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# Investigation of Active Geodynamics Caused by Performance of Salt Dome Using Radar Interferometry

## (Case Study: The Salt Dome of Qeshm Island)

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## Abstract

Qeshm salt dome is a part of Qeshm unique Geopark, the only Geopark in the Middle East. The present study is a descriptive-analytical. Qeshm Salt Dome study area and required information for this research are radar satellite images, optical satellite images as well as rock, geological information of the area using radar interferometry and paired radar images taken from the site. The European Space Agency is first developing some ground-level models for the region by doing some processing. After constructing the elevation model, the Envi software performs several measurements on the ASAR satellite Envisat satellite radar data and performs interpolation to calculate the elevation of Qeshm Island and presents the results digitally. An adaptive filter was used to provide better results. Rate of salt dome changes in the period 2003-2005, 0 to 0.16 m, in the period 2005-2008, -0.03 to 0.085 m and in the period 2008 to 2010, -0.007 to 0.082 m was calculated. Rate of changes in Qeshm Island in the period 2005-2003, 0 to 0.23 m, in the period 2008-2005, -0.2 to 0.15 m and in the period 2010-2008, were -0.03 to 0.23 centimeter.

*Keywords:* salt dome, Qeshm island, diapirism, radar interferometry, envisat

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## 1. Introduction

Salt domes are dome-shaped geological structures which their core composed of salt. Geologists believe that after salt formation, the salt swells overall deposits and pushes them up due to its density and pasty shape. Because in salt domes there are some signs of old stones such as trilobite limes and metamorphic rocks like gneiss and finally old volcanic rocks such as the Hormuz complex, the age of salt information is considered to be older than Paleozoic. During his studies on salt domes, Player confronted the Hormuz complex which is suspended floating in the salt dome (Player, 1969). Remote sensing is knowledge, art and information technology of phenomena and earth’s surface complications using tools installed on the platforms (like dirigible, airplane, satellite and so on) which are not in direct contact with them. Microwaves are capable of penetrating the cloud, fog, dust and rain. Since radar function is different from that of the sensors that work with visible and infrared spectra, it is possible to obtain accurate images by combining the information (Zobeiri and Majd, 2004).

Due to their lower viscosity, the salt layers beneath the sediments can flow and move higher than the surrounding rocks, creating different salt structures such as salt cushions, walls, and salt domes, the study and movement of extinct salt structures provides scientists with accurate information on oil and gas reserves( Mehrabi, 2020).

Diapir is a phenomenon that material with a specific gravity less than its outer layers, comes up and split them up and appears on the earth’s surface. In other words, different states of salt formation substrates can be caused by diapirism. If the applied tectonic flow is rectified, in essence, it is assumed that if applied force to the evaporation is only in one direction, during diapirism performance, the basin wants to escape in the other direction. So, it finally stretches as pages and by diapirism performance, it appears on the earth’s surface, in the form of salt injections, salt apophysis, salt needles, etc (Espahbod, 1990).

There are different views about Iran’s salts domes and how they come. Regarding the Zagros severe folded structure and extensive expansion of Infra-Cambrian salt accumulation in the Paleozoic Platform (the first era), it is possible to justify the concentration of salt tectonics in the Zagros Mountains and its surroundings, especially in the southern regions of Iran (Shayan and Zare, 2011). The most important gathering of salt domes is in the southeastern Zagros and north of Kavir plain. The origin of Zagros salt domes is the Hormuz evaporation basin (Precambrian). The origin of salt domes of Kavir plain and Azarbaijan is Neogene evaporation sediments (Miocene) (Alaei, 2003). From far away to now, geologists have tried to interpret how the salt domes in the Zagros Mountains are dispersed, how they are formed and other features. For the first time, studies in Iran were carried out on the salt domes of Hormuz Island. In the world, some studies have been conducted. For example, there is a study on salt domes of the Southern Gulf of Mexico (Kent, 1978). Due to geographical and geological conditions of Iran, salt domes are visible in different areas which for the first time Hormuz salt domes were studied by Pilgrim (Pilgrim, 1908). After him, other researches including the study of salt domes of southern Iran (Kent, 1958), Zagros salt domes (Kent, 1978), salt domes of Kavir Buzurg in the center of Iran (Jackson et al. 1990), Iran salt domes and their economic values (Folle, 2006) have been carried out. Also, Vincent et al. in China’s nuclear site conducted research and calculated the amount of land uplift using satellite technique (Vincent et al. 2011). Baikpour et al. (2010) calculated changes of the earth’s surface in salt sediments around Garmsar. In another research (Sedighi, 2012) researchers introduced and compared two radar interferometry methods, STaMAP and DePSI and they studied and measured the subsidence in the southwest of Tehran. In this research, an attempt has been made to get the correct digital and functional results for the first time using the experiences of previous researchers and studying new methods in satellite imagery processing.

