Investigation of the Seismic Regime in Har-Us-Nuur fault zone

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2025-08-11

OUTLINE

- **RESEARCH BACKGROUND**
- **GEOLOGICAL AND TECTONIC SETTING**
- **RESULTS AND DISCUSSION**
- **CONCLUSION**

Research Background

- Har-Us-Nuur fault is one seismic activity zone in Western Mongolia.
- Study aims to assess seismic regime and earthquake probability.
- Data Source
  - The Catalogue Provided of IAG, MAS
  - historical (1900–1963) and instrumental (1964–2024).
- Seismic behavior analyzed using G–R law and Poisson distribution.

The Gutenberg Richter relation:

$$\log N = a - bM \qquad (1)$$

Where: M is the minimum magnitude in the data sample. N cumulative number of events in a time intervals with magnitude larger than or equal ***M***; "*b*" and " *a*" are constants (Gutenberg and Richter 1944)

Poisson distribution formula:

$$P(n,\lambda) = e^{-\lambda} * \frac{\lambda^n}{n!} \qquad (2)$$

Where:

- *P(n;λ)* -the probability of observing exactly n events
- λ -the expected (mean) number of occurrences in a given interval
- *e* is Euler's number (*e*=2.71828…)
- *n* — the number of times the event occurs (non-negative integer)
- *n!* — factorial of *n*

Geological and Tectonic Setting

- Har-Us-Nuur fault: ~500 kms long (45^0–50^0N), right-lateral strike-slip system located at eastern margin of Altai Mountains /*Can you see Figure 1*/
- Historical large earthquakes (Mw ~6.9–7.4) from paleoseismic studies (Ramel F.[1], Ritz J-F etc).
- In contrast with the northern and southern sections, the central part of the Har-Us-Nuur fault (46^0–49^0 N) has until now been overlooked, despite it representing an important source of seismic hazard for Hovd (the largest town in western Mongolia, around 50 kms to the west)
- Associated with uplift of Jargalant-Nuruu massif.

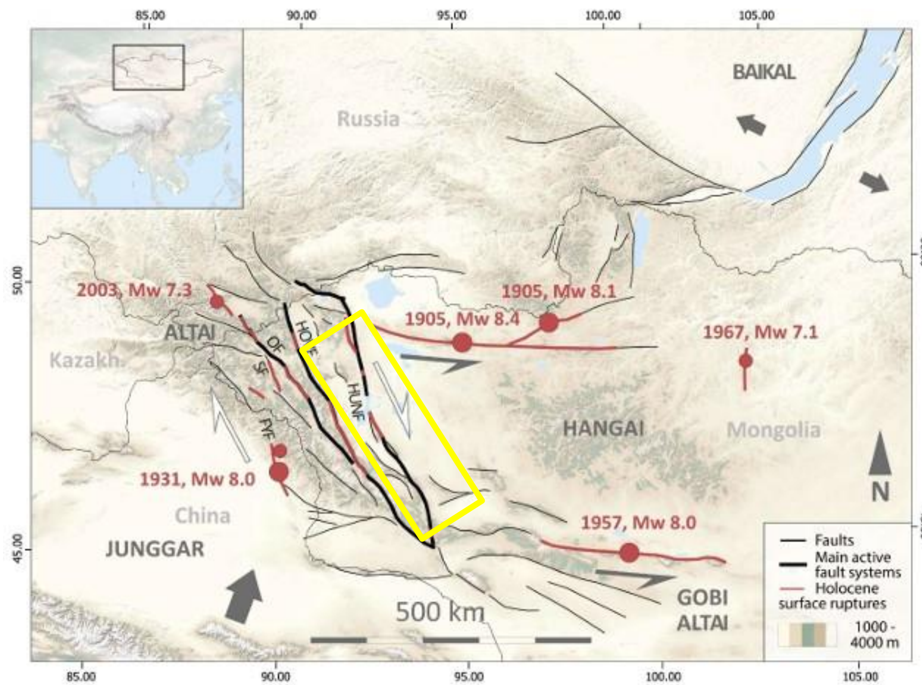


Figure 1 Active faults and Holocene surface ruptures in western Mongolia. HUNF : Har-Us-Nuur Fault /yellow box:study area/, HOVF : Hovd Fault, OF : Olgy Fault, SF : Sagsay Fault, FYF : Fu-Yun Fault. The thin black line corresponds to the Mongolian frontier.

This figure is taken from an article written by Ramel Fabien [9].

Seismic Database and Methods

Har-Us-Nuur fault zone

- Historical data: 1900-1963,
  - **3** large events M>5.0, (M6.6, 1938/12/17), (M5.8, 1931/08/18), (M5.7, 1963/10/29)

- Instrumental data: 1964-2024
  - **4082** events M<1.0 and 2632 events M>=1.0
  - About **23** events, M>=3.5

- >6713 events (M≥0.5)
- Magnitude range: 0.5 to 4.8 (Ml scale).
- Analysis: Gutenberg–Richter law (*b*, *a values*), Data completeness Mc = 1.1, Poisson distribution.

