Journal of Civil Engineering and Urbanism

Volume 4, Issue 6: 562-567 (2014) ISSN-2252-0430

Monitoring Land Subsidence of Mashhad Valley of IRAN Using Leveling, GPS Survey and InSAR Techniques

Mani Amrouni Hosseini* and Hamid Bayat

Department of Surveying, Robat karim Branch, Islamic Azad University, Tehran, Iran

*Corresponding author's E-mail: Mhosseini_rs@yahoo.com

ORIGINAL ARTICLE
Received 25 May. 2014
Accepted 13 Jul. 2014
Published 25 Nov. 2014

ABSTRACT: In Northwest of Mashhad, one of the cities of Iran, land subsidence phenomenon is taking place highly due to the Irregular withdrawal of groundwater. Maximum transfer rate induced land subsidence is estimated about 23 cm per year by help of continuous GPS observations and precise levelling data provided by the National Cartographic Centre of Iran (NCC). GPS stations give precise continuous measurements but at a few sparse points of the deformed area. Therefore, they are not able to map the extent and pattern of the ground surface deformation caused by subsidence. Nowadays, the ability of In SAR in displacement of ground level continuous coverage with high spatial resolution has been proved with less than one centimetre accuracy. In this research, areas and the pattern of land subsidence was measured using the mentioned technique. 10 ENVISAT ASAR Radar images have been used to calculate 17 incremental interferograms and were determined by time series In SAR analysis of ground level in each radar data acquisition date. Present results revealed long and short term land subsidence changes in mentioned period. To detect land subsidence rates, the Average velocity map of movement were prepared with help of In SAR time series analysis results. Areas with different rates displacement was marked in this map. Based on this map, the maximum land subsidence rate was estimated about 24 cm. Comparing time series analysis results of In SAR and GPS measurements and precise levelling showed the high compliance of these data. Then an optimal GPS monitoring network was designed with image of the average speed of displacement to determine the horizontal displacement.

Keywords: Land Subsidence, Mashhad valley, Levelling, GPS Survey, InSAR Techniques.

INTRODUCTION

UNESCO has introduced the subsidence as one of the selected Topics of global research due to its expansion and a special working group composed of the most prominent researchers in this area has formed over the world. This group published the first handbook in the field of land subsidence in 1984 (Gens, 1998). Unfortunately, research on this issue in Iran, was not comparable with the previous research around the world. Land subsidence has about thirty years of experience in Iran and if this phenomenon only occurred in some provinces such as Kerman and Yazd, now the provinces of Isfahan, Khorasan, and Tehran etc. are also suffering from land subsidence and this problem is glaring increasingly in more provinces. Exploited groundwater the only or the most important factor, or at least one of the main causes of land subsidence in all of land subsidence that occurs in Iran. Inappropriate extraction of groundwater caused a drop in groundwater levels and as a result, leads to the phenomenon of subsidence. Groundwater in Iran which is dry and desert is a great importance issue. The annual harvest amount is about 57.082 billion cubic meters of water from groundwater sources (according to 1993 statistics) show the importance of this valuable resource (Berardino et al., 2002). Therefore, groundwater is extremely important in Iran and shall use reasonable, economical and in short optimal. According above and many other reasons, subsidence due to groundwater extraction is one of the most important research areas in groundwater.

Mashhad plain

Mashhad plain (Figure 1) is part of Kashfrud river basin. This basin is located in north of Khorasan province, longitude 58 – 20' to 60 – 8' and latitude 35 – 40' to 36 – 3' and is limited from the north to the ridge of heights of Hezar-Masjed (Kappe Dagh), from south to Binalud heights and from western north to the basin of Atrak river, and from eastern south to the basin of Jamrud (Alizadeh, 2004).

The population of Mashhad city including nearby dependent towns were approximately 3.5 million people in 2003. Regarding to the predicted growth flow, the population of Mashhad would be 5.5 million people in 2016. On the other hand, due to health development in society, the average per capita consumption of water in this point (2003-2016) will be enhanced from 260 litters to 276 litters daily for every people, as well. Thus, the water annual requirement of Mashhad will be enhanced from 330 million cubic meters in 2003 to 560 million cubic meter in 2016. However, the production capacity of water for the city of Mashhad will remain constant, about 150 million cubic meters. Thus, up to the year 2016 about 400 million cubic meters shortage of water of this city shall be supplied by a prompt and sharp planning in various types (Khorasan Regional Water Organization Studies Unit, 1999).

