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Investigation into land surface deformation due to hard rock underground metal mining using differential interferometric synthetic aperture radar (D-InSAR) technique

Differential Synthetic aperture radar interferometry (D-InSAR) is a novel remote sensing technique to measure earth surface deformation. It is capable of obtaining dense information related to the deformation of a large area efficiently, economically and effectively. Therefore, D-InSAR is a promising technology for monitoring the earth surface deformation related to some natural hazardous events, such as earthquake, volcano eruption, land subsidence, landslide. In this research paper, to understand the deformation phenomena in the study area due to hard rock underground metal mining, three archive scenes dated 2011/03/12, 2010/03/09, 2010/01/22 of Alos Palsar single look complex data sets were processed to generate interferogarm. Cartosat-1 stereo pair data sets during the same period (2010/06/13) processed to generate a high accuracy DEM of the study area to eliminate the topographic phase as the area is hilly.

Keywords: *Synthetic aperture radar (SAR), InSAR/D-InSAR, deformation, remote sensing, DEM, cartosat, alos palsar, underground hard rock metal mining etc.*

1.0 Introduction

Subsidence is one of the most noticeable environmental impacts associated with mining. Mine subsidence is a movement of the surface in the form of small scale collapses such as, sinkholes or troughs on the surface and regional settlements as a result of settlement of the overburden due to disintegration or failure of underground mine workings. Subsidence can have severe economical, technical, social, and environmental impacts. The most common impacts of mine subsidence are observed on surface structures, bridges, buildings, services and communications lines, and agricultural land through the disruption of drainage patterns and variations of gradient. The extent of potential impacts of subsidence depends on the type of mining method, geology of the deposit and the overburden, attitude of the mineral deposits, and mitigation measures. Generating appropriate mitigation measures necessitates continuous monitoring and investigation of the mine area and its surroundings. In this sense, remote sensing can provide an effective tool in measuring and interpreting subsidence quickly, accurately, and simply.

Recent developments in satellite geodesy techniques, by using spaceborne Differential Interferometric Synthetic Aperture Radar (D-InSAR), introduced a new tool to detect and measure subtle vertical displacements (cm to sub-centimeter level). Various workers has used this technique for monitoring long-term land subsidence phenomenon (Zebker et al., 1986, 1992; Gabriel et al 1989; Goldstein et al., 1993,1995; Rosen et al., 1996: Galloway et al., 1998; Massonnet et al., 1993, 1997, 1998; Strozzi. et al 2001; Amelung et al., 1999, 2000; Franceschetti et al 1999; Ferretti et al., 1999, 2000, 2001, 2005; Rosen et al., 2000;Usai 2001; Colesanti et al., 1999, 2001; Hansen et al., 2001, 2002, 2005; Fruneau and Sarti, 2000; Berardino et al., 2002; Crosetto et al., 2002, 2003; Lanari et al., 2004; Chatterjee et al., 2006, Raucoules et al., 2007; Hooper et al., 2007 and 2008;). Among the various space-borne techniques available till date for measuring ground deformation, D-InSAR technique is considered to be the most efficient way for measuring spatially-continuous ground deformation with higher precision. The precision and feasibility of D-InSAR technique is largely controlled by the quality of InSAR data pairs, in terms of baseline and wavelength of the SAR signal.

In this study, an integrated measurement and monitoring approach is being attempted using space-borne D-InSAR technique, along with ground based measurements. A satellite-based Differential Interferometric Synthetic Aperture Radar (D-InSAR) technique is being employed to identify the areas affected by land subsidence and an attempt is being made to measure precisely the rate of land subsidence phenomenon in order to prepare a spatially continuous land subsidence map during the 2010 and 2011 for two major

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underground copper mines situated at northern part of Aravali range of hillocks, Rajasthan, India.

Worldwide, many research results suggest that the InSAR/D-InSAR method is capable of detecting vertical ground movements due to underground mining, even over relatively small areas.

