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Original paper

Clustering analysis of 100-year international seismic catalogue for Azerbaijan

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Abstract: Relevance. Azerbaijan is tectonically situated in the Arabian-Eurasian continent collision zone. Due to this collision activity the seismic pattern of the region is observed with the occurrence of frequent moderate and occasionally strong earthquakes. **Research methods.** In this study, we used a catalog of International Seismological Centre through the Azerbaijan region including the neighbor parts and aquatory (Caspian Sea). Catalog has been clustered according to the 6 tectonic mega-zones of Azerbaijan. **Aim.** The purpose of this paper is to expose the seismicity level of Azerbaijan employing the international catalog of earthquakes from 1926 to 2022. **Results.** We estimated the seismicity indicators for each cluster. a - and b -values of Gutenberg-Richter law have been evaluated for each cluster. We examined the precision of them computing the maximum magnitude uncertainty and the results seem to be precise enough where the maximum magnitude uncertainty values are close to 0. We defined magnitude of completeness around or above 4 for the clusters and the bin was defined 0.1 for each. The highest a - and b -values are observed in cluster I (Gusar-Shabran and aquatory) and cluster VI (Talysh mountains and aquatory). a -, b - values for cluster I are 6.97 and 1.16 respectively and for cluster VI are 11.89 and 2.17 respectively. The number of earthquakes with magnitude greater and equal to magnitude of completeness for cluster I and VI is 213 and 30 respectively. For clusters I, II, III, IV, and V, the number of earthquakes ($M \geq M_c$) are 399, 115, 318, 503 respectively. **Conclusions.** The seismic activity for each tectonic segment has been demonstrated in terms of the number of earthquakes with magnitude greater than 3.8, at least.

Keywords: Azerbaijan, seismicity indicators, a -value, b -value, maximum magnitude uncertainty, magnitude of completeness.

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Оригинальная статья

Кластерный анализ международного сейсмического каталога по Азербайджану за 100-летний период

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Резюме: Актуальность работы. Территория Азербайджана тектонически расположена в зоне столкновения Аравийской и Евразийской плит. В связи с этой коллизионной активностью сейсмическая картина региона характеризуется возникновением частых умеренных и порою сильных землетрясений. **Методы исследования.** В данном исследовании был использован каталог Международного Сейсмологического Центра (ISC) по Азербайджану, включая соседние территории и прилегающую акваторию Каспийского моря. Проведен кластерный анализ каталога в соответствии с существующими шестью тектоническими мегазонами Азербайджана. Целью исследования является оценка уровня сейсмичности территории Азербайджана по данным международного каталога землетрясений с 1926 по 2022 годы. **Результаты.** Оценены показатели сейсмичности, такие как параметры a и b в законе Гутенберга-Рихтера для каждого кластера. Проверена достоверность значений, оценивая степень неопределенности максимальной магнитуды. Была определена величина представительной магнитуды $M_s \geq 4$ для кластеров с интервалом в 0,1 для каждого кластера. Самые высокие значения параметров a и b наблюдаются в кластере I (Гусар-Шабран и прилегающая акватория) и в кластере VI (Талышские горы и прилегающая акватория). Значения параметра a и b для кластера I составляют 6,97 и 1,16 соответственно, а для кластера VI – 11,89 и 2,17, соответственно. Количество землетрясений с магнитудой, большей и равной величине представительной магнитуды для кластеров I и VI составляет 213 и 30, соответственно. Для кластеров I, II, III, IV и V количество землетрясений ($M \geq M_s$) составляет 399, 115, 318, 503, соответственно. **Выводы.** Таким образом, с учетом количества землетрясений оценочная сейсмическая активность для каждого тектонического сегмента характеризуется магнитудой $M > 3,8$.

Ключевые слова: Азербайджан, показатели сейсмичности, параметр a , параметр b , неопределенность максимальной магнитуды, представительная магнитуда.

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Introduction

Azerbaijan's seismicity is primarily driven by its location within the tectonically active region, where the Eurasian and Arabian plates are in continuous continent-continent collision, resulting in significant crustal deformation [Kangarli et al., 2022]. This interaction generates a complex seismic pattern characterized by frequent moderate and occasional strong earthquakes. The tectonic compression and faulting associated with

this convergence give rise to a series of active fault systems, most notably the Greater Caucasus thrust and the Lesser Caucasus fault zones, both of which are major contributors to the seismic hazard in the region [Zonenshain, Savostin, 1979].

Continuous seismic monitoring plays a crucial role in understanding the seismic behavior of Azerbaijan. The region experiences frequent tectonic activity due to the interaction of Africa–Arabia–Eurasia Plate System of which the activity is monitored by geodetic observations [Kadirov et al., 2024]. The seismicity in Azerbaijan related to these structural movements is characterized to be high [Kangarli et al., 2022; Khain, 2001; Azizbekov, 1968].

The aim of this study is the utilization of international catalogue in estimation of the seismic level of Azerbaijan in terms of seismicity indicators. The 1926 to 2022 international catalog was analyzed in terms of a - and b -values and the validity of a - and b -values estimations was checked with maximum magnitude uncertainty which all together are called as seismicity indicators [Omni, Hashemi, 2024].