To cite this paper: Amrouni Hosseini M. and Bayat H. 2014. Monitoring Land Subsidence of Mashhad Valley of IRAN Using Leveling, GPS Survey and InSAR Techniques. *J. Civil Eng. Urban.*, 4 (6): 562-567.
Journal homepage: http://www.ojceu.ir/main/

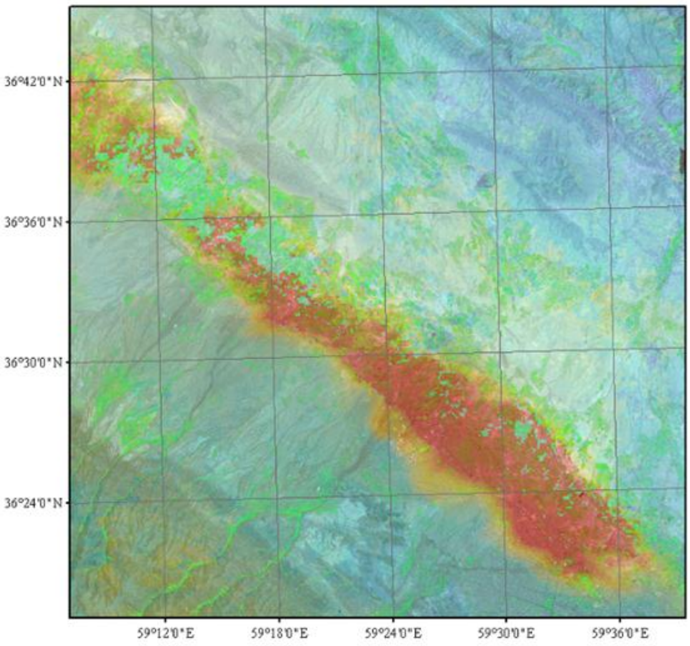

Figure 1. Mashhad plain

In a total conclusion about Mashhad plain and supplying potable water for Mashhad city that Figure 2 indicates, we conclude that in near future the citizens shall provide their potable water by buying water bottles from the stores. Municipal sewage system has a qualitative positive effect and quantitative negative effect on aquifer. The collected sewage enters into Kashfrud River none-purified and only its solid particles were purified, and in case of continuing its usage for near farming fields of treatment plants Parkand Abab and Olang will become barren fields. If the sewage is not purifying, the implementation of sewage network shall be ceased and for the shortage of Mashhad plain storage a fundamental thought is needed (Rum Engineering Services Company, 1998).

Therefore, the extra use of aquifer for farming and supplying the water for Mashhad city causes the emergence of subsidence in Mashhad plain and as a result, more investigations of subsidence and on time prevention from more subsidence of ground a necessary issue.

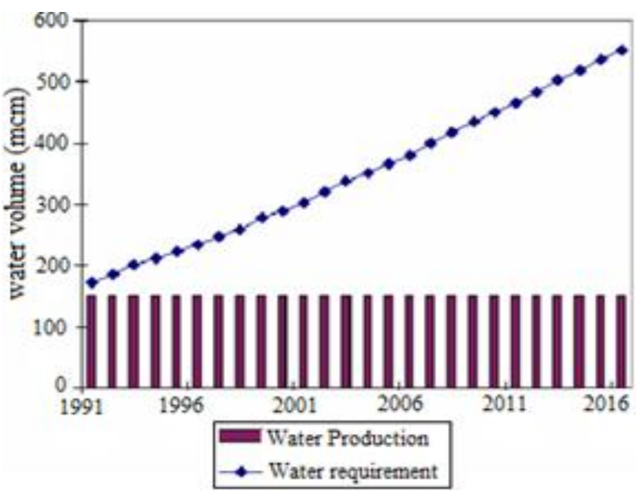

Figure 2. Water requirement of Mashhad plain till 2016 and production of Water requirement

