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IDENTIFICATION AND MEASUREMENT OF DEFORMATION USING SENTINEL DATA AND PSINSAR TECHNIQUE IN COALMINES OF KORBA

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ABSTRACT

Natural Resources extraction for production of goods increases the stress on land and on the environment. Coal Mines are the primary source for energy production. This process increases the continuous deformation on land by disturbing equilibrium beneath the surface. Interferometry techniques have a capability to detect the minute deformation with millimetre precision on the ground using microwave SAR data. The study area covers the largest open cast coal mines of Asia. In this study for minute deformation identification, Persistent Scatterer Interferometry Synthetic Aperture Radar (PSInSAR) technique has been used. Research focuses on the application of PSInSAR technique for terrain deformation detection using 17 SAR scene of Korba, Chhattisgarh, India acquired by the Sentinel-1 satellite of European Space Agency. This technique is capable to monitor the minute deformation in the coal mines of Korba, Chhattisgarh, India. The results predicted that the area is deformed with the velocity up to 30 mm/year in the coal mines and surroundings areas. The PSInSAR technique with the Sentinel-1 data provides the proficient tool for deformation monitoring in coal mines of Korba.

1. INTRODUCTION

Mining deformation in the form of subsidence is the biggest problem in open cast and underground mines and their surrounding areas due to mining activities. Deformation happens in the mining area due to improper extraction methods of the mineral resources or due to the rock/slope failure. The traditional deformation monitoring techniques in India were time-consuming and costly. Recently Microwave remote sensing has gained a significant success to identify the minute deformation. In the Microwave technology, the Persistent Scatterer interferometry (PSInSAR) technology gives a new turn to monitor the subsidence/deformation.

The research focused on spaceborne synthetic aperture radar (SAR) imagery for monitoring mine subsidence which provided an alternative to prediction displacement (Engineering, Informatics, and Systems 2007). The technology has improved with enhancement of different space-borne(Jiang et al. 2011) SAR sensors, which provide high-resolution imagery over a wide area with day-night capturing capability in any atmospheric conditions(Tomiyasu 1978)(Geymen 2014)(Ng et al. 2011). The SAR interferometry concept has been introduced in the last 1980s(Gabriel, Goldstein, and Zebker 1989). Interferometry SAR (InSAR)(Aydoner, Maktav, and Alparslan 2004) techniques are widely used, to measure the topographic profile and surface deformations(Ishwar and Kumar 2017)(Fulton 2000) and for subsidence monitoring(Strozzi et al. 2001). SAR is the radar antenna which synthesizes images by the principle of Doppler effect, the antenna is focused on an object/ element to generate an image in the along track and across track direction. SAR-Interferometry (InSAR) is one of the competent techniques used to understand the land surface motion and land subsidence (land surface sinking) (Ishwar and Kumar 2017) (Strozzi et al. 2001) (Sahu, Pradhan, and Jade 2016) over a large area (Bonì et al. 2017) at a cost lower than the traditional techniques(Ng et al. 2011) (Ferretti, Prati, and Rocca 2001a). The common traditional techniques used for measuring deformation at ground based on regional level are precise leveling, total station, global navigation satellite system (GNSS), etc. that monitor ground subsidence at a pin point location . Though these methods are tedious, require more time, manpower and are costlier, they can measure height information at millimeter to centimeter levels of accuracy on local area levels (Cao et al. 2007).

The mine deformation is the displacement of land due to the extraction of resources. The coal mines have basically three kinds of subsidence, crack, pit hole and sag(Sahu and Lokhande 2015)(Lokhande et al. 2005). The subsidence has been noticed and written in 1556 in the literature of Agricola's De RE Metallica(Singh 1992) but for subsidence engineering, the formal study was started for European coal mines in the 19th century(Ishwar and Kumar 2017). Typically subsidence occurs due to resource extraction (States 1991)(Sahu and Lokhande 2015) and less buoyancy to support the external pressure(Fulton 2000). Deformation has a certain effect of underground mining(Singh 1992) and open cast. The displacement affected area is generally larger than the extracted area of a mine. Mining at any depth can result in subsidence. The deformation, not only impacts the mines but also impacts the ecosystem(Sahu and Lokhande 2015) due to the release of pollutants like toxic gases (Jiang et al. 2011), smog, dust, etc. in the affected areas.