Earthquake Database and Methods

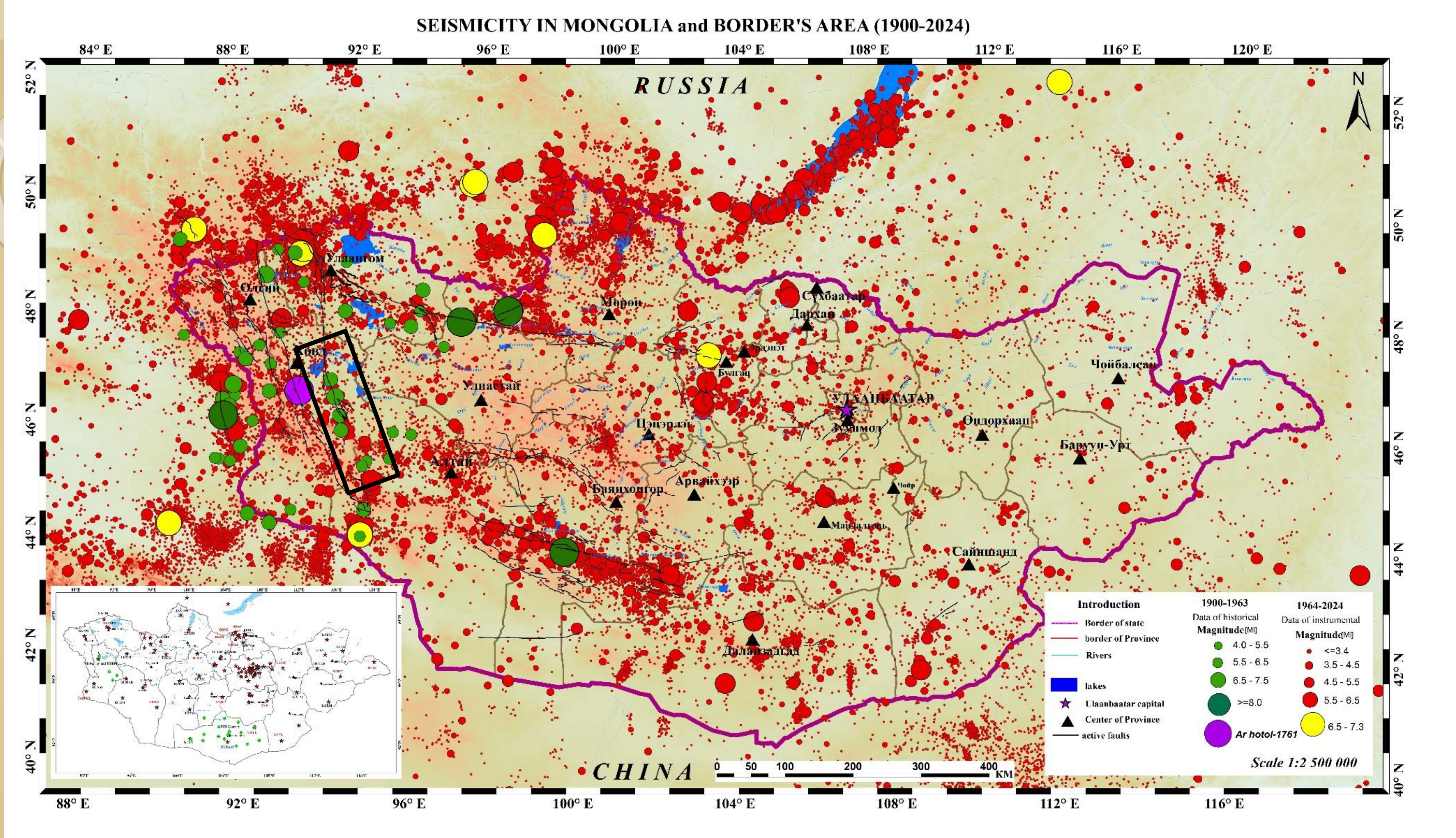


Figure 2. Seismicity in Mongolia and border's area (Ml>=3.5).

green points: historical data 1900-1963 in west region,

red point: instrumental data 1964-2024

Black box: study area /Har-Us-Nuur fault zona/

a.Seismicity of the western region of Mongolia (Altay region)

- Since 1900, 100 earthquakes M>5.5
- 1964-2024, 5 earthquakes with magnitude 6.0 and 2 earthquakes with magnitude 7.0
- 1964-2024, 880 earthquakes M>=3.5
- This represents approximately 20% of all earthquakes with magnitudes greater than 3.5 that occurred in Mongolia

