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Comprehensive Earthquake Catalogs and Seismicity Parameters from Incomplete Earthquake Catalogs of Guilan Region, Iran

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Abstract

Statistics of human losses and financial casualties in Guilan province as one of the most populated and strategic areas in the north of Iran have doubled the importance of having knowledge about earthquake and strategies to reduce its effect. In order to investigate seismic hazard analysis, earthquake records along with selecting the proper distance of intended locations were gathered to make Poissonian catalogs. The earthquake catalogs cover the geographical area limited to 35.0°-39.3°N, 47.1-52.2°E and include around 4,000 earthquake events between the years of 855 to 2016. An extensive amount of efforts and times are required to eliminate duplicated events, to unify the magnitude scales and to cluster the earthquake sequences with variable windows in time and location domains to remove aftershocks and foreshocks. The Final homogenous catalog consists of around 110 events for each region. Magnitude of completeness in different time intervals is reported for Guilan region. Seismicity parameters were achieved using Gutenberg-Richter method by Zmap and Kijko-Sellovell approaches for important cities of Guilan including Rasht, Anzali, Rudbar, and Lahijan. Comparative analysis of the results from Zmap and Kijko-Sellovell approaches shows good consistency in the estimation of seismic parameters with the result of literature.

Keywords: Earthquake Catalog; Seismic Parameters; Annual Rate of Exceedance; Time-Space Windows; Magnitude of Completeness.

1. Introduction

Some of the most tragic disasters of the world have been caused by an earthquake. According to United States Geological Survey earthquake facts and statistics, more than 100 earthquakes with magnitude of 6 or greater, and 10 earthquakes of magnitude 7 or greater happen each year. An earthquake measuring magnitude 6 on the Richter scale or greater, can threat many people around the world.

Iran as one of the most seismic active countries in the Middle East located over the Himalayas-Alp seismic belt. Oil fields, trade routes, geography and terrain, all contribute to the strategic importance of this region in the Middle East. Therefore, it seems crucial to investigate the activity of tectonics and seismicity of Iran. Hessami and Jamali (2006) have shown that the activity of tectonic in Iran is a significant sign of active crustal deformation, which is due to the convergence between Arabia and Eurasia plates, estimated around 2.1-2.5 cm/year [1]. In 1999, Tavakoli and Ghafory divided Iran into several seismotectonic subdivisions and reported seismicity parameters for each subdivision from earthquake catalog [2]. The Span of time for their investigation consisted of the limited range of time and not included historical events. During several past years, great amount of efforts were made in all of regions to improve the earthquake catalog features such as quality and quantity of data, completeness interval in time domain, unification of magnitude scales, and accurate determination of time and location of earthquake events. Therefore, presentation of an updated and homogeneous earthquake catalog of Guilan regions, a densely populated province in the north of Iran, was chosen as one of the primary aim of the study.

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Guilan province is located in southwest of the Caspian Sea in the mountainous area which is surrounded by several active faults including Manjil-Rudbar, Talesh, Fouman, North Alborz, and etc. Industrial, economic and social development of Guilan province due to the moderate climate, appropriate situations for agricultural activities, and possibility of shipping, makes this region one of the most populated areas in the north of Iran. Therefore, the occurrence of an earthquake in such a densely populated province may cause severe consequences. During the last several decades, thousands of the people lost their lives, and severe economic impacts and social damages were experienced in this province. For instance, at 21 PM on June 1990 a destructive earthquake occurred in Guilan province in Rudbar city with moment magnitude of 7.4 Richter scale which induced more than 40,000 people lost their lives, more than 500,000 became homeless, nearly 100,000 buildings were destroyed and 700 villages were demolished [3, 4]. Each earthquake event can highlight the poor performance of structures, lack of knowledge about earthquake hazards and sometimes inefficiency of building codes.

Numerous active faults and earthquake occurrences in mentioned province show the high probability of seismic events, and highlight the significance of seismic hazard evaluation for the cities of Guilan province. Hence the study of probabilistic seismic hazard analysis (PSHA) as a tool for predictions of future ground motion seems crucial. Some of more recent and comprehensive studies can be found widely in different regions all over the world [5-17]. Seismic studies such as PSHA highly depended on accuracy of preparing earthquake catalog by selecting the proper radius of the intended location. Since the data were collected from different databases, many efforts are required to eliminate duplicated events, to unify the magnitude scales and to cluster the earthquake sequences with variable windows in time and location domains to remove aftershocks and foreshocks. After compiling the earthquake catalogs, seismicity parameters of four important cities of Guilan province, including Rasht, Anzali, Rudbar, and Lahijan were evaluated as the other primary aim of the study. Consequently the relationships between the annual rates of exceedance against earthquake magnitude are presented for each city.

2. Tectonic Framework

Earthquake events are the phenomena induced by tectonic activates. Therefore, having knowledge of the tectonic situation and recent movements are vital. Structural province subdivisions are based on similar type and trend of tectonic deformation. Guilan province situated in southwest of Caspian Sea (Alborz region) with a high density of active faults is depicted in Figure 1. This region is situated in the northern part of Himalayan-Alp belt, which is surrounded in south by active thrust belt of Alborz Mountain, in east by Kopeh-Dagh with strike slip faults form conjugate shear faults and in west by north west region trending right-lateral strike slip fault as seen in Figure 2. Talebian and Jackson [18] and Hessami and Jamali [1] stated that the slip vector of structural province subdivisions shows convergence into pure strike slip motion and pure thrust faulting. Geological and seismological data indicate that there are many active faults in different parts of Guilan Province. Table 1. indicates some of the most important active faults affecting the result of research on seismicity parameters of Guilan province. Jackson et al. (2002) estimated the motions of the Caspian basin to be around 13-17 mm/yr to SW to Iran and around 8-10 mm/yr to the NW [19].

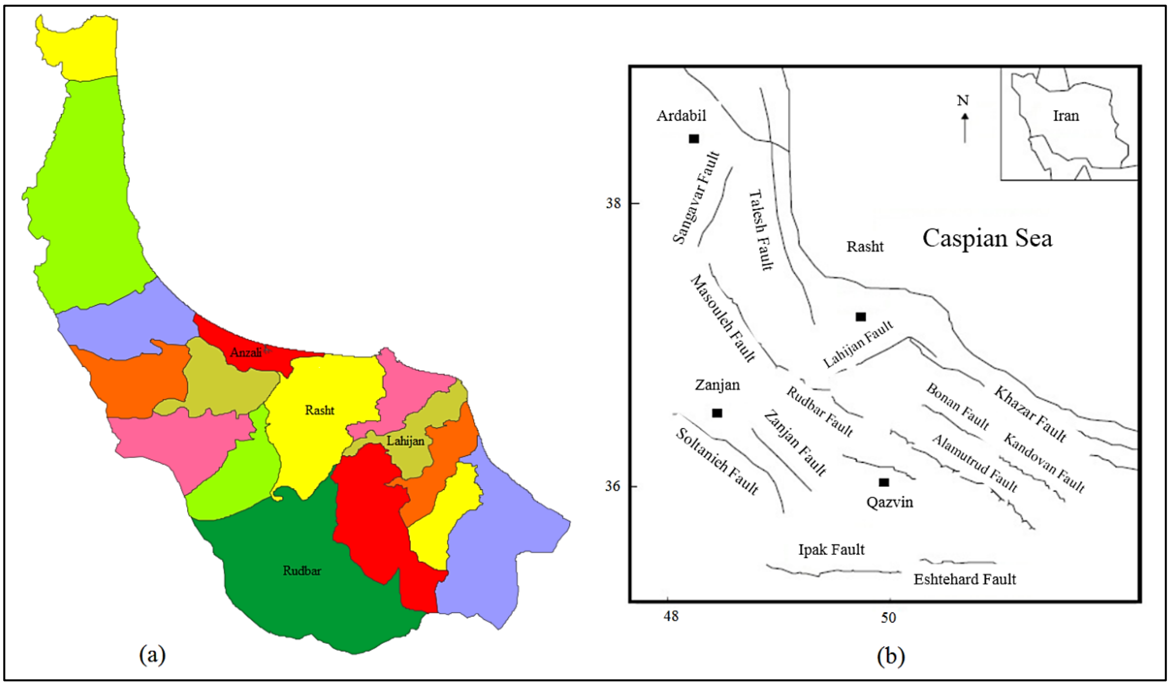


Figure 1. (a) Guilan Province and location of study regions (b) Active Faults of Guilan Province

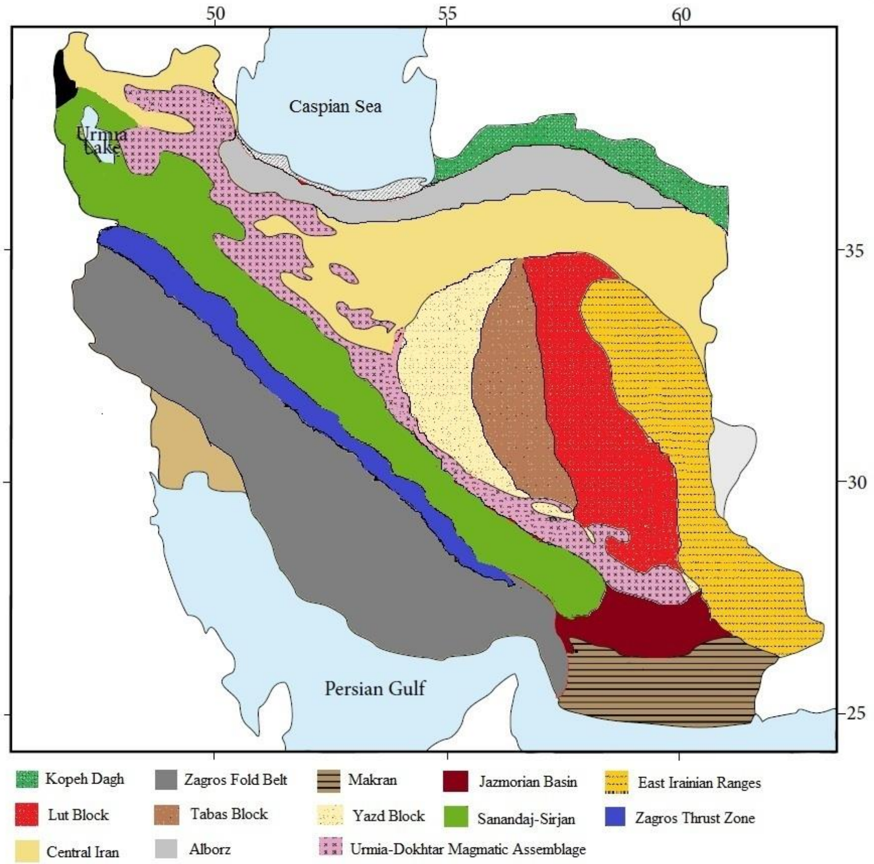


Figure 2. Tectonic setting of Iran and its subdivisions

Table 1. Active fault of Guilan Province

Faults	Length (km)
Manjil-Rudbar	152
North Alborz	300
Talesh	75
Lahijan	51
Masouleh	60
Khazar	600
Bonan	66
North Qazvin	60
Fouman	60

3. Earthquake Catalog and Catalog Features

Gathering and interpreting data are a critical effort for a PSHA investigation. Seismic studies extremely depend on earthquake records as the basic data. Therefore, to minimize the uncertainties of earthquake records such as magnitude, epicenter and hypocenter location, and so on, earthquake events data should be collected from prestigious references, and an extensive amount of effort and time are required to combine the databases to eliminate possible errors. In the first step, earthquake records of Iran were collected from literatures, including the International Institute of Earthquake Engineering and Seismology (IIEES) [20], Geological Survey Institute (GSI) [21], and Iranian Seismological Center (ISC) [22] and other earthquake institute in the country. Then for each city of Guilan province, which has experienced or expected to have seismic activities, the earthquake events recorded in the geographical study area were extruded with a proper distance (200 km) from Iran records. Figure 3. shows the flowchart of preparation of an updated, homogenous earthquake catalog.

The study of earthquake ground motions, associated earthquake hazards and risk mitigation plays an important role in the sustainable development of countries like Iran, where devastating earthquakes have occurred repeatedly. The general approach to seismic hazard evaluation is usually directed towards reducing the uncertainties at various stages of the earthquake catalog process by collecting a sufficient amount of reliable and relevant data. There is generally a trade-off between the effort needed to compile an earthquake catalog and the degree of uncertainty that should be taken into account at each step of the process. More detailed description of each step is presented in the next sections.

By preparing the earthquake catalog, seismic studies such as probabilistic seismic hazard analysis (PSHA) can be done for the intended location. PSHA provides a framework in which these uncertainties can be identified, quantitated and combined in a rational manner to provide a more complete picture of the seismic hazard. Also, the peak Ground acceleration (PGA) over the bedrock can be estimated by probabilistic approach and presented through PGA zonation maps. Besides, seismic hazard maps of the studied area based on PGA over bedrock for 2 and 10 percent probability of exceedance in a life cycle of 50 years, which were used to design resistance building against earthquake (equivalent to recurrence period of 475 and 2475 years, respectively) can be produced. Hopefully, estimation of seismicity parameters will provide a basis for evaluating long term earthquake potential, maximum expected earthquake, rate of recurrence of earthquake and etc. In addition, the result of this paper can be used by National Building Regulations Committee researchers to modify the Iranian Seismic Code of Practice (Code no. 2800) for Guilan region.

