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An Examination on Subsidence in Oil Districts made by Hydrocarbon Fluid Extraction Utilizing Radar Interferometric Method (Case Study: Ilam Province)

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Abstract

The phenomenon of subsidence as one of the geomorphic dangers has sustained a critical stage in some districts of the country in recent years. The frequent and sudden subsidence of the earth's surface is a phenomenon that happens under the effects of natural and artificial developments, gradual subsidence has a slow process and mainly takes place as the results of the extraction of liquids (water and oil) inside the earth. The continuation of subsidence in the long term can create irreparable damage to buildings, roads, bridges, pipelines and transmission lines. There are different methods, such as precise alignment, utilization of GPS (Global Positioning System) and remote sensing technology to monitor subsidence. The use of remote sensing technology in different earth sciences is very common because of the wide coverage of satellite images, the timeliness of the images and its low cost in comparison to terrestrial methods. One of the applications of radar interferometry is to display and control the displacements of the earth's crust due to factors such as earthquakes, landslides, and subsidence. The district studied in this research is an oil field located in the south of Ilam province. To meet the purpose of the study, the ALOS Palsar satellite image was used in the period from 2007 to 2010, as well as the DEM of the area that was prepared earlier, to monitor the subsidence phenomenon. SARSCAPE software was used in ENVI 4.8 platform to process the images, and by creating an interferogram and performing filtering operations, the average amount of subsidence was assigned as 3.4 cm per year.

***Keywords**:* Subsidence, Interferometry, SAR, Remote Sensing

1. Introduction

Subsidence takes place as a result of extracting water, ground fluids, oil, gas and other materials through mines or underground construction. Currently, many subsidence around the world have increased due to the increased rate of use of groundwater, oil, gas, etc. The dangers made by subsidence are much greater than sudden dangers like floods and earthquakes, because the danger of subsidence

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takes place quite slowly and each of them may create widespread damage. Buildings and other man-made structures such as bridges, highways, power lines, railways and underground pipe facilities and drainage canals, because of these factors, there is a demand for careful consideration and monitoring of ground surface changes in order to properly figure out the phenomenon of subsidence and the essential recommendations for use. There is a demand to monitor and control this phenomenon. Among the sensitivities and problems of this phenomenon, we can mention the environmental problems, which, due to its importance, was included in the list of UNESCO research projects, and this program has been on the agenda of the International Hydrological Development Organization since 1975 (Dang et al., 2001). Traditionally, subsidence is measured through accurate mapping and leveling by creating a network of ground control points (benchmarks) in a periodic and repetitive manner, with this method it is possible to determine the subsidence rate with high accuracy, but the above method is time-consuming and expensive in large districts. In recent years, with the development of GPS (Global Positioning System) technology, it was used to investigate subsidence in larger areas, but the radar interferometric method is a cheap and universal method for calculating subsidence with high accuracy in the vertical direction, and also due to its availability of data and quantitative costs are not comparable with other methods (Mirshahi et al., 2012). In recent years, with the artificial aperture radar interferometry (SAR) method, an accuracy of centimeter has been obtained to reveal the rate of subsidence. With this method, a map of the displacements caused by earthquakes and the deformation of the volcano and the dynamics of natural glaciers and subsidence was drawn. In the radar interferometric method, two images are combined and an interferometric phase is produced, which is sensitive to topography. The main conception in radar interferometry is to separate the topography from the displacement map, and there are different methods for this, the best method of which is to use the digital earth model (DEM). Extraction of hydrocarbon fluid from reservoirs with high compression and low permeability gradually changes the shape of the earth's surface and causes the top surfaces to fall, which this matter causes significant damages and expenses (Jafari and Tavakoli 2013).

