SAFETY IN MINING AND PROCESSING INDUSTRY AND ENVIRONMENTAL PROTECTION

Mapping coal fires using Normalized Difference Coal Fire Index (NDCFI): case study at Khanh Hoa coal mine, Vietnam

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Abstract

Khanh Hoa coal mine (Thai Nguyen province) is one of the largest coal mines in the north of Vietnam. For many years, this area suffered from underground fires at coal mine waste dumps, seriously affecting production activities and the environment. This paper presents the results of classification of underground fire areas at Khanh Hoa coal mine using Normalized Diference Coal Fire Index (NDCFI). 03 Landsat 8 OLI_TIRS images taken on December 2, 2013, December 10, 2016, and December 3, 2019 were used to calculate NDCFI index, and then classify the underground fire areas by thresholding method. In the study, the land surface temperature was also calculated from Landsat 8 thermal infrared bands data, and then compared with the results of underground coal fire classification at Khanh Hoa coal mine. The obtained results showed that the NDCFI index can be used effectively in detecting and monitoring underground fire areas at coal mines. The use of the NDCFI index also has many advantages due to its calculation simplicity and rapidness compared to other methods for classifying underground coal fire areas.

ТЕХНОЛОГИЧЕСКАЯ БЕЗОПАСНОСТЬ В МИНЕРАЛЬНО-СЫРЬЕВОМ КОМПЛЕКСЕ И ОХРАНА ОКРУЖАЮЩЕЙ СРЕДЫ

Выявление пожаров на угольных рудниках с использованием стандартизированного относительного индекса горения угля на примере угольного рудника Кханьхоа, Вьетнам

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Аннотация

Угольный рудник Кханьхоа (провинция Тхай Нгуен) – один из крупнейших угольных рудников на севере Вьетнама. В течение многих лет в этом районе происходили подземные пожары в отвалах рудника, что оказывало заметное негативное воздействие на производственную деятельность и окружающую среду. В данной статье представлены результаты классификации участков подземных пожаров на угольном руднике Кханьхоа с использованием стандартизированного относительного индекса горения угля (NDCFI). Космоснимки, сделанные спутником 03 Landsat 8 OLI_TIRS (с использованием инфракрасного сканера) 2 декабря 2013 года, 10 декабря 2016 года и 3 декабря 2019 года, были использованы для расчета индекса NDCFI, а затем классификации участков подземных пожаров методом пороговой фильтрации. В ходе исследования также рассчитывалась температура поверхности земли по данным измерений спутника Landsat 8 в тепловом инфракрасном диапазоне, а затем сравнивалась с результатами классификации подземных угольных пожаров на угольном руднике Кханьхоа. Полученные ре-

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зультаты показали, что индекс NDCFI может быть эффективно использован для обнаружения и мониторинга участков/очагов подземных пожаров на угольных рудниках. Использование индекса NDCFI также имеет много преимуществ благодаря простоте и быстроте расчетов по сравнению с другими методами классификации участков/очагов подземных угольных пожаров.

Ключевые слова

угольный пожар, угольный рудник Кханьхоа, дистанционное зондирование, индекс NDCFI, данные спутника Landsat

1. Introduction

Most types of coal have the ability to self-ignite under certain environmental conditions (endogenous combustion). The generation and accumulation of heat is the major direct cause of the spontaneous coal combustion [1]. Underground fires at coal mines produce many toxic gases, especially carbon monoxide (CO) and carbon dioxide (CO_2). It is very difficult to extinguish underground coal fires. This is an extremely dangerous phenomenon in underground mining, seriously affecting the environment and causing damage to buildings and infrastructure [2, 3].

Underground coal fires occur in practically leading coal producing countries of the world, such as India, China, Venezuela, USA, RSA [4]. There were coal fires covering area up to several hundreds square kilometers, lasting for many years and still not extinguished [5]. In Vietnam, some underground coal fires were recorded in Quang Ninh coal basin (2009), at Nong Son coal mine (Quang Nam province, 2011) and Khanh Hoa coal mine (Thai Nguyen province, 2014).

Remote sensing data are widely used in the world in early detection and monitoring of underground fires at coal mines. Most of these studies use land surface temperature calculated from the thermal infrared data from Landsat and Aster satellite images to monitor underground coal fires [6–12]. These studies all showed that land surface temperatures in underground coal fire areas were much higher than in the surrounding area, even compared to urban areas characterized by impervious surfaces. Research of [13] at the Raniganj coalbelt (India) showed that the temperatures in the overburden dumps of open cast mines ranged 28 to 32 C and within the mine 35 to 38 °C. Moreover, in some places temperature was found to be as high as 68 °C [13]. Due to low spatial resolution of the thermal infrared band data of Landsat and Aster images, some recent studies integrated Landsat 8 and Sentinel 2 images to detect underground fire areas in more details [10, 14].