In India, since last decade, a few research works based on assessment and prediction of land surface subsidence due to subsurface coal mine fire using InSAR/D-InSAR technique have been carried out by CIMFR, Dhanbad and IIRS, Dehradun. A few research work based on assessment and prediction of land surface subsidence due to underground coal mining using InSAR/D-InSAR technique also being carried out. However, no study has yet been focused on investigation into land surface deformation/subsidence due to hard rock metal mining using D-InSAR/space-borne technique.

Subsidence monitoring from space is the latest technique, which provide the way of studying large area in limited time period with less expenditures.

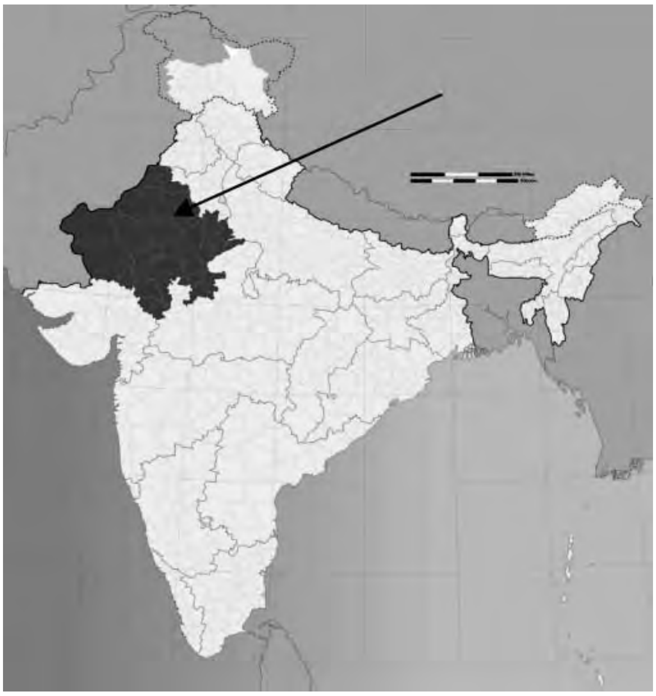

Fig.1 Location map of study area

2.0 Study region

The study area has two major working underground copper mines, namely, Mine A and Mine B. The mining lease area is situated at the northern tip of the Khetri copper belt. It covers an area of 162.23 hectare. The area falls in the Survey of India Topo sheet No. 44 / P16. Main hill ranges in the lease hold area strikes NNE-SSW located at the western side of half of the area. The hill ranges contain the host rock of copper mineralization. The western slope of the hill is steep while the eastern slope is relatively gentle. The lease-hold area is marked on the Survey of India Toposheet no.44P/16 in 1:50000 scale.

The Mine A and Mine B is well connected by metalled road. The nearest railway station is Nizampur on Rewari-Jaipur section (North Western Railway) and another is Chirawa (30 km) on Loharu-Jaipur section (North Western Railway). The geographical location of the Mine A and Mine B is (latitude: N 28 00' 46"- N 28 05'50" and longitude: E 75 45' 32"- E 75 47' 12". Location map of study area is shown in Fig 1.

3.0 Geology

The rocks in the study area belong to the Delhi Supergroup of Precambrian age, which is sub-divided into the Alwar and Ajabgarh groups. The older Alwar rocks are derived from predominantly arenaceous sediments while the younger Ajabgarh rocks were originally more argillaceous; the transition between the two is gradational. All these formations are metamorphosed to quartzites, schists and phyllites. Some intrusive dolerite dykes are present and veins of quartz and carbonate are common.

The general strike of the formation is NNE-SSW with steep to gentle dips towards the WNW. The economic mineralization, which gives rise to the ore bodies, is mainly localized in the upper parts of the amphibole-chlorite-quartzite and garnet-amphibole-chlorite-quartzite/schist. The mineralization occurs in the form of veins, veinlets, stringers and disseminations (rarely massive), oriented in general parallel to the foliation plane.

