วารสารวิทยาศาสตร์บูรพา ปีที่ 28 (ฉบับที่ 1) มกราคม – เมษายน พ.ศ. 2566
BURAPHA SCIENCE JOURNAL Volume 28 (No.1) January – April 2023 บทความวิจัย

การตรวจจับการเปลี่ยนแปลงของขอบเขตการทำเหมืองแร่แบบเปิดด้วยเทคนิคการสำรวจระยะไกลหลายแหล่งข้อมูล

Change Detection for Surface Mining Boundary Based on Multi-source Remote Sensing Data Techniques

กวิภา สุขขี[1], Zhenfeng Shao[2], กฤษนัยน์ เจริญจิตร[1], ฐนิตา เสือป่า[3] และ ปัทมา พอดี[1*]
Kawipa Sukkee[1], Zhenfeng Shao[2], Kitsana i Charoenjit[1], Tanita Suepa[3] and Pattama Phodee[1*]
[1] *คณะภูมิสารสนเทศศาสตร์, มหาวิทยาลัยบูรพา*
[2] *สถาบันสารสนเทศวิศวกรรมการสำรวจการทำแผนที่และภูมิสารสนเทศ, มหาวิทยาลัยอู่ฮั่น*
[3] *ศูนย์ภูมิสารสนเทศสิรินธร, สำนักงานพัฒนาเทคโนโลยีอวกาศและภูมิสารสนเทศ*
[1] *Burapha University, Geoinformatics, Chonburi, Thailand*
[2] *Wuhan University, The State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing (LIESMARS)*
[3] *Geo-Informatics and Space Technology Development Agency, SCGI: Sirindhorn Center for Geo-Informatic*

Received : 15 August 2022
Revised : 6 September 2022
Accepted : 25 September 2022

บทคัดย่อ

จุดมุ่งหมายของการศึกษานี้เพื่อการประเมินประสิทธิภาพและความเหมาะสมของการประยุกต์ใช้เทคโนโลยีดาวเทียมเพื่อการตรวจจับการเปลี่ยนแปลงของการทำเหมืองแร่แบบเปิดทั้งแนวราบและแนวดิ่งของเหมืองแร่ขนาดเล็ก กรณีศึกษาพื้นที่เหมืองแร่ของบริษัท สุรินทร์ออมย่าเคมิคอล (ประเทศไทย) จำกัด และเหมืองแร่ของบริษัทศิลาสานนท์ จำกัด การศึกษานี้มุ่งเน้นการใช้ข้อมูลดาวเทียมจากหลายแหล่งที่เปิดให้บริการฟรีและซอฟแวร์แบบเปิด ข้อมูล Sentinel-1, Sentinel-2 และ Landsat 8 คือข้อมูลดาวเทียมที่นำมาใช้ในการศึกษานี้ Mean Shift Segmentation อัลกอริทึมและ Random Forest (RF) ใช้สำหรับสกัดขอบเขตการทำเหมืองแร่แนวราบจากข้อมูล Sentinel-2 และ Landsat 8 เทคนิค InSAR ใช้สำหรับสกัดขอบเขตการทำเหมืองแร่แนวดิ่งโดยจะได้ข้อมูลเป็นแบบจำลองความสูงเชิงเลข (DEM) จากข้อมูล Sentinel-1 จากนั้นวิเคราะห์การเปลี่ยนแปลงของการทำเหมืองแร่ในแนวราบและแนวดิ่ง เมื่อได้ผลลัพธ์ของการเปลี่ยนแปลงจึงทำการเปรียบเทียบค่าความต่างกับข้อมูลที่รังวัดจากอากาศยานไร้คนขับซึ่งใช้เป็นข้อมูลอ้างอิงและใช้วิธีการทางสถิตหาค่าสัมประสิทธิ์ในการตัดสินใจ (R^2) และ ค่าคลาดเคลื่อนเฉลี่ยกำลังสอง (RMSE) ผลลัพธ์ที่ได้คือ Sentinel-2 แสดงให้เห็นถึงความเหมาะสมปานกลางสำหรับการตรวจจับการเปลี่ยนแปลงของขอบเขตการทำเหมืองแร่แนวราบ เนื่องจากผลลัพธ์ของการเปลี่ยนแปลงมีค่าใกล้เคียงกับข้อมูลอ้างอิงและสามารถยอมรับได้ ในขณะที่ Landsat-8 ไม่ใช่ตัวเลือกที่เหมาะสมสำหรับการตรวจจับการเปลี่ยนแปลงของการทำเหมืองแร่แนวราบ เนื่องจากรูปแบบการเปลี่ยนแปลงไม่มีความสัมพันธ์กับข้อมูลอ้างอิง และ Sentinel-1 ไม่เหมาะสำหรับการตรวจจับการเปลี่ยนแปลงของการทำเหมืองแร่แนวดิ่งในพื้นที่เหมืองขนาดเล็ก เนื่องจากมีความแตกต่างกับข้อมูลอ้างอิงมาก ผลลัพธ์จากการศึกษาครั้งนี้สามารถนำไปประยุกต์ใช้ในการตรวจสอบการเปลี่ยนแปลงของการทำเหมืองแร่ในเบื้องต้นเพื่อค้นหาพื้นที่ต้องสงสัยที่มีแนวโน้มที่จะทำเหมืองแร่ออกนอกขอบเขตที่อนุญาต ช่วยลดเวลาการปฏิบัติงาน ลดค่าใช้จ่ายและป้องกันความเสียหายของทรัพยากรแร่ได้ทันท่วงที

คำสำคัญ : การสำรวจระยะไกล ; InSAR ; Landsat 8 ; Sentinel 1 ; Sentinel 2

Abstract

The aim of this study is to evaluate the optimization and potential suitability by applying satellite technology to detect changes in horizontal and vertical surface mining in Surint Omya Chemicals (Thailand) Co.,Ltd., and Silasanon Co., Ltd.,. This study is focusing on open-source satellite earth observation and free software (QGIS and two plugins of SCP and Orfeo toolbox). Firstly, Sentinel-1, Sentinel-2 and Landsat 8 data were selected as a satellite-based data source in this study. The Mean-Shift segmentation and Random Forest (RF) algorithm were used for extracting horizontal mining boundaries from Sentinel-2 and Landsat 8 data. In addition, The InSAR technique was used for extract vertical mining with a DEM from Sentinel-1 data. Finally, the horizontal and vertical mining change detection were validated using the high-resolution data obtained by UAV and statistic approach by calculation of R^2 and RMSE. The result reveals that Sentinel-2 is shown a medium suitability for horizontal boundary mining change detection because the result of the change is accordingly related to the reference and can be accepted. While Landsat-8 is not a suitable choice for horizontal change detection in small area mining because the change pattern has not relation to reference, and Sentinel-1 is not suitable for detecting the change in vertical mining in the small mining areas. The results from this study can be applied to investigate changes in mining initially to find suspicious areas that are likely to mine outside the permissible limits. Reduces operating time Reduce costs and prevent damage to mineral resources in a timely manner.

