Induced Seismicity at Upstream Petroleum Sector in Turkey

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ABSTRACT

In this study, the relationship between hydrocarbon production and earthquake activities in Turkey has been investigated. The crude oil production in southeastern Turkey and the natural gas production in the Thrace Basin have also been worked out. The production and earthquake data between the years 1990-2015 have been selected for the statistical approach. It has been observed that there is a linkage between the natural gas production and number of earthquakes in Thrace Basin region based on the regression analysis and graphical study. However, similar correlation in southeast Turkey is not observed. Main evaluations and suggestions regarding the petroleum activities in the region have been mentioned in the research. This manuscript is the first publication in this area in Turkey.

Keywords: Human-Induced Earthquake, Induced Seismicity, Geostatistics, Upstream Petroleum Activities

1. INTRODUCTION

There are two hydrocarbon regions in the Turkish upstream petroleum sector. The northwestern part of Turkey, called Thrace Basin, is a natural gas production region whereas the southeastern Turkey is the crude oil production region.

There are several studies and publications in the literature worldwide regarding human-induced or human-triggered earthquakes from energy related activities; such as, hydrocarbon production, enhanced oil recovery, wastewater injection, geothermal activities, hydraulic fracturing (shale gas and shale oil), coal and solution mining and surface water reservoirs. The relationship between seismic activity and the timing of petroleum activity, the amount and rate of fluid injected or produced, and other factors are still uncertain and are current research topics (Folger and Tiemann, 2016). On the other hand, there is no publication on induced seismicity at upstream petroleum sector in Turkey.

Pore pressures act against gravitational and tectonic forces and may lead to rock failure in case of sufficient pressure changes. Pre-existing fractures may be stable in the stress regime before hydrocarbon production or water injection; however, decrease/increase in the pore pressure leads to an opposition to the normal stress. When the normal stress is overcome, shear failure will occur (IEAGHG, 2013). In the most of the hydrocarbon fields induced seismicity has either not been monitored, not studied in detail or not reported publically in the literature. Because of this insufficient data or missing information, there are limitations to understand the mechanisms about the causes and the risks of induced seismicity in petroleum fields (IEAGHG, 2013). Anyhow, induced/triggered seismicity may be caused by pressure changes in the reservoir pores.

Some researchers state that the rates and maximum magnitudes of induced earthquakes generally increase with rising reservoir pressures, total fluid volumes and injection/production rates (Nicol et al, 2011). Turuntaev et al (2015) concluded that there are some kinds of correlation between the volume of hydrocarbon produced and seismic activity rate based on the data of Sakhalin Oil Field. Seismic events have been monitored and felt at some of the energy development sites in the United States. Seismic events caused by or likely related to energy activities have as well been reported in several states of the USA (NAS, 2013).

It is also discussed in the literature that the effect of petroleum production could be observed several kilometers away from hydrocarbon fields. Gas reservoir depletion can affect the surrounding pressure of the area and transmit significant pore changes at 20-30 km distance on the regional active faults (Grasso, 1992). Grasso (1992) has also observed that such effects are possible at a distance up to 40 km with some time delays.

In Turkey the crude oil production region, Southeastern Anatolia, is close to the East Anatolian fault. The crude oil production in Southeastern Region is performed at more than 1,300 oil wells and daily production is more than 55,000 barrels from more than 120 oil fields from an average interval depth of 2,075 meter (ranging from 1,500 m to 3,000 m) currently. The East Anatolian Fault is a major strike-slip fault zone in the eastern part of Turkey (Şengör, 2005). The fault system forms the transform type tectonic boundary between the Anatolian Plate and the Arabian Plate. The relative movement of the two plates is apparent in the lateral motion towards the west along the fault.

The natural gas production region in Turkey, Thrace Basin, is very close to the North Anatolian Fault. There are almost 70 small-tiny natural gas fields scattered throughout the Thrace Basin producing more than 1 million m^3 gas daily from an average interval depth of 1,150 meter (ranging from 225 m to 3300 m) with more than 200 wells, at present. There is negligible water production and no injection in this region. North Anatolian Fault is one of the most energetic and longest earthquake creating faults in the world. It is an active right-lateral strike-slip fault in northern Anatolia running along the transform boundary between the Anatolian and Eurasian Plates. The fault extends westward from a junction with the East Anatolian Fault at the Karlıova Triple Junction into the Aegean Sea along a length of 1,500 kilometers. It runs beneath the Sea of Marmara about 20 km south of Istanbul.