The differential radar technique is capable of measuring displacements taking place over a wide range of crustal coverages. In contrast, the GPS system is only able to provide point-by-point displacement measurements. InSAR vertical displacement measurements are more successful than GPS measurements. Finally, considering the current situation of different regions of the country, which are constantly subsiding and causing a lot of damage to underground resources, in this study, in order to investigate and measure the subsidence rate of the oil regions in the south of Ilam province, one of the numerous capabilities of the radar interferometric technique using satellites Remote sensing and signal processing techniques were used (Alipour et al. 2008). considering the display of land subsidence because of the extraction of oil and hydrocarbon fluid from oil sources in 2004 Mehdi Akhundi due to the lack of access to radar images in an oil region in Iran with the desired conditions of Radarsat satellite images related to an oil region in California, USA investigated the subject of the contract (Akhundi, 2004). In the summer of 2010, Ms. Negin Fuladi Moghadam, Mr. Ali Akbar, Mohammad Reza Haji, and Ms. Meh Asa Raushi from the Department of Remote Sensing and Geographical Information of the Faculties of Engineering and Earth Sciences of Shahid Beheshti University and Khajeh Nasiruddin Tousi, conducted radar interferometric detection in the Aghajari oil field in Dezful was investigated and the amount of subsidence was estimated which was about 19 mm per year (Fouladi Moghadam et al. 2019). Also, in this regard, Qu et al. conducted a study in 2023 on the zoning of land deformation characteristics in the middle of 2007 to 2011 in the Gulf coasts, the results of their research using L band and InSAR method indicated that the reduction of reservoirs Petroleum and aquifer density has been the main factor in changing the shape of the earth over time (Qu et al. 2023). In 2022, Hayati and his colleagues investigated and predicted the subsidence rate in flood-prone areas of Indonesia using the technique of short baselines and InSAR time series. (Hayati et al. 2022). In a 2022 study, Haley et al. investigated land subsidence in the coastal areas of Texas. The results of their research indicated a change in the rate of land displacement in coastal areas (Haley et al. 2022).

2. Materials and Methods

2.1. Study Area

The area studied in this research is located in Dehlran city in Ilam province. Dehleran is located at 47 degrees 16 minutes longitude and 32 degrees 41 minutes latitude and 200 to 450 meters above sea level. Dehlran is located 224 kilometers south-east of Ilam and on the Ilam-Dezful road. Its climate is hot and dry and its annual rainfall is about 285 mm.

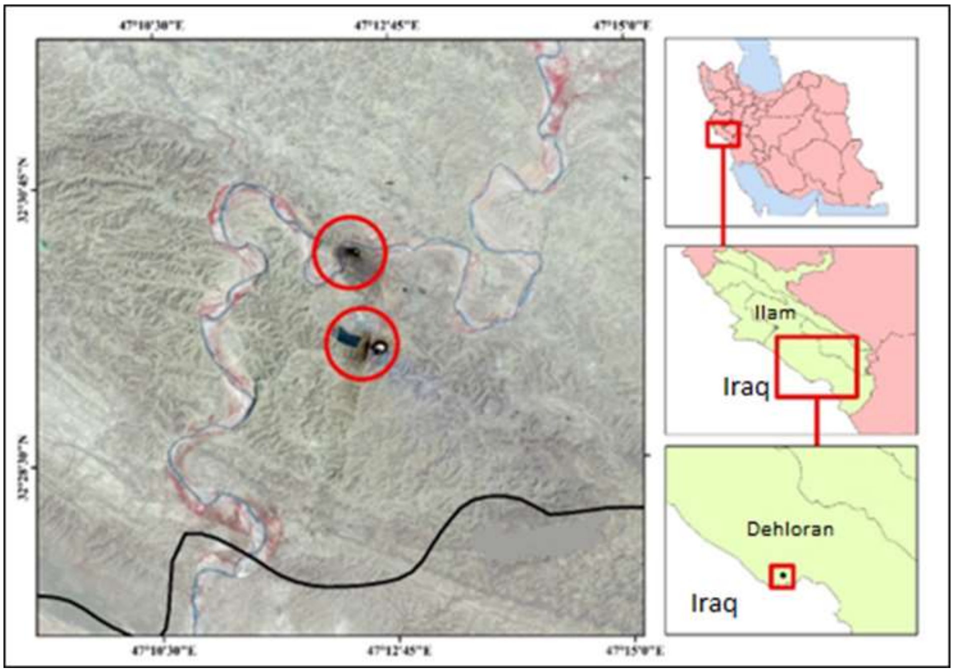

Figure 1. Geographical location of the study area

In this research, in line with the objective of the investigation, which is to investigate subsidence in oil areas caused by the extraction of hydrocarbon fluid, using radar interferometric method, various data and tools were used, which will be explained as follows.

