1.1 INTRODUCTION

Mining is one of the primary activities in the world, and in developing and populous countries it assumes great importance for many reasons. Mining in these countries often does not require huge economic investment to extract minerals from smaller sized mines, but if they are large in size, they have a larger footprint on the local and regional environment. A clustering of smaller mines in an area may also lead to significant environmental impacts. Mining being a concentrated activity tends to draw attention to its physical imprint on land. Moreover, there is a resource dimension to mineral extraction. Minerals are to be treated as a ‘fund resource’ in environmental sustainability and any future developmental plans are affected by the care with which they are extracted. In the Raniganj coalbelt too, mining has led to significant environmental changes. This thesis studies these impacts with special emphasis on coal fires. Mining, therefore, creates economic development on the one hand and at the same time leads to environmental degradation on the other hand. It is evident that any kind of mining activities create economic development and at the same time it creates for environmental degradation, which is not an exception in coal mining. But coal mine fire or coalfires, which is a common problem in most coal producing countries, has a more deep impact on the environment besides great loss of a non-renewable resource.

Coalfire is a natural phenomena in most mining operations, though sometimes it is human induced as seen in some Indian coal mines (Sinha, 1986). Mine fire is a natural phenomenon all colliery areas of the world (Prakash and Gupta, 1998). It is a serious problem in many coals producing countries. These fires burn out precious natural energy resources, hinder mining operations and pose danger to humans and machines, besides leading to environmental pollution and problems of land subsidence etc. Coal fires are mainly of two types, surface and subsurface coal fires. Surface and subsurface coalfires are a ubiquitous problem in almost all coal-mining areas. Combustion can occur either spontaneously or can be assisted by an external heat source, and occur within the surface in coal seams themselves or in piles of stored coal or in spoil dumps on the surface. These fires are widespread in many coal producing countries such as India, China, Indonesia and many other developing countries (Van Genderen et al., 1996, Saraf et al., 1995).
India is rich in natural energy and mineral resources and is the third largest producer of coals in the world. Coal is an important energy store base for India for the twenty-first century.

Mining impacts on the environment in both positive and negative ways. The thesis discusses the harmful aspects of mining for the environment. Overall, The objective is to study the environmental impacts of mining, with special emphasis on the coal fires. Mining areas are suffering from some the poor quality of the environment and degradation in vegetation cover, soil, drainage, relief, flora and fauna. The question is, how much and where? Also, how can we preserve the pristine environment? What role do the coalfires play in further damaging environmental quality? These questions are to be addressed in this thesis. That’s why the title of the thesis has been selected as mine fire problem: A study in environmental impact of mining in the Raniganj coalbelt, West Bengal.

Among the coal-mining countries, China, Australia and India are prone to coal fires. Coal fires are an important issue in mining regions in India. Jharia and Raniganj coalfields are facing the problem. Thus, we can say that the issue addressed in the thesis is a national level problem with international ramification, although we have maintained a close focus on the Raniganj region in this study.

The justification for selecting the theme of environmental impacts of mining with special emphasis on coal mine fires is for its co-relation between international and national issues. Mining activities and their impacts on environment are represented on the spatial features such as land use, thus justifying the geographical nature of the study. We know mining is a primary economic activity has in both in large and small-scale production level. Therefore, our study is related to economic geography.

Mining has impacts on both physical and human environments at different scales. People in the mining area are influenced severely respect of social and cultural aspects. These changes in the mining area put more emphasis the social and cultural geographical nature of our study. However, the greater achievement of the study is the use of satellite images to locate areas of coalfires.

Overall discussion in the thesis is about coal mining activities and its impacts on the environment in a specific geographical region. Such studies have wider geographical significance at every level of space.
1.2 COAL MINING, COALFIRES AND THE ENVIRONMENT

Coal is one of the non-renewable energy sources used in the majority of developing countries. With time, the use of coal has increased in the industrial sector as well as in other sectors. Coal mining and its related activities not only provide the energy resources, but also causes environmental hazards. Underground or opencast, any kind of coal mining operation has enough negative impacts on environment. Mining operations are directly related to deforestation, subsidence, lowering of groundwater table, air and noise pollution, destruction of microbes in the soil, which recycle the biodegradable matters, and the dereliction and degradation of land. Of all these, coal fires have most significant harmful effects on the environment. The environmental effects of the coal mine fires can be felt at both local and global levels.

