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Terrain Mapping for the Southwestern Desert of Iraq Using Interferometry Method from Sentinel-1A Images

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Terrain Mapping for the Southwestern Desert of Iraq Using Interferometry Method from Sentinel-1A Images

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Abstract. Synthetic aperture radar Interferometry is a popular three-dimensional imaging technique for creating a Digital Elevation Model. Using traditional methods for creating DEMs and terrain mapping is one of the methods that require high cost and time-consuming, which has affected the creation and updating of terrain maps in Iraq, so this study aims to use the InSAR technology to generate DEM, which contributes to the creation of terrain maps. In this work, the synthetic aperture radar interferometry approach was used on the interference stack generated from a pair of Sentinel-1A images within the SNAP program to generate a DEM and a terrain map of the desert region in south-western Iraq. The elevations of the digital elevation model were compared with those of the RTK-GCPs points in the region of interest. The results obtained from this study are a terrain map with the contour lines generated from the digital elevation model created by the InSAR technique with an accuracy of 18 m, with the root mean square error of the DEM being 8.17. The outputs prove the effectiveness of InSAR technology in generating accurate DEM that contributes to creating terrain maps in less time and cost than traditional methods.

Keywords: Sentinel-1A; SAR; InSAR; DEM; Terrain Map.

1 Introduction

Radar with synthetic aperture Interferometry (InSAR) is a popular 3D imaging technique for creating a Digital Elevation Model [1]. Because it is an active system with cloud-penetrating capabilities, SAR is a microwave imaging approach that works at all hours of the day and night, and Interferometry SAR, or InSAR, offers exact measurements of the radiation travel route since it is coherent. In addition, the development of a DEM and the measurement of precise surface deformations of the terrain are made possible by the measurements of path travel modifications as a result of the satellite's position and acquisition time [2].

Digital terrestrial, aerial, and satellite technology has evolved tremendously, and one of these advances is the ability to estimate height variations, which may be shown using a DEM [3]. In general, DEM is a term that encompasses all sorts of topographic digital covering data as well as the method for assessing the effects of elevation differences between measurements [4]. In this technique, the phase difference between two complex radar SAR scans acquired from slightly different sensor locations is used in interferometry synthetic aperture radar (InSAR) to collect information about the earth's surface [5].

Sentinel-1A/B, on the other hand, is a set of satellite radar observations produced in collaboration between the European Union and the European Space Agency. The S-1A and S-1B platforms are combined on an orbital plane with a 180-degree phase difference in this idea (between A and B). Sentinel-1 has SAR sensors that operate at a frequency of 5.405 GHz, which covers the C-band of the spectrum [6]. After a 6-day revisiting period, Sentinel-1A/B may collect SAR pictures with a variety of polarization, including

