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Detection of Surface and Sub-surface Coal Mine Fire of Jharia Coalfields using Remotely Sensed and Ground Thermal Data

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Abstract

Detection and mapping of the Jharia coal mine fire through the integration of satellite-based observed data with ground thermography data have been used and described in this work. This assimilation has been achieved using three types of data set viz., Landsat satellite images, topographical area map, and ground temperature survey of different fire-affected sites of Jharia Coalfields (JCF). Thermal anomaly, as observed from the satellite imagery, is one of the most important characteristics of the coal fire detection process. It has been used as a prime indicator for the fire area's extent and intensity. Ground thermographic measurement has also been conducted to further substantiate the thermal anomaly. The obtained amalgamated data is plotted on topographical maps of different sites of JCF. The study reveals that around 70% of the total coal mines of JCF are in grip of either surface fire or sub-surface fire or both surface and sub-surface fire. About 93% of fires detected in the year 1988 were shifted to new locations or in a dormant condition, whereas the remaining about 7% of fires were still burning at the same locations mostly due to the shifting of these fires from the upper coal seam to the lower coal seam or vice versa. The temperature detected by satellite data was 10 to 15 times lower than the actual fire condition measured on the ground during field observation. The study concludes that the detection of several years long-standing fire conditions historical satellite data will be the best option to delineate the fire condition.

1. Introduction

Coal, an important fossil fuel, is a unique gift of nature to mankind as a key energy source. Coal is still maintained as single largest world resource for power generation. Presently, around 36% of global and 71% of Indian energy requirements are being fulfilled by coal, and is expected to be the prime source of energy in foreseeable future. The proven coal reserves worldwide are estimated at 1.1 trillion tonnes and the majority of reserves are in the USA, Russia, China, Australia, and India [1, 2]. The estimated coal reserves in India were estimated as 319.04 billion tonnes and 98.26%, of which are confined in the eastern and south-central parts of India. Despite being such a useful resource to mankind, the mining of coal is inherently associated with risks and hazards. It may sometimes leads to disasters resulting in loss of human life, production, and productivity. Fire and explosion are one of the major causes of coal mine disasters, which have led to about 40% of all the disasters and about 50% of the total fatalities in Indian coal mines during 1947-2015 [3, 4].

The problem of coal mine fires exists in several coal-producing nations spreading over various continents in the world [5, 6]. The coal mine fires in China (Mongolia, North China), the USA (Pennsylvania), and India (Jharia and Raniganj coalfield) are still considered to be a major socio-technological problem in the global arena [7]. It creates vast impacts on the environment,

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economy, society and safety. Burning of huge quantities of natural resources causes economic loss and substantial operational difficulties including a reduction in production and productivity [8]. Coal combustion liberates a substantial amount of obnoxious and greenhouse gases (GHG) along with a large number of particulate matter [9]. It has been estimated that around 30 MT oxides of carbon are emitted every year due to coal fires only [10]. The coal fire emits a huge amount of unproductive heat worldwide and contributes to the increased temperature of the earth [11]. Subsidence caused by sub-surface coal mine fire extensively damages the surface structures influencing social activities of the locality [12].

Plenty of techniques are available for delineating the coal mine fire from underground, surface, airborne, and space-borne platforms. However, detection of coal mine fire precisely is still a challenging issue [13]. The detection methods depend upon various site-specific situations, requirements, and status of coal mine fire [6]. Hence, appropriate methods must be adopted to locate the surface and subsurface fire. For monitoring changes in prolong coal mine fire status and its extent, previously available remote sensing historical datasets will be the better option.

Since early 1960, the remote sensing technique has proven its importance and suitability in detecting and mapping coal fires. Globally, several researchers have successfully attempted remote sensing techniques as a tool for studying different aspects of coal mine fire [14, 15,16, 17, 18, 19, 20, 21, 22, 23, 24]. The coal fire studies based on airborne and satellite remote sensing data have been reported since 1990 in India in general and JCF in particular [7, 25, 26, 27, 28, 29, 30, 30, 31, 32, 33, 34, 35, 36, 37, 38]. However, most of the research was confined to the delineation of coal mine fires in JCF in terms of surface and sub-surface fire areas in different years using available satellite data during the study periods. These studies were focused on remote sensing image-based analysis of fire areas with limited ground observations. Since the several fire areas in JCF are smaller in size than the pixel size of satellite data, it would be quite difficult to detect and delineate coal fire by this technique efficiently and effectively without confirming ground reality. The present study is aimed at describing the benefits of integration of surface and space-borne methodology for improved detection and assessment of temporal transition of coal mine fire in the last 25 years.

2. Geological setting

The Jharia coalfield (JCF) falls under the eastern part of India, and it is situated in the heart of the Damodar river valley. It is located in Dhanbad district of Jharkhand, at about 260 km in the NW of Kolkata city and about 1150 km in the SE of Delhi (Figure 1). JCF is covering about 380 sq km coal bearing area spreading 38 km from East to West and 19 km from North to South between latitudes 23°38'00” N and 23°52'00” N and longitudes 86°08'00” E and 86°30'00” E [10, 39].

The Jharia coalfield is approximately sickle-shaped, synclinal basin formation occurred as dipping towards the west direction and striking in east-west direction. The general dip of the formation is 10 to 15 degrees. In this coalfield, the Gondwana sequence of strata occurs as an outlier within the granitic rocks and gneisses of the Precambrian era [40]. The rock strata contain mainly sandstone and shale. The Barakar and Raniganj are main formations of coal seams in JCF (Figure 2). There are almost 40 coal seams of Barakar and 10 coal seams of Raniganj measures existing in the JCF [41]. The most of the coal seams of the Barakar formation mainly consist of medium grey-white sandstones, shales and the Raniganj formation consist of grey-greenish feldspathic sandstones, shales. The basement of Jharia basin is represented by metamorphic rocks of the Achaean age, consisting of gneisses and mica-schists with quartz veins [42]. The generalised stratigraphic successions of the Jharia Basin are illustrated in Figure 3.

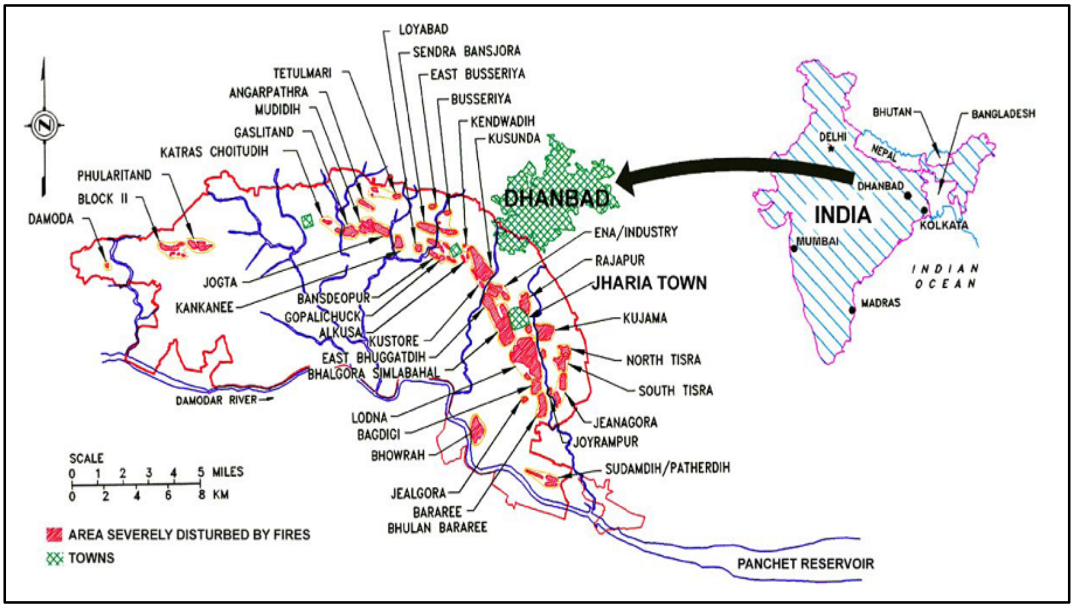

Figure 1. Geographical location of Jharia coalfield illustrating major fires affected coal mines [43].

