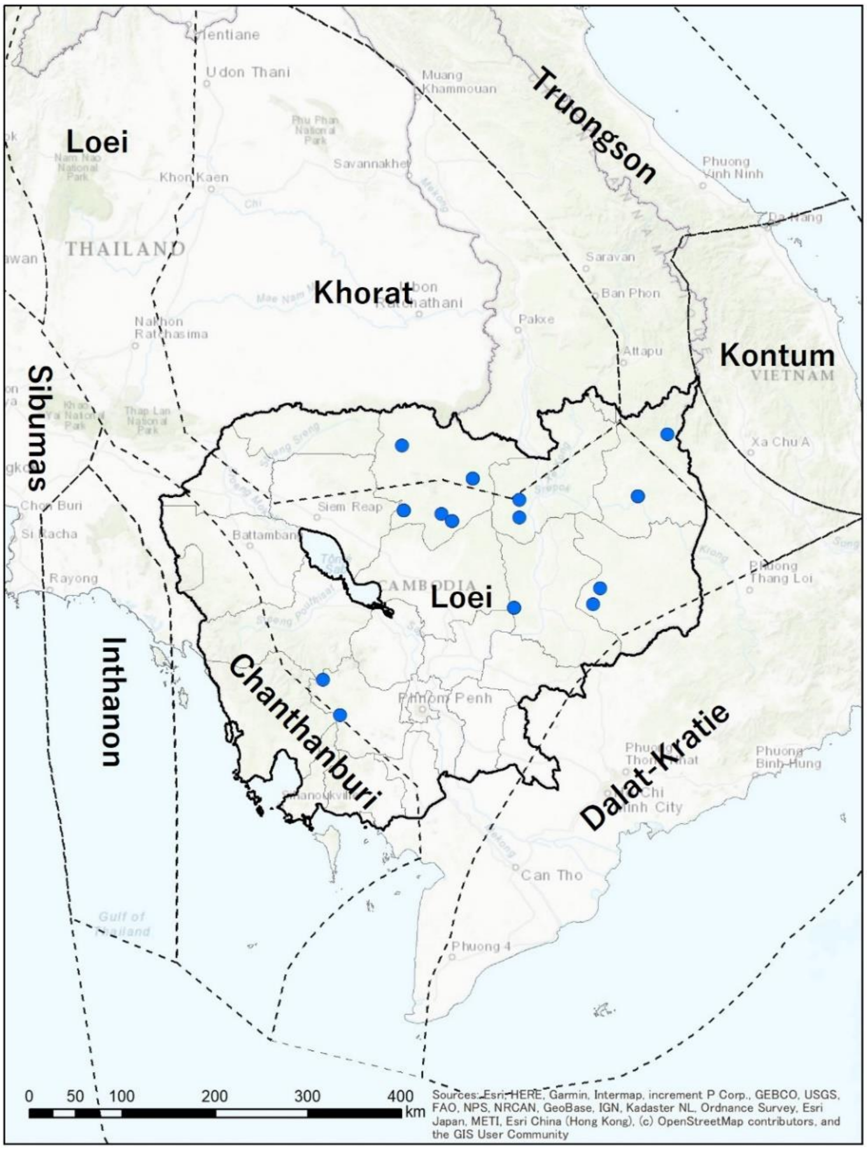


Figure 6-7 Distribution of copper (Cu) mineral resources in Cambodia

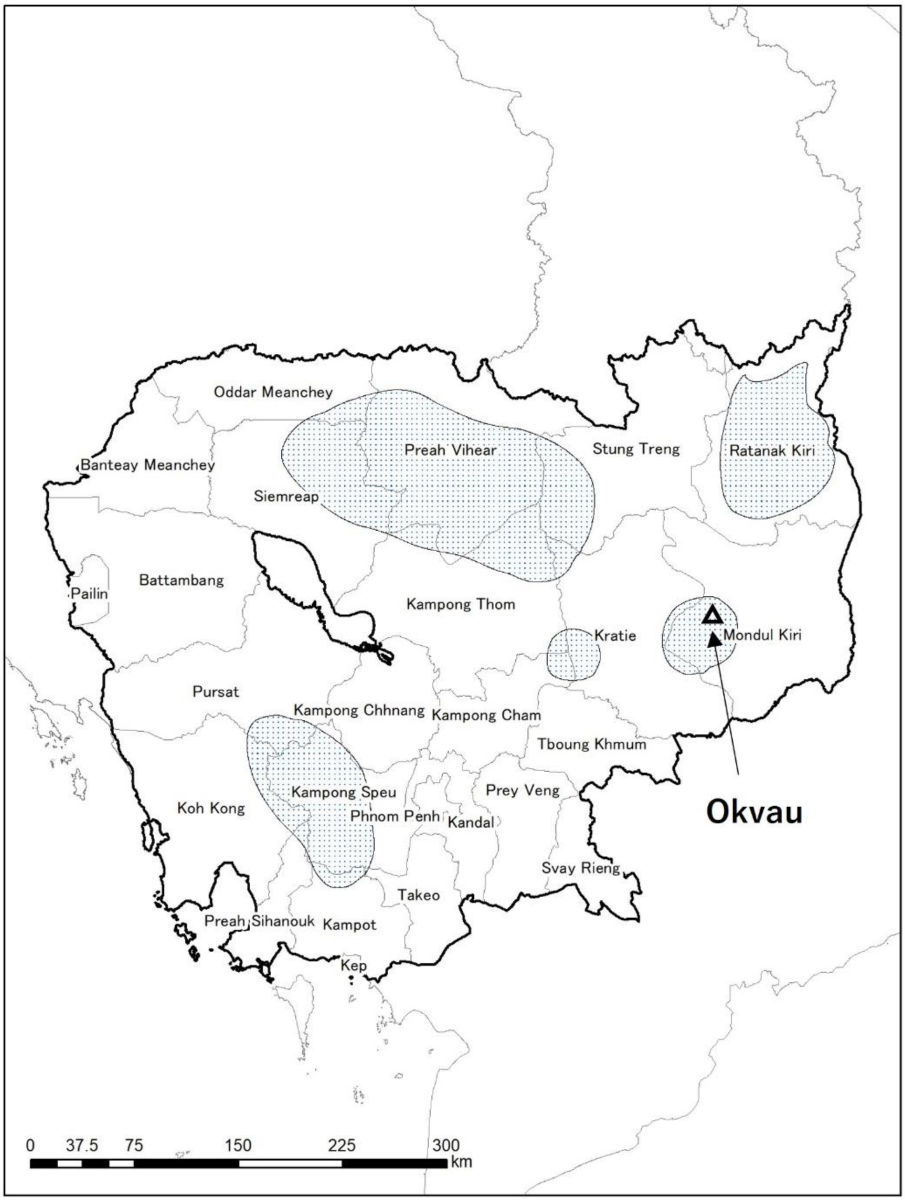


Figure 6-8 Potential area of copper (Cu) mineral resources in Cambodia

6.3.3 Bauxite (Al)

The distribution of bauxite (Al) mineral resources (mines, mineral occurrences, etc.) in Cambodia is shown in Figure 6-9. In addition to the known mineral distribution, the potential area of bauxite (Al) mineral resources considering the geology and geological structure is shown in Figure 6-10.

Bauxite in Cambodia is basically formed by weathering of late Neogene to Quaternary basalt, and is distributed in Battambang province in the west and Mondulkiri province in the east. In general, bauxite in Battambang is of high grade but small scale, while bauxite in Mondulkiri is of low grade (Al_2O_3 40-50%), making development difficult. Mitsubishi Corporation conducted bauxite exploration in Mondulkiri province jointly with BHP Billiton in 2006, but withdrew in 2009, and Vietnamese companies have also conducted exploration since 2011.

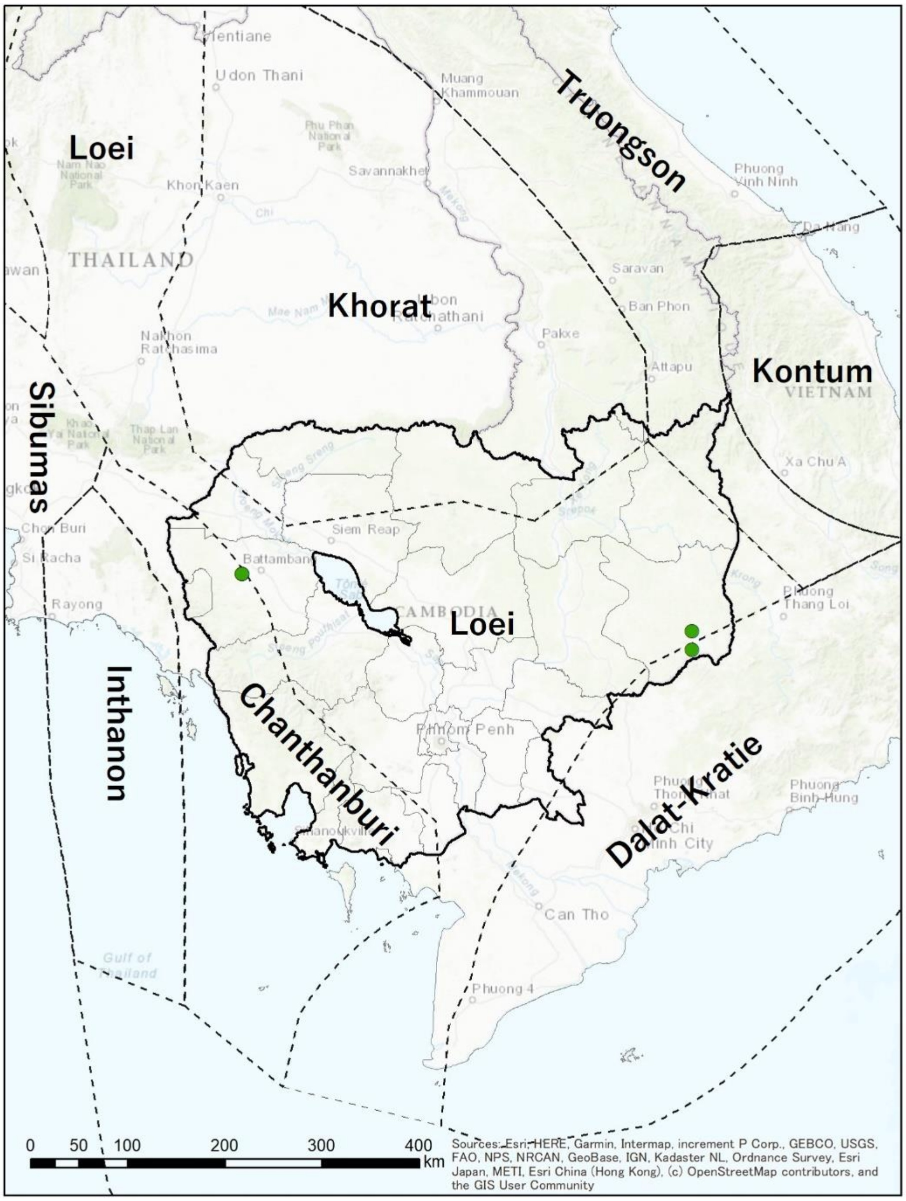


Figure 6-9 Distribution of bauxite (Al) mineral resources in Cambodia

Figure 6-10 Potential area of bauxite (Al) mineral resources in Cambodia

6.4 Mining administration

6.4.1 Mining policy

At national level, to promote sustainable mining practices to achieve the policy vision of “Wealth for All”, the government has adopted the Sub-Decree No.72 on Management of Exploration and Industrial Mining Licenses and the Circular No.360 on Granting Mineral Exploration License on October 07, both in 2016. The framework outlines the Ministry’s sector vision “Wealth for All” in transforming mining, oil, and gas sector into an important pillar of the country’s socio-economic development.in Cambodia. This vision encompasses three key strategic objectives: fiscal, economic, and social.

Furthermore, the national policy was developed in tandem with the ASEAN Minerals Cooperation Action Plan (AMCAP) 2016-2025 to ensure the sustainable development of the mining sector and achieve ASEAN Economic Integration as planned by 2025.
Mining activities are allowed relatively freely, and many companies, including foreign companies, are engaged in exploration activities, particularly for gold. According to the Ministry of Mining and Energy, royalty income earned from mining operators in 2020 was US$21m, up 5% from the previous year. According to Yos Monirath, director of the Mining Department of the Ministry of Mining and Energy, royalty revenues increased relatively modestly, but all mining operators continue to be active in the sector. As of May 2021, the ministry had issued operating licenses to more than 100 mining operators and 40 exploration projects (JOGMEC, 2022)

6.4.2 Law and regulation related to mining

The Law on Management and Exploitation of Mineral Resources and all related activities relating to the mining operation was promulgated on 13 July 2001 by the Royal Government of Cambodia, to attract domestic and foreign mining companies to invest in mineral exploration and mining in Cambodia. The Law allows Cambodian people and natural persons or legal entities to apply for the following 6 categories of mineral license:

1. Artisanal mining license
2. Pits and quarries mining license
3. Gem Mining license
4. Mineral [Gemstone] Transforming license
5. Mineral exploration license
6. Industrial mining license

Sub-decrees were issued by the Cambodian Government to manage mineral resource exploration licenses and industrial mining licenses:
-The Sub-Decree No 8 dated 31 January 2005 and Sub-Decree No113 dated 29 September 2005 stipulate the determination of investment principles on all types of mineral resources. Under sub-decree No.72, only finished products (manufactured or processed in plants build in Cambodia) can be allowed for export.
-The Regulation, dated 25 May 2004 define the detailed procedures to apply for Registration and Mineral Licenses, Renewal and Transfer Right of mineral license.
For a large-scale project of special national significance, the Minister in charge of mineral resource determines shall enter negotiations with the applicant reach a supplementary Mineral Investment Agreement to be appended to the license.

6.4.3 National budget mining sector

(1) Financial Obligations

A special tax regime shall be established for application to the output and revenue gained from the 6 (six) categories of the mining licenses as provided in Article 31 of the Law on Mineral Resource Management and Exploitation.

The Prakas No.453 determines the regulations on taxes, the rate on mineral operations. This Prakash stipulated the tax on profit at a rate of 30% of taxable profit generated from petroleum or mineral resources after deduction of all expenses permitted by the legislation.

The rates and payment procedures of royalties for each type of mines is defined according to the inter-ministerial Prakas No.284 amended by the Inter-ministerial Prakas No. 760.

(2) Use of the Tax and royalties

The Inter-ministerial Prakas specifies that 40% of the royalties allocated to the central government, 40% to the sub-national (provinces, districts, municipalities, communes and sangkats) and 10% to the withholding income.

(3) The excess profit

The excess profit ratio would be the ratio of accumulated gross income to accumulated operating expense up to the current year. The method of calculation of the excess profit ratio, excess profit and tax on excess profit, together with the rules and procedures for controlling the collection of exploitation of petroleum and mineral resources will be determined by a Prakas issued by the Ministry of Economy and Finance operations.

An excess profit tax would be imposed at progressive rates as is shown in the table below.

Excess profit ratio	Tax rate
1.3 or less	0%
More than 1.3 to 1.6	10%
More than 1.6 to 2	20%
More than 2	30%

The minimum tax would not apply.

(4) Non-tax revenue

The sub-decree No. 72 ensures the collection of non-tax revenue. “Non-tax revenue” refers to recurring income obtained by the ministry through sources other than taxes such as licensing fees, land leases, royalties and penalties, according to Yos Monirath, the ministry’s former director-general for Mineral Resources.

6.4.4 Management system of mining sector

Except for oil and petroleum, most extractive industries are regulated by the Ministry of Mines and Energy (MME), formerly the Ministry of Industry, Mines and Energy, or MIME. MME is mainly in charge of the mining administration, licensing, managing, and inspecting mining operations, and ensuring that the mining law provisions are respected.

The Royal Decree No.Chor.Sor/Ror.Kor.Tor/0198/020, dated 22nd January 1998 gives authority to the Cambodian National Petroleum Authority (CNPA) under the Ministry of Mines and Energy manages the petroleum resources, to manage the exploration for and development and production of petroleum and gas. The sub-Decree 72 dated May 05, 2016 provides the management and procedures, formalities and conditions related to the issuance of exploration licenses and industrial mining licenses. Rights and obligations of licensees are also regulated by Sub-Decree 72.

The Regulation on Registration and Procedures for Applying for Mineral Licenses, Renewal and Transfer Right dated 25 May 2004, issued by the Ministry of Industry, Mines and Energy issued, stipulates the following procedure:

- A director/shareholder must come to complete a registration form in person at the Ministry of Commerce. And then, he /she has to come to complete a registration in person at the MIME.
- Application for Memorandum of Understanding (MOU) on Geological Survey to the MIME.
- If the technical reports are approved, he/she required to sign Mineral Agreement with the MIME to be responsible for conducting mineral operations.
- Exploration license is issued under the condition of Mineral Agreement. Mining license can be applied for any time during exploration period.
- Mining proposal shall be submitted to CDC through MIME for approval.
- If it was approved, he/she shall make and submit EIA report to MOE for approval
- Mining license is issued, provided that his/her mining proposal and EIA report were approved accordingly.

Model of Mineral Agreement – some keys terms of mineral agreement are as follows:

1. Period of Exploration – is 6 years.
2. Period of Mining - could be 30 years. It may extend 2 times for a period of 5 years each time upon his/her request is approved.
3. Conditions to Issue and Renew Mineral Licenses Exploration License – is valid for 2 years. At the end of the 6th year of the exploration period, an additional limited period is approved where he/she need it to finalize his/her feasibility study of mineral deposit or to proceed to apply for mining license. Mining License – is valid for 5 year and shall be renewed up under the conditions of agreement.
4. Work Obligations of Concessionaire - Conducting mineral operation by using modern techniques with accountability and environmental consideration.
5. Financial Obligations – registration, mineral licenses, annual land rentals, royalties, other charges and taxes.
6. Valuation of Finished Products - by both parties, based on international market price.

7. Export and Sale of Finished Products - Apply for other licenses to concerned ministries/ institutions.
8. Right to Employ Immigrant Aliens – to the extent that qualified Cambodian nationals cannot be found to fill the positions required. Foreign employees hired longer than 6 months shall pay tax on salary.
9. Obligations to Employ and Train Cambodian Nationals – in order for them to participate in Mineral Operations.
10. Restoration and Safety Measures - After the permanent shutdown of Mineral Operations, the mined areas shall be restored reasonably under the accepted mining practices.
11. Restricted Sites - Conducting Mineral Operations in the perimeter of archeological, patrimonial and historical properties, burial places, railway, public roads, ponds, and land reserved for other public purposes are prohibited.
12. Settlement of Disputes - shall be made under the laws of Cambodia.
13. Suspension and Revocation of Mineral License – are subject to violation of the provisions of the Law.
14. Termination of Mineral Agreement - Where mineral license was revoked, the Agreement shall be terminated.

6.4.5 Issues

Various laws, policies and regulatory frameworks have been developed in mining industry, however there are still some recurrent issues occur in mining activities. The following issues are gathered from the reviewed literatures.

(1) Administration

- Leaking information: A possible malpractice scenario relates to the preliminary assessment done by Ministry of Mine and Energy (MME) official. The company could influence DMEM staffs to release insider information or result of preliminary assessment, so they have a comparative time advantage to prepare for mineral exploration application. This risk compromises the level playing field, impacting fairness and competitiveness and application process.
- No confidentiality: There are no guidelines and operational protocols to ensure that the information of preliminary assessment remains confidential under the current mining regulatory framework.
- Criteria for selecting applicant will not be public knowable: If the evaluation criteria, including technical and financial credentials for selecting applicant are not clear, it creates opportunities for manipulation and interference in the evaluation process. No evaluation criteria for evaluation company’s capacities and work program are evident in the current regulatory framework and no official evaluation guideline have been developed.
- Lack of institutional capacity and a lack of education courses covering this industry in Cambodia

(2) Land Rights:

Uncertainty or poor understanding of surface rights by the local communities creates incentives and opportunities for poor governance, leading to potential issues of forced access and illegal land-grabbing.

(3) Public Consultation and Land Loss

Lack of an exhaustive public consultation process prior to the start of mining operations and the forced sale of land to make way for the mine, which had triggered several protests around the time that exploration started.

(4) Social and Environmental Impacts

Natural water sources (called “chrobs” in many indigenous languages) contamination (e.g. at the Peak villagers). The mining company is currently constructing a waste pit located around 200 meters from the O’Trer stream, and villages are concerned runoff from the pit will further degrade the quality of the water from the stream.

(5) Infrastructure Improvement

The mining company did not materialize their promise on infrastructure development support of the local: bridge, wells for every household, water reservoir.

6.5 Environment administration

6.5.1 Environment policy

Facing the challenges between rapid economic growth in contrast with the social cost, loss and degradation of the environmental and natural resources, the Royal Government of Cambodia committed to ensure the balance between the development and conservation.

To address the challenges of natural resources and the environment degradation and to respond the impacts of climate change as well as to benefit from the opportunities of green growth, the Royal Government of Cambodia has been formulating two documents: the Environment and Natural Resources Code of the Kingdom of Cambodia and the National Environment Strategy and Action Plan (NESAP) 2016-2023. Both documents are a strategic response to the needs for modernizing the management and governance of the environment and natural resources.

The Environmental Code strengthens, modernizes, and generally bolsters the management of environmental protection through the conservation and restoration of natural resources, biodiversity, and ecosystems.

The National Environment Strategy and Action Plan 2016–2023 (NESAP) is a political agenda and a roadmap adopted to sustain and consolidate the efforts for the development, protection and conservation of the environment and natural resources

The vision of NESAP is: “To strengthen enabling conditions and leverage for the environment and natural resources management and conservation for sustained and stable socioeconomic growth in Cambodia (NESAP p.26). This roadmap reinforces cross-sectoral coordination for mainstreaming environment and natural resources sustainability and strengthen and scale up inter-ministerial collaboration modalities for promoting sustainable and multi-uses of Natural resources and Environment (NRE).

The formulation of NESAP is developed in pursuant to Article 59 of the Constitution of the Kingdom of Cambodia, the Law on Environmental Protection and Natural Resource Management and in line with the Royal Government of Cambodia's key development policies and strategic plans. Activities outlined in the NESAP will help Cambodia to achieve its sustainable development goals and strengthen cooperation between ministries, institutions and stakeholders who are responsible for sustainable development goals given that environment is a cross-cutting issue.

NESAP 2016-2023 is aligned to Rectangular Strategy Phase III (RS Phase III), that reaffirms the Royal Government of Cambodia (RGC)'s mission and commitment to sustainable development and poverty reduction responding to the people's will and changing contexts of national and international developments.

NESAP 2016-2023 identifies and promotes implementation of activities designed for supporting, advising, and advancing sustainability measures, and supporting the core objective of SDGs by strengthening institutional and organizational capacity along the principles of good environmental governance and rule of law, sustainable financing mechanism, and promotion of green economy.

6.5.2 Law and regulation related to environment protection

Cambodia has taken measures to address and prevent the loss of the natural resources and ecological balance that would compromise the country's ability in achieving sustainable development and livelihoods for the people.

At global scale, Cambodia has ratified international conventions related to environment including:

-Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) – 1997

-Measures on prevention of climate change, ozone depletion, on freshwater resource protection and on sustainable forest ASEAN – 1999

- International Conventions and Agreements Kyoto Protocol ratified – 2002

-ASEAN Heritage Convention (National Parks: Bokor and Virakchey) (regional) – 2003

According to the sub-decree No.72, all projects must go through an Initial Environmental Impact Assessment (IEIA) to determine whether an EIA is required. The Ministry of Environment (MOE) issued the Sub-Decree No.72 (1999) and Prakas No. 021 (2020) on Environmental Impact Assessment Process and Classification of Environmental Impact Assessment for Development Project, respectively. On 20 November 2014, the Ministry of Economy and Finance (MEF) and the Ministry of Environment (MOE) jointly issued the Joint-Prakas No. 1428 on public service fees.

The goal of this Prakas is the classification of environmental impact assessments for development projects which are required to have environmental protection contracts or initial environmental impact assessments (IEIA) or full environmental impact assessments (EIA)

The Law on Environmental Protection and Resource Management is supported by various governmental regulations including, inter alia, the Sub-Decree on Environmental Impact Assessment the Sub-Decree on Water Pollution Control, the Sub-Decree on Solid Waste Management and the Sub-Decree on Control of Air and Noise Disturbance.

On September 2009, the Government of Cambodia enacted a Prakas or declaration No.376 BRK.BST on general guidelines for developing initial Environmental Impact Assessments (IEIA) and full Environmental Impact Assessment (EIA) reports.

On 29 June 2023, the King approved Environment and Natural Resources Code. The code is based on the main principles: legal documents in the field of environment and natural resources are integrated, harmonized, and modernized in response to the evolving trends of society. The code, as with all Cambodian law, will need to comply with the Constitution, which includes a requirement for environmental protection.

The Ministry of Environment (MoE) is the ministry with overall responsibility for environmental governance. As the environment is a cross-sectoral issue, other 16 governmental bodies and institutions are directly engaged including the Ministry of Ministry of Water Resources and Meteorology (MOWRAM), Ministry of Agriculture, Forestry and Fisheries (MAFF), and the Council for the Development of Cambodia (CDC).

6.5.3 National park

The 1993 Royal Decree on the Protection of Natural Areas, administered by the Ministry of Environment, recognized 23 protected areas in four categories:

- Natural parks,
- Wildlife preserves,
- Protected scenic view areas, and
- Multi-purpose areas.

At the time, these covered more than 18% of the country's total land area. Cambodia's Resource Governance Index 'poor' grade of 30 out of 100 points in 2017 placed it 79th out of 89 countries and 14th out of 15 countries in the Asia/Pacific. The score, for its early-stage gold mining, reflected poor ratings for national budgeting and licenses in particular.

Natural parks (or National parks) are defined as areas reserved for nature and scenic views, protected for scientific, educational and entertainment purposes. Below is the list of the 07 Natural parks in Cambodia:

- Kirirom (Kampong Speu and Koh Kong) 35,000 hectares
- Bokor (Kampot) 140,000 hectares
- Kep (Kampot) originally 5,000 hectares, later amended to 1,152 hectares
- Ream (Kampong Som) 150,000 hectares
- Botum Sakor (Koh Kong) 171,250 hectares
- Phnom Koulen (Siem Reap) 37,500 hectares
- Virachey (Stung Treng and Ratanik Kiri) 332,500 hectares

The national parks and wildlife sanctuaries comply with category II and IV of IUCN's classification system. The protected landscapes and multiple use areas conform to category V and VI of the IUCN's classification system respectively.

In 2008, the Royal Government of Cambodia (RGC) adopted the Law on Protected Areas introducing and defining a new zoning system to manage the protected areas in Cambodia. The objectives of this law are to ensure the management, conservation of biodiversity, and sustainable use of natural resources in protected areas. This law is under the jurisdiction of the Ministry of Environment.

6.5.4 Environmental survey related to mineral resources development

The Prakas No.021 aims to facilitate and guide private and public development project owners in implementing the EIA process efficiently. Based on the nature and/or scale of the project this Prakas classifies the EIA for development projects as follows:

- For the projects having small impact to the environment and society as mentioned in the Annex to the Prakas, the project owners are required to prepare the Environmental Protection Agreement together with the Environmental Management and Monitoring Plan.
- For the projects having medium impact to the environment and society as mentioned in the Annex to the Prakas, the project owner is required to prepare the Initial Environmental and Social Impact Assessment (IESIA) report.
- For the projects having serious impact to the environment and society as mentioned in the Annex to the Prakas, the project owner is required to prepare the full Environmental Impact and Social Assessment (ESIA) report.

This Prakas is applied to all proposals of development projects including existing and ongoing projects of private individuals or private companies, joint-venture companies, public companies, or government ministries/agencies.

6.5.5 Issues

(1) Administration

- Lack of efficiency in managing mineral resources and in collecting revenue
- The development activities that impact the environment and the local communities.
- Limited access to Environmental Impact Assessment (EIA) reports online is one of the biggest challenges for the public in providing comments on EIA reports and ensuring meaningful consultation.
- The review of the strategic documents, plans, and programs show that some of adopted cross-cutting or sector strategies and action plans have limited success in their implementation and follow-ups. This is mainly due to the limitation in financial, technical and management capacity; over-crowded but unrealistic or unattainable priorities being identified; and lack of effective coordination and collaboration. In some cases, the lead ministries or institutions for cross-cutting strategies are often relatively “weaker” in terms budget allocation and capacity for ensuring consistent follow-up, compliance, enforcement, coordination, monitoring and evaluation.
- The incorporation of natural resources and environment sustainability in sectoral planning and programming, especially in sub-national planning and programming is still limited.

(2) Onsite:

- Unauthorized mining activities

6.6 Satellite image analysis

6.6.1 Mining area

The location of the survey area (described above in section 2.2.1) and the three mining areas are shown in Figure 6-11. The background is a Sentinel-2 true color image, with the red box representing the satellite image analysis area and the blue box representing the mining area. The target ore types in Cambodia are gold, copper, and bauxite, but only gold is actually being mined.

Three mining areas (Okvau gold mine, Late Cheng gold mine and Delcom gold mine) and two ASGM sites (Okvau and Phnum Proek) were analyzed.

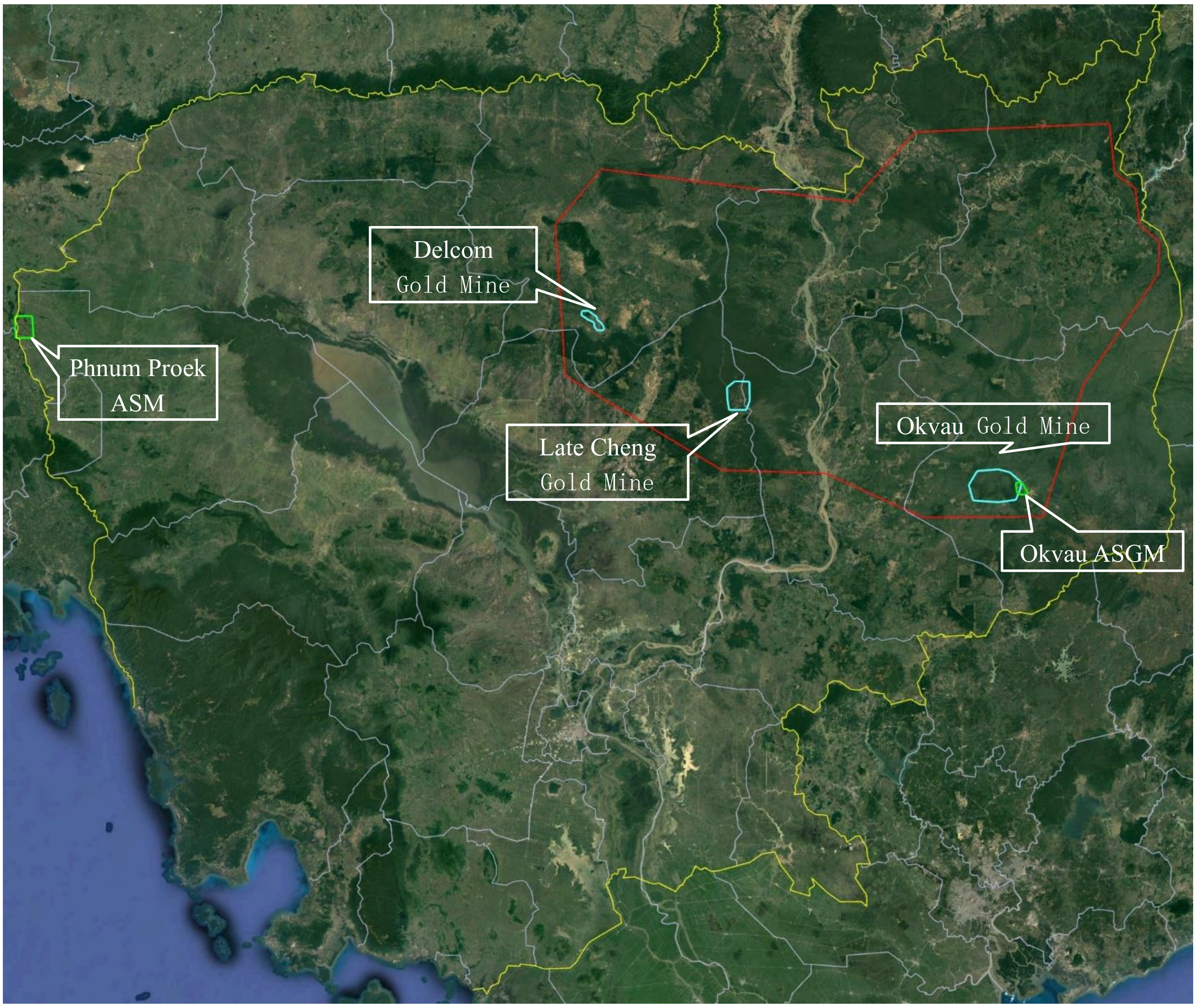


Figure 6-11 Mining areas in Cambodia

6.6.2 Time series change

(1) Okvau gold mine

A time series of Sentinel-2 true color images of Okvau gold mine for each year from 2018 to 2023 are shown in Figure 6-12. Okvau mine is the first private mining company to commercially mine gold in Cambodia and began gold production in 2022.

Exploration activities are taking place in the current opencut section in 2018, with pit excavation beginning in 2020. It is observed that mine development has begun in 2021, with a tailings dam being constructed in 2022.

