CHAPTER III
REMOTE SENSING AND COAL FIRES

3.1 REMOTE SENSING APPLICATION IN ENVIRONMENTAL STUDY
Remote sensing is a very commonly used term, but it is rarely defined because of its largely self-explanatory nature. Remote Sensing is the science and art of obtaining information about an objective area or phenomenon through the analysis of data acquired by a device that is not in contact with the objective, area or phenomenon under investigation (Lillesand and Kiefer, 1994). Remote sensing is broadly defined as collecting and interpreting information about a target without being in physical contact with the object (Sabins, 1987).

The term remote sensing is commonly restricted to methods that employ electromagnetic energy (such as light, heat, and radio waves) as the means of detecting and measuring target characteristics. The definition of remote sensing is restricted to mean the process the acquiring information about any objective without physically contacting it in anyway, regardless of whether the observer is immediately adjacent to the object or millions of miles away. It is further required that such sensing may be achieved in the absence of any matter in the intervening space between object and observer. Constantly the information concerning the object must be available in a form that can be impressed on a carrier that can transport the information even through a complete vacuums. The information carries or communications link is electromagnetic energy.

The sensing system without being in physical contact with the object, records electromagnetic radiations either reflected or emitted by the earth’s surface (rock, soil, vegetation, water bodies etc.) and are modified by the processes of absorptions and transmission. This characteristic spectral reflectance of an object in a range of electromagnetic radiations is called spectral signature and forms the basis of its discrimination from other objects in an image data set.

3.1.1 Historical development of remote sensing
Remote sensing at first started through the launch of small rockets in 1890s to obtain a bird’s eye view of the earth’s surface features from a height. It received a great boost during the 1940s using small cameras on board small rockets. There was a remarkable progress, even though remote sensing was not the main mission, during the war period. In
many ways, the early activities precluded the development of modern remote sensing techniques. Missions with human being in rockets followed in 1950s and 1960s, and helped scientists to acquire unprecedented amounts of knowledge about the earth.

As human missions are of short duration, the amount of useful survey information obtained is minimal. To satisfy the need for more comprehensive coverage, Landsat-1 (ERTS-1-Earth Resources Technology Satellite) was launched. This was the first unmanned satellite specifically designed to acquire data as an experiment to test the feasibility of collecting earth resource data from such satellites. As the data obtained was useful, other Landsats were launched (Landsat-1, 2, 3, 4, 5, 6, & 7). Meanwhile, SPOT satellites, which are near polar arbiters, were launched by France for commercial purposes. India began its remote sensing related space mission with the launching of Indian Remote Sensing Satellite (IRS) system. The IRS I-A was launched on March 17, 1988, and the latest in the series is IRS 1-D in September 29, 1997. At present the IRS data do not come in thermal bands and hence Landsat data were used in the study.

Remote sensing includes two distinct wings viz. (i) aerial remote sensing which is mainly concerned with conventional aerial photographs, (ii) satellite or space remote sensing which mainly deals with the digital data transmitted from the space-borne sensors to the ground control stations. Before, 1960, aerial photography was the triumph card in the hands of earth scientists and was the only means to getting up to-date information (Reeves, 1975).

During the last thirty years there has been a tremendous development of this technology mainly due to the revolutionary changes in information processing and data analysis techniques.

3.1.2 Components of remote sensing
The essential components of remote-sensing are as follows (Jain, 1993).

i) **Energy source:** Sun is the main energy source as the reflectance of an object in the recording of image depends solely on the sun's radiating energy (wavelengths or frequency)

ii) **Atmosphere:** Intervening atmosphere plays a significant role in the attenuation or filtration of radiation, both on its way to and way back from earth surface. It may be
pointed out that the attenuation is wavelength selective and only certain wavebands are nearly free from it, which is termed as 'Atmospheric windows'. For this reason sensors with all spectral bands are designed within these windows only.

