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GIS APPLICATION FOR MONITORING THE MINE AREAS

APLIKASI GIS UNTUK MEMANTAU WILAYAH TAMBANG

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ABSTRACT

Technology development is growing fast, such as satellite imagery and GIS for various applications, one of them is mining technology. Several regulations for the mining sector regarding the mandatory use of satellite imagery have been stated in some regulations to be implemented in mining sectors. Some mine environmental studies showed that the remote sensing and the GIS analysis could detect the small changes in its environment area with effective cost as the coverage of the sensory images is quite broad. The purpose is to monitor land alteration by observing the changes at the taking place, in either the number of voids or their area, using the 2019 and 2020 SPOT 6/7 image data. The algorithm change detection analyzes the number and void changing, mainly to provide a visual description of the void image trend and other applications. The trend of void numbers and its area can be predictable and correlated with the coal mine activities yearly. The results of 2019 SPOT 6/7 image showed that the total area of pit area increased from 2% of the total area of the IUP to 2.53% in 2020. But, its allegation of environmental changes due to the mining activities will be strengthened by a ground check survey that cannot be conducted now.

Keywords: geographical information system, satellite imagery, environmental monitoring, coal mine.

ABSTRAK

Teknologi saat ini berkembang pesat begitu juga dengan perkembangan teknologi citra satelit dan SIG untuk berbagai kebutuhan, salah satunya adalah pemanfaatan citra satelit untuk pertambangan. Berbagai regulasi untuk sektor pertambangan tentang kewajiban pemanfaatan citra satelit ini telah dituangkan dalam berbagai peraturan untuk dilaksanakan oleh pelaku usaha pertambangan. Beberapa studi lingkungan tambang menunjukkan bahwa penginderaan jauh dan analisis SIG mampu mendeteksi perubahan kecil di wilayah lingkungannya dengan biaya yang efektif karena cakupan citra sensorik yang cukup luas. Tujuan penelitian adalah memantau perubahan lahan dengan mengamati perubahan yang terjadi, baik jumlah rongga maupun luasnya, menggunakan data citra SPOT 6/7 2019 dan 2020. Jumlah dan perubahan void *dianalisis dengan algoritma deteksi perubahan, terutama untuk memberikan gambaran visual tentang tren citra* void *dan penggunaan lahan lainnya. Tren jumlah* pit *dan luasnya dapat diprediksi, yang dapat dikorelasikan dengan kegiatan penambangan batubara dari tahun ke tahun. Hasil citra SPOT 6/7 2019 menunjukkan total luas* pit *meningkat dari 2% dari total luas IUP menjadi 2,53% pada 2020. Namun, dugaan terjadinya perubahan lingkungan akibat penambangan kegiatan akan diperkuat dengan survei* ground check *yang belum dapat dilakukan saat ini.*

Kata kunci: sistem informasi geografis, citra satelit, pemantauan lingkungan, tambang batubara.

INTRODUCTION

The use of geographical information systems or GIS in mining industries is widely applied. Technical applications in the mining industries are relatively a limited compared to the other natural resource discipline. A delay reason in using GIS may be caused by the popularity of computer-aided drafting (CAD) and its interface, especially in mining

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software. Most mining software packages in the mine planning process and geological modeling are all-powerful and feature-rich in their internal modeling and evaluation processes. Still, they need more focus in managing the data and inter-operating with other systems to develop a complete solution mines plan. These mining packages are costly to acquire some obligations such as setup, training, and ongoing maintenance.

The research will explore capabilities of GIS presently used at the coal mine area. Evaluate the existing data and acquire data from other sources. The study intends to produce thematic maps of specific themes with all maps compiled on the same coordinate system so it may be overlaid and create relevant reports to assist mine management with the decision-making.

Due to long-consuming constraints, high safety expectations, and production goals to meet, mine management has frequently to provide quick decisions with the information made based on the availability at the time. Reliable data are needed to produce information and reduced uncertainty in decision-making. So, the data has become a vital resource that should manage well to maximize the efficient decision-making.

The study aims to expand the current GIS, gather all relevant data, and then input the data into the GIS. This geographic information can use to produce thematic maps from detailed analysis results to present technical problems in a graphical format and allow management to make immediate decisions based on the visual representation of that data. This case focused on the existing condition of voids surface mine. It is focused in applying remote sensing technology for monitoring the development of open pit mines and voids in coal mining and also in obtaining a method of identification and evaluation of remote sensing image data for the management of ex-mining land (Paull *et al.*, 2006).

Based on the detailed analyses the number and area of pits and their voids can calculate. The produced maps can also describes a void that has been or has not been rehabilitated through backfilling and reclamation. Here, the remote sensing will also help to monitor the implementation of reclamation progress.

Environmental Management Using GIS

Several literatures have discussed the GIS and its application in the mining sector, such as for mapping mining areas in South Sumatera (Fenando, 2021) and Ngawi Regency, East Java (Fanani and Sari, 2018).