In 2020 Mehrabi examined the effect of different water, weather, and weather conditions on the movement of non-sample masses using the ASAR Image Interference Method (Case Study: Salt dome, Shah Ghayeb Lorestan, 2003-2008). According to the results, there is a direct correlation between the rate of displacement and the average rate of increase, so that with increasing temperature, the level of salt level increases, and the rate of subsidence decreases. Therefore, to some extent, the secondary changes of salt after the discovery of the salt dome on the ground can be considered to be affected by water and air conditions, especially temperature.

Afshari et al. (2016) study was carried out to investigate the diadyrism of Gchine salt dome using ENVISAT satellite ASAR images over a period of years (Afshari et al., 2016). (Karimzadeh, 2016) studied the Tabriz subsidence using radar interferometry. For this purpose, in this paper, 17 Envisat satellite images from 2003 to 2010 were used and the SBAS technique was compared and the results were compared with GPS station measurements. The results showed that the maximum subsidence was 4 cm which was not significant for the analyzed period of about seven years and therefore did not pose a threat to this area.

Matthews et al. (2017), combined the geological and hydrological data of the subsidence of the Granada region in Spain with the PSInSAR method. Radar images of 5 Envisat, COSMO-SkyMed and 1A-Sentinel satellites were used. The results of applying radar interferometry with permanent diffraction technique indicated that the highest amount of subsidence occurred during the period of 2003-2009, which coincided with the drought, and that the soil type was high in climates (Matthews et al., 2017).

Motagh et al. (2017) the Rafsanjan Plains subsidence was studied using the SBAS technique in DORIS software with the radar data of ALOS, Envisat and 1-Sentinel satellites between 2004 and 2016. The results of this study showed that the minimum and maximum subsidence rates in Rafsanjan plain were 5 and 20 cm /year, respectively. Because the plain alluvium contains untreated sediments about 300 m thick, the impact of groundwater harvesting has been greater than in other areas. Comparison and output validation of this study with the results of alignment indicated that the results were high and the accuracy of radar interferometry was high. In this research, it is tried to calculate the amount of salt displacement and growth rate of Qeshm salt dome using previous researches and new methods of processing satellite images.

## 2. Materials and Methods

In this research, at first, a ground elevation model for the region is made by doing some processing methods, then the differential of the Envisat satellite radar of the sensor ASAR is estimated and the rise of Qeshm Island is calculated by using interferometry. Then the results are presented digitally. An adaptive filter was used to provide better results from images. This investigation is an applied research and the method is quantitative. The geographic area is the Qeshm salt dome. The data required for this research are radar satellite images, optical satellite images, and also the information related to the type of the rock, the geology of the region. Radar satellite images related to the study area were gotten from the European Space Agency Website and they were analysed using Are GIS and Envi software with Sar Scape modules.

