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DETECTION OF LAND SURFACE TEMPERATURE CHANGE IN COAL MINING AREA USING REMOTE SENSING AND GIS TECHNIQUES - A CASE STUDY IN QUANG NINH PROVINCE, VIETNAM

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ABSTRACT

This research explores Land Surface Temperature (LST), which represents the energy exchange between the land surface and the atmosphere, as well as with the biosphere. Variations in surface temperature can lead to the formation of heat islands characterized by higher temperatures compared to surrounding areas. The study focuses on the application of Remote Sensing (RS) and Geographic Information Systems (GIS) to detect changes in LST in a coal mining area in Vietnam. Landsat images spanning from 1986 to 2022 were used to quantify these changes. The analysis revealed that the radiant temperature in 1986 ranged from 14.2ºC to 30.5 ºC, whereas in 2022, it was significantly higher, ranging from 17.4 ºC to 32.3 ºC. A change map was created to visualize the temporal changes in land surface temperature distribution during the study period. The research employs scientific and efficient methodologies to investigate whether enhancing the ecological environment in coal-mining regions can help alleviate the conflict between human activities and nature, thus fostering sustainable development in these areas.

1. INTRODUCTION

Coal is the most important mineral resource in Vietnam and has made great contributions to Vietnam's economic development and social progress. Coal mining activities that are not well managed will have an impact on the occurrence of environmental damage. The generation and accumulation of heat is the major direct cause of spontaneous coal combustion (Binh, 2017). Open-pit mining operations are processes of denudation, handling and accumulation (Ha, 2020). Therefore, open-pit mining areas are not only affected by vegetation, soil and terrain but also create big pits, transit sites, solid waste and changes in land use land cover (LULC) (Ha et al., 2021).

The land surface temperature (LST) comprehensively reflects the energy exchange between land and the atmosphere, which is an important geophysical parameter in the ground-air system (Li et al., 2016; Zhu et al., 2016). Calculating LST from remotely sensed images is needed since it is an important factor controlling most physical, chemical and biological processes of the Earth (Becker et al., 1990;). Remote sensing instruments are key players in studying and mapping land surface temperature (LST) at temporal and spatial scales (André et al., 2015; Nguyen & Vu, 2019). Remote sensing methodology requires less time and lower cost than field methods to investigate various phenomena on the land surface (Niu et al., 2015).

Standard techniques for detecting coal fire zones encompass both geophysical and remote sensing methods. The geophysical approach involves workers carrying specialized equipment for on-site investigations, demanding significant manpower and material resources. Consequently, these methods prove inadequate for analyzing and monitoring extensive or successive coal fires across wide areas. Nowadays, a diverse range of monitoring sources and remote sensing data is at our disposal and their abundance is progressively growing. This escalation in availability underscores the heightened benefits of utilizing remote sensing technology to identify areas affected by coal fires. The advantages of using remote sensing methodology are the repetitive and consistent coverage, high resolution and evaluation of land surface characteristics (Owen et al*.,* 1998; Trinh et al., 2017). Thermal infrared (TIR) data in remote sensing can help us obtain quantitative information of surface temperature. Coal mining has been most extensively practiced in the area of Cam Pha city, Northeast Vietnam. As a result, the original landscape has been converted to mine spoils.

The aim of the study is to generate a statute of coal mines in the area and estimate LST, then analyze the change in the distribution of LST in the area through the period of 1990-2010 and 2010-2020.

