DETECTION OF SUB-SURFACE COAL FIRES USING LANDSAT THEMATIC MAPPER DATA

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ABSTRACT:

The potential utility of Landsat-5 Thematic Mapper (TM) thermal infrared (band 6) and short wavelength infrared (bands 5 and 7) data for detecting and mapping sub-surface coal fires is analysed. The short wavelength infrared sensors have been used to locate the position of the fire front. The thermal band has been useful in distinguishing gross thermal anomalies from the background of solar warming. The resultant surface temperature anomalies are compared to surface temperatures derived from infrared thermal aerial survey and ground measurements. Correlation of these data indicate that the relatively high resolution of the TM data enabled the detection, mapping and quantifying of sub-surface coal fires zones.

KEY WORDS: Thermal, IR, Landsat, Mapping, Image Interpretation.

1. INTRODUCTION

The application of thermal infrared imagery in detecting sub-surface coal fires makes use of the fact that heat produced from the burning coal does not necessarily escape directly from the surface, but the ground above the fire will be heated by conduction and this will be indicated in the data by a thermal anomaly. There are many problems associated with coal mining, one of which is self combustion. Incipient heating, both in the mines and in storage, at times gives rise to fires; these can be detrimental to the production and overall quality of coal and can constitute a major hazard to miners causing injuries or fatalities due to burns or poisoning by noxious gases. It is therefore important that zones of self combustion be detected at the earliest possible moment and, thereafter, continously monitored until such time as suitable remedial action has been successfully effected.

The conventional methods for locating underground coal fires are thermometric electroprospecting and geochemical methods. These method are however somewhat conjectural, particularly if the data points are sparse. The infrared linescanner provides a very attractive alternative. It is capable of supplying a continuous record of very small temperature changes without having to come too close to the source itself.

The ability of channel 3 (3.55 -3.93 μm) of the Advanced Very High Resolution Radiometer (AVHRR) to detect sub-resolution high temperature sources, or 'hot spots', has been well documented in studies of gas flares, forest and range fires and steel production plants (Matson and Dozier 1981, Muirhead and Cracknell 1984, Matson et al. 1987). Rothery et al. (1988) have recently drawn attention to the potential use of short wavelength infrared (SWIR) sensors for the discovery and monitoring of the thermal events at volcano sites. However, little effort has been made to detect sub-surface high temperature sources such as coal fires. Slavecki (1964), and recently Mukherjee et al. (1991) and Bhattacharya et al. (1991) have successfully used airborne thermal infrared data to detect sub-surface coal fires. Since the airborne thermal infrared (TIR) sensors has proved to be very successful in detecting the sub-surface coal fires, it is tempting to extend the work to data from space-borne SWIR and TIR imagers which would be cheaper and more regular.

In this study, SWIR and TIR images from the Landsat-5 Thematic Mapper (TM) and NOAA-9 AVHRR instruments are used to detect, quantify and map land surface temperature (LST) affected by sub-surface coal fires.

2. METHODOLOGY

2.1 Study Area and Data

The study area extends from 86° 24'E to 86° 27'E longitude and from 23° 41'30"N to 23° 45'30"N latitude. The Jharia coal coalfield is comprised of Permian coal bearing rocks. There are outcrops of coal bearing suites of 0.6 to 14 m thick, which have a low dipping angle (10°). On this deposit which has been mined for about 100 years, a number of fires including those coming out on the surface have been very well known. The effectiveness with which these fires can be extinguished or controlled largely depends on the detection and accurate location of the fire fronts, or areas of intense burning.

2.2 Data Processing and Interpretation

The data used in this study are from the TM on the Landsat-5 (bands 5, 6 and 7) and the AVHRR (channels 3, 4 and 5) on the NOAA-9 satellites. For temperature ranging

from -50°C to 100°C, TM band 6 has been used successfully by many researchers (Lathrop and Lillesand 1987, Schott and Volchok 1985) to study high temperature related geo-environmental features. According to Planck's formula, the shorter wavelength TM sensors, bands 5 and 7, are capable of measuring pixel-integrated temperatures in the range of approximately 160-420°C (Rothery et al. 1988). With its comparatively small nominal field of view of 30 m by 30 m for these two bands, the TM should in principle easily be capable of detecting and monitoring phenomena with high temperature sources such as coal fires. Several sets of night time AVHRR data and one set of TM day time data covering the Jharia coalfield have been analysed.

