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Land Subsidence Vulnerability Assessment of Rural Settlements in Fars Province

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Abstract

Purpose- Land subsidence is caused by natural factors and human activities around the world. Fars Province, located in the south of Iran, is subject to land subsidence due to the uncontrolled exploitation of groundwater, causing damages to the population and human settlements and also environmental, social and economic areas.
Design/methodology/approach- The present research is descriptive in terms of describing land subsidence in the case study region, whereas it is also analytical as time series analysis techniques based on Radar Interferometry (InSAR) is applied to monitor temporal changes in subsidence in Darab and Fasa Plains, including 470 rural points. Using 8 ENVISAT ASAR images spanning between 2005 and 2010, nine Interferograms were processed. In the study area. Geographic Information System (GIS) is then used to study groundwater level decline at the well locations in a 24-year period (from 1991 to 2015).
Findings- The results of the research confirm that there is a significant correlation between groundwater water level decline and land surface subsidence. Time series analysis of the processed Interferograms indicate the mean displacement velocity map, demonstrating the maximum subsidence rate of 25 cm/yr. The InSAR analysis reveal within the study area subsidence rate of 25 cm/year in 24 years period and locally exceeding 30 cm/yr in the last decade. This area of significant subsidence is limited in its spatial extent to the agricultural land and is partly influenced by the large-scale over-exploitation of groundwater resources in the region study. The temporal and areal relationships of subsidence and groundwater level data suggest that a significant part of the observed subsidence in the Darab region is caused by intense groundwater extraction which has led to widespread compaction within the upper parts of the up to 300m. Socioeconomic analysis and the subsidence hazard map show that 105523 people are generally at risk of subsidence, of 65068 who are at high risk. In addition, there are 2679 socioeconomic infrastructures such as public service at risk of damage by land subsidence.
Research limitations/implications- Limitation in In SAR data access, especially for long-term data was one of the main limitations in land subsidence research and also in this research.
Practical implications- Integrated water resource management and the observed extraction of groundwater could influence the subsidence rate in the regions exposed to land subsidence.
Originality/value- This research will be important to provide vulnerability in regions with groundwater overexploitation.
Key words- Vulnerability, Land subsidence, Socio-economic consequences, Radar interferometry.
Paper type- Scientific & Research.

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1- Introduction

Natural hazards annually threaten people's lives in all around the world including Iran. Actions taken in order to reduce the risk will protect the lives. Communities, government officials and development organizations can minimize the risk of these crisis by understanding and predicting the future consequences of hazards (Thomas & Anderson, 2005). Due to its proximity to the underlying substances as a threat to infrastructures and center of human activity on one hand and its vulnerability due to the lack of planning on the other hand, this phenomenon is considered as a concern.

Land subsidence caused by over-exploitation of groundwater is one of the natural hazards with devastating consequences in all around the world including Unites States of America, Japan, Italy, Thailand and Indonesia (Larson, Bas Agaoglu & Marino, 2001). Large cracks and fractures on the ground surface caused by land subsidence are considered as its consequences. Moreover, land subsidence causes significant changes in the earth's hydrologic properties such as the direction and speed of the groundwater flow (Holzer & Galloway, 2005). Other subsidence consequences also include damage to engineered structures such as buildings, roadways, pipelines and well casings. The areas with a lack of rainfall suffering from drought are mainly subject to land subsidence. In Iran land subsidence due to the groundwater level withdrawal was first reported in Rafsanjan in 1967. Monitoring the subsidence, including studying its rate and spatial extent ,has been performed in many parts of Iran (e.g. Dehghani, Valadanzoej, Entezam, Saattchi & Shemshaki, 2010; Haghighatmehr et al., 2011; Sharifikia, Malamiri & Shayan, 2011). Studying the geomorphological phenomenon caused by land subsidence in terms of recognition tools are largely parallel with the issue of identifying the subsidence rate which mainly faces differential radar interferometry technique in the Iranian context (Sharifikia, Afzali & Shayan, 2015). Radar interferometry as the most appropriate monitoring method is able to measure the surface deformation at high spatial resolution with sub-centimeter accuracy. Various studies have been conducted in different parts of Iran such as Tehran (Karimi, Ghanbari & Amiri, 2013; Khamechiyan, Mohmoudpour, Nikudel & Ghassemi, 2016; Sharifikia, Malamiri & Shayan, 2013), Yazd (Amighpey & Arabi, 2016), Mashhad (Dehghani, 2015; Kazemi, Parhizkar, Ajdari & Emamgholizadeh, 2015) and Ardebil (Amirahmadi, Maali Ahari, & Ahmadi, 2013). These studies mainly focus on measuring the subsidence rate and its behavior in time using time series analysis.

However, the studies conducted to identify and extract the effects of subsidence have received less attention because few researchers have addressed them (Komakpanah, 2006). Moreover, the influence of subsidence on human societies has been less studied.

In Iran, the overdraft of groundwater produces major groundwater problems in Fars Province today. Since about 1950, the use of groundwater for irrigation in this province has increased rapidly (Esp. in Fasa, Darab, Marvdasht and Shiraz Plains). When the pumping is excessive, the management of groundwater resources in the basin presents numerous problems with various degree of complexity in each area. In Iran, Regional Water Organization (RWO) in every province is responsible for surface and groundwater management. Fasa and Darab are under the responsibility of RWO in Fars Province. The base data and information for this study were supplied by this organization.

Land subsidence existing throughout of Fasa and Darab Plains has increased in the recent decade. In most of the reports published about the Fasa and Darab Plains and other plains in Fars, groundwater withdrawal has been mentioned as the main factor of land subsidence. Overdraft of groundwater in long period is Fasa and Darab Plains for agriculture proposes is the main cause of subsidence.

The main purpose of this paper is to study the deformation rate and its temporal behavior in Fasa and Darab Plains located in Fars Province in Iran. The results obtained from the time series analysis will then be compared with the groundwater level fluctuations. Finally, the vulnerability assessment of human settlement regarding subsidence phenomenon in the study area will be performed.

However, we must consider that the severity of a natural phenomenon is not seen as a disaster, but its consequences are significant. However, as the human population increases and urban constructions and also consequently urban areas develop, the potential damages in comparison with the number of approaches applied for decreasing the consequences increase (Mahalati, 1994).

Moreover, there have been various studies conducted around the world such as Mexico (Castellazzi et al., 2016; Chaussard, Wdowinski, Cabral-Cano & Amelung, 2014; Sowter et al, 2016), Greece (Nikos et al., 2016), America (Sharma, Jones, Dudas, Bawden & Deverel, 2016), China (Chend-sheng et al., 2014; Gong et al., 2015; Lu et al., 2014), and Indonesia (Setyawan, Fukuda, Nishijima & Kazama, 2014) to study the land subsidence.

