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Land Subsidence Analysis in the Adjacency of Gas Pipelines Based on Radar Interferometry (A Case Study in Central Iran)

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Abstract

The land subsidence phenomenon as a geomorphic hazard has reached to a critical level in some parts of central Iran recently. The gradual and sudden land subsidence is influenced by natural and artificial parameters. The gradual land subsidence has a slow pace mainly due to the overextraction of underground water or oil resources. The continued land subsidence can, in the long period, deliver irreversible damages to buildings, roads, bridges and pipelines. The application of remote sensing technology in earth survey is very common due to the wide coverage of satellite imagery, the timeliness of images and its lower required budgets versus ground-based methods. One of the applications of remote sensing is to control the movement of the ground surface due to various factors such as earthquakes, landslides and land subsidences. In this research, two satellite images of SENTINEL1 from 2015 to 2017 and DEM of the mentioned region have been used. Special software was used for processing images by forming an interferogram and performing filtration, consequently the land subsidence was determined at this time interval. Investigations confirmed that the excessive use of underground water resources has led ro substantial amounts of land subsidence in Yazd province. Interferograms resulting from the processing of radar images showed the occurrence of land subsidence within the neighbourhood of gas distribution and transmission pipelines in specific at an average of 8 to 10 cm around several cities, in specific Ardakan and Meybod.

***Keywords**:* Remote Sensing, Land Subsidence, Radar Data, Interferometry, GIS Application

1. Introduction

The excessive extraction of groundwater sources during last decade has led to a drastic drop of groundwater tables and consequently a decrease in pore pressure, resulting in an increase in interparticle pressure which eventually leads to substantial land subsidences (Terzaghi, 1925). Such phenomenon can cause major environmental and financial losses in the regions with considerable amounts of problematic soils in specific, since the main factor governing the behavior of such soils is their water content. The environmental consequences of land subsidence are mainly due to damages to

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man-made structures such as buildings, streets, bridges and powerlines, and also creating cracks in the surface of the earth (Hoffman et al. 2003). Different methods are used to calculate land subsidence, such as:

- Application of GPS,
- Precise alignment,
- Intermetric method in remote sensing.

Each of these methods have some advantages and disadvantages of their own. Nowadays, many are aware of the importance of GPS, which one of its applications is the representation of the displacement of the earth crust, both in horizontal and vertical directions. This requires using high precision control points; therefore, due to the limitation of land stations, application of this method is limited. Another method is to use precise alignment which requires the repetition of first-order alignment observations. This method is not cost-effective for wide coverages. On the other hand, interferometric technology has many advantages in measuring and displaying ground movements including high sensitivity to dynamic changes, high spatial resolution, wide coverage and the lack of need for ground control points. By using a few SAR images of dynamic changes of a region, an interprogram can take changes into account with a precision of about millimeters; furthermore, this method can calculate vertical and horizontal displacements due to land subsidence. In this method, combined radar images containing phase values and the return wave amplitude from side-to-side sensors are combined and a picture called interferogram interference is generated. The interference is the image mapping that results from the phase difference of the two images obtained at two different time points, geometrically accurately matched to each other (Daniel et al. 2003). The SAR system is a radar device that measures microwave transmission to the target (ground level) and measures the return signal. In the 1990s, with successful advancements of INSAR technology, radar interferometry was used to investigate thrust, earthquake and land subsidence successfully. A simple demonstration of intermetric method in remote sensing procedure is provided in Figure 1.