MATERIAL AND METHOD

SAR Interferometry Method in Subsidence Monitoring

Interferometry Synthetic Aperture or InSAR is practical method for manifestation and measuring the movements of ground surface. In this technology, by using the mixture of obtained data from imaging systems of installed radar on the satellite platforms or airplanes, the movement, height and changes of earth surface will be surveyed (Khamechiyan, 1995). The basis of the work in measuring the movements of earth surface is by using repeated images of radar. The image which is taken from a region in a specific time will be merged with the image taken in another time by the same radar. By this technology, the movements, the changes due to phenomena such as earthquakes, volcanoes, glaciers, landslides and subsidence due to the exit of underground waters, oil and etc. can be studied (Khamechiyan, 1995).

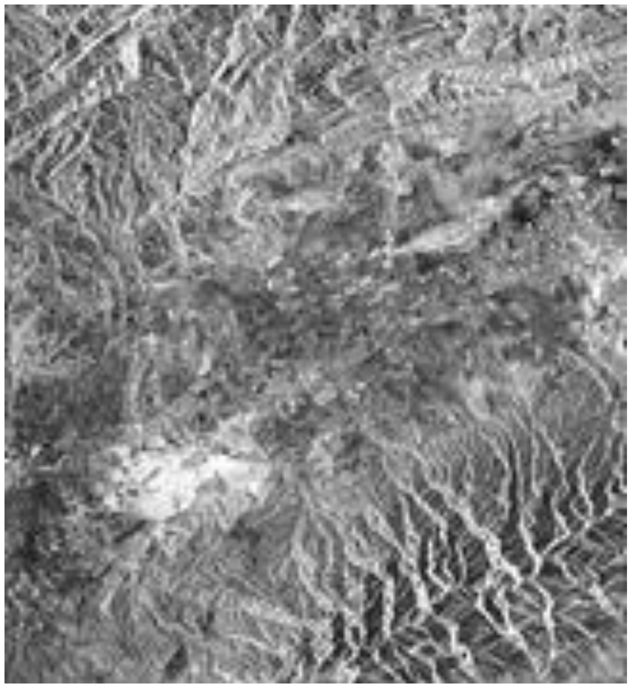

Figure 3. MLI picture of Mashhad palian

For evaluating the land changes of Mashhad plain InSAR technique is used. To achieve such target 10 images has been taken from ENVISAT ASAR between the years 2003 to 2005 which were provided by space agencies in Europe has been used. Figure 3which is taken, indicates Multi look image. Then, by using these 10 images and their circuit parameters 17 interferograms have been made. Figure 4 indicates the way of distribution of processed interferograms, the horizontal axis indicates the timeline basis and the vertical axis indicates the spatial-line basis of interferograms.

To reduce time incoherence, the images which had time distance less than 6 months has been used and also or reduction of the noise of basic line, the interferograms with smaller spatial basic lines have been processed. To obtain interferograms GAMMA software based on Linux is needed. First, unprocessed interferograms which has flat earth effects, topography and circuit errors and etc.

have been obtained. In next stage, for earth referencing and elimination of topography effect we shall use a DEM. In this stage, it is used SRTM_DEM with 90 m spatial resolution which covers region of imaging. To reduce the noise of interferograms without the topography effect, Goldstein Adaptive Filter has been applied. Reduction of noise is done to facilitate in Phase unwrapping (Gilli and Rius, 2000).