2.2. Topographic Data

The state of topography has always been one of the most basic data in all scientific research related to earth changes. Various sources have been used in various researches to prepare this matter. Among the important sources in the preparation of this layer of information, we can mention the topographic coverage maps of the country, digital elevation models obtained from stereo pair images and photogrammetry methods, as well as digital elevation models obtained from radar data (Lofgern et al. 1969). In this research, in order to perform geocoding operations of radar images and create a physiographic surface of the earth to check the amount of subsidence, SRTM physiographic data with a spatial resolution of 30 meters were used, the specifications of which are shown in Table 1.

Table 1. Specifications of SRTM height digital model

Output format	Date of shooting	Basic imaging system	Spatial resolution	Type of output product	gauge
GEOTIFF	February 2000	Radar	30meter	Raster elevation digital model	SRTM
GEOTIFF	February 2000	Radar	90meter		

2.3. Preparation and Processing of Satellite Data

In order to determine the affected area and finally estimate the amount of subsidence, the radar interferometric method was used as a reliable method to measure the changes of the earth's surface with great accuracy, wide coverage and high spatial resolution. To achieve this goal, in the first step, appropriate data must be prepared to achieve this goal. In this research, in line with the purpose of the research, PALSAR sensor radar satellite data related to ALOS sensor was used. The reason for using the satellite data of this gauge is its high efficiency in the matter of subsidence, which has been proven in many studies. Also, the wide coverage of its data and the availability of data in the studied area are other reasons for using the data of this meter. The specifications of the satellite data used in the research are indicated in Table 2.

Table 2. Specifications of satellite data used in the research

Date of shooting	Polarization	Frequency Range (MHz)	Spatial resolution	Number Path	Number Frame	Name
2007/08/02	HH+VV	1270	30× 5	579	640	ALPSRP0735796404411-L1.1
2007/11/16	HH+VV	1270	30× 5	579	640	ALPSRP0735796404421-L1.1
2008/02/04	HH+VV	1270	30× 5	579	640	ALPSRP0735796403214-L1.1
2008/04/28	HH+VV	1270	30× 5	580	640	ALPSRP0735806404825-L1.1
2008/07/15	HH+VV	1270	30× 5	580	640	ALPSRP0735806404698-L1.1
2008/10/12	HH+VV	1270	30× 5	580	630	ALPSRP0735806305235-L1.1
2010/01/03	HH+VV	1270	30× 5	579	630	ALPSRP0735796306425-L1.1
2010/04/23	HH+VV	1270	30× 5	579	640	ALPSRP0735796404458-L1.1

2.4. Satellite Data Pre-Processing

PALSAR ALOS images are presented at processing level 0.1 in SLC format. PALSAR sensor images are typically at 1.0, 1.1 and 1.5 levels. The images of level 0.1 are the result of raw data processing at level (0), where each pixel is expressed as a complex number I + Qj. I and Q are real and imaginary values of SLC image at 1/1 level. 1.1 level images are domain images obtained by processing the real and imaginary components of the image. These images are not ground-referenced and the amplitude value of each pixel is obtained by the following equation (Larson et al. 2001).

$$Amplitud = \sqrt{I2 + Q2}$$

Level 1.5 images are the same as domain images, but they are ground-referenced. Along with ALOS images at level 1.0, two files with PRM extensions. and A__0. There is PRM file which contains information related to the measuring hardware parameters such as the average radius of the earth, equatorial and polar radius of the earth, Doppler frequency, pulse length, wavelength, sampling frequency along the range and dimensions of the desired image, and the file with the extension A__0. which is also known as the Leader file, contains the exact date of taking the image with a fraction of a second accuracy, as well as the exact circuit parameters such as the position and speedometer vectors. The existence of both files is required in order to reference the images. At this stage, in order to eliminate topographical effects, SRTM digital height model with resolution of 30 meters was used.

