

Detecting Illegal Mining Activities in Zimbabwe through Earth Observation: A Case of Beitbridge District in Zimbabwe

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Research Article

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Abstract

The Zimbabwean economy heavily relies on agricultural and mining activities which are the major boosters of the market and common business for regional and international trade [1]. These two sectors have seen a lot of investment potential and rise over the years and as such, illegal activities have since been on the rise in the mining industry. Across the country, most of the free, state land has become the breeding grounds for illegal mining activities, and this has caused quite several devastating effects and damage to the environment which have also contributed immensely to an uneven balance of biodiversity in the country [2]. The government on the other hand, has made various calls to action through its law enforcement agency to curb and spread of such illegal activities which pose a significant danger to both the environment and the economy [3]. Unfortunately, many of these efforts have been to no avail as many of these activities are going undetected leaving the law enforcement agencies together with the environmental protection agencies and partners without a starting point for countermeasures against such activities.

Through Earth Observation technology and data, the government of Zimbabwe can be able to detect illegal mining activities and be in a better position to draft countermeasures which assist in curbing this national problem. On the other hand, Environmental Protection and Management agencies in Zimbabwe can be able to assess the damage caused by such activities among others for the benefit of crafting a sustainable future which leads to a balanced ecosystem which supports and promotes biodiversity at all levels.

This paper provides a short case study of earth observation technology, techniques, and data applications in one of the well-known and well-assumed illegal mining hotspot towns of the country. It serves as a demonstration of how such technologies can be leveraged for development, enforcement and governmental approaches to issues affecting the environment and the future of today and tomorrow. The paper also gives a quantitative study and analysis of the damage that has been made by such illegal mining activities in the study area.

1. Introduction

Mining plays a crucial role in Zimbabwe's economic development, contributing significantly to the country's gross domestic product (GDP) and generating employment for thousands of people. However, the mining industry in Zimbabwe also faces a major challenge with a substantial amount of illegal mining activities taking place. These illicit mining activities pose a significant threat to both the environment and the country's economy, resulting in environmental degradation, biodiversity loss, and other detrimental impacts. Despite the government's efforts to address this issue by calling for action against illegal mining, the problem persists and remains largely unresolved.

To tackle this pressing challenge, this research paper focuses on the utilization of earth observation technology to detect and monitor illegal mining activities in Zimbabwe. Earth observation technology

offers a powerful and effective means of identifying and tracking illegal mining operations, thereby enabling the development of appropriate countermeasures. This paper presents a case study that demonstrates the application of earth observation technology in a well-known town that is notorious for illegal mining and smuggling activities within Zimbabwe.

While the strategic implementation of methodologies and decisions solely rely on government actions, the primary objective of this research paper is to showcase the efficacy of earth observation technology in detecting and monitoring illegal mining activities. Furthermore, it seeks to provide a quantitative analysis of the extent of damage caused by such illicit mining activities in the specific study area. Additionally, the paper aims to offer valuable insights into the potential applications of earth observation technology for environmental protection and management throughout Zimbabwe.

1.1 Literature Review

Earth observation technology provides a valuable and effective tool for detecting and monitoring illegal mining activities. Various studies have been conducted to explore the use of this technology in detecting and monitoring such activities in different regions.

For instance, [4] conducted a study in Ghana, utilizing Sentinel-2 satellite data to identify and monitor illegal mining activities. Their findings demonstrated that earth observation technology was capable of accurately detecting and monitoring illegal mining, providing crucial data for environmental protection and management.

Similarly, a change detection study employed Landsat-8 data to detect and monitor illegal mining activities in Jordan [5]. The study confirmed that earth observation technology was successful in effectively identifying and monitoring these illicit activities, thereby contributing to environmental protection and management efforts.

In the context of Zimbabwe, several studies have also been conducted utilizing earth observation technology for environmental monitoring and management. For example, Sentinel-2 data was employed to monitor changes in land use and land cover in the Mazowe catchment area of Zimbabwe [6]. The study revealed that earth observation technology was highly effective in monitoring these changes, providing valuable data for informed environmental management.

These studies highlight the significant potential of earth observation technology in detecting and monitoring illegal mining activities, as well as its valuable contribution to environmental protection and management. Building upon these previous studies, this research paper presents a case study focusing on the utilization of earth observation technology to detect and monitor illegal mining activities specifically in Zimbabwe as well as determine and measure the impact of these activities.

In Zimbabwe, the issue of illegal mining is particularly prevalent in Mt Darwin, Beitbridge and Kwekwe Districts, as reported in [7]. [8] reported the presence of makeshift structures throughout Beitbridge district,

some of which are situated in the river basin. The noise of generators used to power water pumps can be heard along the river, indicating the extent of these illegal activities.

The case of these affected communities and areas exemplifies the urgent need to employ effective monitoring measures, such as earth observation technology, to detect and address illegal mining activities in Zimbabwe.

2. Material and methods

2.1 Study Area

The area under investigation for this research is one of the well-known illegal mining hotspots in Zimbabwe, located in Matabeleland South Province, Ward 6 under Beitbridge District.