iii) *Surface features:* Earth surface features interact with the incoming solar radiation and wavelength selectively reflect, scatter, transmit/absorb and finally emit this radiation. It may be mentioned that variations in reflectivity, scattering, transmission and emission depend on the variable character and nature of the objects on the earth’s surface.

iv) *Sensors:* Sensors quantitatively record the outgoing solar radiation in various pre selected spectral bands as equivalent electric charge while passing over an area.

v) *Transmission:* Data or signals recorded by different sensors are telemetered to the ground control station where these data/signals are recorded on high density digital tapes (HDDT).

vi) *Data processing:* The recorded data/signals on high density digital tapes are outputted in computer compatible tapes (CCT) or as imagery on film/paper after due corrections (radiometric and geometric).

vii) *Multidisciplinary use:* Finally different scientists use this data for specific purposes by selecting appropriate band. The results are being obtained either through visual interpretation of imagery or through the analysis of digital data in selected spectral band.

### 3.1.3 Electromagnetic energy

Electromagnetic energy refers to all energies that move with the velocity of light in a harmonic wave pattern. A harmonic pattern consists of waves that occur at equal intervals of time. The wave concept explains how electromagnetic energy propagates (moves), but this energy can only be detected as it interacts with matter. Suits (1983) describes the characteristics of electromagnetic energy that are significant for remote sensing.

Properties of electromagnetic waves can be described in terms of their velocity, wavelength (λ) and frequency (v). All electromagnetic waves travel at the same speed (C). This velocity is commonly referred to as the speed of light, which is one form of electromagnetic energy.
3.1.4 Electromagnetic radiation (EMR)

Electromagnetic Radiation (EMR) is a dynamic form of energy, which is propagated as a wave motion at a velocity of light. Electromagnetic waves are energy transported through space in the form of periodic disturbances of electric and magnetic fields. All electromagnetic waves travel through space at the same speed, \( (2.99792458 \times 10^8 \text{ m/s}) \) commonly known as the speed of light. An electromagnetic wave is characterized by a frequency and a wavelength. These two quantities are related to the speed of light by the equation,

\[
\text{speed of light} = \text{frequency} \times \text{wavelength} \quad (c = \lambda \nu)
\]

The frequency (and hence, the wavelength) of an electromagnetic wave depends on its source. There is a wide range of frequency encountered in our physical world, ranging from the low frequency of the electric waves generated by the power transmission lines to the very high frequency of the gamma rays originating from the atomic nuclei. This wide frequency range of electromagnetic waves constitute the Electromagnetic Spectrum.

3.1.5 Electromagnetic spectrum

The electromagnetic spectrum is the continuum of energy that ranges from matters to nanometers in wavelength, travels at the speed of light, and propagates through a vacuum such as outer space. All matter radiates a range of electromagnetic energy, with the peak intensity shifting toward progressively shorter wavelengths with increasing temperature of the matter. In remote-sensing, it is common to categorize electromagnetic spectrum.

Waves are different by their wavelength location within electromagnetic spectrum. The electromagnetic spectrum can be divided into several wavelength (frequency) regions (figure-3.1), among which only a narrow band from about 0.4 to 0.7 (\( \mu \text{m} \)) is visible to the human eyes and 8 to 14 \( \mu \text{m} \) being used for thermal satellite remote sensing.
The electromagnetic spectrum that is divided on the basis of wavelength into different regions, ranges from the very short wavelengths of the gamma-ray region to the long wavelengths of the radio region. The visible region (0.4 μm - 0.7 μm wavelength) occupies only a small portion of the spectrum. The maximum amount of energy is reflected at 0.5 μm wavelength, which corresponds to the green band of the visible region and is called the reflected energy peak. The earth also radiates energy both day and night with the maximum energy radiating at 9.7 μm wavelength. This radiant energy peak occurs in thermal band of the IR region.