3.1. Earthquake Catalog Database

It's worth noting that earthquake records are classified into two distinct categories, namely historical (pre-instrumental) and instrumental earthquake records. Historical earthquake records are referring to the events happened before 1900 while instrumental records, sort chronologically in two bifurcations including before and after the establishment of the global seismic network in 1964 all around the world. Obviously the quality and quantity of earthquake records during modern instrumental era is more than the early instrumental era.

Study of historical earthquakes provides significant signs of possible future events. Thus, determination of fault activity history is reasonable. Clearly, the historical Iranian earthquake catalogs are incomplete, especially for small to medium magnitude of the earthquake. The completeness and accuracy of available information about earthquakes have evolved with time. Large magnitude earthquake with long period of recurrence time, which are generally rare were only reported for historical events. Therefore, it is important to expand the seismic catalogs as far as possible back in time. Table 2. shows resources of historical earthquake records of Iran among the literatures.

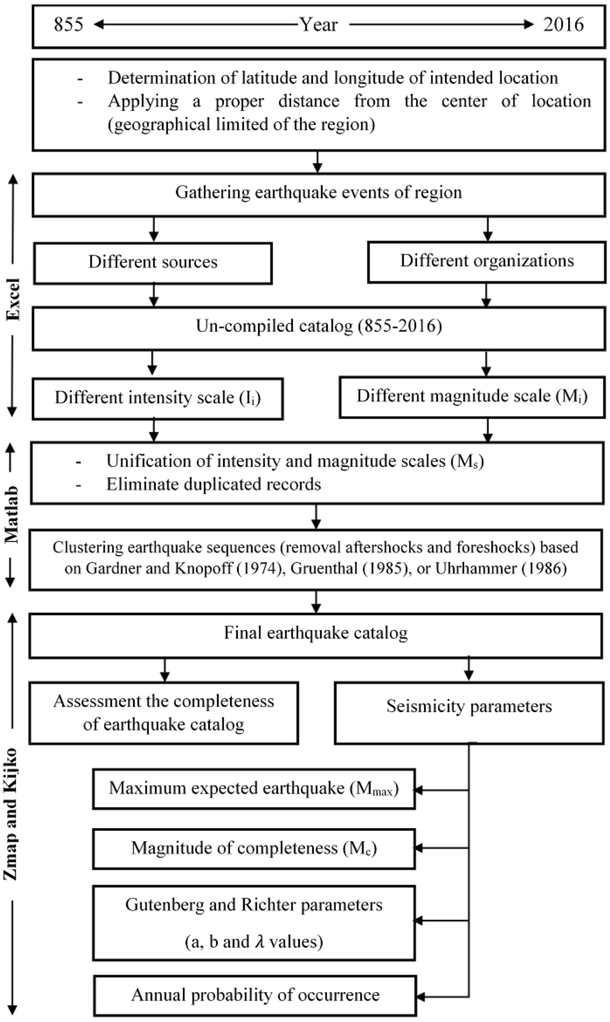


Figure 3. Flowchart of preparing earthquake catalog for a region

Table 2. Historical seismic database sources for Iran earthquake catalog

Catalog database	Remarks
Wilson (1930) [23]	Highly inaccurate (old style of reporting events)
Ambraseys (1968) [24]	North central Iran
Berberian(1976) [25]	
Nabavi (1978) [26]	Include duplicates, errors & dubious events
Poirier & Taher (1980) [27]	Events between 528-1760
Ambraseys & Melville (1982) [28]	Simplified intensity scale
Berberian (1994) [29]	Natural hazards and the first earthquake catalog of Iran
IIEES [20], GSI [21], ISC [22]	The main references of Iran earthquake events

Generally, the historical Iranian earthquake records are incomplete for:

- Small to medium magnitude earthquakes
- Large magnitude in rural, sparsely populated

Meanwhile the question of how these records obtained, interpreted and proof of their reliability are needed to be answered to achieve a catalog benefited from proper quality and homogeneity. Figure 4. shows the historical earthquake map of Iran presented by Ambraseys & Melville [28]. As seen in Figure 4, many historical earthquakes occurred in the north and northwest of Iran.

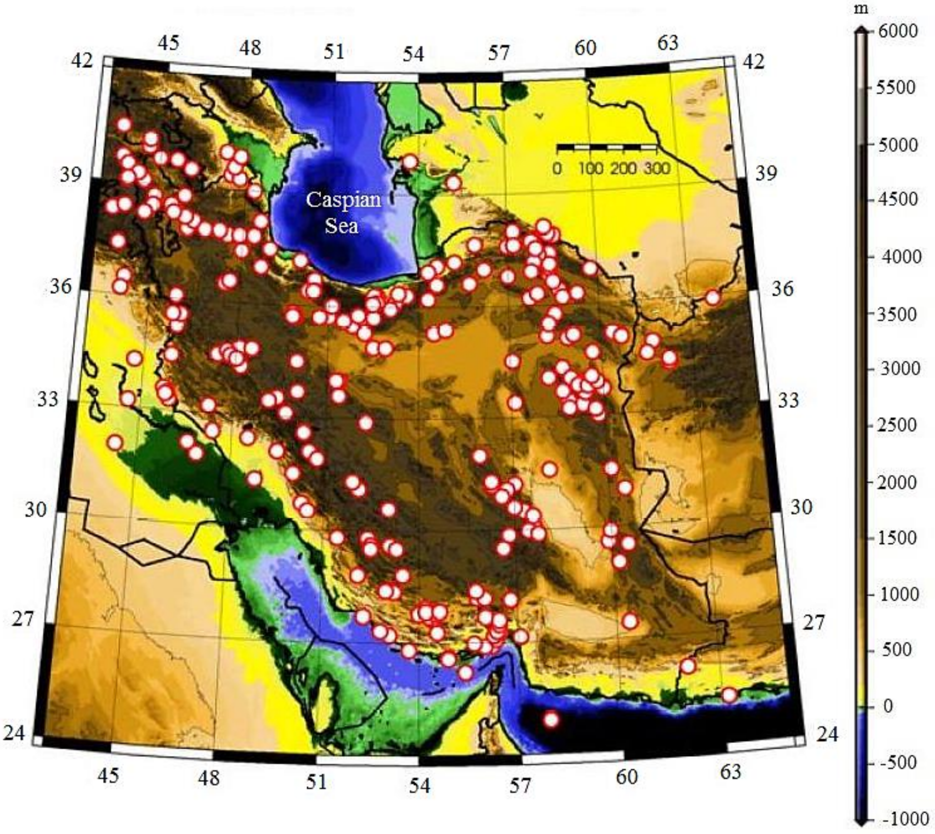


Figure 4. Historical earthquake Map of Iran

Seismicity of Iran has gained attention of many domestic and foreign researchers among several decades. There are also frequent discrepancies in the epicenter location, magnitude, depth and time of earthquakes reported by different researchers. With regard to the promotion of qualitative and quantitative seismic instruments in the world, earthquake seismologists divided instrumental earthquake era into two major categories:

- The early instrumental era (1900-1963)
- The modern instrumental era (1964- Up to now)

Seismicity for a period of 1900 to 1963, before the establishment of the global seismic network, is still poorly understood due to the limitation in the distribution of instruments, response characteristics, and converting intensity to magnitude. Iran's first seismograph stations were established in the Geophysics institute at Tehran University in 1958. Over the time, other stations were situated in Shiraz, Tabriz, Mashhad, Semnan, Isfahan, Yazd and etc. For the period up to 1963, the number of earthquakes in Iran, which magnitude is reliably known is small and for almost all smaller shocks, magnitudes remain unknown. The modern instrumental era is the time span covered by a global seismic network assigning a body wave magnitude (mb) or surface wave magnitude (Ms) for all the events. A major problem for global seismicity data in the modern era is reporting magnitude by the different size of descriptor for each earthquake. Table 3. shows some of the most reliable resources of instrumental earthquake records of Iran among the literatures.

Table 3. Instrumental seismic database sources for Iran earthquake catalog

Catalog database	Remarks
Karnik (1969) [30]	Databases of NW events of Iran
Nowroozi (1976) [31]	
Nabavi (1978) [26]	Include duplicates, errors & dubious events
Ambraseys & Melville (1982) [28]	The main resources of earthquake events for 1900-1963
Raid & Meyers (1985) [32]	Events between 1900-1983
Ambraseys (1988) [33, 34]	
Moinfar et al. (1994) [35]	Historical and instrumental record of Iran catalog
Mirzaei et al. (1997) [36]	
IIEES [20], GSI [21], ISC [22]	The main references of Iran earthquake events
United States Geological Survey [37]	Scientific agency for natural sciences, including earth science and biology

Figure 5. shows records of instrumental earthquake events and their distribution in Iran. As seen in this figure, numerous events happened in north and northwest of Iran.

