The Satistics of Earthquakes in Iran

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SUMMARY:
The time-independent seismic hazard models are characterized by Poissonian distribution of the mainshocks. The result of the randomness of the main-sequence events depends on successful removing of the dependence events. The well-known window algorithm developed by Gardner and Knopoff in 1974 was applied to eliminate the aftershocks of Iranian earthquakes. In this paper we tried to localize and modify the spatial and temporal windows using the well documented events. In this respect, the local data was used to modify the spatial and temporal windows. Homogenized seismic catalogue of Iran for the time period of 1972 to 2008 was examined and 21 different sequences of mainshocks and aftershocks were selected. The magnitude of the mainshocks ranged between M*w* 5.4 to 7.1. The updated temporal and spatial windows were applied to the seismic catalogue in different seismotectonic zones of Iran. The result of Kolmogorov-Smirnov test showed that the declustered catalogues in different seismic zones of Iran follow the Poissonian distribution.

Keywords: window algorithm, aftershock, Poisson distribution, Kolmogorov-Smirnov test, Iran

1. INTRODUCTION

Following Poisson distribution is one of the assumptions of time-independent seismic hazard studies. Numbers of seismic hazard studies have done in Iran without further investigation in the result of statistical test on dependency. One of the processes to eliminate dependent event is the window algorithm developed by Gardner and Knopoff in 1974. In this paper we tried to localize and modify the spatial and temporal windows using the well documented events which happened in Iran. Regard to this purpose 21 sequences of mainshocks and aftershocks were chosen.

Temporal distribution of earthquakes is treated as a random process. Homogeneous Poisson processes have independent, identically distributed exponential inter-event times (Luen & Stark 2012). The statistical tests were done on both times between successive events and the number of event in the time intervals; nevertheless the result of statistical test on the number of events is presented in this paper. The statistical analysis of earthquake occurrences was conducted utilizing the new updated earthquake catalogue of Iran (Karimiparidari et al. n.d.). The earthquake catalogue in the time period of 1964 to April 2010, which includes more than 9,600 events, was used to check the independency of the mainshocks.

2. TECTONIC SETTINGS

Many authors have studied continental deformation in Alpine – Himalayan orogenic belt. This system begins in Western Europe, passing through Middle East to India and China. Iranian plateau is a part of Alpine – Himalayan orogenic belt which has a high level of seismic activity and a unique pattern of deformation. Iranian plateau is located between Arabian Plate in the south-east, and the Turan Shield in the orth-west, nd the pressure caused by the convergent movement between these plates has built

Iran mountain ranges. Based on geodetic data, the convergence rate is estimated to be about 21 mm/year at a longitude of 52 E (Vernant et. al. 2004).
By merging the seismotectonic maps developed by Mirzaei et al. 1998, Tavakoli, 1996 and Nogol Sadat, 1994 the country can be divided into seven major zones, each with distinct properties (Fig. 1); Alborz Mountain Range, Azerbaijan, Central Iran, Kopet Dag, Makran, North-West Zagros Mountain Range and South-East Zagros Mountain Range.