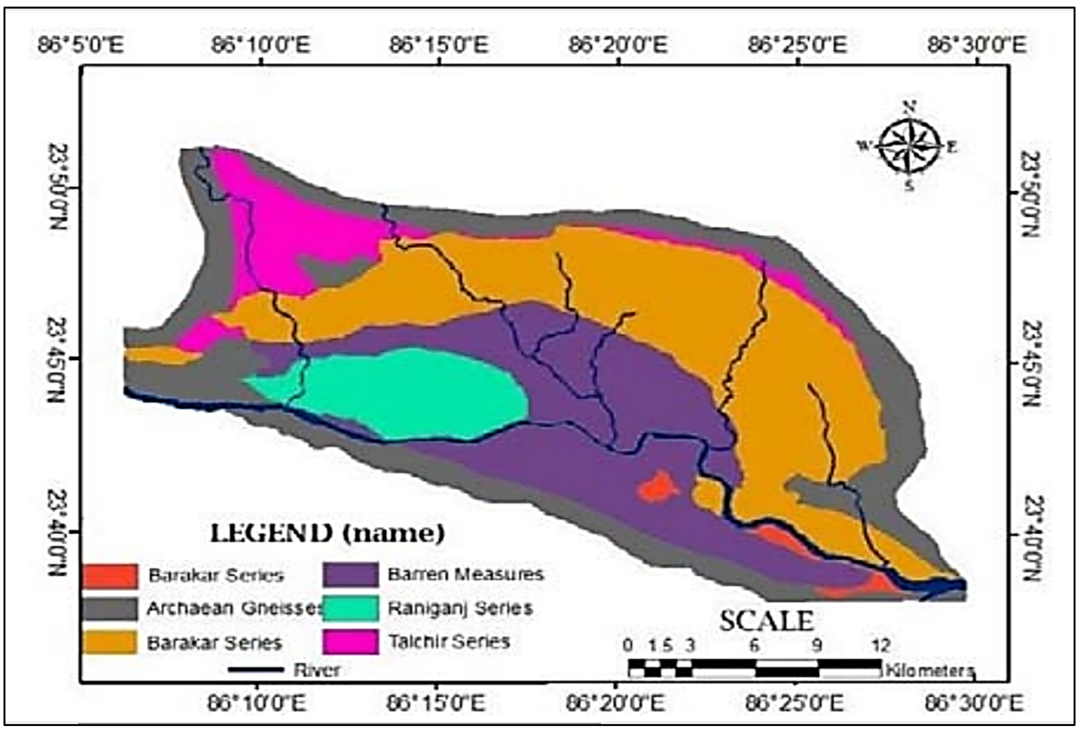

Figure 2. Geological map of the Jharia coalfield showing the major formations [44].

Period	Formation and Thickness (m)	Section symbols	Litho-type
Recent	ALLUVIAL		Soil, Sandy sandstone
Early Triassic			UNCONFORMITY
	PANCHET FORMATION (Igneous intrusive)		
			UNCONFORMITY
Late Permian	RANIGANJ MEASURES (800m)		Fined Grained Sandstone, shale, coal seams
Early Permian	BARREN MEASURES (730m)		Buffed Coloured Sandstone and shale, carbonaceous shale
Early Permian	BARAKAR FORMATION (1250m)		Course and Medium Grained Feld spathic Sandstone, Grit shale, carbonaceous shale and coal seams
Early Permian	KARHARBARI		
Early Permian Late Carboniferous	TALCHIR FORMATION (245m)		Very Fined Grained Sandstone, Greenish Shale, Sandy shale, Conglomeritic and Basaltic Rock
Late Carboniferous Precambrian Basement	METAOMORPHICS		Granite, Mica Schist, Quartzite, Amphiboles

Figure 3. Stratigraphic column illustrating different formations of Jharia Basin.

The Damodar River is the main rivers, which passes through the Jharia basin and controls the drainage system of JCF. Many geological structures like folds, faults, sills, dikes etc. and fractures are present in the area. The great southern fault is the major fault in the JCF, representing the southern boundary of the Jharia basin. The coal seams in the JCF have thicknesses ranging from 0.91 to 22.44 m [45]. It has one of the highest concentration of thin to thick coal seams in confined location in the world with favourable mining conditions at relatively shallow depths [42].

2.1. Impacts of coal mine fire in JCF

Coal mine fires have several major adverse effects on the environment, economy, safety, and society. Coal mining in JCF adversely affects the ecosystem as a whole and mine fire expedites its intensity. The environmental pollution caused by coal mine fires adversely affects air, water and land [3, 46, 47]. The combustion of coal releases several gases such as oxides and dioxides of carbon (CO, CO_2), oxides of nitrogen and sulphur (NOx, SOx) along with particulate matters (PMs), which directly affect the health of the local people and emission of GHGs (CO_2, CH_4, H_2) contributing towards climate change [48, 49]. All of them are commonly associated with environmental and human health hazards [50, 51]. The release of PMs, TDS (total dissolved solid), and heavy metals are the main cause for polluting water and degrading land day by day, which downgrades the health of the residents severely. Seasonal rivers and ponds are also heavily contaminated and harmful to living creatures. This leads to the disruption of the growth and reproduction of aquatic plants, flora and fauna in surface water bodies. The coal mine fire leads to the degradation of land in the form of an undulating surface caused by subsidence and affects vegetative land by degrading the fertility of the soil. The forest cover has decreased sharply and several native natural floras and faunas are replaced by exotic species [52]. The aesthetic look of JCF is drastically damaged due to mass deforestation and fire-induced surface subsidence.

Moreover, huge loss of non-renewable natural resources and damage to surface infra structures are national economical setbacks besides environmental issues. Mine safety and operational complications are other major ramifications of the coal mine fire. Moreover, the loss of prime coking coal due to burning; the cost of fire fighting, control system and management result in enormous economic losses to the nation [3]. The other associated economic losses are related to human health, damage to surface structures and dissemination effects. The rehabilitation measures for the displaced population incur substantial expenditure.

The coal mine fire in JCF has also exerted some direct and ripple nature of impacts on society. Most common problem associated with coal fire is involuntary displacement and unemployment. Several coal mines are perpetually under fire and going to close resulting vast amount of jobless workers. Degradation in the quality of air and water critically affects the health of society. Health-related issues especially lung and respiratory diseases, neuro problems, high blood pressure, heat stroke etc., are very common in fire-affected areas. Despite this, poverty compels people are continued to reside in unsafe and inauspiciousness environment areas.

There are several important surface structures and features of JCF that are in grip of fire and under constant threat to safety due to coal mine fire-induced subsidence [3]. Several schools, banks, offices, miners’ dwellings and colonies are shifted to safer locations. Dhanbad-Jharia-Sindri railway line via Patherdih has been dismantled and permanently closed. Moreover, the Dhanbad–Chandrapura railway line via Katras and Adra-Gomoh railway line of East Central Railway along with several other important railway lines and roads passing over JCF are under threat of fire and proposed to be diverted considering safety issues [53, 54, 55, 56]. Most of the coal seams are under fire and consequently underground mining is becoming complicated for extraction and leading to the loss of prime coking coal. Presently, at some locations fire affected coal seams at shallow depths are being worked by the opencast method, which further creates some operational difficulties apart from safety and health hazards to the miners. Despite numerous efforts, the problem of fire is persistent and creates continuous safety threats to new areas.

