Investigate of Iran Recurrence Earthquakes by the Network

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Research Article

Keywords: Complex Network, Earthquake, spatio-temporal recurrence

Posted Date: March 23rd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1425179/v1

Abstract

Human beings have encountered numerous natural disasters over time, that the earthquake phenomenon is one of the most damaging of all and has a very complex nature. Earthquakes manifest spatio-temporal complex behavior that can be studied using complex networks, which enabled us to recognize the global features of Earthquake. Studies on the earthquakes using the network method are based on how the network is constructed. In this paper, by constructing the network, the spatio-temporal recurrence of earthquakes occurring in the Zagros region, which is recorded at all the broadband and short-period stations of the Iranian Seismological Center (ISC, http://irsc.ut.ac.ir), are subject to statistical review. The results showed that in the Zagros area the spatio recurrence is about 0.020 km, and the time recurrence for all the thresholds of magnitude is similar to power relationship ($^1/T^{\alpha}$) with a α =-0.9 .

1. Introduction

Earthquake is one of the most harmful natural disasters, which is very complex and unpredictable in nature, and its occurrence without warning causes thousands of deaths and catastrophic economic damage in such areas. The Iranian plateau is considered as one of the seismic regions of the world due to its special position on the orogenic and seismic belt of the Alpine Himalayas. Due to the convergence of the Arabian and Eurasia plates, Iran has suffered a lot of human and economic losses in the distant past as well as in recent years due to earthquakes. Therefore, it is necessary to study different aspects of earthquakes in seismicity areas such as Iran, which will help to better understand this complex phenomenon.

In recent years, complex network theory has been used as a powerful tool to describe complex phenomena (Costa et al. 2011). Earthquakes are a temporally and spatially complex phenomenon that occur suddenly due to the displacement of faults in the Earth's lithosphere (Stein et al. 2003).

It is difficult to consider all the factors that cause faults to move and place them in a set of mathematical equations that can describe the phenomenon of earthquakes, and due to the lack of access to the depths of the earth where the earthquake occurs, we are facing to certainty.

statistically study is one of the ways to study earthquakes. Since the number of earthquakes is large and there are complex correlations in terms of space, time and intensity between earthquakes, so earthquakes can be considered as complex systems.

Two well-known classical laws, Gutenberg-Richter and Omori, confirm the complexity of earthquakes (Omori 1984; Gutenberg et al. 1941).

Therefore, complex networks are defined tools for studying complex systems, can be used to study earthquakes. In complex network theory, it is not necessary to know the details of the fault system, but only by knowing the magnitude, time and epicenter can different aspects of the earthquake phenomenon be studied.

In this method, the components of the system, the epicenter of the earthquake as a node and the interaction between them are shown as edges between the nodes of the network, and due to the lack of dependence of system components on fault parameters, relative to kinematic and dynamic analysis of earthquakes is much simpler and is far from heavy calculations and solving complex mathematical equations, and only with the catalog information of earthquakes, various aspects of the complex phenomenon of earthquakes can be studied.

For example, examining the parameter of the recurrence interval of earthquakes helps to understand this complex phenomenon. Analysis of the recurrence interval of large earthquakes is closely related to the dynamic of seismic faults and is a key parameter for assessing seismic risk in a fault zone (McCalpin 2009; Yeats et al. 1997).

In this study, using the networking and statistically methods, the temporal and spatial return period of earthquakes occurred in the Zagros region, which is recorded in the stations of seismic networks affiliated to the Institute of Geophysics, University of Tehran.

2. Zagros Sesismotectonic

One of the youngest and most active continental collisions on Earth is the Zagros thrust folded belt, which is part of the Alpine Himalayan mountain belt (Snyder and Barazangi 1986). It is about 1500 km long with a width of 200 to 400 km from the Taurus Mountains in southeastern Turkey until the Minab fault in the east of the island of Hormuz in southern Iran (Berberian 1995; Alavi 1994).

The formation of the Zagros Folding Belt, ZFTB (Koyi 1988) began after the closure of the Neotethys Ocean and the collision of the plates of Saudi Arabia and Central Iran in the main Zagros Trust (MZT).

The main Zagros thrust fault marks the northern boundary of seismicity in the Zagros. This fault is in fact a suture zone between the two colliding planes of Saudi Arabia and Central Iran, which continues with the direction of northwest-southeast from west of Iran to the north of Bandar Abbas, then trend is changing to west-east.

Convergence North-Northeast of Saudi Arabia to Eurasia is divided into thrust and strike-slip faults in the Zagros Mountains (Maggi and Priestley 2005; Talebian and Jackson 2002). The highest part of the Zagros Mountains is in the form of a narrow width (10 to 65 km) which is sometimes called the high Zagros (HZ).

The northeastern boundary of this sub-zone closes to the main thrust of the Zagros and the south-western boundary with an important thrust (HZF) (Fig. 1).

Zagros is the most seismic region in Iran and most of the Zagros earthquakes occur at a depth of 12 – 8 km. One of the most important earthquakes in the region is the 1957 earthquake with a magnitude of 6.7 on the scale of surface waves in the Kermanshah region and mentioned the earthquake of 17 May 1999 with a magnitude of 6.2 on a global scale in the Kahmareh region of Fars province.