Most of the literature is on GIS and the monitoring the environment surrounding mine area. The studies concentrate on the mining environmental effects that could be monitored by observing the physical change over time. Other articles have discussed the subject of the environment ranging from mine area rehabilitation to monitoring soil sediment runoff into the ecosystem stream systems.

GIS-based research on the mine's environmental management can be classified into three topics: mine operation environment management, mine-induced hazard management, and mine rehabilitation design. In real terms, it isn't easy to separate these three studies. Each will be related to each other.

Mining operations cause negative changes to the environment. Therefore, such areas require constant monitoring, which can benefit from remote sensing data. Therefore, monitoring and protecting areas under the influence of mining is an essential issue since changes caused by mining are irreversible in many cases, so the rehabilitation of such areas can take up to several years. The use of aerial images or photos obtained from remote sensing activities can currently monitor environmental conditions in an area to a temporal, accurate, and immediately known extent (Shofiyanti, 2011; Widiyatmoko, Wasis and Prasetyo, 2017; Suwarsono *et al.*, 2018).

Monitoring mining areas is aimed to observe the changes taking place, to define their extent, and to determine the threat level of a given displacement phenomenon. On the other hand, the environmental protection is associated with the implementing solutions in technological processes related to the operation. This monitoring will minimize the undesirable environmental impact and mitigate the adverse effects through rehabilitation.

Environmental degradation depends primarily on the method of exploitation of raw materials like open pit or underground methods. However, this paper will take a look at the open pit mining impact. The GIS offers tools for various spatial analysis and graphic visualization of the results. One of the applications of remote sensing in mining is detecting terrain displacements caused by the active or terminated mining. The terrain study (vegetation condition, land use and changes in the range of water reservoirs). Noteworthy scientific publications on remote sensing in monitoring and environmental impact assessment are presented in Table 1.

The studies cited in Paull *et al.* (2006) show a clear division between passive and active remote sensing techniques. Passive remote sensing is suitable for investigating the environment in the context of land cover changes, while active remote sensing allows for detecting terrain deformation. Both passive and active methods are used to assess the condition of mining areas, enabling the creation of a sustainable mining strategy.

The above studies confirm the validity of using individual aspects of remote sensing, GIS and machine learning classification and regression algorithms to identify open zones in mining areas. This is because remote sensing is characterized by systematic observation of large areas. Additionally, the time needed to download and process imagery is shorter than that of obtaining it during the field measurements. Another advantage is a short interval for image acquisition of the same area like satellites provide new imagery every day and the possibility of researching past phenomena as long as the satellite images for the studied period are available.

Increasing the number of satellite missions in observing the surface and easier universal access to earth images and open-source software for satellite data processing make remote sensing and related computing methods dynamic. As a complement to remote sensing research, GIS will provide many tools for further processing in conjunction with other spatially referenced data. The linking of environmental, geological-tectonic, topographic, and mining variables in the research areas will be obtained by combining with time and space. The GIS is also identified with the storing, indexing, data management, and modeling various phenomena. Classification and regression machine learning algorithms enable the appropriate adjustment and generalization of the dataset in the statistical analysis of dynamic phenomena (Paull *et al.*, 2006).

Table 1. Application of Remote Sensing Technology and GIS for Mine Environmental Monitoring Activities

Activities	Location	Remote Sensing	GIS	Author
Remote Sensing Technology for Environmental Monitoring on Ajkwa river, Papua Using Change Detection Algorithm	S. Ajkwa, Papua	citra satelit Landsat-7 TM	Map-Info	Wibowo *et al.* (2005)
Biomass Estimation of Secondary Forests and Reclamation Areas Using Remote Sensing and Geographic Information Systems Technology	PT. Gunung Bayan Pratama Coal	Alos Palsar	Arc-GIS	Lutfi and Antono (2011)
Identification of Tin Mining Areas Using Sentinel-1 Satellite Data with Object Based Image Analysis (OBIA) Method	PT. Timah, Bangka-Belitung	Sentinel-1	Q-GIS	Nugroho, Kushardono and Dewi (2019)
Coal Mining Exploitation and Reclamation Monitoring Method Using Sentinel-2 Satellite Data	Rangda Malingkung, North Tapin, Tapin Regency, South Kalimantan Province	Sentinel-2	Q-GIS & Arc-GIS	Arifin *et al.* (2020)

Source: R and D Center for Mineral and Coal Technology Collection

GIS implementation process starts with initial decision to use a GIS then it proceeds through the system selection, installation, database development, and product generation. The research project discusses considerations related to each phase and focuses on other areas of GIS pertinent to underground coal mine planning and management. The research involved reviewing literature on implementing the GIS in underground mines and the resource sector. The research then explores the capabilities of GIS presently used at the coal mine area and compares that system to other systems on the market. Develop a program of data collection. Evaluate the existing data and acquire data from various sources. The project intends to produce thematic maps of various themes with all maps compiled on the same coordinate system so it may be overlaid and produce relevant reports to assist mine management with decision-making.

The study was carried out to monitor the environmental impact of coal mining in East Kalimantan, Indonesia, against the landscape change. The change in the landscape is in the form of large holes, either filled with water or still in empty condition. The big holes are known as voids.

