Detection of underground mining induced land subsidence using Differential Interferometric SAR (D-InSAR) in Jharia coalfields

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Abstract - ***Mining induced land subsidence is very common in the areas of extensive underground coal mining which affects the overall geo-environmental scenario of the area. Jharia coalfields in Jharkhand has been experiencing land subsidence for several decades essentially due to underground mining and coal fire. Differential interferometric SAR (D-InSAR) technique has been used widely to identify and measure land subsidence. In this study, six ALOS PALSAR data pairs acquired during 2007-2008 were used to study land subsidence phenomenon in the Jharia coalfields. Two-pass D-InSAR was used in this study which uses two SAR images of the same area taken at different times to calculate the Line-of-Sight (LOS) path difference of a target point due to land displacement with the help of an external Digital Elevation Model (DEM). Well defined subsidence fringes were obtained in most of the differential interferogram pairs. The fringe areas were integrated to obtain the total subsidence affected areas during the observation period with rates of subsidence (in cm/year). The maximum subsidence rate calculated from D-InSAR processing is found to be 56.72 cm/yr and the minimum is 7.88 cm/yr. The total affected area in the study area is 7.2 sq kms. Field checks were done for confirmation of D-InSAR based subsidence results.***

Keywords - Underground mining, Subsidence, D-InSAR, ALOS PALSAR

1. Introduction

Subsidence is the lowering or sinking of the surface due to various natural or anthropogenic causes. It is one of the inevitable consequences of underground mining. If not properly planned, removal of underground materials causes surface subsidence and affects surface environmental conditions. Coal mining in India has a history of hundreds of years and the occurrence of thick coal seams at shallow depths in many areas is one of the major reasons for subsidence in these areas. Intensive underground mining causes significant damage to surface and sub-surface properties such as houses, communication and transport networks, fields, drainage channels and water courses.

In India, coal from underground is basically extracted by two methods – bord and pillar method and longwall method. The bord and pillar method is more common and is used in more than 90% of Indian coalfields [1]. In this method coal is extracted from two sets of galleries which are normally perpendicular to the other, forming pillars between them of a standard size. The study area (Jharia coalfield) has underground mines which mainly use this type of extraction method. After primary mining by bord-and-pillar technique, secondary mining by depillaring or caving takes place with or without sand stowing. Jharia coalfield is one of the main sources of coking coal in India having 18 seams of nearly 10 m thickness each. It has been facing tremendous problems due to subsidence as a result of underground mining of these coal seams. Coal fire induced subsidence is also common in this coalfield.

In this study, an attempt has been made to study the subsidence scenario in the study area using differential interferometry. Differential Synthetic Aperture Radar interferometry (D-InSAR) is a technique useful for accurately detecting the ground displacement or land deformation in the antenna line-of-sight (slant-range) direction using synthetic aperture radar (SAR) data taken at two separate acquisition times [2],[3]. Recently, this technology has been used effectively in various fields to measure ground displacement and retrieve three-dimensional surface information [4]. This technique has also been used over the last decade in the estimation of temporal and spatial surface motions due to subsidence, particularly in mining subsidence cases [5],[6]. It uses the phase difference of two correlated images to detect displacements upto the millimetre level [7].

D-InSAR can be applied to all kinds of surface deformation processes. Gabriel et al. first used SAR images to measure surface motions on an experimental basis with positive results [8]. Since then, various studies have been done on surface deformations with the use of interferometry. Herrera et al. used 14 ERS and Envisat images to find out surface deformations and compare it with levelling data and a good agreement has been found [5]. Mostly Envisat and ERS images acquired in the C-band have been used for subsidence related studies. But since the launch of ALOS PALSAR in 2006, various studies have been done with the L-band (23.6 cm) images. Cao et al. used both Envisat and ALOS PALSAR data for coal mine land subsidence monitoring in China [9]. He concluded that compared to C-band, L-band interferometry keeps higher coherence, although the accuracy of subsidence detection of L-band is lower than C-band, time series L-band SAR data can form more effective differential InSAR results. Guang et al. made a comparative study of C-band and L-band data for subsidence monitoring and concluded that use of C-band in subsidence is restricted due to its perpendicular baseline [10]. Bauyaji et al. used ALOS PALSAR data for mapping urban subsidence in Jakarta, Indonesia and estimate total subsidence area and subsidence volume and the results were reasonable compared to GPS measurements [11].

Much research has been done on mining and related factors in Jharia because of its importance in the coal mining sector of India. Most of India's coal comes from Jharia and mining has started in this region as long back as 1894 by the British.