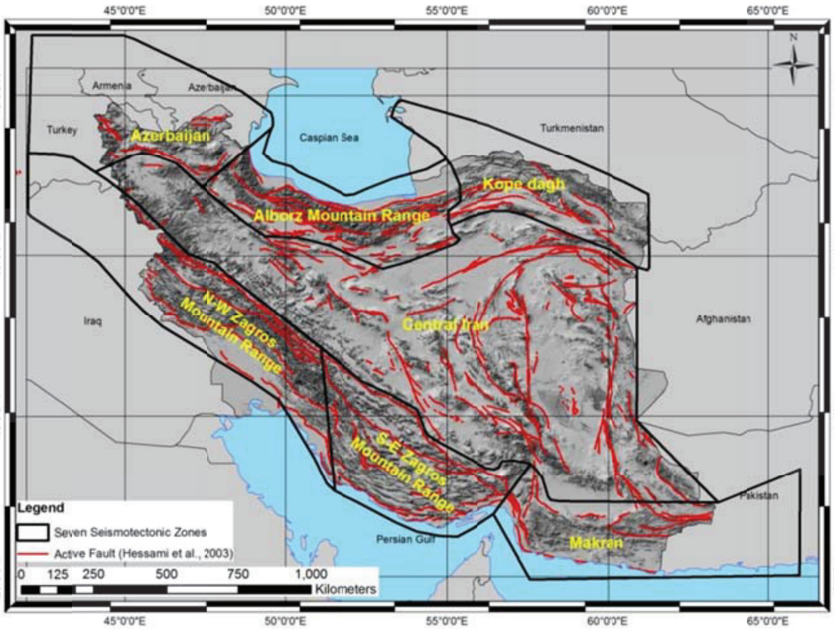

Figure 1. Simplified tectonic map of Iran showing seven seismotectonic zones of Iran (Alborz Mountain Range, Azerbaijan, Central Iran, Kopet Dag, Makran, North-West Zagros Mountain Range and South-East Zagros Mountain Range). This map is prepared by merging the Seismotectonic maps developed by Mirzaei et al. 1998, Tavakoli, 1996 and Nogol Sadat, 1994.

3. DATA

The area under study is extending between latitudes 25°–41° N and longitudes 42° W–63.5° E. The Earthquakes data, corresponding to this region with magnitude range Mw 3.5 – 7.4; occurred from beginning of 1964 till April 2010 were collected from different national and international databanks (Fig. 2). All magnitude types have been converted to moment magnitude using proper relations (Karimiparidari et al. n.d.).

Iran has a non-homogeneous distribution of seismic activity (Fig. 2). While large magnitude events are mostly occurred in Central Iran, Kopet Dag, Ajerbaijan and Alborz, the Zagros shows very frequent with lower magnitude seismicity.

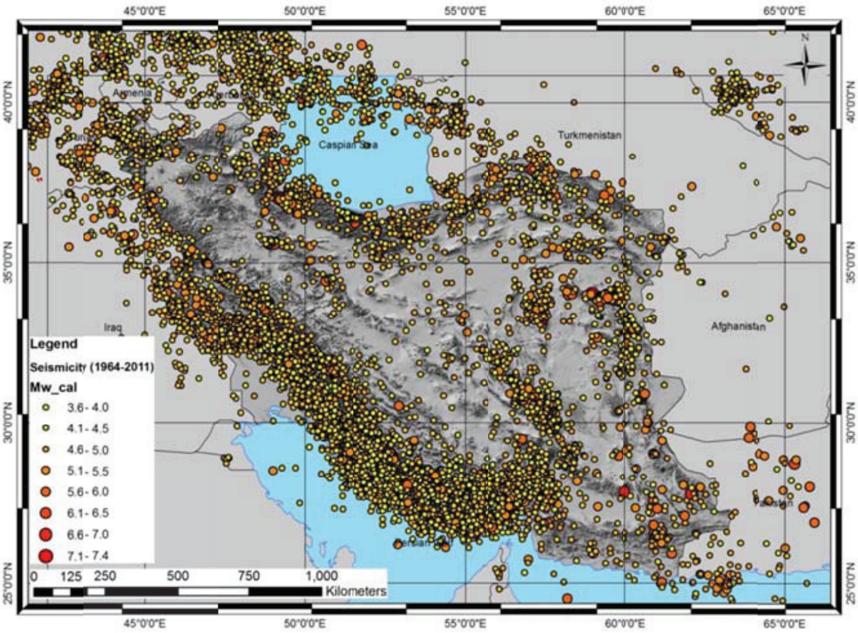

Figure [illegible]. Catalogued earthquakes for the period of 1964 to 2010 (Karimiparidari et al. n.d.) Symbol size and colour is proportional to earthquake; magnitude range Mw 3.5 – 7.4.

[illegible]. TEMPORAL AND SPATIAL WINDOWS

The result of the randomness of the main-sequence events depends on successful removing the dependence events (Gardner & Knopoff 1974). The well-known procedure by Gardner and Knopoff, 1974 was applied for the exclusion of aftershocks. The idea behind this technique is that a number of earthquakes occurring near a large event in both space and time. Gardner and Knopoff used the catalogue of earthquakes in Southern California described by Allen et al. 1965. In present study we try to localize both spatial and temporal windows.