3. Materials and Methodology

Remote sensing thermal data of coal mine fire of JCF has been primarily used for detection and mapping followed by substantiations using ground thermography in the present study. The data used in this study includes satellite images, topographical maps, and ground thermal data. Satellite data acquired for the study are Landsat 8 of the year 2013; Landsat 7 ETM+ of 2003 and Landsat 5 TM of 2008, 1998, 1993 and 1988 are collected from the United States Geological Survey (USGS) and technical details from corresponding satellites metadata. The Survey of India topographical map of JCF on a scale of 1:50,000 geo-referenced to the UTM (universal transverse marketer) WGS 84 coordinate system is used in this study as a base map for geometric correction and registration of images. The conical projection system on Everest 1956 ellipsoid and the spherical coordination system is used for the present study. The thermal IR images and ground coordinates were collected from field measurements for ground-truthing and validation at some selected mine fire sites of JCF.

Predawn time of the winter season thermal band satellite data of different years are primarily used in the present study for temperature calculation. However, other bands are also applied for analysis and generating normalized difference vegetation index (NDVI) maps. The product data sets were resampled in 30 m x 30 m pixel size resolutions of Landsat 5 TM (120 m x 120 m), Landsat 7 ETM+ (60 m x 60 m), Landsat 8 bands 10 and 11 data (100 m x 100 m). The technical details viz. spatial and spectral resolution of different bands, row, path, swath width, image size etc. of the utilized Landsat satellite Images are furnished in Table 1.

Table 1. Technical details of Landsat satellites images.

Landsat 5 Thematic Mapper			Landsat 7 Enhance Thematic Mapper Plus (ETM+)			Landsat 8 (OLI and TRIS)		
Spectral bands	**Spectral resolution (µm)**	**Spatial resolution (m)**	**Spectral bands**	**Spectral resolution (µm)**	**Spatial resolution (m)**	**Spectral bands**	**Spectral resolution (µm)**	**Spatial resolution (m)**
Band 1	0.45 - 0.52	30 x 30	Band 1	0.45 - 0.52	30 x 30	Band 1	0.43-0.45	30 x 30
Band 2	0.52 - 0.60	30 x 30	Band 2	0.52 - 0.60	30 x 30	Band 2	0.45-0.51	30 x 30
Band 3	0.63 - 0.69	30 x 30	Band 3	0.63 - 0.69	30 x 30	Band 3	0.53-0.59	30 x 30
Band 4	0.76 - 0.90	30 x 30	Band 4	0.77 - 0.90	30 x 30	Band 4	0.64-0.67	30 x 30
Band 5	1.55 - 1.75	30 x 30	Band 5	1.55 - 1.75	30 x 30	Band 5	0.85-0.88	30 x 30
Band 6	10.40 - 12.50	120 x 120	Band 6	10.40 - 12.50	60 x 60	Band 6	1.57-1.65	30 x 30
Band 7	2.08 - 2.35	30 x 30	Band 7	2.09 - 2.35	30 x 30	Band 7	2.11-2.29	30 x 30
			Band 8	0.52 - 0.90	15 x 15	Band 8	0.50-0.68	15 x 15
						Band 9	1.36-1.38	30 x 30
						Band 10	10.60-11.19	100 x 100
						Band 11	11.50-12.51	100 x 100
IFOV at Nadir 30 x 30 m for band 1 to 5,7 and 120 x 120 m for band 6			IFOV at Nadir 30 x 30m for band 1 to 5,7 and 60 x 60m for band 6, 15 x 15m for band 8			IFOV at Nadir 30 x 30m for band 1 to 7, 9; 15 x 15m for band 8 and 100 x 100 m for band 10 and 11.		
Quantization Level 8 bit (From 0 - 255)			Quantization Level 8 bit (From 0 - 255)			Quantization Level 16 bit (from 0 -65535)		
Revisit 16 days			Revisit 16 days			Revisit 16 days		
Altitude 705 km			Altitude 705 km			Altitude 705 km		
Swath width 185 km			Swath width 183 km			Swath width 183 km		
Inclination 98.2°			Inclination 98.2°			Inclination 98.2°		
Image Size 185 km X 172 km			Image Size 183 km X 170 km			Image Size 183 km X 170 km		
Data Acquisition Date and Time: 23 January 1988, 04:12:33AM; 05 February 1993, 04:04:50 AM 04 December 1998, 04:22:18 AM 15 February 2008, 04:32:00 AM			Data Acquisition Date and Time 25 February 2003, 04:32:00 AM			Data Acquisition Date and Time 11 November 2013, 04:44:42 AM		
Data Acquisition Path: 140 Data Acquisition Row: 043 & 044			Data Acquisition Path: 140 Data Acquisition Row: 044			Data Acquisition Path: 140 Data Acquisition Row: 043		

The methodology consists of three basic steps viz. data acquisition and image processing procedure; extraction of pixel from the processed data sets and finally delineation of coal mine fire area along with the generation of fire map of JCF. The ground truthing and validation is carried out at some selected fire areas of JCF using a thermal imaging camera for ground thermal mapping and a differential global positioning system (DGPS) for locating the extent of the fire. The number of reports and documents relevant to JCF fire was also used for truthing the state and extent of fire in the previous years. Based on fire map, the temporal transitions of coal fire in the last 25 years are investigated. The changes in status and extent of fire in the previous 25 years from 1988 to 2013 were investigated. The work flow chart of the methodology used for detection and delineation of JCF fire is illustrated by successive Figure 4.

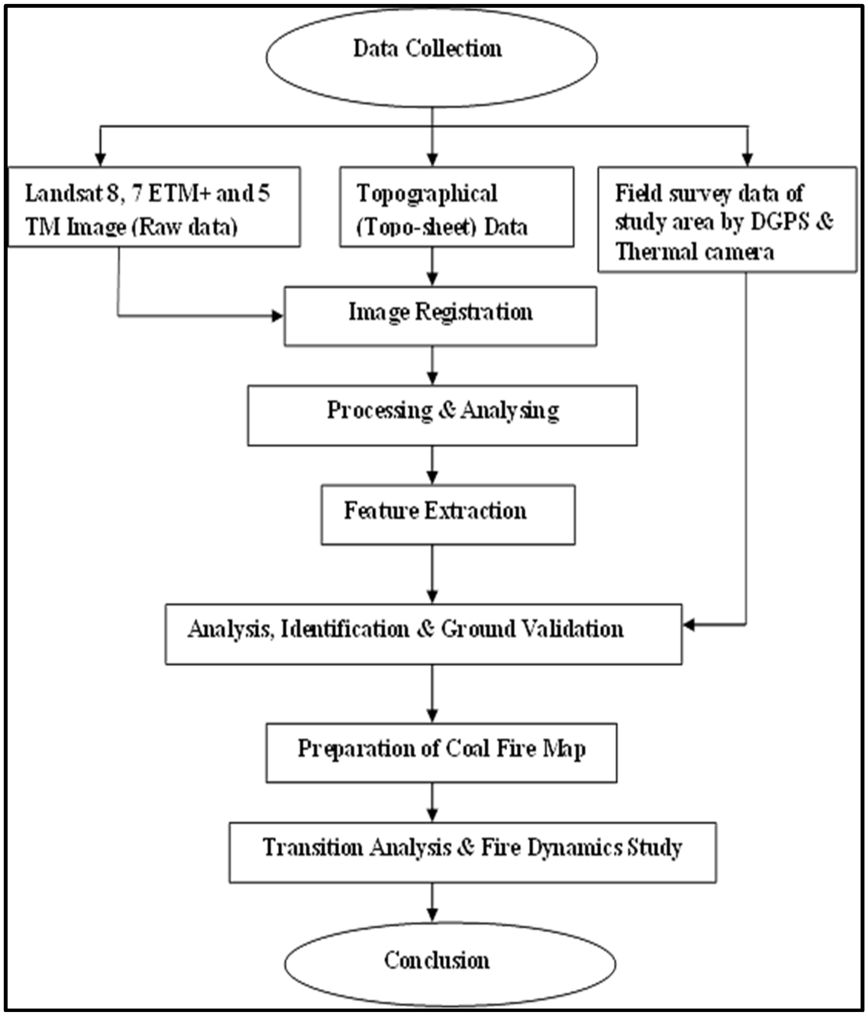

Figure 4. Work flow of the methodology used for detection and delineation of JCF fire.