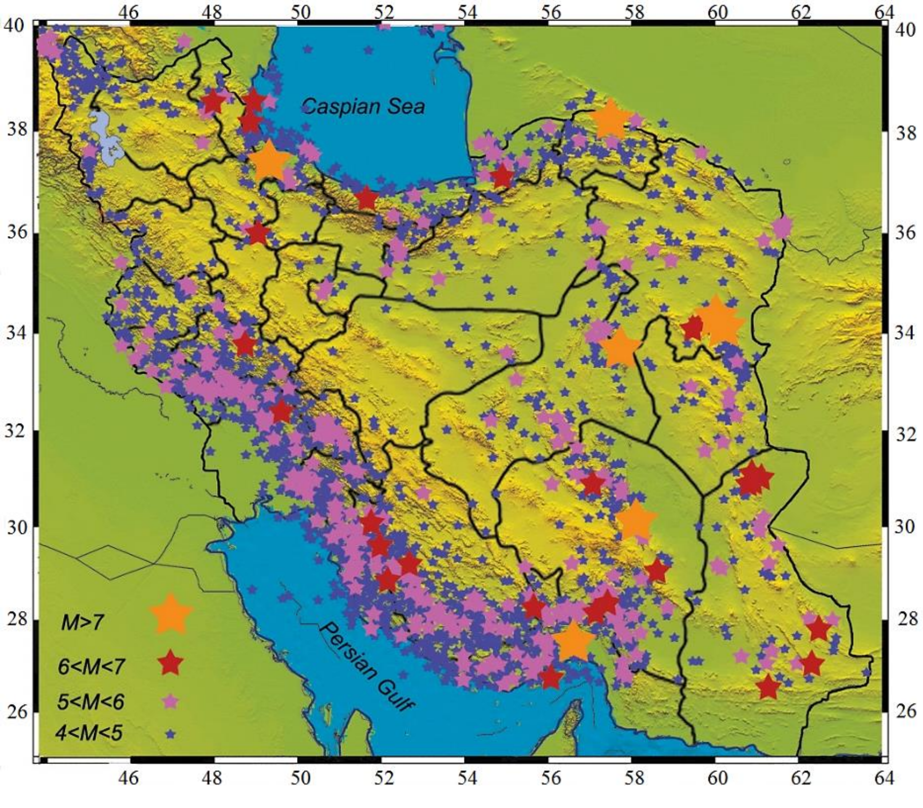


Figure 5. Instrumental earthquake Map of Iran

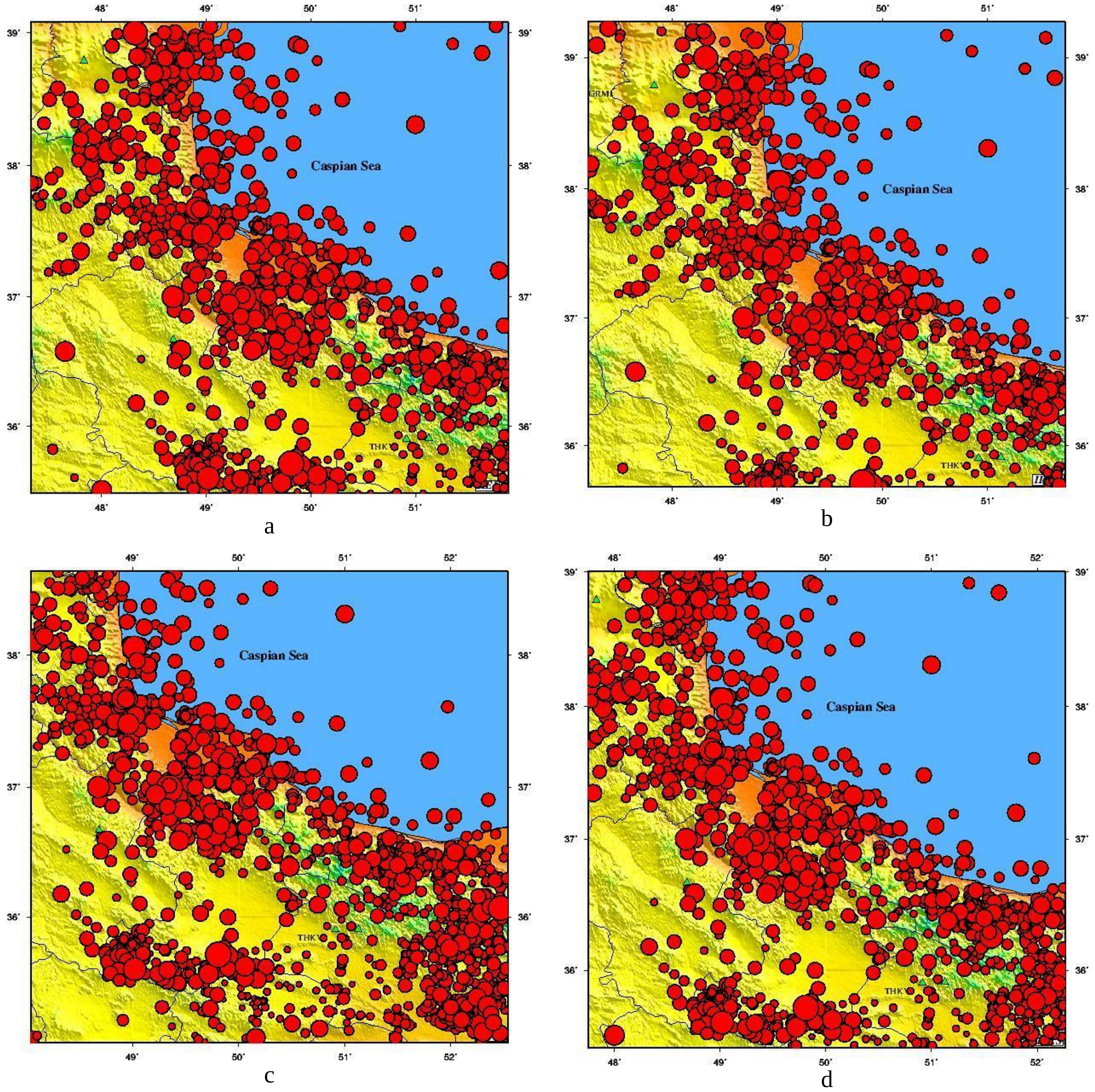
3.2. Earthquake Catalog of Intended Cities

Selected areas of Guilan Province show tectonic activities with surface deformation during past and present time. The earthquake catalog of each city should be extruded from Iran records. In this project, the study area of each region was limited to the 200 km from the center of the city. For instance, quadrangle limitations for Rasht are 35.478°N to 39.078°N and 47.321°E to 51.885°E and a total area of approximately 160,000 km^2. Table 4. and Figure 6. show the range of latitude and longitude of the cities and the epicenter of earthquake records in these regions respectively.

Table 4. The range of latitude and longitude of Rasht, Anzali, Rudbar, and Lahijan

City	Latitude	Latitude Range, °N	Longitude	Longitude Range ° E
Rasht	37.278	35.478-39.078	49.588	47.321-51.885
Anzali	37.473	35.673-39.273	49.468	47.201-51.735
Rudbar	36.823	35.023- 38.623	49.426	47.178-51.674
Lahijan	37.201	35.401-39.001	50.007	47.751-52.263

The numbers of earthquake events at this step in the instrumental era are 3822, 3745, 3868, and 4019 for Rasht, Anzali, Rudbar, and Lahijan respectively. Undoubtedly, duplicated records, foreshocks and aftershocks exist among these earthquake records that should be compiled to reach final earthquake catalog. The procedure to find duplicated events was based on two criteria, including epicenter distance and time differences of events from different databases [38].



a b c d

Figure 6. Earthquake recorded in the region of a) Rasht b) Anzali c) Rudbar d) Lahijan

3.3. Earthquake Magnitude Scales and Conversion to Surface Magnitude

Various magnitude scales were assigned to the earthquake events by different databases. Hence converting different scales to an appropriate scale seems to be essential. The Magnitudes of historical earthquakes in Iran are equivalent to surface wave magnitude scale assigned by Ambraseys and Melville in 1982 [28]. The surface wave magnitude (Ms) is a worldwide scale of magnitude based on the amplitude of Rayleigh waves with a period of time about 20 sec [39]. For 80% of recorded earthquake events in instrumental era, only the magnitude of body wave (mb) was reported [40]. The body wave magnitude is also a worldwide scale based on the amplitude of the first few cycles of P waves defined by Kramer [39]. There is different magnitude scales defined from different parts of instrumental records. Relationships between different scales are shown in Figure 7.

As seen in Figure 7, saturation of instrumental scales was happening when the slopes of each line to reach near zero at higher magnitude values. Singh et al. in 1983 reported that the saturation value for mb is around 6.2 and stated that this scale didn't have the capability to demonstrate higher magnitude while the saturation value for Ms is around 8 [41]. The only magnitude scale with ability to describe the size of large earthquake which is not depend on ground shaking levels and consequently not saturated is moment magnitude (Mw), but this value is reported for a few earthquakes in Iran. As seen in Figure 7, the moment magnitude (Mw) has good consistency with surface wave magnitude (Ms). Therefore the surface wave magnitude used to describe historical events, was also used to describe instrumental events.

In almost all of the tectonic subdivision, surface wave magnitude relationship varies linearly with body wave magnitude. Mirzaei et al. proposed this relationship for earthquake regions of Iran, which can be seen in Table 5 [40].

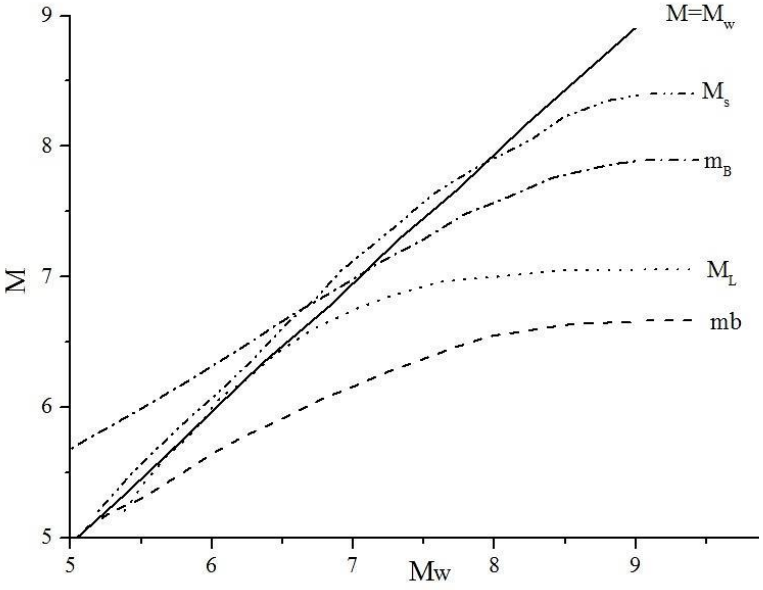


Figure 7. Different scales of earthquake magnitude [39]

Table 5. Ms - mb relationships for Iran earthquake regions [40]

Earthquake regions	Ms - mb relationships	Magnitude range
Zagros	$Ms = 1.79mb - 4.32$	$4.0 \leq mb \leq 6.2$
Azarbayejan-Alborz, Kopeh-Dagh	$Ms = 2.01mb - 5.28$	$4.0 \leq mb \leq 6.2$
Central-East Iran	$Ms = 2.0mb - 5.28$	$4.1 \leq mb \leq 6.2$
Makran	$Ms = 1.58mb - 3.11$	$4.0 \leq mb \leq 5.9$

In this study, the relationship proposed by IRCOLD (Iranian Committee on Large Dams) was used for the conversion of mb into Ms to evaluate the equivalent magnitude [42]. This relationship showed as Equation 1, can be employed for all areas in Iran as Equation 1.

$$Ms = 1.21mb - 1.29 \tag{1}$$

3.4. Uncertainty of Earthquake Parameters

There are many shortcomings leading to substantial uncertainty in various parameters including the magnitude, epicenter and focal depth of earthquakes and consequently reducing the accuracy of the result. Some of them are as below:

- Complicated geologic structures of the country in different seismotectonic provinces
- Insufficient seismic data for all of seismic sources
- Incompleteness and inhomogeneity of seismicity in time and space due to the factors such as
    - Lack of uniform distribution of seismographic station

- Lack of reported earthquakes of all magnitude
- Inappropriate speed models for each seismotectonic subdivisions

The magnitude of the earthquake as the main value in determining seismic parameters, and the geographical coordinates of the earthquake epicenter and hypocenter as a guide in describing and identifying potential seismic sources, play key roles in seismic risk assessment. Therefore, it is necessary to consider their corresponding uncertainty in the evaluation of these parameters at different stages of seismic risk analyses. Obviously the uncertainties of magnitude reduced over the time. The hypocenters location of the earthquake had more uncertainty than epicenters. In fact determination of reliable focal depth need high density network of seismographs.

Empirical formulas that are used to determine the magnitude of earthquake, simplify the complex processes occurring during the earthquake. Kasahara (1985) stated that determination of earthquake magnitude in the most favorable conditions has ±0.2-0.3 unit errors [43]. Mirzaei et al. (1997) reported that for historical events, the uncertainty in magnitude vary from ±0.4 to ±0.8 unit and this value varies from ±0.32 to ±0.5 unit of magnitude which is directly read from the device and vary from ±0.4 to ±0.6 for values converted from different scales to appropriate one [36]. Table 6. indicates the value of magnitude uncertainties for different eras for Iran’s earthquake.

Table 6. Magnitude uncertainty values for historical and instrumental records

		Mirzaei et al. (1997) [36]	**Moghadam et al. (2009) [44]**	**Present Study**
Historical records		0.4-0.8	0.5	0.5
Instrumental records	Before 1964	0.32-0.5	0.1-0.3	0.4
	After 1964	0.32-0.5	0.1-0.3	0.3

Mostly, the coordinates of densely populated cities have been determined as the center of historical earthquake. Mirzaei et al. found that the location of historical earthquakes is accompanied with uncertainties about 50 km on average [40]. For instrumental records reported by USGS and ISC, the most prestigious references, there are significant differences in some cases. It’s worth noting that the rate of errors becomes greater for small magnitude of earthquakes.

Molnar and Chen (1983) reported that focal depth of earthquake can be determined relatively accurate when distinguish between velocity of S and P waves are well documented i.e. focal depth more than 70 km [45]. In addition, determination of reliable focal depth needs high density network of seismographs in such a way that the distance of the nearest station to the center of the earthquake should not be less than focal depth. Furthermore the average distance between stations is not allowed to be more than 2 times of focal depth. Therefore, the focal depth of shallow earthquake should be viewed with suspicion. Focal depth distribution of earthquake events has significant peaks at 0 to 40 km, indicating that most of earthquake occurred near surface.

3.5. Elimination of Foreshocks and Aftershocks

Many efforts have been done to evaluate the Poisson distribution of earthquake events over the several decades. Obviously the main sequence events were significantly non-Poisson in local and global catalogs. Earthquake events should be completely independent, to be used to estimate earthquake parameters [46]. Therefore, it’s necessary to identify foreshocks and aftershocks and eliminate them to prepare final earthquake catalogs. The designation of an earthquake as foreshock, main shock or aftershock is only possible after the full sequence of events have happened.

Aftershocks are earthquakes events happened consequently after the main shock. A catalog consists of main shocks and aftershock clusters which make catalog non-Passion. One of the first approaches to omit aftershocks from the catalog was proposed by Knopoff in 1964 [47]. In this approach, only time intervals were considered to separate aftershocks. The disadvantage of this method is that some of the main shocks were deleted from the catalog while some of the aftershocks still remaining. The main method of finding the sequence of aftershocks is using separation method such as time and space windows [T (M), L (M)]. The purpose of using time and space windows is to define a distance between the epicenters of earthquake events and time intervals for each event. Gardner and Knopoff was firstly proposed time-space windowing method in 1974 which is the most common one [48]. Gruenthal [49], Reasenberg [50] and Uhrhammer [51] presented the same method with different values for time and space windows. Amini (2014) and Telesca et al. (2016) compared different declustering approaches from the points of viewing time and space correlation to achieve Poissonian catalogs and assess performance of each approach [52,53]. Table 7. and Figure 8. show the time and space windows proposed by Gardner and Knopoff (1974), Gruenthal (1985), and Uhrhammer (1986). These windows are function of earthquake magnitude like Equations 2 and 3.

$$T(M) = \log T = a_1 M + b_1 \tag{2}$$

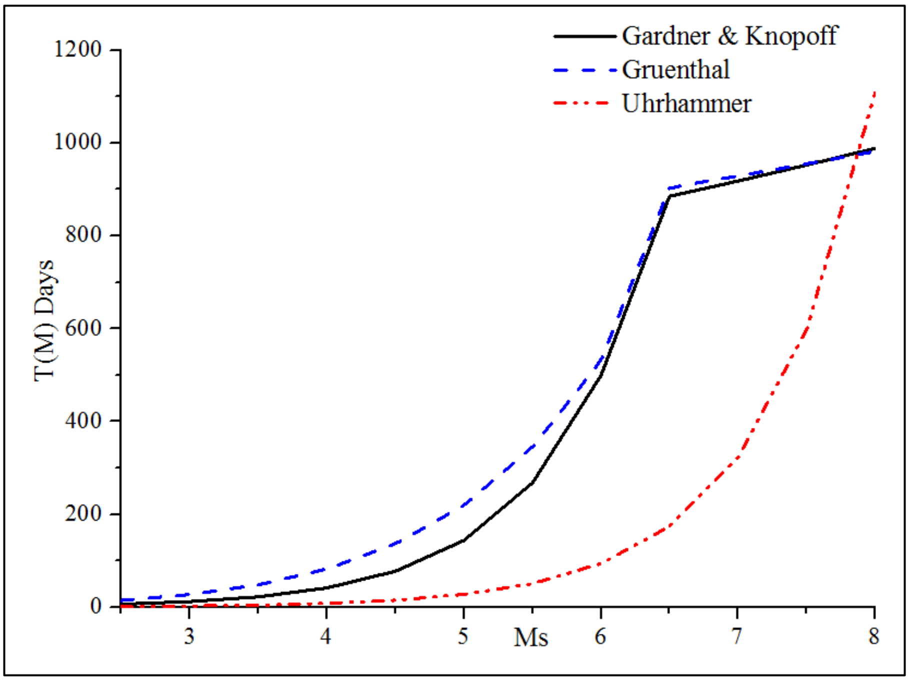
$$L(M) = \log L = a_2 M + b_2 \tag{3}$$

A Matlab code was written to eliminate aftershocks based on Gardner and Knopoff, Gruenthal and Uhrhammer approaches. It should state that the approach proposed by Gardner and Knopoff in 1974 has been greeted by the majority of literatures and this time-space window was used to cluster the main shocks and aftershocks. All events occurring at T(M) and L(M) after the main shock, were declustered as aftershocks. For example, consider an earthquake with magnitude of 6 in Richter scale. Any recorded events in time interval of 500 days and 53 km with lower magnitude, is the aftershock of the first earthquake. Despite of these conditions, the shock should be considered as a new main shock.