The homogenized seismic catalogue of Iran was used to modify and redefine the spatial and temporal windows. In the first step 21 different mainshocks with the magnitude range Mw 5.4 -7.1, which have sequences of aftershocks were selected (Table 1).

Using table 1 a least upper bound in the exponential form was fit to both time and distance of the aftershocks. In order to develop a reliable relationship for the time window, we applied analysis for two magnitude ranges: (a) events with magnitude Mw< 6.5, and (b) earthquakes with magnitude 6.5≤ Mw. The established relationships for time window are:

$$T = 0.2496 \times e^{1.2803 \times m} \qquad \text{Mw}<6.5 \qquad (1)$$

$$T = 324.86 \times e^{0.1727 \times m} \qquad 6.5\leq\text{Mw} \qquad (2)$$

Where T is the time in days and m is the moment magnitude, Mw. For the spatial window the relationship found to be:

$$R = 10 \times e^{0.286 \times m} \qquad (3)$$

Where R is the distance in Km.

Table 1. Selected sequences of earthquakes by the temporal and spatial distances of aftershocks to the mainshock.

Date			Location		Mw	Days after mainshock that aftershocks occurred	Distance from mainshock that aftershocks occurred (Km)
Year	Month	Day	Lat.	Long.			
1981	7	28	29.97	57.77	7.1	852	56
1977	3	21	27.58	56.36	7.0	1072	46
1972	4	10	28.41	52.79	6.8	1052	67
1998	3	14	30.14	57.59	6.6	711	54
2003	12	26	28.90	58.28	6.5	927	58
1990	4	21	28.15	55.61	6.4	835	53
1999	3	4	28.27	57.21	6.4	609	58
1999	5	6	29.52	51.91	6.3	763	58
2005	2	22	30.72	56.78	6.3	595	31
2008	9	10	26.94	55.72	6.1	490	-
1993	3	1	29.14	52.64	6.0	410	34
2006	2	28	28.13	56.79	6.0	293	35
1983	7	12	27.60	56.40	5.9	285	30
2005	11	27	26.79	55.81	5.8	191	36
2006	3	25	27.50	55.62	5.8	120	51
1998	8	11	29.88	51.66	5.8	175	36
2003	7	10	28.33	54.16	5.6	288	37
1988	3	30	30.85	50.18	5.6	127	35
2002	9	25	32.06	49.32	5.5	157	39
1990	12	16	29.02	51.31	5.5	120	37
1998	11	13	27.80	53.64	5.4	172	37

The result of present study is compared with Gardner and Knopoff, 1974 in table 2 numerically and in Figures 3 and 4 graphically. The newly results show continues increasing change for the distance of aftershocks versus magnitude of the mainshocks. Using earthquakes sequences of Iran gives higher spatial window for all magnitude ranges compared to Gardner and Knopoff, 1974 (Fig. 3). The temporal window expresses two different trends (Fig. 4); the first part for the events with magnitude Mw$<$ 6.5 which has the same result of Gardner and Knopoff, 1974 and the second part, events with magnitude 6.5$\leq$ Mw, with higher time span of the aftershocks. The slope of the curve for the events with magnitude Mw$<$ 6.5 is much higher than the events with magnitude 6.5$\leq$ Mw (Fig. 4).

To have better comparison between the result of present study and Gardner and Knopoff, 1974, the residuals are shown in figures 5 and 6. The spatial residual verses magnitude of the mainshocks has a stable increasing trend while the temporal residual verses magnitude of the mainshocks has two different trends; for the events with magnitude less than Mw 6.5 both studies reached the same result, whereas present study indicates incremental tendency for events with magnitude above Mw 6.5 (Fig. 6).

T□□e □. Comparison of the spatial and temporal windows from present study and Gardner and Knopoff, 1974.