Coal fires, contribute to greenhouse gases and leads to local and global warming. Noxious gases often affect the immediate surroundings of an active subsurface coal fires. As well as being unpleasant, this pollution especially that caused by carbon monoxide, can have fatal consequence. The general degradation of the land results as plants in the area are killed by the heat or are poisoned by the gases. The fire-affected villages face another major problem – that is land subsidence. Mining induced subsidence, on the other hand, cause horizontal and vertical movement in the land surface and open cracks and fissures that serve as inlets for oxygen, which in turn aggravates the problem of coal fires. In case of underground fire-related subsidence, the land does not recover to its pre-existing condition even if careful rehabilitation measures are undertaken. Thus, it is lost forever to humankind as a resource. In the Raniganj region, such fires and subsidence have significantly affected agricultural activities in negative ways. Thus both the human and natural resources of the region are endangered.

Heating due to subsurface fires has caused drying of the soil. The dryness of the soil has increased its reflectance and also rendered it locally unfit to support vegetation over the subsurface fire areas. Thus, the thermally anomalous regions are notably barren. Dry and barren higher temperature areas can be easily identified on satellite sensor images and these many serve as indicators of the presence of subsurface fires (Gupta and Prakash, 1998).
1.3 BACKGROUND OF COAL FIRES

Underground and surface coal fires are serious geological hazards in many coal mine regions in the world. Spontaneous fire can occur either within the underground coal seams themselves or in piles of stored coal and in spoiled dumps on the surface.

Coal fires can cause grievous economic and environmental problems. Firstly, the coal fires consume a huge amount of coal resources causing economic loss. Secondly, the environmental effects of coal fires cause serious problems at both local and global levels. During the burning of coal fires, there are some kinds of noxious gases diffuse out. Such gases are sulphur dioxide (SO$_2$), nitrogen oxides (NO), carbon monoxide (CO), carbon dioxide (CO$_2$) and methane (CH$_4$) (Bhattacharya and Reddy, 1994). Unfortunately, these gases contribute to the green house effect. The smoke and windblown ash can plague the areas around coal fires. In general, fires cause land degradation and vegetation. Furthermore, in some areas, the coal fires may even cause desertification.

Widespread cracking and subsidence of the land surface are other associated problems. Surface collapse may cause extensive damage to infrastructure, such as buildings, roads, railways, etc. Problems caused by coal fires are:

1. Loss of coal resource;
2. Effect or damage to coal mining infrastructure or surrounding infrastructure;
3. Degradation of the land and vegetation and damage to the ecological system;
4. Serious environmental pollution; and
5. Safety and health risk for miners, and local residents.

1.3.1 Mechanism of coal fires

Coal, the most used fossil fuel, is a readily combustible rock containing more than 50 percent by weight of carbonaceous material, formed from compaction and induction of variously altered plant remains. Unpredictable amounts of other chemicals such as sulphur, chlorine, sodium, and various other minerals can be found in coal.
The physical properties of coal, such as colour, specific gravity, and hardness, vary considerably. This variance depends on the composition and the nature of preservation of the original plant material that formed the coal, the amount of impurities in the coal, and the amount of time, heat and pressure that has affected the coal since it was first formed. Time, heat and pressure also determine the rank of the coal, which is classified according to the increasing amount of carbon as lignite, subbituminous coal, bituminous coal, and anthracite.

Coal is a complex mixture of chemical compounds, mostly organic. Separate chemical compounds can be isolated from a single lump of coal, but most are combinations of the elements carbon, hydrogen, oxygen, nitrogen and sulphur.

Oxidization of coal is a chemical process, which can be defined, in a simplified form as:

\[ \text{COAL} + \text{O}_2 \rightarrow \text{CO}_2 + \text{Energy} \]

In simplest terms, coal fires are caused by oxidation of coal. A broad outline of the mechanism of the chain of reaction is stated below (following Banerjee, 1985, Schmal, 1987). There are several ways coal fires can be ignited, these include forest fires (Berstin and Mathews, 1982, 1985) lightning (Guan, et al., 1996) manmade fires, and most importantly, spontaneous combustion.

