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Investigating the Effect of Aquifer Water Table Variation on the Subsidence Phenomenon and Balancing Strategies of the Aquifer (Case Study: Ali-Abad Plain, Qom)

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ABSTRACT: Ali-Abad Plain of Qom Province, located in the center of Iran, is among the areas recently affected by the subsidence phenomenon due to water overexploitation. In this research, using the differential radar interferometry and Sentinel-1 images, vertical land deformation was monitored for 18 months from March 2015 to September 2016. The results showed maximum subsidence of 240 mm. Moreover, it was found that subsidence in this plain is a progressive and continuous phenomenon with an almost constant spatial distribution. Next, groundwater table fluctuations were measured in Saveh Plain for 14 years ranging from September 2002 to September 2016. The results showed a maximum water table decline of -44 m. Comparison of the ground deformation map with groundwater level fluctuation map revealed a direct relationship between spatial distribution and ground deformation intensity and groundwater drop. In addition, comparing the alluvium thickness variations with ground deformation indicates that the alluvium thickness of the Ali-Abad Plain varies from 20 m in its eastern part to 300 m in the western and central areas. The results do not show any significant relationship between these two parameters in the study area. Moreover, it was found that layering type and the presence of thick fine-grained formations are among other factors affecting the intensity and rate of subsidence in the plain. Regarding the direct relation between groundwater table fluctuations and subsidence rate in the study area, the water yield of the plain showed an annual deficit of 88.17 million cubic meters. Investigating the exploitation resources and the consumption type of groundwater resources in the study area showed that above 98% of the water extraction from the aquifer is through the wells, of which 92% is consumed for agricultural purposes. Hence, exploitation management of the wells, control of illegal exploitation, and revision of cultivation and irrigation are among the major strategies for restoration and balancing the groundwater resources in the study area.

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1- Introduction

Over-pumping of groundwater increases the effective stress in the aquifer system. Changes in the effective stress also, in turn, cause the accumulation of fine sediments, and consequently, the aquifer system subsidence [1]. The phenomenon of land subsidence, if not properly managed to restore and balance the groundwater resources, can provide irreparable damages. Groundwater restoration and equilibrium refer to all activities aimed at improving the quality and quantity of groundwater aquifers and controlling groundwater levels and preventing its continued decline in the plain [2]. The first step in managing and controlling the subsidence phenomenon is to accurately identify the subsidence points and determine the annual rate of the subsidence. Radar interferometry is a useful tool for remote sensing. This technique measures ground surface displacement with accuracy that is comparable to precise leveling measurements and the positioning system [3]. Ali-Abad Plain, located on the border between the provinces of Qom and Central (Central Iran), has been involved in the phenomenon of subsidence in recent years. Signs such as protruding wells and slits in the plain margins can be attributed to this phenomenon. In the present study, using remote sensing technology and geographic information system, the subsidence status in the Ali-Abad region and the influence of groundwater fluctuations and geological formations on land surface changes are investigated. Accordingly, in this paper, after presenting the geological and hydrological features of the study area, the relationship between spatial distribution and subsidence intensity over the 18 months (March 2015 to August 2016) and groundwater changes is investigated.