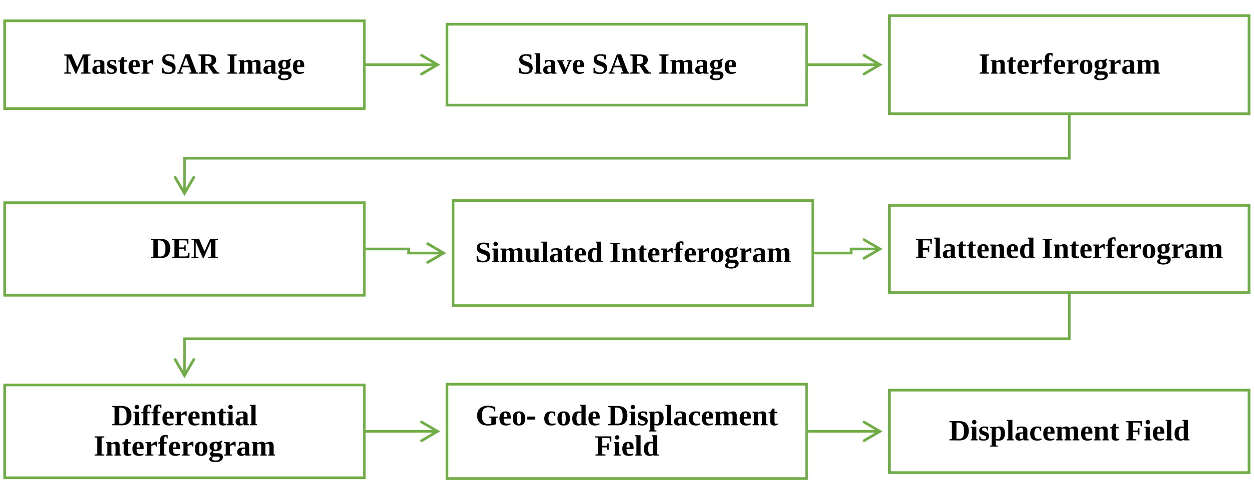


***Figure 1***. Flowchart (Source: authors).

### 2.1. Study Area

Qeshm County which its center is Qeshm city includes four small and big islands (Qeshm, Hengam, Larak and Hormuz) and it is surrounded by the Persian Gulf. It is the entrance to the Strait of Hormuz and located in 55° 15′ to 56° 30′ eastern longitude and 26° 32′ to 27° 6′ northern latitude. Its distance to the provincial capital (Bandar- Abbas) is 23 kilometers. Qeshm Island is located in the form of strings parallel to the coast, which is in fact a continuation of the Zagros, and its connection with the main region of the Zagros is cut off because of rising sea level and it appears as an island. Generally, the seismicity in the Qeshm area is affected by seismotectonic properties of the orogen transitional zone of Zagros continental collision and Makran oceanic continental convergence zone. Seismicity in the Qeshm area is associated with a shallow earthquake (WWW. Ngdir.ir).