The study area covers approximately 572 square kilometres, and it includes both free state land and private land. Much of the land is used for Cattle ranching with little to no farming activity in some parts of the areas as the land is usually deemed unfit for cropping as according to the natural region in Zimbabwe. Additionally, Matabeleland South is a province in southwestern Zimbabwe. With a population of 760,345 as of the 2022 Zimbabwean census, it is the country's least populous province [9].

2.2 Data Collection and Resources

The data used in this research were obtained from the Sentinel-1 and Sentinel-2 satellites as well as Landsat imagery. The Sentinel-2 satellite was chosen for its high spatial resolution (10 meters) and its ability to provide multispectral data. The Water Observation from Space (WOfS) product was also adopted for this study. In addition, the Sentinel-1 data was acquired as the image quality of radar data is independent of daylight and weather conditions as opposed to optical data which can be affected by harsh weather conditions and cloud cover when it comes to large scale aerial mapping of landcover and land use.

The data were obtained for a period of five years beginning in the year 2018 spanning up to 2022. The data were processed and analysed in the cloud environment in this case, the Digital Earth Africa (DEA) platform was utilized to minimize the need for resources during the exercise.

2.3 Data Processing

To detect activity in the study area, proxies for degradation and change in environmental status were used in this case and this included computing and carrying out analysis on the vegetation change, land use and landcover and built-up area detection.

The built-up area detection analysis was carried out to detect any forms of settlements that exist in rare instances where people would choose to settle in areas which are less likely to be habitable because of the resource shortages and limitations that exist in such areas in this case being the Matabeleland South Provinces, Ward 6 in Beitbridge District.

After having used these proxies to locate possible mining sites, a surface mining detection algorithm was then implemented using remote sensing images from Sentinel-2 GEOMAD and Digital Earth Africa's WOfS product.

3. Theory and calculation

Various means, equations and algorithms were adopted to measure, quantify, and analyse the satellite imagery to provide the visual analysis for the general and overall outputs.

3.1 Vegetation Change Analysis

Detecting regions of deforestation and afforestation in satellite imagery is complicated by the need to distinguish real land use changes from the natural changes introduced by climate variability. To determine regions that have undergone significant change, we can apply hypothesis testing techniques to stacks of remotely sensed satellite images to determine where change is statistically significant relative to the natural, background variability.

For the vegetation change detection and analysis, we measured the presence of vegetation from Landsat imagery and applied a hypothesis test to identify areas of significant change (along with the direction of the change). For these purposes two indices which represent vegetation were used thus the normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI).

Both processes employed the formalized and standardized formula for this process as indicated below.

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

And

$$EVI = \frac{2.5x(NIR - Red)}{NIR + 6xRed - 7.5xBlue + 1}$$

To perform the test, the total samples were split in two, formulating a baseline sample and a postbaseline sample, which respectively contained the data before and after the time baseline date which in this case was set to be January of the year 2020 as this was the middle date between the chosen analysis timeframes.

To look for evidence that the average index value has changed between the two samples (either positively or negatively), the Welch t-test was implemented. This was used to test the hypothesis that our chosen study area before and after the base timeline had equal averages.

3.2 Built-up Area Detection and Land use and Land Cover Mapping

As according [10], most of the illegal mining activities that are taking place in Zimbabwe are also fuelling illegal and squatter settlements around the areas of the well-known mineral establishments that are being extracted illegally.

While built-up areas can be mapped using optical data, the image quality is strongly affected by weather conditions such as cloud cover. This limits the temporal availability of clear images.

The image quality of radar data is independent of daylight and weather conditions, which makes it more suitable for built-up area mapping.

The ESA World Cover map was used to determine the land use zones and cover that exists in the area under study for the year 2020 as this was also the base timeline for the study. From the mapped-out land use and land cover zones, the built-up areas were extracted to review the pattern of settlement which was being adopted in Ward 6 of Beitbridge district. Lastly and in addition to the built-up area mapping, change detection was also implemented for this built-up section of the study to determine the rate of change between the chosen timeframe of the study.

3.3 Surface Mining Detection

The NDVI (for Sentinel-2) was used to determine vegetation loss, where loss occurs and if the change in vegetation index was negative. Additionally, the WOfS was then used to identify sources of water within the study.

This study aimed to identify instances of vegetation loss in areas where water bodies coexist, as existing theories suggest that water often serves as a resource in illegal mining operations due to its role in facilitating the purification process [11]. The findings from this study can be utilized by local government bodies and environmental protection units striving to eliminate such illicit activities on a broader scale.

The underlying premise for this analysis, which incorporates both vegetation and water indicators, is that if an area exhibits concurrent loss of vegetation and water, it is highly probable that mining activity is involved [12]. The analysis covered the period from 2018 to 2020, as the WOfS product used for this study provides data up until 2020.

4. Results

The results of the analysis have been presented in a step-by-step format as showcased in this section.

As can be observed in the vegetation analysis for the NDVI and EVI, the vegetation across the study area barely varies across the timeline, in this case between the beginning of the study until the end of the study (January 2018 – December 2022) and this ranges between 0 and 0.5.

