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Geotectonic Critical Analysis with Emphasis on Active Remote Sensing (ASAR Sensor) Case study: Persepolis

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Abstract

The main reason for subsidence in Iran is the large amount of water withdrawn from underground resources, which, if not managed properly will cause irreparable damages. To deal with such a problem, it is necessary to identify the subsidence areas. Most country's ancient artifacts have been built on fertile plains, and due to the dryness of the past decade, and the abundance of groundwater from the subsidence, it accelerates the destruction of ancient works in these areas. In this research, the area of Persepolis, which is 57 km northeast of Shiraz and 10 km north of Marvdasht city, is based on the level of the land subsidence using differential radar interferometry technique. Using Eoli-SA 9.4.3 software, two images were taken from the ASVAR data series of the ENVISAT satellite. The data processing with SARSCAPE 4.3 software, a radar differential interference method, has been implemented at two different times in a region. A new image called an interferogram or interferometer was provided that contains the target geophysical information. Therefore, the amount of subsidence or uplift was determined in the three interlaced states. During the research period from 23/12/2004 to 17/12/2009, which is 1820 days, it has been clear that the ancient area of Persepolis, the historic city of the pool and the role of Rustam between two and three centimeters subsided, and the role of Rajab is also between the four has seen up to five centimeters of subsidence.

Keywords: Geotechnical, Radar interferometry, Subsidence, Persepolis

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1. Introduction

Earth subsidence is the gradual or sudden collapse of the earth's surface due to the changes in the shape and displacement of particles (Rahman and Kazemifar, 2006), which is affected by natural factors (volcanoes, landslides at the site of disintegrating rocks, stiffness) and human factors (mining, extraction underground water, oil and gas, and construction) (Hunt, 2007).

The phenomenon of subsidence by altering the topographic state of the area can cause significant changes in the hydrology of the region. On the other hand, this phenomenon can lead to abnormal results by altering the aquifer status of the area, such as the direction and the speed of the flow of underwater, underground water basins and so on.

Therefore, the damage caused by the occurrence is suppressed and its phenomena associated includes the anomalous variation in elevation and slope of rivers, waterways and structures of water transfer, and failure or exhaust of the pipe walls of the wells as a result of compressive stresses due to the density. The aquifers and disturbance in the utilization of groundwater resources (Holzer, 1989) are also the advancement of waves in coastal areas and the reduction of groundwater quality and increase in salt water (Hajizadeh et al., 2013). Techno-logical properties of landforms and energy-efficient ones resulting from electromagnetic waves, plays a role in the geomorphological and environmental changes of each region, and determines the controlling factors of landforms. Earth subsidence as one of the consequences of karstization may be created as a sudden subsidence or gradual formation. When the earth's surface moves down gradually, the wider area of the earth subsides and suddenly falls. The dry climatic conditions in most parts of Iran and the increasing use of groundwater resources have provided favorable conditions for this phenomenon (Sharifi Kia, 2011). Also, the persistence of droughts and increased pumping of groundwater resources has expanded this phenomenon in humid areas of western and northwestern Iran (Faladi Moghadam, 2009). Utilization of oil and gas resources in addition to groundwater harvesting has led to the emergence of this phenomenon in the southwest of the country (Haghighat Mehr, 2010). Measuring the magnitude and extent of subsidence through satellite data is a new method in monitoring this phenomenon. In this regard, differential radar interferometry is one of the most accurate and least expensive remote sensing methods. Therefore, its footprint is deserted in the Persepolis area and the deformation analysis spatial and temporal dimension is necessary using the radar differential interference technique in order to manage the incident and to identify and reduce the damage caused by it.

Wang et al. (2011), using COSMO-SkyMed radar images and radar interferometry technology, surveyed the subsidence of the Shanghai metro subway tunnel, whose results showed that the metro caused subsidence at a high rate of 5 to 20 mm per year at most stations. Vincent et al. (2011) have studied the abnormal behavior of ground-level outage caused by the activities of the Chinese Lop-Nin atomic site using radar interferometry, which used ERS satellite radar data between 97-99 and determined that the height of the upper surface is about 2.7 centimeters.