2. Research Theoretical Literature

2.1. Interferometry Time Series

SAR Interferometry makes use of the phase measurements of two Single Look Complex (SLC) SAR images acquired at different times to produce the deformation map. The phase difference known as *interferometric phase* composes of different components including deformation ($\phi_{D,x,i}$), earth curvature ($\phi_{Curv,x,i}$), topographic effect ($\phi_{topo,x,i}$), atmospheric signal ($\phi_{Atm,x,i}$), and noise phenomenon due to decorrelation ($\phi_{N,x,i}$) as shown in Eq. 1 (see below):

$$\psi_{x,i} = W\{\phi_{D,x,i} + \phi_{Curv,x,i} + \Delta\phi_{topo,x,i} + \Delta\phi_{Atm,x,i} + \phi_{N,x,i}\} \quad (1)$$

In order to extract the deformation, all components should be estimated and removed from the interferometric phase so as to generate the differential interferogram. Time series analysis using a significant number of interferograms allows us to monitor the long-term as well as short-term behavior. The main idea in time-series analysis is to invert the interferograms to obtain the deformation at each date of acquisition using the least-squares method. Suppose D = $[d_1, d_2, d_3 \ldots]$ is the vector of the deformation on each acquisition date to be estimated and I = $[i_{12}, i_{23}, i_{34} \ldots]$ is the observation vector containing the range changes obtained from the interferograms. The relation between vectors *D* and *I* is:

$$AD = I \qquad (2)$$

Where *A* is the design matrix. In the inversion solution, the deformation of the first date was set to zero ($d_1 = 0$). To mitigate the atmospheric artefacts, noise and unwrapping errors, the smoothing constraint is incorporated into the inversion problem (e.g. Lundgren et al., 2001; Schmidt & Burgmann, 2003). Using a finite difference approximation for the second-order differential of the time-series as a smoothing constraint, Eq. (1) is written as Eq (2):

$$\left(\frac{A}{\gamma^2 \partial^2/\partial t^2}\right) D = \binom{I}{0} \qquad (3)$$

Where γ is the smoothing factor, a trade-off methodology should be applied to select the most appropriate smoothing factor regarding the reduction of the errors as well as the preservation of the subtle deformation signal (Dehghani, Valadan Zoej, Entezam, Mansourian & Saatchi, 2009). There are two main products as the results of time series analysis indicate: i) subsidence rate (long-term behavior), which highlights the main deformation features, and ii) deformation time series (short-term behavior).

In the present study, the interferometry time series analysis will be employed to extract the subsidence rate as well as the subsidence time series. The block diagram of the proposed method for subsidence vulnerability assessment of settlements in Fars Plaines is presented in Fig. 1. In the first step, the radar images are processed to generate interferograms. The interferograms should be characterized by small spatial and temporal baselines to mitigate the spatial and temporal decorrelation. The processed interferograms are then inverted to obtain the subsidence at each acquisition date using Small Baseline Subset (SBAS) algorithm, which has already been introduced. The subsidence rate extracted from the time series analysis is then used to identify the areas at high risk. On the other hand, the groundwater level information at piezometric wells are compared with the interferometry results in order to study the subsidence causes. The comparison results as well as the subsidence risk map are finally applied to assess the vulnerability of human settlements in the study area.

A new smoothing constraint must be added for each additional acquisition date. If the acquisition dates are not evenly spaced, which is usually the case, the irregular time spacing must be included in the finite difference expression by applying the minimum curvature concept, that is, *constant velocity*.

The smoothing factor,γ should be determined optimally. The optimal estimation of the smoothing factor results in the smooth deformation time-series, whereas the non-linear deformation components are preserved. The time-series results can become rough by decreasing the smoothing factor. In this case, the observed fluctuations in the results are mostly due to the sources of error in each interferogram. If a large smoothing factor is selected, any non-linear deformation will be damped, and the over weighted smoothing will force the time-series to be a straight line. If the smoothing is infinite, the best-fit average deformation rate is achieved. Indeed, a trade-off methodology should be applied to select the most appropriate smoothing factor regarding the reduction of the errors as well as the preservation of the subtle deformation signal. There are several approaches to determine the optimum smoothing factor; one of these is to plot the overall RMS (misfit) that results from least-squares solution against different corresponding smoothing factors. The RMS is the root mean square of the residuals in least-squares solution as follows:

$$rms=\sqrt{\frac{\sum_{i=1}^{n}(\hat{r}_i)^2}{n}}, \qquad (3)$$

Where, according to Eq. (1), $\hat{r}$ is defined as

$$\hat{r} = A\hat{D} - I \qquad (4)$$

Where $\hat{D}$ is estimated phase via the least-squares solution. The misfit will be minimum with a zero smoothing factor and will increase with higher values. The resulting plot is a curve with an elbow. Although the choice of the optimum smoothing factor is arbitrary, depending on the plot scale, the middle point on the curve is an estimate for the smoothing factor, which is a good compromise between the removal of noisy fluctuations and the preservation of the nonlinear seasonal deformation. Finally, the entire time-series process is repeated using the optimally selected smoothing factor.

Considering the theoretical framework of this research, a conceptual model of research has been presented (see Fig. 1) to better understand the research variables and the effects of the implementation of various actions of guide plans in changing the various aspects of the assessment of the vulnerability of human settlements regarding land subsidence.

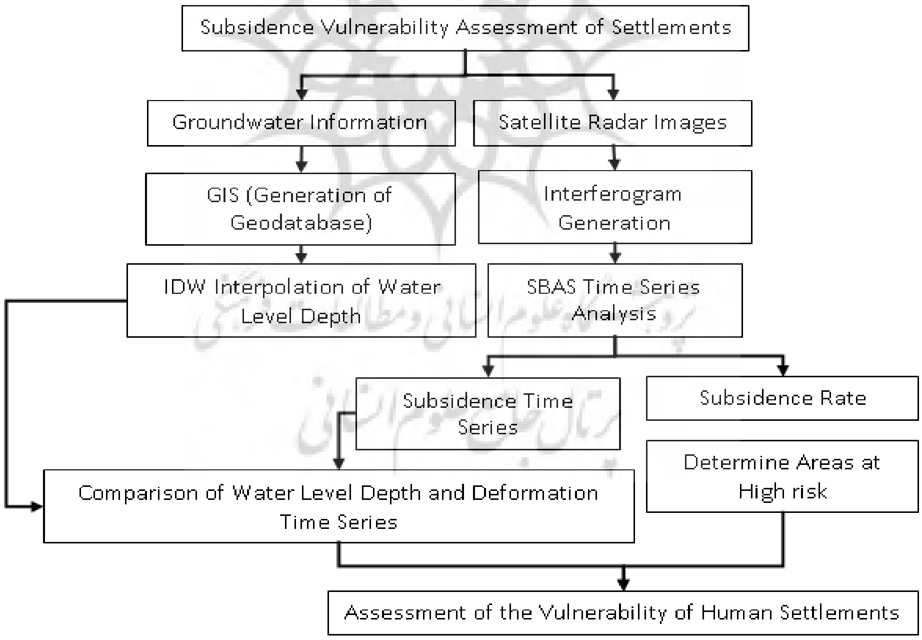


Figure 1. Block diagram of the proposed method for assessment of the vulnerability of human settlements regarding land subsidence