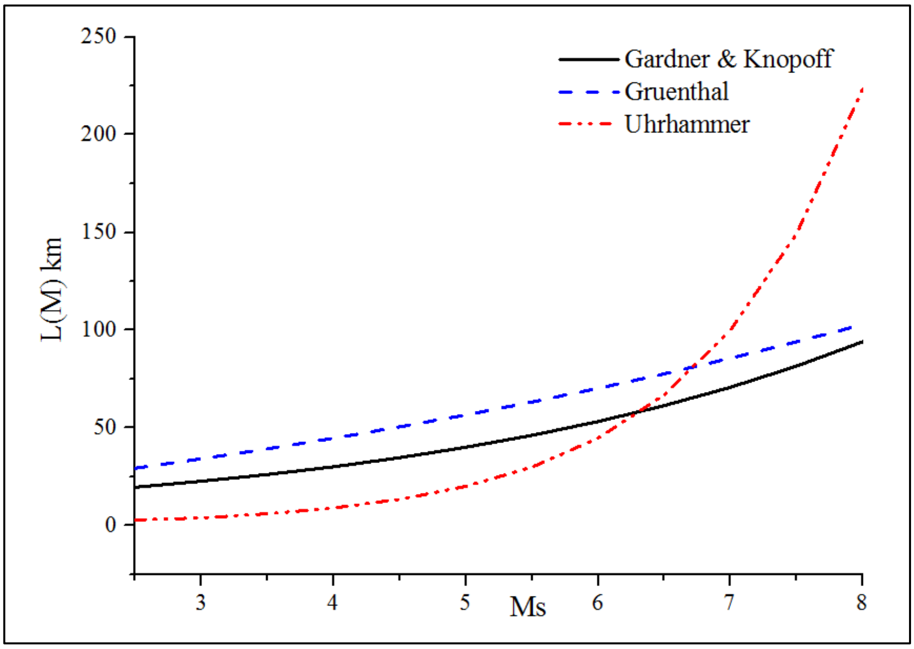
Table 7. Time and space windows to eliminate aftershocks

M	Gardner & Knopoff [48]		Gruenthal [49]		Uhrhammer [51]	
	L (km)	T (days)	L (km)	T (days)	L (km)	T (days)
2.5	19.61	6.39	29.32	14.54	2.68	1.24
3.0	22.62	11.90	34.12	27.15	4.01	2.30
3.5	26.08	22.19	39.22	48.21	5.99	4.27
4.0	30.07	41.36	44.66	82.32	8.95	7.92
4.5	34.68	77.10	50.45	136.10	13.38	14.69
5.0	39.99	143.71	56.63	219.02	20.01	27.25
5.5	46.12	267.89	63.20	344.41	29.90	50.53
6.0	53.19	499.34	70.20	530.85	44.70	93.69
6.5	61.33	884.91	77.64	903.65	66.82	173.73
7.0	70.73	918.12	85.54	928.97	99.88	322.14
7.5	81.56	952.58	93.93	954.99	149.31	597.35
8.0	94.06	988.33	102.83	981.75	223.18	1107.65

After declustering aftershocks, foreshocks should be deleted form earthquake catalogs. Foreshocks are relatively smaller earthquakes that precede the main shock in a series, which are related to the main shock in both time and space. The average period of 30 days between the occurrence of main shocks and foreshocks was reported from Chinese seismic surveys. In California, most of the foreshock was seen in a period of 2 days with 20 km space window. Markušić et al. stated that foreshocks were identified using a 5-times shorter as time span [38]. In this study, the time and space windows adopted to the values proposed by Jones (1985) were used to eliminate foreshocks [54].



(a)



(b)

Figure 8. (a) Time and (b) Space windows to eliminate aftershocks

3.6. Completeness of Earthquake Catalog

Statistical analysis using incomplete data may lead to unacceptable results. Therefore, the completeness of earthquake catalog in probabilistic seismic analysis is a paramount issue. Completeness and reliability of information are the basis of seismology research. Hence, knowledge of the quantity and quality of information to adopt appropriate methods for analyzing the data is inevitable.

No formal method can be devised to test the completeness of long term data other than by testing their implication. Seismic activities are regional and long-term dependent. As the earthquake catalog involves a long period of time, undoubtedly, in terms of time and location, quality and quantity of information is unequal. For historical era, catalog reported only large magnitude events. By development of seismographs and their sensitivity and increase in densely stations of the global network, the completeness levels vary with time. Mirzaei et al. in 1997 divided Iran into several regions based on the characteristics of tectonic and assessed the completeness of earthquake statistics for each region [36]. Table 8. shows the time of completeness record for different range of magnitude since they could be catchable. Table 9. shows the result of completeness magnitude in the Guilan region in different time intervals. Magnitude of completeness (Mc) for historical and instrumental records in Table 9. is in good consistency with the value of Table 8. reported by Mirzaei et al. [36].

Table 8. The time of completeness record for different regions of Iran [36]

Regions	$4.0 \le Ms < 4.5$	$4.5 \le Ms < 5.0$	$5.0 \le Ms < 5.5$	$5.5 \le Ms < 6$	$6.0 \le Ms$
Alborz-Azarbayejan	1975	1945	1900	1900	1860
Kopeh-Dagh	1975	1963	1925	1904	1850
Zagros	1975	1965	1944	1925	1860
Central-East Iran	1975	1955	1955	1900	1900
Makran	1975	1965	1950	1919	1919

Table 9. The time of completeness record for Guilan region

Guilan Region	1975	1945	1900	1860
Earthquake Magnitude	4	5.3	6.1	≤6.5

The resultant catalog after elimination of duplication events, foreshocks and aftershocks is not the final one. A threshold magnitude should be considered, and all of the events with lower magnitude of threshold earthquake should be removed from the catalog because earthquake measuring less than threshold events, rarely cause significant damages. Kramer [39] suggested this value around 4 to 5 while Ghodrati Amiri et al. [55] reported this value 4 Richter in their study. Threshold magnitude reduced over the time, because the technology and its ability to record earthquake events increase day by day. The final catalogs of each city can be found in tables of A1 to A4 in appendix-1. It's worth stating that the number of earthquake events in the final catalog in instrumental era is equal to 89, 92, 88 and 95 for Rasht, Anzali, Rudbar, and Lahijan respectively. While the number of earthquakes in the historical era for these cities are 21, 20, 22, and 19.

4. Results and Discussion

4.1. Gutenberg and Richter Recurrence Law

In probabilistic seismic hazard analysis, it's assumed that past earthquake activities are the reliable signs of future activities which can simulate the future events through recurrence law. In addition, seismic hazard analysis can predict the return period of future events with definite magnitude by extending the mathematical models. Gutenberg and Richter recurrence law, relate the annual cumulative rate (N) of earthquake occurrence to magnitude of earthquake events equal or greater than M usually expressed by Equation 4. as below:

$$\log\ (N) = \log\ (\lambda_m) = a - bm \tag{4}$$

Where λm is the mean annual rate of exceedance of magnitude m, 10^a is the mean yearly number of earthquakes with magnitude greater than or equal to zero and the value of b describes the relative likelihood of large and small earthquakes. The parameters of a and b ($\alpha = 2.303a$ and $\beta = 2.303b$) can be obtained by fitting a line to the seismic data of the regions. By preparation of the final catalogs, seismicity parameters can be estimated.

4.2. Determination of Seismic Parameters by Zmap and Kijko- Sellevoll

Zmap (Matlab based, open source code) software was written in 1994 by Stefan Wiemer [56, 57]. This software was modified to use for Guilan province and cities of this region. Graphical user interface (GUI) of Zmap makes this software suitable for engineers to analyze catalog data. Some of the various capabilities and application of Zmap are: (1) quality assessment of catalog; (2) mapping seismicity parameters of earthquake; (3) estimating seismicity rate changes caused by a large earthquake; (4) representative of stress-tensor and stress field of regions; and (5) Evaluating magnitude of completeness.

Tables 10 and 11. show the result of historical and instrumentals seismic parameters in each city respectively obtained by Zmap. The annual rate of exceedance can be computed from the values of Gutenberg-Richter parameters. It is worth to state that, Zmap has the ability to present Gutenberg-Richter parameters with different approaches such as least square method and maximum likelihood method including automatic, maximum curvature, best combination and etc. Drawing a straight line with some of these methods underestimates the exceedance rate of small magnitude, while it can overestimate the exceedance rate for large magnitude of earthquake. Therefore, selecting the best approach is crucial. Most of the time, the result of maximum likelihood approach with best combination was reported. Meanwhile the results of maximum likelihood method with best combination were double checked by result of Kijko-Sellevoll method [58, 59]. Figure 9. shows the convergence of seismicity parameters of Gutenberg and Richter recurrence law for instrumental era. It's evident that seismicity parameters should be converged during the number of earthquake events to obtain accurate values.

Table 10. Seismic parameters of historical events by Zmap

Historical Earthquake				
Rasht	Least Square Method	Maximum likelihood Method		
		Automatic	Maximum Curvature	Best Combination
b Value	0.5±0.05	0.57±0.11	0.59±0.1	0.57±0.1
a value (annual)	1.60±0.1	1.66±0.06	1.66±0.06	1.66±0.06
Anzali	Least Square Method	Maximum likelihood Method		
		Automatic	Maximum Curvature	Best Combination
b Value	0.48±0.05	0.58±0.12	0.58±0.1	0.58±0.1
a value (annual)	1.58±0.1	1.65±0.06	1.65±0.06	1.65±0.06
Rudbar	Least Square Method	Maximum likelihood Method		
		Automatic	Maximum Curvature	Best Combination
b Value	0.5±0.05	0.6±0.11	0.6±0.1	0.6±0.1
a value (annual)	1.61±0.1	1.68±0.07	1.68±0.07	1.68±0.07
Lahijan	Least Square Method	Maximum likelihood Method		
		Automatic	Maximum Curvature	Best Combination
b Value	0.52±0.07	0.59±0.11	0.57±0.1	0.57±0.1
a value (annual)	1.60±0.1	1.66±0.07	1.66±0.07	1.66±0.07

Table 11. Seismic Parameters of instrumental events by Zmap

Instrumental Earthquake				
Rasht	Least Square Method	Maximum likelihood Method		
		Automatic	Maximum Curvature	Best Combination
b Value	0.54±0.07	0.7±0.09	0.68±0.1	0.68±0.1
a value (annual)	2.40±0.1	2.52±0.08	2.52±0.08	2.52±0.08
Anzali	Least Square Method	Maximum likelihood Method		
		Automatic	Maximum Curvature	Best Combination
b Value	0.55±0.06	0.70±0.09	0.69±0.1	0.69±0.1
a value (annual)	2.43±0.1	2.55±0.08	2.55±0.08	2.55±0.08
Rudbar	Least Square Method	Maximum likelihood Method		
		Automatic	Maximum Curvature	Best Combination
b Value	0.56±0.06	0.65±0.07	0.65±0.07	0.65±0.07
a value (annual)	2.40±0.1	2.50±0.07	2.50±0.07	2.50±0.07
Lahijan	Least Square Method	Maximum likelihood Method		
		Automatic	Maximum Curvature	Best Combination
b Value	0.55±0.07	0.68±0.08	0.67±0.09	0.68±0.08
a value (annual)	2.43±0.1	2.57±0.07	2.57±0.07	2.57±0.07