Karimzadeh (2016) drops the Tabriz area using 17 ASAR images and Radar differential interferometry between 2003 and 2010, which shows the results of a residual 4-cm subsidence. Babaee et al. (2016) calculated the subsidence rate of Qazvin plain between 2003 and 2010 by analyzing the time series of radar images using short-length line and permanent dispersers of 20 to 35 mm per year.

2. Study area

2.1. Location and Geographical Coordinates of Persepolis

Persepolis is built on a mountain cliff of Rahmat Mountain, 57 km northeast of Shiraz and 10 km north of Marvdasht. The structure is 1770 meters above sea level. Geographical coordinates are located along the east 52º53'25" and 29º56'04" degrees latitude. This work was registered on 16 September 1931 with record number 20.

Figure 1. Location of the Jamshid Bed in coordinates 52º53'25" N and 29º56'04" E

2.2. Naghsh-e-Rostam

The Naghsh-e-Rostam is one of the most important historical works of the Elymian, Achaemenid and Sasanian period and is a collection of works made in the heart of the mountain. The Naghsh-e-Rostam and Mount Hajiabad are 5 km north of Persepolis, and it is commonplace for people and their inhabitants to consider the magnitude of their bodies, the figure of Rostam, the famous mythologist of Iran, known as the Naghsh-e-Rostam. In this mountain, there are huge tombs of Kheshayar Shah, Dariush Kabir, Ardeshir I and Dariush II.

2.3. Naghsh-e-Rajab

The Naghsh-e-Rajab is on the slopes of Mount Mehr (Mount of Rahmat), which has been painted on Ardashir Babakan and Shapur I. This work has been registered as number 22 on 16/09/1931. Naghsh-e-Rajab is 3 km northeast of Persepolis in Mount Rahmat.

2.4. Estakhr City

The ancient site of Estakhr City is located 5 kilometers north of the Persepolis. The most important way of connecting Marvdasht plain with Pasargad and Fars with the inner parts of the Iranian plateau, is the modest doors that are the bedrock of the river Pular. The city of Estakhr is located at the entrance to the valley to Marvdasht, and this has given it a superior geographic feature during its establishment. This work has been registered with the number 18 on 16/9/1931 (Pirnia, 2006).

ENVISAT Satellite

The study has used ENVISAT Europe satellite imagery with a brief description. The ENVISAT satellite was orbited from 2002 to early 2012. It has a repeating orbital period of 35 days with spatial resolution of 30 meters. The monitors installed on the ENVISAT satellite include ASAR MERIS, GOMOS RA-2, AATSR, SCIAMACHY, MIPAS, MWR, LRR and DORIS.

The selection of ASAR images should be out of snow and ice time, the ASAR sensor works in the C band, which is reflected by snow surface. Therefore, there is no vegetation during winter to check proper land subsidence. The selected images are related to the months with low vegetation and snow on the ground.

3. Research Methodology

3.1. Data collection and stages of work

First, using EOLI 9.4.3 software, two images of the ASAR data series of the ENVISAT Europe Satellite C Data Band were taken for specific dates. The data processing has been done with SARSCAPE 4.3 software with the use of differential interference method Radar which is suppressed by the region. The GPS has been used to accurately select the ground subsidence points.

By selecting ASAR sensor images from ESA website and matching the coupled images of Slave and Master geometrically, Radiometry and Radar, an initial preparation of interferometer from the region, and removing the topographic effects and restoring the remaining phase by the SARSCAPE 4.3 software has been conducted, Extracting the phase associated with the earth surface deformation, and eventually obtaining the map of subsidence of the region. Also, the variables studied in the form of a conceptual model and description of how to examine and measure the variables has been shown in Figure 2. The figure also shows the method and the selected images for this research with track number 142 and shooting time between 18:31 and 18:32. The calculation period for the subsidence is 1820 days from 23/12/2004 to 17/12/2009).

