DIGITAL ELEVATION MODEL IN SOUTHWESTERN DESERT OF IRAQ USING INTERFEROMETRY METHOD FROM SENTINEL-1A IMAGES

MURTADHA ARYAN MENEKHER

UNIVERSITI TEKNOLOGI MALAYSIA

DIGITAL ELEVATION MODEL IN SOUTHWESTERN DESERT OF IRAQ USING INTERFEROMETRY METHOD FROM SENTINEL-1A IMAGES

MURTADHA ARYAN MENEKHER

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of science (Remote Sensing)

Faculty of Built Environment and Surveying
Universiti Teknologi Malaysia

13 FEBRUARY 2022

DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Dr. ABD WAHID BIN RASIB , for encouragement, guidance, critics and friendship. Without their continued support and interest, this thesis would not have been the same as presented here.

My fellow student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

ABSTRACT

One of the essential goals of remote sensing applications is to create a highly accurate digital elevation model. Synthetic aperture radar Interferometry (InSAR) is a popular three-dimensional imaging technique for creating a Digital Elevation Model (DEM). The phase difference between the complex SAR images creates an interference fringe pattern that may be used to calculate the elevation of any point on the observed landscape. The use of traditional methods for creating DEMs and drawing terrain maps, which require Costly and time-consuming, has clearly affected the creation and updating of terrain maps in Iraq. This study aims to use InSAR technology to easily create accurate DEMs that contribute to the generation and updating of terrain maps periodically. In this study, the synthetic aperture radar interferometry approach was used on the interference stack generated from a pair of Sentinel-1A images 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 in the region of interest. The results obtained from this study is 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 (RMSE) of the DEM was 8.17, and The Mean Absolute Error (MAE) is 8.31. The results were analysed using F-Test, T-Test, and Chi-Square Tests, and the results of the statistical analysis showed that there are no significant variances in the levels of the errors between the values of RTK-GCPs and the values of elevations of the generated digital elevation model. The output proves the authenticity with the precision of the used Sentinel-1 image for synthetic aperture radar interferometry technique to DEM generation which is of great importance for the knowledge of terrain features and for accurate terrain mapping with a short time compared to the old traditional methods.

ABSTRAK

Salah satu matlamat penting aplikasi penderiaan jauh adalah untuk mencipta model ketinggian digital yang sangat tepat. Interferometri radar bukaan sintetik (InSAR) ialah teknik pengimejan tiga dimensi yang popular untuk mencipta Model Ketinggian Digital (DEM). Perbezaan fasa antara imej SAR kompleks mencipta corak pinggir gangguan, boleh digunakan untuk mengira ketinggian mana-mana titik pada landskap yang diperhatikan. Penggunaan kaedah tradisional untuk mencipta DEM dengan melukis peta rupa bumi memerlukan kos yang tinggi serta memakan masa telah menjejaskan penciptaan dan pengemaskinian peta rupa bumi di Iraq. Kajian ini bertujuan untuk menggunakan teknologi InSAR bagi mencipta DEM yang tepat, mudah dalam menyumbang kepada penjanaan dan pengemaskinian peta rupa bumi secara berkala. Dalam kajian ini, pendekatan interferometri radar apertur sintetik digunakan pada timbunan gangguan yang dijana daripada sepasang imej Sentinel-1A untuk menjana DEM dan peta rupa bumi kawasan padang pasir di barat daya Iraq. Model ketinggian digital dibandingkan dengan ketinggian RTK-GCP di kawasan yang diinginkan. Hasil yang diperolehi daripada kajian ini ialah peta rupa bumi dengan garisan kontur dihasilkan daripada model ketinggian digital dan teknik InSAR dengan ketepatan 18 m dengan ralat min kuasa dua punca (RMSE) DEM ialah 8.17, dan min ralat mutlak terkecil (MAE) ialah 8.31. Keputusan dianalisis menggunakan Ujian-F, Ujian-T, dan Ujian Khi Kuasa Dua, dan keputusan analisis statistik menunjukkan bahawa tidak terdapat perbezaan yang signifikan dalam tahap ralat antara nilai RTK-GCP dan nilai ketinggian model ketinggian digital yang dijana. Keputusan membuktikan ketulenan dengan ketepatan imej Sentinel-1 yang digunakan dalam teknik interferometri radar apertur sintetik kepada penjanaan DEM sangat penting untuk pengetahuan ciri rupa bumi dan untuk pemetaan rupa bumi yang tepat dengan masa yang singkat berbanding kaedah tradisional lama.

TABLE OF CONTENTS

LIST OF TABELS

LIST OF FIGURES

LIST OF ABBREVIATIONS

DEM	-	Digital Elevation Model
SAR	-	Synthetic aperture radar
InSAR	-	Interferometry synthetic aperture radar
DInSAR	-	Differential Interferometry
SNAP	-	Sentinel Application Platform
SRTM	-	Shuttle Radar Topography Mission
DSM	-	Digital Surface Model
DTM	-	Digital Terrain Model
ESD	-	Enhanced Spectral Diversity
TOPS	-	Terrain Observation with Progressive Scans
IW	-	The Interferometric Wide (IW) swath
ASF	-	Alaska Satellite Facility
LOS	-	Line-Of-Sight
SLC	-	Single Look Complex
TIN	-	Triangular Irregular Network
ESA	-	European Space Agency
DN	-	Digital Number
RTF	-	Radiometric Terrain Flattening
WGS84	-	The World Geodetic System 1984
UTM	-	Universal Transverse Mercator

GCP	-	Ground Control Points
AOI	-	Area of Interest
QGIS	-	Geographic Information System (GIS) Software
RMSE	-	Root Mean Square Error
SD	-	Standard Deviation
MAE	-	Mean Absolute Error

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

A prominent 3D imaging approach for constructing a Digital Elevation Model is radar with a synthetic aperture Interferometry (InSAR) (Maryam and Beth, 2013). SAR is a microwave imaging method that operates at all hours of the day and night since it is an active system with cloud-penetrating capability. Because it is coherent, interferometry SAR, or InSAR, provides perfect measurements of the radiation travel route. The measurements of path travel changes as a result of the satellite's location and acquisition time enable the construction of DEM and measurement of accurate surface deformations of the terrain (Braun, 2019). The DEM is one of the most important technologies to know the differences in elevations of the terrain, as the advanced digital terrestrial, aerial, and satellite technology have contributed greatly in this field. (Julzarika and Harintaka, 2019). DEM is a word that refers to all types of topographic digital covering data and the approach for evaluating the implications of elevations between measurements (Maune and Nayegandhi, 2018). A digital surface model, on the other hand, is a depiction of the top of reflective surfaces such as buildings and plants

(Jurjevic et al., 2021). DTMs are digital representations of topographic surfaces and other topographic characteristics (Li et al., 2005). The terms "digital terrain models" (DTM) and "bare-earth DEM" are interchangeable (Maune et al., 2001). There are various ways for creating DEMs, including SAR Interferometry (InSAR), Differential Interferometry (DInSAR), Triangular Irregular Network (TIN), stereo, LIDAR, and combining DEMs (fusion and integration). The InSAR approach is one of the most essential (Julzarika and Harintaka, 2019).