Magnitude (M*w*)	Time (Days)		Distance (Km)	
	This Study	Gardner and Knopoff, 1974	This Study	Gardner and Knopoff, 1974
4	42	42	31	30
4.5	79	79	36	35
5	150	150	42	40
5.5	285	285	48	46
6	541	541	56	53
6.5	998	818	64	61
7	1088	881	74	71
7.5	1186	944	85	81
8	1293	1007	99	94

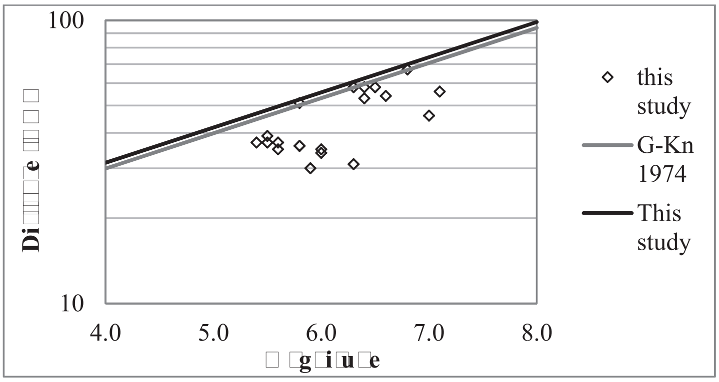

Figure 3. Spatial cure drive from present study compares with the result of Gardner and Knopoff, 1974. The diamond symbol is the data from 21 sequences of Iran earthquakes. The black thin line is the exponential least upper bound fitted to the present data. The thick gray (red) line is the spatial curve from Gardner and Knopoff, 1974.

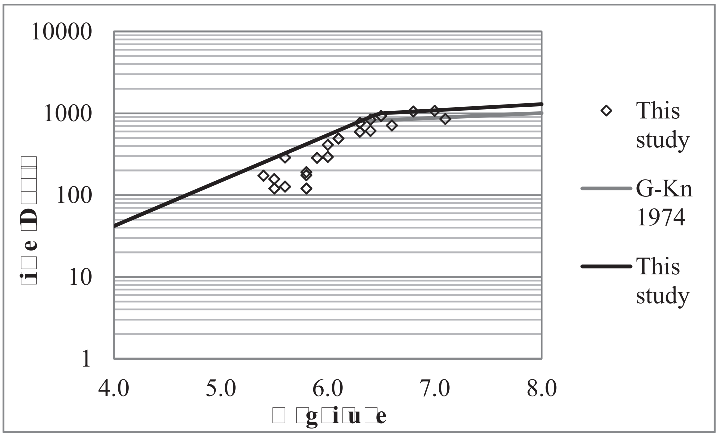

Figure □. Temporal cure drive from present study for two magnitude ranges: Mw< 6.5 and 6.5≤ Mw compares with Gardner and Knopoff, 1974. The diamond symbol is the data from 21 sequences of Iran earthquakes. The black thin line is the exponential least upper bound fitted to the present data. The thick gray (red) line is the temporal curve from Gardner and Knopoff, 1974.

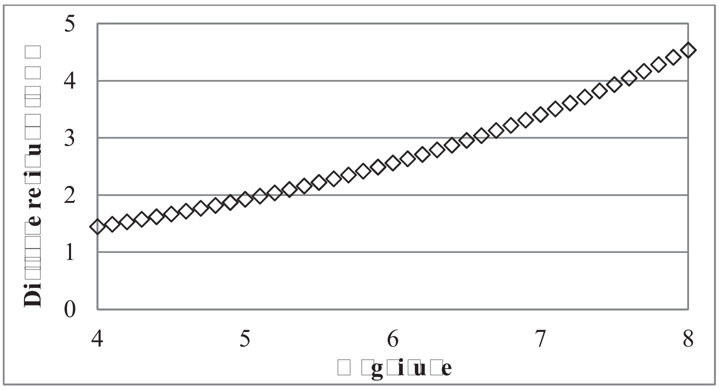

Figure □. Residuals of the distance of aftershocks versus magnitude of the mainshocks achieved by present study and the spatial window from Gardner and Knopoff, 1974.