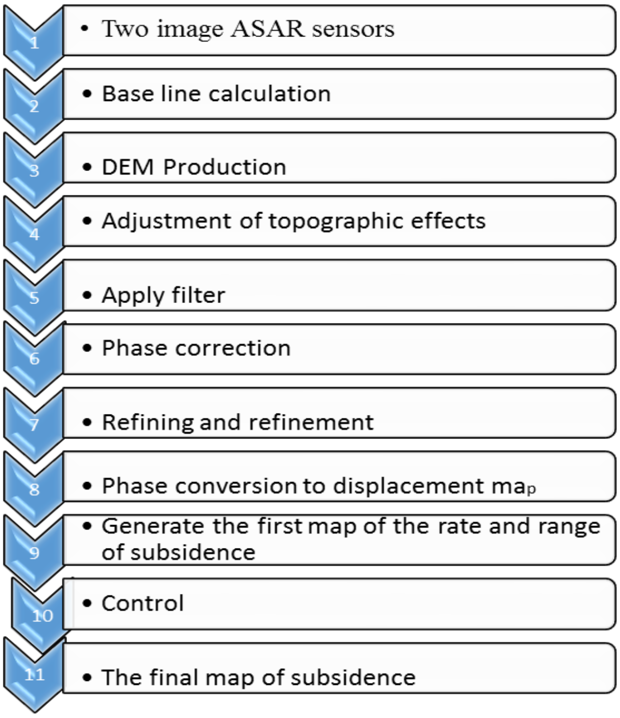

Figure 2. Research methodology flowchart

4. Data analysis method

In this project, after obtaining ASAR image sensors during the period 2002-2012 and the digital elevation model with a spatial resolution of 90 meters as the altitude for eliminating topographic effects, and using the SARSCAPE 4.3 software, the ENVI 4/8 platform changes the gap between ground and radar photographer along the satellite's line of sight with a precision of the fraction of the radar wavelength (cm or millimeter) during the data entry step into the software, measuring the base line, creating the DEM, eliminating the effects of the topography, applying the filter, correcting the phase. The phase transformation to the map of the displacement was fine-tuned the initial map of the rate and the range is generated, controlled and measured. Finally, in order to analyze and identify the area of high risk sites, minimum and maximum subsidence has been prepared. For this purpose, the D-InSAR image pair is selected based on two principles:

1. Time difference between images
2. The vertical line with the distance between the circuits, the shorter of which is the score type

4.1. Data used

ASA_IMS_1PTDPA20041223_183202_000000162033_00142_14725_9198.N1
ASA_IMS_1PTDPA20060216_183156_000000162045_00142_20737_9202.N1
ASA_IMS_1PTDPA20071108_183156_000000162063_00142_29755_9201.N1
ASA_IMS_1PTDPA20091217_183147_000000162085_00142_40777_9200.N1

For ASAR sensor data, orbital modification is needed to be introduced separately. The satellite in its orbit is free-fall and diverges from its orbit for various reasons, such as the moon, The sun, etc. The process of orbital correction is such that by moving the sensor called DORIS, the ASAR circuit rotates within 24 hours and corrects the satellite circuit with a 0.1 mm accuracy with the help of land sensors working with LIDAR. Therefore, for ASAR sensor orbital correction, DORIS sensor files should be used with 24 hours' time difference.