3.1. Detection and mapping of coal mine fire

The mapping of the coal mine fire of JCF has been carried out using winter season predawn time satellite imageries for the years 1988, 1993, 1998, 2003, 2008, and 2013. The spectral radiance for each pixel of these images was calculated using the gain and bias values of different satellite metadata. Based on spectral radiance value, the radiant temperature of each pixel of these data sets of Landsat satellite was determined using different equations as described by Markham and Barker (1986), Gupta (2003), and Mishra *et al.* (2020) [57, 58, 37]. The kinetic temperatures were calculated using NDVI based thermal emissivity values of different classes of corresponding pixel data as described by Chatterjee (2006) [59]. The distribution of temperature over surface cover has been analysed based on the kinetic temperature of these images. The pixel-integrated temperature of JCF has been calculated and the coal mine fire-induced thermal anomalous area has been identified based on image analysis of a few known fire-affected sites. The threshold temperature value of the area under investigation was decided based on several major influencing factors, like acquisition seasons (month) and time, locations as well as periodical local weather conditions. Predawn images were used in this investigation; therefore, the influence of heat due to solar illumination has not been encountered. The coal fire anomalous area has normally shown elevated temperature than the background area. Whereas, the surface coal mine fire area has a much higher temperature field than the subsurface coal mine fire area. Although profile-based image analysis of some potential known fire-affected sites has been carried out to decide the sub-surface coal fire threshold temperature versus non-coal fire areas (background). Based on sub-surface fire area and non-fire area of known sites, the temperature threshold of other sites of JCF has been considered. Finally, the coal fire map of JCF of different years classifying surface fire area, subsurface fire area and background area have been generated based on above mentioned methodology in pseudo colour (Figure 5 to Figure 10).

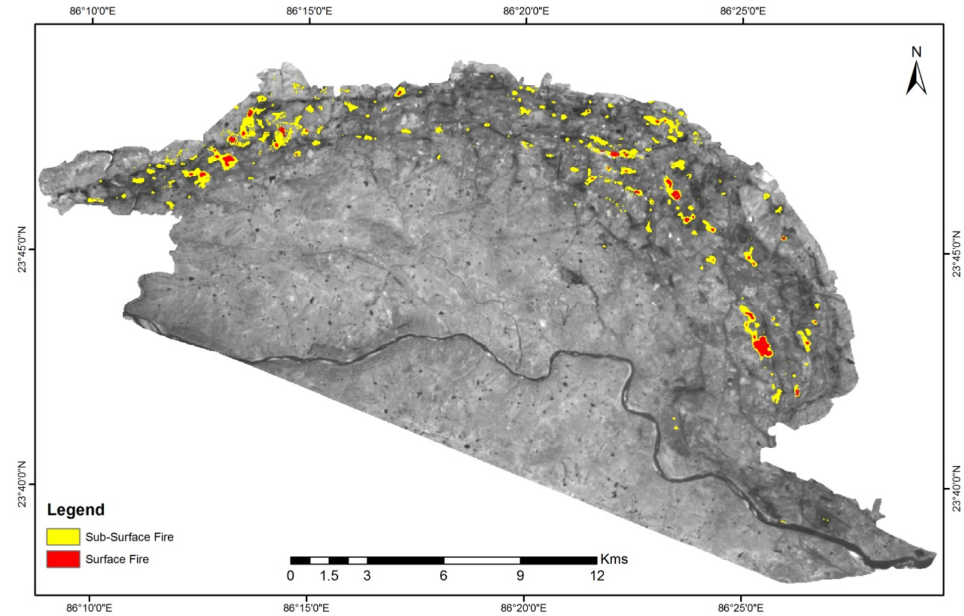

Figure 5. Coal fire map of JCF produced from Landsat 5, band-6 for the year 1988, showing subsurface and surface fire areas.

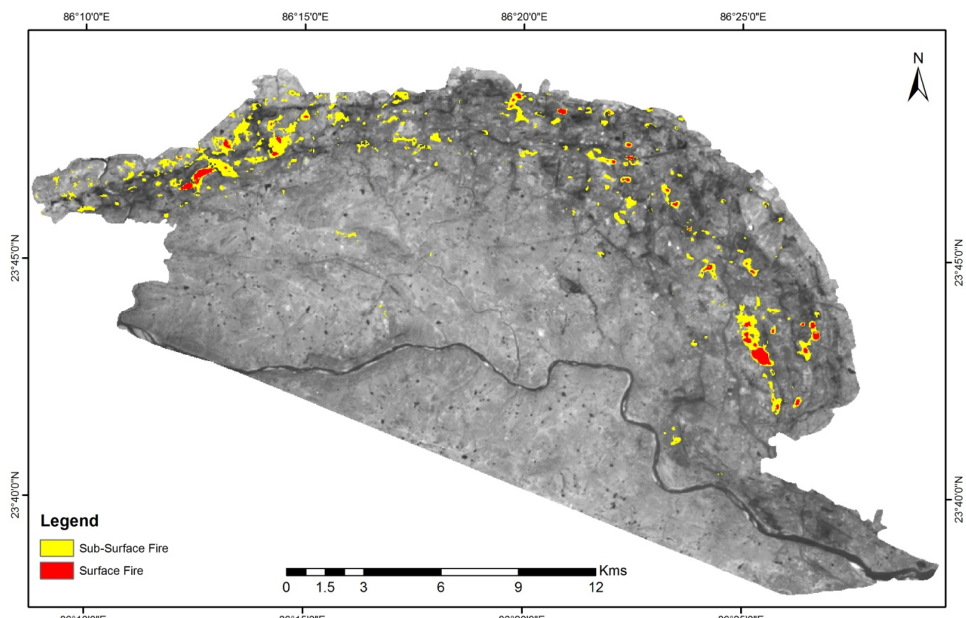

Figure 6. Coal fire map of JCF produced from Landsat 5, band-6 for the year 1993, showing sub-surface and surface fire areas.

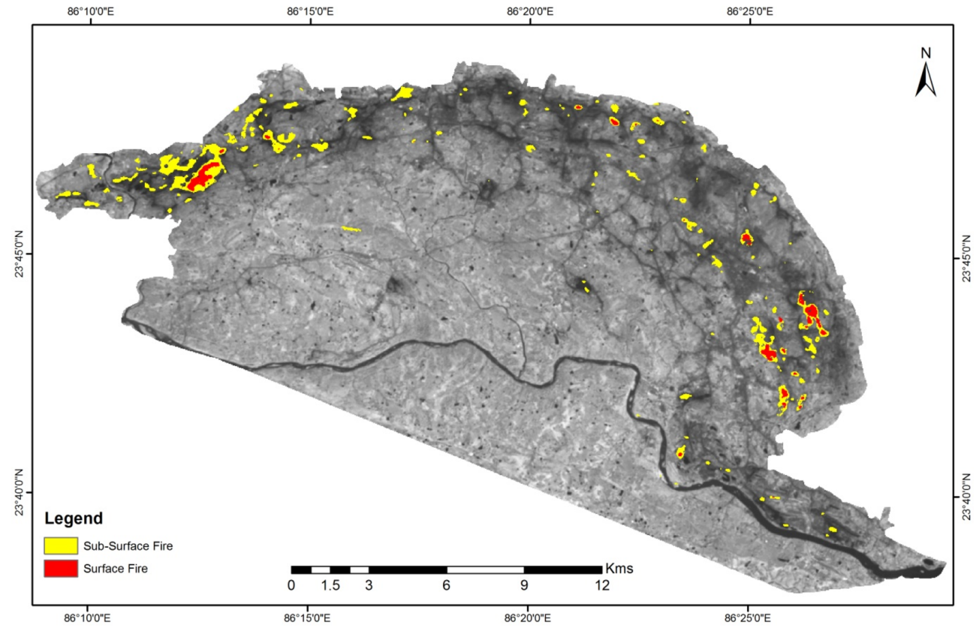

Figure 7. Ccoal fire map of JCF produced from Landsat 5, band-6 for the year 1998, showing sub-surface and surface fire areas.