These satellite images were geometrically distorted and have been rectified. Clouds over the study area have been detected and masked. Ground-based geothermic survey and aerial photographs have been made available by the Institute of Remote Sensing, St Petersburg, for verification.

Mining areas without much vegetation cover were distinguished from surrounding lands using band ratio technique. After this initial segmentation, density slicing was applied to TM bands 5, 6 and 7. Excellent thermal contrast/gross anomaly was obtained from band 6. These anomalous thermal zones were found to be well correlated with the known fires. As for bands 5 and 7, there are a few very high intensities falling in the suspected thermal zones. However, careful interpretation has to be done. This is due to the fact that thermal radiance at shorter wavelength is combined (in daytime data) with solar radiance which has been reflected by the surface and scattered by the atmosphere. For a meaningful analysis, absolute temperature have to be obtained.

2.3 Determination of Brightness Temperature

The Thematic Mapper product (P-tape) data have been radiometrically corrected so that there is a linear relation between radiance and the corresponding DN. Digital numbers from satellite data were first converted to radiance values using the calibration coefficients given by Markham and Baker (1986). Using Planck's equation, the derived radiance values from bands 5 and 7 were then converted to brightness temperatures. As for band 6, the procedures suggested by Markham and Baker (1986) and Wukelic et al.(1989) were followed. The digital numbers for the AVHRR bands 3, 4 and 5 were converted to brightness temperatures using procedures suggested by Singh (1984).

2.4 Atmospheric corrections

To obtain the LSTs from satellite data with reliability one has to apply corrections to the brightness temperatures for the emissivity of the land surface and for the atmospheric effects. The emissivity of the land surface depends on the wavelength, on the view angle and on the surface type. It is unknown and generally different from unity. Removal of the atmospheric effects from the AVHRR and TM data has been the most difficult problem. Therefore, the absolute accuracy of the satellite data depends on accuracy of the emissivity used as well as on the accuracy of the atmospheric correction algorithm. Because of these difficulties, in this work we used an a priori value for the emissivity of the land surface. Since the temperature anomaly was found not sufficiently strong to demonstrate the occurrence of fires, atmospheric corrections were applied to the brightness temperatures to attempt to isolate the anomaly from solar warming. We have used the procedure suggested by Wukelic et al.(1989) to correct the radiances leaving the surfaces. Model atmospheres supplied by the LOWTRAN 7 (Kneizys et al. 1988) were used to estimate the transmittance and the path radiance but no improvement in the strength of the anomaly was actually obtained.

3. RESULTS AND DISCUSSION

3.1 Landsat-5 TM Data

Figure 1(a) shows the Landsat-5 Thematic Mapper scene recorded on 6 December 1987. It covers the Jharia coalfield. The grey scale ranges from 42°C (bright) to 27°C (dark). As seen on this thermal image, two elongated strips of intensive burning are clearly visible. The first one (western) extend from Jharia Town through the Lodna-Bararee-Bulanbararee collieries. The second one (eastern) is somewhat less intensive and extends from North Tisra through the South Tisra-Jeenagora-Jayrampur collieries. Figure 1(b) shows an extract of thermal anomalies which can be group as follows :
(i) areas of most intensive burning,
(ii) areas of high heat flow from coal seams in fires.