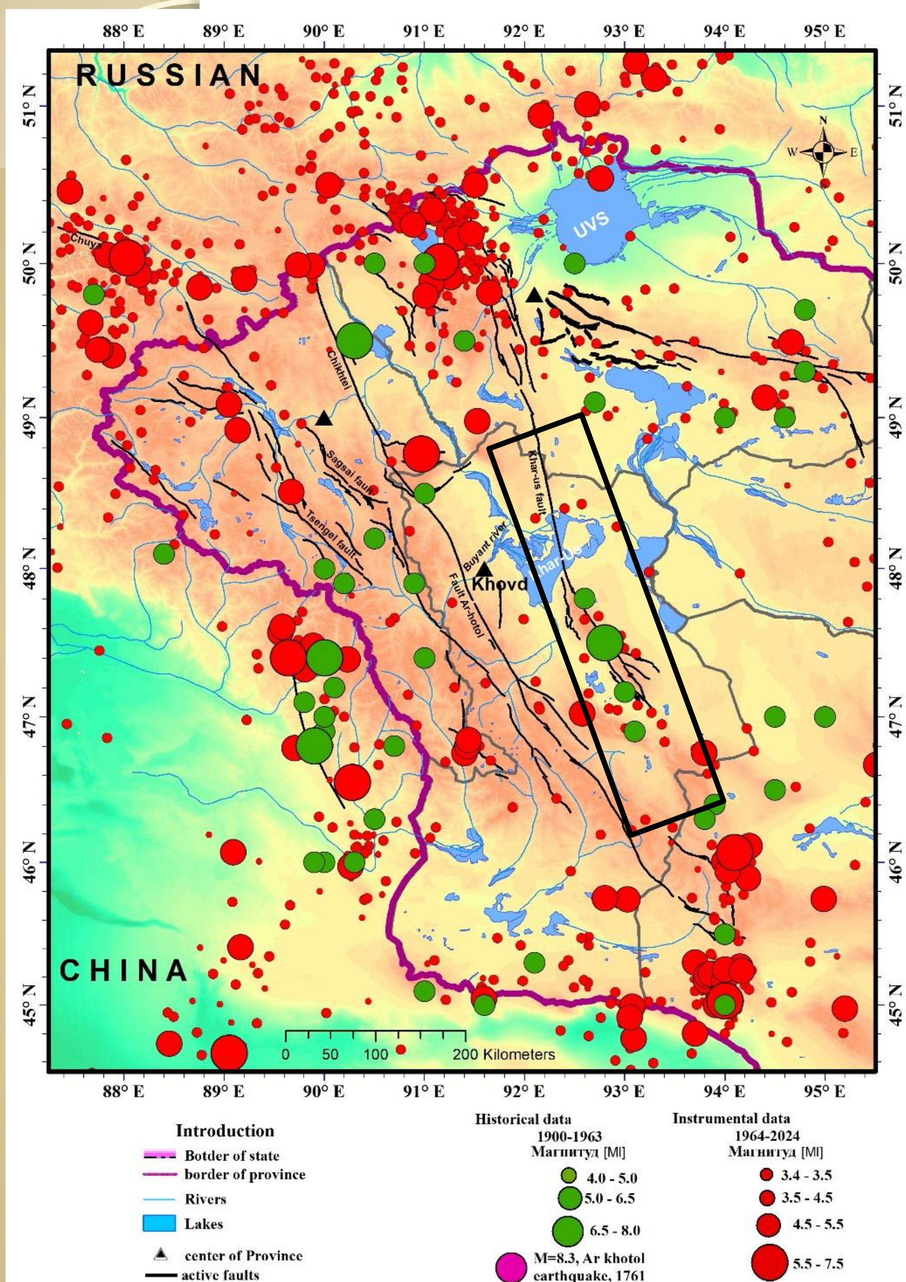
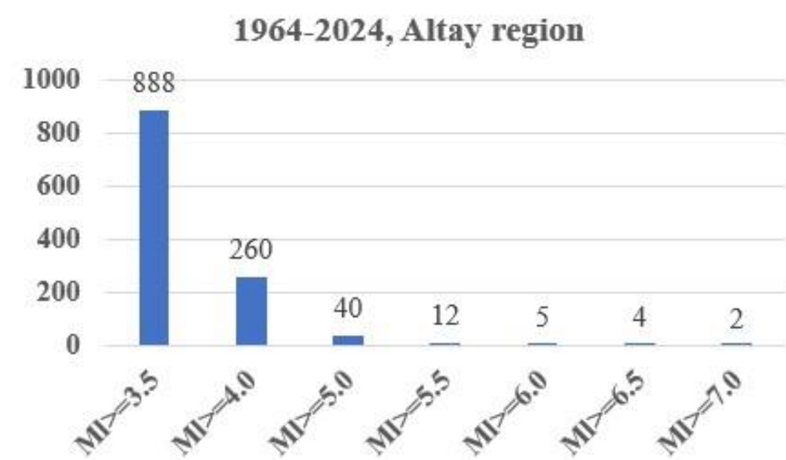
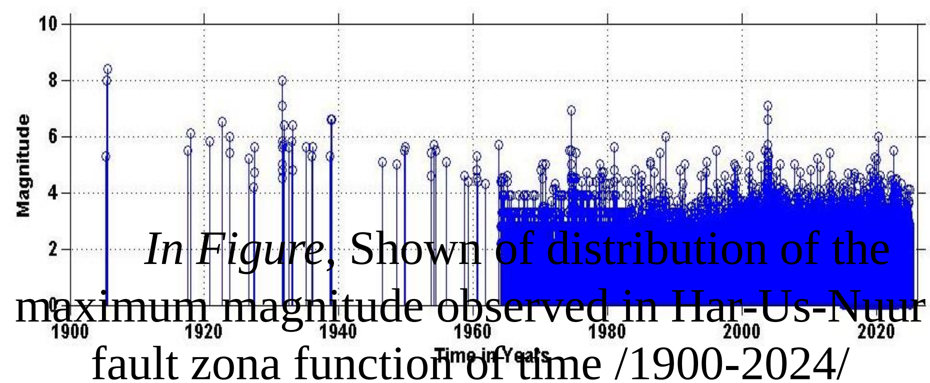