Located in Southeast Asia, Vietnam is rich in mineral resources with 10 billion tons of anthracite coal, more than 200 billion tons of brown coal in the northern delta area [15]. In recent years, a number of studies on the application of remote sensing data in early detection and monitoring of underground coal fires in Vietnam were performed. Trinh and Zablotskii [11] used multi-temporal Landsat image data to monitor the change of land surface temperature at Khanh Hoa coal mine. The obtained results showed that the land surface temperature within coal mines and waste dumps was usually higher than 35 °C, while some areas had temperatures above 40 °C [11]. Landsat 8 image data and spatial analysis techniques were also used to predict underground fire locations at Khanh Hoa coal mine [12, 16]. Based on the analysis of the distribution of land surface temperatures calculated from Landsat satellite images, these studies enabled predicting fire locations, thereby providing information to help managers to promptly respond to underground fires at Khanh Hoa coal mines.

The use of land surface temperature data calculated from remote sensing images in monitoring of underground coal fires has the advantage of high accuracy of the results, but the calculation process is rather complicated. Band rationing method based on multi-spectral images with the advantages of simplicity in calculation and time-saving can be used effectively in classifying coal mining areas, including areas where underground fires occur [17]. Raju (2015) proposed using the Normalized Difference Coal Fire Index (NDCFI) to quickly map the areas where underground fires occur in the Jharia coalfield (India). In study [17], he observed that the spectral reflectance value of the pixels attributed to the fire exhibits maximum and minimum intensity response in band 8 (SWIR, 2.295 – 2.365 µm) and band 4 (SWIR, 1.600 – 1.700 µm) of Aster image, respectively. These spectral bands of the Aster images correspond to band 7 (SWIR2, 2.11 – 2.29 µm) and band 6 (SWIR1, 1.57 – 1.65 µm) of Landsat 8 OLI images. Thus, it is possible to use Landsat shortwave infrared bands to calculate NDCFI index for classification of underground coal fire areas.

This study presents the results of classification of underground fire areas at Khanh Hoa coal mine (Thai Nguyen province, northern Vietnam) based on Landsat 8 multi-temporal data using NDCFI index. 03 Landsat 8 images taken on December 2, 2013, December 10, 2016 and December 3, 2019 were used to calculate the NDCFI index, and then classify the underground coal fire areas using the thresholding method. In the study, we also compared the obtained results and the surface temperatures determined from the Landsat 8 data. This comparison allowed to demonstrate the effectiveness of the NDCFI index in classifying underground fire areas compared to the traditional method based on the land surface temperature measuring.

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2. Materials and methodology

Study area

Thai Nguyen is the province with the second largest coal reserves in Vietnam (reserves about 15 million tons of fat coal, 90 million tons of coal) after Quang Ninh province. Khanh Hoa coal mine is the largest coal mine in Thai Nguyen province with mining area and waste dump covering more than 300 hectares; the annual coal extraction capacity exceeds 600 kt of coal. Underground fires at coal mines and waste dumps of Khanh Hoa coal mine proceed for a long time, seriously affecting the quality of living environment and production activities. Although many solutions were applied, so far the problem of underground fires at Khanh Hoa coal mine has not been completely solved. Geographical location of Khanh Hoa coal mine (Thai Nguyen province) is shown in Fig. 1.