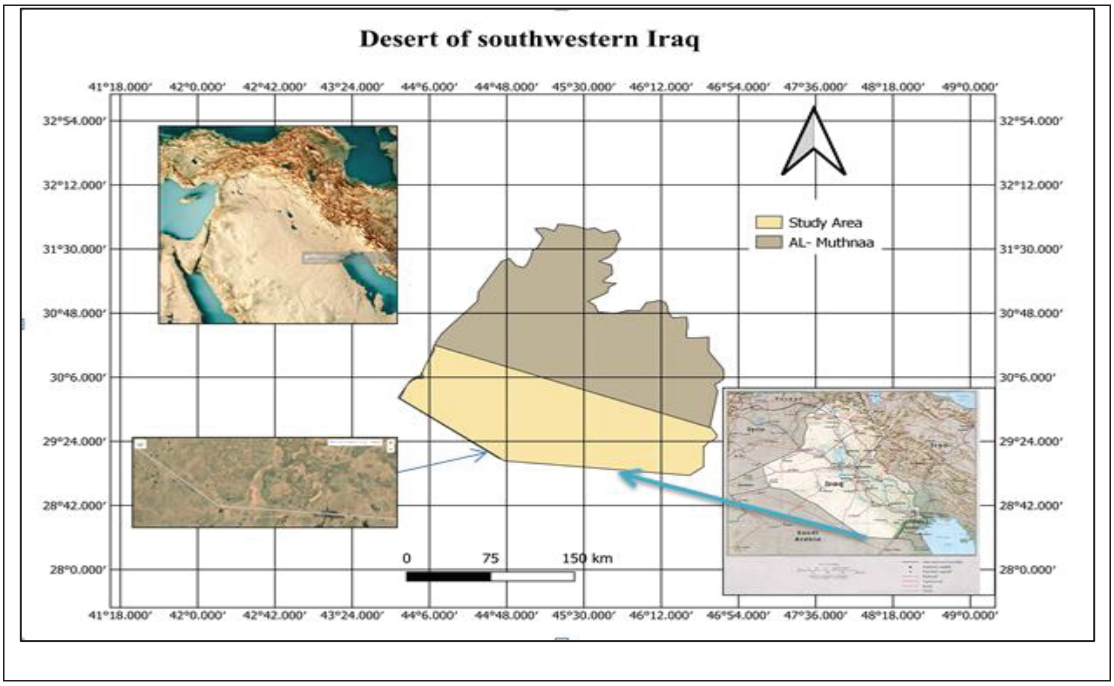
HH, HV, VV, and VH, and the incidence angle of this satellite is 29.1°–46°. IW mode is Sentinel-1's primary picture configuration for interferometry. The swath width in this case is 250 kilometers. The spatial resolution is 5 meters in the azimuth direction and 20 meters in the range direction [7]. Because of these important qualities, Sentinel-1 images have a lot of promise for DEM creation. [8]. The purpose of this study is to verify the importance and accuracy of using InSAR in generating DEM to contribute to the creation of a terrain map to cover desert lands in the study area in southwestern Iraq.

2 Materials And Method

2.1 The area of Study

The area of interest is existing in the southwest of Iraq within the Governorate of Al-Muthanna. (29°02′17.91″N; 46°25′43.54″E). The study area is characterized as a desert area containing dunes with flat terrain and equal in level in most of its areas, with an average elevation about of 326 m. Since the terrain of this area is part of the sedimentary plain in Iraq, it is rare to see heights in it except for some sandy hills that cover unexcavated archaeological sites. The study area extends over an area of 25,000 km2. The climate of this region is characterized by hot and dry summers, with temperatures reaching 50 degrees in July and August. In winter the climate is cool and sometimes rainy, and the temperatures are in December and January. February could reach 3 degrees below zero. Figure 1 depicts the study region in southwestern Iraq.

Figure 1. The study area in the desert of Southwestern Iraq.



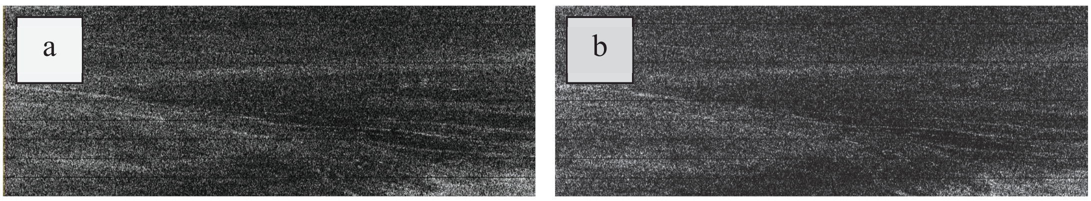
2.2 Data Acquisition and Method

Sentinel-1A Synthetic aperture radar images were used. These were obtained by radar sensors onboard the satellite S-1A operating in C - band (5.405 GHz central frequency, and 5.547 cm wavelength), which are phased at 180 with Sentinel-1B along the same near-polar, sun-synchronous orbit at 693 km altitude [9][10]. A pair of SAR data (Sentinel-1A) with a temporal interval of 12 days, and the length of the perpendicular baseline is 152 m, taken in 2015, was utilized to create the DEM. To reduce atmospheric effects and temporal decomposition, a short temporal baseline was used. The photos were taken at night time to achieve a good coherence, as well as a Descending track. The acquisition mode IW was used, which is based on the TOPS Scan SAR [11]. The IW sweep width was 250 km, and the LOS (line-of-sight) incidence angle ranged between 31 and 46 degrees from near to far range (i.e., 39 degrees at scene center). The pixel spacing was 2.3 meters in slant range and 14.1 meters in azimuth, resulting in ground range and azimuth resolution of 5 meters and 20 meters, respectively. Sentinel-1 IW images were taken in this study with vertical polarization VV. Table 1 lists the picture details, and figure 2 depicts the raw Sentinel-1A photos (slave and master) of the research region obtained at various times.