Interferometry synthetic aperture radar (InSAR) collects information about the earth's surface by using the phase difference between two complex radar SAR scans collected from slightly different sensor sites (Braun, 2021). Under certain conditions, InSAR can detect and track ground deformations with the centimeter scale, making it a useful tool for analyzing them through large areas (Raucoules et al., 2009). On the other side, the differential synthetic aperture radar Interferometry is the strong R.S technology founded on the contribution carried by the band difference between two or more Synthetic aperture radar data for the same area from similar geometries can be exploited due to the high stability of satellite orbits (Ferretti et al., 2007; Braun, 2019; Veci, 2020). The combination of the vast data group and a multi-pass Differential synthetic aperture radar Interferometry technique allows for a more accurate assessment of atmospheric contribution and topographic phase component, as well as a reduction in error sources (Yu, C et al., 2020). DInSAR is the term used to describe the process of removing the topographic component from interferograms. However, the phrase might be deceptive at times because, on the one hand, the subtraction process, on the other hand, maybe pushed farther and in different directions, as interferometry is a differential method from the start (e.g. subtraction of an expected geophysical contribution through an earthquake or volcano dynamic modeling). DInSAR efficiently aids in the detection of changes in the topography of the Earth's surface throughout time by creating digital elevation models for such periods (Ferretti et al., 2007).

Interferometry Synthetic Aperture Radar technology has provided many interested in terrain mapping the ability to create terrain maps with accuracy commensurate with the parameters of each area to be created (Veci, 2020), by taking advantage of the three-dimensional imaging method for SAR because it is a form of radar. Which is used to create two-dimensional images or three-dimensional images (Braun, 2021). SNAP tools contribute to the formation of an interferogram from two SAR images to create a digital elevation model, which is then used to form a terrain map with the help of the QGIS software (Jurjevic et al., 2021). The nature and topography of the area for which DEM is to be established affect the accuracy of the results, as the accuracy of the results of digital elevation models for mountainous areas, differs from that of flat ones (Ghannadi et al., 2020), and the accuracy of the application of the InSAR technology in areas with vegetation cover is affected by those that are barren and arid depending on the wavelengths of the satellites used to apply this technique (Nuthammachot et al., 2020). In the same context, InSAR technology is a promising technology in terrain mapping because of its many advantages in creating accurate digital elevation models that contribute to the creation of terrain maps at an ideal cost and time, in contrast to the prevailing traditional methods that require more time and effort, which made it difficult to create terrain maps and thus affected Negatively update the previous maps (Varoujan and Saffa, 2015).

Sentinel-1A/B, on the other hand, is a series of satellite radar observations developed jointly by the European Union and the ESA. S-1A was launched in 2014, and its data has been available to the general public since October 2014. This concept combines the S-1A and S-1B platforms on an orbital plane with a 180-degree phase difference (between A and B). Sentinel-1 is equipped with SAR sensors that operate at a frequency of 5.405 GHz, covering the C-band of the spectrum (Nuthammachot et al., 2020). Sentinel-1 can gather SAR images with multiple types of polarizations such as HH, HV, VV, and VH after a 6-day revisiting period. This satellite's incidence angle is 29.1°–46°. Sentinel-1's principal image setting for interferometry purposes is IW mode. In this case, the swath width is 250 kilometers. In the azimuth direction, the spatial resolution is 5 meters, and in the range direction, it is 20 meters (Yague et al., 2016). Sentinel-1 photos offer significant potential for DEM production because of these valuable properties (Mohammad et al., 2020). The purpose of this study is to investigate the importance and accuracy of using InSAR in generating DEM to cover the desert lands of the study area in Muthanna Governorate, which is the least expensive alternative to conducting field surveys that require a great time and cost to complete, which gives this research its importance.

1.1 Background of the Study

InSAR is similar to DEM generation in that it uses the phase difference amidst two SLC SAR scans acquired from a little different sensor's sites to retrieve data about the ground's face (Ghannadi et al,. 2020). S-1's Interferometry Wide swath mode is the primary acquisition mode above ground, and it plays a significant role in completing this mission with high precision (Braun, 2019), hence the InSAR approach, which uses Sentinel-1A/B data and SNAP software, is more successful than SRTM for obtaining the most accurate DEM production measurements. In addition, the methods used to generate DEM maps and topographic maps in Iraq today are the traditional survey methods based on traditional field surveys that contain many gaps that affect the generation of accurate digital elevation models DEMs. Also, the continuous and rapid changes in the topography as well as in the terrain of the lands in Iraq require continuous updating of the terrain maps, so creating a DEM using InSAR technology contributes effectively to the construction and update of terrain maps with appropriate accuracy and in a shorter time and cost.

1.2 Problem Statement

Terrains refer to the natural features, relief, and man-made features that exist on the ground's surface. Cartographic rules are used to represent all of them in the topographic map (Luh et al., 2014). Three-dimensional terrain analysis provides a comprehensive perspective of ground surface topography and landscape representation (Thannoun et al., 2021). In poor countries, there are few accurate maps available. Accurate mapping typically necessitates expensive technology and fieldwork, both of which are unavailable in many nations, especially given the grave security situation (Mohammed et al., 2017). The process of updating maps using the traditional methods now in use in Iraq is an expensive and time-consuming operation. In Iraq, the traditional topographical mapping approach has many flaws that make it an expensive and time-consuming process. The traditional method is based mostly on field surveys, in which data on natural land levels are estimated and gathered using GPS ground control points located near the areas of interest (Varoujan et al., 2012). This work is time-consuming, expensive, and demands a lot of effort. Furthermore, due to the movement of dunes, which are widespread in desert environments, topographical changes occur frequently and rapidly (Manzoni et al., 2021). This necessitates continuous monitoring and updating of DEMs for such areas, which is impossible due to the long time it takes to create DEMs using the traditional method.

As a result, the Iraq Geological Survey is committed to updating the published geological maps almost regularly and as data becomes available (Varoujan and Saffa, 2015). The Geological Map of Iraq, at a scale of 1: 1000 000, is one of the newly updated maps. The 4th edition (Sissakian and Fouad, 2012) is the most recent (Appendix A). In the same vein, Iraq's Office of Military Survey provides 1:100,000 scale maps of all of the country's regions, although they aren't sleek enough and haven't been updated in a long time. SRTM data was also provided by the US military to the Ministries

(Mohammed et al., 2017). However, since the spatial resolution of the SRTM is 30 m, obtaining a high spatial resolution using InSAR technology with the Sentinel -1 contributes strongly to the production of accurate terrain maps with the spatial resolution reach to 20m in the optimum situation. As the requirements for the application of this technology are available free of charge to the public through the use of the SNAP program and the Sentinel-1 data download sites supported by the ESA. In Iraq, a variety of topographical map-making techniques have been used, including Shaded Relief Maps. The terrain hill shade is a function that is affected by the aspect and slope of the terrain and is similar to the elevation difference raster (Mukul et al.,2017). This method, which calculates the value of changing both the vertical angle (altitude) and the horizontal angle (azimuth) of the sun to estimate the shadow of each image, is ineffective in Iraq's central and southern regions and lacks the essential accuracy. Slope maps, on the other hand, are based on the amount of elevation variation in a certain area (Choanji, 2016). It is mostly determined by the parameters of the region's DEM (Thannoun et al., 2021).