Materials

In this study, multispectral cloud-free Landsat 8 OLI_TIRS images with spatial resolution of 30 m (multispectral bands) and 100 m (thermal infrared bands), taken on December 2, 2013, December 10, 2016, and December 3, 2019 in the Thai Nguyen province (northern Vietnam) were used for calculating NDCFI index. The Landsat 8 data present the L1C level product, downloaded from
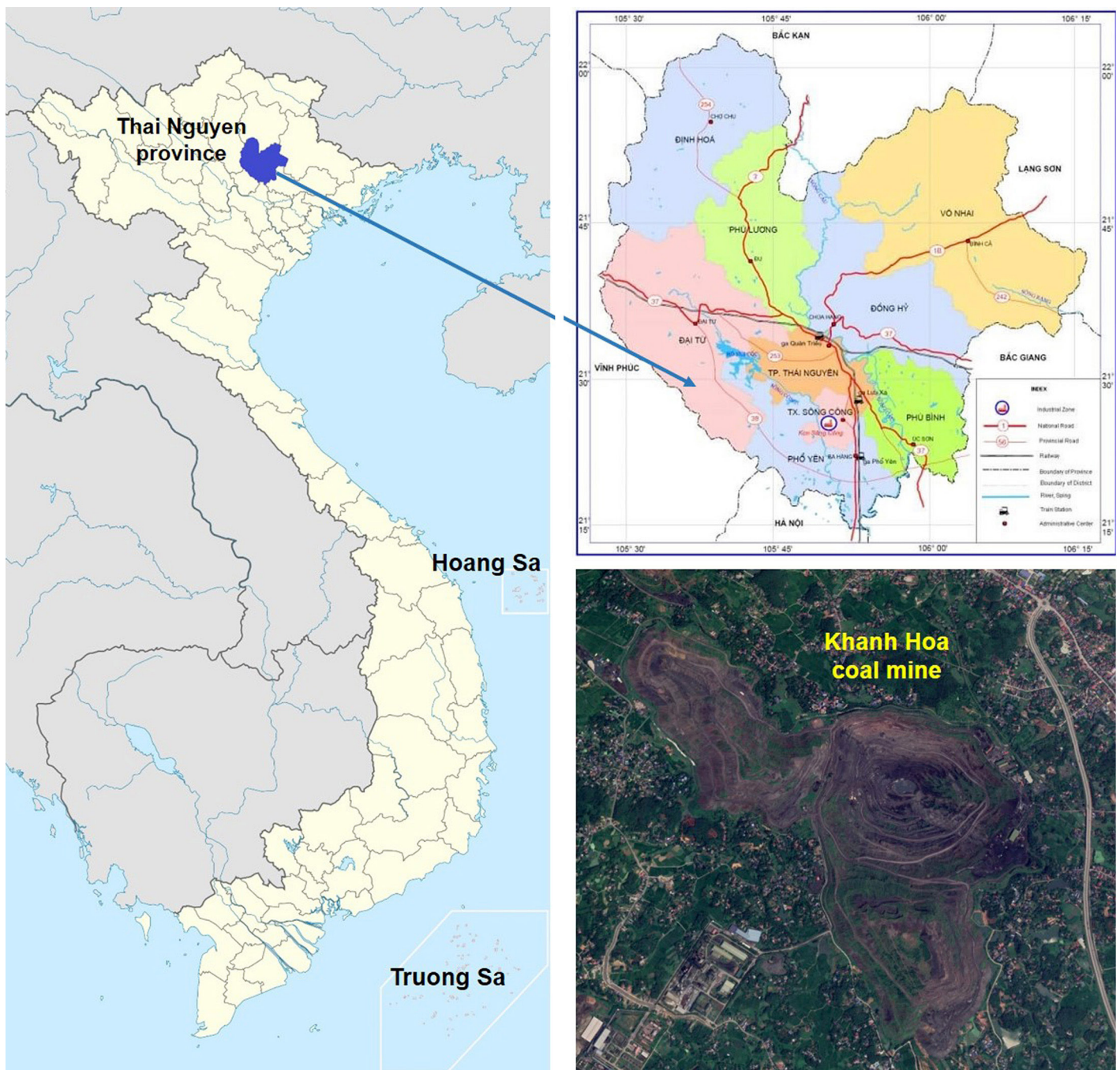

Fig. 1. Location of Khanh Hoa coal mine, Thai Nguyen province, Vietnam

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the United States Geological Survey website[1]. Landsat 8 image data used in this study are presented in Fig. 2, RGB = NIR:RED:GREEN.

Methodology

After acquiring, the Landsat 8 data were subjected to atmospheric correction [18] and geometric correction. The spectral reflectance values at short-wave infrared bands (band 6 and band 7) were used to calculate NDCFI index using the following formula [17]:

$$NDCFI = \frac{\rho_{SWIR2} - \rho_{SWIR1}}{\rho_{SWIR2} + \rho_{SWIR1}}. \qquad (1)$$

After calculating NDCFI index, thresholding method was applied to classify the underground coal fire areas. The threshold value was selected based on the NDCFI index analysis histogram.

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[1] http://glovis.usgs.gov (Accessed: July 18, 2021)

In order to compare the results of the underground coal fire classification, we also calculated the land surface temperatures based on the Landsat 8 thermal infrared bands data. The split-window algorithm was used to calculate land surface temperatures from Landsat 8 data using the following formula [19–21]:

$$T_s = T_{B10} + c_1(T_{B10} - T_{B11}) + c_2(T_{B10} - T_{B11})^2 + \\ + c_0 + (c_3 + c_4 w)(1 - \varepsilon) + (c_5 + c_6 w)\Delta\varepsilon, \qquad (2)$$

where: T_s – land surface temperature; T_{B10}, T_{B11} – brightness temperature of bands 10 and 11 of Landsat 8 imagery; w – atmospheric water vapor content (g/cm²). The value of atmospheric water vapor content was calculated using formula proposed by Huazhong [22]; ε – mean emissivity; $\Delta\varepsilon$ – emissivity difference; c_0 to c_6 – values of split-window coefficients [23].