The DORIS files required are as follows:

DOR_VOR_AXVF-P20120424_170100_20041223_215528_20041225_002328
DOR_VOR_AXVF-P20120424_205700_20060216_215527_20060218_002327
DOR_VOR_AXVF-P20120425_164900_20071108_215527_20071110_002327
DOR_VOR_AXVF-P20120425_223600_20091217_215526_20091219_002326

The XCA file was used to modify the parameters of the satellite orbit and data sources prior to 2005

ASA_XCA_AXVIEC20070130_111449_20040412_000000_20050101_000000

4.2. Baseline

The baseline is based on two types of time line and spatial basis lines. The time line represents the duration of the images. If the time interval is too large, it increases the lack of correlation and reduces the phase coherence between the two images (Liu et al, 2013). The spatial basis is the distance between the two transmissions of the sensor. To test the subsidence, one needs to use images that have a zero point of reference. The table below shows slave and master images, as well as the intervals of each one (Table 1)

Table 1. Radar images and their titles

R	Date image master	Date image slave	Time interval (day)
1	2004/12/23	2006/02/16	421
2	2006/02/16	2007/11/08	630
3	2007/11/08	2009/12/17	770

The information provided after calculating the baseline by the software includes:

Normal Baseline: The distance between two satellites when shooting.

Critical Baseline: Maximum allowed space for two satellites.

Ambiguity height

Range shift: Displays the Range value of the Master image to the Slave

Azimuth shift: Shifts the master image to the slave in Azimuth.

Doppler Centroid difference: By placing the Doppler gravity center of the images, the slave indicates the difference between the slave and the master.

The values obtained for the Baseline are images complying with the table below (Table2).

Table 2. A coupled picture base line

Date of the images	Couple image number	Normal Baseline (m)	Critical Baseline (m)	2PI Ambiguity height (m)	Range Shift (pixels)	Azimuth Shift (pixels)	Doppler Centroid diff
2004/12/23 2006/2/16	A	136.623	2157.670	135.105	-14.267	22.993	-4.169
2006/2/16 2007/11/8	B	335.859	2157.584	54.958	-31.932	21.654	-12.485
2007/11/8 2009/3/12	C	307.722	2157.537	59.982	-26.118	9.140	-4.123

5. Results

5.1. Results of the subsidence between 2004-2006

Between 2004 and 2006, the area drops to a maximum of 12 centimeters and has seen 10 centimeters above ground level. The greatest amount of subsidence related to the coordinates are 29º 56' 11" N and 52º 51' 21" E. During this time, the center of the ancient temples of Persepolis was between two and three centimeters. The northern region of these areas fell between three to four centimeters, the northwest and north-east between two to three centimeters subsided, as well as forest park between one to two centimeters subsided. The ancient Naghsh-e-Rajab and its northern and western regions subsided between 2.5 to 3 centimeters, and the eastern, southeast, and southeast regions subsided between 3 and 3.5 centimeters. The historical and ancient Estakhr city has been down between two and nine to three centimeters. The study revealed that the northern, northeastern and northwest parts of Naghsh-e-Rostam were between five to six centimeters high and southern, southwestern, and southeast areas four to five centimeters above the surface. During this period, most of the regions were between two and four centimeters.