2. MATERIAL AND METHODS

2.1 Study area

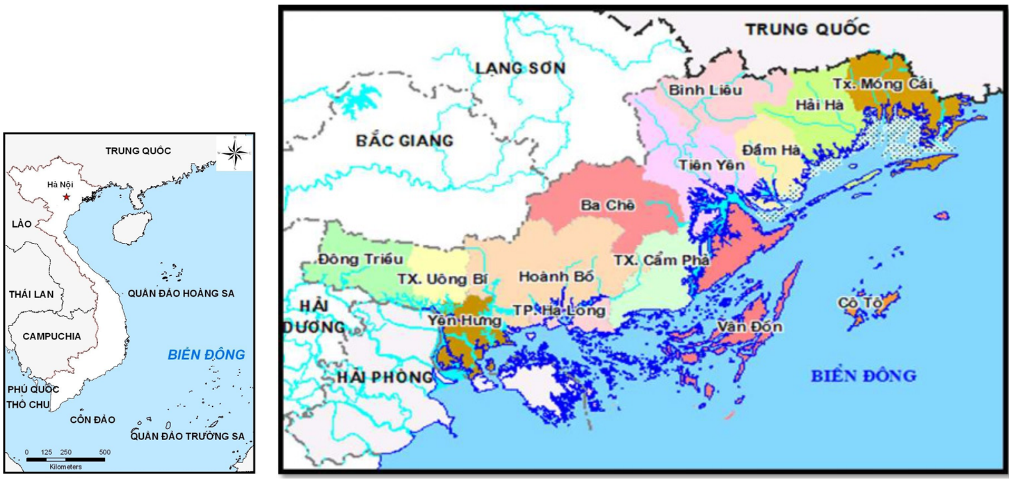


Figure 1. Location of the study area.

Quang Ninh, located in the Northeastern region of Vietnam along the coast, is often compared to a microcosm of Vietnam due to its rich diversity of geographical features, including seashores, islands, plains, hinterlands, hills, mountains and borders (Figure 1). In terms of economic development planning, Quang Ninh holds significance not only as a vital economic hub in the northern part of the country but also as an integral component of the Northern Coastal Region. It is renowned as Vietnam's primary coal mining province and is famous for being home to Ha Long Bay, a UNESCO World Heritage Site and natural marvel. Currently, Quang Ninh is actively promoting tourism as a focal point while simultaneously placing a high priority on safeguarding its marine and island ecosystems. The total economy of the region is highly dependent on coal mining.

Quang Ninh is one of the 25 provinces and cities that share a border. However, it is the only province that shares both land and sea borders with China. Its land border stretches for

118.825 km, while the delineation in the Gulf of Tonkin at sea spans over 191 km. Furthermore, Quang Ninh is one of the 28 coastal provinces and cities, boasting a coastline that extends for 250 kilometers. Within this stretch, there are 40,000 hectares of tidal flats and over 20,000 hectares of bay mangroves. It is also home to 2 out of 12 island districts in the entire country.

2.2 Data and methodology

2.2.1 Data sources

Landsat data were used for this study. Three Landsat data selected to classify land cover of the study area consist of two Landsat-5 TM data acquired in 1990 and 2010 and a Landsat-8 OLI data acquired in 2020 (GLOVIS, 2023).

The details of Landsat data are described in Table 1.

Table 1. Characteristics of satellite data used in the study area.

Sensor	TM, OLI
Spatial resolution	30 m
Processing Level	2A
Acquired Date	26/11/1990 03/12/2010 12/11/2020

While Landsat-5 TM data has 7 spectral bands, including a thermal band:

- Band 1 Visible Blue (0.45-0.52 µm) 30 m
- Band 2 Visible Green (0.52-0.60 µm) 30 m
- Band 3 Visible Red (0.63-0.69 µm) 30 m
- Band 4 Near-Infrared (0.76-0.90 µm) 30 m
- Band 5 Near-Infrared (1.55-1.75 µm) 30 m
- Band 6 Thermal (10.40-12.50 µm) 120 m
- Band 7 Mid-Infrared (2.08-2.35 µm) 30 m

Ground Sampling Interval (pixel size): 30 m reflective, 120 m thermal

The details of Landsat 8-9 OLI and TIRS data are described in Table 2.

Table 2. Landsat 8-9 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS).