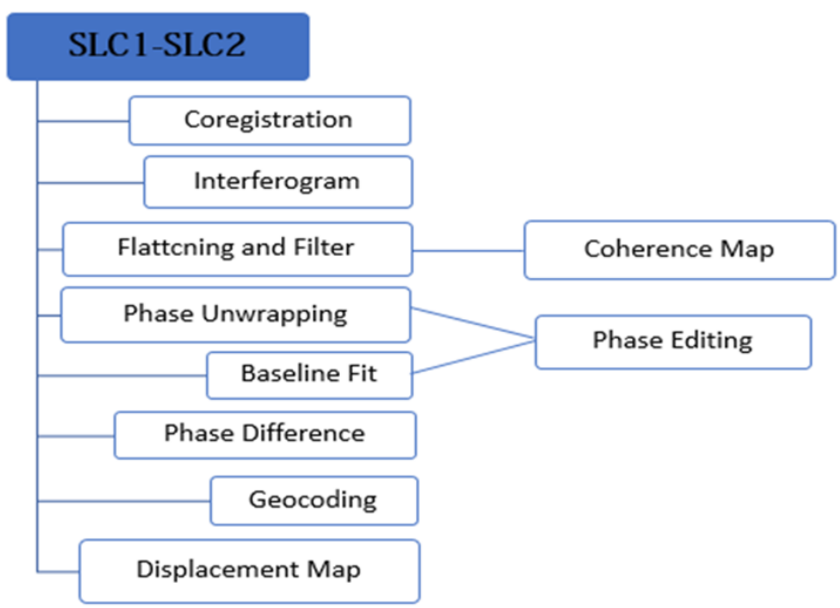


Figure 1. Intermetric method in remote sensing procedure

There are various sources for land subsidence including: Landslide subsidence (Depending on the earth category, geological layers of ground, and the degree of permeability or impenetrability); land subsidence due to human activities (Urban spreading, extraction of groundwater and oil resources, etc.); and different methods of land subsidence monitoring (Global Positioning System (GPS), precise alignment and radar interferometry).

The radar interferometry is in fact radar imaging with an artificial valve which it is a coherent imaging method by microwave waves with a long diaphragm (Haqiqatmehr et al. 2012). In other words, SAR is a generic image system that uses an artificial antenna to improve the resolution of images. It should be noted that in radar interferometry, two SAR images from two different circuits at different times of a specific area are combined with each other (Tazio Strozzi, 2001).

Using radar interferometry technique, an interferogram will be constructed. An interferogram is an image that contains a phase difference between the two radar images that are geometrically recorded in regard with each other (Daniel et al. 2003).

With the launch of the Sentinel project, studies have been conducted to improve the production of a DEM model using Sentinel 1 images with the help of radar interferometry (Martinez et al. 2016). Sentinel 1 records images from the surface in four modes. These four modes are (Lazecky and et al. 2017):

- Stripmap mode (SM)
- Interferometric Wide Swath mode (IW)
- Extra Wide Swath mode (EW)
- Wave Mode (WM)

The IW mode is the main type of Sentinel imaging for radar interference applications. The imaging width is 250 km. The spatial resolution of this type of imaging is 5 meters along the azimuth and 20 meters along the path (www.Earth.esa.int). This reflects the large size of these images and the need for methods and software with the ability to process heavy data.

Due to the importance of subsidence in the country and the world, it is necessary to study this issue in different periods. In this study, land subsidence in the vicinity of gas pipelines is analyzed based on radar interferometry (a case study in Central Iran).

2. Literature Review

Keshavarz et al. (2015), studied the subsidence of Faryab Industrial Zone using Sentinel 1 images for 2015-2017 and the results showed that the average amount of land subsidence in 2015 was 7 cm, 9 cm in 2016 and 7 cm in 2017.

Ghahroudi Tali et al. (2017), investigated the evaluation of slope instability in Lorestan railway area using radar differential interferometry method. The results of this study showed that radar data and differential interferometric processing method have a good potential for detecting domain instability and calculating their displacement due to extensive coverage and data frequency and high accuracy. Interpretation of time series diagrams showed that the highest amount of amplitude movements occurred in autumn and spring and the highest amount of amplitude movements in the period of 2015 to 2018 was about 28.8 cm in the range of Tang Haft to Tang Panj station.

Sedaghat et al. (2020), studied the assessment of subsidence risk due to groundwater abstraction in Isfahan metropolis and the obtained results showed that by moving from southeast to northwest in the study area, groundwater reduction increased from 4 to 36 meters. According to the obtained results, the most severe subsidence occurred in the western border of the city and has been calculated to be about 73 cm during 14 years. In addition, the specific non-static skeletal reserve (Sskv) for fine-grained sediments was calculated during the mentioned period and based on the interpolation map, the maximum specific values of rigid skeletal storage, as well as the maximum predicted subsidence happened due to gradual depletion of groundwater of the city .