The 'visible' portion of electromagnetic spectrum is an extremely small one, since the spectral sensitivity of the human eye extends only from about 0.4 μm to approximately 0.7 μm. The colour 'blue' is ascribed to the approximate range of 0.4 to 0.5 μm 'green' to 0.5 to 0.6 μm and 'red' to 0.6 to 0.7 μm. Ultraviolet (UV) energy adjoin's the blue and of the visible portion of the spectrum. Adjoining the red end of the visible region are three different categories of infrared (IR) waves: near – IR (from 0.7 to 1.3 μm), mid – IR (from 1.3 to 3 μm) and thermal – IR (beyond 3 μm). At much longer wavelengths (1 mm to 1m) is the microwave portion of the spectrum.

Region of electromagnetic spectrum which are primary concern in remote sensing:

1. Optical wavelength (Visible, Near IR, Middle IR) – 0.3 μm – 16 μm.
2. Microwave wavelengths – 1 milimetre to 1 metre.

3.1.6 Interaction of energy with matter

Electromagnetic energy that encounters matter, where solid, liquid, or gas is called incident radiation. Interactions with matter can change the following properties of the incident radiation: intensity, direction wavelength, polarization and phase.

During interactions between electromagnetic radiation and matter, mass and energy are conserved according to basic physical principles. The incident radiation may be (Sabins, 1978).

i) Transmitted, that is, passed through the substance. Transmission through media of different densities such as from air into water causes a change in the velocity of electromagnetic radiation.

ii) Absorbed, giving up its energy largely to heating the matter.

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iii) *Emitted* by the substance, usually at longer wavelengths, as a function of its structure and temperature.

iv) *Scattered*, that is deflected in all directions.

v) *Reflected*, that is returned from the surface of a material with the angle of reflection equal and opposite to the angle of incidence. Reflection is caused by surfaces that are smooth relatively to the wavelength of incident energy. Polarization or direction of vibration of the reflected waves may differ from that of the incident wave.

Emission, scattering, and reflection are called surface phenomena because these interactions are determined primarily by properties of the surface, such as colour and roughness. Transmission and absorption are called volume phenomena because these interactions are determined by the internal characteristics of nature, such as density and conductivity. These interactions between matter and energy are recorded on remote sensing images, from which one may interpret the characteristics of matter.

### 3.1.7 Energy interactions in the atmosphere

The radiation detected by remote sensors, passes through some distance or path length of atmosphere. The net effect of the atmosphere varies with these differences in path length and also varies with the magnitude of the energy signal being sensed, the atmospheric conditions present and the wavelengths involved. The effects are caused principally through the mechanisms of atmospheric scattering and absorption.

### 3.1.8 Energy interactions with the Earth’s surface

When a light wave is incident on a surface, it will be reflected, transmitted, or absorbed. Furthermore, the energy of the absorbed radiation can be re-emitted as other form of radiation. When EM radiation is incident on a given surface feature, out of the three fundamental processes the reflected part is often of interest in remote sensing. The reflected part will be different for different earth features depending on the type of material and the condition of the material (e.g. dry or wet). Reflectivity is also dependent on the wavelength or frequency of the incoming radiation.
Different objects have very distinct spectral reflectance curves. It is the differences in spectral reflectance that allows one to distinguish different materials and objects using remotely sensed reflected radiation.

For thermal infrared wavelengths, the reflected radiation is outweighed by the emitted energy of the surface features. Hence in the thermal infrared, the radiation received from an object depends on its emissivity and temperature. Meanwhile, the temperature of an object will depend on its absorptivity (how much radiation it absorbs), its thermal conductivity (rate at which heat pass through a material), thermal capacity (ability of a material to store heat), and thermal inertia (thermal response of material to temperature change).

The EMR as an interaction experiences a number of changes: in magnitude, direction, wavelength, polarization and phase. These changes are detected by the remote sensor and enable the analyst/interpreter to obtain useful information about the object of interest. The remotely sensed data contains both spatial information (size, shape and orientation) and spectral information (tone, colour, spectral signature).