In Mine A, there are two distinct ore lodes, namely Madhan (or footwall) lode and the Kudhan (or hanging wall) lode. The Madhan lode is fairly persistent, containing a number of ore lenses. The Kudhan lode, on the other hand, is narrower, poorer in copper, and the lenses are less persistent. It is well formed in the central part of the mine. At the Mine B, there are three distinct lode systems: Lode I (south lode), Lode II (north lode) and Lode III (east or footwall lode). Of these, Lode I and III are persistent but Lode II is not persistent in depth.

4.0 Objectives

1. Digital elevation model generation using high resolution optical stereo pair data set (Cartosat-1 sensor)
2. Investigation into open stope induced land surface deformation in hard rock metal mine area using Differential Interferometry Synthetic Aperture Radar (D-InSAR) Technique.

5.0 Remote sensing data used

5.1 Cartosat-1 stereo pair

Cartosat-1 or IRS-P5 is a stereoscopic earth observation satellite in sunSynchronous, and the first one of the

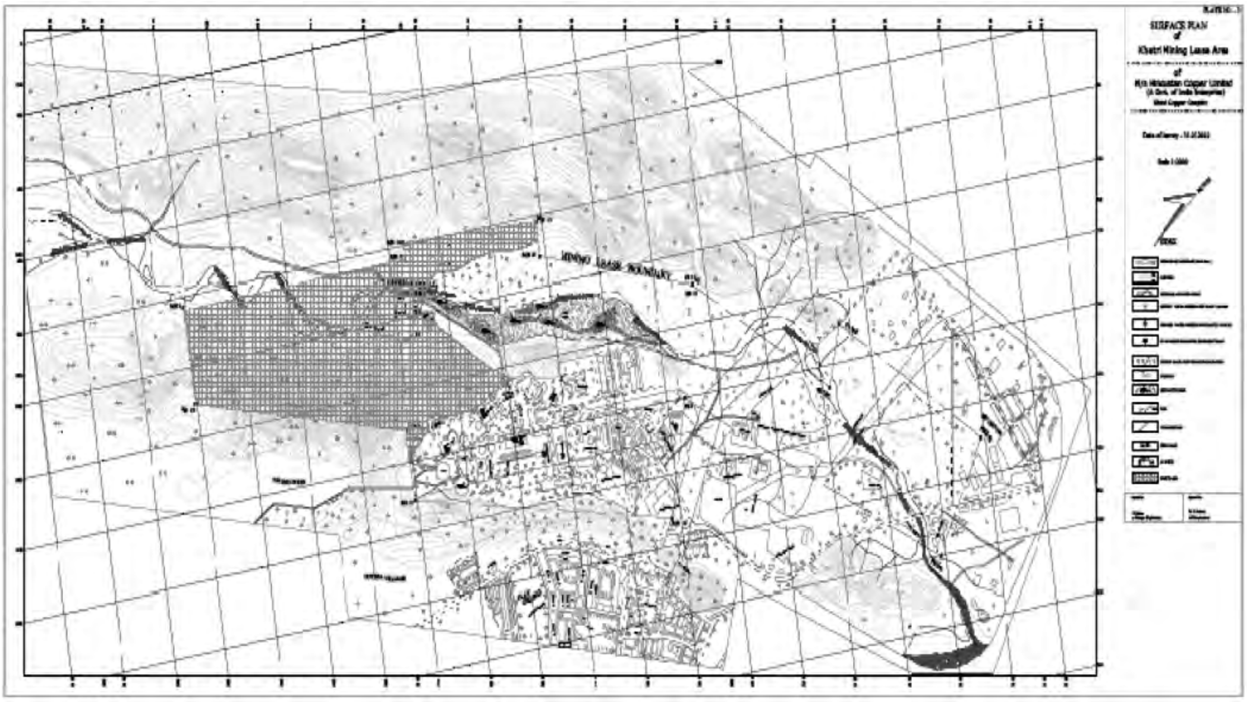

Fig.1a Surface plan of mine A

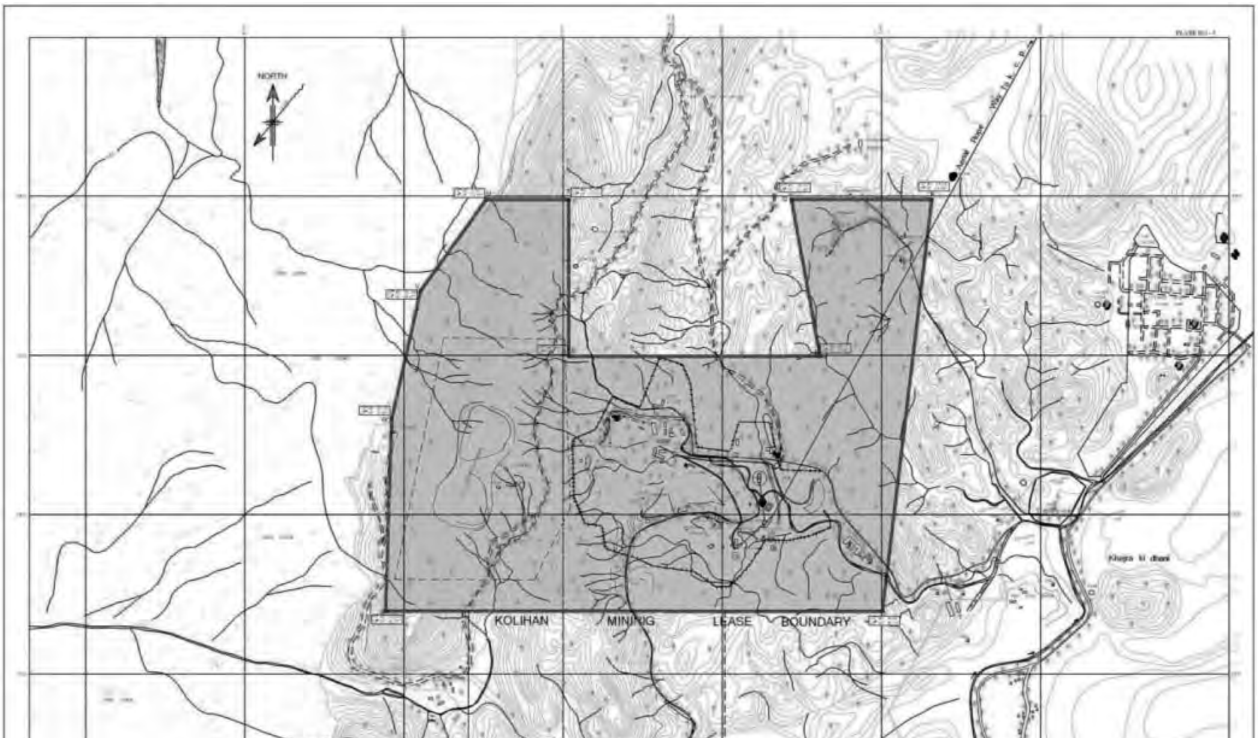

Fig.1b Surface plan of mine B

In land surface deformation studies phase due to topography , atmospheric and phase due to noises are unwanted phases. Eliminating of unwanted phases from the interferogram is called differential interferometry SAR (D-InSAR). The process flow of D-InSAR technique is given in Fig,2.

