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Detecting Ground Subsidence on the Yazd-Ardakan Railway Using Radar Interferometry

Zahra, Sheikhi Kouhsar[1], Seyed Ali Almodaresi[2*], Ali, Sarkargar Ardakani[3], Parastoo, Sahebalzamani[4]

[1]Department of Remote Sensing & GIS college of Engineering, Yazd Science and Research Branch, Islamic Azad University, Yazd, Iran
[2]Civil Engineering College, GIS&RS Department, Yazd Branch, Islamic Azad University, Hesabi Blv, Safaeie, Yazd, Iran
[3]Engineering College, Remote Sensing and GIS Department, Islamic Azad University, Science and Research Branch of Yazd
[4]Technical research and infrastructure - Centre for Railway Research and Education, Tehran, Iran

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ABSTRACT

The ground subsidence because of excessive pumping and fall of the groundwater level causes some problems and hazards in an expanded level. This phenomenon causes some problems for farmers, destruction of communication lines and substructures and some other problems. The subsidence of substructure is one of the most important concerns of railway safety. A small deformation in the railway, may lead to derail of the train and other serious accidents. Therefore safety of the railway as a vital artery of country is necessary. In this research the differential Interfrometry synthetic aperture radar (DInSAR) is used to depict the subsidence area and zoning the subsidence hazard toward the railway of Yazd-Ardakan region. Results of InSAR indicate that, the maximum subsidence in the under studying region is about 10.75 cm/year for the period 2007 to 2008 and the maximum rate of subsidence in the railway line is 3.2 cm/year. And this indicates a decrease in subsidence toward the previous years. The subsidence is occurred in the line of railway in distance of 582.4 to 596 km of Ardakan station to Meibod and in 757 to 768.42 km of Yazd station to Yazdgerd, and Shamsi station to Nazar Abad.
KEY WORDS: Differential Interfrometry Synthetic Aperture Radar, subsidence, railway, groundwater, risk zoning.

1. INTRODUCTION

One of the prevalent hazards all over the word is land subsidence. The anthropogenic activities of excessive groundwater utilization in agriculture, aquaculture, industry and urban area give rise to serious land subsidence. Consequently, land subsidence could result in environmental hazards such as exhaustion of groundwater resources, damage of infrastructures, increase of risks of inundation and inland sea water intrusion [7].

Most of the reports about the ground subsidence all over the world is related to the arid and low rainfall regions during the past this phenomenon was reported in several parts of the world such as Arizona and California States of America, Osaka and Tokyo of Japan, and also in Italy, Bangkok in Thailand, Jakarta in Indonesia, Kolkata in India, and Mexico city in Mexico [9].

Subsidence in Iran is observed, reported and is developing in plains such as Arak, Nahavand, Khomein, Natanz, Nofagh and Behraman plain (Sharifi Kia, 2012), Hashtgerd plain (Haghighat Mehr et.al., 2010), Neyshabour plain (Dehghani et.al., 2009; Mo′tagh et.al., 2007), Mashhad (Lashkari Pour et.al., 2005, Akbari et.al., 2008), Kashmar plain in Khorasan Razavi Province (Lashkari Pour et.al., 2006), Rafsanjan (Rahnama and Kazemi Far, 2006). Nur Khakim and et al., [11], studied Land subsidence in the Bandung basin, West Java, Indonesia with differential Interfrometry Synthetic Aperture Radar (DInSAR) and interferometric point target analysis (IPTA). they generated interferograms from 21 ascending SAR images over the period 1 January 2007 to 3 March 2011. The estimated subsidence history shown that subsidence continuously increased reaching a cumulative 45 cm during this period. Tan et al.,[13], analyzed railway subgrade deformation using satellite interferometry in Qinghai-Tibet plateau permafrost region. Their analysis results is shown that settlement is the main behavior of railway subgrade deformation and the deformation amount of railway bridge is less than the sliced or the crushed rock embankment along the Qinghai-Tibet railway and all these results are in good agreement with the ground measurements and other

***Corresponding Author**: Seyed Ali Almodaresi, Civil Engineering college, GIS&RS Department. Yazd Branch, Islamic Azad University, Hesabi Blv, Safaeie, Yazd, Iran. Email: Almodaresi@iauyazd.ac.ir

relevant studies. Chen et al. [3], considered the ground subsidence in The Qinghai–Tibet Railway (QTR), the highest and longest plateau linear structure in the world using 19 L-band ALOS PALSAR SLC images (acquired from 21 June 2007 to 30 December, 2010) and 38 C-band ENVISAT ASAR SLC images (acquired from 18 November 2004 to 17 December, 2009) through Satellite SAR Interfrometry Technique, in this research the distinct surface motions are observed along the embankment in the range of -20 to 20mm/yr. And near the Beijing- Tianjin railway [10], the maximum amount of deformation is observed about 100mm/yr.

