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Earthquake-induced site effect in the oil field deposit of Absheron peninsula (Azerbaijan)

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Abstract. Absheronpeninsula(Azerbaijan) area was hit by the strong Caspian earthquakes on November 25, 2000 with Mw6.1 and 6.2 magnitudes. The seismic networks successfully recorded the foreshock, main shock and many aftershocks at respective locations. By using probabilistic analysis, magnitude of design earthquake for the current study in the oilfield was taken as 6.3. From this concept design (scenario) earthquake, accelerations were estimated for the distance of 35 km. In the second phase of the study, soil amplification factors and site characteristics data from boreholes were determined and estimated. In the next phase, the study uses synthesized accelerograms formed on the basis of simulation of the seismic wave propagation processes through ground layer aiming to determine the quantitative characteristics of seismic effect on the oilfield region. Soil amplification values estimated by empirical relationships in terms of shear wave velocities are in the range of 0.7 and 1.9 values. Shear wave velocity (Vs, 30) values are 100 and 110 (m/s). The PGA values for the study area were evaluated by considering the local site effects. Peak ground acceleration varies between 100 – 380 gal. On the basis of the empirical relationship between MSK-64 and peak ground acceleration, the special distribution of intensity of the design earthquake with intensity of >8 is represented. Finally, the study presents possible relationship between seismic effect and daily oil recovery which states the direct proportional characteristics.

Keywords:ground classification, oilfield, scenario earthquake, Vs30, amplification factor, peak ground acceleration

Following the strongest Caspian earthquake on the South Caspian Fault in November 25, 2000 (Mw=6.3, epicentre located 35 km southward from peninsula), the earthquake hazard in Absheron peninsula with the capital Baku city has become a great concern. Absheron peninsula is located on the north-western part of the South Caspian region and experiences earthquakes from its own focal zone, the Caspian Sea and Shamakhi-Gobustan seismically active zones (Fig. 1).

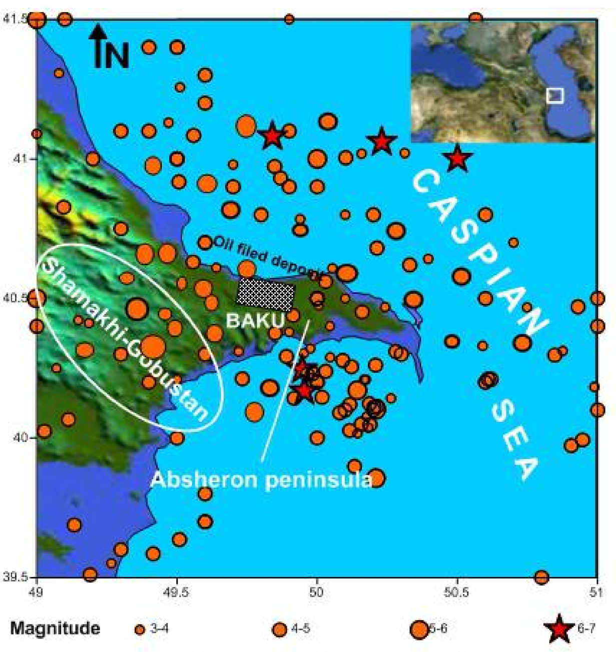

Figure 1. Absheron peninsula with earthquakes' distribution for the period 1842-2018
Note: Location of the research area is highlighted by the quadrangle polygon

In the recent decades, the disaster risk in Absheron peninsula has increased due to overcrowding, erroneous land-use planning, inadequately supervised constructions, insufficient control of infrastructure development and lack of environmental regulations. Strong earthquakes with Mw 6-7 are rare phenomena in this area. Statistically, when strong earthquakes are rare, it is very difficult to prepare a representative database of recorded strong motion signals that could be analyzed to define valid ground parameters for seismic hazard estimations (Nunziata et. al., 2012). For effective management, seismic hazard should be assessed prior to the strong earthquake strikes, even if it occurs rarely. Ground motion simulation of the 2000 Caspian earthquake in this study for Absheron peninsula has been performed with Deterministic Seismic Hazard Assessment (DSHA). The main objective of this present work is to study earthquake-induced site effect in the oil field deposit of Absheron peninsula (Azerbaijan) through hazard analysis at regional level by means of the peak ground acceleration distribution and intensity level calculated and estimated for Absheron peninsula from the strongest 25th November 2000 earthquake. Tectonically, Absheron peninsula is complicated by tectonic fractures, which can be divided into major (folded zones) and secondary fractures which are mainly cross faults, not extending beyond one foldand being confined to their top portions (Shikhalibeyli, 1996: Kadirov et.al., 2012: Alizade et.al., 2016; Alizade et.al., 2017; Babayev et. al., 2017; Telesca et.al., 2017) (Fig. 2).