Study Area. Azerbaijan

Geotectonics

Azerbaijan is laid on 6 tectonic structures: Samur (Gusar) – Devechi (Shabran), Eastern Greater Caucasus, Kur depression, Outer Lesser Caucasus, Inner Lesser Caucasus, Talysh Mountains [Alizadeh et al., 2016]. Samur-Devechi and Eastern Greater Caucasus megazones are part of the Greater Caucasus Fold-Mountain System. Eastern Greater Caucasus megazone consists of southern and southeastern slopes. Zagatala, Sheki, Lahich regions are included to the southern slope while the Bazarduzu, Shakhnabad-Khizi, Shakhdagh, Tengi-Beshbarmag, Shamakhi, Gobustan, Absheron regions are part of the southeastern slope. Kur depression is divided into Ganykh-Airichay valley, Jeiranchel-Ajinour submountain region, Kur-Araz depression, Pre-Lesser Caucasus sloping plain. Outer Lesser Caucasus and Inner Lesser Caucasus are the megazones of the Lesser Caucasus. The Outer Lesser Caucasus is divided into northeastern slope, eastern slope, southwestern slope while the Inner Lesser Caucasus megazone consists of Garabagh volcanic upland, Near-Araz ridges, Nakhchivan (Middle Araz) depression (fig. 1) [Alizadeh et al., 2016].



Fig. 1. Geomorphology map of Azerbaijan [Alizadeh et al., 2016].

Note: The legend of the map is given in table 1

Table 1

The legend of the Figure 1

Province	Region	Subregion	District
1	2	3	4
<i>The Crimean-Caucasian Mountain Land</i>			
Piedmont depressions and uplands	I Samur-Devechi (Shabran)		1. Samur-Devechi lowland 2. Gusar sloping plain
The Greater Caucasus	II Eastern Greater Caucasus	II ₁ Southern slope	3. Zagatala 4. Sheki 5. Lagich
		II ₂ Southeastern slope	6. Bazardyuzyu 7. Shakhnabad-Khizi 8. Shakhdagh 9. Tengi-Beshbarmag 10. Dyubrar 11. Shamakhly 12. Gobustan 13. Absheron
South Caucasian depression	III Kur depression	III ₁ Ganykh-Airichay valley	14. Ganykh 15. Ismailly
		III ₂ Jeiranchel-Ajinour submountain region	16. Jeiranchel 17. Ajinour 18. Lengebiz-Alyat 19. Kharamy
		III ₃ Kur-Araz depression	20. Shirvan plain 21. Southeastern Shirvan 22. Near-Kur plain 23. Mughan plain 24. Salyan plain
		III ₄ Pre-Lesser Caucasus sloping plain	25. Ganja-Gazakh plain 26. Garabagh plain 27. Mil plain
<i>Western Asian Highlands</i>			
The Lesser Caucasus	IV Outer western ridges	IV ₁ Northeastern slope	28. Agstafa 29. Shamkir 30. Dashkesan-Agjakend 31. Shakhdagh 32. Murovdagh
		IV ₂ Eastern slope	33. Lower Araz
		IV ₃ Southwestern slope	34. Kelbajar 35. Mykhteken 36. Kharmin
	V Inner Lesser Caucasus	V ₁ Garabagh volcanic upland	37. Gyzylbogaz-Ishygly 38. Alagel-Chalbayir 39. East Goycha 40. Yazyn
		V ₂ Near-Araz ridges	41. Daralagez 42. Zangazur 43. Bargushad
		V ₃ Nakhchivan (Middle Araz) depression	44. Sharur 45. Negram 46. Ordubad
	VI Talysh Mts.		47. Lenkaran lowland 48. Burovar ridge 49. Yardymly 50. Peshtasar ridge 51. Zuvand 52. Talysh

The Samur-Devechi and Kur structures are mostly covered with Quaternary rocks. The significant part of Inner Lesser Caucasus and Talysh mountains contain Paleogene volcanic-sedimentary rocks. Inner Lesser Caucasus also contains Devonian, Cretaceous, Neogene, Quaternary rocks, while Outer Lesser Caucasus contains mostly Jurassic and Cretaceous rocks. The Eastern Greater Caucasus range features a diverse geological composition, including Jurassic, Cretaceous, Paleogene, and Neogene rocks, along with slight Quaternary formations [Alizadeh et al., 2016].

Geodynamics

GPS measurements are necessary for studying crustal deformations. The deformation rates in Greater Caucasus Mountains range between 2 and 14 mm/year in the direction of NW to SE. The GPS observations show that the Earth's crust along the Kur depression moves towards the NNE. The GPS measurements state active convergence between the Lesser Caucasus, Kur Depression and the Greater Caucasus [Kadirov et al., 2024]. The Arabian Plate together with the Iranian block pushes the Lesser Caucasus towards the Kur depression which makes the Kur depression move under the Greater Caucasus at a rate of 8 mm/year that results with a thrust fault or a subduction zone [Aktug et al., 2009, 2013; Yetirmishli, Kazimov, 2022].

Seismicity

In the history of Azerbaijan, a large number of strong and destructive earthquakes have occurred in the past. The seismicity study in Azerbaijan involves two periods: pre-instrumental – historic and instrumental periods [Babayev, Agayeva, 2021]. In the historic period, the destructive and strong earthquakes were noted in ancient Arabic chronicles, manuscripts and travel books [Ashurbeyli, Bakuvi, 1958]. As the significant strong historical earthquakes in Azerbaijan following events could be noted: the earthquake of 427, the Ganja (Goygol) 1139, the Ganja 1235, the East Caucasus 1667, the Mashtaga 1842, several Shamakhi earthquakes (1192, 1667, 1668, 1669, 1828, 1859, 1868, 1872, 1902), the Ardabil 1924, the Lankaran 1913, the Caspian earthquakes (957, 1812, 1842, 1852, 1911, 1935, 1961, 1963, 1986, 1989, 2000). These earthquakes are well known for their severity that resulted with the Earth's surface relief deformations, buildings destructions, human losses [Babayev, Agayeva, 2021].