Flowchart (methodology) for the underground coal fire classification using NDCFI index calculated nased on Landsat 8 OLI_TIRS data is shown in Fig. 3.

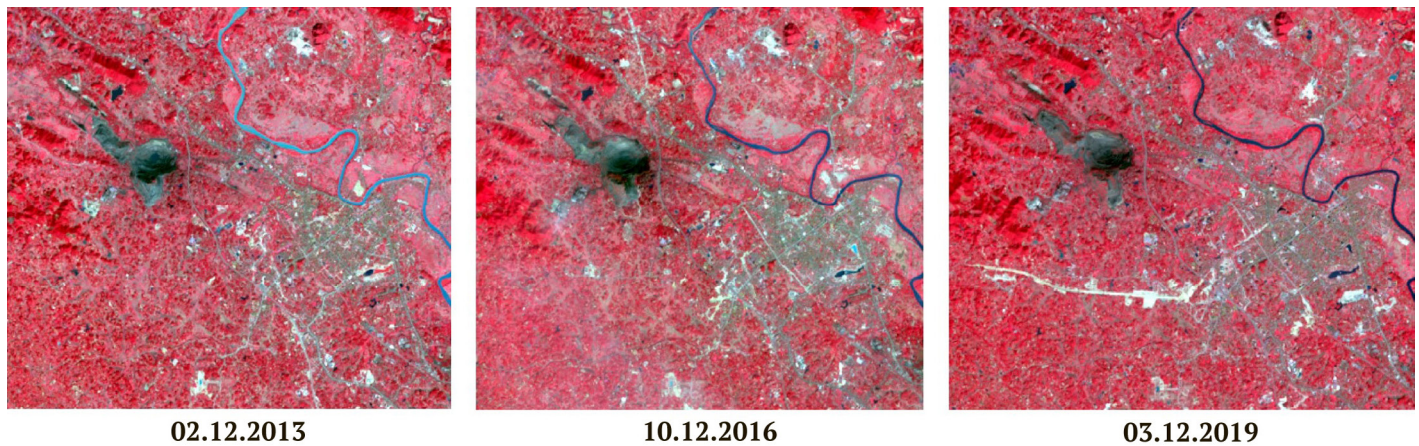| 02.12.2013 | 10.12.2016 | 03.12.2019 |

Fig. 2. Landsat multi-temporal imagery data for Khanh Hoa coal mine area
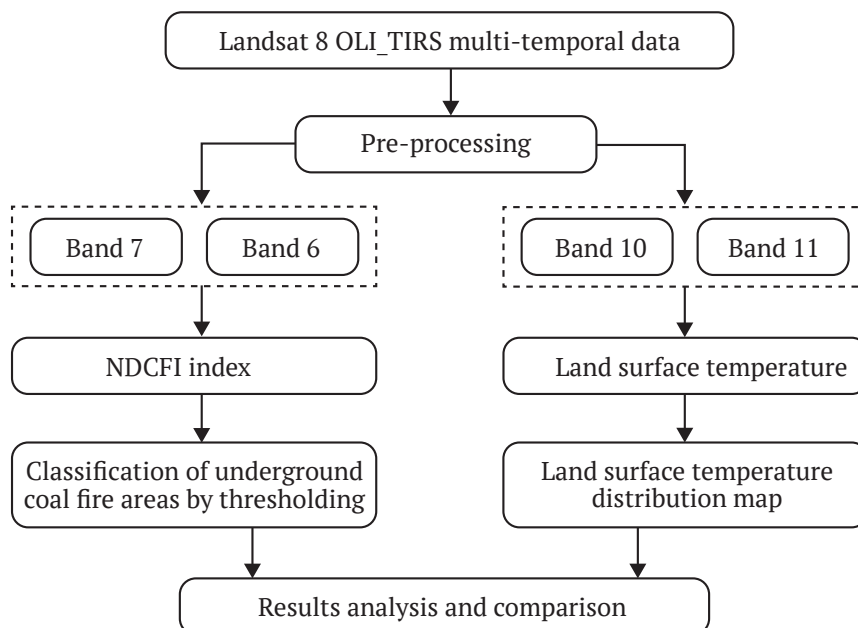
Fig. 3. Flowchart (methodology) for underground coal fire classification

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3. Results and discussion

Figure 4 shows the NDCFI indices for Khanh Hoa coal mine (Thai Nguyen province) calculated based on Landsat 8 images taken on December 2, 2013, December 10, 2016 and December 3, 2019. On the NDCFI images, the Khanh Hoa coal mine is represented by bright pixels, differing from the surrounding area. The area within the Khanh Hoa coal mine and the waste dump, where the underground coal fire occurred, has the brightest color. This can be explained by the fact that the reflectance value of underground coal fire pixels at waveleng 2.11–2.29 µm (band 7 of Landsat 8 image) is much higher than at waveleng 1.57–1.65 µm (band 6 of Landsat 8 image). Meanwhile, the reflectance value of vegetation in band 7 is lower than in band 6 of Landsat 8 image, so vegetation is represented by dark pixels on the NDCFI index images. Built-up lands and bare lands are light gray on the NDCFI images because the difference in their spectral reflectance value in bands 6 and 7 of Landsat 8 image is not marked.

