DETERMINATION OF LAND SUBSIDENCE IN GORGAN PLAIN WITH INSAR METHOD (GOLESTAN, NE IRAN)

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ABSTRACT

Golestan Province is classified as an area of high risk concerning natural hazards. Earthquakes, floods, landslides, and land subsidence are among the disasters that affected this region. In recent years, remote sensing techniques have played a key role in determining land subsidence events that produce significant environmental problems in various plain areas around Iran (e.g., Hashtgerd, Qara Bulaq, Damghan, South West Tehran, Golpayegan, South Mahyar, and Gorgan plains). Land subsidence events can be clearly identified by employing remote sensing and geodetic methods such as well-known and frequently used GPS measurements and InSAR studies. Any changes on the ground surface caused by deformation events can be accurately calculated using the InSAR technique. Basically, this method compares pairs of satellite images of a region, which acquired before and after the deformation event, and detects the possible changes between them.

Application of the InSAR analysis technique on ENVISAT satellite data acquired between 26.01.2007-11.12.2009 in Gorgan Plain, located in the western part of Golestan Province, has revealed the occurrence of 4.8 cm and 1.1 cm of land subsidence amounts for the Gorgan and Akkale areas, respectively. InSAR analysis results also suggest that land subsidence has been distributed in a relatively east-west direction. This orientation is consistent with the Khazar (Caspian) Fault Zone geometry, which affects the Golestan Province and exhibits a curved geometry with ENE-WSW and NE-SW directions. The active Khazar Fault Zone displays reverse/thrust fault characteristics and has produced many significant earthquakes during the instrumental period with magnitudes ranging from 4.0 to 6.2.

Lower amounts of precipitation and, consequently, sudden decreases in the groundwater level can be an alternative reason for the observed subsidence in the region. However, it is noteworthy that the land subsidence displays a linear distribution rather than a homogeneous propagation in the study area. This condition indicates that the continuous land subsidence events in Gorgan Plain are dominantly related to the ongoing tectonic processes in the region. Also, our observations demonstrate that meteorological processes contribute to the occurrence of land subsidence events.

Keywords: Khazar fault zone, Naturel disaster risk, InSAR method, Golestan, NE Iran

INTRODUCTION

In recent years, land subsidence events resulted in serious environmental issues in several plains of Iran, such as Zarand Kerman (Rahmanian, 1986), Sirjan plain (Abbasnejad, 1998), Ardekan Yazd (Alemi, 2002), Famanin-Kbudar Ahang Hamedan (Amiri et al., 2004), Moein Abad Varamin (Shemshaki and Entezam, 2005), Tehran-Shahryar (Blourchi, 2005), Golpayehan (Jannat et al., 2009), Hashtgered (Shemshaki and Boulurchi, 2011), Tehran plain (Mirshahi et al., 2013), Damghan (Afzali et al., 2013), Mashhad (Maddah et al., 2013), Nishabur (Rakni et al., 2016) and this problem is becoming more and more evident in more areas in Iran. Land subsidence is the sudden sinking or gradual downward settling of land with little horizontal motion (Bates and Jackson, 1980), caused by a loss of subsurface support that may result from several natural phenomena (earthquakes, soil compaction, glacial isostatic adjustment, erosion, sinkhole formation, adding water to fine soils deposited by wind) but also due to human activities (mining for various resources, oil recovery operations or enhanced water withdrawal from aquifers). Human beings have increased the severity and number of these problems by unprincipled and irrational exploitation of natural resources. However, according to studies conducted in the plains of Iran, which are suffered from this phenomenon, the main cause of land subsidence indicates factors such as declining groundwater levels, dissolution of subsurface formations, and karst collapse. Nevertheless, other human activities such as land-use change, construction, operation or loading of engineering structures, drainage of organic soils, subsurface mining, or oil pumping are among the factors that can trigger subsidence (Eskani Kozazi et al., 2000). In the United States, more than 17,000 square miles in 45 states have been affected by land subsidence, and more than 80 percent of the subsidence has been affected by uncontrolled groundwater extraction (Galloway et al., 1999). In many dense urbanized areas, extreme and uncontrolled exploitation of underground water from aquifers, particularly in the areas build over unconsolidated deposits, triggered land subsidence (Chen et al., 2016; Sato et al., 2006; Suganthi et al., 2017, Hung et al., 2018; Malik et al., 2018) .

