MONITORING GROUND DEFORMATION OF MUD VOLCANOES USING RADAR INTERFEROMETRIC METHOD (SBAS) AND THERMAL DATA CASE STUDY: THE SOUTH-EASTERN PART OF THE CASPIAN SEA

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ABSTRACT:

Mud volcano, as the most attractive geomorphological natural phenomena, includes the internal resources such as water sources or hydrocarbon reservoirs such as oil and gas fields. Therefore, monitoring their deformation and temperature anomaly has some important information of subsurface activity and mud-volcano structure. Interferometric synthetic aperture radar (InSAR) has shown to be an effective instrument for calculating mud volcano deformation. The purpose of this study is to monitor the deformation of the mud volcanoes and also its characteristics to thermal anomaly using SBAS method by ENVISAT (C-band) radar satellite images from 2003 to 2011. Therefore, the Landsat-8 image was used to retrieve the land surface temperature (LST). The results show the most surface deformation belongs to the mud volcanoes located in the northern part of Golestan Plain, and decreased towards the southern mud volcanoes. Moreover, the highest temperature belongs to Ounegh Yilghay and Sofikam mud volcanoes, but they indicate up-lifting (207 mm) and down-lifting (-14.64 mm) respectively.

1. INTRODUCTION

The mud volcanoes are the most attractive geomorphological phenomena, which are often conical in shape and made of clay. Their height is estimated between 2 and 500 meters and the diameter of its base is between 20 and 3500 meters (Johubov et al., 1971; Barber et al., 1986). Mud volcanoes are found both onshore and offshore, but they are in active tectonic plates (Mazzini 2009; Bonini 2012; Mazzini and Etiope 2017). Gas supply is the most important factor in generation of a mud volcano. Methane, carbon dioxide and hydrocarbon gases usually emit from some mud volcanoes especially in Southern Caspian Basin and the Gulf of Mexico (Judd, 2003; Brown, 1990; Hedberg, 1974; Kopf, 2002; Dimitrov, 2002; Judd, 2003; Milkov, 2005). In fact, the location of mud volcano indicates that gas and oil are being formed in younger layers showing underground reservoirs (Bentacor, 2015; Bonini, 2012). The Interferometric SAR technique (InSAR) is used an effective instrument for calculating mud volcano deformation like volcano deformation and interpreting magma- supply dynamic over large areas (Massonnet *et al.* 1993; Peltzer *et al.* 1998; Amelung et al. 2000; Fruneau & Sarti 2000; Tesauro *et al.* 2000; Crosetto *et al.* 2002; Wicks et al. 2002; Pritchard and Simons 2004; Chatterjee *et al.* 2006; Motagh *et al.* 2006 Wright et al. 2006; Biggs et al. 2010; Lu et al. 2010; Pagli et al. 2012). Niu et al., (2019)analyzed 192 interferograms derived from 106 synthetic aperture radar (SAR) images acquired by the JERS-1 (L-band), ERS-1/2 (C-band), RADARSAT-1 (C-band), and ALOS PALSAR (L-band) satellites to measure ground deformation at Shrub mud volcano before, during, and after its reactivation. Lio and Furuya (2018) Using ALOS/PALSAR and ALOS-2/PALSAR-2 InSAR and multiple-aperture interferometry, detected the mud volcanoes 'surface displacements in Ayaz-Akhtarma. The purpose of this study is to measurement surface deformation and examine its relationship to thermal anomaly. Then We analyzed 105 interferograms derived from 15 synthetic aperture radar (SAR) images acquired by ENVISAT satellite to characterize ground deformation at the south-eastern part of the Caspian Sea in 2003- 2011. Because mud volcanic processes associated with geothermal activities, thermal bands are used to map land surface temperature (LST).

2. MATERIALS AND METHODS

2.1. Study Area

the south-eastern part of the Caspian, As the main focus of mud volcanoes in the world, is famous because of their frequency, oil and gas resources (e.g., Yusifov and Rabinowitz, 2004; Feyzullayev, 2012; Bonini et al., 2013; Oppo et al., 2014; Oppo and Capozzi, 2016). Four important mud volcanoes are reported from in the Gorgan plain: the Gharenyaregh, Neftlijeh, Sofikam (Ghobkeljeh) and Inche mud volcanoes (Figure, 1-b). All of them are active and erupting mud and gas. There are 23 mud volcanoes in the south-eastern of the Caspian Sea (Figure 1-a,b; Table 1), but some of them locates in scenes (Figure 1, b).The geographic coordinates of mud volcano, both active and extinct are listed in Table 1.