8.0 Observations

TABLE 3: BASELINE ESTIMATION

SAR pair	Normal baseline (m)	Temporal baseline (days)	Range shift (pixel)	Azimuth shift (pixel)	Doppler shift difference (Hz)
1-2	518.477	46	53.407	27.671	-14.809
2-3	1842.301	367	268.772	-163.944	8.616
1-3	2298.418	413	322.035	-136.374	-6.193

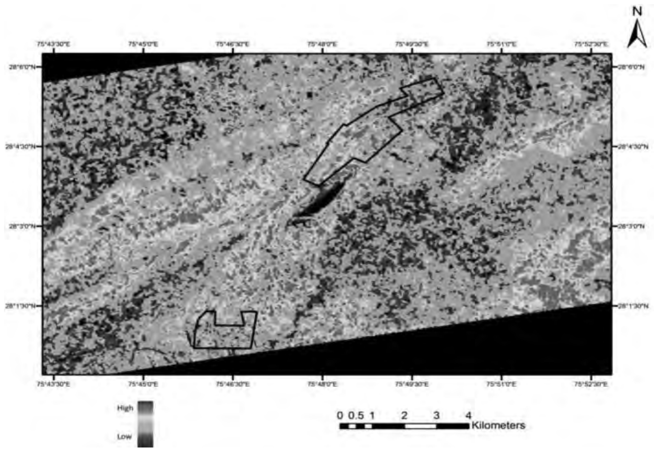

Fig.3 Mining lease boundary overlay on filtered coherence map of SAR pair 1-2

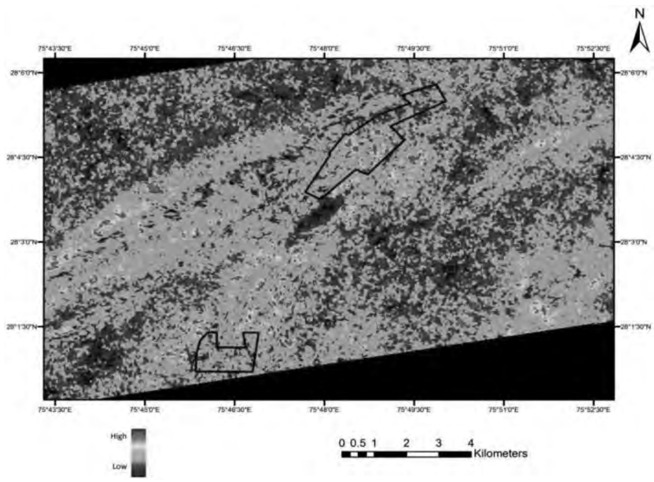

Fig.4 Mining lease boundary overlay on filtered coherence map of SAR pair 2-3

9.0 Results and discussion

1. Filtered coherence maps were generated from SAR pairs 1-2, 2-3 and 1-3 as shown in Figs.3 to 6. It was observed that coherence value is higher in the case of SAR pair 1-2, which could be due to the less spatial as well as temporal decorrelation as shown in Table 1. It was also observed that there was loss in coherence value in the case of SAR pair 2-3 and 1-3, which could be due to significant spatial as well as temporal decorrelation.
2. Filtered differential interferograms (after orbital refinement) were generated from SAR pairs 1-2, 2-3 and 1-3 using CARTOSAT 1 DEM and SRTM DEM (1 arc second) as shown in Figs.7 to 11. It was observed from differential interferograms, complex topographic phase could not be fully compensated in both the cases. Phase difference due to movement could only be measured after complete removal of topographical phase.

10.0 Conclusion

Coherence loss is not in user's control. It is more dependent on data acquisition strategy therefore cannot be resolved fully however topographical phase can be removed applying a more precise DEM of the study area.