Figure 3 Seismicity in western region of Mongolia and border's area (1900-2024, Ml>=3.5, Black box: study area (Har-Us-Nuur fault zona)





In Figure, Shown of distribution of the maximum magnitude observed in Har-Us-Nuur fault zona function of time /1900-2024/

b.Historical and instrumental seismicity of the Har-Us-Nuur fault zone

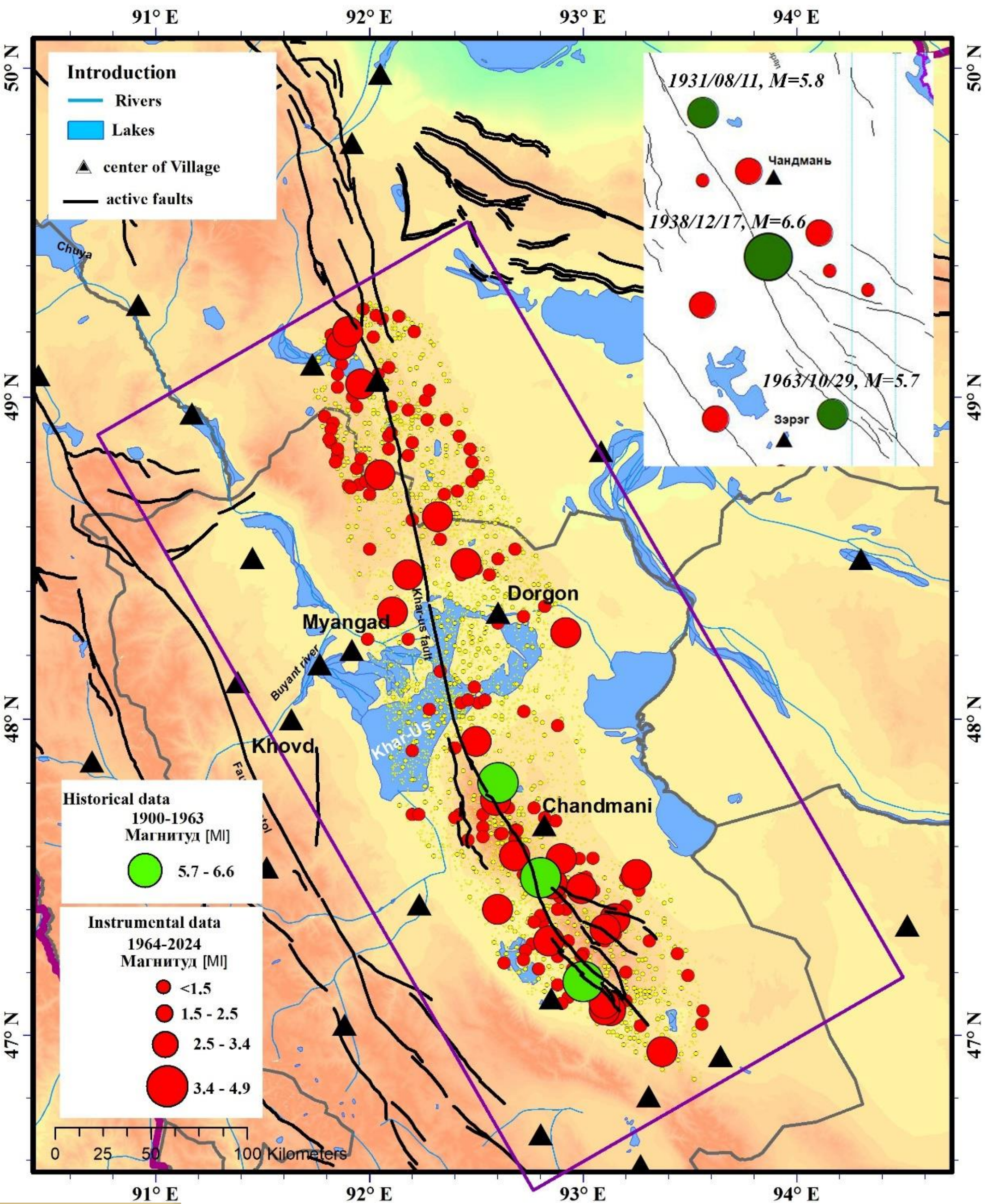
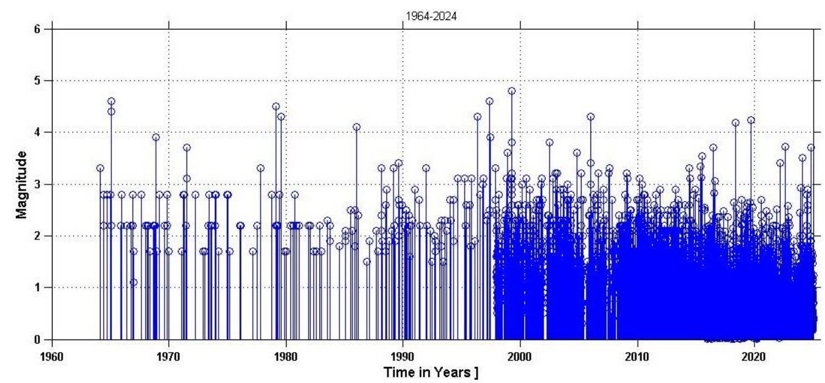