Thermal profiles of digitally recorded temperature data along ground profiles were studied across a known geological section in order to correlate them with anomalous temperatures associated with the fires. One typical temperature profile, along with the fire affected coal seam, is shown in Figure 2. The temperature profiles depict distinct anomalous zones with respect to the background temperature. The fluctuations along the profiles seem to be due to the variations in temperature associated with the inhomogeneity of the top soil and the sandstone. There were also contributions from fires which comes through cracks and fractures. To infer the position of fire fronts, the relatively high intensity values depicted by band 5 and 7 were superimposed onto the density sliced band 6. The thermal profiles recorded by band 7 and band 5 were studied carefully together with the profiles recorded by
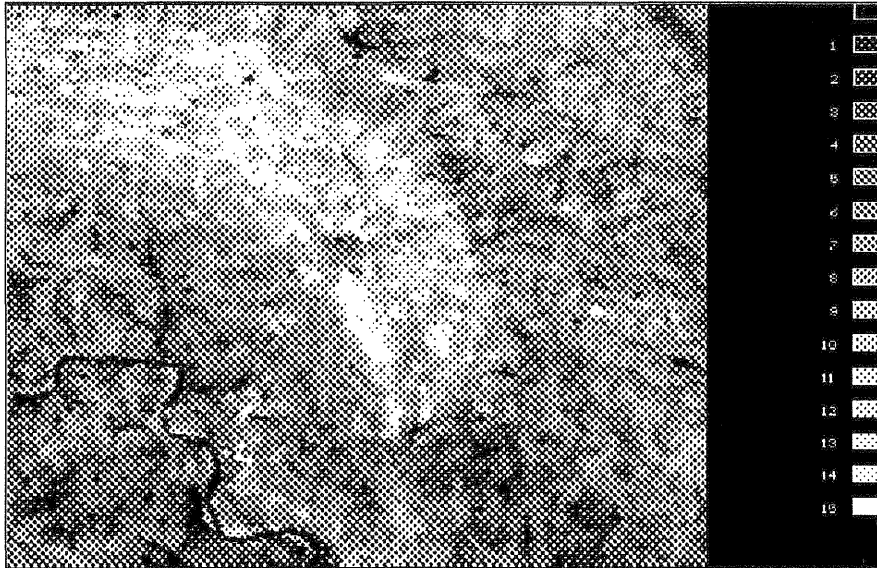
Fig. 1(a) : Thermal anomalies depicted by band 6.
          The grey scale ranges from 42°C (bright)
          to 27°C (dark)

Damodar
River

0   2km

■   Areas of intensive burning

▨   Areas of high heat flow
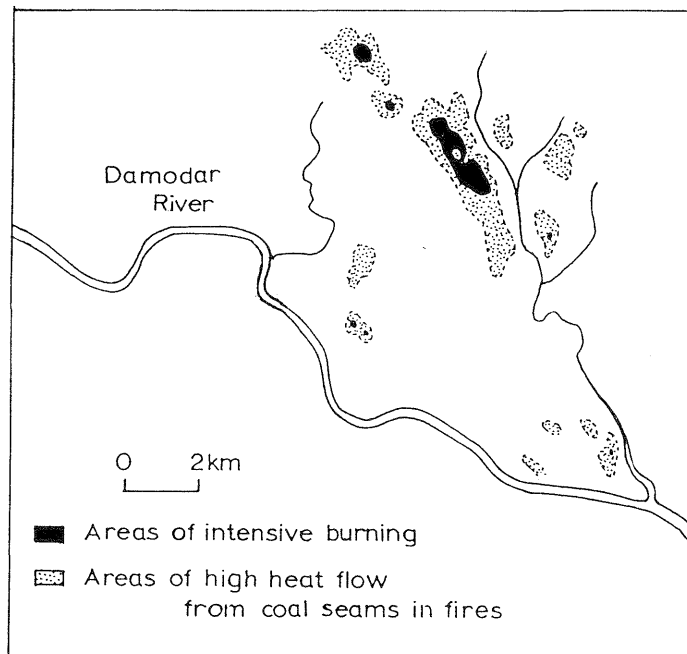   from coal seams in fires

Fig. 1(b) : Thermal anomalies extracted
           from TM data

band 6. It was found that a very high temperature anomaly with respect to the background was shown by both profiles of band 5 and 7. Similar results or patterns were observed at other locations and profiles. After checking with the thermal zones depicted by band 6, these suspected positions of fire fronts were found to be well correlated.