Figure 3 significant change in deforestation can be seen in the image above (bottom left) where the line strip in which most of the deforestation takes place is that of Umzingwane River which is also located in Beitbridge district.

The other portion reviews a statistically significant change in the vegetation without specific direction of change meaning this could either be positive change or negative change.

Table 1 below outlines the statistical changes that have been noticed from this vegetation analysis.

Table 1
Statistically significant changes over
the investigation timeline

	Percentage	Area (sq.km)
SCD	34.17%	195.45
CD	5.1%	29.17

*SCD – significant change in any direction

* CD – confirmed deforestation

On the other hand, the ESA World Cover for land use and land cover classification reviewed that most of the land in Ward 6 of Beitbridge, Matabeleland South Province is mainly classified as shrub land as can be seen in the Fig. 4 below.

This observation tallies with the vegetation observation where much of the land does not meet the vegetation standards for activities like agriculture and forestry. Croplands can still be observed to follow along the water body path which represents a river within the study area. Water sources can also be observed from the land use and land cover analysis while a smaller portion of dense built-up areas can be seen on the south-eastern side.

The settlement patterns which we extracted from the world cover analysis reviewed the observation as seen in Fig. 5.

The analysed Geomedians for the surface mining detection were plotted in RGB image as displayed in Fig. 6 below and have been represented in RGB form.

The annual vegetation loss indicated a significant loss in vegetation from the period starting mid-2018 ending mid-2019 when it was at its peak per square kilometre.

Where water loss and vegetation loss are coincidental, this is assumed to be a potential surface mining activity [13] thus indicated in the potential mining zone map in Fig. 8 below.

Figure 8 displays the possible mining sites identified from the analysis to be covering the identified water source (river) in which the settlements around the area have also been known to occupy over time. A few spots can also be identified in the northern region of the study area.

5. Discussion

While climate change plays an additional role towards drastic changes in landscape and vegetation across various regions, Beitbridge District located in Matabeleland South Province in Zimbabwe is well known for mining activities that have since dominated the area and this is a result of various reasons such as economic change and hardships that are being experienced. Additionally, the vegetation analysis spanning the study period provides concept that the overall vegetation of this area is generally lower and is rather considered not suitable for farming. Despite this situation, people however still practice subsistence farming in order to sustain their livelihoods as can also be observed from the analysis where croplands are identified but are spatially spaced and following along the river path.

Umzingwane river appears to be the source of minerals in the study area as most of the activities resulting in degradation and deforestation are following the path of the river from the north going down towards the south-eastern side of the ward. The vegetation analysis indicates deforestation to have taken place along this course as well as the built-up area analysis also indicates evidence that most illegal miners have settled along the riverbanks in search of the previous minerals found in this region and in this case, this also proves to be the same area in which minerals are being extracted from.

The amount of deforestation in this region which in this case constitutes five percent of the area under investigation is a result of the mining activity which creates demand for natural resources supply such as firewood resulting in the cutting down of trees as well unmonitored and uncontrolled water usage from the river required to wash and clean minerals which results in water contamination.

The surface mining detection algorithm implemented in this case provides evidence of the surface mining activities that are taking place within the area and all activities appear to be taking place along the Umzingwane River in Ward 6 of Beitbridge District.

6. Conclusions

Satellite data has provided some evidence of land degradation due to the illegal mining activities taking place within the area under investigation.

Additionally, the analysis provides evidence of illegal surface mining activities that have taken place or are currently taking place in the mentioned area. Unfortunately, the analysis performed only provides an extent and overview of surface activities and cannot provide a more in-depth analysis of what could be taking place beneath the ground as underground mining is also another method of mining.

To counter these activities before they cause serious damage to the environment, it would be more ideal to have these detection systems being automated and installed within the various departments at government and law enforcement level to take immediate action on the onset of these devastating developments.

Additionally, it is also crucial to build capacity within governments and environmental management agencies as this will go a long way in strengthening the efforts to combat such activities while utilising

technology hence reducing some costs associated with traditional methods that are currently being applied in identifying illegal mining activities in Zimbabwe.

Acronyms/Abbreviations

WofS – Water Observation from Space

NDVI - Normalized Difference Vegetation Index

EVI – Enhanced Vegetation Index

Declarations

Competing interests: The authors declare no competing interests.