Shamakhi region is one of the seismically active regions of Azerbaijan [Babayev et al., 2020; Telesca et al., 2017]. Shamakhi region experienced a powerful earthquake with a magnitude of 6.9 on February 13, 1902 that is known as the Shamakhi earthquake which is considered the beginning of instrumental seismic studies in Azerbaijan [Babayev, Agayeva, 2021]. This event reached an intensity of IX in Shamakhi and Ismayilli cities [Weber, 1903]. The first earthquake in Azerbaijan of which the epicenter was determined by instrumental data is the Caspian earthquake of June 7, 1911 [Babayev, Agayeva, 2021].

One of the strongest earthquakes in recent history is the November 25, 2000 Baku-Caspian earthquake. The earthquake which was felt in Baku, occurred in two shocks of $M = 6.5$ and 6.3 with three minutes pause and the depth of the earthquake was $h = 35$ km [Babayev, Agayeva, 2021].

In 2023 and 2024 both the region of Azerbaijan and its neighbors sustain their activity. In fig. 2 we present the map of epicentral distribution of some selected earthquakes which occurred in 2023 and 2024 in Azerbaijan and close regions with local magnitude $M_l \geq 4.1$.

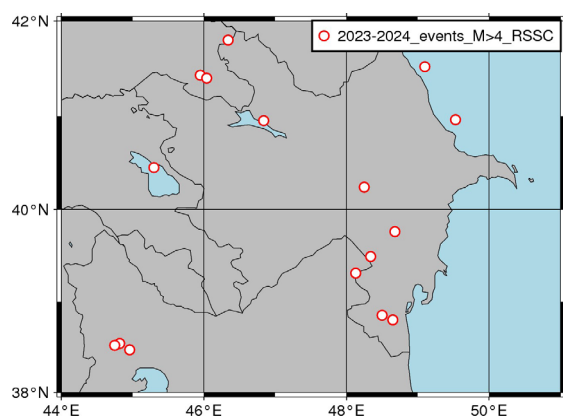


Fig. 2. Epicentral distribution of earthquakes occurred in 2023-24 years in Azerbaijan and neighbor regions (locations of the epicenters have been obtained from Republican Center of Seismological Service, RCSS)

Figs 3 and 4 represent the ground motion levels of those earthquakes occurred in 2023 and 2024 respectively, according to their acceleration data taken from IRIS and processed using ObsPy library of Python [Beyreuther et al., 2010].