Table 1. The Images Characteristics

Dataset	Satellite	Acquisition Date	Data Type/Mode	Pass Direction	Remark
Image1	Sentinel1-A	13/7/2015	SLC-IW	Descending	Quick-Look
Image2	Sentinel1-A	25/7/2015	SLC-IW	Descending	

Figure 2. Raw images of Sentinel-1A for the study area in southwestern Iraq.



Back geocoding was used for co-registration, and ESD was used to produce the AOI interferogram when precise orbit data was implemented [12], followed by TOP Split, which condenses the single look complex image into a single sub-swath and a set of bursts [13], as well as interferogram generation (including flat-earth phase removal). Coherence was also calculated during the interferogram construction. The product is then de-burst to easily combine all of the burst info into a single picture [14]. Then, using Multi-Looking and Goldstein Filters, apply various filters to the interference diagram to aid in the accurate completion of the unwrapping process [5]. The snaphu is the mean statistical-cost network-flow algorithm for phase unwrapping, and it is an independently licensed utility that performs phase unwrapping outside of the Sentinel Application Platform [15]. The unwrapped phase is then imported into the Sentinel Application Platform, where it is converted to metrical units using an external reference digital elevation model [16], and geocoded using the terrain correction [1]. The transformed output was geocoded into the WGS 84 and exported while still in radar geometry to Google Earth as well as to QGIS for post-analysis and visualization. Figure 3 illustrates a procedure for generating DEMs from Sentinel-1A/B SLC picture pairings.

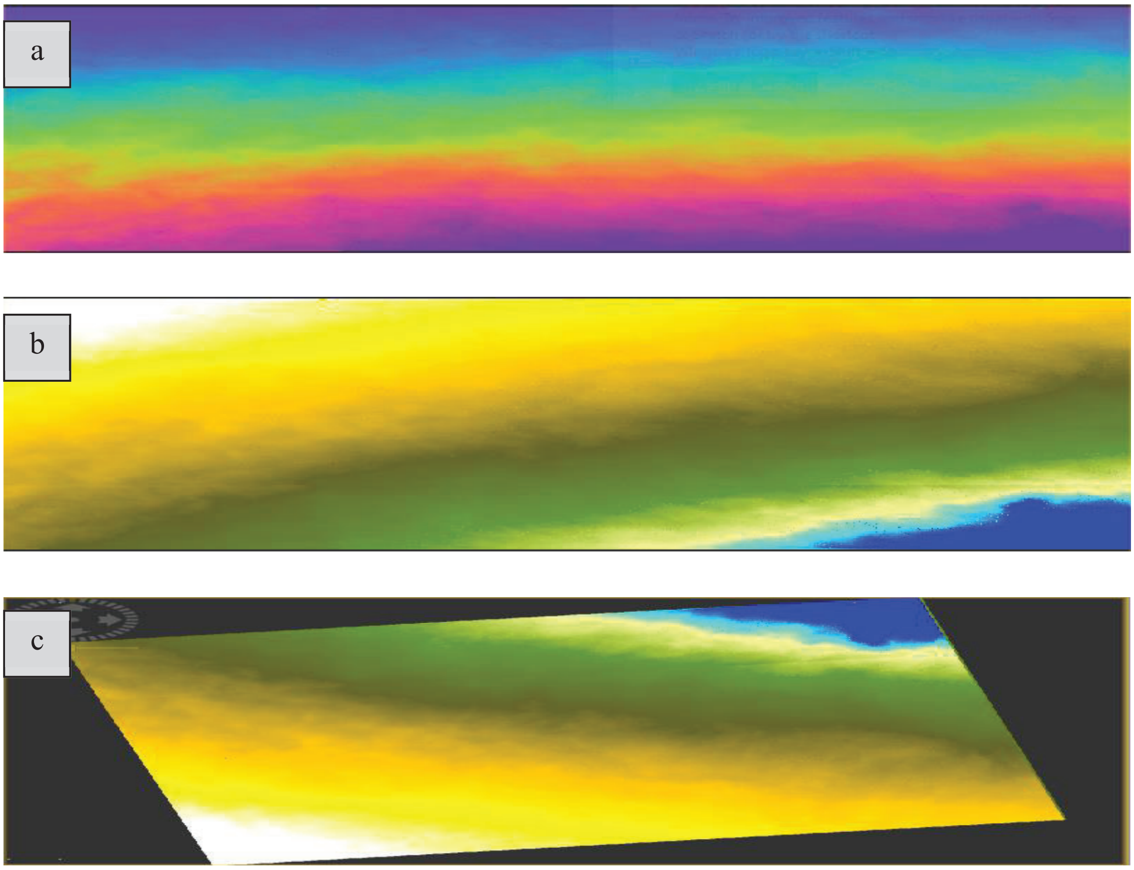
Figure 3. The standard Interferometry Processing workflow within SNAP software