For monitoring the surface of mine environment, the advantages of satellite imagery are the economical cost, high resolution, and can cover a large area. From Indonesia mine point of view, the satellite imagery has some advantages to monitoring before, during, and post-mining activities, like:

1. Producing high-resolution satellite imagery maps for the mineral and coal mining companies in work planning and budgeting. Maps provide in natural color and in the form of raw and raster data,which had been corrected geometrically;
2. Providing time series of changes in mining progress activities year by year, from the pre to post-mining activities;
3. Giving accurate observations in the form of a high-resolution satellite imagery map on the progress of the mine reclamation;
4. Organizing ex-mining land (post-mining) according to its primary designation;
5. Giving an overview that the opened surface area for the extracted mineral and coal does not violate the permitted area. This technology promises to implement monitoring of the open condition;
6. Mining industries, as IPPKH holders, must submit six months of periodic reports, including high-resolution image maps in GeoTIFF format;
7. Monitoring the minimum fulfillment of the distance requirement from the edge of the mine hole to the boundary concession. It is at least 500 meters from the settlements mentioned in the environmental baseline;
8. Monitoring the ASGM activities located nearby the mineral and coal mine. The ASGM mine void, either number or are of mine pit void, can be detected;
9. Preliminary exploration for mineral and coal mining (Mine Portal).

Surface Mine Alteration Techniques

Remote sensing technology, combined with geospatial analysis, is an integrated methodology in the case of monitoring vegetation. Those have the capabilities to convert the quantitative image values into the sets of the data that can be read visually and contains qualitative values. Remote sensing methods are generally used to make easier spatial-based data retrieval (Abdollahnejad, Panagiotidis and Bílek, 2019; Nguyen *et al.*, 2020).

Change detection analysis is one of the methods used to identify, describe, and quantify the differences between two images of the same image at different times or conditions. Various methods can be used either individually or in a combination of several methods to obtain the best results. However, the main principle is to compare the difference between the final condition and the initial one, which is also commonly referred to as image differencing. If the difference is too small, the final and initial image ratio can be used by comparing the image in those conditions (Research Systems Inc., 2004). The change detection method was also developed by Gong (2001).

In Mishra, Shrivastava and Dhurvey (2017), for detecting and analyzing the change on the surfaces, various techniques are employed. Before using various change detection techniques, it is necessary to know about change detection procedure. There are six main essential steps that Jensen mentions. Those are as follows:

- nature of change detection problems;
- selection of remotely sensed data;
- image preprocessing;

- image processing or classification;
- selection of the change detection algorithm;
- evaluation of change detection results.

The goal of change detection is to discern those areas on digital images that depicts the change in the feature of interest between two or more image dates. The reliability of the change detection process may be strongly influenced by various environmental factors that might change between the image dates. The different changes of the detection techniques that are commonly used cover post-classification, image rationing, and image differencing. Here, it will be globally discussed, the last two processings that included:

a) Image Differencing.
Image differencing is a method of detecting changes by searching the difference between the pixels in the first-year images and the pixels in the newer ones.The method calculates images differently in the final and the initial state, from a single band in the scene that has to be analyzed. The differences are grouped into classes and defined by the difference threshold value. The positive changes will be seen in pixels that become lighter in color (brightness in the final state is greater than brightness in the initial state). In contrast, the negative changes will be seen in pixels that become dimmer (brightness in the final state is smaller than brightness in the initial state). A series of pre-processing needs to be carried out on the image bands to sharpen the brightness difference.

The general mathematic formula of this procedure is (Mishra, Shrivastava and Dhurvey, 2017):

$$Dx_{ij}^{k} = X_{ij}^{k}(T_2) - X_{ij}^{k}(T_1)$$

With:
$X_{ij}^{k}(T_1)$ and $X_{ij}^{k}(T_2)$: DN value of pixel X located at row i and column j for and k at time T_1 and T_2

Further,to emphasize the non-vegetation image, the bands used in the analysis are generally bands 3, 5, and 7, which usually have high reflectance values because, in principle vegetation will reject infrared light.

b) Image-to-image Ratio
The primary principlemethod of image-to-image ratio is taken by comparing the pixel value at the initial time with the pixel value at the final. The image rationing method is considered a rapid tool for change identification.

Image rationing is performed by calculating the ratio of the DN values of corresponding pixels on the two registered images at different times with one or more bands. The comparison between data is made based pixel by pixel. The general mathematical approach is (Mishra, Shrivastava and Dhurvey, 2017):

$$Rx_{jl}^{k} = \frac{X_{il}^{\,k}(t1)}{X_{il}^{\,k}(t2)}$$

With:
X_{il}^{k} (t_1) : pixel value of k band for pixel x atrow i and column j at time t1
X_{il}^{k} (t_2) : pixel value from k band for pixel x atrow i and column j at time t2

If there is no change in the pixel, then the ratio is assumed as 1, but if there is a change, the value of the ratio will shift from 1 (Mishra, Shrivastava and Dhurvey, 2017).