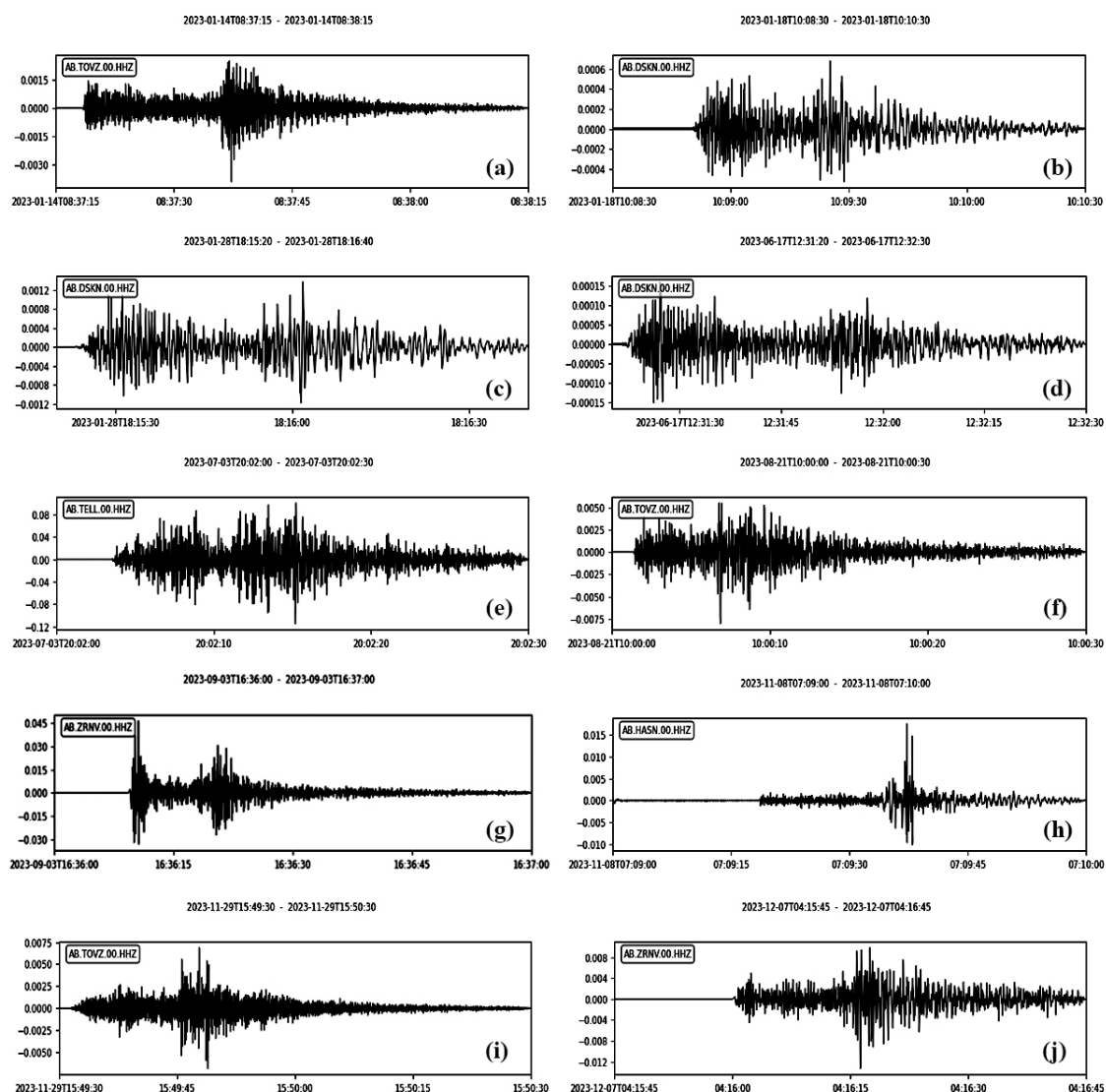


Fig. 3. Acceleration records of the earthquakes occurred in Azerbaijan and neighbor regions in 2023 (IRIS, n.d.; dates and magnitudes of the given earthquakes have been obtained from RCSS); (a) 14.01.2023 M_L 4.4 in Georgia-Azerbaijan border, (b) 18.01.2023 M_L 6.0 in Khoy city of Iran, (c) 28.01.2023 M_L 6.1 in Khoy city of Iran, (d) 17.06.2023 M_L 5.1 in Khoy city of Iran, (e) 03.07.2023 M_L 5.6 in Caspian Sea (Khachmaz), (f) 21.08.2023 M_L 4.1 in Armenia, (g) 03.09.2023 M_L 5.2 in Kurdamir, (h) 08.11.2023 M_L 4.7 in Azerbaijan-Iran border, (i) 29.11.2023 M_L 4.5 in Mingachevir, (j) 07.12.2023 M_L 5.6 in Caspian Sea (Altiaghac).

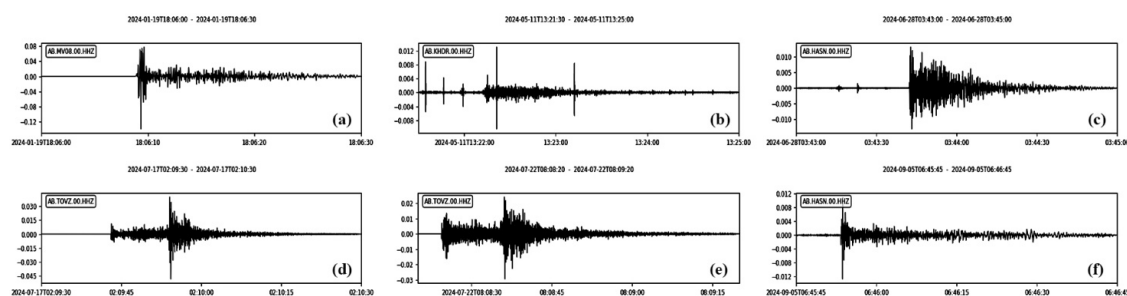


Fig. 4. Acceleration records of the earthquakes occurred in Azerbaijan and neighbour regions in 2024 (IRIS, n.d.; dates and magnitudes of the given earthquakes have been obtained from RCSS); (a) 19.01.2024 MI 5.1 in Saatli-Sabirabad regions' border, (b) 11.05.2024 MI 5.3 and MI 4.4 in Lenkeran, (c) 28.06.2024 MI 5.0 in Lerik, (d) 17.07.2024 MI 4.8 in Georgia (close to the border with Azerbaijan Balaken region), (e) 22.07.2024 MI 4.9 in Georgia (close to the border with Azerbaijan Balaken region), (f) 05.09.2024 MI 4.5 in Bilesuvar

The selected earthquakes shown in figs 2, 3, 4 have the local magnitude $M_l \geq 4.1$. In 2023, we observe relatively active behavior in Iran (Khoys city), in the shores of the Gusar-Shabran megazone with relatively high magnitudes ($M_l \geq 5.1$). In 2024, we observe activity in Lower Kur depression and Talish mountains. It is important to note that in 11.05.2024 two shocks of earthquake occurred in Lankaran with M_l 5.3 and M_l 4.4 with ~ 1.5 minutes pause (fig. 4b). Also, In July we observe two shocks of M_l 4.8 and M_l 4.9 in the territory of Georgia very close to Balaken region of Azerbaijan almost in the same place (figs 2, 4d, 4e). This region is tectonically included to Middle Kur depression (fig. 1).

Methods and Materials

Catalog

Seismicity analysis can be conducted using various catalog-based methods, such as statistical estimation of the a- and b-parameters of the Gutenberg-Richter law [Gutenberg, Richter, 1956], analysis of temporal and spatial b-value variations, and estimation of maximum magnitude uncertainty. These methods are collectively referred to as seismicity indicators, which are used to characterize the seismicity level [Omami, Hashemi, 2024].