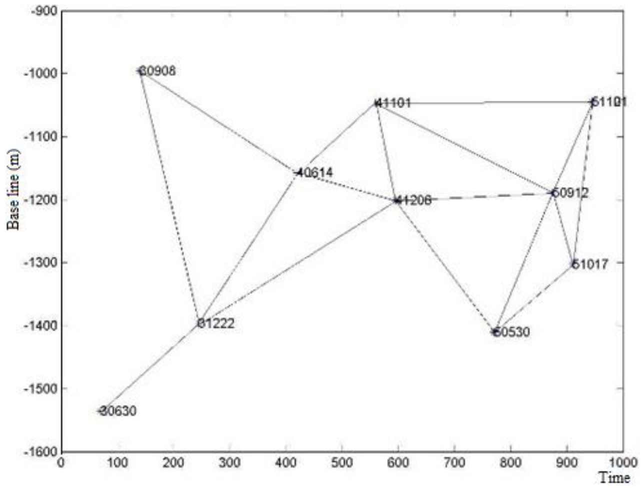

Figure 4. Distribution of Processed interferograms

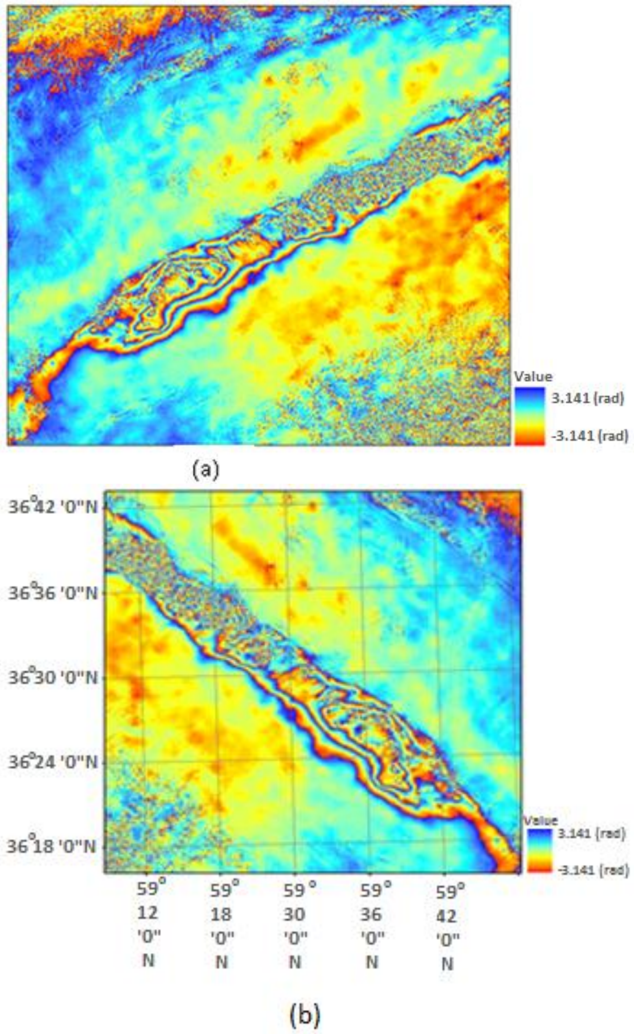

Figure 5. D14 interferograms in two states: (a) Movement fringes of d14 interferograms after applying filter, (b) D14 interferograms without topography effect

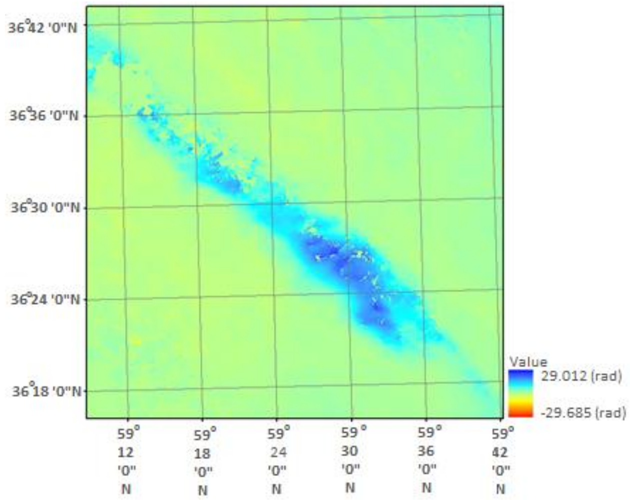

Figure 6. D14 interferograms after refining phase's action

Figure 5a indicates movement fringes of D14 interferograms after applying filter and Figure 5b indicates d14 interferograms without topography effect.

Figure 6 indicates d14 interferograms after refining phase's action. After processing interferograms the circuit errors shall be eliminated, to do so, minimum 4 points out of subsidence area, in an area without form change has been considered and from these 4 points a surface has been crossed and from the fraction of this surface from all interferograms, circuit error which is like a linear ramp and also atmosphere linear term will be eliminated (Gamma Software documentation).

