P-313

Mapping of Potential Coal-Mine Fire Zones in Jharia Coalfield using Differential InSAR (DInSAR)

Nishant Gupta* & T.H. Syed, *Indian School of Mines*

Summary

Coal-mine fires in the Jharia coalfield pose a serious threat to natural resources and cause significant societal and environmental degradation. In order to implement effective preventative or mitigating measures, it is critical to detect areas affected by coal-mine fires and also to monitor the extent of the existing ones.

The current research emphasises on the potential for operational use of DInSAR technique for mapping the areas affected by subsidence as a consequence of subsurface coal-mine fire in the Jharia coal fields.

Keywords*: Coal-mine fire, Jharia coalfield, DInSAR*

Introduction

Jharia coalfield is one of the highly populated areas, bounded by the latitudes 23°39'–23°50'N and longitudes 86°05'-86°30'E (Figure 1) in the state of Jharkhand, India. The sickle shaped coalfield, occupies an area of nearly 450 sq. Km. Bharat Coking Coal Limited (BCCL) operates on the majority of area which is about 258 sq. km. (57 percent of the coalfield) with Tata Iron and Steel Co. (TISCO) and the Indian Iron and Steel Co. (IISCO) holding another 32 sq. km., and the remaining areas are mostly occupied by industrial, forest, and agricultural areas (Prasad 1989; Bharat 1991; Sinha 1989). The Jharia coalfield contains the only remaining reserves of prime coking coal in India. This coalfield has been burning underground for nearly a century and hosts the maximum number of known coalmine fires among all coalfields in India. Monitoring of coalmine fire, because of its socio-economic and environmental impacts, presents an interesting challenge to scientists and policy-makers alike. The health and safety of the local population justifies an assessment for determining the extent of the fires and their direction of propagation for identification of methods for controlling and preventing the fires from further expansion.

DInSAR presents a cost-effective way of obtaining detailed and high- resolution information to monitor land subsidence as surrogate of subsurface mine fire. DInSAR can provide two-dimensional deformations on the line of sight (LOS) of radar over areas of thousands square kilometers (Massonnet and Feigl, 1998). It has certain advantages over other geodetic techniques such as GPS by virtue of its wide and continuous coverage, high precision, cost effectiveness and feasibility of recording data in all weather conditions.

In the Jharia coalfields, mine fire is propagating in different directions. The burning of coal leads to the formation of voids due to volume reduction due to the transformation of coal to ashes. The surface displacement related to mine fires, together with mining- induced subsidence leads to subsequent subsidence of overlying strata. This subsidence leads to formation of cracks and fissures leading to creation of ventilation paths through which oxygen circulates and further supports the internal combustion thus aggravating underground coalmine fires. (Jiang et.al 2011).

Earlier works on investigation of coal fires in Jharia coal field were mostly based in the utilization of optical, multispectral and thermal infrared data. Majority of these studies concentrated on surface feature extractions and

Department of Applied Geology, Indian School of Mines, Dhanbad-826004
E-mail-nishantgupta@ismu.ac.in

thermal analyses related to coalmine fires (Chatterjee 2006; Chatterjee et.al 2007; Agarwal et.al 2006).

In this study, we utilize DInSAR technique to monitor and analyze land subsidence related to uncontrolled coalmine fires located within the Dhanbad district which is a part of the larger Jharia coalfield.

Data Used

ENVISAT ASAR data was obtained from the European Space Agency (ESA) from 2004 to 2010 for the Jharia coalfield area. ENVISAT ASAR is a C band sensor with incidence angle of 23 degree and 35 days revisit. Two interferometric pairs with the highest coherence were chosen to perform the differential InSAR processing. All the interferometric pairs along with the ones used for DInSAR are listed on Table.1. These interferometric pairs reveal the land subsidence changes over the Jharia coal-field.

The Digital Elevation Model (DEM) used in the DInSAR processing was obtained from Shuttle Radar Topography Mission (SRTM). Orbit data was acquired from Delft University and the population data of the Dhanbad district was acquired from the Panchayat Samiti of Dhanbad district.

Methodology

Interferograms were produced using the Repeat Orbit Interferometry Package (ROI PAC) which was developed at the Jet Propulsion Laboratory and the California Institute of Technology (JPL/Caltech). The SAR interferometric phase comprises of deformation phase, topographic phase, flat earth phase, atmospheric phase and noise. The deformation phase is derived from the differential InSAR (DInSAR) technique by subtracting the topographic phase and flat earth phase from the interferometric phase.

