

## **2.0 THE STATE OF THE ART**

The CSF is caused due to natural and manmade activities. Continuous propagation of such fires, results in the significant environmental impacts, in the long run. The conventional approaches of the bore hole drilling, geophysical and radioactive methods have been deployed worldwide to develop techniques for mapping and the monitoring of the CSF. This chapter attempts to identify causes, influencing factors and the suitable techniques and the available technologies for the monitoring and mapping of the CSF for its effective assessment and containment.

### **2.1. CAUSES OF OCCURRENCE OF THE CSF**

The main causes identified<sup>9</sup> for the occurrence of the fires in the Indian coal seams are summarised in the table 2.1 below:

**Table: 2.1 Classification of the causes of CSF**

<b>S. No.</b>	<b>Mining factors</b>	<b>Coal Seam factors</b>	<b>Geological factors</b>
1	Mining Methods	Rank of coal	Seam Thickness
2	Rate of Advance	Petrographic Composition	Seam Gradient
3	Pillar Conditions	Temperature	Caving Characteristics
4	Roof Conditions	Available Air	Faults/dykes
5	Crushing of coal seams	Particle Size	Coal Outbursts
6	Stowing/ Packing quality	Moisture content	Friability
7	Effect of Timber	Sulphur content	Depth of Cover
8	Ventilation associated Leakages & Pressure	Effect of previous oxidation	
9	Multi Seam Working	Physical properties	
10	Coal Losses	Heating due to earth movement	
11	Upkeep of Mine Roads	Presence of Bacteria	
12	Worked Out Areas	Presence of other Minerals	

## **2.2. CSF MONITORING AND MAPPING METHODS**

The principal methods for CSF monitoring and mapping are:-

1. Field Survey
2. Topographic Mapping
3. Remote Sensing
4. Airborne Survey
5. Colliery Interviews
6. Borehole Drilling
7. Monitoring Borehole Temperatures & Gasses and
8. Geological Modelling.

The above methods are discussed below briefly.

### **2.2.1. Field Survey**

The field survey involves delineation of natural features like river, geomorphology, exposed geological rocks and artificial structures like roads, settlements and dams. These features are observed and recorded with locations and relevance for the study of CSF. Field survey also comprises of geotagging of CSF with clinometers or Global Positioning System (GPS).

### **2.2.2. Topographical Mapping**

The topographic maps are used to locate CSF. The topographic mapping method of JCF was used to create CSF maps for the field. CSF topographical mapping excludes the coordinate system due to subsidences and interferometer differences.

### **2.2.3. Satellite based RS**

The satellite based RS use the MSS and Thematic Mapper (TM) sensors on board for observing ground surface heating and to determine the spread of the fire throughout the coal field in time and space.

### **2.2.4. Airborne Thermal Infrared (TIR) survey**

TIR imaging from aircraft is carried out by the low flying aircraft. The CSF shows bright tone in infrared flight sensors. The TIR product is represented in graphs of temperature differences between CSF and objects.

### **2.2.5. Colliery Interviews**

The interviews conducted with coal mine management, surveyors and the other officials or staff is useful tool in assessing the proneness and the spread of the CSF. Their long experience and inputs are important in the prediction of the advancement of the CSF.

### **2.2.6. Borehole Drilling**

Borehole drilling is used to understand and estimate the underground conditions in the available coal seams for defining sub - surface structures and providing observation points for temperature and gas sampling.

Monitoring of the borehole temperatures and gasses are carried out as given below. CSF possibility and existence is analyzed by collecting mine water level, gas and temperature data.

#### **2.2.6.1. Temperature Testing**

The temperature of strata is collected using a thermostat and thermocouple RS probes in drill bits during the drilling in the rock-formations and the coal seams. The portable ANSI K: Chromel / Alumel thermocouples are used to create temperature profiles for most of the boreholes.