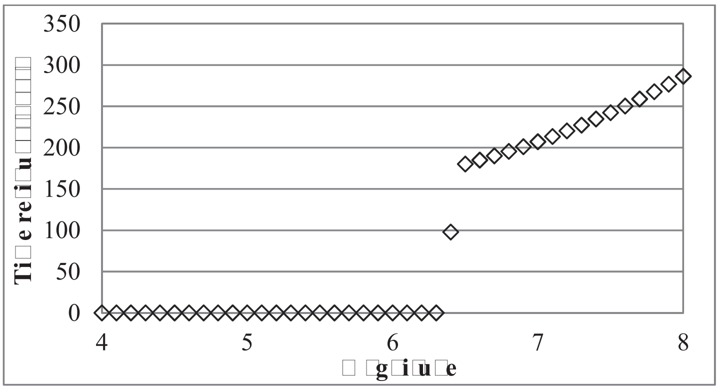

Figure □. Residuals of the time of aftershocks versus magnitude of the mainshocks achieved by present study and the temporal window from Gardner and Knopoff, 1974.

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Kolmogorov-Smirnov test (KS-test) tries to determine if two datasets differ significantly. The benefit of using this test compares to Chi-square goodness-of-fit in this type of studies is that; The KS-test use the original data and does not need to classify the data for low frequency observations. The KS-test statistic is:

$$\max (|F(X) - G(X)|) \tag{4}$$

Where F(x) is the empirical cumulative distribution function and G(x) is the fixed reference cumulative distribution function.

To test the independency of the mainshocks we used the seismicity catalogue contains events from early 1964 to April 2010 with magnitude range Mw 3.5 – 7.4. The seismicity catalogues of each seven seismotectonic zones of Iran, which were mentioned before, were detected and by using the updated spatial and temporal windows, dependent events were removed. The KS-test was used to check if the mainshocks follow the Poissonian distribution. The results of removing aftershocks, testing magnitude of completeness and the One-Sample KS Test on catalogue of mainshocks present in table 3. The result shows the updated window caused removing 36%, 29%, 45%, 26%, 19%, 36% and 50% of Alborz Mountain Range, Azerbaijan, Central Iran, Kopet Dag, Makran, North-West Zagros Mountain Range and South-East Zagros Mountain Range seismicity events respectively. The result of One-

Sample KS test on mainshocks specified that all declustered catalogues in all seismotectonic zones follow the Poissonian distribution.

Table 3. The result of removing aftershocks, testing magnitude of completeness and One-Sample Kolmogorov-Smirnov Test for seven seismotectonic zones of Iran.

Zone Name	Total No. of events	No. of mainshocks	Mag. Threshold (M*w*)	Mean	Most Extreme Differences	KS Z	P-Value
Alborz Mountain Range	507	325	4.2	0.12	0.003	0.12	1.00
Azerbaijan	738	526	4.2	0.15	0.004	0.15	1.00
Central Iran	1266	698	3.9	0.32	0.030	1.23	0.10
Kopet Dag	351	260	4.1	0.11	0.005	0.22	1.00
Makran	306	249	4.2	0.10	0.005	0.19	1.00
NW Zagros Mountain Range	1853	1192	4.5	0.32	0.017	0.69	0.74
SE Zagros Mountain Range	2559	1280	4.4	0.35	0.015	0.61	0.86

CONCLUSIONS

Localizing the spatial and temporal windows of well-known Gardner and Knopoff, 1974 window algorithm was the object of present paper. To achieve these purpose 21 well documented sequences of Iran earthquakes were used; most of them from Zagros mountain Range. The magnitudes of the mainshocks are in the range Mw 5.4-7.1.

Comparing the results of the newly localized and updated windows with the Gardner and Knopoff, 1974 show higher distance of aftershocks for all magnitude ranges. The residuals display a steady increasing trend. The temporal window expresses two different trends; events with magnitude less than, Mw 6.5, which is similar to the result of Gardner and Knopoff, 1974 and the event with magnitude equal and more than Mw 6.5, with higher time span of the aftershocks.

By merging three different seismotectonic maps, Iran divided into seven main zones (Alborz Mountain Range, Azerbaijan, Central Iran, Kopet Dag, Makran, North-West Zagros Mountain Range and South-East Zagros Mountain Range). The earthquake catalogues of each seven seismotectonic zones which contain events from1964 to April 2010 were identified. Following removal of aftershocks, using the newly updated spatial and temporal windows, the catalogue of mainshocks prepared. The result of KS test determined that the declustered seismicity catalogues of all seven seismotectonic zones follow the Poissonian distribution.

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