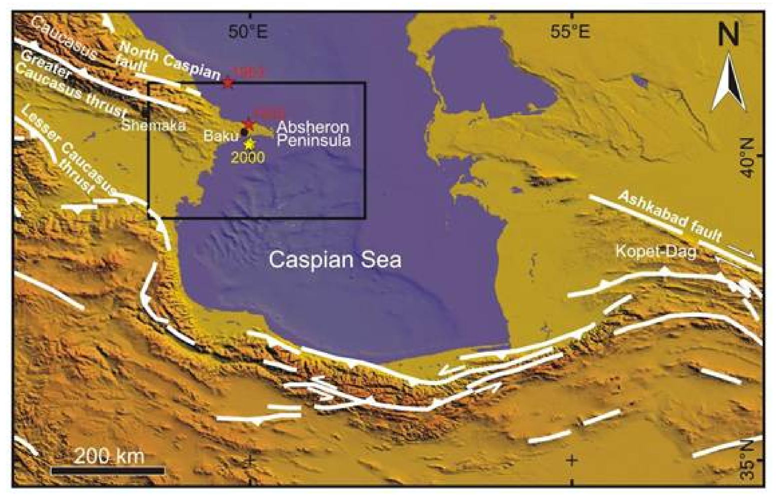

Figure 2. Topography and simplified tectonics with the main Quaternary faults of Caucasus to Kopet-Dag region.

The epicentres of the two studied 2000 earthquakes are marked by yellow stars. Red stars mark the other important earthquakes that affected Absheron Peninsula showing also their dates. Box shows the studied Absheron Peninsula area. (Tectonics modified after Kadirov, 2000; Jackson et al., 2002;Kadirov, 2004; Babayev et al., 2010; Kadirov et. al., 2012).

By analysing the existing local and international catalogues, moderate to large earthquakes originating in Absheron peninsula occurred in 1842 (Ms5), 1910 (Ms4.9), 1922 (Ms5), 1935 (Ms3.5), 1937 (Ms5), 1946 (Ms5.1), 1958 (Ms2.9), 1971-1973 (Ms5.1-5.6), 1979 (Ms4.4), 1983 (Ms5), 1992 (Ms4.5) (Babayev, 2009; Babayev et.al., 2010)(Babayev, 2009; Telesca et. al., 2013; Babayev et. al., 2014; Alizadeh et al., 2017; Babayev et. al., 2017a; Babayev et. al., 2017b; Telesca et. al., 2017; Babayev et.al., 2019). However, one of the potential seismic hazard to Absheron peninsula comes from the Caspian earthquakes, such as Central Caspian 1986-1989 (Ms=6.1-6.3,), North Caspian 1963 (Mw6.3) and South Caspian 2000 (Ms6.2-6.3). Overall, the compiled catalog contains earthquakes from 1842 to 2012 with event moment magnitude (Mw) ranging from 2.5 to 6.8 (Telesca et. al., 2012). By using probabilistic analysis, magnitude of design earthquake for the current study in the oilfield was taken as 6.3. From this concept design (scenario) earthquake, accelerations were estimated for the distance of 35 km. The strong 2000 Caspian earthquakes (Ms6.2 and Ms6.3) occurred in the southern zone (35 km to the south from Baku): the main shock together with numerous aftershocks caused 35 casualties, 1289 damaged and 3 collapsed buildings. Estimation of strong ground motion is still one of the main uncertainties for earthquake scenarios in Absheron peninsula and improved inventory of scenario of the last strong earthquake is required (Babayev et. al., 2010). Generalized intensity based on the existing catalogues for the area based on the macroseismic data is demonstrated in Figure 3, with epicenters in the Caspian Sea close to Absheron peninsula and their focal mechanisms.