Because more than 75% of Iraq's territory is flat or desert, using SAR data to create digital elevation models helps to produce accurate topographic maps for the vast majority of the country. It is easy to distinguish between contributions to the InSAR coherence due to the lack of flora in desert locations (Teresa and colleagues, 2017). Variations in soil moisture in the same situation. The radar interacts with a greater depth range in drier soils, and scatterers at deeper depths below the surface contribute more to the backscattered signal than in moist soils (Jordan et al., 2017; Scott et al ., 2017). All of these variables, such as a lack of or complete lack of vegetation cover, a dry environment, and a flat land surface, help to create a precision digital elevation model using the InSAR approach (Havivi et al., 2017). It's worth mentioning that the research area is a desert flat land with many ancient sites dating back over 7000 years that have yet to be investigated or utilized as worldwide tourist attractions. Furthermore, the study area, along with the southern areas in general, possesses the world's largest oil reserves. As a result, given the region's importance, a digital elevation model for these areas is urgently needed to aid in the updating of current maps and the resolution of numerous difficulties linked to the development of these areas and the optimal utilization of their resources. This research shows how the DEM created by the InSAR technology may be used to create a terrain map of the desert region of southern Iraq.

1.2.1 Issues Topographic Maps in Iraq

The Iraqi Geological Survey, which is dedicated to updating the maps on a regular basis, has not updated the maps in about seven years due to recent events and insecurity in many parts of Iraq (Varoujan and Saffa, 2015). The last time the topographical maps of Iraq were updated was in 2012 when the fourth edition geological map was revised and developed at a scale of 1:1000000 (Sesakian and Fouad, 2012). The following materials were utilized to accomplish the upgrade: (Varoujan et al., 2012)

- **i.** The results of extensive geological mapping carried out from 2001 to 2012.
- **ii.** Using 19 Quick bird and Landsat pictures of various sizes and across different coverage regions.
- **iii.** Using 93 Google Earth photos (A4 size), at various sizes and with varying coverage regions.
- **iv.** Conducting 37 field inspections in Iraq's northern, northeastern, eastern, and southern regions between 2006 and 2012.

The 4th Edition of the Geological Map at 1: 1000 000 scales (Sissakian and Fouad, 2012) (Appendix A) differs significantly from the 3rd edition (Sissakian, 2000). Many topographical changes were seen at that time, particularly in the desert areas, which make up the majority of Iraq's regions (Al-Safi et al., 2012; Zaini et al., 2012).

One of the most significant issues influencing the process of updating maps in Iraq is the expense connected with the time component, such as field visits to perform field surveys, which demand a significant amount of money and time (Varoujan et al., 2012). This was the biggest impediment to Iraqi maps being updated regularly. It's worth mentioning that the precision of the work in the desert areas was not up to par, since these locations have a volatile and extremely hot climate in the summer and extremely cold environment in the winter, affecting the accuracy of the data in those places significantly (Ajar et al., 2011). Furthermore, the topography of such locations was profoundly influenced by the continual movement of dunes in those areas according to the direction of the winds (Al-Safi et al., 2012; Zaini etal., 2012; Al-Shuwaily et al., 2012). With the advancements in remote sensing technology, we believe there is a glimmer of hope in using this technology to create and update topographic maps of Iraq, through the use of InSAR technology to create the DEMs for the regions of Iraq that contribute to updating and exploring the topographical changes that occur continuously through data that can be obtained easily and at no cost from Europe (ESA).

1.2.2 The Issue with the Topographic Update in Iraq

Over the last few years, Sentinel-1 photos have shown to be valuable in mapping and surveillance of otherwise inaccessible locations, such as desert areas in Iraq (Petrie, 2003). In several parts of the world, including Saudi Arabia, Alaska, and Indonesia, such photos have been used to update maps or create a whole new mapping (Daoudi et al., 2020). High-resolution satellite imagery can provide a speedy, high-quality data source for the generation of terrain maps to suit a range of purposes in these locations, such as Iraq, which typically lack the resources necessary to gather and edit aerial photos. In the same context, The updating of topographic maps in Iraq suffers from great obstacles as The Iraq Geological Survey is committed to updating the published geological maps nearly regularly and as new data becomes available. The Geological Map of Iraq, with a scale of 1: 1000 000, is one of the newly updated maps. This is the fourth edition of the book. The third edition (Sissakian, 2000) was published in 2000, whereas the first and second editions were published in 1986 and 1990, respectively (Jassim et al., 1986 and 1990). This weakness in updating the maps in Iraq has led to a deterioration in the accuracy of the existing maps, which do not accurately describe the topography of the lands, as many changes occurred on the lands that were not represented in the maps until now. In the southern desert of Iraq, the geology of the area extends from AL- Najaf to AL Nassiriyah, passing through the city of Muthanna along the Euphrates River, with a width of approximately (100-150) km, has changed (Varoujan and Saffa, 2013). About structural components and tectonics, all previously documented faults in the southern desert are shown in the revised geological map of Iraq in the Southern Desert, and/or by field checking excursions to the areas concerned. During the recent thorough geological mapping, were not discovered (Zaini et al., 2012; Al-Safi et al., 2012; Ajar et al., 2012; Al-Shuwaily et al., 2012). Therefore, due to the delay in updating the maps of the region, many changes occurred on the topography of the land, and that the maps were not updated. Hence, creating digital elevation models (DEMs) in a short time effectively contributes to the continuous updating of the topographic maps in Iraq.

1.3 Objectives of the Study

The aim of the study is to construct a terrain map for the area of interest using DEM extracted with InSAR technology from Sentinel-1A images, and the following is a list of the study's objectives:

i. To extract digital elevation model using interferometry method from sentinel-1 data for Southwestern Iraq.
ii. To produce a terrain map with the contour line from the digital elevation model created using sentinel-1 data for Southwestern Iraq.
iii. To analyze the digital elevation model extracted from sentinel-1 data for Southwestern Iraq.

1.4 Research Question

The research questions for this study are:

i. What is the precision of the DEM that is generated by the InSAR technology?
ii. What are the advantages of using the InSAR technique for creating accurate terrain mapping? and
iii. What are the effects of sand cover on the accuracy of the backscattered signal of Synthetic aperture radar?

1.5 Scope of the Study

The study's scope is restricted to creating the DEM, InSAR uses Sentinel Application Platform (SNAP), which was advanced and supplied by European Space Agency. The standard SLC synthetic aperture radar images recorded with C-band by the S-1 were used. The radar wavelength of this C band is 5.6 cm. IW mode with vertical polarization was used to capture the images (VV polarization). In terms of polarization for Sentinel data, due to the typically smaller amplitude of cross-polarized imagery, using VH data alone leads to worse performance in terms of candidates and final persistent targets identification (Shamshiri et al., 2018). In the same context, the use of the VV polarization for Sentinel images significantly improves performance due this polarization is characterized by a high backscattering (Azadnejad et al., 2019). The C-band was chosen in this study as it has a good penetration of a few centimeters to the surface that is good to represent the surface with good accuracy (Jose and Mehrez, 2016). Also, the small incidence angle for the Sentinel's signal is helpful to eliminate the geometric decor relation especially when we compare with the view direction of the X-band antenna and the high incidence angle for it (Sousa et al., 2016; Umut, 2013). In the same context, the time interval obtained between the two SAR images of Sentinel-1A with C-band is short and does not exceed 12 days, which effectively contributes to reducing the temporal decor relation. In contrast, the satellite that uses X-band has larger temporal baselines of at least 35 days that increase the temporal decor relation (Herrera et al., 2011; Sousa et al., 2016). The Sentinel-1, a two-satellite mission, is in a SUN-Synchronous, Near-Polar orbit. As a result, it passes over the AOI on a 12-day repetition cycle in both rising and descending flights This is considered one of the advantages that support the use of this satellite in the formation of DEMs, because the short re-visit period contributes effectively in eliminating or reducing temporal decor relation.

