RISK ASSESSMENT OF APSHERON PENINSULA OIL AND GAS FIELD USING MICROWAVE SENSING TECHNOLOGIES

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Abstract

A number of productive oil and gas fields are located in the Apsheron Peninsula of Azerbaijan. The primary goal of the presented study was to quantitatively assess the ground deformation rates of oil and gas fields, determine natural and man-made influencing factors and predict deformation trends. The determined maximum displacement rates of subsidence and uplift processes were −26 mm/y and +23 mm/y, respectively. However spatial density analysis of deformation velocity presented the natural patterns of uplift and subsidence tectonic processes. This allowed to determine that two oil and gas fields hold a higher probability of being affected by man-made oil and gas exploration activities, whereas the one oil field is affected by both natural and man-made processes.

Keywords: PS-InSAR; SBAS; remote sensing; geospatial; pipelines; oil and gas; radar; interferometry

I. Introduction

Possible causes of surface deformation are earthquakes, mud volcanism, groundwater changes, and man-made activities for hydrocarbon or gas withdrawal. Among these ground deformation causing factors, it is well known that hydrocarbon fluid or gas withdrawal activities have a direct impact to the subsidence and uplifts processes of oil and gas fields. Traditional ground surveying methods are important to accurately assess the subsidence and uplift rates, however, they are costly in terms of necessary equipment, human involvement, availability of historical baseline as a reference for the detection of continuous ground movement rates and velocity and limited territorial coverage for the assessment of spatial ground movement patterns. This research is focusing on the quantitative assessment of ground movements caused by petroleum and gas activities. Interferometric Synthetic Aperture Radar (InSAR) is a well-known and proven remote sensing technique that uses the phase information of SAR images to measure ground surface displacements. For the Apsheron Peninsula, the first studies based on InSAR were performed by Mellors *et al.* [1]. These studies used the SAR images to generate Digital Elevation Models which have been compared with topographic maps and independently derived topographic information. Feyzullayev *et al.* [2] developed the scheme of vertical movements in the Apsheron Peninsula based on results of repeated ground-based geodetic levelling and indicated that the intensive development of oil-and-gas fields causes natural disbalance and wide progress of deformation processes. Yaschenko [3] conducted repeated ground levelling in the Apsheron Peninsula during 1977–1984 and indicated that the annual velocity of subsidence was 0.21–5.6 mm/year in the southern part of the Apsheron Peninsulla, whereas maximal subsidence rates were observed for Syrakhany (−18 mm/year), Baladjary and (12 mm/year), Bibi-Heybat (12 mm/year) oil and gas fields [4, 5]. The main goals of the present study are the following:

a. Detect ground deformations (subsidence and uplift) of oil and gas fields in the Apsheron Peninsula

b. Assess the natural and anthropogenic factors influencing these deformation processes

c. Predict the liner trends of ground deformation

The present research holds novelty insofar as PS-InSAR technique has never been used for this part of the globe. Besides, our approach considers the advanced geospatial statistical analysis of PS-InSAR ground movement derivatives, quantitative assessment of natural and anthropogenic factors influencing the ground deformation processes and also the forecast of vertical movement trends and rates.

II. Methods

The Apsheron Peninsula is of the world's most ancient oil and gas producing regions. In 1846, Azerbaijan drilled its first oil well in Bibi-Heybat oil field. The Apsheron Peninsula extends 60 km eastward into the Caspian Sea, and reaches a maximum width of 30 km (Figure 1a). As can be seen in Figure 1(b), there are 11 oil and gas and 17 oil fields under exploitation [6]. The Apsheron Peninsula has a temperate semi-arid climate with warm and dry summers, cool and occasionally wet winters, and strong winds all year long. The peninsula is the most arid part of Azerbaijan with an average precipitation of 263 mm per year. The annual mean air temperature is approximately 14°C. Summers are warm with typical maximum air temperatures in the order of 35–40°C. January is the coldest month with an average of 0°C. Wind speeds typically range from 0.5 to 12 m/s. Based on the past historical records of earthquakes (1950–2020) from United States Geological Survey (USGS), the Apsheron peninsula is an active seismic area with surrounding faults. Rapid population growth, increasing social and industrial infrastructure and intensive oil and gas exploration activities significantly raised the seismic vulnerability of the Apsheron peninsula and natural hazards consequences [7].