3. DInSAR Processing Steps

The processing of radar images includes the steps of reading radar images, using orbital parameters, registering two images relative to each other, resampling the image, filtering along the range and azimuth, producing interferogram, removing the flat ground component; And finally, interferograms are calculated. Following the difference between the interferograms, the obtained interferogram becomes the reference ground

3.1. Select a Pair of Captured Image

Appropriate and optimal selection of pairs of radar images for interferometry is one of the first and most important steps in radar interferometry operations. In this context, measuring frequency, spatial perpendicular baseline, temporal baseline, spatial overlap and spectral overlap in the direction of flight (azimuthal) are basic factors in selecting a pair of images (Dehghani, 2015). The Palsar Alos meter is active in the L band with a transmitting and receiving antenna. The use of this sensor in areas where the vegetation cover is relatively extensive, due to more penetration from the cover surface and more favorable redistribution from the ground surface, provides more satisfactory results in interferometry. In the current study, due to the specific characteristics of the region, Palsar Alos sensor images were used in the period from 2007 to 2010. In SARSPACE software with ENVI platform, interferometric operations were performed with DEM (Digital Elevation Model of the Earth) that the interferogram is actually the same image resulting from the phase difference of two radar images and shows their changes.

3.2. Comparing Baseline Images with Normal and Critical Baseline

The baseline is actually the distance between the first image and the second image, the shorter the baseline, the better the processing will be, in fact (Normal Baseline)/ (Critical Baseline) should be less than 500. At this stage, the captured images are placed in the software and the baseline of the images is calculated. If the baseline of the images follows the above formula, we will use the image in the processing steps, otherwise, that image will not be included in the processing steps and will be removed from the data.

By placing all the images that have radar interferometry condition and selecting the initial image as Super Master image in the software, the baselines of the studied area are extracted in the images.

At this stage, after entering the Palsar Alose sensor image frames into the SARSCAPE software, the necessary measures were taken to calculate the baselines of the images, the results of which are shown in the Table 3.

The results of the analysis of critical baselines and normal baselines indicated that all the received images have the necessary potential to perform interferometric operations, so all of them were used in order to achieve the goals of the research.

Table 3. The amount of baselines calculated in the received images

Critical baseline	Normal baseline	Kind of shooting	Date of shooting	Name
-	-	Master	2007/08/02	ALPSRP0735796404411-L1.1
941.07	313.75	Slave	2007/11/16	ALPSRP0735796404421-L1.1
844.65	408.22	Slave	2008/02/04	ALPSRP0735796403214-L1.1
901.50	362.25	Slave	2008/04/28	ALPSRP0735806404825-L1.1
945.98	311.01	Slave	2008/07/15	ALPSRP0735806404698-L1.1
886.44	445.25	Slave	2008/10/12	ALPSRP0735806305235-L1.1
865.89	398.34	Slave	2010/01/03	ALPSRP0735796306425-L1.1
918.63	323.07	Slave	2010/04/23	ALPSRP0735796404458-L1.1

3.3. Registration and Production of Interferogram with DEM

In this step, the geometrical errors related to the difference in position of the sensor antenna during imaging are removed from a region. Calculating the degree of overlap of two radar images and calculating the coordinates of a series of points in the common area of the two images, in the SLAVE image, determining the image coordinates of the same points in the MASTER image using matching methods, determining the communication function in order to connect the two images, transferring the image of the SLAVE points to the MASTER image Resampling means interpolating the MASTER image so that these points are placed in a regular grid in the MASTER image and in the nearest Node. After selecting the appropriate images to perform interferometric operations, it was necessary to register all the images. In this regard, by selecting Slave and Master images, using matching methods, with the introduction of DEM, the desired interferograms were prepared. The formed image, which is the result of the phase difference of two radar images and shows their changes, and is displayed with the suffix dint, has a large amount of noise that must be filtered. An example of the prepared interferogram is indicated in Figure 2.