Subsidence and its effects on surface-level structures poses serious problems for the development and maintenance of building stock and other human-made structures, such as roads and railway lines [14]. It has very important engineering significance for railway infrastructure long-term deformation monitoring [12].

There are some reports of accidents and events due to derail of the train. For example, in 25 August of 2003, derail of four railway wagons of local train from Sealdah - Dankuni in India, lead to injury of 25 persons (Journal of India, 2005). It was reported that the main reason for derail of the train was subsidence of the ground under the railway. Therefore, control and supervise the deformation of ground along the railway is so important. One of the regions in Iran that faced subsidence phenomenon is Yazd – Ardakan Plain. Subsidence in this plain is the reason of disruption on the road surfaces, breakage of the water pipes and fracture of structures [2].

The aim of this study is to indicate the ability of differential Interfrometry (DInSAR), to show the land deformation near the railway, the InSAR method has demonstrated that is capable to measure the crustal and topographic deformation with good spatial resolution in very wide coverage about tens meters [15].

The railway of Yazd Province causes connection of this province with Isfahan and Kerman Provinces and causes connection of mineral and industrial centers of Iran. The main communication line of Yazd Province, known as Santo road, is considered as one of the most traffic communicational networks of Iran, especially in transporting the loads with heavy vehicles. Researches which were conducted in our country in the case of studying the subsidence of railway were very scattered or few or were done using the methods of engineering geology and geotechnical of the route for example a study was conducted in the route of Tehran – Tabriz railway Tunnel in the 17th region of Tehran. And in Iran studying the subsidence of railway using the InSAR method is performed for the first time. Due to the importance of this phenomenon as one of the natural hazards in compiling the management practices to recognize and prevent, decrease and compensate the effective structural damages, it seems that studying in this case is a necessary affair. In this research we aim to consider the effect of subsidence on the railway of Yazd-Ardakan region and evaluate the zoning of subsidence hazard toward the railway and also its amount.

(a) (b)

Figure 1. (a) Subsidence adjacent to the railway of Yazd –Ardakan route, between the Shamsi – Nazar Abad station**,** (b) subsidence adjacent to the railway bridge (March,2013).

2. MATERIALS AND METHODS

Under studying region is the railway of Yazd-Ardakan route that is located in the biggest plain of Yazd Province, this plain is limited to ShirKooh mountain from west and south west, and to Kharanegh mountains from east, and to pan of Bahadaran in south and to pit of Oghada in the north. This region is a part of Siyah Kooh salt desert catchment that is located between the 53 degree and 45 minutes to 54 degree and 50 minutes longitudes and 31 degree and 15 minutes to 32 degree and 30 minutes latitudes (figure 2). Yazd- Ardakan plain with length of 60 km and average width of 15 km is located between Yazd and Ardakan cities. Climate of this region is arid that according to the 18 years statistics the average of annual rainfall in this plain is 61 mm. The main aquifer of groundwater in the plain is started from the region of Fahraj to Mohammad Abad in suburb of Yazd and continues in direction of south east – north west to the region of Chah Afzal and its area is about 2088 km^2 [8].