Based on the analysis of the NDCFI index histogram, threshold value was selected to classify the underground coal fires. In the study area in Khanh Hoa coal mine (Thai Nguyen province), the threshold value to classify underground coal fire areas / surrounding areas was −0.22. The image processing to select the threshold value was performed using ENVI 5.2 software.

The results of the underground coal fire classification at Khanh Hoa coal mine (Thai Nguyen province) based on the NDCFI index calculated from Landsat 8 satellite images dated December 2, 2013, December 10, 2016 and December 3, 2019 are shown in Figure 5, where the underground coal fire areas are painted red, while the surrounding areas are white. The underground coal fire areas classified based on the NDCFI index in 2013, 2016, and 2019 covered 103.68 ha, 98.01 ha, and 93.87 ha, respectively.

To compare the results of underground coal fire classification at Khanh Hoa coal mine by using NDCFI index, the land surface temperatures were also calculated from Landsat 8 images. The land surface temperatures in the study area calculated from the Landsat 8 satellite images of 2013, 2016, and 2019 are presented in Fig. 6. The lowest and highest land surface temperatures on
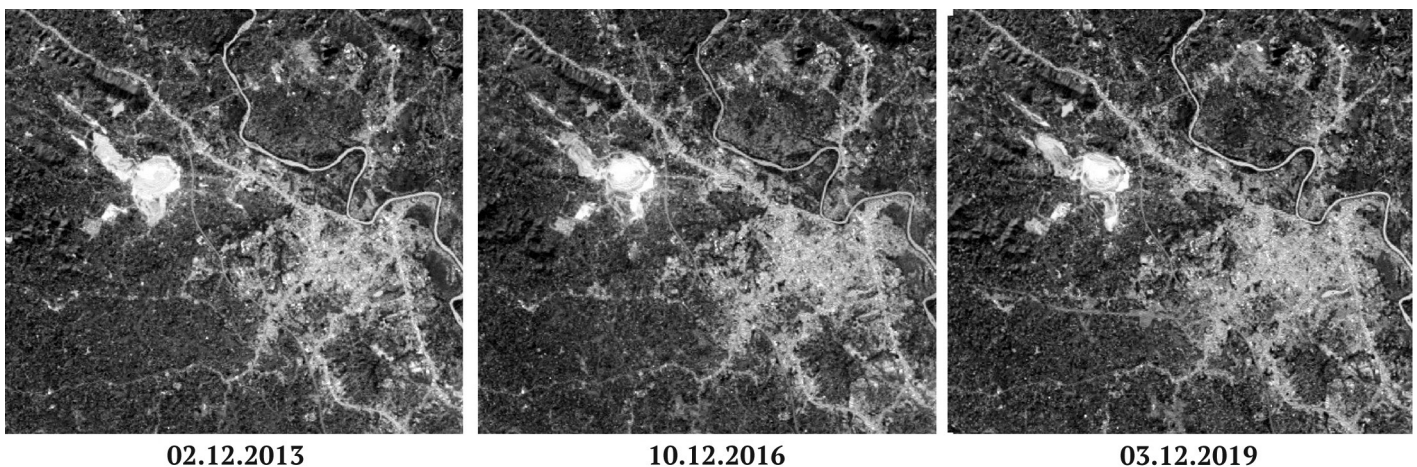
| 02.12.2013 | 10.12.2016 | 03.12.2019 |

Fig. 4. NDCFI index calculated based on Landsat images in the period of 2013–2019

| 02.12.2013 | 10.12.2016 | 03.12.2019 |

Fig. 5. The results of underground coal fire identification at Khanh Hoa coal mine based on NDCFI index by thresholding method

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December 2, 2013, December 10, 2016, and December 3, 2019 were 21.02 °C and 38.82 °C, 20.95 °C and 38.31 °C, 19.86 °C and 38.92 °C, respectively. It can be seen that the difference between the highest and lowest land surface temperatures in the study area is not large. Areas of high land surface temperatures are locally distributed in Khanh Hoa coal mine area (shown by white pixels). The land surface temperatures in the inner city of Thai Nguyen are lower (about 30 to 35 °C), while the agricultural lands and forest areas have the lowest surface temperatures (less than 30 °C).