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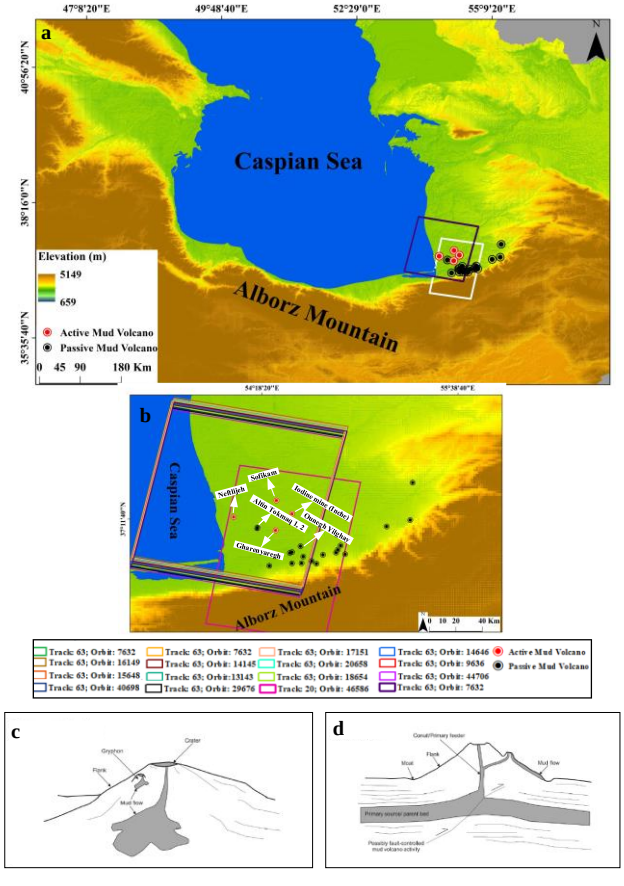

Figure 1. The geographical location of the South Caspian Basin (a), the location of active and inactive volcanoes (b), as well as the schematic view of the cross-section of the active volcano and its mechanism of action are presented in parts (c) and (d) respectively (Kirkham, 2015).

NO.	Mud Volcano	Longitude	Latitude	Statue
1	Neftlijeh*	54° 6' 37.49"	37° 12' 27.02"	active
2	Gharenyaregh*	54° 23' 51.05"	37° 7' 3.12"	active
3	Iodine mine (Inche)*	54° 30' 35.85"	37° 13' 43.40"	active
4	Sofikam*	54° 24 '9.48"	37° 19' 14.95"	active
5	Altin Tokmaq*	54° 16' 20.26"	37° 8' 14.81"	inactive
6	Ghalami	55° 19' 5.12"	37° 11' 15.24"	inactive
7	Neghinshahr	55° 24' 24.23"	37° 8' 37.71"	inactive
8	Gala Jig	54° 29' 44.51"	36° 57' 47.65"	inactive
9	Sorkhan kalateh	54° 34' 29.49"	36° 53' 36.97"	inactive
10	Torang Tapeh	54° 35' 11.15"	36° 56' 17.90"	inactive
11	Altin Tokmaq*	54° 16' 20.90"	37° 8' 6.06"	inactive
12	Ounegh Yilghay	54° 34' 3.98"	37° 0' 33.13"	inactive
13	Gala Jig	54° 30' 37.10"	36° 58' 9.04"	inactive
14	Sangdevin	54° 50' 31.77"	37° 0' 49.29"	inactive
15	Qushkorpi	54° 16' 20.90"	36° 59' 6.90"	inactive
16	Emam Abad	54° 48' 39.63"	36° 57' 54.65"	inactive
17	Mazraeh	54° 52' 24.39"	36° 57' 17.28"	inactive
18	Kamal Abad	54° 30' 33.08"	36° 53' 32.79"	inactive
19	Hajji Qushan	55° 20' 5.83"	37° 26' 32.33"	inactive
20	Ghroogh	54° 40' 37.20"	36° 53' 23.56"	inactive
21	Now Deh Malek	54° 38' 41.19"	36° 54' 28.21"	inactive
22	Ghroogh	54° 41' 21.91"	36° 54' 48.17"	inactive
23	Shirang-e-Olya	54° 43' 17.36"	36° 57' 2.06"	inactive