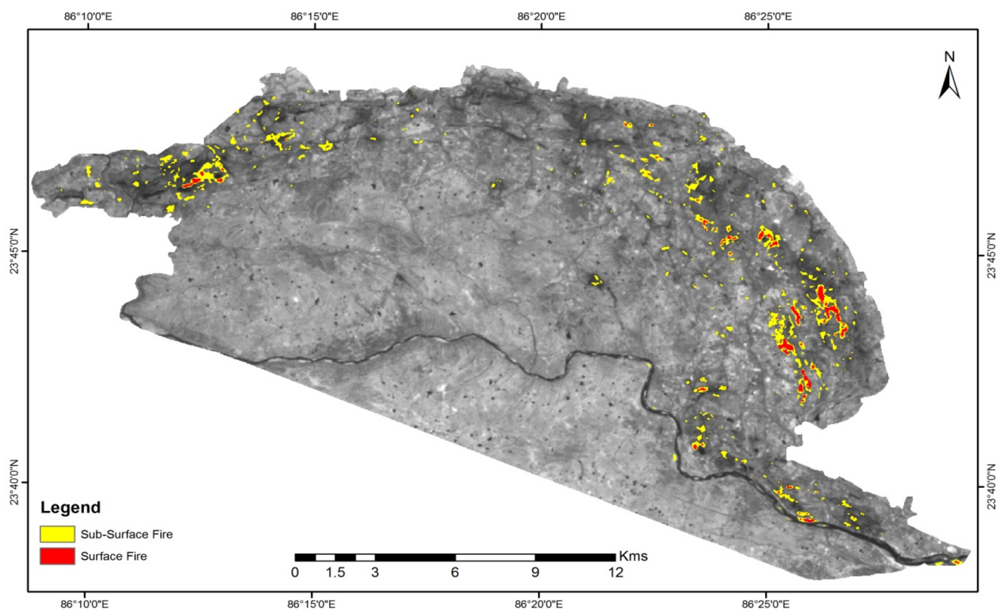

Figure 8. Coal fire map of JCF produced from Landsat 7 ETM+, band-6 for year 2003, showing sub-surface and surface fire areas.

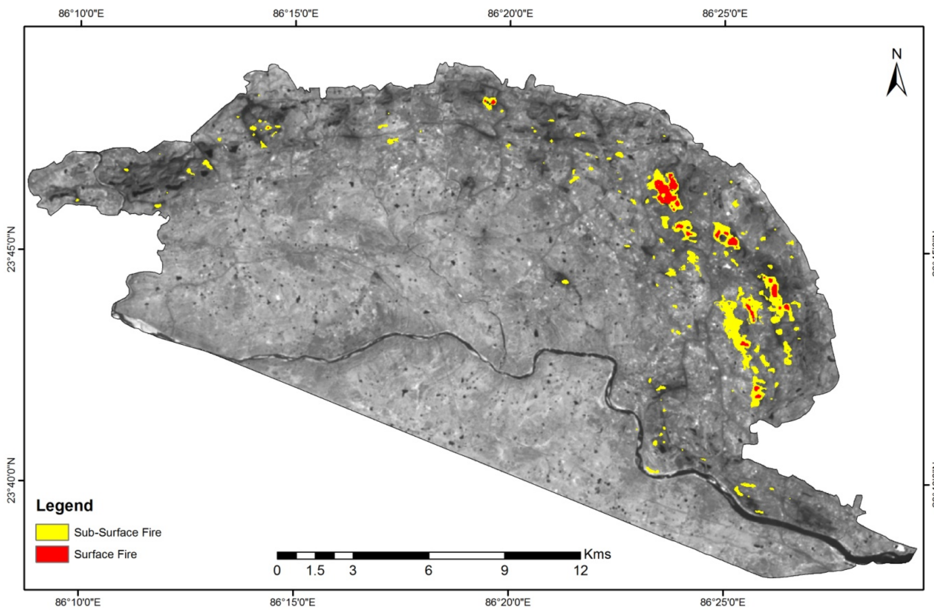

Figure 9. Coal fire map of JCF produced from Landsat 5 TM, band-6 for the year 2008, showing sub-surface and surface fire areas.

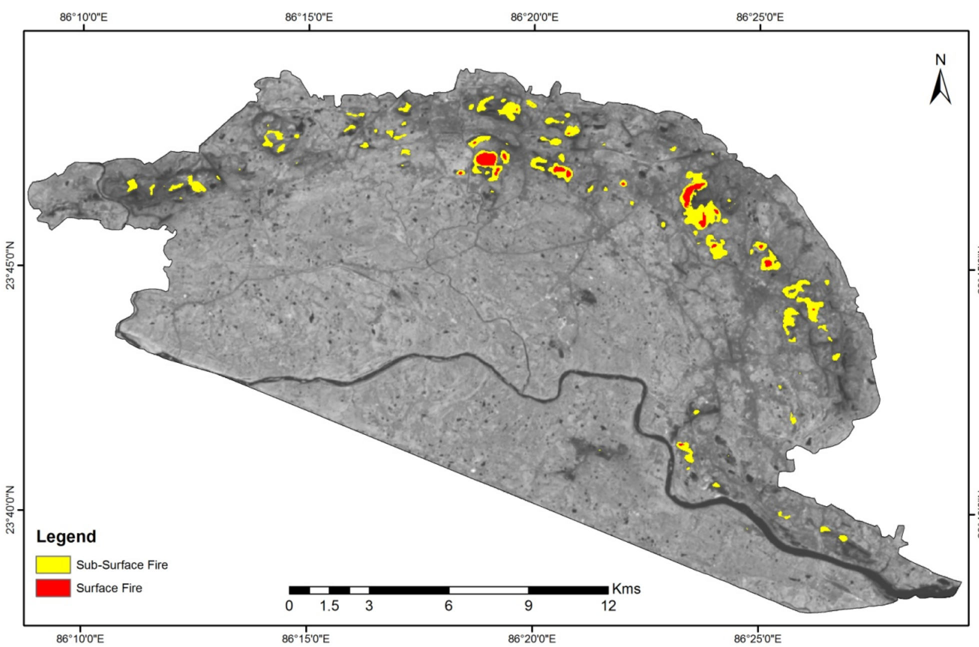

Figure 10. Coal fire map of JCF produced from Landsat 8, band-10 for the year 2013, showing sub-surface and surface fire areas.

The coal mine fire areas of JCF during the year 1988 to 2013 at five-year intervals have been investigated. The spatial distributions of the surface and subsurface coal mine fire area of JCF during the year 1988 to 2013 at five-year interval have been presented in Figure 5 through Figure 10. The minimum temperature (T_{Min}), maximum temperature (T_{Max}), mean temperature (T_{Mean}), Standard Deviation (SD), surface and subsurface threshold temperature, etc., obtained from year-wise image analysis are presented in Table 2.

Table 2. Observed temperatures retrieved from satellite image analysis during different years.