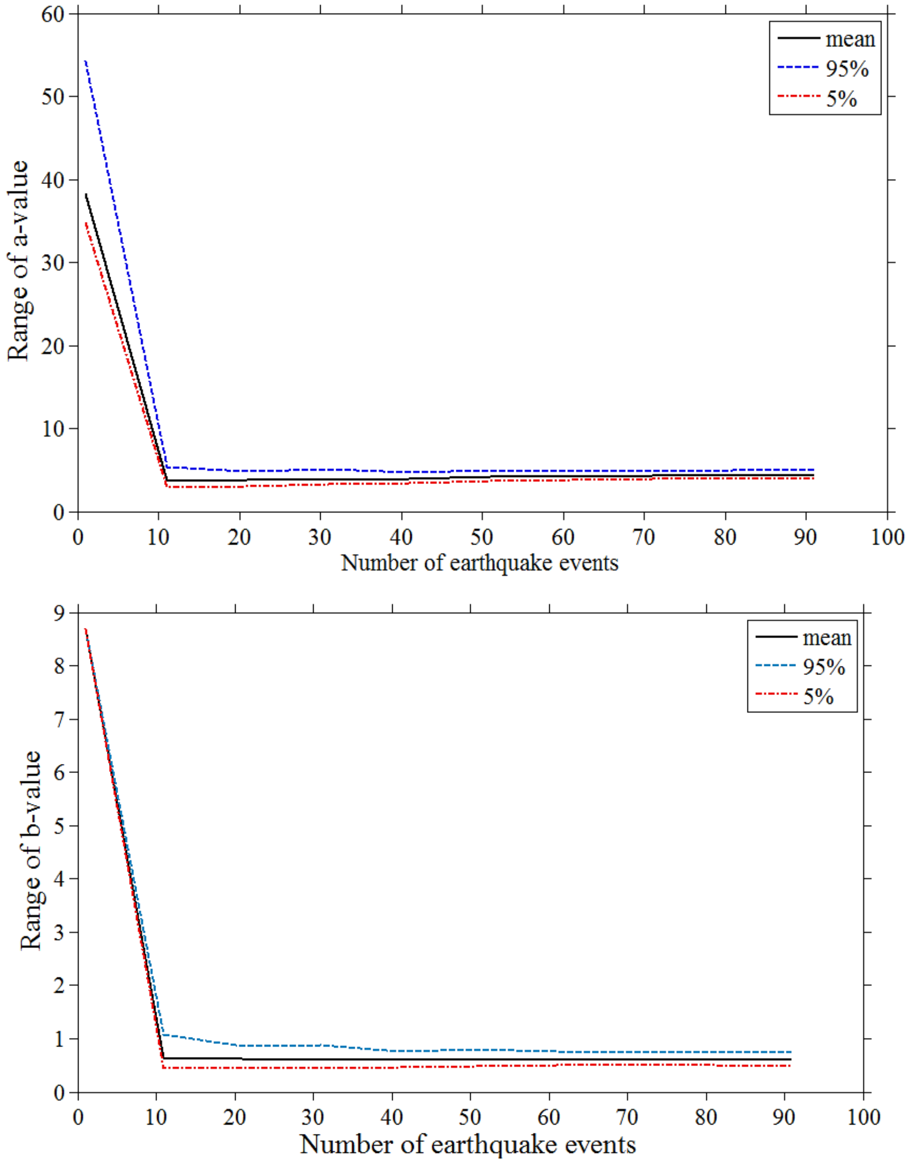


Figure 9. Convergence of seismicity parameters of Gutenberg and Richter recurrence law for instrumental era

Figure 10. indicates the probability of occurrence overt the time of one year against magnitude of earthquake for each city after combination the result of historical and instrumental records. As seen in Figure 10, the probability of occurrence an earthquake with large magnitude in Rudbar which has experienced a destructive earthquake with a moment magnitude equal to 7.4 in 1990 is more than other cities in Guilan region.

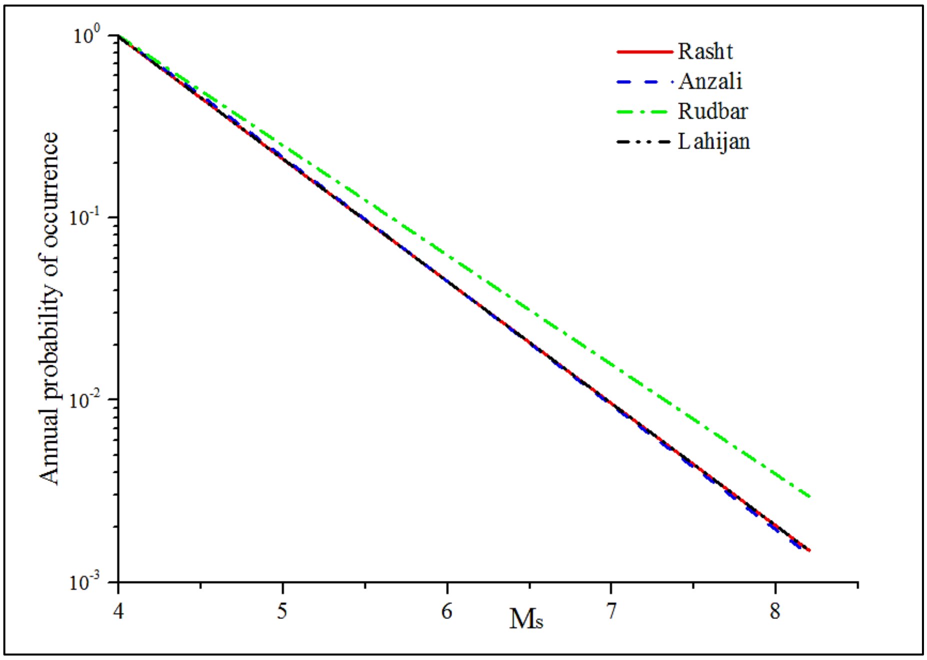


Figure 10. Probability of occurrence of an earthquake - Ms for Rasht, Anzali, Rudbar, and Lahijan by Zmap

Kijko program was written in 1989 by Kijko and Sellevoll. The modified version containing the uncertainty of seismic parameters was established in 1992 and became one the best tools to estimate seismic parameters. This program has the ability to compute the maximum expected earthquake, the annual rate of exceedance, seismic parameters, data contributions of historical and instrumental records for different values of seismic parameters and etc. Table 12. and Figure 11. show the results of Kijko program for Rasht, Anzali, Rudbar, and Lahijan.

Table 12. Seismic parameters of historical and instrumental events by Kijko

Historical Earthquake of Rasht			
β	b	λ(Ms=4)	M_{max}
1.32±0.18	0.57±0.08	0.31±0.11	8.20-0.71
Instrumental Earthquake of Rasht			
β	b	λ (Ms=4)	M_{max}
1.50±0.12	0.65±0.05	0.7±0.08	7.90-0.58
Historical-Instrumental Earthquake of Rasht			
Data Contribution to Parameters			
		β (%)	λ (%)
Historical		58.7	17.5
Instrumental		41.3	82.5
β	b	λ (Ms=4)	M_{max}
1.61±0.09	0.6±0.04	0.64±0.06	8.20-0.58
Historical Earthquake of Anzali			
β	b	λ (Ms=4)	M_{max}
1.30±0.18	0.57±0.08	0.30±0.11	8.20-0.71
Instrumental Earthquake of Anzali			
β	b	λ (Ms=4)	M_{max}
1.52±0.12	0.66±0.05	0.73±0.08	7.90-0.58
Historical-Instrumental Earthquake of Anzali			

Data Contribution to Parameters			
		β (%)	λ (%)
Historical		58.2	16.4
Instrumental		41.8	83.6
β	b	λ (Ms=4)	M_{max}
1.62±0.09	0.6±0.04	0.66±0.06	8.20-0.58
Historical Earthquake of Rudbar			
β	b	λ (Ms=4)	M_{max}
1.38±0.18	0.60±0.08	0.37±0.12	8.20-0.71
Instrumental Earthquake of Rudbar			
β	b	λ (Ms=4)	M_{max}
1.49±0.09	0.65±0.04	0.69±0.07	7.90-0.58
Historical-Instrumental Earthquake of Rudbar			
Data Contribution to Parameters			
		β (%)	λ (%)
Historical		61.6	18.4
Instrumental		38.4	81.6
β	b	λ (Ms=4)	M_{max}
1.64±0.11	0.61±0.05	0.64±0.06	8.20-0.58
Historical Earthquake of Lahijan			
β	b	λ (Ms=4)	M_{max}
1.34±0.19	0.58±0.08	0.34±0.12	8.20-0.71
Instrumental Earthquake of Lahijan			
β	b	λ (Ms=4)	M_{max}
1.51±0.10	0.66±0.04	0.75±0.08	7.90-0.58
Historical-Instrumental Earthquake of Lahijan			
Data Contribution to Parameters			
		β (%)	λ (%)
Historical		55.5	15.1
Instrumental		44.5	84.9
β	b	λ(Ms=4)	M_{max}
1.58±0.08	0.62±0.04	0.69±0.07	8.20-0.58

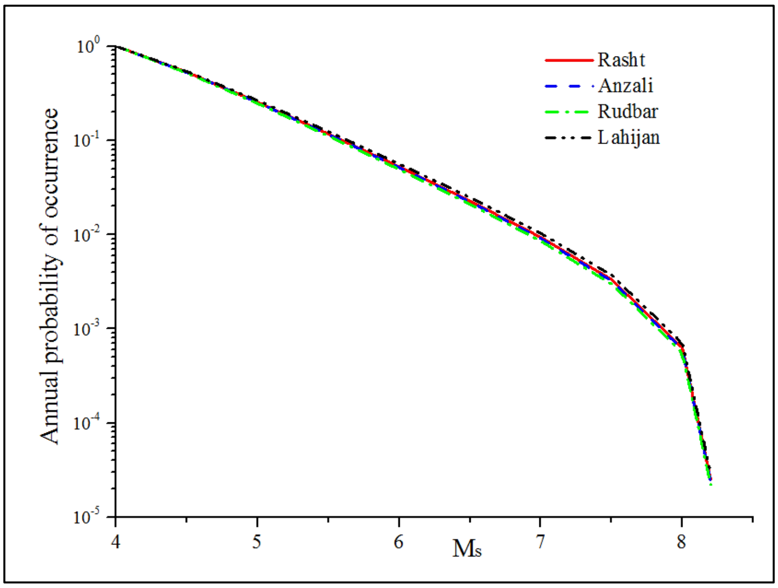


Figure 11. Probability of occurrence an earthquake - Ms for Rasht, Anzali, Rudbar, and Lahijan by Kijko

Figure 12. shows the compression of the annual rate of exceedance against the magnitude of earthquake form Zmap and Kijko software. Good consistency of the result can be seen in this figure, which can be motivated user to do probabilistic seismic hazard investigation for these cities.

As stated before Tavakoli and Ghafory (1999) divided Iran into several seismotectonic subdivision and reported the value of b parameters around 0.6±0.04 to 0.7±0.07 for subdivision number 15 that include Guilan region and the maximum expected magnitude of earthquake around 7.9±0.3 Richter in 1999 for the area of Guilan province [2].

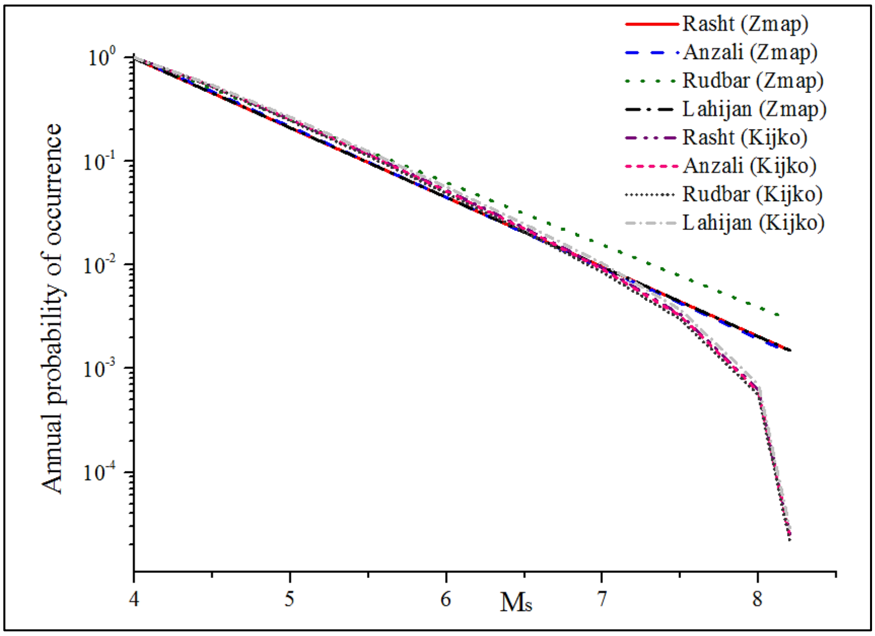


Figure 12. Comparison the result of annual rate of exceedance form Zmap and Kijko software

It should be stated that 71 earthquake events in their research is not only related to the Guilan region and include wide range of Mazandaran region. Obviously, this study improves the result of Tavakoli and Ghafory in 1999. The discrepancy of maximum expected earthquake events are related to the span of times and occurrence of large magnitude earthquakes in historical events. Fortunately, the number of large earthquakes affecting significantly on Gutenberg-Richter parameters during the span of time 1995-2016 are a few. Therefore the annual rate of exceedance and Gutenberg-Richter parameter reported by Tavakoli and Ghafory in 1999 is close with the result of this study. Abdollahzadeh et al. (2013) classified north of Iran into Alborz- Azarbayejan and Kope Dagh seismotectonic provinces [4]. They reported 505 declustered events, including 344 events in Alborz- Azarbayejan and 161 events in Kope Dagh seismotectonic. Definitely the structural and geological conditions of these seismotectonic regions are different. Assuming active and potential faults in their study is one of the main shortcomings which can be stated in their study. Kramer (1996) stated that, the mere presence of a fault does not indicate the likelihood of future earthquakes. Hence the seismicity parameters and also the annual rate of exceedance reported higher than calculated values of this study. The values of β parameters are 1.71 and 1.70 for Alborz- Azarbayejan and Kope Dagh respectively which had discrepancies around 7% with the result of this study (β ≈1.6 for intended cities as seen in Table12.) and around 25% for the annual rate of exceedance. One of the main sources of this difference related to the higher range of standard deviation for earthquake magnitude in Abdollahzadeh et al. (2013) study. Table 13. compares the result of this study with seismicity values reported by Tavakoli and Ghafory in 1999 and Abdollahzadeh et al. in 2013 for north of Iran. The upper and lower bounds of maximum expected earthquakes show good consistency with each other and show discrepancies around 7%, 5% with the result of literatures.