For this study, the selection of a catalog has been done from International Seismological Centre. The catalog has been downloaded from the website of the ISC Bulletin with 22,239 events [Storchak et al., 2020]. The catalog has been passed through some filtration steps in order to get ready for the research. The events with unknown magnitude types and depths have been removed. The events with magnitude type "M" and "Mn" have been removed, since we regarded them as unknown types. Events with depth of 0 km have been removed since we supposed that these were the events for which the depth could not be estimated. The events $M \geq 3$ and h (depth) ≥ 5 km are used for this study. The catalog contains the earthquakes from 1926 to 2022, since the data on or after 2022/09/01 have not been reviewed by the ISC. The earthquakes located in latitudinal range $Lat < 36^\circ$ and $Lat > 43.5^\circ$ have been removed in order to sustain the research in Azerbaijan and very close regions. Finally, we converted all the magnitude types to a uniform format using related equations. At the end, we remained with the 3,916 events with moment magnitudes (fig. 5). The relations for the conversion of different magnitude types to a moment magnitude is taken from [Zare et al., 2014]. The relations are shown in equation (1):

$$\begin{aligned}
 M_b, M_w : \quad M_w &= 0.87M_b + 0.83 \\
 M_s, M_w : \quad M_w &= 0.66M_s + 2.11, \quad \text{if } 2.8 \leq M_s \leq 6.1 \\
 \& \quad M_w &= 0.93M_s + 0.45, \quad \text{if } 6.2 \leq M_s \leq 8.2 \\
 M_l/M_d, M_w : \quad M_w &= 1.01M_l/M_d - 0.05
 \end{aligned}
 \tag{1}$$

* *Local (M_l) and duration (M_d) types are converted with the same equation [Sawires et al., 2023].*

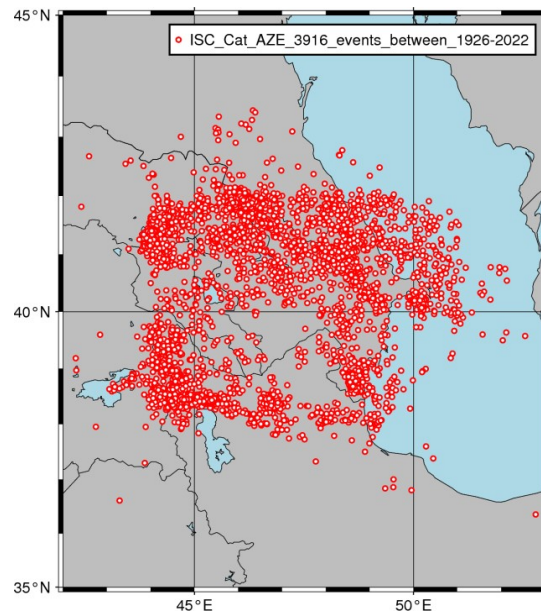


Fig. 5. Epicentral distribution of the 3916 events from the catalog between 1926-2022

The next step for the research is to divide the catalog into the clusters. We clustered the events into 6 segments according to their location in the tectonic megazones of Azerbaijan (table 2, fig. 6). The catalog has been clustered in a manual way using ArcGIS 10.7 (ESRI, 2017) software. Using the georeferencing method fig. 1 was located into the coordinates and the epicenters clustered according the tectonic megazones of Azerbaijan proposed by Alizadeh et al. [2016]. During the clustering 3 events have been lost and the whole catalog has been left with 3913 events.

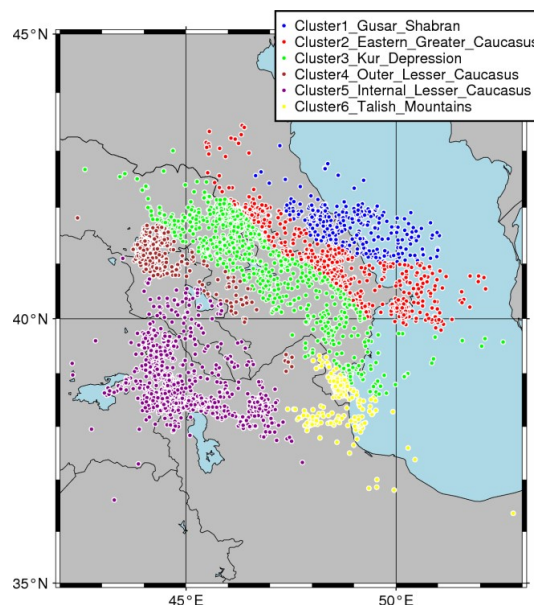


Fig. 6. Six clusters from earthquake catalogue according to the tectonic megazones of Azerbaijan

Table 2

Clusters appropriated to the tectonic megazones

Cluster	I	II	III	IV	V	VI
Tectonic MZ	G-S and aquatory	Eastern GC and aquatory	Kur Depression and aquatory	Outer LC	Internal LC	Talish Mts and aquatory

* **MZ** – Megazone, **G-S** – Gusar-Shabran, **GC** – Greater Caucasus, **LC** – Lesser Caucasus, **Mts** – Mountains

Upon catalog completion, the following seismicity indicators were assessed for each cluster: the a - and b -parameters of the Gutenberg-Richter (G-R) law, the completeness magnitude (M_c), the maximum magnitude up to which the G-R law applies ($M_{\max}$), the number of earthquakes with $M \geq M_c$ (N), and the maximum magnitude uncertainty (ΔM).