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1- Coastal aerosol	0.43-0.45	30
Band 2- Blue	0.45-0.51	30
Band 3- Green	0.53-0.59	30
Band 4- Red	0.64-0.67	30
Band 5- Near Infrared (NIR)	0.85-0.88	30
Band 6- Shortwave Infrared (SWIR) 1	1.57-1.65	30
Band 7- Shortwave Infrared (SWIR) 2	2.11-2.29	30
Band 8- Panchromatic	0.50-0.68	15

Bands	Wavelength (micrometers)	Resolution (meters)
Band 9- Cirrus	1.36-1.38	30
Band 10- Thermal Infrared (TIRS) 1	10.6-11.19	100
Band 11- Thermal Infrared (TIRS) 2	11.50-12.51	100

2.2.2 Method of determining the surface temperature from the infrared thermal images

To calculate land surface temperature, in the first step, Landsat 5 TM band data must be converted to TOA spectral radiance using the radiance rescaling factors provided in the metadata file (LANDSAT Conversion to Radiance, Reflectance and At-Satellite Brightness Temperature):

$$L_{\lambda} = M_L.Q_{cal} + A_L, \quad (1)$$

where:

L_{λ} - TOA spectral radiance (Watts/[m^2*srad*µm]),

M_L - Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number),

A_L - Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number),

Q_{cal} - Quantized and calibrated standard product pixel values (DN).

Table 3. LANDSAT 5 TM and LANDSAT 8 OLI spectral radiance M_L, A_L dynamic ranges.

Data type	LANDSAT 5 TM	LANDSAT 8 OLI
Band	6	7
M_L	0.055×10^{-4}	3.3420×10^{-4}
A_L	1.18243	0.10000

(Note that $\mathbf{M_L}$ and $\mathbf{A_L}$ are derived from the metadata of Landsat 5 TM and Landsat 8 OLIdata)

In the second step, the LANDSAT thermal band data can be converted from spectral radiance to brightness temperature using the following equation (LANDSAT Conversion to Radiance, Reflectance and At-Satellite Brightness Temperature):

$$T = \frac{K_2}{\ln(\frac{K_1}{L_{\lambda}} + 1)}, \quad (2)$$

where: T- At satellite brightness temperature (K)

K_1- Calibration constant 1 [W/(m^2.sr.µm)]

K_2- Calibration constant 2 [K]

Table 4. LANDSAT 5 TM and LANDSAT 8 OLI thermal band calibration constants.

Data type	LANDSAT 5 TM	LANDSAT 8 OLI
Band	6	7
K_1 (W/(m^2.sr.µm))	666.09	774.89
K_2 (Kelvin)	1,282.71	1,321.08

For determining a land surface temperature from LANDSAT data, the land surface temperature can be calculated by the following equation (Grishchenko, 2012; Trinh, 2014; Kumar, 2012):

$$T = \frac{K_2}{\ln(\frac{K_1}{L_\lambda} + 1)}, \tag{3}$$

where: T- brightness temperature (K^o)

λ- wavelength (11.5 μm)

ε- land surface emissivity, $\rho = \frac{h.c}{\sigma}$

h- Plank's constant ($6,626 \times 10^{-34}$ J.sec)

c- velocity of light ($2,998 \times 10^{8}$ m/sec)

σ- Stefan Boltzmann's constant, which is equal to 5.67×10^{-8} $Wm^{-2} K^{-4}$.

3. RESULTS AND DISCUSSION

3.1 Evaluate the accuracy of surface temperature extraction results from Landsat satellite images

To assess the accuracy of the current status of land surface temperature values in the study area, the research team collected and compared data from environmental monitoring results in Quang Ninh province in the period 2015-2020 with frequency. Two times/year at 16 locations (Table 5).

In addition, to have a more scientific basis for evaluating the reliability of extracting surface temperature values from remote sensing images, the research team added 16 additional temperature monitoring points in each month, January 2021. Results are summarized in the following Table 5.

