A satellite-based study of coal fires and open-cast mining activity in Raniganj coalfield, West Bengal

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Satellite-based mapping of coal fire is an effective technique in terms of cost and time. At present, ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is the only available spaceborne sensor, which provides multi-channel thermal data. ASTER provides moderate-resolution thermal data useful for mapping of coal fires, which generally have small spatial dimension. In the present study, night-time thermal data of ASTER have proved useful to map the latest distribution (December 2006) of coal fires in Raniganj coalfield. The coal-fire map shows that major fires are associated with open-cast mines of the coalfield. This suggests that the mining method may have played key role in aggrandizing this environmental hazard in the coalfield. It has been also observed that most open-cast mines occurring at the NW portion of the colliery are affected by coal fire.

Keywords: ASTER, coal fire, open cast mines, thermal channels.

THERMAL sensors of spaceborne satellites play an important role in detecting thermal anomaly. In the entire electromagnetic spectrum, 3–60 μm is considered as thermal infrared, whereas 3–5 and 8–12 μm are actually used in thermal remote sensing. Thermal infrared remote sensing exploits the fact that everything above absolute zero (–273.8°C) emits radiation in the thermal infrared range of the electromagnetic spectrum. Thermal infrared radiation of an object is controlled mainly by the characteristics of the surface: emissivity, geometry of the object and its temperature[1].

Therefore, remote sensing technique in thermal band offers a cost-effective and time-saving method for mapping various geoenvironmental features like coal fires, forest fires, etc. and therefore older technologies such as *in situ* measurement of coal-fire temperature, and estimation of bore-hole temperature for detection of subsurface coal fire have been almost replaced by this advanced technology.

With the advent of thermal remote sensing, researchers addressed issues like retrieval of true spectral radiance from raw digital data using scene-specific calibration of coefficients of the detectors, measurement of thermal emissivity of surface materials to obtain kinetic temperature at each ground resolution cell of satellite data and also evaluated its influence on the accuracy in estimating coal-fire temperature[2]. Calculation of accurate land-surface emissivity is crucial for estimating accurate coal-fire temperature. It also has been proved that using a single thermal band it is impossible to get such information from the available methods, such as temperature emissivity separation (TES) algorithm[3].

In India, the Jharia coalfield, which is 250 km northwest of Kolkata, has severe problems with respect to coal fire. Therefore, most of the remote sensing-based coal-fire studies have been carried out for the Jharia coalfield[4–7]. In the recent past, work also has been carried out for the delineation of coal fires using single-band thermal channel of Landsat TM data in Raniganj coalfield[8,9].

The Raniganj coalfield is one of the important coalfields in the eastern part of India. It has been producing coal and coal-related resources from the coaliferous rocks of Raniganj and Barakar formations of Gondwana Super group. Coal fires pose a serious problem in this coalfield and cause environmental and resource degradation. The main severity associated with coal fire hazard is that it is difficult to control, once initiated. Moreover, coal fires not only occur due to different causes, it also has a long history[10]. Coal fire not only burns valuable coal, but also creates difficulties in mining by increasing the cost of production or making existing operations difficult. Noxious gases like sulphur dioxide, nitrogen oxide, carbon monoxide and carbon dioxide, which are the result of coal-burning processes, often affect the immediate surroundings of an active coal fire[11]. In the Raniganj coalfield, high-grade coal is being mined using the open-cast mining technique and coal gets easily affected by fire. Naturally occurring coal, under favourable conditions, has a tendency to burn spontaneously, and continue to burn for years unless the conditions change or are controlled by human intervention. Sunlight falling on coal seams, oxygen from air and presence of some moisture may be sufficient to ignite the coal spontaneously. In areas of active and abandoned mines, mining activities result in breaking/crushing of coal and the spreading of small fragments of coal, carbonaceous material and coal dust in the vicinity of the main coal seam. This porous coal rubble is more prone to spontaneous combustion than a thick coal seam. Though the coal dust may ignite by spontaneous combustion and the fire may so be classified as one occurring from natural causes, the problem is certainly initiated and aggravated by human influence. In this sense coal fires fall under man-made hazards. Additionally, frictional energy from mining machines and negligent acts of mine workers can also trigger coal fires. Finally, the reason for the start of the fire becomes a secondary issue. The most important fact is that once the coal seam catches fire the problem gets more difficult to tackle[1]. In the Raniganj coal field, high grade coal is

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being mined by open-cast mines in the Ramnagar, Sangramgarh, Benjimari and Jambad collieries.