Keywords : remote sensing ; InSAR ; Landsat 8 ; Sentinel 1 ; Sentinel 2

*Corresponding author. E-mail : pattamap@go.buu.ac.th

Introduction

Mining is an important industry in Thailand. On December 22th, 2020, there were 927 mining concessions with the Department of Primary Industries and Mines (DPIM), being the main government authority and responsible for regulating and promoting mining in Thailand (DPIM, 2014). Most of the mines in Thailand are surface mining, also known as opencast mining or open-pit mining, which refers to the method of extracting minerals from the earth by their removal from an open pit (Dalto, 2017). There are many disputed cases of unauthorized mining, due to the illegal mining area expansion. Essential evidences of unauthorized mining are mining boundary surveying reports, reports of volume and value of minerals, damages reports, etc. While each of the mentioned case has millions THB damaged values, the surveyed data is the primary data for estimating the impact of loss and damage. DPIM has applied remote sensing technology from UAV together with GNSS satellite technology for surveying, resulting in orthophotos and DEM which can be accurately used to check the horizontal and vertical mining boundary and can be accepted in government agencies and related agencies. However, it is time consuming and labour intensive in surveying as well as the prevention of errors in the products is not as good as it should be. Applying satellite data to solve such problems is a good choice. Satellite technology in remote sensing technologies has been widely used in mining-related applications. Regarding to mining field, several research have made use of satellite data and remote sensing techniques to extract and detect changes in mining areas, i.e., Multispectral images were used to delineate open-pit mining boundaries, Sentenel-2 data is being used to extract the boundary, Orfeo Toolbox (OTB) was used for digital processing of imageries, Mean-Shift segmentation algorithm and RF algorithm are used for extraction horizontal mining boundary (Kotaridis & Lazaridou, 2020). InSAR coherence has been used to evaluate the feasibility of detecting illegal surface mining process by Sentinel-1data. The result found that InSAR coherence is suitable for identifying mining activities (Wang *et al*., 2020). Small-scale surface mining of gold placers such as detection, mapping, and temporal analysis by the application of free Sentinel-2 satellite imagery was conducted to identify mining areas and to understand the dynamics in landcover (Ibrahim *et al*., 2020). Many studies focused on either there were horizontal or vertical changes in mines, but the changes of mines literally occurred in both directions. The one-dimension inspection could not effectively prevent illegal expansion of mining. There was also a study about combining TanDEM-X and SRTM DEMs and spectral images to improve the detection of large open excavation areas using multi-temporal DEM and multispectral satellite imagery, object-based image analysis, and RF algorithms. The results show that this method can be applied to larger areas (Wu *et al.,* 2020). However, most of the mines in Thailand are small and these satellite images and processing techniques have not been applied to detect mining changes. This study aims to use the freely available satellite imagery including Sentinel-1, Sentinel-2 and Landsat-8 and open-source software to detect the changes in the horizontal and the vertical boundary of surface mining at the small-scale mining area. Two mining areas in Thailand were selected based on average size of all mining area throughout the country. Because these two areas have different terrain, they can represent all mines in Thailand.

Study area

The first study areas is a calcite mining area of Surint Omya Chemicals (Thailand) Co.,Ltd., located in Lopburi Province, with a mining permit of 271,395.893 m². This study area is characterized by flat terrain and the mean elevation of the surrounding area is about 73 m (msl) shows in Figure 1(a). The second study area is an industrial stone area for the construction industry of Silasanon Co., Ltd., located in Saraburi Province, with an area of 410,008.780 m². This mining area is characterized by mountainous slope mining. shown in Figure 1(b). The study used two periods of data to detect mining changed, including April (First mining) and October (Second mining)

(a)

(b)

Figure 1 Study area

Data and tool

The satellite data used in this study are freely available data, which are Sentinel-2, Landsat 8, and Sentinel-1. The validating data is derived from the governmental organizations which are responsible for reference data used in this study to ensure reliability and accuracy. Orthophotos were used as a reference for validate the result of horizontal mining boundary changing. Meanwhile, DEM were used as a reference for validate the result of vertical mining boundary changing. Both orthophoto and DEM acquired by UAV.
The data are listed as Table 1.

Table 1 Data detail

Data	Resolution	Date	Description	Source
Orthophoto (UAV)	7.5 cm	May and October 2018	- Bands: Red, Green, Blue - The geometric correction was done by Ground Control Points (GCPs) and surveyed by RTK GNSS.	Department of Primary Industries and Mines
Sentinel-2 A	10 m	April and October 2018	- Bands: band 2 (blue), band 3 (green), band 4 (red) (Agency, E. S., 2021)	European Space Agency
Landsat 8 level 1	30 and 15 m	April and October 2018	- path 129, row 50 - Bands: band 2 (blue), band 3 (green), band 4 (red), and band 8 (pan). (Administration, N. A. a. S., 2021)	NASA and the U.S. Geological Survey
DEM (UAV)	7.5 cm	May and October 2018	- Bands: Grey - The geometric correction was done by Ground Control Points (GCPs) and surveyed by RTK GNSS.	Department of Primary Industries and Mines
RTSD DEM	30 m	April 1996	- Scale 1:50000 map series L7018 - Horizontal coordinate referencing geographic coordinates on the WGS84 datum and the mean sea level (MSL) reference height value on the EGM96 geoid model are in meters (Organization, G.-I. a. S. T. D. A. P., 2013)	Royal Thai Survey Department
Sentinel-1 L1 SLC	5x20 m	April and October 2018	- Interferometric Wide (IW) acquisition mode at 250 km. - 5×20 m resolution - The polarization VV (Agency, E. S., 2021)	European Space Agency

This study focuses on free-accessibility software consisting of SNAP (for processing data) (Agency, E. S. SNAP, 2021), Global Mapper (for analyzing vertical changes in mining), QGIS (Jangid, 2017), Orfeo Toolbox (Toolbox, O., 2019), and SCP plugin QGIS (Congedo, 2021) (for process data from optical remote sensing and extracting the mining boundary, the horizontal changes in mining).

Methods

The methods used in this study are shown in Figure 2. They are divided into 3 parts consist of data preprocessing, comparison and validation, and the results were used to assess the suitability for application in small-scale mining operations.

1. The horizontal analysis used Sentinel 2 and Landsat 8 then preprocess, extract the mining boundaries, segmentation by mean-shift algorithm is used. Then, RF algorithm is used to classify the data into 5 classes; mining area, bare soil, road, water, and vegetation. Then visually modify the boundary of the mining for that the data is more accurate based on the real boundary from UAV data and dissolve the classes into two classes: mining and non-mining areas. Lastly, a validation of the classification was performed.