i. The purpose of this research is to create a terrain map of the area of interest with an area of 25000 square kilometers located in the southwestern of Iraq using the DEM extracted by InSAR technology from Sentinel-1A images.

ii. The application of the InSAR technology is investigated using a pair of images from Sentinel-1A in desert areas because the study area is a desert area, as well as knowing the most important challenges and advantages in using this technology in such areas.

iii. Acquisition of data for the study area is carried out in suitable weather conditions free from rain and snow, where the data (the master and slave images) were collected in the summer, as well as with an interval of 12 days and an orthogonal baseline with a length of 152 m to obtain good coherence results in the interferogram, thus obtaining DEM precise. Two satellite pictures (SLC) SAR acquired by the S-1A satellite were used. With the Interferometry Wide swath mode and co-vertical polarization, this radar wave wavelength is 5.6 cm as it descends with the C-band (VV). Apply orbit file, Radiometric calibration, De-bursting, Multi-looking, Speckle filtering, Terrain correction, and Convert to dB are the steps in the Sentinel-1A data pre-processing. Co-registration, Interferogram Formation, Coherence maps, Complex multi-looking Filtering, Goldstein Phase Filtering, Phase Unwrapping for InSAR DEM Reconstruction, Unwrapping with snaphu, and From Phase to Elevation and Terrain Correction were the main processing steps performed on Sentinel-1A data to generate the DEM for the study area.

iv. Using SNAP (Sentinel-1 Toolbox) software, the InSAR approach will be utilized to extract the DEM for the area of interest. The resulting retrieve heights are WGS84-referenced, resampled to a standard pixel spacing and translated into a coordinate system framework based on geographical coordinates or the Universal Transverse Mercator. As a result, the DEM will be created using the levels collected using the InSAR approach to build a digital elevation map of the area of study.

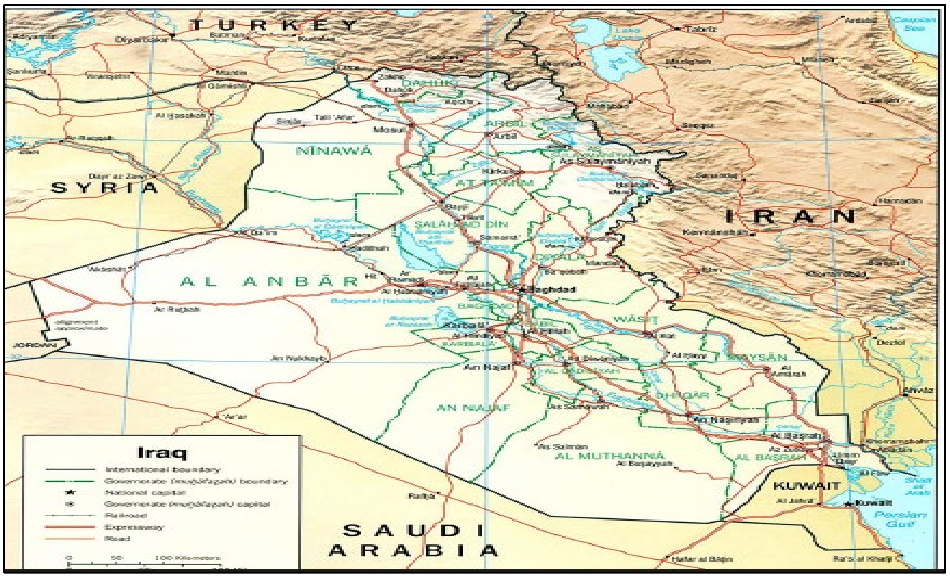
v. By comparing the results of the geocoding to the data, a quantitative and qualitative analysis of the results that were transferred to the WGS84 coordinate system was carried out. In terms of qualitative analysis, the degree of coherence in the interferogram between the two images of master and slave was used to determine the quality of the DEM created. To know and determine the accuracy of the work performed, a quantitative analysis was performed by comparing the elevations obtained from the DEM generated by the InSAR technique with the elevations of the RTK-GCPs for the region of interest.

1.6 Significance of the Study

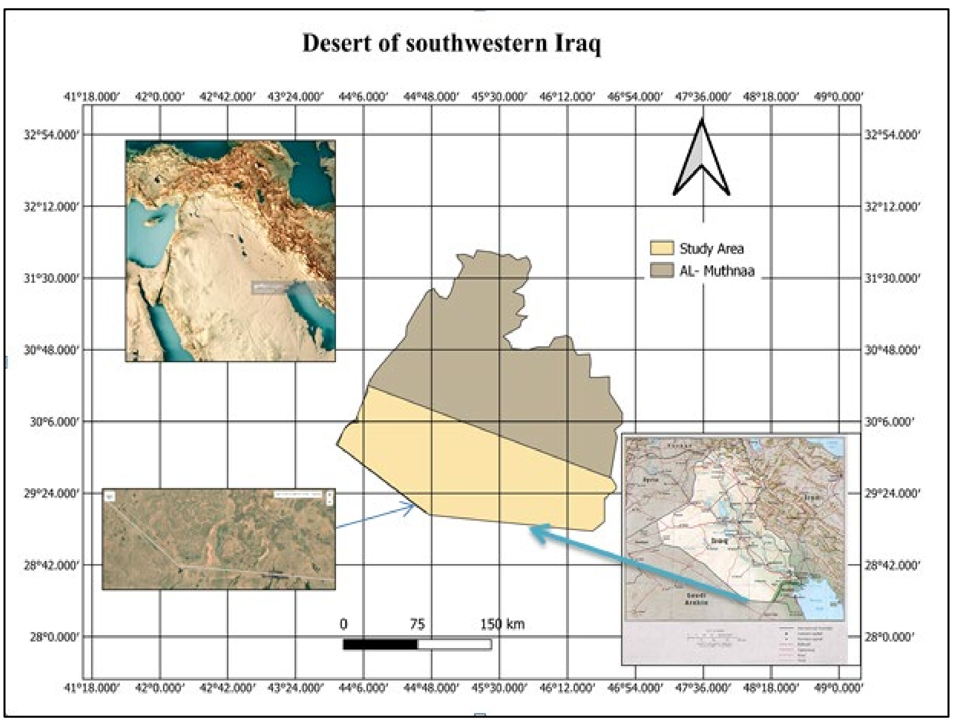
Because of its importance in demonstrating the appropriateness of the project sites' topography with the nature of those projects, the digital elevation model has gained tremendous importance in many infrastructure projects in Iraq. It is regarded as the basis for deciding the locations of many projects (Alaban et al .,2020). In the same context, the basic stage in defining the courses of roads and the locations of bridges for those roads is based mostly on the topography of the areas for which the road is to be constructed, so the Roads and Bridges Agency received the largest share of this benefit. The terrain and topography of the land play an important role in determining the best road routes (Jasim, 2019). In a similar vein, the Iraqi Agency for Oil Exploration uses the topography of the regions surrounding oil wells to choose extraction and refinement sites. In general, accurate digital elevation models (DEMs) generated by InSAR technology provide a precise description of the terrain of the land of interest. To determine how accurate the DEM elevations have described the terrain for the land of interest, the results were also compared with the GCPs. The speed with which the InSAR technology employing Sentinel-1A data and the SNAP platform can generate a DEM with high precision is one of the most essential elements of the technology, and this will effectively contribute to the cost of making maps of the region of interest.