(2) Late Cheng gold mine

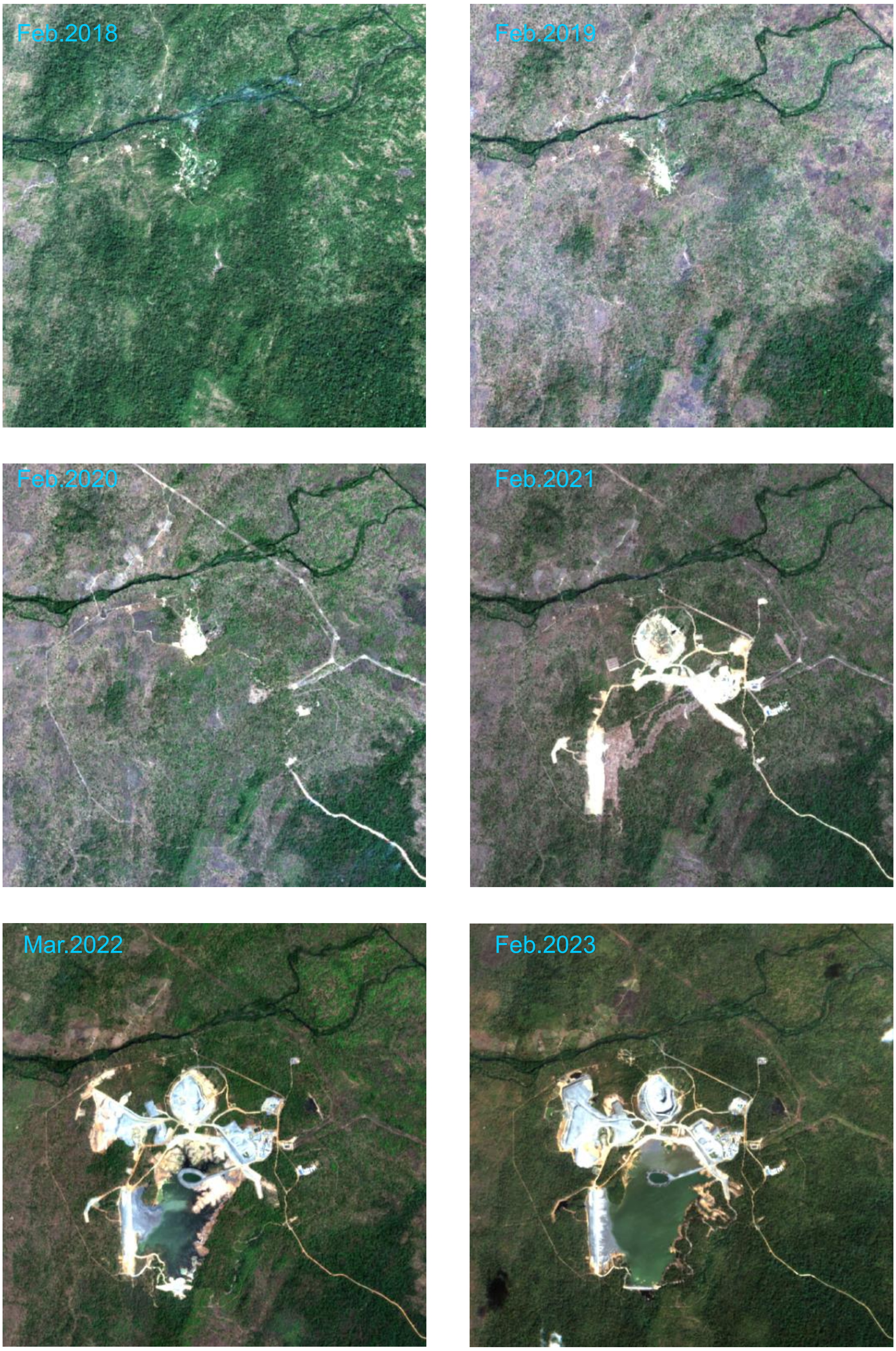
Sentinel-2 true color images of Late Cheng gold mine for each year from 2018 to 2023 are shown in time series in Figure 6-13. Late Cheng mine received a mining license in 2022. Pilot gold production was planned for 2023.

It is observed that exploration activities were in full swing by 2021 and mine development has begun by 2022. It is assumed that exploration for satellite deposits has begun by 2022. On the other hand, the area is in a wildlife reserve and legal issues have been raised against mining development.

(3) Delcom gold mine

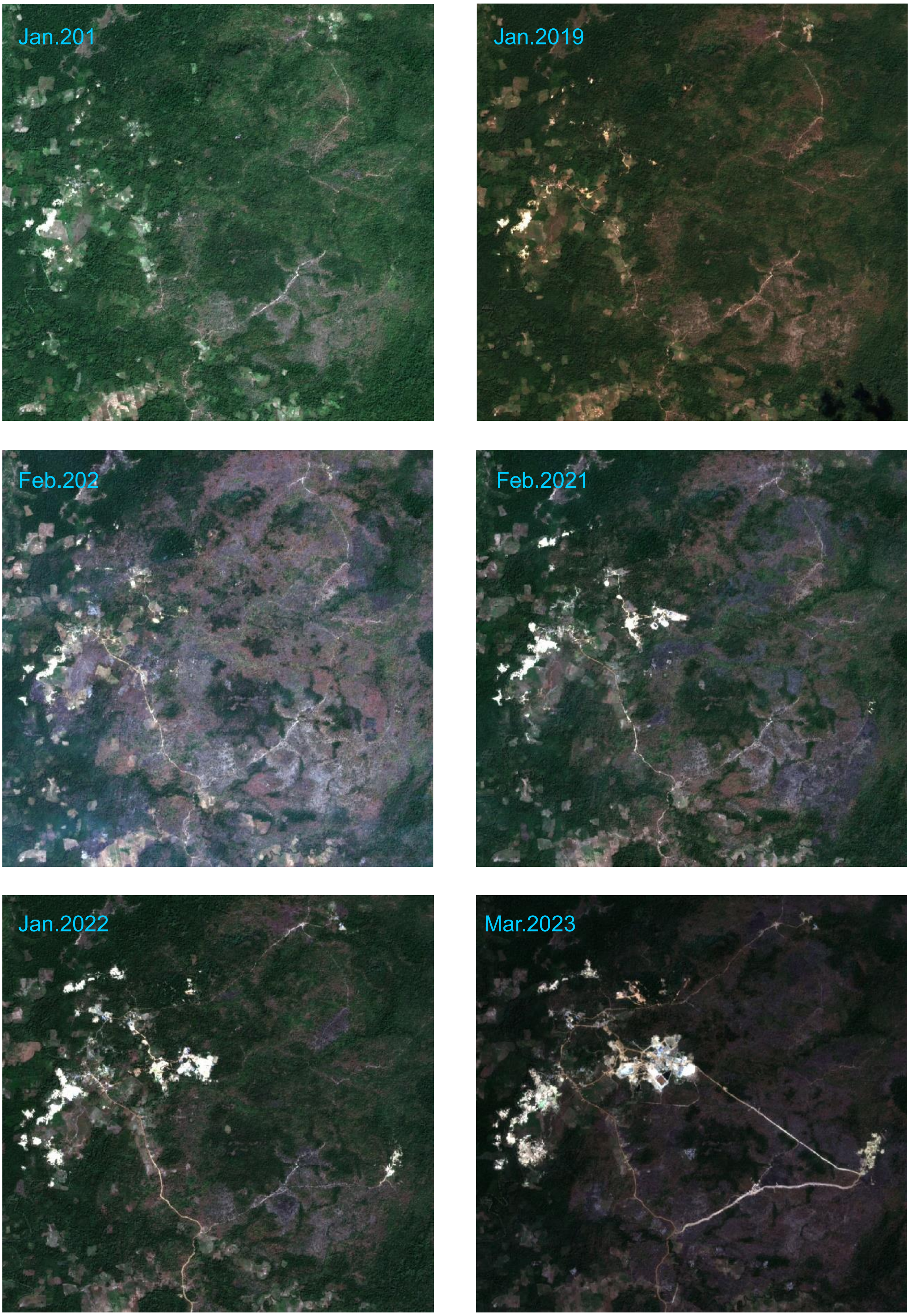
Sentinel-2 true color images of the Delcom gold mine for each year from 2017 to 2023 in time series are shown in Figure 6-14. The Delcom mine began pilot gold production in 2022.

It is observed that some mining activity occurred prior to 2017. It is unclear whether these are operations of the said mine or ASM activities, but according to the time series images after 2017, it is recognized that the location of operations has moved over the years.



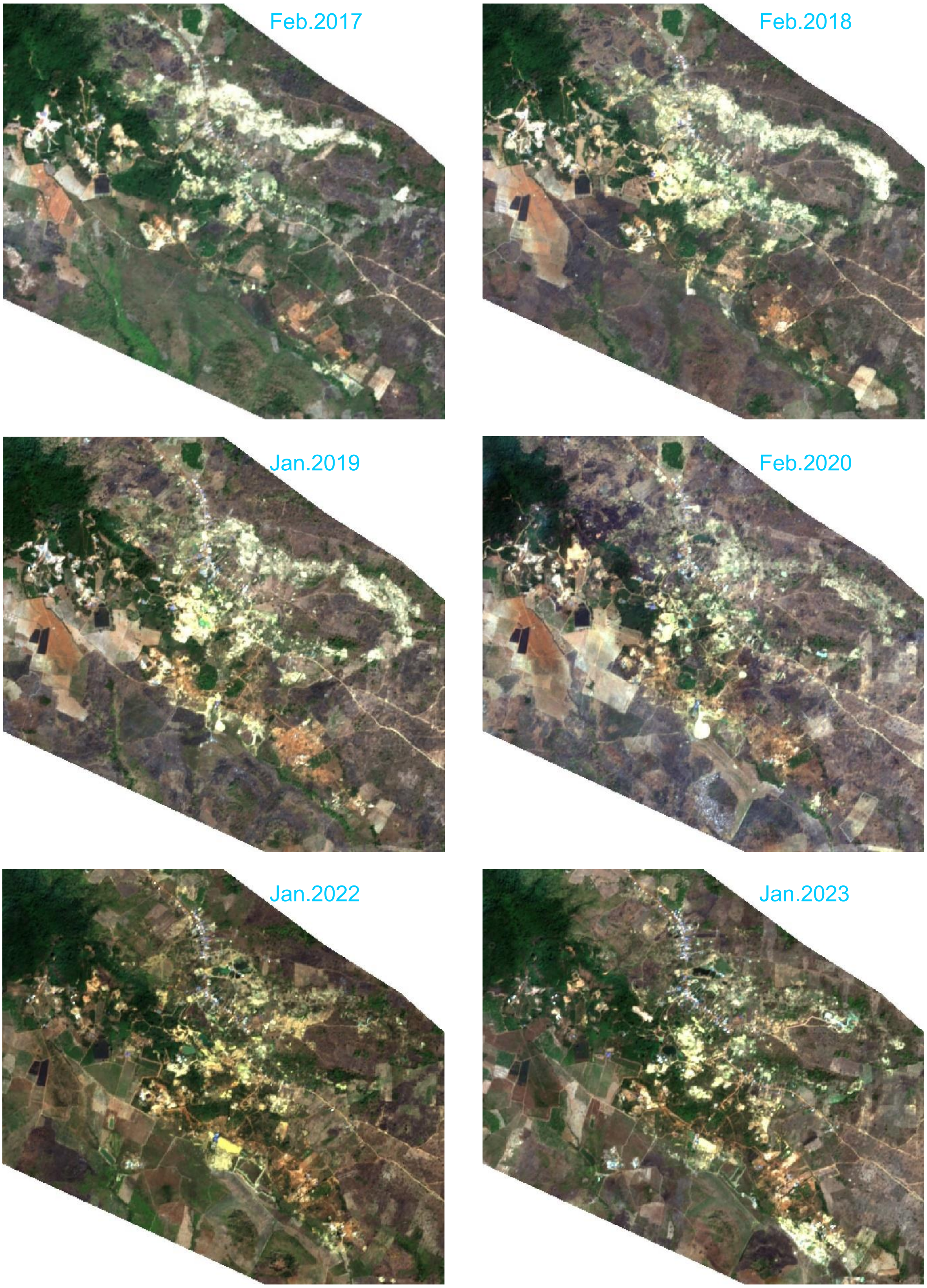
Note: The annuals are newer from top left to right, middle left to right, and bottom left to right, in that order.

Figure 6-12 True color images of Okvau mining area from 2018 to 2023



Note: The annuals are newer from top left to right, middle left to right, and bottom left to right, in that order.

Figure 6-13 True color images of Late Cheng mining area from 2018 to 2023



Note: The annuals are newer from top left to right, middle left to right, and bottom left to right, in that order.

Figure 6-14 True color images of Delcom mining area from 2017 to 2023

(4) Okvau ASGM

Sentinel-2 true color images of Okvau ASGM site for 2018, 2019, 2021 and 2023 are shown side by side in Figure 6-15. During information gathering at MME during the first field survey, it was confirmed that gold ASM operations were being conducted in this area, so new satellite data was obtained and analyzed. Currently, MME has issued an order of prohibition of operations and no operations are taking place in the area.

In the Sentinel-2 image, it is difficult to identify the location of ASM operations in this area. Google image barely shows ASM operations, but the area of operation is small and recognized to be a fairly small-scale mining operation. In fact, comparing the time-series Sentinel-2 images, not much change was observed. It is assumed that the mining site is located along a river, but it is almost impossible to distinguish it from cultivated or bare land.

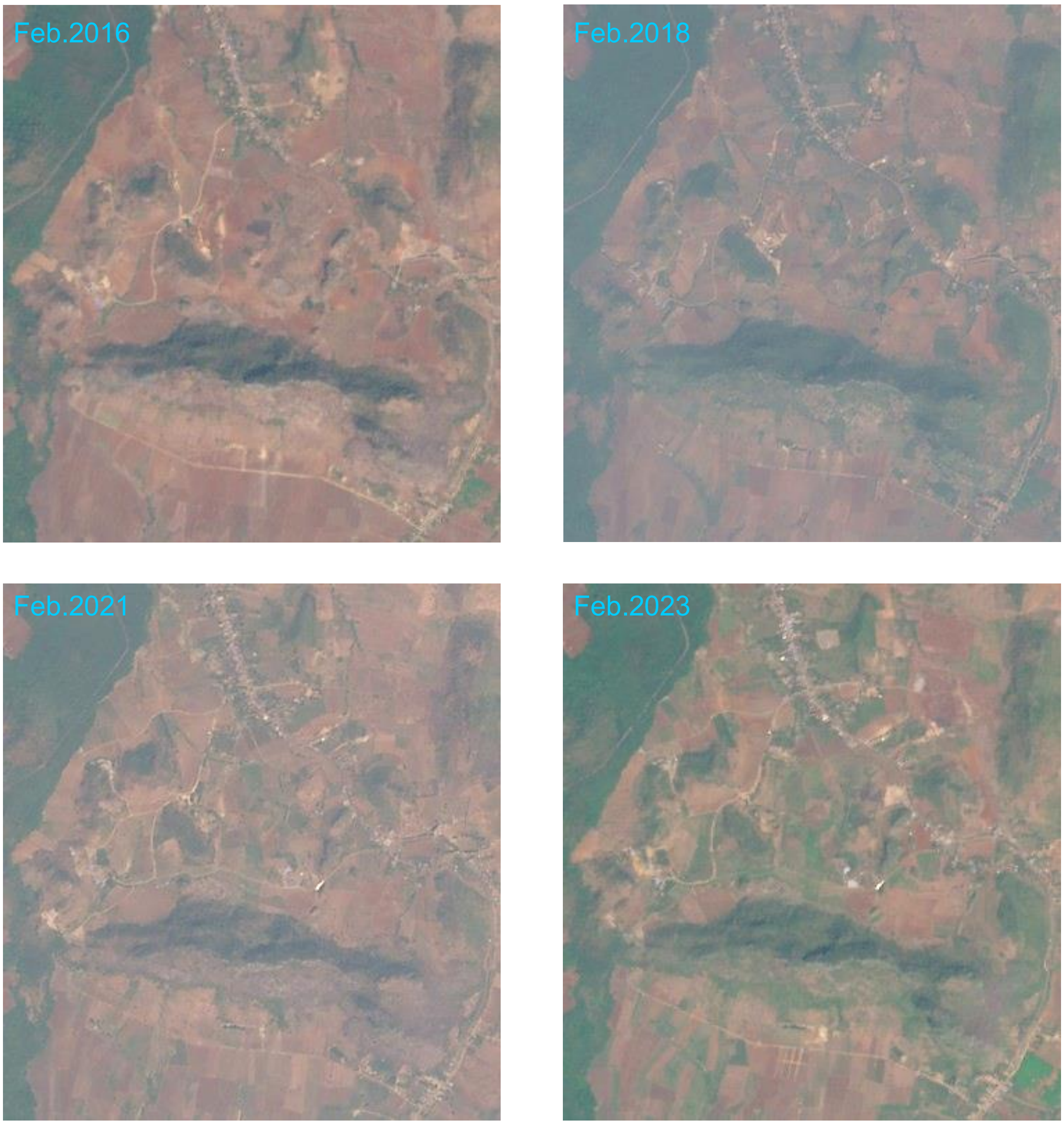
Note: The annuals are newer from top left to right, middle left to right, and bottom left to right, in that order.

Figure 6-15 True color images of Okvau ASGM area from 2018 to 2023

(5) Phnum Proek ASM

There are few existing documents and information on ASM in Cambodia, and very little information describing the detailed location of ASM sites. Based on the data that a gold ASM site exists around this area, we carefully checked Google images and, for analysis, selected a location that looked like it. However, when we reported the results of our analysis of this area during the second field survey, we were told that it was probably a quarry ASM, not a gold ASM. As a result, this case study shows how difficult it is to extract and confirm ASMs by satellite image.

Sentinel-2 true color images of the Phnum Proek ASM site for 2016, 2018, 2021 and 2023 are shown side-by-side in Figure 6-16. It is difficult to determine if these images represent ASM operations, although it is possible to see that the areas of soil exposure have changed in the time series images.



Note: The annuals are newer from top left to right, middle left to right, and bottom left to right, in that order.

Figure 6-16 True color images of Phnum Proek area from 2018 to 2023

6.6.3 Analysis result

(1) Okvau gold mine

Figure 6-17 shows a time series changes in the mining area of Okvau gold mine. In this figure, the operating area for each year from 2016 to 2023 in Figure 6-12 is deciphered and drawn in GIS, with the polygon for the most recent year, 2023, at the bottom, and the polygons for the older years in turn overlaid with different coloring.

The Okavu gold mine is a new mine that began operations in 2021 and currently has only one opencut pit. It is deciphered that initial exploration was conducted around 2017, mine development began around 2019, pit opening began in 2020, and development progressed all at once in 2021.

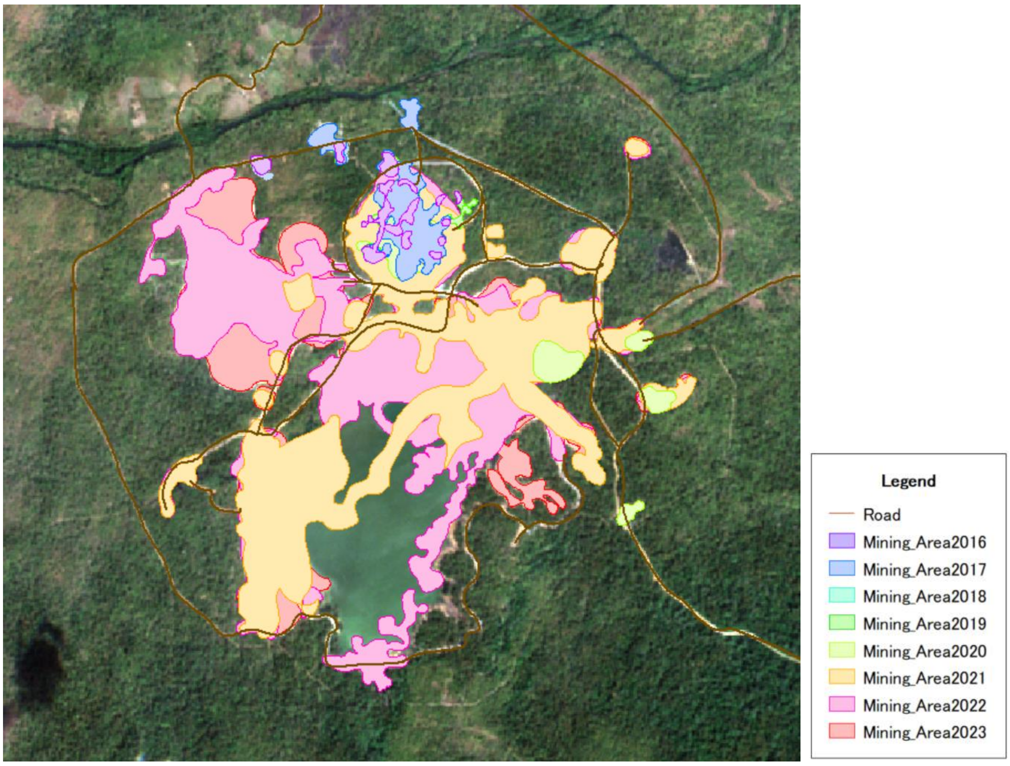


Figure 6-17 Time series changes of Okvau Mining Area

At Okvau mine, the mining site, plant, and other associated facilities are all in one location. A Sentinel-2 image in 2023 is shown in Figure 6-18. In this image, opencut pit, waist rock deposition site, plant, mine building, tailings dam, tailings disposal area, and road under the power line are legible. From the image of time series change (Figure 6-12), it can be recognized that the construction of these mine facilities began in 2021.

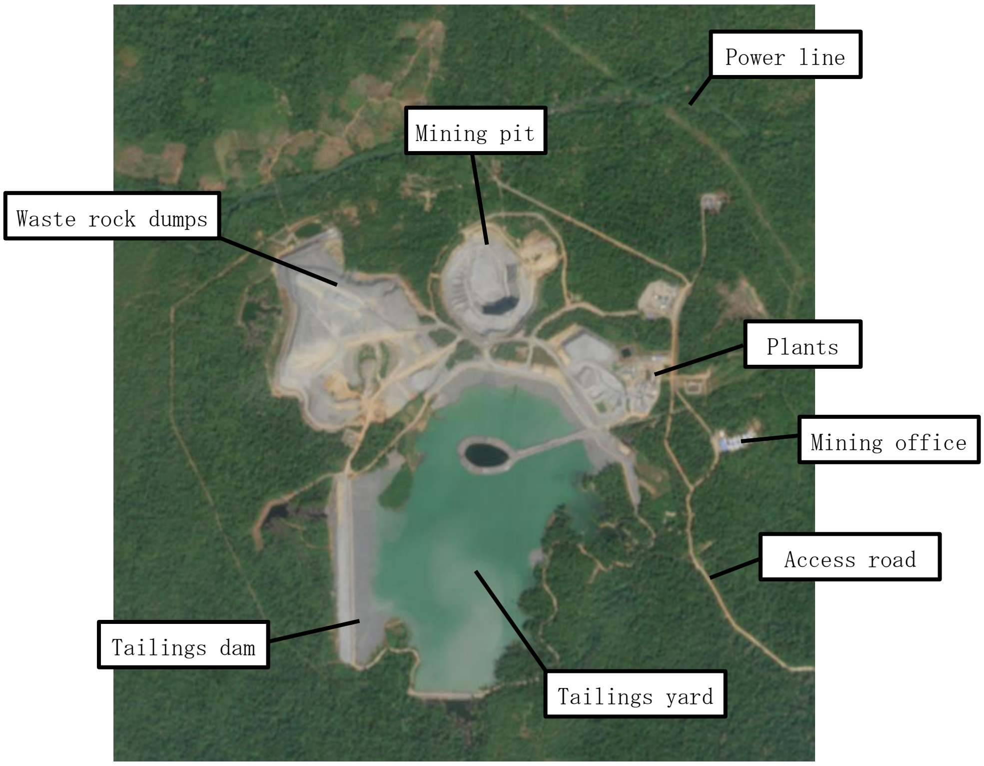


Figure 6-18 Decipherment of Okvau mine facilities

(2) Late Cheng gold mine

Figure 6-19 shows time series changes in the mining area of Late Cheng gold mine. In this figure, the operating area for each year from 2016 to 2023 in Figure 6-13 is deciphered and drawn in GIS, with the polygon for the most recent year, 2023, at the bottom, and the polygons for the older years overlaid with different colors.

Late Cheng gold mine is a new mine that received its mining license in 2022. It can be deciphered that the mine development started in 2021 and the extent of development has been expanded up to the present. A portion of the mine is inferred to be an exploration area for satellite deposits.

In the main operation site of Late Cheng mine, opencut mining pits, waste rock deposition site, tailings dams, plant, and other related facilities are all located together in one area. In addition to this main operation site, surface mining areas, satellite deposit sites, and tailings dams are distributed in the surrounding area. The locations of these sites are shown in Figure 6-20, Figure 6-21, and Figure 6-22, which are Sentinel-2 images taken on December 16, 2023. From these images, can be deciphered opencut pits, waste rock deposition sites, plant, mine building, tailings dam, tailings disposal sites, surface mining sites, and communication roads. At the satellite site, what appears to be a runway is recognized.

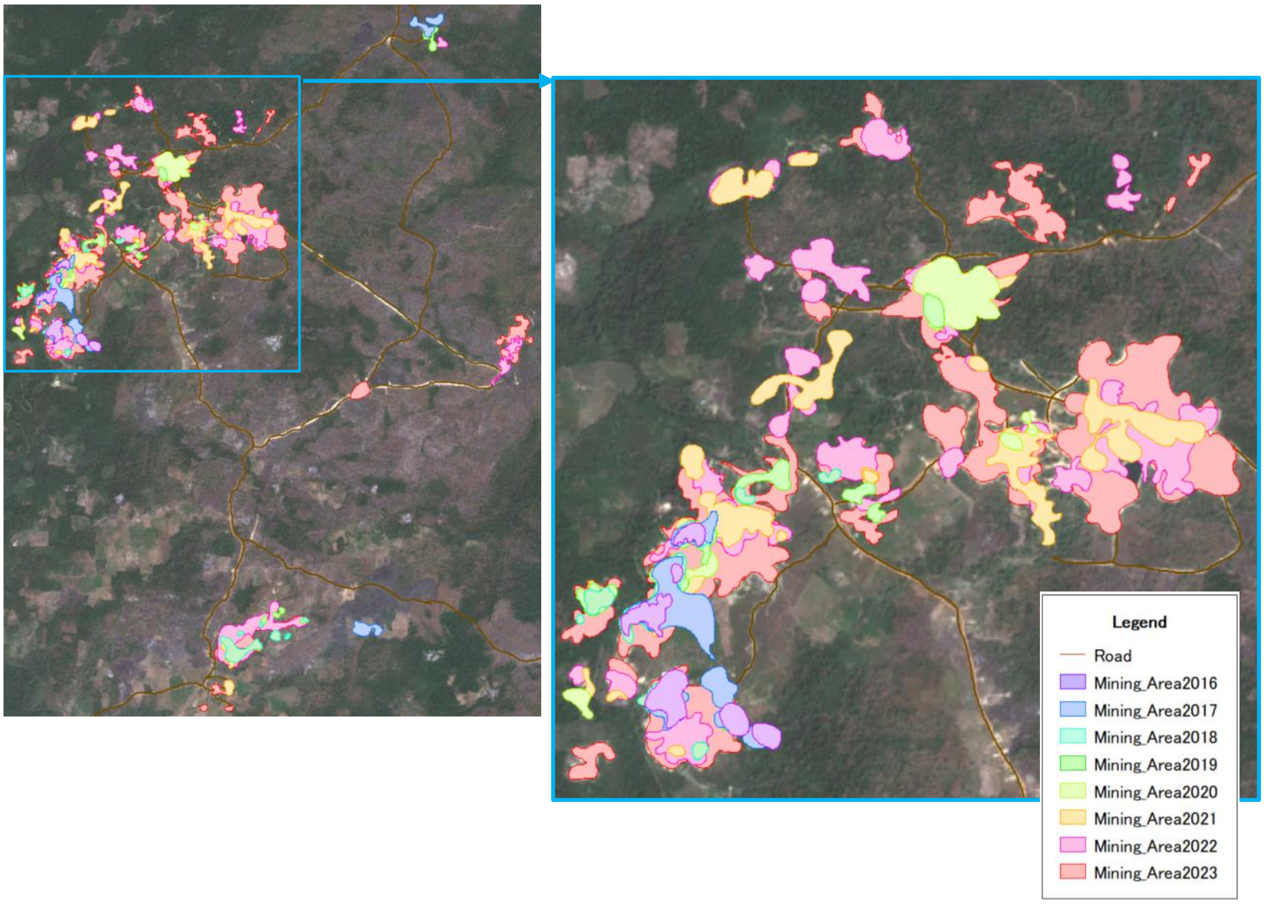


Figure 6-19 Time series changes of Late Cheng mining area

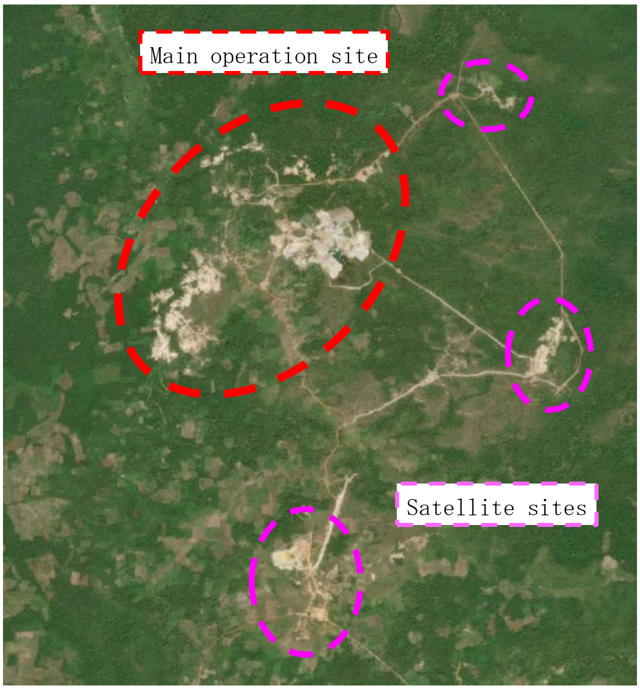


Figure 6-20 Late Cheng mining area

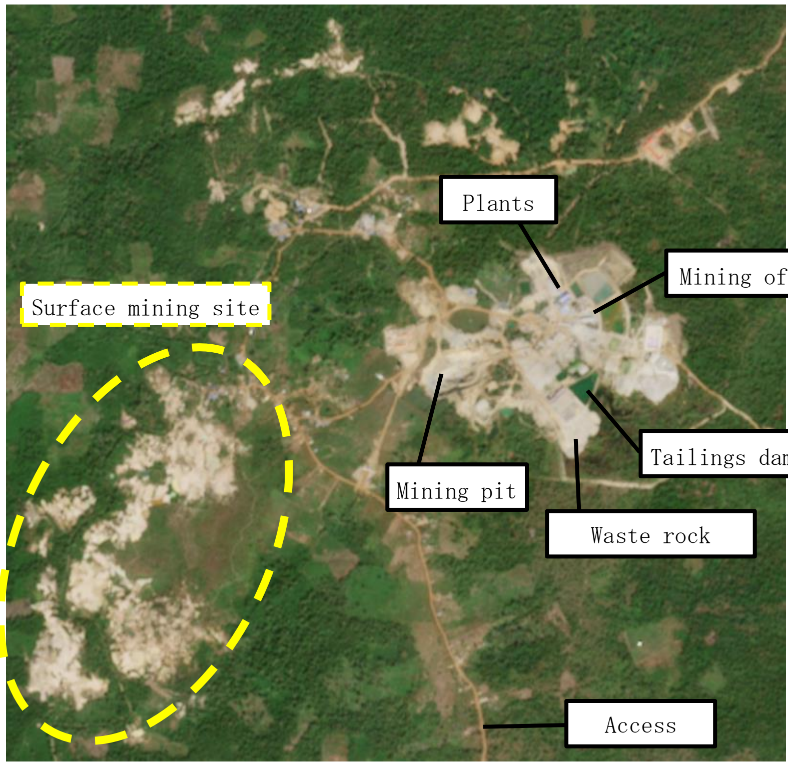


Figure 6-21 Decipherment of Late Cheng mine facilities

Left image： south site of Figure 6-20 、Right-upper image：north site of Figure 6-20、Right-lower image：east site of Figure 6-20

Figure 6-22 Satellite sites of Late Cheng mine

(3) Delcom gold mine

Figure 6-23 shows time series changes in the mining area of the Delcom mine. In this figure, the operating area for each year from 2016 to 2023 in Figure 6-14 is deciphered and drawn in GIS, with the polygon for the most recent year, 2023, at the bottom, and the polygons for the older years in turn overlaid with different colors.

Delcom mine is a new mine that began pilot gold production in 2022. Mining activity (surface alteration) is discernible prior to 2016. After 2016, it is discernable that the location of the operation has moved over the years.

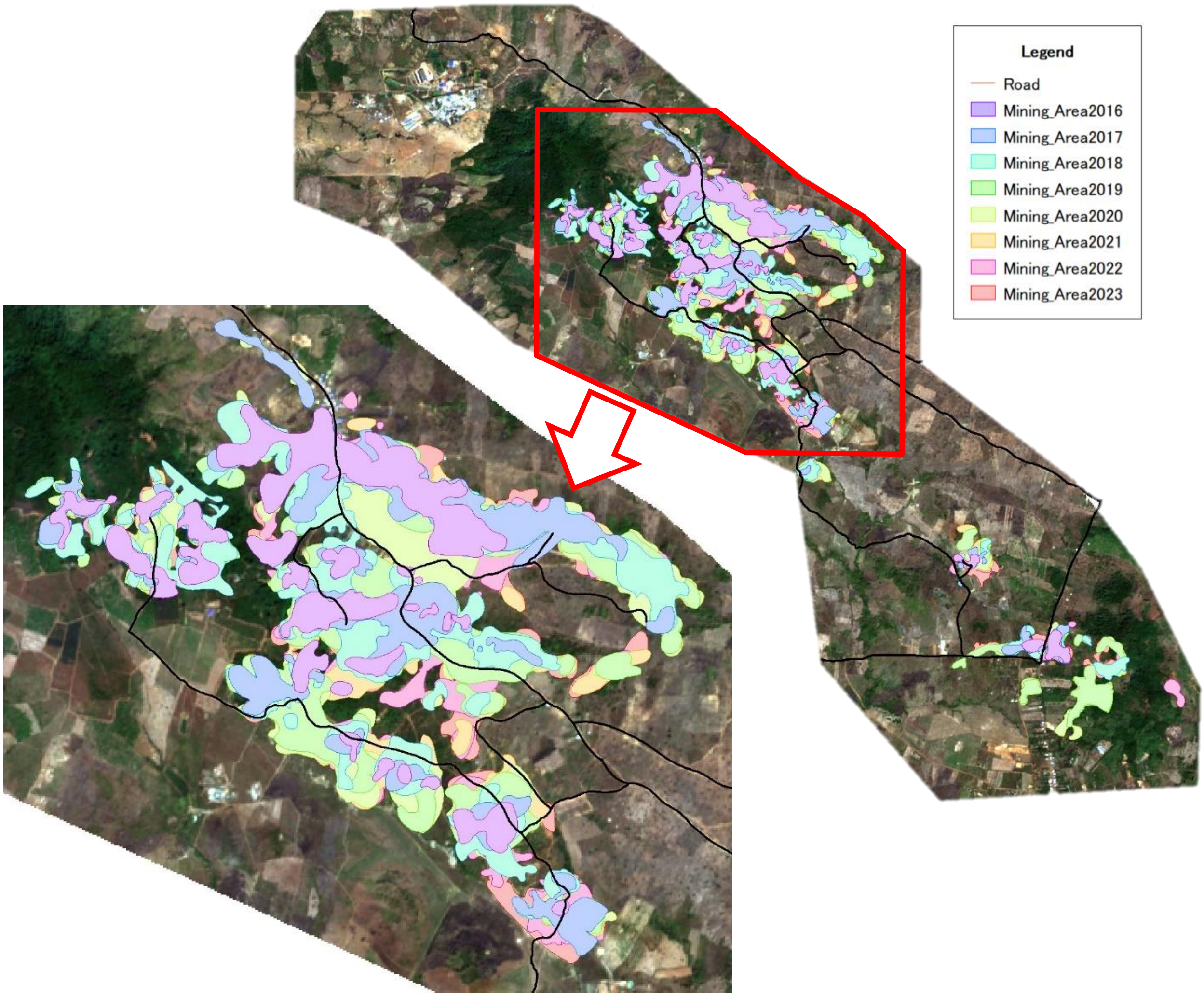


Figure 6-23 Time series change of Delcom mining area

(4) Okvau ASGM

ASGM is generally mining gold sand (gold grains) deposited on the river bed, called "river gold". Therefore, the mining site for ASGM is where the current or past river sediments are distributed. Such ASGM requires the use of large amounts of water to sort the gold grains by flushing and panning (see Figure 6-24), and generally many reservoirs are created.