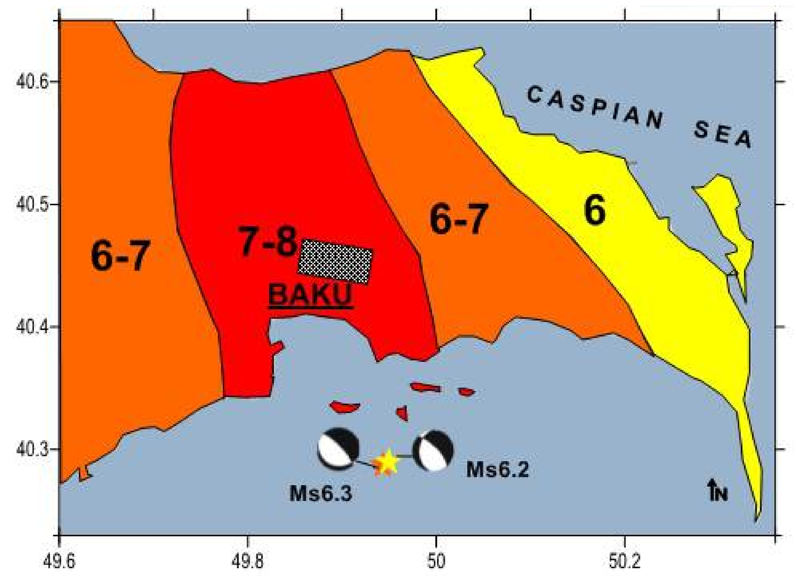

Figure 3. Generalized MSK-64 seismic intensity sketch-map for the study area based on the macroseismic data for the 2000 Caspian earthquakes.

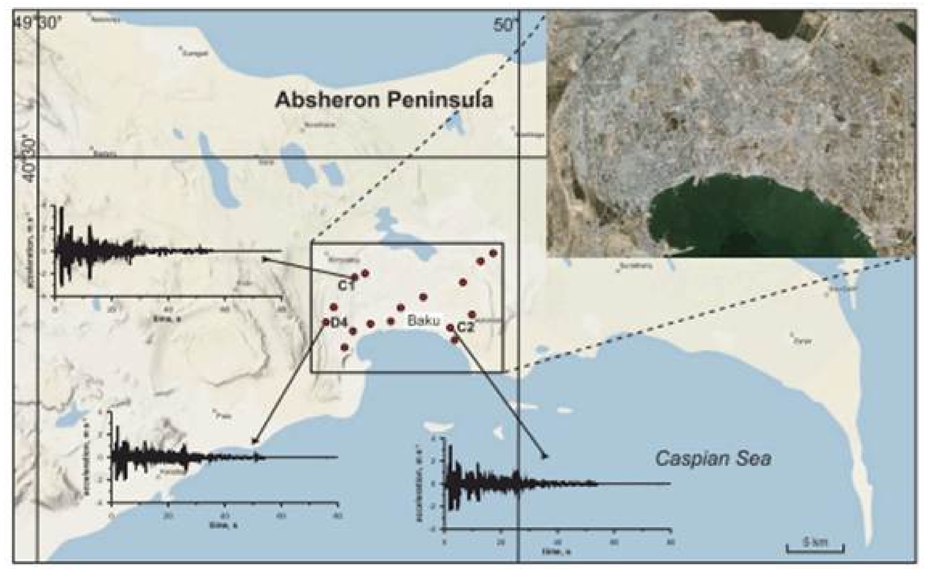

Figure 4. Topography of the Absheron peninsula. The dots indicate the sites of drilled boreholes; the geological and geophysical data from these boreholes were used in this study.

Note: Satellite image of the Baku city (the capital of Azerbaijan) is presented in the inset.The modelled accelerograms are presented for three typical subsurface models C1, C2, and D4 throughout the area (see Table 1 and 2 for the subsurface model description).

Table 2. Physical parameters of the principal soil units in the Absheron peninsula

Lithology	Measured of P-wave velocity, Vp,km/s^{-1}	Calculated of S-wave velocity, Vs,km/s^{-1}	Density (gcm^{-3})	Amplification factor
Quaternary clay	1,9	0,557	1,90	0,90
Sandy clay	1,1	0,289	1,80	1,19
Sand (Paleogene-Neogene)	1,2	0,320	1,81	1,14
Quaternary sandy clay	1,3	0,351	1,82	1,10
Limestone (Pliocene-Quaternary)	4,0	1,681	2,32	0,57
Shellstone, soft weathered limestone (Paleogene-Neogene and Quaternary)	1,0	0,260	1,79	1,25
Sandy clay (Paleogene-Neogene)	1,3	0,351	1,82	1,10
Sandstone (Miocene-Quaternary)	2,6	0,848	2,01	0,76
Eolian-delluvial (modern deposits)	0,75	0,189	1,76	1,43
Mild clay (Pliocene-Quaternary)	0,9	0,231	1,78	1,31
Loamy sands	0,85	0,217	1,77	1,35
Conglomerates (Miocene-Quaternary)	1,6	0,450	1,86	0,99
Pebble with sandy intrusions	1,03	0,269	1,79	1,23
Forestry mild clays	0,65	0,162	1,75	1,52