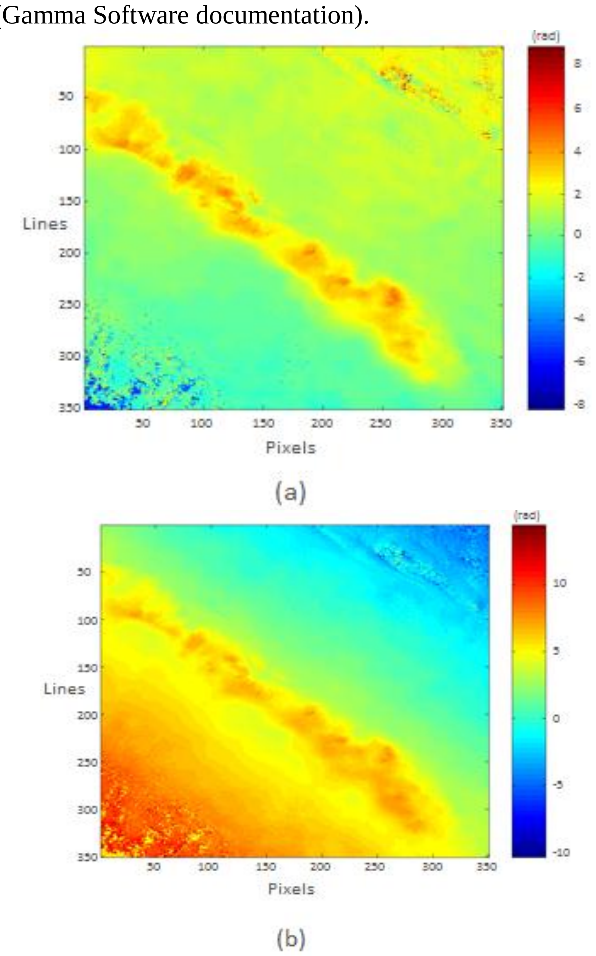

Figure 7. D8 inteferograms in two states: (a) after elimination of circuit error (b) before elimination of circuit error

To cite this paper: Amrouni Hosseini M. and Bayat H. 2014. Monitoring Land Subsidence of Mashhad Valley of IRAN Using Leveling, GPS Survey and InSAR Techniques. *J. Civil Eng. Urban.*, 4 (6): 562-567.
Journal homepage: http://www.ojceu.ir/main/

Figure 7 indicates inteferograms before and after elimination of circuit error. By starting from the first interferograms and adding next interferograms we can create a time series from total changes between the beginning time and the date of each image taking. Now, by using time series and 17 processed interferograms we obtain the amount of movement in each date comparing to the first image (in which the movement is considered zero). By using the obtained result from time series analysis mean displacement velocity map can be obtained that such map indicates the rate of movement according to time. Figure 8 indicates the obtained results from time series analysis.

As seen in Figure 8, the places that are dark blue have more displacement rate rather than the places which are light colours. From this map regions which have highest rates and lowest rates are determined. The highest displacement rate is about 20 cm per year.