Table 13. Comparing the result of this study, [2, 4]

	Tavakoli and Ghafory (1999) [2]	**Abdollahzadeh et al. (2013) [4]**	**Present study**			
			Rasht	**Anzali**	**Rudbar**	**Lahijan**
Span of Time	1927-1995	743-2012	855-2016	864-2016	855-2016	855-2016
b value	0.6±0.04	≈0.74*	0.6±0.04	0.6±0.04	0.61±0.05	0.62±0.04
Mmax	7.9±0.3	8.0±0.8	8.2±0.6	8.2±0.6	8.2±0.6	8.2±0.6
λ(Ms=4)	0.68±0.04	≈0.82*	0.64±0.06	0.66±0.06	0.64±0.06	0.69±0.06
Number of events	71	344**	110	112	110	114

* Equivalent value of *b* and *λ*

** 344 earthquake events for Alborz- Azarbayejan region

5. Conclusion

Numerous earthquake occurrences show the high probability of seismic events in Guilan province, and highlight the significance of seismic hazard evaluation for some of the most important cities of Guilan Province. Therefore, the study of earthquake, seismology, and probabilistic seismic hazard analysis for this area seems to be essential. Seismicity parameters were evaluated after assessment of the completeness and homogeneity; elimination of duplicated events, foreshocks and aftershocks; and applying threshold value to the earthquake catalog. For this means Zmap and Kijko programs were used to calculate Gutenberg-Richter parameters from final catalogs with a proper distance (200 km) of intended cities of Guilan province, including Rasht, Anzali, Rudbar, and Lahijan between the geographical area limited to 35.0°-39.3°N, 47.1-52.2°E.

The mean values of seismic parameters (b) for these four intended cities vary around 0.57 to 0.6 for historical events while the mean values of (b) parameters have the range of 0.65 to 0.69 for instrumental records. Calculated values of Gutenberg-Richter relationship for (b) parameters are around the values reported by Tavakoli and Ghafory in 1999 and a bit lower than Abdollahzadeh et al. in 2013. The number of large earthquakes during the span of time 1995-2016 affecting significantly on Gutenberg-Richter parameters is a few, Hence good consistency existed between the result of this study and Tavakoli and Ghafory research. Discrepancies of maximum expected earthquake events are related to the span of times and occurrence of large magnitude earthquakes in historical events. The result of seismicity parameters, maximum expected earthquakes, annual rates of exceedance and probability of occurrence of earthquake for all of the cities are almost equal. The closeness of these values could be related to the short distance ($\leq$ 50 km) of these cities and almost the same catalogs for them. The resultant values form Zmap and Kijko software show good consistency and the differences between Zmap and Kijko software for (b) values are less than 5%. The magnitude of completeness decreases over the time. Form the instrumental era, these values varies from 4 to 4.3 on the Richter scale while greater values are reported for historical era varies from 5.3 to 6.1. All of the earthquakes reported for historical era, had large magnitude hence, the data contribution values for β (almost b) in historical era are generally higher than these values for instrumental record. While data contribution values for λ in the instrumental era are much higher than historical era because of the numerous recorded events reported for instrumental era.

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Appendix-1

Table A1. Rasht earthquake catalog

Rasht catalog of earthquake occurring in a 200 km distance									
Year	**Month**	**Day**	**Hour**	**Minute**	**Latitude**	**longitude**	**Depth**	**Magnitude**	**References***
855	0**	0	0	0	35.6	51.5	0	7.1	AMB
864	1	0	0	0	35.7	51	0	5.3	AMB
894	1	6	0	0	37.7	47.5	0	7.7	ULM
958	2	23	0	0	36	51.1	0	7.7	AMB
986	11	0	0	0	36.2	48.1	0	6.1	ULM
1052	0	0	0	0	36.6	50.3	0	6.8	BER
1119	12	10	18	0	35.7	49.9	0	6.5	AMB
1177	5	0	0	0	35.7	50.7	0	7.2	AMB
1485	8	15	0	0	36.7	50.5	0	7.2	AMB
1593	0	0	0	0	37.8	47.5	0	6.1	AMB
1608	4	20	12	0	36.4	50.5	0	7.6	AMB
1639	0	0	0	0	36.6	50	0	6.1	ULM
1678	2	3	6	0	37.2	50	0	6.5	AMB
1803	0	0	0	0	36.33	48.95	0	5.3	BER
1808	12	16	18	0	36.4	50.3	0	5.9	AMB
1844	5	13	19	0	37.6	47.8	0	6.9	AMB
1863	12	30	22	0	38.2	48.6	0	6.1	AMB
1876	10	20	15	0	35.8	49.8	0	5.7	AMB
1879	3	22	4	0	37.8	47.8	0	6.7	AMB
1880	7	4	0	0	36.5	47.5	0	5.6	AMB
1896	1	4	15	0	37.8	48.4	0	6.7	AMB
1901	5	20	12	29	36.39	50.48	0	5.4	AMB
1903	2	9	5	18	36.58	47.65	0	5.6	AMB
1903	6	24	16	56	37.48	48.96	0	5.9	AMB
1905	1	9	6	17	37	48.68	0	6.2	AMB
1910	12	4	14	2	38.8	48.8	33	5.1	MOS
1913	4	16	6	0	38.7	48.5	33	5.2	KAR
1917	6	2	2	8	38	48.5	30	4.7	NOW
1924	2	19	7	0	39	48.32	0	5.9	AMB
1924	11	8	9	5	35.5	48	0	5.5	NOW
1932	5	24	23	31	37.8	48.2	33	4.5	MOS
1933	4	16	6	54	39	48.5	33	4.8	NOW
1944	11	9	19	39	38	48.4	33	4.2	KAR
1951	6	5	3	34	36.18	48.33	81	4.6	NOW
1954	8	16	14	56	39	48.7	33	4.5	KAR
1957	5	6	15	6	36.4	51.5	12	4.8	NOW
1959	5	1	8	23	36.38	51.16	33	5.3	NOW
1962	9	1	19	20	35.55	49.83	35	7.2	AMB
1964	2	8	6	28	37.1	51.04	40	4.3	ISC
1965	10	29	15	59	37.9	48.7	33	4.3	ISC
1966	11	8	3	14	36.1	50.75	41	4.5	ISC
1967	8	25	12	26	35.56	49.24	36	4.4	MOS
1968	6	4	1	44	37.5	49.19	49	4.3	ISC
1968	8	2	3	59	36.85	49.33	36	4.4	ISC
1970	4	16	1	26	38.81	48.61	66	4.3	ISC

Rasht catalog of earthquake occurring in a 200 km distance									
Year	**Month**	**Day**	**Hour**	**Minute**	**Latitude**	**longitude**	**Depth**	**Magnitude**	**References***
1970	7	11	22	41	37.54	49.03	47	5.0	ISC
1971	5	15	4	53	37.96	49.04	49	4.4	ISC
1972	1	18	21	12	37.5	48.83	33	4.5	ISC
1973	7	13	10	5	38.46	49.52	40	4.2	ISC
1973	9	17	4	6	36.53	51.11	47	4.4	ISC
1975	3	13	17	33	37.08	50.7	27	4.0	ISC
1975	4	11	14	26	35.61	50.27	33	4.4	ISC
1978	11	4	15	22	37.68	48.91	36	6.1	ISC
1979	11	8	5	22	38.71	48.9	33	4.2	ISC
1980	5	4	18	35	38.05	49.02	35	6.1	ISC
1980	7	22	5	17	37.32	50.27	36	5.1	ISC
1981	8	4	18	53	36.45	51.27	39	4.4	ISC
1981	8	5	0	13	38.5	49.7	33	4.0	ISC
1983	4	2	0	32	38.98	48.7	50	4.4	ISC
1983	7	22	2	41	36.95	49.22	43	5.0	ISC
1983	12	20	22	21	36.85	50.85	26	4.5	ISC
1983	12	21	0	7	36.93	51.31	33	4.0	ISC
1984	9	9	17	55	35.53	49.28	0	4.3	ISC
1984	9	30	15	33	37.92	49.16	58	4.3	ISC
1985	5	9	18	50	39.04	49.03	33	4.0	ISC
1985	11	2	9	34	37.83	49.48	33	4.0	ISC
1986	1	27	16	35	38.92	48.72	55	4.3	ISC
1986	4	29	22	7	37.9	49.11	50	4.6	ISC
1989	2	15	10	10	37.31	50.44	47	4.4	ISC
1990	6	20	21	0	37	49.22	19	7.4	ISC
1990	6	20	23	27	36.65	50.05	33	5.0	ISC
1990	6	20	23	55	37.37	49.98	20	4.0	ISC
1990	9	24	6	35	38.16	48.15	10	4.3	ISC
1993	3	8	19	13	36.51	51	57	4.0	ISC
1994	11	2	12	31	38.25	48.26	10	4.3	ISC
1994	12	3	1	35	37.65	49.32	16	4.3	ISC
1995	5	15	0	16	38.49	49.43	47	4.2	ISC
1995	5	27	21	21	38.92	48.93	33	4.4	ISC
1995	6	26	21	12	36.6	51.19	22	4.2	ISC
1995	10	15	6	56	37.02	49.47	63	4.6	ISC
1996	1	3	8	42	38.97	48.74	62	4.6	ISC
1997	2	28	12	57	38.12	48.08	39	6.1	ISC
1997	5	28	5	4	38.73	48.51	69	4.5	ISC
1997	6	7	20	29	36.51	50.36	27	4.2	ISC
1998	2	28	0	39	36.96	48.77	53	4.1	ISC
1998	6	29	3	37	36.72	49.43	55	4.2	ISC
1998	7	9	14	19	38.72	48.52	55	5.5	ISC
1999	3	17	23	45	36.92	49.51	33	4.2	ISC
1999	3	26	12	6	36.54	50.14	33	4.2	ISC
2001	10	29	10	4	38.79	48.62	40	4.2	ISC
2001	11	17	6	33	38.87	51.64	50	4.0	ISC
2002	4	19	13	46	36.51	49.77	29	4.6	ISC
2002	6	22	2	58	35.59	49.03	0	6.4	ISC

Rasht catalog of earthquake occurring in a 200 km distance									
Year	**Month**	**Day**	**Hour**	**Minute**	**Latitude**	**longitude**	**Depth**	**Magnitude**	**References***
2004	5	28	12	38	36.25	51.57	27	6.3	ISC
2004	5	28	17	34	36.56	51.08	28	4.0	IIEES
2005	9	26	18	57	37.33	47.71	16	4.2	IIEES
2006	11	5	20	6	37.56	48.93	14	4.0	IIEES
2007	7	11	6	51	38.82	48.64	27	4.2	IIEES
2008	5	27	6	18	36.51	48.68	14	4.3	IIEES
2010	10	22	8	0	37.91	49.06	15	4.6	IIEES
2011	3	4	9	46	37.73	48.61	14	4.3	IIEES
2012	1	13	12	35	35.82	49	14	4.0	IIEES
2012	2	4	20	4	37.7	49.53	40	4.5	IIEES
2012	3	18	2	38	36.82	49.2	14	4.5	IIEES
2012	7	27	21	39	36.82	51.34	7	4.2	IIEES
2013	7	6	17	7	37.52	48.72	17	4.3	IIEES
2014	9	18	22	29	38.74	48.59	34	4.4	IIEES
2015	3	2	6	8	35.73	48.76	17	4.6	IIEES
2015	3	12	0	42	38.21	49.11	14	4.7	IIEES
2015	5	10	22	8	36.75	49.86	16	4.5	IIEES

