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# Study of coal fire dynamics of Jharia coalfield using satellite data

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## ABSTRACT

Jharia coalfield (JCF) is a treasure trove of the best quality prime coking coal of the country. In the present paper, study reveals the coal fire propagation of JCF during the period from 1990 to 2006 with the help of Landsat-5 TM and Landsat-7 ETM+ band 6 data. The Landsat-5 TM satellite thermal dataset acquired in the year 1990, 1994, 1996 and Landsat-7 ETM+ in 2006 were used to find out the lateral propagation. On the other side coal fire affected area has decreased during the said period confirmed by the field study.

**Keywords:** Landsat-5 and Landsat-7 ETM+ data; Fire dynamics; Thermal imagine camera; Jharia Coalfield (JCF);

## 1. Introduction

Coal fire exists in many coal bearing countries like USA, South Africa, Venezuela, China and India. India has the largest prime coking coal resource in the world; however these are endangered by the coal fires. It has been estimated that nearly 50 millions tones of good quality cooking coal has been lost and about 200 million tones are locked due to fire (CMPDI-NRSA report 1999). Regular monitoring of this fire will generate the idea for prevention of coal fire propagation. Many researchers have used remote sensing data to identify coal fire and its propagation (Prakash and Gupta 1999). Voigt et. al. (2004) described an integrated satellite remote sensing approach for detection and monitoring of near surface coal seam fires by observing subtle land surface changes induced by the fires. In Jharia coalfields, Prakash et al. (1997) used the Landsat-5 Thematic Mapper (TM) band 6 night-time data to identify surface and subsurface fires. Based on a dual band approach for TM data, Prakash and Gupta (1999) evolved a method for calculating the area of surface fires. Prakash and Vekerdy (2004) designed an unique processing and analysis tool to detect, map and monitor coal mine fire in time. These tools also help to generate maps showing fire depth, fire risk and priority for fire fighting. The propagation and location of surface coal fire of JCF was assessed on field based modeling of pixel integrated temperature for differentiating surface and subsurface fire pixel in Landsat TM thermal IR 1996, 1992 data (Chateerjee, 2006). On the basis of a fire dynamics study of JCF the spatial coverage of surface and subsurface coal fires was found to change from 0.42 and 2.06 km$^2$ in 1992 to 0.33 and 1.36 km$^2$ in 1996 and 0.08 and 1.60 km$^2$ in 2001 respectively (Chatterjee et. al., 2007). Mishra et al., 2011, found a correlation between satellite image temperature and surface temperature of the JCF. The temperatures obtained with satellite image gave a scaled temperature variation as compared to the results obtained by thermal image camera indicating the surface and subsurface fire. The derived correlation equation is capable to find out the temperature of unapproachable fire places. Remote sensing technique used to Landsat 5 TM band 1 data to detect the air pollution of JCF. Which is mostly due to mine fire. Gautam (2008) used

National Oceanic and Atmospheric Administration (NOAA)/ Advance Very High Resolution Radiometer (AVHRR) data to detect the surface hot spot of JCF region by developing an algorithm to find out the subsurface hot spot with operational satellite data Mishra et. al., 2012, estimates the air pollution and establishes a relation between satellite data and ground data. It also show that the eastern part of JCF are more affected due to coal mine fire in comparison to western part, so the above study indicates that eastern part is more pullulated in comparison to western part. Thermography technique are effective for periodical & effective monitoring system for fire dynamics. This technique was used to detect the direction and intensity of fire area using thermal images from thermal camera (Pandey et al., 2011). This paper focused on detection and dynamics of coal fire using various space-borne remote sensing data and its validation has been done through field investigation using hand held GPS and thermal imaging camera. Various factors are responsible for initiation of fire and its propagation, some of them are three dimensional disposition of the affected coal seam , presence of neighboring coal seam, coal debris accumulation and coal bearing overburden dumps, density and orientation of fractures, their depth consistency and occurrence of opencast mines. It appears more feasible to obtain the direction of lateral propagation than the vertical propagation with the help of satellite thermal data.

## 2. Study area

Jharia coalfield (JCF) was selected as the investigation site for the study of coal fire dynamics. It is situated near Dhanbad town lying at 260 km in North-West of Kolkata and at 1150 km in South-East of Delhi. This region is situated between latitude 23° 35' N to 23° 55' N and longitude 86° 05' E to 86° 30' E. The coal field is spread over an area of 450 $km^2$ approximately. The location plan and satellite imagery of Jharia coal field is shown in figure 1.