#### **2.2.6.2. Gas Testing**

The regular monitoring through gas tester of the composition of the mine-air may indicate the possibility of spontaneous CSF. The mine roadway roof conditions and the ventilation regulating devices can alter air flow in coal mines. The dissipation of the heat produced, through proper ventilation, reduces the possibility of the CSF.

#### **2.2.7. Geological Modelling and Mine Planning**

The preliminary mine plans are formulated to evaluate the open pit and underground coal mines. Mine modelling and micro mine planning software's use stratigraphic information for the prediction of the CSF potentials of coal seams through geological modelling.

### **2.3 CSF MONITORING WITH RS**

Fire in coal seams is globally an issue of great concern. Majority of the CSF are caused due to spontaneous combustion of coal. This is an outcome of the interaction of the coal with oxygen in the air, even at ambient temperature. The accurate mechanism of the reaction of oxygen with coal in the chemical environment of coal is not yet fully determined. The reaction of oxygen with coal occurs on the surface and forms oxygen and water complexes. This complex later decomposes to a simpler CO, CO<sub>2</sub> and H<sub>2</sub>O molecules. These fires emanate an enormous amount

of harmful gases in the atmosphere that is devastating to the ecological balance of the local & global environment.

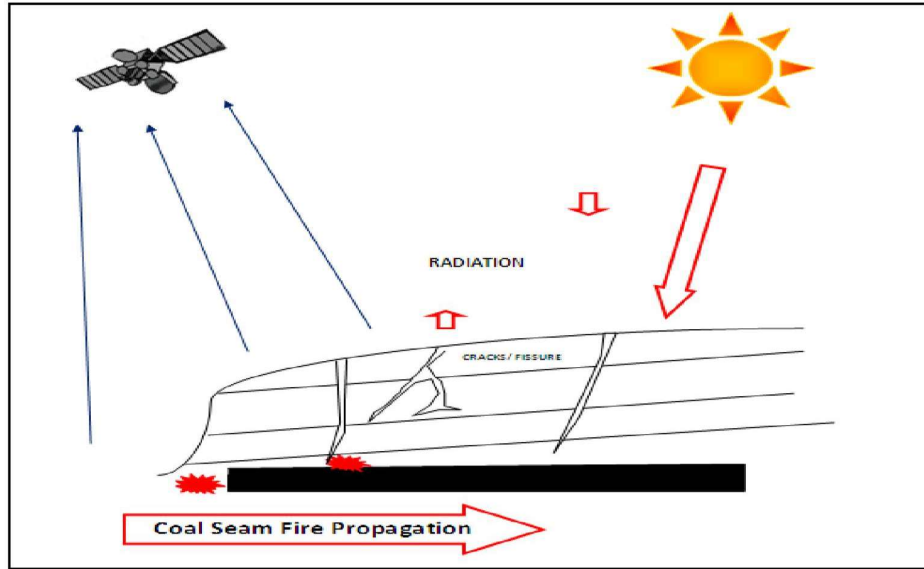
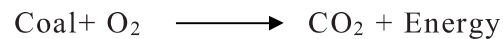


Fig: 2 RS of CSF

Burning coal is a chemical process that can be defined in a simplified form as



The overall reaction <sup>77</sup> & <sup>78</sup> for the chemical process is as given below:



The fires of coal seams are usually found in zones of lower mining and excavation related activities eg. stocks and abandoned open surface gets connected through cracks with the underground workings also.

These cracks feed fresh air to the goaf where coal readily oxidizes. The coal fire is ignited due to spontaneous combustions that then spread out over larger areas. RS tracks this spread of the CSF.