(Source: Research findings, 2018)

2.2. Preliminary research

Land subsidence causes damages in infrastructures and buildings in many regions in world (Abidin et al., 2001; Shamshiri et al., 2014). Monitoring the spatial magnitude and temporal evolution of surface deformation associated with water overexploitation is critical to mitigate hazards associated with this phenomenon (Herrera, Fernández, Tomás, Cooksley & Mulas, 2009; Huang, Shu & Yang, 2012).

Among the ground and space-based geodetic methods used for measuring land subsidence (see Abidin et al., 2008), space-borne interferometric synthetic aperture radar (InSAR) enables a unique imaging capability for the assessment of subsidence in response to water overexploitation from subsurface reservoirs and ground water (Galloway et al., 1998; Teatini et al., 2005). Differential Interferometric SAR (DInSAR) and advanced multi-temporal interferometry methods (e.g., permanent/persistent scatterer interferometry (Ferretti, Prati & Rocca, 2001) and small baseline subsets (Berardino, Fornaro, Lanari & Sansosti, 2002) provide high spatial-resolution (up to 25 cm) techniques for accurately mapping the temporal and spatial distribution patterns of deformation (sub-centimetre to sub-millimetre accuracy) (Casu, Manzo & Lanari, 2006; Ferretti et al., 2007; Manzo, Fialko, Casu, Pepe & Lanari, 2012), allowing a better characterization of the elastic and inelastic properties of aquifer systems with high degrees of spatial resolution in both space and time (Canova, Tolomei, Salvi, Toscani & Seno, 2012; Ezquerro et al., 2014; Hoffmann, Zebker, Galloway & Amelung, 2001; Rigo, Béjar-Pizarro & Martínez-Díaz, 2013; Tomás et al., 2010; Tung et al., 2016). InSAR measurements also help to identify the influence of geological structures on spatial patterns of subsidence (Bawden, Thatcher, Stein, Hudnut & Peltzer, 2001; Burbey, 2008; Calderhead, Therrien, Rivera, Martel & Garfias, 2011; Motagh et al., 2007).

Decades of extensive groundwater extraction from aquifers, which are used mainly for agricultural activities, have caused substantial land subsidence in developed groundwater basins across Iran in which it exceeded 20–30 cm/yr at some locations (e.g., Akbari & Motagh, 2012; Anderssohn et al., 2008; Davoodijam, Motagh & Momeni, 2015; Dehghani et al., 2009; Dehghani et al., 2013; Motagh et al., 2007).

3. Research Methodology

3.1. Geographical Scope of the Research

Fars Province with an area of 133,000 Km2 is located in the south of Iran. It is divided into 29 counties, 93 cities, 204 districts and 8349 villages. In the analysis of human settlements, 470 villages placed in the radar image frames are considered within the study area. This study focuses on the Darab Plain, which is located in the Fras Province in the southeast of Iran (see Fig. 2).

The study area contains parts of Fasa Plain named Sheshdeh-Ghrebolagh and Darab Plain. Figure 2 illustrates the study area in which the radar image frame is depicted. The study area is covered by the cultivated lands, and the groundwater is extracted mainly for the irrigation purposes.

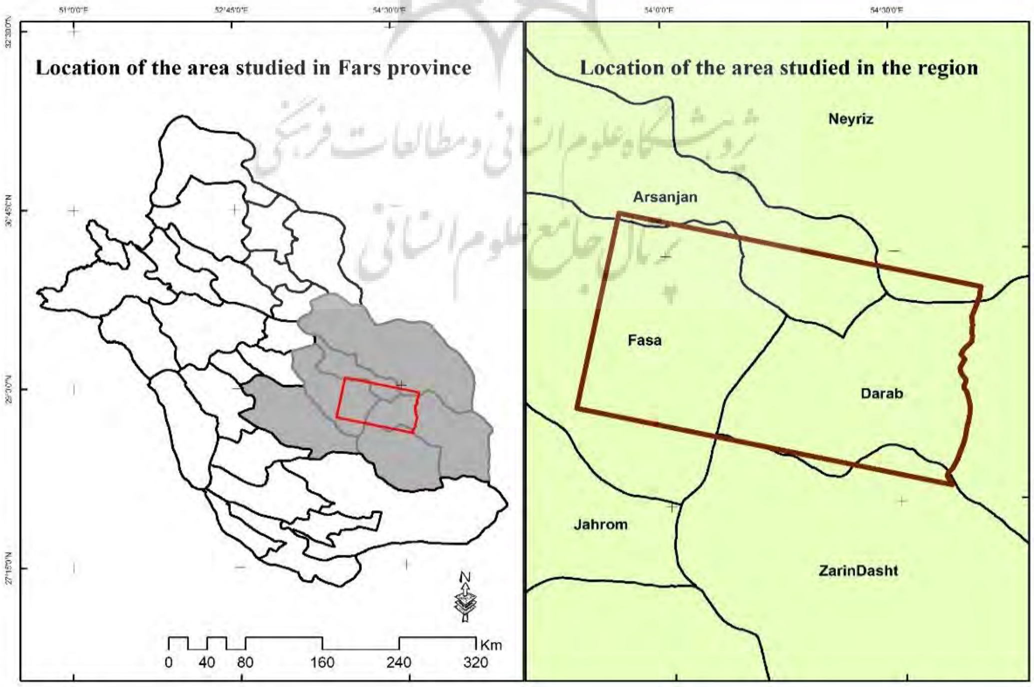


Figure 2. Location of the area studied in the Fars Province and region
(Source: Research findings, 2018)

3.2. Methodology

The research methodology is implemented into five phases: data preparation (wells data in region and ENVISAT ASAR images spanning between 2005 and 2010), modelling of level decline, Interferogram generation by MATLAB, the accuracy assessment of the model, the data integration, and the preparation of landslide hazard maps. The overall methodology is shown in Fig. 1. The main steps taken include:

a. Volume loss of the aquifer

Groundwater level measurements carried out in wells are of key importance for the interpretation of surface deformation in developed ground water basins (Hoffmann et al., 2003; Lu & Danskin, 2001; Tomás et al., 2010). The storage coefficient or storativity (S) is one of the main hydraulic parameters which can be used for a better understanding of reservoir properties and deformability characteristics of an aquifer system (Riley, 1969). It is defined as the volume of water of an aquifer released from or taken into storage Vw per unit area A per unit change in the hydraulic head h (Bundschuh, 2010):

$$S = \frac{d}{dh} \cdot \left(\frac{Vw}{A}\right) \qquad (5)$$

Fars RWO (FRWO), water basin database for surface and groundwater, is used to analysis in Fasa and Darab are under the responsibility of RWO in Fars Province. The base data and information for this study were supplied by this organization.

