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TECHNICAL COMMUNICATION

Thermal Infrared Imaging to Identify Surface Mines

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Abstract

Mines show spectral resemblance with other landscape features; hence, their identification with satellite imagery can be difficult. To address this, land surface temperature (LST) derived from thermal infrared images of satellite remote sensing data was used to differentiate mines. Higher surface temperatures were observed for mined land than other classes (built-up and fallow land) in nighttime data. This indicates that the increased surface temperature of the other classes is due to solar heating while geothermal and pyrite oxidation contribute warmth at mined sites. Nighttime LST can be used to locate mines and their spatial extent despite the low spatial resolution of satellite data. It also confirms a mine's heat island phenomenon due to geothermal energy.

Keywords Geothermal energy · Land surface temperature · Remote sensing · Renewable energy

Introduction

Mining and its impacts is a global environmental issue (Hudson-Edwards 2016). The extent of mining's adverse environmental impacts depends on the magnitude of ore extraction and waste management strategies. Spatial tools including remote sensing are widely used to monitor and map mined land and its surrounding environment (Rathore and Wright 1993). However, the spatial resolution of satellite data often poses challenges in mapping small, inactive or abandoned mines.

Mine water in abandoned and operating mines are recognized as a potential source of geothermal energy (Hall et al. 2011; Watzlaf and Ackman 2006). Identification of these sites is important for the potential establishment of geothermal energy extraction infrastructure. Geothermal energy is a renewable energy source that can be used for heat production (Banks et al. 2019) and electricity generation (Clauser 2006). Among renewable energy sources, geothermal energy is considered to be one of the most promising options due to its relatively low pollutant emissions and energy generation cost (Popiel et al. 2001).

The spectral resolution of satellite data can help identify surface mines often missed due to spatial resolution and the heterogeneity of the mining landscape. For this, indices such as normalized difference water index [NDWI = (green − NIR)/(green + NIR)] (McFeeters 1996), normalized difference vegetation index [NDVI = (NIR − red)/(NIR + red)] (Rouse et al. 1973), bare soil index {BSI = [(SWIR + R) − (NIR + B)]/[(SWIR + R) + (NIR + B)]} (Li and Chen 2014), and normalized difference built-up index [NDBI = (SWIR − NIR)/(SWIR + NIR)] (Zha et al. 2003) are used to distinguish water bodies, vegetation, barren land, and built-up land, respectively. Developing a spectral index for identification of surface mines is difficult as their spectral signature is similar to areas with low moisture and vegetative cover, such as barren and built-up land.

Mining leads to loss of vegetation and soil moisture, increasing ambient and surface temperatures. Thus, remotely sensed spectral data captured in the thermal infrared (TIR) band can assist in identifying and mapping mining landscapes. Additionally, the feasibility of mine water for geothermal energy can be assessed. With this premise, we have used the TIR imaging capability of Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite data to identify surface mines in the Aravalli ranges of Rajasthan and their geothermal energy potential. These ranges are famous for sulphide mineralization, and surface and underground mines. An active surface mine

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(Zn–Pb) located in the Rampura Augucha, Bhilwara district of Rajasthan was selected for the present investigation.

Materials and Methods

The TIR bands (B10 = 8.12–8.47, B11 = 8.47–8.82, B12 = 8.92–9.27, B13 = 10.25–10.95 and B14 = 10.95–11.65 μ) of Terra-ASTER data with 90 m of ground spatial resolution and a 60 km swath was used to compute land surface temperature (LST) (Artis and Carnahan 1982). We used both the day (07 November 2014 and 17 November 2012) and night (12 January 2018 and 08 October 2017) data for this study. Summer months were avoided to minimize the effect of seasonal heating.

For temperature computation, the digital number (DN) of each thermal band (B10–B14) was converted into temperature (Yang et al. 2011). The raster calculator of ArcGIS was used to calculate the temperature and map thermal anomalies.

Results and Discussion

A significant variation in surface temperatures was observed across landscape features such as mine, mine infrastructure, mine waste, water body, built-up land, fallow land, riverbed, and vegetation (Fig. 1). Across the seasons, lower LSTs were observed in water bodies (max = 24 ± 0.17 °C) than that in built-up (max = 31 ± 0.6 °C) and fallow land (max = 36 ± 0.6 °C), and mined land (max = 32 ± 2.6 °C).