Table 5. Assessing the difference in surface temperature values in the Cam Pha - Ha Long area in 2020.

No	Monitoring location	Temperature value		
		Temperature values in December 2020 and January 2021	Temperature value from Landsat 8 OLI image in December 2020	Difference in temperature value (^{o}C)
1	Vietnam-Soviet Friendship Cultural Palace, Ha Long city	23.8 ^{o}C	27.1 ^{o}C	-3.3
2	Cai Dam market, Bai Chay	24.0 ^{o}C	28.0 ^{o}C	-4.0
3	Department of Natural Resources and Environment	23.1 ^{o}C	24.8 ^{o}C	-1.7
4	Ha Tu market, Halong city	23.5 ^{o}C	28.8 ^{o}C	-5.3
5	Dia Chat market, Campha city	24.2 ^{o}C	29.8 ^{o}C	-5.6
6	Cam Pha square, Campha city	24.0 ^{o}C	29.1 ^{o}C	-5.1
7	Mong Duong river, (21^{o}06'04,4" N; 107^{o}33'51,0" E)	22.5 ^{o}C	20.9 ^{o}C	1.6
8	Mong Duong river, (21^{o}06'08,1" N; 107^{o}34'99,4" E)	22.2 ^{o}C	20.2 ^{o}C	+ 2.0
9	Cau 2 River, (20^{o}99'96,8" N; 107^{o}29'75,42" E)	22.5 ^{o}C	20.5 ^{o}C	+ 2.0
10	Cau 2 River, (21^{o}00'97,1" N; 107^{o}29' 94,54" E)	22.5 ^{o}C	20.7 ^{o}C	+1.8
11	Cau 2 River, (21^{o}00'98,7" N; 107^{o}29'95,48" E	22.9 ^{o}C	20.9 ^{o}C	+ 2.0
12	Location of the discharge gates behind the Coc Sau mine treatment system (21^{o}00'28,3" N;107^{o}32'51,8" E).	23.5 ^{o}C	22.5 ^{o}C	1.0

13	Location of the discharge gates behind the Coc Sau mine treatment system (21°00'96,5" N; 107°32'60,0" E);	23.2 °C	22.2 °C	1.0
14	Lo Phong river, (20°95'68,48"N;107°17'32,58" E)	21.6 °C	19.3 °C	2.3
15	Lo Phong river,(20°96'47,8"N; 107°16'03,65"E)	25.0 °C	23.7 °C	1.3
16	Lo Phong river, (20°97'41,9"N; 107°14'54,1" E)	24.9 °C	27.0 °C	-2.1

The assessment results comparing temperature values extracted from remote sensing images with those from monitoring points in 2020 reveal a notable disparity, particularly in regions with high population density. In these areas, the temperature values measured on the images often appear higher than the actual observed values. This discrepancy arises because the surface temperature of objects is pinpointed precisely at that pixel on the image, while field measurements can be influenced by weather conditions, wind, humidity and other factors.

In a general sense, despite some deviations in the baseline temperature values at individual points, the average temperature values across the entire area, as determined from remote sensing images and monitoring data, do not exhibit significant differences. However, variations are more pronounced in coastal regions, areas featuring extensive river and lake systems and densely populated zones. Therefore, these findings underscore the reliability and feasibility of utilizing Landsat image data for constructing large-scale surface temperature maps within the study area.

