
Land Subsidence in Mahyar Plain, Central Iran, Investigated Using Envisat SAR Data

M. Davoodijam, M. Motagh, and M. Momeni

Abstract

In recent decades land subsidence and its associated fissures have been observed in many plain aquifers of Iran. Knowledge of the deformation field in groundwater basins is of basic interest for understanding the cause and mechanism of deformation phenomenon, and for mitigating hazard related to it. In this paper the result of Envisat InSAR time-series analysis for monitoring land subsidence in Mahyar Plain, Central Iran, is presented. Long-term extraction of groundwater, which started in 1970 with the development of agriculture in this area, has caused substantial subsidence and formation of many earth fissures in Mahyar. Our analysis indicates significant subsidence bowl south of Mahyar plain with an elliptical pattern directed northwest–southeast along the axis of the plain. The velocity map obtained by the time-series analysis of InSAR data shows a maximum subsidence velocity of ~ 9 cm/year in the line of sight from the ground to the satellite in the year 2003–2006.

Keywords

Ground water • Interferometry • Land subsidence • Mahyar plain

1 Introduction

Subsidence is defined as the downward motion of a surface relative to a datum such as sea level (Waltham 1989). Generally, compaction of sediments, extraction of ground water, oil and gas result in compression of the clay layers beneath the land surface and subsequently elevation of the land surface is lowered. In recent years, with the growing population of the world and lack of water caused by global warming there has been an increased request for groundwater to supply domestic, industrial and agricultural needs. Excess exploitation of this resource causes underground fluid pressure to decrease. Thus the supportive effective stress on the

rock matrix increases and rock compaction or land surface subsidence occurs (Murk et al. 1995; Jachens and Holzer 1982).

Several problems are associated with land subsidence including damages to underground infrastructure and civil engineering structures such as buildings, roads, canals and bridges, and increasing inland flooding along streams and waterways due to changes in stream gradient. Decreasing water level also increases pumping cost, as deeper wells are required to be built to extract water. It has been addressed in the literature that land subsidence caused by over extraction of ground water is increasing around the world. It is also a widespread problem in Iran (Motagh et al. 2008). This paper presents the result of an InSAR time-series method, called Small Baseline Subset (SBAS) (Berardino et al. 2002) for analyzing temporal and spatial variability of land subsidence in Mahyar plain, south of Isfahan province in Central Iran. The analysis done in this paper is based on 15 C-band ASAR radar images acquired by the Envisat satellite during 2003–2006.

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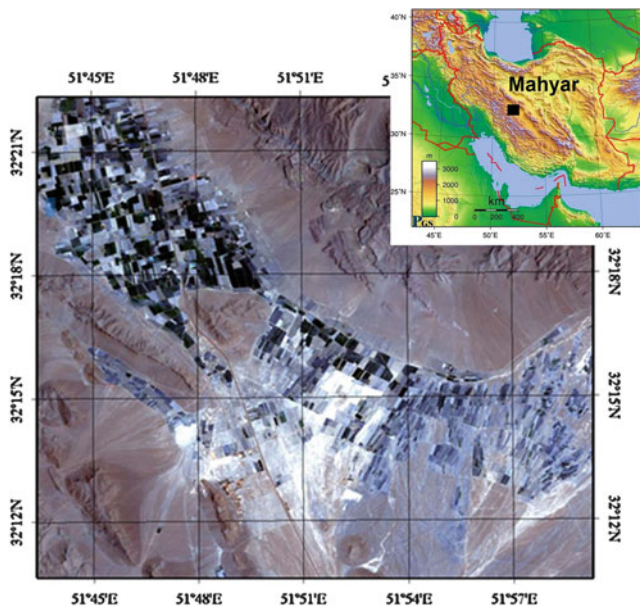


Fig. 1 Geographical location of Mahyar plain in Iran

2 Study Area

Located in an arid and semiarid region of Iran with an unconfined aquifer of an area of 158 km² (Ajalloein et al. 2006), Mahyar Plain is a NW–SE trending plain south of Isfahan province in central Iran (Fig. 1).

Long-term extraction of groundwater, which started about 30 years ago with the development of agriculture in this area, has caused subsidence and formation of many earth fissures in Mahyar, in turn leading to substantial damages to houses, farms, channels and roads in the region. Land subsidence monitoring is important in order to investigate the temporal and spatial extent of subsidence and for mitigating hazard related to it.