S.N.	Data Acquisition Date, Time & Scene ID	Data Type	T_{Min} (°C)	T_{Mean} (°C)	T_{Max} (°C)	S.D.	Fire Threshold Temperature	
							subsurface (°C)	surface (°C)
1	23.01.1988, 04:12:33 AM, "LT51400441988023SGI00"	Landsat-5 TM, band-6	17.2	25.1	39.1	3.096	32.0-33.5	33.5-39.1
2	05.02.1993, 04:04:50 AM, "LT51400431993036ISP01"	Landsat-5 TM, band-6	16.7	25.2	42.3	2.996	30.5-32.0	32.0-42.3
3	04.12.1998 04:22:18 AM, "LT51400441998338BKT00"	Landsat-5 TM, band-6	18.1	25.2	45.5	3.385	32.5-35.0	35.0-45.5
4	25.02.2003 04:32:00 AM, "L71140044_04420030225"	Landsat -7 ETM+ band-6	20.9	30.1	52.2	3.068	38.0-41.0	41.0-52.2
5	15.02.2008, 04:32:00 AM,. "LT51400442008046BKT00"	Landsat- 5 TM, band-6	16.7	27.4	46.3	3.600	35.0-39.0	39.0-46.3
6	11.11.2013, 04:44:42 AM, "LC81400432013315LGN00"	Landsat- 8 TM, band-10,11	21.9	27.5	56.2	4.418	37.0-43.0	43.0-56.2

The monitoring of the coal mine fire of JCF from 1988 to 2013 consists of mapping of suspected coal fire-induced thermal anomalous area. The higher temperature signature areas in the corresponding year image were considered as surface coal fire areas (Table 2), while the intermediate temperature area between surface fire and background was considered as subsurface coal fire areas. During the analysis of raw data for determination of threshold temperature value of anomalous and background (non-fire), some known fire sites of JCF were validated on the ground.

3.2. Ground substantiation of satellite-observed temperatures

The actual status of coal mine fire temperature and corresponding remotely observed temperature were validated by ground thermal mapping at selected 60 numbers of locations of JCF. The thermal imaging camera (range: -20 to 2000 °C with sensitivity accuracy of ±2 °C) was used for ground thermography. The ground coordinates of all temperature monitoring locations are determined by GNSS multi-frequency receivers. To avoid solar influence, ground validation was conducted in the early morning hours. The ground-observed fire temperature was detected as much higher as compared to remote sensing data. The analysis of acquired data sets viz. satellite observed fire temperature and actual fire temperature at the ground of same locations of around sixty selected coal fire-affected sites in JCF. At a few selected sites (Figure 11) temperatures are recorded and the thermal profiles of those sites are generated using the Surfer software package as illustrated by Figure 12 to Figure 15. The Kriging method is used for this geo-statistical profile analysis owing to the irregular distribution of datasets.

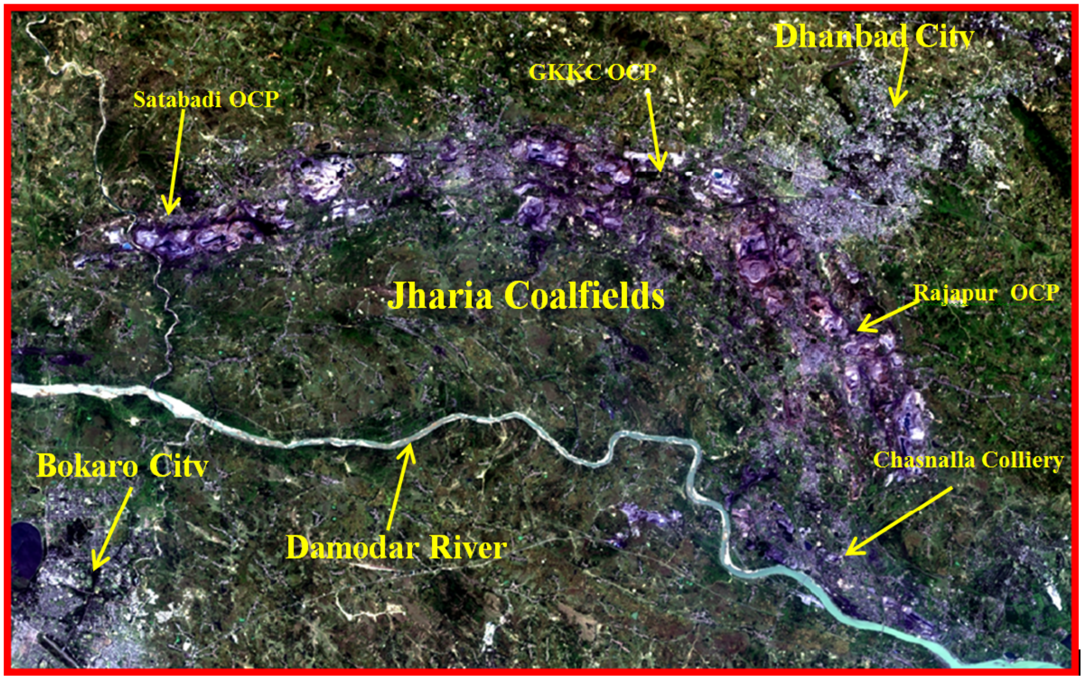

Figure 11. Locations of different study sites in Jharia Coalfield.

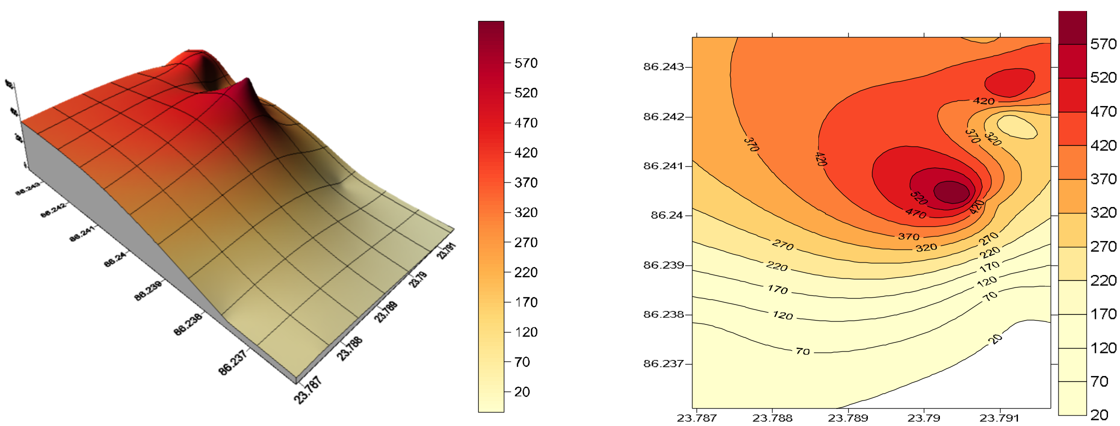

Figure 12. Thermal profile of fire affected zone at Shatabdi OCP of JCF.

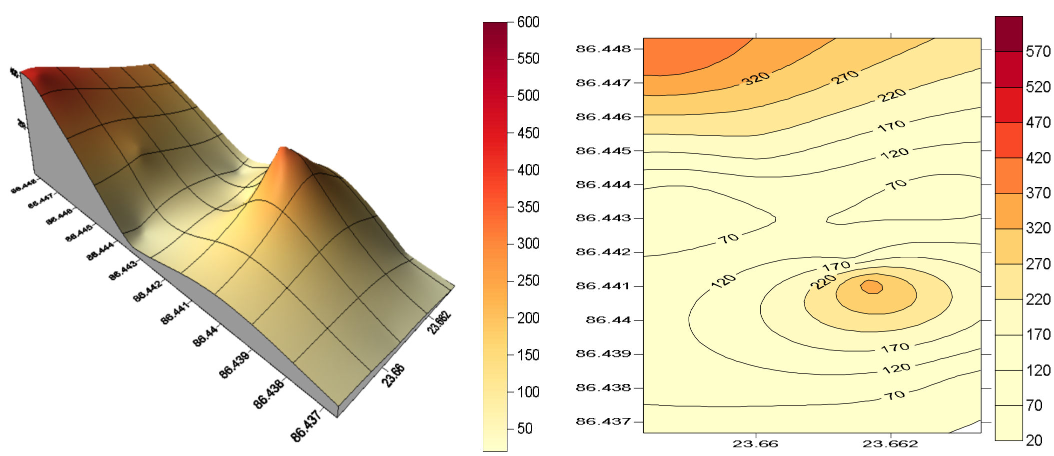

Figure 13. Thermal profile of fire affected zone at Chasnalla colliery of JCF.