3. Methodology Of Earthquake Network

Network theory, which is one of the largest branches of mathematics, was first proposed in 1736 with the publication of an article by Leonard Euler, which is closely related to algebra and matrix theory. In mathematician terms, a network is a set of interconnected points and lines. In fact, a network is a mathematical model for a discrete set whose members are interconnected in some way. Network members are defined as a set of nodes and the interaction between members by a set of edges. The members of a set in society can be human beings and the edge between them can be a friendship, and in a molecular set, atoms as members of the set and the edge between them can be chemical bonds (Babelian 2007)

Recent advances in mathematics, especially in its applications, have led to the dramatic expansion of network theory, so that network theory is now a very useful tool for research in various fields such as coding theory, statistical operations research, electrical networks, Computer science, chemistry, biology, social sciences, design of electrical circuits, geometric modification of streets to solve traffic problems, in urban planning and civil engineering and other fields. In some networks, such as the network of earthquakes, due to various unknown parameters of earthquakes, it is more complex to understand the behaviors of complex networks, methods derived from statistical mechanics and define statistical quantities such as degree distribution function, cluster coefficient and etc, useful to provide information about the general state of the network (Boccaletti et al. 2006).

To examine these qualities an appropriate network must be set up. To build any network (earthquake network), firstly, must know the nodes and edges that are the main parameters of each network. There are two main approaches to constructing an earthquake network, which are as follow:

In the first approach, the geographical area under study is divided into boxes of the same size. If earthquakes occur in these boxes, the earthquakes will act as a node. Edges are also defined in such a way that consecutive seismic events are connected by edges in terms of time. This network model is related to the model presented by Abe and Suzuki (Abe and Suzuki 2009, 2007, 2005, 2004; Abe et al. 2011). They showed that the network of earthquakes is scaleless and has the structure of a small world. Also, the effect of box size on the characteristics of Iran seismic networks has also been studied and network characteristics such as degree distribution function, cluster coefficient and characteristic length have been obtained and the study of seismic active points in Iran has been obtained (Darooneh et al. 2014).

In the second approach, seismic events are considered as nodes and two nodes are connected when they are interconnected by the relationships that are true for an earthquake event. Telesca and Lovallo used phenomenal algorithms to make connections between earthquakes, which This algorithm was proposed as a tool for time series analysis (Lacasa et al. 2008).

Baiesi et al. (2004) to express the relationship between earthquakes, presented a quantitative relationship that included the quantities of time interval and spatial distance between two earthquakes, as well as the magnitude of the first earthquake.

Davidson et al. (2003) used the recursive seismic method to construct the earthquake network, which is the method used in this study to construct the earthquake network. This method uses the concept of waiting time to return the occurrence of earthquakes in space and time. Two earthquakes, *A* and *B*, are considered to have occurred in time A before earthquake *B*. Earthquake *B* is a return from Earthquake *A* provided that no other earthquakes have occurred spatially closer to Earthquake *B* after Earthquake *A*.

In fact, $\bar{AB}$should be the lowest value in terms of distance, in the time interval $[t_A - t_B]$ that time between the event *A* to *B*. Each return is denoted by the interval $L = \bar{AB}$ and the time interval $t_A - t_B$. In other words, the space window is the center of the first event, and each return to this event is at the closest spatial distance to the other events.

The distribution of *L* intervals between return events for different thresholds of magnitude m is calculated using the centrifugal coordinates of the earthquake catalog and using Eq. 1 presented by Baiesi et al. (2004).

$$L_{ij} = R_0 Arccos[sin\left(\theta_i\right) sin\left(\theta_j\right) + cos\left(\theta_i\right) cos\left(\theta_j\right) cos(\phi_i - \phi_j)$$

1

In relation to index *i* and *j*, respectively, represent the first and second earthquakes, and θ and φ are the longitude and latitude of the epicenter of the earthquake, respectively, and R_0, the radius of the earth.

Earthquake networks are constructed in such a way that seismic events represent nodes, and to create an edge between nodes in the earthquake catalog, define the temporal and spatial return of earthquakes, and each return from the next event to the previous event is represented by an edge between a pair of nodes in the temporal and spatial series of earthquakes.

Separate events have different input and output edges that indicate their relationship to other events, and thus nodes have different degrees. The output edges of each node determine the structure of the returns in its neighbors. In other words, the output edges of each node are the input edges of its neighbors.

4. Data

In this study, we used earthquakes that occurred in the Zagros region in the period time from January 1, 2006 to January 1, 2016 with 77245 earthquakes, which are recorded in the permanent stations of the national seismic network to the Institute of Geophysics, University of Tehran (http://irsc.ut.ac.ir). Figure 2 is shown frequency of earthquakes in terms of magnitude that earthquakes are mostly less than 3 on the Nuttli (M_n) scale.

To determine the magnitude threshold (m_c) for data processing, plotted magnitude by year, shown in Fig. 3, that the value of the large threshold for starting the process is m_c=2.