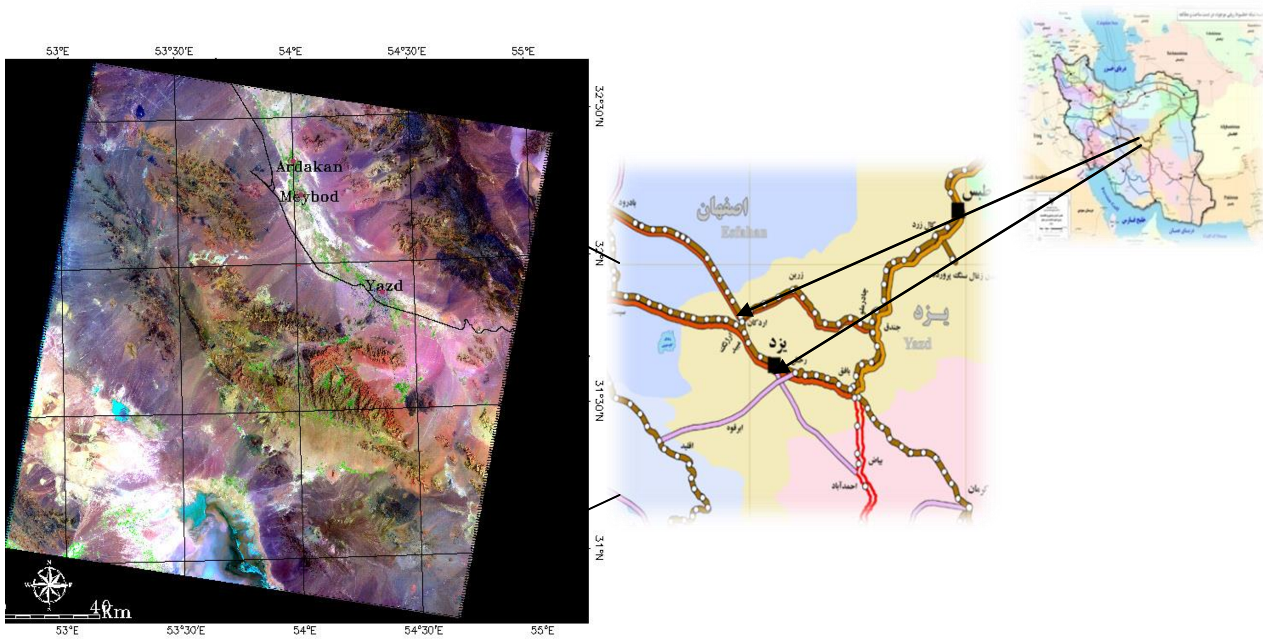


Figure2. Yazd – Ardakan railway was overlaid on a LANDSAT TM false colour image (B147).

One of the powerful tools to measure the subsidence phenomenon is InSAR technique. This method is able to determine the changes of ground surface during a specific period of time by comparing the phases of two radar images which are taken from one region in two different times. The taken phase from one phenomenon and event on the ground surface is proportionate with its distance to the Radar Sensor. In this technique the complex radar images, that contain the amounts of phases and amplitude of backward waves from the event toward the sensor, are combined each other and create an image that is named Interferogram. Interferogram is a image that is created from phase difference of two taken images at two different times that coincide with each other exactly geometrically [4].

The basic strength of the InSAR technique, that the difference in slant ranges from the two antenna positions can be measured with the fractional wavelength accuracy in terms of phase difference. The phase difference is related to Slant-range difference and can be processed to derive height information, that is, generat a Digital Elevation Model (DEM) [5]. The Interferogram phase contains the topographic information, orbit errors, displacement and atmospheric disturbances. To measure the displacement of ground surface during a specific period of time, the orbital errors, topographic influences and atmosphere noise must be removed from Interferogram.

In this study the four images are used that are acquired on January, February, April and December from 2007 to 2010 with ENVISAT ASAR (C band) with wavelength of 5.6 cm. Image pairs having perpendicular baseline smaller than 255 m have been selected for processing. And Interferometric processing has been performed using the SARSCAPE software. The characteristics of images are shown in table (1).

Table 1. ENVISAT ASAR images used in this investigation. (SLC[1] images)

orbit	Incidence angle (θ_c)	Date
152055	40	2007.01.29
162068	40	2008.04.28
162085	40	2009.12.14
162087	40	2010.02.22

To provide an Interferogram with a pair of SLC images, with relatively high coherence, the determined exact orbital parameters, and suitable normal baseline, with a DEM are used to study the subsidence. At first two images are co-registered toward each other and coincident with each other exactly from geometric viewpoint. In a differential Interferogram, a complete 2π phase change, is equivalent to a height displacement of half of the wavelength of the radar signal in the slant range direction, or so-called line of sight (LOS), that is in the look direction of the radar. The orbital errors were adjusted using the exact orbital information which was taken by Doris satellite of European Space Agency (ESA). The atmospheric component is Mainly due to the fluctuations of water

[1] Single Look Complex

vapour in the atmosphere in the path of the radar beam between the satellite and the ground. The atmospheric delay can be identified using the fact that its fringe structure is independent over several interferograms, or can be modeled by using a local GPS network [6]. To remove the noise of Interferogram the adaptive filter was used. And in the next stage, the unwrapped phase can be converted to deformation that indicate the displacement of Earth's crust. These changes are measured along the line of sight (LOS) between the ground target and the satellite and in the vertical and horizontal direction. Finally, is the stage of flattening the interferograms to remove the phase component that is caused by topographic effects, and a Digital Elevation Model with resolution of 90 meter and 10 m height accuracy was used that is prepared by shuttle radar topography Mission(SRTM). Characteristics of interferograms are shown in table 2. At last five displacement images were prepared and the shape file of railway was overlaid on the displacement images and zoning the subsidence hazard toward the railway were prepared.