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Figures

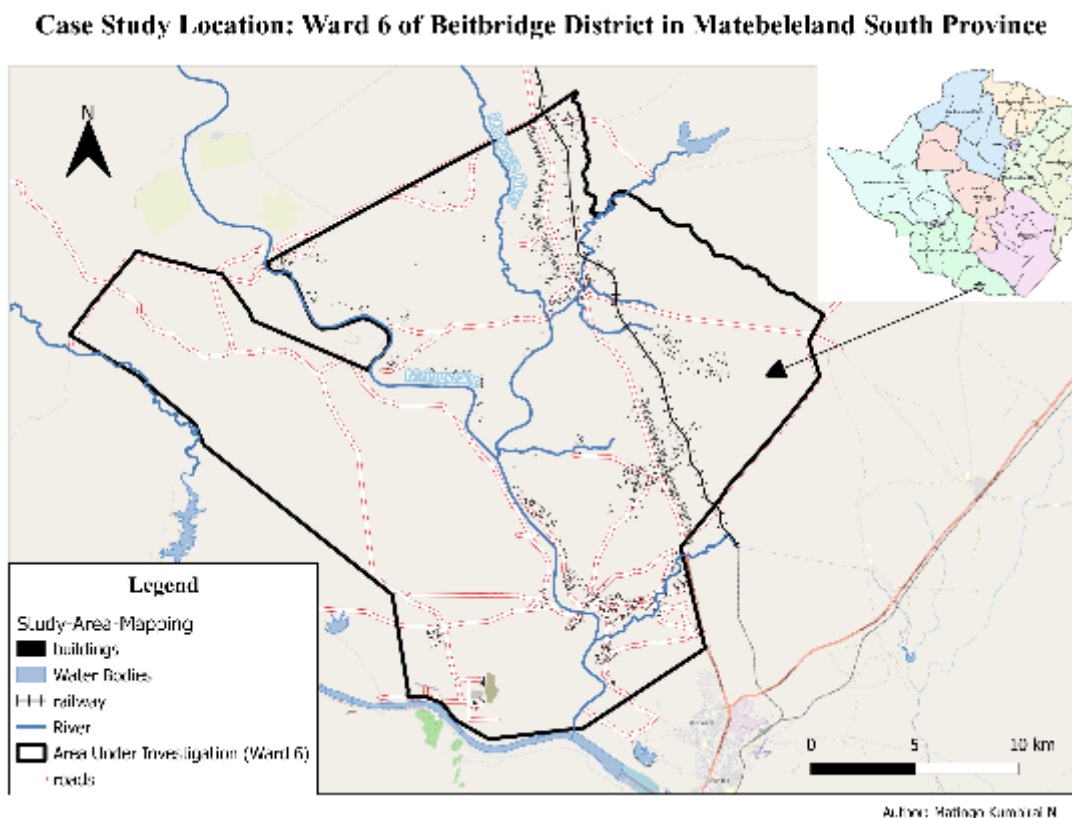


Figure 1

Area under investigation