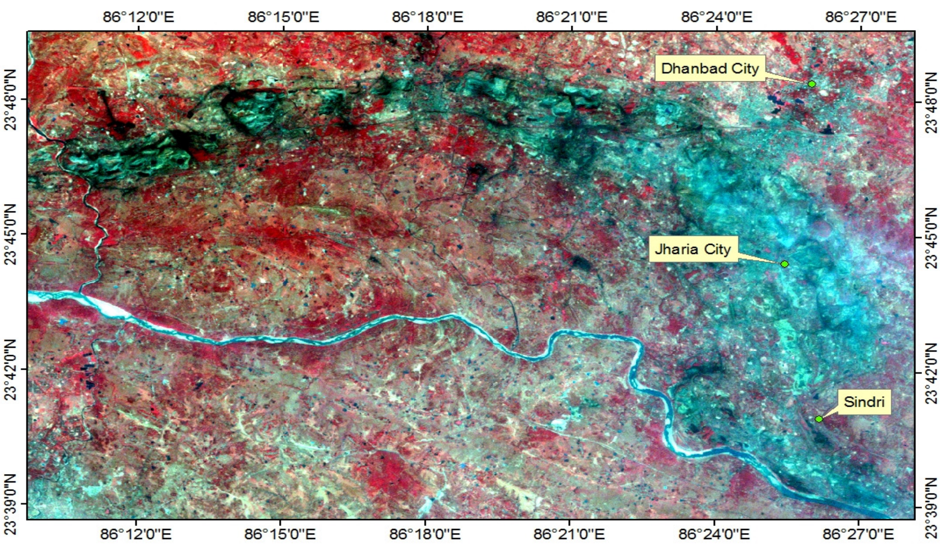



**Figure 1:** Satellite imagery (Landsat-5) of the Jharia coalfield (reproduced from Mishra et al., 2012)

## 3. Data used

Multi-spectral Landsat-5 TM and Landsat-7 ETM+ thermal data have been used for the study. Theses data are used for identification of the surface /sub-surface coal fires and for the calculation of the fire affected area. Field data was collected in the form of thermal image with the help of GPS, thermal imagine camera. Daytime thermal band 6 data of Landsat-5 of year 1990, 1994, 1996 and Landsat-7 ETM+ of year 2006 are used. During the field survey in the year 2009, hot spot locations through GPS and their temperatures were obtained. Thermal profile of the fire affected area was observed using thermal imagine camera. Validation is required for proper assessment of image data. The GPS points were used as ground control points to optimize the result of image geometric correction and registration and some of them helped to locate the position of coal fire area. Surface temperature of the coal fire affected area was obtained by IR image of the thermal scanning camera. Thermo-graphic measurement was conducted in various fire affected areas of JCF using Infrared Imaging Camera (Model ThermaCAM – P 65) having temperature range between -20 °C to +2000°C. The temperature sensitivity of this camera is ± 2°C. The camera acquires visual as well as thermal IR image and displays it on 4” colour monitor. The coal mine fire map reveals that the coal fire is distributed mostly in the eastern part of the JCF (Figure 2-5). Some thermal images and its corresponding visual images of the field are shown in Figure 6 & Figure 7. The comparative study of the thermal camera IR -images temperature and satellite image observed temperature was done.

## 4. Methodology

The thermal infrared images are used to detect coal fire affected high temperature zone. The approach adopted for this study consist three steps. (i) Identification of thermal anomalies covered (hot points) areas with remote sensing data, (ii) Validation of thermal anomalies by GPS and thermal IR camera, and (iii) The dynamics of coal fire in two dimensions. The surface temperature was obtained from the remote sensing data. The spectral radiance of the Landsat-5 TM band6 & Landsat-7 ETM+ band6 for each pixel of theses data set was calculated using the equation (1) (Markham and Barker, 1986)

$$L_{\lambda} = \frac{L\max(\lambda) - L\min((\lambda)}{(Q_{cal}\max)} \times (Q_{cal}) + L\min(\lambda) \tag{1}$$

Where, $L_{\lambda}$= spectral radiance, $Q_{cal}\max$ = Maximum grey level i.e 255; $Q_{cal}$ = Digital Number or Grey level of analyzed pixel, $L\min(\lambda)$ = Minimum detected spectral radiance

$L\max(\lambda)$ = Maximum detected spectral radiance.