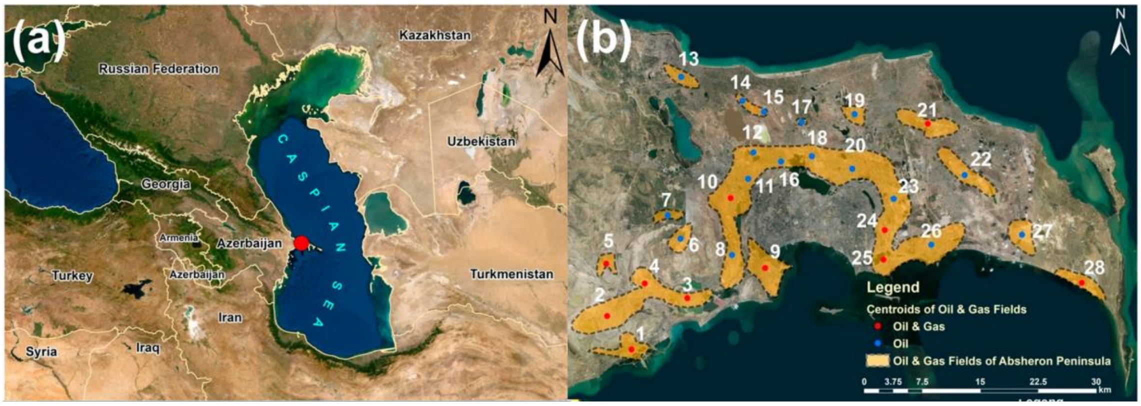

Fig. 1: (a) *Geographic location of the Apsheron Peninsula; (b) Oil and gas fields of Apsheron Peninsula*

Persistent Scatterer Interferometry (PSI) is a proven differential interferometric technique which involves processing of multi-temporal Synthetic Aperture Radar (SAR) data to identify persistently reflecting ground features and their motion rates with millimetre precision [8]. The PS-InSAR concept for the measurement of precise displacement is based on finding of permanent scatters with phase stability over a long period of time, removal of atmospheric phase contribution, DEM error and system/thermal noise etc. [9]. Monitoring and characterisation of the ground deformation processes of oil and gas fields of the Apsheron Peninsula have been carried out by using a stack of 28 Sentinel-1 Synthetic Aperture Radar (SAR) satellite images from

European Space Agency (ESA) acquired for the period of 2015–2017. The Sentinel-1 SAR instrument operates at 5.405 GHz (C-band, corresponding to a radar wavelength of about 5.6 cm). Sentinel-1 VV polarization bands were used since co-polarized bands provide higher coherency [10]. The following workflow shown in Figure 2 was used for the Persistent Scatterer PS-InSAR, geospatial and statistical analysis. The main processing steps of PS-InSAR consist of interferogram generation, multi-temporal persistent scatterers (PS) processing and removal of atmospheric phase screen [11].