### 2.3.2. Basic requirements for the RS studies

- i. Energy Source and Illumination
- ii. Interaction with target
- iii. Interaction with atmosphere
- iv. Recording of energy by Sensor
- v. Transmission, Reception and Processing
- vi. Interpretation and Analysis

#### **2.4. RS- GIS TECHNIQUES FOR DELINEATION OF CSF AREA**

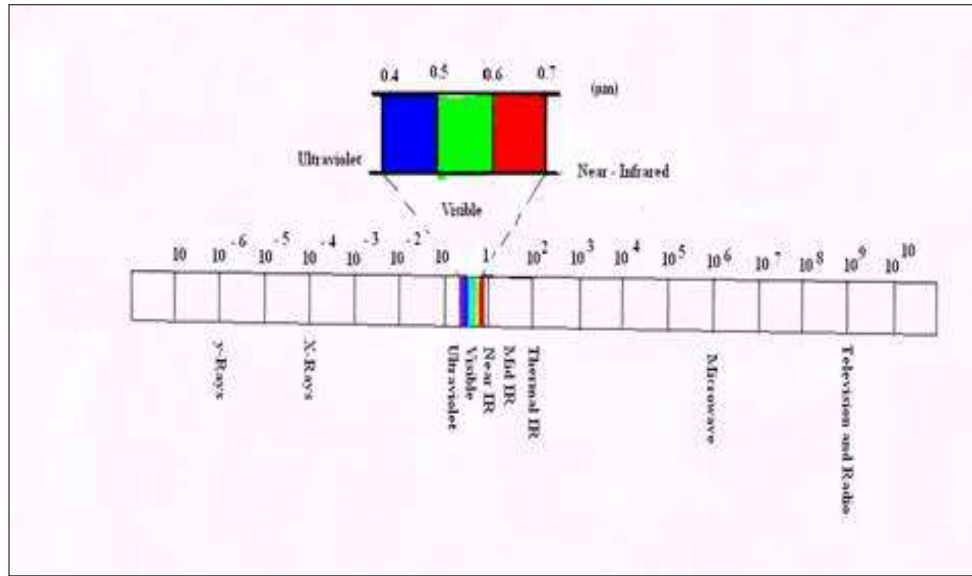
RS of coal fires is mostly based on the fixed emissivity of the surface temperature, for any study. The coal fire zones are identified by RS based on surface heat disturbances in the form of digital pixels of unit pixels. The digital values of the pixels depend largely on the depth of the fire (thermal conductivity) and the cracking system (thermal density).

The remotely sensed data used for GIS processing belongs to different ranges of wavelength- varying from 3 to 60  $\mu\text{m}$  for EM spectra and 3–5 $\mu\text{m}$  and 8–12 $\mu\text{m}$  for thermal spectra. GIS works with data obtained from variety of sources such as IKONOS and other Indian and Russian satellites. The outcome of literature review work on this topic reveals that four types of RS methods are generally used for the earmarking of the fire zones in the coal seams.

##### **2.4.1. Optical MSS- RS**

A MSS simultaneously acquires images in multiple bands of the EM Radiation (as in Fig - 3) spectrum of space. The MSS on board of the first five Landsat missions had 4 operational bands: 0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 $\mu\text{m}$ . Similarly, IRS LISS-III sensors operated in four bands (0.52-0.59, 0.62-0.68, 0.77-0.86, and 1.55-1.70 $\mu\text{m}$ ), the first three visible and near the infrared regions and the last in the central infrared band of the EMR spectrum. Different features of the spectral reflectance in different wavelength bands are identified in the images by comparing their

response. Thematic Mapper (TM) has been introduced by National Aeronautics Space Administration (NASA) in the Landsat - 4 missions, which works in 7 bands.



**Fig: 3 EMR spectrum showing atmospheric absorption regions**

#### 2.4.2. Hyper Spectral RS

Hyper spectral sensors are imaging spectrometers that acquire images in several narrow and contiguous spectral bands. They may be deployed along track or across-track. A typical hyper spectral scanner records in more than 100 bands <sup>79</sup>. Two hyper spectral indices had been developed to monitor the environment by analyses of biogeochemical effects of the dominant mineral properties.

#### 2.4.3. Thermal RS

Thermal scanners are a special kind of across-track scanner equipped with detectors of electrical charge carriers for sensing radiations of the object in the form of photons. Most commonly used detectors are Mercury-doped Germanium, Indium Antimonide and Mercury-Cadmium-Telluride sensitive in EMR range of 3-14µm, 3-5µm and 8-14µm respectively. The objects sensed by

detectors transmit their images by electronics as shown below using thermal sensor operational principle.