3.2 Spatial distribution of radiant surface temperature in the Campha-Halong city, Quang Ninh, in 1990, 2010 and 2020.

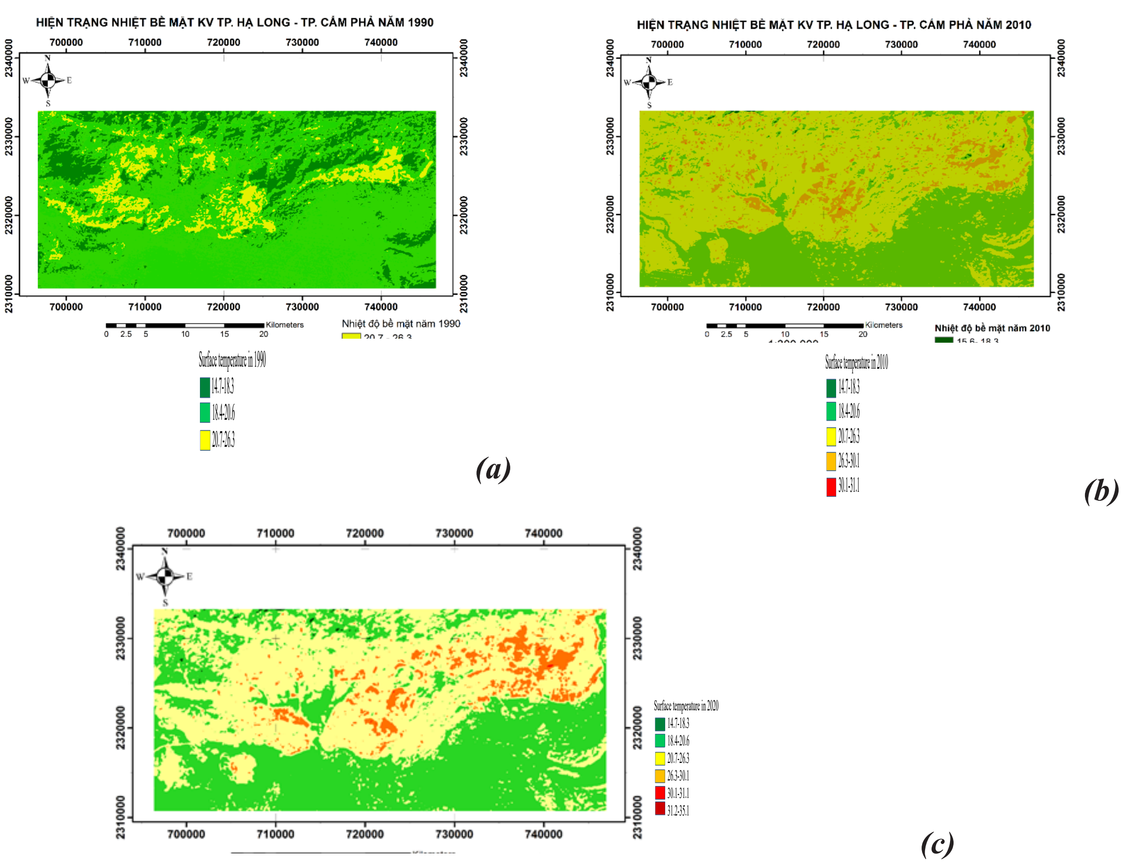


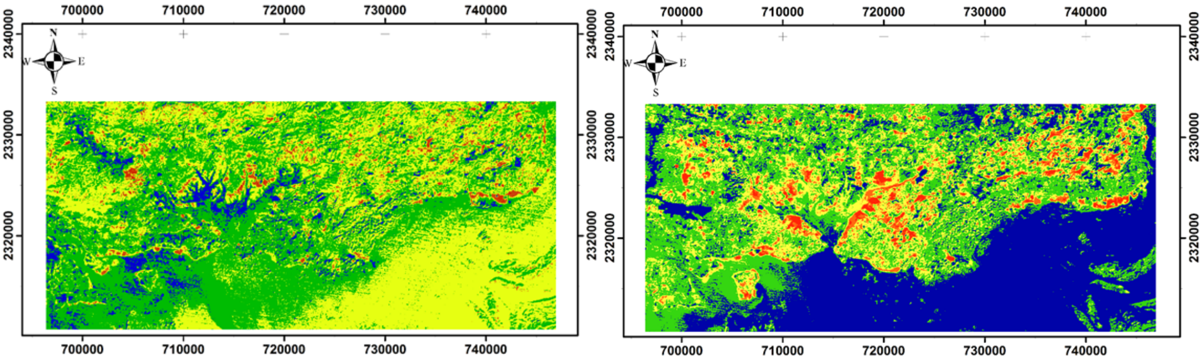
Figure 2. Spatial distribution of radiant surface temperature in the Campha-Halong city.