2. DEM extraction from Sentinel-1 data using InSAR technique according to the manual of DEM generation with Sentinel-1 challenges and workflow from SkyWatch Space Applications Inc. (Braun, 2020) consists of 11 steps: 1) TOPSAR-Split, as the first step in extracting DEM, S-1 TOPS Split has been applied to the selected data only those bursts which are required for the analysis. 2) Apply-Orbit 3) Back-Geocoding and 4) Enhanced-Spectral-Diversity, this stage is critical because the correction of the topographic effects of the SAR images backscatter is required. The images are referenced to a DEM. DEM referenced in the processing is ASTER GDEM version 3 with a spatial resolution of 30 m. 5) Interferogram, 6) TOPSAR-Deburst, this step contributes to faster the processing time and obtain higher data accuracy. 7) Topographic Phase Removal, the Interferogram can then be flattened by removing the topographic phase. 8) Goldstein Phase Filtering, noise from temporal and geometric volume scattering, decorrelation, and other processing errors can all degrade interferometric phase in this step. 9) Snaphu Unwrapping to convert phase to useful units. 10) Phase to Elevation, to convert the radian units into absolute heights. It translates the phase into surface heights along the line-of-sight (LOS) in meters. The LOS is the line between the sensor and a pixel. A DEM is used to put the elevation values in the correct level. 11) Range Dropper Terrain Correction Terrain Correction is done by correcting SAR geometric distortions with a digital elevation model (DEM) and generating a map-projected product. Finally, reprojection modifies the coordinate system of data obtained from the InSAR process to the same coordinate system as the referenced data. It uses the Universal Transverse Mercator (UTM) World Geodetic System (WGS) 1984 zone 47 north coordinate system, which is a coordinate system used in Thailand. The output is DEM 14 fourteen-meter resolution. Then, I have calibrated by 506 five hundred and six checkpoint from RTSD DEM. Finally, DEM is adjusted by the average value of the error with the raster calculator for the entire area. Then analyze the changing volume using data from UAV as references.

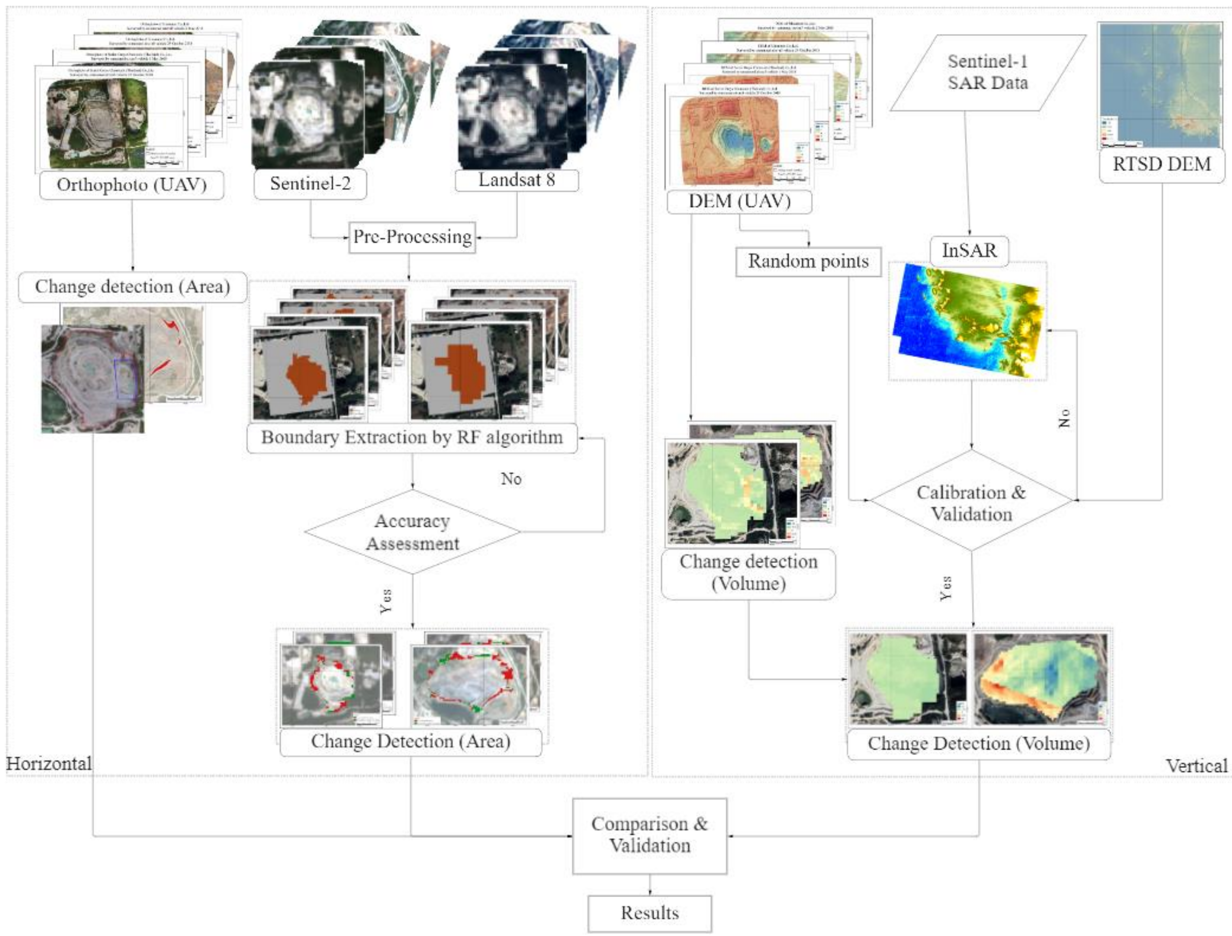


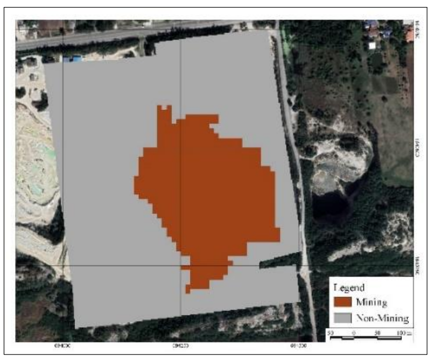
Figure 2 Flowchart of method

3. Data Change & Comparison- Validation, the analysis of change detection of horizontal mining is conducted by comparing the boundaries of horizontal mining obtained by UAV and the boundary from extraction process. The data was analyzed for changes in 2 periods using Land cover change operator in SCP plugin in QGIS software. Then, analyzing changes in vertical mining using DEM data obtained from InSAR technique and analyzing the volume changes of 2 periods using measure volume between the surface operator in Global Mapper software. Comparison and validation by statistics method using R^2 and RMSE.