Figure 7 shows the land surface temperature spatial distribution maps for the area of Khanh Hoa coal mine location, which were obtained from Landsat 8 data. In this Figure, seven zones were identified with the following temperatures: below 20 °C, 20–23 °C, 23–26 °C, 26–29 °C, 29–32 °C, 32–35 °C, and above 35 °C. It can be seen that the land surface temperatures within the Khanh Hoa coal mine area was much higher than those in the surrounding areas, even compared to Thai Nguyen city, which was characterized by impervious surface.

Areas with land surface temperatures higher than 35 °C were concentrated within Khanh Hoa coal mine (shown by red in Fig. 7).

The areas with land surface temperatures higher than 35 °C calculated from Landsat 8 images in December 2, 2013, December 10, 2016 and December 3, 2019 covered 101.16 ha, 96.60 ha, and 92.05 ha, respectively. Thus, it can be seen that the results of the underground coal fire classification using NDCFI index have very strong correlation with the high surface temperature areas, above 35 °C – the threshold temperature value for identifying underground coal fires [5]. The correlation coefficient between the NDCFI index and the land surface temperature on December 2, 2013, December 10, 2016, and December 3, 2019 reached 0.867, 0.807, and 0.862, respectively. The above findings show that NDCFI index can be effectively used in early detection and classification of underground coal fires. The use of NDCFI index for studying underground coal fires has advantages of its simplicity and rapidity compared to the method based on using land surface temperatures.
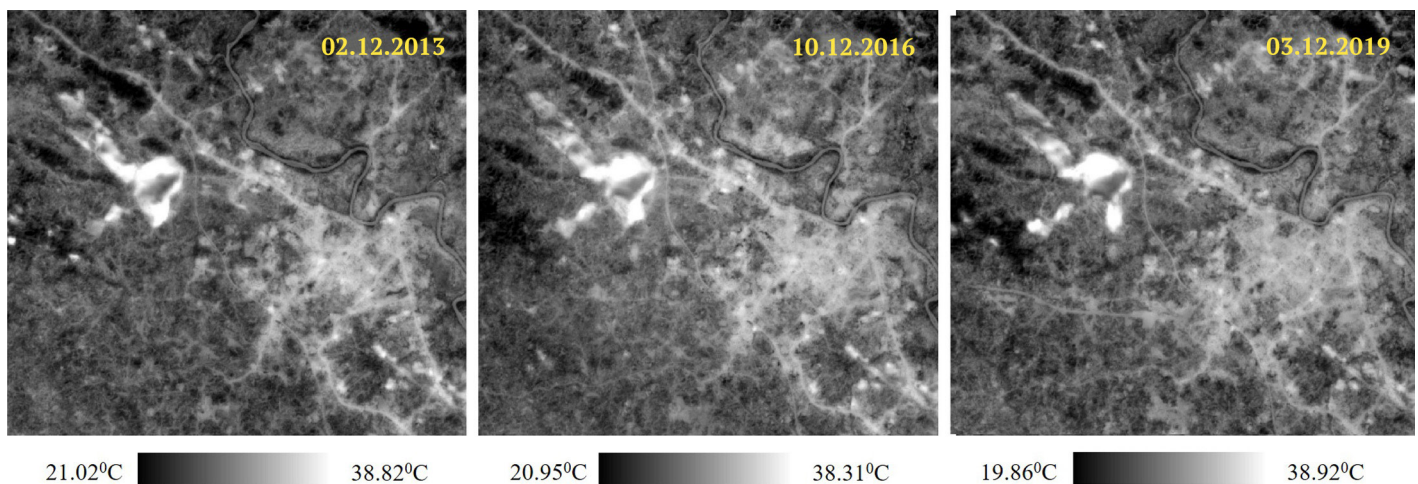