Figure 4: *Artisanal Gold Mining Activities in Cambodia (Lay, 2015)* Source：MoE(2016)

Figure 6-24 Gold mining methods at ASGM in Cambodia

ASGM is characterized by its location along a river, widespread exposure to muddy sand, and many reservoirs. Particular attention was paid to the fact that there are many reservoirs, and an attempt was made to extract ASGM through image data analysis.

As an index for extracting water bodies, there is Modified Normalized Difference Water Index (MNDWI). The formula for calculating MNDWI is as follows.

MNDWI = (green band value − short-wavelength IR band value) / (green band value + short-wavelength IR band value)

For Sentinel-2 data, this is as follows.

MNDWI＝(Band3-Band12)/(Band3+Band12)

Next, the exposure of muddy sand along the river could be identified where there is no vegetation and where soil is distributed. For Sentinel-2 data, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Soil Index (NDSI) are calculated by use of the following formulas.

NDVI＝(Band4-Band3)/(Band4+Band3)

NDSI＝(Band11-Band8)/(Band11+Band8)

A color composite image was created by use of the above three indices, with MNDWI for red, NDVI for green, and NDSI for blue. For convenience, this color image is referred to as the Water-Vegetation-Soil Classification (WVS CLN). We propose using this classification to extract ASGM in this study. In this classification, water areas are usually represented by red color system, vegetation areas by green color system, and soil areas by blue color system. In ASGMs where numerous reservoirs are created, this classification may be useful in identifying the location of ASGM operations.

Okvau ASGM site is located approximately 10 km east of Okvau gold mine. Figure 6-25 shows a true color image (taken on December 11, 2023), MNDWI and WVS-CLN. ASGM operation site is located within the broken line box in the same figure. In MNDWI of Figure 6-25, values greater than 0.1 are colored red and values between 0.0 and 0.1 are colored yellow, and these colored areas indicate the presence of water. The rivers in the northern and eastern parts of the image are extracted.

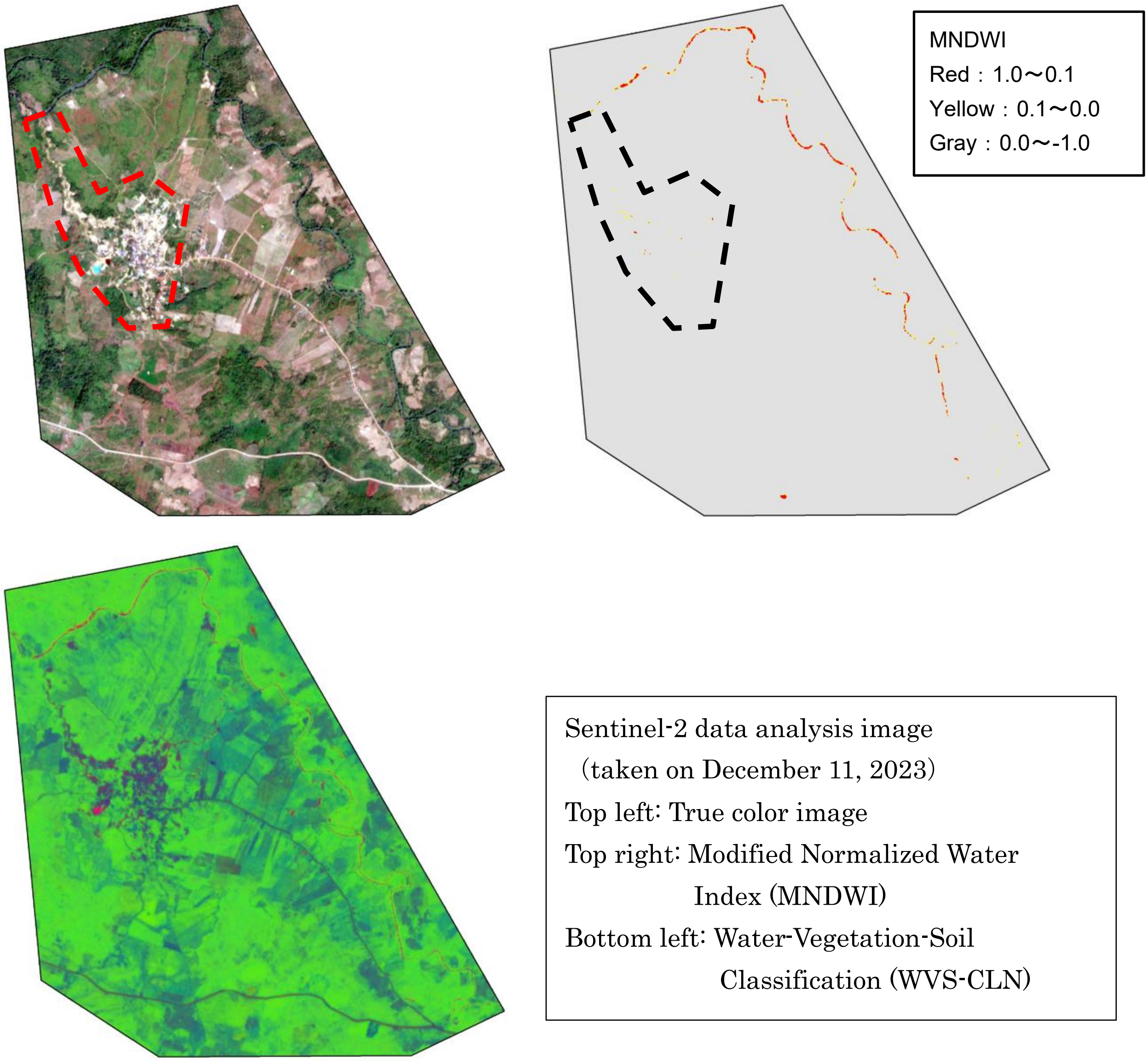
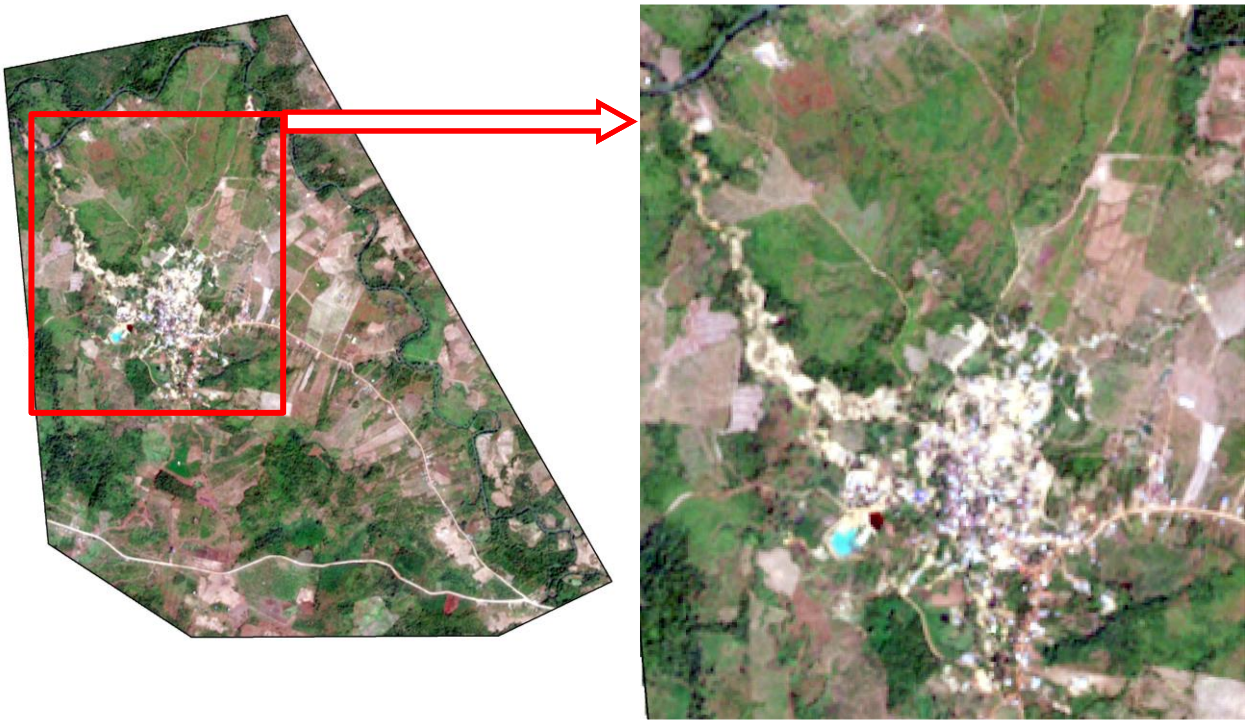


Figure 6-25 Modified Normalized Water Index and Water-Vegetation-Soil Classification for Okvau ASGM Site

In WVS-CLN of Figure 6-25, a stream crossing the village is recognized, and many reddish-purple colored areas are observed around the village, and the surroundings of these areas are blue in color. Thus, the areas where reddish and blueish colors are mixed along the stream indicate most probably ASGM sites. Figure 6-26 shows a magnified image of ASGM site in Figure 6-25. In WVS-CLN, the river and pond are clearly recognized around the village. Thus, the effectiveness of WVS-CLN for ASGM extraction is verified.



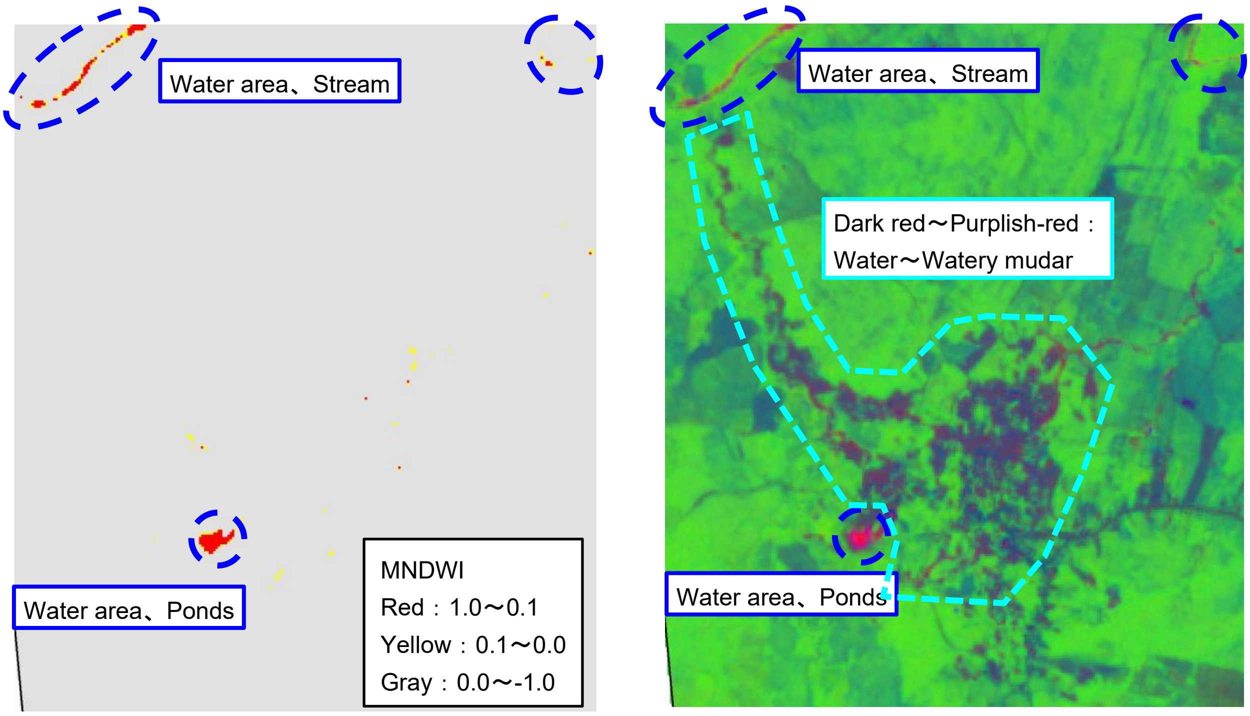
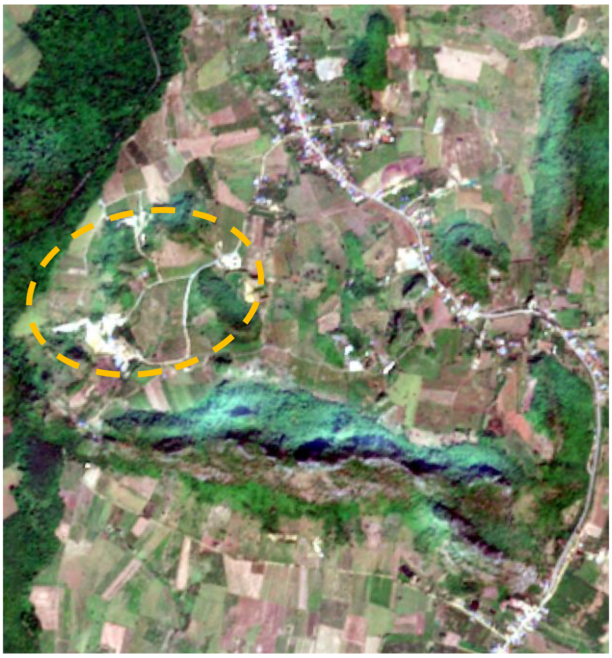


Figure 6-26 Modified Normalized Water Index and Water-Vegetation-Soil Classification for Okvau ASGM site (zoom in)

However, the effectiveness of WVS-CLN is premised on the existence of water bodies that can be recognized at a resolution of 20 m in the Sentinel-2 data, so the effectiveness may be reduced if, for example, the puddles are gone during the dry season or the pond is too small to be recognized.

(5) Phnum Proek ASM

Phnum Proek ASM site is located in northwestern Cambodia bordering Thailand. Figure 6-27 shows a true color image taken on November 29, 2023 and MNDWI. ASM site was estimated to be within the yellow broken line box in this figure. In MNDWI of Figure 6-27, values greater than 0.1 are colored red and values between 0.0 and 0.1 are colored yellow, indicating the presence of water in these colored areas. Here, however, a portion of the topographic shadow area was misidentified as water. As previously discussed in Section 6.6.2, this analysis area was not a gold ASGM, but rather a quarry ASM.



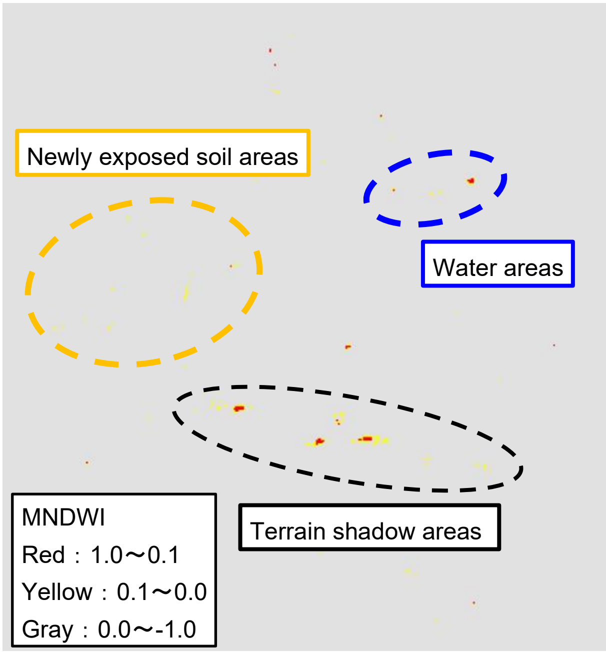


Figure 6-27 Modified Normalized Water Index and Water-Vegetation-Soil Classification for Phnum Proek ASM site

6.6.4 Contents of mining development status grasped

As mentioned above, analysis and interpretation of Sentinel-2 image generally deciphers the mining development status of relatively large mines such as Okvau mine, including opencut mining pits, waist rock deposition area, tailings disposal areas, tailing dam, plant, various mine buildings, and work roads.

On the other hand, special data analysis (MNDWI, NDSI) revealed that it is possible to extract reservoirs and soil exposures specific to ASGM.

6.6.5 Monitoring plan of mining development status

If satellite image monitoring is to be implemented in the future, Sentinel-2 data, free of charge, available via the Web, and having a high imaging frequency, would be the only option.

The method of monitoring mining development status, using Sentinel-2 image, is summarized below. Normally, good quality cloud-free image is only available during the dry season, but since Sentinel-2 data is acquired every 5 days, it is required to check the Copernicus website at least once a month to check the image. Weekly checks are required, especially if environmental impacts are to be monitored.

(1) Identification of operation area

- Used image 1: True color image (RGB=Band 4, Band 3, Band 2)
- Decipherment 1: Location of mining sites, waist rock deposition sites, various mining facilities, etc. are identified to determine the operation area.
- Used image 2: Normalized vegetation index (NDVI) image (formula = (Band4-Band3)/(Band4+Band3))
- Decipherment 2 : Since there is usually no vegetation in the operation area, the area with a vegetation index of zero is determined to be the operation area.

(2) Identification of mining sites and waist rock deposition sites

- Used image 1: True color image (RGB=Band 4, Band 3, Band 2)
- Decipherment 1: Distribution of mining sites and deposition sites are identified.
- Used image 2: False color image (RGB=Band12, Band4, Band2)
- Decipherment 2 : Distribution of rock and soil is determined by color tone.

(3) Identification of reservoirs and tailings disposal sites

- Used image 1: True color image (RGB=Band 4, Band 3, Band 2)
- Decipherment 1: Distribution of reservoirs and tailings disposal sites are identified.
- Used image 2: Band ratio calculation image (RGB=Band11/Band12, Band12/Band4, Band4/Band2)
- Decipherment 2 : Vegetation, water bodies, and soils are distinguishable, and the distribution of water bodies and deposition site is determined by color tone.

(4) Environmental impacts such as soil runoff and others

- Used image 1: False color image (RGB=Band 12, Band 4, Band 2)
- Decipherment 1: Distribution of rock and soil is determined by color tone.
- Frequency: As often as possible to capture the changes over time

(5) Environmental impacts against vegetation

- Used image 1: Normalized vegetation index (NDVI) image (formula = (Band4-Band3)/(Band4+Band3))
- Decipherment 1: This index indicates the distribution and activity of vegetation and thus determines

the impact on vegetation.

・Frequency: As often as possible to capture the changes over time

(6) Identification of AGSM site

・Used image 1: True color image (RGB=Band 4, Band 3, Band 2)

・Decipherment 1: Location of mining sites is identified.

・Used image 2: Band Ratio Calculation Image (RGB=MNDWI,NDVI,NDSI)

The formula for the ratio calculation is as follows

MNDWI＝(Band3-Band12)/(Band3+Band12)

NDVI＝(Band4-Band3)/(Band4+Band3)

NDSI＝(Band11-Band8)/(Band11+Band8)

・Decipherment 2：Usually, water areas are represented by red tones, vegetated areas by green tones, and soil areas by blue tones. In ASMs, since large amounts of water is used, ponds are often created. Identifying the dense distribution of ponds and rivers by this image may be useful in determining the location of ASGM activities.

6.6.6 Issues

The challenges for government agencies involved in the mining industry and the environment to use Sentinel-2 satellite data in order to monitor mining activities can be summarized as follows.

(1) Human resources

There are few engineers who fully understand the theories and techniques related to satellite data handling and data analysis.

There are no engineers who analyze satellite data on a daily basis.

(2) Training for satellite data analysis

It cannot be assumed that engineers with some data analysis skills and experience can provide technical guidance to others within their organizations. Therefore, technical training by outside experts is necessary. In fact, training was requested during the interviews at the target organizations.

The contents of training include satellite data theory, data analysis methods, deciphering and interpretation of analyzed images, database construction, introduction of analysis cases, analysis of actual data and field verification surveys of analysis results, and monitoring methods, etc.

(3) Field survey

Information that can be deciphered and monitored only by satellite data analysis needs to be verified even if periodically (once a year, at the same time as mine inspections, is acceptable). However, due to the constraints of budget and human resource, it is unlikely that many such opportunities will be available.

(4) Organizational structure

When it comes to the monitoring of mining activities, the department most related to the mining industry should be in charge, but it will also be necessary to collaborate with the departments that manage licenses and environmental management. It is necessary to establish a system that allows various data to be shared among multiple departments.

6.7 Potential of mining development

Mineral types with high potential for mining development include gold from drifting sand or hydrothermal deposits, copper from skarn deposits, and bauxite from weathered basalt. The long civil war and political turmoil have caused exploration to lag far behind that of neighboring countries, and until recently there has been no production of nonferrous metal mineral resources on a statistically significant scale. However, as represented by the start of gold production in 2021, the potential of these mineral resource has been reevaluated in recent years, and exploration activities, especially for gold and copper, by foreign companies have begun to increase.

The potential areas for these types of minerals are widely distributed in the north and south of Cambodia, and the development of mining corridors and port infrastructure, as well as the development of human resources, especially in the mining industry, which is in short supply in Cambodia, are expected to contribute to the country's promotion.

6.8 Study by country visit

6.8.1 Collection of Information during the first field survey

During the first round of field survey, we visited the following relevant organizations in the capital city of Phnom Penh from September 11 to 13, 2023, to gather information and conduct interviews.

・General Department of Mineral Resources (GDMR), Ministry of Mines and Energy (MME)
・Department of Mineral Operational Inspection, MME
・Department of Mineral Geology (DMG), MME
・Department of Industrial Mining (DIM), MME
・General Directorate of Environmental Protection (GDEP), Ministry of Environment (MoE)

Information obtained in Cambodia were as follows.

① Cooperation with JICA projects

Both Ministry of Mines and Energy (MME) and Ministry of Environment (MoE) expressed a high level of interest in the project contents (especially monitoring through the satellite image) and mentioned that they would cooperate with us in providing information.

They expected us to strengthen the relationship between the two countries by resuming technical cooperation projects in the field of mineral resources implemented by JICA in the past and by continuing issue-specific training and Kizuna program (it was confirmed that the former is not included in the scope of this project, while the continuation and importance of the issue-specific training and Kizuna program were confirmed).

② Mine management

MME administers the mining licenses. In total, it licenses more than 500 mines with all statuses, including mines under development study and mines in operation.

Department of Operational Inspection (DOI) specializes in inspections of operating mines. However, due to chronic shortages of budget and staff, the current situation is that monitoring and inspections of operating mines are not being fully implemented.

③ Monitoring status of mining activities

Inspections by DOI are limited to industrial raw material resource mines. Currently, inspections are not being conducted at metallic mineral mines such as the Okuvau gold mine, but this is planned for the future. Mine inspections use a checklist, developed with the support of JICA. Most of the observation targets in the inspections are concerned with the aspects of safety. Basically, inspections are conducted once every three months, and at the same time, periodic reports on the operation are also received from the operators. The number of inspected mines is about 80 metal mines (mostly gold sand) and about 200 raw material mines (including precious stones).

MoE monitors the environmental impact of mining operations in accordance with Environmental Management Plan (EMP) established in the mining plan after the obtention of mining license. Basically, MoE checks the periodic activity reports submitted to MME and MoE by the mining right holders, and conducts on-site inspections when on-site confirmation is necessary. MoE's Department of Inspection and Law Enforcement conducts inspections. 2 to 3 weeks ago, an urgent inspection was conducted based on a report of river pollution from the site. The inspection did not include analysis of water quality, etc., but only a visual check. A drone was also used for the inspection, but its purpose was only to confirm the situation from the sky. The analysis during the inspections is outsourced to the Institute of Technology of Cambodia (ITC).

④ Status of the use of satellite data and utilization technology

None of the MME organizations use satellite data, including traditional LANDSAT data, and they do not possess satellite image processing and analysis software. However, there are some technicians who personally use free versions of ENVI, Arc GIS, and QGIS, but they are few in number.

Several staff members have participated in training on basic theory and usage of satellite image and GIS in Japan (@ AIST) under the auspices of JICA. However, under the current circumstances described above, there are no plans to develop the use of a satellite data, etc.

⑤ Drone

GDMR has begun using drones to confirm the extent of mineralized areas and to manage royalties. However, the actual drone surveys are outsourced to outside private consultants (currently three companies). The work includes the creation of three-dimensional topographic data of quarry mines using drones and the calculation of mining volumes (The counterpart has showed us a demo video of a drone survey created by the contractor).

Currently, there are no laws concerning drones. Drones can be flown freely except restricted areas.

⑥ Status of ASM (artisanal/small-scale *mining*)

Five to seven ASM areas, mined for gold, are recognized in MME and MoE. Many ASMs are located in the vicinity of operating gold mines, such as the Okuvau gold mine. Especially, control of illegal ASMs is difficult, and no on-site inspections are conducted.

ASM uses cyanide for gold extraction, which has caused water pollution and is considered as problematic.

⑦ Status of the assistance from other countries

From China, MME has received short-term training, assistance in geological mapping, mineral potential assessment, and capacity building for analytical laboratories, and also, training on mining from Australian mining companies and the Australian government.

6.8.2 Collection of Information during the second survey

During the second field survey, we visited the following relevant organizations in the capital city of Phnom Penh on January 11 and 12, 2024, to report the results of satellite data analysis, and collect information and conduct interviews.

・General Department of Mineral Resources (GDMR), Ministry of Mines and Energy (MME)
・General Directorate of Environmental Protection (GDEP), Ministry of Environment (MoE)

Information obtained in Cambodia were as follows.

① Comments on the report of the survey team

Almost the same comments from MME and MoE.

・They were interested in the satellite image analysis : very effective and useful in mining and environmental management.
・They would like to receive more training on this type of image analysis. They would like to have a training course that is not short, like a few days, but practical, from the basics to the applications (with a specific target for analysis), lasting at least one or two weeks.
・Cooperation with JICA is expected. Technical support for the satellite image analysis and ASGM monitoring are also good themes.

＊Comments on PPT contents

・Development and Partnership in Action (DPA), which prepared the Artisanal Small-scale Gold Mining (ASGM) report (2012), is an NGO.
・The location of ASGM indicated at Phnum Proek is a limestone quarry, and the gold mining area is further north.
・Since iron hydroxide may be formed around ASM, it would be useful if this could be extracted by satellite image analysis (we have answered that this is possible if the area is large enough).

② Mining licensing and management
・MME manages the mining licenses; Mining Department is responsible for gold and metallic minerals, and Department of Industrial Mining is responsible for non-metallic, coal, limestone, silica stone, river sand, and other quarries.
・Small-scale mines are defined by the mining law as having an area of less than 1 ha, open-pit mining (depth of 5 m or less), with less than 10 employees.
・The local government has jurisdiction over small-scale mines (transferred from the central government). Currently, the licensed mines are quarries, sand and gravel mines.

③ Inspection and monitoring
・Mining Inspection Department of MME conducts inspections (operation, safety, working conditions) of industrial raw material resource mines (other than ASM) and Okvau gold mine.
・DILF (Department of Inspection and Law Enforcement) of MoE conducts environmental inspections and monitoring in accordance with EIA. The monitoring frequency is once every 3-6 months. DILF of MoE pays attention to water pollution caused by mining activities.
・The central government, local governments, police, etc. have been separately conducting inspections of mines, but the unification of these inspections, including their items, is being considered.
・MME uses UAV (Unmanned Aerial Vehicle) for monitoring of the operation and inspections concerning quarries and earthworks, and has commissioned private companies to calculate the volume of quarries and earthworks using UAV (used to verify royalties).
・MME inspects more than 300 mines a year, and has 30 inspectors, 20 of whom carry out on-site inspections.
・When residents in the vicinity of a mine detect a problem in the operation of the mine, they report it to the local government, which brings it to the attention of the central government.

④ ASM/ASGM
・The local governments have jurisdiction over ASM. When some problems occur. MME cooperates with them and supports them in the management procedures, etc.
・MME and MoE do not inspect ASM.
・There is no official ASM for gold. There are two illegal ones, both located near existing gold mines, and MME, police and military have stopped the activities of these ASMs.
・MoE is in charge of the Minamata Convention on Mercury. A plan of action for ASGM is currently being submitted and will probably be approved and started by the end of the year.

・Mercury may have been used until about 10 years ago, but is no longer used as far as they know. Cyanide is used in large gold mines.
・Legally, the use of chemicals and traditional mining methods are prohibited in ASM.

⑤ Problems, systems, etc.
・MME does not have a department for satellite image analysis and lacks in human resources, technology and knowledge. There is no analysis software.
・MoE and Forestry Department seem to be using satellite images, for checking the development in protected areas.
・There is a high interest in satellite image, and its effectiveness is well recognized.
・MME is responsible for overall management of the mining industry, while MoE is responsible for management of the mine environment in accordance with EIA. If some environmental problems occur, the two ministries will cooperate with each other. MME has the authority to shut down operations against operators, while MoE has no authority to shut them down.
・Mining licenses and EIA seem to be properly managed.
・MME is in a position to supervise illegal mining, but it is practically difficult.

6.9 Summary and recommendations

6.9.1 Summary

(1) Mineral Resources
In Cambodia, mining development of metallic mineral resources has only recently begun, with three gold mines currently in operation. Exploration activities are underway in various locations, and the mining industry is expected to develop in the future. ASMs for gold and jewelry exist, but their actual status is unclear.

(2) Management of mining development
Ministry of Mines and Energy (MME) administers mining licenses and inspects safety aspects, while Ministry of Environment (MoE) approves EIA for mining developments and inspects environmental aspects. Their roles are properly performed. However, the reality is that MME's inspection of mines are rarely conducted.

(3) Monitoring mining development with satellite image
Relevant ministries and agencies have little experience in the use of satellite image. The relevant organizations showed a much interest in satellite image analysis, etc. in this project, and came to recognize its effectiveness of the project.

(4) ASM
There are no more than 10 ASM areas known to MME and MoE, but in reality there are numerous ASMs.

Most of them are illegal. It is difficult to manage them, and their detailed information is lacking.

(5) Cooperation with Japan

All of the ministries and agencies showed a great interest in the use of satellite image, and they are looking forward to JICA's support and cooperation.

(6) Japanese Involvement

JICA is providing assistance in the mining sector. Cambodia is a recipient of the Kizuna program and its students are admitted to Japanese universities.

JOGMEC is investing in and conducting resource exploration.

A Japanese company is conducting resource exploration.

6.9.2 Problems

(1) Mining development

Only three gold mines are currently in operation. Deforestation, soil runoff, and water pollution are problems in some areas, and MME and MoE do not appear to be adequately addressing these environmental issues.

(2) ASM

There is little information on ASM and the actual situation is unclear. It is not the central government but the local governments that manage ASM, and it is questionable whether the current situation is appropriate or not.

(3) Natural environment

Cambodia has abundant in forest resources, with forest area covering nearly 50% of the country's land. However, in recent years, the forest area has been rapidly decreasing due to agricultural land and infrastructure development. Mining development is also causing deforestation, which requires appropriate environmental management and countermeasures.

(4) Human resources

Although relevant organizations showed a great interest in satellite image analysis and monitoring, the reality is that there is an absolute shortage of technology, know-how, and human resources, and therefore, adequate support is needed for technical education, maintenance, and sustainable development.

6.9.3 Support measures

(1) Establishment of a system for mine inspections and human resource development

Since mine inspections are rarely conducted, support should be provided so that a system for mine inspections should be established and adequate inspections can be conducted in terms of safety and environment. Training and human resource development related to the following items should be conducted. The relevant departments of Ministry of Environment may be included.

1) Establishment of inspection method
   - Creation of safety check sheet
   - Creation of environmental check sheet
   - Establishment of procedures and methods for implementation
2) Implementation of Inspections
   - Inspection is carried out twice a year during the rainy season and dry season
   - Observation by drone during inspection
   - Creation of programming for drone operation and automatic flight
   - Monitoring using Sentinel-2 satellite images

(2) Human resource development for satellite data analysis

Training and human resource development for the following items, using Sentinel-2 satellite data on the Copernicus website, will be conducted. The website allows free data analysis through data processing programming.

- How to use the Copernicus website
- Script programming for data analysis on the Copernicus website
- Data analysis methods for resource exploration
- Monitoring of mining operations and the environment
- Monitoring of land alteration

For the above analyses, on-site verification surveys at key sites will be carried out. Based on the results of the field verification surveys, programming improvements and new analysis methods will be developed. In the field verification survey, a drone will be used to compare and verify the results with the results of satellite data analysis.

(3) Human resources development to manage mineral resource development

In Cambodia, the development of metal mineral resources has very recently begun, and there are few engineers with sufficient knowledge regarding mineral resource exploration and mine development. On the other hand, mineral resource-related companies, including Japanese companies, have been currently conducting mineral exploration in several regions. Considering this situation, by providing the training and practical training to acquire a range of knowledge related to mineral resource development, such as mineral resource exploration methods, data analysis and interpretation methods, techniques and methods necessary for mine development, investment and external environment, etc., the support to develop human resources who can manage the mining development properly is proposed.

7. Study result: Laos

7.1 Basic information

7.1.1 Natural and social environment

Laos is located in Southeast Asia and is a landlocked country with a long north-south axis, bordering Thailand, Myanmar, China, Vietnam, and Cambodia. The total land area is 236,800 km^2 and the total population is approximately 7.8 million. The country is rich in mineral resources such as copper, gold, tin, lead, and zinc. Laos, Cambodia, and Vietnam are former French Indochina, and Laos is geographically influenced by the economic zones of Thailand and Vietnam. In recent years, however, Chinese influence has increased.

Figure 7-1 Map of Laos

7.1.2 Topography

About 75% of the country is mountainous area with an elevation of over 500 meters. Near the border with Thailand on the west, the Mekong River flows from north to south. The eastern border with Vietnam consists of the Annamese Mountains, which divide the Mekong River basin on the Lao side and the East China Sea. The highest elevation point is located in the southern part of the plateau in northern Laos, at 2,819 meters above sea level. The Mekong River traverses the country, reaching a length of 1,900 km.

The mountainous areas have steep terrain, narrow rivers, and are not suitable for agriculture. The mountainous areas in the north are inaccessible and have a very low population density. The area around the Mekong River is an alluvial plain, forming a granary.

7.1.3 Vegetation

Laos has a tropical monsoon climate. The forested area is estimated to be about 40% of the country's total land area. The vegetation is highly varied due to the topographical elevation and the long north-south length of the country. The low population density and the large forested area have helped maintain a diverse ecosystem.

7.1.4 Infrastructure

The construction of Laos-China Railway and Laos-China Expressway as part of China's "One Belt, One Road » initiative is deeply involved in the recent infrastructure development of Laos. Laos-China Railway is a high-speed railroad connecting Boten on the border with China's Yunnan Province, to the capital Vientiane. This Railway opened in December 2021. There is also a direct connection with the Chinese railroad, with international trains from Vientiane to Kunming in Yunnan Province. Laos-China Highway is a parallel route to Laos-China Railway and is planned to run from Vientiane to Boten. The section between Vientiane and Vang Vieng, about 25% of the entire route, opened in December 2020. This is the first highway in Laos. Road transportation is the main means of travel and transport in Laos, but the pavement coverage is only about 20%.

Laos-Vietnam Railway is also planned to connect Vientiane with Vung Ang, port city of north-central Vietnam.