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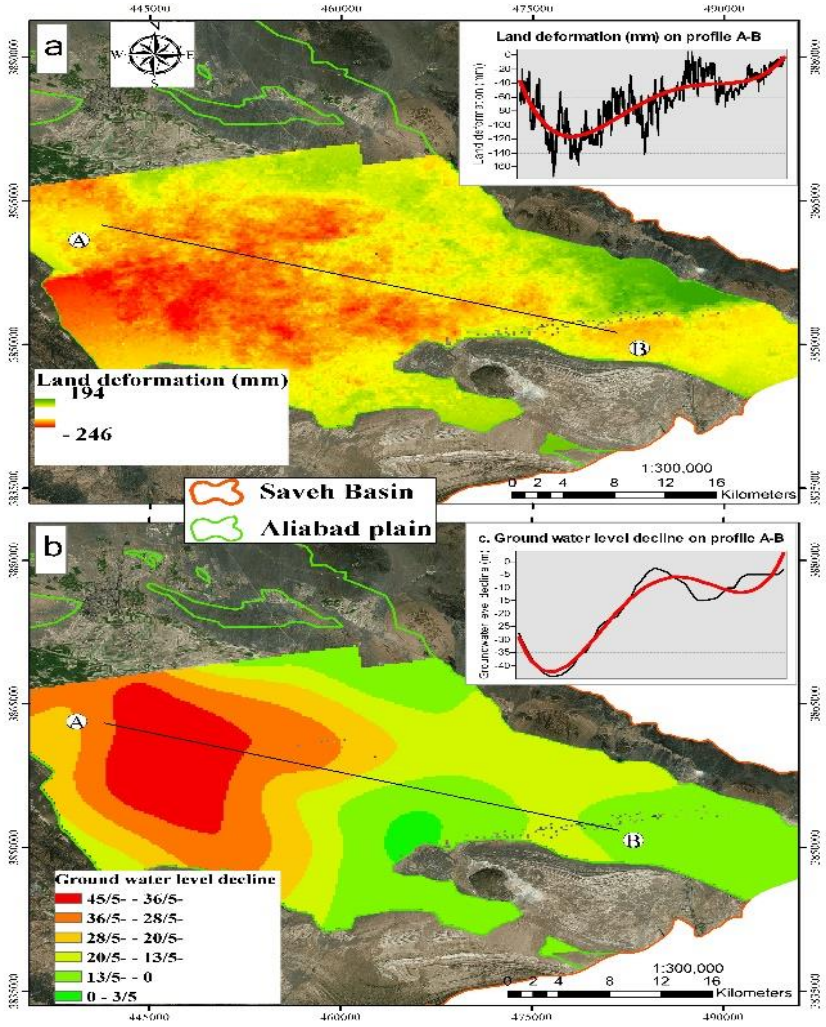

Fig. 1. (a) Ground deformation map and graph of landform changes on A-B profile over the total study period (tTotal), (b) Groundwater level change map and graph of changes in A-B profile over the inter-annual period of 2002 to 2016 in Ali-Abad Plain

2- Methodology

The study area, Ali-Abad plain, is part of the Saveh basin and is located in Qom and central provinces (located in central Iran). Radar interferometry, because of its large coverage, low economic cost, and high accuracy in large areas, is one of the most suitable options among the subsidence monitoring and land deformation determining methods. For this purpose, Sentinel 1 satellite images were used in this study. In this study, the land subsidence in Ali-Abad Plain was investigated using radar image processing over 18 months (March 2015 to August 2016) (t_{Total}). Monitoring was also conducted at 4 time- intervals between March 2015 and August 2016 (t_1 to t_4) to evaluate the impact of study duration on the results of ground deformation. In this research, ENVI software and Sarscape plug-in [5] have been used to exploit raw data and satellite images. Other inputs include the map of groundwater level changes in the Saveh plain from October 2002 to August 2016 and the values of the mechanical parameters of the geological formations in the various layers of boreholes.

3- Results and Discussion

Based on the results of radar interferometry analysis using the Sentinel 1 sensor, Ali-Abad Plain experienced maximum ground subsidence of 246 mm during the 506-day study period. Besides, the maximum subsidence values in the four studied periods (t_1 to t_4) were 171, 143, 142, and 104 mm, respectively. The ground deformation raster map for the total studied period (t_{Total}), along with the raster map of groundwater level changes for 2002 to 2016, is shown in Fig. 1. Accordi 3.Results and Discussion ng to the figure, the spatial distribution of subsidence areas corresponds to the locations that experienced the greatest reduction in groundwater levels. To illustrate the relationship between these two effects, the diagram of the ground deformation compared to groundwater level decline in profile A-B, is shown in Fig. 1. The fitting curves of the two graphs (red line in Fig. 1a and b) have the same trend, with the highest subsidence occurring in the A-B profile where the greatest amount of groundwater level decline has occurred.