Table 1: Characteristics of Mud volcanoes in the study area (west of Golestan province) (Omrani and Raghimi, 2018).
* The mud volcanoes exanimated in this study.

2.2. Data

In this study, 15 SAR images are acquired from ENVISAT (C-band) satellite along a descending track from 2003 to 2011 (Table 2). Also, The thermal data is used from Landsat-8 that (LC08_L1TP_163034_20210118_20210306_01_T) obtained from the USGS website on 2021-01-18.

No.	Date	Orbit	Track	Pass
1	2003-08-16	7632	63	Descending
2	2004-01-03	9636	63	Descending
3	2004-09-04	13143	63	Descending
4	2004-11-13	14145	63	Descending
5	2004-12-18	14646	63	Descending
6	2005-02-26	15648	63	Descending
7	2005-04-02	16149	63	Descending
8	2005-06-11	17151	63	Descending
9	2005-07-16	17652	63	Descending
10	2005-09-24	18654	63	Descending
11	2006-02-11	20658	63	Descending
12	2007-11-03	29676	63	Descending
13	2009-12-12	40698	63	Descending
14	2010-09-18	44706	63	Descending
15	2011-01-27	46586	20	Descending

Table 2. Specifications of the ENVISAT images used.

2.3. Land surface of temperature

The Land surface temperature (LST**)** is an important factor in the study of biological, chemical and physical processes of the earth (Alavipanah, et al, 2007). In order to calculate the surface temperature using Landsat-8, The single-channel algorithm is utilized. In the single-channel method, the temperature of the earth's surface is estimated by using a thermal band. The SC method is the best method for data with only one thermal band (Price, 1983).

2.4. Interferometric synthetic aperture radar (InSAR)

Interferometric synthetic aperture radar (InSAR) combines two or more SAR images of the same area acquired at different times to map surface deformation (Massonnet and Feigl, 1998; Mazzini and Etiope, 2017). InSAR time-series analysis, such as the permanent scatterer method (PS) and the short baseline

algorithm (SBAS), reduce the limitations of traditional radar interferometry such as atmospheric errors, orbital errors, and ground errors (Luo, et al., 2014). SBAS method is used in where the possibility of high coherence pixels is very low (Berardino et al., 2002). To monitor the surface deformation, SBAS algorithm is used. Figure 2 shows the steps of SBAS interferometry processing. In the SBAS method, only pairs of images are used whose vertical components of the baseline are less than the critical value of the baseline, and their time baseline is also minimum at the same time. In this way, only interferograms are formed that have good quality. After the formation of 105 interferograms, a network of images is created, then the displacement value of each pixel is estimated using the least squares method. we also used band 10 of Landsat-8 to calculate the land surface temperature of mud volcano zone in winter time.

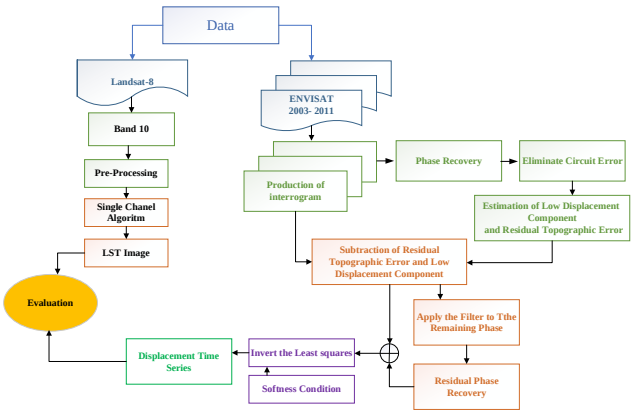

Figure 2. Flowchart of the fundamental work steps.