5. Discussion

To describe seismicity, we examined earthquakes in the Zagros region in Iran with algorithm of Davidson et al. (2005). In this way, the seismic network was first constructed by considering seismic events as nodes and defining the spatial and temporal return relationship as the edge between nodes. For this purpose, the distribution of *L* distances between return events for different thresholds of magnitude m, was calculated using the centrifugal coordinates of the catalog of earthquakes and the relation of Baiesi et al. (2004).

The shortest distances specified are shown schematically in Fig. 4. The black nodes at the center of the earthquakes and the shortest distance (*L*, in meters) of each earthquake with the next earthquake are represented by colored arrows.

Using Baisei et al. (2004) equation, the shortest distance between adjacent earthquakes was calculated. Firstly, we consider a given magnitude, for example, earthquakes with a magnitude greater than 2, and we get all the spatial distances that have recurrent earthquakes and are calculated with the relation *Lij*. The P function is a function of the distribution of distances that specifies how many data with a distance *L* there are in the data. Because distances are real numbers, and it is certainly rare to find several earthquakes that have exactly the same distance, so to count, we consider the same spatial intervals and, for example, specify how much data there is that distance is between 10 and 11 and ....

In Fig. 5, the distribution of distances *L*, ($P_m(L)$) between recurring events was plotted for earthquakes in the Zagros region for different magnitudes $m_c \geq 2$ that in the graph *L**, for any magnitude m, the distance is the place where the distance distribution function reaches its maximum value on the graph.

As shown in Fig. 5, it can be seen that the value of the distance *L**(m) increases by magnitude m where the distribution function reaches its maximum value at the peak. As shown in the figure, for large values of *L*, the distribution functions show a descending behavior with a slope of 1.65 to the point where there is no more data and the points of the graph are exhausted.

As shown in Fig. 6, as the magnitude of the earthquake increases, the value of *L** shifts to the right. It seems that by performing a series of mathematical operations on the graphs, all of these graphs show the same behavior, in which the appropriate scale must be selected. For this purpose, different equations with different coefficients were investigated. For earthquakes in the Zagros region with a value of 0.5 m, the behavior of the graphs with different magnitudes was the same as shown in Fig. 5.

The experimental relationship of the F function, which is a function of the Scaling Factor, can be calculated for the Zagros region according to Fig. 6, by extrapolation as Eq. 2.

$P_m(\mathrm{L})\tilde{\mathrm{L}}^{-1.65}\mathrm{F}(\mathrm{l} / 10^{0.5m})$ (2)

According to Fig. 6, it can be seen that for the F function at low values, there is a power relationship with the power 2.9 and an almost constant behavior at high values.

The transfer point between these two states, which is shown by the dashed line on the figure, was obtained by extrapolation, L_0 = 0.020 km. The obtained experimental relation $L^* \approx 0.020 \times 10^{0 \cdot 5m}$, is established for this diagram.

In the study of Wells and Coppersmith (1994), the value of $L*$ is expressed as the length of the L_R rupture, and in their study they obtained the value of $L_R \approx 0 \bullet 018 \times 10^{0 \cdot 46\mathrm{m}}$ for the California region. Also in the Kagan (2000) study for the California region, the relation $L_R \approx 0 \bullet 02 \times 10^{0 \cdot 5\mathrm{m}}$ was calculated.

The results of the present study for the values obtained in the Zagros region are in good agreement with the values suggested by Wells and Coppersmith (1994).

In addition to calculating the spatial return of recurrent events, the temporal return of earthquakes in the Zagros region was also studied. To calculate this quantity, two earthquakes *A* and *B* are considered, in terms of time, earthquake *A* occurred before earthquake *B*. Earthquake *B* is considered a time return from Earthquake *A* if it is the closest time distance from Earthquake *A*. The time return for earthquakes in the Zagros region in Iran is calculated and the graph changes of the distribution function of return events over time can be seen in Fig. 7.

As shown in Fig. 7, for all magnitude thresholds, there is a similar power behavior ($1/T^{\alpha}$) with a value of α = -0.9. As shown in the Fig. 7, for long periods of time this behavior does not follow the law of power because the number of long time intervals between earthquakes is small. Even in small amounts of time, this relationship is not established, which can be due to an error in determining the times used in the catalog. In the study of Davidson et al. (2005) for the California region also showed a graph of the function of the distribution of recurring events over time with similar power behavior with a slope of -0.95.

6. Conclusion

In this study, the results of the network model of earthquakes phenomenon about the temporal and spatial return period of earthquakes by method of Davidson et al. (2005) were studied in the Zagros region.

The results showed that:

- In the Zagros region, the spatial return period of earthquakes is about 0.020 km.

-The time return period for all magnitude thresholds greater than 2 ($m_c \geq 2$) has the same power behavior ($1/T^{\alpha}$) with value of α =-0.9.

Declarations

ACKNOWLEDGMENT

We would like to express our gratitude to the National Seismic Network (ISC) affiliated to the Institute of Geophysics, University of Tehran, for providing data on the database.