3 Methodology

To assess the temporal and spatial scale of land subsidence in Mahyar, we use the SBAS method as implemented in the STAMPS software (<http://radar.tudelft.nl/~ahooper/stamps/index.html>)

This method uses a large number of SAR acquisitions and implements a combination of a properly chosen set of multi-looked DInSAR interferograms computed from these data. The unwrapped interferograms are input data for the least-squares method (Berardino et al. 2002), which is used to produce spatio-temporal evolution of ground surface deformation.

The following steps are done by STAMPS in order to generate time series analysis:

1. Generating subsets of small baseline interferograms
2. Selection of slowly decorrelating filtered phase (SDFP) pixels, defined as pixels whose interferometric phase after azimuth and range filtering shows slow decorrelation over short time intervals
3. 3-D phase unwrapping on SDFP pixels
4. Generating time series and mean velocity maps according to coherent pixels (Hooper 2008).

4 Experimental Results and Analysis

4.1 InSAR Result

In this study 15 radar images of the study area, acquired by the European Space Agency (ESA)'s Envisat satellite, are used. The dataset consists of ASAR images recorded in a descending trajectory spanning the year 2003–2006. Thirty-seven differential interferograms were generated and analyzed using the SBAS method. The topographic correction was done using the 90-m SRTM DEM. Figure 2 illustrates the final network of interferograms that we used for the time-series analysis.

Figure 3 presents an example of a geocoded differential interferogram in our study area. The interferogram covers the time interval between April 2003 and November 2004. One complete cycle of color from blue to yellow corresponds to half a wavelength of apparent range change (about 28 mm for the C-band radar onboard the Envisat satellite) between the spacecraft and the Earth's surface.

The obtained result indicates significant land subsidence occurring south of Mahyar. The subsidence area delineates an elliptical pattern directed northwest–southeast along the axis of the Mahyar plain.

Figure 4 illustrates the average subsidence rate in Mahyar obtained by the time-series analysis of Envisat SAR data. The negatives values in the map represent subsidence signals in the LOS direction (motion away from the satellite). We observe a maximum rate of LOS subsidence of about 9 cm/year in the southern part of Mahyar plain. Because of the steep incidence angle of the Envisat satellite (~23°) interferometric results are more sensitive to vertical than horizontal displacement (Hanssen 2001). This, coupled with field and hydrological evidence for aquifer compaction in the valley (next section), led us to interpret the LOS displacement as indicating mainly land subsidence in the valley.

Figure 5 shows displacement time series for four selected points, A, B, C, and D in Fig. 4. Point A lies in the area of maximum subsidence. The maximum amount of Line of Sight (LOS) displacement is about 23 cm during 2003–2006 (Fig. 5a). Point B lies on the main road that connects two metropolitan Isfahan and Shiraz. Here we obtain ~9.3 cm displacement in the LOS direction. Point C and D are