2. STUDY AREA

The study area is in Korba coal field of Chhattisgarh, which lies between the 22º18′N to 22º24′ N 82º46′E to 22º.29′E. In the research area opencast and underground coal mines are presently shown in figure 1. The underground mine (Surakchhar) was started in 1963 and the opencast Gevera mines are the largest open-pit mine in Asia. The Husdo river unequally divides the study area into two parts. The shale, coal and sandstone are present in this region

3. DATA USE AND METHODOLOGY

A stack of 17 Interferometric Wide Swath (IW) Single Look Complex (SLC) Sentinel-1 images spanning from February

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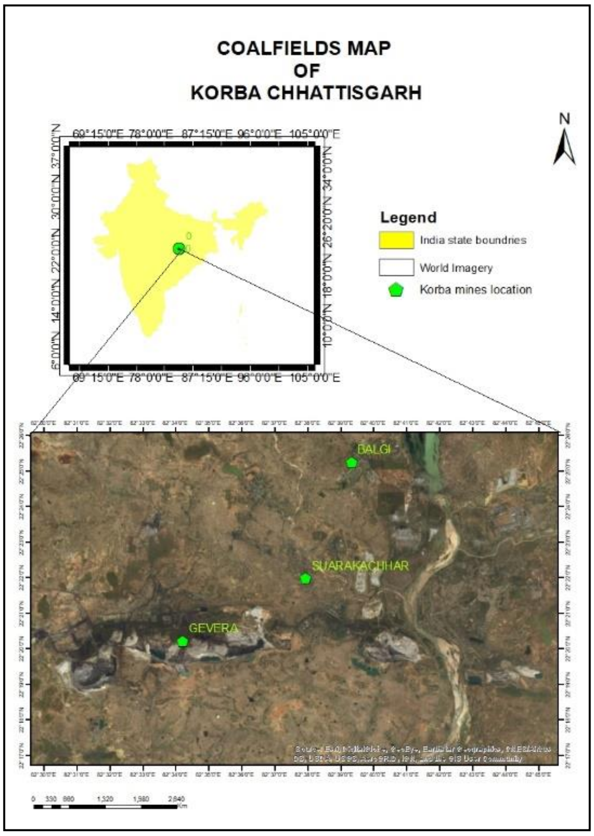

Figure 1 Coalfields of Korba, Chhattisgarh

2015 to February 2017 of Sentinel-1 data acquired freely from the European Space Agency (ESA) has been used in the present study. The acquired data specifications are given in table1. Sentinel-1 has launched on 4th April 2014 by ESA. It acquires interferometric C-band SAR data and improved data acquisition capability as compared to previous C-band SAR sensors (ERS1/2, Radarsat). Sentinel-1A acquired images with a swath width of 250 by 180 with revisiting time 12 days in the IW data acquisition mode, it is reduced to 6 days if the images acquired by the Sentinel-1B satellite are available. These data are freely available and highly beneficial for deformation monitoring in coal mine area of Korba, Chhattisgarh.

The methodology adopted in the present study is shown in the flowchart in figure 2. The methodology is having three sections

S.No.	Data acquisition	Polarization	Temporal baseline
1	2015/02/28	VV	-323.999919
2	2015/06/28	VV	-203.999947
3	2015/07/10	VV	-191.999956
4	2015/07/22	VV	-179.999944
5	2015/12/13	VV	-35.999985
6	2015/12/25	VV	-23.999992
7	2016/01/06	VV	-11.999996
8	2016/01/18	VV	0.000000
9	2016/02/23	VV	36.000152
10	2016/05/29	VV	132.000065
11	2016/07/16	VV	180.000096
12	2016/07/28	VV	192.000103
13	2016/09/02	VV	228.000123
14	2016/09/14	VV	240.000130
15	2016/12/07	VV	324.000191
16	2017/01/12	VV	360.000164
17	2017/02/05	VV	384.000157

Table 1 Acquired Data specification

preprocessing, estimation and visualization and interpretation. Each segment is important for deformation estimation of Korba Coalfields.

From the stack of 17 images, the image acquired on 2016/01/18 has been chosen as reference or master image other 16 images are slave images. By using the reference image all the total images are analyzed for temporal baseline, perpendicular baseline, coherence, PS estimation, etc. In pre-processing, coregistration is done by cross-correlation of slave with the referenced image and interferograms has been generated by averaging the corresponding amplitude and differencing the corresponding phase at each point in the image(Ferretti et al. 2007).