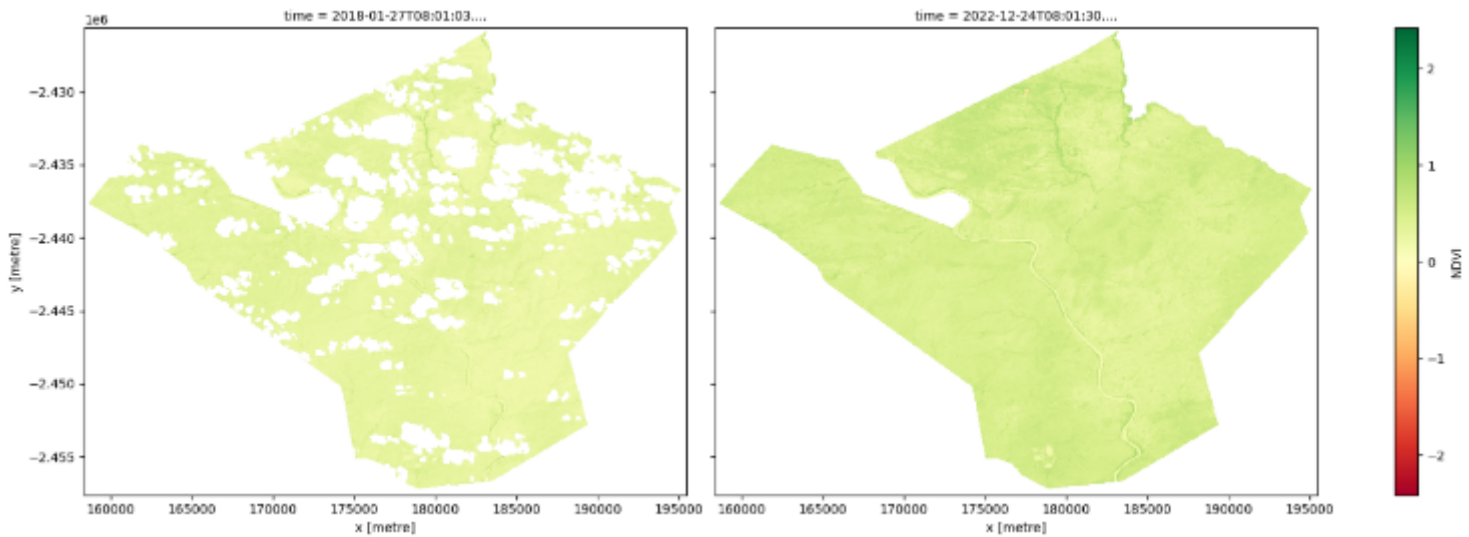


Figure 2

Vegetation analysis for 2018 and 2022

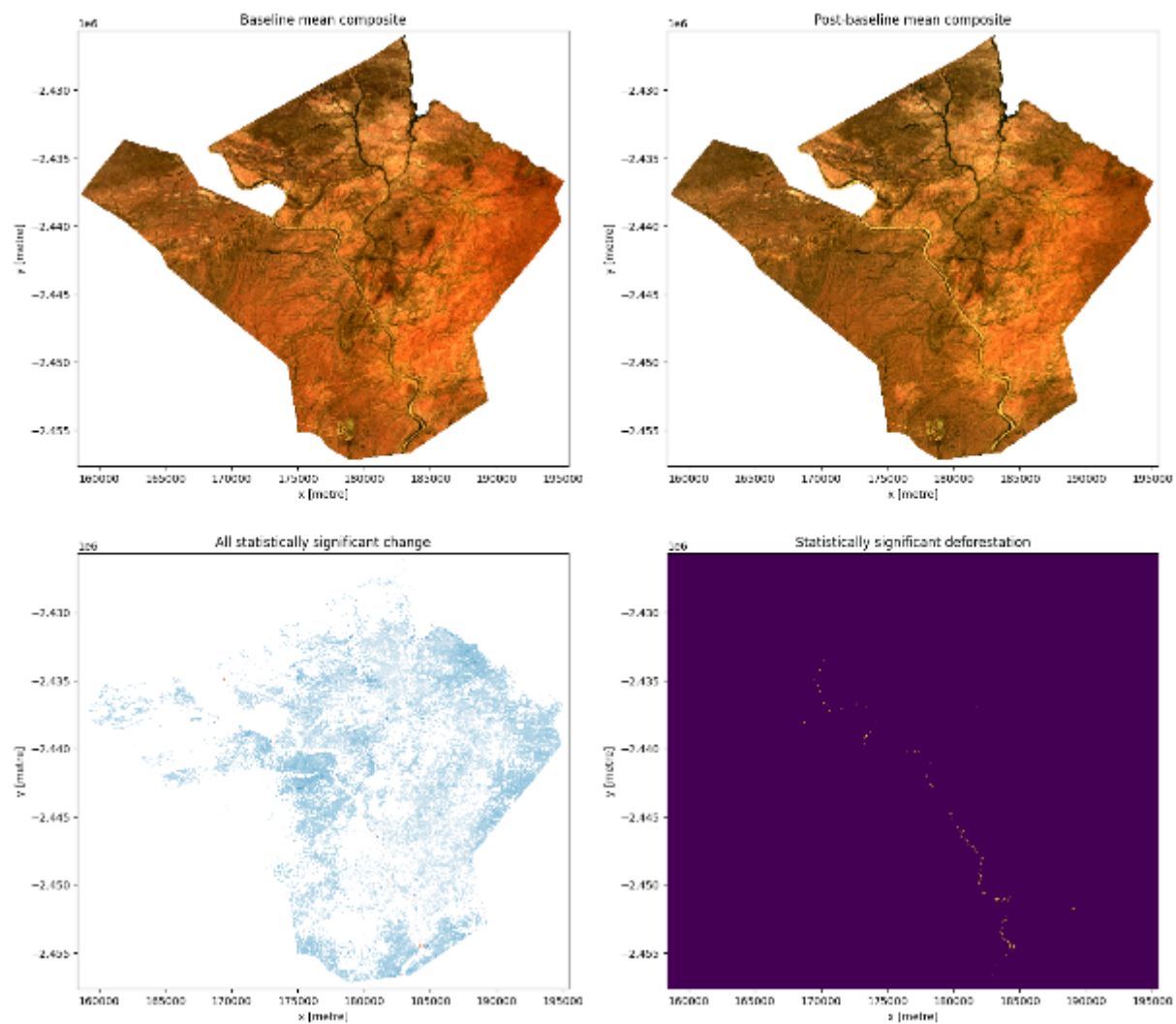


Figure 3

Change detection between 2018 and 2022

