Structural Controls on Coal Fire Distributions – Remote Sensing Based Investigation in the Raniganj Coalfield, West Bengal

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Abstract: Coal fires are serious problem in Raniganj coalfield as it is the case for some of the other coalfields of India like Jharia coalfield. Earlier efforts were made to map the coal fires of this coal-field based on satellite observation. But the restricted distribution of major coal fires in the particular portion of the coalfield makes the basis for finding the geological control if responsible for coal fire distribution. In present study, night time thermal data of ASTER (Advance spaceborne thermal emission and reflection radiometer) is used to map the latest distribution (December, 2006) of coal fires in the Raniganj coalfield. Coal fire map shows that most significant zone affected by fire is at the north-western portion of the coalfield; where NE- trending open cast mines are affected by fire. This fire zone is associated with high grade coal of the Barakar Formation. Coal fires are also mapped in open cast pits of Jambad-Mangalpur area occurring over rocks of the Raniganj Formation. By integrating geological map and satellite-derived coal fire map of Raniganj coal field, it is observed that the coal fires detected by remote sensing study are spatially associated with intraformational faults. These faults may have played significant role in supplying oxygen to these coal-fires and allowing them to propagate down the depth along the trends of the faults.

Keywords: ASTER, Coal fire, Intraformational faults, thermal channels, West Bengal.

INTRODUCTION

Thermal sensors of space borne satellites are effective for their role in detecting thermal anomaly. The entire electromagnetic spectrum within the range of 3–60 mm is considered as thermal infrared, whereas 3–5 and 8–12 µm is specifically used in thermal remote sensing. Thermal-infrared remote sensing utilises the fact that everything above absolute zero (-273.8 C) emits thermal radiations. The wavelength of thermal infrared radiation of an object is controlled mainly by the characteristics of the surface: emissivity and its temperature (Gangopadhyay et al. 2005). Therefore remote sensing technique in thermal band offers a cost-effective and time-saving method for mapping various thermally anomalous geoenvironmental features like coal fires, forest fires, etc. and older technology such as in situ measurement of coal fire temperature, estimation of bore hole temperature for detection of subsurface coal fires 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 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. The calculation of accurate land surface emissivity is crucial for estimating accurate coal fire temperature. It is also proved that using a single thermal band it is not possible to get such information from the available methods such as temperature emissivity separation algorithm (TES) (Gillespie et al. 1998).

In India, the Jharia coalfield, which is 250 km northwest from Kolkata (Calcutta), has severe problems of coal fire. Therefore, most of the remote sensing based coal fire studies were carried out for the Jharia coal field (Cracknell and Mansor, 1992; Reddy et al. 1993; Saraf et al. 1995; Prakash, 1997; Chatterjee, 2006). In recent past, researches have been carried out for delineation of coal fires using single band thermal channel of Landsat TM data in the Raniganj coalfield (Martha et al. 2005; Gangopadhyay et al. 2006; Guha et al. 2008).

The Raniganj coal field is one of the important coalfields in the eastern part of India. It has the record of producing coal and coal related resources from the coaliferous rocks of Raniganj and Barakar Formations of Gondwana Supergroup. Coal fires pose serious problem in this coal field and cause environmental and resource degradation. The
main severity associated with coal fire hazard is that it is very difficult to control once it is initiated. Coal fire not only occurs due to different causes; it also has long history (Zhang et al. 2004). 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, carbon dioxides, which are the result of coal burning processes often affect the immediate surroundings of an active coal fire.

In the Raniganj coalfield, high grade coal is mined by open cast mining technique. Naturally occurring coal, under favourable conditions, has a tendency to burn spontaneously, and once the fire is caught it continues to burn for years unless the conditions change or are controlled by human activity. Sunlight falling on coal seams, oxygen and moistures ambient atmosphere are sufficient to start the coal to burn spontaneously. In areas of active and abandoned 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. The coal dust catches fire, which then spreads to the neighboring coal seam. It has also been observed the frictional energy from mining machines and negligent acts of mine workers can also trigger coal fires. The mine openings, goofs (empty spaces in underground mines where coal has been already extracted), boreholes, cracks etc. all provide additional vents and spaces to supply and circulating of oxygen, further aggravating the problem. Beyond these factors, geological elements may play important role in localizing and also in aggrandizing these environmental hazard. The aim of the present work is to evaluate the role of geological element; if any, in coal fire development by assessing their spatial proximity/association.