The comparison of subsidence and groundwater levels in the underlying aquifer system has been successfully used in previous research to identify the strong correlation between the two (Chai et al., 2004; Galloway et al.,1998; Ketelaar, 2009). Groundwater level measurements data was performed by WRO in Fars RWO (FRWO). The volumetric groundwater extractions in Fasa and Darab wells were extracted from FRWO database. The assessment of using the groundwater resources was based on the extraction from private and public registered (legal) wells. To evaluate the extraction of the legal wells, an updated dataset containing 434 operational wells was obtained from the FRWO. For each well, the location, capacity, extraction depth and several other parameters were processed. The depth and capacity of these wells are also shown in Fig. *. Finally, the extraction volumes were plotted in Fasa-Darab plain area by Inver distance weighted (IDW) interpolation method in GIS.

b. InSAR analysis

To derive the spatial and temporal changes in land subsidence in the study area, we utilized 5 sets of SAR images, including 9 ENVISAT ASAR images from a descending track covering 2005–2010.

InSAR technique is a method where phase information of radar carrier is used to obtain the land deformation. In the InSAR technique, if the ground deformation is happened during the two images being captured, the interferometric fringes generated by these two images mainly include some phase information as mentioned in Eq. 1.

4. Research Findings

4.1. Time Series Analysis Results

Using the time series analysis, the short-term as well as the long-term behaviors of the subsidence were studied. In order to highlight the major features of the deformation, the mean displacement velocity map was generated using the time series analysis results (Fig. 3). Accordingly, the maximum subsidence rate is 25 cm/yr. which is the cause for a concern.

Another time series analysis for products is the subsidence time series, showing the short-term behavior of the deformation. The subsidence time series compared with the groundwater level fluctuations at piezometric wells are presented in Fig. 4. The piezometric wells are located in different parts of the subsidence area (Fig 3). The subsidence time series show a decreasing trend, indicating that the aquifer system is compacted at a constant rate. According to the time series results, the seasonal fluctuations are insignificant, showing that the aquifer system is not sufficiently recharged in the recovery seasons.

Alongside the subsidence behavior, the groundwater depth time series at piezometric wells are illustrated in Fig. 4. In all piezometric wells, the water level significantly declines due to the over-exploitation of groundwater for the agricultural purposes. The increase in the cultivated area for comparative advantage of agricultural crops in Fars Province in last decades especially in study region is the main cause of over-exploitation (Qorbani, Rafiei & Amjadi, 2014)

Most parts of the Fars Province, including the study area, is subject to the groundwater depth as shown in Fig. 5. The situation is even worse in the south of the province. The maps in Fig. 5 are generated from the piezometric wells using Inverse Distance Weighted (IDW) interpolation method. Due to the high correlation between water level decline and subsidence phenomenon, we expect to observe the subsidence in other parts of the province. The subsidence, however, is a function of not only the water level decline but also other factors including soil types composing the aquifer system. The investigation of the relation between soil types and subsidence rate is considered as future work.

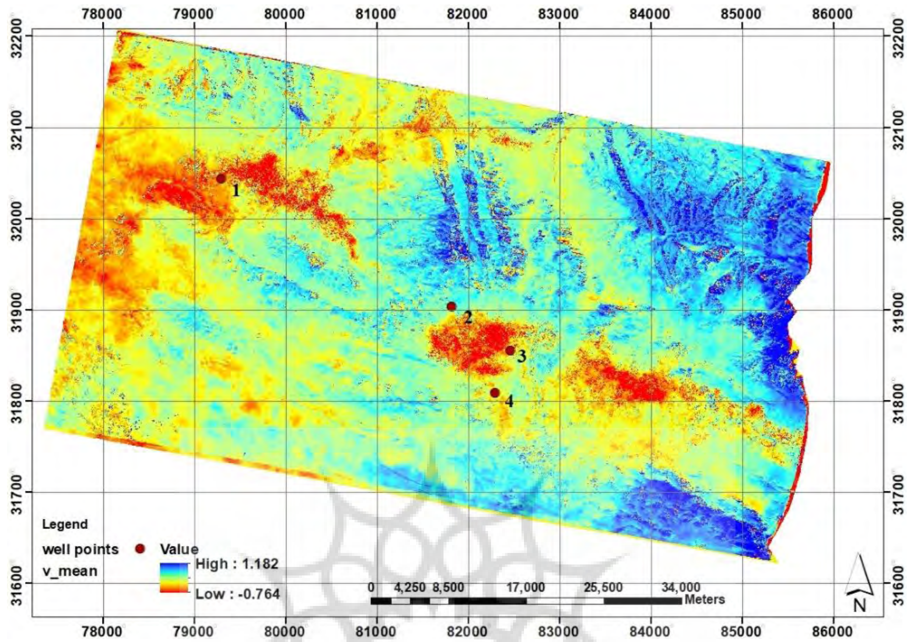
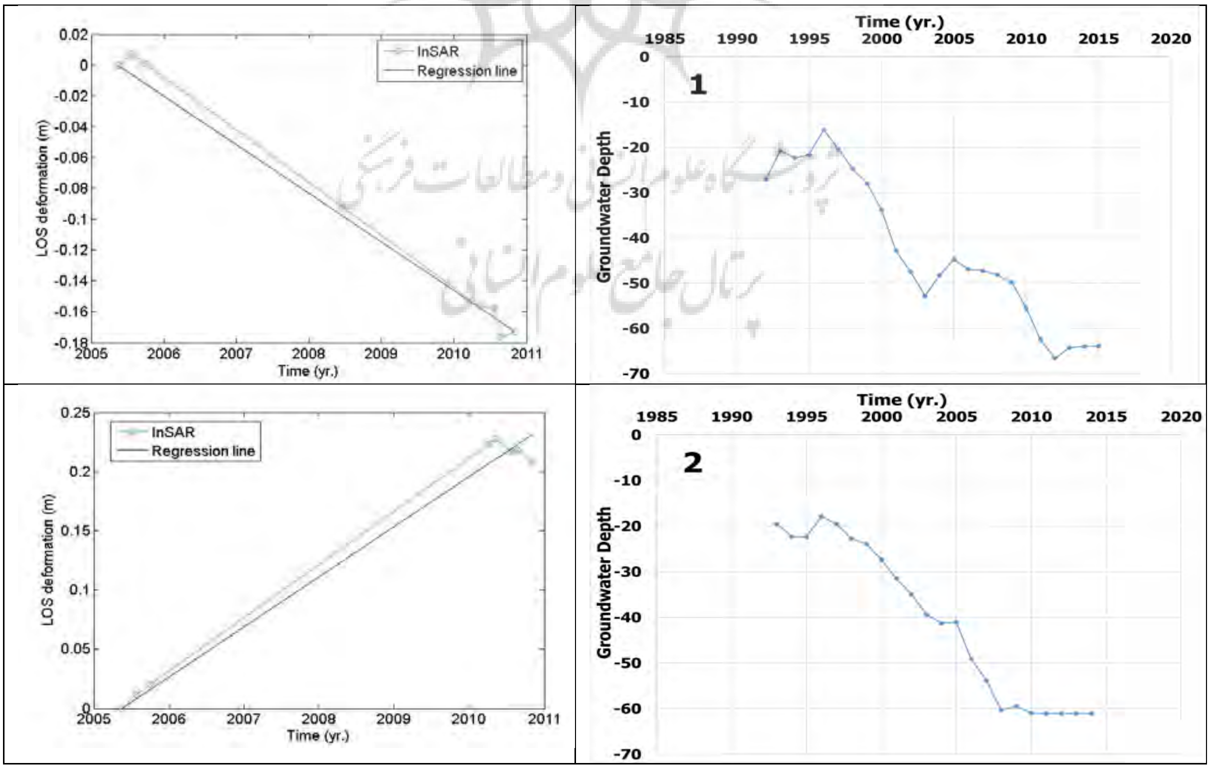