The potential for spontaneous combustion of coal lies in its ability to react with oxygen at ambient temperature. This occurs through the *absorption* of oxygen at the surface of the coal and is an exothermic reaction. The temperature of the coal then starts to rise. If the temperature reaches what is often called the ‘threshold’ temperature – somewhere between 80°C and 120°C – a steady reaction resulting in the production of gaseous products such as carbon dioxide ensues. The temperatures of the coal will then almost certainly continue to rise until, somewhere between 230°C and 280°C, the reaction becomes rapid and strongly exothermic – in other words, the coal reaches ‘ignition’ or ‘flash’ points and starts to burn.
FIGURE-1.1: Mechanism of coalfires

Adsorption of oxygen at the coal surface, temperature starts to rise

\[ \downarrow \]

Reaches threshold temperature (80°C – 120°C)

\[ \downarrow \]

Production of CO\(_2\)

\[ \downarrow \]

Further rise in temperature

\[ \downarrow \]

Ignition at ‘flash’ point.


External factors also play a role in the oxidation reaction. Oxidation requires an adequate supply of air and so cracks, fissures and porosity of rock and soil over the coal seams may encourage underground coal fires by allowing oxygen to reach the coal. A very rapid air flows or by conduction through the coal itself and the surrounding rocks may remove the heat produced by the oxidation. But in general the thermal conductivity of coal is quite poor. The removal of heat is only likely stopping the process in the initial stages of the oxidation reaction. Once the threshold temperature is reached and the second stage of the reaction begins. Heat is usually generated at too great a rate and the temperature of the coal will continue to rise until combustion starts (Van Genderen et al., 1996).

The presence of water also has some important effects; coal with a very low moisture content tends to exhibit a low oxidation rate. However a minimum amount of water is considered necessary for the reaction to continue.

Because of the intrinsic ability of coal to react with oxygen even at ‘normal temperatures’ it is also possible that the fire can occur in coal seams without any human influence (Zhang and Kroonenberg, 1996). A few fires are entirely anthropogenic, that is human made. These are caused by an external heat source setting fire to the coal, such as the
illegal distillation of the alcohol in Indian coal mines (Sinha, 1986). Thus unauthorised mining leading to the formation of cracks, which help breathing of oxygen into coal seams.

Coal in the Raniganj is prone to form spontaneous combustion when in contact with oxygen. Furthermore, the problem of spontaneous combustion is aggravated because of the irregular mining.

Spontaneous combustion of coal occurs due to the accumulation of heat liberated from the interaction of oxygen in air with coal, in ambient temperature and its poor thermal conductivity favouring heat accumulation. This interaction with oxygen is chiefly due to the oxidation of carbonaceous matter in coal. The other factors that might also assist in the generation of heat are due to the oxidation of pyrite present in coal and absorption of water vapour in coal. Heating due to bacterial action (as in the case of spontaneous heating of haystacks of jute) or from earth movements are, however, not of practical importance (Banerjee, 1985). Under the circumstances, there are two factors to be considered: the first one is coal itself, the other one is the physical conditions influencing the incoming oxygen, moisture and heating etc.

Coal is a combustible material, making it susceptible to a variety of ignition scenarios. One of the most frequent and serious causes of coal fires is spontaneous combustion. Spontaneous combustion of coal occurs due to the accumulation of heat liberated from the interaction of oxygen in air with coal in ambient temperature. This interaction with oxygen is chiefly due to the oxidation of carbonaceous matter in coal. Under the circumstances, there are two factors to be considered: the first one is coal itself, the other one is the physical conditions influencing the incoming oxygen, moisture and heating etc.

There are several theories of spontaneous combustion. The most important and accepted theory is the coal-oxygen complex theory. According to this theory the following stages are involved (Ziangmin, 1998):

Stage – I – An initial physical adsorption of oxygen, this only plays a major role below 0°C.
Stage – II – Chemical adsorption (chanisorption) leading to the formation of the coal-oxygen complexes.
Stage – III – Chemical reactions leading to the break down of the less stable coal-oxygen complexes, often resulting in the formation of gaseous products such as CO, CO₂, H₂O.

\[ \text{Coal + Oxygen} \rightarrow \text{Coal-oxygen complex} \rightarrow \text{Oxidized coal} + \text{CO, CO}_2, \text{H}_2\text{O} \]
A number of factors are responsible for the speed of the reactions. The main factors are:

- Oxygen
- Exposed surface area of the coal
- Temperature
- Composition of coal

Several important factors influence spontaneous combustion, such as the nature of the coal including its rank (Zhang and Tang, 1994), contents of volatile ash, oxygen (Banerjee, 1985), moisture (Sondereal and Ellman 1998 (ed.)), Pyrite methane (Vinogradoa et al., 1972) and petrography. Other important factors are the porosity of the coal seam, initial temperature and evaporation/condensation of moisture (Schmal, 1987).