A thermal scanned image provides pictorial representation of the detector response of terrain causing different infrared radiations from various objects responsible for wide range of contrast in the image. The relationship between the radiated energy is recorded by the sensor to obtain the surface temperature drawn by Planck's distribution function. Tan, K., Zhou, R., Wan, Y., Li, X., (2007)<sup>80</sup> & Zhang, Genderen and Kroonenberg (1997)<sup>81</sup> carried out calibration activities for developing relationship between digital number (DN) and ground temperature on the scanned/observed areas by linear and exponential regression analyses.

Information about the heating extremes and the cooling rates of terrain are used to interpret the type and condition of the objects.

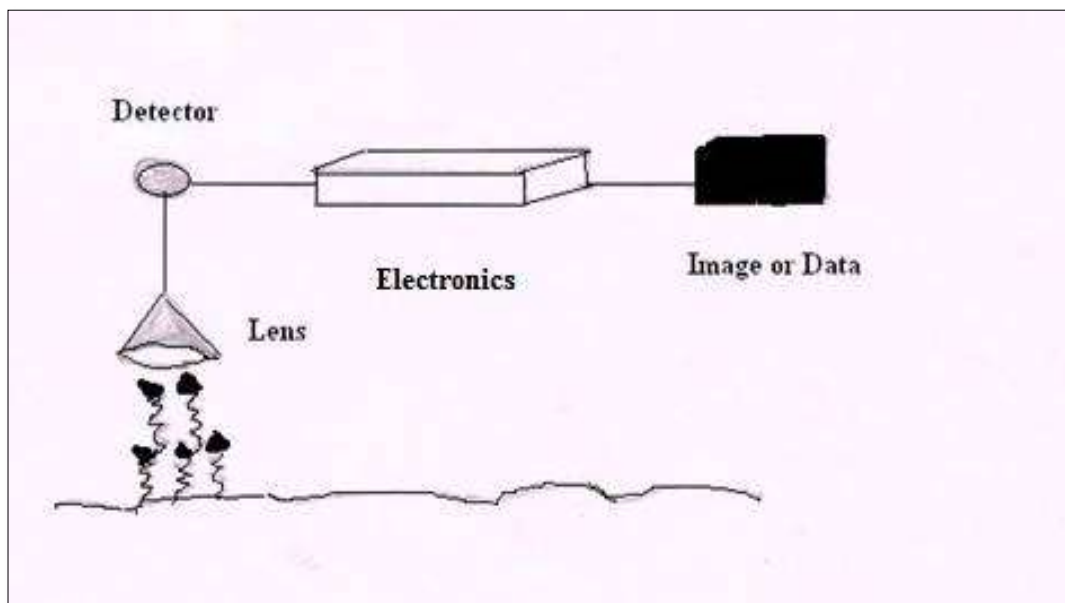


Fig: 4 Schematic representation of a thermal sensor operational principle

Some of the thermal scanners of this type with polar synchronous satellites including Daedalus, TIMS, ASTER, TERRA, AVHRR on NOAA series, MODIS, Aries – France, BIRD, Digital

Thermal Line Scanners, TABI 320, and OMIS1 are being used in detection, monitoring and surveillance of surface fires. Similarly, some other sensors on geostationary satellites like GOES, GOMS, GMS and Feng – Yun are being used for cloud top temperature monitoring and fire prediction.

#### 2.4.4. Radar RS

The interferometric synthetic aperture radar (In SAR) is a RS technique that measures the phase difference of a point over the surface after observing it from different locations from space.