Li et al. (2019) investigated the development features and mechanism of land subsidence and land rift in Jian, using SAR time series interferometry. The results showed that rift belts are generally in typical faults in Jian. But asymmetric ground-surface habitat can also cause abnormal activity of fissure belts that pose a serious threat or damage to building structures. In addition, it can also be found that the surface elevation zone in 2012 in terms of sand layer of the same thickness is located in both the tectonic depression and the boundary zone.

Xi-cunHe (2019), examined land subsidence control and environmental protection policy in Shanghai. The results of the research showed that for controlling the subsidence, Shanghai identified three areas of subsidence control, where special measures have been taken. From a Strategic Environmental Assessment (SEA) perspective, the 2013 regulation scores high, indicating that groundwater abstraction and recharge control was effective. Land subsidence observed over the past six years also confirmed the effectiveness of the 2013 regulation with the SEA paying the most attention to sustainable environmental protection in Shanghai.

3. Study Area

Yazd province is located in the center of Iran between the 29°48'30 degrees and 33°30' N, longitude 52°, 45° to 56° and 30' east longitude from the prime meridian. It is about 72156 square kilometers, accounting for approximately 37.40 percent of the total area of the country (Figure 2). This province is located in the central part of the Iranian central desert, having numerous hills and pits and desert plains. The dry climate of Yazd province has two main causes; first it is located on the dry world belt and second is that it is far from the Oman Sea, the Persian Gulf or any other lake or sea. This fact has increased the demand for groundwater extraction due to the development of agricultural land and urban areas, which resulted in the overusing of underground resources around urban areas, municipal facilities and distribution or transmission pipelines.