3 Results and Discussion

InSAR is an active remote sensing approach founded on the idea that the information contribution conveyed by the phase difference between two or more synthetic aperture radar pictures looking at the same scene from comparable geometries can be exploited due to the very high stability of satellite orbits [17][1][18]. On the other side, Sentinel-1 is carrying SAR sensor equipment with a center frequency of 5.405GHz which covers the C-band of the spectrum [6]. The revisiting duration is 6 days and S-1 can acquire SAR images with different types of polarizations such as HH, HV, VV, and VH, with the spatial resolution being 5 m in the azimuth direction and 20 m in the range direction [19]. According to such valuable features, Sentinel-1 images have a high potential for DEM generation [15]. In addition, a high degree of coherence between the two pictures acquired is essential, and it is also advised that the acquisition periods for the pair of synthetic aperture radar images be close in time to reduce coherence loss [20].

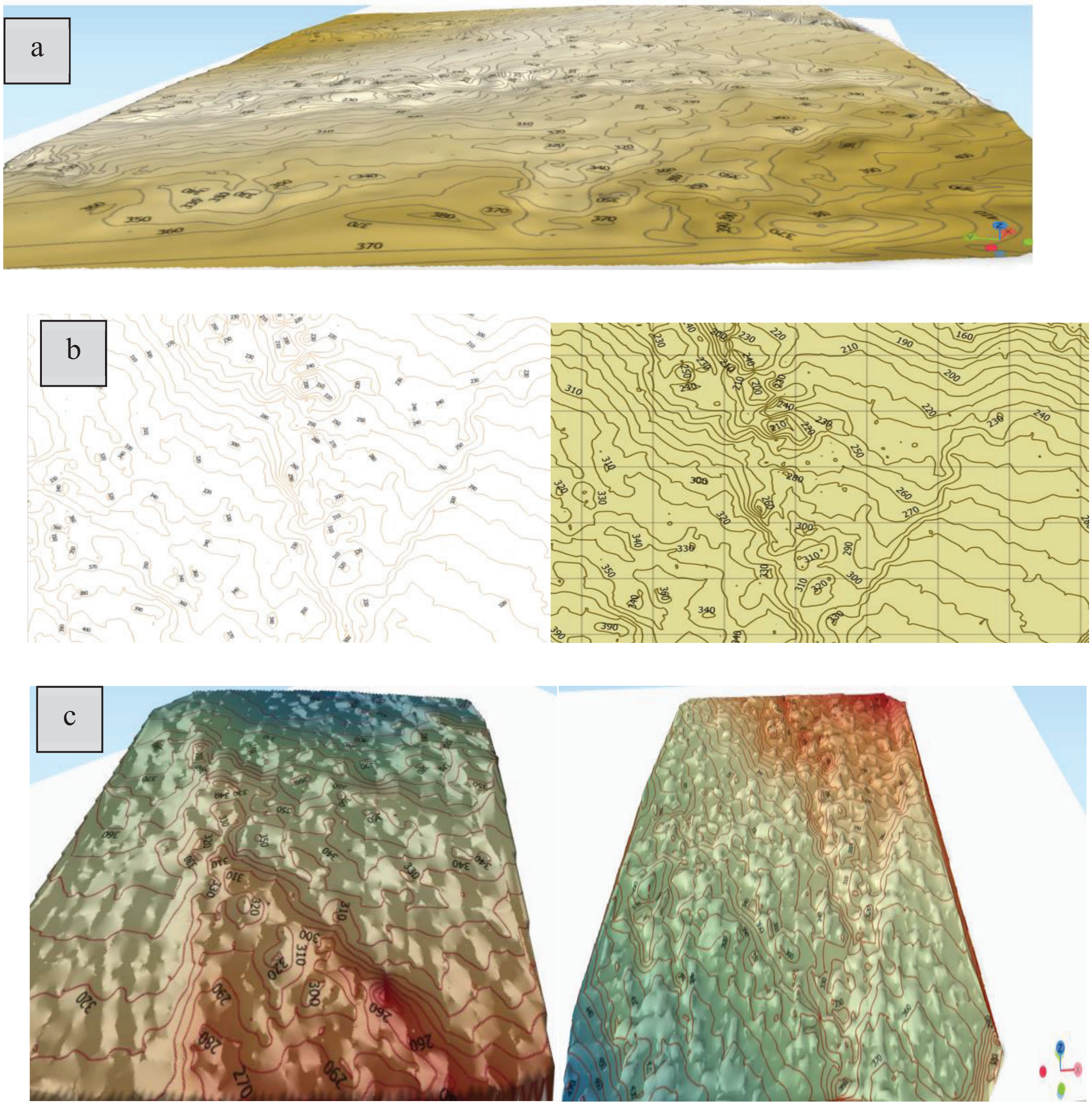