1.7 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). Al-Muthanna state is considered one of the southern governorates in terms of geographical location and one of the governorates of the Middle Euphrates administratively. Where the study area is characterized as a desert area containing sand dunes with flat terrain and equal in level in most of its areas, with an average elevations 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. It extends over an area of 51,000 km2 and thus is the second largest governorate in Iraq in terms of area. It is bordered to the north by the governorates of Qadisiyah and Dhi Qar, to the south by the Kingdom of Saudi Arabia and the State of Kuwait, to the east by the governorates of Basra, and to the west by the Najaf governorate. The population of Al-Muthanna Governorate, according to the latest statistics, is about (650000) six hundred and fifty thousand people, and it is now approximately one million people. 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. This province is known for its abundant resources, the most important of which is oil. It was also an important agricultural location in Iraq due to its enormous arable land. It has gained great importance as a result of its vast areas and geographical location, which connects southern Iraq with the central and northern governorates, as well as being on the borders with Kuwait and Saudi Arabia. As a result, the government is now focusing on developing the exploitation of wealth in this region and establishing many important projects. Figure 1.1 (a) depicts a map of Iraq, while figure 1.1 (b) depicts the study region in southwestern Iraq.



(a)



(b)

Figure 1.1: (a) The Iraq Map, (b) The study area in the desert of Southwestern Iraq

1.8 Structure of Thesis

The general structure of this thesis, which deals with the creation of a terrain map for the southwestern region of Iraq by applying InSAR technique with Sentinel-1A satellite images, consists of five sections:

i. **Chapter One:** This chapter briefly describes the background that justifies the importance of conducting this research to create a DEM for terrain mapping. It also shed light on the current problems experienced by various sectors in Iraq, which depend in many of their projects on the nature of the topography of the land to present it as the problem statement. Then in order to address those gaps, the research objectives were identified, accompanied by research questions. The chapter also emphasized the scope and importance of the research to develop an accurate DEM that describes the topography of the area of interest in southern Iraq. Moreover, the feasibility of topographical mapping employing the DEM was confirmed which was generated by the InSAR technique by using the Sentinel-1A images.

ii. **Chapter Tow:** The second chapter includes a comprehensive survey of the kinds of literature related to theories, algorithms, and applications related to this study, and in particular, a literature review of desert regions to see the most important challenges facing the generation of a digital elevation model in such regions. The recent literature related to DEM generation using the InSAR method has been critically evaluated to obtain a set of important information. In addition, appropriate parameters and data used in the formation of DEMs were reviewed.

iii. **Chapter Three:** This chapter provides accurate details about the research methodology that includes the collection of raw data (SAR images) and the pre-processing of that raw data, and image processing to form the DEM for the study area using the InSAR technique.

iv. **Chapter Four:** The fourth chapter presents, discusses, and analyzes the results obtained from the research methodology to achieve the mentioned goals in drawing a terrain map based on the DEM generated by the InSAR technique using the Sentinel-1A satellite images and the SNAP software. Moreover, the generated model is implemented and demonstrated.

v. **Chapter Five:** The thesis concludes with the achievements of the objectives and useful suggestions and recommendations for future research work.

REFERENCES

A. O. Jain, T. Thaker, A. Chaurasia, P. Patel, and A. K. Singh. (2017). "Vertical accuracy evaluation of SRTMDEM-GL1, GDEM-v2, AW3D30, and CartoDEM-V3.1 of 30 m resolution with dual frequency GNSS for Lower Tapi Basin India,".1343392.

Ahmed Mutasim Abdalla Mahmoud, Alessandro Novellino, Ekbal Hussain, Stuart Marsh, Panagiotis Psimoulis, and Martin Smith. (2020). The Use of SAR Offset Tracking for Detecting Sand Dune Movement in Sudan. Nottingham NG12 5GG, UK.

Andreas Braun and Luis Veci, (2020). SAR Basics Tutorial. Copyright © 2020 Array Systems Computing Inc.

Andreas Braun. (2021). Retrieval of digital elevation models from Sentinel-1 radar data – open applications, techniques, and limitations. 72070.

ASTER NASA. Global Digital Elevation Model (GDEM). (2019). Accessed 15 May 2020.

Berardino, P.; Fornaro, G.; Lanari, R.; Sansosti, E. (2002). A new algorithm for surface deformation monitoring basedon small baseline differential SAR interferograms. IEEE Trans.

Bhuyian. N.M. Bhuyian, A.J. Kalyanapu, F. Nardi. (2015). Approach to digital elevation model correction by improving channel conveyance J. Hydrol. 1943-5584.0001020.

Bodart, C.; Ozer, A. (2007). The Use of SAR Interferometric Coherence Images to Study Sandy Desertification in Southeast Niger: Preliminary Results. European Space Agency, (Special Publication) ESA SP..

C. P. Scott, and R. B. Lohman & T. E. Jordan . (2017). InSAR constraints on soil moisture evolution after the March 2015 extreme precipitation event in Chile. 14853, USA.

Canadian Space Agency, 2014. (2016). RADARSAT-1. 21 March. (accessed 2016).

Canadian Space Agency, 2015. (2016). Satellite characteristics. 7. October. http://www.asc-csa.gc.ca/eng/satellites/radarsat/ radarsat-tableau.asp (accessed 2016).

Chaussard, E.; Amelung, F.; Abidin, H.; Hong, S.-H. (2013). Sinking cities in Indonesia: ALOS PALSAR detects rapidsubsidence due to groundwater and gas extraction. 2013,128, 150–161.

Chaussard, E.; Wdowinski, S.; Cabral-Cano, E.; Amelung, F. (2014). Land subsidence in central Mexico detected by ALOS InSAR time-series. Remote Sens. Environ. 2014.

Chen C, Liu F, Li Y, Yan C, Liu G. (2016). A robust interpolation method for constructing digital elevation models from remote sensing data. Geomorphology. 268:275–287.

Chen CW, Zebker HA. (2002). Phase unwrapping for large SAR interferograms: statistical segmentation and generalized network models. IEEE. 2002;40:1709–19.

Choudhari. P.P. Choudhari, G.K. Nigam, S.K. Singh, S. (2018). Thakur Morphometric based prioritizationof watershed for groundwater potential of Mula river basin, Maharashtra, India Geology, Ecology, and Landscapes. 256-267.

De Zan, F., and Guarnieri, A.M. (2006). TOPSAR: Terrain Observation by Progressive Scans. IEEE Trans.

De Zan, F., Parizzi, A., Prats-Iraola, P., López-Dekker, P., (2014). A SAR interferometric model for soil moisture. IEEE Trans. 52, 418–425.