G-R law is a linear relation (2) presenting frequency-magnitude distribution [Gutenberg, Richter, 1956]:

$$\log N = a - bM \quad \text{or} \quad N = 10^{a-bM} \quad (2)$$

where N – is the number of earthquakes greater than and equal to magnitude M , a - and b - are real constants.

a - and b -values are important parameters characterizing the seismic features. a -value characterizes the seismic activity, while b -value shows the relation of large to small quakes [Gutenberg, Richter, 1956].

b -value is the slope of the linear G-R relation and a -value is the intersection of this linearity with logarithm of cumulative distribution of earthquakes [Popandopoulos, 2018].

The b -value can be estimated by plotting the linear regression of the cumulative frequency-magnitude distribution for a catalog. In fig. 8, the cumulative number of earthquakes with magnitudes $M \geq M_c$ (where N is the cumulative number of events, and M_c is the magnitude of completeness) is plotted against magnitude for each cluster. We defined M_c as the magnitude of completeness, $M_{\max}$ as the maximum magnitude up to which the linear fit applies, and the magnitude bin as the interval used for grouping magnitudes in the cumulative distribution plot [Godano et al., 2014; Papadopoulos, 2018]. For this study, we set the bin size to 0.1.

As a result of linear fitting, a -value is deduced from the G-R relation as follows (3):

$$a = \log N + bM_c, \quad M \geq M_c \quad (3)$$

Using a - and b -values, we can find out the number of earthquakes in the catalog with magnitudes $M \geq M_c$.

ΔM – Maximum magnitude uncertainty, is proposed by Ommi, Hashemi [2024] as one of the seismic indicators. In this study we estimated ΔM for each cluster using the equation below (4):

$$\Delta M = M_{\max}^{\text{obs}} - M_{\max}^{\text{exp}} \quad (4)$$

where $M_{\max}^{\text{obs}}$ is maximum observed magnitude in the catalog and $M_{\max}^{\text{exp}}$ is the expected maximum magnitude which is estimated as follows: $\frac{a}{b}$.

Results and Discussion

Fig. 7 illustrates the G-R law representation of each cluster for defined M_c , M_{max} and bin.

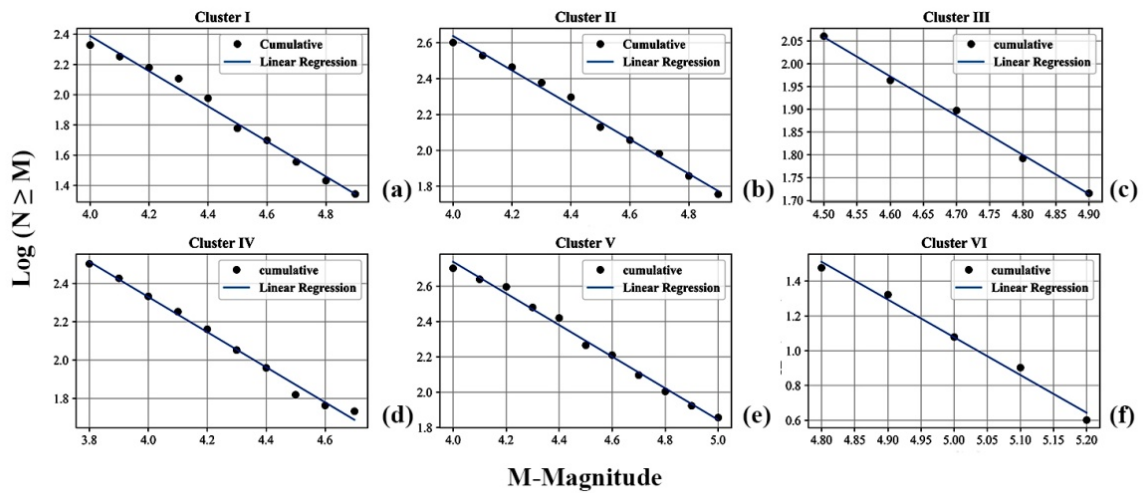


Fig. 7. Linear G-R relation and the logarithm of the cumulative number of earthquakes with magnitudes $M \geq M_c$. Clusters (a) I, (b) II, (c) III, (d) IV, (e) V, (f) VI

The estimated seismicity indicators; M_c , M_{max} , a - and b -values and $N (M \geq M_c)$ for each cluster have been shown in table 3 and the trends of them have been illustrated in figs 8 and 9.

Table 3

Seismicity indicator estimations for each cluster

Cluster	M_c	M_{max}	a -value	b -value	$N (M \geq M_c)$
I	4	5	6.97	1.16	213
II	4	5	6.44	0.96	399
III	4.5	5	5.93	0.86	115
IV	3.8	4.7	5.99	0.92	318
V	4	5.1	6.28	0.89	503
VI	4.8	5.2	11.89	2.17	30