3.1.9 Application of remote sensing
Successful application of remote sensing is premised on the integration of multiple, inter repeated data sources and analysis procedures. Conceptually, all designs of successful remote sensing efforts involve at a minimum (i) clear definition of the problem at hand, (ii) evaluation of the potential for addressing the problem with remote sensing techniques, (iii) identification of the remote sensing data acquisition procedures appropriate to the task, (iv) determination of the data interpretation procedures to be employed and the reference data needed, and (v) identification of the criteria by which the quality of information collected can be judged. The success of many applications of remote sensing is improved considerably by taking a multiple view approach to data collection.

3.2 THERMAL REMOTE SENSING
All objects above absolute zero emit radiation by virtue of their molecular collision. The changes in energy, emitted as radiations, fall in the thermal infrared region (3-15 μm) of the electromagnetic spectrum and can be detected externally using appropriate sensors. Thermal energy of a substance is indicated by its kinetic temperature (internal: measured by thermometers) or its radiant temperature (external: measured by radiometers). It is the quantity of radiant temperature which is usually measured by remote sensors. The
observations in the thermal wavelength of the electromagnetic spectrum is known as the thermal remote sensing. The wavelength is limited in between 3-14 μm. Thermal IR (Infrared) region – IR radiation at wavelengths of 3-14 μm is called thermal IR region. Different types of scanner are used to detect it.

The most important physical laws which form the fundamental basics of thermal IR remote sensing are as follows:

a) Planck’s Law
Certain emitting surfaces exist whose radiation characteristics are completely specified if their temperature is known. These are the ideal thermal radiators known as ‘black bodies’. The spectral distribution of the radiation emitted by a black body is given by Planck’s law as,

\[ L_{BB\lambda} = \int_\lambda^{\lambda_1} \left( \frac{2hc^2}{\lambda^5} \left( \frac{1}{e^{\frac{hC}{\lambda kT}} - 1} \right) \right) d\lambda \]

(1)

where,

- \( L_{BB\lambda} = \) spectral radiance emittance W/m²/Sr.
- \( \lambda = \) wavelength (m).
- \( h = \) Planck’s constant = 6.63 x 10⁻³⁴ Joule-Sec.
- \( T = \) Absolute temperature K
- \( C = \) speed of light = 3 x 10⁸ mt./sec.
- \( K = \) Boltzmann constant = 1.38 x 10⁻²³ Joule/K.

b) Stefan – Boltzmann’s law
This law states that the total radiation emittance integrated over all wavelengths depends on the fourth power of absolute temperature of the body. The relation between the radiant temperature, the quantity usually measured by remote sensors, and the kinetic temperature can be derived from the Stefan – Boltzmann law. It is given as:

\[ L_{BB\lambda} = \varepsilon \sigma T_{kin}^4 \]

(2)

where,

- \( L_{BB\lambda} = \) total emitted radiance W/m²
- \( \varepsilon = \) Stefan Boltzmann constant 5.66997 x 10⁻⁸ W/m²/K⁴
- \( T_{kin} = \) Temperature of the blackbody K.

All real bodies are characterised by radiant temperatures that are less than their kinetic temperature by a factor known as emissivity (\( \varepsilon \)).
c) Wien's displacement law
The relationship between the temperature of the radiation is known as the Wien's displacement law, obtained by differentiating Plank's law, which is given as follows:

$$\lambda_{\text{max}} = \left(\frac{2897.8}{T}\right) \mu m \cdot k$$

(3)

All matter radiates energy at thermal IR wavelengths (3 to 15 micro meter) both day and night. The ability to detect and record this thermal radiation in image form at night takes away the cover of darkness and obvious reconnaissance application.