Ding, C.; Zhang, L.; Liao, M.; Feng, G.; Dong, J.; Ao, M.; Yu, Y. (2020). Quantifying the spatio-temporal patterns of dune migration near. Environ. 236, 111498.

Duan Uys. (2016). InSAR: an introduction. Department of Earth and Planetary Sciences Macquarie University duan-hugo.uys@students.mq.edu.au

Elizabeth Loesch, and Vasit Sagan, (2018). SBAS Analysis of Induced Ground Surface Deformation from Wastewater Injection in East Central Oklahoma, MO 63108, USA.

El-Magd, I.; Hassan, O.; Arafat, S. (2013). Quantification of Sand Dune Movements in the South Western Part of Egypt, Using Remotely. Syst., 5, 498–508.

Engineering and Technology History. (2015). Synthetic Aperature Radar. (accessed 29 March 2016).

ESA. 2013. (2020). European Space Agency Sentinel-1 User Handbook, GMES-S1OP-EOPG-TN-13-0001. Available online: sentinel.esa.int/ (accessed on 26 February 2021).

ESA. Copernicus Open Access Hub. (2020) . https://scihub. copernicus.eu/. Accessed 150.5.2020.

Farkas, P., Hevér, R., Grenerczy, G., (2015). Geodetic integration of Sentinel-1A IW data using PS InSAR in Hungary. p. 13483.

Ferretti A, Monti-Guarnieri A, Prati C, and Rocca F. (2007). InSAR processing: part B: a practical approach. Noordwijk, The Netherlands: ESA Publications; 2007.

Ferretti, A. (2013). Satellite inSAR Data Reservoir Monitoring from Space. EAGE.

Ferretti, A., Fumagalli, A., Colombo, D., Novali, F., and Rucci, A. (2015). InSAR data for monitoring land subsidence: time to think big. Report, Milano: Open Access PIAHS.

Ferretti, A., Fumagalli, A., Novali, F., Prati, C., Rocca, F., and Rucci, A. (2011). A New Algorithm for Processing Interferometric Data-Stacks: SqueeSAR. IEEE Trans.

Ferretti, A., Monti-Guarnieri, A., Prati, C., Rocca, F., and Massonnet, D. (2007). InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation; TM-19; ESA Publications.

Ferretti, A., Prati, C., and Rocca, F. (2001). Permanent Scatterers in SAR Interferometry. IEEE Trans.

FU Bolin, LI Ying3, GAO Ertao, FAN Donglin, and LOU Peiqing. (2019). Study on accuracy assessment of DEM in the marsh using with interferometric PALSAR, Sentinel-1A and Terra SAR-X images. Changchun 130102, China.

G. Riegler, S. D. Hennig, and M. Weber. (2015). "WorldDEM–A novel global foundation layer," ISPRS Int. Arch. Photogramm. 183–187,

Gaber, A., Abdelkareem, M., Abdelsadek, S.I., Koch, M., and El-Baz, F. (2018). Using InSAR Coherence for Investigating the Interplay of Fluvial and Aeolian Features in Arid Lands: Implications for groundwater Potential in Egypt. Remote Sens.

Gatelli, F., Monti Guarnieri, A., Parizzi, F., Pasquali, P., Prati, C., and Rocca, F. (1994). The wavenumber shift in SAR interferometry. IEEE Trans. 1994, 32, 855–865.

Gens R, and van Genderen JL. (1996). SAR interferometry: Issues, techniques, applications. 1996;17:1803–35.

Gerardo Herrera Davide NottiI Juan Carlos Garcia- Davalillo Oscar Mora Geraint Cooksey Monica Sánchez Alain Arnaud Michele Crosetto. (2011). Analysis with C- and X-band satellite SAR dataof the Portalet landslide area. DOI 10.1007/s10346-010-0239-3.

Ghannadi MA, Saadatseresht M, Izadi M, and Alebooye S. (2020). Optimaltexture image reconstruction method for improvement of SAR image matching 1229–1235.

Ghannadi MA, Saadatseresht M, Izadi M, and Alebooye S. (2020). Optimaltexture image reconstruction method for improvement of SAR image matching. 1229–1235.

Gonzlez C, and Brutigam B. (2015). For InSAR-based DEMs. 8(11):5352–5360.

Grandin R. (2015). Interferometric processing of SLC Sentinel-1 TOPS data. FRINGE 2015; 23–27 March 2015. Frascati, Italy: European Space Agency; 2015.

GSI, 2004. (2016). History of inSAR. http://vldb.gsi.go.jp/sokuchi/sar/ mechanism/history01-e.html (accessed 2016).

Hakan A. Nefeslioglu, Beste Tavus, Melahat Er, Gamze Ertugrul, Aybuke Ozdemir, Alperen Kaya, and Sultan Kocaman. (2021). Integration of an InSAR and ANN for Sinkhole Susceptibility Mapping: A Case Study from Kirikkale-Delice (Turkey). 06800.

Hanssen R. (1998). Assessment of the role of atmospheric heterogeneities in ERS tandem SAR interferometry. 1998;12:137.

Hensley, S., and Rosen, P. A. S. (2001). Synthetic aperture radar interferometry: IEEE 88, no. 3 (November).

Hooper, A. 2008. A multi-temporal InSAR method incorporating both persistent scatterer and small baseline approaches.

Hu, J., Li, Z.W., Ding, X.L., Zhu, J.J., Zhang, L., and Sun, Q. (2014). Resolving three-dimensional surface displacements from InSAR measurements: A review.Earth Sci.

Huber M, Wessel B, Wendleder A, Hoffmann J, and Roth A. (2015). A framework for an automatical editing of TanDEM-X digital elevation models. (IGARSS).

IOGP. (2015). Geodetic referencing in Iraq. England and Wales. version 0.1. 209–215 Blackfriars Rd.

J. D. DeWitt, T. A. Warner, and J. F. Conley. (2015). “Comparison of DEMS derived from USGS DLG, SRTM, a statewide photogrammetry program, ASTER GDEM and LiDAR: implications for change detection,” Gisci. Remote Sens., vol. 52, no. 2, pp. 179–197, Mar. 2015.

Johannes Boer, Hauke Fiedler, Gerhard Krieger, Manfred Zink,, Markus Bachmann,, Jaime Hueso Gonzalez. (2008). “TanDEM-X: A Global Mapping Mission,”. 14-19, 2008, URL:

Jung-Rack Kim, Cheng-Wei Lin, and Shih-Yuan Lin. (2021). The Use of InSAR Phase Coherence Analyses for the Monitoring of Aeolian Erosion. Seoul 02504, Korea.

Karolina Owczarz, and Jan Blachowski. (2020). Application of DInSAR and Spatial Statistics Methods in Analysis of Surface Displacements Caused by Induced Tremors. 50-370Wrocław, Poland.

Keren Dai, Zhenhong Li, Roberto Tomás, Guoxiang Liu, Bing Yud, Xiaowen Wang, Haiqin Chenge, Jiajun Chen, Julia Stockamp. (2016). Monitoring activity at the Daguangbao mega-landslide (China) using Sentinel-1 TOPS time series interferometry. Chengdu 610031, China.

Kwarteng, A., Touzi, R., and Aljassar, H.K. (2000). Utilization of satellite SAR imagery for mapping sand dunes in Kuwait. Honolulu, HI, USA, 24–28 July 2000.