The only international airport is in the capital city of Vientiane, while domestic flights have eight routes from Vientiane.

7.1.5 Environmental reserve area

Laos has 20 nature reserves, covering a total area of about 14% of the country's land area. They are characterized by tropical monsoon forest areas, and unique topography and geology.

Two wetlands are registered under the Ramsar Convention. Three sites are registered as cultural heritage of the World Heritage Site.

7.1.6 Geology

The geology of Laos consists mainly of Paleozoic metasedimentary and granitic rocks and Mesozoic sedimentary and igneous rocks. The Paleozoic strata consist of sandstone, shale, limestone, and granite, while the Mesozoic strata consist of sandstone, shale, limestone, and acid volcanic rocks. The geologic structure is predominantly northwest-southeast system.

7.1.7 Mining

The principal mineral products are copper, gold, lead, zinc, tin, gypsum, and gemstones.
The main mines currently in operation are listed below (JOGMEC, 2021). In addition, gold and gemstones are mined by small-scale mines and private miners, but the actual situation is unclear

・Sepon：copper, gold
Interests：Chifeng Jilong Gold Mining（China）90％, government of Laos 10％

・Phu Kham： copper, gold, silver
Interests：PanAust (Australia) 90%, government of Laos 10%.

・Ban Houayxai：copper, silver
Interests：PanAust (Australia) 90%, government of Laos 10%

・Phapon：gold
Interests：Tianjin Huakan Group (China), Shengda Resources (China)

There are also many exploration projects, covering copper, gold, molybdenum, nickel, and bauxite.

7.2 Mineral resources

7.2.1 Metallic mineral resources

Laos is rich in metal mineral resources such as gold, copper, tin, lead, and zinc, However, the development of the mineral resources is currently limited due to the country's steep mountainous terrain and undeveloped transportation infrastructure. Figure 7-2 shows the distribution of gold, copper, tin, lead, and zinc mineral resources (mines, mineral occurrences, etc.).

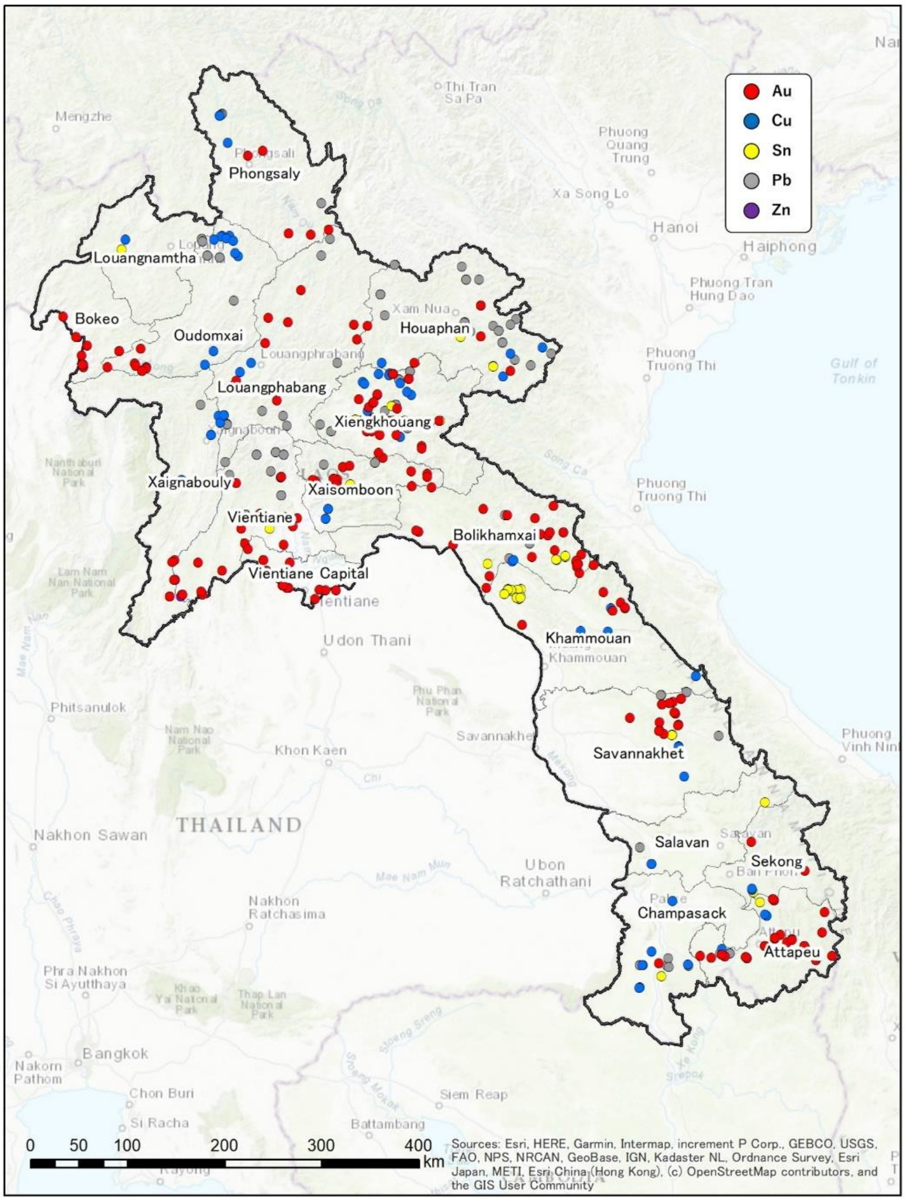


Figure 7-2 Distribution of metallic mineral resources in Laos (only target minerals)

Sirisokha (2019), Khin Zaw et al. (2014), and Wang et al. (2023) provide detailed explanations of the geology and mineralization of the Indochina Peninsula, including Laos. Based on these recent research results, the distribution of metallic mineral resources in Cambodia is reviewed here.

The geology of the Indochina Peninsula consists of the South China, Indochina, and Sibumasu blocks that collided and re-aggregated from the Permian to the Triassic after separating from the Gondwana continent from the Devonian to the Permian (e.g., Ueno and Hisada, 1999). There are multiple fold belts such as Loei belt and Truongsong belt in between the blocks. Most of Laos's land lies in the Truongson fold belt and Loei fold belt that developed to the east and west of the Indochina massif respectively. (Figure 7-3).

The Truongson fold belt was formed by westward subduction during the Late Carboniferous to Early Permian period. It has a high potential of metal mineral resources related to hydrothermal activity during subduction (Figure 7-4). In the Truongson fold belt, rhyolitic dacite porphyries are found mainly in

Thengkham and Padan in southeastern Laos. The Sepon mine, one of the most famous mines in Laos, is located in this Truongson fold belt. The Sepon deposit consist mainly of skarn-type gold and copper deposit that developed at the contact of rhyolitic dacite porphyries intruded into limestone host rock, and carlin-type gold-bearing pyrite dissemination deposit that developed along fissures. It also has their secondary enrichment. In addition, in the vicinity of the junction with the Loei fold belt in the northwest, there are some deposits such as the porphyry-skarn type Phu Kham deposit (Kamvong et al., 2014) and the low sulfidation epithermal vein type Ban Houayxai gold deposit (Manaka et al. 2008).

The Loei fold belt which was formed during the Permian to Triassic period during the eastward subduction of Paleo-Tethys oceanic crust into the Indochina massif. is another high potential area for metal mineral resources. Same as Truongson belt, Loei belt also plays an important role in forming hydrothermal deposits associated with magmatic activity during subduction (Figure 7-4). Specifically, calc-alkaline I-type granites (quartz diorite, granodiorite, quartz monzonite, etc.) associated with the subduction relates to porphyry-type, skarn-type, and epithermal vein-type mineralization. Along the southern extension of the Loei fold belt to Thailand, many hydrothermal deposits such as porphyry-skarn type Phu Lon deposit (Pisutha-Arnond et al., 1993), the Putep deposit (Kamvong et al., 2014), and epithermal vein type Chatree gold deposit (James and Cumming, 2007), which all are associated with calc-alkaline magmatism. Similar deposits of porphyry type, skarn type, epithermal vein type are also expected in Laos. In addition, since basic volcanic rocks that are thought to have been formed in the back-arc basin are also distributed in the Loei fold belt, there is a possibility that volcanic massive sulfide deposits exist (e.g., Panjasawatwong et al., 2006). Furthermore, it has recently been pointed out that the Phapon deposit around Phongsali in northern Laos may be an orogenic gold deposit (Guo et al., 2019). Thus, the Loei Belt is one of the areas with the largest potential for metal mineral resources as well as Truongson belt.

In addition, the Sukhothai Belt, which is located to the west of the Loei Belt, is also an area with potential for metallic mineral resources related to hydrothermal activity associated with subduction and collision with the Indochina block. There is particularly high gold potential, such as orogenic gold deposits and epithermal gold deposits.

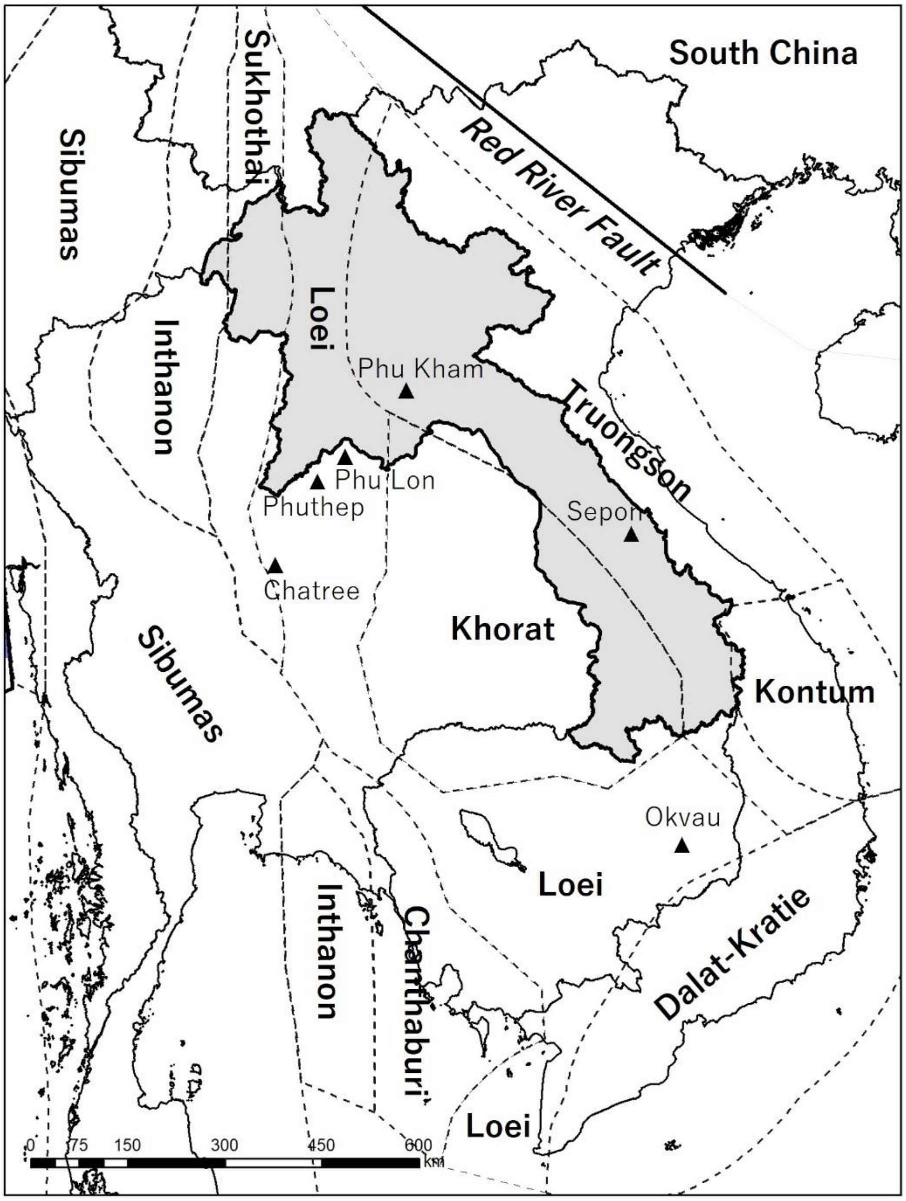


Figure 7-3 Regional tectonic map around Laos (Adapted from Khin Zaw et al., 2014)

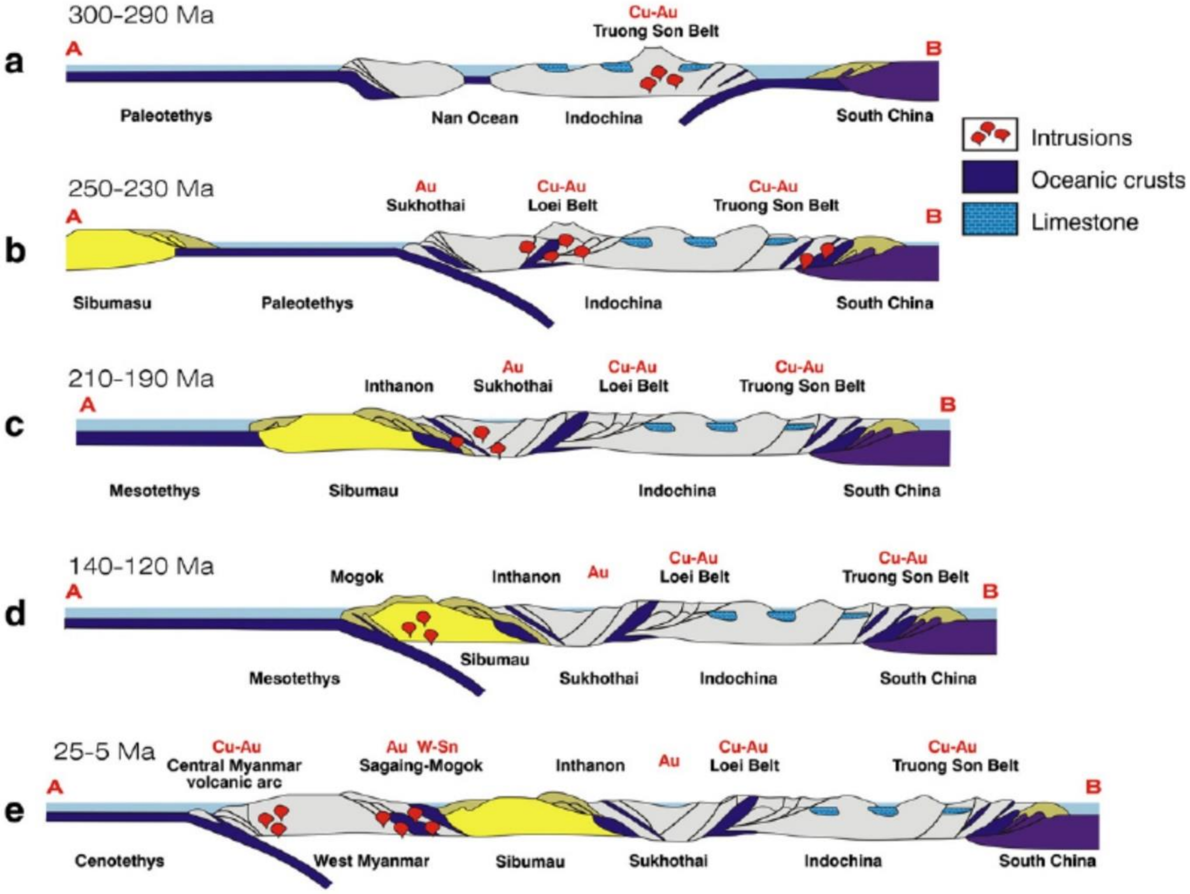


Figure 7-4 Schematic diagrams of tectonic and metallogenic evolution of SE Asia including Laos (Adapted from Khin Zaw et al., 2014)

7.2.2 Past surveys

Since the founding of Laos, there have been many foreign surveys conducted in Laos. Czech Republic conducted survey from Pak Beng (Xayabouli, Oudom Xai Province) to Muong Tha Deua for placer gold, while Bulgaria focused on placer gold in central to eastern Laos. Vietnam surveys included Xam Nua, Khang Khay, and Vientian in the 1980s with an creation of 1/200,000 scale geological map. A geological map (1:250,000 scale) was created for gold surveys at four locations supported by the former Soviet Union, along with a detailed survey of 69 placer deposits (JICA, 2008). In October 2009, Sojitz Corporation and Nittetsu Mining Co., Ltd. jointly acquired the exploration rights for copper deposits in the Moune area (approximately 226km^2), located approximately 100km west of Vientiane, and began exploration activities. In November 2012, JOGMEC joined the JV exploration as “overseas geological survey” (JOGMEC, 2014). Major exploration projects in Laos are shown in Table 7-1.

Table 7-1 Major exploration projects in Laos (only target minerals)

Project name	Project owner	minerals
Moune	Sojitz Corporation, Nittetsu Mining, JOGMEC	Copper
Luang Namtha	Amanta Resources Ltd.	Copper

7.2.3 Products of mining and industry

Active mines (only for target minerals) in Laos are listed in Table 7-2. The Sepon and Phu Kham mines lead the country’s copper production. The Ban Houayxai mine in addition to the Sepon and Phu Kham accounted for the gold production.

The Sepon Mine (Savannakhet Province) is an open pit copper and gold mine, which started operation in January 2003 by Lane Xang Minerals. It has identified 14 million tonnes of ore containing 46.7 tonnes (1.5 million ounces) of gold and 80.9 tonnes (2.6 million ounces) of silver. The smelter was expanded in 2004, and the adjacent Khanong copper mine was developed in March 2005 to start production of copper cathodes. The copper smelter was expanded in the same year. Since December 2013, due to declining gold reserves and profit margins, production has been limited to copper (gold production has been suspended). In 2018, China's Chifeng Jilong acquired a 90% stake in Sepon Mine from MMG (Wu Mining Resources) for 275mUS$, and it resumed gold ore processing in June 2020. Copper production is by the Solvent Extraction Electrowinning (SX-EW) method, while gold and silver production is by the Carbon in Leach (CIL) method. The production recorded 5,341 tons of copper cathodes and 192,998 ounces of gold dole in 2021. This has produced 1.1 million tonnes of copper cathodes and 1.5 million ounces of gold dole since it began operations in 2003. This means that more than US$1.6 billion has been paid to the Lao government, including taxes, royalties and dividends. The contribution also includes not only local employment and development but the economic development of Laos.

Phu Kham Mine (Xaisomboon Province) located approximately 120 km north of Vientiane is an open pit copper and gold mine, which was started in 2005 by Phu Bia Mining (90% by PanAust of Australia + 10% by the Lao government). It confirms the presence of 31.1 tonnes (1 million ounces) of gold. Trial operation started in May 2008, and commercial production started in July of the same year. It consists of gold-copper porphyry-type deposits and some skarn deposits, and is embedded in intrusive granite, felsic tuff, carbonate-rich shale, sandstone, siltstone and limestone.

The Ban Houayxai mine, located about 25km west of the Phu Kham mine, is an open pit gold mine. The operation was started by Phu Bia Mining Company in 2012. Production is under the Carbon In Leach (CIL) method, with the production of 68,715 ounces of gold and 635,715 ounces of silver in 2020.

Table 7-2 Active mines in Laos (only target minerals)

Mine site	Mine owner	minerals	Production in 2020	Remarks
Sepon	Chifeng Jilong 90% Lao government 10%	Copper	39,730 t	Conc.
		Gold	64,809 oz	Dore
Phu Kham	PanAust Ltd. 90% Lao government 10%	Copper	48,433 t	Pure
		Gold	43,274 oz	
Ban Houayxai	PanAust Ltd. 90% Lao government 10%	Gold	68,715 oz	
Phapon	Tianjin Huakan Group Co. Ltd. Shengda Resources Co. Ltd.	Gold	Unknown	

7.2.4 Metal prices of the world

Gold: Gold price remained low at US$500/oz for nearly 20 years from the 1980s to the 1990s. However, in the 2000s, there was an upward trend due to geopolitical risks such as the September 11 terrorist attacks and the Iraq War. After that, the price rose further due to the development of the pandemic and the Russia-Ukraine war, and in 2020, the price exceeded US$ 2,000 / oz for the first time in history. Since then, the price has remained high at around US$ 2,000 / oz, although there have been some fluctuations.

Copper: Prices remained low at US$2,000/t until 2003, but reached around US$3,000/t in 2004, then exceeded US$5,000/t. Prices temporarily reached around US$10,000/t in 2011, and are currently around US$8,000/t. Prices basically fluctuate according to the demand situation in China, the largest importer, and the operating conditions in Chile, Peru, and other countries that are the largest producers.

Tin: The price once fell from the upper US$10,000/t to just over US$5,000/t in the mid-1980s, and remained at around US$5,000/t until the early 2000s, after which it began to rise again, reaching a temporary peak of around US$30,000/t in 2011 and US$32,000/t in 2021. The price is still at about US$25,000/t, and the price fluctuates widely but remains at a high level. China is the largest producer, accounting for about half of global production.

Lead and zinc: The prices of lead and zinc, which are used for lead batteries and plating materials, have been stable in the past compared to base metals such as copper and other rare metals. Since 2007, the prices have been around US$2,000/t for lead and US$2,000/t for zinc. China is the largest producer, with more than half of the world's share, including production in Peru and Australia.

7.3 Mineral resources potential of target minerals

Khin Zaw et al. (2014) and Wang et al. (2023) reported metal mineral resource potential of Laos comprehensively as well as Japanese journals such as Sudo et al. (1996), JOGMEC (2005) and JICA (2008). Here, we will discuss the potential of Laos's gold, copper, tin, lead and zinc mineral resources.

7.3.1 Gold (Au)

The distribution of gold (Au) mineral resources (mines, mineral occurrences, etc.) in Laos is shown in Figure 7-5. In addition to the known mineral distribution, the potential area of gold (Au) mineral resources considering the geology and geological structure is shown in Figure 7-6.

Gold is widely distributed in Laos with a wide variety of type such as orogenic gold, placer gold, epithermal gold, and porphyry gold, although the development is currently limited. In particular, placer gold is well known throughout the country, and local people collect them in bowls along the rivers on a small scale. Placer gold has also been getting a lot of attention to several foreign countries. Czech Republic conducted survey from Pak Beng (Xayabouli, Oudom Xai Province) to Muong Tha Deua for placer gold, while Bulgaria focused on placer gold in central to eastern Laos. Chinese miners investigated placer gold in Phonesavan in Xiangkhoang province. Such placer gold deposits are distributed from the northwest to the southeast of Laos, in the Ou and Seng river basins north of Louangphabang province, the Koh and Segui river basins about 100 km west of Vientiane, and Huay Xay in Bokeo province (Myanmar and Thailand border), in Paksan, and in the Sewung River basin (northern Thakhek). On the other hand, there are relatively few studies on primary gold mineralization such as orogeny type, epithermal type and porphyry type. However, Several potential areas have been recognized as seen in the recent development of the Sepon and Phu Kham mines. Such primary gold mineralization is often associated with porphyry intrusions and some of them are possible source rocks for the placer gold mentioned above.

Potential of gold mineral resources in Laos are concentrated in the following three geological zones.

1) Truongson belt
2) Loei belt
3) Sukhothai belt

The Sepon mine, one of the most famous mines in Laos, is located in this Truongson fold belt. The Sepon deposit consist mainly of skarn-type gold and copper deposit that developed at the contact of rhyolitic dacite porphyries intruded into limestone host rock, and carlin-type gold-bearing pyrite dissemination deposit that developed along fissures. In addition, in the vicinity of the junction with the Loei fold belt in the northwest, there are some deposits such as the porphyry-skarn type Phu Kham deposit (Kamvong et al., 2014) and the low sulfidation epithermal vein type Ban Houayxai gold deposit (Manaka et al. 2008).

There is no active gold mine in Loei belt in Laos, but along the southern extension of the Loei fold belt to Thailand, many hydrothermal deposits such as porphyry-skarn type Phu Lon deposit (Pisutha-Arnond et al., 1993), the Putep deposit (Kamvong et al., 2014), and epithermal vein type Chatree gold deposit (James and Cumming, 2007), which all are associated with calc-alkaline magmatism. Similar deposits of porphyry type, skarn type, epithermal vein type are also expected in Laos. Furthermore, Phapon deposit in Phongsali province in northern Laos has an orogenic gold feature (Guo et al., 2019), and the similar occurrence continues in Louangphabang province in the south. The Sukhothai Belt, which is located to the west of the Loei Belt, is also an area with potential for metallic mineral resources related to hydrothermal activity associated with subduction and collision with the Indochina block. There is particularly high gold potential, such as orogenic gold deposits and epithermal gold deposits. In addition, some epithermal gold features are recognized in the Triassic rhyolite along the border with Cambodia in Champasak province and Attapeu province.

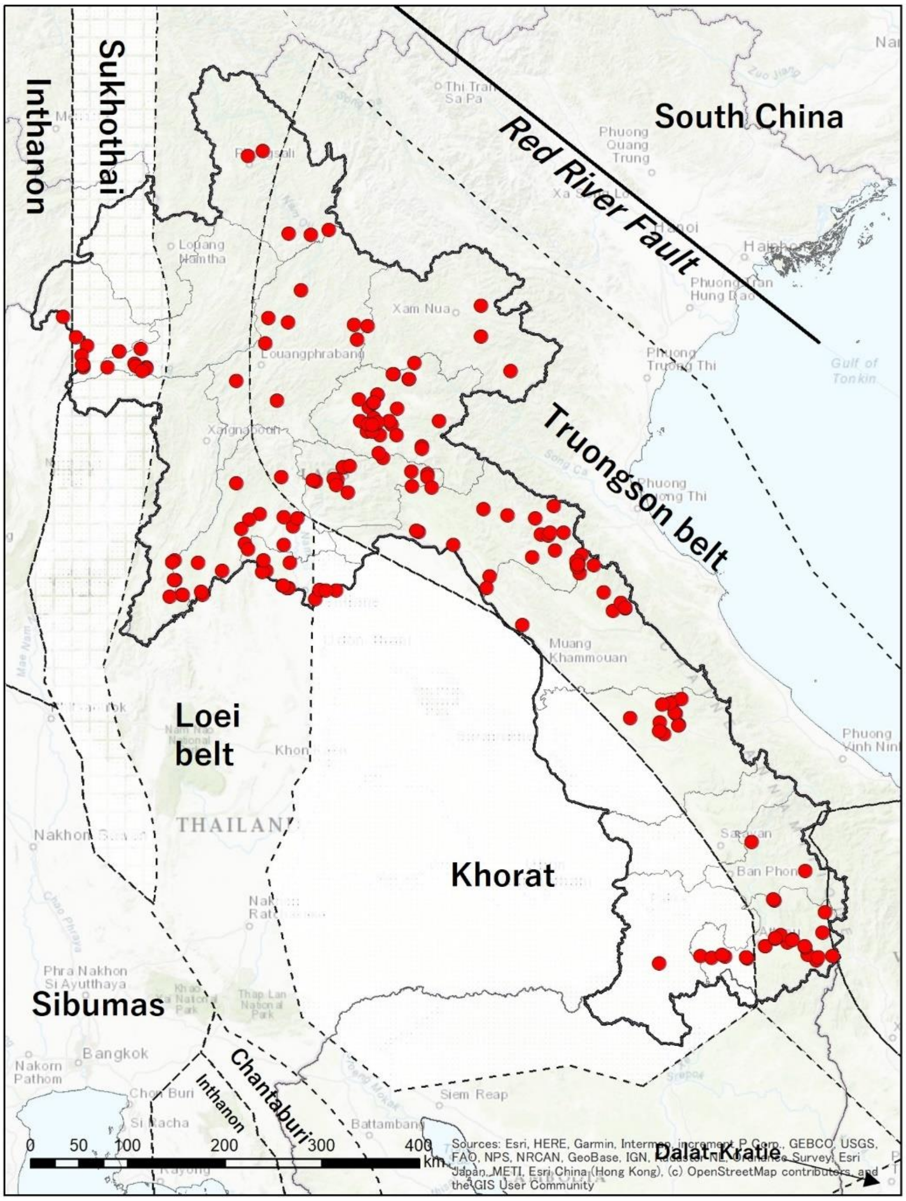


Figure 7-5 Distribution of gold (Au) mineral resources in Laos

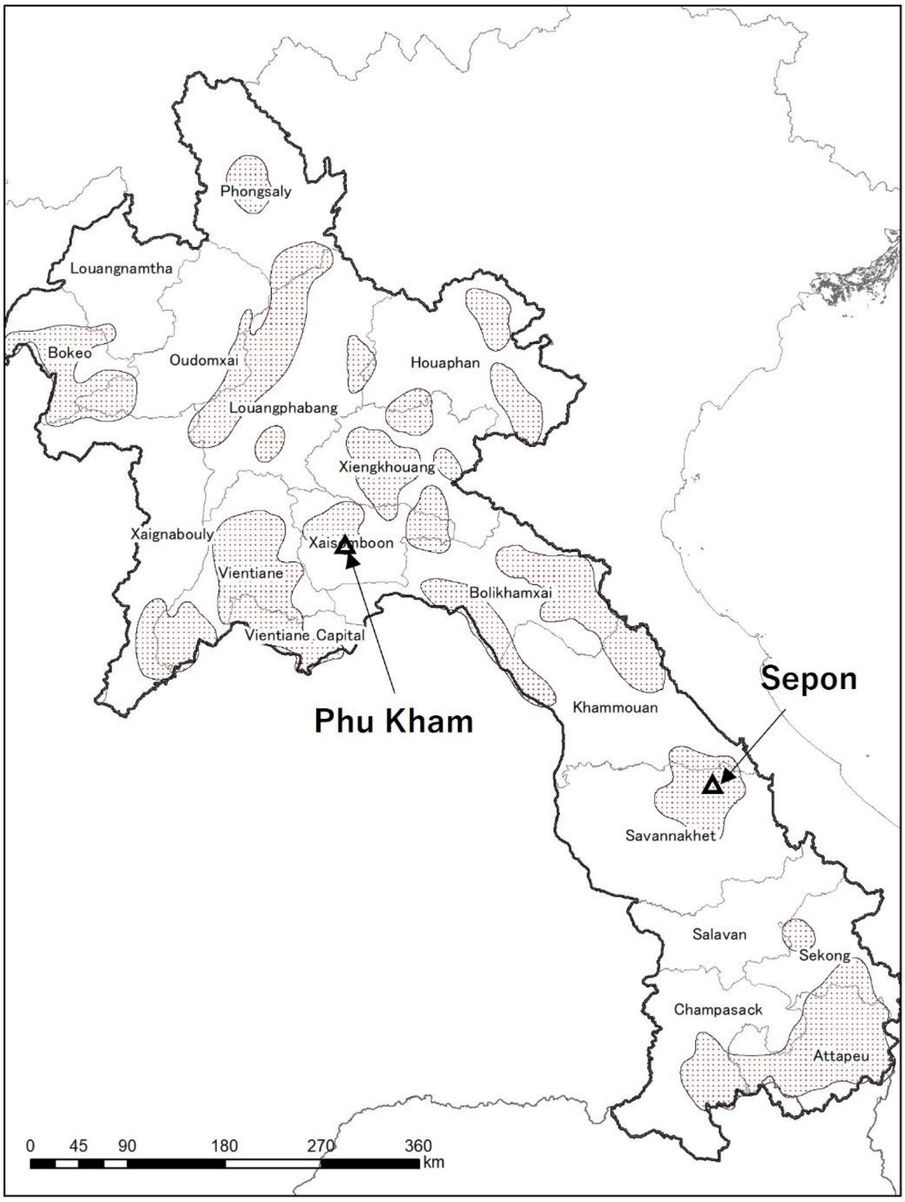


Figure 7-6 Potential area of gold (Au) mineral resources in Laos

7.3.2 Copper (Cu)

The distribution of copper (Cu) mineral resources (mines, mineral occurrences, etc.) in Laos is shown in Figure 7-7. In addition to the known mineral distribution, the potential area of copper (Cu) mineral resources considering the geology and geological structure is shown in Figure 7-8.

Potential of copper mineral resources in Laos are concentrated in the following two geological zones.

1) Truongson belt
2) Loei belt

Truongson belt is one of the most promising area for copper mineral resources. Not only the fact that the Sepon mine and Phu Kham mine are located in this Truongson fold belt, other bodies have newly discovered in the vicinity of these mines within the belt.

Loei belt is another potential area for copper minerals. There is no active copper mine in Loei belt in Laos, but along the southern extension of the Loei fold belt to Thailand, many hydrothermal deposits such as porphyry-skarn type Phu Lon deposit (Pisutha-Arnond et al., 1993), the Putep deposit (Kamvong et al., 2014), which both are associated with calc-alkaline magmatism. Similar copper deposits of porphyry type or skarn type are also expected in Laos. There is also another possibility that copper-bearing volcanic massive sulfide deposits are developed since basic volcanic rocks formed in the back-arc basin are distributed in the Loei fold belt (e.g., Panjasawatwong et al., 2006).

There is high potential for porphyry copper deposits and skarn copper deposits in the area from Xiengkhouang to Xaisomboon provinces, north of Vientiane. Phu Kham deposit is a good example. To the west, in Louangphabang province, disseminated chalcopyrite are recognized in veins cutting volcanic rocks and carbonate rocks of Devonian to Permian ages. Further north, in Oudomxai province, there is a cluster of old copper mining sites as the Nam Phak copper deposit. Covellite, chalcocite, chalcopyrite and their secondary minerals filling veins and breccia cut red sandstone and conglomerate (Baniczky, 1980). On the other hand, there are copper occurrence in Champasak province along the border with Cambodia in the south, and copper mineralization in red sedimentary rocks has been reported (Baniczky, 1980). This copper occurrence develops in the subbasal shale and sandstone of the Upper Triassic, suggesting that the mineralization may extend widely.