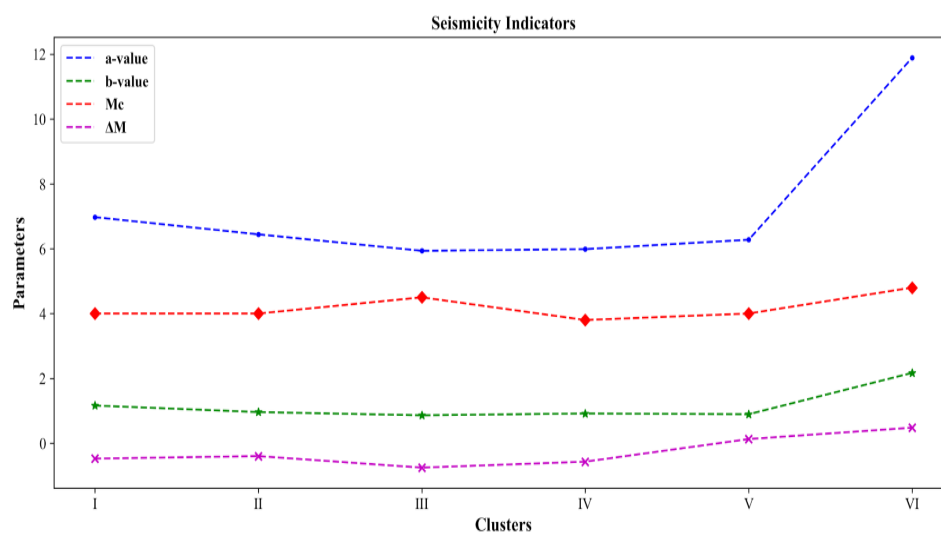


Fig. 8. Seismicity Indicators

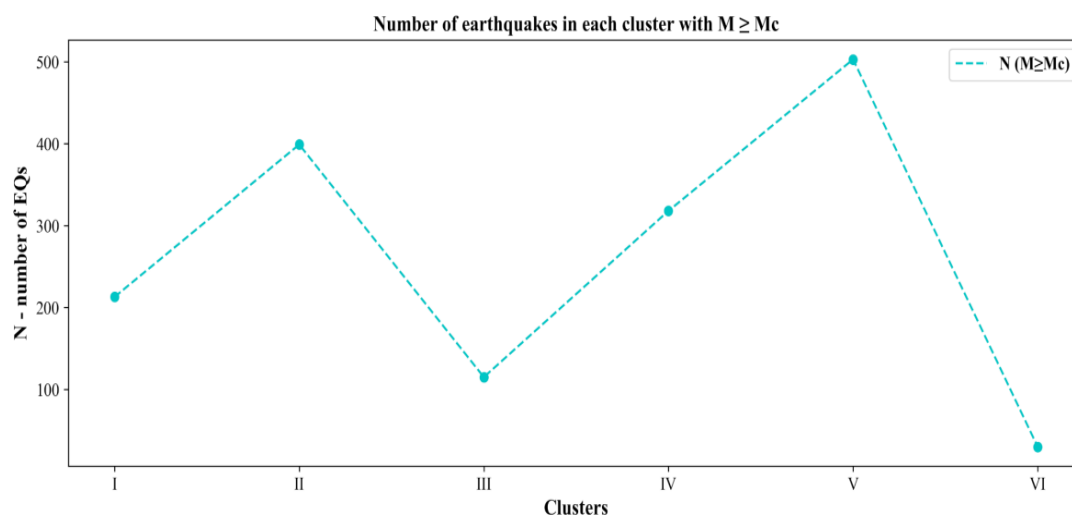


Fig. 9. Number of earthquakes in each cluster with $M \geq M_c$

We observe relatively high b -values in clusters I and VI (1.16 and 2.17 respectively), while the other clusters have $b < 1$. b -value is an indicator of the dynamics of the tectonic regime in the study area and decrease of b -value is implied as higher stress in the region [Popandopoulos, 2018]. To clearly observe this relation, Babayev T. et al. [2023] study can be viewed which shows the temporal variation of b -value for the Kahramanmaraş region after the disastrous 6th February, 2023 earthquake till May 2023. From the study, it is obviously seen that b -value increased, while the number of earthquakes decreased during February – May, 2023 period which can be interpreted as the stress level decreased after the disastrous earthquake during several months [Babayev et al., 2023]. Low b -value signs for the compression zone, whereas the higher b -value signs for the extension zone [Popandopoulos, 2018]. Therefore, temporal variation of b -value can be useful in earthquake predictions. Based on Popandopoulos (2018), in 75% cases in several regions over the world, temporal anomalies in the value of b were observed before strong earthquakes with magnitudes higher than 5. Moreover, it is stated that time variations of b -value have reverse proportionality with V_p and V_p/V_s (V_p – P-wave velocity, V_s – S-wave velocity) which means that V_p and V_p/V_s increase in lower b -value [Popandopoulos, 2018].

Generally, for the whole Earth, b -value is supposed to be around 1 [El-Isa, Eaton, 2014]. Meanwhile, it can vary above and under 1. b -values of clusters II and IV are the closest to 1, 0.96 and 0.92 respectively. Moreover, the clusters have close b -values, except cluster VI, 2.17. During the estimation of b -value for the cluster VI, we firstly defined M_c as 3.5 and M_{max} as 4.4. According to the maximum magnitude uncertainty, we explored that b -value estimated with M_c as 3.5 and M_{max} as 4.4 is wrong which was 0.34 (a -value: 3.29). We decided to set M_c as 4.8 and M_{max} as 5.2 and got b -value 2.17 (a -value: 11.89). We will mention about this issue when we discuss the maximum magnitude uncertainty.

Meanwhile, we observe close values of a -value among the clusters. Exceptionally, Cluster VI has the highest value which is 11.89. a -value helps to rate the seismicity [Anbazhagan et al., 2015]. By a - and b - values, we can imply the number of earthquakes with the magnitudes above the M_c with the equation (2). We observe the highest a - and b -values and lowest N – the number of the earthquakes in cluster VI (table 3). Fig. 8 illustrates that the clusters have almost the linear trend of completeness of magnitude. Thus, magnitude of completeness for each is ≥ 4 (M_c -IV = 3.8). We noted that b -value represents the relation of large to small earthquakes. In Cluster VI, which has the highest magnitude of completeness and have 30 earthquakes with magnitude above 4.8, which

can be seen as a high seismic hazard level in terms of magnitude (figs 8, 9), while in the other clusters more events with smaller magnitudes are observed.