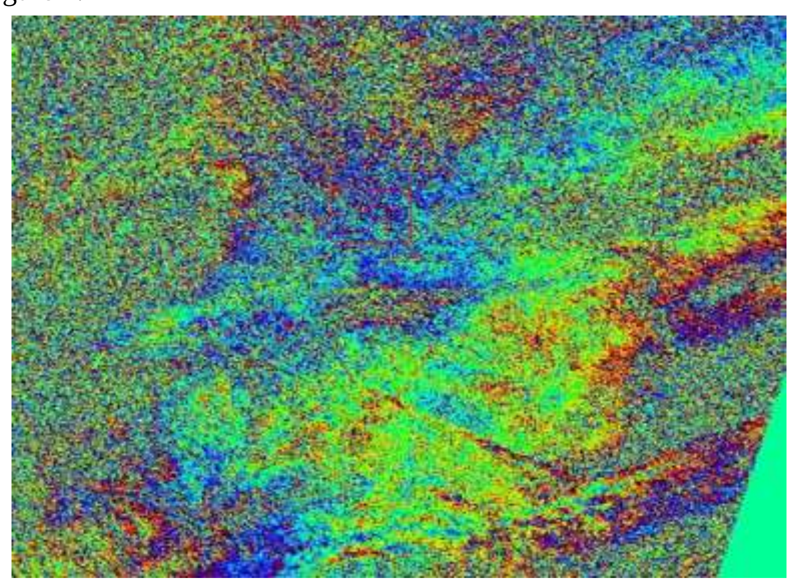

Figure 2. Interferogram image without filter

In order to smooth the curves and remove excessive amounts of noise, the final interferograms are filtered to reduce the noise that takes place during the phase recovery process. Three types of filters can be utilized to remove these noises and also to improve interferometry. The first filter is Adaptive; this filter does not cause any change in the phase. It is recommended to use this filter in researches where the goal is to prepare DEM or measure the amount of subsidence. The second Boxcar filter is between the first and second filters; But the third filter is Godstein. Unlike adaptive, this filter creates a big change in the phases and correlation of the waves. It is recommended to use this filter when the goal is to provide an expressive output of the changes in the correlation of the waves. After the slave image corresponds to the master image pixel by pixel, the images can be multiplied pixel by pixel to display the phase difference of both interferogram images. In order to improve the signal-to-noise ratio and to remove the point noise and achieve the approximate square shape of the pixel, the interferogram is interpolated with 1x5 filters along the azimuth and range lines of MultiLooK, part of which is shown in Figure 3.

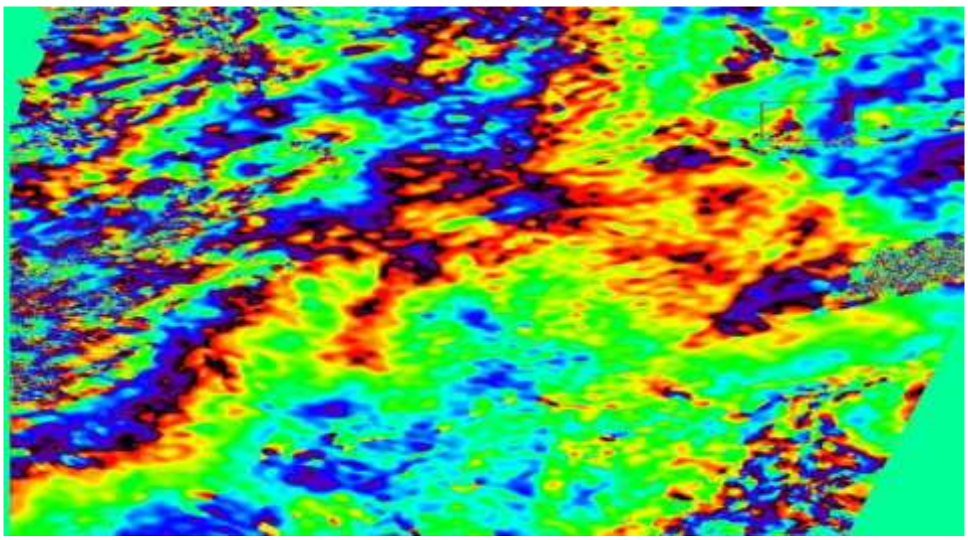

Figure 3. Filtered interferogram image

In this stage, the discontinuities of the two phases in the areas with high coherence disappear, in other words, the phase of the intergram is circular, that is, from 0 to 360 degrees in the form of (0-180-360-180-360) continuously (...- 720-540-360-180-10) Each cycle of the 2π phase value in differential interferometry is equal to half the wavelength used in the radar system and represents the amount of displacement along the line of sight of the antenna. After refining and double phase correction, now the resulting absolute phase can be converted to displacement values or displacement map and reference ground. The map obtained at this stage has positive displacement values related to the movement of the earth's surface towards the radar sight (rise) and negative values indicating the earth's surface moving away from the sensor in the direction of the radar sight (subsidence).