STUDY AREA

The study area encompasses entire portion of the Raniganj coalfield and are located at the western, northwestern fringe of Burdwan district, West Bengal. The study area is bounded by a quadrangle with latitude from 23°25' N to 23°55' N and longitude from 86°35' E to 87°25' E (Fig. 1). This area falls in Survey of India toposheet no. 73 M/1, 2, 5, 6, 73 I/13, 14.

GEOLOGY

Raniganj coalfield is occupied dominantly by rocks of Gondwana group of Early Permian to Lower Cretaceous (320 m.y. to 98 m.y.). Gondwana rocks are deposited in half graben tectonic framework and mostly fluvial-fluvio lacustrine in origin but the lowest or oldest facies of Gondwana is deposited in glacial and glacio-fluvial environment. Raniganj coal field is situated in Damodar valley basin and Gondwana rocks of this valley basin have specific character in terms of thickness of each facies, intraformational faults and microfacies variation. In the Raniganj coalfield, both the Raniganj and Barakar Formations exhibit prolific development of coal, the resources from the latter, however, being larger. At the eastern part of the coalfield, alluvial and residual soils with laterite cappings of Quaternary period blanket the older Gondwana rocks; whereas at western and southern part, Gondwana rocks are exposed. Although in the study area, rocks from Precambrian to Quaternary age are exposed but the major portion of the study area is occupied by Gondwana Group of rocks . The generalized stratigraphy of study area is given in Table 1.

DATA

Nighttime data received by Advance spaceborne thermal emission and reflection radiometer (ASTER) is used for the purpose of the present study. The study area is larger than the area can be covered in single acquisition of ASTER. Therefore multi date acquisition was required in the first and third week of the month December, 2006 to cover the entire area. Four geocoded scenes were taken to cover the entire area. The data is procured for the month of December,
2006. ASTER provides five thermal channels in the thermal region within 8.125 -11.65 µm wavelength domain. The detail of sensor is given in Table 2.

### METHODOLOGY AND RESULTS

Satellite sensor can measure the radiances emitted from surface element and temperature can be computed from the radiance received by the sensor. Temperature thus computed is very useful in delineating coal fires and other high temperature features. Once the high temperature pixels are delineated, limited ground truth survey would be sufficient in separating coal fires from other high temperature elements. Therefore, coal fire map can be produced from the satellite data. This map would highlight the spatial distribution of fires. Moreover, ASTER channels working in visible domain are useful in mapping the active and abandoned open cast mining activity. Abandoned mines are occupied by water in many places and circular to oval in shape and very easily can be detected in satellite image. Multichannel thermal data of ASTER (Advance Spaceborne Thermal Emission Radiometer) of EO-1 satellite is used to delineate the coal fires in Raniganj coalfield (Guha et al. 2009). Published geological map (Fig.2) prepared by GSI is brought into the common spatial reference with that of coal fire map with a aim to find out geological control, if any, responsible for the occurrences of coal fires. Field work along selected

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<tr>
<th>Eonothem Eon</th>
<th>Erathem</th>
<th>System/Period</th>
<th>Formation</th>
<th>Description</th>
<th>Maximum thickness (m)</th>
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<tbody>
<tr>
<td>Phanerozoic</td>
<td>Cenozoic</td>
<td>Quaternary</td>
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<td>Alluvial and residual soils</td>
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<tr>
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<td>Tertiary Sediments</td>
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<tr>
<td>Mesozoic</td>
<td>Cretaceous</td>
<td>Igneous Intrusive</td>
<td>Basic (dolerite dyke), Ultra basic (mica peridotite sills, mica-lamprophyre sills)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Rajmahal Formation</td>
<td>Fine to medium grained vesicular porphyry basalt and volcanic breccias</td>
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<td></td>
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<td></td>
<td></td>
<td>Late Triassic Supra Panchet</td>
<td>Red and grey sandstones and shales</td>
<td>300</td>
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<tr>
<td></td>
<td></td>
<td>Early Triassic Panchet Formation</td>
<td>Micaceous yellow and grey sandstones with slump structures, red and greenish shales</td>
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<td></td>
</tr>
<tr>
<td>Paleozoic</td>
<td>Upper Permian Raniganj Formation</td>
<td>Grey and Greenish soft micaceous feldspathic sandstones, shales and coal seams</td>
<td>1150</td>
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<td></td>
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<tr>
<td></td>
<td>Middle Permian Ironstone Shales (Barren shales)</td>
<td>Dark carbonaceous shales with ironstone bands</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Lower Permian Barakar with Karharbari (?) Formation at base</td>
<td>Coarse and medium grey and white arkosic sandstones, (often cross bedded)</td>
<td>750</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper Carboniferous to Lower Permian Talchir Formation</td>
<td>Tillite, coarse sandstones and greenish shales, rhythmite with drop stone</td>
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<table>
<thead>
<tr>
<th>Spectral Region</th>
<th>Band No.</th>
<th>Spectral Range (µm)</th>
<th>Spatial Resolution (m)</th>
<th>Quantization Levels</th>
</tr>
</thead>
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<tr>
<td></td>
<td>2</td>
<td>0.63-0.69</td>
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<td></td>
<td>3N</td>
<td>0.78-0.86</td>
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</tr>
<tr>
<td>SWIR</td>
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<td>8 bits</td>
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<td></td>
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<td>2.145-2.185</td>
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<td>6</td>
<td>2.185-2.225</td>
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<td>7</td>
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<td>8</td>
<td>2.295-2.365</td>
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<td>9</td>
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<tr>
<td>TIR</td>
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<td>90</td>
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<td></td>
<td>13</td>
<td>10.25-10.95</td>
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<td></td>
<td>14</td>
<td>10.95-11.65</td>
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</table>
traverse also was carried out to validate results obtained from the satellite based study.