Table 1. Groundwater balance of the Ali-Abad Plain alluvial aquifer (million cubic meters per year)

Aquifer name	Balance Area (km^2)	Recharge volume						Discharge volume					Storage volume changes
		Input groundwater flow	Aquifer surface rainfall intrusion	Surface water flows intrusion	Agricultural water intrusion	Drinking and industrial water intrusion	Total recharge	Well, aqueduct, and spring discharge	Drainage	Aquifer evaporation	Transfer and underground output	Total discharge	
Saveh	1632.8	87.46	44.31	109.27	246.02	34.31	521.37	564.46	0	0	45.05	609.54	-88.17

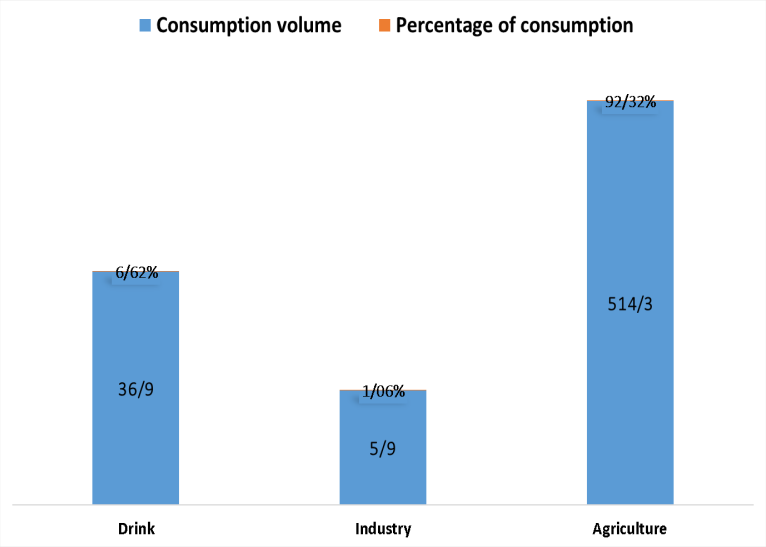

Fig. 2. The type of water consumption from the groundwater resources of Ali-Abad Plain

Table 2. Groundwater exploitation resources in Ali-Abad Plain (million cubic meters per year)

Resource type	Number	Discharge	Percent
Well	1334	557.10	98.69
Spring	2	0.06	0.01
Aqueduct	18	7.3	1.30
Total	1354	564.46	100

Regarding the direct relation between ground subsidence and groundwater depletion in Ali-Abad Plain, in another part of this study, the groundwater balance of the alluvial aquifer of this plain was investigated. The results of groundwater balance including the volumes of recharge and discharge components of the aquifer as well as the volume change of the alluvial aquifer storage are presented in Table 1. According to this table, the total volume of aquifer recharge and discharge components was 521.37 and 609.54 million cubic meters per year, respectively, which confirms the aquifer storage deficit of 88.17 million cubic meters per year. Groundwater exploitation resources of Ali-Abad Plain aquifer, based on observational wells statistics in Qom province, are shown in Table 2. As shown in the table, more than 98% of Ali-Abad Plain aquifer is exploited from wells in this area, and springs and aqueducts account for a small percentage. Fig. 2 illustrates the type of exploited water from the Ali-Abad aquifer, based on the statistics of the wells. According to Fig. 2, a total of 557.10 million cubic meters per year of groundwater is extracted from Ali-Abad Plain wells. More than 92 percent of this amount (514.3 million cubic meters) is used for agriculture, 7 percent for drinking water, and 1 percent for industry.

4- Conclusion

The study of the ground deformation at different time intervals also shows that the subsidence in this region is a continuous phenomenon with a relatively constant spatial distribution. The results show that there is a direct relationship between these two factors in the study area. Besides, the studies show that the type of stratification and existence of layers including fine-grained thick formations are other influential factors on the intensity and rate of subsidence in the Ali-Abad Plain. The results of the groundwater balance survey of the Ali-Abad Plain aquifer revealed 88.77 million cubic meters of aquifer storage deficit per year. Groundwater exploitation resource survey of Ali-Abad Plain showed that organizing well utilization and control of unauthorized exploitation should be prioritized in updating the water resources balance plans. Also, considering that 92% of the plain groundwater is consumed in agriculture, a revision of the cultivation and irrigation pattern is recommended as the next necessary measure in restoring and balancing the groundwater resources of Ali-Abad Plain.

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