* See table A1-5

** Unknown value = 0

Table A2. Anzali earthquake catalog

Anzali catalog of earthquake occurring in a 200 km distance									
Year	**Month**	**Day**	**Hour**	**Minute**	**Latitude**	**longitude**	**Depth**	**Magnitude**	**References***
864	1	0**	0	0	35.7	51	0	5.3	AMB
894	1	6	0	0	37.7	47.5	0	7.7	ULM
958	2	23	0	0	36	51.1	0	7.7	AMB
986	11	0	0	0	36.2	48.1	0	6.1	ULM
1052	0	0	0	0	36.6	50.3	0	6.8	BER
1119	12	10	0	0	35.7	49.9	0	6.5	AMB
1177	5	0	0	0	35.7	50.7	0	7.2	AMB
1485	8	15	0	0	36.7	50.5	0	7.2	AMB
1593	0	0	0	0	37.8	47.5	0	6.1	AMB
1608	4	20	12	0	36.4	50.5	0	7.6	AMB
1639	0	0	0	0	36.6	50	0	6.1	ULM
1678	2	3	6	0	37.2	50	0	6.5	AMB
1803	0	0	0	0	36.33	48.95	0	5.3	BER
1808	12	16	18	0	36.4	50.3	0	5.9	AMB
1844	5	13	19	0	37.6	47.8	0	6.9	AMB
1863	12	30	22	0	38.2	48.6	0	6.1	AMB
1876	10	20	15	0	35.8	49.8	0	5.7	AMB
1879	3	22	4	0	37.8	47.8	0	6.7	AMB
1880	7	4	0	0	36.5	47.5	0	5.6	AMB
1896	1	4	16	0	37.8	48.4	0	6.7	AMB
1901	5	20	12	29	36.39	50.48	0	5.4	AMB
1903	2	9	5	18	36.58	47.65	0	5.6	AMB
1903	6	24	16	56	37.48	48.96	0	5.9	AMB
1905	1	9	6	17	37	48.68	0	6.2	AMB

Anzali catalog of earthquake occurring in a 200 km distance

Year	Month	Day	Hour	Minute	Latitude	longitude	Depth	Magnitude	References*
1910	12	4	14	2	38.8	48.8	33	5.1	MOS
1913	4	16	6	0	38.7	48.5	33	5.2	KAR
1917	6	2	2	8	38	48.5	30	4.7	NOW
1924	2	19	7	0	39	48.32	0	5.9	AMB
1928	3	24	10	53	37.8	47.3	33	4.9	NOW
1932	5	24	23	31	37.8	48.2	33	4.5	MOS
1933	4	16	6	54	39	48.5	33	4.8	NOW
1944	11	9	19	39	38	48.4	33	4.2	KAR
1951	6	5	3	34	36.18	48.33	81	4.6	NOW
1954	8	16	14	59	39	48.7	33	4.5	KAR
1956	4	12	22	34	37.33	50.26	30	5.3	NOW
1957	5	6	15	6	36.4	51.5	0	4.8	MEA
1959	5	1	8	23	36.38	51.16	33	5.3	NOW
1962	9	1	19	20	35.55	49.83	35	7.2	AMB
1964	2	8	6	28	37.1	51.04	40	4.3	ISC
1965	10	29	15	59	37.9	48.7	33	4.3	ISC
1966	11	8	3	14	36.1	50.75	41	4.5	ISC
1967	8	25	12	26	35.56	49.24	36	4.4	MOS
1968	6	4	1	44	37.5	49.19	49	4.3	ISC
1968	8	2	3	59	36.85	49.33	36	4.4	ISC
1970	4	16	1	26	38.81	48.61	66	4.3	ISC
1970	7	11	22	41	37.54	49.03	47	5.0	ISC
1971	5	15	4	53	37.96	49.04	49	4.4	ISC
1972	1	18	21	12	37.5	48.83	33	4.5	ISC
1973	7	13	10	5	38.46	49.52	40	4.2	ISC
1973	9	17	4	6	36.53	51.11	47	4.4	ISC
1975	3	13	17	33	37.08	50.7	27	4.0	ISC
1975	4	11	14	26	35.61	50.27	33	4.4	ISC
1978	11	4	15	22	37.68	48.91	36	6.1	ISC
1979	11	8	5	22	38.71	48.9	33	4.2	ISC
1980	5	4	18	35	38.05	49.02	35	6.1	ISC
1980	7	22	5	17	37.32	50.27	36	5.1	ISC
1981	8	4	18	53	36.45	51.27	39	4.4	ISC
1981	8	5	0	13	38.5	49.7	33	4.0	ISC
1983	4	2	0	32	38.98	48.7	50	4.4	ISC
1983	7	22	2	41	36.95	49.22	43	5.0	ISC
1983	12	20	22	21	36.85	50.85	26	4.5	ISC
1983	12	21	0	7	36.93	51.31	33	4.0	ISC
1984	9	9	17	55	35.53	49.28	0	4.3	ISC
1984	9	30	15	33	37.92	49.16	58	4.3	ISC
1985	5	9	18	50	39.04	49.03	33	4.0	ISC
1985	11	2	9	34	37.83	49.48	33	4.0	ISC
1986	1	27	16	35	38.92	48.72	55	4.3	ISC
1986	4	29	22	7	37.9	49.11	50	4.6	ISC
1989	2	15	10	10	37.31	50.44	47	4.4	ISC
1990	6	20	21	0	37	49.22	19	7.4	ISC

Anzali catalog of earthquake occurring in a 200 km distance

Year	Month	Day	Hour	Minute	Latitude	longitude	Depth	Magnitude	References*
1990	6	20	23	27	36.65	50.05	33	5.0	ISC
1990	6	20	23	55	37.37	49.98	20	4.0	ISC
1990	9	24	6	35	38.16	48.15	10	4.3	ISC
1993	3	8	19	13	36.51	51	57	4.0	ISC
1994	11	2	12	31	38.25	48.26	10	4.3	ISC
1994	12	3	1	35	37.65	49.32	16	4.3	ISC
1995	5	15	0	16	38.49	49.43	47	4.2	ISC
1995	5	27	21	21	38.92	48.93	33	4.4	ISC
1995	6	26	21	12	36.6	51.19	22	4.2	ISC
1995	10	15	6	56	37.02	49.47	63	4.6	ISC
1996	1	3	8	42	38.97	48.74	62	4.6	ISC
1997	2	28	12	57	38.12	48.08	39	6.1	ISC
1997	5	28	5	4	38.73	48.51	69	4.5	ISC
1997	6	7	20	29	36.51	50.36	27	4.2	ISC
1998	2	28	0	39	36.96	48.77	53	4.1	ISC
1998	6	29	3	37	36.72	49.43	55	4.2	ISC
1998	7	9	14	19	38.72	48.52	55	5.5	ISC
1999	3	17	23	45	36.92	49.51	33	4.2	ISC
1999	3	26	12	6	36.54	50.14	33	4.2	ISC
2001	10	29	10	4	38.79	48.62	40	4.2	ISC
2001	11	17	6	33	38.87	51.64	50	4.0	ISC
2002	4	19	13	46	36.51	49.77	29	4.6	ISC
2002	6	22	2	58	35.59	49.03	0	6.4	ISC
2004	5	28	12	38	36.25	51.57	27	6.3	ISC
2004	5	28	17	34	36.56	51.08	28	4.0	IIEES
2005	9	26	18	57	37.33	47.71	16	4.2	IIEES
2006	11	5	20	6	37.56	48.93	14	4.0	IIEES
2007	7	11	6	51	38.82	48.64	27	4.2	IIEES
2008	5	27	6	18	36.51	48.68	14	4.3	IIEES
2010	10	22	8	0	37.91	49.06	15	4.6	IIEES
2011	3	4	9	46	37.73	48.61	14	4.3	IIEES
2012	1	13	12	35	35.82	49	14	4.0	IIEES
2012	2	4	20	4	37.7	49.53	40	4.5	IIEES
2012	3	18	2	38	36.82	49.2	14	4.5	IIEES
2012	7	27	21	39	36.82	51.34	7	4.2	IIEES
2013	4	23	8	1	39.17	48.72	15	4.1	IIEES
2013	7	6	17	7	37.52	48.72	17	4.3	IIEES
2013	11	8	10	12	37.86	47.27	15	4.5	IIEES
2014	9	18	22	29	38.74	48.59	34	4.4	IIEES
2015	3	2	6	8	35.73	48.76	17	4.6	IIEES
2015	3	12	0	42	38.21	49.11	14	4.7	IIEES
2015	5	10	22	8	36.75	49.86	16	4.5	IIEES

* See table A1-5

** Unknown value = 0

Table A3. Rudbar earthquake catalog

Rudbar catalog of earthquake occurring in a 200 km distance									
Year	**Month**	**Day**	**Hour**	**Minute**	**Latitude**	**longitude**	**Depth**	**Magnitude**	**References***
855	0**	0	0	0	35.6	51.5	0	7.1	AMB
864	1	0	0	0	35.7	51	0	5.3	AMB
894	1	6	0	0	37.7	47.5	0	7.7	ULM
958	2	23	0	0	36	51.1	0	7.7	AMB
986	11	0	0	0	36.2	48.1	0	6.1	ULM
1052	0	0	0	0	36.6	50.3	0	6.8	BER
1119	12	10	18	0	35.7	49.9	0	6.5	AMB
1177	5	0	0	0	35.7	50.7	0	7.2	AMB
1485	8	15	0	0	36.7	50.5	0	7.2	AMB
1593	0	0	0	0	37.8	47.5	0	6.1	AMB
1608	4	20	12	0	36.4	50.5	0	7.6	AMB
1639	0	0	0	0	36.6	50	0	6.1	ULM
1678	2	3	6	0	37.2	50	0	6.5	AMB
1803	0	0	0	0	36.33	48.95	0	5.3	BER
1808	12	16	18	0	36.4	50.3	0	5.9	AMB
1844	5	13	19	0	37.6	47.8	0	6.9	AMB
1863	12	30	22	0	38.2	48.6	0	6.1	AMB
1876	10	20	15	0	35.8	49.8	0	5.7	AMB
1879	3	22	4	0	37.8	47.8	0	6.7	AMB
1880	7	4	0	0	36.5	47.5	0	5.6	AMB
1883	5	3	12	0	37.9	47.2	0	6.2	AMB
1896	1	4	16	0	37.8	48.4	0	6.7	AMB
1901	5	20	12	29	36.39	50.48	0	5.4	AMB
1903	2	9	5	18	36.58	47.65	0	5.6	AMB
1903	6	24	16	56	37.48	48.96	0	5.9	AMB
1905	1	9	6	17	37	48.68	0	6.2	AMB
1913	9	24	16	56	38.5	48.9	0	4.2	MOS
1917	6	2	2	8	38	48.5	30	4.7	NOW
1924	11	8	9	5	35.5	48	0	5.5	NOW
1927	6	15	6	46	35.5	48	0	4	NOW
1927	10	31	6	23	36.5	49	0	4	NOW
1928	3	24	10	53	38.14	48.17	0	5	NOW
1932	3	2	9	0	38.5	48.3	0	4.0	MOS
1944	11	9	19	39	38	48.4	33	4.2	KAR
1948	6	30	19	31	36.66	49.48	0	5	NOW
1951	6	5	3	45	36.18	48.33	81	4.6	NOW
1952	7	18	0	43	37.16	50.14	0	4.7	NOW
1955	1	11	4	6	38.1	47.9	0	4	NOW
1955	5	10	11	32	38.6	48	0	4	MOS
1956	4	12	22	34	37.33	50.26	0	5.5	NOW
1957	5	6	15	6	36.4	51.5	12	4.8	MEA
1958	7	6	10	46	38.5	48.4	0	4	MOS
1958	11	2	9	14	36.61	51.42	0	4.5	NOW
1959	5	1	8	23	36.38	51.16	33	5.3	NOW
1962	9	1	19	20	35.55	49.83	35	7.2	NOW