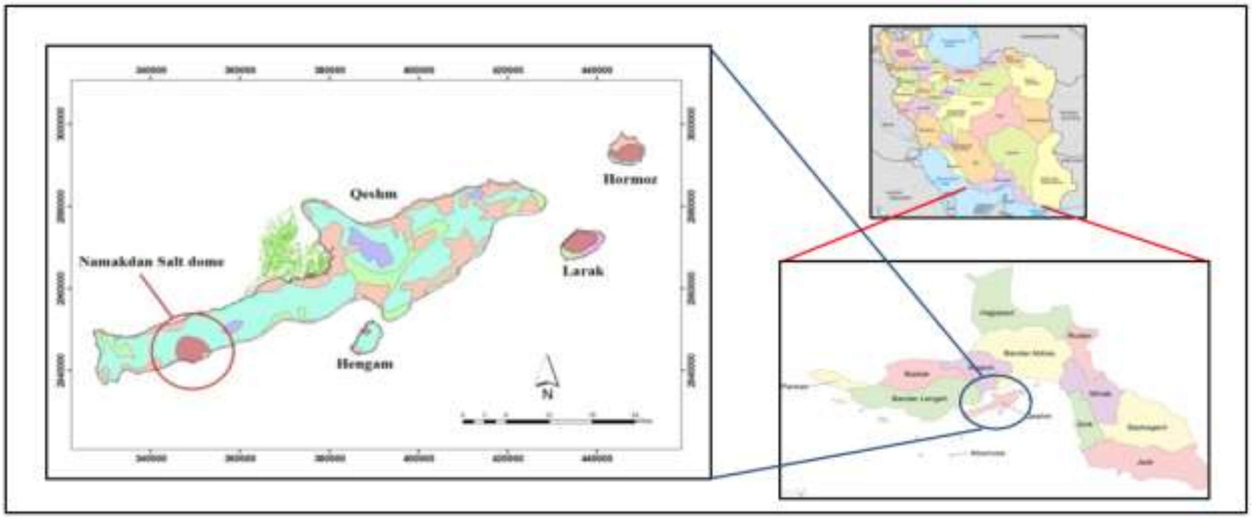


***Figure 2***. Location of the study area (Source*:* Ngdir website)

## 2.2. Satellite Data Used

Radar interferometry with extensive coverage and high resolution is a suitable method for the detection of displacements such as diapirs (Ayazi, 2018). Considering the high ability of radar images in detection of the amount of ground movement, images of four different times were chosen and the rate of rising of the island and salt growth. The following table shows information about the received images.

***Table 1***. Data of Obtained Images from European Space Site

| Row | Date | satellite | Sensor | Data | Pixel size (meter) |
|---|---|---|---|---|---|
| 1 | 20.03.2003 | ENVISAT | ASAR | ASA_IMS_1P | 19.97×4.05 |
| **2** | 28.04.2005 | ENVISAT | ASAR | ASA_IMS_1P | 19.97×4.05 |
| **3** | 17.04.2008 | ENVISAT | ASAR | ASA_IMS_1P | 19.97×4.05 |
| **4** | 09.09.2010 | ENVISAT | ASAR | ASA_IMS_1P | 19.97×4.05 |

To import data and make SLC in the SARscape format, it is necessary to change the data which is possible through the implementation of the standard command. After entering the required data, the software begins to make SLC. In addition to the created SLC, data such as power and phase is also required.

3.4. Study of Baseline Images Features and Deciding to Choose the Best Pair

As given in table 2, the displayed number in the part of critical Doppler centroid represents the maximum amount of suitable centroid for processing in interferometry. Displayed number in the part of Doppler centroid should not reach or exceed this value. Also, the baseline number should not be close to the critical baseline number. If the baseline number is close to the critical baseline, this image pair is not suitable for calculating differential.

***Table 2.*** Data of Base Line Images

| Base line | Critical base line | Height ambiguity | Range displacement | Azimuth displacement | Doppler centroid | Critical Doppler centroid |
|---|---|---|---|---|---|---|
| 2003-2005 | 519.482 | 930.884 | 17.708 | 45.986 | 45.986 | 1652.416 |
| 2005-2008 | 648.366 | 932.237 | 14.206 | -29.450 | -29.460 | 1652.416 |
| 2008-2010 | 113.875 | 932.270 | 80.886 | -17.144 | -17.144 | 1652.416 |

## 3. Results and Discussion

### 3.1. Modeling the Salt Dome of D- Insar

Due to the mechanism used in radar interferometry and also the se of different software in remote sensing, it is possible to create a salt dome model. Results show the main factor of changes in the area is salt growth in the dome and its development in the earth’s surface around the dome.

### 3.2. Interferogram Creation and its Products

A digital elevation method (DEM) and at least a pair of SLC are needed to create an Interferogram. SLC images have stretched in the direction of the range and the size of the pixels is approximately 4.05 × 4.05. But with interferogram creation, stretching disappears and the size of pixels is modified and in fact, these modified pixels are the same size as pixels on the ground. In the next step, to locate the image on a real ground location and that study area is in which part of the image, geocode command is used. In fact, georeferencing is done by processing the image.

### 3.3. Phase Movement Creation

This part of the processing is the most important part of the project because the outputs of this stage of processing show the amount of movement of the earth’s surface. Now the amount of displacement, whether uplift or subsidence are studied, according to Adaptive filter used statistically in centimeters.

**Table 3.** The Amount of Displacement of Salt Dome (Adaptive Filter)

| | 2003-2005 | 2005-2008 | 2008-2010 |
|---|---|---|---|
| Minimum displacement | 0 | -0.03 | -0.007 |
| Maximum displacement | 0.16 | 0.08 | 0.08 |
| Average displacement | 0.04 | 0.01 | 0.02 |