One of the best examples of land subsidence is the event that occurred in the Konya basin in Turkey. The subsidence has started in the middle of the 1970s due to the decrease in underground water levels due to intensive use of underground water resources, resulting in deformation and compression events in aquifer systems (Ustun et al., 2015).

Damages caused by land subsidence events and land fissures are seldom classified as irreparable and, when human intervention is possible, the necessary works are considered expensive. Therefore, studying land subsidence in suspected areas is essential to reduce risks and casualties.

Several methods can be applied to assess different aspects of land subsidence events. Underground voids are seldom a source of land subsidence in mining and karst areas. In such a context, the geophysical methods (Rahnema and Mirasi, 2013), especially gravity and electrical resistivity methods, represents the only possibility of a non-invasive investigation of the subsoil. Using measurements made at the earth's surface, it is possible to detect underground voids presence and monitor their geometry and stability in time. GPS measurements, remote sensing techniques, and particularly Radar interferometry methods (e.g., Afzali et al., 2013; Khorrami et al., 2016; Shemshaki and Boulurchi, 2011) are tools for observing the effects even at early-incipient stages. Synthetic Aperture Radar Interferometry (InSAR) is one of the procedures that led to great revolutions in the studies of deformations in Earth's crust (e.g., subsidence) with very high accuracy, comprehensive coverage, and high spatial resolution (e.g., Gabriel et al., 1989). In this study, we applied the InSAR technique to determine the areas with a high risk of vertical surface deformations around Gorgan city.