To determine the degree of coherence of the images used in this research, the degree of coherence of the pair of images was calculated by introducing the images in the SARSCAPE software, the results of which are indicated in Table 4.

Table 4. The table of the degree of coherence calculated from the received images

Coherence	Kind of shooting	Date of shooting	Name
-	Master	2007/08/02	ALPSRP0735796404411-L1.1
0.9223	Slave	2007/11/16	ALPSRP0735796404421-L1.1
0.9145	Slave	2008/02/04	ALPSRP0735796403214-L1.1
0.9288	Slave	2008/04/28	ALPSRP0735806404825-L1.1
0.8441	Slave	2008/07/15	ALPSRP0735806404698-L1.1
0.8869	Slave	2008/10/12	ALPSRP0735806305235-L1.1
0.8003	Slave	2010/01/03	ALPSRP0735796306425-L1.1
0.7908	Slave	2010/04/23	ALPSRP0735796404458-L1.1

In the studied districts, because of the fact that the region is a desert in terms of geomorphic structure and less variable effects are observed, therefore, the selected pairs of images often show high coherence. As a result, the resulting interferograms will have a high accuracy factor.

4. Results

As it was said, before determining the amount of displacement, a series of control points that have the lowest amount of displacement (assuming that they do not have any displacement) must be selected. In this regard, first, the points with the highest possible coherence were identified using the SPATIAL PIXEL EDITOR tool in the ENVI software platform and matched on the satellite image of the region. In the next step, the areas of them that had certain complications in the field were identified and their three-dimensional coordinates were taken by referring to the place using a GPS device. After taking the coordinates and introducing them to the software, the necessary measures were taken to prepare the displacement map. In the next step, by selecting MASTER and SLAVE images for each time period, the displacement of the land shape was calculated, the results of which are indicated in Table 5.

Table 5. The table of displacement amount calculated from interferograms

The average amount of subsidence	Time period (days)	SLAVE Image	MASTER Image	Row
-2 Cm	104	ALPSRP0735796404421-L1.1	ALPSRP0735796404411-L1.1	1
-3.5 Cm	184	ALPSRP0735796403214-L1.1	ALPSRP0735796404411-L1.1	2
-3.6 Cm	270	ALPSRP0735806404825-L1.1	ALPSRP0735796404411-L1.1	3
-4.1 Cm	349	ALPSRP0735806404698-L1.1	ALPSRP0735796404411-L1.1	4
-5.6 Cm	436	ALPSRP0735806305235-L1.1	ALPSRP0735796404411-L1.1	5
-7.8 Cm	517	ALPSRP0735796306425-L1.1	ALPSRP0735796404411-L1.1	6
-9.1 Cm	630	ALPSRP0735796404458-L1.1	ALPSRP0735796404411-L1.1	7

-1.8 Cm	92	ALPSRP0735796403214-L1.1	ALPSRP0735796404421-L1.1	8
-2.0 Cm	178	ALPSRP0735806404825-L1.1	ALPSRP0735796404421-L1.1	9
-3.05 Cm	258	ALPSRP0735806404698-L1.1	ALPSRP0735796404421-L1.1	10
-4.9 Cm	345	ALPSRP0735806305235-L1.1	ALPSRP0735796404421-L1.1	11
-7.9 Cm	425	ALPSRP0735796306425-L1.1	ALPSRP0735796404421-L1.1	12
-8.8 Cm	538	ALPSRP0735796404458-L1.1	ALPSRP0735796404421-L1.1	13
-3.0 Cm	86	ALPSRP0735806404825-L1.1	ALPSRP0735796403214-L1.1	14
-4.2 Cm	166	ALPSRP0735806404698-L1.1	ALPSRP0735796403214-L1.1	15
-5.5 Cm	253	ALPSRP0735806305235-L1.1	ALPSRP0735796403214-L1.1	16
-8.6 Cm	333	ALPSRP0735796306425-L1.1	ALPSRP0735796403214-L1.1	17
-9.65 Cm	446	ALPSRP0735796404458-L1.1	ALPSRP0735796403214-L1.1	18
-4.3 Cm	80	ALPSRP0735806404698-L1.1	ALPSRP0735806404825-L1.1	19
-5.0 Cm	167	ALPSRP0735806305235-L1.1	ALPSRP0735806404825-L1.1	20
-7.9 Cm	247	ALPSRP0735796306425-L1.1	ALPSRP0735806404825-L1.1	21
-9.01 Cm	360	ALPSRP0735796404458-L1.1	ALPSRP0735806404825-L1.1	22
-5.6 Cm	87	ALPSRP0735806305235-L1.1	ALPSRP0735806404698-L1.1	23
-6.8 Cm	168	ALPSRP0735796306425-L1.1	ALPSRP0735806404698-L1.1	24
-8.6 Cm	281	ALPSRP0735796404458-L1.1	ALPSRP0735806404698-L1.1	25
-8.9 Cm	81	ALPSRP0735796306425-L1.1	ALPSRP0735806305235-L1.1	26
-9.6 Cm	194	ALPSRP0735796404458-L1.1	ALPSRP0735806305235-L1.1	27
-8.8 Cm	113	ALPSRP0735796404458-L1.1	ALPSRP0735796306425-L1.1	28