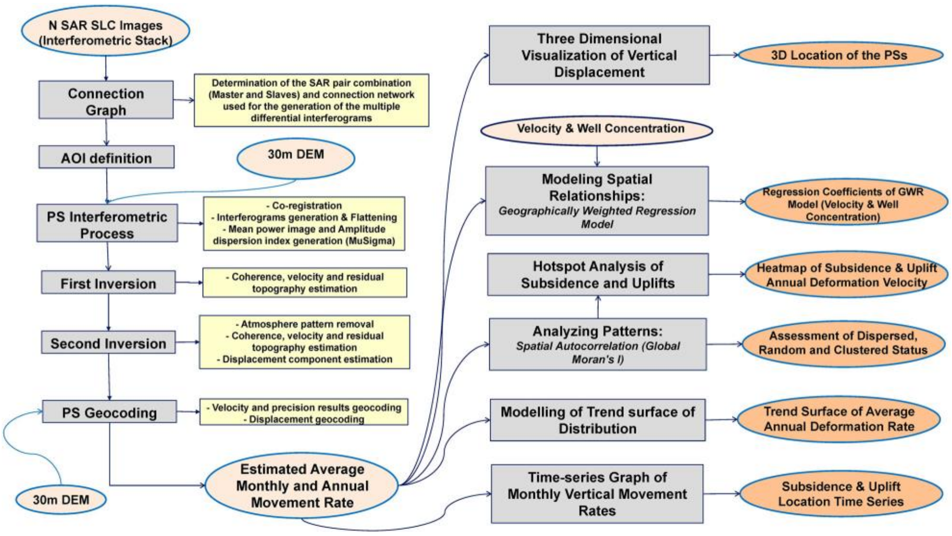

Fig. 2: *Workflow of PS-InSAR, geospatial analysis and predictions of ground deformation processes.*

III. Results and Conclusions

The present studies allowed to primarily determine the hotspots, controlling factors and spatiotemporal trends of ground movements for the oil and gas fields of the Apsheron peninsula (Figure 3a-f). The present research demonstrated the capacity of low-cost and safe technology to monitor the ground movements of the oil and gas fields. Besides, the produced results contribute to the larger scale and reliability of observations with enhanced clarity of ground deformations rather than measurements for single points. The presence of ground-deformation processes in the Apsheron oil and gas fields was observed with the highest rates of subsidence processes at the Hotspots A5 (Bibiheybat), A6 (Zigh) and A7 (Balakhani-Sabunchi-Ramani) and the highest rates of uplifts in Hotspot A1 (Garadagh), Hotspot A2 (Kergez-Giziltepe-Shongar) and A4 (Bibi-heibat). Determined maximum movement rates of subsidence and uplift processes were −26 and 23 mm/y, respectively (Figure 3a-f). Trend and concentration analysis of deformation velocity presented the natural patterns of uplift and subsidence tectonic processes from west to North-East and South-East. Among the detected hotspots of uplifts, Hotspot A1 (Garadagh) and Hotspot A2 (Kergez-Giziltepe-Shongar) were observed to be within the detected natural tectonic process of uplift and Hotspot A7 (Balakhany- Sabunchi-Ramani) is within the detected natural subsidence processes. Hotspot A4 (Bibi-heibat) did not reveal any regression with either concentration of wells or elevation factors and requires further in-situ investigations to understand the controlling factors and causes of ground uplifting processes. The ground-based geodetic levelling in the Apsheron Peninsula conducted during 1977-1984 allowed to validate that the Hotspots of A3, A5 and A7 continue to subside. The subsidence of Oil Field 23 (Surakhani) was not detected, instead the uplift process was observed in this area and this uncertainty may be related to several reasons as follows: discontinuation of subsidence processes in this area, failure in the in-situ ground measurements, interferometry calculations and applied injection technology. The present research demonstrated the contribution of SAR technologies to the safe operational monitoring of petroleum and gas fields without human ground-based measurements, significant cost reduction, reliability and broad scale of observations. The present study allowed to perform combined Persistent Scatterer Interferometry and the geospatial machine learning - based geostatistical analysis which allowed to develop and understand broader picture of the ground deformation processes over the oil and gas fields of the Apsheron Peninsula.