Chandra did a detailed study on the geology of Jharia which has helped researchers a lot in understanding the area [12]. The geological features of Jharia Coalfields and the drainage pattern of the region have already been mapped by remote sensing data [13],[14]. Choubey studied the impact of coal mining on the ground water quality of this area and concluded that there was a decline in groundwater table directly above panels where coal was being extracted [15]. A mapping of coal fire regions and the lateral spread of coal fire using multi-temporal imagery was done to study the coal fire in Jharia coalfields with the help of thermal remote sensing [16]. Sarkar et al. studied the overall geo-environmental setting of Jharia using statistical tools and GIS to understand the impact of mining on air and water quality of the region and its relation with the population [17]. Studies on subsidence due to coal mining have also been done earlier and are still going on.

2. Study area

The study area comprises of the Jharia coalfields which is one of the most important coalfields of India. It is situated in the Damodar River valley in the eastern part of the country within the administrative boundary of Jharkhand. The coalfield is bounded within latitudes 23039'N and 23048'N and longitudes 860 11'E and 86027'E covering an area of 450 km2. The crescent-shaped field to the north of the Damodar River is about 38 km long in east-west and 18 km in north-south direction. Fig.1 shows the location of the study area.

Jharia coalfield is characterized by gently undulating topography with a general slop towards the east-southeast. The southern part of the study area is bounded by a major fault. The general dip of the formation is about 5 to 10 degrees with even flatter dip at places. The southern part however shows steeper dipping beds upto 70 degrees near the Southern Boundary Fault (SBF).

In the study area, Precambrian basement metamorphic rocks are overlain by Talchir Formation and are followed upward by Barakar Formation which is the main coal-bearing horizon. This is turn is overlain by Barren Measures and followed by Raniganj Formation, which is the second coal-bearing horizon in the coalfield. The Damodar river is the main drainage along the coalfield.

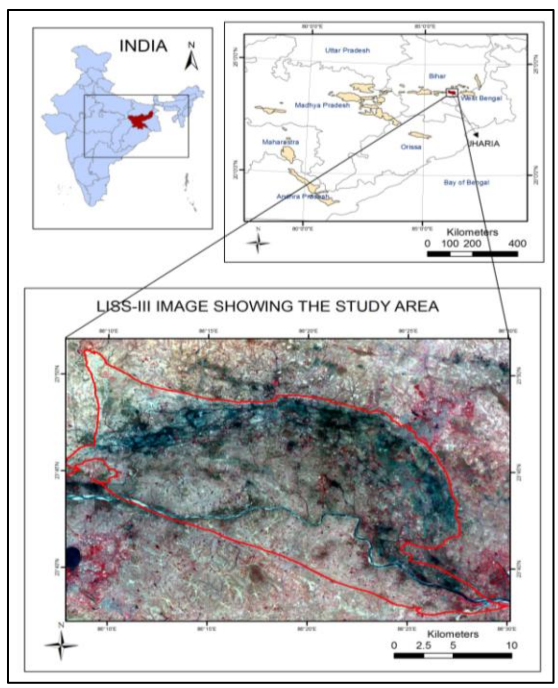

Figure. 1 Location map of the study area

In Jharia coalfields, there are about 65 underground coal mines. The usual method of extraction of coal from these mines is the bord and pillar method of mining as is practised in most other parts of the country. The Barakar Formation contains 18 standard coal horizons (numbered I to XVIII) of variable thickness and ranging from inferior to superior quality.

About 57% area of Jharia is affected by mining related hazards like subsidence, coal fires, overburden dumps and abandoned quarries. Subsidence alone affects 33% of the area [18].

3. Materials and methods

Remote sensing data used for the present study is L-band (23.6 cm) SAR data acquired from Japanese ALOS PALSAR microwave satellite with an incidence angle of 34.3 degrees. The details of scenes utilized are given in table I. Besides these, geocoded IRS-LISS III and PAN merged image for the study area was acquired for 2006. Merged SRTM and Cartosat Digital Elevation Model (DEM) of 90 m resolution was used for elevations. Softwares used were Sarscape v. 4.2 for INSAR processing, ArcGIS for database creation, organization, integration and analysis while Envi was used for standard image processing. Field verifications were performed using Magellan handheld GPS.