Figure 4 Seismicity in Har-Us-Nuur fault zona (1900-2024)

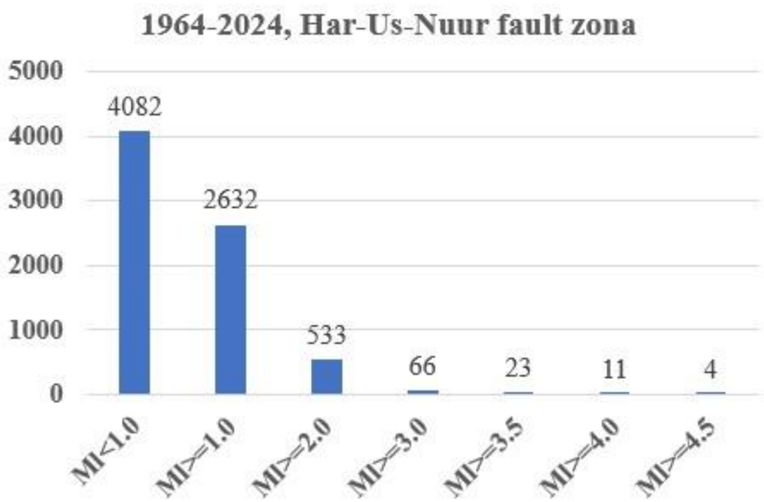
From 1964 to 2024, Mongolia seismic network stations recorded 4082 earthquakes with magnitude Ml<1.0 and 2632 earthquakes with magnitude Ml>=1.0 in Har-Us-Nuur fault active zona. Also, occurred 23 earthquakes with magnitude Ml>3.5 in this region



In Figure, Shown of distribution of the maximum magnitude observed in Har-Us-Nuur fault zona function of time /1964-2024/

RESULTS and DISCUSSION

1.Study of the Seismic regime of the Har-Us-Nuur fault zone (1964-2024)



Graphic 2. Magnitude distribution of earthquakes in Har-Us-Nuur fault zona for 1964-2024