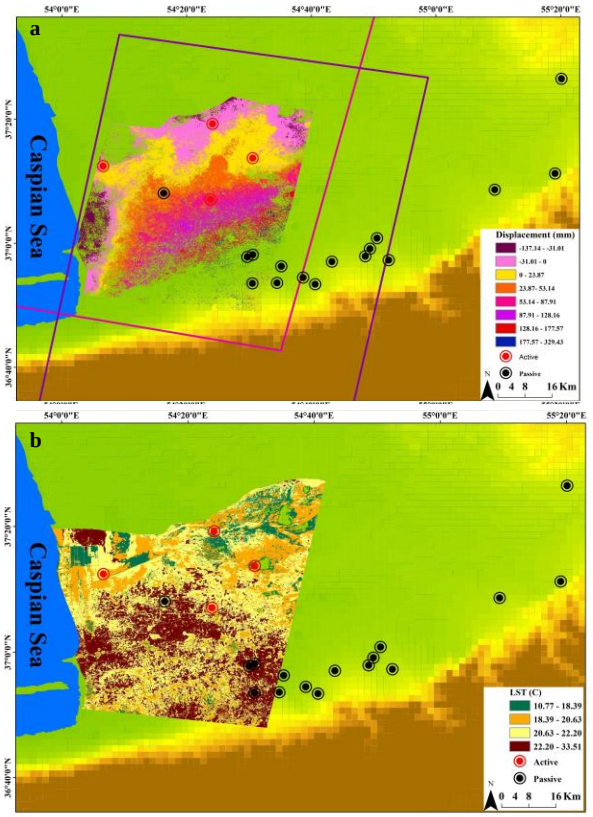

Figure 3. Map of the average annual displacement rate of the earth's surface along the line of sight of the satellite (in meters per year) resulting from SBAS algorithm (a), Surface temperature map for the study areas (b).

3. DISCUSSION AND RESULTS

The results of the present study showed that displacements of the south-eastern part of the Caspian Sea are around -137.14 and 329.43 mm, during the period of 2003 to 2011 (4-a). In general, according to the surface displacement map which is classified into 8 classes (4-a), the area near the coast (Gomishan lagoon) has the highest amount of subsidence (-137.14 to -31.01). By moving away from the coast, the amount of subsidence decreases and uplifting increases.

In this study, in order to calculate LST, the single-channel algorithm was applied to calculate the land surface temperature using Landsat-8. LST map is classified into four classes (Figure, 4-b). Maximum and minimum temperature are 10.77 and 33.51 degrees Celsius, respectively.

regular pattern, the lowest temperature is assigned to the northern part of the plain and the highest temperature is assigned to its middle and southern parts. By overlapping LST and surface displacement maps, only 6 volcanoes have both displacement and temperature values (Figures, 1,3), some of the mud volcanoes do not have the recorded value in both maps. In order to have a better visual understanding, a buffer with a radius of 500 meters is created around each of 6 mud volcanoes in surface displacement and LST maps separately. the result presents in Figure 4.