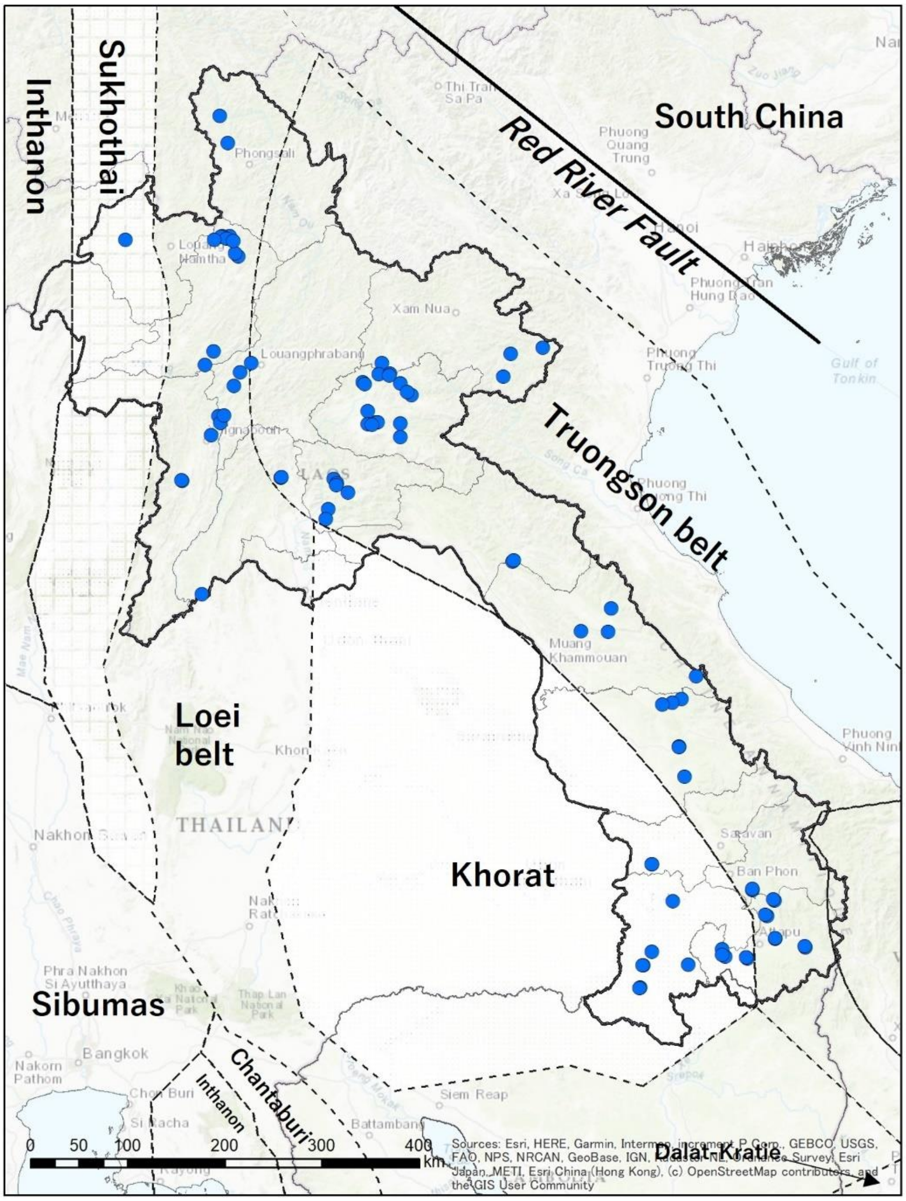


Figure 7-7 Distribution of copper (Cu) mineral resources in Laos

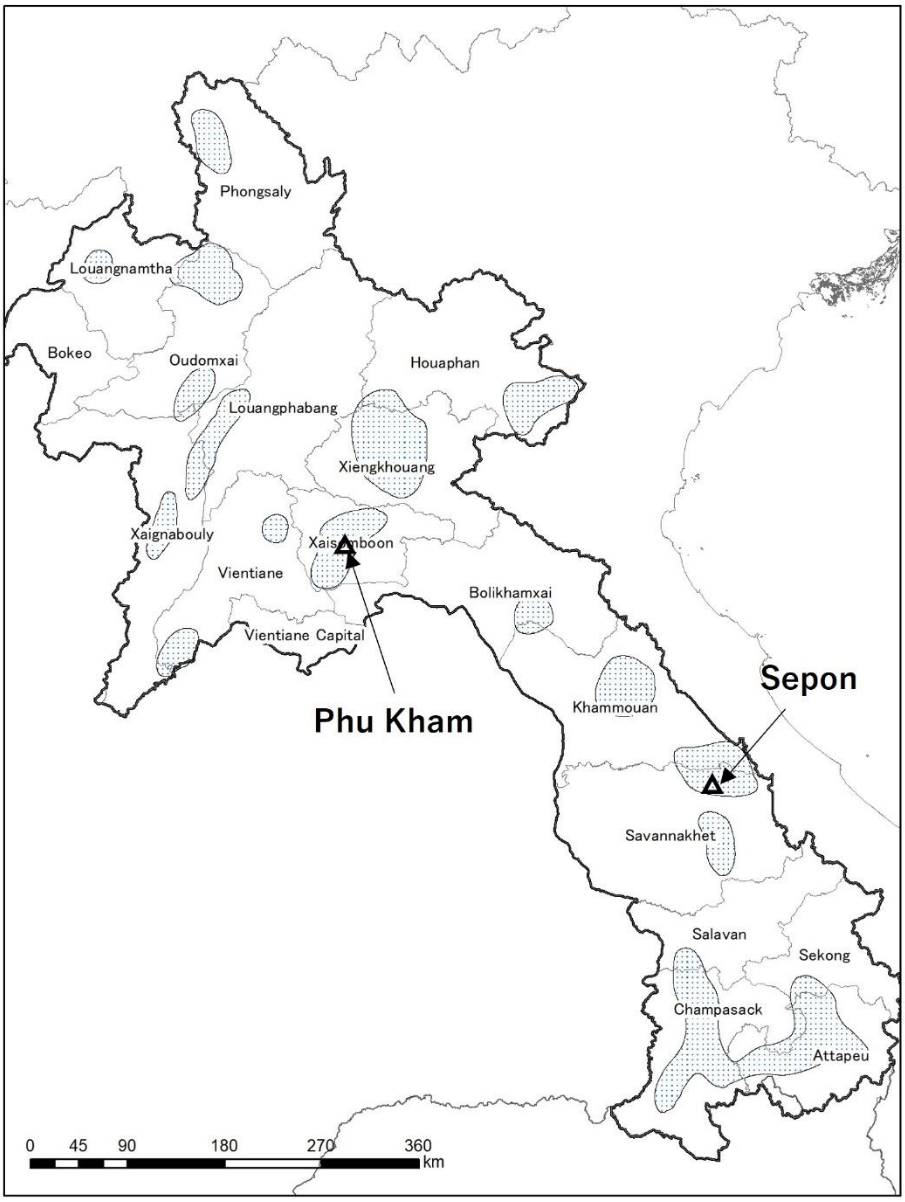


Figure 7-8 Potential area of copper (Cu) mineral resources in Laos

7.3.3 Tin (Sn)

The distribution of tin (Sn) mineral resources (mines, mineral occurrences, etc.) in Laos is shown in Figure 7-9. In addition to the known mineral distribution, the potential area of tin (Sn) mineral resources considering the geology and geological structure is shown in Figure 7-10.

Potential of tin mineral resources in Laos are concentrated in Truongson belt. In general, tin resources are closely related to tin granite. In Laos, the largest tin occurrence is recognized in the Nam Pathene valley, about 60km north of Thakhek in Khammouane province. There are weathered remnants of the tin granite surface and associated sediment and alluvial deposits in young sediments, which have been mined until recently. An average annual production of 430 tons (28-32% Sn) was exported to the former Soviet Union from 1983 to 1988 (Sudo et al., 1996). The confirmed ore reserves of tin are said to be about 65,000 tons, but the actual reserves are expected to be much higher. Similar tin resources from granite weathering granite and alluvial deposit are expected to reserve in the Annamite Mountains along the Vietnamese border. Houaphan and Xiangkhoang provinces in the northeastern part of Laos are another potential areas, where cassiterite and scheelite are recognized. In addition, a tin-tungsten-antimony mineralization zone are known in Louangnamtha province near the Thai border in northwestern Laos. This mineralized belt is continuous from the Chaing Mai-Chiang Rai tin-tungsten mineralized belt in Thailand and extends north into China as the Sanjiang fault zone.

Tin granite is often associated with S-type granite. Veeravinantanakul et al. (2021) pointed out that igneous rocks in the Sibumasu and Inthanon belts are S-type granites originating from old crustal material, and associated tin-tungsten deposits are abundant. In contrast, Sukhothai zone tends to have orogenic gold-antimony-tungsten deposits and epithermal gold-antimony deposits since the igneous rocks in the Sukhothai zone have transitional properties between I-type and S-type.

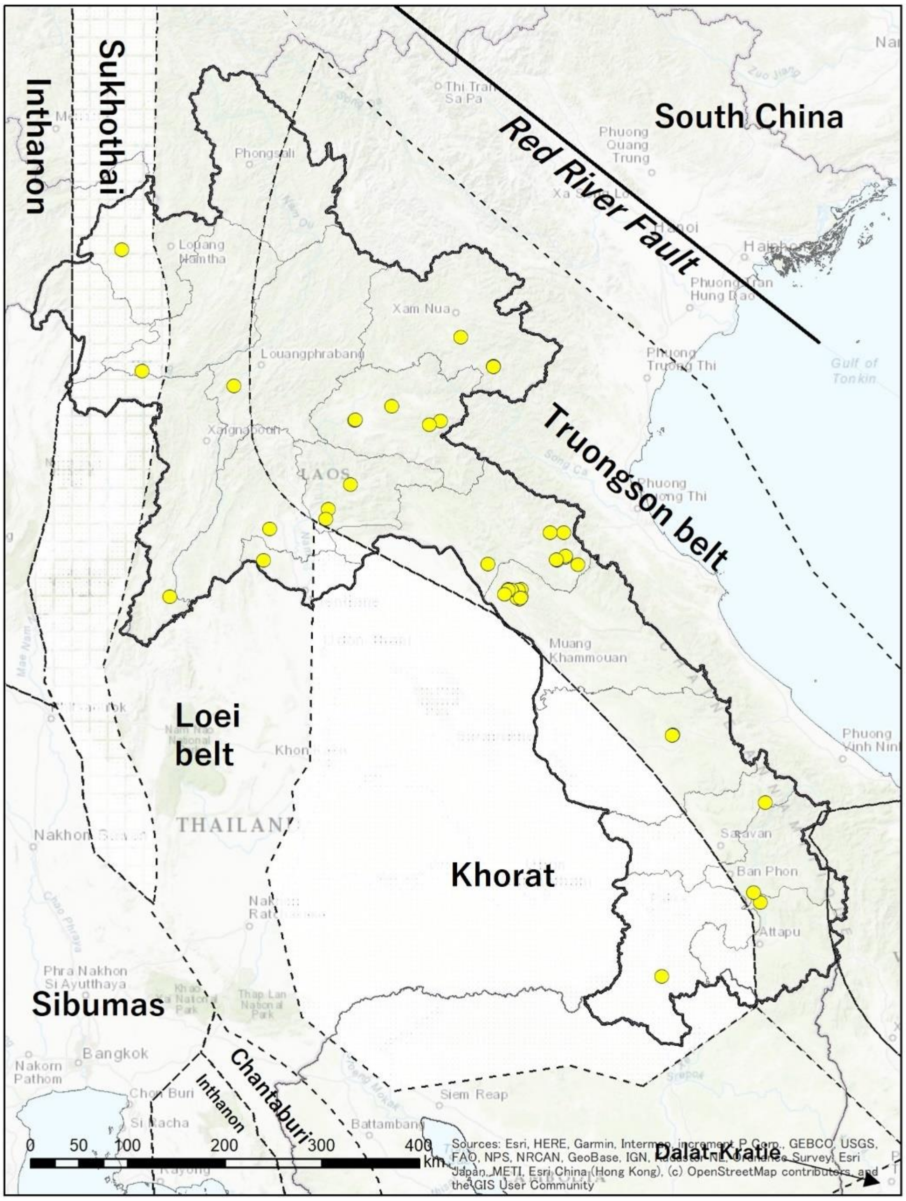


Figure 7-9 Distribution of tin (Sn) mineral resources in Laos

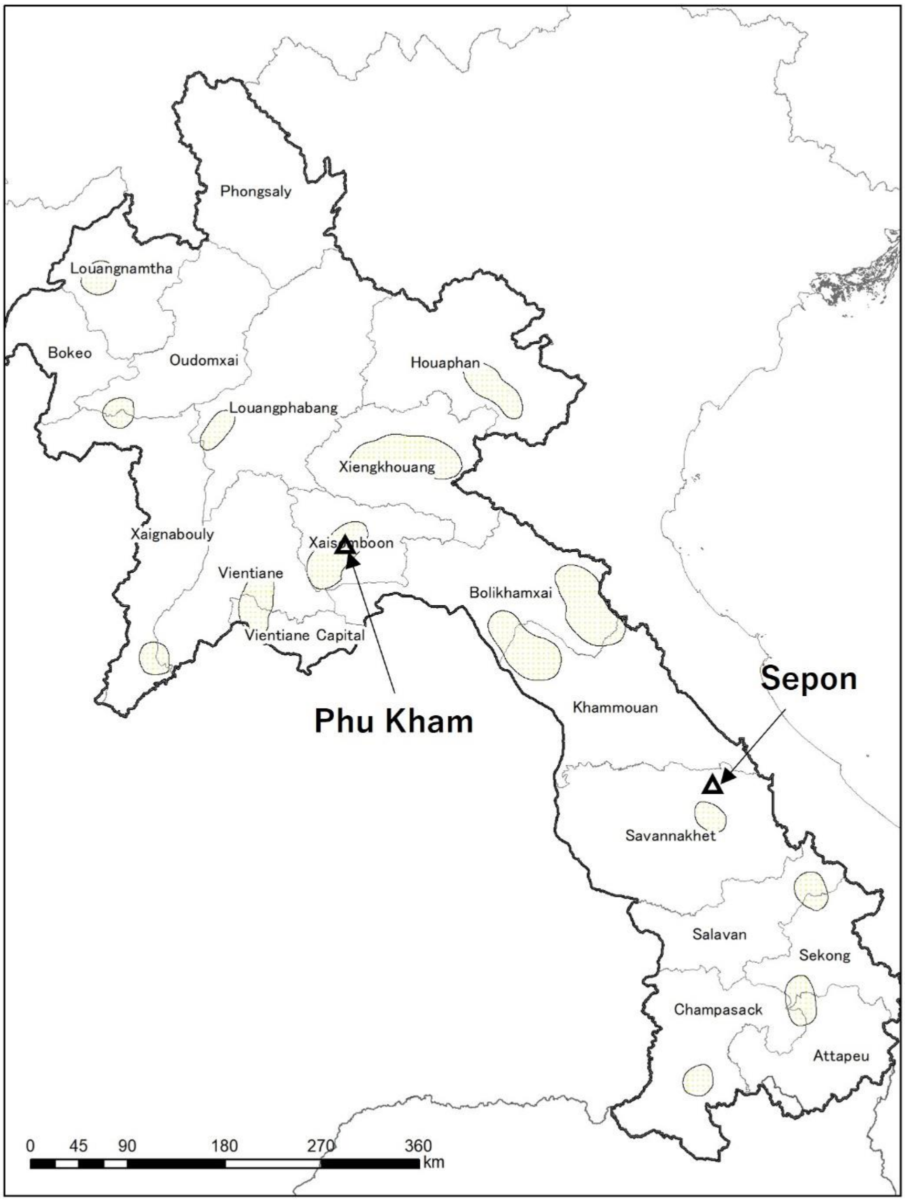


Figure 7-10 Potential area of tin (Sn) mineral resources in Laos

7.3.4 Lead (Pb)

The distribution of lead (Pb) mineral resources (mines, mineral occurrences, etc.) in Laos is shown in Figure 7-11. In addition to the known mineral distribution, the potential area of lead (Pb) mineral resources considering the geology and geological structure is shown in Figure 7-12.

Potential of lead mineral resources in Laos are concentrated in the following two geological zones.

1) Truongson belt
2) Loei belt

Lead mineral resources in Laos are broadly classified into the Skarn type and the Mississippi Valley type. Xiangkhoang province is well known for lead-zinc endowments, and silver-bearing galena and sphalerite are found in Pa Hia and Phou San areas. In Vientian province, the lead-zinc mineralization of Pha Luang and Van Vieng has a relatively wide range of galena and sphalerite mineralization accompanied by adglesite and pyrrhotite. Pha Luang preliminary survey by JOGMEC and Vietnam in 1988 to 1989 found mineralization of 50-60% galena and 17-22% lead sulfate. In the northwestern part, lead are associated with barite and fluorite (JOGMEC, 2005). Other lead and zinc mineralization is found in the Sepon area of Savannakhet province and Champasak province near the border with Cambodia in the south. In addition, since basic volcanic rocks that are thought to have been formed in the back-arc basin are also distributed in the Loei fold belt, there is a possibility that lead-bearing volcanic massive sulfide deposits exist (e.g., Panjasawatwong et al., 2006).

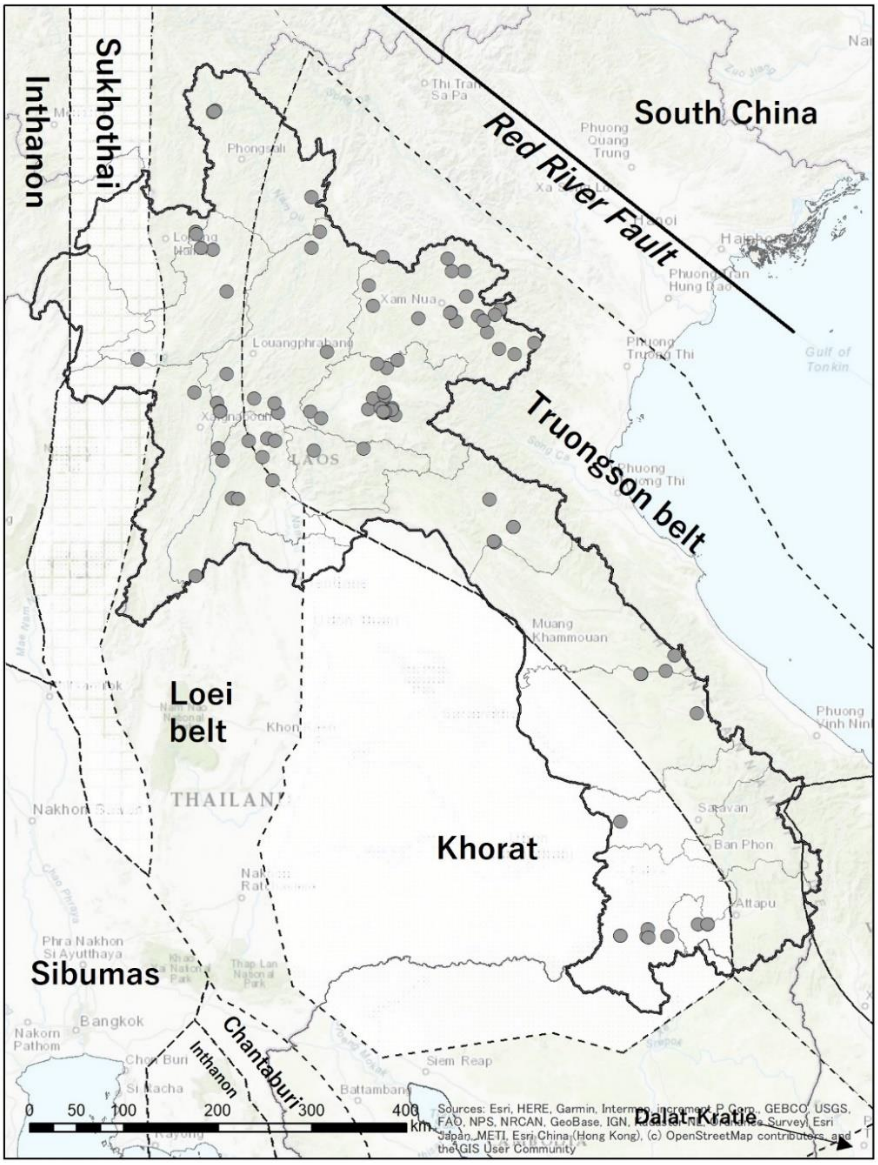


Figure 7-11 Distribution of lead (Pb) mineral resources in Laos

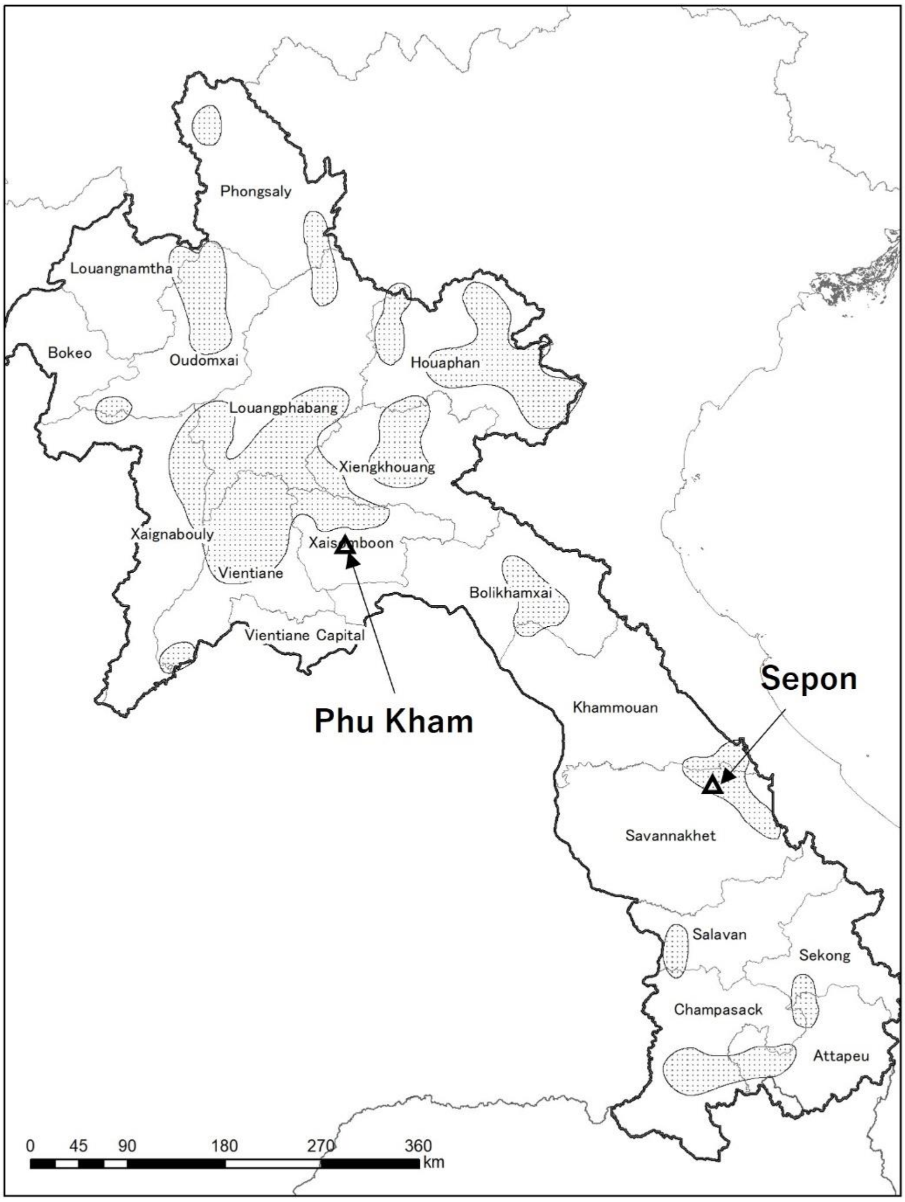


Figure 7-12 Potential area of lead (Pb) mineral resources in Laos

7.3.5 Zinc (Zn)

The distribution of zinc (Zn) mineral resources (mines, mineral occurrences, etc.) in Laos is shown in Figure 7-13. In addition to the known mineral distribution, the potential area of zinc (Zn) mineral resources considering the geology and geological structure is shown in Figure 7-14.

Potential of zinc mineral resources in Laos are concentrated in the following two geological zones.

1) Truongson belt
2) Loei belt

In general, zinc is often produced together with lead, and their distributions and potentials commonly overlap. Zinc is abundant in the junction of the Troungson and Loei belts, as represented by the Kaiso mine (Vientiane province), which Phadeang Industry Public (Lao) Company Ltd. started operating in 2001.

Zinc mineral resources in Laos are broadly classified into the Skarn type and the Mississippi Valley type, but since basic volcanic rocks that are thought to have been formed in the back-arc basin are also distributed in the Loei fold belt, there is a possibility that zinc-bearing volcanic massive sulfide deposits exist (e.g., Panjasawatwong et al., 2006).

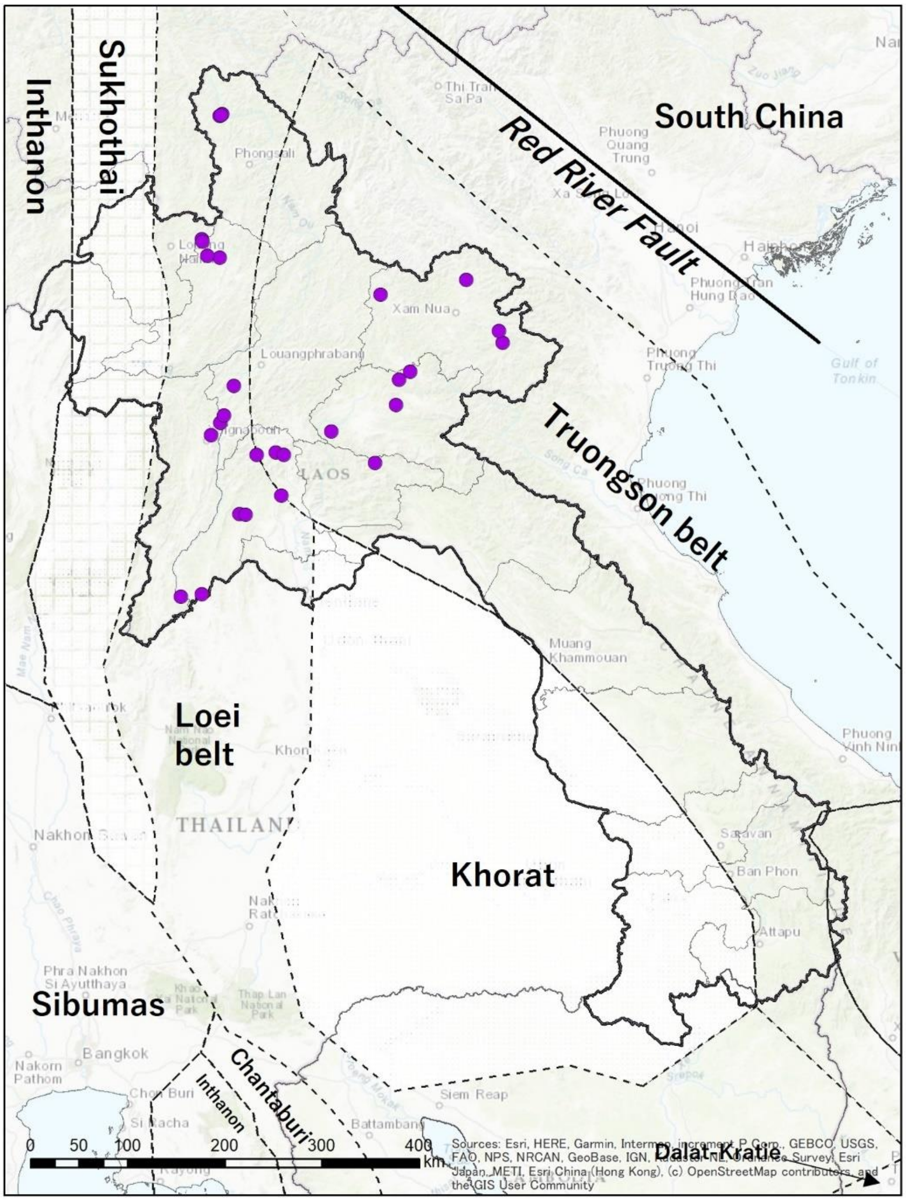


Figure 7-13 Distribution of zinc (Zn) mineral resources in Laos

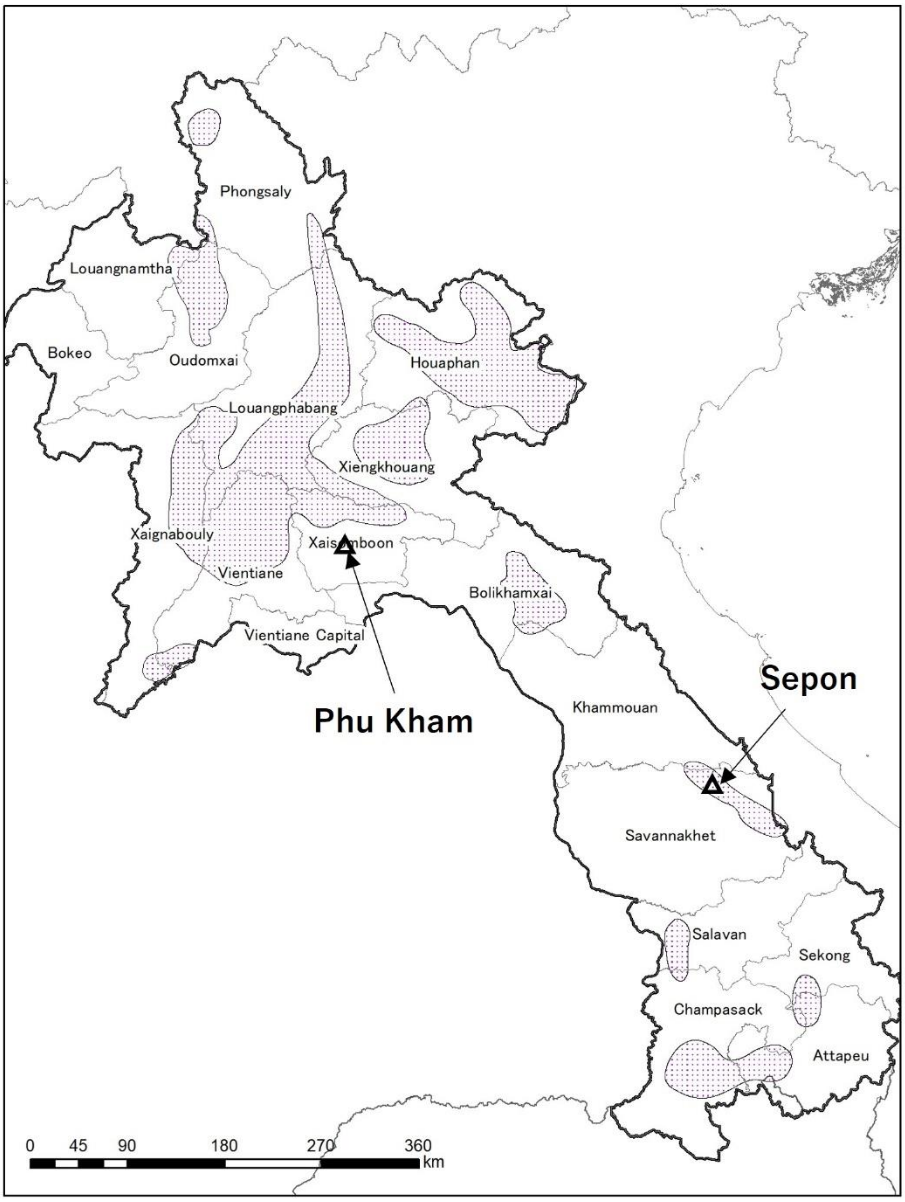


Figure 7-14 Potential area of zinc (Zn) mineral resources in Laos

7.4 Mining administration

7.4.1 Mining policy

Against the backdrop of successive mining developments by foreign capital, coupled with soaring metal prices due to the natural resource boom, the share of the mining industry in Laos' GDP rose sharply during this period, from 0.3% in 2002 to 10.6% in 2008. Since then, however, growth in the mining sector has been limited, partly due to falling resource prices.

(1) Five Year National Socio-Economic Development Plan

Major objectives of 8th Five Year National Socio-Economic Development Plan 2016-2020:

• Diversify Goods and Services and Diminish Natural Resources.

• To Increase the promotion of mineral processing and reduce the export of unprocessed minerals

• Improve mineral production so that raw mineral ores are processed and value added before exporting them.

• Mining areas will be upgraded for regular excavation avoiding socio-environmental impacts.

• Establish sustainable financial mechanisms to manage natural resources and protect the environment.

(2) Financial and technical criteria set for investments in the mineral exploration sector

In 2020, the Lao Ministry of Energy and Mines set certain financial and technical criteria for investments in the mineral exploration sector. The financial criteria call for a minimum of US$10m to be secured for the exploration of precious metals such as gold and silver. The technical criteria require that mining companies have at least five years of experience in the mining industry, or if they do not have any experience, they must contract with a company or expert with experience to conduct exploration. This is because some mining companies have been experiencing delays in their plans and environmental pollution due to financial and technical reasons. There have been cases of resale of project approvals, and since 2016, the government has been conducting nationwide investigations and revoking project approvals for projects that have not been started or have been delayed significantly.

7.4.2 Law and regulation related to mining

Artisanal and small-scale gold mining (ASGM) is an increasingly important economic activity in Lao PDR with the potential to help alleviate rural poverty, in particular, as an income supplement for subsistence farming families. However, the use of mercury and other toxic chemicals in ASGM is known to cause health and environmental risks that affect aquatic ecosystems, miners and their families, and local communities.

To reduce and eliminate the use of mercury in the artisanal and small-scale gold mining sector, the Government of the Lao PDR adopted the National Action Plan for Artisanal and Small-Scale Gold Mining in Lao PDR in accordance with the Minamata Convention on Mercury 2020-2030. This National Action Plan is comprised of 6 objectives and 71 activities to be implemented during the period of 2020-2030.

In 2017, the Lao PDR Mining Law No.04/97/NA of 12 April 1997 and the Law on Minerals No.02/NA of 20 December 2011 were amended to include provisions for specific regions to practice Traditional Mineral Panning. Traditional Mineral Panning is defined by Article 85 of the Lao PDR Law on Minerals No. 291/POR, 2017.

According to the article 38 of the Law on Minerals of 2017, two types of licenses can be delivered following the two types of the mining business (table 1.):

1. Mining Business: Mining Business is the activities on prospecting, exploration, Technical-Economic Feasibility Studies, mining including the action on mining concession right.
2. Business on Specific Categories of Mineral: Business on specific categories of minerals does not

have to follow all the steps of prospecting and exploration in the operation of its mining business.

Types of business related to special categories of minerals are as follows:

1. Traditional metallic minerals refining
2. Non-Metallic minerals mining for construction
3. Non-Metallic minerals mining for industries

According to the article 70 of the Law on Minerals 2017, Large Mining Projects shall be provided in specific regulations and request consideration from the Prime Minister.

7.4.3 Budget related to mining sector

(1) Fiscal regime

According to the existing documents, below are the tax, royalties, fees, and duties for the mining activities in Lao PDR:

• Rental fee for:

-Prospection, Exploration and Pre F/S: 0.5 – 1 USD/ha/y

-Mining: 3-12 USD/ha/y

• Royalty: 1 – 7 % depend on type of Mineral and type of product

• Cooperate income tax: 25 -35 % depend on size of project and type of mineral.

• Option share: Government have right to have 10 % of option share by borrowing from investor and Reimbursement capital and interest by future dividend

• Value added tax 7-10%

• Withholding tax: 30% for gross profit rate and 6% for the profit tax deemed rates

• Intangible fixed assets, Tax adjustment on Mining exploration and research costs: 20%

• Import and supplies of minerals in the domestic market: VAT 7%.

• Concession fee (not mentioned in the law or decree)

• Other incentives:

1. Exemption of import duties and taxes on raw materials and capital equipment (not including vehicle and fuel)

2. Exemption of export duty on export products

3. 10% personal income tax on expatriate employees

4. Additional tax holidays, reduced tax rates for large projects with special concession are available upon negotiation.

(2) Bilateral Investment and Taxation Treaties

A bilateral investment agreement between Japan and Laos came into effect in 2008, and the two countries are working to improve the investment environment through joint public-private dialogue. In addition, this bilateral cooperation was upgraded to a ‘Strategic Partnership’ in 2015, and the ‘Japan-Laos Joint Development Cooperation Plan was signed in 2016, strengthening the bilateral cooperative relation

(3) State-Owned Enterprises

The Lao government maintains ownership stakes in key sectors of the economy such as telecommunications, energy, finance, airlines, and mining. The article 106 in the Law of Minerals 2017 stipulates that: “The government has the rights to undertake the share of minerals business in maximum of 20%”. And the payment of Share by Government shall be implemented in accordance with Enterprise Law or Joint venture agreement.