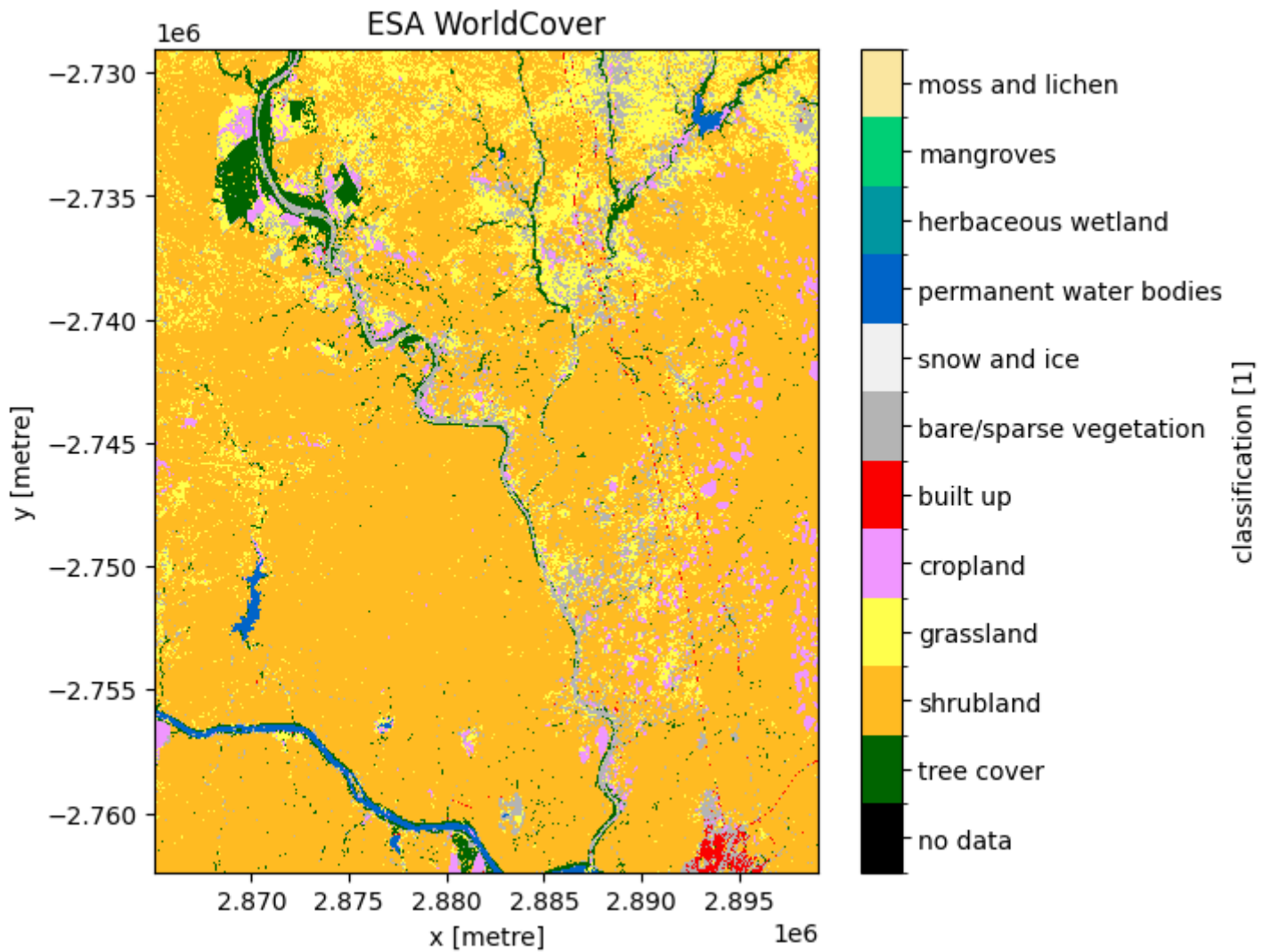


Figure 4

ESA World Cover for land use and land cover

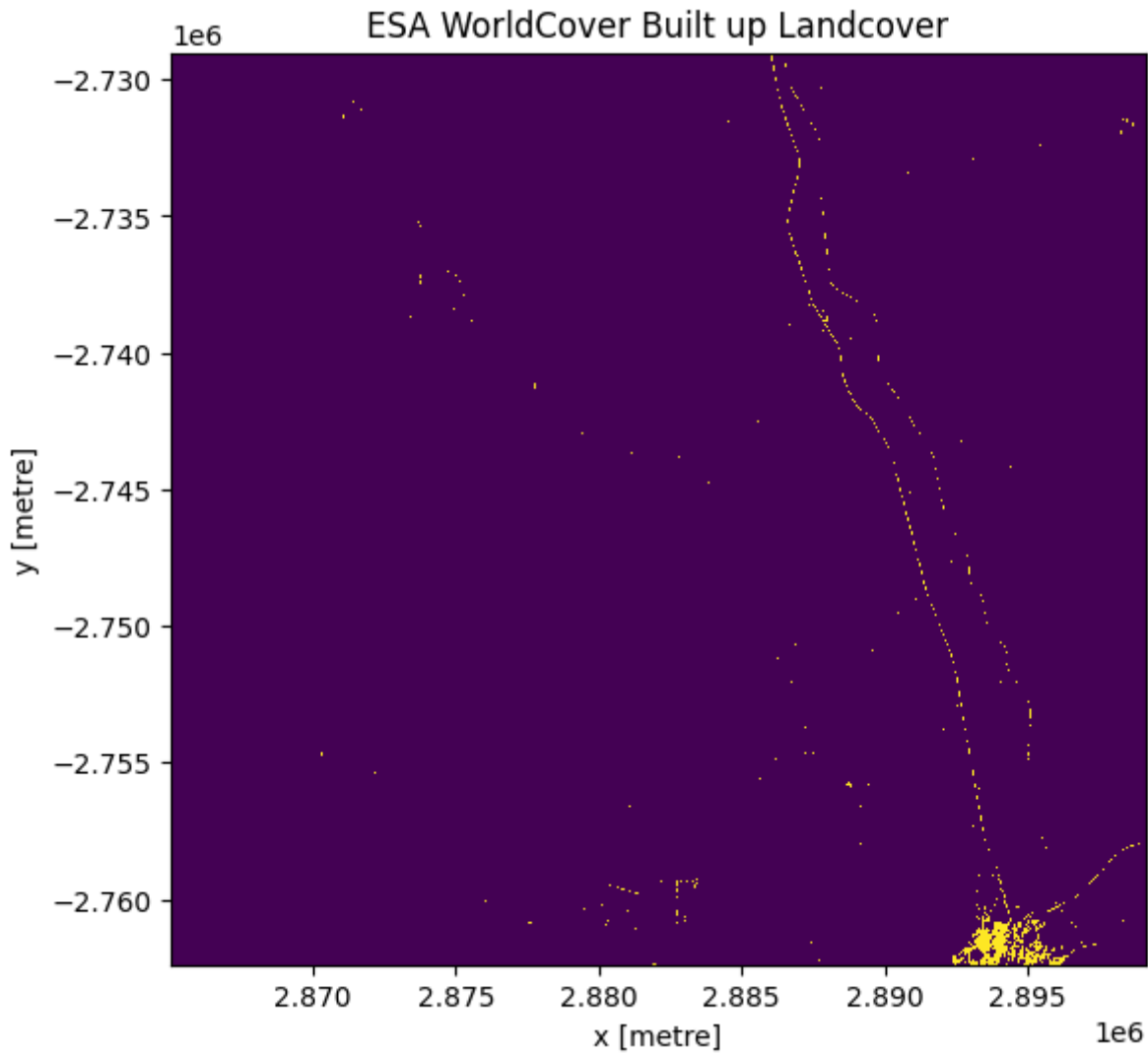