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Figures

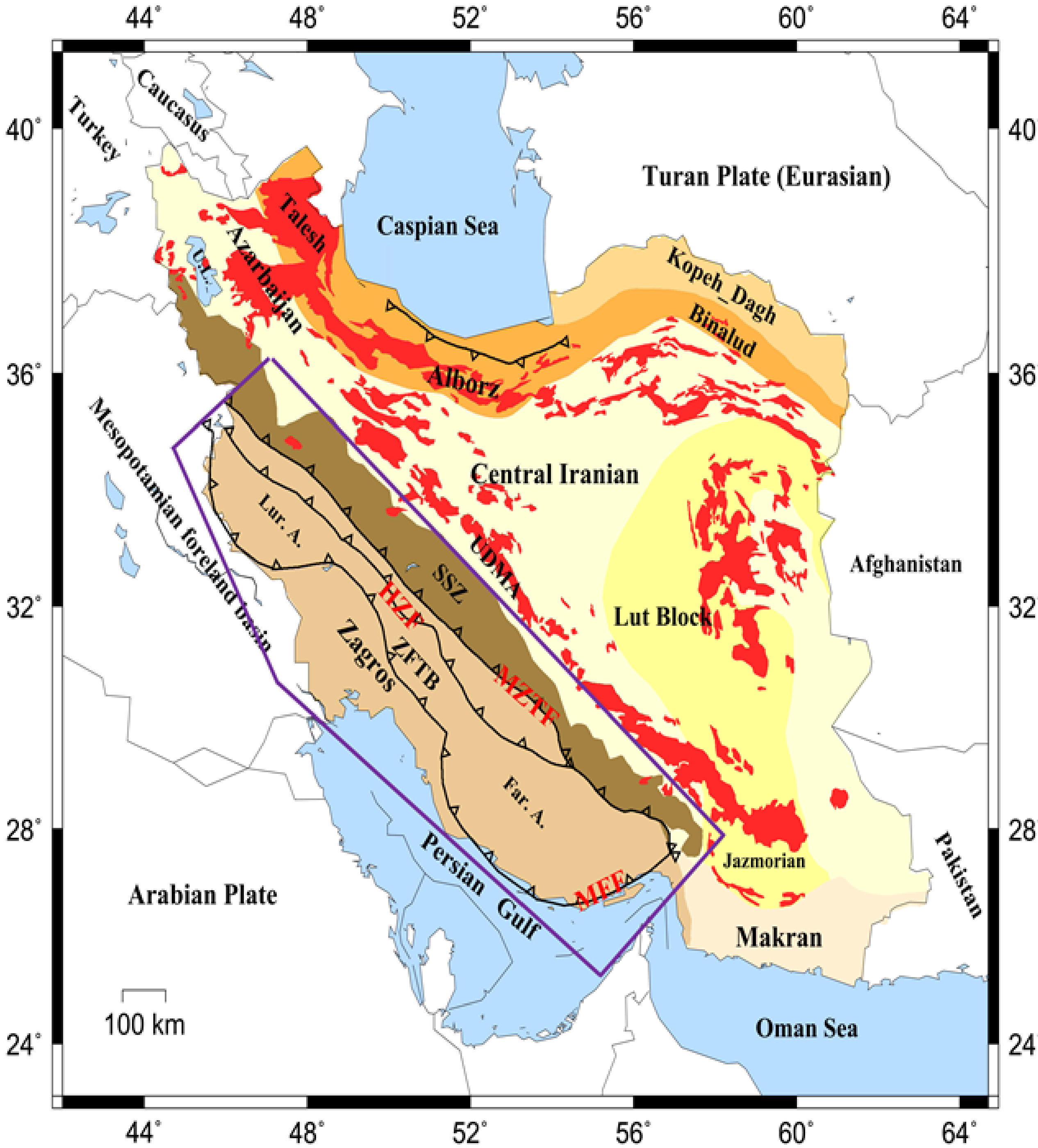

Figure 1

The location of the study area (Zagros) in the purple box and its main faults are shown. Red spots indicate intrusive rocks in the area. The fault file is taken from Jime ezNez-Munt et al. 2012.