Triggering of earthquakes by the hydrocarbon production is a controversial discussion topic. The effect of reservoir pressure change is certainly important. However, much work is needed to understand the mechanism fully behind the human-triggered earthquakes which is out of the scope of this paper. The possible relationship of earthquakes with the hydrocarbon production of Turkey is revealed in the study that focuses the statistical relationship between the amount of fluid (hydrocarbon and water) production, water injection and the number of earthquakes. Graphical study and statistical analysis have been used to show the effects of petroleum production on seismic activities, if any.

2. METHODOLOGY

The annual hydrocarbon productions and the number of earthquakes in certain regions have been used for the regression analysis. In the southeastern region crude oil production, water injection and number of earthquakes are correlated. In the Thrace Basin natural gas production and number

of earthquakes are correlated. The hydrocarbon (crude oil and natural gas) production, water production and water injection data are obtained from the General Directorate of Mining and Petroleum Affairs, Ministry of Energy and Natural Resources. Earthquake data is obtained from the Disaster and Emergency Management Presidency.

Most earthquakes recorded by seismometers whether natural or induced, are too small to be noticed by people. These small earthquakes are often named "micro earthquakes". In this study, the earthquakes having magnitude lower than 3 are accepted as micro earthquakes. The earthquakes with magnitudes 3 or above are selected for the statistical analysis.

The selected study area that includes the production and earthquake data is colored in Figure-1. The location of the East Anatolian Fault and the Southeastern Region are given in Figure-2 and the location of the North Anatolian Fault and the Thrace Basin Region in Figure-3. The annual crude oil production in the Southeastern Region versus annual number of earthquakes is presented in Figure-4 (AFAD, 2018; GDMPA, 2018). However, no relation is observed by analyzing the distributions of the curves. The annual natural gas production of the Thrace Basin versus annual number of earthquakes is presented in Figure-5 (AFAD, 2018; GDMPA, 2018). On the same Figure-5 it is seen that the number of earthquakes occurred in the region has some parallelism with the variation in the natural gas production amount. The graphical distribution is tested by statistical approach if the parallel behavior of curves is just a coincidence or not.