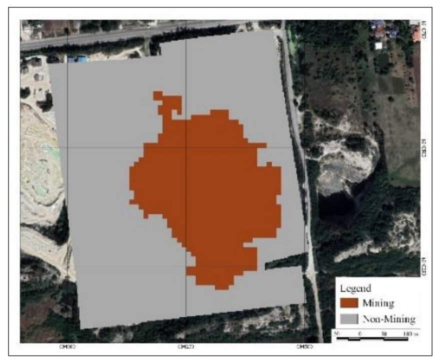
Results

1. Boundary Extraction

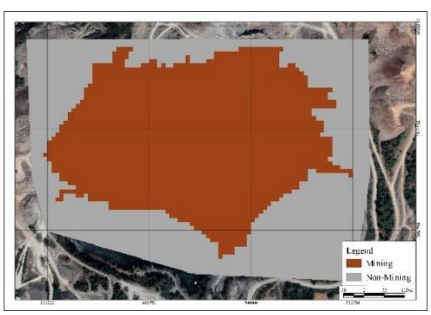
The result of mining boundary extraction from segmentation with Mean-Shift Segmentation algorithm and classified with RF algorithm are classified into two types which are mining area and non-mining area. According to figure3, brown area represents mining area and gray area represents non-mining area. For accuracy assessment using the 32 observations for study area 1 and 34 observations for study area 2 from the test samples, based on a reference from the UAV. The kappa statistic is used to calculate overall accuracy. The results are grouped by the source of satellite data as follow: Boundary extraction from Sentinel-2 imagery show in Figure 3, and Boundary extraction from Landsat 8 imagery shown in Figure 4. And summarize as shown in Table 2.



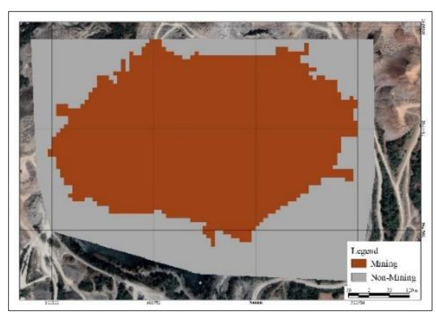
(a) First mining in study area 1, covered area of 72,600.000 m² and overall accuracy is 95.66%.



(b) Second mining in study area 1 covered area of 80,700.000 m². and overall accuracy is 97.47%.

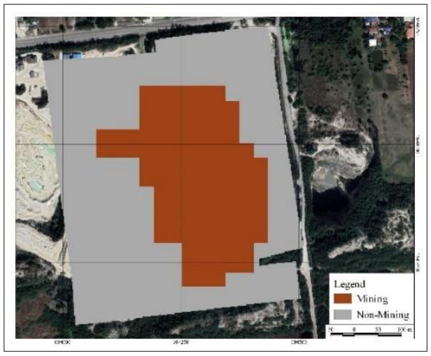


(c) First mining in study area 2 covered area of 237,400.000 m² and overall accuracy is 100%.

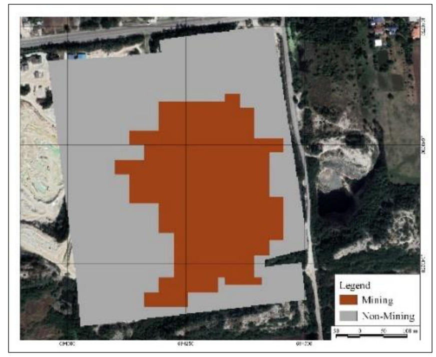


(d) Second mining in study area 2 covered area of 253,708.789 m² and overall accuracy is 99.26%.

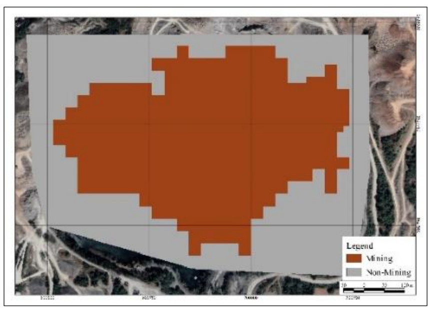
Figure 3 Mining extraction result from Sentinel-2



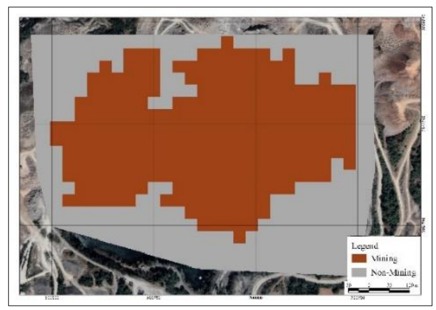
(a) First mining in study area1 covered area of 95,908.760 m² and overall accuracy is 86.57%



(b) Second mining in study area 1 covered area of 101,570.418 m² and overall accuracy is 96.50%



(c) First mining in study area 2 cover area of 234,583.948 m² and overall accuracy is 99.35%



(d) Second mining in study area 2 covered area of 240,300.000 m² and overall accuracy is 95.90%

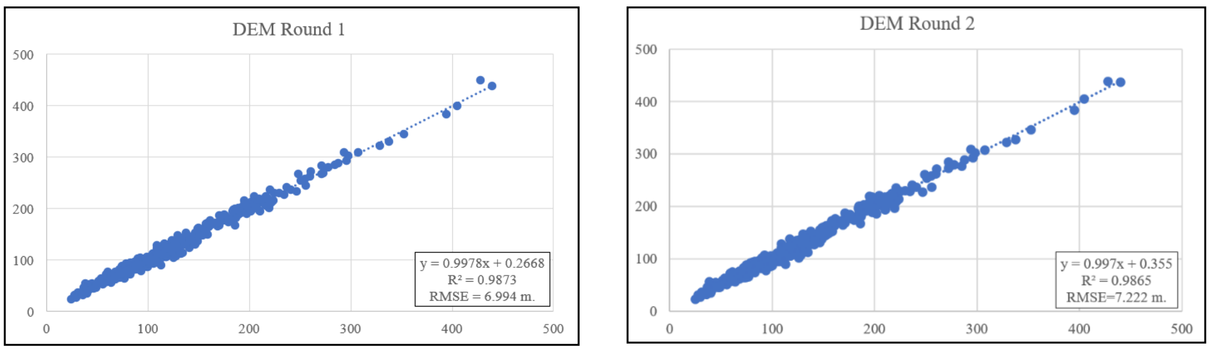
Figure 4 Mining extraction result from Landsat 8

Table 2 Results of horizontal boundary extraction

Study Area	Area (m²)	Data	Accuracy
1	271395.893	Sentinel-2	First mining = 95.66%, Second mining = 97.47%
		Landsat 8	First mining = 86.57%, Second mining = 96.50%
2	410008.780	Sentinel-2	First mining = 100%, Second mining = 99.26%
		Landsat 8	First mining = 99.35%, Second mining = 95.90%

2. DEM Extraction and Calibration

The process of DEM extraction using two pairs of satellite image from Sentinel 1 SLC product. The duration is 12 days in time range with 70.25 m and 60.43 m of perpendicular baseline. Using InSAR technique with SNAP software processing. Calibration used the checkpoints which extracted from RTSD DEM and correct DEM by total area correction by mean difference value from assessment. After process of correction, the R^2 and RMSE in first mining and second mining is obtain as 0.9873, 6.994 m and 0.9865, 7.222 m respectively, shown in Figure 5(a) and Figure 5(b).