I. **TABLE I**. ALOS PALSAR DATA SPECIFICATIONS

S.no	Orbit	Path	Date of Pass	Node	Polarization
1	5173	509	13.01.2007	Ascending	HH
2	5421	510	30.01.2007	Ascending	HH
3	5844	509	28.02.2007	Ascending	HH
4	10118	510	18.12.2007	Ascending	HH
5	10541	509	16.01.2008	Ascending	HH
6	10789	510	02.02.2008	Ascending	HH
7	11212	509	02.03.2008	Ascending	HH
8	11460	510	19.03.2008	Ascending	HH
9	11883	509	17.04.2008	Ascending	HH

3.1 Pre-processing of ALOS PALSAR data

The raw files obtained were first imported into Sarscape in Single Look Complex (SLC) format. Since it is difficult to identify features in this format, it is converted into Multi Look Complex (MLC) images for the purpose of preparing subsets for interferogram generation. Interferogram pairs were then generated and the baselines and ambiguity height of each pair was calculated.

3.2 D-InSAR Processing

Sarscape software was used to generate interferogram for the pairs using the DEM of the study area. Interferogram flattening for topographic phase removal was done on the interferograms. The Goldstein filter was applied to the noisy interferogram to remove the noise and smoothen the interferogram. The final filtered interferograms were geocoded using SRTM and Cartosat merged DEM for the study area.

3.3 Post-processing on interferograms

Probable fringes due to subsidence were delineated on the interferograms in vector layers for different time periods using ArcGIS software. Comparison with DEM and a field survey was done to check the delineated fringes due to topography or land subsidence. Final subsidence map was prepared showing the unified subsidence areas during the observation period. The total rate of subsidence in the vertical direction was calculated using the total number of cycles within a fringe. ALOS PALSAR has a wavelength of 23.6 cm, hence each cycle in the interferogram represents a LOS (Line of sight) displacement or slant range displacement of 11.8 cm. If it is assumed that changes have occurred only in the vertical direction then vertical displacement, Δz is given by the formula [19],

$$\Delta z = \Delta sl/\cos\theta \qquad \text{..............................} \qquad (1)$$

Where Δsl is the slant range change and θ is the incidence angle.

4. Result and discussion

The filtered differential interferograms generated from ALOS PALSAR data pairs (Fig. 2) show probable subsidence fringes. Some fringes are observed in the north of the interferogram and these are found to be isolated hillocks. It is observed that some fringes are seen in interferograms which denote continued subsidence. The differences in shape and size of these multiple fringes indicate differential subsidence effects with time. Interferograms with longer temporal baselines are noisier than the ones with shorter temporal baselines but with larger phase difference which facilitate to estimate the rate of subsidence.

But well-defined fringes are generally seen in the interferograms with shorter temporal baselines. Almost all the interferograms show subsidence fringes in the eastern part of the coalfields which shows three fringes in the western part of the study area. Fringes are seen in the area affected by extensive underground coal mining. Fringes were checked in the field and subsidence areas were confirmed.

The fringes observed in these interferograms were numbered and were overlain on IRS PAN image for localization of the subsidence areas (Fig. 3). The subsidence fringe areas were vectorized from each of the interferograms and a union of these vectors were done to integrate the subsidence affected areas during the observation period. The total affected area of these fringes was overlain on a LISS III+PAN merged image with the rates of subsidence in the affected areas (Fig. 4).

It is observed that most of the subsiding areas towards the east and southeast have lower rates than those in the north and west except one area in the west. The maximum subsidence rate calculated from D-InSAR processing is found to be 56.72 cm/yr and the minimum is 7.88 cm/yr. The total area affected by subsidence in the study area is around 7.2 sq. kms. Table II shows the area and vertical subsidence of each fringe.

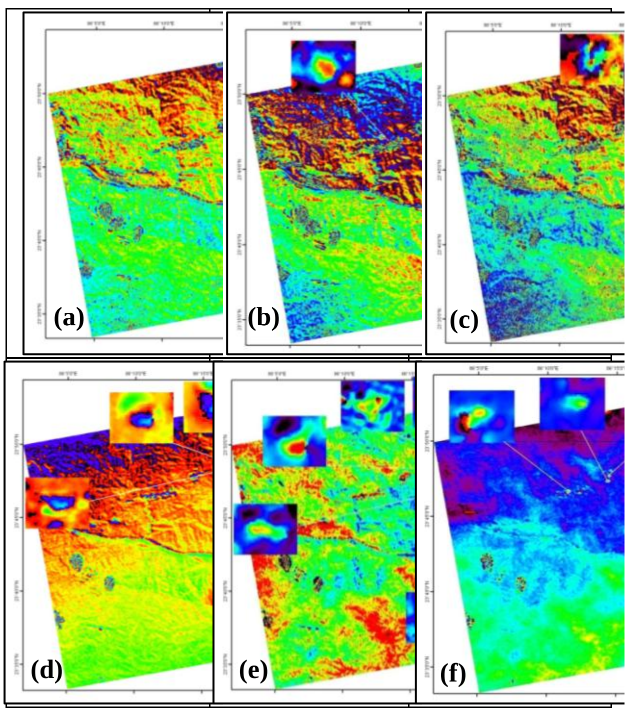

Figure. 2 Differential interferograms generated from ALOS PALSAR data; (a) 5421-10118, (b) 5421-10789, (c) 5421-11460, (d) 10118-10789, (e) 10118-11460, and (f) 10789-11460 of 2007 – 2008