Figure 3. Mean displacement velocity map. The red areas within the center and the south east of the map illustrates the subsidence signal

(Source: Research findings, 2018)



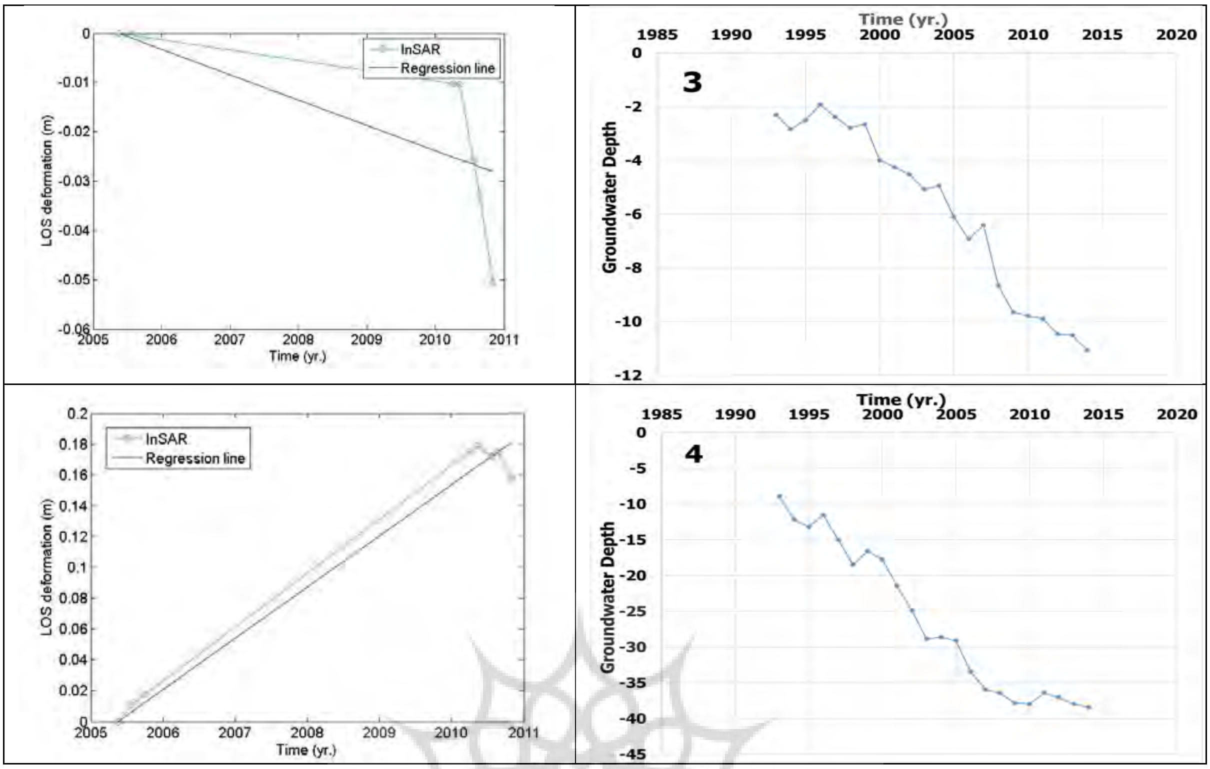


Figure 4. Comparison between the time series obtained from radar interferometry method and well points
(Source: Research findings, 2018)