ASTER Level 1B data (in hdf format) is used for the purpose of the present study. The geocoded Level 1B data is imported to software compatible file format with radiance value information. The digital scenes covering the entire study area is mosaiced with necessary corrections and the study area is extracted. ASTER has five thermal channels and each channel has potential to detect coal fires. However, Band 13 (10.25-10.95 µm) is considered here to delineate the coal mine fire zones as transmission of thermal wave is highest in this channel. Moreover, emissivity varies within the short range from 0.93 to 0.96 in this channel and therefore this channel facilitates in assuming average emissivity to calculate kinetic temperature of the land surface features (Gangopadhyay, 2003). Therefore in this study, emissivity is assumed as a constant value (0.96) to calculate the surface kinetic temperature from the radiant temperature. 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 (Schmugge et al. 2002).

Night time data give better equilibrium state of surface heat energy budget as it has negligible solar flux contribution. Therefore night time georectified radiance data for 13th thermal channel is used in a model for calculating the radiant temperature from the radiance values using following equation:

\[ T_{rad} = \frac{C_2}{\lambda \ln((\epsilon \lambda L_{\lambda}) / (\pi L_{\lambda} \epsilon^2)) + 1} \]

Where
- \(C_1 = \frac{2\pi hc^2}{\lambda} = 3.742 \times 10^{-16} \text{ Wm}^2\)
- \(C_2 = \frac{hc}{k} = 0.0144 \text{ mK} \) (\(h = \text{Planck’s constant = } 6.26 \times 10^{-34} \text{ J s; } c = \text{Speed of light = } 3 \times 10^8 \text{ m/s})
- \(\epsilon = \text{Emissivity}\)
- \(L_{\lambda} = \text{Spectral radiance in band-13 of ASTER (W/m}^2\text{/Sr})\)
- \(T_{rad} = \text{Radiant Temperature (K)}\)

Fig. 2. Geological Map (GSI, 2003) of the Raniganj Coalfield (Updated by Satellite interpretation)
After deriving the radiant temperature image from the radiance image, kinetic temperature image is derived by simple model created in ERDAS platform implementing equation 2.

\[ T_K = T_R \cdot \epsilon^{1/4} \]  

(2)

Where \( T_K \) = Kinetic temperature of pixel; \( T_R \) = Radiant temperature of the pixel and \( \epsilon \) = 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 interactively in such a fashion that all the land use features, drainage etc. can be grouped as background elements. In this case, knowledge on the night time temperatures 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°C- 25°C. Therefore the threshold temperature is fixed as 25°C to delineate fire from background.

Fieldwork is carried out to validate the result of density slicing and also proved useful to isolate coal fire pixels from other high temperature pixels. It is observed that some of the high temperature pixels are due to the presence of chimney of steel plant (in Burnpur) or presence of cluster of chimneys of brick factory occurred within a pixel or presence of furnaces of wrought iron factory (near Mangalpur) (Fig.3). Rest of the high temperature pixels are attributed to coal fire. The coal fire bearing pixels are mainly concentrated in the western and north western portion of the coalfield (Fig.4).