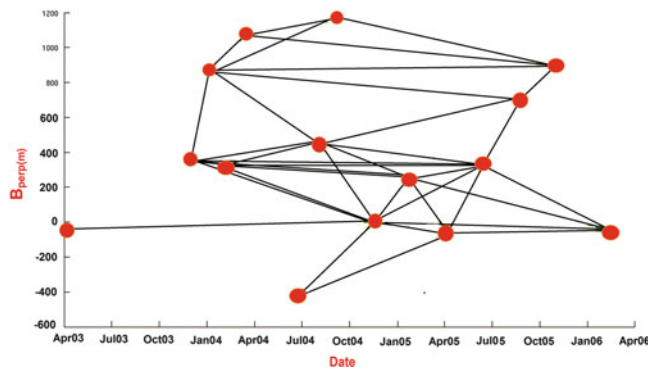


Fig. 2 The network of interferograms used in this study

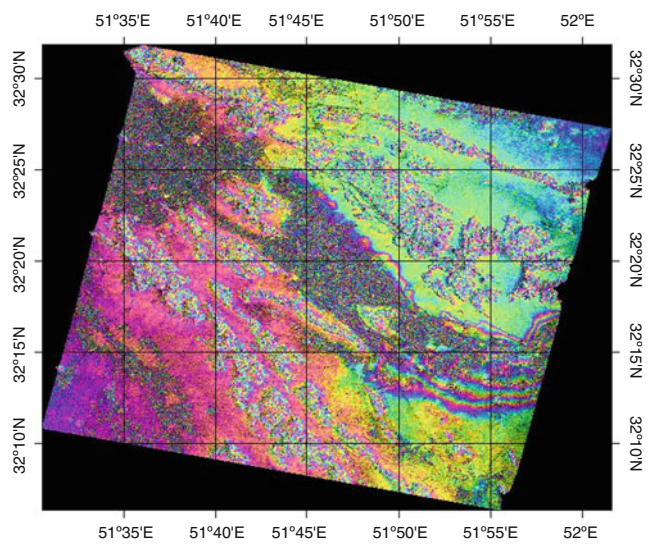


Fig. 3 An example of a geocoded differential interferogram in Mahyar between April 2003 and November 2004

two arbitrary points and their time-series results confirm that most parts of the Mahyar plain sustained significant subsidence in the year 2003–2006.

4.2 Earth Fissures

After InSAR observations a field survey of area for positioning of the fissures caused by land subsidence was done in the summer 2010. The observed fissures have been overlaid a descending interferogram in Fig. 6. As shown in Fig. 6 no fissure was observed to the south part of the southern Mahyar plain. In contrast, several parallel fissures were detected in other parts of region.

Many reasons contribute to the generation of fissures in areas affected by land subsidence. Factors such as decline in the water table, faults, aquifer heterogeneities, bedrock knob protruding into the aquifer system and presence of

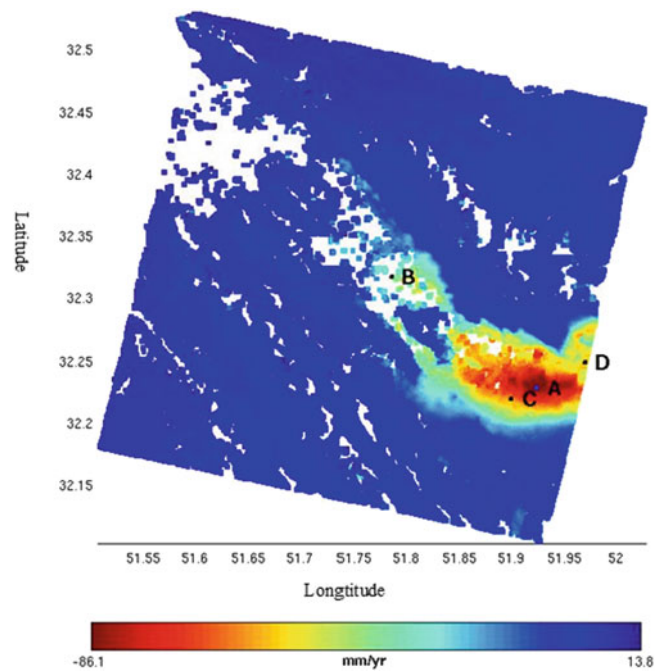


Fig. 4 Mean velocity map of subsidence area in Mahyar

weakness plain in aquifer system control the progress of fissuring (Burbey 2002).

4.3 Piezometric Records

Piezometric record in Mahyar plain shows a correlation between the pattern of land subsidence and the decline in water level. As shown in Fig. 7, the water table in the region has a clear declining trend with a head decline of ~12 m between 1983 and 1995 and only small periodic recoveries, probably caused by seasonal rainfall. Such a decline in water table record suggests that land subsidence in Mahyar plain results from overdrafting of the aquifer system.

Conclusions

This paper has demonstrated the capability of C-band ASAR images for investigating land subsidence in Mahyar plain, an agricultural region south of Isfahan province in Central Iran. Results obtained from the time-series analysis of 15 ASAR images acquired in a descending orbit between 2003 and 2006 indicates a subsidence bowl south of the plain with maximum LOS velocity of ~9 cm/year. Analysis of the piezometric records suggests that subsidence likely results from overdrafting of the aquifer system that has caused an average decline of ~1 m/a in the water table since 1982.

