

Land Subsidence Assessment in Isfahan-Borkhar Plain Using Radar Data and Create Land Subsidence Potential Map Using Combination of Analytical Hierarchy Process (AHP) With Fuzzy Logic in GIS Environment and Multiple Linear Regression Models

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Abstract

In recent decades, due to population growth and necessity of food and job production, special attention has been given to the expansion and development of agriculture and the construction of several industrial zones in the vicinity of large and populous cities. On the other hand, because of the decrease in precipitations and deficiency in surface water resources, groundwater resources have been extracted through drilling wells in order to supply agricultural and industrial water. In Isfahan-Borkhar Plain, the number of deep and semi-deep wells has increased from a few hundred to more than 6,000 wells over the past forty years. This has led to a drop in water level with an annual average of about one meter. The continuous drop in groundwater level in susceptible areas had led to land subsidence. In this research, the amount of subsidence occurred in Isfahan-Borkhar Plain during the years 2014 to 2017 was determined by using Radar images and the factors affecting subsidence and the impact of each of them on the amount of subsidence was investigated. Furthermore, a combination of Analytical Hierarchy Process (AHP) with fuzzy logic in GIS environment and Multiple Linear Regression models was used to create Land Subsidence potential map of the area. According to the results obtained from the interferometric method, the subsidence occurred in the study period was measured at a maximum of 11 cm per year. Comparison of the results obtained from the Analytical Hierarchy Process and the linear regression method shows the greater efficiency of the linear regression method in calculating the subsidence potential.

Key Words: *Land Subsidence, Interferometry, Time Series, Multiple Linear Regression, AHP, Fuzzy Logic.*

Extended Abstract:

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1. Introduction

The term land subsidence refers to the gradual or sudden sinking of a part of the Earth's surface, which occurs when vertical displacement takes place during subsidence (Galloway & Burbey, 2011). Causes of land subsidence include subsurface dissolution of some Earth-building materials (such as salt, carbonates, etc.), subsurface mechanical erosion, lateral flows, land compaction (due to loading, drainage, and groundwater extraction), and tectonic movements (Poland, 1984).

Groundwater extraction plays a direct role in land subsidence due to the compaction of aquifers. Land subsidence resulting from the extraction of underground fluids is one of the well-known reasons for the occurrence of land subsidence. Land subsidence can lead to damage to existing infrastructure in an area, such as buildings, roads, railways, and significant damage to aquifers (Galloway & Burbey, 2011).

The Esfahan Basin aquifer area includes important population centers, extensive agricultural lands, numerous historical sites, and major infrastructures such as refineries, power plants, industrial zones, etc. The increasing use of underground water resources for drinking water supply, industry, and agriculture has led to a severe decline in groundwater levels due to reduced annual precipitation. In many areas within this region from the southeast (Esfahan Airport) to central areas (Ashghabad neighborhood), land subsidence features such as building cracks are visible. All these factors highlight the importance of studying land subsidence in this region and emphasize the need to identify influencing factors and measure the extent of subsidence that has occurred in past years.

The use of Interferometric Synthetic Aperture Radar (InSAR) as one of the most common methods for measuring land subsidence is well-known and widely used in research related to this phenomenon (Dehghani et al., 2013-2; Dehghani et al., 2013; Chaussard et al., 2013; Raucoules et al., 2013). Although traditional InSAR methods have the capability to estimate relatively accurate levels of subsidence in large-scale areas over long time scales, the use of time series for examining subsidence behavior on short-term time scales has become widespread (Dehghani et al., 2009). In this study, using 33 available Sentinel-1 satellite images for the study area from October 27, 2014 to February 18, 2017, the amount of subsidence that occurred was determined and the annual subsidence rate was calculated using a time series algorithm.

To identify potential subsidence areas in the region, a combination of Analytical Hierarchy Process (AHP) and fuzzy logic analysis in GIS environment along with multiple linear regression method was used to prepare a subsidence potential map. Finally, the results obtained from combining AHP and fuzzy logic analysis methods with measured subsidence values from radar images were compared.

2. Materials and methods

In this study, the amount of subsidence in the region during the years 1393 to 1395 and in specified short time intervals was determined using interferometry method. Additionally, a time series method was used to determine the long-term subsidence behavior. In the next step, to determine the areas with subsidence potential and using parameters affecting subsidence, a hierarchical-fuzzy analysis method and multiple linear regression method were used.

To study subsidence in the Esfahan-Borkhar Plain, 33 Sentinel-1 satellite images were used within the time frame of October 27, 2014, to February 18, 2017. Using the GMTSAR software, 45 differential interferograms with a short temporal and spatial range were generated from these images.

The results of the time series analysis include a map of the average subsidence rate, which represents the long-term subsidence behavior. From this map, the annual subsidence rate can be extracted for each pixel. Based Time series results, the maximum subsidence value in the region are estimated to be 11 centimeters per year.

In the next step, after standardizing the criteria and placing all values between zero and one, the map of parameters is multiplied by the coefficients obtained from the hierarchical analysis method. Finally, using fuzzy logic and the Fuzzy Overlay tool and the OR operator in GIS software, the criteria are combined together, and the final map of subsidence potential in the area is obtained.

In the next step, considering the measured subsidence by radar images as the dependent variable and six effective parameters as independent variables, using multiple linear regression in SPSS software, coefficients between independent variables and dependent variables are determined. The general relationship between the dependent parameter and independent parameters can be shown as equation number 5:

$$S = 742 + 0.112WLC + 0.112FP - 0.059AD + 0.00000139HC + 0.00000108SC - 0.207WW$$

In this equation:

S: Subsidence

WLC: Water level changes

FP: Fine sediment percentage

AD: Water depth

HC: Hydraulic conductivity

SC: Storage coefficient

WW: Groundwater level depth

After determining the coefficient of each variable, in a GIS environment, the map of each parameter is multiplied by its corresponding coefficient, and the potential subsidence is obtained.

3. Results and Conclusion:

In this study, land subsidence in the Isfahan-Borkhar aquifer area was investigated in the time period of 1393-1395. The annual subsidence rate in the region was calculated by determining the amount of subsidence that occurred in this time period using radar images and interferometry method, through the analysis of time series and short-time baseline interferograms. The highest annual subsidence rate was estimated to be 11 centimeters per year in the Isfahan-Borkhar plain area. The highest amount of subsidence was observed in the central, southwest, and southeast regions of the aquifer.

By using effective criteria in subsidence and combining the AHP method with fuzzy logic and their integration as well as multiple linear regression model, a subsidence vulnerability map of the region was extracted. According to both methods, variables such as groundwater level decline and percentage of fine sediments will have a greater impact on subsidence occurrence compared to other

variables. Additionally, based on the root mean square error, correlation coefficient, and mean absolute percentage error determined, the subsidence vulnerability level determined by the multiple linear regression method shows better consistency with the measured subsidence amount from radar images compared to the hierarchical analysis method.

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