Methodology

Ground motion simulation of the 2000 Caspian earthquake has been performed with deterministic seismic hazard assessment (DSHA). The objective is to build a ground-motion data base that can be used to define: 1) regional seismic wave attenuation relations, and site response, 2) near-field values of ground shaking, 3) the effects of soil and rock on seismic wave attenuation and site response, and 4) intensity of shaking. Although probabilistic seismic hazard assessment (PSHA) considers uncertainties in earthquake source, path, and site conditions, there are several points of criticism related to this assessment: e.g., validity of a point source model; ground motion uncertainties in the mathematical formulation of the method; and incapability to correctly model the dependencies between large numbers of uncertain random parameters (Klugel, 2011; Panza et al., 2011). DSHA is an alternative method for hazard analysis and is based on a specified earthquake scenario. For a given earthquake, the DSHA model analyses the attenuation of seismic energy with distance to determine the level of ground motion at a particular site. Ground motion calculations capture the effects of local site conditions and use the available knowledge on earthquake sources and wave propagation processes. Namely, attenuation relationships are used for a given earthquake magnitude to calculate ground shaking demand for rock sites, which is then amplified by factors based on local soil conditions. Although the occurrence frequency of the ground motion is usually not addressed in DSHA, the method is robust for an assessment of seismic hazard due to specified events and remains a useful approach for a decision-making. We use a scenario-based deterministic approach in a view of the limited seismological data and the local irregularities associated with strong events. For this strong motion simulation, we select near-field target earthquake scenario. The selection of this target earthquake was based on the following criteria: (i) the distance of the epicenter of the event from Baku, (ii) the magnitude of the event; (iii) the effect of the earthquake on the study area, (iv) the event location with respect to the regional fault system, and (v) the re-occurrence of the event within the certain time interval. We consider the 2000 Ms6.3 Caspian earthquake (the epicentre was located 35 km southward from Baku) as a near event (marked by yellow in Fig. 2). Theoretical and empirical estimations of the physical parameters of the ground, the thickness and lithology of soil, the soil amplification, attenuation, and dynamic properties of the ground in the region were studied on the basis of drilled borehole data and seismic and geological profiles. The subsurface structure down to the seismic bedrock is modelled by the horizontally multi-layered structure, in which shear-wave velocity, thickness, and density vary with layers. The P -wave velocities measured in several boreholes are used to develop the subsurface ground model for each cell and to identify types of sediments, their thickness, and variations of underlying rock layers. The typical sub-surface models used in our study are presented in Table 1; one of these subsurface models is assigned to each model.

Table 1.Typical sub-surface models for the Absheron peninsula

Model	Thickness, m	Age	Lithology
C1	4	Q	sand, gravel-pebble
	5	Q	clay, argillaceous sand
	20	Q	clay
	3800	N	clay, sand, argillaceous, sandstone and limestone
C2	7	Q	sand, water-saturated sand
	7	Q	clay, pebble, soft-weathered
	23	Q	limestone, shale
	3200	N	clay, organic clay, argillaceous sandstone
D4	7	Q	limestone, sands
	20	Q	sand, clay, limestone
	1390	N	conglomerate, dolomite, tuff, sandstone, breccia, shale

Models C1, C2, and D4 correspond to three typical subsurface models. Notations: Q, Quaternary; N, Neogene and P, Paleogene

A surface PGA is calculated by a multiplication of the bedrock PGA beneath the cell (as the input acceleration) with the amplification factor of thesubsurface structure beneath the cell (Tonouchi and Kaneko, 1984). The amplification factor (and the relevant accelerogram) for all subsurface models has been determined using the SHAKE software (Schnabel et al., 1972). Amplification function becoming amplitude dependent (difference between weak and strong motions) is an indication of non-linearity (Beresnev and Wen, 1996). In Figure 4, the sites of drilled boreholes were demonstrated. The geological and geophysical data from the boreholes were used in this study.Figure 4 also presents the computed accelerograms for some typical subsurface models, and Table 2 presents the measured and calculated seismic wave velocities, density, and calculated amplification factor for the principal subsurface units used in the modelling. The synthesized accelerogram of maximum possible effect on the reference ground in Absheron peninsula was calculated (Figure 4). Synthesized accelerograms for the typical etalon grounds at the maximum Caspian Sea earthquake with Ms6.3 were obtained using the SHAKE software as an output signal. These accelerograms, formed on the basis of simulation of seismic wave distribution processes through the certain ground layers were used for the defining the quantity characteristics of the seismic effect on the study area.