The aim of the present work is to delineate the recent spatial distribution of coal fires latest by December 2006 in the Raniganj coalfield and also to understand the spatial relationship between coal fires and open-cast mines to find out whether mining practices have any role in aggrandizing fire in the coalfield.

The study area encompasses the entire portion of Raniganj coalfield (Figure 1). The study area is bounded by a quadrangle with longitude from 86°35′E to 87°25′E and latitude from 23°25′N to 23°55′N. The area falls in Survey of India toposheet no. 73 M/1, 2, 5, 6, 73 I/13, 14.

Night-time ASTER data were used for the present study. The data is procured for December 2006. Four geocoded scenes is taken to cover the entire area and scenes is collected during the first and third week of December 2006. The study area is larger than the area that can be covered in single acquisition of ASTER. Therefore, multi-date acquisition was required in the first and third week of December 2006 to collect the data for the entire area. ASTER has 14 channels out of which five are in thermal domain within the spectral range 8.125–11.65 μm. ASTER has three channels in VNIR (visible–near infrared) domain and six channels in SWIR (short wave infrared) domain. Spectral domain of VNIR channels ranges from 0.52 to 0.86 μm and that of SWIR channels lies within 1.6–2.43 μm.

ASTER Level 1B data is received in hdf format. The geocoded Level IB data is imported to software compatible file format with calibrated radiance value information. The digital scenes covering the entire study area are mosaiced with necessary geometric and radiometric corrections and the study area is extracted. Multi channel ASTER data is very useful to derive emissivity by using temperature emissivity algorithm and allows to observe the thermal anomaly within the range of entire thermal domain of ASTER. However, Band 13 (10.25–10.95 μm) is used here to delineate the coal mine fire zones as transmission of thermal wave is highest in this channel and upwelling (generated by the additive radiance of atmosphere) appear lowest in this particular thermal channel (Figure 2 *a* and *b*). Moreover, emissivity varies within the short range from 0.93 to 0.96 in this channel and therefore, this channel facilitates to assume average emissivity to calculate kinetic temperature of the land-surface features[2]. This assumption would not effect the identification of anomalous thermal pixels/coal fires from relative temperature variations of thermal pixel. Thermally emitted radiance from any surface depends on two major factors.

(1) Surface temperature, which is the expression of state of heat energy budget on the surface and also indicate the equilibrium thermodynamic state of incident and emitted thermal energy fluxes.

(2) The surface emissivity, which determines the efficiency of surface for transmitting the radiant energy[12].

Moreover, night-time data give better equilibrium state of surface heat energy budget, as it has negligible solar flux contribution. Therefore, night-time band 13 data appears suitable to derive the coal-fire map for Raniganj coalfield.

The georectified radiance data for 13th thermal channel is used in a model for calculating the radiant temperature from the radiance values using the following equation[13]:

$$T_{\text{rad}} = \frac{C_2}{\lambda \ln((\varepsilon C_1/\pi L_\lambda \lambda^5)+1)}, \tag{1}$$

where $C_1 = 2\pi hc^2 = 3.742 \times 10^{-16}$ Wm^2, $C_2 = hc/k$ = 0.0144 mK (h = Planck's constant = 6.26×10^{-34} J s; c = Speed of light = 3×10^8 m/s), ε is the emissivity, L_λ the spectral radiance in band-13 of ASTER (W/m^2/Sr), T_{rad} the radiant temperature (K).

After deriving the radiant temperature image from the radiance image, kinetic temperature image is derived by simple model created in ERDAS platform implementing the following equation.

$$T_K = T_R/\varepsilon^{1/4}, \tag{2}$$

where T_K = kinetic temperature of pixel, T_R = radiant temperature of the pixel, ε = emissivity.

Density slicing technique is used on the kinetic temperature image to differentiate the high-temperature pixels from the background. Threshold temperature used for delineating fire pixels is selected iteratively in such as fashion that all the land-use features, drainage, etc. can be

Figure 1. Location map of Raniganj coalfield.