Lanari, R., Casu, F., Manzo, M., Zeni, G., Berardino, P., Manunta, M., and Pepe, A. (2007). An overview of the small baseline subset algorithm: A DInSAR technique for surface deformation analysis. Pure Appl. Geophys.

Lasswell, S. W. (2005). History of SAR at Lockheed Martin (previously Goodyear Aerospace). Proceedings of the Society for Photo-Instrumentation Engineers, 5788, 1–12.

Luh, L, C., H Setan, Z Majid, A K Chong, and Z Tan. (2014). High resolution survey for topographic surveying. 8th International Symposium of the Digital Earth (ISDE8).

M. Bartusch, H. J. Berg, O. Siebertz, “The TanDEM-X Mission. (2008). Proceedings of EUSAR 2008, 7th European Conference on Synthetic Aperture Radar, Germany.

Mandeville, P.A. Jakarta Maps get a Facelift, Imaging Notes, March/April 2001, (Accessed 28th April 2004)

Marcelo Cando Jacome, A. M. Martinez-Grana and V. Valdes. (2020). Detection of Terrain Deformations Using InSAR Techniques in Relation to Results on Terrain Subsidence (Ciudad de Zaruma, Ecuador). 37008 Plaza de la Caidos s / n., Spain.

Marcelo Cando-Jacome and Antonio Martinez-Grana. (2019). Determination of Primary and Secondary Lahar Flow Paths of the Fuego Volcano (Guatemala) Using Morphometric Parameters. 37008 Salamanca, Spain.

Marco Manzoni, Monia Elisa Molinari, and Andrea Monti-Guarnieri. (2021). Multitemporal InSAR Coherence Analysis and Methods for Sand Mitigation. 34/5, 20133 Milan, Italy.

Marios Tzouvaras, Chris Danezis, and Diofantos G. Hadjimitsis. (2020). Differential SAR Interferometry Using Sentinel-1 Imagery-Limitations in Monitoring Fast Moving Landslides: 3036 Limassol, Cyprus.

Maryam Rahnemoonfar, and Beth Plale. (2013). DEM Generation with SAR Interferometry Based on Weighted Wavelet Phase Unwrapping. Indiana University Bloomington, USA.

Massonnet, D., and Feigl, K. (1998). Radar interferometry and its application to changes in the Earth's surface. Rev. Geophys.

Massonnet, D., Rossi, M., Carmona, C., Adragna, F., Peltzer, G., Feigl, K., and Rabaute, T. (1993). The displacement fieldof the Landers earthquake mapped by radar interferometry.

Maune and Nayegandhi. (2018). Digital elevation model technologies and applications : the DEM user's manual.

Milillo, P., Giardina, G., DeJong, J.M., Perissin, D., and Milillo, G. (2018). Multi-Temporal InSAR Structural Damage Assessment.

Mohammad Amin Ghannadi, Saeedeh Alebooye, Moein Izadi & Amirreza Moradi. (2020). A method for Sentinel-1 DEM outlier removal using 2-D Kalman filter. Iran.

Mukul, M., Vinee,S., Sridevi,J., Malay,M. (2017). Uncertainties in the Shuttle Radar Topography Mission (SRTM) Heights. 7: 41672.

Nestor Yague-Martinez, Michael Eineder, Ramon Brcic, Helko Breit, Thomas Fritz. (2010). "TanDEM-X Mission: SAR Image Coregistration Aspects," Proceedings of EUSAR 2010, 8th European Conference on Synthetic Aperture Radar, June 7-10, 2010, Aachen, Germany.

Nestor Yague-Martinez, Pau Prats-Iraola, Fernando Rodriguez Gonzalez,Ramon Brcic, Robert Shau, Dirk Geudtner,Michael Eineder, and Richard Bamler. (2016). Interferometric Processing of Sentinel-1 TOPS Data. vol. 54, no. 4, april 2016.

Nuthammachot N, Askar A, Stratoulias D, Wicaksono P. (2020). Combined use of Sentinel-1 and Sentinel- 2 data for improving above-ground biomass estimation. Geocarto Int. 1–11.

Oday Zakariya Jasim. (2019). Using of machines learning in extraction of urban roads from DEM of LIDAR data: Case study at Baghdad expressways, Iraq. ISSN 2303-4521.

P. Hu, X. Liu, and H. Hu. (2009). "Accuracy assessment of digital elevation models based on approximation theory," Remote Sens., vol. 75, no. 1, pp. 49–56, Jan. 2009.

Pepe, A., and Calo, F. A. (2017). Review of Interferometric Synthetic Aperture RADAR (InSAR) Multi-Track Approaches for the Retrieval of Earth's Surface Displacements.

Petrie, G., 2003, "Monitoring Iraq – Imagery Options for Monitoring and Gathering Intelligence" in GI News January/February 2003

Plank, S. Rapid. (2014). damage assessment by means of multi-temporal SAR—A comprehensive review and outlook to Sentinel-1. Remote Sens.

Popiolek, E., Ostrowski, J., Czaja, J., and Mazur, J. (2001). The Impact of a Strong Mining Tremor on the Subsidence of the Area Surface in the Legnica-Glogow Copper Area. USA, 19–22 March 2001; pp. 77–80.

Qin, Y.; Hoppe, E.; Perissin, D. (2020). Slope hazard monitoring using high-resolution satellite remote sensing. Geo-Inf. 2020, 9, 131.

Qiong Wu, Chunting Jia, Shengbo Chen and Hongqing Li. (2019). SBAS-InSAR Based Deformation Detection of Urban Land, Created from Mega-Scale Mountain Excavating and Valley Filling in the Loess Plateau. Changchun 130000, China.

Raheem H Abed Alaban, Murtadha Sirhan Sachet, Heba Sahib Dakheel. (2020). Building a digital model to protect the city of Nasiriya from hydrological hazards by using topographic survey methods and GIS. DOI: 10.1007/978-3-030-32816-0_109.

Renganathan Mahesh, Kaladevi Jayadevan Sarunjith, Sam bandan Rajakumari, Ram akrishnan Muruganan dam, Ram a chandran Ramesh. (2021). Quality assessment of open sourced digital elevation models in southeast coast of India.ejrs.2021.03.006.

Richards MA. (2007). A beginner's guide to interferometric SAR concepts and signal processing. 2007;22:5–29.

Rozenstein, O., Siegal, Z., Blumberg, D.G., and Adamowski, J. (2016). Investigating the backscatter contrast anomaly in synthetic aperture radar (SAR) imagery of the dunes along the Israel–Egypt border. 46, 13–21.

Ryan Ramirez, Seung-Rae Lee, and Tae-Hyuk Kwon. (2020). Long-Term Remote Monitoring of Ground Deformation Using Sentinel-1 Interferometric Synthetic Aperture Radar (InSAR): Applications and Insights into Geotechnical Engineering Practices. Daejeon 34141, Korea.

Ryszard Hejmanowski, Agnieszka A. Malinowska, Wojciech T. Witkowski, and Artur Guzy. (2019). An Analysis Applying InSAR of Subsidence Caused by Nearby Mining-Induced Earthquakes. 30-059 Kraków, Poland.