The topographic contribution to the phase difference was carefully removed using a DEM (Massonnet and Feigl, 1998). Atmospheric disturbances present can either be accounted for by using independent observations such as GPS, or neglected if the tropospheric delay is considered to be homogeneous at the time of the radar image acquisition.

The precise orbit data can be used to to remove noise and estimation of the spatial baseline and registering the DEM to SAR coordinates.

No	Sensor	Master Acquisition time	Slave Acquistion time	Temporal Baseline (days)
1	ENVISAT	2004-05-01	2007-04-21	1085
2	ENVISAT	2007-04-21	2010-01-30	1015

Table 1: Interferometric SAR image pair list

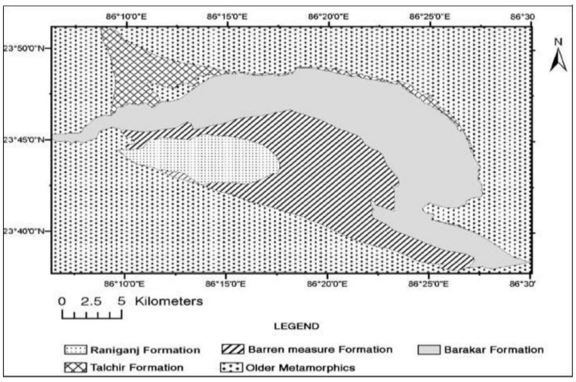

Figure 1: Jharia Coalfiled (derived from Chatterjee 2006)

Results

Shown in Figure 2a and 2b are the differential interferograms for the portion of the Jharia coalfield lying within the district of Dhanbad. While subsidence is clearly observed in the subsidence maps, the magnitude and spread of subsidence observed in the subsidence map of 2004-2007 (Figure 2a) is higher than the subsidence map of years 2007-2010(Figure 2b).

The negative values of subsidence observed in different blocks of Dhanbad district can be attributed to upliftment in these areas.

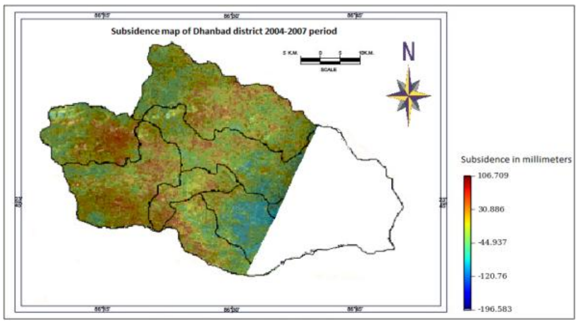

Figure 2a: Subsidence map of Dhanbad district for 200405-200704 interferometric pair.

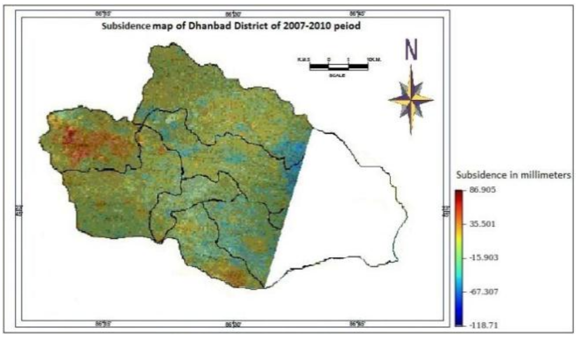

Figure 2 b: Subsidence map of Dhanbad district for 200704-201001 interferometric pair.

The reasons for the upliftment observed in the study area during the period of study can be accounted by various factors, details of which are presented in the discussion of the results.

Figure 3 illustrates the population density map of the district of Dhanbad.

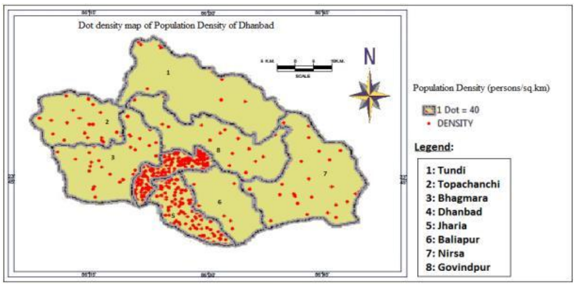

Figure 3: Population Density map of Dhanbad showing maximum population density in Dhanbad and Jharia block