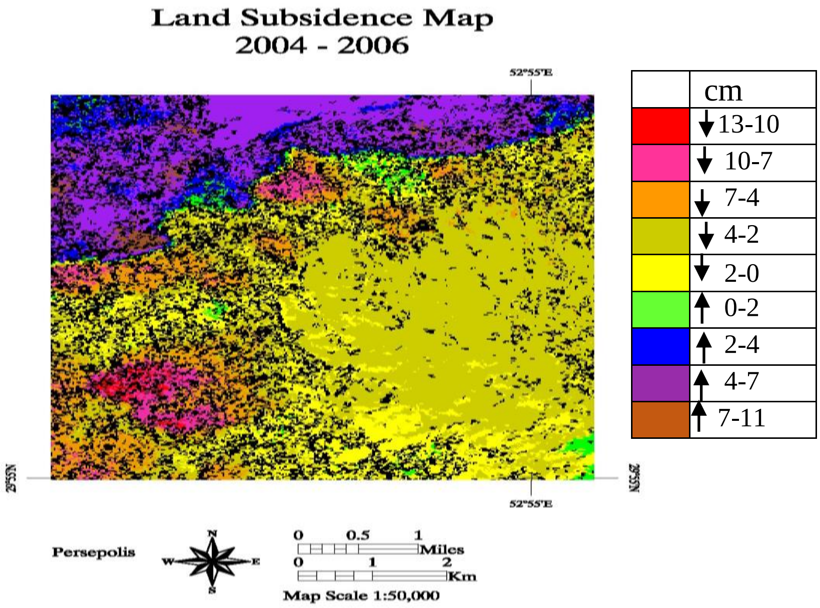

Figure 3. Subsidence between the years 2004 to 2006

5.2. Results of the subsidence between 2006-2007

Between 2006 and 2007, in this region, the largest amount of 8-meter subsidence is related to the coordinates of 29° 55' 23" N and 52° 55' 11" E. It is noteworthy that during these 630 days the maximum surface area has been two centimeters and the study area had an average of one centimeter subsidence. During this time, the center of the ancient temples of Persepolis was between zero and one centimeter. The northern, southern, eastern and western parts subsided between zero and one centimeter and also a forest park between one and two centimeters subsided. The ancient artifacts of Naghsh-e-Rajab and its surrounding areas dropped from zero to one centimeter. And the historical and ancient Estakhr city has been between zero and one centimeter of subsidence. The study found that the ancient area of Naghsh-e-Rostam, other than its northern parts, between 1 and 2 centimeters, has been observed, and in other areas with a maximum of one centimeter subsidence. During this period, most areas had subsided from zero to two centimeters.

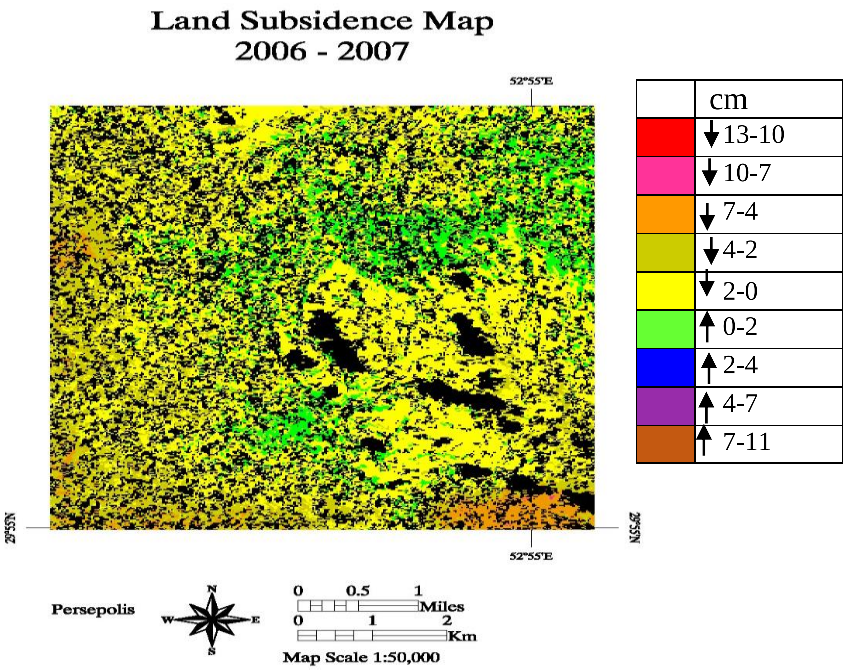

Figure 4. Subsidence between the years 2006 to 2007

5.3. Results of the subsidence between 2007-2009

In this study, it was found that between 2007 and 2009, the area had the lowest subsidence compared to previous years. During the 770 days in the third pixel of the images, the maximum abandonment is related to the coordinates of 29^o 58' 42" N and 52^o 51' 26" E to seven centimeters and the maximum area elevation during this period was three centimeters. During this period, the average changes were zero and the changes in the Persepolis are as follows:

The collections of works and the northern, southern, eastern and western areas, as well as the forest park between zero and 0.5 centimeters, have been the lowest in recent years. The Naghsh-e-Rajab's collection has subsided between zero and 0.5 centimeters in this period. Also, the collection of the historical Estakhr city, like Naghsh-e-Rajab between zero and 0.5 centimeter, has been abandoned. The study revealed that the ancient area of Naghsh-e-Rostam and the northern, eastern and southern parts of Naghsh-e-Rostam were between 2 or 2.5 centimeters, and western regions between 2.5 to 3 centimeters subsidence. The northeastern parts of this work had dipped between 3.5 to 4 centimeters. It is worth mentioning that black points are points without information in radar images.

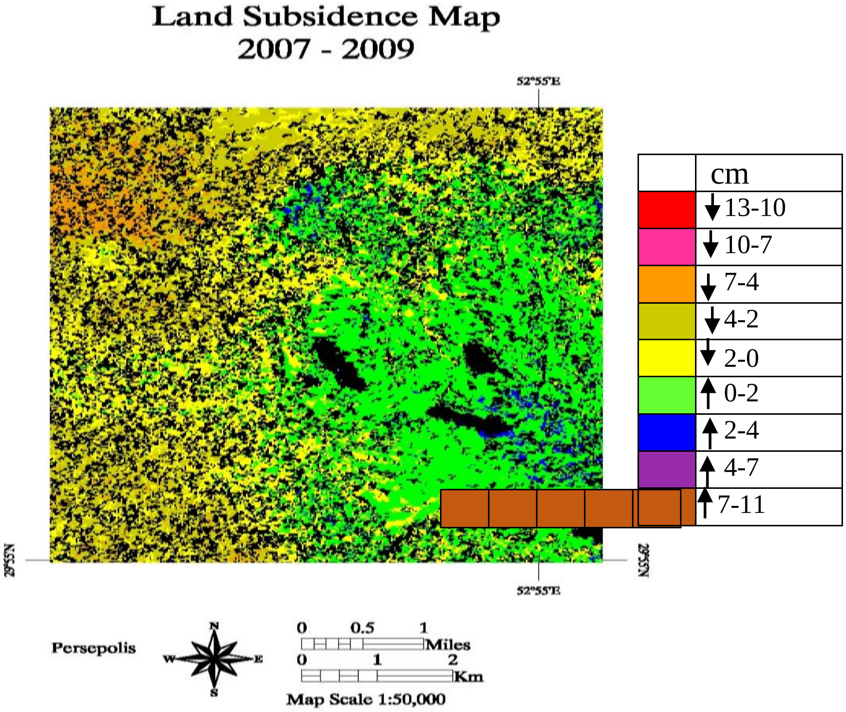

Figure 5. Subsidence between the years 2007 to 2009

5.4. **Conclusion**

The figure shows1820 days. The maximum descent of thirteen centimeters corresponds to the coordinates of 29º 56' 12'' N and 52º 51' 36'' E, with a maximum height of 8 centimeters. The entire region has generally dropped by three centimeters. During this period, the ancient area of Persepolis fell between two and three centimeters, and the southeastern region subsided between zero and one centimeter and the northeastern region between three and four centimeters. There is also a forest park between two or three centimeters of subsidence.

During this time, the historical Estakhr city and the surrounding area was between two to three centimeters subsided. In this research, it was found that Naghsh-e-Rostam area was between two and three centimeters, which according to the climate of this region in 2004 to 2006, the subsidence of the region is more than other regions. Naghsh-e-Rajab subsided between four and five centimeters and its southeastern sections between three and four centimeters and southward between two and three centimeters.