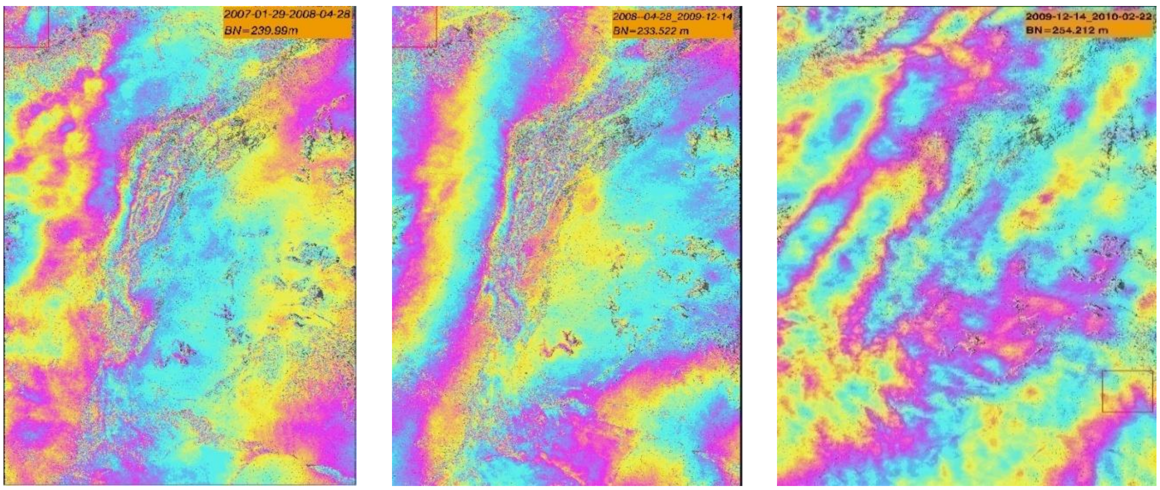


Figure 3. Differential interferograms of the ENVISAT images in Yazd – Ardakan plain from 2007-2010, period of time and normal baseline are shown on the images.

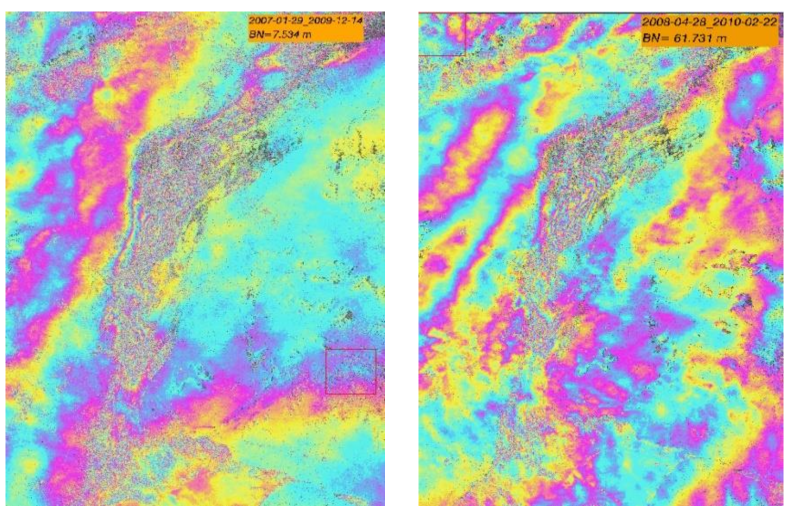


Figure 3. (continued).

Table 2. Characteristics of processed interferograms in the study area (Yazd – Ardakan plain).

Interferogram	Slave Image (yyyy_mm_dd)	Master Image (yyyy_mm_dd)	Height ambiguity (m)	Perpendicular baseline (m)
a	2008.04.28	2008.01.29	76.943	239.99
b	2009.12.14	2008.04.28	79.079	233.522
c	2010.02.22	2009.12.14	72.633	254.212
d	2009.12.14	2007.01.29	2451.104	7.534
e	2010.02.22	2008.04.28	299.15	61.731