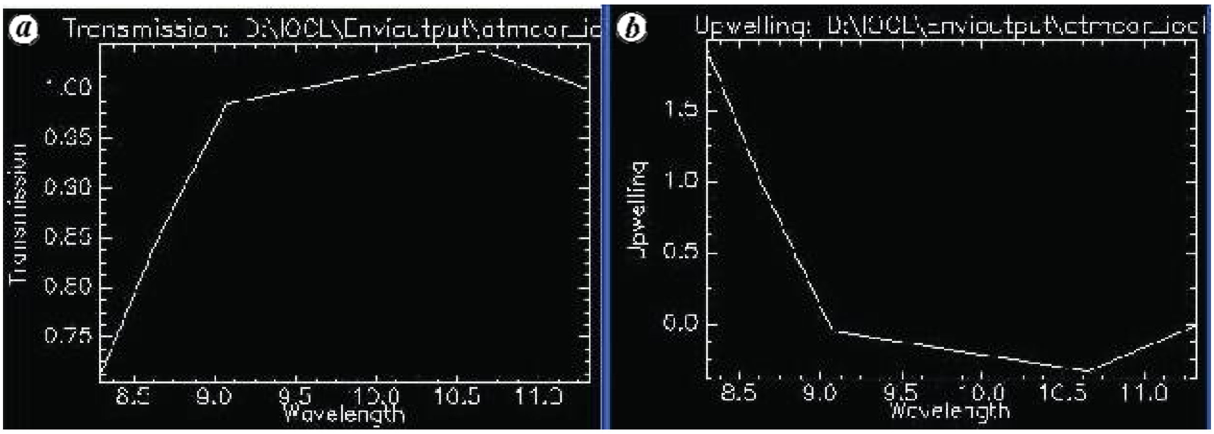

Figure 2. Transmission profile (***a***) and upwelling profile (***b***) of thermal channels in ASTER.