METHODOLOGY

The study area located in 117° 03' 55" - 116° 47' 37,2" East Longitude and 00° 24' 46" - 00° 26' 59,4"South Latitude as shown in Figure 1. Geographically, study area is in East Kalimantan, Indonesia Archipelago.

SPOT 6 and SPOT 7

The SPOT 6 and SPOT 7 satellites are designed to continue the SPOT-5 mission in obtaining wide-swath and high-resolution imagery. The SPOT-6 and SPOT-7 successfully enhanced technical performance with the experience of SPOT-5 to maintain a high-level coverage capability by capturing bandwidth of 60 km and up to 120 km in one pass mosaic, providing ortho-imagery at 1.5 m spatial resolution, obtaining native natural color images by adding a blue near-infrared band, collect images of both large areas and small objects around 3 million km^2 for each satellite per day, support responsive tasking up to 6 program plans for each satellite per day to get cloud-free imagery, get images of vegetation for agricultural management due to added near-infrared spectral band (B3), provide the option of daily revisit, make the data applicable for geographical modeling due to radiometric and geometric specifications, maintain a prolonged lifetime of a satellite up to 10 years, acquire panchromatic and multi-spectral images to generate color products automatically and get stereoscopic imagery along the track (Earth Observing System/ EOS).

This study uses a combination of SPOT 6 and SPOT 7 data because it is not obtained in that area that ultimately uses the same image. A summary of the data processing methodology is shown in Figure 2.

Mine location consists of 5 IUPs (IUP A, B, C. D, and E) with different areas. These pits are still active even though some are filled with water due to heavy rain in this location.

RESULTS AND DISCUSSION

The 2019 and 2020 SPOT 6/7 image data showed that some areas do not change in the mine pit area compared to the IUP area base map. The changes can be seen clearly from the image after processing but the detailed reason might not be explained well because the field ground check must be implemented in this type of monitoring survey.