In the estimation part, PS points are stable points and derived from the temporal data or single coherent pixel called permanent scatterer (Ferretti, Prati, and Rocca 2001b). PS points are calculated evaluating the amplitude dispersion index value and Atmospheric Scatter Index (ASI) which derive from backscattered of each pixel. Atmospheric phase screen (APS) is

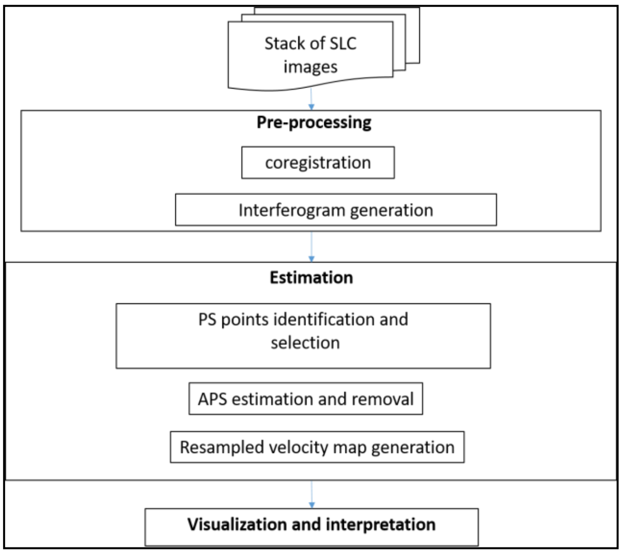

Figure 2 Methodology flow chart

responsible for phase fluctuation of the received signals in linear phase term in range and azimuth direction so it needs to estimated and removed for better results for deformation measurement. The subsidence is monitored by the pixel by pixel estimation of the reference of PS candidates and radar parameter estimation of phase displacement or movement in the image. The images of 2 years data acquired from 28 Feb’2015 to 05 Feb’2017 were stacked to form the stacked interferogram of the 21 images. The images of 2 years data acquired from 28 Feb’2015 to 05 Feb’2017 were stacked to form the stacked interferogram of the 17 images. The PSs supports for an algorithm for linear contribution to monitor displacement measurement in coalfield of Korba. The interferometric phase (ϕ) analysis for all the k permanent point selected point in the pixel in nth flattened and topographically corrected interferogram is(Qiu, Ma, and Guo 2016)

$$\varphi_{diff,n,k} = \phi_{flat,n,k} + \phi_{topo,n,k} + \phi_{,aps,n,k} + \phi_{scat,n,k} + \phi_{noise,n,k} \quad (1)$$

Where,

$\phi_{diff,n,k}$ is total phase difference due to all the factors along the LOS observed by two different satellite or displacement.

$\phi_{flat,n,k}$ is a phase of flat terrain, $\phi_{aps,n,k}$ is the phase difference occur due to supplementary atmospheric disruption.

ϕscat,n,k is the phase difference occur due to echo characteristic. $\phi_{noise,n,k}$ is the noise in the phase by geometrical and temporal decorrelation.
Linear displacement and velocity relation to measuring deformation by assuming that the movement is linear in time:

$$\varphi_{disp,n,k} = \frac{4\pi}{\lambda}\, \Delta v(k)\, B_{n,k} \qquad (2)$$

Where,

Δv is the relative velocity
$B_{n,k}$ is temporal baseline.

Subsidence is monitor by referenced PS points and displacements along the line of sight of the satellite.
By estimating resampled velocity data visualized and interpreted on an interface of google earth for results justification.

4. RESULTS AND DISCUSSION

The PSI products derived with the help of the 17 scenes of IW SLC Sentinel-1 images, spanning the period from February 2015 to February 2017 are accumulated displacement map and the time series of the deformation derived. In figure 3, a total area which has been processed is about 450 sq.km. in which the approx. 300 sq.km area has been under observation for deformation monitoring in the present study. The points in the figures are showing PS candidates which undergo deformation in observed in the areas. The observation is done in and around coal mine area of Korba (marked as rectangles in figure 3). The total processed area map of time series has been superimposed on Google Earth is showing in figure 3 and the area under