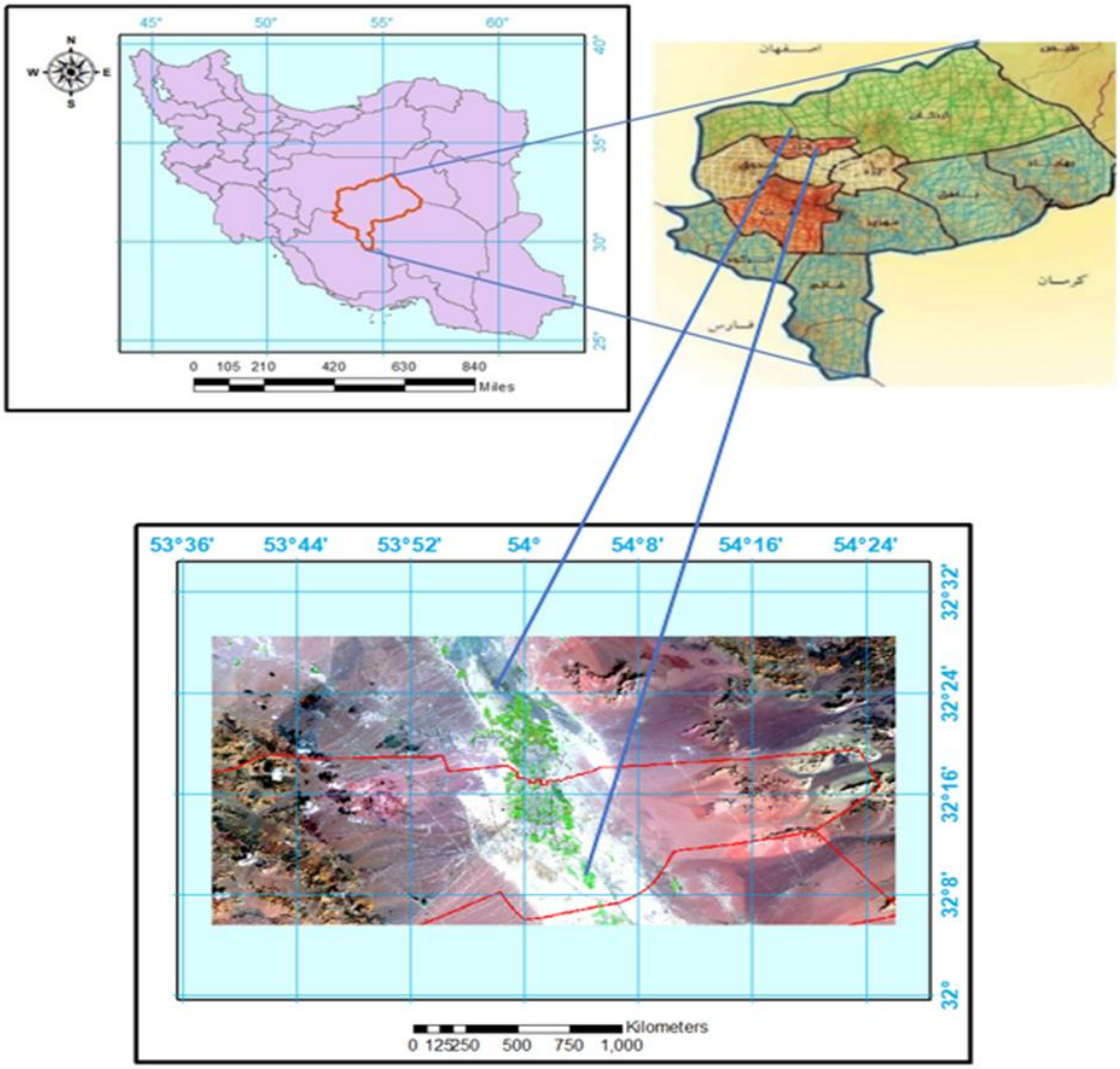


Figure 2. The Geographical location of the investigated area

4. Methodology

As mentioned earlier, in order to illustrate changes of the ground surface, a couple of images of a specific region at different times are needed. Thus, in this study the images of the two periods of time are used, the older image is considered as MASTER and the second image is considered as SLAVE, compared and measured against the MASTER image.

4.1. Selection of Coupled Images from the Sentinel Sensor

The optimal selection of coupled radar images for interferometry is the first and the most important step in radar interferometry operations. The main factors in the selection of the coupled images are the frequency of the sensor, the perpendicular basis of the baseline, the timeline, the spatial overlapping and the overlapping spectrum along the flight (Azimutal). The SENTINEL sensor has a transmitter and receiver antenna that is active in the C band (with wavelength of 6.2 cm). Due to specific considerations of this study, SENTINEL images were used from the 2015-2017 period. In ENVI software, the SARSCAPE plug-in was developed with a DEM (digital terrain elevation) which is an image of the phase difference of two radar images and shows their changes. The topographic error and flatness of ground will be removed by having the DEM of the area. DEM models have many applications such as natural resources management, infrastructure projects, archeology, risk assessments, landslide detection, topography mapping, land subsidence detection and production of spatial information systems (Makineci and Karabork, 2016).

4.2. Baseline Definition

The baseline is actually the distance from the first image to the second image, the more normal the baseline is the better the processing will be. In fact, the baseline should be less than 500.

4.3. Radar Interference Condition

The surface of the earth, which is represented by a radical image pixel, includes hundreds of terrestrial incidents. Each of these complications affects a pixel with a different reflection coefficient. The condition of radar interferometry can be explained as this: the phase difference of the corresponding pixels of two images is not more than half the wavelength. This condition restricts the distance between the orbital path of satellites during the acquisition of two images to 1 km or less. Fortunately, the satellite circuits are designed to simulate the imaging as a whole, after a circular orbit, and generally this condition is in place. It should be noted that the local ground slope affects these conditions. In near-intermediate conditions, even a gentle gradient with false justification will fade the fringes (Figure 4). Furthermore, the sharpening angle, high resolution and short wavelengths can make the process even harder. It is essential for the viewpoint to be similar for the two images (Dang et al. 2014).

4.4. Registration

In this step, the geometric errors associated with the difference in position of the sensor antenna during the imaging of an area are eliminated. The steps of this procedure are as follows (Haqiqatmehr et al. 2012):

- Calculating the overlapping of two radar images and calculate the coordinates of the points in the joint area of the two images in the SLAVE image.
- Determining the coordinates of the image of the points in the MASTER image using the methods of matching.
- Determining the communication function for the purpose of linking the two image transfer images. SLAVE points to the MASTER image.
- Performing RESAMPLE which is the same as interpolating the MASTER image so that these points lie in a regular grid in the MASTER image and in the closest Node.