During the day, the average LST of fallow land (36 ± 0.6 °C in 2014 and 34 ± 0.7 °C in 2012) was higher than that of the mined land (32 ± 2.6 °C in 2014 and 29 ± 2.4 °C in 2012), as shown in Fig. 2. Low soil moisture content due to lack of irrigation and scanty vegetation increases the surface temperature of fallow land, but it is hard to differentiate mined and fallow lands using daytime surface temperature. However, at night, the average surface temperature was higher for the mined land (27 ± 0.5 °C in 2017 and 15 ± 1 °C in 2018) than other locations including fallow (21 ± 0.3 °C in 2017 and 10 ± 0.3 °C in 2018)

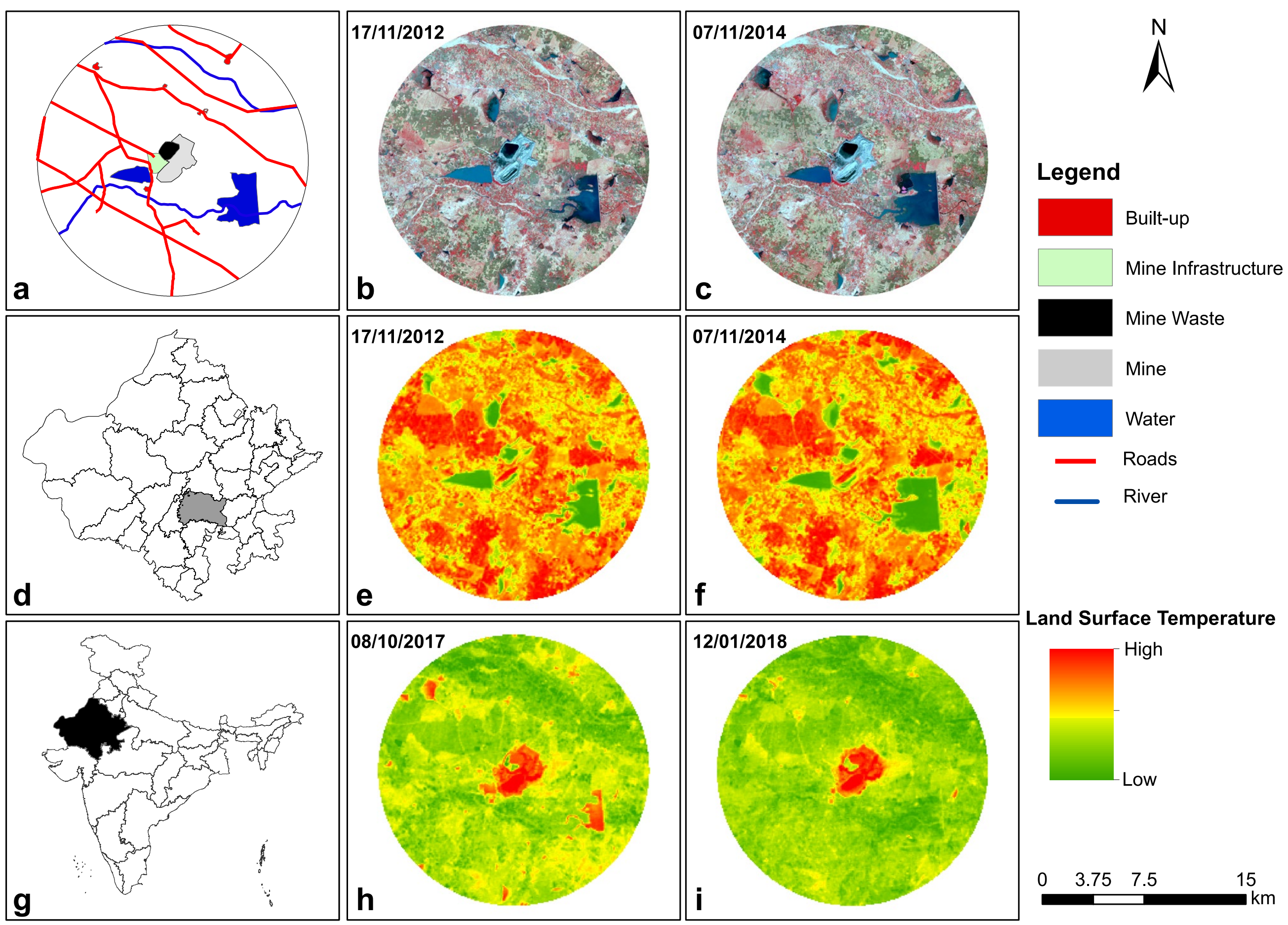

Fig. 1 Study area and thermal anomalies at mine during day and night

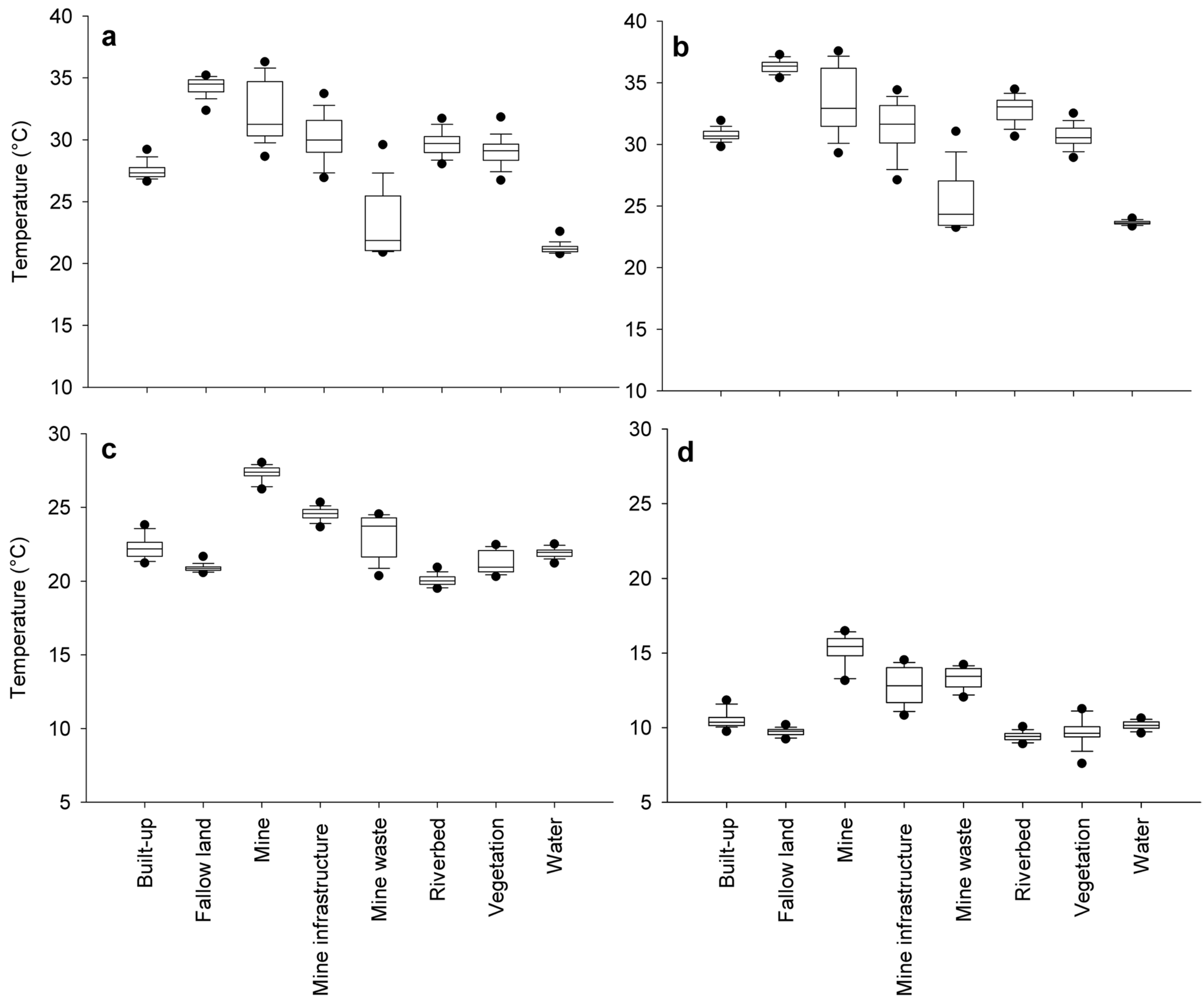

Fig. 2 Temperature variation in different classes during daytime (**a** 2012, **b** 2014) and nighttime (**c** 2017, **d** 2018)

and built-up (22 ± 0.8 °C in 2017 and 11 ± 0.6 °C in 2018) land, suggesting easy detection and identification of mines using nighttime LST data. Still, differentiating among these classes on standard false color and true color composites is often misleading, if not supported with intensive ground truthing.

While the surface temperature of fallow land significantly differs between the daytime (36 ± 0.6 °C) and nighttime (21 ± 0.3 °C), mining locations exhibit high LSTs during both daytime (29 ± 2.4 °C) and nighttime (27 ± 0.6 °C). This indicates that the increase in surface temperature of fallow land is due to solar heating, while at mined sites, other factors like geothermal heating and pyrite oxidation also contribute. The higher temperatures of mined land confirms that like urban areas, that they can have a heat island effect.