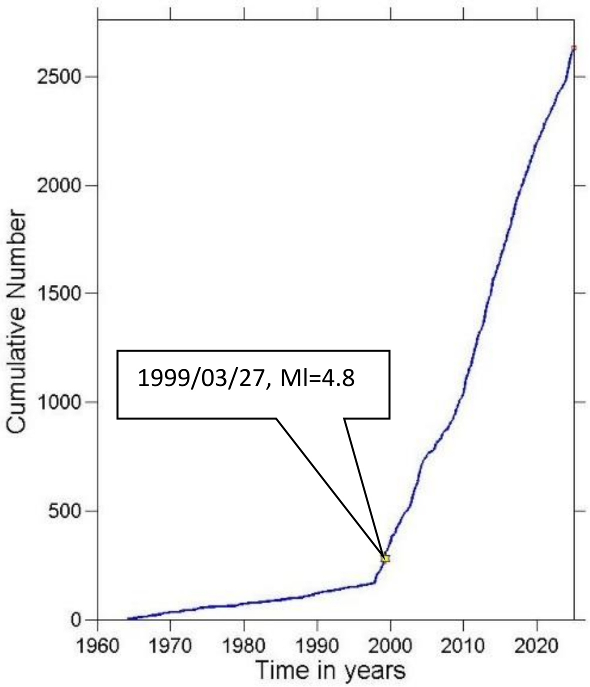
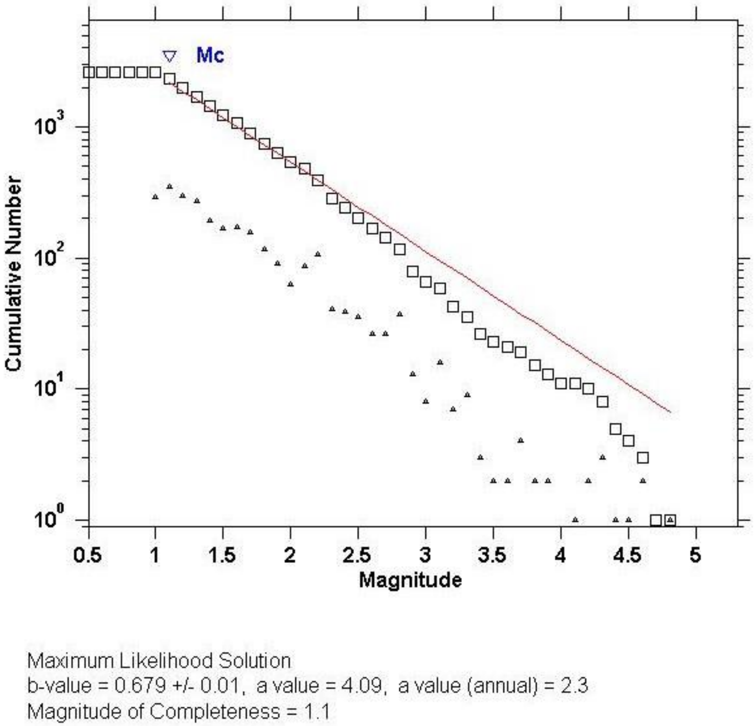
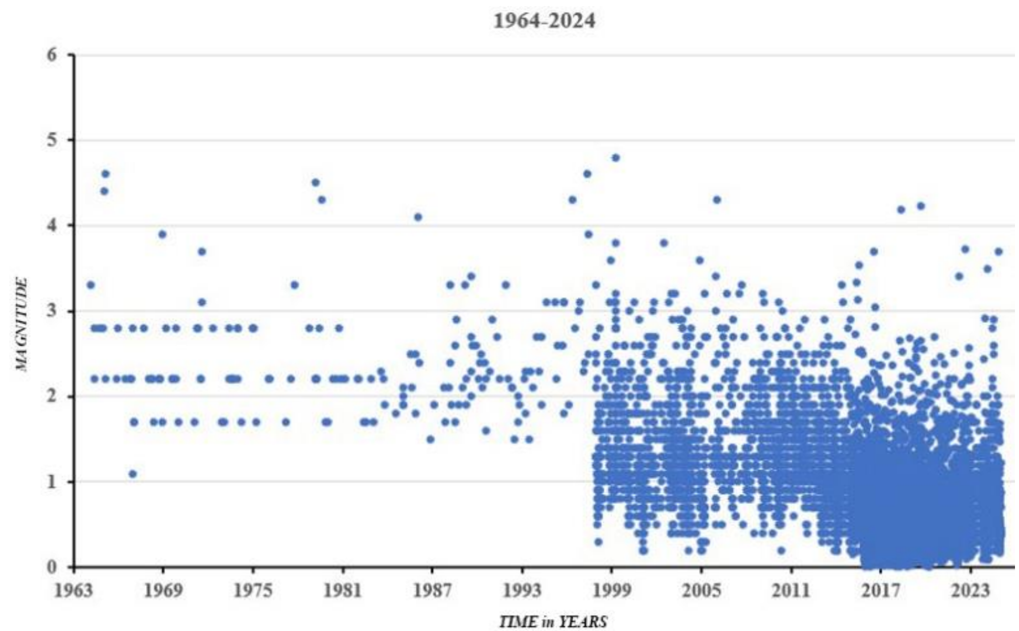


Figure 5. Cumulative number of detected events with time in Har-Us-Nuur fault zona

The strongest recorded earthquake in the Har-Us-Nuur fault zone occurred on March 27, 1999, with a magnitude of 4.8. Also Eartquake occurred on May 14, 1997, with magnitude 4.6.