(a) (b)

Figure 5 DEM Calibration, X represents to elevation from UAV DEM and Y represents to elevation from Sentinel-1

After the data has been calibrated, it clips specific the study area to validate the data with DEM obtained from the UAV. In each study area, the results were as follows: First mining of study area 1, DEM results are shown in Figure 6(a) and the validation results R^2 was 0.6038 and RMSE was 34.279 m, shown in Figure 6(b) by X represents to elevation from UAV DEM and Y represents to elevation from Sentinel-1. Second mining of study area 1, DEM results are shown in Figure 6(c) and the validation results R^2 was 0.5621 and RMSE was 35.731 m, shown in Figure 6(d). First mining of study area 2, DEM results are shown in Figure 6(e) and the validation results R^2 was 0.2947 and RMSE was 55.704 m, shown in Figure 6(f). Second mining of study area 2, DEM results are shown in Figure 6(g) and the validation results R^2 was 0.2666 and RMSE was 57.603 m, shown in Figure 6(h).

3. Change Detection

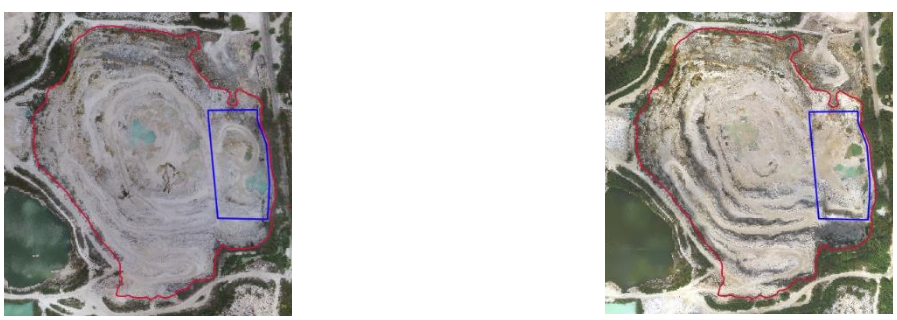
Change detection of the mining area is including both vertical and horizontal directions. The study results shown in Table 3.

Table 3 Results of change detection

Study area	Horizontal base on UAV (m^2)	Horizontal (Sentinel-2) (m^2)	Horizontal (Landsat 8) (m^2)	Vertical base on UAV (m^3)	Vertical (Sentinel-1) (m^3)
1	0	11,400	19,956	141,779.71	69,915.20
2	5,572	26,700	31,936	481,996.86	635,501.98

3.1 Horizontal changing in study area 1

The result of analyzing horizontal change detection in the study area 1 using data from UAV found that there is no change in the mining boundary. The boundary of horizontal mining in the first mining round is shown in Figure 7(a) and the boundary of horizontal mining in the second mining round is shown in Figure 7(b). The red line indicates the boundary of horizontal mining whereas the blue line represents the mining area in the study period. As in both figures, mining has occurred only in a vertical direction. There is no change in horizontal expansion during a period of study.



(a) (b)

Figure 6 (a) Mining boundary area 1 of round 1, (b) Mining boundary area 1 of round 2

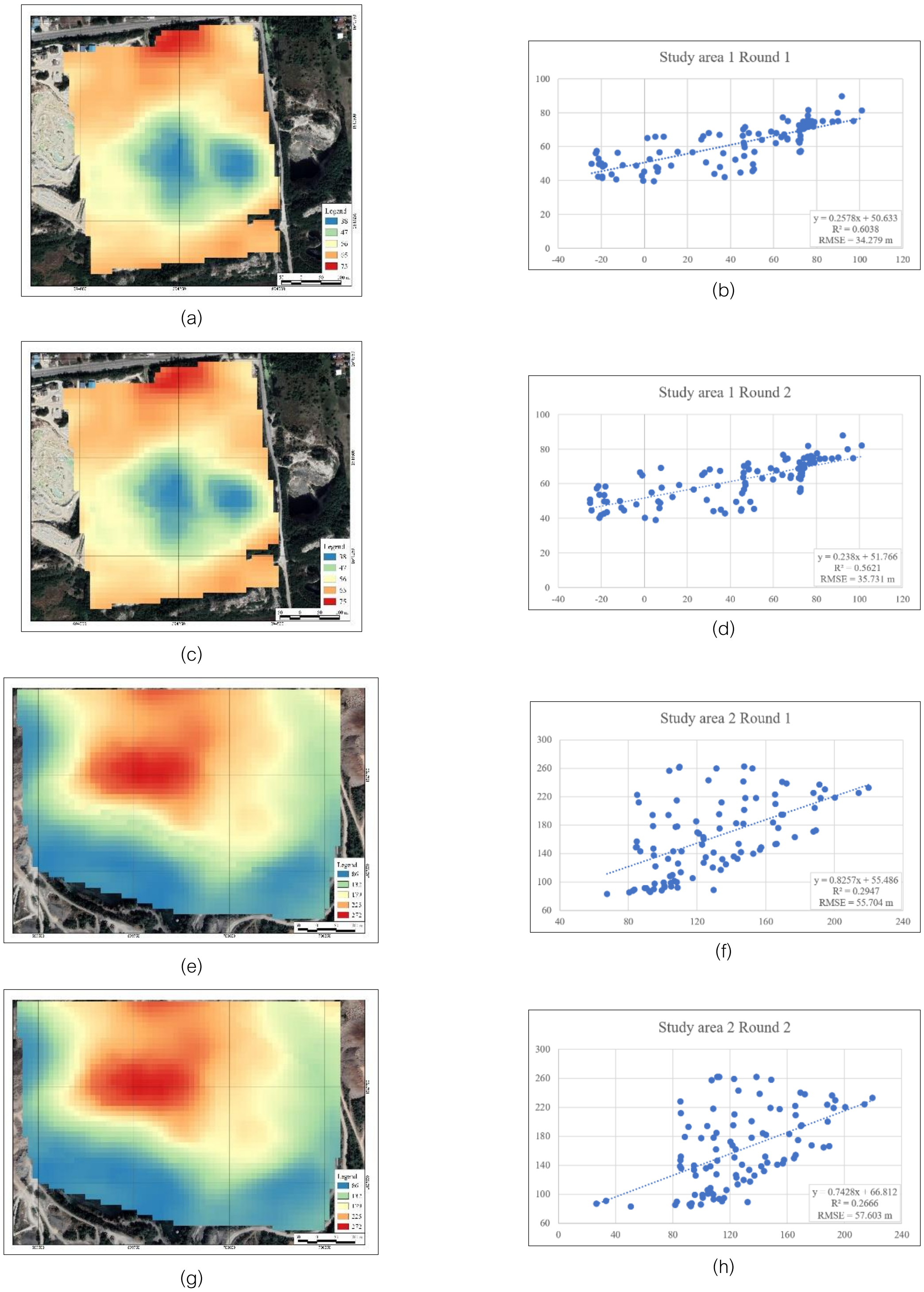
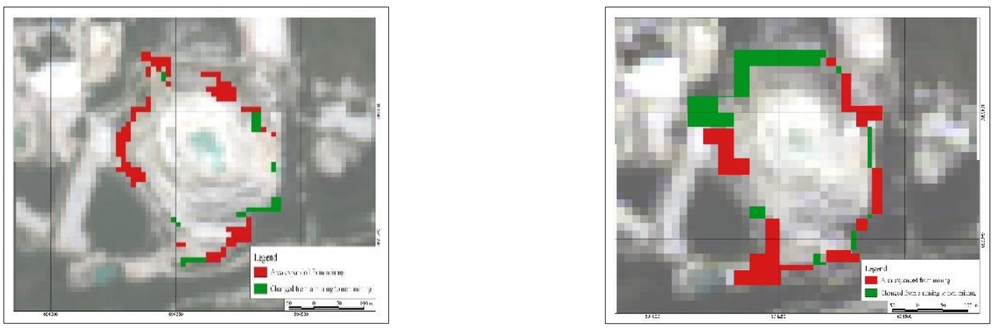