Rudbar catalog of earthquake occurring in a 200 km distance

Year	Month	Day	Hour	Minute	Latitude	longitude	Depth	Magnitude	References*
1964	2	8	6	28	37.1	51.04	40	4.3	ISC
1965	10	29	15	59	37.9	48.7	33	4.3	ISC
1966	11	8	3	14	36.1	50.75	41	4.5	ISC
1967	8	25	12	26	35.56	49.24	36	4.4	ISC
1968	4	26	2	58	35.06	50.16	22	5.0	ISC
1968	6	4	1	44	37.5	49.19	49	4.3	ISC
1968	8	2	3	59	36.85	49.33	36	4.4	ISC
1970	6	27	7	57	35.13	50.76	66	4.5	ISC
1970	7	11	22	41	37.54	49.03	47	5.0	ISC
1971	5	15	4	53	37.96	49.04	49	4.4	ISC
1972	1	18	21	12	37.5	48.83	33	4.5	ISC
1973	7	13	10	5	38.46	49.52	40	4.2	ISC
1973	9	17	4	6	36.53	51.11	47	4.4	ISC
1975	3	13	17	33	37.08	50.7	27	4.0	ISC
1975	4	11	14	26	35.61	50.27	33	4.4	ISC
1978	11	4	15	22	37.68	48.91	36	6.1	ISC
1979	11	21	15	36	38.19	47.23	0	4.2	ISC
1980	5	4	18	35	38.05	49.02	35	6.1	ISC
1980	7	22	5	17	37.32	50.27	36	5.1	ISC
1981	8	4	18	53	36.45	51.27	39	4.4	ISC
1981	8	5	0	13	38.5	49.7	33	4.0	ISC
1983	7	22	2	41	36.95	49.22	43	5.0	ISC
1983	12	20	22	21	36.85	50.85	26	4.5	ISC
1983	12	21	0	7	36.93	51.31	33	4.0	ISC
1984	9	9	17	55	35.53	49.28	0	4.3	ISC
1984	9	30	15	33	37.92	49.16	58	4.3	ISC
1985	11	2	9	34	37.83	49.48	33	4.0	ISC
1986	4	29	22	7	37.9	49.11	50	4.6	ISC
1989	2	15	10	10	37.31	50.44	47	4.4	ISC
1990	6	20	21	0	37	49.22	19	7.4	ISC
1990	6	20	23	27	36.65	50.05	33	5.0	ISC
1990	6	20	23	55	37.37	49.98	20	4.0	ISC
1990	9	24	6	35	38.16	48.15	10	4.3	ISC
1993	3	8	19	13	36.51	51	57	4.0	ISC
1994	11	2	12	31	38.25	48.26	10	4.3	ISC
1994	12	3	1	35	37.65	49.32	16	4.3	ISC
1995	5	15	0	16	38.49	49.43	47	4.2	ISC
1995	6	26	21	12	36.6	51.19	22	4.2	ISC
1995	10	15	6	56	37.02	49.47	63	4.6	ISC
1997	2	28	12	57	38.12	48.08	39	6.1	ISC
1997	6	7	20	29	36.51	50.36	28	4.2	ISC
1998	2	28	0	39	36.96	48.77	53	4.1	ISC
1998	6	29	3	37	36.72	49.43	55	4.2	ISC
1999	3	17	23	45	36.92	49.51	33	4.2	ISC
1999	3	26	12	6	36.54	50.14	33	4.2	ISC
2002	4	19	13	46	36.51	49.77	29	4.6	ISC

Rudbar catalog of earthquake occurring in a 200 km distance									
Year	**Month**	**Day**	**Hour**	**Minute**	**Latitude**	**longitude**	**Depth**	**Magnitude**	**References***
2002	6	22	2	58	35.59	49.03	0	6.4	ISC
2004	5	28	12	38	36.25	51.57	27	6.3	ISC
2005	9	26	18	57	37.33	47.71	16	4.2	IIEES
2006	11	5	20	6	37.56	48.93	14	4.0	IIEES
2008	5	27	6	18	36.51	48.68	14	4.3	IIEES
2010	10	22	8	0	37.91	49.06	15	4.6	IIEES
2011	3	4	9	46	37.73	48.61	14	4.3	IIEES
2012	1	13	12	35	35.82	49	14	4.0	IIEES
2012	2	4	20	4	37.7	49.53	40	4.5	IIEES
2012	3	18	2	38	36.82	49.2	14	4.5	IIEES
2012	7	27	21	39	36.82	51.34	7	4.2	IIEES
2013	7	6	17	7	37.52	48.72	17	4.3	IIEES
2013	10	16	8	49	35.29	49.73	6	4.6	IIEES
2013	11	8	10	12	37.86	47.27	0	4.5	IIEES
2014	2	27	6	5	38.53	48.54	22	4.1	IIEES
2014	7	12	11	20	35.06	48.05	18	4.1	IIEES
2015	3	2	6	8	35.73	48.76	17	4.6	IIEES
2015	3	12	0	42	38.21	49.11	14	4.7	IIEES
2015	5	10	22	8	36.75	49.86	16	4.5	IIEES

* See table A1-5

** Unknown value = 0

Table A4. Lahijan earthquake catalog

Lahijan catalog of earthquake occurring in a 200 km distance									
Year	**Month**	**Day**	**Hour**	**Minute**	**Latitude**	**longitude**	**Depth**	**Magnitude**	**References***
855	0**	0	0	0	35.6	51.5	0	7.1	AMB
864	1	0	0	0	35.7	51	0	5.3	AMB
958	2	23	0	0	36	51.1	0	7.7	AMB
986	11	0	0	0	36.2	48.1	0	6.1	ULM
1052	0	0	0	0	36.6	50.3	0	6.8	BER
1119	12	10	18	0	35.7	49.9	0	6.5	AMB
1177	5	0	0	0	35.7	50.7	0	7.2	AMB
1485	8	15	0	0	36.7	50.5	0	7.2	AMB
1608	4	20	12	0	36.4	50.5	0	7.6	AMB
1639	0	0	0	0	36.6	50	0	6.1	ULM
1665	6	0	0	0	35.75	52.08	0	6.5	BER
1678	2	3	0	0	37.2	50	0	6.5	AMB
1803	0	0	0	0	36.33	48.95	0	5.3	BER
1808	12	16	18	0	36.4	50.3	0	5.9	AMB
1844	5	13	19	0	37.6	47.8	0	6.9	AMB
1863	12	30	22	0	38.2	48.6	0	6.1	AMB
1876	10	20	15	0	35.8	49.8	0	5.7	AMB
1879	3	22	4	0	37.8	47.8	0	6.7	AMB
1896	1	4	15	0	37.8	48.4	0	6.7	AMB
1901	5	20	12	29	36.39	50.48	0	5.4	AMB
1903	6	24	16	56	37.48	48.96	0	5.9	AMB

Lahijan catalog of earthquake occurring in a 200 km distance

Year	Month	Day	Hour	Minute	Latitude	longitude	Depth	Magnitude	References*
1905	1	9	6	17	37	48.68	0	6.2	AMB
1910	12	4	14	2	38.8	48.8	33	5.1	MOS
1913	4	16	6	0	38.7	48.5	33	5.2	KAR
1917	6	2	2	8	38	48.5	30	4.7	NOW
1924	2	19	7	0	39	48.32	0	5.9	AMB
1924	11	8	9	5	35.5	48	0	5.5	NOW
1930	10	2	15	32	35.76	51.99	0	5.2	AMB
1932	5	24	23	31	37.8	48.2	33	4.5	MOS
1933	4	16	6	54	39	48.5	33	4.8	NOW
1944	11	9	19	39	38	48.4	33	4.2	KAR
1951	6	5	3	34	36.18	48.33	81	4.6	NOW
1954	8	16	14	59	39	48.7	33	4.5	KAR
1955	11	24	0	0	35.76	52.05	0	4.0	BER
1956	4	12	22	34	37.33	50.26	30	5.5	NOW
1957	5	6	15	6	36.4	51.5	0	4.8	MEA
1959	5	1	8	23	36.38	51.16	33	5.3	NOW
1962	9	1	19	20	35.55	49.83	35	7.2	AMB
1964	2	8	6	28	37.1	51.04	40	4.3	ISC
1965	10	29	15	59	37.9	48.7	33	4.3	ISC
1966	11	8	3	14	36.1	50.75	41	4.5	ISC
1967	8	25	12	26	35.56	49.24	36	4.4	MOS
1968	6	4	1	44	37.5	49.19	49	4.3	ISC
1968	8	2	3	59	36.85	49.33	36	4.4	ISC
1970	4	16	1	26	38.81	48.61	66	4.3	ISC
1970	7	11	22	41	37.54	49.03	47	5.0	ISC
1971	5	15	4	53	37.96	49.04	49	4.4	ISC
1972	1	18	21	12	37.5	48.83	33	4.5	ISC
1973	7	13	10	5	38.46	49.52	40	4.2	ISC
1973	9	17	4	6	36.53	51.11	47	4.4	ISC
1975	3	13	17	33	37.08	50.7	27	4.0	ISC
1975	4	11	14	26	35.61	50.27	33	4.4	ISC
1978	11	4	15	22	37.68	48.91	36	6.1	ISC
1979	11	8	5	22	38.71	48.9	33	4.2	ISC
1980	5	4	18	35	38.05	49.02	35	6.1	ISC
1980	7	22	5	17	37.32	50.27	36	5.1	ISC
1981	8	4	18	53	36.45	51.27	39	4.4	ISC
1981	8	5	0	13	38.5	49.7	33	4.0	ISC
1983	3	26	4	7	35.99	52.25	20	4.9	ISC
1983	4	2	0	32	38.98	48.7	15	4.4	ISC
1983	7	22	2	41	36.95	49.22	43	5.0	ISC
1983	12	20	22	21	36.85	50.85	26	4.5	ISC
1983	12	21	0	7	36.93	51.31	33	4.0	ISC
1984	9	9	17	55	35.53	49.28	0	4.3	ISC
1984	9	30	15	33	37.92	49.16	58	4.3	ISC
1985	11	2	9	34	37.83	49.48	33	4.0	ISC
1986	1	27	16	35	38.92	48.72	55	4.3	ISC

Lahijan catalog of earthquake occurring in a 200 km distance

Year	Month	Day	Hour	Minute	Latitude	longitude	Depth	Magnitude	References*
1986	4	29	22	7	37.9	49.11	50	4.6	ISC
1989	2	15	10	10	37.31	50.44	47	4.4	ISC
1990	6	20	21	0	37	49.22	19	7.4	ISC
1990	6	20	23	27	36.65	50.05	33	5.0	ISC
1990	6	20	23	55	37.37	49.98	20	4.0	ISC
1990	9	24	6	35	38.16	48.15	10	4.3	ISC
1993	3	8	19	13	36.51	51	57	4.0	ISC
1994	11	2	12	31	38.25	48.26	10	4.3	ISC
1994	12	3	1	35	37.65	49.32	16	4.3	ISC
1995	5	15	0	16	38.49	49.43	47	4.2	ISC
1995	5	27	21	21	38.92	48.93	33	4.4	ISC
1995	6	26	21	12	36.6	51.19	22	4.2	ISC
1995	10	15	6	56	37.02	49.47	63	4.6	ISC
1996	1	3	8	42	38.97	48.74	62	4.6	ISC
1997	2	28	12	57	38.12	48.08	39	6.1	ISC
1997	5	28	5	4	38.73	48.51	69	4.5	ISC
1997	6	7	20	29	36.51	50.36	27	4.2	ISC
1998	1	9	19	6	36.38	52.14	15	4.4	ISC
1998	2	28	0	39	36.96	48.77	53	4.1	ISC
1998	6	29	3	37	36.72	49.43	55	4.2	ISC
1998	7	9	14	19	38.72	48.52	55	5.5	ISC
1999	3	17	23	45	36.92	49.51	33	4.2	ISC
1999	3	26	12	6	36.54	50.14	33	4.2	ISC
2001	10	29	10	4	38.79	48.62	40	4.2	ISC
2001	11	17	6	33	38.87	51.64	50	4.0	ISC
2002	4	8	18	30	36.46	52.01	9	4.1	ISC
2002	4	19	13	46	36.51	49.77	29	4.6	ISC
2002	6	22	2	58	35.59	49.03	0	6.4	ISC
2002	10	10	12	13	35.82	52.25	33	5.6	ISC
2004	5	28	12	38	36.25	51.57	27	6.3	ISC
2004	5	28	17	34	36.56	51.08	28	4.0	IIEES
2006	11	5	20	6	37.56	48.93	14	4.0	IIEES
2007	7	11	6	51	38.82	48.64	27	4.2	IIEES
2008	5	27	6	18	36.51	48.68	14	4.3	IIEES
2010	10	22	8	0	37.91	49.06	15	4.6	IIEES
2011	2	20	11	22	35.47	51.78	26	4.2	IIEES
2011	3	4	9	46	37.73	48.61	14	4.3	IIEES
2012	1	13	12	35	35.82	49	14	4.0	IIEES
2012	2	4	20	4	37.7	49.53	40	4.5	IIEES
2012	3	18	2	38	36.82	49.2	14	4.5	IIEES
2012	7	27	21	39	36.82	51.34	7	4.2	IIEES
2013	7	6	17	7	37.52	48.72	17	4.3	IIEES
2014	5	10	22	4	36.1	52.06	14	4.0	IIEES
2014	9	18	22	29	38.74	48.59	34	4.4	IIEES
2015	3	2	6	8	35.73	48.76	17	4.6	IIEES
2015	3	12	0	42	38.21	49.11	14	4.7	IIEES

Lahijan catalog of earthquake occurring in a 200 km distance									
Year	**Month**	**Day**	**Hour**	**Minute**	**Latitude**	**longitude**	**Depth**	**Magnitude**	**References***
2015	5	10	22	8	36.75	49.86	16	4.5	IIEES

* See table A1-5

** Unknown value = 0

Table A5. Abbreviation of Earthquake References

Abbreviation	Full name
AMB	Ambraseys and Melville, 1982
ULM	Catalog of earthquakes compiled by V.I. Ulomov ; Russian Academy of Sciences, Moscow
BER	Berberian, 1994
MOS	Moscow, USSR
KAR	Karnik, 1969
NOW	Nowroozi, 1976
MEA	Riad and Meyers, 1985
ISC	International Seismological Center
IIEES	International Institute of Earthquake Engineering and Seismology