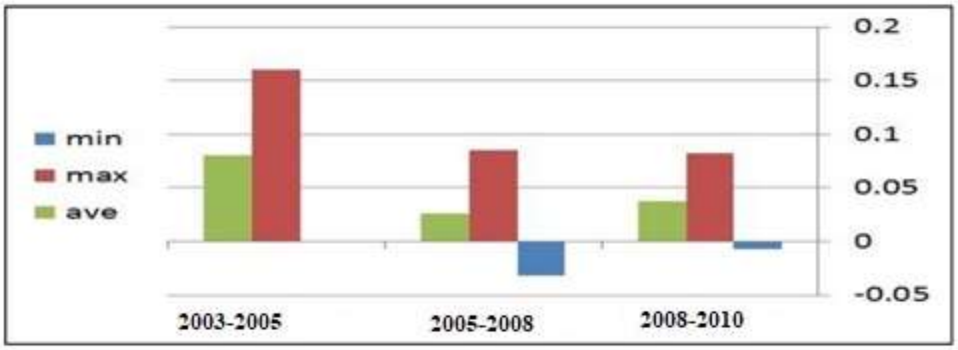


***Figure 3.*** The amount of displacement of salt dome (Adaptive filter)

Positive numbers represent earth uplift and negative numbers show earth subsidence which has been gotten statistically from the area and maximum, minimum and average displacement of the area are displayed in them. The numbers in the tables are statistical information related to DN of the image pixels. Through the processing done on radar images and drawing longitudinal profiles in different directions, the amount of displacement of the salt dome from 2003 to 2010 was studied. The obtained results show there has been no subsidence in the study area from 2003 to 2005. And the maximum of earth uplift is about 16 centimeters in the southeast and 10 to 12 centimeters in the south and 8-10 centimeters in the east and center of the salt dome. The minimum uplift is in the west and northeast of the salt dome (Figure 4).

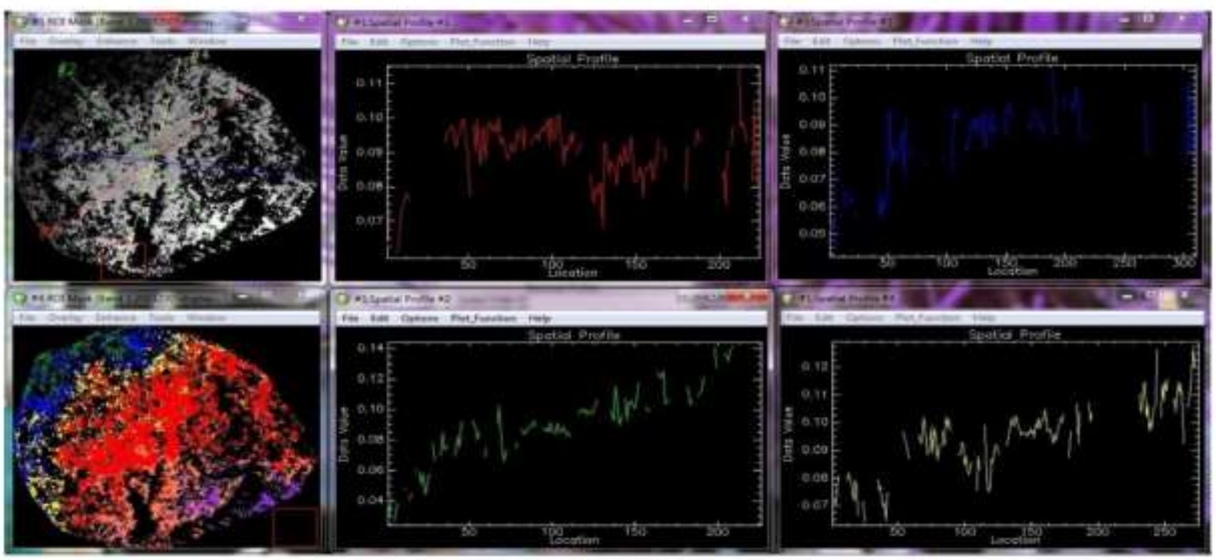

***Figure 4.*** Profiles on salt dome in 2003- 2005

From 2005 to 2008 there was a subsidence of about 3 centimeters in the southeast and east of the salt dome. The maximum salt dome uplift was about 6 to 8 centimeters in the west and almost center (*Figure 5*).