Table 4 shows ΔM for each cluster.

Table 4

ΔM for the clusters

Cluster	I	II	III	IV	V	VI
ΔM	-0.47	-0.40	-0.75	-0.57	0.13	0.48

Minus sign shows that expected maximum magnitude is greater than observed maximum magnitude. As seen from the values, ΔM for all clusters is close to zero ($-1 < \Delta M_{(I, II, III, IV, V, VI)} < 1$). Closer ΔM to 0 means closer maximum observed and expected magnitudes, which means that expected magnitude estimation is in the acceptable level of accuracy. Back to the estimation of the a - and b -values of Cluster VI, as noted, we first defined M_c as 3.5 and M_{max} as 4.4 for Cluster VI, by which a - and b -values were obtained 3.29 and 0.35 respectively. Using these values, the expected maximum magnitude and thus, ΔM was estimated for Cluster VI. We obtained $\Delta M = -3.55$ for Cluster VI which is a quite high uncertainty meaning the expected maximum magnitude (9.51) is very higher than observed maximum magnitude (5.96). As the expected maximum magnitude is the ratio of a to b , we deduced that estimation of a - and b -values were done incorrectly (because the uncertainty is quite high). Therefore, we re-defined the range between completeness and maximum magnitudes where the G-R linearity fitting is sustained.

A comparison of our estimated seismicity parameters with previous studies reveals consistency in b -value trends while highlighting key methodological differences. Babayev G. et al. [2020] reported a spatial variation in b -values ranging from 0.5 to 1.1 for the Eastern Greater Caucasus slope. For the same region, our study estimates a single b -value of 0.96. According to Babayev G. et al. [2020], b -values exceed 0.85 in the northern parts of the slope, whereas the majority of the region exhibits lower values (0.5–0.7), indicative of subduction or compressional stress exerted by the Kur Depression from the south—an observation supported by other studies, including Babayev, Aliyev [2019].

Another relevant study by Ahadov, Ozturk [2021] provides a broader-scale assessment, estimating b -values across the Eastern Mediterranean and Caucasus region, including Azerbaijan. For Azerbaijan specifically, they report b -values of approximately 0.8 for the Kur Depression and Eastern Greater Caucasus (corresponding to Clusters I, II, and III in our study) and 1.0–1.3 for the Lesser Caucasus and Talysh regions (Clusters IV, V, and VI). These values reinforce the compressional influence of the Kur Depression and Eastern Greater Caucasus by the Lesser Caucasus and Talysh regions, aligning with previous studies and our findings. However, the b -values obtained by Ahadov, Ozturk [2021] are generally lower than those reported in our study, primarily due to differences in the definition of magnitude of completeness (M_c).

To clarify this discrepancy, we recall that the b -value represents the relative occurrence of strong versus weak earthquakes [Gutenberg, Richter, 1956]. In our study, the completeness magnitudes for Clusters I, II, III, IV, V, and VI are 4.0, 4.0, 4.5, 3.8, 4.0, and 4.8, respectively. This indicates that our b -value estimates are derived from moderate to large earthquakes. In contrast, Ahadov, Ozturk [2021] define lower completeness magnitudes (~ 3.0 – 3.3), thus incorporating a greater proportion of smaller earthquakes into their analysis. For example, Cluster VI in our study, which has the highest completeness magnitude ($M_c=4.8$), also exhibits the highest b -value (2.17). This distinction highlights

the difference in scope: our study focuses on moderate to large earthquakes, whereas Ahadov, Ozturk [2021] consider both small and large events.

Despite these differences, our results remain consistent with global seismicity trends. The b -values for individual clusters, as well as the overall average ($b_{\text{avg}} \approx 1.16$), generally cluster around 1.0 (except for Cluster VI), which aligns with the findings of El-Isa, Eaton [2014]. Furthermore, to our knowledge, no prior studies have reported a -value estimates for Azerbaijan. Additionally, we introduce the concept of maximum magnitude uncertainty, adapted from Omimi, Hashemi [2024], to assess the reliability of our a - and b -value estimations. This parameter has not been previously estimated for Azerbaijan, making our contribution a novel addition to the region's seismicity analysis.

Conclusion

In this study, we presented review of modern seismic regime of Azerbaijan in terms of seismicity indicators. We conducted international catalogue-based analysis and made an insight to the dynamics of Azerbaijan from 1926 to 2022 in terms of seismicity indicators. The catalogue has been clustered relevantly to the tectonic megazones of Azerbaijan region. We observe that the clusters have almost the linear trend of completeness of magnitude. Thus, magnitude of completeness for each is ≥ 4 ($M_c\text{-IV} = 3.8$). We have seen the number of earthquakes in each cluster with magnitude greater than and equal to magnitude of completeness. That means, using the clustering approach, we conceived the seismic activity in respective tectonic segments in terms of the number of earthquakes with magnitude greater than at least 3.8. We conclude that the clusters I-V are active in terms of the events with smaller magnitudes and higher number of occurrences (relatively less b -value), while cluster VI is active or hazardous in terms of the events with higher magnitudes and lesser number of occurrences (relatively higher b -value).

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