Figure-1, *The Selected Study Area in Turkey*

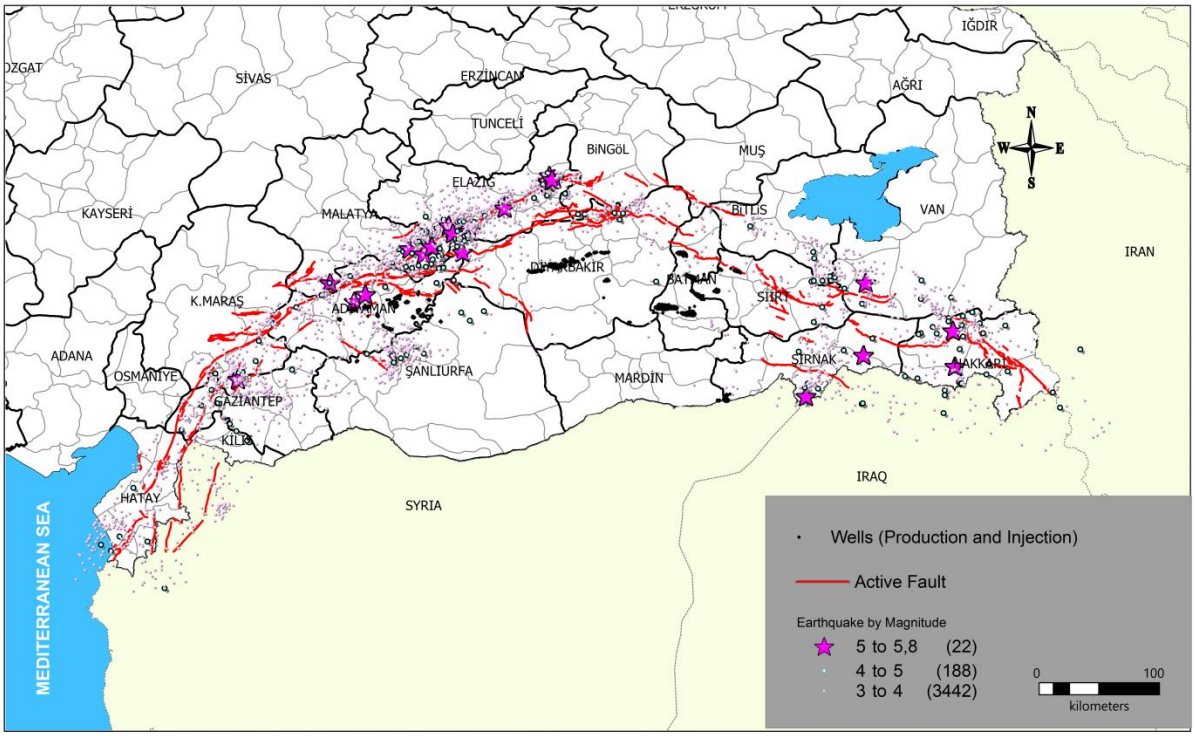

Figure-2, *Southeastern Anatolian Region in Turkey*

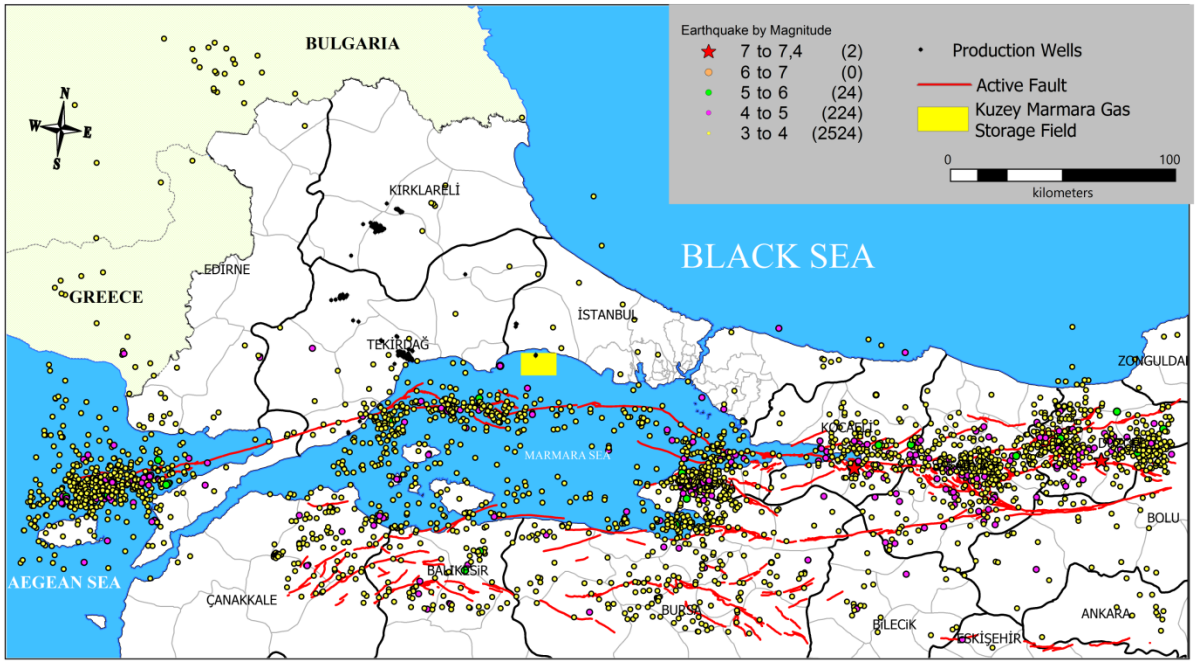

Figure-3, *Thrace Basin (Marmara) Region in Turkey*

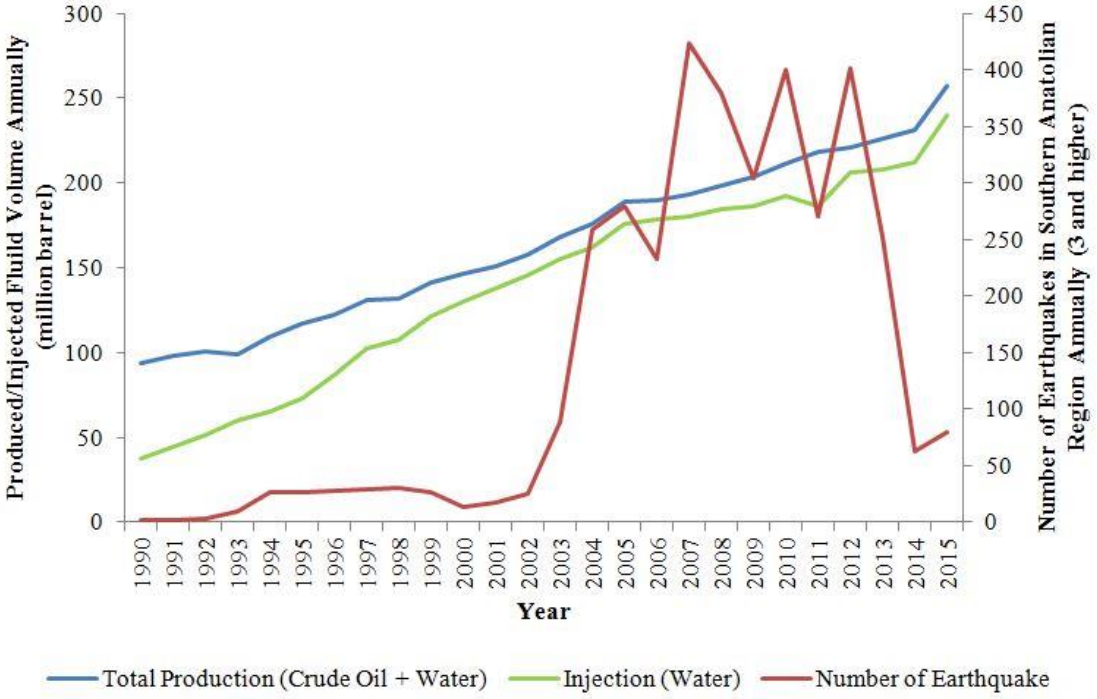

Figure-4, *Production and Earthquake Data in Southeastern Region*

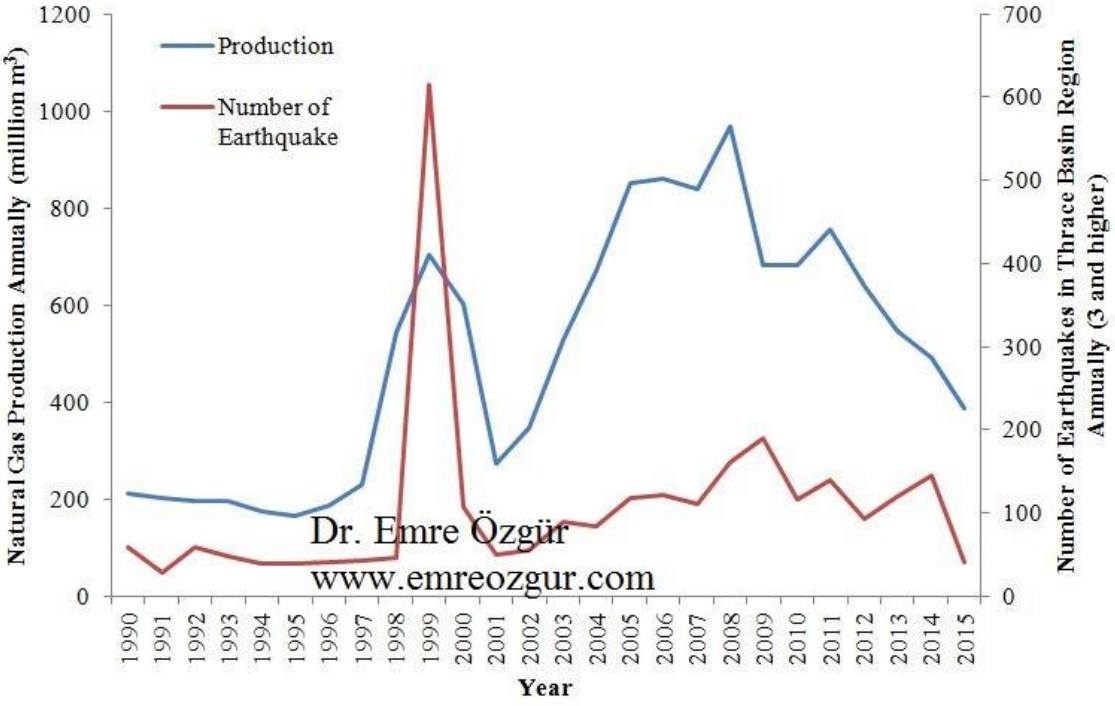

Figure-5, *Production and Earthquake Data in Thrace Basin Region*

3. STATISTICAL ANALYSIS

The statistical relationship between the hydrocarbon production and the number of annual earthquakes are tested using the regression analysis in Minitab Software. The data set used in the study is for the years between 1990 and 2015. The coefficient of determination (R^2) is found as 27% for the southeastern region which includes crude oil production, water production and water injection. In the literature this coefficient R^2 is considered to range as follows:

0-19: very weak, 20-39: weak, 40-59: medium, 60-79: strong, 80-100: very strong.