The image is formed as a result of the phase difference of the two radar images and reflects their variations and is displayed with a dint link that has a lot of noise to be filtered.

4.5. Filtration

To soften the curves and remove large amounts of noise, the final interferograms are filtered to reduce the noise that occurs during the phase retrieval process. You can use three types of filters to remove noise and improve interference. The first filter is adaptive; it does not change any of the phases. In researches that aim to provide DEM or measure the land subsidence, then applying of this filter is recommended. The second filter is Boxcar which is something in the middle between the first and third filters. The third filter is Godstein, which unlike adaptive it creates a large change in phases and in the waves' bonding. If the goal is to provide a rational output for correlations of waves, applying of this filter is recommended.

4.6. Coherence

The coherent image is an image that is coherent with the correlation of the power of two coherent images. This image represents the correlation coefficient of the signal strength values in two images taken at two different times. The correlation value varies from 0 to 1, which is effective in the quality of the interoperability process. In general, if the value of this indicator is low for a couple of images used in interferometry, it means that this pair is not suitable for interference measurement. Coherence represents the correlation between the two-image phases. The closer this coherence rate is to 1, the greater correlation exists between these two images (usually rocks have the highest coherence), on the other hand, if this coherence rate is close to zero, this indicates the lack of correlation between the images (usually water areas have this nature).

4.7. Phase recovery process (unwrap phase)

In this stage, the discontinuities of the two phases are eliminated in areas with high coherence, in other words, the interferogram phase is rotationally varying from 0 to 360 degrees (0 - 180 - 360 - 180 - 360) and continuously (10 - 180 - 360 - 540 - 720 – etc.). In order to convert unwrap phase to the original phase, a series of GCP ground control points is required.

4.8. Selection of control points (GCP)

Prior to the displacement determination, a series of control points should be selected that satisfy the following conditions:

- High coherence and no displacement at all,
- Correlation in which the vector points are introduced and stored.

4.9. Phase-to-displacement mapping

Each cycle of the phase in differential interferometry is equal to half the wavelength used in the radar system and indicates the displacement along the antenna line. After refining and double correction of the phase, the resulting absolute phase can be converted to the displacement or displacement map and be considered as reference ground. The obtained map at this stage has positive displacement values related to radar motion (uplift) and negative values indicating that the ground is moving away from the sensor in the direction of the subduction radar. At this stage, after the removal of pixels with positive values (uplift) and the remaining pixels of negative values (land subsidence), the land subsidence map was determined.

5. Results and Discussion

According to the resulting maps (obtained from https://scihub.copernicus.eu), gas distribution networks in Ardakan (Figures 3 and 4), gas transmission networks and gas pressure reduction stations in Meybod industrial zone (Figures 3 and 4) are more exposed to land subsidence due to the unreasonable extraction of groundwater sources for agricultural fields and pistachio gardens. Due to the lack of required facilities and two accurate GPS frequencies for field surveys, land subsidence in these two time periods was measured from the arisen wellbore tubes due to significant ground settlements and the generated land subsidence maps from 2015 to 2017. The results showed that a land subsidence of about 8 to 10 cm has occurred in the Yazd-Ardakan plain (Figure 5).