1.Study of the Seismic regime of the Har-Us-Nuur fault zone (1964-2024)



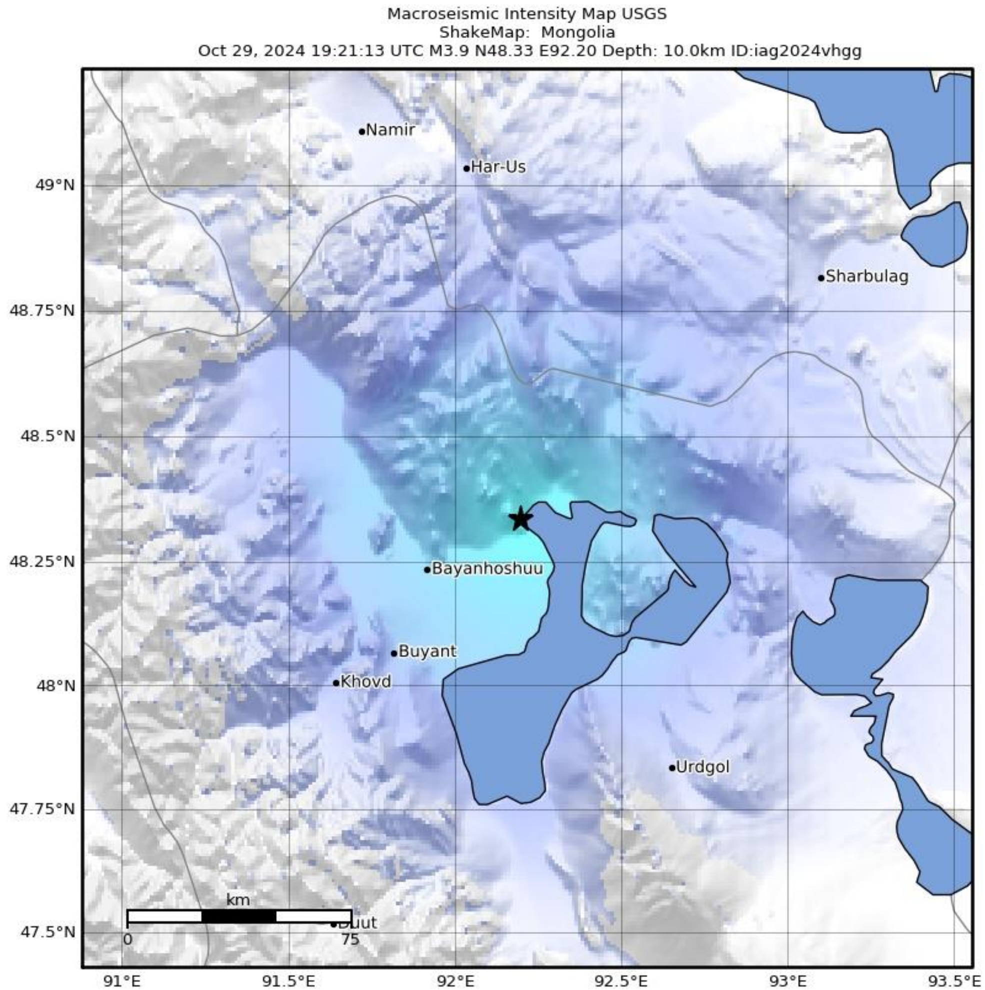


Magnitude–Time Relationship based on Completeness-Adjusted Earthquake Data (1964–2024)

Gutenberg - Richter law (frequency-magnitude distribution) for the period of 1964 to 2024. The apparent cut off magnitude appears to be Mc = 1.1

b-value=0.679+/-0.01, *a* value=4.09

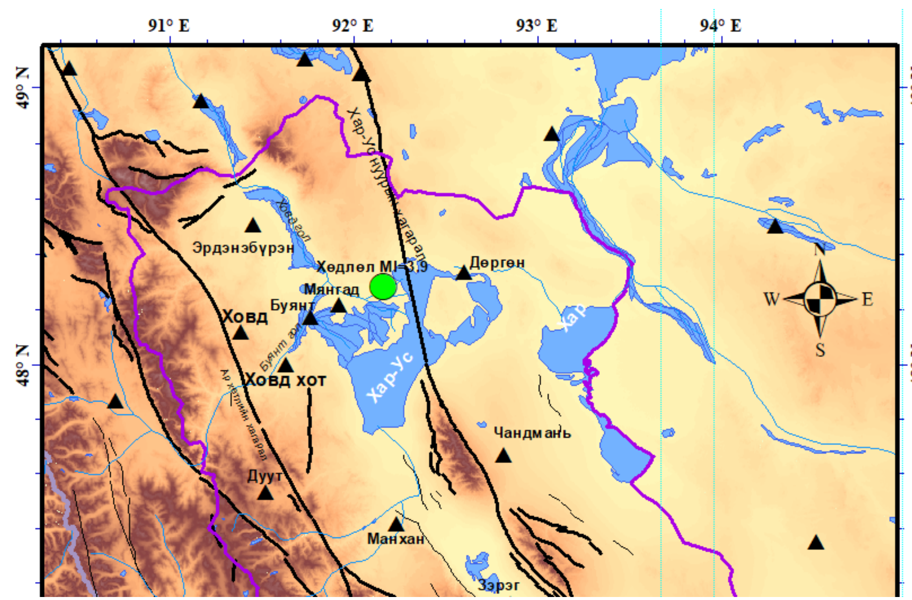
1.Study of the Seismic regime of the Har-Us-Nuur fault zone (1964-2024)