Figure 5

ESA built-up area coverage

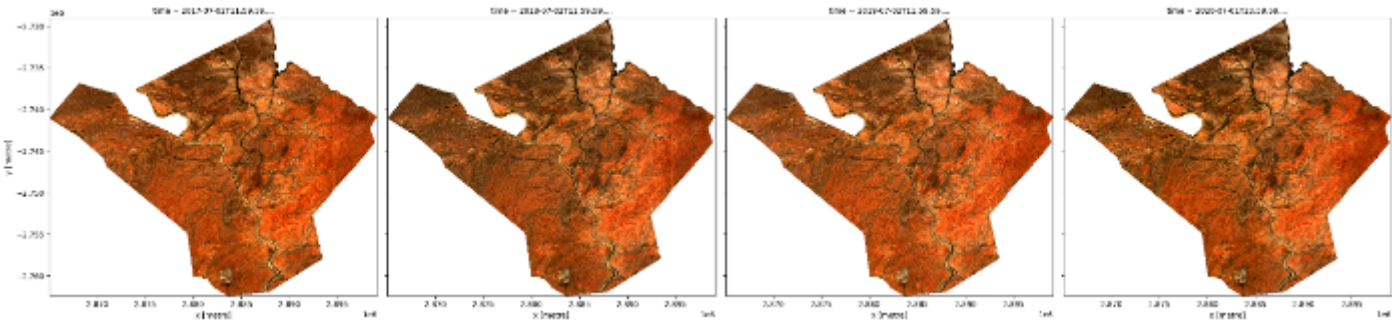


Figure 6

Analysed Geomedians in RGB format

