Hot spot analysis and high/low clustering of earthquakes in the Zagros region (Iran)

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ABSTRACT

In this research, statistical point pattern analysis of earthquake locations in the Zagros region of Iran during 1976-2019 was carried out. For this purpose, Local Getis-Ord's Gi* index was estimated and computed for the data catalog. Results obtained indicate a completely clustered pattern of epicenters for the whole region and also indicate that earthquakes with greater magnitudes show higher degrees of clustering. Also, a spatial autocorrelation of higher values of magnitudes are observed. Hot spot areas presented in this study for this region well spatially correlate with the trends of major active faults of the region, which can be interpreted as areas with higher crustal strength.

Keywords: Seismicity, Seismotectonics, Zagros, Spatial analysis, Earthquake clustering

INTRODUCTION

Study of the spatial distribution of earthquakes has long been a focus of research by seismologists and statisticians. Spatial statistical analysis of earthquake locations can provide us useful information regarding seismicity and seismotectonic nature of active regions. During the past decades, point pattern analysis techniques widely have been used for exploring the internal structure of stochastic point processes such as earthquakes. Many works have used spatial statistical methods to evaluate earthquake data and produce predictions for the future (e.g., Yamada et al., 2011; van Lieshout and Stein, 2012; Bray and Schoenberg, 2013; Trofimenko and Bykov, 2017).

The Zagros region in Iran, as a continent-continent collision zone, is one of the most seismically active regions of the world. It is beleived that the seismic activity of this belt is related to the Arabia/Eurasia collision initiated at ~ 35 Ma (Mouthereau et al., 2012). This zone extends from eastern Turkey in the northwest to the Strait of Hormuz in the southeast, with a length of about 1200 km and a width of about 200-300 km (Agard et al., 2012). During the past decades many destructive earthquakes occurred in this region. The most recent earthquake of 12 Nov. 2017 with M_w7.3 occurred within this region (in Ezgeleh area), resulted in huge loss of life and property.

This study attempts to presents a spatial statistical analysis of the earthquake epicenters in the Zagros region in order to reveal the characteristics of the distribution pattern of epicenters and to invertigate the spatial associations between earthquakes and faults in this region.

METHODOLOGY

Spatial point pattern analysis is a powerful technique to find the relationships in a spatial data distribution. Theory of this technique has rapidly grown in recent decades and its background has been described in many texts (e.g., Diggle, 2014).

In order to assess the spatial autocorrelation of point patterns, Getis-Ord Gi^* index could be very helpful. Spatial autocorrelation measures the correlation based on both point (epicenter) locations and the feature attributes, simultaneously. Hotspot analysis is a spatial analysis and mapping technique interested in the identification of clustering of spatial phenomena. These spatial phenomena are depicted as points in a map and refer to locations of events or objects. This tool identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots).

Getis-Ord Gi^* statistic identifies statistically significant hot and cold spots. This statistic is calculated as:

$$Gi^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{s\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^{2} - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \quad (1)$$

where x_j is the attribute value for point j, $w_{i,j}$ is the spatial weight between point *i* and *j*, and *n* is the total number of points. A Gi^* value near zero indicates the absence of clustering of either high or low values surrounding the target point. The larger positive Z score is, the more intense the clustering of high values (a hot spot) and the smaller negative Z score is, the more intense the clustering of low values (a cold spot) (Mitchell, 2005).

DATA ANALYSIS AND DISCUSSION

For this study, earthquake data for the study region during the period of the beginning of 1976 to the end of February 2019 were extracted from the USGS catalog. In order to obtain a more homogenized data catalog, and to be sure that all recorded events analyzed in this research are natural earthquakes, events with magnitude less than 4.5 were excluded in this analysis. To avoid edge effects, earthquake epicenters in neighboring regions with a distance of 0.5 geographical degree are also taken into account. An overall view on the spatial pattern of earthquake epicenters in the Zagros region (Fig. 1) indicates that in the northwestern part of the region, where the salt layer (Hormuz formation) is thin or missing (Ni and Barazangi, 1986), the epicenters of earthquakes are restricted to narrower zones surrounding major active faults. In general, the spatial distribution of earthquake epicenters is characterized by the clustering in whole region.