The result after unwrapping appears in Figure 4, a this is how the unwrapped phase looks, Where it is noted through the product image the extent of purity of the product after unwrapping, which is an indicator of the success of unwrapping the interferogram, which is a good indicator of the accuracy of the results in the future. To construct the digital elevation model, the unwrapped phases were transformed to height and then geocoded. Figure 4, b shows the product after converting to elevation, and figure 4, c shows the product after making the geometric correction on it. The values are in meters and indicate the surface heights along the LOS. The line-of-sight between a sensor and a pixel is called the line-of-sight. It creates an output that resembles that of the unwrapped phase (a slightly different predetermined color ramp), but each pixel now contains a metric value showing its height above sea level.

Figure 4. (a) The stack after unwrapping, (b) the product after convert to elevation, (c) After Terrain Correction



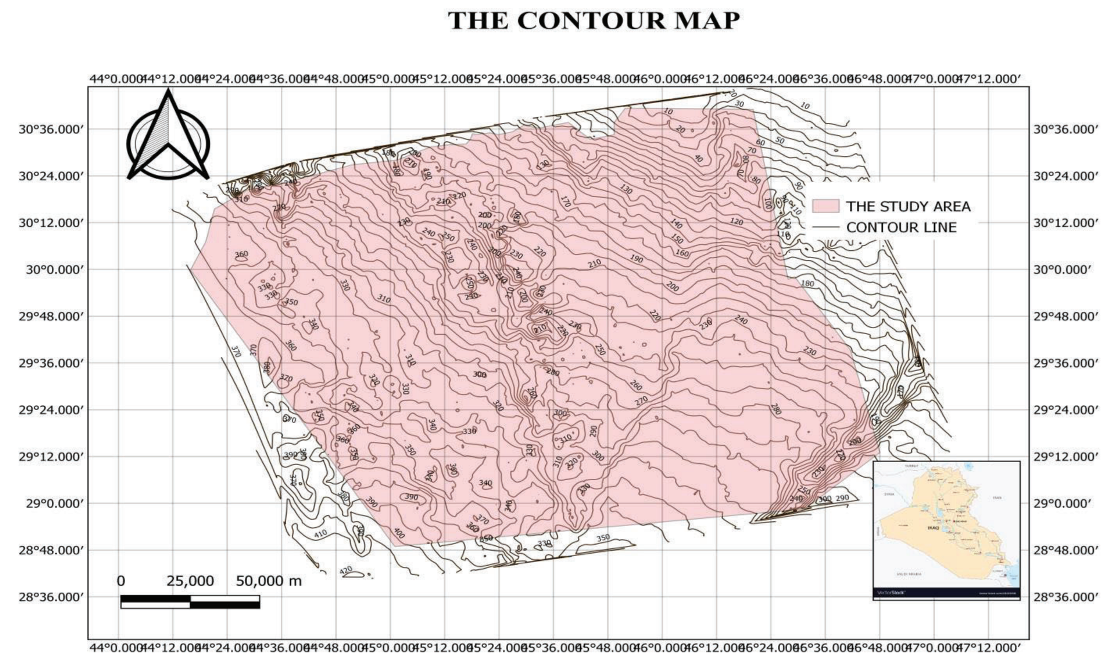
With the help of QGIS and ArcGIS software, a digital elevation model of the area of interest is created with contour lines that show the variations in elevations in the area of interest, as shown in figure 5, a. In the same context, the product with the contour lines is shown in Figure 5, b, and the result with the representation of the hill shadow of the derived DEM in figure 5, c.