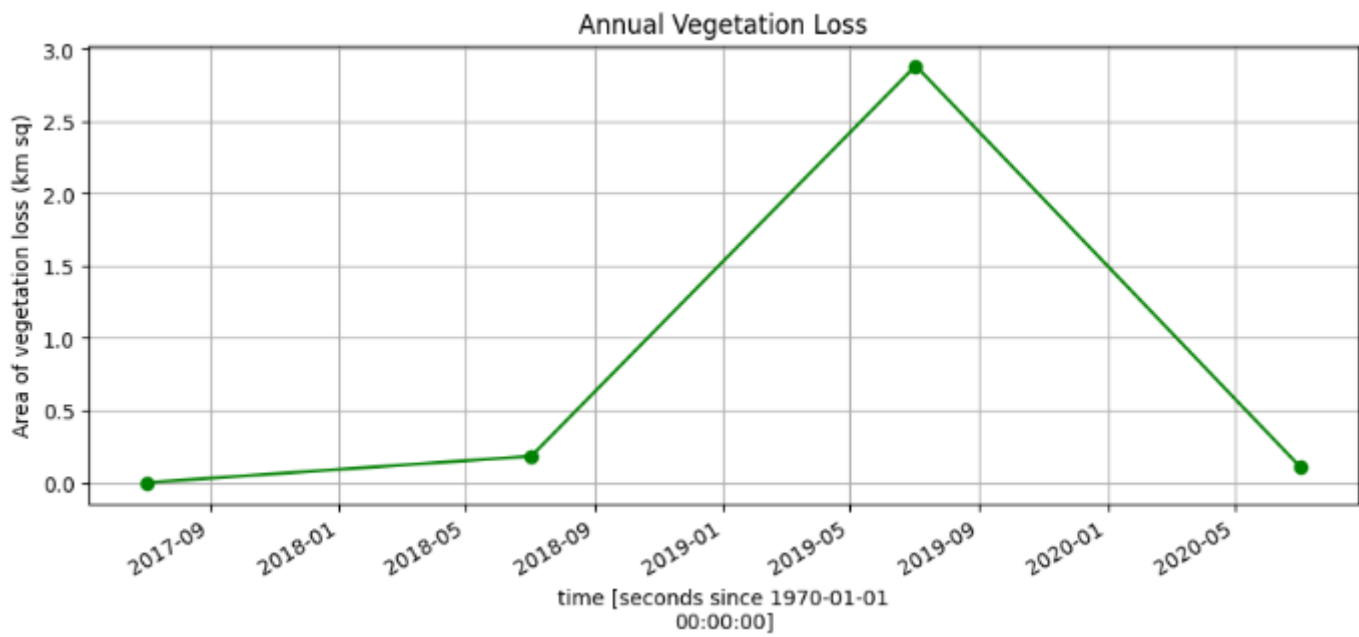


Figure 7

Annual Vegetation loss indicator

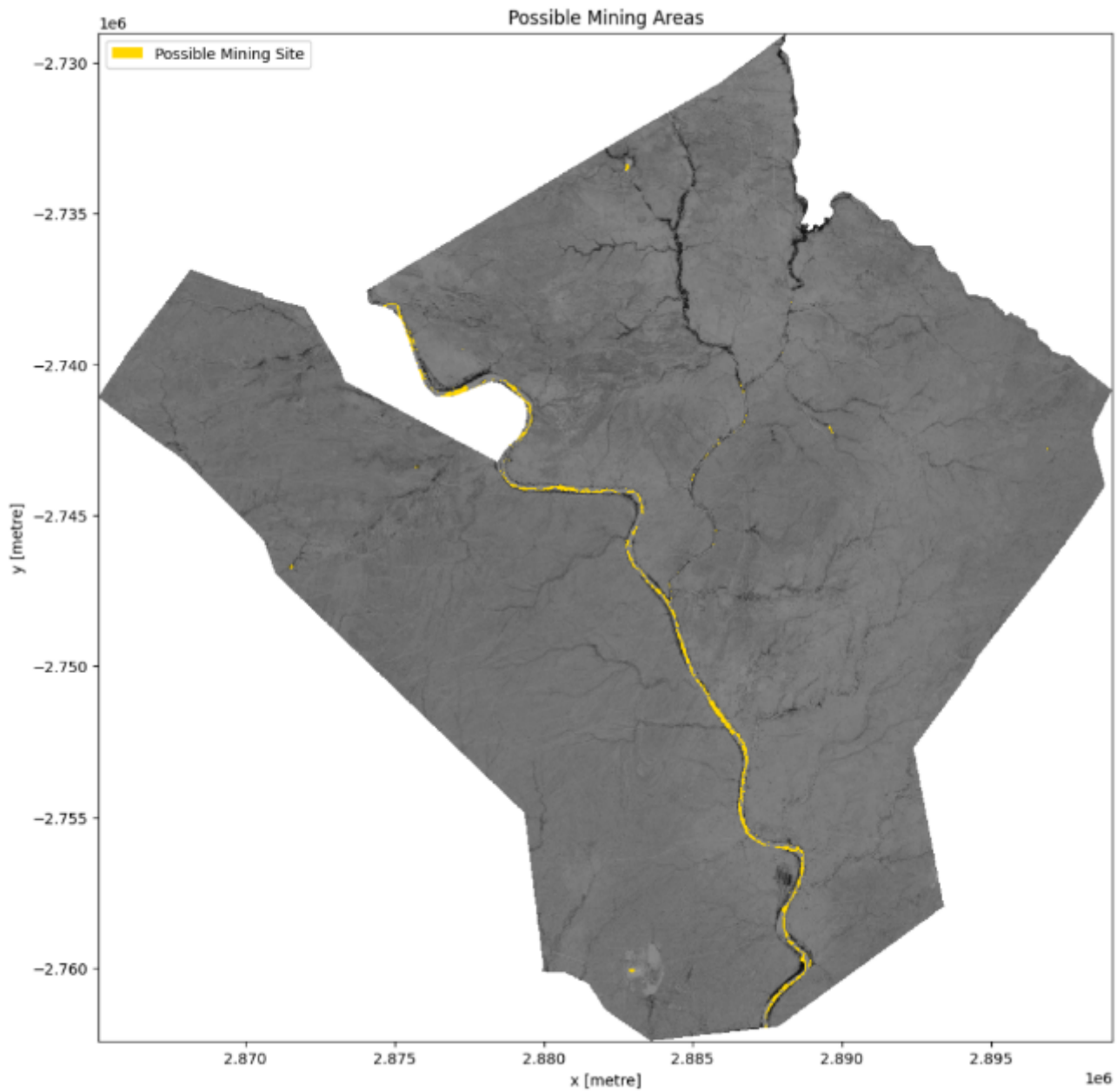


Figure 8

Predicted and possible mining areas