7.4.4 Management system of mining sector

Since 2006, Ministry of Energy and Mines (MEM) is the primary responsible for the mining industry with jurisdiction over policy making, administrative management, strategy, technical management, geological surveys, and environmental protection. This Ministry includes the Department of Geology and Minerals (DGM) and the Department of Mine (DOM). The DGM is responsible of geological survey and DOM oversees the mining concession, management and promotion of mining, mineral further processing and export and import of mineral products, environment and inspection, contracts and licenses, and laws.

The Ministry of Energy and Mines is in close coordination with other agencies, concerned ministries and local administrative authorities for all activities related to the mining and mining environment. The Provincial and Capital Departments of Energy and Mines, District, Municipality, and City Offices have overlapping responsibilities for the management of traditional metallic mineral panning (Article 86 of the Law on Minerals 2017). The Ministry of Energy and Mines, in collaboration with the local administrative authorities, is in charge of issuing the regulations on the management of traditional metallic mineral panning, including the monitoring of their implementation.

Law on Minerals 2017 stipulates that prior to the license application, the legal entities shall apply investment license at the Investment Single window of service office at the Ministry of Planning and Investment (MPI), which is in accordance with the Law on investment promotion. After obtaining the investment licenses, the investors shall apply for the approvals on Prospecting, Exploration and Technical-Economic Feasibility Studies operation to the Ministry of Energy and Mine (MEM).

For large projects, the Acceptance on Technical-Economic Feasibility Study Reports requires evaluation from third party on natural-social environment impact evaluation reports, rehabilitation, and mine closure plans (article 63 of Law on Minerals 2017).

After the completion of Technical-Economic Feasibility Study, the licensed investors can implement mining under the negotiations and contracts with the government. Regarding the licenses, the ministry of Energy and Mine (MEM) is responsible of the issuance of prospection, exploration and mining licenses;

and coordination on the administrative procedure at different levels of the government, ministries, National Assembly and to the Prime Minister.
Ministry of Natural Resources and Environment (MoNRE) is responsible of evaluating and monitoring of the natural-social environment impact evaluation reports of the future mining activities, inspecting and managing plans along with certificate of natural-social environment obligations. Also, monitoring of the mine closure plan, environment rehabilitation plan and along with inspecting plan after mine closure.

7.4.5 Issues

While the Energy and Mine has contributed to the country's socio-economic development and created a solid foundation for industrialization and modernization, the sector is also facing several challenges including:

(1) Administration level:

-Complexity of the administrative process for many foreign business owners and potential investors. It was reported that multiple ministries become involved in the approval process prior to commencing operations. and create confusion about the roles of different ministries.
-Government staff: lack of technical skills and knowledge, limited number
-Rules and regulations for the implementation of the Mining law in accordance with international standards partly missing
-Limited supervision capacity of the mandated authorities

(2) Limitations of the Law on Minerals:

-The timing of submission of the environmental survey: The Law of Minerals 2017 does not clearly define the timing of the environmental survey to be carried out compared to the application of license of each activity (article 46, 50). The text just mentioned the need of result of natural-social environment information collection (article 61) or results of natural-social environment information collection, natural-social environment inspecting and managing plans. (article 62) environmental certificate for the report (article 63).

(3) Limited job opportunities for locals

-Foreign-owned industries/companies prefer foreign workforces (Chinese or Vietnamese) with regard to skilled labor.
-Local villagers indeed often lack the skills for well-paid jobs and thus compete with migrants from China/Vietnam, as well as from other Lao provinces

(4) Infrastructure:

-Lack of infrastructure and limited access to capital and technology

(5) Human Right:

-Risk to health and safety of workers at project sites.

-Limited number and capacity of locals working in the mining sector

(6) Financial issues:

-Lack of financial resources to fulfill the national agendas for 2021-2023 and of the Sustainable Development Goals (SDG)

-Problem of accumulated debt involving mining projects, relating to the payment of concessions and contractual capital.

7.5 Environment administration

7.5.1 Environment policy

Lao PDR is a signatory of the Convention on Biological Diversity (CBD) also known as the Rio Convention in 1996. Under the technical support from IUCN (International Union for Conservation of Nature) and local government offices, NGOS and development partners, the Ministry of Natural Resources and Environment (MoNRE) established the National Biodiversity Strategy and Action Plan (NBSAP) in compliance with the article 6 of the CBD on General Measures for Conservation and Sustainable Use. The recent National Biodiversity Strategy and Action Plan (NBSAP) 2016 -2025. The NBSAP provides broad recommendations to contribute to global, and achieve national, biodiversity targets leading up to 2025. The actions identified within the strategy are designed to be flexible enough to, with appropriate adjustments, support the continuing development of the country.

To address the concern that the growing development will cause irreversible serious ecological and socio-economic damages without adequate and sustainable planning and management of natural resource, the Lao PDR provided the national development agenda to settle the national`s guidelines in order to manage the economy, and to achieve development goals. The Lao PDR Vision toward 2030 and its 10-year Strategy 2016-2025, the 8th Five-Year National Socio-Economic Development Plan, NSEDP, 2016-2020, as well as the National Green Growth Strategy of the Lao PDR till 2030, all policy documents focus on green growth and their contributions to long-term social economic development goals.

In 2015, under collaborative support with various ministries, the Ministry of Natural Resources and Environment (MoNRE) developed a vision toward 2030 and its 10 years strategy 2016-2025 that focuses on making Lao PDR Green, Clean and Beautiful, based on Green Economic Growth, to ensure Sustainable Resilient Development and Climate Change. This strategy aims to ensure sustainable utilization and management of natural resources for future generations, together with improving healthy environment and wealth for all people in Lao PDR. This vision was developed based on the government vision for socio-economic development towards 2030, and international policies such as the Millennium Development Goals (MDGs) and Multilateral Environmental Agreements (MEAs).

In 2018, National Green Growth Strategy of the Lao PDR till 2030 is developed to strengthen the balance between economic expansion, environmental protection, and social development to ensure the maintenance of high, stable, sustained and durable economic growth. In particular, this National Green Growth Strategy of the Lao PDR has focused on: (1) encouraging and promoting the economic growth and poverty reduction in a comprehensive, inclusive and fair manner, allowing all persons in the society to receive the benefits from such development; (2) raising the efficiency and effectiveness of the utilization of limited natural resources of the country to ensure optimal benefits; (3) economic growth that is clean and environmentally-friendly and that decreases wastes and greenhouse gas emissions; and (4) increasing the economic resilience to climate change, natural disasters and of global economic uncertainties.

The medium-term development plans, called, National Socio-Economic Development Plans (NSEDP) provide Lao PDR with the opportunity to continue implementing the SDGs through its national planning frameworks up to 2030. The remaining SDGs indicators and lessons from the previous NSEDP will be integrated into next NSEDPs. The most recent adopted plan was the 9th Five-Year National Socio-Economic Development Plan (NSEDP9) 2021-2025. This Five-year Plan is the continuation of the National Strategy on Socio-Economic Development 2016-2025. It aims to effectively utilize the full country`s potential to ensure the development direction into the quality, inclusive, focused green and sustainable growth to lead the country out of the least developed country status by 2026 and to achieve the Sustainable Development Goals (SDGs). In 2021, the Government of the Lao PDR supplemented the NSEDP9 with the National Agenda 2021-2023 for resolving economic and financial difficulties.

7.5.2 Law and regulation related to environment

The legal framework for environmental management of development projects is embodied in the National Law 02/1999 or the Environmental Protection Law (EPL) which was approved by the President on 03 April 1999 and amended on 18 December 2012. Environmental Protection Law (EPL) in Lao PDR enacted in 1999 was revised by the law No. No:29/NA in 2012. Environmental and Social Impact Assessment (ESIA) regulations requirements are contained in EPL articles 17, 21, and 22. In addition to ESIA-preparation criteria, the regulations include provisions for an Initial Environmental Examination (IEE) process.

In addition, MoNRE issued two Ministerial Instruction to implement the provisions of EPL's Articles 21 and 22: (i) Process of Environmental and Social Impact Assessment of the Investment Projects and Activities No 8030/MoNRE, and (ii) the Ministerial Instruction on the Process of Initial Environmental Examination of the Investment Projects and Activities No 8029/MoNRE

In January 2019, the Government of Lao PDR led by MoNRE, approved a new Decree on Environmental Impact Assessment that aims to close loopholes by incorporating some of the provisions provided in the Regulations No.8030. The new ESIA Decree 2019 No.21/GOL of 31 January 2019 aims to ensure consistency in the conduct of Environmental and Social Impact Assessment applied to all investment projects and activities, both by domestic and foreign enterprises operating in Lao PDR, that cause or are likely to cause environmental and social impacts. The objective is that proponents of investment projects and activities shall conduct effective ESIAs, thereby contributing to the country's sustainable socioeconomic development while mitigating the effects of critical issues such as climate change.

In Lao PDR, private investment projects in the natural resources sector, including hydropower projects, mining projects, and agriculture and forestry projects, are required to enter into a concession agreement with the Government of Lao PDR. The concession agreement (CA) for such projects may contain specific

environmental and social obligations complementary to, and in addition to, the statutory requirements.
ESIA is required for all projects (irrespective of type and size) that include resettlement and compensation in accordance with the Prime Minister's Decree on Compensation and Resettlement of People Affected by Development Projects No 192/PM. An ESIA is also required if the planned project is in a socially or environmentally valuable area, such as a National Protected Area or National Protection Forest or areas that also require project approvals by the Lao PDR National Assembly.
The Law on Minerals No31/NA of 2017 defines that mineral activities shall ensure the safety, sustainable development of mineral area and environmental protection (article 6).
Lao PDR particularly pay close attention to the severe impact of the mercury used by the Artisanal and small-scale gold mining (ASGM) to the environment and the health of the miners and the surrounding communities. After the ratification of the Minamata Convention on Mercury, the Government of Lao PDR adopted the Minamata Initial Assessment (MIA) and National Action Plan (NAP) for the ASGM Project. As a Party to the Convention, Lao PDR has an obligation to take steps, as outlined in Article 7 of the Convention, to reduce, and where feasible eliminate, the use of mercury and mercury compounds in the ASGM sector.

7.5.3 National park

The Forestry Law No. 06/ NA, enacted on 24 December 2007, and replaced by the Law No. 08/NA of 13 June 2019, outlined the Forestland Management, obligation of the Forestland users and rehabilitation.
The article 91 of the Forestry Law of 2019 stipulates that for Concession of Forestland for Mineral Extraction Operations: "The National Assembly shall approve the concession of forestland for large scale mineral extraction projects based on a proposal from the Government. Concessions for other mining projects are based on the decision of Government. Procedures and timeframes for the concessions shall be governed by the Law on Minerals. The concessionaire shall be responsible for paying all fees as stated in Article 82, paragraph two of this law".
The article 82 paragraph two on Obligations in Converting Forestland states as follow: "For the temporary conversion of forestland, the person who receives the approval shall be exempt from paying conversion fees, but shall be responsible for paying technical service fees, forest ecosystem service fees, biodiversity compensation fees and the cost of tree planting offsets and land reclamation. For the conversion of forestland to open-cast mining areas, forestland conversion fees must be paid."
The article 127 define the obligations of Forest and Forestland Users: "The users of forests and forestland have an obligation to reclaim the land, plant trees, and regenerate the forest when mining or other activities have been completed".
The article 148 explains that "the Government manages forest and forestland activities in a centralized and uniform manner throughout the country by assigning the Ministry of Agriculture and Forestry as the central agency to coordinate with the Ministry of Natural Resources and Environment, the Ministry of Industry and Commerce, the Ministry of Energy and Mining, the Ministry of Health, local administrative authorities and other relevant authorities."

7.5.4 Environmental survey related to mineral resources development

Available data is very limited for the ESIA report for the mining sector in Lao PDR. This synthesis on environmental survey is based on the text from decree on Law on minerals, 2017, and decrees on Environmental Impact Assessment (EIA)

The above documents indicate the appropriate environmental survey related to each step of mineral activity:

-For Prospecting:

- Natural-social environment information collection

-For Exploration license:

- Natural-social environment information collection, natural-social environment inspecting and managing plans.

-For Technical-Economic Feasibility Studies:

- Natural-social environment impact evaluation reports, natural-social environment inspecting and managing plans and along with certificate of natural-social environment obligation.
- Environment rehabilitation plan and along with inspecting plan after mine closure

The mining operator will get environmental certificate to be submitted with the report of each mining activity.

7.5.5 Issues

The following issues were collected from the following literatures review.

(1) Administration:

- Lack of technical skills: According to Central and local officials do not have enough technical capacity to properly review ESIAs. The capacity of Provincial/Capital Department of Natural Resources to review IEE is still limited.
- The availability of the data about ESIA is limited
- Lack of financial capacity at government level. Combined with the lack of human skills, the situation hampers the effective control of extractive industries.
- Insufficient monitoring capacities in relevant institutions like the Ministry of Energy and Mines, Ministry of Natural Resources and Environment, and the Ministry of Planning and Investment, along with the lack of communication between them and the respective national, provincial and district levels.
-

(2) Environment:

- The Artisanal and small-scale gold mining (ASGM) contributes to land degradation and pollution that affect the surrounding community and livelihoods (farming, fishing, and livestock) of these communities.
- Deforestation and water resources contamination and health risks by the large mining company

(e.g. Hongsa lignite coal plant and mining project in Xayaboury province)

(3) Limitation of the regulations and laws:
- Lack of compliance with regulations and social and environmental safeguards.

7.6 Satellite image analysis

7.6.1 Mining area

The locations of the survey area (described above in section 2.2.1) and the two mining areas are shown in Figure 7-15, and the locations of the three ASM gold sites are shown in Figure 7-16. The background of Figure 7-15 is a true color image from Sentinel-2, with the red box representing the area of satellite image analysis and the blue box representing the mining area. ASM gold (ASGM) site is located outside the originally planned area of satellite image analysis. Figure 7-16 shows ASGM location map, carried in the National Action Plan in Minamata Convention on Mercury 2020-2030 prepared by MoNRE. Two mining areas of Ban Houayxay copper-gold mine and Phu Kham copper-gold mine and three ASGM sites in Phou Phanh, Thitnoun, and Phugnang were analyzed.
Target ore types in Laos are gold, copper, tin, lead, and zinc.

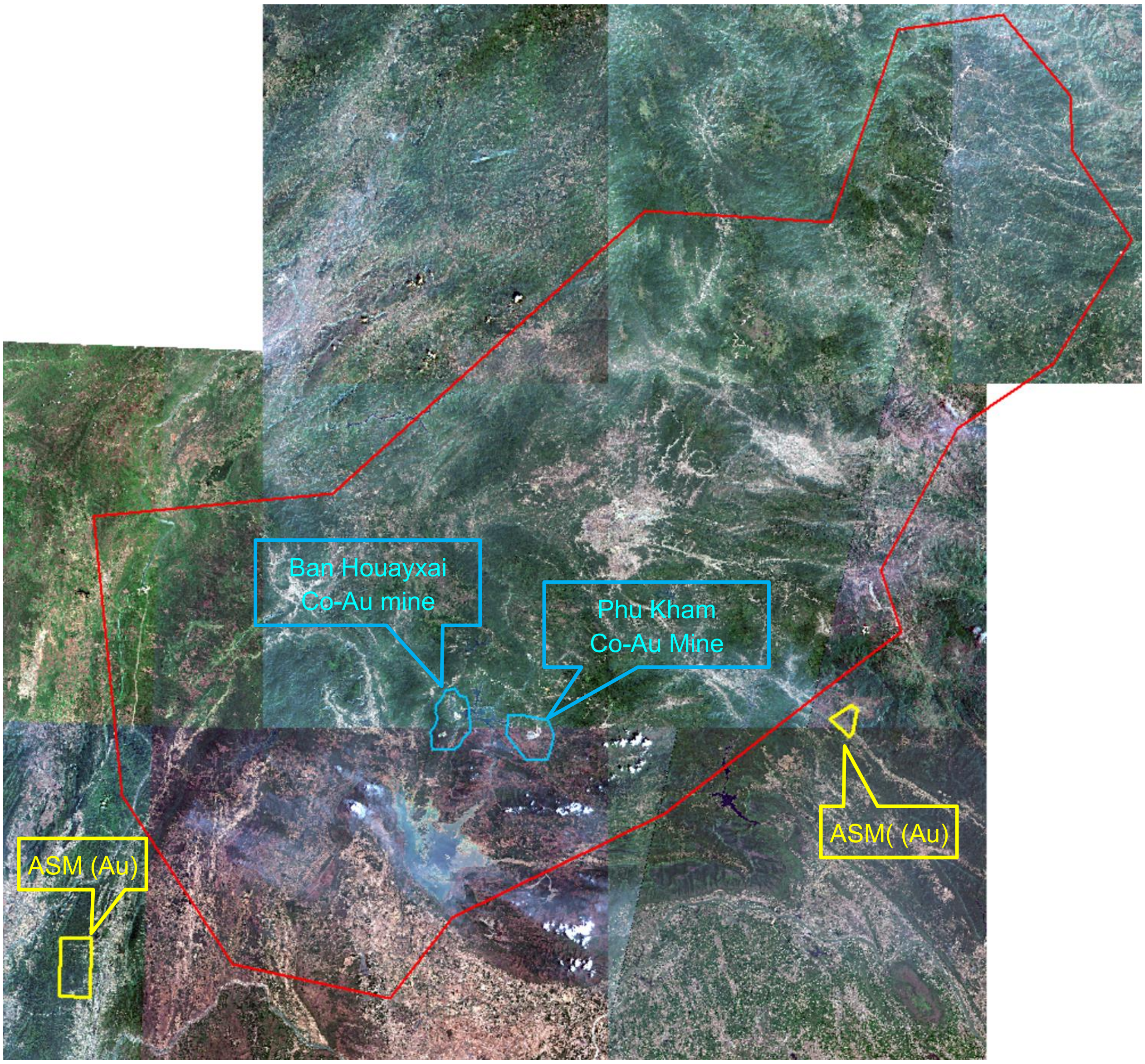


Figure 7-15 Mining areas in Laos

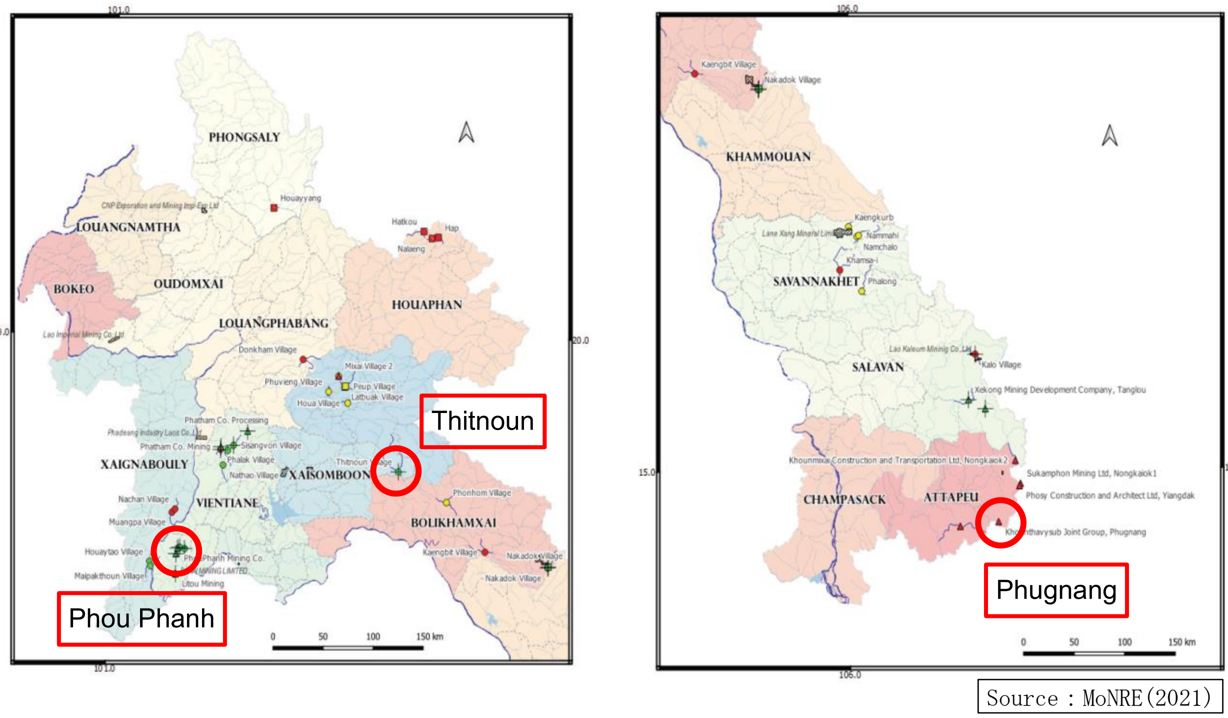


Figure 7-16 ASGM location map and satellite data analysis sites in Laos

7.6.2 Time series change

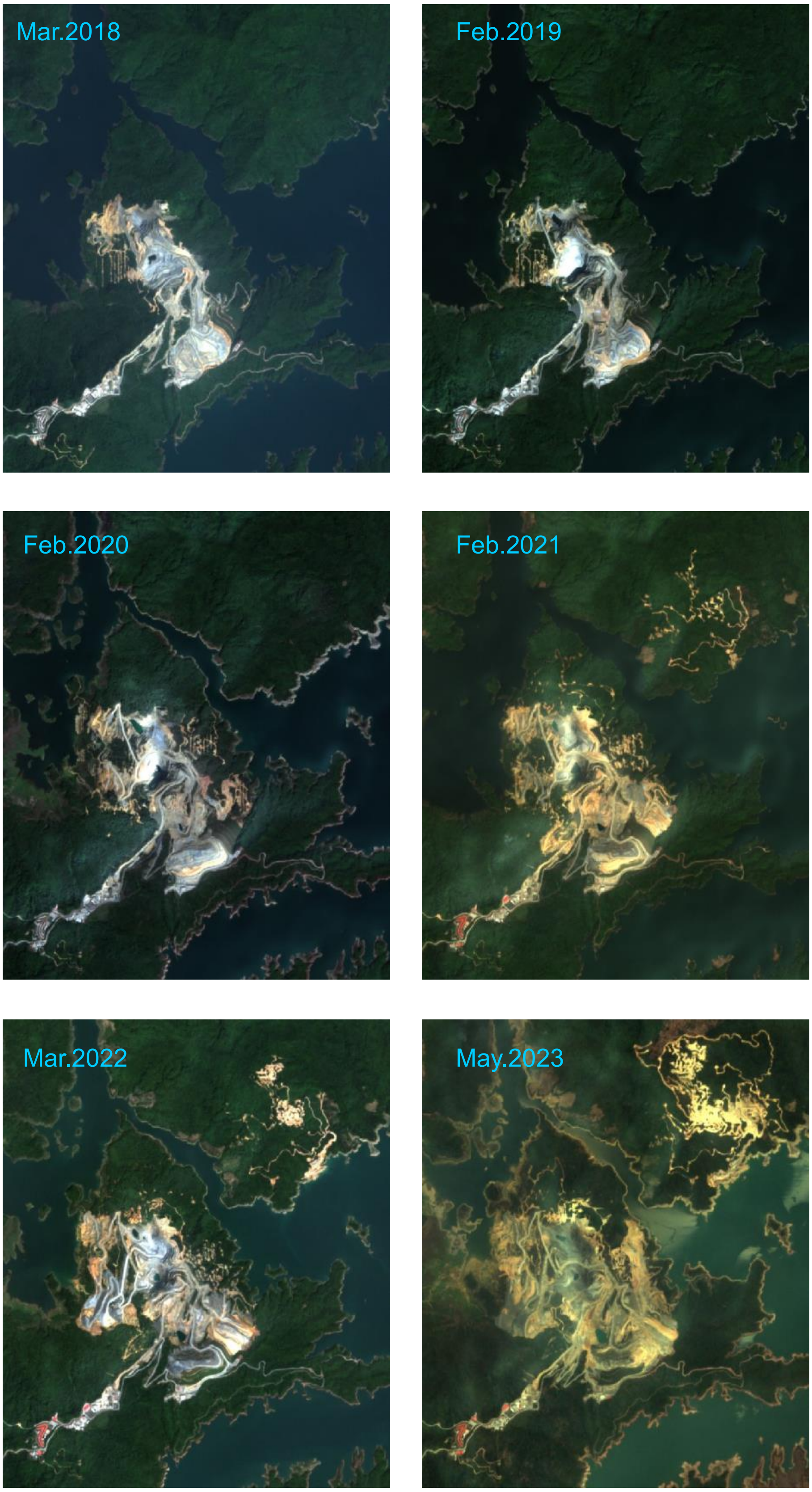
(1) Ban Houayxay copper-gold mine

Ban Houayxay mine started production in 2012, and although the mining area in the north-central part does not appear to have changed much since 2018, the area of opencut mining has been enlarged and the pit depth has deepened. The new construction of pits and waste rock deposition site is discernable. The current area of operation is expected to expand to the north and the west.

On the other side of the dammed lake in the northeast, it can be read that exploration was starting and expanding after 2021.

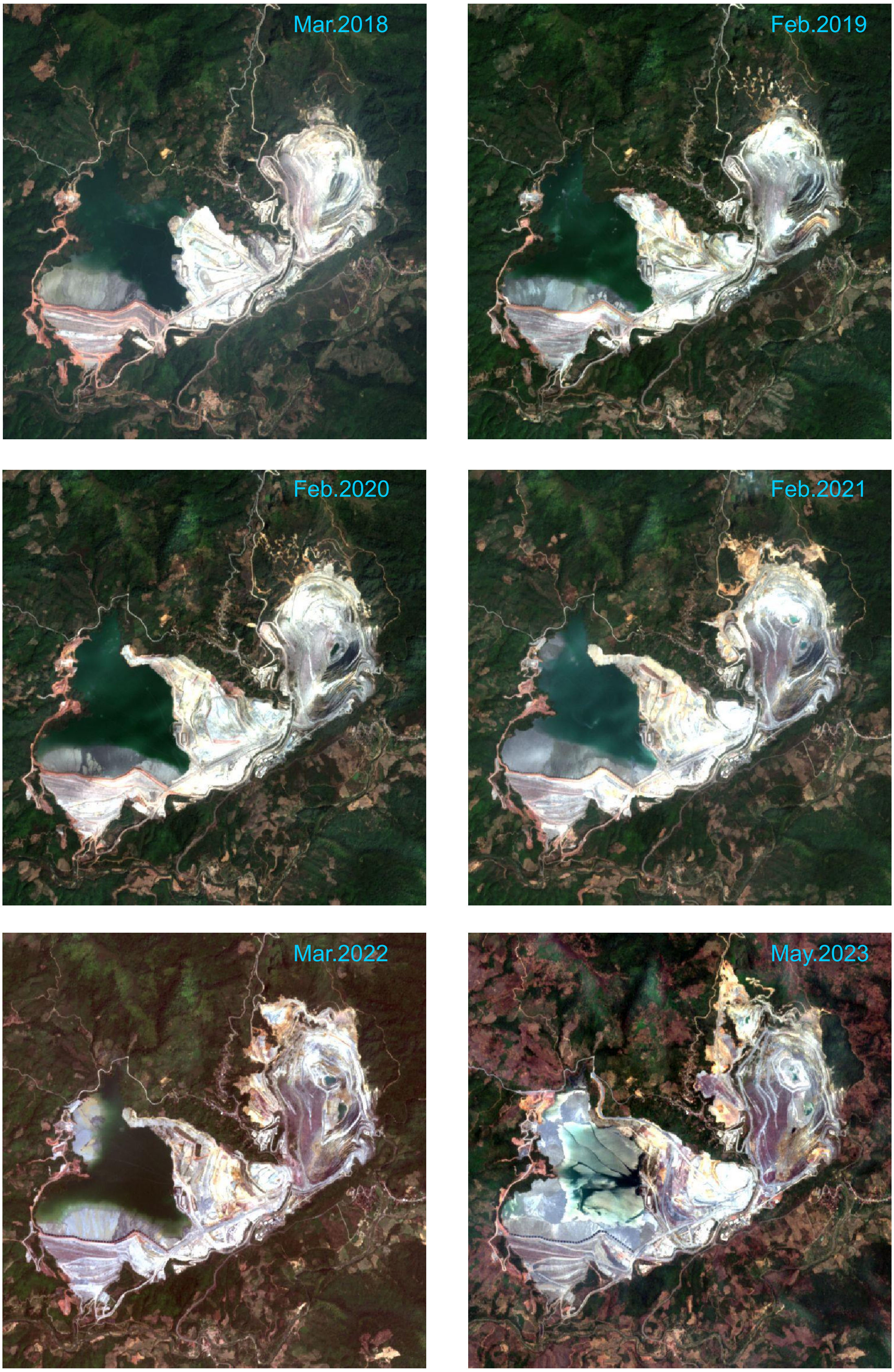
(2) Phu Kham copper-gold mine

The Phu Kham mine has been in operation since 2008, and since 2018, the opencut mining pits can be discerned expanding to the north. In conjunction with this expansion, the waste rock deposition area has also been expanded to the north. It can also be deciphered that exploration has been progressing north of the current main pit since 2019, and that a new pit has been constructed at the same time as the expansion of the pit.



Note: The annuals are newer from top left to right, middle left to right, and bottom left to right, in that order.

Figure 7-17 True color images of Ban Houayxay mining area from 2018 to 2023.



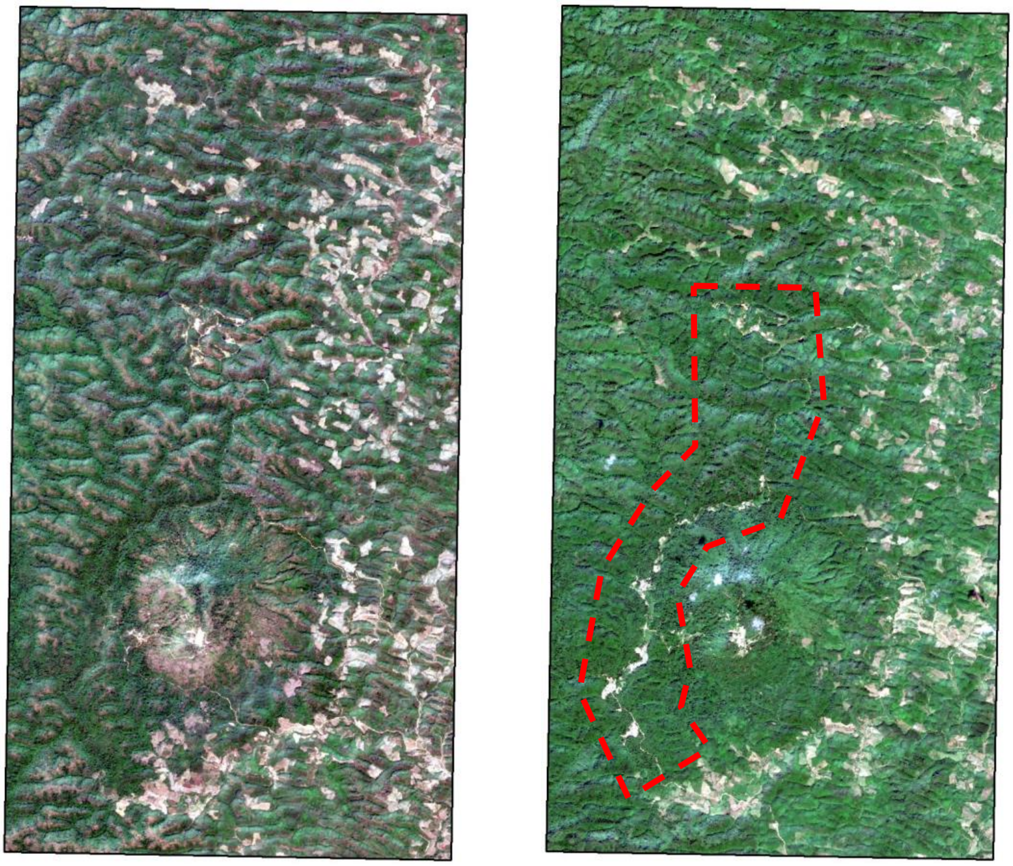
Note: The annuals are newer from top left to right, middle left to right, and bottom left to right, in that order.

Figure 7-18 True color images of Phu Kham mining areas from 2018 to 2023

(3) Phou Phanh ASGM

After examining Google images based on Figure 7-16, a non-vegetated area with numerous ponds along the river, indicated by the broken line box in the right image of Figure 7-19, was identified as ASGM mining site. Sentinel-2 data were analyzed for this area, and the true color images taken in January 2020 and December 2023 are shown side by side in Figure 7-19.

In the Sentinel-2 image, bare areas without vegetation can be seen dotting along the river, but the presence of ponds cannot be recognized. The shape of the bare areas appears unnatural, unlike typical cultivated land, but it is difficult to determine that these are ASM mining areas. This area was covered with vegetation in 2020, after which ASGM mining began.



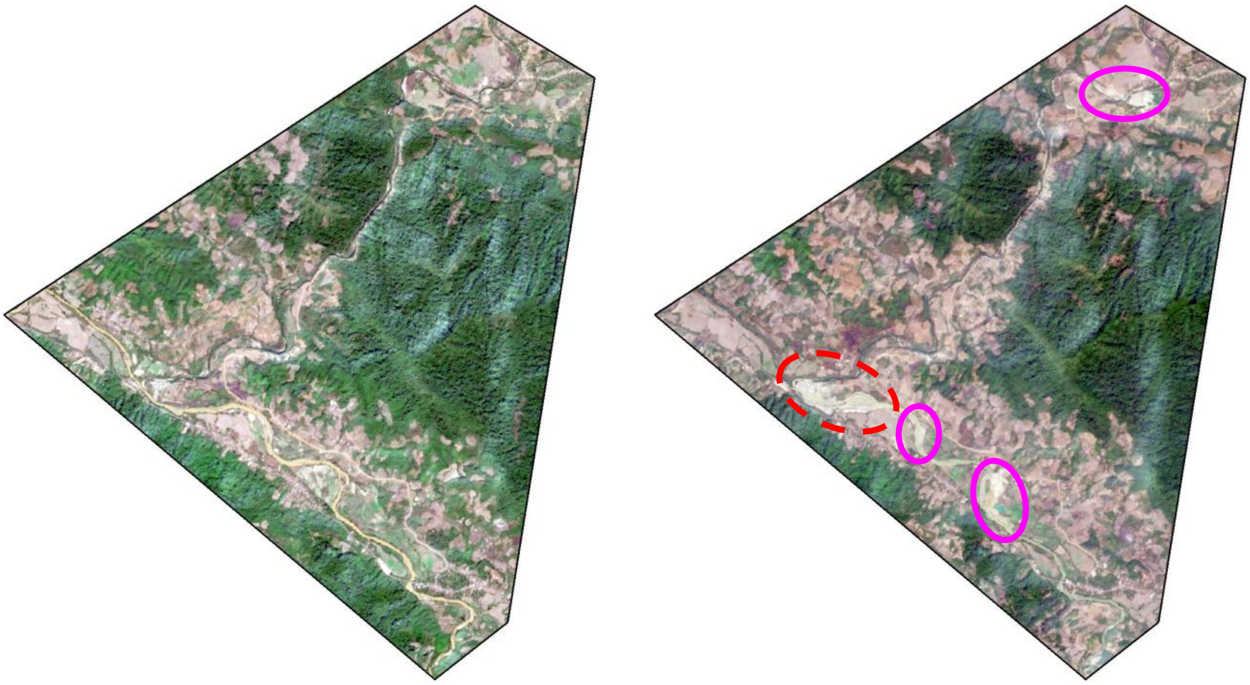
Left: January 2020 image, Right: December 2023 image (ASGM site in red broken line box)

Figure 7-19 True color images of Phou Phanh ASGM site in 2020 and 2023

(4) Thitnoun ASGM

After examining Google images based on Figure 7-16, we identified an area with multiple ponds and bare areas along the river, indicated by the oval line in the right image of Figure 7-20. We considered it as an ASGM mining site. Sentinel-2 data were analyzed for this area, and the true color images taken in January 2020 and February 2023 are shown side by side in Figure 7-20.