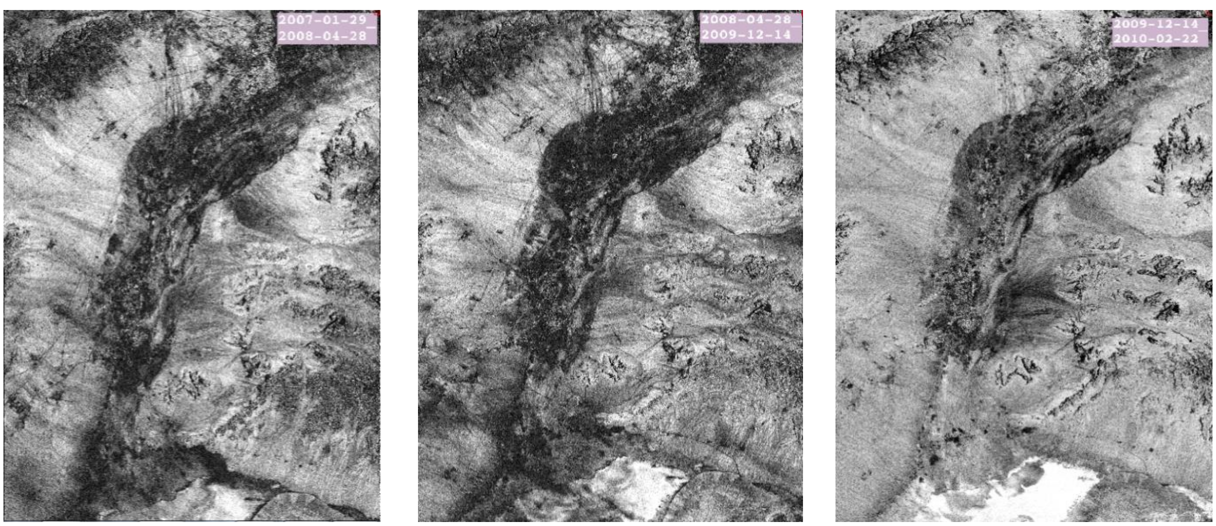
3. RESULTS AND DISCUSSIONS

In this study, the ability of differential Interfrometry Synthetic Aperture Radar (DInSAR) technique to determine and indicate the deformation because of ground subsidence near the railway of Yazd – Ardakan is shown. And using the Radar Interfrometry technique we could measure the amount of subsidence in Yazd – Ardakan plain and the existed railway at that region. The length of Yazd – Ardakan plain is 60 km but one advantage of ASAR data is its high coverage (100 * 70) square kilometer in such a manner that it covered the all the 130 km length of the railway (figure 2). The scene acquired by ENVISAT satellite covered Yazd, Meibod and Ardakan too.

The differential Interfrometry radar technique (DInsar) using two SAR images acquired from two slightly different positions and at different revisit times so that the phase difference are compared so that the phase difference, or Interferogram are obtained and during that measurement of phase difference is done duo to the ground deformation. From processing the images by one year or more than one year intervals 5 interferograms were obtained. And orbital information using the DOR-VOR file that contains the gathered or taken data of DORIS satellite of European Space Agency was used to adjust the distortion of images which are created because of gravitational force of the moon on the images. Maximum of subsidence during the specific period of 2007 to 2009 was obtained about 17.5 cm in Shamsi region. And the most amount of subsidence in the route of railway was evaluated about 4.7 cm. also these results were compared to the study of Amighpey et.al (2009); that indicates the similarity of subsidence pattern in both of the studies. On the basis of the performed statistical survey among the 5 interferograms 4 cases had high accuracy of results that will be interpreted here.

1-3.The analysis of phase correlation between two images (Coherence)

Coherence indicates the amount of phase correlation between two images. Its amount will change between 0 and 1 and distance of 0.7 to 1 is the best amount for it. Also it can be used as a parameter to identify and detect the ground targetes [1]. In this research the Coherence images which have been created during the processing were considered for all the periods. Using the histogram of images and comparing their images we obtained important information about phases. These images are shown in figure (4).



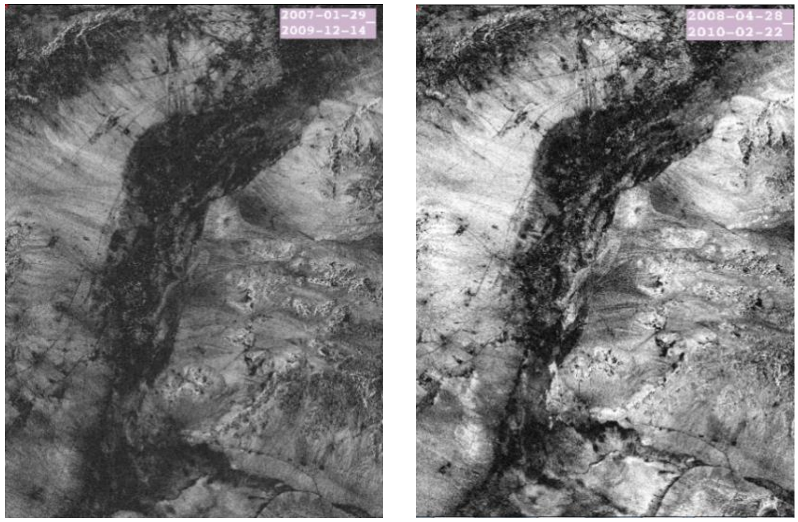


Figure 4. Interferometric coherence images in Yazd – Ardakan plain from 2007 - 2010.

What the less temporal baseline were between interferometric pairs (two images) its coherence will be more and the targets will be observed better on the images. For example, images of 2009 to 2010 (69 days interval) is more obvious and has higher resolution. And the long temporal separation between two images, lead to temporal decorrelation and so loss of all the correlation in interferograms and because of noise increase the coherence images will be darker (for example, images of 2007 – 2009).