Figure 7 DEM Calibration of round 2 of mining X represents to elevation from UAV DEM and Y represents to elevation from Sentinel-1

The result of analyzing the horizontal change in the study area 1 from Sentinel-2 satellite data found that the expansion of mining areas is spread around the area with 11,400 m² in total. Whereas, the area has changed from a mining area to a non-mining area is 3,300 m² in total as shown in Figure 8(a). The result from Landsat 8 obtained a total area of 19,956 m², whereas the area has changed from a mining area to a non-mining area. It obtained a total area of 14,440 m² as shown in Figure 8(b).

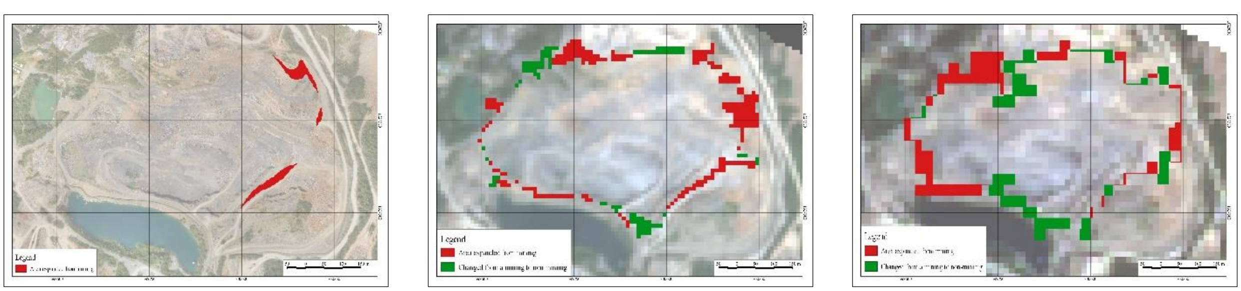


(a) (b)

Figure 8 (a) Area changed based on Sentinel-2, (b) Area changed based on Landsat 8

3.2 Horizontal changing in study area 2

The result of analyzing the horizontal change in study area 2 from UAV data reveals that the expansion of the mining area is mainly in the east of the area. It has a total area of 5,572 m². As shown in Figure 9(a). And from Sentinel-2 satellite data reveals that the expansion of mining areas is spread around the area with a total area of 26,700 m². Whereas the area has changed from a mining area to a non-mining area has a total area of 10,400 m² as shown in Figure 9(b). And from Landsat 8 satellite data reveals that the expansion of the mining area is mainly in the east and west of the area. It has a total area of 31,936 m² and the area has changed from a mining area to a non-mining area. It has a total area of 26,208 m² as shown in Figure 9(c).

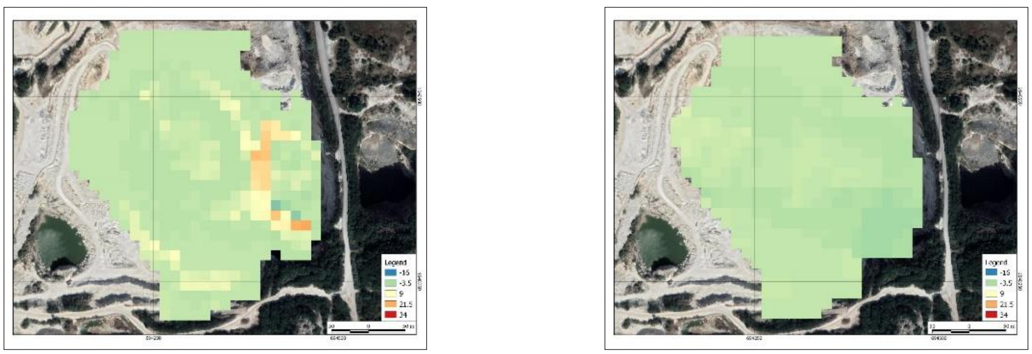


(a) (b) (c)

Figure 9 (a) Area changed based on UAV, (b) based on Sentinel-2, (c) based on Landsat 8

3.3 Vertical changing in study area 1

The result of calculated volume in the first study area using DEM from UAV found that the cut volume is 141,779.71 m³ and fill volume is 37,743.00 m³. The maximum change is detected in the east of study area (orange color) as shown in Figure 10(a). This area is characterized by high hill and steep cliff. Mining process is occurring in the period of data collection. And analyzing DEM from Sentinel-1 found that there is a slightly change of volume. The increasing of volume more than decreasing of mining volume which are fill volume as 69,915.20 m³ and cut volume as 19,945.01 m³ with no correlation with the reference data. Shown in Figure 10(b).