The processing done on the salt dome images of 2008 to 2010 shows the amount of the subsidence in the study area was very small and the maximum was about 8 centimeters in the north and some areas south of the dome *(Figure 6*).

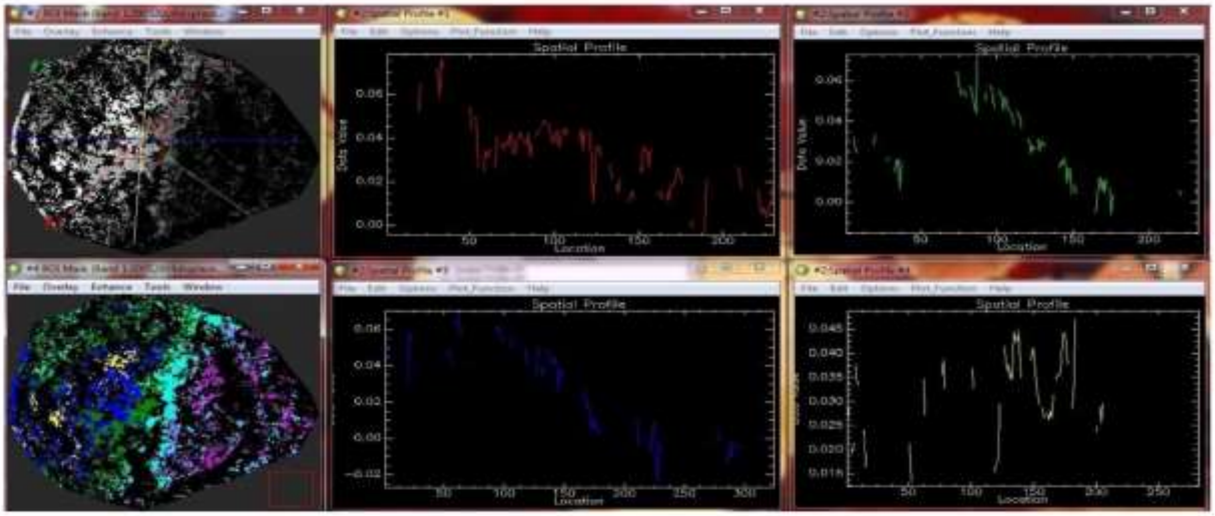


***Figure 5***. Profiles on Qeshm Island 2005-2008

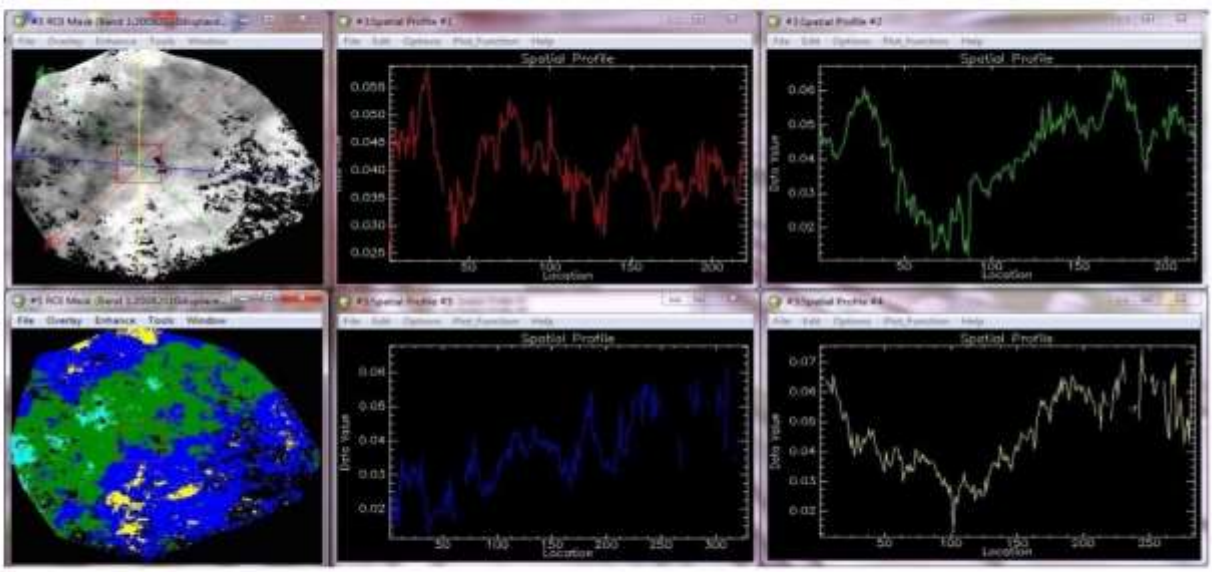


***Figure 6***. Profiles on Qeshm Island 2008-2010

3.6.2. Measurement of the Amount of Qeshm Island Displacement Using Adaptive Filter Statistically

Due to processing done on the radar images, the amount of displacement in Qeshm Island is as follows:

From 2003 to 2005 on the whole island, there was an earth uplift. This uplift reaches 23 centimeters (maximum) in the Gavarzin anticline. The amount of land uplift in the northern part of the island is more than the southern part of the island. And in the south of Harra forests (the center of the island) and between Bandar-e- Table in the north and Bandar-e- Salakh, land uplift is very small and almost reaches zero (Figure 7).