No notable connection has been observed between the crude oil production, water injection and earthquakes in the southeastern region. This may be due to the injection of produced water which provides pressure support for the reservoirs. The pressure support may prevent the triggering of the earthquakes.

R^2 is found as 66% for Thrace Basin Region if the production and earthquake data for the year 1999 is omitted. The big destructive Izmit earthquake with the magnitude 7.4 that occurred in 1999 in the Marmara Region was followed by lots of aftershocks. This misleads the statistical analysis. If all the data for 1999 was included, R^2 is obtained as 26% to lead to incorrect interpretation about the relationship between the production and earthquake data that actually have parallel trends.

The Izmit earthquake of 1999 had occurred during the time of sharp increase in natural gas production in the Thrace Basin Region. In the year 1999, 500 million m^3 of the total 700 million m^3 gas production of the Thrace Basin had been obtained from a Kuzey (Northern) Marmara offshore gas field which is as close as 20 km to the Marmara Sea Segment of the active North Anatolian Fault. Discovered by the Turkish Petroleum Company in 1988, this is the second largest gas field in Turkey. The Field is located in the gas-prone Thrace-Gallipoli Basin in the Marmara Sea, 3 km off the coast.

Kuzey Marmara natural gas field is now a depleted gas field and used as an underground gas storage deposit. The field is in a depth of 1,200 meters below the sea floor with 43-meter water depth. The epicenter of the Izmit earthquake of 1999 is some 100 km away from the Kuzey Marmara gas field. The pressure irregularity along the part of the fault close to the gas field under operation might have played a role on the total pressure balance of the fault to trigger the earthquake that year.

Empirical induced seismicity data from upstream petroleum projects have important information for risk assessment and management. We keep in mind that the active North Anatolian Fault (also known as Marmara Fault) is 20 kilometers away from the underground gas storage field. According to the earthquake experts it is expected that the next big earthquake similar to the Izmit earthquake of 1999 will take place in the Sea of Marmara because of the structural behavior of the North Anatolian Fault creating earthquakes in a direction from east towards west (Şengör et al, 2005). In such a case the gas storage area may be a hotspot for triggering the North Anatolian Fault in the region.

The gas production had started in 1997 in the field and the cumulative production had been about 1,5 billion m^3 until 2003. The production had been stopped in 2003 because of depletion decision. The field was then prepared for storage purpose. After 2007 the storage facility became operational. The injection and production amounts for the storage activity were roughly same in following years to maintain the pressure balance (Şahin et al, 2012). However, the capacity of the

storage field will later be increased. The capacity increase will be performed by the production of recalculated additional reserve and by lowering the cushion gas amount with new production/injection wells. More than extra 1,5 billion m^3 volume of natural gas will be produced because of the added reserve and lesser cushion gas usage when the project extension is performed. It is advisable to reassess this production till the planned urban transformation of Istanbul, including rebuilding many old and risky buildings, is completed in order to prevent the triggering of any earthquakes in the Sea of Marmara.

4. CONCLUSIONS

The relationship between hydrocarbon production and earthquakes in Turkey has been investigated using statistical analysis. Such earthquakes, triggered or induced, occur due to reservoir pressure changes or mass transfer in petroleum production activities. It is clear that there is a significant correlation between natural gas production and annual earthquake numbers in the Thrace Basin region where the location of active North Anatolian Fault is close to the underground gas storage field. In such a case seismicity may be induced by the injection and production loop at the site during storage activities. Consequently, it is recommended to reassess the production/injection amount in the Kuzey Marmara underground gas storage facility until the completion of urban transformation activities to convert all structures earthquake-resistant in Istanbul, the most crowded city in Turkey, to get rid of the risks of the Marmara earthquake expected to happen in the near future.

This study has been the first research in Turkey regarding the relation between petroleum (crude oil and natural gas) production and seismic activities. Another recommendation would be to perform detailed monitoring system measuring the reservoir behavior during the seismic activities for further studies in the future to help understanding the mechanisms behind the triggered earthquakes in the upstream petroleum sector completely.

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