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
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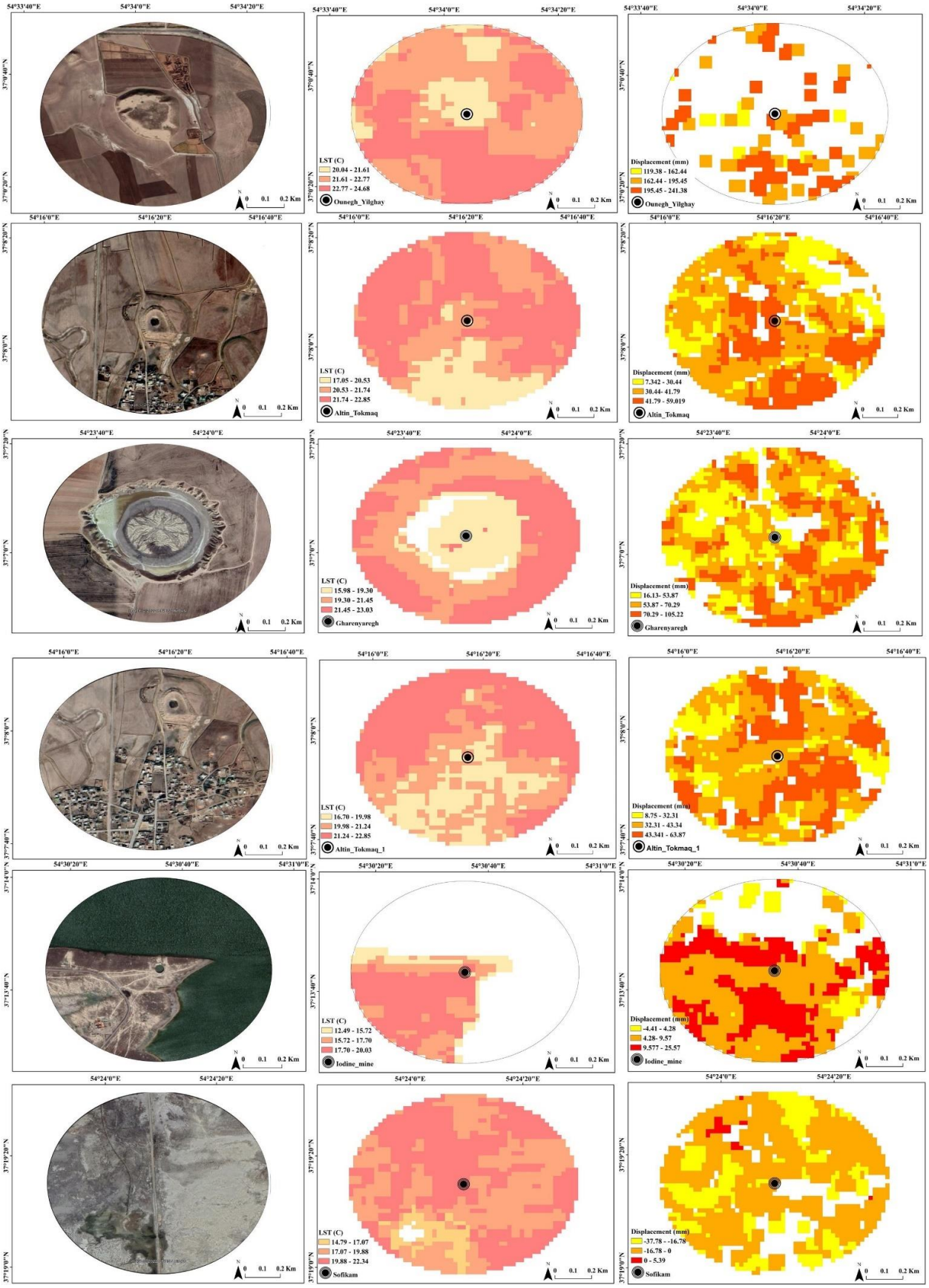

Figure 4. From Left to right, indicates the mud volcanoes extracted from Google Earth, LST and surface displacement maps within a radius of 500 meters.

According to Figure 4, Ounegh Yilghay LST map (middle column) show around temperature is more than the center, but in Sofikam LST map, the center has the highest temperature. Also, central temperature in Ounegh Yilghay is more than Sofikam. The more temperature in Ounegh Yilghay associated with more up-lifting.