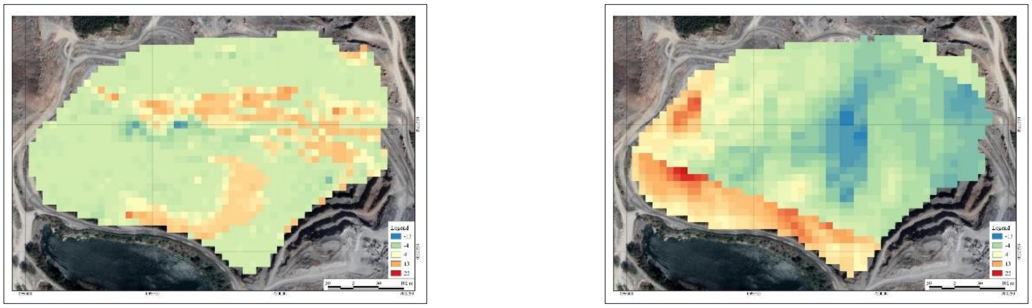


(a) (b)

Figure 10 (a) Volume changed based on UAV, (b) Volume changed based on Sentinel-1

3.4 Vertical changing in study area 2

The vertical change of mining in study area 2 by analyzing DEM from UAV found that there is a change throughout the area. This area has large amount of digging process (orange color) indicated the area of decreasing in mining volume. The cut volume is 481,996.86 m³ and fill volume is 79,979.97 m³ (blue color) indicates the area of increasing in volume. As shown in Figure 11(a). And analyzing DEM from Sentinel-1 found that the missing volume is occur in the south and west of study area (orange color) with total volume of 635,501.98 m³ and increasing volume is found in center of the area (blue color) is 313,934.75 m³. As shown in Figure 11(b) with no correlation with the reference data.



(a) (b)

Figure 11 (a) Volume changed based on UAV, (b) Volume changed based on Sentinel-1

Discussion

This research detected the change of the boundary of the small mines surface in the horizontal and the vertical directions. The main objectives of the research are applying multi-source satellite imagery to change detection for surface mining boundary, focusing on open-source software in processing. The extraction of horizontal boundary from the Sentinel-2 and Landsat 8 data is conducted by using RF algorithm for extraction of horizontal boundary, The result found that the RF algorithm is the best accuracy. Then validate using 32 inspection areas in study area 1 and 34 inspection areas in study area 2, the area for validation is selected from UAV data. The overall accuracy was calculated using the confusion matrix in the first study area round 1 which have an overall accuracy of 95.66% and 86.57%. The accuracy of round 2 of the first study area are 97.47% and 96.50%. In the second study area, round 1, the overall accuracy is 100% and 99.35%. For the round 2 of the second study area are 99.26% and 95.90% respectively. As the result, the Sentinel-2 satellite imagery can provide the best accuracy. However, when analyze data above to change detection, the change from satellite data have change from non-mining area to mining area and mining area to non-mining area. In common, changing from mining area to non-mining area is possible occasionally. As a result of no mining activities for long time therefore vegetation covers that area. But This study only the focuses on the expansion of mining due to the main problem of changes in the boundary of mining is the expansion of mines outside the permissible limits.

The results of horizontal change detection show that the Sentinel-2 imagery has a higher agreement with the referent data than Landsat 8 imagery because the Sentinel-2 imagery has a higher resolution than Landsat 8. As a result, extracting the horizontal boundary of mining from its data has higher accuracy as well. However, the results of Sentinel-2 imagery still have a lot of errors compared to the referent data. The area of 97,964.102 m² during the first mining round in study area 1 was used as a reference value for calculating the error from the satellite data. According to the reference data of change detection result, there is no change of mining in horizontal direction (0% of change comparing to the original area). Meanwhile, the result of Sentinel-2 data found that there is an 11.64 % of change in horizontal mining when compared to the reference data. In the study area2, the mining site covered area of 226,498.761 m² in the first mining round was used as a reference value for calculating the error from satellite data. The change detection result base on reference value found that there is 2% of horizontal expansion compared to the original area. However, the result from Sentinel-2 reveals that there is an 11.79% change in horizontal direction of mining compared to the original area. While analysis of changes in horizontal mining boundary using mining boundary obtained from Landsat 8 in study area 1, mining expansion is 20.37%, and in study area 2, mining expansion is 14.10%.

The extracted DEM from Sentinel-1 with InSAR technique using SNAP Software has 14 m resolution and it had a good correlation when compared to the DEM from RTSD. The correlation value R^2 was 0.987 in the first mining round and 0.987 in the second mining round. However, the RMSE value was 6.994 m in the first mining round and was 7.222 m in the second mining round. Although the DEM data obtained from the InSAR technique has been adjusted, the error values are still high. And when exclude other irrelevant data, the area of study was verified by DEM from UAV, it was found in Study area 1 round 1, R^2 was 0.6038 and RMSE was 34.279 m. Study area 1 round 2, R^2 was 0.5621 and RMSE was 35.731 m. Study area 2 round 1, R^2 was 0.2947 and RMSE was 55.704 m. Study area 2 round 2, R^2 was 0.2666 and RMSE was 57.603 m. This discrepancy has a significant impact on study in small mining areas. Because of the Sentinel-1 data used in this study, each pair of images has very little perpendicular baseline. Consistent with previous research that Sentinel-1 most importantly the length of temporal and perpendicular baselines (Braun, 2021) and they show that the Sentinel-1 mission was mainly designed for the retrieval of deformations (DInSAR) and not good for DEM generation. Therefore, choosing a suitable data to create a DEM would require a perpendicular baseline between 150-300 m long, which in this study, the appropriate data was selected based on a temporal basis with the least value of 12 days, because mining areas are rapidly changing areas. Therefore, two periods of data must be selected with the least time difference. As a result, it is difficult to choose data with perpendicular baseline as required. It is evident that the results of this study are consistent with the results of a previous study on the efficiency of applying data from Sentinel-1 to generate DEM with the InSAR technique. And in the two study areas, there were different topographic, with study area 1 being flat with less error than the second study area near the mountains, due to the area near the mountains, there is a shadow that obscures the area. This causes processing to be inaccurate, as previous studies have mentioned.

The results of the analysis of volume changes analysis during two periods of mining, focusing on changes that caused vertical mining boundaries to expand or increased mining depth. The results showed that the difference in vertical changes using the DEM from Sentinel-1 and the DEM from UAV in study area 1 was 85.93% and 31.85% in study area 2, respectively. This is because of DEM from Sentinel-1 has relatively low in resolution and high in error, resulting in existence of some errors in detecting the mining changes.