The radiant temperature of the pixel calculated using the equation (2) (Gupta, 2005):

$$T_R = \frac{K_2}{\ln\left(\frac{K_1}{L_{\lambda}} + 1\right)} \tag{2}$$

Where, $T_R$ = Radiant temperature in Kelvin,

$L_{\lambda}$ = Spectral radiance in watts/ $m^2$.sr.µm,

$K_1$ & $K_2$ = Calibration constant for satellite sensor.

The radiant temperature changed into the kinetic temperature of the said pixel using following equation (3) and equation (4).

$$T_k = T_R \times \varepsilon_\lambda^{-1/4} \quad (3)$$

$$T_{k'} = T_k - 273 \quad (4)$$

$T_K$ is the kinetic temperature or surface temperature (in Kelvin), $T_{K'}$ is the surface temperature in degree Celsius, $\varepsilon_\lambda$ is the emissivity i.e. 0.97.

Validation includes thermal profiles, GPS measurements and field images from the IR camera through which the final integrated interpretation of location and changes of coal fires affected area were generated.

## 5. Result and discussion

From the day time Landsat-5 TM data of 1990, 1994, 1996 and Landsat-7 ETM+ data of 2006, the spectral radiance and radiant temperature were calculated using Planks radiation equation. Using radiant temperature and assumed emissivity value for the entire coalfield, kinetic temperature of the aforesaid data was calculated. On the basis of field observation and kinetic temperature image, the surface and subsurface coal fire pixel were delineated as shown in figures 2-5. For the ground validation the thermal images (IR) and its respective digital image (figures 6-7) has been taken from thermal camera. The maximum temperature of 104ºC and 460ºC are shown in figures 6 & 7 respectively.