By comparison with the ground thermometric data (B.V. Shilin and V.I. Gornyi, personal communication), there are several other locations of fire fronts that were not depicted by the SWIR data. It appears that the capability of SWIR to locate the position of fire fronts is very preliminary. Thus, it may be concluded that for locating the fire fronts a ground thermometric survey is still needed.
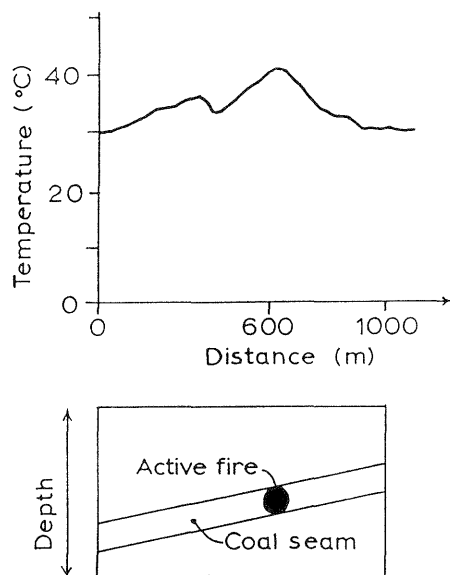
Fig. 2 : Example of thermal profile
over burning coal seam

3.2 NOAA-9 AVHRR Data

The analysis of several sets of AHVRR images did not reveal any significantly high temperature gradient in the distribution and extent of surface temperature. The results reveal the drawbacks of the low spatial resolution of the data.

4.0 CONCLUSIONS

The relatively high resolution of the TM data enabled the detection of sub-surface high temperature sources at the Jharia coal fields. It proved to be an effective tool providing information on the location and intensity of thermal anomalies caused by fires in coal mines. This information can be taken as a basis for planning the detailed ground geothermal operation. By using radiant energy in the short wavelength infrared, we are able to infer the location of fire fronts. Coarse resolution band 6 in the thermal region can be used to delineate zones affected by the underground coal fires. However, the thermal infrared bands of the NOAA satellite data did not reveal significant high temperature sources.

5. REFERENCES

Bhattacharya, A., Reddy, S., and Mukerjee, T.K., 1991. Multitier remote sensing data analysis for coal fire mapping in Jharia coalfield of Bihar, India. 12th Asian Conference on Remote Sensing, Singapore, Oct 30-Nov 5, pp. P221-P226.

Kneizys, F.X., Shettle, E.P., Abreu, L.W., et al., 1988. Users guide to LOWTRAN 7, Optical/Infrared Technology Division, U.S. Air Force Geophysics Laboratory, Hanscom Air Force Base, Massachusetts, Technical Report AFGL-TR-88-0177.

Lathrop, R.G. and Lillesand, T.M., 1987. Calibration of TM thermal data for water surface temperature mapping : Case study on the Great Lakes. Remote Sens. Environ. 22:297-307.

Markham,B.L. and Barker,J.L., 1986. Landsat MSS and TM post-calibration dynamic ranges exoatmospheric reflectance and at-satellite temperatures. EOSAT Landsat Tech. Notes (Aug), pp 3-8.

Matson, M., and Dozier, J., 1981. Identification of subresolution high temperature sources using a thermal IR sensor. Photogramm.Eng.Remote Sens. 47:1311-1318.

Matson, M., Stephens, G., and Robinson, J.M., 1987. Fire detection using satellite data. Int.J. Remote Sens. 8:961-967.

Muirhead, K., and Cracknell, A.P., 1984. Identification of gas flares in the North Sea using satellite data, Int.J. Remote Sens. 5:199-212.

Mukherjee, T.K., Bandyopadhyay, T.K., and Pande, S.K., 1991. Detection and delineation of depth of subsurface coal mine fires based on an airborne multispectral scanner survey in a part of the Jharia Coalfield, India. Photogramm.Eng.Remote Sens. 57:1203-1207.

Rothery, D.A., Francis, P.W., and Wood, C.A. ,1988. Volcano monitoring using short wavelength infrared data from satellites. J.Geophys.Res.93:7993-8008.

Schott, J.R. and Volchok, W.J., 1985. Thematic mapper thermal infrared calibration. Photogramm. Eng.Remote Sens. 51:1351-1357.

Singh, S.M., 1984. Removal of atmospheric effects on a pixel by pixel basis from instruments on satellite AVHRR. Int.J. Remote Sens. 5:161-183.

Slavecki, R.J., 1974. Detection and location of subsurface coal fires,Proceedings of the third Symposium on Remote Sensing of Environment, Institute of Science and Technology, University of Michigan, Ann Arbor, Michigan, pp. 537-547.

Wukelic, G.E., Gibbons, D.E., Martucci, L.M. and Foote, H.P., 1989. Radiometric calibration of Landsat TM thermal band. Remote Sens. Environ.28:339-347.