The application of data and methodology in this research is used to detect changes in horizontal and vertical of surface mining boundary. Sentinel-2 has medium level of suitability for change detection of horizontal mining boundary since the change characteristic is accordingly relative to the reference data. Therefore, it has the potential for the application as a preliminary change detection to identify suspected area of mining outside the permissible boundary before the in-situ investigation and surveying. Instead of traditional regulation method of random checking including case of complaint. The adoption of Sentinel-2 images significantly reduces time and cost as well as prevents unnecessary resource loss. On the contrary, the study results suggest that Landsat-8 is not a suitable choice for horizontal change detection in small area mining because the pattern of change did not agree with the reference data. Whereas the vertical change detection of the DEM from Sentinel-1 extracted by InSAR technique found that the Sentinel-1 is not suitable for detect change in vertical mining in small mining area because the difference between it and the reference data is relatively high. In conclusion, the resolution of the satellite image has significantly affected to the discrepancy value in change detection of small mining areas.

Conclusions

In this research, the study used the Sentinel-2 satellite and Landsat 8 satellite datasets to detect the horizontal boundary change in mining areas. Using QGIS software and two plugins (SCP plugin and Orfeo toolbox). Since the acquiring satellite images, preprocess, extract horizontal boundary of mining, validate, to detect change, it this suggested that the software can download materials faster than downloading from websites as well as processing is also faster. From the materials in this research, the study found that the Sentinel-2 had higher accuracy than Landsat 8 in horizontal boundary extraction using Mean-Shift segmentation algorithm and RF algorithm. However, the results are moderately satisfied in change detection compared to reference data from UAV. In conclusion, the satellite image's resolution is directly affecting the correction of analyzed change detection horizontally. The more limits of mining area it is, the more resolution of satellite image is required. The InSAR technique to generate the DEM from Sentinel-1 data using SNAP software, which is a tool for processing data from Sentinel satellites, it has good performance in data processing, but requires a highly efficient computer to reduce processing time. Once processed, a DEM is 14 m resolution. Although calibrate has been applied to RTSD DEM but when compared to DEM data from UAV in each area, there are still a lot of differences. Findings from the study can be answer about application for horizontal and vertical change detection in the small mining area that Sentinel-2 has medium level of suitability for change detection of horizontal mining boundary since the change characteristic is accordingly relative to the reference data. While Landsat 8 and Sentinel-1 has low suitability.

This research has succeeded in goal of applying multi-source satellite imagery to change detection for surface mining boundary, focusing on open-source software in processing. However, the accuracy can be enhanced by using Sentinel-2, Landsat 8, Sentinel-1 data and all method in this study for monitoring changes in mining. Therefore, I recommend 1) Higher-resolution satellites should be used to get good results because this study opted for satellite data with free access, which is medium resolution, so the results were not as good as selecting for high-resolution satellite data, since the resolution of the image point directly affects the accuracy of the result. 2) Choosing a larger study area may make the results more accurate. This study used study area is small size mining because it suits the mining area in Thailand. Using medium-resolution satellite images to analyze change detection in horizontal and vertical mining causes quite a lot of error. 3) Index value of reflection of each type of mineral should be used to help classify the boundary of mining, resulting in better extraction results in the boundary of mining because the different minerals have different reflective values of objects. As a result, classifications using satellite data are also different. 4) Mining data should be selected two periods at least one year apart to make the area change more clearly. Because, this study used two periods of mining data, which had a period of 6 months apart, to analyze changes in mining areas. And in study area 1, there was no change in the horizontal mining area. 5) Reference DEM with a resolution greater than 30 m should be used in the InSAR process to obtain DEM data from sentinel-1 with high accuracy.

Acknowledgements

We are grateful for the Department of Primary Industries and Mines and Royal Thai Survey Department for provided data for my dissertation.

References

Administration, N. A. a. S. (2021). Landsat Science. Retrieved October 15, 2021, from https://landsat.gsfc.nasa.gov/landsat-8/landsat-8-overview

Agency, E. S. SNAP. Retrieved October 20, 2021, from https://earth.esa.int/eogateway/tools/snap

Agency, E. S. (2021). Level-1 SLC Products. Retrieved December 10, 2021, from https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-1-sar/products-algorithms/level-1-algorithms/single-look-complex

Agency, E. S. (2021). Sentinel-2. Retrieved September 12, 2021, from https://sentinel.esa.int/web/sentinel/missions/sentinel-2

Braun, A. (2021). Retrieval of digital elevation models from Sentinel-1 radar data – open applications, techniques, and limitations. *Open Geosciences, 13*(1), 532-569. doi:doi:10.1515/geo-2020-0246

Braun, A. (2020). TOPS Interferometry Tutorial for DEM generation.

Congedo, L. (2021). Semi-Automatic Classification Plugin: A Python tool for the download and processing of remote sensing images in QGIS. *Journal of Open Source Software, 6*(64).

Dalto, J. (2017). What Is Surface Mining. Retrieved August 13, 2021, from https://www.vectorsolutions.com/resources/blogs/what-is-surface-mining/

Department of Primary Industries and Mines. (2014). Mission. Retrieved November 5, 2021, from http://www.dpim.go.th/en/mission.php

Ibrahim, E., Lema, L., Barnabé, P., Lacroix, P., & Pirard, E. (2020). Small-scale surface mining of gold placers: Detection, mapping, and temporal analysis through the use of free satellite imagery. *International Journal of Applied Earth Observation and Geoinformation*, *93*, 102194. doi:https://doi.org/10.1016/j.jag.2020.102194

Jangid, A. (2017). Introduction to QGIS.

Kotaridis, I. & Lazaridou, M. (2020). Delineation of Open-Pit Mining Boundaries on Multispectral Imagery. Kotaridis, I. and Lazaridou, M.*(2020).*'Delineation of Open-Pit Mining Boundaries on Multispectral Imagery'. in Remote Sensing. IntechOpen. doi, 10.

Organization, G.-I. a. S. T. D. A. P. (2013). Fundamental Geographic Data Set: FGDS.

Ponguta, S. Global mapper. Retrieved September 25, 2021, from https://www.geoilenergy.com/en/software/geosoluciones/global-mapper

Toolbox, O. (2019). Open Source processing of remote sensing images Retrieved July 22, 2021, from https://www.orfeo-toolbox.org/

Wang, S. *et al*. (2020). Evaluating the Feasibility of Illegal Open-Pit Mining Identification Using Insar Coherence. *Remote Sensing, 12*(3), doi:10.3390/rs12030367

Wu, Q., Song, C., Liu, K., & Ke, L. (2020). Integration of TanDEM-X and SRTM DEMs and Spectral Imagery to Improve the Large-Scale Detection of Opencast Mining Areas. *Remote Sensing, 12*(9), 1451. [Online]. Retrieved June 18, 2021, from https://www.mdpi.com/2072-4292/12/9/1451