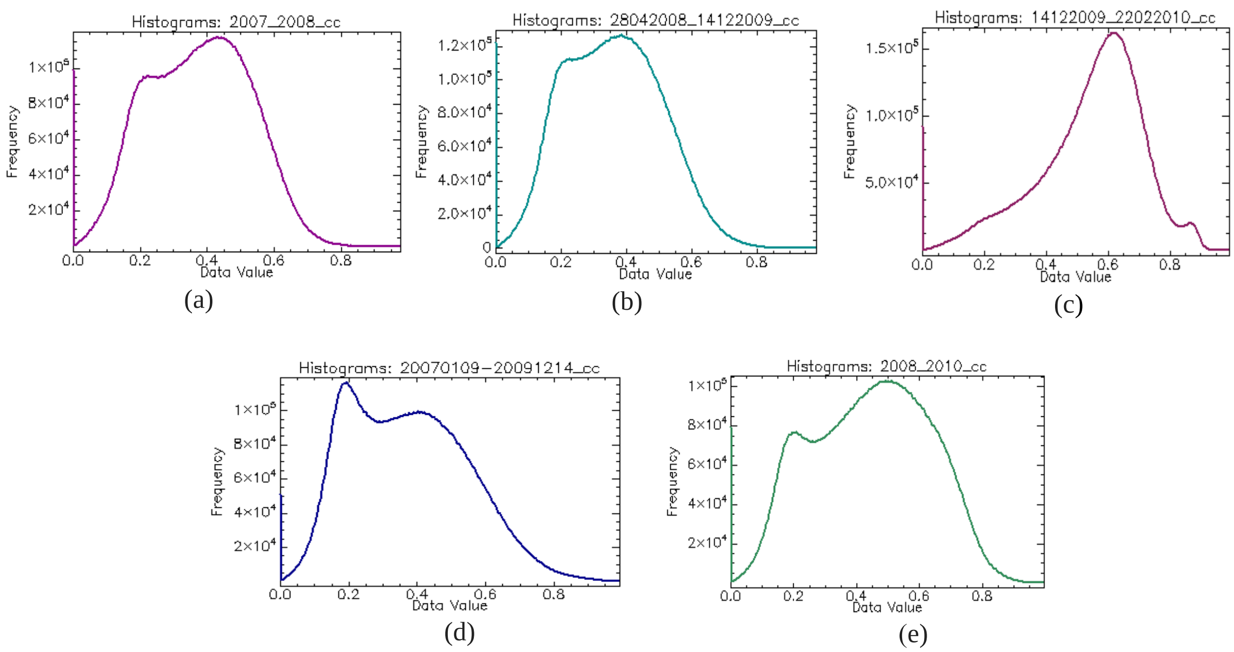


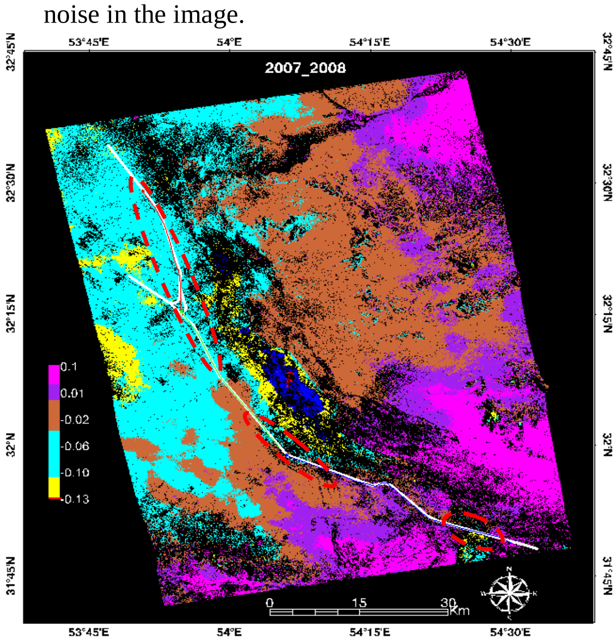
Figure 5. Histogram of coherence amount distribution (X axis) and pixel frequencies (Y axis) in coherence images, Temporal baseline in histogram (a) is 455 days, in (b) 595 days, in (c) 69 days, in (d) 1050 days and in (e) 664 days.

Table 3. The under consideration statistical data of each coherence image that is prepared to select the best couple of images from coherence viewpoint.

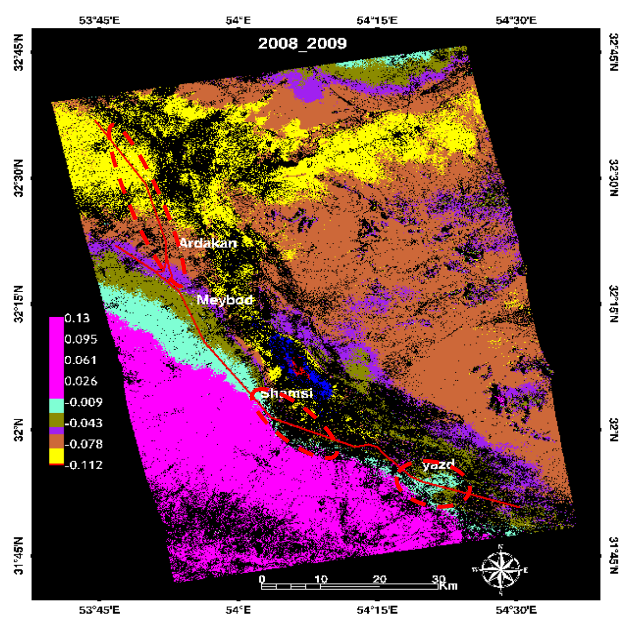
Coherence image	Max.	Min.	mean	Standard deviation(St. dev.)	Temporal baseline, B_t (days)	Normal Baseline B⊥ (m)	Distribution of coherence amounts maximum of pixel frequencies	The coherence amount of maximum frequency
2007-2008	0.977	0	0.376	0.152	455	239.99	0.2 - 0.6	0.4 - 0.6
2008-2009	0.98	0	0.358	0.149	595	233.522	0.2 - 0.6	0.4 -0.6
2009-2010	0.99	0	0.5465	0.167	69	254.212	0.4 – 0.8	0.5- 0.7
2007-2009	0.99	0	0.374	0.172	1050	7.534	0.2 – 0.6	0.2
2008-2010	0.99	0	0.44	0.186	664	61.731	0.2 – 0.6	0.4 – 0.6