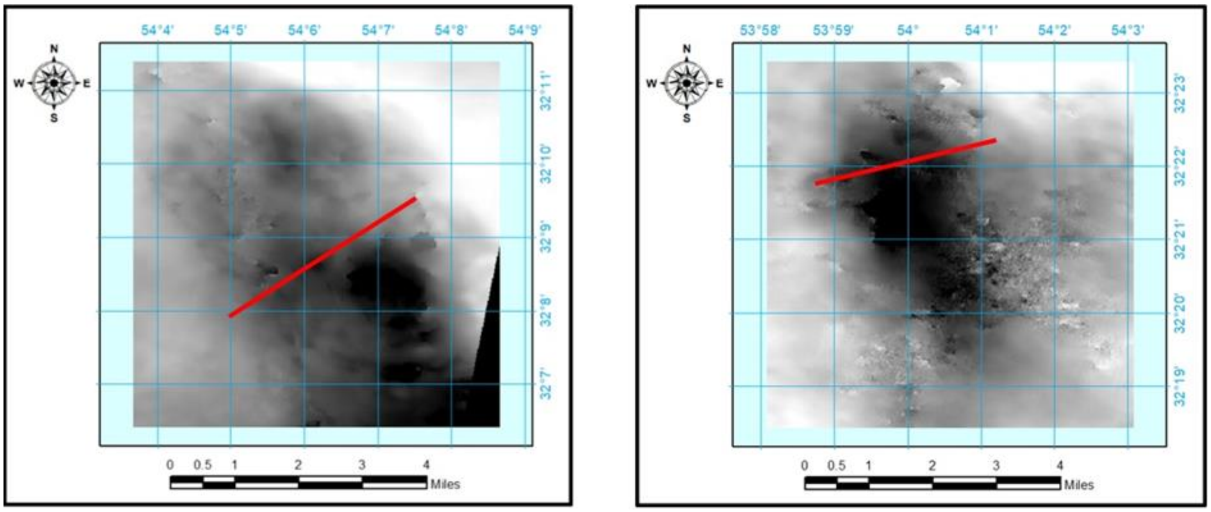
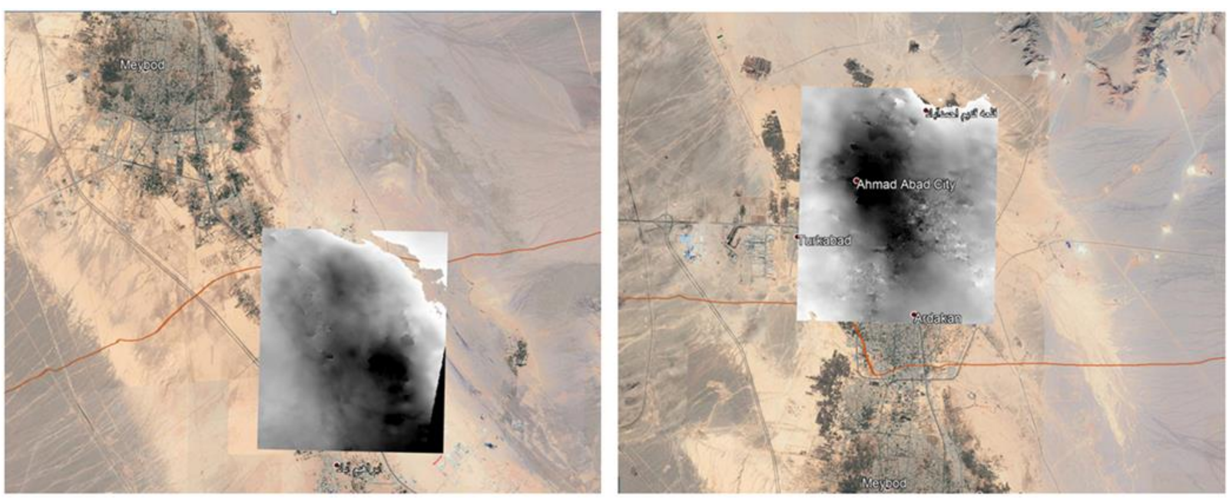


Figure 3. Displacement maps for evaluation of land subsidence in longitudinal profile method (Right: Ardakan, Left: sub-province Meybod sub-province) (https://scihub.copernicus.eu)



5.1. Estimation of Land Subsidence Displacement

Unwrapping on the obtained interphrograms were done using the SARSCAPE, converting the phases to the amounts that represent displacements of the earth's crust. These changes are calculated in both direction of the satellite's sight and in the horizontal and vertical directions. By examining the displacement maps of areas experiencing land subsidence, it can be concluded that these regions have a point as the center point of land subsidence. The more distance from this point the less displacements due to land subsidence will be observed. In order for each pixel in the image to have the correct location on the ground, the acquired map of changes using the orbital information of the geometric correction satellite will be obtained finally by referring to the acquired interferogram after removing the ground errors. The final resulting maps are arranged together and the control points for measuring land subsidence are determined by the fringes (Figure 4). Then by using the longitudinal profile of the land subsidence level in the Yazd province between 2015 and 2017 a land subsidence of about 8 to 10 cm was measured.