### 1.3.2 Nature of coal fires

#### Surface fires

An open fire is defined as a coal fire that burns in direct contact with the atmosphere (Rosema et al.; 1999). Open fires are commons in spoil dumps of coal and open cast mine projects (OCP), but not at a large scale. Though open or surface fires are easily detectable and extinguishable.

#### Subsurface coal fires

With the other factors, oxygen supply is the main catalytic agent on which the rate of subsurface combustion depends. For subsurface combustion, the requisite oxygen enters via cracks or fissures at the surface, old abandoned mine tunnels or subsided land over the mines, which are not sand stowed properly after mining. It can be said subsurface coalfires and subsidence have a close relation.

Both surface and subsurface coal fires are found in the Raniganj coalbelt (RCB). Surface fires are relatively small in their aerial extent and are controlled efficiently. On the other hand, subsurface fires are extensive and widespread and are marked by wider surface thermal anomalies, spontaneous combustion is the major cause of fires in most coal field, and takes place whenever a coal seam comes in contact with oxygen in the air. Air may pass through cracks, fractures, vents etc. to reach the coal seams. Abandoned mines and mine refuse dump are very prone to fires, which can spread to the adjoining working mines. Extraction of coal from the subsurface without completely filling the empty spaces or goals with sand has caused widespread subsidence and has also left the area prone to
subsidence in the future. Besides damaging the infrastructure above and near the subsided area, blocking the coal reserves and causing damage to the environment, land subsidence may cost the lives of mines worker if it occurs during mining operation. The cracks and fissures associated with subsidence provide greater access to air moisture, increasing the problem of underground coalfires. Increased extraction of coal from the underground to meet the ever-expanding resource demand is bound to aggravate the problem of land subsidence.

Negligence on the part of mine workers may also start a subsurface coalfires. A few fires are entirely ignited by humans such as by an external heat source setting fire to the coal. One example would be the fire caused by the illegal distillation of alcohol (Sinha, 1986) and illegal mining (Lahiri-Dutt, 1999) in Indian coal mines.

The origins of subsurface fires in coal mines cannot be identified accurately. The subsurface fires spread continuously from their points of origin, and turn a huge land into void by burning the coal into ash. Such fires lead to the occurrence of large-scale subsidence and ground collapse in the coal mining regions. Thus there is clearly a nexus between the phenomena of fire-void-subsidence.

The breathing of oxygen into the coal seam may be triggered in many ways but in the RCB, it mostly occurs through one or another factor in this nexus. Subsurface fires fundamentally damage land, which is a great loss to the economy of a nation like India where land is the main resource. Consequently, they lead to erosion of the subsistence base of the livelihoods of local communities.

1.3.3 Classification of coal fires

Coal fires can be distinguished into different types (Yang Hong, 1995).

(A) According to the depth where the coal fires are, divided into:
   (i) Surface fire: spontaneous combustion of coal is on the surface of the earth
   (ii) Subsurface fire: spontaneous combustion of coal is buried under the surface

(B) According to how the coal fires got started, they are divided into:
   (i) Coal field fire: is caused by spontaneous combustion of coal seams in a coal field
   (ii) Coal mine fire: is caused by spontaneous combustion of coal seams during pit mining
(C) According to the starting time of the coal fires, they are divided into:

(i) Paleo coal fire: started in non historic time, most of them are extinguished
(ii) Recent coal fire: started recently because of human interaction.