Figure 5. (a) The DEM for the study area, (b) The contour line , (c) hill shadow of the derived DEM.



As for the contour map of the study area, the data of the digital elevation model generated by InSAR technology with the study site was used to form the contour map using the QGIS program, as shown in figure 6 shows the contour map of the site of interest.

Figure 6. The contour map of the Southwestern Desert of Iraq using the interferometry method.



The results were acquired in this study by combining the InSAR approach with Sentinel -1A SAR data and open-source for the Sentinel Application Platform SNAP software tools to demonstrate its capabilities to generate DEM. The key limiting variables in the proper implementation of Sentinel-1 SAR interferometry are geometric and temporal decor relations [21][5]. Geometric decor relation arises when the master and slave pictures' geometries do not match each other due to variations in look angle and non-parallel orbits [22]. Geometric decorrelation is more common in non-zero baselines. On the other hand, temporal decorrelation arises because the time difference between SAR measurements is mostly due to the Earth's dynamic surface changes. A shorter temporal baseline guarantees that these changes are associated with the SAR phase, thereby reducing temporal correlation, so to limit the phase signal caused by topography, a shorter perpendicular baseline is preferred. In addition to these decorrelations, atmospheric disturbances impact the propagation of SAR signals [14]. As Sentinel-1 approaches the edge of the atmospheric window, the proportion of short wavelength to the size of water molecules increases, making it vulnerable to atmospheric effects, the electromagnetic wave is delayed and accelerated by the troposphere and ionosphere, respectively, resulting in inaccurate elevation calculations. In hilly areas, geometric distortions such as layover, foreshortening, and shadowing may cause miscalculations [23]. It is noted that the digital elevation model generated by this technique and for the study area is a consistent model due to several reasons, the most important of which is that the period for the acquisition of the master and slave images was short and did not exceed 12 days, as well as that the perpendicular baseline did not exceed 152 m, and the acquisition period was completed In the summer, rain is rare in such areas at that time. All these factors contributed to obtaining an accurate DEM with an amount of uncertainty commensurate with the accuracy of this technique, which in ideal conditions is about 20 m.

4 Conclusion

One of the most prevalent approaches is to generate digital elevation models using the synthetic aperture radar interferometry methodology, which is particularly fascinating for geosciences researchers. The goal of this study was to employ the InSAR approach to create a digital elevation model using S-1A pictures, and use it to generate a terrain map for the study region in southern Iraq. The results of the DEM obtained for the region of interest were satisfactory, especially when compared with the elevations for the RTK-GCP to verify the precision of the digital elevation model produced, as the elevations of that region were produced with medium accuracy. It is worth mentioning that the true potential of the SAR rests on the use of phase information, which permits terrain variation to be measured using synthetic aperture radar interferometry. Finally, through verification and analysis of the obtained results, it was found that the InSAR technique is very suitable for producing precision DEMs in a short time, especially for desert areas or those that do not contain vegetation cover.

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