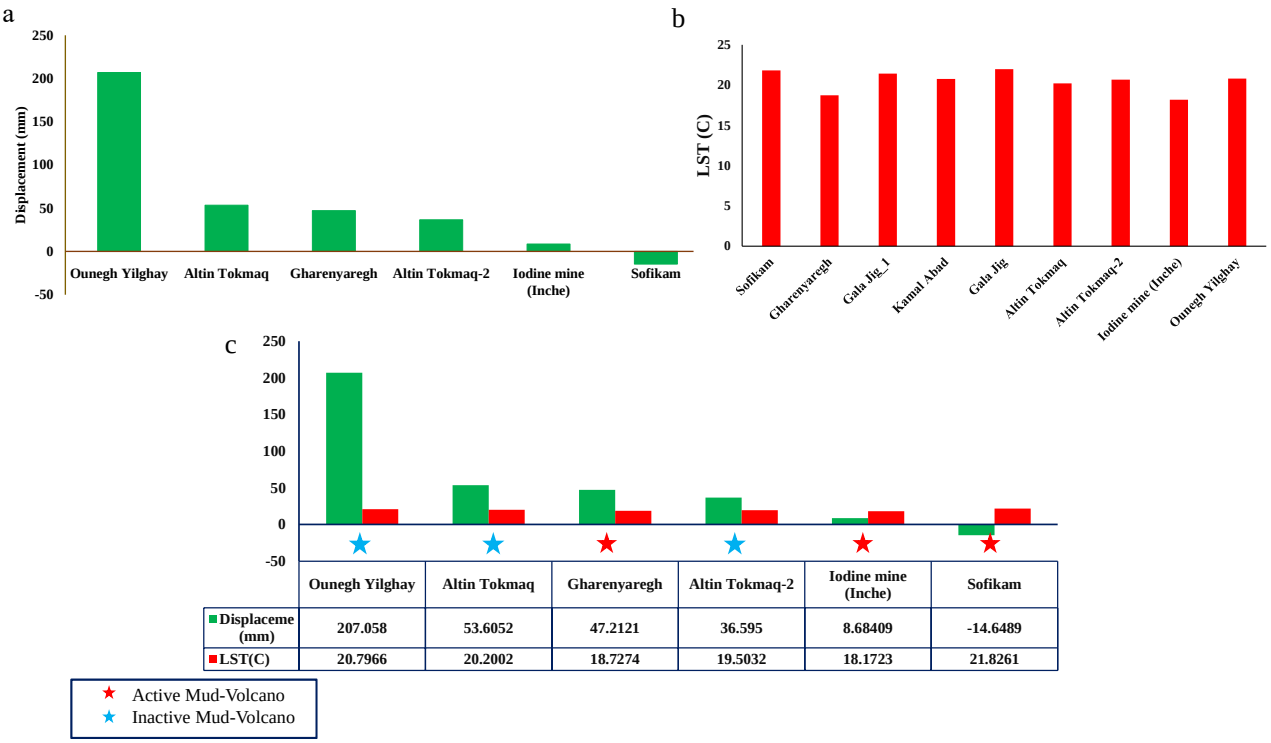

Figure 5. displacement map (mm) (a); LST map (b); Comparison of surface displacement and LST mud volcanoes (c).

According to Omrani and Raghimi (2018) and Oppo and Capozzi (2016), mud volcanoes located in the Turkmenistan region show Meaningful correlation with gas and oil fields.

The surface displacement mud volcanoes are shown in bar chart in Figure (5-a). Ounegh Yilghay, Gharenyaregh, Iodine mine (Inche), Altin Tokmakh 1 and 2, and Sofikam mud volcanoes show up-lifting. Now, The Ounegh Yilghay, a dormant mud volcano, has the highest rate of uplifting among the other 5 mud volcanoes. It is likely to be active in future. Unlike other five mud volcanoes, Sofikam shows down-lifting. The range of mud volcanoes temperature is 18 to 22 degrees Celsius (Figure, 5-b). In order to better comprehensive, the statistical information about each map is extracted (Figure, 6-c). Sofikam and Ounegh Yilghay mud volcanoes have the highest temperature, but they show down-lifting and up-lifting respectively. The other four mud volcanoes also show uplifting, which is insignificant compared to Ounegh Yilghay.

4. CONCLUSION

Mud volcanoes are a natural phenomenon associated with mud deposits bringing fine-grained sediments upwards from the subsurface, also known with oil and gas fields. In this study, we used InSAR and the Landsat-8 data to characterize the ground deformation and calculate LST respectively. The surface displacement is not the same in the south east Caspian Basin.
The Sofikam as an active mud volcano shows down-lifting, instead, some dormant mud volcanoes such as Ounegh Yilghay, Altin Tokmakh 1, Altin Tokmakh 2, and some active mud volcanoes like Iodine mine (Inche) and Gharenyaregh indicate up-lifting. However, the highest temperature belongs to Ounegh Yilghay and Sofikam, they indicate different surface displacement. Ounegh Yilghay and Sofikam have the most (207 mm) and lowest (-14.64 mm) surface displacement accordingly in 2003- 2011.

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
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