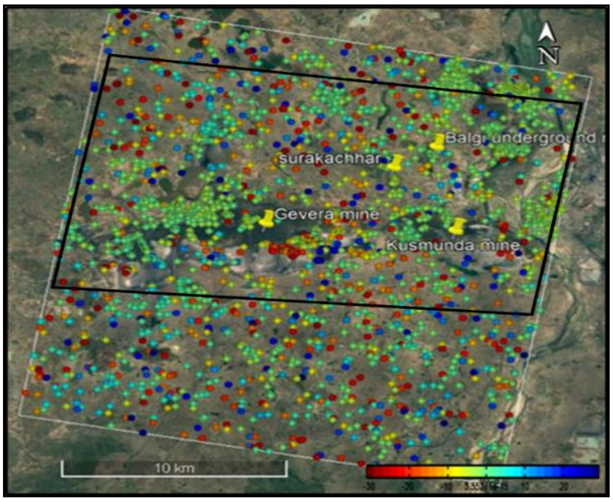

Figure 3 Resampled map of the total processed area and in black color rectangle is mine's area under observation.

investigation is shown in figure 4. Figure 4 shows the accumulated displacement map obtained with the direct integration of the consecutive interferogram. The more

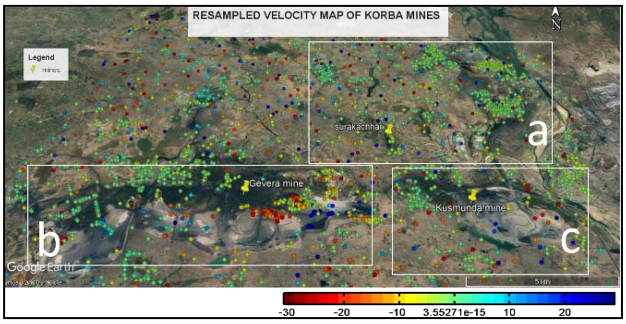

Figure 4 Resampled velocity map superimposed to Google Earth. The rectangle area are the mines (a) Surakachhar, (b) Gevera and (c) Kusmunda

deformed areas are demarcated or encircled shows the rate of deformation occurring in and around coal mine of Korba. The points in the figure3, 4 shows a good coverage of PS candidate over all the area of coal mines and its surrounding area and have a good connection between all the urban areas. Figure 4 shows accumulated displacement map over an area of Korba coalfields and its nearby areas which have been superimposed on to Google Earth for deformation estimation. Figure 4 shows the area of 4a Surakchhar, 4b Gevera, and 4c Kusmunda opencast coal mine. The zoomed view of underground coal mine of

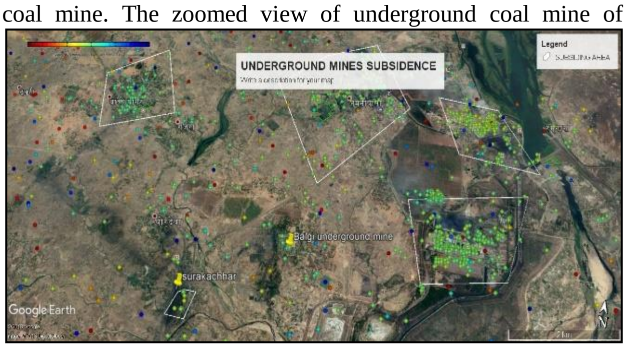

Figure 5 Zoomed view of in and around underground mine Surakachhar

Surakachhar has been shown in figure 5, rectangles in the figures showing more deformation in the area where broadly the deformation rate varies from -3 to -27 mm/year. The Balgi underground mine and its surrounding areas show more deformation demarcated by rectangles in figure 5. Both the underground mines affect the area slowly and gradually in the form of deformation. The rate of deformation is slow but at some places, it's demarcated at a high rate (red color points in the area) which is more than -25mm/year. The area is deformed mainly active mining area and settlements which are permanents feature and having more PS points in the regions. Which provide precision for deformation monitoring. This cannot be neglected due to the presence of underground mines in the area. In the future, this adverse effect in the area can be dangerous for the property and life of the people.