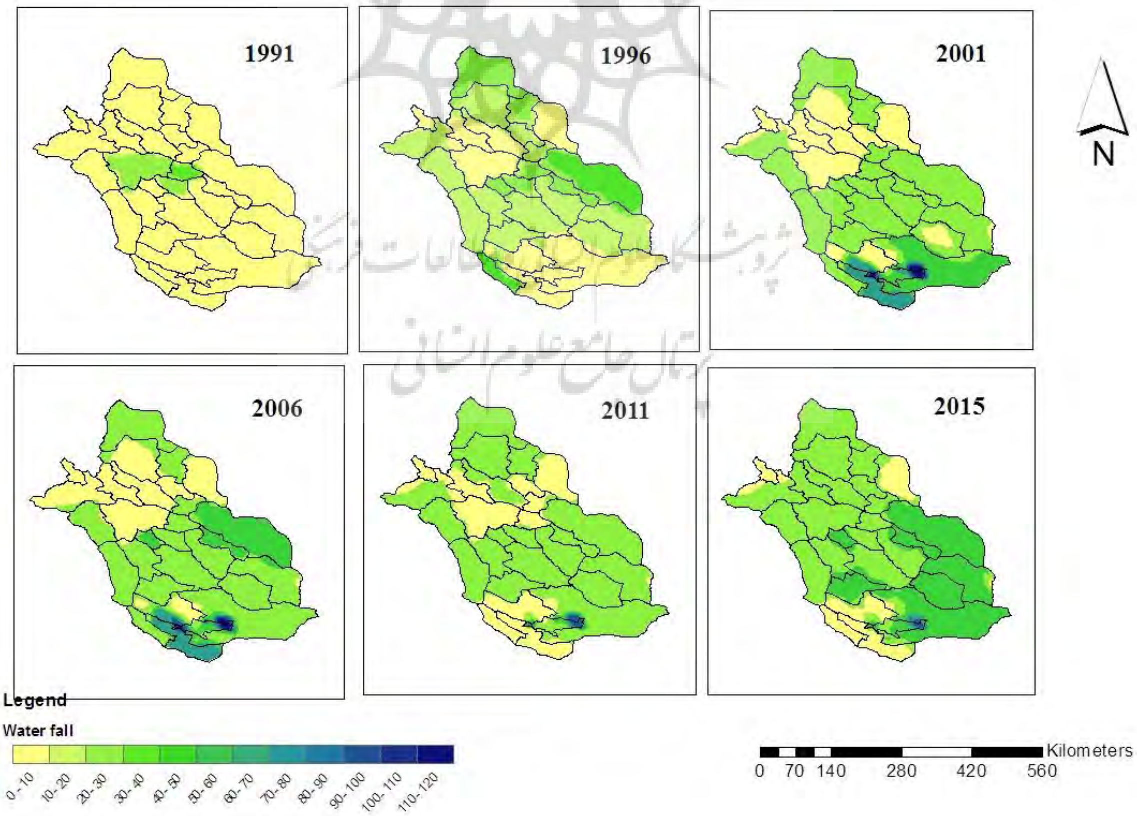


Figure 5. Groundwater depth in the Fars Province
(Source: Research findings, 2018)

4.2. Subsidence Hazard Zoning

The subsidence rate estimated from the time series analysis results is applied for the subsidence hazard zoning. The rate map is categorized into three main classes, including high-risk, medium risk and no-risk areas based on the deformation rate (see Table 1).

Table 1. Classification of the subsidence rate into three main classes

(Source: Research findings, 2018)

Hazard zoning	The subsidence by cm
High-risk	-0.41 to -0.25
Medium risk	-0.25 to -0.1
No-risk	-0.1 and more

As seen in Fig. 6, the residential areas presented as black dots are partly concentrated on the areas with high and medium risks. The main parts of the residential areas, however, are located in the areas with no-risk. It should be noted that the areas with high and medium risks are mainly covered by the cultivated lands rather than the residential areas.

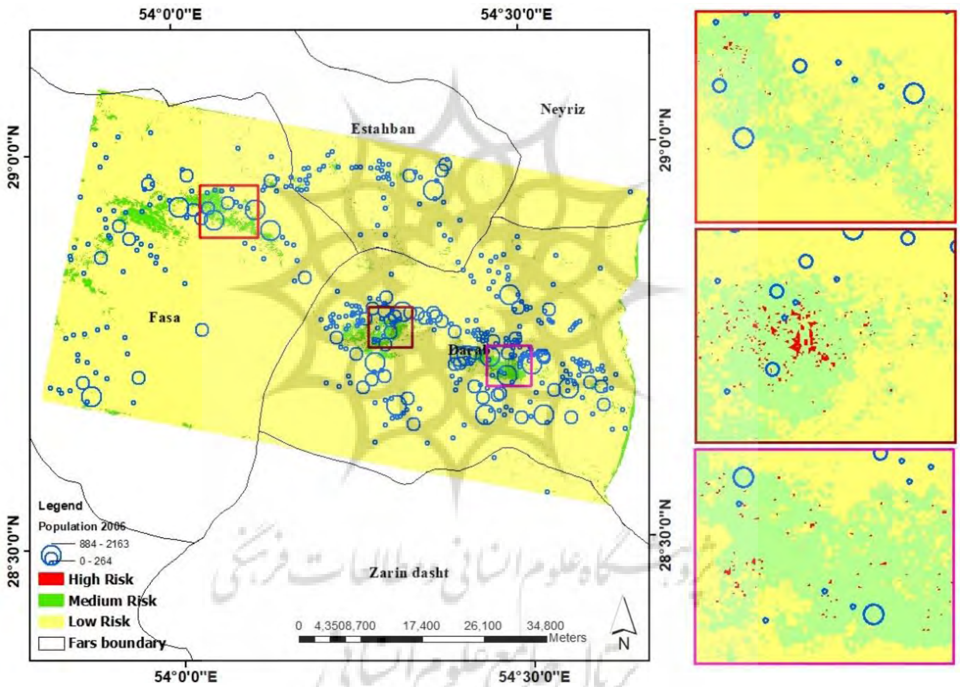


Figure 6. Subsidence zoning result that is showing three main classes: high risk (red), medium risk (green) and no-risk areas (yellow). Black dots illustrate the residential areas.

(Source: Research findings, 2018)

5. Conclusions and Discussion

The agricultural sector uses up to 92 percent of Iran's water. The desire for improved agricultural productivity has encouraged the growth of cultivated areas and infrastructure across the country, especially in Fras Province. However, this sector is not yet mechanized and is suffering from outdated farming machineries and practices leading to very low efficiency in irrigation and production. The agricultural sector in Fars Province is economically inefficient and its contribution to gross domestic product has decreased over time. Irrigated agriculture is the main practice, while the economic return on water use in this sector is significantly low and crop patterns across the counties are inappropriate and incompatible with water availability conditions in most areas. Recently for two decades, food security has been an enduring challenge in Iran. Limited water availability, high population and political instability make Iran vulnerable to food shortages. Therefore, food security has ranked high on the agendas of Iran government and the desire for self-sufficiency in food has been a common theme with dramatic impacts on water resources. The role of Fars Province in the production of strategic crops causes over-exploitation of groundwater resource. In addition, farmer's interest to improving their quality of life and increasing their income's, with expansion of the agricultural farms and cultivated areas across the counties, so increase in over-extraction of groundwater resource cause to land subsidence in different region of Fars.

This study concludes that subsidence has occurred in the study area by using the results of the interferogram and time series analysis and the results obtained from the analysis of well data. We use the census data to assess the vulnerability of human settlements caused by land subsidence occurring. Because our unit of analysis is the frame of satellite images; therefore, the number of villages in each county will be different. In this regard, the comparison of the number socio-economic infrastructure of each county will not be a practically possible. Table 2 shows the cities and the number of villages of each of them.