The map shows a highly uneven distribution, with Dhanbad block and Jharia block being most densely populated. Comparison of Figures 2 and 3 demonstrates that the magnitude of subsidence in both these blocks is very large further signifying the necessity of determination of zones of subsidence due to mine fire for better planning and devising of the required preventive measures. Classification of images for Jharia coalfield during both the periods 2004-05-01/2007-04-21and 2007-04-21/2010-01-30 are shown in Figures 4a and 4b respectively.The purpose of this Subsidence Hazard Map is to classify the areas on the magnitude of subsidence in the Jharia coal field and delineate boundaries of the hazardous zones for better management and application of prevention measures. The subsidence caused can be due to coal mine fire and mining activities. The subsidence due to mining is limited both spatially and in magnitude due to preventive measures undertaken by Bharat Coking Coal Limited (BCCL) to prevent subsidence due to mining related activities (Bharat, 2008). Subsidence is also observed in the zones lying outside the mining area. The subsidence observed in these zones can be attributed entirely due coal mine fire. The spread of the hazardous zone is dependent majorly on the coal mine fire. The coal mine fire which is not continuous spatially leads to varying degrees of subsidence (high to low).

The reasons for the varying intensity of coal mine fire can be attributed to:

- Heterogeneity of the coal seam layer
- Proximity to the land surface as cracks and fissures developed on the land surface form the ventilation paths for supplying air leading to propagation of coal mine fire.

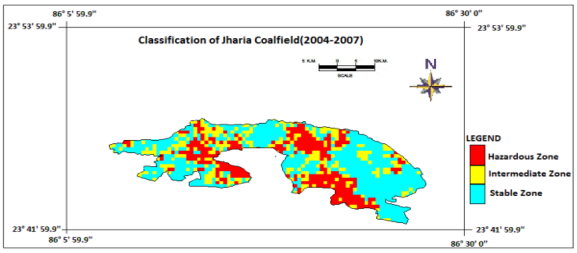

Figure 4 a: Classification image of Jharia coalfield for 200405-200704 interferometric pair showing hazardous zone in the coalfield.

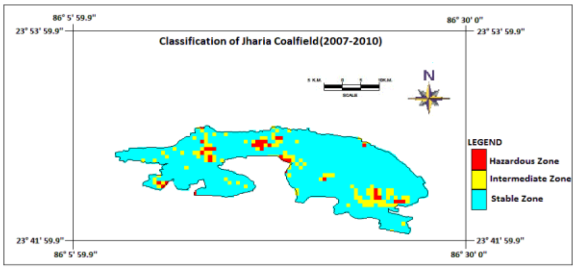

Figure 4 b: Classification image of Jharia coalfield for 200704-201001 interferometric pair showing hazardous zone in the coalfield.

Additionally, subsidence maps of the Jharia coalfield showing the speculative location of fire areas in different collieries for the time periods of 2004-05-01 /2007-04-21 and 2007-04-21/2010-01-30 are displayed in Figures 5a and 5b respectively. The polygons marked on the maps show the location of fire areas based on field survey established by BCCL in their mine plan for 2008. The correlation between surface subsidence and coal mine fire is evidenced by overlaying subsidence map and the coal fire distributions from the field surveying in Figure 5a and Fig 5b. The subsidence rates observed within speculative coal mine fire zones are high during the study period 2004-2007(Fig 5a).

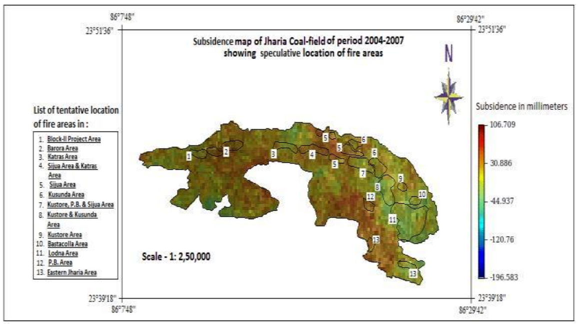

Figure 5 a: Subsidence map of the Jharia coalfield showing the speculative location of fire areas in different collieries for the image pairs 2004-05-01 /2007-04-21