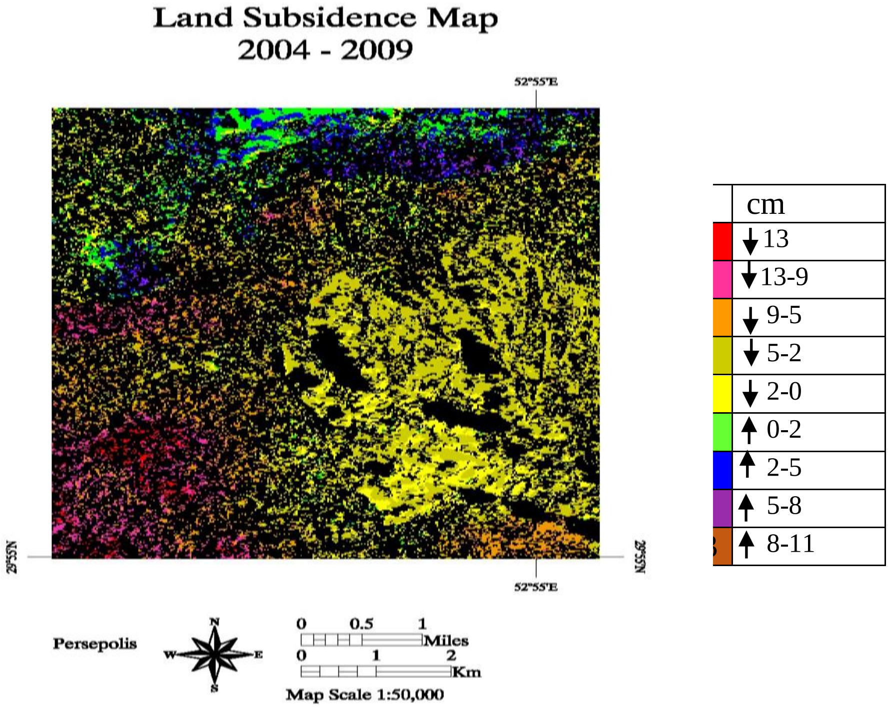

Figure 6. Subsidence results between the years 2004 to 2009

With the addition of three layers of paired images, the image shows the amount of dying between 2004 and 2009. besides, it should be noted that in each image, the pixel value is NONE. In the overall image, its pixel value is also NONE, so in the overall image, the number of points with NONE value is more than other images.

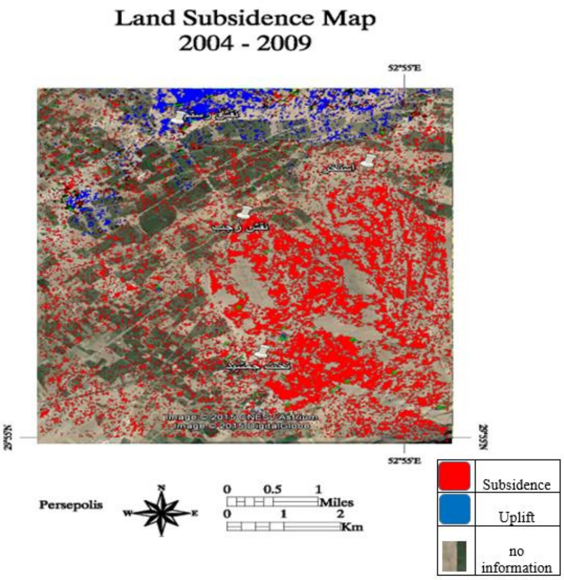

Figure 7. Subsidence of the region between 2004 and 2009

It is seen in Figure 7 that during the research period (i.e.1820 days) most of the areas have been abandoned which is shown in red, and the blue sections represent the areas that were on the highway during that time. With regard to the elevation of these areas due to the isostatic law, it can be concluded that, the only reason for subsidence is not due to the underground groundwater. It is worth noting that these areas are the northern mountains of Naghsh-e-Rostam. It should be noted that this is the first research on subsidence in the flat area of the oblast, and there are no other studies for comparing the results.

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