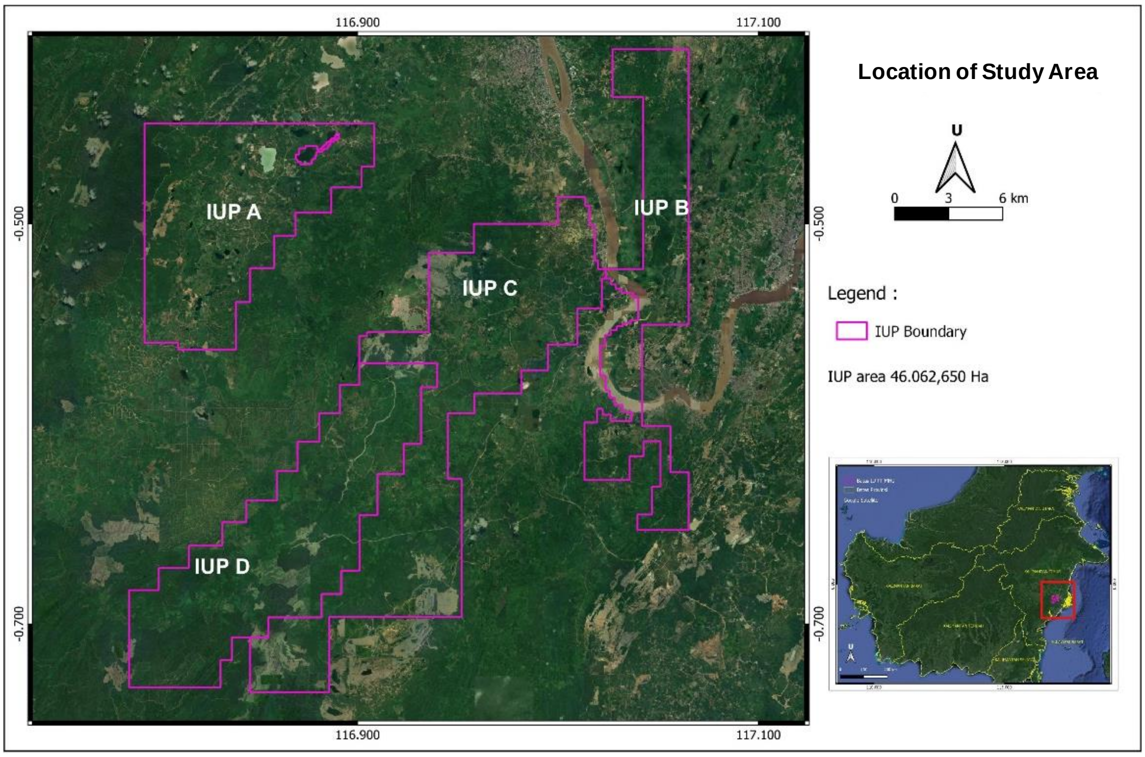


Figure 1. Location of study area

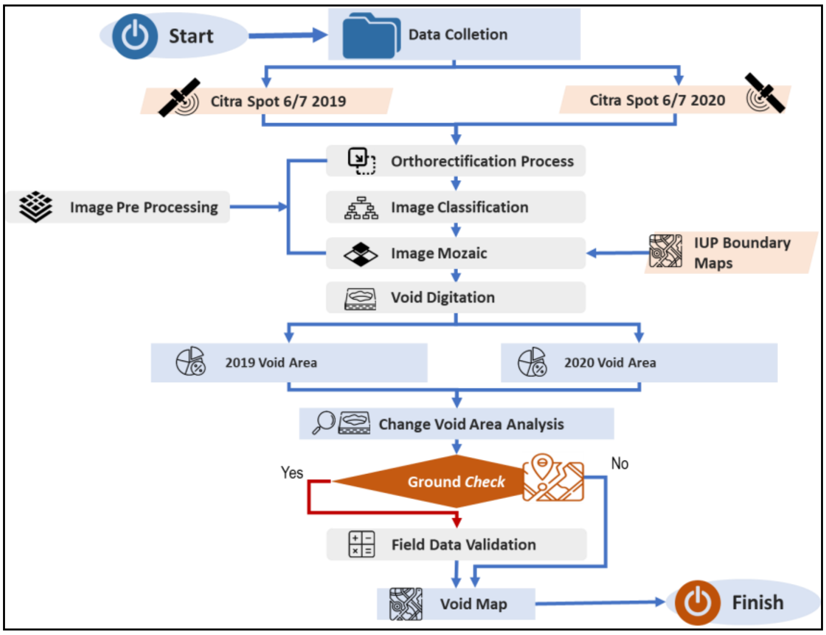
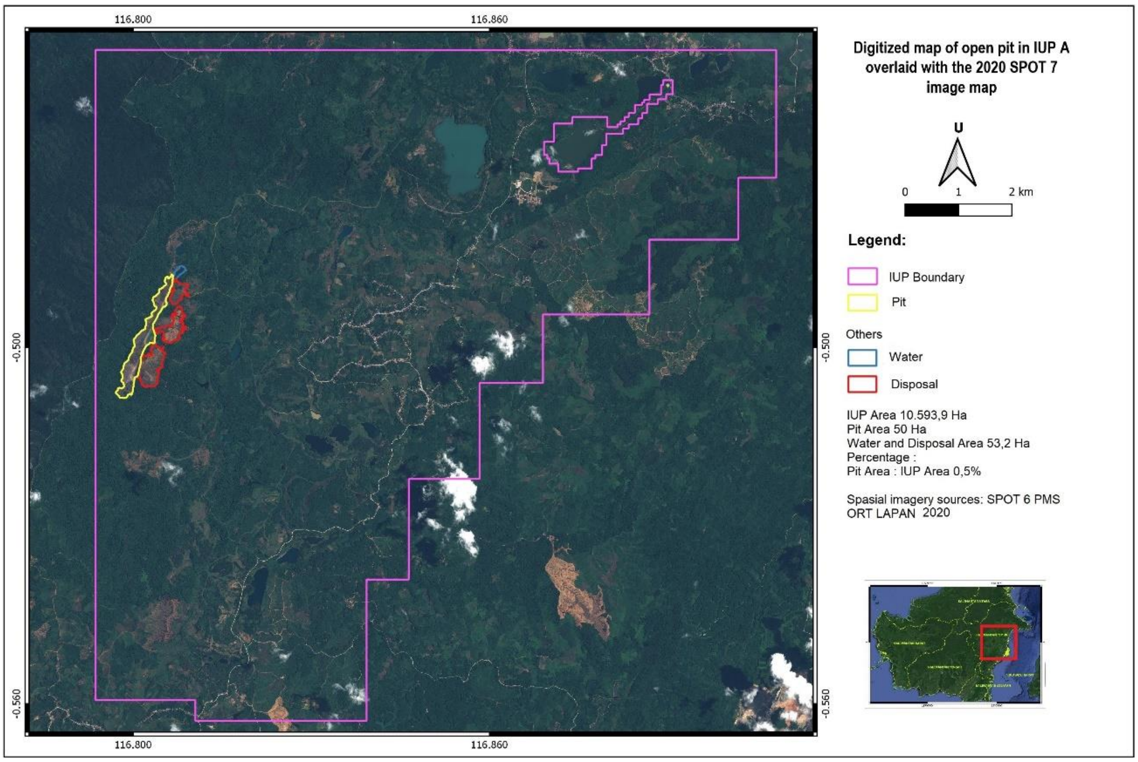


Figure 2. Image processing methodology

IUP A Void Area Identification

IUP A images taken from SPOT 7 2019 and 2020 images do not show significant changes in the area. It is thought due to the temporary cessation of mining activities or other reasons.