Sources of High Temperature

The observed high LST for mining locations is due to multiple physio-chemical reasons. Among them, the most important and potential reason is the presence of abundant geothermal energy below the earth surface. Removal of the overburden leads releases geothermal energy to the immediate environment; the deeper the mine, the more geothermal energy is released. Other studies have confirmed that geothermal energy can be extracted from mine water (e.g. Loredo et al. 2017).

Pyrite oxidation also releases energy in the form of heat (Harries and Ritchie 1981). Hence, the presence of unrecovered sulfides can increase ambient and surface temperatures. Low soil moisture content and vegetative cover also contribute to the higher temperatures of mined landscapes. Remote sensing data reveals that the LST is negatively related to soil moisture and vegetation (Deng et al. 2018).

Similarly, high surface temperature was observed for mining infrastructure (24 ± 0.4 °C in 2017 and 13 ± 1.3 °C in 2018) and mine waste (23 ± 1.4 °C in 2017 and 13 ± 0.7 in 2018), compared to fallow (21 ± 0.3 °C in 2017 and 10 ± 0.3 °C in 2018) and built-up lands (22 ± 0.8 °C in 2017 and 11 ± 0.6 °C in 2018) at nighttime. The presence of dispersed dark color sulfides in the mining premises has high heat absorptivity, which increases the surface temperatures of mines (Harries and Ritchie 1981). Additionally, mineral extraction processes add to the temperature of mining infrastructure.

Surface Mine Water: A Potential Source of Geothermal Energy

Higher LSTs was observed at old mining sites (36 ± 1 °C in 2014 and 35 ± 1.4 °C in 2012) than new mining sites (32 ± 1.5 °C in 2014 and 30 ± 1.1 °C in 2012) during the daytime. This is attributed to the combined effect of geothermal and pyrite oxidation processes. The high temperature at the Rampura Agucha surface mine indicate its suitability as a potential source of geothermal energy. Reports suggest minimum and maximum temperature varies from 12 to 32 °C for existing geothermal energy installations (Hall et al. 2011). Coal mines of Park Hills (14 °C) and Shettleston (12 °C) at Missouri and Scotland, respectively, are successfully being used for space heating (Hall et al. 2011). Similarly, a mine at Heerlen, Netherland with a temperature of 30–35 °C or 16–19 °C is a potential source for space heating or cooling (Verhoeven et al. 2014).

Low temperature geothermal energy sources (temperatures less than 90 °C) are generally used for direct usage or water-to-water and water-to-air heat pumps (Lund 2007). This has been shown to be a reliable and inexpensive source of energy for heating/cooling purposes in various countries, including Canada, Germany, Hungary, Scotland, USA, Norway, and Poland (Hall et al. 2011). A Pittsburgh, Pennsylvania coal mine in the USA with temperatures of 10–13 °C was found suitable for such an application, with mine water extraction capacity of 2.0×10^{11} L/year (Watzlaf and Ackman 2006). Exploration of geothermal energy sources in semi-arid and temperate regions is neglected and need more investigation.

Future Scope of Research

Most studies have focused on the use of water from active or abandoned underground mines for geothermal energy (Al-Habaibeh et al. 2018; Bao et al. 2019). However, the observed high temperatures (27 ± 0.6 to 36 ± 1 °C) at Rampura Agucha indicates the possible use of surface mine water for geothermal energy. As far as we can tell, no other study has suggested the use of surface mine water for geothermal energy. The major disadvantage could be that the direct contact of surface mine water with the atmosphere that leads to heat loss. However, elevated temperatures can exist in lower layers of pit lake water due to geothermal energy and thermohaline stratification (Bao and Liu 2019; Reichart et al. 2011). This unique feature is extremely complex and hard to predict. Sustainability of the geothermal energy exploration depends on the distribution and temperature variations of the mine water (Malolepszy 2003).

Surface mines can be scanned using night time satellite imagery (TIR bands), allowing rapid recognition of potential geothermal sites. In India, the use of geothermal energy from abandoned mines is completely neglected. Thus, this study suggests the potential feasibility of using mine water for geothermal energy.

Conclusions

The present study proposes identifying the location of mines and their spatial extent using nighttime LST data. The LST of a mining site is higher than other spectrally similar classes like built-up and fallow land at nighttime. The spatial representation of LST encourages the identification of mine locations and mines heat island effect with limited ground truthing. Spatial tools including remote sensing are widely used because of their potential application at regional level. Thus, using TIR imaging capability of remote sensing aids in the rapid identification of mines at regional level. Additionally, the study confirms the resemblance of surface mines with urban heat island phenomena and their impact on the thermal regimes of mining areas at the local level.

