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Mashhad Subsidence Monitoring by Interferometric Synthetic Aperture Radar Technique

M. Khorrami[1], S. Abrishami[1*] , Y. Maghsoudi[2]

[1] Department of Civil Engineering, Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

[2] Department of Photogrammetry and Remote Sensing, Faculty of Geodesy and Geomatics, K.N. Toosi University of Technology, Tehran, Iran

ABSTRACT: Deep groundwater withdrawal in Mashhad, one of the largest municipalities in Iran, caused severe land subsidence. Land subsidence in this area can be destructive for urban infrastructures and can create serious environmental issues and structural damages. The main aim of this research is to precisely determine the vertical ground deformations in Mashhad to evaluate and compare the current situation with the previous reports on this area. For this purpose, we have applied Persistent Scatterer Interferometric Synthetic Aperture Radar technique to complement previous works by using more accurate data and procedure in the interested urban area. Furthermore, we considered geotechnical properties which were not focused in the previous studies. For this purpose, 69 descending and ascending C-band radar images, provided by relatively high-resolution Sentinel-1A satellite, were used to estimate the deformation-trend. The method was applied to the images from October, 2014, to February, 2017. The assessment procedure demonstrated a high-rate of subsidence in northwest of Mashhad with the significant deformation of 140 mm/year. The outputs were validated using in-situ measurements data and hydraulic head variations respecting piezometric data extracted from groundwater wells. Subsequently, the geotechnical properties of the chosen area were considered to interpret the results. The results of this study illustrated that the land subsidence in the case study is brutally continuous in most areas and there is no sign of decrease in the amount of deformation rate.

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1. INTRODUCTION

Groundwater overextraction has been dramatically increased in many regions around the world which caused land subsidence as one of the geological hazards [1]. For instance, from literature [2-6], it is reported that a number of cities and valleys in Iran have been experiencing a high subsidence rate. So, in the present study, we focused on measuring the subsidence in Mashhad during the recent years to complement the previous studies [2, 3, 7, 8] in this area.

There are several methods to measure the land deformations and among them, Synthetic Aperture Radar Interferometry (InSAR) is proven as a powerful method to map displacements of terrain and urban areas. This method is more advantageous than such geodetic techniques as leveling and GPS because it can effectively provide an opportunity to retrieve extensive land movements data [9, 10].

This work presents the results of Persistent Scatterer Interferometric Synthetic Aperture Radar (PSInSAR) analysis obtained by the exploitation of radar data provided by Sentinel-1 archives from October, 2014, to February, 2017, to monitor land subsidence in the interested area. The previous studies on Mashhad valley only analyzed agricultural regions indicating Mashhad aquifer is subsiding with the maximum annual rate between 15 and 25 cm. It should be noticed that these researches did not considered urban areas and also did not used a sufficient number of SAR images to achieve an appropriate accuracy. In the present research work, we have studied the subsidence in Mashhad urban area using 69 Sentinel-1A radar images using PSInSAR technique.

2. STUDY AREA

In this paper, we have studied the subsidence in the city of Mashhad, a megalopolis in Iran located in the Khorasan-Razavi province with semi-arid and arid climate.

During the last decades, groundwater has been a main resource of water supply in Mashhad. Insufficient natural recharge and groundwater withdrawal, because of the city expansion, population growth and tourism industry, has resulted in reduction of water table level and land subsidence.

Investigating geotechnical properties in Mashhad showed that the soil texture in the south and southwest is mostly coarse-grained. It gradually changes to silt and clay toward north and east which can consolidate gradually with groundwater extraction and insufficient recharge.

*Corresponding author's email: s.abrishami@um.ac.ir

3. METHODOLOGY

The previous studies did not consider the Mashhad urban areas and also did not use a sufficient number of radar images as an important factor in achieving more accurate outputs. Thus, in the present work we have collected 35 ascending and 34 descending C-band radar images, provided by Sentinel-1A. Then we have implemented PSInSAR analysis [11] as a powerful processing technique for mapping vertical deformation in urban areas. For this purpose, SAR images of the same area are the prerequisite. Then, one single master acquisition is chosen based on the measured baselines in time and space to achieve an appropriate coherence in interferograms. The final calculations are on the basis of phase estimation which depends on some factors forming the following equation [12].

$$\Delta\varphi_{pq}^{ij} = \Delta\varphi_{Flat} + \Delta\varphi_{Height} + \Delta\varphi_{Disp} + \Delta\varphi_{Atmo} + \Delta\varphi_{Noise} \quad (1)$$

Where the first term is related to earth curvature, the second term is related to the DEM error, the third term resembles the linear displacement velocity, the next term is related to the atmospheric phase delay, and the last one is related to the noises.

In the process of PS selection, each pixel was chosen based on the condition called amplitude stability index. It should be noted that it is assumed that the ground displacement rate is linear.

After the initial SAR analysis which resulted in a map showed Line Of Sight (LOS) deformations, we combined the two separate outputs, from ascending and descending images, to obtain the vertical deformation (subsidence). Finally, to interpret and validate the outputs, we collected groundwater level data and GPS information.

4. RESULTS AND DISCUSSION

The results displayed the average velocity map of ground subsidence in the studied area, from October 2014 to February 2017. It can be noticed that the results of both ascending and descending data analysis are in good agreement. Also, from extracted maps, it can be obtained that northwest of Mashhad is experiencing a high rate of settlement with the maximum annual rate of 14 cm. The deformation pattern over the interested area, also, shows low amounts of uplift in east of Mashhad.

To compare and validate the outputs of PSI analysis, we considered all GPS stations neighboring Mashhad, which showed a good agreement exists between them. It should be noted that there are insufficient number of GPS stations to map the land displacements in this area. The fluctuations in GPS results referred to such factors as seasonal effects and the instrument inherit error. These are the GPS disadvantageous compared to the SAR analysis.

From the previous researches and reports on Mashhad, groundwater withdrawal has caused the reported subsidence in Mashhad. Therefore, we collected the piezometric data to measure the effect of water level variations on the settlement in the interested area. Comparing the ground water level data and PSInSAR results displays that the vertical displacements obtained from the PS analysis agrees well in both magnitude and trend with vertical displacements measured along the Mashhad-Qouchan highway in the period, 2014-2017.

5. CONCLUSION

The main aim of this study was to investigate the current situation of subsidence rate in the city of Mashhad to complement the previous researches. For this purpose, interferometric analysis of space-borne Sentinel-1A SAR was applied to determine ground settlement in the case study. Then, piezometric data and the information provided by GPS stations were also analyzed to interpret the results.

Hence, the main conclusions of this work are as follow.

1. Subsidence rates in northwest of Mashhad are mostly linear with the maximum annual rate of 14 cm.

2. The results indicate that the subsidence area is moving from the northwest towards the city center, and it may have irreversible consequences in the future.

3. The deformation pattern over the area, displays low amounts of uplift in east of Mashhad.

4. The groundwater level has been decreasing in the areas with the maximum subsidence rate. The relation between water level variations and subsidence depends on the soil type in each region.

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