3.2.1 Blackbody, emissivity and radiant temperature

a) Blackbody: An ideal thermal emitter called a blackbody. It is good observer and good radiator. It is an ideal radiator that totally absorbs and re-emits all energy incident upon it. The concept of a blackbody is fundamental to understanding heat radiation. A blackbody is a material that absorbs all the radiant energy that strikes it, which means: absorptivity = 1. A blackbody also radiates all of its energy in wavelength distribution pattern that is dependent only on the kinetic temperature.

b) Emissivity: The emitting ability of a real body compared to a blackbody, is referred as a material's emissivity. Emissivity is the ratio of radiation emitted by a blackbody or a surface and the emissivity for a blackbody is one, but for all real materials is less than one. Emissivity is wavelength dependent, which means that the emissivity of a real material will be different when measured at different wavelengths of radiant energy.

Emissivity is a measure of the ability of a material both to radiate and to absorb energy. Materials with a high emissivity absorb large amounts of incident energy and radiate large quantities of kinetic energy. Materials with low emissivities absorb and radiate lower amounts of energy. It depends on (1) surface geometry, (2) composition, (3) wavelength

c) Radiant temperature \(T_{\text{rad}}\) – Most thermal IR remote sensing systems record the radiant temperature \(T_{\text{rad}}\) of terrain rather than radiant flux (is the time rate with which the energy passes a certain spatial position). Radiant temperature may be measured with non-imaging remote sensing devices called radiometers.
3.3 PROPERTIES OF THERMAL RADIATION

The following properties illustrate some basic concepts that are useful for understanding the physics behind remote sensing.

Applying the Energy Law for non-directional, spectral quantities, it is clear that the energy from each photon incident on a surface must go somewhere. Under equilibrium and non-directional conditions, this also means that the sum of the ratio's absorptance, reflectance, and transmission is unity.

\[ \alpha + \rho + \tau = 1 \]

Kirchhoff's Radiation law for non-directional, spectral quantities the hemispherical absorptance (that from all angles) of a material in thermodynamic equilibrium with its surroundings equals the hemispherical emissivity. In other words, good emitters are good absorbers.

\[ \alpha = \varepsilon \]

Combined with the conservation of energy, this means that with no transmission, emissivity is the complement of reflectance.

\[ \varepsilon = 1 - \rho \]

The physics of radiometry in the thermal infrared is no different than that in other parts of the electromagnetic spectrum, except that both reflected and emitted radiation makes a significant contribution to the total signal. Radiometric quantities are most generally spectral and the units are per unit wavelength interval. When the spectral values are integrated across a detector's response band, they are called band-averaged quantities. In addition, these quantities are most generally directional, in other words, they vary with source or detector angle. Often, radiometric properties are approximated as non-directional, meaning that the value is the same from (or to) any direction.

In its idealized form, thermal radiation is modelled as blackbody radiation, which has a well-defined spectral curve that depends only on temperature, and is perfectly diffuse (no directional characteristics). More generally, emitted thermal radiation from objects can be modelled as the blackbody curve corresponding to a particular temperature multiplied by the spectral emissivity. If the emissivity is approximated as a constant with wavelength
and if there is no directional dependence, an object is said to be a grey body. This is a common approximation for natural materials. Some natural and man-made materials have a significant variation of emissivity and reflectance with angle and this must be measured or modelled by some means.

However, if the body were to be a perfect radiator, a blackbody, then the emitted energy would be a function of temperature only. A black body is an ideal absorber, absorbing all radiation impinging on it. It also a ideal emitter, transforming kinetic energy to radiant energy at the maximum rate possible, as determined from the law of thermodynamics. Planck’s law, which related spectral radiant emittance to temperature, is as follows:

\[
\frac{w_{\lambda}}{\lambda^5} = \frac{2\pi h c^2}{\lambda^5} \frac{1}{(e^{h c / \lambda k T} - 1)} \varepsilon_{\lambda}
\]

where,
- \(\lambda\) Wavelength in meters
- \(w_{\lambda}\) Spectral radiance
- \(h\) Planck’s constant = 6.63 \times 10^{-34} \text{ Js}
- \(T\) temperature in K
- \(\varepsilon_{\lambda}\) Spectral emissivity
- \(k\) Boltzmann’s constant = 1.38 \times 10^{-23} \text{ JK}^{-1}
- \(c\) speed of light = 2.99 \times 10^8 \text{ mt per second}