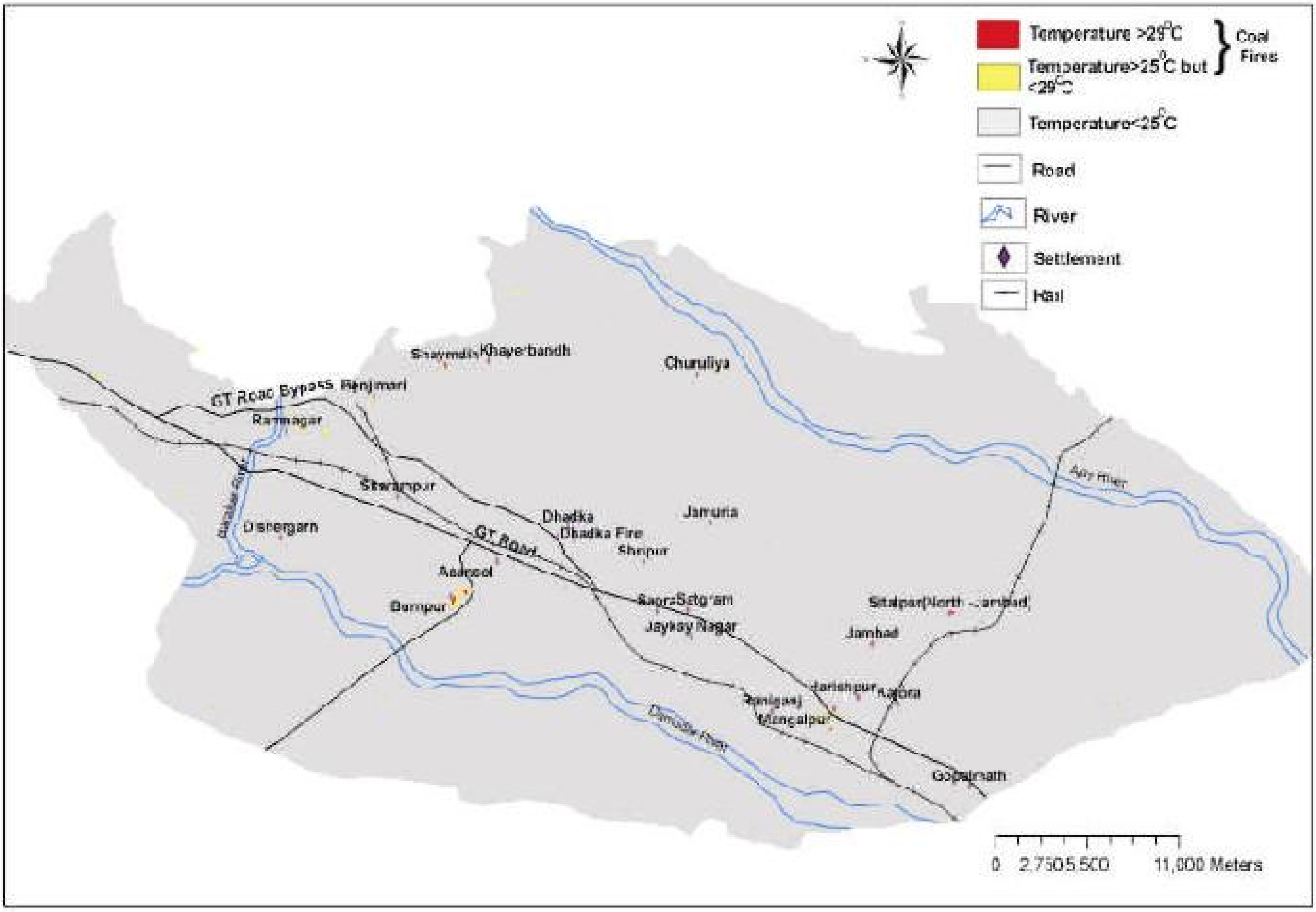

Figure 3. Coal fire map of Raniganj coalfield.

grouped as background elements. In this case, knowledge on night-time temperature of land surface features is also essential to fix the threshold temperature. In the month of December 2006, night-time temperature of the land-surface features like agricultural crops, oil, road, etc. varies in the range of 15–25°C. Therefore, the threshold temperature is fixed as 25°C to delineate fire from background.

Moreover, fieldwork is carried out to validate the result of density slicing and fieldwork also proved useful to isolate coal-fire pixels from other non coal fire high-temperature pixels. It is observed that some of the high-temperature pixels are due to the presence of chimney (steel plant in Burnpur) or presence of cluster of chimneys (brick factory) occurred within a pixel or presence of furnaces (wrought iron factory near Mangalpur; Figure 3).