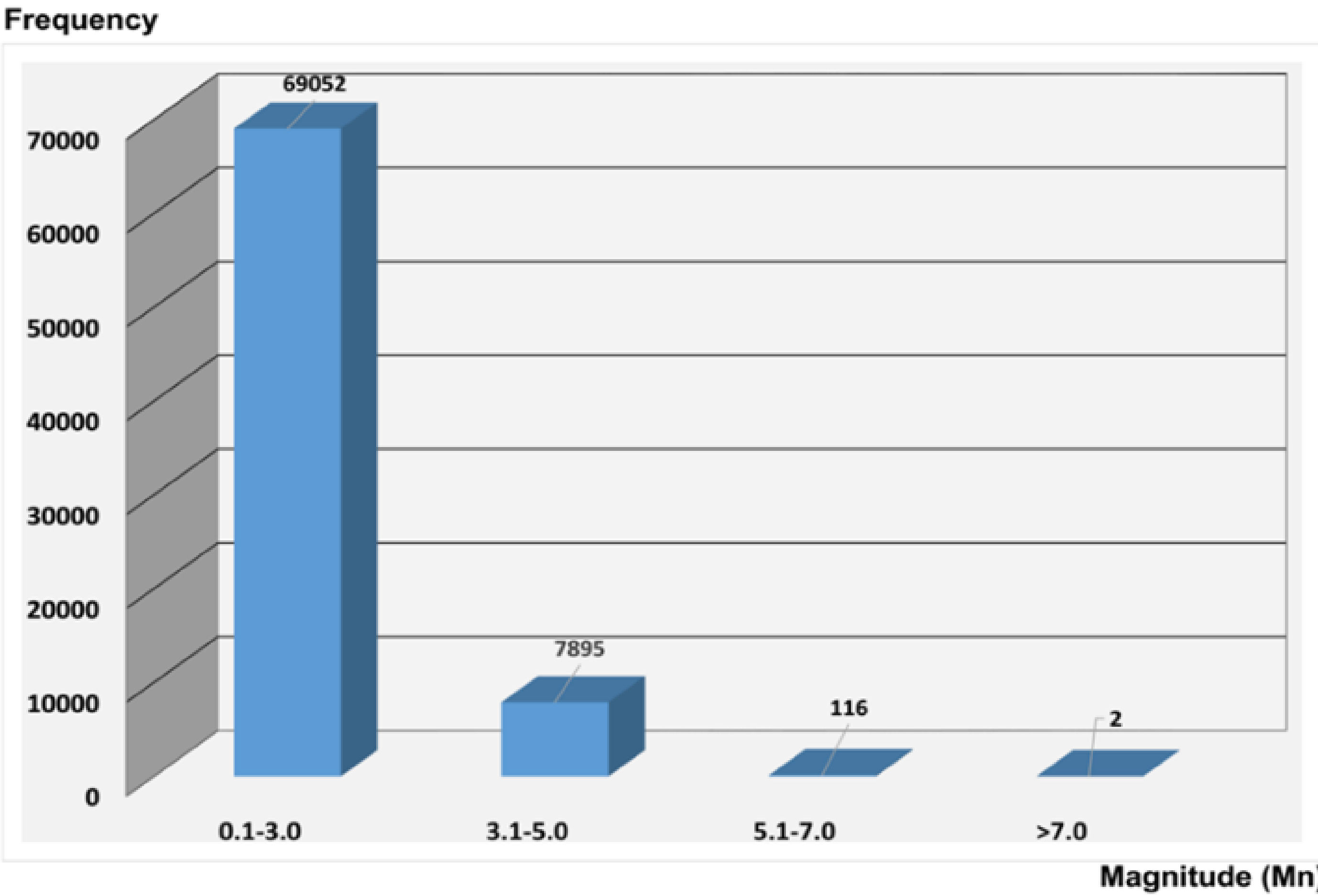

Figure 2

Distribution data in term Mn.