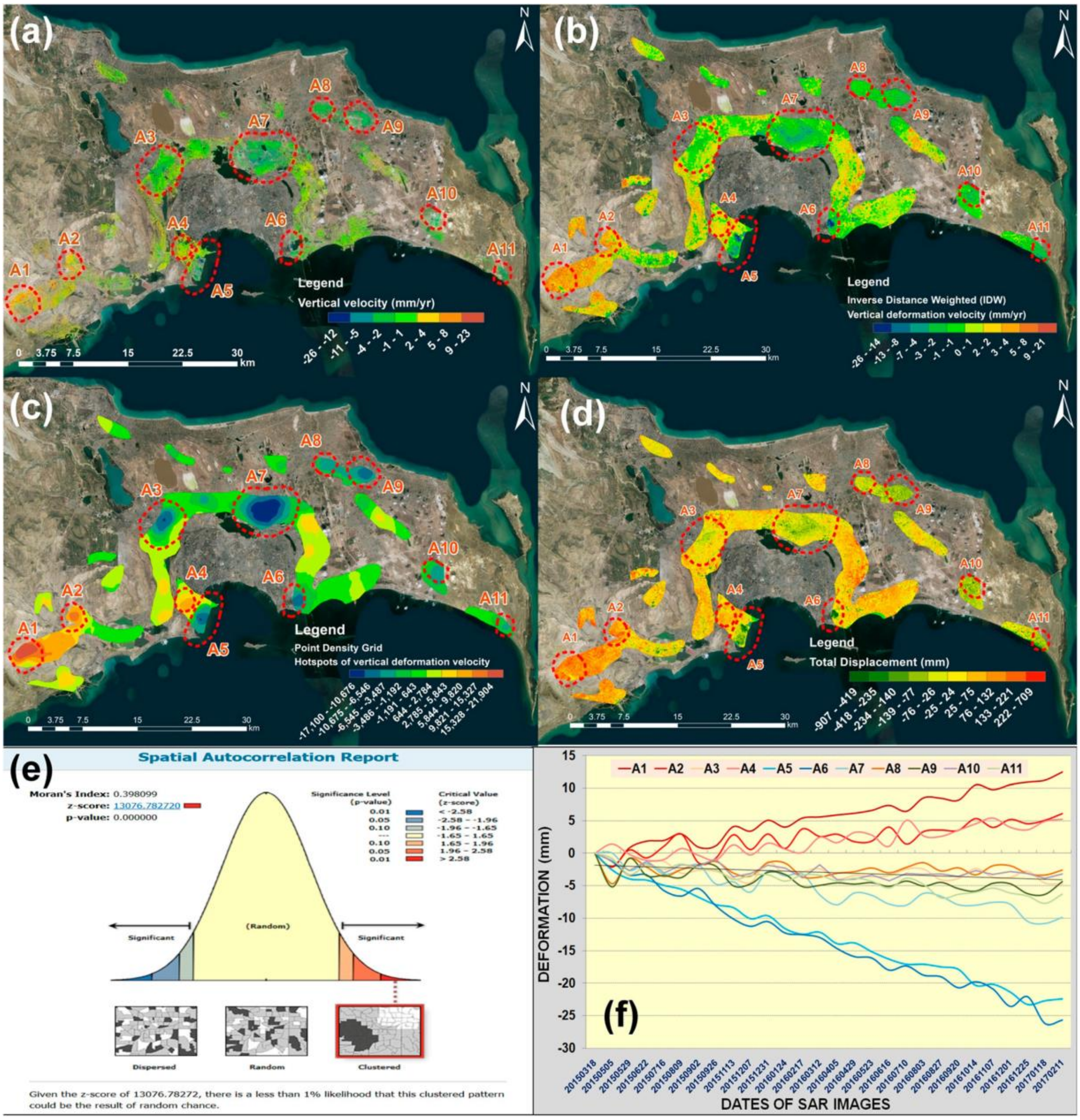

Fig. 3: *(a) Deformation map of subsidence and uplifts of the Apsheron oil and gas fields; (b) Inverse Distance Weighted interpolation of deformation values of persistent scatterers; (c) hotspots of vertical deformation velocity; (d) Inverse Distance Weighted interpolation of total deformation values of persistent scatterers; (e) Spatial autocorrelation of deformation velocities; (f) time series deformation curves of Hotspot A1–11 in millimetres.*