(Fig. 5). Various InSAR Platforms and their salient features are tabulated in table: 3

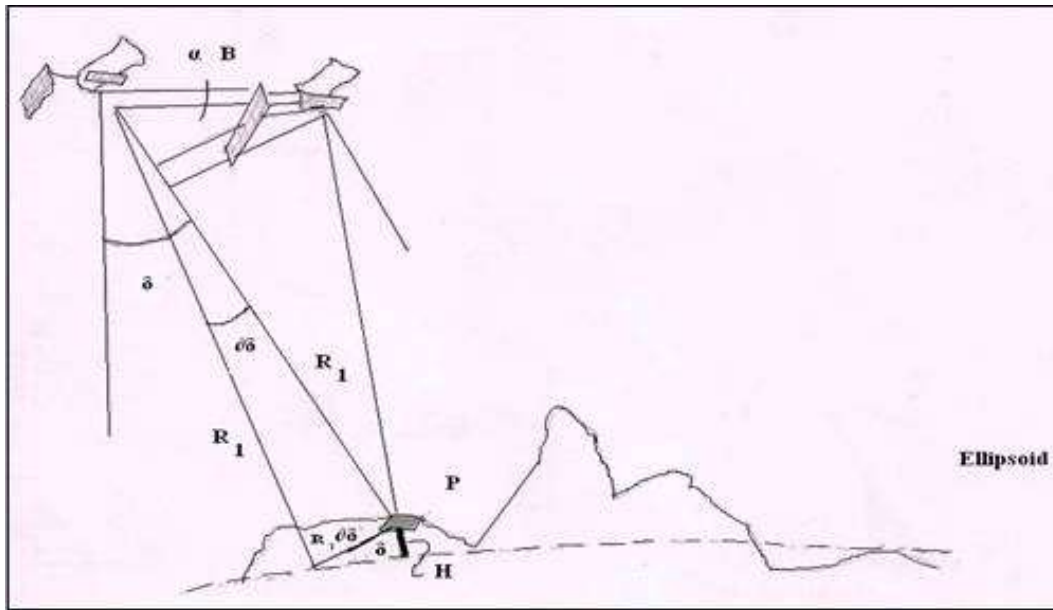


Fig: 5 Phase-height relationship

**Table: 3 Various InSAR Platforms and their salient features**

Characteristics/ Satellite	ERS*1/2	JERS	Radarsat	Envisat	ALOS	Terra SAR – X
Operator	ESA	Japan	Canada	ESA	Japan	Germany

<b>Operational Time</b>	1991-2004	1992-1998	1995	2002	2006	2007
<b>Wavelength</b>	C-band (6cm)	L-band (24cm)	C-band	C-band band	L-band	X-band (3 cm)
<b>Orbit Repeat</b>	35 days	44 days	24 days	35 days	46 days	11 days

The two coherent SAR images are used to form an interferogram, acquired from two antennas on the same space platform and located perpendicularly to the flight direction using SAR interferometry technique. An alternate method can be to use different passes of the same SAR antenna at different times using repeat pass interferometry technique. The phase ( $\xi$ ) of the range compressed signal is calculated by <sup>82</sup> Equation (2).

$\phi(\xi) = \frac{4\pi r(\xi)}{\lambda} = \frac{4\pi}{\lambda} \sqrt{r_0^2 + v^2 \xi^2} \approx \frac{4\pi}{\lambda} r_0 + \frac{2\pi}{\lambda r_0} v^2 \xi^2$	.....(2)
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Where,  $v_t$  is the velocity of onboard satellite,  $h$  is the height of flight above ground,  $r_0$  and  $r_t$  are distances of target from radar at different positions, and  $\lambda$  is the wavelength (Fig 15).