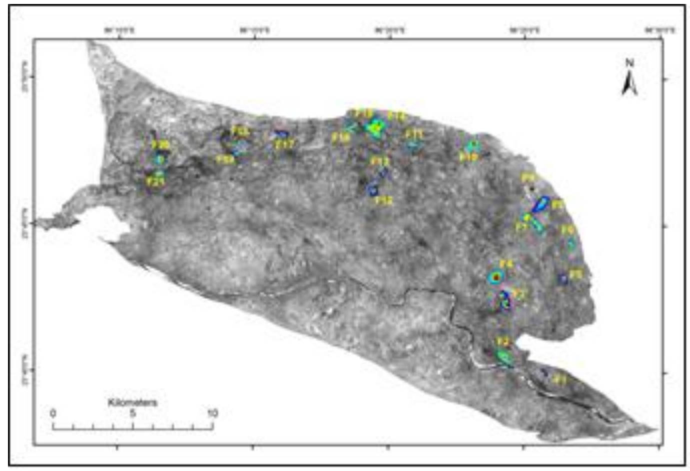

Figure. 3 Subsidence fringes placed over PAN image of Jharia coalfields

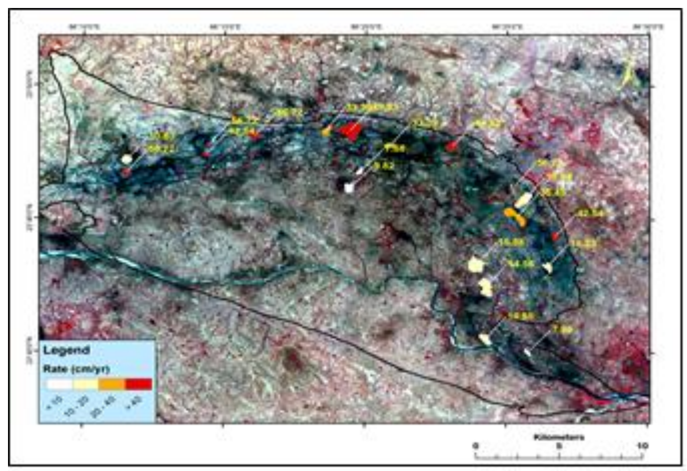

Figure. 4 subsidence vectors placed over merged LISS IV+ PAN image of Jharia coalfields

I. TABLE II. AFFECTED SURFACE AREA AND RATES OF VERTICAL SUBSIDENCE CALCULATED FROM D-INSAR

Fringe_ID	Area(sq. km.)	Rate (cm/yr)
F1	0.1247	7.88
F2	0.3709	18.55
F3	0.7509	14.56
F4	0.8119	15.58
F5	0.2499	18.23
F6	0.2026	42.54
F7	0.6786	35.45
F8	0.6174	18.55
F9	0.0551	56.72
F10	0.3669	44.52
F11	0.1987	33.39
F12	0.3309	9.82

F13	0.1465	7.88
F14	1.0244	49.63
F15	0.0807	56.72
F16	0.2631	33.39
F17	0.2721	56.72
F18	0.0728	56.72
F19	0.1191	42.54
F20	0.3151	10.63
F21	0.154	56.72

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5. Conclusion

It is seen that ALOS PALSAR L-band data can be used successfully for delineating moderate to rapidly subsiding areas. Most of the subsidence occurred in the sickle-shaped mining area where Barakar coal bearing formation is exposed. Some isolated but well defined fringes in the central part of the area near Moonidih. The rates of subsidence calculated from the interferograms are found to show a decreasing trend with the increase in temporal baseline. Further analyses with more data pairs and simultaneous ground measurements are required for studying the temporal evolution of subsidence. Subsidence areas from ALOS PALSAR data were also compared with that obtained from ENVISAT data and areas marked by BCCL and Tata Steel based on ground survey. The subsidence areas identified from ALOS PALSAR data shows some new places of subsidence with high rates as compared to the areas identified previously from ENVISAT ASAR data. For example, two well defined fringes namely F3 and F4 (with subsidence rates 14.56 cm/yr and 15.58 cm/yr respectively) were observed in ALOS PALSAR based differential interferograms in the southeast of the study area.