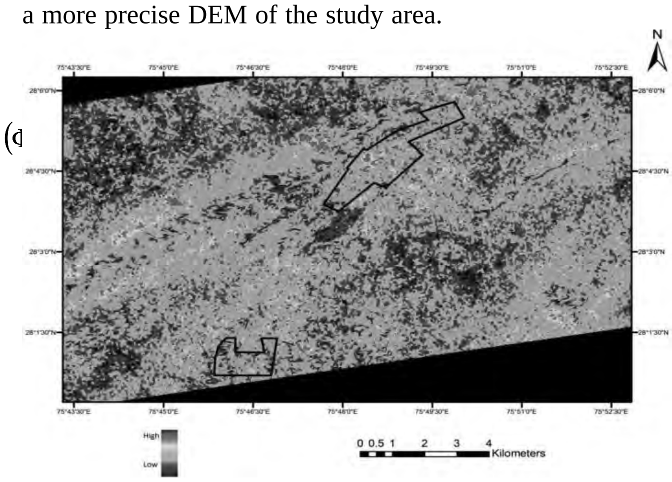

Fig.5 Mining lease boundary overlay on filtered coherence map of SAR pair 1-3

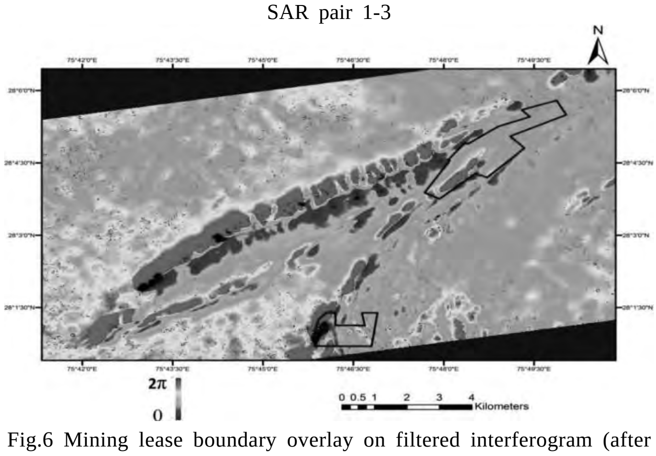

Fig.6 Mining lease boundary overlay on filtered interferogram (after orbital refinement) using Cartosat-1 DEM (pair 1-2)

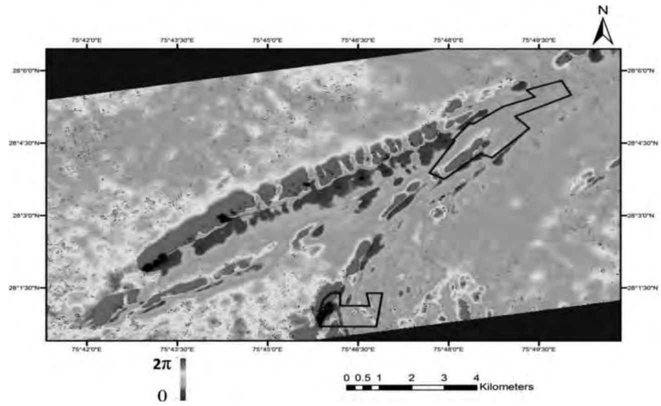

Fig.7 Mining lease boundary overlay on filtered interferogram (after orbital refinement) using SRTM DEM (pair 1-2)

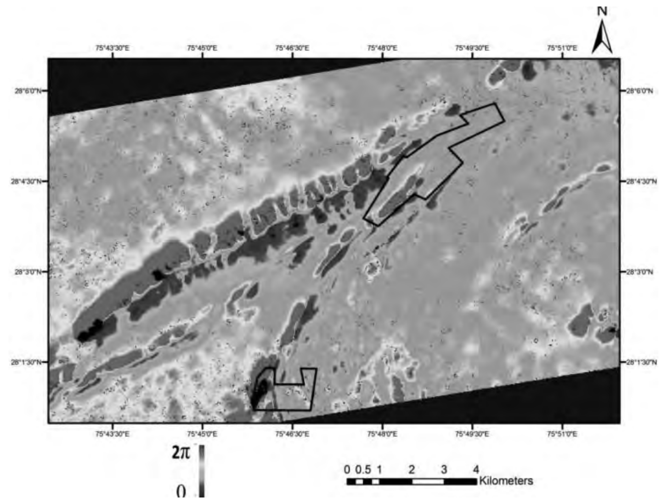

Fig.8 Mining lease boundary overlay on filtered interferogram (after orbital refinement) using Cartosat-1 DEM (pair 2-3)

