Land subsidence due to the overexploitation of the aquifers in arid regions. The case of Remah and Al Wagan areas, Al Ain, UAE.

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Introduction

United Arab Emirates (UAE) characterised by arid climate with limited resources of fresh water and high-water demand in sectors of domestic, agriculture, and industry. Water resources in the UAE can be classified into conventional water resources (seasonal floods, springs, falajs, and groundwater) and non-conventional water resources (desalination water and Treated wastewater) (Rizk & Alshahran, 2003). Due to this limitation in water resources, sustainable groundwater practices are required to maintain the available resources to diminish. One of the most crucial groundwater practices are monitoring of groundwater dynamics, in quality and quantity, and the implications of unsustainable groundwater usage.

Al Ain region is located at the eastern part of Abu Dhabi Emirate, UAE at the border with Sultanate Oman. It is characterised by arid climate with scarce rainfall in winter and high annual evapotranspiration. The region is geomorphologically consists of Jabal Hafit and Oman mountains, a gravel plain at the western side of Oman Mountains known as Al Jaww Plain, and large Sand Dunes. Groundwater aquifers in the UAE can be classified into limestone aquifers, ophiolite aquifers, gravel aquifers, and sand dune aquifers (Elmahdy & Mohamed, 2015). Groundwater system of the Al Ain region is composed of the last two aquifers with dominant of the sand dune aquifers. This region occupies 50% of the Abu Dhabi Emirate agricultural activities consumes huge amount of groundwater with annual discharge more than 200 million m^3.

The current study aims at investigating the deformations occurring at the site due to the overexploitation of the aquifers by combining SAR satellite data, with ground water level measurements and ground truth surveys for the verification of the deformations.

Synthetic Aperture Radar (SAR) is a radar satellite system which transmits its own signal and measure the backscatter signal, stores in amplitude and phase signal, to satellite sensor. SAR satellite system differs from the optical satellite system due to its independence of sun and weather. SAR Interferometry (InSAR) technique has the capability to measure the effect groundwater dynamics on land surface with millimetric resolution (Ferretti et al. 2007). InSAR techniques have been utilised to detect land surface deformations occurred due to extraction of subsurface materials such as groundwater, oil, and gas. InSAR techniques rely mainly on measuring the phase difference between two SAR scenes acquired from different orbit location or at different time. Monitoring of land surface deformations require implementing InSAR technique with a time-series SAR scenes acquired over the area of interest. The interferometry depends on identifying targets with stable phase during the period of the study known as Permanent or Persistent Scatterers (PS) such as buildings, rocks, pavement roads, etc. In the last two decades, many InSAR approaches have been developed in order to process InSAR time-series data, includes Persistent Scatterer Interferometry (PSI) (Ferretti et al. 2001), Small Baseline Subset (SBAS) (Berardino et al. 2002), and Stanford Method for PSI (StaMPS) (Hooper et al. 2004).

Applications of the InSAR technique for surface deformations in the UAE are limited due to the wide coverage of the sand dunes (more than 70% of the country) where the SAR signal experiences temporal decorrelation and there is a significant drop in interferometric coherence. Coarse-resolution investigation for the Al Ain region using SBAS technique and ENVISAT (C-band) data aimed to detect regional land surface deformations in the eastern part of Abu Dhabi Emirate (Cantone et al., 2013). This investigation delineated a significant subsidence in the Remah and Al Wagan areas. The coarse resolution in combination with the coherence change of the sand limited the reliability of this study.

Methods

As already mentioned, this study was conducted by combining SAR satellite data, with ground water level measurements and ground truth surveys for the verification of the deformations. Sentinel-1 data, provided by the European Space Agency (ESA), were used to process the SAR interferometry over the study area. Water level data were provided by the Environment Agency of Abu Dhabi (EAD), and they were used to determine zones affected by groundwater overexploitation. Land surfaced subsidence evidences were identified in the field, confirming the deformations identified by the SAR interferometry data. The dataset used consists of 37 Sentinel-1A Single Look Complex (SLC) images acquired along the ascending orbit from path 130 and frames 73 and 75, for a time span between February 2015 and May 2019. The image acquired on 22 October 2017 was selected as a primary, or master, image to increase the expected coherence due to it is minimum spatial and temporal baselines.

The water level dataset indicated an extensive depression cone covering the area under investigation (Figure 1). The extended network of irrigation wells has systematically affected the unconfined sand dune aquifers unit and resulted in lowering the groundwater level with a maximum drawdown at its centre of approximately 40 to 50 m. As expected, at the perimeter of the cone, the ground water lowering gradually decreases in relation to the distance from the centre of the cone. The great discharge from the aquifer, more than 240 million m^3, along with a very low hydraulic conductivity of the aquifer resulted in a low annual groundwater recharge.

Land surface deformations were observed during the field visit and can be summarized as follow; leaning of some fracture walls caused by the differential settlements of their foundations, well casings experienced protrusion due to the land surface subsidence, and dislocated electrical pillars with the wires tensioned due to the differential surface movements (Figure 2).