Nowadays, identifying new potential sources of renewable energy is important from the environmental point of view. In recent years, the potential use of mine water for geothermal energy is catching the attention of the scientific community. The present study indicates that nighttime TIR may be helpful in identifying potential sites for geothermal energy.

References

Al-Habaibeh A, Athresh AP, Parker K (2018) Performance analysis of using mine water from an abandoned coal mine for heating of buildings using an open loop based single shaft GSHP system. Appl Energy 211:393–402

Artis DA, Carnahan WH (1982) Survey of emissivity variability in thermography of urban areas. Remote Sens Environ 12:313–329

Banks D, Athresh A, Al-Habaibeh A, Burnside N (2019) Water from abandoned mines as a heat source: practical experiences of open- and closed-loop strategies, United Kingdom. Sustain Water Res Manag 5:29–50

Bao T, Liu Z (2019) Thermohaline stratification modeling in mine water via double-diffusive convection for geothermal energy recovery from flooded mines. Appl Energy 237:566–580

Bao T, Meldrum J, Green C, Vitton S, Liu Z, Bird K (2019) Geothermal energy recovery from deep flooded copper mines for heating. Energy Convers Manag 183:604–616

Clauser C (2006) Geothermal energy. Landolt-Bo ̈rnstein, group VIII: advanced materials and technologies. In: Heinloth K (ed) Renewable energies, vol 3(C). Springer, Heidelberg, pp 493–604

Deng Y, Wang S, Bai X, Tian Y, Wu L, Xiao J, Chen F, Qian Q (2018) Relationship among land surface temperature and LUCC, NDVI in typical karst area. Sci Rep 8:641

Hall A, Scott JA, Shang H (2011) Geothermal energy recovery from underground mines. Renew Sustain Energy Rev 15:916–924

Harries JR, Ritchie AIM (1981) The use of temperature profiles to estimate the pyritic oxidation rate in a waste rock dump from an opencut mine. Water Air Soil Pollut 15:405–423

Hudson-Edwards K (2016) Tackling mine wastes. Science 352(6283):288–290

Li S, Chen X (2014) A new bare-soil index for rapid mapping developing areas using LANDSAT 8 data. Int Arc Photogramm Remote Sens Spat Inf Sci 40(4):139–144

Loredo C, Ordóñez A, Garcia-Ordiales E, Álvarez R, Roqueñi N, Cienfuegos P, Peña A, Burnside NM (2017) Hydrochemical characterization of a mine water geothermal energy resource in NW Spain. Sci Total Environ 576:59–69

Lund JW (2007) Characteristics, development and utilization of geothermal resources. Geo Heat Cent Q Bull 28:1–9

Malolepszy Z (2003) Low temperature, man-made geothermal reservoirs in abandoned workings of underground mines. In: Proc, 28th Workshop on Geothermal Reservoir Engineering, Stanford, California, pp 259–265

McFeeters SK (1996) The use of the normalized difference water index (NDWI) in the delineation of open water features. Int J Remote Sens 17:1425–1432

Popiel CO, Wojtkowiak J, Biernacka B (2001) Measurements of temperature distribution in ground. Exp Therm Fluid Sci 25:301–309

Rathore CS, Wright R (1993) Monitoring environmental impacts of surface coal mining. Int J Remote Sens 14(6):1021–1042

Reichart G, Vaute L, Collon-Drouaillet P, Buès MA (2011) Modelling heat and salinity related convective processes in deep mining flooded wells. In: Proc, 11th International Mine Water Assoc Congress, IMWA, Aachen, Germany, pp 183–187

Rouse JW, Haas RH, Schell JA, Deering DW (1973) Monitoring vegetation systems in the Great Plains with ERTS. Proc 3rd ERTS Symp NASA 351I:309–317

Verhoeven R, Willems E, Harcouët-Menou V, De Boever E, Hiddes L, Veld PO, Demollin E (2014) Minewater 2.0 project in Heerlen, The Netherlands: transformation of a geothermal mine water pilot project into a full scale hybrid sustainable energy infrastructure for heating and cooling. Energy Procedia 46:58–67

Watzlaf GR, Ackman TE (2006) Underground mine water for heating and cooling using geothermal heat pump systems. Mine Water Environ 25:1–15

Yang G, Pu R, Zhao C, Huang W, Wang J (2011) Estimation of subpixel land surface temperature using an endmember index based technique: a case examination on ASTER and MODIS temperature products over a heterogeneous area. Remote Sens Environ 115:1202–1219

Zha Y, Gao J, Ni S (2003) Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. Int J Remote Sens 24:583–594