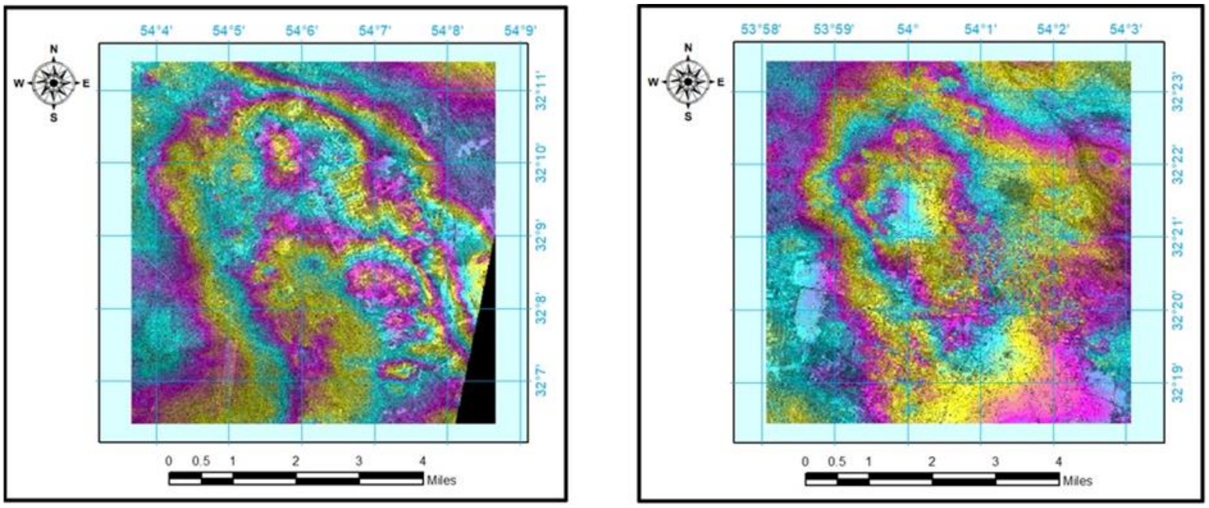
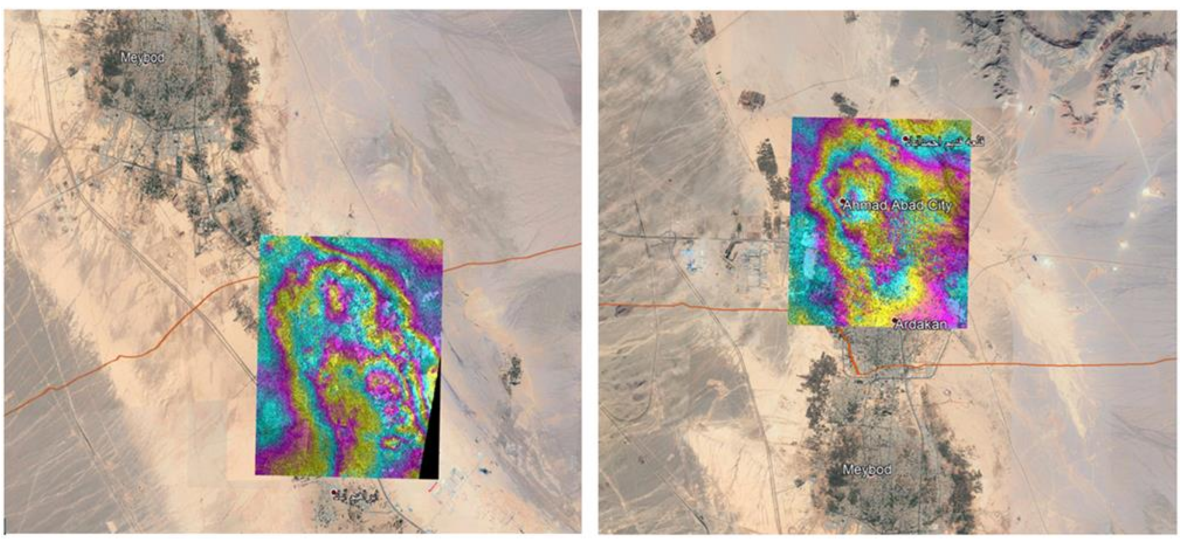