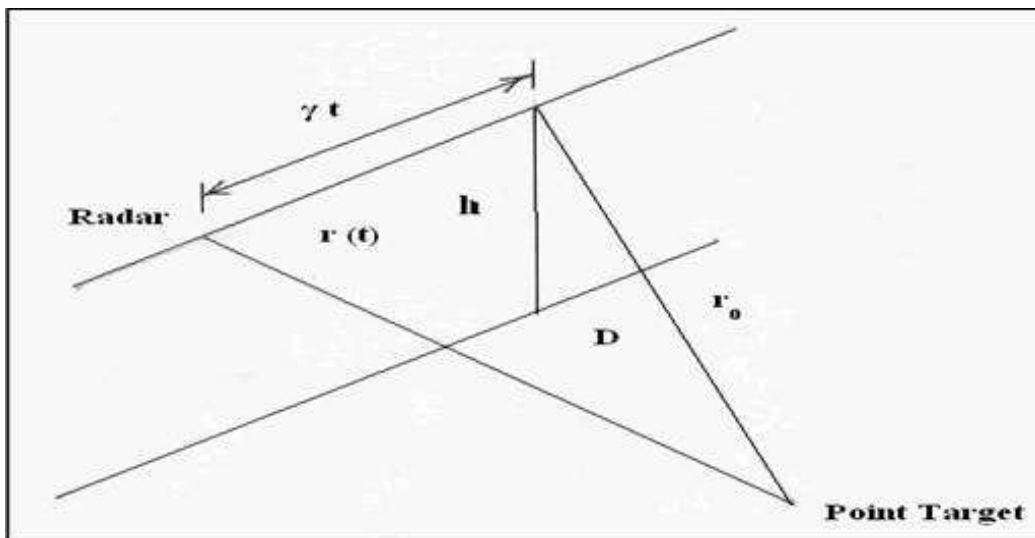


Fig: 6 Components of air borne radar platform during image capturing in various phases

## 2.5 INTERNATIONAL APPROACH FOR THE CSF MONITORING

The RS technique was first used in the 1960's for detecting the coal fires in the USA. Subsequently, this technique had been used in some of the Australian and Chinese coalfields for assessing CSF <sup>10 & 11</sup>. The RS of the surface thermal anomalies in the form of digital pixels depends on the flame depth (heat transfer) of the corresponding CSF, the reciprocal of the crack system (thermal convection) and the resulting physico-mechanical thermal state conditions.

Ellyett and Fleming (1974) <sup>12</sup> remarked that the CSF existed since the Pleistocene age. They conducted their study on Burning Mountain in South Wales, Australia using a Daedalus sensor (NASA - USA) that operated in the 8-14  $\mu\text{m}$  regions. USA uses space RS to detect coal fires through a "Reconofax" thermal scanner on an airborne platform. CSF of Chinese coal fields were monitored using ETM and Bird satellite data. Hyper spectral RS technology was used in mapping of the CSF in Dexing, Ruqigou, Gulaben and Wuda mining areas of China. The night time band data of 8-12.5  $\mu\text{m}$  provides the highest 3-5 $\mu\text{m}$  daytime band data has the highest ability to provide coal fire detection.

The sub-pixel-high-temperature and thermal anomaly could be corrected on applying Bi-spectral method <sup>13, 14 & 15</sup>. The various threshold methods such as trial and error <sup>16, 17; 18</sup>, thermal mean value derivation adding a standard deviation of two <sup>19 & 20</sup> and the slope of the histogram of thermal values <sup>21</sup> had been used to estimate the thermal anomalies. Permanent Scatterer (PS) stacking and 2-pass DInSAR were applied in the Wuda coalfield of Northern China to demarcate the subsidence occurring due to the coal fires <sup>21</sup>. Table 4 summarizes the published work by the researcher on the monitoring of the CSF world over.