Fig. 6. Land surface temperatures in the study area calculated from Landsat 8 images in the period of 2013–2019
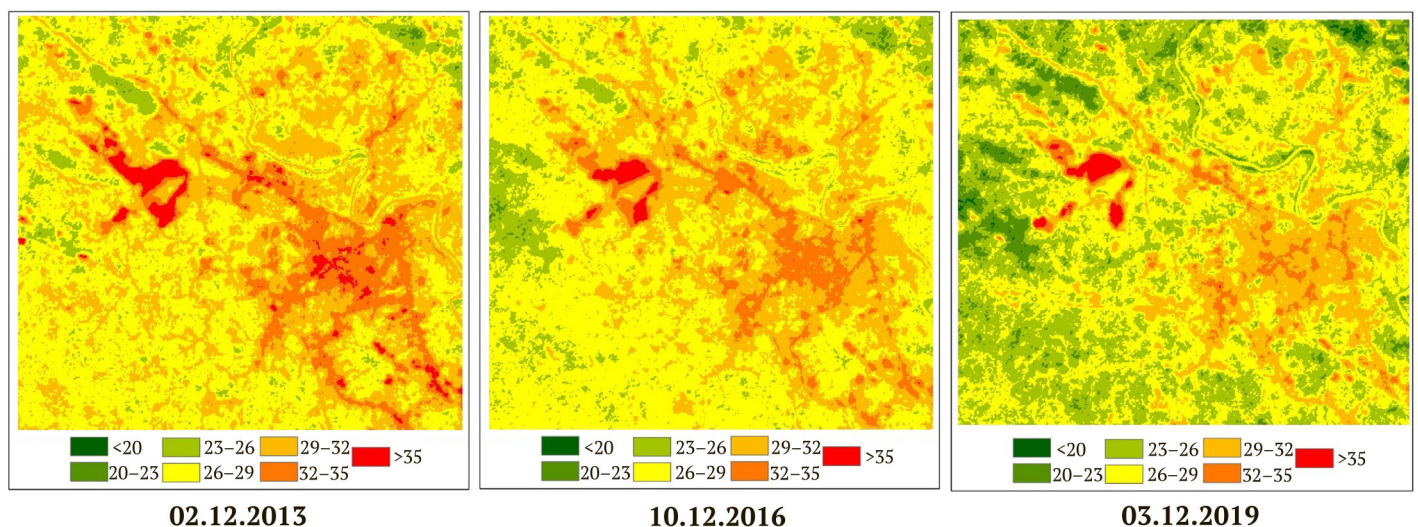

Fig. 7. NDCFI index calculated from Landsat images in the period of 2013–2019

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4. Conslucsion

Underground coal fires are very dangerous phenomenon in coal mining, greatly affecting the environment and production activities. Early detection of areas with high risk of underground fire is an urgent task; it is necessary to effectively respond to underground coal fires. This paper presents a solution for early detection and monitoring of areas with high risk of underground coal fire based on NDCFI index calculated from Landsat satellite data. The obtained results showed that NDCFI index has very high correlation with the land surface temperature. Areas with NDCFI values higher than −0.22 practically correspond to areas with land surface temperature above 35 °C. Applying NDCFI index allows providing timely information for managers to effectively respond to underground fires in coal mining sector.

References

1. Zhang Y., Wang A., Chen L., Liu C. Study of thermal characteristics and functional group changes of Yanghuopan Coal during spontaneous combustion. *Journal of Thermal Analysis and Calorimetry.* 2021. https://doi.org/10.1007/s10973-021-10802-6

2. Stracher G., Prakash A., Sokol E. Volume 3: Case Studies – Coal Fires. In: Stracher G. B., Prakash A., Sokol E. V. (eds.). *Coal and Peat Fires: A Global Perspective.* Elsevier Science; 2015. http://doi.org/10.1016/C2010-0-68844-4

3. Wolf K. H., Bruining J., Meeuwis R. Understanding underground coal fires for utilization. In: *68th EAGE Conference and Exhibition incorporating SPE EUROPEC 2006.* 2006. https://doi.org/10.3997/2214-4609.201402110

4. Prakash A., Gupta R. P. Surface fires in Jharia coalfield, India – their distribution and estimation of area and temperature from TM data. *International Journal of Remote Sensing.* 1999;20(10):1935–1946. https://doi.org/10.1080/014311699212281

5. Mishra R. K., Roy P. N. S., Pandey J., Khalkho A., Singh V.K. Study of coal fire dynamics of Jharia coalfield using satellite data. *International journal of Geomatics and Geosciences.* 2014;4(3):477–484. URL: https://www.researchgate.net/publication/281833491_Study_of_coal_fire_dynamics_of_Jharia_coalfield_using_satellite_data

6. Chen Y., Li J., Yang B., Zhang S. Detection of coal fire location and change based on multi – temporal thermal remotely sensed data and field measurements. *International Journal of Remote Sensing.* 2007;28(15):3173–3179. https://doi.org/10.1080/01431160500444889

7. Cracknell A. P., Mansor S. B. Detection of sub-surface coal fires using Landsat Thematic Mapper data. *International Archives of Photogrammetry and Remote Sensing.* 1992;29:750–753. URL: https://www.isprs.org/proceedings/XXIX/congress/part7/750_XXIX-part7.pdf

8. Guha A., Kumar K. Structural controls on coal fire distributions – Remote sensing based investigation in the Raniganj coalfield, West Bengal. *Journal of the Geological Society of India.* 2012;79:467–475. https://doi.org/10.1007/s12594-012-0071-6