(D) According to the state of the coal fires, they are divided into:

(i) Extinct coal fire: is extinct and has no potential danger of burning again
(ii) Dormant coal fire: is extinct on the surface but the temperature inside is still very high and there is a potential danger of burning
(iii) Active coal fire: is still burning at present

(E) In other ways coal fires can be classified into four groups according to its occurrence

(i) Underground mine fire: which is occurring in the areas of underground coal mining. They are restricted to the mines and can be detected by remote sensing techniques only if they are less than 30 metres in depth in areas where there are no cracks or fractures to lead the underground heat to the land surface
(ii) Coal seam fires or coal field fires: normally start due to the spontaneous combustion of a coal seam at the outcrop of the coal seams or at a coal seam at shallow depth. They can also develop from underground coal mine fires spreading to the surface.
(iii) coal refuse fire: burning mainly due to spontaneous combustion.
(iv) coal stack fire: more or less similar to the coal refuse fire (Zhang, 1998).

(F) Coal fires also can be classified in to three types of coal fire according to the depth of the fire:

(i) shallow fires: with the depth up to 10 metres
(ii) Intermediate fires, with the depth from 10-30 metres;
(iii) deep fires over 30 meters in depth (Greene, Moxham, 1969)

(G) A distinction has made between spontaneous combustion and anthropogenic coal fires according to their mode of origin. Similarly, coalfires may be classified into either surface or subsurface (in-seam) fires according to their location in the coal-producing region.

**FIGURE-1.2: Coal fire classification**

<table>
<thead>
<tr>
<th>Mode of origin</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spontaneous Combustion</td>
<td>Anthropogenic</td>
</tr>
<tr>
<td></td>
<td>Surface</td>
</tr>
<tr>
<td></td>
<td>Sub-surface</td>
</tr>
</tbody>
</table>
1.3.4 Cause of fires in the Raniganj coalbelt

Fire may loosely be defined as a rapid chemical reaction occurring with the evolution of heat and light. A combination of three parameters are needed for the occurrence of fire, namely:

i) fuel capable of burning vigorously,

ii) adequate quantity of heat for the reaction, and

iii) supply of oxygen.

These three parameters causing fires are illustrated below in the combustion triangle (Genderen and Haiyan, 1997).

FIGURE-1.3: Triangle of spontaneous combustion: cause

Source: Environmental monitoring of spontaneous combustion in North China coalfields, 1997

In this case solid fuels (coal) burn slowly at first with a steady rise of temperature. At this stage, with fresh onrush of air, there may be sudden bursting out of flames all over, resulting in a fast spread of fire known as flashover stage. Delayed action in combating any fire, makes it very difficult to deal with.

An underground fire is much more hazardous to deal than those are at the surface. An immediate danger arises from the evolution of toxic fumes, particularly from CO, affecting even far off places in the return end of the mine.

Coal mine fires normally start from the spontaneous combustion of a coal seam at the outcrop of the coal seams or at a shallow depth until the ground water is reached and then spread along both directions of the strike and dip of the coal seam. They can also develop from underground coal mine fires spreading to the surface.
1.4 OBJECTIVES

Keeping in view of the problems of the study area and the utility of remote sensing data analysing techniques in conjunction with ground truth information, the present study has aimed at achieving the following objectives:

1. to identify the environmental impacts of coal mining in the RCB and make an overall assessment of them;
2. to identify the locations of mine fires both surface and subsurface;
3. to map the land surface temperatures (at 1: 50,000 scale) region and to examine human vulnerability to fires from a safety and security perspective;
4. to identify the causes (both natural and human-induced) of both type of fires through extensive and intensive field surveys; and case studies; and
5. to explore possible means of effective control of these mine fires

There are some secondary objectives which the thesis addressed through some questions. Can coal mining continue in the future with minimum adverse effects? What should we do about getting all the information and analysis? How can human beings live safety and get applied benefits with mining activities? what are the sophisticated possible means of control of fires? The thesis answers these questions in course of the following chapters.

The state governments where coal occurs and mining takes place are thinking about coal fire measurement, and ways to save million tonnes of coal from being destroyed by fires. They are taking steps against fire through conventional means. Our objective is to use satellite imageries to identify, location and fire depth and intensity. The governments have started to prevent coal fires by huge economic investments recently. No doubt it is a new trend in managing coal fires successfully. Therefore, the significance and justification of the thesis work, lies in its usefulness.