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References

[1] R. P. Singh and R. N. Yadav, ‘Subsidence due to coal mining in India’, in Land Subsidence , Proceedings of the Fifth International Symposium on Land Subsidence, The Hague: IAHS Publication, 1995.

[2] S. Stramondo, C. Bignami, M. Chini, N. Pierdicca, A. Tertulliani, ‘Satellite radar and optical remote sensing for earthquake damage detection: results from different case studies’, International Journal of Remote Sensing, Vol. 27, pp. 4433-4447, 2006.

[3] D. M. Tralli, R. G. Blom, V. Zlotnicki, A. Donnellan, D. L. Evans, ‘Satellite remote sensing of earthquake, volcano, flood, landslide and coastal inundation hazards’, ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 59, pp. 185-198, 2005.

[4] F. Amelung, S. H. Yun, T. R. Walter, P. Segall, S.W. Kim, ‘Stress Control of Deep Rift Intrusion at Mauna Loa Volcano, Hawaii’, Science, Vol. 316, pp. 1026-1030, 2007.

[5] G. Herrera, R. Tomás, J.M. Lopez-Sanchez, J. Delgado, J.J. Mallorqui, S. Duque, J. Mulas, ‘Advanced DInSAR analysis on mining areas: La Union case study (Murcia, SE Spain)’, Engineering Geology, Vol. 90, pp. 148 – 159, 2007.

[6] H. C. Jung, S-W. Kim, H-S. Jung, K. D. Min, J-S. Won, ‘Satellite observation of coal mining subsidence by persistent scatterer analysis’, Engineering Geology, Vol. 92, pp. 1 – 13, 2007.

[7] D. Massonnet and K. L. Feigl, ‘Radar interferometry and its application to changes in the Earth’s surface’, Reviews of Geophysics, Vol. 36, pp. 441-500, 1998.

[8] A. K. Gabriel, R. M. Goldstein and H. A. Zebker, ‘Mapping small elevation changes over large areas: differential radar interferometry’, 1989.

[9] L. Cao, Y. Zhang, J. He, G. Liu, H. Yue, R. Wang, L. Ge, ‘Coal mine land subsidence monitoring by using spaceborne InSAR data: A case study in Fengfeng, Hebei Province, China.’, in The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (presented at the ISPRS Congress, Beijing, P.R. China, 2008), pp. 255-261.

[10] L. Guang, G. Huadong, F. Jinghui, G. Xiaofang, Z. Perski, Y. Huanyin, ‘Mining area subsidence monitoring using multi-band SAR data’, in Urban Remote Sensing Event, 2009 Joint, 2009, pp. 1-6.

[11] L. Bayuaji, J. T. S. Sumantyo and H. Kuze, ‘ALOS PALSAR D-InSAR for land subsidence mapping in Jakarta, Indonesia’, Canadian Journal of Remote Sensing, Vol. 36, pp. 1-8, 2011.

[12] D Chandra, Jharia coalfields, 1st edn, Bangalore, Geological Society of India, 1992.

[13] R. S. Chatterjee, J. Roy and A. K. Bhattacharya, ‘Mapping geological features of the Jharia coalfield from Landsat-5 TM data’, International Journal of Remote Sensing, Vol. 17, pp. 3257-3270, 1996.

[14] V. Srivastava, ‘Study of drainage pattern of Jharia Coalfield (Bihar), India, through Remote Sensing technology’, Journal of the Indian Society of Remote Sensing, Vol. 25, pp. 41-46, 1997.
[15] V. D. Choubey, ‘Hydrogeological and environmental impact of coal mining, Jharia coalfield, India’, Environmental Geology, Vol. 17, pp. 185-194, 1991.
[16] R.S. Chatterjee, ‘Coal fire mapping from satellite thermal IR data - A case example in Jharia Coalfield, Jharkhand, India’, ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 60, pp. 113-128, 2006.
[17] B. C. Sarkar and others, ‘Geo-environmental quality assessment in Jharia coalfield, India, using multivariate statistics and geographic information system’, Environmental Geology, Vol. 51, pp. 1177-1196, 2006.
[18] R. P. Singh and R. N. Yadav, ‘Prediction of subsidence due to coal mining in Raniganj coalfield, West Bengal, India’, Engineering Geology, Vol. 39, pp. 103 – 111, 1995.
[19] J. C. Curlander and R. N. McDonough, Synthetic Aperture Radar: Systems and Signal Processing, Toronto, Ontario, Wiley Series in Remote Sensing and Image Processing, 1991