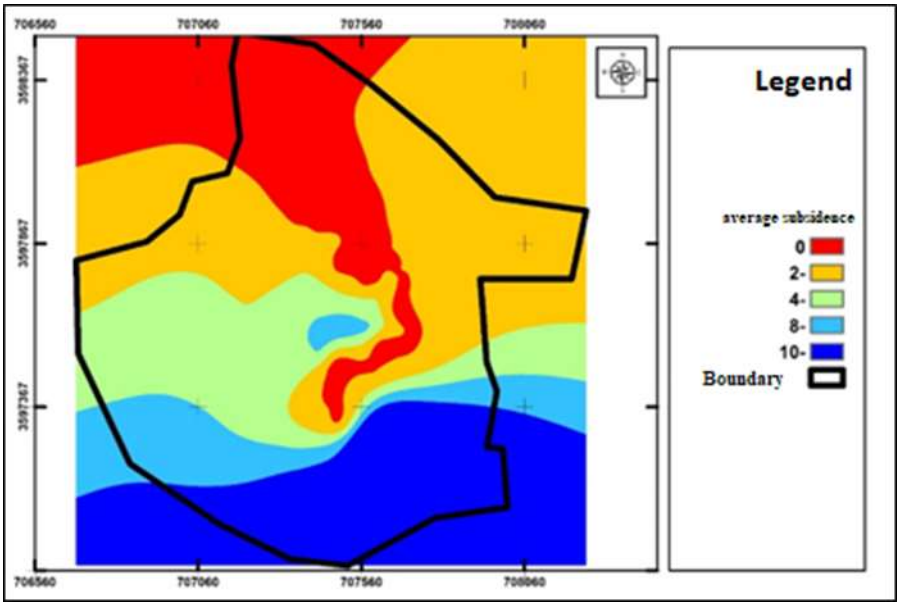

Figure 4. The final map of the average amount of land subsidence in the studied district

The figure above shows the average subsidence. The maximum subsidence rate in this area, which was extracted from the average rate map, is 10 cm per year. It should be noted that the amount of subsidence is in line with the line of sight of the satellite.

5. Discussion

In the present study, radar interferometric technique was used to monitor subsidence in Dehlran oil field located in Ilam province due to oil and gas extraction. The results of the present research, which was conducted using 8 radar images of the PALSAR sensor of the ALOS satellite in the time period of 2007 to 2010 with the formation of 28 interferograms, confirm the occurrence of the subsidence phenomenon with an average rate of 3.4 cm per year, which if harvesting from underground resources to which if this continues, there will be a serious risk of subsidence.

6. Conclusion

In this article, in order to monitor the amount of subsidence in the area of oil condensate extraction, the radar interferometric method was used, and the results of the investigations indicate the vertical displacement of the ground due to the extraction of fluids. In the end, it is suggested that due to the sensitivity of the oil-rich areas in the process of extraction and subsidence, as well as the presence of experts in remote sensing in the country and the low cost of this method, all oil fields need to be monitored by this method and prevented before any incident of its occurrence.

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