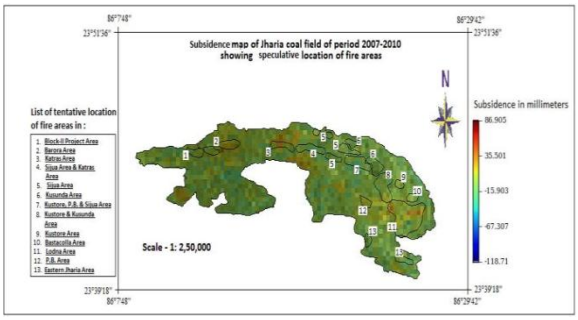

Figure 5 b: Subsidence map of the Jharia coalfield showing the speculative location of fire areas in different collieries for the image pairs 2007-04-21/2010-01-30

During the study period of 2007/04/21-2010/04/21, subsidence observed (Fig 5b,) are much lower compared to that of 2004-2007(Fig 5a) in the areas lying within and outside the fire location boundaries established by BCCL in 2008.

The subsidence observed outside the fire location boundaries can be related to two main causes-

- The existence of the fire sites outside the region can be attributed to two main causes i.e. either due to vertical and/or lateral propagation of the subsurface fire or starting of fresh surface/sub-surface fire with the progress of new opencast or underground mining activities (Chatterjee et.al 2007).
- Due to mining activities: but the signature of subsidence observed due mining activities is negligible because of the preventive measures taken by BCCL for prevention of subsidence due to mining activities.

The magnitude and spread of upliftment or negative subsidence observed during 2007-2010(Fig 5b) is higher than upliftment observed during 2004-2007(Fig 5a) study period at the fire locations, this is due to various measures adopted by Bharat Coking Coal Limited, Dhanbad for controlling the propogation of fire in their mine plan for 2008:

- Surface sealing and blanketing with cohesive and incombustible material eg sand, soil etc. Over 22 million cubic metre of surface blanketing work has been carried by BCCL.
- Filling of the opencast high walls, shafts, inclines and other subsided areas.

Subsidence maps of the Jharia coalfield showing the unstable, uncontrollable sites in Jharia coalfield suffering from subsidence during the study period 2004/05/01-2007/04/21 and 2007/04/21-2010/01/30 are displayed in figure 6a and 6b. The subsidence patterns observed in the unstable, uncontrollable zones are evident from the in-situ inspections in 2008 (Bharat, 2008).

Figure 6a clearly reveals an accelerated progress in subsidence during the study period 2004-2007. This can be attributed to the existence and or propagation of coal mine fire and also due to mining activities such as old workings with full height extraction and wide galleries, multi-seam and multi-section development under shallow depths, existence of developed seams under extracted lower seam with stowing etc.

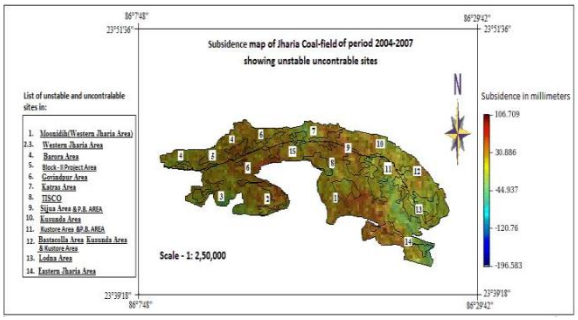

Figure 6 a: Subsidence maps of the Jharia coalfield showing the unstable, uncontrollable sites in Jharia coalfield for the image pair 2004-05-01 /2007-04-21

Due to various preventive measures undertaken by BCCL subsidence observed during the study period 2007-2010 (Fig 6b) is lower in magnitude than during the study period 2004-2007 (Fig 6a)in many unstable sites.

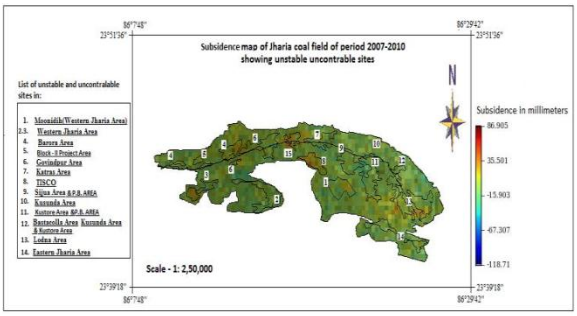

Figure 6 b: Subsidence maps of the Jharia coalfield showing the unstable, uncontrollable sites in Jharia coalfield for the image pair 2007-04-21/2010-01-30.