The performed SAR interferometry analysis was the Parallelized Persistent Scatterer Interferometry (P-PSI) an open-source software implementing a distributed processor for fully automated and computational efficient for detecting land surface velocities along line-of-sight (LOS) via PSI and long time-series dataset of Sentinel-1. The P-PSI uses two main software packages, Interferometric Scientific Computing Environment (ISCE) and Stanford Method for Persistent Scatterer Interferometry (StaMPS). ISCE was implemented with topsStack processor for creating a stack of co-registered SLC images. Then it has been utilised for interferogram generation, coherence maps, differential interferogram generation, and spatial subset. After that, StaMPS was implemented for the time-series interferometric analysis and computation of land surface velocities. The topographic incorporated phase was estimated and removed using an external Digital Elevation model, while phase noise was corrected by removing all pixels exceeding 1.0 interferometric phase standard deviation. The Atmospheric Screen Phase (APS) was estimated and removed by applying the open-source Toolbox for Reducing Atmospheric InSAR Noise (TRAIN). Finally, after removing all incorporated phase components the phase of land surface displacement remains and was used to estimate the annual ground displacement.

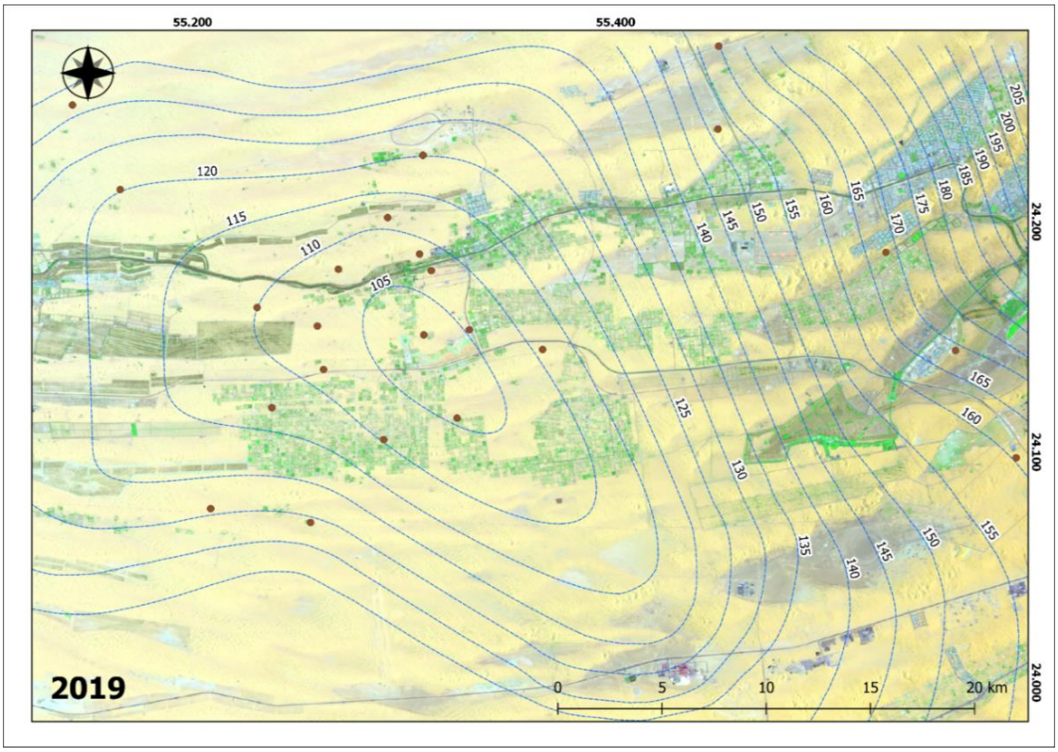

Figure 1 Groundwater level contours, blue doted lines, indicate the depression cone during 2019. The brown dots indicate the monitoring water wells.

Figure 2 Land surface subsidence evidences. On the left the leaning wall, at the middle the protrusion well casing, and on the left the leaning of electrical pillars.

Conclusions

This study showed an extensive land surface subsidence with a rate of 40 mm/year in the period between 2015 and 2019. The cone of depression for the water level drawdown in the study area was found in spatial correlation with the detected land surface subsidence bowl. This can be concluded that the land surface subsidence was triggered by the groundwater over extraction.

Furthermore, it was proved that the repeat-pass satellite SAR interferometry can provided substantial information about the actual extent of the land subsidence phenomenon. Space-based technologies are cost effective, providing high spatial coverage. So, they are able to fill the data and knowledge gaps and reduce the uncertainties by providing high spatial and temporal valuable information about the extend and the progress of the subsidence.

Finally, it should be noted that the detection of the phenomenon at an initial stage is extremely important, as further expansion of the affected area and damages on settlements and infrastructure can be prevented. The information provided by these studies can give rise to focused geotechnical and hydrogeological studies.

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