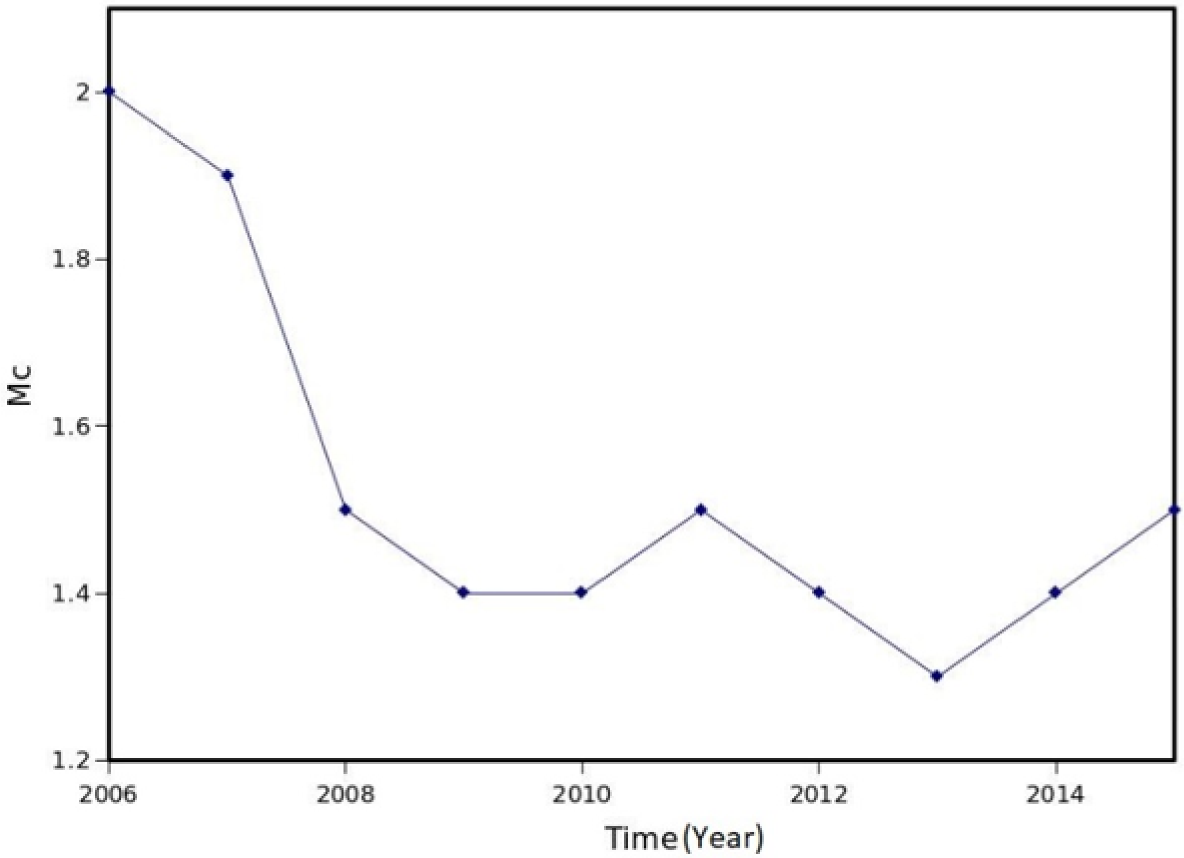

Figure 3

Analysis of m_c by year for the catalog of data used in this research from time interval of 2006 to 2016.

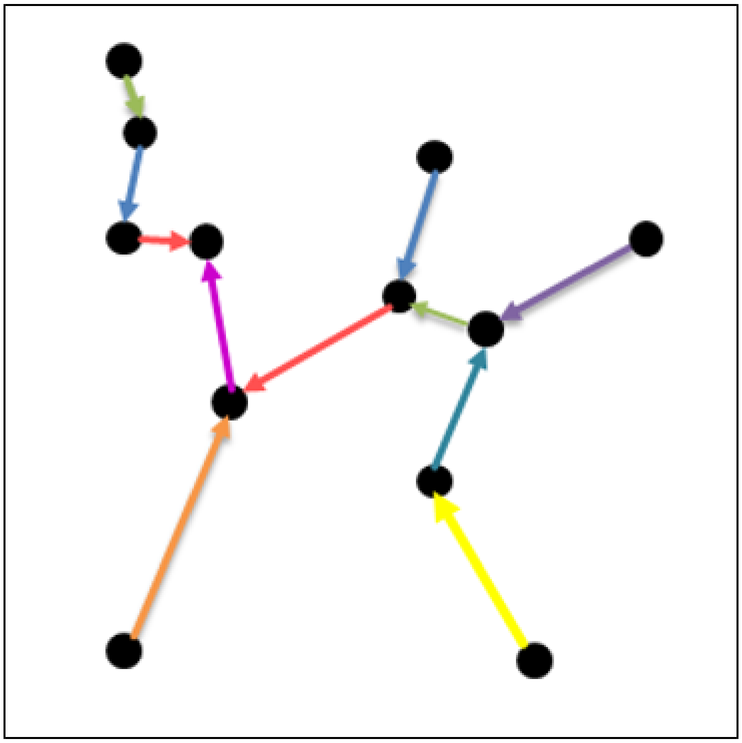

Figure 4

Schematic diagram of a spatial return between earthquakes. The solid black dots are the center of earthquakes and the colored arrows are the shortest distances from both adjacent earthquakes.