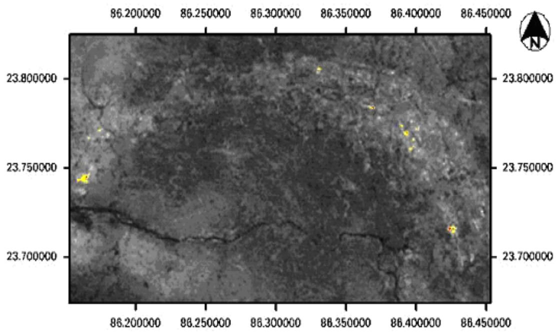



**Figure 2:** Surface/subsurface fire in 1990

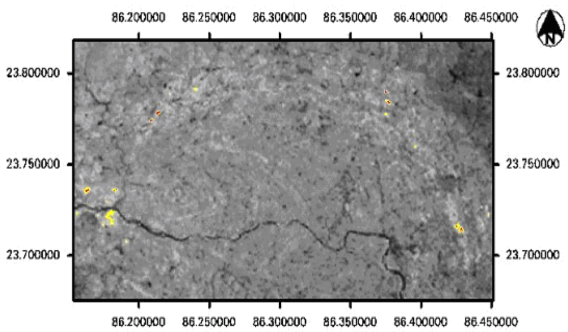



**Figure 3:** Surface/subsurface fire in 1994

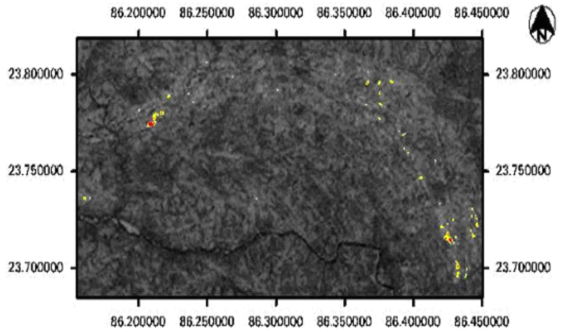



**Figure 4:** Surface/subsurface fire in 1996

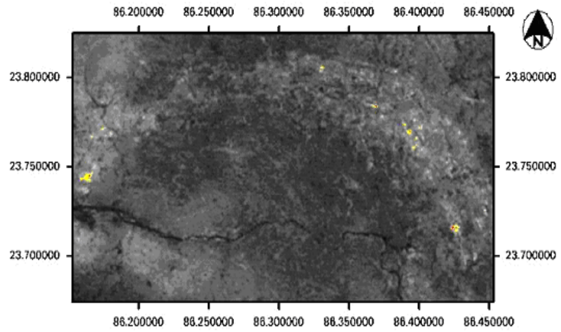
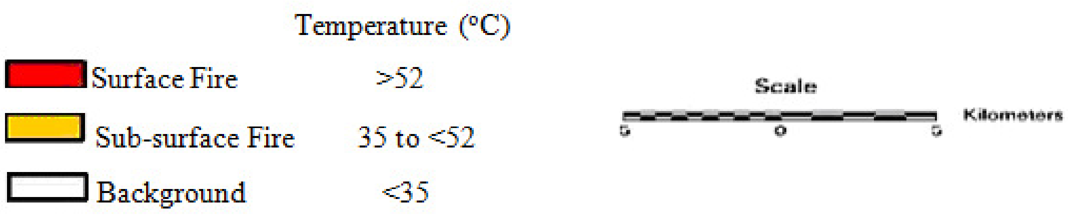



**Figure 5:** Surface/subsurface fire in 2006



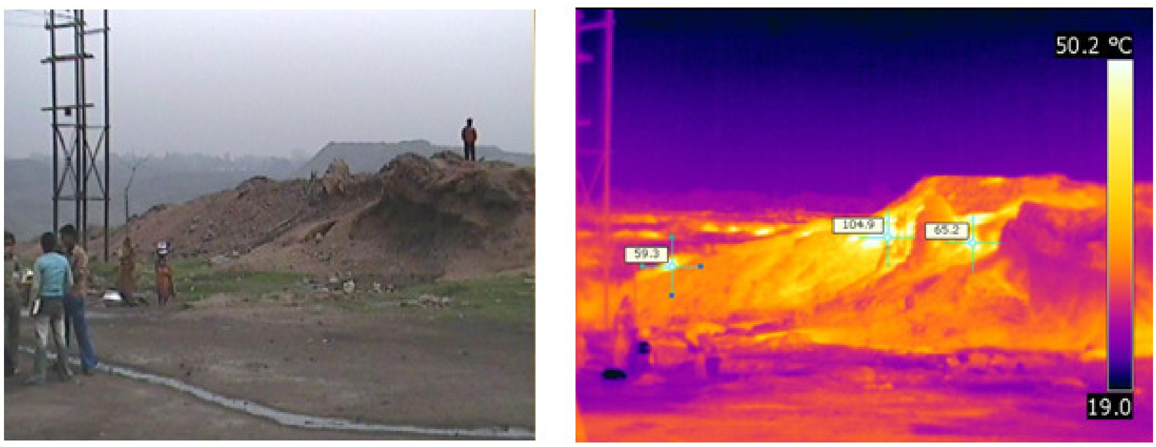




**Figure 6:** Digital image and its respective IR image of Boka Pahari area max temp 104 ºC

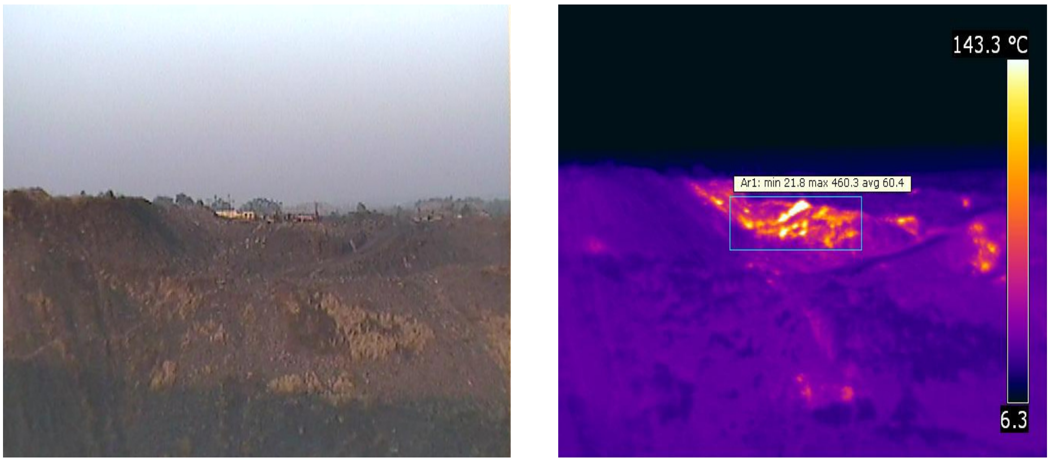



**Figure 7:** Digital image and its respective IR image Boka Pahari area max temp 460 °C

The surface and subsurface coal fire areas were calculated through thermal image (Table-1), figure (8).