**Table: 4 work done for CSF monitoring**

S. No	Monitoring Method	Deliverable for the CSF	Limitations	Associated workers
1.	Borehole drilling	Detection of the Side-view and the vertical distribution	Time consuming	Xinjiang <sup>22</sup>
2.	Underground gasses measurement	-the state of underground burning. The concentrations of adsorbed radon gas on carbon seams or on sediments on top are greatly increased due to high temperature.	Cannot distinguish gases that are derived from carbon fires. Time consuming	Gaetano, et al. <sup>23</sup> , Xie, et al <sup>24</sup> , Lu, et al. <sup>25</sup> Krietsch, et al. h <sup>26</sup> ,Schloemer ,et al. <sup>27</sup> & Litschke, et al. <sup>28</sup>
3	Surface temperature measurement	-Distinct areas of CSF by thermal disruption. -all stages of the fire, with the exception of extinguished fires, -ground level measurement, - cracking and - gas temperatures	Time consuming	Yu, et al. <sup>29</sup> , Kuenzer, et al. <sup>30</sup> , Litschke, T et al. <sup>31</sup> & Schloemer et al. <sup>32</sup>
4	Ground mapping of surface features	- the carbon leakage area, -the density & the cracks in the rocks -Surface properties associated with mapping by observation and field work	Time consuming	Kuenzer et al. <sup>33</sup> , Kuenzer et al. Kuenzer et al. <sup>34</sup> & Kuenzer et al. <sup>35</sup>
5	Self-potential Method	-the carbon dioxide zones -active fire and fire direction.	show superficial carbon fires	Kuenzer et al. <sup>36</sup> , Luo et al. <sup>37</sup> Shao et al. <sup>38</sup> & Zhang et al. <sup>39</sup>
6	2-D electrical imaging method	-the depth of the fire, -the location of a combustion center, caves and burning zones,	Time consuming, -it is impossible to confine the layers;	Li et al. <sup>40</sup> & Shao et al. <sup>41</sup>

		-all the rough steps, except for flammable fires. - Moisture content, - porosity, - sediment,	-it is difficult to detect new fire;  -limiting the terrain;  -limited scale of measurement	
7	Transient Electromagnetic method (TEM)	-detect the fire protection and combustion center -caves and demolitions	Time consuming	Cai et al. <sup>42</sup> & Dai et al. <sup>43</sup>
8	Magnetic techniques	- Magnetic abnormalities - the burnt rocks as magnetic deviations	-Time-consuming (soil survey), -expensive (airborne research),	Schaumann et al. <sup>44</sup> , Wang et al. <sup>45</sup> , Zhang et al. <sup>46</sup> , Shao et al. <sup>47</sup> , Xiong et al. <sup>48</sup> , Lindner et al. <sup>49</sup> , & Schaumann <sup>50</sup>
9	Ground penetrating radar	-Weak zones -Habitation, caves and ruins that recognize the depth of a single fire; -burning and extinguished fires with broken areas and caves	Time-consuming -low sensitivities for coal fires - limitation of depth penetration	Chen et al. <sup>51</sup> Gundelach <sup>52</sup> Yang et al. <sup>53</sup>
10	Aerial photographs	-Detection of heat -Smoke, mining-affected area and patterns of land parcels	Expensive	Zhang et al. <sup>54</sup>
11	Spectral RS	LULC the direction of fire.	Expensive	Sun et al. <sup>55</sup> , Zhang et al. <sup>56</sup> & Zhang et al. <sup>57</sup>

12	UAV with thermal camera	CSF thermal disruption	Expensive	Vasterling et al. <sup>58</sup> & Vasterling <sup>59</sup>
13	HSS RS	-Temperature abnormalities -burnt rocks	Expensive	Wan et al. <sup>60</sup> , Tan et al. <sup>61</sup> & Mao <sup>62</sup>
14	Space borne MSS, Landsat.	-Detection of surface properties of carbon fire zones	Low precision; solar radiation,	Kuenzer et al. <sup>63</sup> , Kuenzer et al <sup>64</sup> , Wen <sup>65</sup> , Kuenzer et al, Kuenzer et al, Kuenzer et al <sup>66</sup> , Kuenzer et al <sup>67</sup> , Tetzlaff <sup>68</sup> & Huo et al <sup>69</sup>
15	High resolution (Ikonos,)	-Cracks and Mining activity -Infrastructures	Limited spectral analyzes and data collection	Kuenzer <sup>70</sup> , Yang <sup>71</sup> & Chen <sup>72</sup>
16	Radar	Land parcel distinction	Small accuracy	Liu <sup>73</sup> , Zhou <sup>74</sup> & Huang <sup>75</sup>