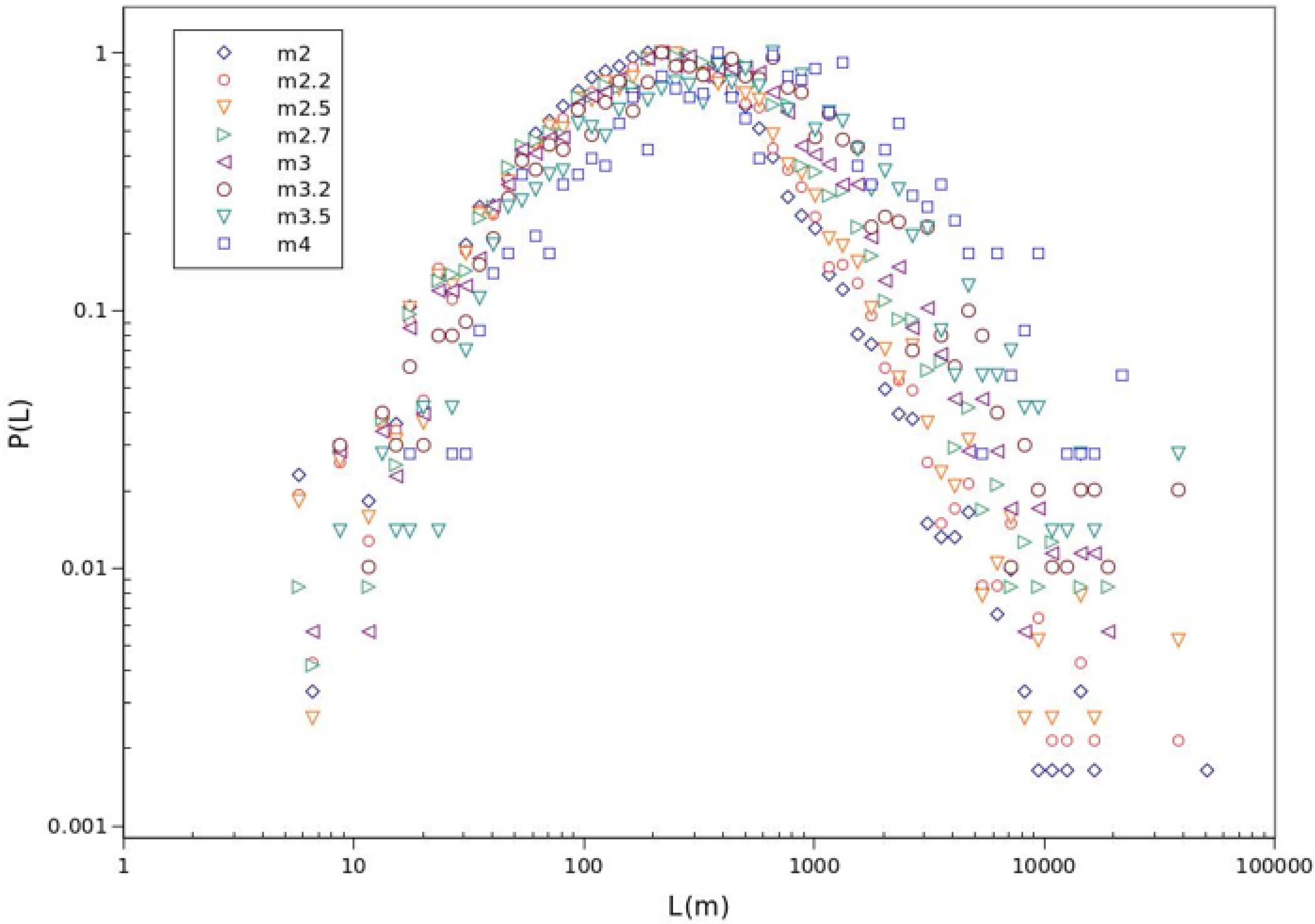

Figure 5

Graph of the function of the distribution of L distances between return events for different thresholds of magnitude. Where the distribution function reaches its maximum value, L* (m) increases.