According to table (3), the maximum coherence amount is in the period of 2009- 2010 with 69 days interval and also its histogram has the most amount (pixel frequency) between the coherence amount of 0.6 – 0.8. That is the level of histogram with coherence amount in the range of 0.6 -0.8 (high coherence) in it is more than other images but generally its diagram has less level in other ranges and amounts of coherence and it seems that so many of phases are lost. In this reason the displacement image of this period is different with others and in one part the spatial baseline (254.212 m) in this period has the highest and most amount and at last the deformation plan indicates the 4 cm subsidence regarding the short time interval of 69 days that was unexpected. Comparison of 5 histograms of images indicate that 4 other histograms are somewhat similar and their final displacement images are also similar in generalities of subsidence and the deformation places are occurred similar each other in them.

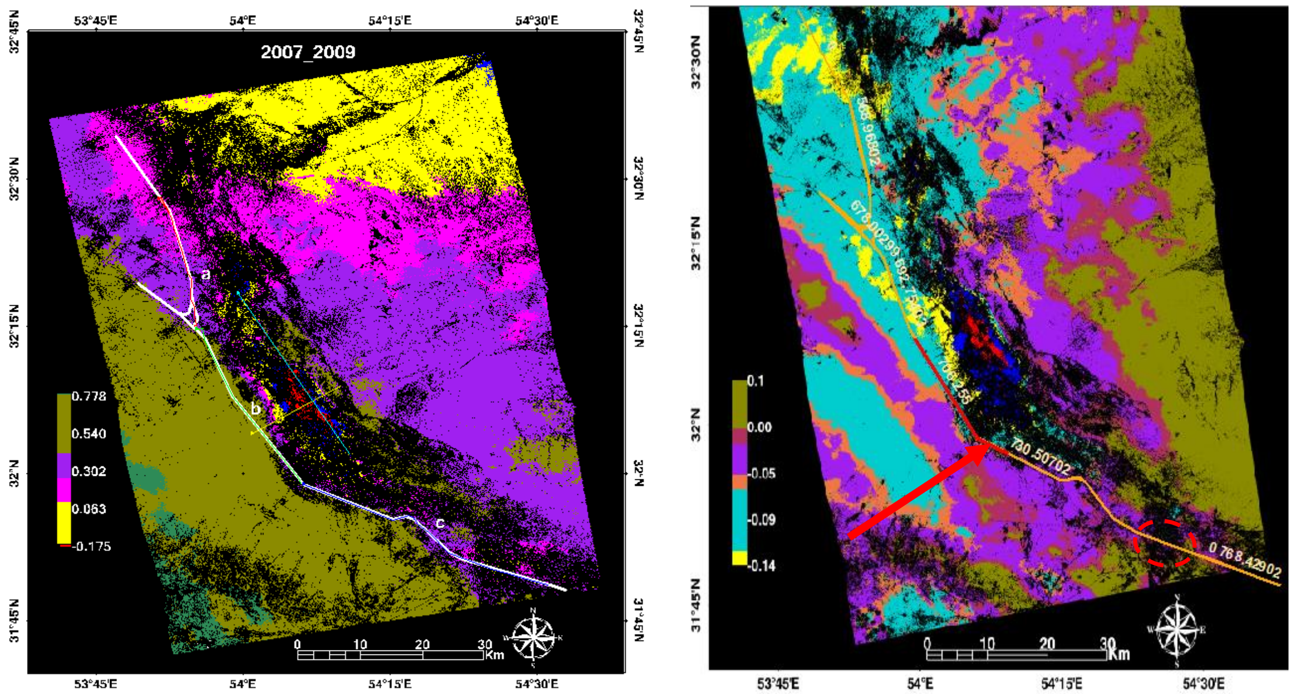
According to the information of table (3) and histogram of coherence images (Fig5), the less standard deviation was related to the period between 2008 – 2009 and 2007 – 2008 (histograms (a) and (b) respectively) and according to the last two columns, these images have better coherence are more suitable. And also having both of the short temporal and spatial baselines, the results showed less phase noise due to decorrelation. And also it can be concluded that by increase of temporal baseline the incoherence in the images will be increased. For example, histogram of image 2007- 2009 with Temporal baseline of 1050 days is the highest and most pixel frequency in coherence of 0.2 that incoherence in this image is more than other images and by increase in the Temporal baseline the standard deviation (the mean of standard deviations) and also incoherence will be increased that causes a lot of noise in the image.