Table 2. Main cities and number of villages in Study region
(Source: Research findings, 2018)

County	Main city	Number of rural settlements	Rural Population - 2016	Urban Population -2016
Estahban	Estahban	40	20343	48416
Darab	Darab	320	111105	90384
Zarindasht	Zarindasht	2	28788	44411
Fasa	Fasa	105	63589	141598
Neyriz	Neyriz	3	48550	64748
Total	6	470	272375	389557

In the past two decades, land subsidence and ground failure in the Darab-Fasa region has caused significant damages to the existing roads and structures. This phenomenon is a direct result of the aforementioned subsidence. In fact, earth rupture has affected numerous settlements in the region, including rural and urbans. All human settlements including urban and rural contains infrastructure, such as educational centers, cultural infrastructure, healthcare system, etc. to meet the population needs in these regions. Now hazards and natural disasters can destroy the infrastructure and will suffer the population in the regions. Table 3 shows the different infrastructures in all counties.

Table 3. Number of infrastructures by counties
(Source: Research findings, 2018)

Infrastructure city	Transportation	Health	Electricity Water, gas	Political official	Cultural	Educational	Housing	Household	Population
Estahban	12	10	24	16	49	10	752	867	3069
Darab	179	187	263	200	458	199	15373	16674	62670
Zarindasht	0	0	2	2	3	1	22	22	71
Fasa	79	138	141	95	170	91	9914	10956	39662
Nyriz	0	0	2	0	4	1	14	14	51
Total	270	335	432	313	684	302	26075	28533	105523

As shown in table 3, there are many public infrastructures in the study area which are treated by land subsidence. Without implementation integrated groundwater management plans, it is estimated that continued pressure on the groundwater resources in Fars Province with rates of extraction far beyond those of natural recharge might cause serious damages to urban/rural settlements, agricultural and industrial areas in the region. The maximum annual subsidence rate of 41 mm/yr inferred based on InSAR measurements in this study is one of the highest rates of deformation ever recorded for groundwater basins. Land subsidence and earth cracks resulting from over-exploitation of water are serious geologic hazards, the impacts of which will increase as more water is withdrawn from aquifers in the Darab-Fasa region without sufficient replacement.

Long-term and large-scale over-exploitation of groundwater resources is the main factor causing land subsidence in different regions in the world and Iran. Natural recharge of the aquifer system, which is mainly provided by rainfall, infiltration of irrigation waters, leakage from the bed of the major rivers, and subsurface flow from the mountain ranges bounding the northern part of the plain, was not able to balance the resource exploitation. Land subsidence observed in the recent decades on the many areas of Iran and in Fars Province has been qualitatively and quantitatively interpreted by acting a large-scale multi-temporal analyses of data regarding soil properties, groundwater levels and rural settlements population trends. The current study focused on the relationship between the groundwater level decline and the land subsidence in Sheshdeh and Darab /planes. Major steps for the analysis have been the processing of InSAR data (2005 ~ 2010) and GIS using spatial analysis methods, the modelling of the groundwater lowering, and rural settlement changes induced by the changes of population in recent census (2005 & 2011), and the mapping of all variables with a geographical information system. Results by groundwater wells point during study period showed about 2.85cm withdrawal in water level in year. Also, the InSAR data analysis indicated nearly 25cm subsidence in study planes.

The extent and distribution of land subsidence over the studied area have been demonstrated as the result of the combined action of groundwater lowering, which produce and increase subsidence area's in case study planes.

The socioeconomic analysis along with the subsidence hazard map found that 105523 people were generally at risk of subsidence, of 65068 whom were at high risk. Furthermore, there are 2679 socioeconomic infrastructures such as public service (school, bank branches, post office, gas station, etc.). In Fasa-Darab Plain, where most of rural areas are in the high risk zones, need to adoptable policies and plans to reduction the occurrence of the crisis, efforts should be made to reduce any damage in human settlement and infrastructure in these areas.

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ارزیابی آسیب‌پذیری سکونتگاه‌های روستایی ناشی از فرونشست زمین در استان فارس

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چکیده مبسوط

۱. مقدمه

پدیده فرونشست زمین ناشی از عوامل طبیعی و فعالیت‌های انسانی در نقاط مختلف دنیا و در طی سال‌های اخیر در کشور ایران بخصوص استان فارس به علت برداشت بی‌رویه از آب‌های زیرزمینی، خشک‌سالی و عوامل دیگر پدیدار شده است و باعث آسیب‌رسانی به نقاط جمعیتی و سکونتگاه‌های انسانی و خسارت‌های زیست‌محیطی، اجتماعی و اقتصادی شده است. در ایران فرونشست زمین، پیشینه سی‌وچند ساله دارد و اگر زمانی این پدیده تنها در برخی از استان‌ها مانند کرمان و یزد رخ می‌داد، اینک استان‌های اصفهان، خراسان، تهران و غیره نیز متحمل فرونشست هستند و این مشکل به طور روزافزون در استان‌های بیشتری خودنمایی می‌کند. در همه فرونشست‌هایی که در ایران رخ می‌دهد، استخراج بی‌رویه آب‌های زیرزمینی، تنها عامل یا مهم‌ترین عامل ایجاد فرونشست است. پیامدهای محیطی پدیده فرونشست، اساساً شامل آسیب رساندن به سازه‌های دست‌ساز بشر مانند ساختمان‌ها، خیابان‌ها، پل‌ها و خطوط انتقال نیرو، ایجاد شکاف‌هایی بر روی سطح زمین و سیلاب است. در ایران مطالعه پدیده فرونشست به سبب فراگیری فضایی آن مورد توجه طیف وسیعی از محققان قرار گرفته، مطالعات نسبتاً زیادی صورت گرفته است.