Conclusion

The predicted surface peak ground acceleration and intensity level for the target Caspian 2000 earthquake scenario are plotted in Fig. 5 and in Fig. 6. The plotted models demonstrate the level of ground shaking over the study area and identify regularities in the attenuation of intensities, respectively, describing the likelihood of damaging earthquakes affecting the city area. Peak ground acceleration varies between 100–380 gal. On the basis of the empirical relationship between MSK-64 and peak ground acceleration, the special distribution of intensity of the design earthquake with intensity of equal and more than 8 is represented.

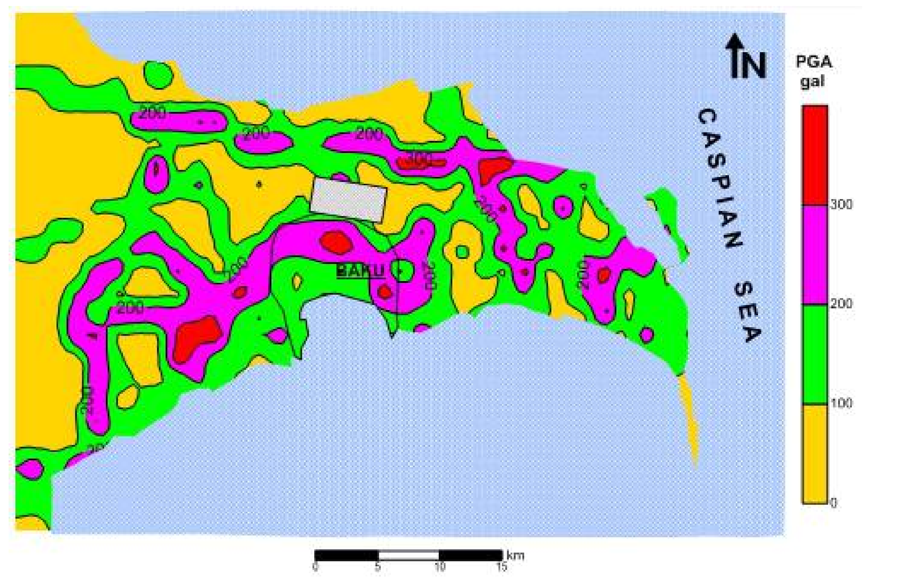

Figure 5. The scenario (design) of strong motion distribution of 25th November 2000 Caspian earthquake for Absheron peninsula expressed in the values of Peak Ground Acceleration (PGA).
Note: Location of the oil field deposit area is highlighted by the quadrangle polygon. The border of Baku city (the capital of Azerbaijan) is marked by black curves (also in Fig. 6).

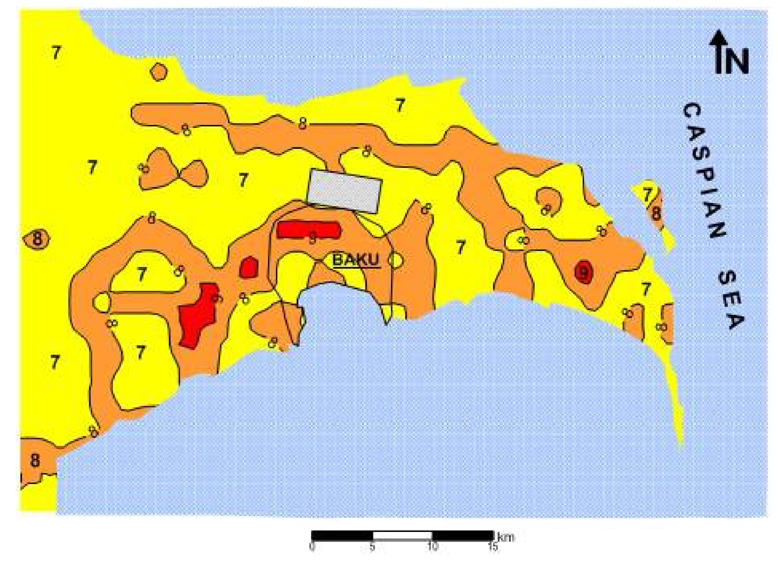

Figure 6. Intensity level for Absheron peninsula using existing correlation relationship between peak ground acceleration (Fig. 6) and intensity MSK-64
(Murphy et. al., 1977; Trifunac et. al., 1975)