1.5 METHODOLOGY

The methodology of present research has four main components, these are:

Data collection ⇒ Processing ⇒ Calibration and Comparison ⇒ Decision

The first component has two parts, field and satellite data collection (Landsat TM, IRS). The field observation consists of temperature data collection of specified test locations, gather information about coalfires and related hazards from local people, mining authority and other resources. Second component is mostly focused on image processing of
different remote sensing data and compilation of field observations. After processing, the third step is comparison of processed data sets with field observations for validation purpose. The last and fourth component is decision-making about the results derived from aforesaid steps and assessing how much the pre-defined objectives are achieved. The detailed methodology of image processing is described in chapter VI. The schematic diagram (Figure-6.1) describes the methodology in detail.

1.6 DATA BASE AND DATA CONSTRAINTS

- **Remote Sensing Data:** Landsat TM and IRS-1D LISS-III digital data.
- **Computer & Software:** PIII 500 MHz based system with softwares - Erdas Imagine for image processing and ARC View and ARC Info for Geographical Information System.
- **Ancillary Data:** Survey of India toposheets and journals, books and other study materials.

By using visible, infrared and thermal imagery the locations of coalfires were identified and validated with ground truth. Because of some uncertainty real time ground truth was not possible and with a limited budget it was not possible to acquire another tasked data. So a gap between satellite data and ground truth information is expected. Poor ground resolution (120 metres) of Landsat5 TM6 is also a reason where a pixel integrated temperature of thermal anomaly and surrounding is expected rather than the actual temperature data. In case of unauthorized mining, some extent of error is expected, as some quarries are as small as 3 metres - 5 metres - which is not detectable by Landsat (30 metres) or IRS LISS-3 (15 metres) data. Though extensive ground truth was helpful but it was always quite impossible to get correct responses from either local people or officials a due to the rampant corruption in the field.

Besides these data limitations mentioned above, some limitations have arisen due to external conditions also. Because the research fellowship is time bound and it need to finalized in a certain time period. Moreover the non-availability of state of the art books and journals in the local libraries was also limited the study.
1.7 TIME SPAN AND WORKING STEPS

The time span studied in this research is quite long—beginning with history of coal mining in the region in late eighteenth century and ending with current observations in the field. For historical information, we have used secondary sources and reference books. For studying post nationalization expansion of coal mining industry, we have used official as well as census data in addition to previous work. The satellite data used to measure the location and extent of coal fires from 1997 data, but the overall impacts have been studied since that year (when I was an MA student and did my field work in the region) till mid 2002. The case studies were done during 2001 and 2002.

Working steps have been done in step by step, are

1. Problem identification, literature survey and research theme selection
2. Extensive field study
3. Collection of maps
4. Data collection from different Governmental institutions, and intensive field study
5. Preparation of chart, table and maps
6. Final step was to organize observations and thought in form of a research report.

1.8 USEFULNESS

In geography, remote sensing is a new technique for spatial studies. We have used it in the case of a coal mining areas to identify the location, extent and fire prone areas. For the overall impacts of mining, we have done field surveys and have used previous studies completed on the area. These studies on coal mining, and its physical and environmental impacts on human beings are excellent but my addition to them is the incorporation of a new angle: identification of surface and surface fires. We are able to draw the thermal anomalies map locating the abnormality of temperatures in mining of areas of the RCB.

The research will be useful for the district administration and planning bodies such as Zilla Parisad and to Eastern Coal Fields Limited (ECL) and coal India Limited (CIL). It will also be use full to Coal Mines Planning and Design Limited (CMPDIL), a subsidiary of CIL looking after research on mining. Other academic institutions like the Indian School of Mines, Dhanbad, and Central Mining Research Institute may also benefit from the research.

Thus, satellite data is able to aware the human being to protect themselves from adverse effect of mine fires.
1.9 LITERATURE SURVEY

The collection of field information side by side with the development of conceptual thinking through the gathering of in-depth knowledge about coal mining, its impacts, coalfires and their impacts took place simultaneously. Information collection was done from different levels of administrative and planning office namely Eastern Coalfield Limited (ECL), BCCL (Bharat Coking Coal Limited), CMPDIL (Coal Mines Planning and Design Institute Limited, DGMS (Director General of Mines Safety), Coal India Limited and the conceptual background was developed through the reading of specific books and journals. Satellite data were collected from the NRSA, Hyderabad.

The presentation of two seminar lectures during research stage helped to gather feedback and valuable suggestions. This state was followed by mapping, computation and analysis of data through several quantitative procedures to establish the nature of mine fires and final thesis writing.