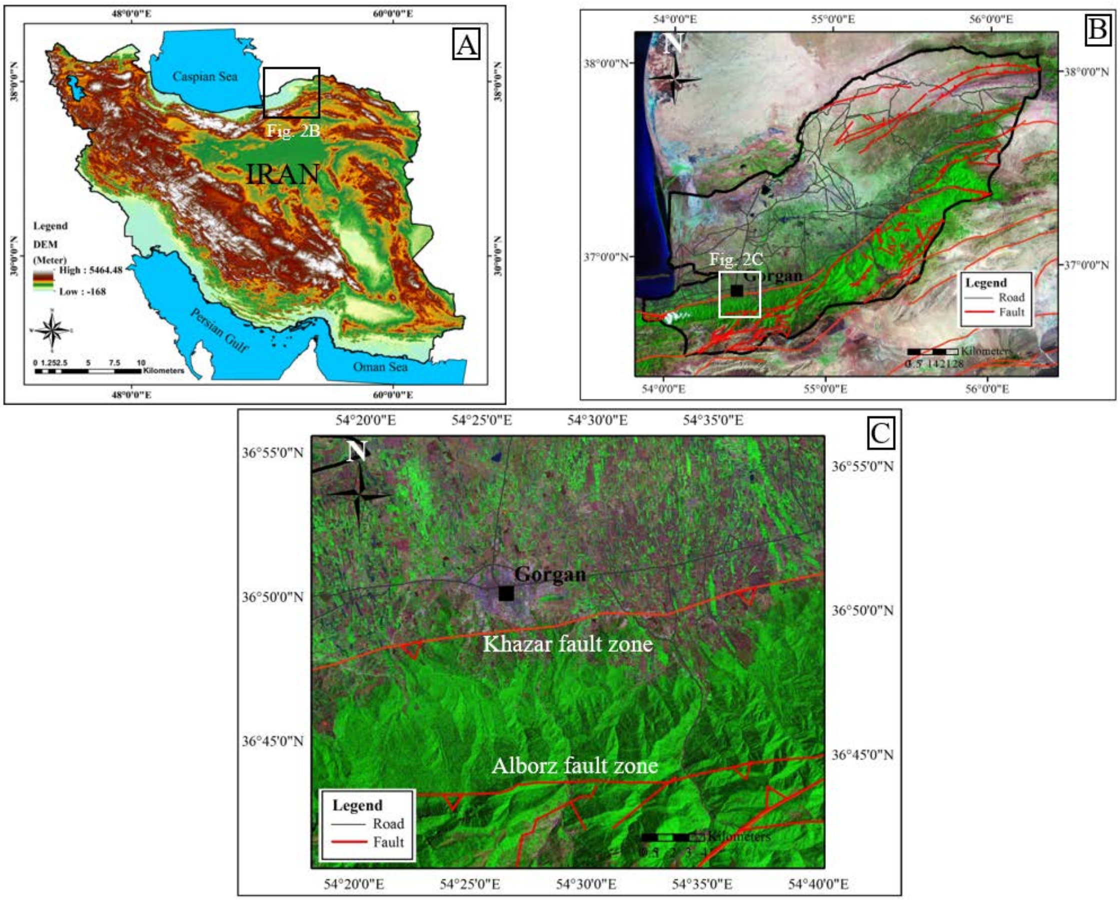

Figure 1- A) Digital Elevation Model (DEM) map of Iran, B) Satellite map showing the location of the Golestan Province, C) Satellite map of the Gorgan city. Red lines are showing active faults that are adopted from Hesami Azar et al. (2011).

TECTONIC SETTINGS

Gorgan Plain is located in Northeast Iran, east of the South Caspian block and north of the Eastern Alborz Mountains (Figure 1A), representing a transition zone between the uplifting Kopeh-Dagh belt to the west and the subsiding South Caspian region to the east (Ghasemi et al., 2007). The East Alborz mountain range, an active orogenic belt, borders the southern parts of the study area. The most significant faults of the studied area are the Khazar and North Alborz fault zones, limiting the northern margin of the Alborz Mountains (Figure 1B). These fault zones exhibit ENE-WSW and NE-SW directions with reverse/thrust and left-lateral strike-slip fault characteristics with reverse component (Shahpasandzadeh, 2004; Hollingsworth et al., 2008; Nemati et al., 2011).

The curved-shape Khazar fault zone, one of the important active fault zones within the Golestan province, consists of several fault segments (e.g., Minoodasht, Behshahr, Sari, and Amol segments). Axen et al. (2001) and Allen et al. (2003) suggested that the thrusting of the Alborz Mountains towards the south of the Southern Caspian block occurs along the Khazar fault zone. The zone represents a south-dipping thrust fault characteristics in Gorgan and its surroundings, which locally thrusts Gorgan schists over young Quaternary sediments (Allen et al., 2003). The active Khazar fault zone displays reverse/thrust fault characteristics and has produced many significant earthquakes during the instrumental period with magnitudes ranging from 4.0 to 6.2.

METHODOLOGY

Synthetic Aperture Radar (SAR) interferometry (InSAR) technique compares the taken reversal signals phase from two sets of Synthetic Aperture Radar data of a region, at two different times. By processing two radar images in a given period and generating an interferogram, it is possible to evaluate the changes at the Earth's surface for the selected time (Massonnet and Feigle 1998), therefore being suitable for monitoring of subsidence and structural stability. In the generated interferograms, the areas where different displacement amounts have occurred are separated from stable areas by numerous colored bands ranging from blue to red. In this study, the InSAR analyses have been done for a set of RADAR images (26.01.2007-11.12.2009) in the Gorgan Plain (Figure 2C). The ENVISAT satellite images, which acquires images in the microwave C band (56 cm), were obtained from the Europe Space Agency. The information of the image sets is given in Table 1.

Table 1. Basic information of ENVISAT image sets used in this study

Mission	Sensor	Track	Pass	Swath	Date	Orbit
ENVISAT	ASAR/IM	56	Ascending	I6	26.01.2007	25661
ENVISAT	ASAR/IM	56	Ascending	I6	11.12.2009	40691

The standard image processing was done using SARScape software on Envi 4.8 platform. For this study, the raw data was changed to SLC (single look complex) format. Thus interferogram images are generated from selected master (first) and slave (second) satellite images. To reduce noise, radar image couples with a relatively short period and suitable spatial baseline were used. Finally, an interferogram has been made, and the map was generated with an estimation of the subsidence amount.