Properties of the Planck function are:
1. The product of the wavelength of the maximum and the temperature is a constant. \(\lambda T_{\text{max}} = 2896 \text{ K} \mu\text{m}\) High temperature sources emit at short wavelengths.
2. At long wavelengths or low frequencies (\(h \nu << kT\)) the radiance becomes proportional to temperature (\(E_{\nu} \sim 2\nu 2kT / c^2\)).
3. The total power emitted per unit area integrated over all frequencies is \(\nu T^4\) where \(\nu\) is the Stephan-Boltzmann constant.

### 3.4 STRUCTURE OF THERMAL REMOTE SENSING DEVICE AND CHARACTERISTICS

The pattern of radiant temperature variations of the terrain may be recorded as an image by air/space borne infrared scanners. Thermal remote sensing data used to collect by radiometers and scanners. Thermal Radiometer is non-imaging device, and thermal scanner is a imaging device. Thermal IR images; are produced by remote sensing scanner systems that consists of three basic components: (1) optical-mechanical scanning system,
(2) thermal IR detector, and, (3) image recording system. Quantum or photon detectors are used as thermal detectors are surrounded by liquid nitrogen at 77°K.

On most thermal IR images the brightest tones represent the warmest radiant temperatures and the darkest tones represent the coolest temperature. For thermal IR images, a semi conductor device detects the energy, and film serves only as a medium to display radiant temperatures.

3.5 APPLICATION OF THERMAL REMOTE SENSING
1. Geology – Dense rocks have higher thermal inertia, they show warm signature in night.
2. Military – Unusual concentration, Jungle trails can be identified by total changes.
3. Hydrology – Hot industrial effluents, hot springs.
5. Botany – Leaf temperature can be measured using 3-5 μm band, plant health, age etc.
6. Forestry – Forest fire beneath a forest cover, damage can be assessed even under excessive smoke condition.

3.6 COALFIRES AND SURFACE TEMPERATURE
The temperature of a surface depends on several factors. Those factors are not only inherent properties of a surface, but are also affected by the conditions of the surrounding area. In the case of a subsurface coalfires, the surface temperature also depends on rock and soil type, topography, local atmosphere, emissivity, crack or fissures on the surface, and depth of fire etc.

3.6.1 Effect of local atmosphere on surface temperature
Atmospheric factors that influence and decrease the surface temperature are evaporation and strong wind. Evaporation from a wet surface causes a strong decrease in surface temperature amplitude. It has been observed, if the surface is wet the overall heat transfer coefficient is larger than in the case of a dry surface (Rosema et al., 1999). Strong winds cause a reasonable impact on surface temperature and decrease the temperature amplitude.

3.6.2 Effect of ground material on surface temperature
Most of the ground material is composed of sediments and rocks, these materials are related to the thermal conductivity and volumetric heat capacity. Together with these
thermal properties, radiative properties also play a significant role in the temperature response of the surface to solar radiation, which is directly related to surface albedo or reflectivity ($\rho$) and the emissivity ($\varepsilon$). Table 3.1 describes thermal and radiative properties of some materials (which are geologically available in the RCB):