In this research, high/Low clustering of epicenters was analyzed by calculating Local Getis-Ord Gi^* statistic and considering magnitude as weighting attribute. Positive and significant values of this statistic suggest a cluster of high values, whereas negative and significant values suggest a cluster of low values. This statistic returns a Z-score and p-value for each point in the data set. The higher the value of the Z-score (significant positive values), the more intense the clustering of high values (hot spots) is, and in contrast, the smaller the value of the Z-score (significant negative values), the more intense the clustering of low values (cold spots) is. A Z-score value near zero indicates no apparent spatial clustering.

Through this analysis, clusters of high-magnitude spatially auto-correlated epicenters (hot spots) and low-magnitude spatially auto-correlated epicenters (cold spots) can be identified. Map shown in Fig. 2 clearly presents hot and cold spot patterns of earthquake occurrence in this region. According to this map, it is observed that hot spots represent earthquakes with high magnitudes, which are surrounded by high-magnitude neighboring earthquakes. These areas could be considered as higher strength behavior of the crust, and in contrast, cold spots may be evidence of crustal weakness areas of the region. Hot spot areas presented in this figure (Fig. 2) well spatially correlate with the trends of major active faults of the region. Especially, hot spots located near to the Makran region, are very clear. As a result, this map provides greater certainty in terms of where hot spots are located, i.e., the most risky areas of the region from the viewpoint of seismic hazards.

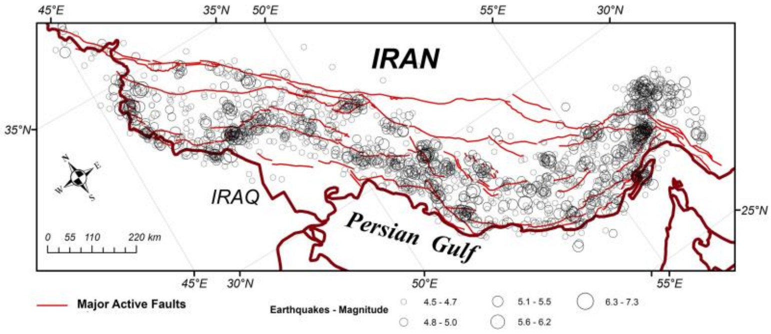

Figure 1. Map showing major active faults of the Zagros region and the epicentral distribution of M ≥ 4.5 earthquakes that occurred in the Zagros region during the period 1976-2019.

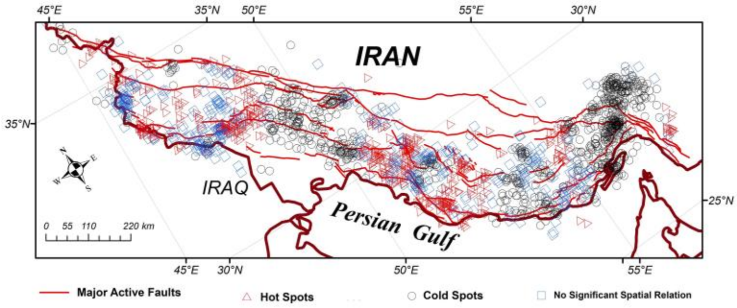

Figure 2. Map showing the spatial pattern of hot and cold spots, resulted from spatial autocorrelation of earthquake data over the examined region.

CONCLUSIONS

In this study, the spatial distribution of earthquake epicenters in the Zagros region was studied. The most recent release of ArcGIS package (version 10.7) has been employed for this analysis and for providing maps. The Local Getis-Ord Gi^* analysis indicates clear hot and cold spots showing areas with spatial autocorrelation of high- and low-magnitude earthquakes, respectively. Hot spot areas can be interpreted as areas with higher crustal strength and in contrast, cold spot areas may be considered as areas with crustal weakness.

As a result, in regions such as Zagros which surface fault ruptures associated with earthquakes is extremely rare and most information about the active faulting comes from earthquakes, the spatial point pattern analysis can be a very powerful tool to discriminate the seismicity linked to a particular fault and to easily reveal the trend of major hidden (blind) active faults.

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