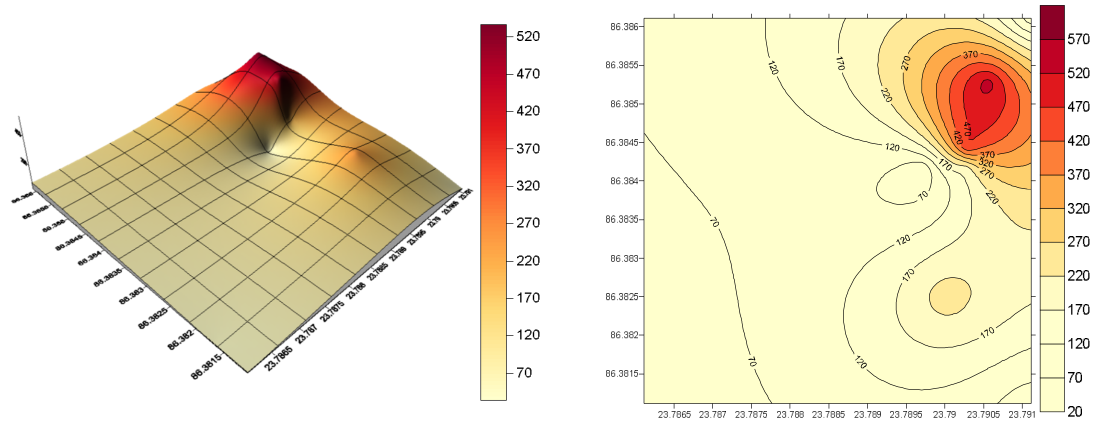

Figure 14. Thermal profile of fire affected zone at GKK OCP of JCF.

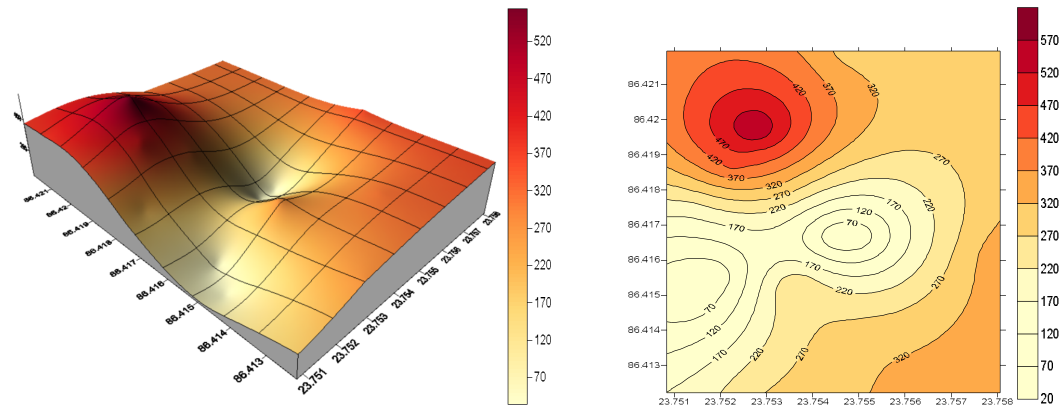

Figure 15. Thermal profile of fire affected zone at Rajapur OCP of JCF.

4. Results and Discussion

The delineation of the spatial coverage of coal fires in the Jharia coalfield in more than 25 years since 1988 reveals that it is maintained almost similar lateral coverage of around 9 km^2, excluding 11 km^2 in the year 1993 (Figure 16). The surface and subsurface coverage were observed as 1.09 km^2 and 8.13 km^2 in the year 1988 and 1.37 km^2 and 9.58 km^2 in the year 1993, respectively. Moreover, the total spatial coverage of the fire area in the year 1998 was found as 8.96 km^2, of which 1.35 km^2 consists of the surface fire area and 7.61 km^2 measured as subsurface fire area. The total spatial fire area was marked as 8.21 km^2 in the year 2003 of which 1.23 km^2 consists of the surface fire area and 6.98 km^2 of subsurface fire area. The total spatial fire area in the year 2008 was found as 8.20 km^2, which 1.22 km^2 consists of the surface fire area and 6.98 km^2 of sub-surface fire area. The total spatial fire area in the year 2013 was found as 8.38 km^2, of which 0.98 km^2 areas observed as surface fire and 7.40 km^2 as sub-surface fire area. Moreover, the fire area continued almost similar status in the year 2018.

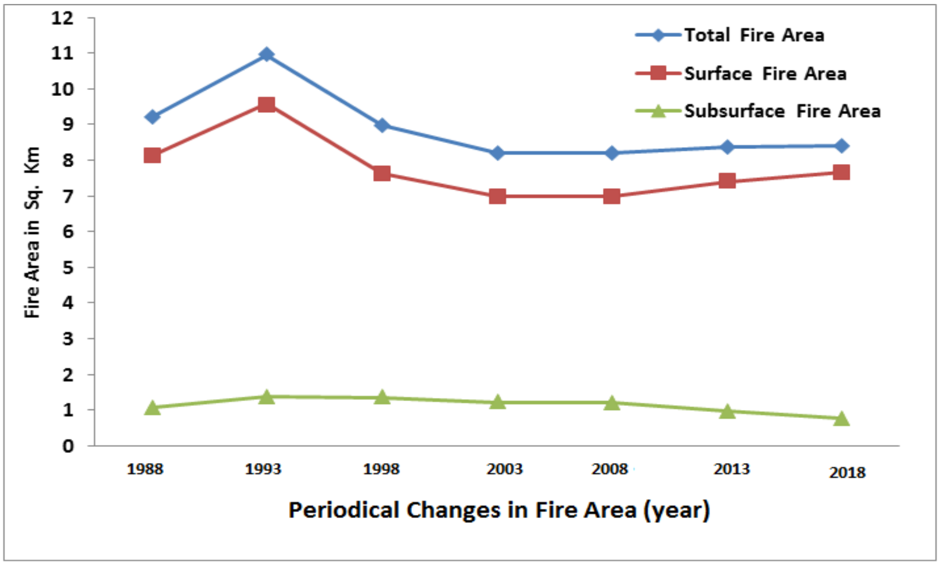

Figure 16. Observed spatial coverage of coal mine fire in JCF during five years intervals.

The substantial observation of periodical changes in the status and extent of the coal fire area of JCF based on Landsat thermal imageries within the lapses of 25 years from 1988 to 2013 were also carried out. The observation of lateral changes in fire area during this time interval confirms that around 93% of the coal fire area observed in the year 1988 are in dormant or controlled conditions in the year 2013. It has also been noticed from Figure 17, a small fire area which is around only 3% of the surface and sub-surface fire area observed in the year 1988 was to be continued in the year 2013 at the same location. Moreover, around 4% of fire areas at the similar location changed their status to either surface to sub-surface or sub-surface to the surface during this period. This may be because of the shifting of fire from the upper coal seam to the lower coal seam or vice-versa at those locations. The majority of fire areas detected in 2013 were almost new fire areas, which were not observed in the year 1988. This may be due to the depletion of coal or carbonaceous matters as a result of continuous and uncontrolled burning over some time including management or removal of fire-affected coal seams by opencast mining, overburden dumping over the fire-affected portions, etc.