**TABLE 3.1: Thermal and radiative properties of some materials (cgs units for 20°C)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity $K$</th>
<th>Density $\rho$</th>
<th>Thermal capacity $C$</th>
<th>Thermal diffusivity $\kappa$</th>
<th>Thermal inertia $P$</th>
<th>Emissivity $\varepsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>0.0120</td>
<td>2.5</td>
<td>0.19</td>
<td>0.013</td>
<td>0.054</td>
<td>0.85</td>
</tr>
<tr>
<td>Shale</td>
<td>0.0042</td>
<td>2.3</td>
<td>0.17</td>
<td>0.008</td>
<td>0.034</td>
<td>0.95</td>
</tr>
<tr>
<td>Sandy soil</td>
<td>0.0014</td>
<td>1.8</td>
<td>0.24</td>
<td>0.003</td>
<td>0.024</td>
<td>0.92</td>
</tr>
<tr>
<td>Limestone</td>
<td>0.0048</td>
<td>2.5</td>
<td>0.17</td>
<td>0.011</td>
<td>0.045</td>
<td>0.93</td>
</tr>
<tr>
<td>Coal</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.5</td>
<td>0.95</td>
</tr>
<tr>
<td>Coal dust</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Source: Siegal B.S and Gillespie A.R. ed.

3.6.3 Effect of terrain on surface temperature
Topography and earth cover type (i.e. barren or vegetated, material type) of an area under investigation also has a significant effect on surface temperature. Slope and aspect play an important role with regard to surface temperature. Particularly during daytime, due to solar heating, the same surface has a different temperature compared to nighttime.

3.6.4 Effect of emissivity on surface temperature
Emissivity or emitting capability of a surface compared to a blackbody depends on the intrinsic properties of the surface. Emissivity depends on surface roughness, phase of matter and temperature of the body, it has a significant contribution towards the radiant temperature of a surface.

3.7 REMOTE SENSING METHODS USED FOR THE DETECTION OF COAL FIRES
There is a close relationship between remote sensing and coal fire. The remote sensing technique can explain and detect the fire prone area properly. In this chapter we have discussed the remote sensing in brief and relation in case of coal fire shortly.
A number of studies dealing with subsurface and surface coalfire detection and monitoring are presented in literature. Most of these studies are based on Landsat TM imagery or airborne thermal scanner data. In the following paragraphs the results of previous research will be discussed.

Borehole temperature measurements were the main tool to detect subsurface coalfires until the 1960s. The advantage of this method was that temperature measurements are done very close to the fire. It was difficult to gather enough data to give a large-scale synoptic view. At the early sixties when airborne thermal scanner data and later satellite borne thermal scanner data started to become available, remote sensing based coalfire detection and monitoring became possible. Many researchers worked on coalfire in the United States, Australia, India and China. Concentrating on coalfire detection, monitoring, depth estimation and thermal modelling mostly using Landsat TM and/or airborne thermal data.

3.8 DATA CHARACTERISTICS
To extract emissivity and temperature from multispectral thermal data for coal fire detection and monitoring purposes, different kinds of data sets with different spectral, spatial and temporal resolution are currently available. The satellite data used for this study to detect surface fires is Landsat 5 TM6.

3.9 OTHER METHODS FOR COALFIRE DETECTION
The conventional method is borehole temperature measurement in coal seams to identify anomalies. This method is useful to validate the processed remote sensing data and to identify deep subsurface fires. To measure the subsurface temperature anomalies using remote sensing, some geophysical methods are also being used. Two of them are described below.

3.9.1 Radioactive method
Sedimentary rocks contain radioactive elements like Uranium ($^{235}$U, $^{238}$U), Thorium ($^{232}$Th) etc. These radioactive elements emit $\alpha$ particles during decay. During this process they are transformed into Radon ($^{222}$Rn, $^{220}$Rn, $^{219}$Rn) having a half-life of 3.96 sec to 3.825 days. The concentration of $\alpha$ particles measured, depends on
temperature, that is, if temperature is higher the transportation of α particles is higher. Factors other than temperature influence the transportation are pressure, porosity and water content.

3.9.2 Resistivity method

By this method the resistance of rock is measured using a few electric poles. By measuring resistance in ohms (Ω) per meter and comparing these with the standard value. In normal condition the resistance of sedimentary rock is 600-800 Ω/m but in burnt rock it goes up to 1200-3000 Ω/m, because of high porosity, cracks and low water content.

In this chapter we have discussed remote sensing in brief. Because it is clear that coal fire detection is possible by proper remote sensing techniques.