S. Mukherjee, P. K. Joshi, S. Mukherjee. (2013). A. Ghosh, R. D. Garg, and A. Mukhopadhyay, "Evaluation of vertical accuracy of open source digital elevation model (DEM),". 205–217, Apr. 2013.

Santillan, J, R, and M. Makinano-Santillan. (2016). "Vertical accuracy assessment of 30-M resolution ALOS, ASTER, and SRTM global DEMS over Northeastern Mindanao, Philippines,". 149–156, Jun. 2016.

Schreier G. (1993).SAR geocoding: data and systems. Karlsruhe: Wichmann;; 1993.

Shimada, M. (2009). Advanced land-observation satellite (ALOS) and its follow-on satellite, ALOS-2. Proc. 26–30 January 2009, Frascati, Italy (ESA SP-668, April 2009).

Shiran Havivi, Doron Amir, Ilan Schvartzman, Yitzhak August, Shimrit Maman, Stanley R. Rotman, and Dan G. Blumberg1. (2017). Mapping dune dynamics by InSAR coherence. 84105, Israel.

Simons, M. and Rosen, P.A. (2015). Interferometric Synthetic Aperture Radar Geodesy. 339–385.

Solutions. (2019). Harris Geospatial ENVI SAR Scape, 5.4; Broomfield, CO, USA.

SUN Qian, ZHU Jian-jun, LI Zhi-wei, YIN Hong-jie, HU Bo, JIANG Mi. (2009). A new adaptive InSAR interferogram filter based on SNR [J]. 38(5): 437−442.

Sun, Q.; Hu, J.; Zhang, L.; Ding, X.L. (2016). Towards slow-moving landslide monitoring by integrating multi-sensor InSAR time series datasets: The Zhouqu case study, China. Remote Sens. 2016, 8, 908

Teresa E., Jordana, Rowena B., Lohmana, Lorenzo Tapiab, Marco Pfeifferc, Chelsea P. Scottd ,Ronald Amundsone, and Linda Godfreyf, Rodrigo Riquelmeb. (2017). Surface materials and landforms as controls on InSAR permanent and transient responses to precipitation events in a hyperarid desert, China. Ithaca, NY, USA.

The American Surveyor. (2005). November • Copyright 2005 Cheves Media

Togi Tampubolon, Rita Juliani, Juniar Hutahean, Jeddah Yanti,. (2020). Deformation Mapping of the 2018 Sulawesi Earthquake by Satellite Radar and Optical Remote Sensing. Medan, 20221, Sumatera Utara, Indonesia.

Tzouvaras, Chris Danezis, and Diofantos G. Hadjimitsis. (2020). Small Scale Landslide Detection Using Sentinel-1Interferometric SAR CoherenceMarios. Limassol 3036.

Umut Gunes Sefercik, Gurcan Buyuksalih, Can Atalay, Karsten Jacobsen. (2018). Validation of Sentinel-1A and AW3D30 DSMs for the Metropolitan Area of Istanbul, Turkey. Incivez St., 67100 Zonguldak, Turkey.

Umut Güneş Sefercik. (2013). Productivity of TerraSAR-X 3D Data In Urban Areas: A Case Study In Trento. 67100, Zonguldak, Turkey.

Vasco Conde, Giovanni Nico, Pedro Mateus, Joao Catalao, Anna Kontu, Maria Gritsevich. (2016). On the estimation of temporal changes of snow water equivalent by spaceborne SAR interferometry: a new application for the Sentinel-1 mission. 1749-016 Lisboa, Portugal.

Wei, M.and Sandwell, D.T. (2010). Decorrelation of L-Band and C-Band Interferometry Over Vegetated Areas in California. 48, 2942–2952.

Weibel, R., Heller, M. (1990). A framework for digital terrain modeling. In: For the International Symposium on Spatial Data Handling, Zurich, Switzerland, (pp. 219-229).

Wessel, P. 2013. (2016). GMT. http://gmt.soest.hawaii.edu/ (accessed2016).

Wheaton. J.M. Wheaton, J. Brasington, S.E. Darby, D.A. Sear. (2010). Accounting for uncertainty in DEMs from repeat topographic surveys: improved sediment budgets Earth Surf. Proc. Land., 35 (2) (2010), pp. 136-156.

Wojciech Milczarek. (2019). Application of a Small Baseline Subset Time Series Method with Atmospheric Correction in Monitoring Results of Mining Activity on Ground Surface and in Detecting Induced Seismic Events. 27, 50-370Wrocław, Poland.

Xiaohong Chen , Qian Sun, and Jun Hu. (2018). Generation of Complete SAR Geometric Distortion Maps Based on DEM and Neighbor Gradient Algorithm. Appl. Sci. 2018, 8, 2206; doi:10.3390/app8112206.

Yague-Martínez N, Zan FDe, Prats-Iraola P. (2017). Coregistration of interferometric stacks of Sentinel-1 TOPS data. IEEE Geosci Remote Sens Lett. 2017.

Yue, L., Shen, H., Zhang, L., Zheng, X., Zhang, F., and Yuan, Q. (2017). High-quality seamless DEM generation blending SRTM-1, ASTER GDEM v2 andICESat/GLAS observations.ISPRS J. Photogramm. Remote Sens.123, 20–34.doi.

Z. Hu, J. Peng, Y. Hou, and Shan, J. (2017). "Evaluation of recently released open global digital elevation models of Hubei, China," Remote Sens., vol. 9, no. 3, Mar. 2017, Art. no. 262

Zebker, H.A. (1992). Decorrelation in interferometric radar echoes. IEEE Trans. Geosci. Remote Sens.

Zefa Yang, Qingjun Zhang, Xiaoli Ding, Wu Chen. (2019). Analysis of the Quality of Daily DEM Generation with Geosynchronous InSAR. Changsha 410083, China.

Zhang D, Wang F, Huang Z, Zhou L, and Wu Y. (2012). Reconstruction of InSAR DEM using ERS-1/2 interferogram, and SRTM data. Springer; p. 129–136.

Zhang, Y., Liu, Y., Jin, M., Jing, Y., Liu, Y., Liu, Y., Sun, W., Wei, J., and Chen, Y. (2019). Monitoring Land Subsidence inWuhan City (China) using the SBAS-InSAR Method with Radarsat-2 Imagery Data.Sensors2019,19, 743.

Zhou, L., Guo, J., Hu, J., Li, J., Xu, Y., Pan, Y., and Shi, M. (2017). Wuhan Surface Subsidence Analysis in 2015–2016 Basedon Sentinel-1A Data by SBAS-InSAR.Remote Sens.

Zhu, J., Li, Z., and Hu, J. (2017). Research Progress and Methods of InSAR for Deformation Monitoring. Sin.2017,46, 1717–1733.

Zribi, M., Kotti, F., Amri, R., Wagner, W., Shabou, M., Lili-Chabaane, Z., and Baghdadi, N., (2014). Soil moisture mapping in a semiarid region, based on ASAR/Wide Swath satellite data. Res. 50, 823–835.

Zwieback, S., Hajnsek, I., and Hensley, S., (2013). Observational analysis of soil moisture effects on DInSAR signals. 4046–4049.

Zwieback, S., Hensley, S., and Hajnsek, I. (2017). Soil moisture estimation using differential radar interferometry: toward separating soil moisture and displacements. 55, 5069–5083.