1.10 COALFIRE RESEARCH IN UNITED STATES

As most coal producing countries, the United States also has a serious coalfires problem. In 1962, the United States Bureau of Mines, reported 223 coalfires (Slavecki, 1964). With the help of advanced technology the United States was the first country, to apply remote sensing for coalfires detection. Using the ‘Reconofax’ thermal scanner on an airborne platform, Slavecki (1964), Kunth (1968) and Greene et al. (1969) studied fires on waste coal and subsurface coalfires in Pennsylvania, the state where coalfires was a serious problem. Greene et al. also studied the depth of fire and they classified fires in three types: shallow fire (up to ten metres deep), intermediate fires (10 to 30 metres deep) and deep fires (more than 30 metres deep).

1.11 COALFIRE RESEARCH IN AUSTRALIA

Among the natural coalfires, the burning mountain in New South Wales is a well-known coalfires, which was discovered in 1828. Later Ellyett and Fleming (1974) estimated the age of the fire to be at least 6000 years. Today the fire is more than 152 metres underground, and is still slowly burning the coal.

1.12 COALFIRE RESEARCH IN INDONESIA

In south Sumatra, Indonesia, coalfires are well recognized by the coalfires researcher community. Some of them are quite old, even 17300 years, it has assumed that these ancient coalfires were ignited by lighting. Wildfire, lightning and a warm climate favour the spontaneous combustion in exposed layers.
1.13 COALFIRE RESEARCH IN CHINA

With an enormous resource of coal, coalfires is also an immense problem in northern China. Using Daedalus data, Huang et al. (1991) presented an interesting study. In Xinjinag and Ningxia Hui regions several ITC researchers worked on coalfires. By using pre-dawn airborne thermal scanner data, Yang (1995) identified several coalfires in these areas, which correlated well with field observations. Later Wan and Zhang (1996), and Zhang et al. (1997) carried out a detailed study in the same area. They used daytime Landsat TM band 6 data to estimate the relative amount of solar illumination during the overpass time, which was used to correct for the effect of terrain. Because the spatial resolution of Landsat 5 thermal band is quite poor (120 metres) and cannot detect small fires, Zhang et al. (1997) tried a sub-pixel temperature estimation method and found if a pixel has considerable higher temperature than surrounding background, is easy to detect. They also highlighted how a fire can be identified if the background temperature is known. In 1996, Genderen et al. developed a method to synergistic use of remote sensing data to detect underground coalfires. Cassels (1996) did an attempt to underground modelling of coalfires in Kelazha area, north China. By analyzing SWIR spectra of rocks, Zhang Jianzhong (1996) could identify the burnt rocks, which is also an indication of coalfires. In 1997, Peng et al. did attempt some fire depth estimation in the Kelazha area. In Xinxiang province, Wang (2002) identified coalfire-affected areas with ASTER and Landsat TM data.

1.14 COALFIRE RESEARCH IN INDIA

The Jharia coalfield, which is 250 kilometres northwest from Calcutta, along with the Raniganj coalbelt is producing one third of the coal in India. Many researchers, Bhattacharya (1991), Cracknell and Mansoor (1992), Reddy et al. (1993), Saraf et al. (1995), Prakash et al. (1995) worked on the Jharia coalfire. Using airborne predawn thermal and daytime multispectral data Bhattacharya et al. (1991) could distinguish the fires from the background. To detect the coalfires another attempt was made by Mukherjee et al. (1991) using pre-dawn airborne thermal data. They also attempted to estimate the depth of the fire using a linear heat flow equation. Cracknell and Mansoor (1992) first used Landsat-5 TM and NOAA-9 AVHRR data and found that night time NOAA data was quite useful to isolate the warm areas from the background. Reddy et al. (1993) used the short-wave infrared (SWIR) region of the EMR, which is covered by Landsat TM band 4,5 and 7. They described that the hotspots found in the image corresponded well with the field measurements. In the same area, using Landsat TM band 6 and 7, Saraf et al. (1995) found comparatively high temperature zones must have surface fires, where the less warm areas should have subsurface fires. Later Prakash et al. (1997) used the Landsat TM TIR and SWIR bands to identify surface and subsurface fires separately. Based on a dual band approach for TM data, Prakash and Gupta (1999) attempted a method for calculating the area of surface fires. The main problem they faced while developing this method was reflected solar energy in the SWIR region.