## 2.6. CSF RESEARCH IN INDIA AND JCF

In India, JCF is the worst affected coalfield by surface and subsurface CSFs. A total of 78 CSF in JCF and 11 in the western part of Raniganj coalfields (RCF) are reported. The majority of the RS studies in India were based on the hyper spectral, optical RS, thermal RS or radar data. A number of researches carried out by<sup>83,84,85,86 & 87</sup> for coalfire detection in JCF used airborne pre-dawn thermal infrared and daytime multispectral data. They attempted to estimate the depth of the fire using a linear heat flow equation.<sup>88</sup> Reddy, C. S. S., Srivastav, S. K. and Bhattacharya (1993) used Landsat TM bands 4, 5 and 7 of SWIR (Short Wave Infra Red) region of EMR for detection.

Prakash et al.<sup>89</sup> used TM TIR and SWIR band data of Landsat dual band approach to identify CSF in JCF. Chatterjee, et al.<sup>90</sup> carried out, field based modelling with pixel integrated temperature approach to differentiate surface and subsurface coal fire pixels for assessing the propagation and the location of the surface coal fires. Coalfire dynamics were monitored using Landsat TM thermal infrared, medium resolution optical multispectral satellite (NIR and red-band) of Landsat-5 TM, IRS 1C LISS-III and Landsat-7 ETM+ sensor data in JCF. Nishant Gupta, Tajdarul H Syed and Ashiihrii Athiphro (2013)<sup>91</sup>, worked on DinSAR data for the assessment of the subsidence related to underground coalfire. Surface displacement between two sets of data was estimated by integrating the phase differences of two consecutive Din SAR data.

## **2.7. LAND USE AND LAND COVER AND CSF**

LULC change is an important concern all over the world, which reveals environmental alteration<sup>92</sup> exceptional anthropogenic disorder<sup>93</sup>. Land is the inherent resource of extreme importance and original source of all material wealth of human being. The extraction of natural resources is invariably associated with land use land cover changes<sup>94</sup>. Current techniques of mining using heavy equipment can produce sudden alterations in land cover, both ecologically and hydrologically<sup>95 & 96</sup>. Mining operations result in the transformation of the topography<sup>97</sup> and drainage pattern<sup>98, 99 & 100</sup>. Its principal environmental effects are physical disturbance such as landscape<sup>101 & 102</sup>, soil erosion and degradation<sup>103</sup> and environmental alterations<sup>104 & 105</sup>. The natural resources occur in environmentally complex and endangered forest cover areas. About 95% of the coal reserves of India are produced from 44 known coal fields of Peninsular India<sup>106</sup>. It is essential to investigate the effect of mining on land use land cover changes to minimize its impact on the environment as well as for proper land management for CSF decision making

<sup>107</sup>, <sup>108</sup>, <sup>109</sup> & <sup>110</sup>. To ascertain such changes, earth resource satellite data are critically important and useful for land use/land cover change studies <sup>111</sup>. Extensive underground mine fires is continuing since long time in JCF of Indian sub-continent, destroying millions of tonnes of coal. The RS & GIS tools with satellite imageries have been used for the surveillance, identification and transformation of land parcel as LULC for assessing CSF. The CSF detection, using airborne predawn thermal infrared and day time multi spectral data was done by <sup>112</sup> & <sup>113</sup> after the traditional method of bore hole drilling. Landuse alterations were computed by the satellite model obtained from the temperature values of the pixels representing surface and sub-surface CSF. They attempted to estimate the depth of the fire using a linear heat flow equation. The surface and the immediate subsurface characteristics heavily influenced LULC. For any site, the natural and the artificial integuments under CSF surveillance of land parcels, include forests, grasslands, croplands, soil, topography, surface water, groundwater, human structures and urban structures. The design of the land use classes and the monitoring of their changes with temporal interval require information system. These RS & GIS tools are important in studying LULC patterns, associations and the related dynamics.