۲. مبانی نظری تحقیق

روش تداخل‌سنجی راداری (InSAR) مبتنی بر سنجش‌ازدور راداری، در سال‌های اخیر به‌عنوان یکی از روش‌های غیر ژئودتیک در شناسایی تغییرات ارتفاعی در سطح زمین مطرح شده که با توجه به مزایایی که نسبت به دیگر روش‌ها دارد، بسیار مورد توجه قرار گرفته است. این روش در میان روش‌های زمینی و فضایی به‌عنوان کارآمدترین روش برای اندازه‌گیری تغییرات سطح زمین با دقت و قدرت تفکیک مکانی بسیار بالا به شمار می‌رود. از جمله مزایای این روش می‌توان به‌دقت بسیار بالا، پوشش وسیع، قدرت تفکیک مکانی بالا و نداشتن نیاز به کار میدانی، مقرون به‌صرفه بودن و امکان دستیابی به اطلاعات در هر شرایط آب و هوایی اشاره کرد. در این فناوری با استفاده از تلفیق داده‌های به دست آمده از سامانه‌های تصویربرداری رادار نصب شده بر سکوهای ماهواره‌ای یا هواپیمایی، حرکت، ارتفاع و تغییرات سطح زمین نقشه‌برداری می‌شوند. اساس کار در اندازه‌گیری تغییرات سطح زمین، استفاده از تصاویر تکراری رادار است. تصویری که از یک منطقه در یک زمان مشخص برداشت می‌شود، با تصویری که در زمان دیگر توسط همان سنجنده رادار برداشت می‌شود، تلفیق می‌شود. روش تداخل‌سنجی راداری، شناسایی مناطق در حال نشست و تعیین وسعت آن‌ها را ممکن می‌سازد. روش‌های تداخل‌سنجی راداری سنتی، به طور گسترده‌ای به منظور مشخص کردن فشردگی سفره آب زیرزمینی در مقیاس زمانی زیاد، مورد استفاده قرار گرفته‌اند.

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۳. روش تحقیق

تحلیل سری زمانی در تعیین نرخ فرونشست- در این پژوهش با استفاده از تحلیل سری زمانی مبتنی بر تکنیک تداخل‌سنجی راداری به پایش تغییرات زمانی فرونشست در دشت فسا و داراب که شامل ۴۷۰ نقطه روستایی می‌باشد؛ پرداخته شد. با استفاده از ۸ تصویر ENVISAT ASAR و تشکیل ۹ تداخل‌نگاشت، تحلیل سری زمانی در بازه زمانی ۲۰۰۵ تا ۲۰۱۰ انجام و مقدار میانگین ۲۵ سانتی‌متر سالیانه فرونشست زمین در این دشت‌ها استخراج گردید. با استفاده از تکنیک آنالیز سری زمانی که به صورت یک برنامه کدنویسی شده در نرم‌افزار Matlab اجرا شد و بکار بردن ۹ اینترفروگرام تغییرات سطح ناشی از فرونشست را در منطقه دشت ششده و قره‌بلاغ فسا و دشت داراب مورد پایش قرار گرفت. برای ایجاد آنالیز سری زمانی InSAR به منظور پایش فرونشست دشت‌های فسا و داراب ۸ تصویر خام ENVISAT ASAR اخذ شده بین سال‌های ۲۰۰۵ تا ۲۰۱۰ مورد استفاده و سپس با استفاده از این ۸ تصویر، ۱۴ اینتروگرام به کمک نرم‌افزار Sarscape تشکیل شد و به دلیل وجود خطاهای زیاد از جمله نویز، خطاهای اتمسفری و ... ۵ اینترفروگرام از تحلیل‌ها کنار گذاشته شد و در نهایت تحلیل‌ها با ۹ اینترفروگرام انجام شد. برای ایجاد سری زمانی تغییر شکل عمل معکوس‌سازی اینترفروگرام‌ها به همراه شرط نرم‌شدگی انجام شد. با استفاده از فاکتور نرم‌کنندگی بهینه به مقدار ۰.۰۵ خطاها از جمله خطاهای اتمسفری، بازیابی فاز و خطاهای باقیمانده تا حد نسبتاً زیادی کاهش یافت.

برای نمایش پهنه‌بندی خطر فرونشست زمین با استفاده از نرم‌افزار GISبه تهیه نقشه پهنه‌بندی خطر بر روی تداخل‌نگاشت میانگین فرونشست که حاصل از تحلیل سری زمانی می‌باشد؛ پرداخته شد و منطقه مورد مطالعه در ۳ طبقه پرخطر، خطر متوسط و بدون خطر پهنه‌بندی گردید.

۴. بحث و نتیجه‌گیری

هدف پژوهش حاضر ارزیابی آسیب‌پذیری سکونتگاه‌های انسانی ناشی از فرونشست زمین در دشت فسا-داراب در استان فارس بود. برای دستیابی به این هدف ابتدا با تحلیل داده‌های نقاط چاه در بازه زمانی ۲۴ ساله ۹۴-۷۰ به بررسی میزان افت سطح آب‌های زیرزمینی پرداخته شد و مشخص گردید که سطح آب در دشت مورد مطالعه کاهش یافته و سطح آب چاه‌ها در بازه زمانی ۱۳۸۰ تا ۱۳۹۰ به بیشترین حد کاهش خود رسیده‌اند؛ که می‌تواند متأثر از سیاست‌های خودکفایی تولید محصول استراتژیک گندم در این استان و فشار بیش از حد به منابع آب‌های زیرزمینی در این سال‌ها باشد. همچنین با استفاده از تحلیل سری زمانی مبتنی بر تداخل‌سنجی راداری میزان فرونشست در دشت فسا و داراب به‌صورت میانگین ۲۵ سانتی‌متر سالیانه فرونشست زمین در بازه زمانی ۲۰۰۵ تا ۲۰۱۰ استخراج شد. مقایسه بین تحلیل‌های مستخرج از داده‌های نقاط چاه و تصاویر ماهواره‌ای نیز مؤکد رابطه بین پایین آمدن سطح آب‌های زیرزمینی و فرونشست زمین در منطقه مورد مطالعه است. در نهایت با استفاده از داده‌های مرکز آمار ایران به تفکیک نقاط روستایی به ارزیابی آسیب‌پذیری اقتصادی و اجتماعی سکونتگاه‌های انسانی در منطقه مورد مطالعه پرداخته شد بر اساس این تحلیل‌ها و با استفاده از نقشه پهنه‌بندی خطر فرونشست مشخص شد که به‌طورکلی ۱۰۵۵۲۳ نفر در محدوده خطر فرونشست زندگی می‌کنند که ۶۵۰۶۸ نفر آن در پهنه پرخطر قرار می‌گیرند. همچنین به ترتیب ۲۳۳۶ و ۳۴۳ زیرساخت و سرمایه اقتصادی در این پهنه قرار می‌گیرند که بیشترین تعداد در پهنه پرخطر واقع شده‌اند. در نهایت باید گفت که بیشتر نقاط روستایی منطقه مورد مطالعه در پهنه‌بندی خطر فرونشست، در پهنه پرخطر قرار می‌گیرند و ضروری است سازمان‌های و نهادهای متولی با اتخاذ سیاست‌ها و برنامه‌ریزی‌های مناسب، پیش از وقوع بحران درصدد کاهش هرگونه آسیب به سکونتگاه‌های انسانی، جمعیت و زیرساخت‌های موجود در این مناطق باشند.

کلیدواژه: فرونشست، سنجش‌ازدور، تداخل سنجی راداری، اینترفروگرام، دشت فسا-داراب.

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