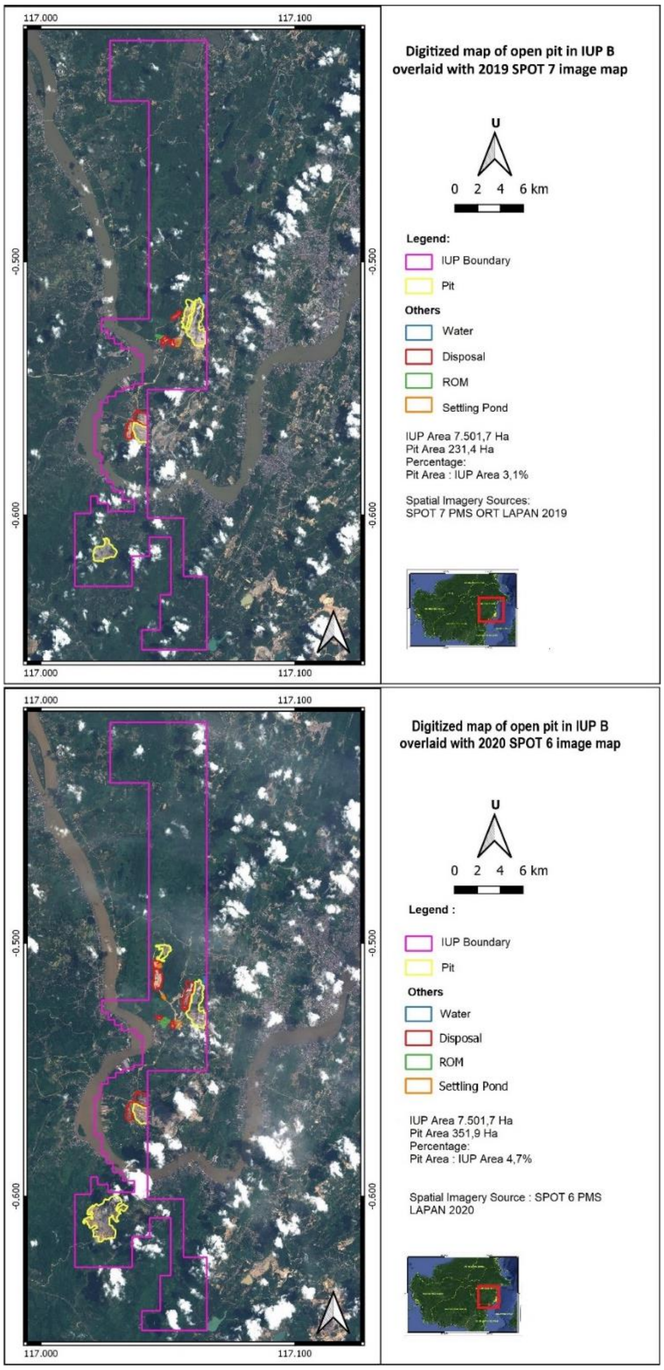


Source: SPOT 6 Image PMS ORT LAPAN 2020

Figure 3. Digitized map of open mining pit A overlaid with the 2020 SPOT 7 image base map

IUP B Void Area Identification

At this location, there was an increase in the area of the pit, from the original area of 231.4 Ha to 251.9 Ha in 2019 but the other areas such as disposal, water, ROM (Run of Mine), and settling ponds also increased. In 2019, there was 75.1 Ha to147.4 Ha in 2020. This increase was due to the mining activities in the area. This difference can be observed clearly in the IUP B 2020 SPOT 7 image compared to the 2019 image.