INSAR RESULTS

We have used the SAR interferometry method in this study to investigate land subsidence in the Gorgan Plain for radar images acquired on 26.01.2007 and 11.12.2009, where the period between two image sets was 34 months and 15 days. Analyzing generated interferogram images, separation of color range band from blue to red (Figure 2) revealed significant subsidence in the studied area, corresponding to the north of Gorgan city.

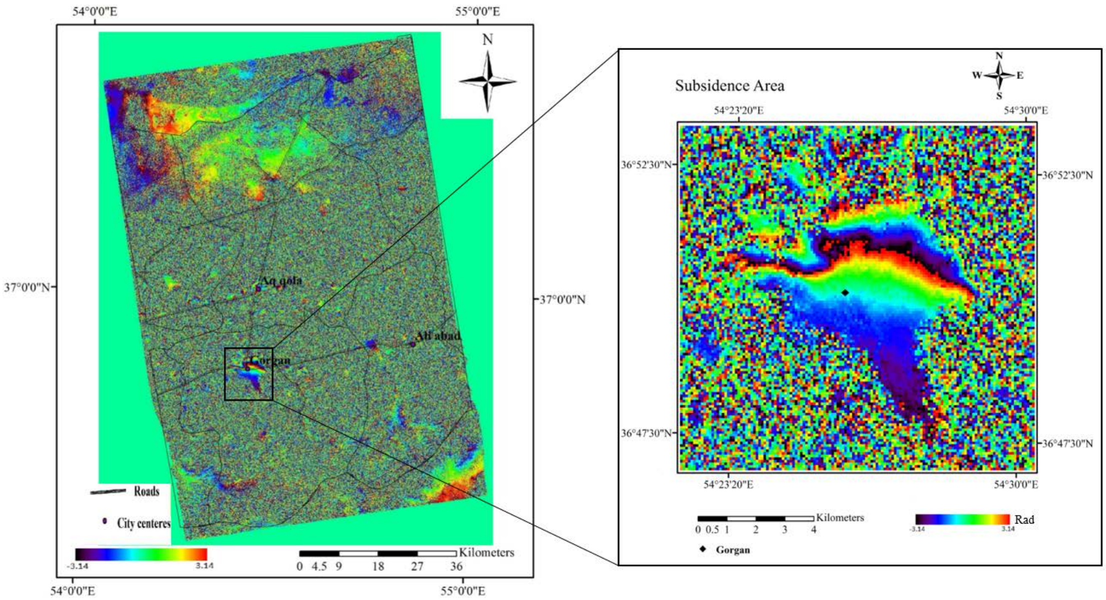

Figure 2 - Generated interferogram map of the Gorgan city and its surroundings

One of the significant issues affecting the land stability is considered to be the sudden drops in groundwater level. The annual rainfall and the changes in groundwater levels for the study area are given in Figure 3. The rainfall graph for the period of 2001 to 2013 shows that the lowest rainfall values are correlated with the studied period on which the subsidence was assessed from the SAR data (Figure 3A). The water level graphs related to the Gorgan and Anjirab stations also show a downward trend for the period of 26.01.2007 to 11.12.2009, despite seasonal fluctuations (Figure 3B). The decrease in precipitation leads to overexploitation of the aquifer, as it was necessary to extract a higher amount of water to resist the drought. Therefore, we consider this as a cause of the observed subsidence.

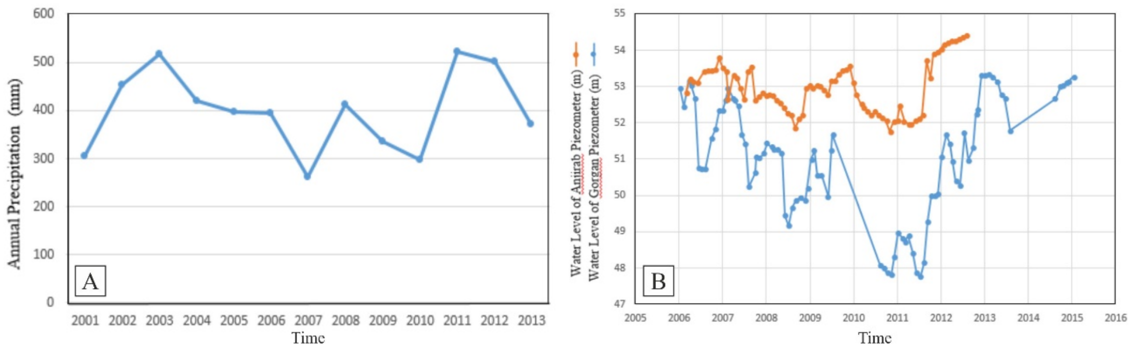

Figure 3 - A) Annual precipitation, B) Groundwater levels at Gorgan and Anjirab stations