According to the findings depicted in Figure 2, starting from 1990, the surface temperature remained below 30 °C, indicated by the yellow color on the map (a). However, in the surface temperature maps for 2010 and 2020, there is a noticeable expansion of regions where temperatures exceed 30 ^oC and some areas have even experienced surface temperature increases of up to 35 ^oC (b, c).

This observation underscores the clear connection between surface temperature variations and changes in land use, primarily driven by socio-economic development initiatives in Quang Ninh province. Notably, areas characterized by open-pit mining activities, such as Coc Sau, Deo Nai, Cao Son in Cam Pha City, Nui Fat and Ha Tu in Ha Long city, exhibit a notable and abrupt rise in temperature when compared to their surrounding areas.

3.3 Changes in radiant surface temperature in the Campha-Halong city, Quang Ninh from 1990 to 2020.

The surface temperature fluctuation maps in Figure 3 reveal some noteworthy trends. During the period from 1990 to 2010, surface temperature fluctuations there emerged areas where temperature fluctuations exceeded 6 degrees Celsius, notably in expanded mining regions and areas affected by industrial activities.



(a) *(b)*

Figure 3. Changes in radiant surface temperature in the Campha-Halong city, Quang Ninh from 1990-2010 (a), from 2010-2020 (b).

Moving forward to the periods from 1990 to 2010 and from 2010 to 2020, the maps illustrate a further expansion of areas experiencing temperatures surpassing 6 degrees Celsius, now encompassing regions with altered surface cover. This clearly demonstrates a correlation between surface temperature alterations and changes in land use driven by socio-economic development initiatives within Quang Ninh province.

The results concerning surface temperature fluctuations in various time spans indicate that coal mining, waste disposal and environmental remediation activities have predominantly expanded over the past two decades. This expansion coincides with a significant reduction in vegetation cover and bare soil areas. Additionally, the area of surface water and bare land has considerably decreased due to reclamation processes along coastal areas for tourist development on residential land. This shift in land use for socio-economic development has contributed to rising surface temperatures, further exacerbated by the context of climate change.

The initial surface temperature maps, depicting temperature changes over ten-year intervals at various locations, provide a visual representation of the distribution of these temperature alterations.

4. CONCLUSION

The approach of using Landsat data's thermal infrared bands to ascertain surface temperature proves highly effective for extensive study areas, yielding historical data. This is particularly valuable for regions where surface cover experiences fluctuations due to activities like mineral extraction and urban expansion, notably in coastal tourism zones.

Landsat satellite images, with their spatial resolution ranging from 60 to 100 meters for thermal infrared channels, offer suitable data for calculating surface temperature across vast study areas encompassing numerous coal mines and an extensive coastline within Quang Ninh province.

The outcomes of the surface temperature analysis reveal that over the past two decades, activities such as coal mining, waste disposal and environmental remediation have expanded their geographical footprint. This expansion has led to significant reductions in both vegetation cover and exposed soil areas. Additionally, the extent of surface water and open land has considerably diminished due to coastal land reclamation for residential and tourist development. The transformation of land use for socio-economic development purposes has contributed to elevated surface temperatures. Moreover, within the context of changing atmospheric conditions, temperatures are experiencing further increases.

The surface temperature maps, showcasing temperature changes over the past 30 years, indicate the need for further investigations into temperature variations across diverse geographical locations. Such studies would provide a more comprehensive understanding of the distribution of these temperature changes.

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