The ground observed temperature at study sites reveals much higher than the Landsat thermal imageries extracted temperatures. During ground thermography small fires, which were less than pixel size of satellite images were also recorded. Hence, authers has opined that ground thermography integration with remote sensing based thermal monitoring serve betterways in planning of management strategy for dealing with high temperature coal mine fire areas as well as those fires which were not recorded in remote sensing observations. Therfore, integration of remotely sensed and ground thermal data will serve the purpose in more precise and safe manner rather than single method in delineating and dealing coal mine fire of JCF in totality.

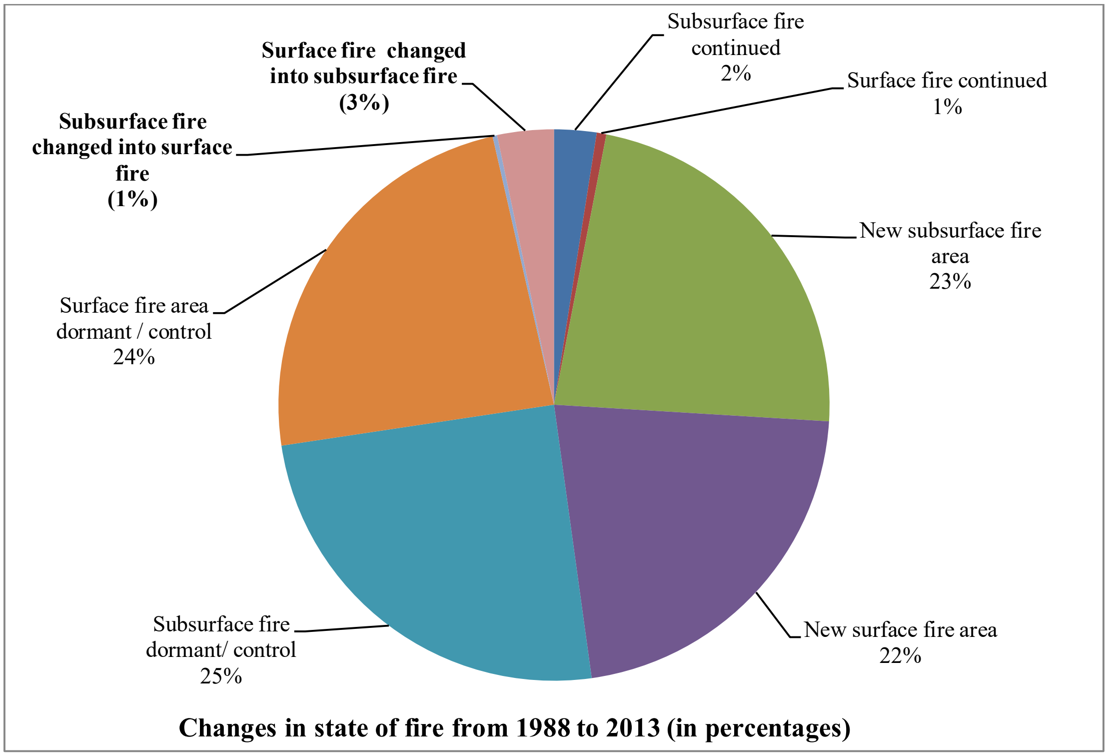

Figure 17. Changes of state and extent of fire area observed in 2013 with respect to 1988 of JCF.

5. Conclusions

The coal mine fire of JCF is seriously affecting the society, environment, economy, and miners' safety. Loss of prime coking coal resources and damage to surface structures due to fire-induced subsidence is another major ramification of the coal mine fire. Several efforts have been made to overcome the issue but in the vain. Coal fire is gradually spreading over new areas and endangering the lives of people residing in the vicinity of the fire area of JCF.

In the present study, extent and periodical changes of surface and subsurface coal fires of the entire coalfield during 25-year duration were observed through satellite data. An effort has also been made to compare the data observed remotely with the integration of the actual ground situation of a few selected fire sites of JCF. The study concludes the following major observations based on the field thermography and remotely observed data:

a) The coal mine fire in JCF continued since last century and created several direct and cascading impacts on the economy, populace, environment, surface infrastructure, and mining safety.

b) Due to the existence of a large number of out-cropping and shallow depth coal seam in the eastern part of JCF, densely affected with coal seam fire. However, presently fire is progressively spreading towards newer areas in the strike and dip directions leading to more complications in its mitigation.

c) The total coal mine fire-affected coal mines in JCF covers 45% of surface fire, 23% of sub-surface and 32% of both surface and sub-surface fires based on their existence.

d) The coal mine fire of JCF continuously sustained its status for last 25-30 years having coverage of about 8.5 to 9.5 km^2, out of which around 8 to 8.5 km^2 was surface fire and 0.75 to 1.25 km^2 subsurface fire areas.

e) More than 93% of fire areas detected in 1988 were presently in dormant condition excluding 7% of fire areas which are continuing due to the shifting of fire status to the lower coal seam.

f) The temperature observed in the coal burning area recorded by satellite data was around 50-55 ºC. However, the actual fire temperature condition at the same location was found between 500 ºC to 700 ºC during ground validation using thermal imaging camera image analysis.

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تشخیص آتش‌سوزی سطحی و زیرسطحی معدن زغالسنگ میدان‌های زغالسنگ Jharia با استفاده از داده‌های حرارتی سنجش از دور و زمین

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چکیده:

شناسایی و نقشه برداری از آتش‌سوزی معدن زغالسنگ Jharia از طریق ادغام داده‌های مشاهده شده مبتنی بر ماهواره با داده‌های ترموگرافی زمینی استفاده شده است و در این کار شرح داده شده است. این همسان سازی با استفاده از سه نوع مجموعه داده به دست آمده است، تصاویر ماهواره‌ای لندست، نقشه منطقه توپوگرافی و بررسی دمای زمین سایت‌های مختلف متاثر از آتش‌سوزی میدان‌های زغالسنگ Jharia (JCF). ناهنجاری حرارتی، همانطور که از تصاویر ماهواره‌ای مشاهده می‌شود، یکی از مهمترین ویژگی‌های فرآیند تشخیص آتش زغالسنگ است. به عنوان شاخص اصلی برای وسعت و شدت منطقه آتش استفاده شده است. اندازه‌گیری ترموگرافی زمین نیز برای اثبات بیشتر ناهنجاری حرارتی انجام شده است. داده‌های ادغام شده به دست آمده بر روی نقشه‌های توپوگرافی مکان‌های مختلف JCF رسم شده است. این مطالعه نشان می‌دهد که حدود ۷۰ درصد از کل معادن زغالسنگ JCF درگیر آتش‌های سطحی یا آتش‌سوزی زیرسطحی یا آتش‌سوزی سطحی و زیرسطحی هستند. حدود ۹۳ درصد از آتش‌سوزی‌های شناسایی‌شده در سال ۱۹۸۸ به مکان‌های جدید یا در شرایط غیرفعال منتقل شدند، در حالی که حدود ۷ درصد باقی‌مانده از آتش‌سوزی‌ها همچنان در همان مکان‌ها می‌سوختند که عمدتاً به دلیل جابجایی این آتش‌ها از لایه زغالسنگ بالایی به درز زغالسنگ پایین یا بالعکس بود. دمای شناسایی شده توسط داده‌های ماهواره‌ای ۱۰ تا ۱۵ برابر کمتر از شرایط واقعی آتش‌سوزی اندازه‌گیری شده بر روی زمین در طول مشاهده میدانی بود. این مطالعه نتیجه می‌گیرد که تشخیص داده‌های ماهواره‌ای تاریخی شرایط آتش‌سوزی چندین ساله بهترین گزینه برای ترسیم شرایط آتش‌سوزی خواهد بود.

کلمات کلیدی: حفاظت از زمین، علوم زمین، پدیده جدید، حفاظت، میراث زمین شناسی، ژئوسایت.