**Table 4.** The Amount of Displacement of Qeshm Island (Adaptive Filter)

| | 2003-2005 | 2005-2008 | 2008-1010 |
|---|---|---|---|
| Minimum displacement | -0.05 | -0.22 | -0.05 |
| Maximum displacement | 0.47 | 0.16 | -0.25 |
| Average displacement | 0.01 | 0.00 | 0.007 |

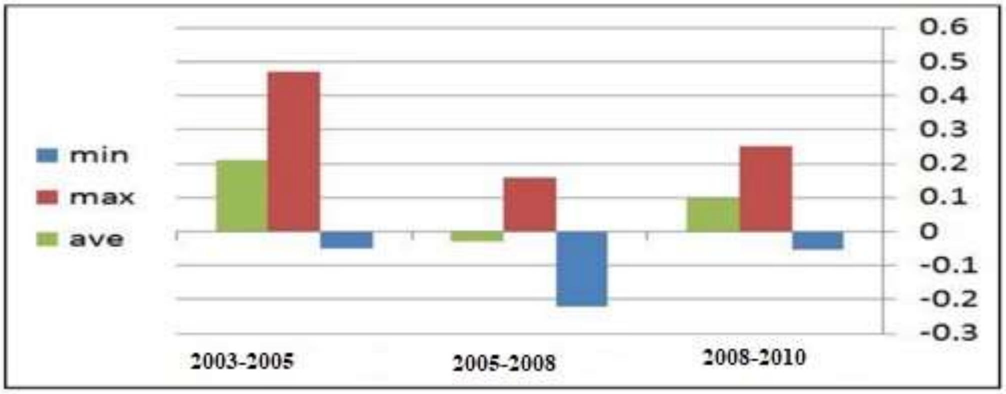


***Figure7*.**The amount of displacement of Qeshm Island (Adaptive filter)


***Figure 8.*** Profiles on Qeshm Island 2003-2005

From 2005 to 2008, small land subsidence about 2 centimeters in the east and some parts of the south of Qeshm Island (the east of the salt dome) has occurred and uplift of about 5 to 10 centimeters is visible. The maximum land uplift is at the westernmost point of the island and it is about 10 to 15 centimeters (*Figure 8*).

From 2008 to 2010 in the study area (Qeshm Island) there is subsidence about 0.03 centimeters in the east (urban area) and also around the northernmost point of the island (Bandar-e- Left). In all parts of the island, uplifts of about 5 to 23 centimeters can be seen. The total uplift of the island is from 5 to 10 centimeters on average (*Figure 9*).