Figure 4. Finalized mapping with a mean land subsidence rate of 8 to 10 centimeters from 2015 to 2017 (Right: Ardakan, Left: sub-province Meybod sub-province) (https://scihub.copernicus.eu)



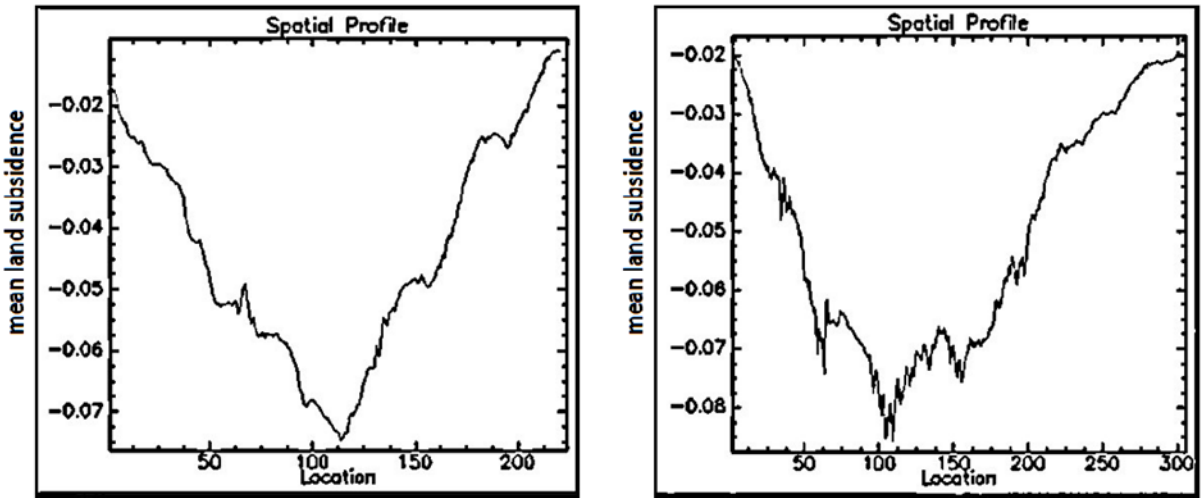


Figure 5. Longitudinal profile with a mean land subsidence rate of 8 to 10 centimeters from 2015 to 2017 (Right: Ardakan, Left: sub-province Meybod sub-province

6. Discussion

According to the results of the present study, as well as the results of similar researches and studies that have been done in this direction, it is clear that the use of satellite images and remote sensing and GIS, as well as radar techniques, have the ability to respond to this issue and investigate the amount of subsidence in different areas., Ghahroudi et al. (2019), Sedaghat et al. (2020), Keshavarz et al. (2018), Li et al. (2019), Xi-cunHe (2019), all concluded acceptable results and in line with this research and this showed the high accuracy and satisfaction of RADI techniques and remote sensing such as SAR technique.

7. Conclusion

In general, the present study shows that the excessive extraction of underground water resources has caused land subsidence in Yazd province. The interferograms resulting from the processing of radar images during the period from 2015 to 2017, confirms the occurrence of a land subsidence phenomenon with an average of 8 to 10 cm around the cities of Yazd, Ardakan and Meybod, mostly near the gas facilities, distribution and transmission pipelines. If this trend of overusing underground water resources continues, it can lead to serious financial and environmental issues. Several methods for monitoring land subsidence are available such as precise leveling, GPS and InSAR. Each of these methods has advantages and disadvantages of themselves. Since the monitoring of land subsidence usually have large areas to evaluate and control them and methods of land Time. They are costly and cost effective. Due to the fact that the interferometric method is a suitable and accurate method, due to the wide coverage of satellite images and their availability, it is possible to study and control earth transitions using this method. Interferometric phase component topography and Coherence very sensitive to eliminate error due to the topography of the DEM area is used to maintain the coherence can be pictures in a short period of use, and as much as possible, baseline small in comparison. It is suggested that considering the use of remote sensing in the native country and the possibility of using this method by experts at a cost, all subsurface extraction of underground resources is monitored by this method and before any incident it prevented its occurrence.

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