In open cast mine of Gevera, and Kusmunda the deformation has been estimated very high up to -30mm/ year, zoomed view shown in figure 6 and Figure7. The areas in green to red color showing that the area continuously away from the line of sight (LOS) of the satellite and rate of deformation which has been noticeable in the area upto30mm/year. Gevera mine deformation rate is more demarcated in the figure 6, green point's area showing the deformation has been started in the Gevera mines and surrounding area. The area in yellow shows the moderte rate of deformation occurs with the rate of -5 to -

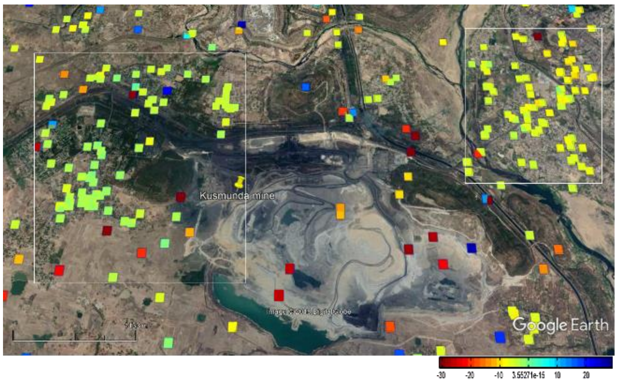

Figure 7 Zoomed view of Kusmunda opencast mine

10mm/year and red color in opencast mine is showing that moderate to the very high rate of deformation is occurring in the area. The points have been noticed in the mines are permanent features like dumping zone, working stations, coal washeries, etc. so it finds more PS point in this region which helps to improve the accuracy of deformation results. The more deformed area demarcated or encircled in figure 6 and 7. In Gevera and Kusmunda due to mining activities directly or indirectly disturbs the area of mine and its nearby areas by drilling, blasting, waterlogging, water sprinkling, slumping and heavy vehicle activities which deformed the infrastructure.

In opencast mines, waterlogging can easily identify on google earth high-resolution images which provide good information for interpretation. Figure 8 showing some zoomed view of

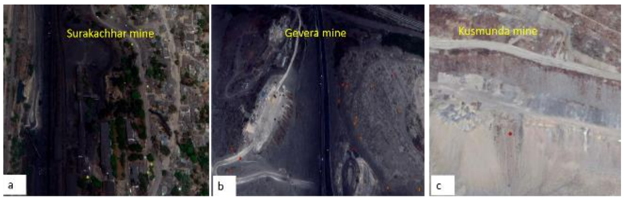

Figure 8 Coal mine areas of Korba zoomed view of deformation points (a) Surakachhar, (b) Gevera and (c) Kusmunda

deformed areas on google earth images of underground and opencast mines of Korba. In the underground mine of

Figure 4 Ground photographs of Kusmunda mine area

Surakachhar, the zoomed view of the area near the working station in which infrastructure undergo deformation up to 10 mm/year has been shown in figure 8a. Underground activities of mining disturb the areas of Surakchhar mine and surrounding residential area slowly which can be a cause of the forthcoming disaster, so it requires frequent attention and maintenance. In figure 8b opencast mine Gevera, roads, slumping areas and dumping sites which deformed highly from -15 to -30mm/year. In figure 8c and figure 9 opencast mine Kusmunda, zoomed view of slumping site near the road is showing the deformation rate is -26.5mm/year. Figure 9, showing some photograph of Kusmunda mine which indicates the deformation of the mine areas. The results in the present study showing more deformation in the opencast mine as compare to underground mines. Gevera mines, having very high deformation rate as compared to all mines present in the present study area because it is having more production as compared to other.

5. CONCLUSION

The deformation monitoring is very necessary for the areas of coal mining for prediction of change and monitoring the indicators of forthcoming hazard. In the present study, PSInSAR technique and C-band sentinel-1 data have been used for deformation monitoring in underground and opencast mines of Korba, Chhattisgarh. The PS point's estimation has been done for deformation monitoring using 17 IW SLC images. The results have been estimated in Korba mines showing that -3 to -30 mm/year deformation occur in different areas of underground and opencast mines. This study also helps to predict deformation in other coal mines of the India and world.

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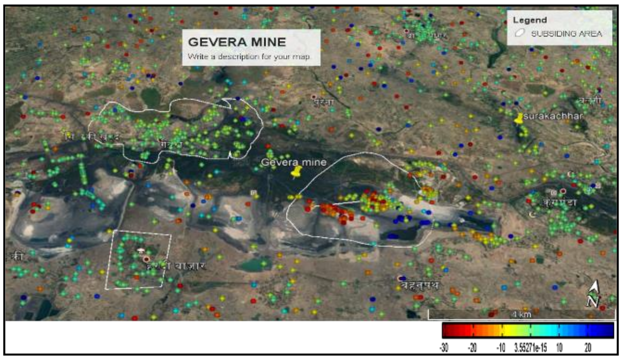

Figure6 Zoomed view of in and around opencast mine Gevera

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