From satellite data it is not possible to get the temperature of each fire directly; instead of which we can measure the temperature of the pixel; which contains the fire. 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 it is of low in intensity often gets subdued by the background temperature of other features within the pixel and does not appear distinct as thermally anomalous pixels. Only large and high temperature bearing coal fires can be detected from thermosatellite data. On the other hand false color composite of visible channels of ASTER is used to delineate the latest extent of open cast mines in the coal field so that the spatial relation between coal fires and open cast mines can be established. The relation between open cast mining activity and the coal fires are well understood and it has been proved that the open cast mining activity is one of the

![Fig.3. Coal fire Map of Raniganj Coalfield. Coal-fire areas are highlighted with ellipse (Guha et al. 2008).](image-url)
causative factor in digging out coal fires or spreading them (Guha et al. 2008).

The thermal data processing and field survey revealed that there are two broad zones in Raniganj coalfield affected by coal fire. Main fire affected zone is situated at the western to north-western portion of the coal field and restricted to Barakar Formation. This zone is extended along the stretch from Ramnagar OCP (open cast pits)- Sangramgarh OCP- Banjimari OCP. The other zone is restricted along North Jambad-South Jambad–Harishpur–Mangalpur OCP.

Coal fire map (Fig.3) of the Raniganj coalfield shows the overall distribution of the coal fire and it is observed that the most of the important fire zones are located at the north-western part of the basin; where presence of several open cast mines aggrandizes the fire hazard. In Fig.4, the most devastating coal fire area is shown. Here open cast pits of Ramnagar colliery is fire affected. Similarly Benjimari open cast mines, (Fig.4) are also affected by fire but the intensity of fire is less in these collieries as observed during ground truth survey. In the Ramnagar area; coals are burnt to ash and associated rock also got churned and sulphur rich coating is formed on burnt residue (Fig.5). Sulphur is an important component in coal and its presence is felt 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). It is found that the intraformational faults present within Barakar Formation are spatially very close to the fire spots of the open cast pits (Fig.6). This observation appears ubiquitous and therefore these faults may be responsible in supplying oxygen down the depth and thereby allowing fire to propagate down depth;

Fig.4. Coal fires in Ramnagar and Benjimari opencast collieries.

Fig.5. Red–hot baked zone over sandstone in Ramnagar colliery
Fig. 6. Spatial relation between fault and coal fire in Ramnagar-Benjimari-Shymdih coal fire zone.

Fig. 7. Coal fires and open cast mining areas in Jambad Collieries; Raniganj coalfield.
where it keeps on burning coal seam under the higher temperature environment of depth and coal fire sustains life for long time. Coal fires are also seen within the open cast pits of Jambad colliery and fire are also present at north Jambad colliery (Fig. 7). Presence of coal fire is also evident by the smoke emanating from the wall of open cast pits (Fig. 8) of Jambad colliery. It is found coal fires are also present in all the collieries occur within Raniganj Formation, especially in Ramnagar Harishpur-Mangalpur-Jambad-Sitalpur colliery area and all the fire spots are especially very close to the intraformational faults occurring within Raniganj Formation (Fig. 9).

CONCLUSIONS

The main interesting observation made from this study is that, most of coal fires were spatially close to the intraformational faults. These faults might have played crucial role in allowing high temperature bearing underground coal to get in contact with ambient oxygen through fractured zones created along the trend of the fault and thereby providing constant supply of oxygen required for igniting the coal in shallow subsurface temperature and thereby allow fire to spread down the depth along the trend of the fault. But the true mechanism on how these fault controls the coal fires is yet to be explored. The future work in this regard should focus on understanding the mechanism on how brittle structures coal fire and its distribution dynamics.

Acknowledgements: Authors express their deep sense gratitude to Dr. V.K. Dadhwal, Director, NRSC for his...
support and encouragement during the course of work and approval of fund for colour reproduction of photographs. Authors are also grateful to G. Behera; Deputy Director, RS & GIS AA for his constant encouragement for carrying out in depth research on geoenvironmental aspect. Authors are also thankful to Dr. P.S. Roy, Director, IIRS and Ex-Deputy Director, RS & GIS Application Area for providing the necessary training and technical guidance required for this work during the initial stage of the project. Authors are also grateful to Dr. Y.V.N. Krishnamurthy, Deputy Director, RSA for his support and recommendation for fund for colour reproduction of figures.

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(Received: 7 February 2011; Revised form accepted: 16 August 2011)