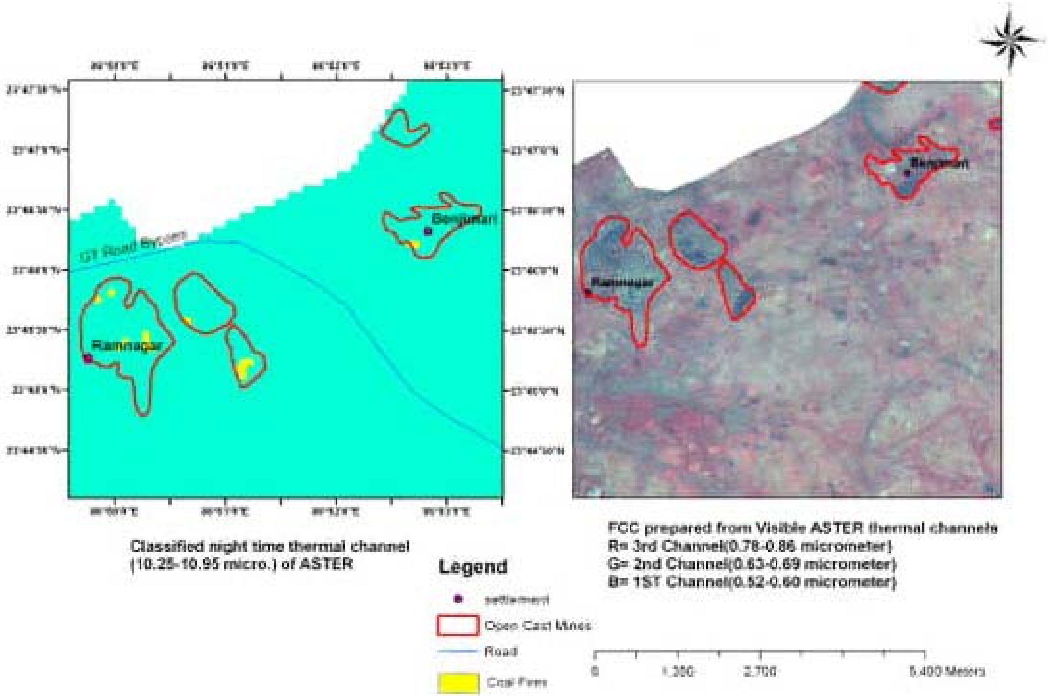

Figure 4. Coal fire in Ramnagar and Benjimari open-cast colliery.

Rest of the high-temperature pixels are attributed to coal fire. The coal fire-bearing pixels are mainly concentrated in the western and northwestern portion of the coalfield (Figure 4).

From satellite data it is not possible to obtain the temperature of each fire directly. Instead, we can measure the temperature of the pixel; which contains the fire. Otherwise, it is very difficult to measure the temperature of fire. Therefore, fire of very small dimension is often not possible to detect if the spatial extent of fire is too small in comparison to the pixel size of thermal data. Therefore coal fire, which occupies the small portion of the sampled pixel or is of low intensity, often gets subdued by the background temperature of other features within the pixel and does not appear distinct as thermally anomalous pixels. On the other hand, false colour composite of visible channels of ASTER is used to delineate the latest extent of open-cast mines in the coalfield, so that spatial relation between coal fires and open-cast mines can be established.

The conjugated study of thermal data processing and field survey reveal that there are two broad zones in Raniganj coalfield affected by coal fire. One zone is situated at the western to northwestern portion of the coalfield. This zone extends along the stretch from Ramnagar OCP (open-cast pits), Sangramgarh OCP to Banjimari OCP. The other zone is restricted along North Jambad-South Jambad OCP. Beside these, there are few isolated places where fires and smoke are noticed on the surface. One of such place is at Harishpur–Bakhtarnagar area and the other is at Dhadka. The fire at Dhadka is very small in size (roughly 4 m^2 in size) and therefore could not be detected by satellite data. It is also observed that smokes emanating out from fractures and gas seepage zones at Harishpur and Bakhtarnagar area does not produce noteworthy temperature anomaly in ground (temperature measured over smoke varies between 55°C and 65°C by infrared thermometer at surface). Therefore, pixel-integrated kinetic temperature of these fires may not be quite different than background and therefore is not detected by satellite based thermal sensor. These small fires are the result of emission of combustionable methane gas to surface.

Coal-fire map (Figure 3) of the Raniganj coalfield shows that the most of the important fire zones are located at the northwestern part of the Raniganj coalfield, where presence of several open cast mines aggrandizes the fire hazard. Figure 4 shows the Ramnagar colliery open cast, which is severely affected by coal fire. The grade of coal of this colliery is very high. Whenever high grade coal comes in contact with sunlight for a long time, it initiates fire. Once initiated, fire is very difficult to control if immediate measures are not taken. In the Ramnagar area, coals are burnt to ash and associated rock also get churned and red oxidized coating is formed on burnt residue (Figure 5). Sulphur is an important component in coal and its presence is felt during fieldwork with the smell of sulphur in fire smoke and green oxidized residue of sulphur-oxides over the burnt coal residue. During field survey, temperature measured in a place in Ramnagar OCP over burning coal-residue is greater than 336°C and the average background temperature around fire-affected area is also quite high here (around 80°C). Similarly Benjimari, Shaymdih open-cast mines are also affected by fire but the intensity of fire is less in these collieries than the fires of Ramnagar colliery. Another important open cast mines affected by coal fires is Jambad colliery. Presence of coal fire is evident by the smoke emanating from the wall of open-cast pits (Figure 6). A pie diagram (Figure 7) reflects the total surface coal-fire area in each significantly affected collieries, most of which are open cast collieries.