(a)



(b)



(c) (d)

Figure 6. The plans of subsidence hazard zoning toward the railway of Yazd – Ardakan, which indicates the amount and scope of subsidence on the displacement images during the period 2007- 2010, some parts of the railway that are located in the subsidence region are shown by dash and arrow.

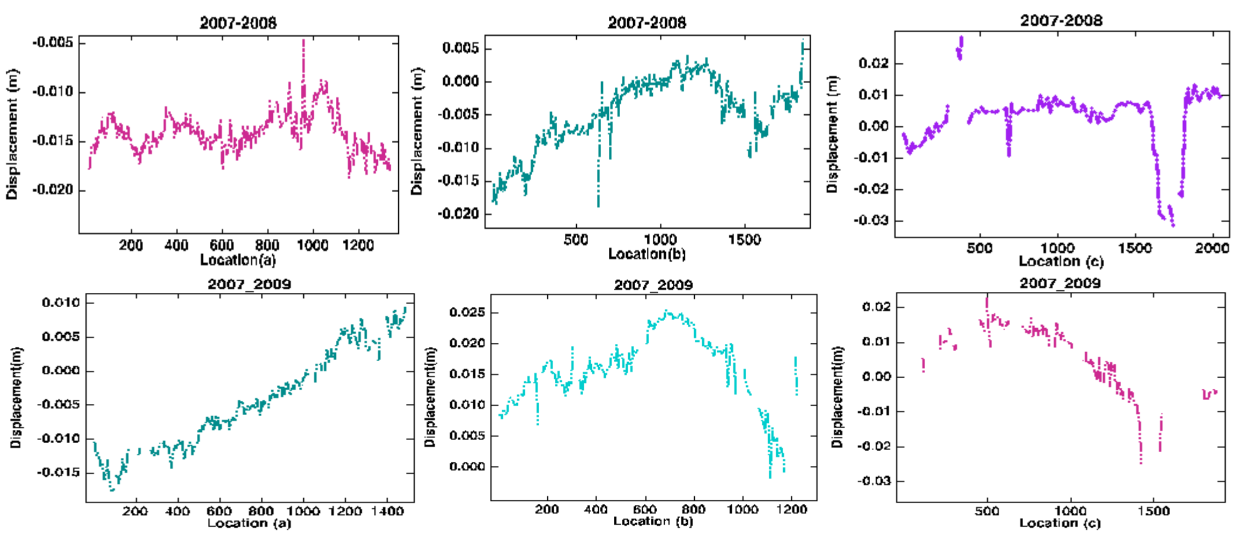


Figure 7. The extracted profiles from displacement images of the period 2007 - 2008 and 2007 - 2009 along the railway that contains 3 parts from Ardakan and in the image are specified by a, b and c respectively, in part (a) and (c) the most amount of subsidence was occurred and in (b) uplifting is occurred.

As it is shown in figure 6, generally the subsidence occurred in three regions of the railway, one in the end of the route in the station of Yazd to Yazdgerd between kilometer 757 to 768.4 (from direction of Tehran) in Yazd, the second one is in the station of Shamsi to Nazarabad and the third one is in the station of Ardakan to Meibod between kilometer 582.4 to 596.

Table 4. The maximum rate of annual subsidence and uplifting in the period from 2007 to 2010 in the route of Yazd-Ardakan railway.

Displacement image	The maximum rate of subsidence in the railway (cm/Year)	The maximum rate of uplift(mm/Year)
2007-2008	3.2	40
2008-2009	1.23	78.5
2007-2009	1.39	27
2008-2010	2.58	26

4. CONCLUSION AND SUGGESTIONS

According to the results in this research the maximum rate of annual subsidence in Yazd – Ardakan plain was about 10.75 cm and in the railway rout it was about 3.2 cm in the period of time between 2007 and 2008 that has an approximately declining trend (table 4), and its causes can be considered. The rate of subsidence in the railway route in Yazd is also more because of excessive extraction of groundwater that is the place of concentration of deep and semi-deep wells and it is indicative of the fact that effect of the ground subsidence is not multiplied yet and it seeks the consideration and optimum management of the problem in this region.

It seems that it’s necessary to distinguish and detect the regions that are susceptible to subsidence because of risk. The urban areas are particularly more susceptible because of population, buildings and vital arteries concentration. It is suggested that in the future studies the ALOS PALSAR L band images are used due to their suitable capability to penetrate into the plant canopy together with the ENVISAT ASAR C band images to overcome the problem of decorrelation that is caused because of vegetation in the plain. And also adjustment of the deep and semi-deep wells and exploited subterranean canals must be considered to measure the subsidence.

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