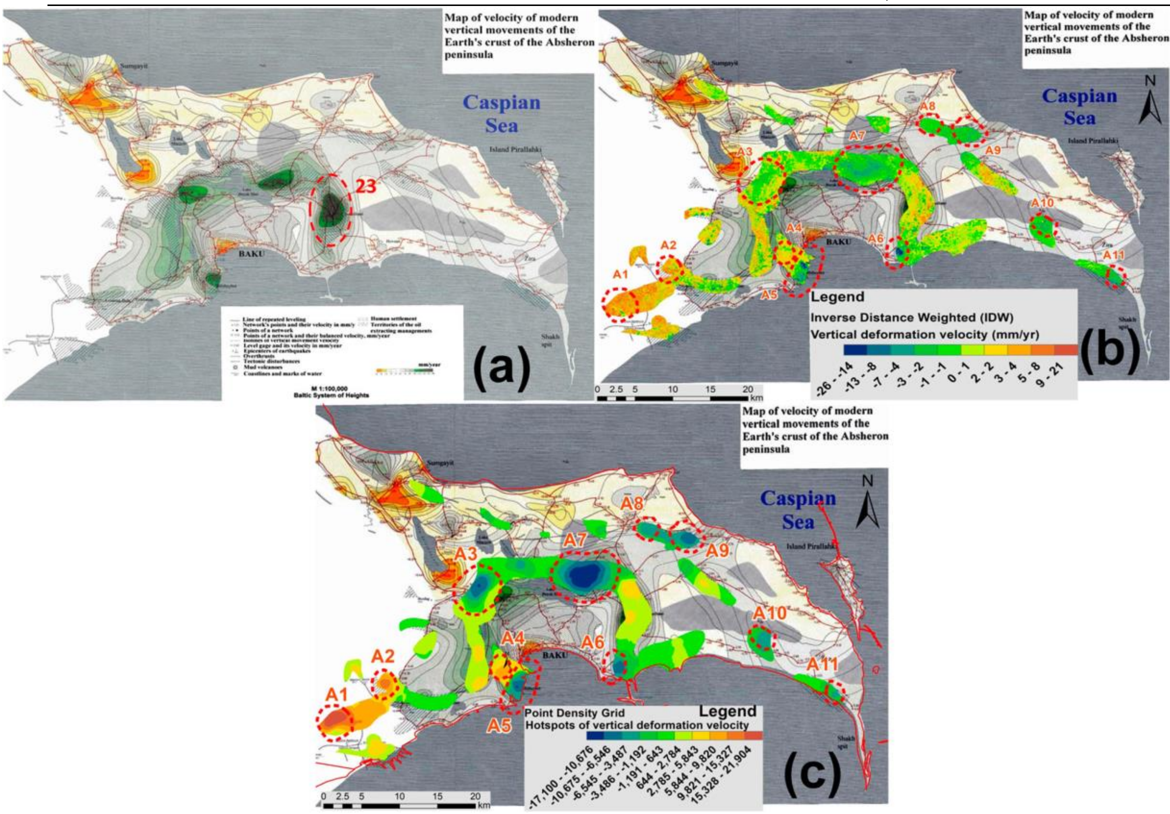

Fig. 4: (a) *Subsidence map of oil and gas fields developed as a result of ground levelling measurements conducted during 1977–1984 (Yaschenko 1989; Alizadeh et al. 2016a, 2016b) and indication of oil field not detected by PS-InSAR technology; (b) detected vertical deformation velocity using PS-InSAR technology; (c) hotspots of detected vertical deformation velocity using PS-InSAR technology.*

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