Therefore, it is evident from present study that major coal fires are restricted to open- cast mines in the Raniganj coalfield, where high- to moderate-grade coals are mined by open cast methods. During open cast mining, whenever high-grade coal remains in contact with sunlight for a considerable time, it gets ignited. Moreover, in areas of active open-cast mines, mining activities result in breaking/crushing of coal and spreading small fragments of coal, carbonaceous material and coal dust in the vicinity of the main coal seam. This porous coal rubble is much more prone to spontaneous combustion than a thick coal seam would be. Therefore, most of the prominent coal fires are restricted to open-cast mine areas in this coalfield.

Figure 5. Red-hot baked zone over sandstone in Ramnagar colliery.

Figure 6. Smoke coming out from coal fire in Jambad colliery.

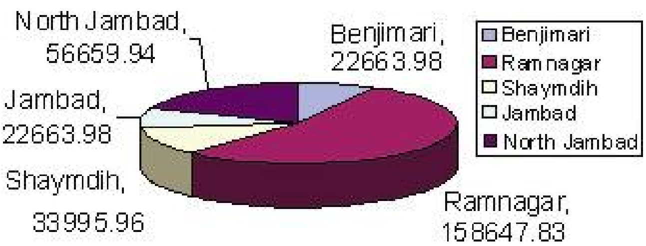

Figure 7. Pie diagram showing total active fire area in each affected coal mine (coal fire area given in square meter).

1. Gangopadhyay, P. K., Maathuis, B. and van Dijk, P., ASTER derived emissivity and coal-fire related surface temperature anomaly a case study in Wuda, North China. *Int. J. Remote Sensing*, 2005, **26**, 5555–5571.
2. Chatterjee, R. S., Coal fire mapping from satellite thermal IR data – A case example in Jharia Coalfield, Jharkhand, India ISPRS. *J. Photogramm. Remote Sensing*, 2006, **60**, 113–128.
3. Gillespie, A. R., Rokugawa, S., Hook, S., Matsunaga, T. and Kahle, A. B., A temperature and emissivity separation algorithm for advanced spaceborne thermal emission and reflection radiometer (ASTER) images. *IEEE Trans. Geosci. Remote Sensing*, 1998, **36**, 1113–1126.
4. Cracknell, A. P. and Mansor, S. B., Detection of sub-surface coal fires using Landsat Thematic Mapper data. *Int. Arch. Photogr. Rem. Sens.*, 1992, **29**, 750–753.
5. Prakash, A., Gupta, R. P. and Saraf, A. K., A landsat TM based comparative study of surface and subsurface fires in the Jharia coalfield. *India Int. J. Remote Sensing*, 1997, **18**, 2463–2469.
6. Reddy, C. S. S., Srivastav, S. K. and Bhattacharya, A., Application of thematic mapper short wavelength infrared data for the detection and monitoring of high temperature related Geoenvironmental features. *Int. J. Remote Sensing*, 1993, **14**, 3125–3132.
7. Saraf, A. K., Prakash, A., Sengupta, S. and Gupta, R. P., Landsat-TM data for estimating ground temperature and depth of subsurface coal fire in the Jharia coalfiled, India. *Int. J. Remote Sensing*, 1995, **16**, 2111–2124.
8. Gangopadhyay, P. K., Lahiri-Dutt, K. and Saha, K., Application of remote sensing to identify coal fires in the Raniganj Coal belt, India. Int. *J. Appl. Earth Obs. Geoinf.*, 2006, **8**, 188–195.
9. Martha, T. R., Bhattacharya, A. and Vinod Kumar, K., Coal-fire detection and monitoring in Raniganj coalfield, India – A remote sensing approach. *Curr. Sci.*, 2005, **88**, 21–24.
10. Zhang, J., Wagner, W., Prakash, A., Mehl, H. and Voigt, S., Detecting coal fires using remote sensing techniques. *Int. J. Remote Sensing*, 2004, **25**, 3193–3220.
11. Gangopadhyay, P. K., Coalfire detection and monitoring in Wuda, North China, A multispectral and multi-sensor approach. Ph D thesis, ITC, The Netherlands, 2003.
12. Schmugge, T., French, Ritchie, J. C., Rango, A. and Pelgrum, H., Temperature and emissivity separation from multispectral thermal infrared observation. *Remote Sensing Environ.*, 2002, **79**, 189–198.
13. Gupta, R. P., *Remote Sensing Geology*, Springer-Verlag, 2003, 2nd edn, pp. 183–216.

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