***Figure 9.*** Profiles on Qeshm Island 2005-2008

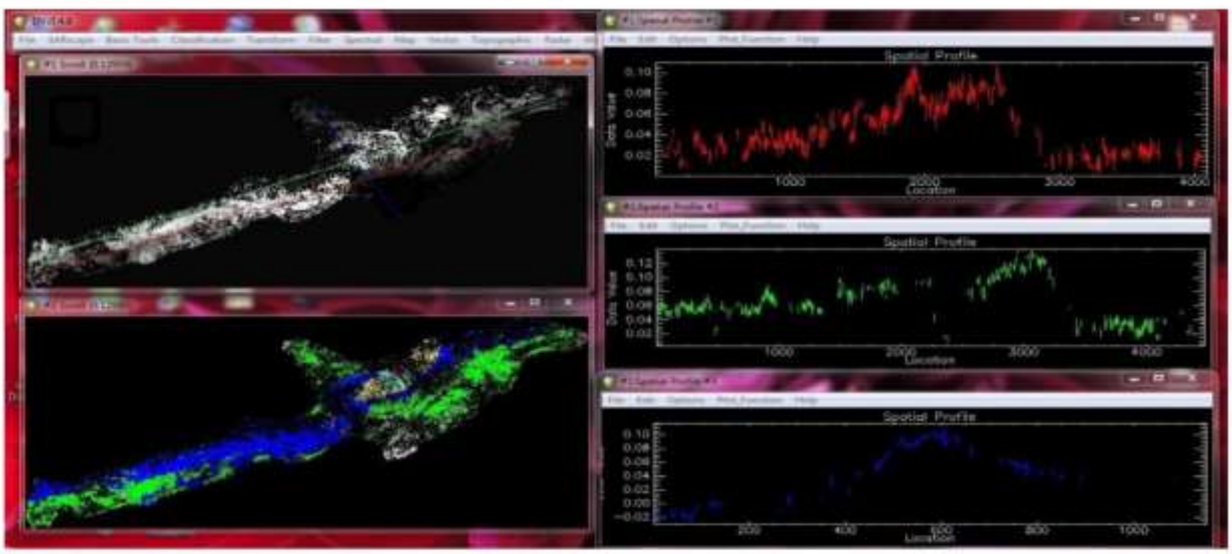


***Figure 10.*** Profiles on Qeshm Island 2008-1010

Processing radar images and calculating the amount of the uplift of the salt dome and Qeshm Island and their comparison with the southern coast of the country (coast of Bandar-Abbas) show the maximum amount of movement (uplift) has occurred in Gavarzin anticline. In total, Qeshm Island is located at an altitude of about 15 to 20 meters higher than its northern coast (Bandar-Abbas coast). According to Mehrabi's results on the Shah Gheib salt dome in Lorestan in 2020, it can be concluded that by using radar images and interferometry techniques, acceptable results in this field were obtained and the amount of displacement of salt domes was calculated. In fact, the use of ASAR images to study salt domes is acceptable. These results are similar to those of (Afshari et al., 2016) who carried out a study to investigate the active dihydrochloride of the Gchine salt dome using the ENVISAT satellite ASAR images over a period of years using differential interferometry to extract the displacement value of the Gchine salt dome. The results were used to validate the results, geological field observations and permanent geodynamic network points of the National Survey Organization, which indicate the tectonic movements of the dome during these periods. The results of this study indicate that the salt dome is rising in the years 2006 and 2007 and its dip in the years 2010, as well as a case study of Kinejad, the role of diapirism on the stratigraphic evolution of the Mangarak salt dome sedimentary basin southwest of Firouzabad was investigated. Extreme in the sedimentary environment near the salt dome, the amplitude of the changes was dependent on the depth of the deposition environment and tectonic movements of the area. And with another study on the coastline of Qeshm Island and Bandar Abbas beaches, it was found that the maximum displacement was related to the 23 cm displacement of the Gorzine anticline as well as the seafront offshore in the vicinity of the dome approximately 300 meters offshore and off the coast of Bandar Abbas.

## 4. Conclusions

Calculation of displacement and growth rate of salt dome of Qeshm island in a given period of 7 years using radar image processing which is much more accurate than ground studies. 2003 to date 2010 Salt Dome has uplifts and crustal variations, a result of active diapirism in the region that reflects both tectonics and salt performance. Seismic data was used to obtain more accurate breadth and depth of salt infiltration and 3D modeling. When ordering radar images, select times when there is no snow on the ground as they cause processing errors. Adaptive filters should be used to study subsidence, elevation, and displacement issues during image processing because they are more accurate and precise. It should be noted that while not being able to clearly distinguish the boundary between the frames, by selecting the Goldstein filter, the percentage will increase.

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