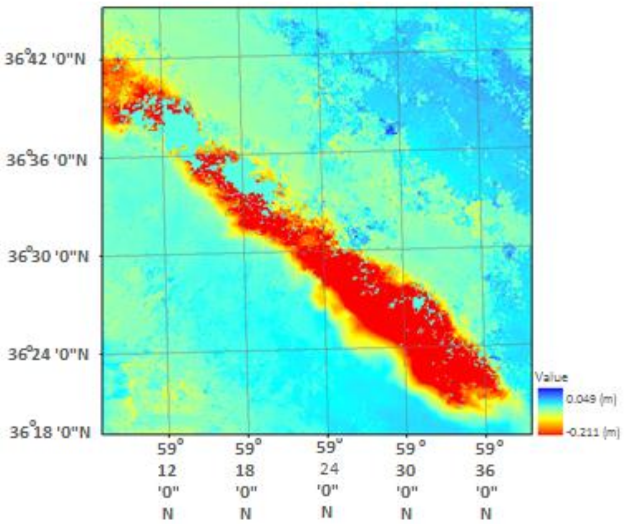

Figure 8. The average speed map

Using InSAR Results in Designing Optimal GPS Network

The results of InSAR only indicate displacements in the radar line of sight. Since, the sight angle of the small radar is 23 degree and also the highest rate of displacement is due to vertical subsidence phenomenon, it can be said that the displacement in the line of sight of radar is almost the same as vertical one, as a result, horizontal displacement which is very low comparing with vertical one cannot be determined from InSAR results. Therefore, in order to measure the rate of horizontal displacement we can use GPS observations. So, for achieving complimentary information from rates of subsidence and better surveying of subsidence, by using vertical and horizontal displacement a GPS network with the help of map, the average speed of displacement has been designed. Points which have the highest rates of subsidence due to time interval between two period of GPS observation with displacement indicators are significant changes of X, Y and Z. to enhance the strength of 3 pointed network out of subsidence area, means considering an area in which it has no change and also 3 points inside the subsidence area means, the areas which have the highest displacement rate and also in edges and margins of the subsidence area which has the highest horizontal displacement rate has been located (Gareth et al., 2005). This network has been designed for obtaining horizontal components of subsidence area.

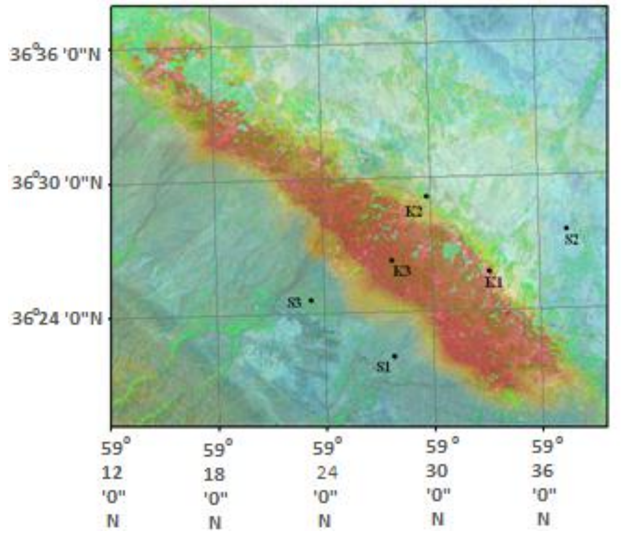

Figure 9. GPS network matched with the average speed map (K points are inside and S points are outside of the subsidence area)

Figure 9 indicates planned GPS network matched with the average speed map. So, after consideration of points in areas with highest horizontal and vertical displacement rates caused the optimization of the number of network points and obtaining the most information from the studied area and as a result causes optimization of GPS costs, because, by adding a point to the points of GPS its cost goes up exponentially. Also, designing network in the forms of 2 rectangle networks with 2 diameters will enhance reliability of the network for accuracy and strength.

RESULT AND DISCUSSION

Comparing the Results of InSAR with GPS And Accurate Balancing

In order to evaluate the results of InSAR from the GPS data and precise levelling data has been used. GPS data have been read by National Cartographic Center in Toos station from 1.1.2005 and the observations have been collected continually within 24 hours of a day. For evaluating InSAR data the read observations of GPS between 1/1/2005 to 10/6/2006 have been considered. Figure 10 indicates data related to Z component of Toos station GPS to 1/10/2005. In this Figure, it is observed that during 10 months the changes of Z component were extremely high and also can conclude that the changes of earth surface due to subsidence is extremely descending and does not face seasonal fluctuations.

By comparing obtained Toos station displacement data from InSAR with Toos station displacement data obtained from GPS in the radar line of sight, it is determined that the displacement data obtained from GPS and InSAR are almost similar (Figure 11).

In order to quantitative comparison of GPS and InSAR the quantity Root Mean Squared Error between GPS and InSAR data have been measured 0.008 meter. By taking a glance at the evaluated quantity we can

To cite this paper: Amrouni Hosseini M. and Bayat H. 2014. Monitoring Land Subsidence of Mashhad Valley of IRAN Using Leveling, GPS Survey and InSAR Techniques. *J. Civil Eng. Urban.*, 4 (6): 562-567.
Journal homepage http://www.ojceu.ir/main/

understand that the InSAR results are highly matched with GPS data and their difference is less than a centimetre.