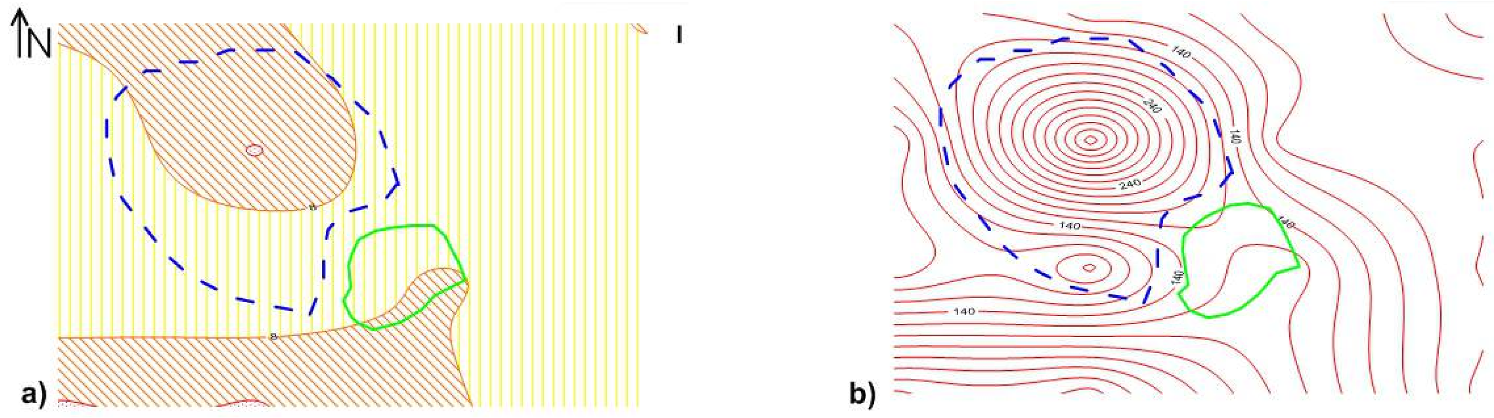

Figure 7. Intensity distribution (a) and PGA distribution (b) in oil field in Absheron peninsula considering parameters of the design 25.11.2000 Caspian earthquake.
Note: Dotted line illustrates the area of the oil field deposit, while green line highlights the populated area. Mapscale1:50,000.

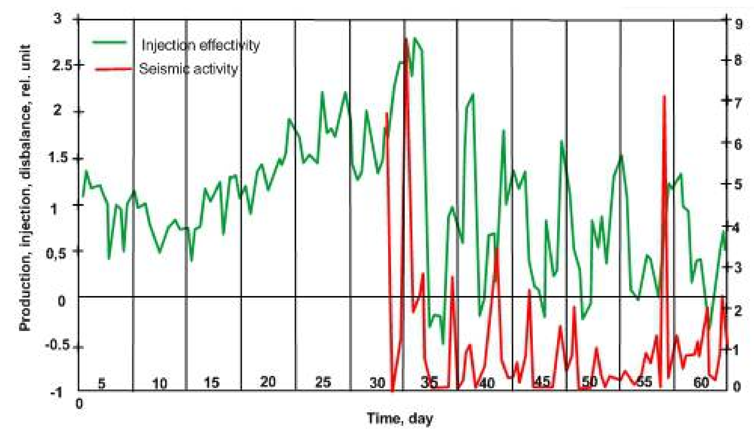

Figure 8. Dependency graph between effectivity of injection (difference between production and injection) in oil field deposit of Absheron peninsula and seismic activity (red colour) during 11.2000-12.2000.

Figure 8 presents possible relationship between seismic effect and daily oil recovery which states the direct proportional characteristics.The model estimations could provide sufficient information for decision makers. The results might represent an interest for integrated seismic geodynamic monitoring of the oil and gas bearing objects (sites) in future. Moreover, results can be a good trigger in plotting modified maps (models) for seismic zoning of the oil and gas fields. Besides, results can serve for land-use planning within an intensive infrastructure development of the Baku city and Absheron peninsula as a whole and for the insurance companies operating in the region.