**Table 1:** Surface and subsurface fire areas in different year calculated by Landsat data

| Sl No | Year | Surface Fire Area ($Km^2$ ) | Sub-surface Fire Area ($Km^2$ ) | Total fire area ($Km^2$ ) |
|---|---|---|---|---|
| 1. | 1990 | 1.53 | 14.34 | 15.87 |
| 2. | 1994 | 1.39 | 12.28 | 13.67 |
| 3. | 1996 | 1.08 | 8.31 | 9.39 |
| 4. | 2006 | 0.73 | 6.45 | 7.18 |

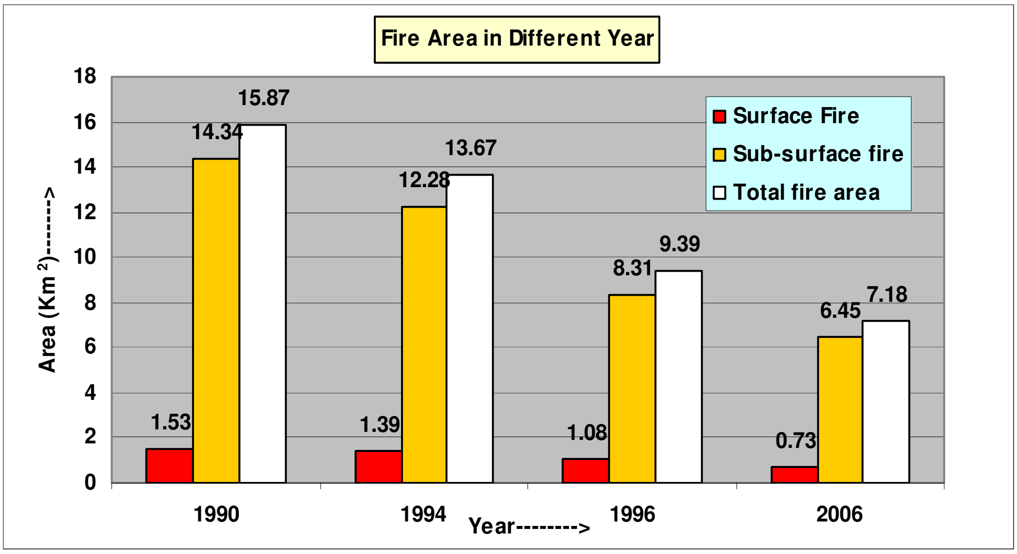



**Figure 8:** Bar diagram showing change of surface / subsurface and total fire affected area in JCF in different year

The study shows that the total coal fire affected area (surface and subsurface) was reduced from 1990 to 2006. The total coal fire affected area in JCF (including surface and subsurface fire) was found in decreasing order 15.87 $km^2$ in 1990 to 13.67 $km^2$ in 1994 and to 9.39 $km^2$ in 1996 and to 7.18 $km^2$ in 2006. The fire area accounts for decrease of 14% during 1990-1994; 31.30% during 1994-1996, 23.53% during 1996-2006. Decrease of coal fire affected area is due to different reasons as like as (i) removal of fire affected coal seam through opencast mining operation (ii) surface blanketing by incombustible materials e.g fly ash, soil and sand followed by dozing (iii) quenching coal fire by water-pooling or fire fighting chemicals (iv) isolation of fire by trenching around the fire affected coal seams (v) isolation of fire by construction of sand /cement grout cut off barriers (vi) infusion of inert gas (vii) stowing through bore hole.

Some old abandoned mining area was slowly catching fire due to sometimes man made or self ignition due to oxidation of coal and become uncontrolled to stop. The direction of coal fire propagation is an important role for arresting and controlling coal fire. In this study an attempt was mode to find the net lateral propagation of surface coal fire during 1990 to 2006. It is observed that during 1990 -96 the propagation of surface coal fire was towards south and towards west on the other hand during 1996-2006, it was generally towards north. The surface and subsurface coal fire changed their area from 1.53 and 14.34 $km^2$ in 1990 to 1.39 and 12.28 $km^2$ in 1994 to 1.08 and 8.31 $km^2$ in 1996 to 0.73 and 6.45 $km^2$ in 2006 respectively. It is observed that during the period 1990-96 coal fires propagated towards south and on the other hand during the period 1996-2006 towards west. Generally, it was present towards north of JCF.