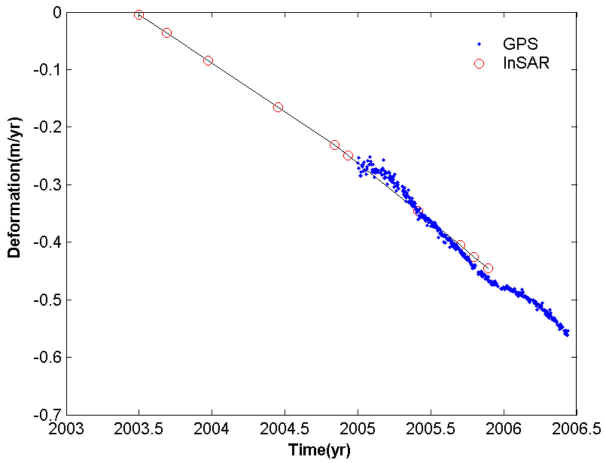

Figure 10. Data Toos station GPS data between 1/1/2005 to 1/10/2005.

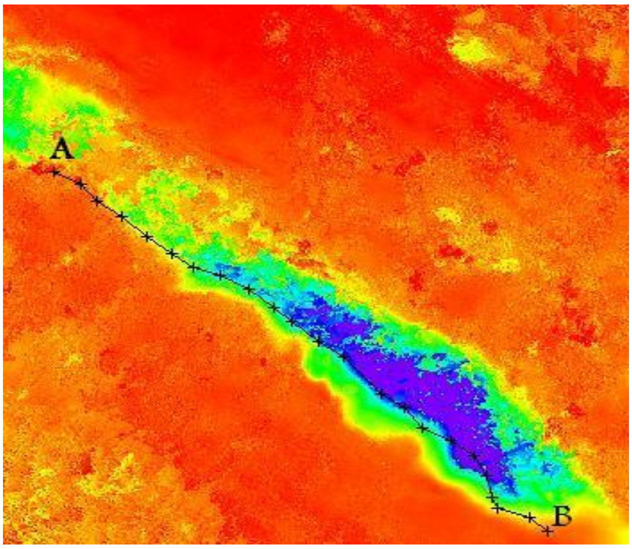

Figure 11. Display of correspondence data from InSAR with Toos station

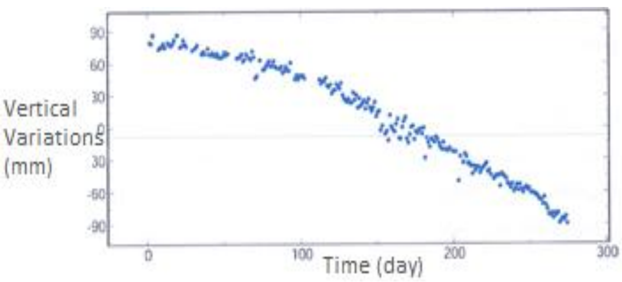

Figure 12. Location of precise leveling crossed beside the subsidence area

This issue indicates that the existing errors in InSAR including atmosphere error, re-finding phase error and etc. are highly adjusted. In the next step for validation and evaluation of InSAR data, precise levelling data have been used. Precise levelling data are collected in 3 epochs in years 1994, 2002, and 2005.

Figure 12 indicated the location of precise levelling crossed beside the subsidence area. Between these 3 epochs, two epochs of 2002 and 2005 which had most time overlaps with InSAR data have been chosen. The comparison of results out of InSAR data and accurate levelling indicated a very good similarity between these couples.