In the time series images of Sentinel-2, modification of stream channel is observed along the river, and several areas of artificial bare ground have appeared, and similar bare ground can be seen in the upstream area of the north side. This area was covered by cultivated land or vegetation in 2020, after which ASGM mining began.



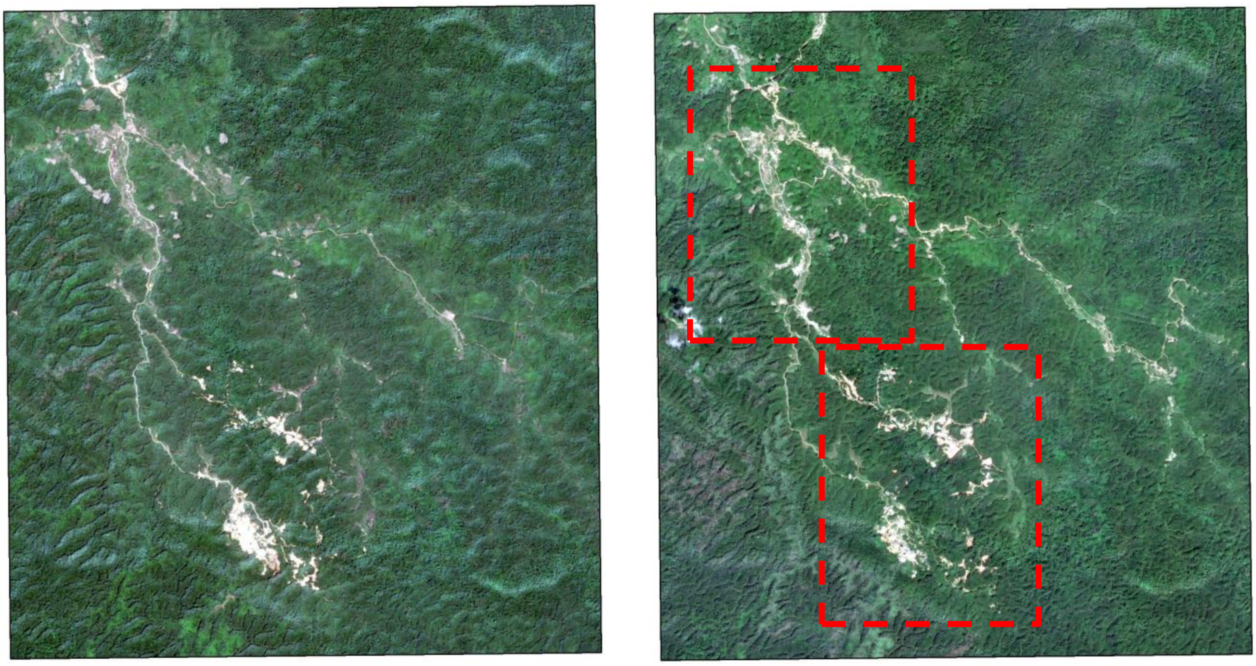
Left: January 2020 image, Right: February 2023 image (ASGM site is in the oval line box)

Figure 7-20 True color images of Thitnoun ASGM site in 2020 and 2023

(5) Phugnang ASGM

Examination of Google images based on Figure 7-16 identified a non-vegetated area with numerous ponds along the river, indicated by the broken line box in the right image in Figure 7-21. We considered it as an ASGM mining site. Sentinel-2 data were analyzed for this area, and the true color images taken in January 2020 and December 2023 are shown side by side in Figure 7-21.

In the Sentinel-2 image, a series of bare areas without vegetation along the river in an irregular shape is observed, and the presence of a pond is also recognized, which looks like an ASGM mining site. In this area, it can be read that the mining sites have moved from year to year (vegetation has recovered after the end of mining).



Left: January 2020 image, Right: December 2023 image

Figure 7-21 True color images of Phugnang ASGM site in 2020 and 2023

7.6.3 Analysis result

(1) Ban Houayxay copper-gold mine

Ban Houayxay mine began production in 2012. In Figure 7-22, the operating area for each year from 2018 to 2023 in Figure 7-17 is deciphered and drawn in GIS, with the polygon of the most recent year, 2023, at the bottom, and the polygons of the older years in turn overlaid by different coloring.

Figure 7-17 shows that the central mining area has not changed significantly since 2018, and that the development has progressed on the periphery. Exploration at both sides of the dammed lake in the northeastern area began in 2021, and its extent has expanded over the years.

The latest Sentinel-2 image (taken on December 17, 2023) of the Ban Houayzay mine operation area is shown in Figure 7-23. In this image, the opencut pit (in operation and partially submerged), waste rock deposition area, mine building, plant, tailings dam, and tailings disposal area can be discerned.

The left image in Figure 7-23 is a more extensive image and shows that a new road has been built and exploration is underway at the north of the main mine.

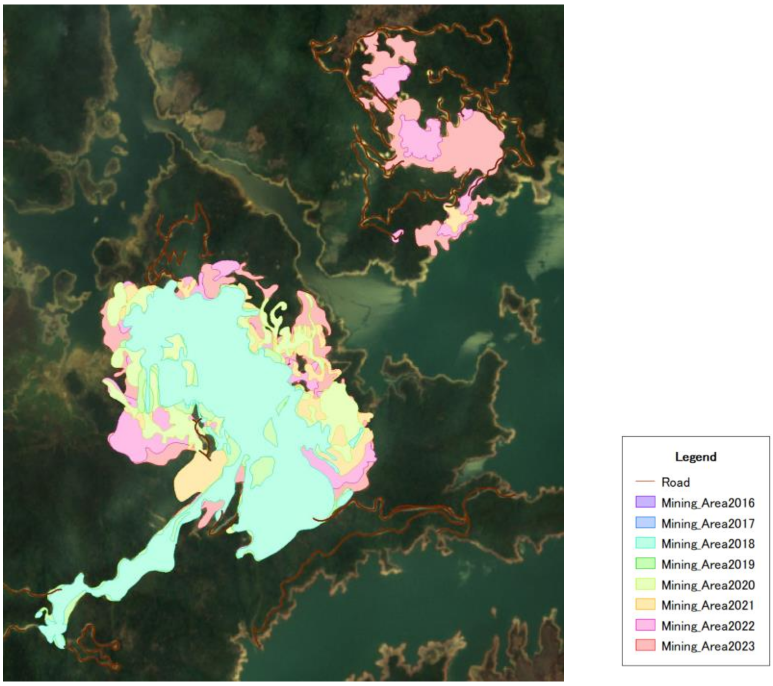


Figure 7-22 Time series changes from 2018 to 2023 for Ban Houayxay copper-gold mine

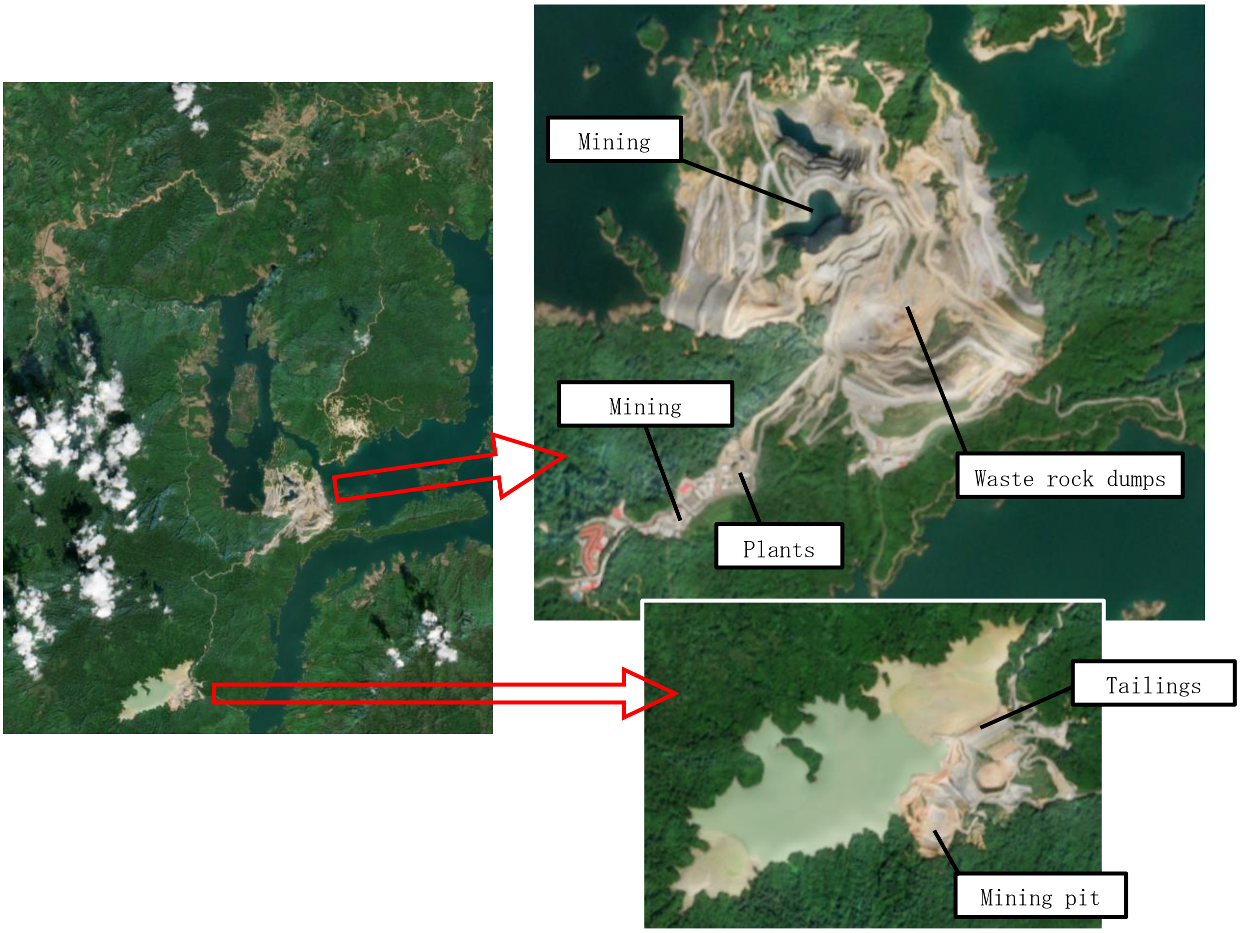


Figure 7-23 Facilities of Ban Houayxay copper-gold mine

(2) Phu Kham copper-gold mine

Phu Kham mine began production in 2008. In Figure 7-24, the operation area for each year from 2018 to 2023 in Figure 7-18 is deciphered and drawn in GIS, with the polygon of 2023, the most recent year, as the bottom layer, and the polygons of the older years in turn overlaid by different coloring.

Figure 7-24 shows that the opencut mining area has sequentially expanded in extent to the north since 2018, while at the same time the waste rock deposition site has also expanded.

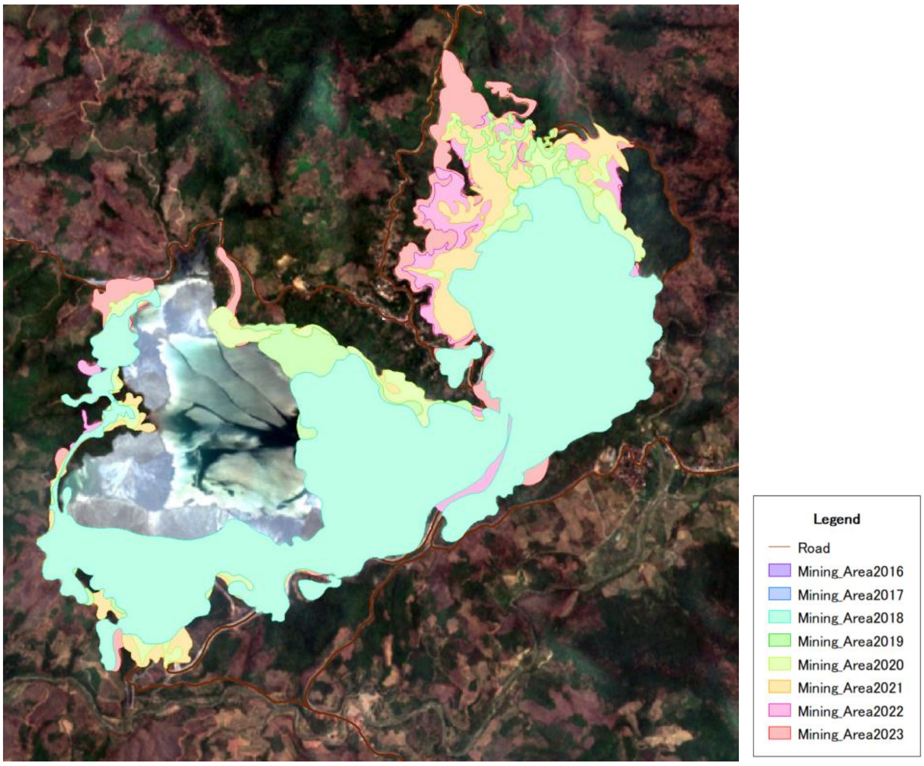


Figure 7-24 Time series changes of Phu Kham copper-gold mine from 2018 to 2023

The latest Sentinel-2 image (taken on December 17, 2023) of Phu Kham mine operation area is shown in Figure 7-25. From this figure, the opencut pit (three locations), waste rock deposition area, mine building, plant, tailings dam, and tailings disposal area can be discerned.

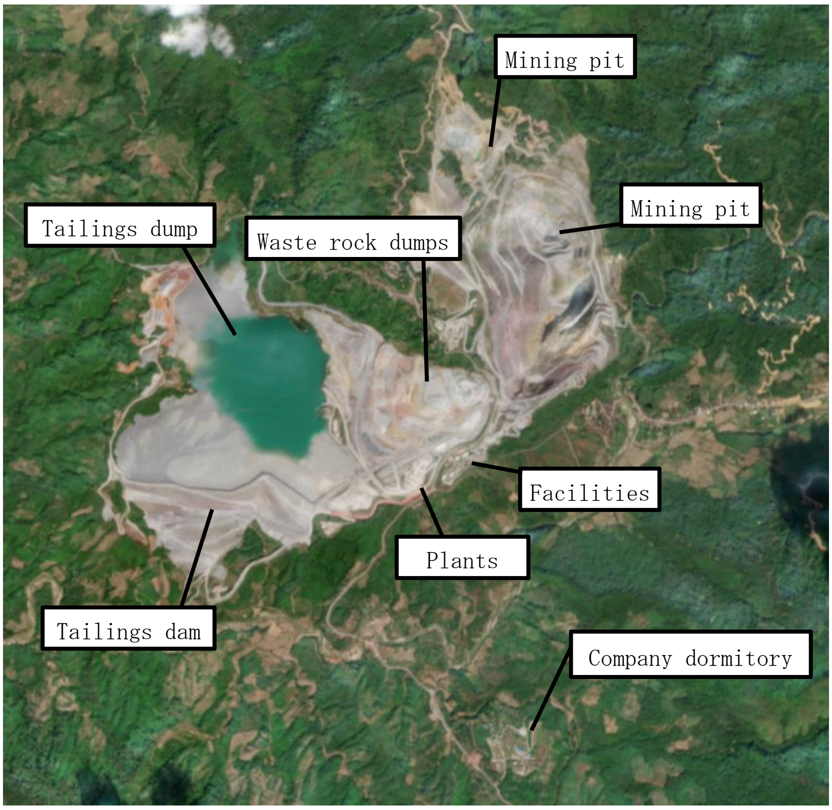


Figure 7-25 Facilities of Phu Kham copper-gold mine

(3) Phou Phanh ASGM

ASGM is generally involved in mining gold sand (gold grains) deposited on the river bed, called "river gold". Therefore, the mining site for ASGM is where the current or past river sediments are distributed. Such ASGM requires the use of large volume of water to sort the gold grains by flushing and panning, which generally results in the creation of many reservoirs (see Figure 7-26).

ASGM is characterized by its location along a river, widespread exposure of muddy sand, and many reservoirs. Particular attention was paid to the fact that there were many reservoirs, and an attempt was made to extract ASGM through image data analysis.

Modified Normalized Difference Water Index (MNDWI) is an index for extracting water bodies. The formula for calculating MNDWI is as follows.

MNDWI = (green band value - short-wavelength IR band value) / (green band value + short-wavelength IR band value)

For Sentinel-2 data, this is as follows.

MNDWI＝(Band3-Band12)/(Band3+Band12)

Next, the exposure of muddy sand along the river should be identified where there is no vegetation and where soil is distributed. For Sentinel-2 data, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Soil Index (NDSI) are calculated, by use of the following formulas.

NDVI＝(Band4-Band3)/(Band4+Band3)

NDSI＝(Band11-Band8)/(Band11+Band8)

A color composite image was created by use of the above three indices, with red for MNDWI , green for NDVI, and blue for NDSI. For convenience, this color image is referred to as Water-Vegetation-Soil Classification (WVS CLN). We advocate using this classification to extract ASGM in this survey. In this classification, water areas are usually represented by red color system, vegetation areas by green color system, and soil areas by blue color system. In ASGM where numerous reservoirs are created, this classification may be useful in identifying the location of ASGM operations.

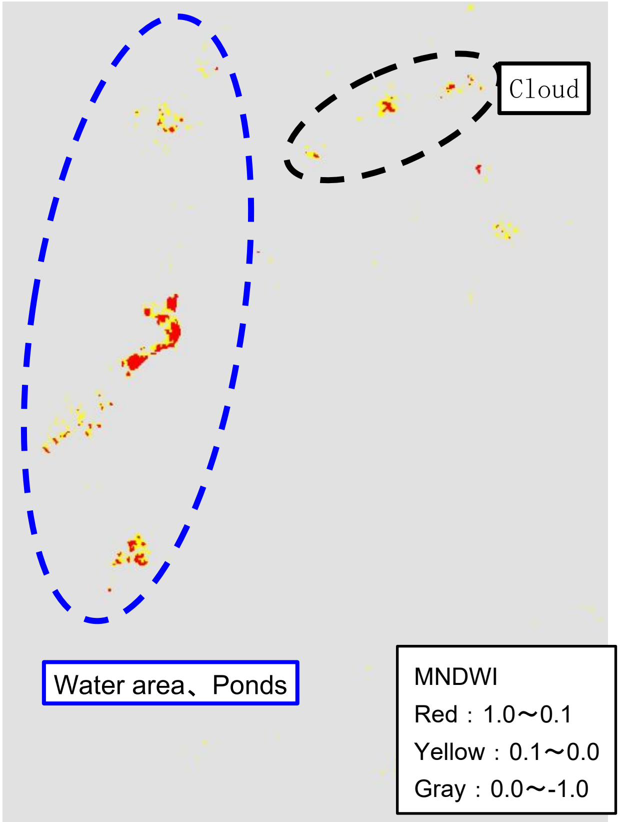
Source：MoNRE(2021)

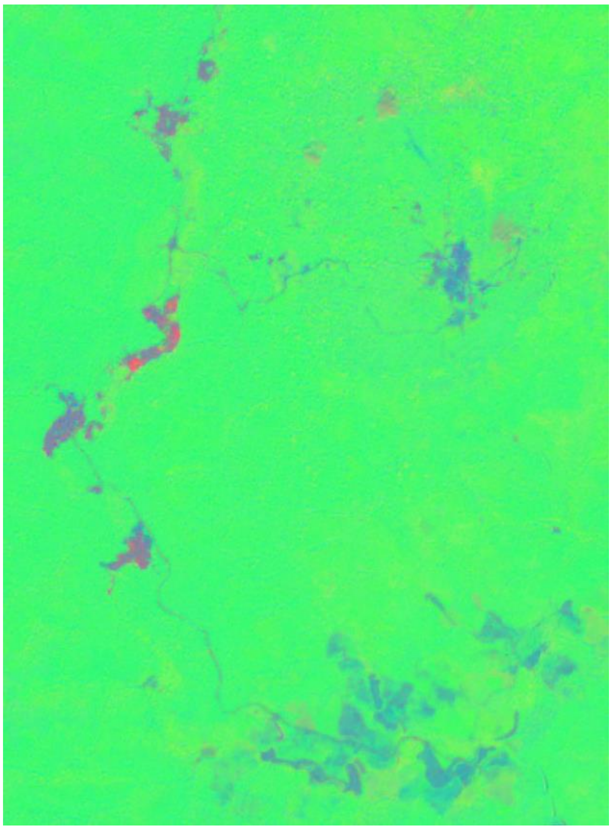
Figure 7-26 Gold mining methods at ASGM in Laos

Phou Phanh ASGM site is located approximately 110 km west-northwest of the capital Vientiane. Figure 7-27 shows true color images, taken on December 27, 2023, MNDWI and WVS-CLN.

The blue broken line box in MNDWI of Figure 7-27 is ASGM operation site. In MNDWI, values above 0.1 are colored red and values between 0.0 and 0.1 are colored yellow, and these colored areas indicate the presence of water. However, clouds are present in the upper right of this image, and the cloud area is colored in the same way. This is due to the fact that the clouds contain water vapor. In addition to ASGM mining site, a cultivated area with exposed soil exists in the lower part of the image, but this area is not colored and is identified.

WVS-CLN clearly recognizes ASGM mining sites that exhibit a red to red-purple color system, as well as cultivated fields and roads in soil exposures that exhibit a blue color system. Thus, the effectiveness of WVS-CLN for ASGM extraction was verified.





Images of data analysis of Sentinel-2
(taken on December 27, 2023)
Upper left：true color image
Upper right：Modified Normalized Water Index (MNDWI)
Lower left：Water-Vegetation-Soil Classification (WVS-CLN)

Figure 7-27 Modified Normalized Water Index and Water-Vegetation-Soil Classification for Phou Phanh ASGM sites

(4) Thitnoun ASGM

Phou Phanh ASGM site is located approximately 160 km northeast of the capital city of Vientiane. Figure 7-28 shows the true color image taken on February 12, 2023, MNDWI and WVS-CLN.

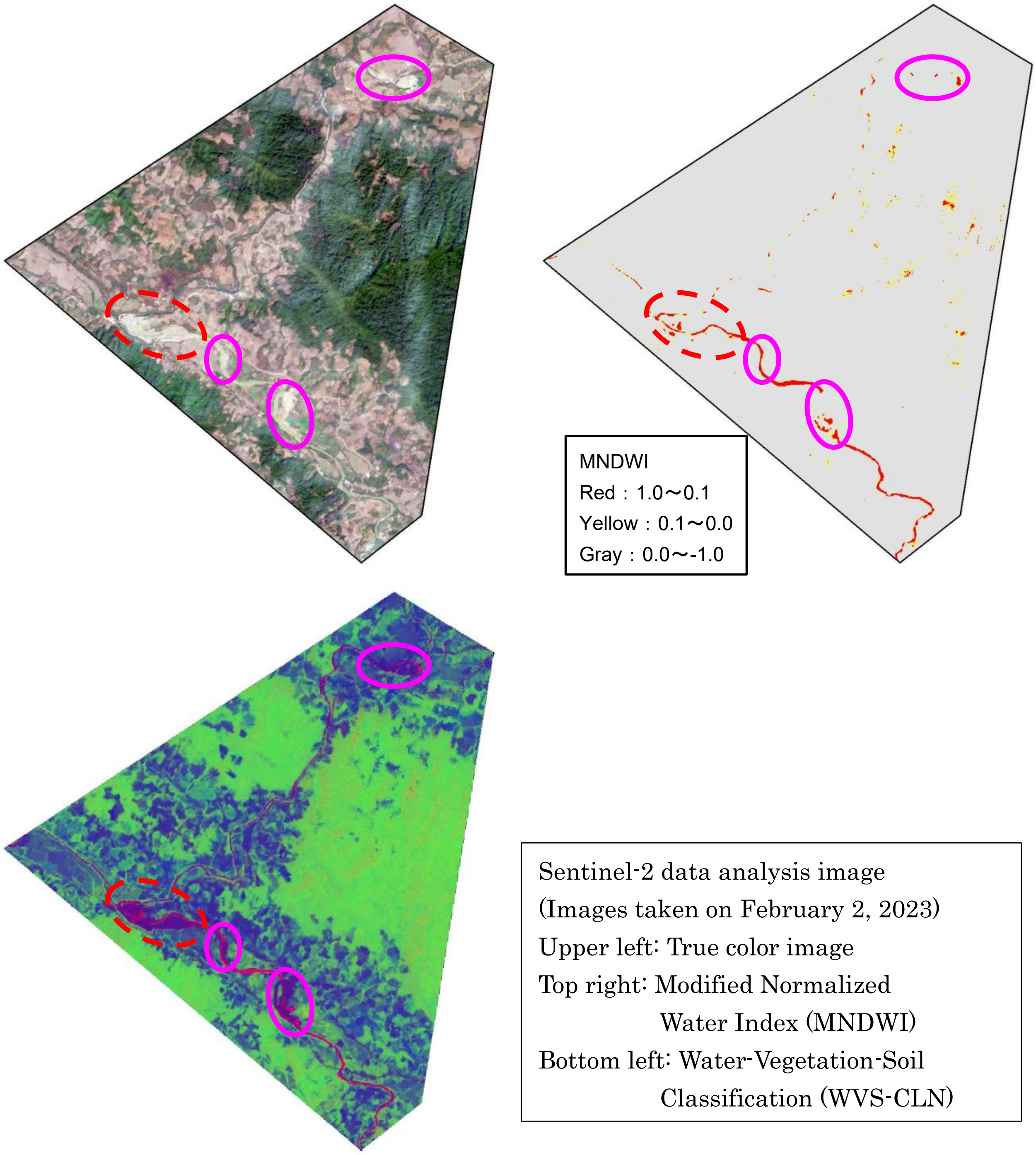


Figure 7-28 Modified Normalized Water Index and Water-Vegetation-Soil Classification for Thitnoun ASGM sites

The area within the oval line in Figure 7-28 is ASGM operation site. In MNDWI, values greater than 0.1 are colored red and values between 0.0 and 0.1 are colored yellow, and these colored areas indicate the presence of water. However, forested areas are widely present in this image, and similar coloration can be seen in some of the forested areas, while at the same time, the true color image shows a whitish color. This is presumed to be the presence of moisture such as fog or frost. In addition to ASGM mining site, there are widespread areas where soil is exposed in cultivated areas, but such areas are not colored. In WVS-CLN, red-colored river waters, reddish to reddish purple ASGM mining sites, and blue-colored soil-exposed areas of cultivated fields and roads are clearly visible.

Figure 7-29 shows a magnified image of the area around the red broken line in Figure 7-28. Muddy sand exposures, which are mining sites along rivers, are reddish in WVS-CLN and are distinguished from cultivated land.

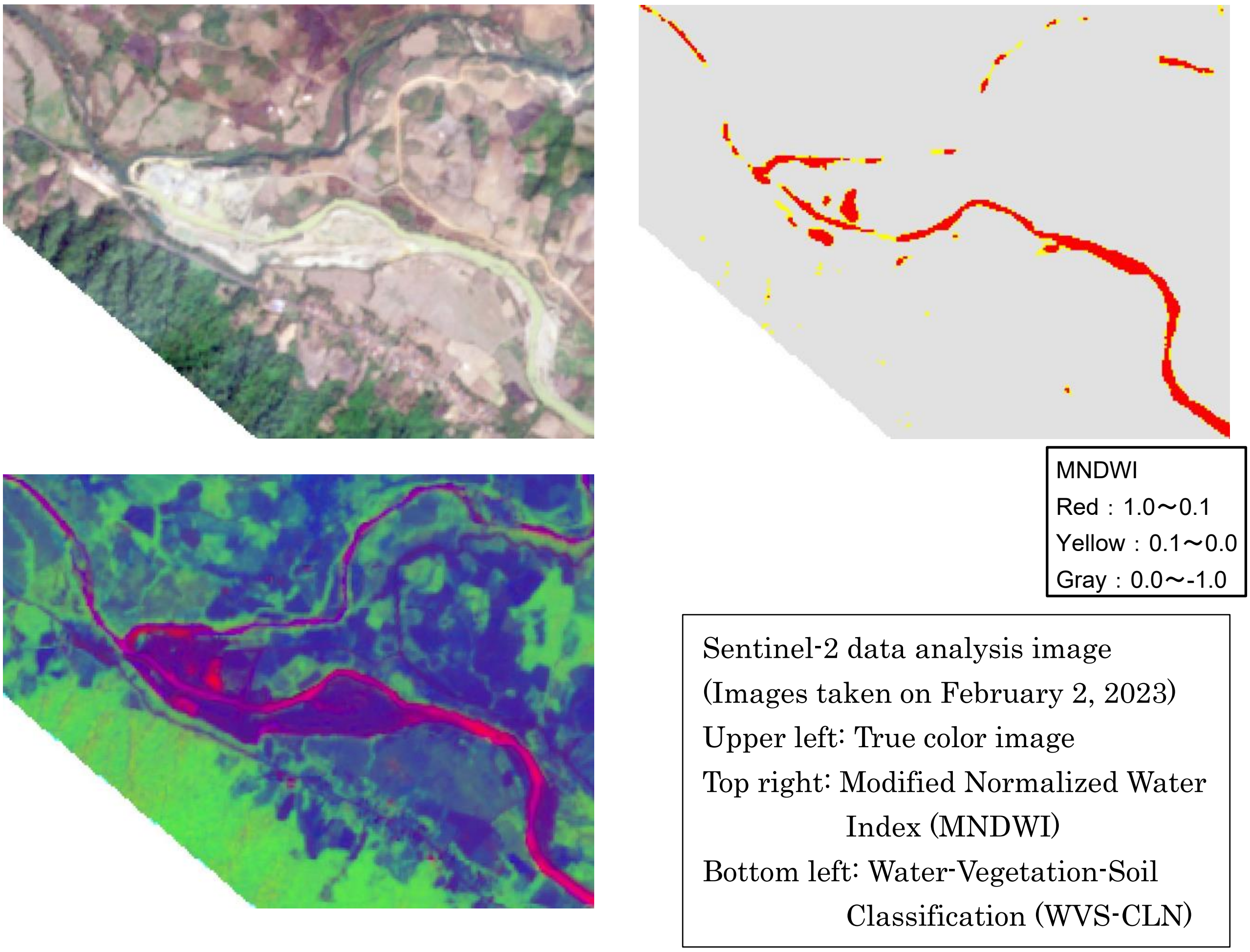
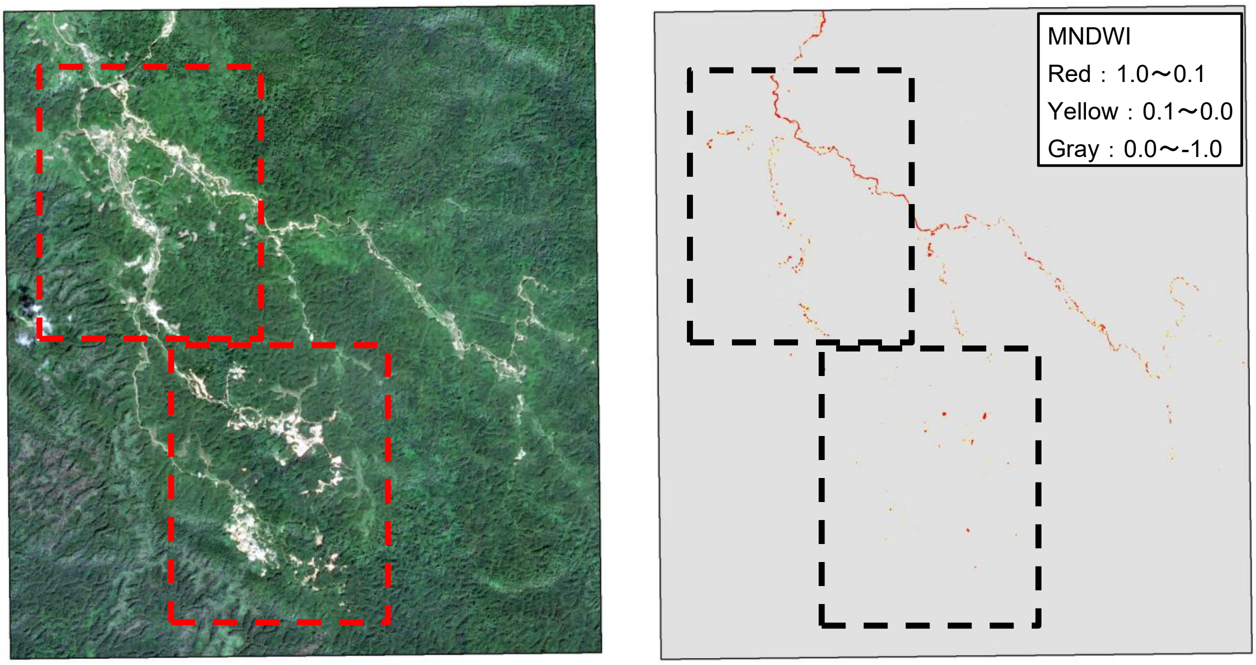


Figure 7-29 Modified Normalized Water Index and Water-Vegetation-Soil Classification (magnified) for Thitnoun ASGM sites

(5) Phugnang ASGM

Phugnang ASGM site is located in the southernmost part of Laos near Cambodian border.

Figure 7-30 shows a true-color image taken on December 6, 2023 and MNDWI. A number of ASGM mining sites are located within the broken line box in the same figure. In MNDWI, we colored red for values greater than 0.1 and yellow for values between 0.0 and 0.1. These colors indicate the presence of water in these areas. The river channel and the ponds along the river are clearly identified.



Left: True color image, Right: MNDWI

Figure 7-30 Modified Normalized Water Index for Phou Phanh ASGM sites

The magnified image in broken line box at the north side in Figure 7-30, plus WVS-CLN, is shown in Figure 7-31. In MNDWI and WVS-CLN, the river channel in the upper right corner of the image is clearly visible with a red color. In the true color image, this stream is light yellowish brown, similar in color to the unpaved road. MNDWI image captures water, while WVS-CLN image captures water and muddy sand, clearly demarcating the muddy, turbid river water from the unpaved road.