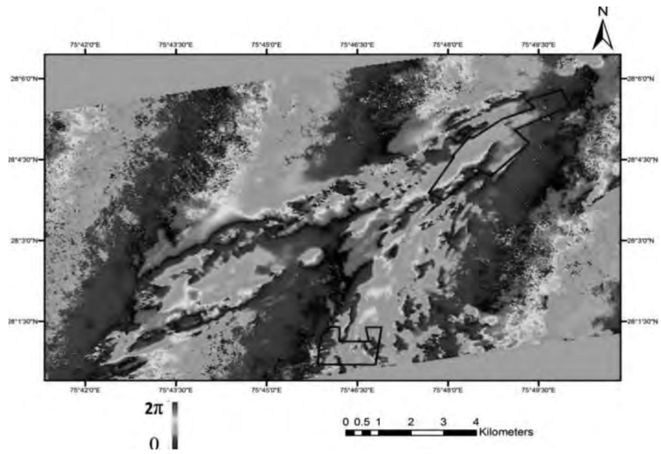

Fig.9 Mining lease boundary overlay on filtered interferogram (after orbital refinement) using SRTM DEM (pair 2-3)

1. Cartosat-1 DEM will be generated further based on Ground Control Points (GCPs) collected from study area using DGPS survey to remove the complex nature of topographical phase in order to improve the result. In the present differential interferometry process, CARTOSAT-1 DEM was generated based on points collected from Google Earth for topographic phase removal.

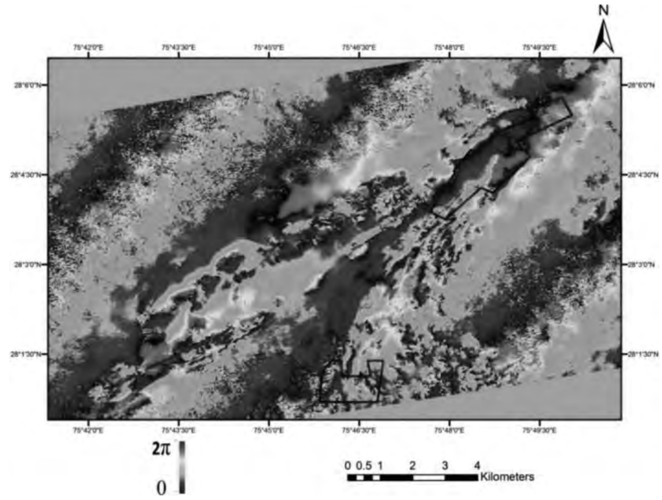

Fig.10 Mining lease boundary overlay on filtered interferogram (after orbital refinement) using Cartosat-1 DEM (pair 1-3)

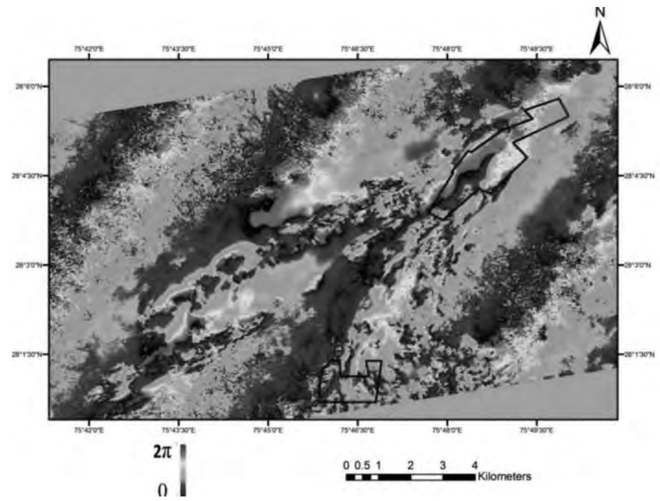

Fig.11 Mining lease boundary overlay on filtered interferogram (after orbital refinement) using SRTM DEM (pair 1-3)

2. Displacement map will be generated for different pairs of SAR imagery and subsequently subsidence rate will be determined and predicted.

11.0 References

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(Continued on page 18)