## 6. Conclusion

The dynamics of coal fire was studied in the terms of change of surface coal fire area and propagation direction of coal fire .With the help of temporal coal fire maps prepared from the Landsat-5 TM and Landsat-7 ETM+ raw and processed data. It is observed that the total fire affected area was reduced substantially from 15.87 $km^2$ in 1990 to 13.67 $km^2$ in 1994 to 9.39 $km^2$ in 1996 to 7.18 $km^2$ in 2006. Of this surface coal fire shared 1.53 $km^2$ , 1.39 $km^2$, 1.08 $km^2$, 0.73 $km^2$ in 1990, 1994, 1996, 2006 respectively and rest amount 14.34 $km^2$, 12.28 $km^2$, 8.31 $km^2$, 6.45 $km^2$ were shared by subsurface coal fires in 1990, 1994, 1996, 2006 respectively. It is observed that, during 1990-1996 the net lateral propagation of coal fires was generally towards the south and at places towards west, where as during 1996-2006 it follows the general trends towards north except at few places where it was towards south. In this paper study the lateral prorogation of coal fire was observed for the fire prorogation in two dimensional but study on the propagation of coal fires requires more detail in three dimensional models.

## 7. Acknowledgement

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## References

1. Chatterjee R. S. et al. (2007), Dynamics of coal fire in Jharia coalfield, Jharkhand, India during the 1990s as observed from space, Current science, 92(1), pp 61-68.

2. Chaterjee, R. S., (2006), Coal fire mapping from satellite thermal IR data - A case example in Jharia coalfield, Jharkhand, India. ISPRS Journal of Photogrametry and remote sensing. 60, 2, 113-128.

3. CMPDI-NRSA, (1999), Fire project report on Jharia Coal Field (JCF) Dhanbad.

4. C.Yunhao et al , 2007, Detection of coal fire location and change based on multi-temporal thermal remotely sensed data and field measurements, International Journal of remote sensing 2007, pp. 1-7,

5. Gupta R.P., (2005), Remote sensing geology (Berlin-Heidelberge: Springer-Verlag, 2nd edition), pp 206-216.

6. Markham, B. L. and Barkar, J. L., (1986), EOST Landsat Technical notes 1, Earth observation satellite Co, Lanham, Maryland, August, pp 3-8.

7. Michalski, S.R. et al., (1997), Investigation of the Jharia Coalfield mine fires—India. Proceedings 14th annual meeting of the American society for surface mining and reclamation, (CD-ROM), Austin, TX, pp 10– 15.

8. Mishra R K., (2010), Study of mine fire in Jharia coalfield (JCF) using remote sensing techniques, M.Tech thesis, Indian School of Mines Dhanbad Jharkhand (India)

9. Mishra R.K., Bahuguna P.P., Singh V.K., (2011), Detection of coal mine fire in Jharia coal field using landsat-7 ETM+ data. International journal of coal geology, 86, pp 73-78.

10. Mishra R.K., Pandey J, Chaudhary S.K, Khalkho A, Singh V.K., (2012), Estamation of air pollution concentration over Jharia coalfield based on satellite imagery of atmospheric aerosol. International journal of geomatics and geosciences, 2(3).

11. Pandey J, Mishra R.K., Khalkho A, Singh R V K., Singh V.K., (2011), Thermographic Technique –A versatile tool for assessment and monitoring of coal mine fire Jharia coalfields, Mine Tech, 32(3), pp 33-41.

12. Prakash A. Gupta R.P., (1999), Surface fire in the Jharia coalfield, India-their distribution and estimation of area and temperature from TM data, International journal of remote sensing, 20(10), pp1935-1946.

13. Prakash, A., Gupta, R. P., Saraf, A. K., (1997), A Landsat TM based comparative study of surface and subsurface fire in the Jharia coalfield, India. International journal of remote sensing, 18(11), pp 2463-69.

14. Prakash, A., Vekerdy, Z., (2004), Design and implementation of a dedicated prototype GIS for coal fire investigations in North China. International journal of coal geology, 59, pp 107-119.

15. Voigt, S., Tetzlaff, A., Zhang, J., Kunzer, C., Zhukov, B., Strunz, G., Oertel, D., Roth, A., Dijk, P. van, Mehl, H., (2004), Integrating satellite remote sensing techniques for detection and analysis of uncontrolled coal seam fire in North China. International journal of coal geology, 59, pp 121- 136.