The river topography can be recognized in the north-south direction in the center of the image, but it is evident that there is no steady flow of water. A series of ponds are present along this river, which is characteristic of ASGM site.

By reviewing the time series images of this area, it can be inferred that the mining sites have moved (vegetation has recovered since the end of mining) and that many of them are no longer operating in the most recent images. Therefore, it is necessary to examine with the changes in time series rather than analyzing only the most recent image data.

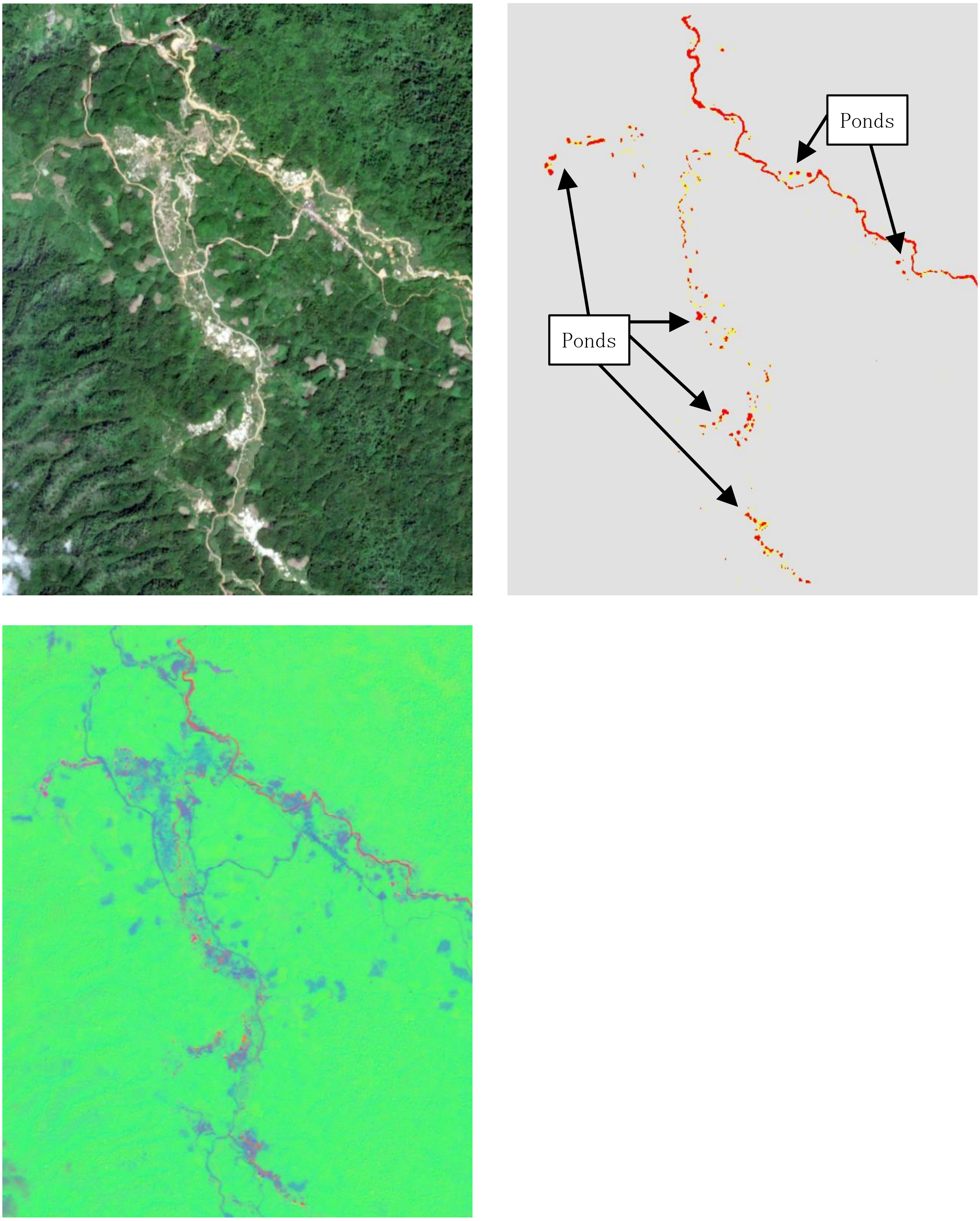


Figure 7-31 Modified Normalized Water Index and Water-Vegetation-Soil Classification for Phou Phanh ASGM sites (magnified)

7.6.4 Contents of mining development status grasped

As mentioned above, the analysis and interpretation of Sentinel-2 images generally deciphers the mining development status of relatively large mines such as Ban Houayxay and Phu Kham mines, including opencut mining pits (operational, abandoned, or submerged), waste rock deposition sites, tailings disposal areas, tailings dams, plants, various mine buildings, and work roads.
On the other hand, for small-scale mining activities such as ASGM, special data analysis (MNDWI, NDSI) was found to be able to extract reservoir and soil exposures specific to ASGM.

7.6.5 Monitoring plan of mining development status

If satellite image monitoring is to be implemented in the future, Sentinel-2 data, free of charge, available via the Web, and having a high imaging frequency, would be the only option.
The method of monitoring mining development status, using Sentinel-2 image, is summarized below. Normally, good quality cloud-free image is only available during the dry season, but since Sentinel-2 data is acquired every 5 days, it is required to check the Copernicus website at least once a month to check the image. Weekly checks are required especially if environmental impacts are to be monitored.

(1) Identification of operation area

・Used image 1: True color image (RGB=Band 4, Band 3, Band 2)
・Decipherment 1： Locations of mining sites, waist rock deposition sites, various mining facilities, etc., are identified to determine the operation area.
・Used image 2：Normalized Vegetation Index (NDVI) image (formula = (Band4-Band3)/(Band4+Band3))
・Decipherment 2：Since there is usually no vegetation in the operation area, the area with a vegetation index of zero is determined to be the operation area.

(2) Identification of mining sites and waist rock deposition sites

・Used image 1：True color image (RGB=Band 4, Band 3, Band 2)
・Decipherment 1： Distribution of mining sites and tailings disposal sites are identified.
・Used image 2：False color image (RGB=Band12, Band4, Band2)
・Decipherment 2：Distribution of rock and soil is determined by color tone.

(3) Identification of reservoirs and tailings disposal sites

・Used image 1：True color image (RGB=Band 4, Band 3, Band 2)
・Decipherment 1：Distribution of reservoirs and tailings disposal sites are identified.
・Used image 2: Band ratio calculation image (RGB=Band11/Band12, Band12/Band4, Band4/Band2)
・Decipherment 2：Vegetation, water bodies, and soils are distinguishable, and the distribution of water bodies and tailings disposal site are determined by color tone.

(4) Environmental impacts such as soil runoff and others

- Used image 1 : False color image (RGB=Band 12, Band 4, Band 2)
- Decipherment 1 : Distribution of rock and soil is determined by color tone.
- Frequency: : As often as possible to capture the changes over time

(5) Environmental impacts against vegetation

- Used image 1 : Normalized Vegetation Index (NDVI) image (formula = (Band4-Band3)/(Band4+Band3))
- Decipherment 1 : This index indicates the distribution and activity of vegetation and thus determines the impact on vegetation.
- Frequency: : As often as possible to capture the changes over time

(6) Identification of ASGM site

- Used image 1 : True color image (RGB=Band 4, Band 3, Band 2)
- Decipherment 1 : Location of mining sites is identified.
- Used image 2 : Band Ratio Calculation image (RGB=MNDWI,NDVI,NDSI)
  The formula for the ratio calculation is as follows
  MNDWI＝(Band3-Band12)/(Band3+Band12)
  NDVI＝(Band4-Band3)/(Band4+Band3)
  NDSI＝(Band11-Band8)/(Band11+Band8)
- Decipherment 2 : Typically, water areas are represented by red tones, vegetation areas by green tones, and soil areas by blue tones. Since ASGM use large volume of water, ponds are often created. Identifying the distribution of dense ponds and rivers by this image may be useful in determining the location of ASGM activity.

7.6.6 Issues

The challenges for government agencies involved in the mining industry and the environment to use Sentinel-2 satellite data in order to monitor mining activities can be summarized as follows.

(1) Human resources
There are few engineers who fully understand the theories and techniques related to satellite data handling and data analysis.
There are no engineers who analyze satellite data on a daily basis.

(2) Training for satellite data analysis
It cannot be assumed that engineers with some data analysis skills and experience can provide technical guidance to others within their organizations. Therefore, technical training by outside experts is necessary. In fact, training was requested during the interviews at the target organizations.
The contents of training include satellite data theory, data analysis methods, deciphering and interpretation

of analyzed images, database construction, introduction of analysis cases, analysis of actual data and field verification surveys of analysis results, and monitoring methods, etc.

(3) Field survey

Information that can be deciphered and monitored only by satellite data analysis needs to be verified even if periodically (once a year, at the same time as mine inspections, is acceptable). However, due to the constraints of budget and human resource, it is unlikely that many such opportunities will be available.

(4) Organizational structure

When it comes to the monitoring of mining activities, the department the most related to the mining industry should be in charge, but it will also be necessary to collaborate with the departments that manage licenses and environmental management. It is necessary to establish a system that allows various data to be shared among multiple departments.

7.7 Mining development potential

The ore types with high potential of mining development include base metals such as copper, lead, and zinc from hydrothermal deposits, gold from various types of deposits such as orogenic, drifting sand, and hydrothermal, and tin associated with tin granite. Among these ores, gold and copper are partially developed in areas accessible from the capital Vientiane, but potential areas for these types of ore cover a wide area from the north to the south of Laos.

The steep mountainous terrain and fragile transportation infrastructure of this landlocked country have been bottlenecks to mining development, Therefore, it is expected that the development of the region as a whole, together with the development of infrastructure in neighboring countries, will lead to the promotion of the region as a whole.

7.8 Study by country visit

7.8.1 Collection of information during the first field survey

During the first round of the field survey, we visited the following organizations concerned in the capital city of Vientiane from September 6 to 8, 2023, to collect information and conduct interviews.

・Department of Mining Management (DMM), Ministry of Energy and Mines (MEM)
・Department of Geology and Mineral (DGM), MEM
・Department of Planning and Finance (DPF), Ministry of Natural Resources and Environment (MoNRE)

Information obtained in Laos were as follows.

① Cooperation with JICA projects

Both the Ministry of Energy and Mines (MEM) and the Ministry of Natural Resources and Environment (MoNRE) expressed a high level of interest in the project contents (especially monitoring through satellite images) and mentioned that they would cooperate with us in providing information. They wished to receive training on remote sensing etc. in the present project, but we confirmed that this is a separate project of JICA.

＊The Embassy of Japan in Laos and JICA's local office in Laos are also interested in the project. (This is due to the background that the country has many metal and mineral resource mines and mining is an important pillar of its economy.)

② Mine management

MEM administers mining licenses and manages 92 mines (relatively large mines excluding ASM). The Department of Mining Management (DMM) manages mining licenses and receives periodic activity reports from mining concessionaires (mining report is obligatory once every three months) and also conducts mine inspections. The Department of Geology and Minerals (DGM) manages exploration licenses and is primarily responsible for verifying the scope of licenses and managing license expiration dates.

③ Monitoring status of mining activities

DMM conducts inspections of all 92 mines. Inspections of the mines of industrial raw material ore types are conducted based on a checklist (basically once a month). A checklist for metalliferous mines is currently being prepared. The checklist was developed with the support of the Federal Institute for Geosciences and Natural Resources (BGR) of Germany (planned for 2013 - August 2024). The majority of the inspections to date have been related to safety.

On-site inspections by DGM of exploration activities have been limited to confirmation of the scope and have not included monitoring of activities.

MoNRE monitors environmental impacts (noise, dust, water quality) from mining operations in accordance with EIA, which is relevant to the mining plan after the obtention of the mining license. In principle, periodic inspections are conducted once a year. Basically, periodic activity reports submitted to DMM by the mining license holder are checked, and field inspections are also conducted when field confirmation is required. Inspections are conducted by the naked eye to check the abnormalities in water quality, animals and plants (e.g., pollution, mortality, etc.).

④ Status of the data use and the utilization technology of satellite

None of MEM organizations use satellite data, including traditional LANDSAT data, and none possess the software of satellite image processing and analysis.

As for the GIS use environment, DGM owns Arc GIS software (sole license), but the license has expired and is only used to manage the mining area maps, etc.

Several staff members have participated in training in Japan, China, and Australia on the basic theory and use of satellite imagery and GIS. However, in the current situation described above, there are no plans to develop the use of satellite data.

⑤ Drone

DMM and DGM have begun using drones for field inspections. The purpose of the use of drone is in-situ verification of the license area and confirmation of the amount of mining in the mine.

Both departments have a combined fleet of 4-5 DJI drones. Pix4D Enterprise software is used to calculate acquired images and position data.

⑥ Status of ASM (artisanal/small-scale *mining*)

As for ASM, the local government grants licenses and manages them. Actually, many ASMs are illegal and it is difficult to manage them.

DMM and DGM do not inspect ASMs. ASMs are in remote areas and it is sometimes difficult to manage and inspect them. There are many ASMs of ruby and sapphire in the prefecture of Kham Muang in central Laos.

⑦ Mining-related work by Ministry of the Environment

MoNRE reviews EIA prior to the mining operations. MEM conducts monitoring of post-mine operation. When environmental pollution or other problems occur at the mine, both ministries conduct individual or joint inspections to assess the situation and implement countermeasures.

Environmental standards are set by MoNRE (noise standards are set by Ministry of Information).

⑧ Status of assistance from other countries

The German BGR is currently providing support to DMM. The support was initiated in 2013 and is currently in its third and final phase, scheduled to end in August 2024. DMM has applied to BGR for an additional support and an extension of the support period. In the first phase, an environmental analytical laboratory was established, and in the second phase, were equipped handheld XRD and water quality measurement equipment, to be used in the field.

From 2012 to 2017, the China Geological Service (CGS) provided assistance to DGM in the preparation of geologic map (1:200,000 scale) and national geochemical maps. Geological maps for three districts in the Northwest region were produced.

In terms of the preparation of geological mapping, it has not yet been implemented in several districts, and the counterpart has expected JICA's assistance in this respect, however it was confirmed that this is not a target of the present project.

7.8.2 Collection of Information during the second survey

During the second field survey, we visited the following relevant organizations in the capital city of Vientiane on January 8 and 9, 2024, to report the results of satellite data analysis, and collect information and conduct interviews.

・Department of Mining Management (DMM), Ministry of Energy and Mines (MEM)
・Department of Planning and Finance (DPF), Ministry of Natural Resources and Environment (MoNRE)

Information obtained in Laos were as follows.

① Comments on the report of the survey team
Almost the same comments from MEM and MoNRE.

・They are interested in satellite image analysis: very effective and useful in mining and environmental management.
・They would like to receive training in this type of image analysis. They would like to see more practical training, from the basics to the applications, lasting more than one or two weeks, rather than a short period of time like a few days.
・They look forward to and cooperate with JICA's support.

② Mining licensing and management
・There is an exploration license (under the jurisdiction of Department of Geology) and a mining license (under the jurisdiction of Department of Mining Management).
・Since the government has stopped involvement of MEM in ASM, it hasn't done so.
・MoNRE and the regional government will manage ASM for non-metals. However, ASM of gold and limestone is managed by the central government.

③ Inspection and monitoring
・MEM conducts inspections for safety, working environment and health. Penalties may be imposed for any violations. Inspections are conducted based on a checklist (prepared with German assistance, but not yet completed).
・The frequency of inspections is basically once every three or six months, but effectively it is about once a year.
・MoNRE certifies the EIA/ESIA for the mine. EIA is reviewed every 3 years. MEM (DMM) approves the closure of the mine.
・The operator submits ESIA and ESMP to MoNRE every three years.
・MoNRE conducts environmental monitoring of mines based on ESIA-based ESMP (Environment and Social Management Plan). For the ecosystem, MoNRE collaborates with Ministry of Forestry.
・MoNRE has an analytical laboratory to analyze water and soil.
・MoNRE has an inspection department that conducts inspections and also conducts field inspections when environmental problems occur.
・JOGMEC organized a workshop on environmental management in mining areas in 2014 and conducted a water system survey to identify environmental pollution in a tin mining area in the prefecture of Khammouane. The tin mine has been in operation for more than 30 years and water pollution (arsenic) has been reported. Around the tin mine, is also present ASM.

④ ASM

・Basically, the local government (Mines and Environment Division) manages the projects and cooperates with MEM (DMM) and MoNRE to deal with any problems.
・Environmentally, ASM of tin and gold is problematic.
・The environment problem of ASM is handled by Mining Division under MoNRE's Department of Environment and Department of Natural Resources and Environment Inspection.
・The aforementioned and Ministry of Health are in charge of The Minamata Convention on Mercury; MEM is not included. The use of mercury is prohibited.

⑤ Problems, systems, etc.

・MEM does not have a department for satellite image analysis. There are no engineers. There is no analysis software.
・They are very interested in satellite image and recognize its effectiveness, and would like to be trained.
・MEM is responsible for the overall management of the mining industry, while MoNRE is responsible for the management of the mining environment in accordance with ESIA. If environmental problems occur, both ministries cooperate with each other.
・Mining licenses and EIA seem to be properly managed.
・MoNRE prioritizes environmental protection (pollution control and forest conservation).
・MoNRE prioritizes environmental protection (pollution control and forest conservation).
・Inspections by MEM and MoNRE have been conducted, but not as frequently as originally planned due to the shortages of budget and staff (it is also affected by the problem of access).

7.9 Conclusion and proposal

7.9.1 Summary

(1) Mineral resources

In Laos, exploration for metallic mineral resources began in the 1990s, and mine development began in the 2000s. Currently, many mines are in operation and exploration activities are underway in various locations, and the mining industry is expected to develop in the future. There are ASMs for gold, tin, and gemstone, but in many areas, the actual situation is unclear.

(2) Management of mining development

Ministry of Energy and Mines (MEM) manages mining licenses and inspects safety aspects, while Ministry of Natural Resources and Environment (MoNRE) approves EIA for mining development and inspects environmental aspects. These roles are properly performed. However, the reality is that mine inspections by MME are not conducted very often.

(3) Monitoring mining development with satellite image

MEM have little experience in the use of satellite image. Satellite image is used in MoNRE for forestry.

The organizations concerned have shown great interest in the analysis of satellite image in this project, and have come to recognize its effectiveness.

(4) ASM

The local governments manage ASMs. In fact, there are many unmanaged ASMs, most of which are illegal and their detailed information is lacking.

(5) Cooperation with Japan

All of the ministries and agencies showed a great interest in the use of satellite image, and they are looking forward to JICA's support and cooperation.

(6) Japanese involvement

JICA is providing assistance in the mining sector. Laos is a recipient of the Kizuna program and its students are admitted to Japanese universities.

7.9.2 Problems

(1) Mining development

Several metallic mineral resource mines are currently in operation, but most of them are located in mountainous areas, so environmental problems have not come to problems. However, water pollution is a problem in some of the mines.

(2) ASM

The local governments manage ASM, so there is little information on ASM and the actual situation is unclear. Gathering information on ASM needs to be consolidated.

(3) Natural environment

Laos has abundant forest resources, with forest area covering nearly 50% of the country's land. However, in recent years, the forest area has been rapidly decreasing due to the agricultural land and infrastructure development. Resource exploration and mining development also bring about deforestation, which requires appropriate environmental management and measures by government agencies.

(4) Human resources

Although relevant organizations showed a great interest in satellite image analysis and monitoring, the reality is that there is an absolute shortage of technology, know-how, and human resources, and therefore, adequate support is needed for technical education, maintenance, and sustainable development.

7.9.3 Support measures

(1) Establishment of a system for mine inspections and human resource development

Since mine inspections are rarely conducted, support should be provided so that a system for mine inspections may be established and adequate inspections may be conducted in terms of safety and environment. Training and human resource development related to the following items should be conducted. The relevant departments of Ministry of Environment may be involved in this task.

1) Establishment of inspection method

- Creation of safety check sheet
- Creation of environmental check sheet
- Establishment of procedures and methods for implementation

2) Implementation of inspections

- Inspection is carried out twice a year during the rainy season and dry season
- Observation by drone during inspection
- Creation of programming for drone operation and automatic flight
- Monitoring using Sentinel-2 satellite images

(2) Human resource development for satellite analysis

Training and human resource development for the following items by use of Sentinel-2 satellite data on the Copernicus website will be conducted. The website allows free data analysis through data processing programming.

- How to use the Copernicus website
- Script programming for data analysis on the Copernicus website
- Data analysis methods for resource exploration
- Monitoring of mining operation and environment
- Monitoring of land alteration
- Development of method to detect ASM activities

For the above analysis, on-site verification studies at key sites will be carried out. Based on the results of the field verification surveys, programming improvements and new analysis methods will be developed. In the field verification survey, a drone will be used to compare and verify the results with the results of satellite data analysis.

(3) Development of ASM information

Since local governments currently manage ASM and the central government does not know the details, the central government is required to consolidate and compile the data. Technology transfer and human resource development will be provided for the following efforts to create the inventory.

- The database system for ASM will be established.
- Data entry will be transferred to local governments, and the central government will check the contents.
- Conduct inspections of important ASM sites to understand the current status.

8. Survey of interests and trends of Japanese companies

Japanese mining companies and trading companies operating in the five countries covered by this study were surveyed regarding their performance and interest in mining activities. The results of the survey are summarized below. The questionnaires were sent to 11 companies, and responses were received from 8 companies.

(1) Questions

Q1. Have you ever conducted business activities in the mining sector in any of the five countries covered by this study?

Yes /No /Decline to answer.

If yes, please give a summary of your activities.

Q2. Do you have any future plan to conduct business activities in the mining industry in any of the five countries covered by this study?

Yes /No /Decline to answer

If yes, please give a summary of your plans.

Q3. Have you ever conducted any type of research using satellite image data in any of the five countries covered by this study?

Yes /No /Decline to answer

If yes, please give a summary of the research.

Q4. When JICA releases the report of this project, would you like to use the information related to mineral resources or the analysis methods and results of the satellite data for your activities?

Yes /No /Cannot say either

Q5. Do you have any expectation for the mining sector in any of the five countries covered by this study?

Yes /None in particular

If yes, please give a summary of your expectation.

(2) Survey Results

Q	Answers (applicables/ respondents)			Summaries described
	Yes	No	Declined	
1	3/8	5/8	0/8	・Human resource development in Zambia and Madagascar ・Operation of integrated production from ore mining to bullion production in Madagascar ・Mineral resource surveys and acquisition of mine properties in Cambodia and Laos ・Satellite image analysis and selection of field survey sites in Mozambique
2	0/8	7/8	1/8	
3	3/8	5/8	0/8	・Investigation of illegal mining activities using the Landsat data in Madagascar ・Verification of conservation status in biodiversity conservation and wildfire occurrence in Madagascar ・Deciphering geological information using ASTER in Lao
4	4/8	3/8	1/8	
5	3/8	5/8	0/8	・Human resource development, country risk reduction, legal reform, and elimination of bribe culture in the five studied countries ・Transparency and stability of the investment environment, release of explored and/ or developed mine properties, infrastructure development, and human resource development in Madagascar

9. Summary

This report summarizes mining situation, mine development status, mineral resources, resource potential, mining policies, and environmental policies in the five countries of Zambia, Madagascar, Mozambique, Cambodia, and Laos. Please refer to the chapters for each country (Chapter 3-Chapter 7) for more information on these topics.

Considering the mineral resource availability and mineral resource potential of each country, a satellite image analysis area was set up and Sentinel-2 satellite data was analyzed for the following mines located in the area.

Country	Large to medium scale mines [number: ore type]	ASM［number: ore type］
Zambia	5：copper（cobalt, gold, silver）	0
Madagascar	1：nickel (cobalt), 2：graphite	2：gemstone, 1：quarry
Mozambique	2 for each：graphite, gemstone, 1 for each：tantalum, titanium	1：gold
Cambodia	3：gold	1：gold, 1：quarry
Laos	2：copper（gold, silver）	3：gold

For large-scale opencut mines, Sentinel-2 true-color images (resolution: 10m) and band calculation processing images were used to decipher and identify various mine facilities and the extent of mine development. In addition, by deciphering the time series images, it was possible to capture changes in the status of mine development (e.g., area expansion, new construction of artifacts, etc.), and it was confirmed that the images can be used for the monitoring of mining development. The Sentinel-2 data will be uploaded to the Copernicus website every 5 days and can be used sufficiently for future monitoring.

On the other hand, it is generally very difficult to identify very small-scale ASM mining activities. For example, even if there is bare land in a forested area, it is difficult to determine whether it is simply tree clearing and farmland cultivation or ASM activities. In ASGM, mining generally takes place along rivers, using large volume of water and creating numerous reservoirs. By capturing the presence of such water, we attempted to determine the location of ASGM mining. As a result, we were able to detect ASGM sites in several countries. Among these, ASGM in Manica province of Mozambique has been extensively developed on a relatively large scale, and we succeeded in extracting the location of the presence of numerous reservoirs.

The following table summarizes the information that can generally be deciphered and identified by Sentinel-2 satellite data analysis. For true color images, the information can be read visually. For analysis of images other than true color images, identification is based on the color-coded display of the band calculation values or the color composite image of the band calculation values. For details of the calculation formulas and the details of the calculation process, please refer to the chapter of each country.

Basically, legibility and identification depend on the size of the object. However, it is usually not possible to read an object of 10 meters square just because the resolution of the satellite data is 10 meters. The size of an object that can be reliably identified depends on the conditions such as its color, shape, and surrounding circumstances. In the case of deciphering the status of mine development and equipment, the accuracy of decipherment is affected by the experience of seeing the site and the actual objects of mine development and operation.

Sentinel-2 true color image (data of visible range with resolution of 10m)		
Large-scale mining artifacts	Opencut mining pits, surface mining sites, tailings dams, tailings disposal sites, waste rock deposition sites Reservoirs (muddy water, algae growth, and shadows cast by topography, etc., may cause misreading in the dark) Thickeners (generally circular in shape and at least 20 m in diameter) Roads (wide enough for large trucks to pass each other in both directions) Buildings (with an area of at least 15m square per building, when several buildings are clustered together. Even at this size, it may be difficult to decipher them individually.)	
ASM's artifacts	Reservoirs (if the water is larger than 20 m square and not muddy) Extensive activity area (the location and shape of the ASM activity area is somewhat different from that of a typical cultivated field, so the activity area may be identifiable) *On the contrary, it is impossible to decipher the status of small-scale activity, etc. other than those listed above.	
Natural objects	Non-vegetated areas (they may correspond to development and operation areas) Amount of vegetation distribution and extent of activity (they may be used for environmental monitoring) Discoloration of water bodies (it may be used for environmental monitoring) Distribution of rocks and soil	
Others	Exploration areas (they may be determined by patterns such as grid/network layout of road construction, placement of exploratory pits, etc.) Areas under development (they may be determined by location, shape, etc.) Objects that can be identified by color (e.g., red roofs on buildings, muddy brown water, red soil, etc.)	
Sentinel-2 data analysis image (using visible and near-infrared data with resolution of 10m)		
Vegetation	Vegetation index（NDVI）	Identification of vegetated and non-vegetated areas: more accurate than deciphering with true color images.
Geological information	Band ratio calculation	Presence of iron oxide minerals
Sentinel-2 data analysis image (using short-wavelength infrared data with resolution of 20m)		
Waters	Water index（MNDWI）	Distribution of water areas: higher accuracy than decipherment with true color images. However, the resolution is lower. (Effective for the extraction of larger reservoirs in the ASGM)
Geological information	Band color composite image, Band ratio calculation	Presence of clay minerals, rocks and mineral soil

Mining-related government agencies in each country have very few technical personnel for satellite data analysis and currently do not have the resources to analyze the data on their own. Mine inspections are not sufficiently conducted due to the lack of manpower and budget, and monitoring using Sentinel-2 satellite images, which are available free of charge, would be extremely beneficial. Given the above situation, one of the first support measures is to provide medium-term training on overall satellite data analysis. Actually, there was a strong demand for training in each country.
The following resources are required for monitoring large-scale mines.

- Remote sensing engineers: Several staff who have mastered the theory, analysis methods, and know-how of satellite data analysis are required.
- Hardware: If the data to be used is limited to Sentinel-2, no specific software is required, so a personal computer with general specifications and levels is all that is needed. However, GIS software is required to put in order the analysis data. The free QGIS has sufficient performance. On the other hand, an internet environment is important, and a faster LAN environment is needed for displaying images and downloading data on the PC.
- Structure: Assuming that the project will be conducted in the mining sector, the technical personnel needed may be mining engineers as well as geological and mineral resource specialists. Remote sensing does not need to be a full-time job. It can be integrated into routine operations. Monitoring by image analysis should be conducted on a regular basis (e.g., at least once a month), and a field survey (e.g., verification of analysis results) should be conducted at least once a year (ideally at the same time as the mine inspection).

Training is essential to bring up engineers. Training course, practical data analysis, and field verification surveys will be conducted over a period of two to four weeks, and if possible, the status of activities and results will be followed up within one year.
Satellite image itself can be also used for environmental monitoring, and collaboration with the environmental sector may be taken into account.
For other support measures specific for each country, see the chapter of each country. In particular, the use of mercury in the extraction of gold has become an environmental problem in ASGM in the Manica province of Mozambique, where activities for the "Minamata Convention on Mercury" are about to begin, and the results of this project may be used and applied in monitoring ASGM, etc., and could be an urgent support measure.

10.References

Devenish, K., Desbureaux, S., Willcock, S., Jones. J. P. G. (2022) On track to achieve no net loss of forest at Madagascar’s biggest mine. Nature Sustainability 5, 498–508.

ESCAP（Economic and Social Commission for Asia and Pacific）, 1993, Geological map at 1:1,500,000 scale and explanatory note, Cambodia. Atlas of Mineral resources of the ESCAP region, Vol. 10, New York, 85p.

Ettler, V., Kribek, B., Majer, V., Knesl, I. and Mihaljevic, M. (2012) Differences in the bioaccessibility of metals/metalloids in soils from mining and smelting areas (Copperbelt, Zambia). J.Geochem.Explor., Volume 113, pp.68-75.

GSi, CCOP Geoinformation Sharing Infrastructure for East and Southeast Asia.: https://ccop-gsi.org/main/

Guo. L., Liu S., Hou L., Wang J., Shi M., Zhang Q., Nie F., Yang Y. and Peng Z. (2019) Fluid Inclusion and H-O Isotope Geochemistry of the Phapon Gold Deposit, NW Laos: Implications for Fluid Source and Ore Genesis. J. Earth Sci. 30, pp.80–94.

Hilson, G. Mondlane, S. Hilson, A. Arnall, A. and Laing, T.(2021) Formalizing Artisanal and Small-Scale Mining in Mozambique: Concerns, Priorities and Challenges. International Growth Center.

Hilson, G., Mondlane, S., Hilson, A., Arnall, A. and Laing T. (2021) Formalizing Artisanal and Small-Scale Mining in Mozambique: Concerns, Priorities and Challenges. International Growth Centre. F-19016-MOZ-1, pp.1-27.

JICA (2008) The geological mapping and mineral information service project for promotion of mining industry in the Lao People's Democratic Republic

JICA (2008) The study for the master plan for promoting the mining industory of Cambodia

JOGMEC (2005) Resource development environmental survey Lao People's Democratic Republic

JOGMEC (2021): The world trend of mining industry 2021, Mozambique

JOGMEC (2021): The world trend of mining industry 2021, Republic of Zambia

Kamvong T., Khim Zaw, Meffre S., Maas S., Stein H., Lai C. (2014) Adakites in the Truong Son and Loei fold belts, Thailand and Laos: Genesis and implications for geodynamics and metallogeny, Gondwana Research, Volume 26(1), pp.165-184.

Khin Zaw, Meffre S., Lai C., Burrett C, Santosh S., Graham I, Manaka T., Salam A., Kamvong T., Cromie P. (2014) Tectonics and metallogeny of mainland Southeast Asia — A review and contribution, Gondwana Research, Volume 26(1), pp.5-30.

Kribek, B., Nyambe, I., Majer, V., Knesl, I., Mihaljevic, M., Ettler, V., Vanek, A.,　Penizek, V. and Sracek, O. (2019) Soil contamination near the Kabwe Pb-Zn smelter in Zambia: environmental impacts and remediation measures proposal. J.Geochem.Explor., Volume 197, pp.159-173.

Nhantumbo1, C. Pondja1, E. Juízo1, D. Cumbane1, A. Matsinhe1, N. Paqueleque1, B. Uamusse1, M. Gettel2, G. Franca, J, M. and Paron, P.(2020) Effect of Mining to Water Quality in Chua and Revué Rivers, Mozambique. International Mine Water Association (IMWA) 2020 “Mine Water Solutions”.

Pardieu, V., (2012): Ruby and sapphire rush near Didy, Madagascar., GIA news from research. 85p.

Schluter, T. and Trauth, M.H. (2006) Geological Atlas of Africa: With Notes on Stratigraphy, Tectonics, Economic Geology, Geohazards, Geosites and Geoscientific Education of Each Country. Springer, 272p.

Shimizu R., Hama Y., Kosaka T., Kusaka R., Matsumoto N., Takahara H., Hatsuya K., Kabashima T. (2011) Copper exploration on South Moune area in Vientiane Province, Lao PDR, Shigen-Chishitsu 61(2), pp.109-120

Sirisokha S. (2019) Lithogeochemistry, Hydrothermal Alteration,Mineralization, Fluid Inclusion and Sulfur Isotope Study of the Halo Porphyry Copper-Molybdenum Prospect, Northeast Cambodia, Doctoral degree thesis, Department of Earth Resources Engineering Graduated School of Engineering Kyushu University, Fukuoka, Japan.

Sudo S., Kamitani M., Hirano H. (1996) Industrial minerals of Laos and Cambodia, Chishitsu News, 506, pp.52-59.

Tanaka T., Yasunaga K., Ichinose T., Kabashima T. (2016) New Discovery of Copper Ore Deposit in South Moune Area in Vientiane Province, Lao PDR, Shigen-Chishitsu 66(2), pp.155-66.

Ueno K., Hisada K. (1999) Closure of Palaeo-Tethys with collision between Indochina and Sibumasu, Chikyu monthly 21， pp.832-839.

USGS (2022)：2017-2018 Minerals Yearbook, MOZAMBIQUE

USGS (2023)：2019 Minerals Yearbook, ZAMBIA

USGS, Mineral Resources Online Spatial Data: https://mrdata.usgs.gov/general/map-global.html.

Veeravinantanakul A., Takahashi R., Agangi A., Ohba T., Watanabe Y., Elburg M.A., Ueckermann H., Kanjanapayont P., Charusiri P. (2021) Zircon Hf-isotope constraints on the formation of metallic mineral deposits in Thailand Resour. Geol., 71 (4) pp.436-469.

Wang D., Lin F., Shi M., Wang H., Yang X. (2023) Geological setting, tectonic evolution and spatio-temporal distributions of main mineral resources in South East Asia: A comprehensive review, Solid Earth Sciences, Volume 8(1), pp.34-48.

World Bank: https://data.worldbank.org/country/

Xu, H. (2016) Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. International Journal of Remote Sensing. 27. 3025–3033.