By generating a line of sight (LOS) displacement map from the interferogram image, the subsidence amount was calculated from 4.8 cm in Gorgan to 1.1 cm in the Agh Ghala area (Figure 4).

Occasionally, the east-west trend of the subsidence signal is consistent with the trend of tectonic structures such as the Khazar fault zone (Figure 4). It shows that the tectonic events in the region may also have an influence in the observed phenomena.

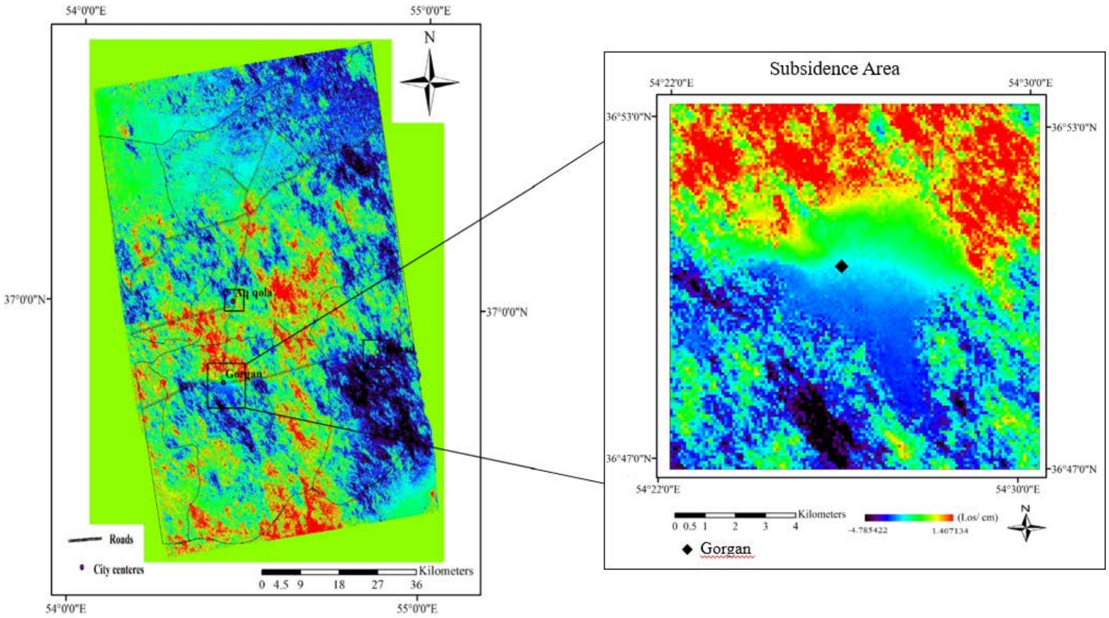

Figure 4 - LOS displacement map of the Gorgan city and its surroundings

CONCLUSIONS

Subsidence events are among the most common natural disasters, especially in plain areas in different parts of the world. In this research, the land subsidence events in the Gorgan area located in NE Iran have been investigated by the InSAR technique using ENVISAT radar images.

InSAR analysis for 34 months and 15 days shows a subsidence area with an east-west trend north of Gorgan. For the studied period, the graphs of annual rainfall and groundwater level changes show a downward trend indicating the linear relationship between subsidence and decrease of groundwater levels. However, it is noteworthy that the land subsidence displays a linear distribution rather than a homogeneous propagation in the study area. This condition indicates that the continuous land subsidence events in Gorgan Plain are dominantly related to the ongoing tectonic processes in the region. Also, our observations demonstrate that meteorological processes contribute to the occurrence of land subsidence events.

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