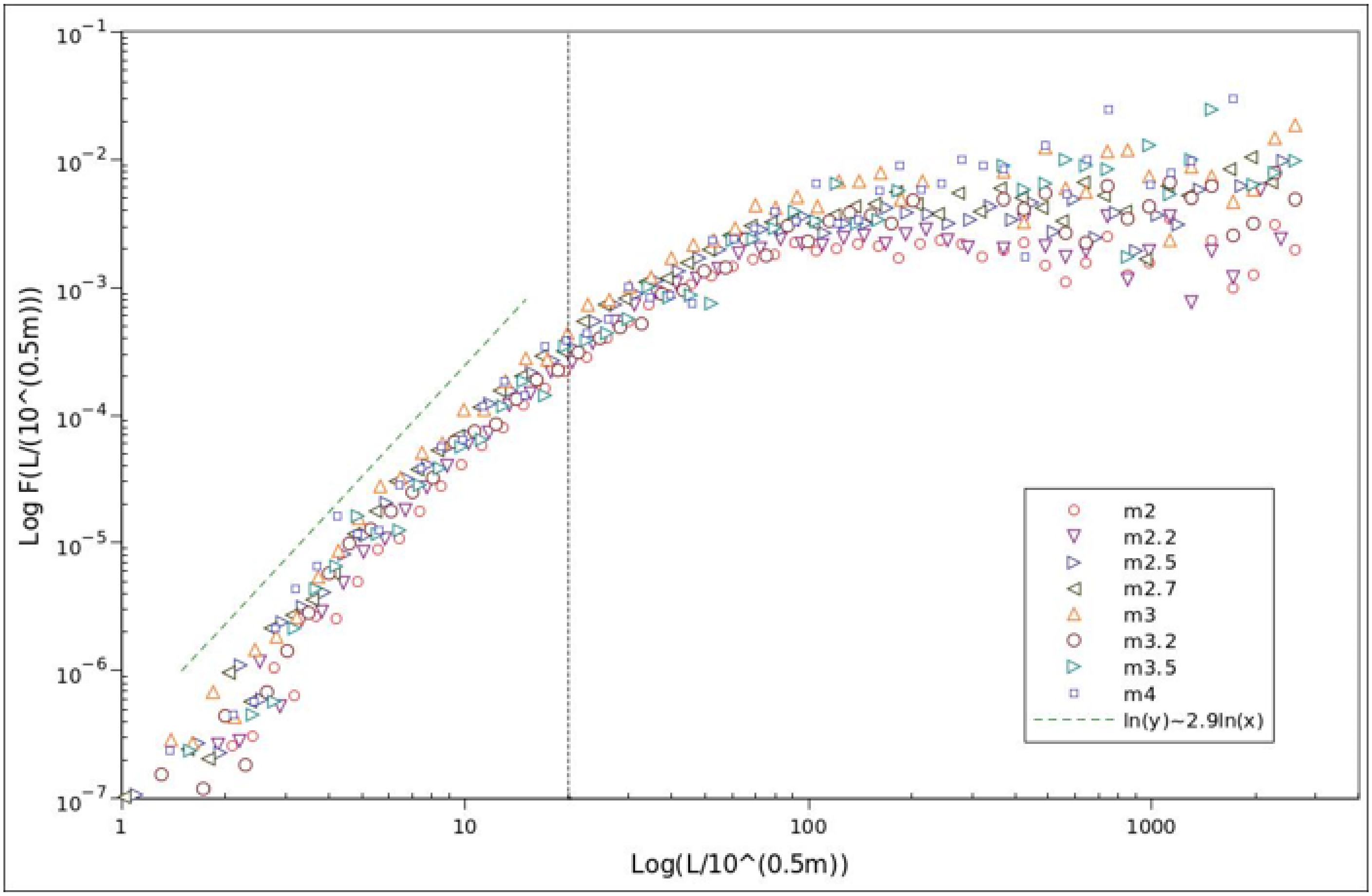

Figure 6

Rescale diagram of distances in terms of their distribution based on the relationship in the Zagros region. The vertical line shows the value of L_0 in the scaling rule for the characteristic distance equal to 0.020 km. The diagonal line shows the power relationship in small values with a slope of 2.9.

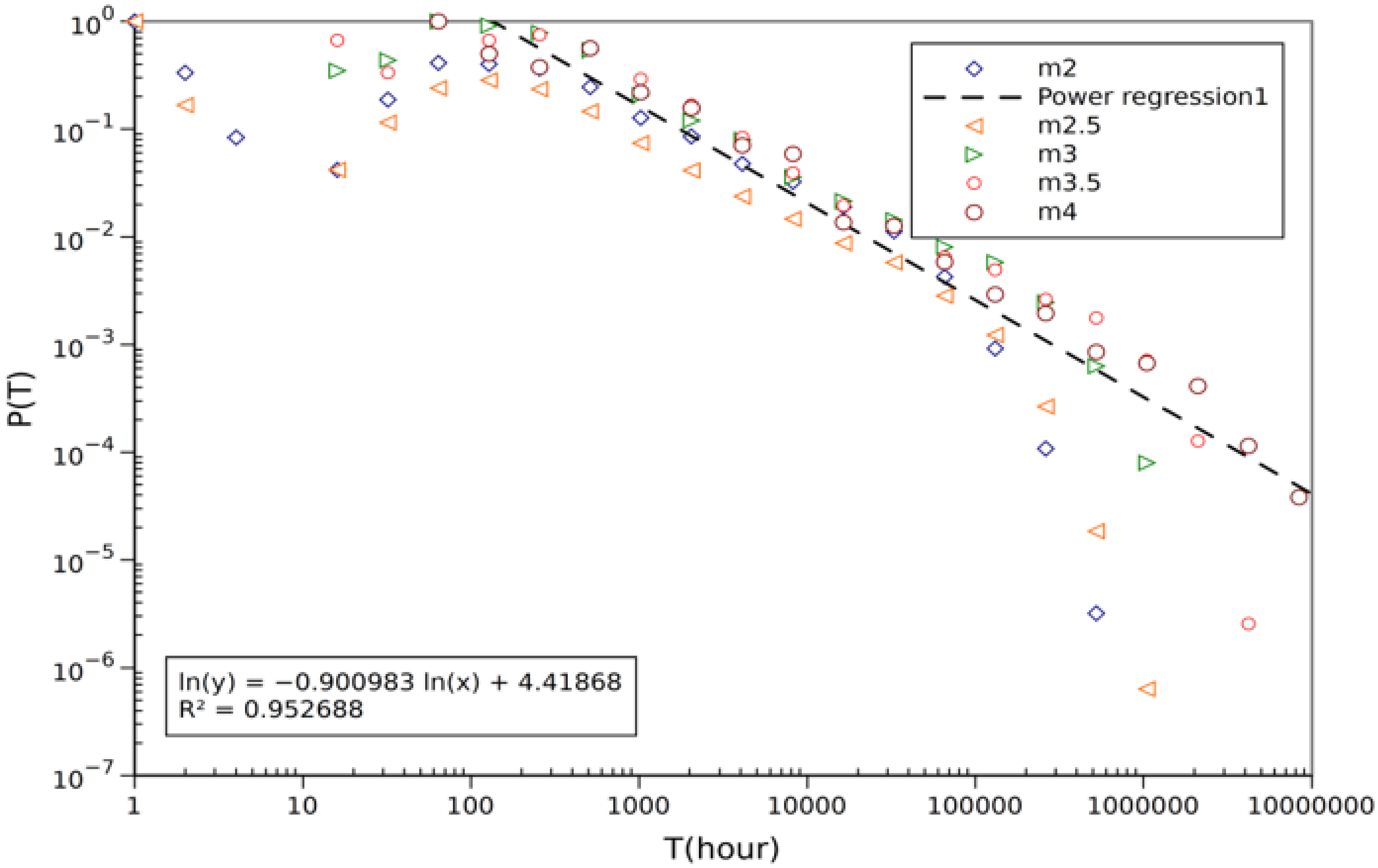

Figure 7

Graph changes in the distribution function of recurring events over time for the Zagros region of Iran in exchange for thresholds of different magnitudes. The dashed line shows the power relationship with the slope of 0.9.