9. Huo H., Jiang X., Song X., Li Z., Ni Z., Gao C. Detection of coal fire dynamics and propagation direction from multi-temporal nighttime Landsat SWIR and TIR data: A case study on the Rujigou coalfield, Northwest (NW) China. *Remote Sensing.* 2014;6(2):1234–1259. https://doi.org/10.3390/rs6021234

10. Liu J., Wang Y., Yan S., Zhao F., Li Y., Dang L., Liu X., Shao Y., Peng B. Underground coal fire detection and monitoring based on Landsat-8 and Sentinel-1 data sets in Miquan fire area, XinJiang. *Remote Sensing.* 2021;13(6):1141. https://doi.org/10.3390/rs13061141

11. Trinh L. H., Zablotskii V. R. The application of Landsat multi-temporal thermal infrared data to identify coal fire in the Khanh Hoa coal mine, Thai Nguyen province, Vietnam. *Izvestiya, Atmospheric and Oceanic Physics.* 2017;53(9):1181–1187. https://doi.org/10.1134/S0001433817090183

12. Vu D. T., Nguyen T. T. Spatio-temporal changes of underground coal fires during 2008-2016 in Khanh Hoa coal field (North-east of Viet Nam) using Landsat time-series data. *Journal of Mountain Science.* 2018;15(12):2703–2720. https://doi.org/10.1007/s11629-018-4997-z

13. Prasun K., Kuntala L., Kanika S. Application of remote sensing to identify coal fires in the Raniganj Coalbelt, India. *International Journal of Applied Earth Observation and Geoinformation.* 2005;8(3):188–195. https://doi.org/10.1016/j.jag.2005.09.001

14. Trinh L. H., Vu V. T., Do T. T. Application of Landsat 8 and Sentinel 2 multi-spatial resolution satellite imageries to determine the land surface temperature in Khanh Hoa coal mine (Thai Nguyen province). *Mining Industry Journal.* 2018;(6):86–90.

15. Luu D. H., Nguyen T. H. L. Renewable energy policies for sustainable development in Vietnam. *VNU Journal of Science: Earth and Environmental Sciences.* 2009;25(3):133–142. URL: https://js.vnu.edu.vn/EES/article/view/1870

16. Nguyen T. T., Vu D. T. Use of hot spot analysis to detect underground coal fires from Landsat-8 TIRS data: A case study in the Khanh Hoa coal field, North-East of Vietnam. *Environment and Natural Resources Journal.* 2019;17(3):1–10. https://doi.org/10.32526/ennrj.17.3.2019.17

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ГОРНЫЕ НАУКИ И ТЕХНОЛОГИИ
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eISSN 2500-0632
https://mst.misis.ru/

Чинь Л. Х., Нгуен В. Н. Выявление пожаров на угольных рудниках...

17. Raju A. *Remote sensing based coal fire studies in Jharia coalfield, India*. PhD thesis. Indian Institute of Technology Roorkee; 2015. 189 p.

18. Chavez P. Image-based atmospheric corrections–revisited and improved. *Photogrammetric Engineering and Remote Sensing*. 1996;62(9):1025–1036. URL: https://www.researchgate.net/publication/236769129_Image-Based_Atmospheric_Corrections_-_Revisited_and_Improved

19. Du C., Ren H., Qin Q., Meng J., Li J. Split-window algorithm for estimating land surface temperature from Landsat 8 TIRS data. In: *IEEE Geoscience and Remote Sensing Symposium*. 2014. Pp. 3578–3581. https://doi.org/10.1109/IGARSS.2014.6947256

20. Jiménez-Muñoz J. C, Sobrino J. A., Skoković D., Mattar C., Cristóbal J. LST retrieval methods from Landsat-8 thermal infrared sensor data. In: *IEEE Geoscience and Remote Sensing Letters*. 2014;11(10):1840–1843. https://doi.org/10.1109/LGRS.2014.2312032

21. Rongali G., Keshari A.K., Gosain A.K., Khosa R. Split-window algorithm for retrieval of land surface temperature using Landsat 8 thermal infrared data. *Journal of Geovisualization and Spatial Analysis*. 2018;2(2):1–19. https://doi.org/10.1007/s41651-018-0021-y

22. Huazhong R., Du C., Qin Q., Liu R. Atmospheric water vapor retrieval from Landsat 8 and its validation. In: *IEEE International Geoscience and Remote Sensing Symposium*. 2014. Pp. 3045–3048. https://doi.org/10.1109/IGARSS.2014.6947119

23. Sobrino J. A., Jimenez-Munoz J. C., Zarco-Tejada P. J., Sepulcre-Canto G., de Miguel E. Land surface temperature derived from airborne hyperspectral scanner thermal infrared data. *Remote Sensing of Environment*. 2006;102(1-2):99–115. https://doi.org/10.1016/j.rse.2006.02.001

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