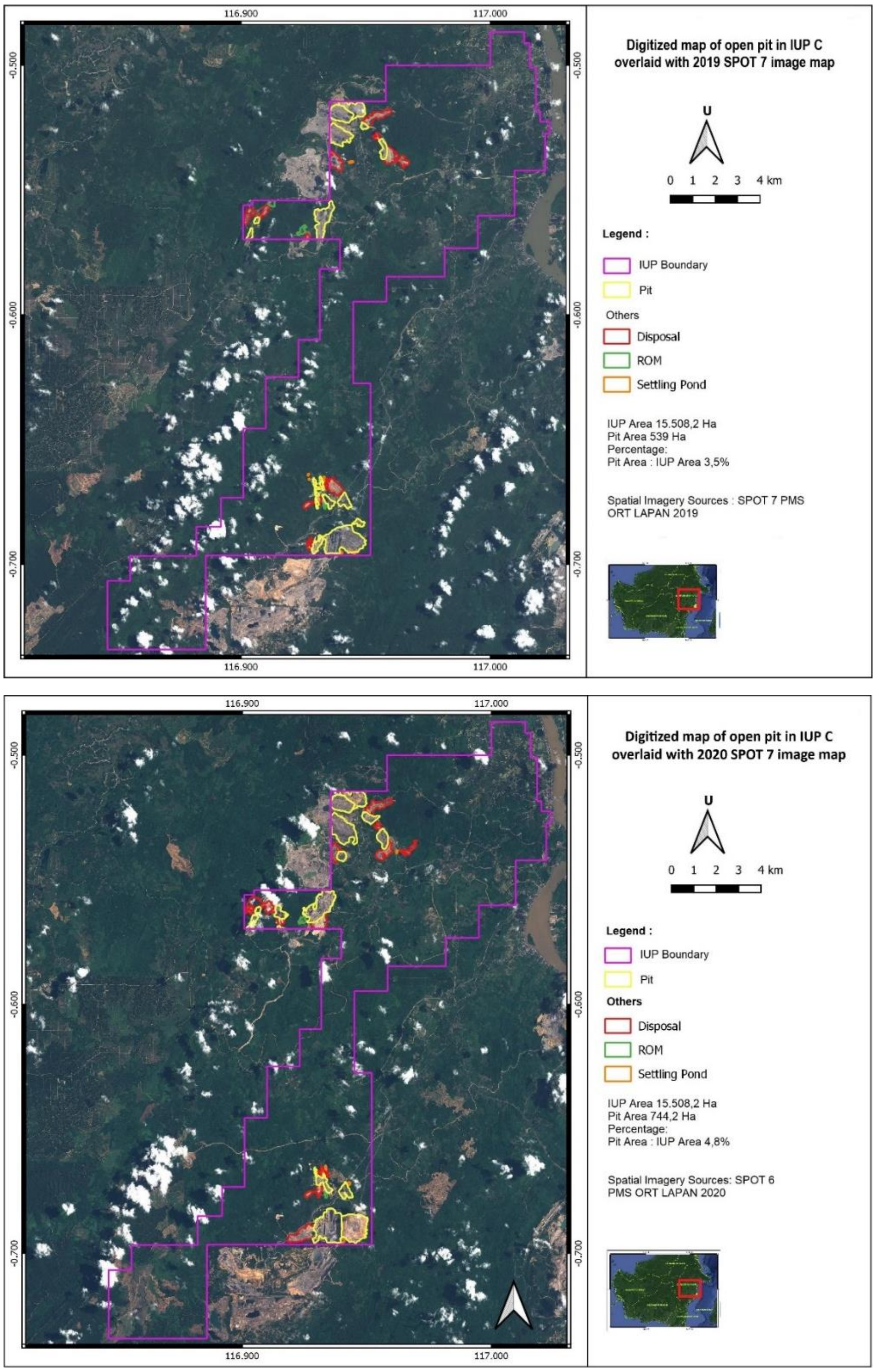


Source:SPOT 7 Image PMS ORT LAPAN 2019 and SPOT 6 Image PMS ORT LAPAN 2020

Figure 4. Digitized map of open mining pit B overlaid with 2019 SPOT 7 image base map (above) and. Digitized map of open mining pit B overlaid with 2020 SPOT 6 image base map (under)

IUP C Void Area Identification

In IUP C, the pit area had increased. In 2019 it was 539.0 Ha, or 3.5% of the IUP area, became 744.2 Ha or 4.8% of the IUP area in 2020. Another area (disposal, ROM and settling pond) had also increased, from 225.5 Ha in 2019 to be 283.3 Ha in 2020.