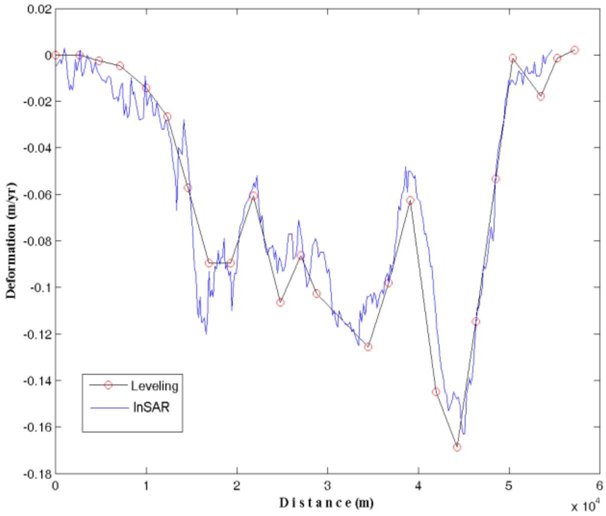

Figure 13. Display of correspondence between InSAR data and accurate levelling

Figure 13 indicate the comparison between InSAR data and accurate levelling, it is necessary to mention that the accurate levelling information are imaged like GPS data in the radar line of sight. According to what the figure indicates, the subsidence pattern in InSAR data and accurate levelling are very similar and eventually in order to do quantitative comparison of accurate leveling and InSAR, the RMSE quantity have been measured and is result were 0.011 meter.

From the comparison of InSAR results with accurate levelling and their very good correspondence to 1 centimetre, we can understand that the flat pattern and height pattern of subsidence which have been taken from InSAR data are well matched with the ground truth.

Good correspondence of InSAR with GPS and accurate levelling manifest such idea that in many case for studying subsidence areas we can use InSAR instead of GPS which is more expensive and time consuming and also utilizing the high advantage of the spatial resolution of InSAR, the other two method are in lack of such advantage.

CONCLUSION

GPS technique is able to measure the changes of ground's surface continues in time with High temporal resolution. But these techniques are able to measure the changes only in limited numbers of places which are those GPS stations .On the other hand, InSAR technique will measure the made changes in ground surface in a certain area in a continues high spatial resolution coverage . In this research by using InSAR Time series analysis and using remarkable number of Interferograms changes in surface derived from subsidence continuously monitored in wide spatial coverage. Average velocity displacement map that represents the displacement rate in the region is gained using time series results. This map makes clear the areas with high and low replacement rate. Through this map, Maximum displacement rate per year was estimated 20 cm. From results of the time series analysis of deformation it indicated that, Earth is in subsidence with relatively constant rate, while remarkable Seasonal effects is not observed the trends of changing of the surface .this will verifies that Underground water bed (Aquifer) cannot be adequately fed in season rainfall. Toos and GPS Precise leveling with continue measurement of InSAR station were obtained and then the results were compared and this comparison showed that InSAR results is consistent greatly with results of GPS and precise leveling.

REFRENCES

Alizadeh, A. (2004). Studies of mathematical model of Mashhad plain. Khorasan Regional Water Organization Studies Unit.

Berardino, P., Fornaro, G., Lanari, R., & Sansosti, E. (2002). A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. Geoscience and Remote Sensing, IEEE Transactions on, 40(11), 2375-2383.

Gamma Software documentation.

Funning, G. J., Parsons, B., Wright, T. J., Jackson, J. A., & Fielding, E. J. (2005). Surface displacements and source parameters of the 2003 Bam (Iran) earthquake from Envisat advanced synthetic aperture radar imagery. Journal of Geophysical Research: Solid Earth (1978–2012), 110(B9).

Gens, R. (1998). Quality assessment of SAR interferometric data. ITC.

Gili, J. A., Corominas, J., & Rius, J. (2000). Using Global Positioning System techniques in landslide monitoring. Engineering Geology, 55(3), 167-192.

Khamechiyan, M., (1995). Study on Geotechnical and Geoenriromental Aspects of land subsidence due to withdrawal of Ground water. PhD. thesis، Saga University, Sapan.

Khorasan Regional Water Organization Studies Unit, (1999). Water balance of Mashhad Plain examples.

Lanari, R., Lundgren, P., Manzo, M., & Casu, F. (2004). Satellite radar interferometry time series analysis of surface deformation for Los Angeles, California. Geophysical Research Letters, 31(23).

Rum Engineering Services Company, 1998, Comprehensive plan to provide drinking water for the city of Mashhad in 2021, along with the proposed funding - Water in Mashhad