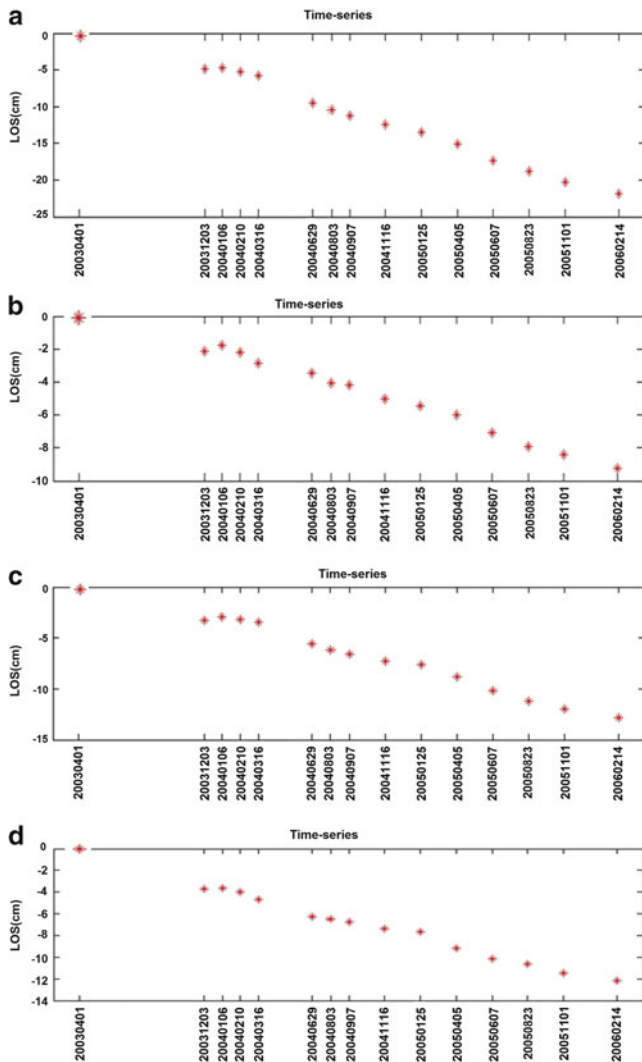


Fig. 5 Examples of time—series results at four selected points. For locations of A, B, C and D please refer to Fig. 4

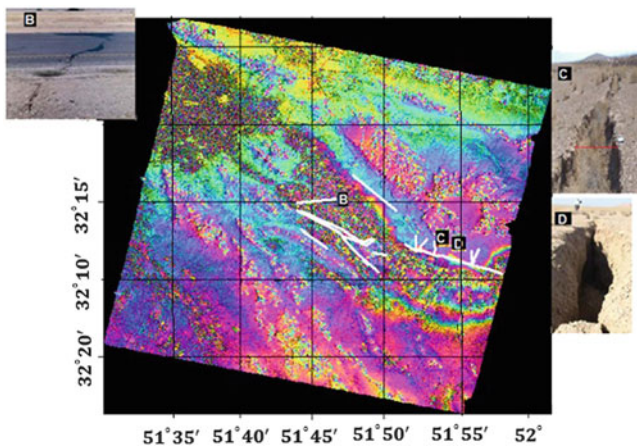


Fig. 6 Fissures detected during field survey of Mahyar plain in 2010. Fissures are overlaid on a descending interferogram. The insets show ground picture of three fissures in Mahyar

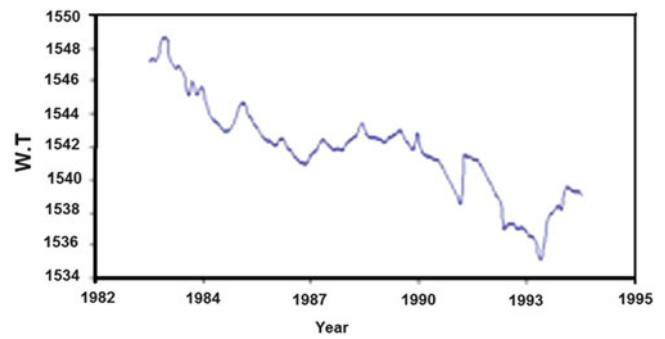


Fig. 7 Average groundwater level decline in Mahyar obtained from piezometric records

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