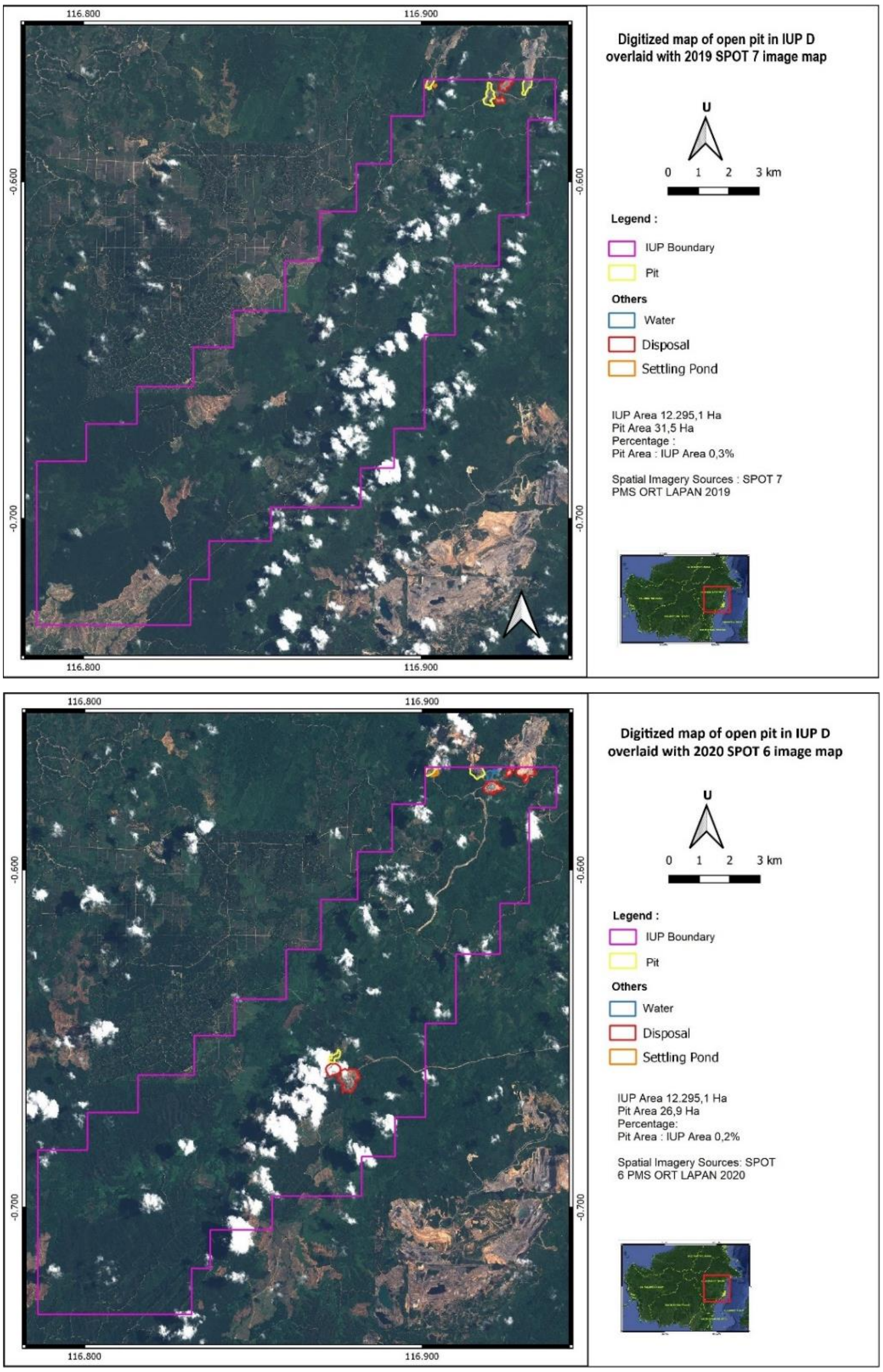


Source: SPOT 7 Image PMS ORT LAPAN 2019 and SPOT 6 Image PMS ORT LAPAN 2020

Figure 5. Digitized map of open mining pit C overlaid with 2019 SPOT 7 image base map (above) and Digitized map of open mining pit C overlaid with 2020 SPOT 7 image base map (under)

IUP D Void Area Identification

In 2019, the open pit area was 31.5 Ha or 0.3% of the IUP D area. Meanwhile, the other place that consists of disposal, water, and settling pond was 16.8 Ha. In 2020, the image SPOT showed that the open pit area decreased. It becomes 26.9 Ha or 0.2% of the IUP area. Meanwhile, the other place, which consists of disposal, water, ROM, and settling pond, is 99.0 Ha (Figure 6).



Source: SPOT 7 Image PMS ORT LAPAN 2019 and SPOT 6 Image PMS ORT LAPAN 2020

Figure 6. Digitized map of open mining pit D overlaid with 2019 SPOT 7 image base map (above) and Digitized map of open mining pit D overlaid with 2020 SPOT 6 image base map (under)

In 2019, the total pit area in IUP A, B, C, and D was 851.8853 Ha, or 1.849 % of the total IUP area (Table 1). In 2020, there was an increase in the pit area of 314.2915 Ha. The percentage of pit area compared to the IUP area was 2.532% (Table 2). It is due to mining activities in the area.

Mine pit analysis in 2019 and 2020 for IUP A, B, C, and D show a fixed number of pits. It is due to changes in land use that switch functions from pit to disposal and reverse. If there are still economical coal reserves at the disposal, the removal will become a pit again. In addition, the land use change comes from opening new land for pit and disposal.

CONCLUSION AND SUGGESTION

This study demonstrates the ability of Remote Sensing and GIS to capture spatial-temporal data. The attempt was made to capture as accurate as possible five land use of land cover classes as they change through time. The urban planners must study change detection for further development to plan the city scientifically. It is evident from the above results that the city has experienced significant rate of growth in the last sixteen years. Urbanization mostly extended towards the southeast of the city during 1995-2011. Most vegetation lands, gardens, and forests have been converted into the urban planning areas.

The change detection analysis using remote sensing technology and GIS has been widely used for various purposes, both in observing changes that occur in land use (Gong, 2001), vegetation (Gomez, 1997), as well as to monitor changes that occur in the mining area, such as the pits or voids.

The analysis results from the 2019 SPOT7 image showed that the pit area is about 851.8853 Ha, or this was almost 2% of the total IUP area. In 2020, there was an increase to be 314.2915 Ha, so the percentage of pit area compared to the IUP area was about 2.532%.

A ground check survey will strengthen the allegation of environmental changes due to the mining activities. Despite mine voids monitoring, either active or inactive, reclamation at surrounding mining areas or other progress activities can be monitored, by satellite imagery technology. It must disseminate more widely to simplify monitoring activities. Based on various existing studies, remote sensing has proven to be cost-effective and accurate in checking the development of mining activities.

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Table 2. Number and area of pit 2019-2020

Location	2019				2020			
	Σ Pit	Pit Area (Ha)	IUP Area (Ha)	Percentage (%)	Σ Pit	Pit Area (Ha)	IUP Area (Ha)	Percentage (%)
IUP A	1	49,9945	10757,944	0,465	1	49,9945	10757,944	0,465
IUP B	4	231,3771	7501,665	3,084	4	351,8389	7501,665	4,690
IUP C	16	538,9819	15508,238	3,475	16	744,2311	15508,238	4,799
IUP D	3	31,5318	12295,107	0,256	3	20,1123	12295,107	0,164
Total	24	851,8853	46062,954	1,849	24	1166,1768	46062,954	2,532

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