The reasons for the decrease in the magnitude and spatial extent of subsidence can be attributed to the implementation of the preventive measures undertaken by BCCL for controlling the subsidence:-

- Excavation of the fire-affected portions of the affected coal seams from the unaffected coal seams.
- Isolating the fire-affected portions of the coal seam by trenching and back filling of these trenches by cohesive material.
- Cooling of the fire-affected portions of the seam by water curtains or in filtration ponds
- Blind flushing of the areas affected by coal-mine fire. More than 50 million cubic meters of sand has been stowed below ground for controlling subsidence related to mining activities.
- Infusion of the inert gas like nitrogen. 3 million cubic meter of nitrogen gas has been flushed below the ground for controlling fire.

Since underground coal seam burning is usually not the only source of the resulting land subsidence the development of new subsiding areas during the study period 2004-2007 (Fig 6a) and 2007-2010 (Fig 6b), thus can be accounted due to both coal fires and other mine related activities.

There are many towns, villages, rivers, jores, roads, railway line etc., in Jharia Coalfield which are standing over small pillars/stooks reported to be water logged. If, by any chance, this water drains away it may cause subsidence. In addition, fire is also active in some areas, causing danger to the surface structure. In many mines, size of pillars, which were left below the surface structures as a protective measure, is not known because of non- availability of offset plans of abandoned workings.

Conclusions

- This study categorizes the unstable areas, based on the amount of subsidence and population density, to zones with varying degrees of hazardous impact in terms of its effect on population.
- The results presented here also have implications for grouping and marking of the boundary of these potentially hazardous mine-fire areas leading to better implementation of methods of fire control and safety measures with increased precision and accuracy.
- The results correlates very well with identified mine fire zones of BCCL (http://www.bccl.gov-.in/PDFs/MPLANBCCL2008.pdf).
- Results are in concurrence with some of the earlier studies carried out to map the subsurface coal mine fire in Jharia coal field using NOAA/AVHRR data (Agarwal et.al 2006) and using Landsat TM thermal IR data (Chatterjee 2006; Chatterjee et.al 2007).
- The study highlights the effectiveness of InSAR to measure surface deformation due to coal mine fire and mining related activities. The separation of land

subsidence effects resulting from coal fires and mining activities is an open issue. Improving the reliability and robustness of land subsidence detection and assessment through interferometry in coal fire areas will be the subject of our future research.

- Another advantage of InSAR measurements over insitu measurements displayed here is the large scale information that can be gathered.

References

Agarwal R., D. Singh, D. S. Chauhan and K. P. Singh (2006), Detection of coal mine fires in the Jharia coal field using NOAA/AVHRR data: Detection of coal mine fires in the Jharia coal field using NOAA/AVHRR data: Journal of Geophysics and Engineering, 3, 212-218.

Bharat Coking Coal Limited (1991), Mine Fires in the Jharia Coalfield. Bharat Coking Coal Limited, Project and Planning Division, Dhanbad, India,117 pp.

Bharat Coking Coal Limited (2008), Master Plan for dealing with the fire, subsidence and rehabilitation in the leasehold of Bharat Coking Coal Limited, Project and Planning Division, Dhanbad, India

Chatterjee, R.S., (2006). Coal fire mapping from satellite thermal IR data – A case example in Jharia Coalfield, Jharkhand, India: ISPRS Journal of Photogrammetry & Remote Sensing, 60, 113–128.

Chatterjee, R.S., Md. Wahiduzzaman, A. Shah, E. V. R. Raju, R. C. Lakhera and V. K. Dadhwal(2007). Dynamics of coal fire in Jharia Coalfield, Jharkhand, India during the 1990s as observed from space: CURRENT SCIENCE, 92, 61-68.

Massonnet D. And K. L. Feigl (1998). Radar interferometry and its application to changes in the earth's surface: Reviews of Geophysics. 36,441-500.

Prasad, R. M. (1989). An Appraisal of Subsidence Problems in the Jharia Coalfield. P. 207-229. Proceedings: International Symposium on Land Subsidence, Vol 1. (Dhanbad, India, Dec. 11-15, 1989).

Sinha, P. R. (1989). Subsidence Problems of Bharat Coking Coal Limited -- An Overview. P. 7-25. Proceedings: International Symposium on Land Subsidence, Vol 1. (Dhanbad, India, Dec. 11-15, 1989).

Acknowledgments

Envisat ASAR data was provided by European Space Agency (ESA) under proposal C1P.9370.

Thanking anonymous reviewers for their guidance for significant improvement of the research paper.