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0464	0.297	2.76	6.2	11.5	21.5	40.1	74.7	>139
PGV(cm/s)	<0.0215	0.135	1.41	4.65	9.64	20	41.4	85.8	>178
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Worden et al. (2012) Version 1: Processed 2024-10-29T19:35:53Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter

Last information, on October 30, 2024, at 03:21:13 Ulaanbaatar time, an earthquake with a magnitude of 3.9 (Richter scale) occurred at coordinates 48.33°N, 92.20°E, near Ulaan Tolgoi, approximately 18 kms east of Myangad soum, Khovd province.



According to macroseismic observations, the intensity of the earthquake was estimated at IV–V near the epicenter, IV in the center of Myangad soum, and around III in the center of Khovd province.

2. Results of the Analysis of the Poisson Distribution and Seismic Probability

The Poisson distribution was applied to estimate the probability of earthquake occurrences per year.

The Poisson distribution was adapted for use in calculating the probability of earthquake recurrence.

$$P(\lambda, t) = e^{-\lambda t} * \frac{(\lambda t)^n}{n!} \quad (5)$$

Let's look at an event occurring on average λ times per year.

$$\frac{events}{time} * time\ period = \lambda \text{ then}$$

$$P(n\ events\ in\ interval\ t) = e^{-(\frac{events}{time} * time\ period)t} * \frac{((\frac{events}{time} * time\ period)t)^n}{n!} \quad (6)$$

Since 1964, based on 60, 40, 30 and 20 years of data, the probability of a strong earthquake in a year was calculated using the Poisson distribution (see t*able 1*). Before that, I learned to explain how the logarithmic value of the annual average number of earthquakes depends on the magnitude using the Gutenberg-Richter law. After 1995, taking into account the conditions that made it possible to fully record strong earthquakes with a magnitude greater than 1.0 the following results were obtained.

M>=	Events	time	average event	LogN
0.3	4960	20	248.000	2.394
0.5	3929	20	196.450	2.293
0.8	2571	20	128.550	2.109
1.2	1802	30	60.067	1.779
1.5	1063	30	35.433	1.549
1.8	605	30	20.167	1.305
2.0	466	40	11.650	1.066
2.5	171	40	4.275	0.631
3.0	57	40	1.425	0.154
3.5	23	60	0.383	-0.416
4.0	11	60	0.183	-0.737
4.5	4	60	0.067	-1.176

Table 2 The methodology used to calculate the data for the period 1964–2024

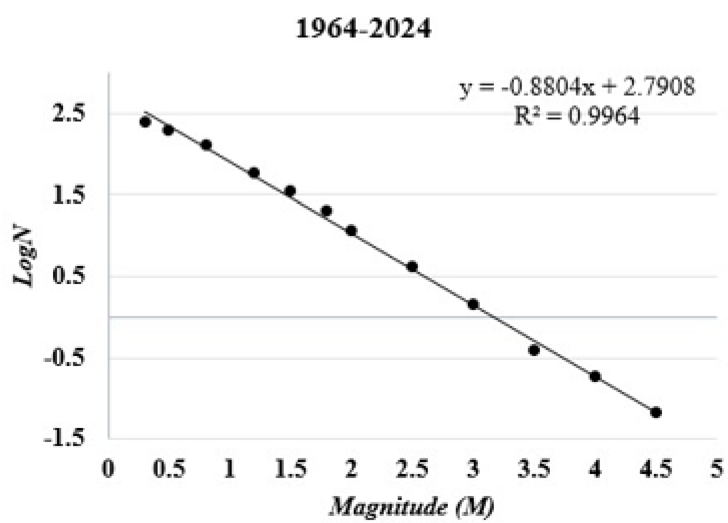


Fig 7 Magnitude–Frequency Relationship for Earthquakes in har-Us-Nuur zona over a 60-year period (Gutenberg–Richter law, 1964–2024, Mc = 0.3)

2. Results of the Analysis of the Poisson Distribution and Seismic Probability

Calculated Poisson Distribution for the Periods 1964–2024 and 1995-2024 (Ml>=3.5)										
Time period	**1 year**		**2 year**		**3 year**		**4 year**		**5 year**	
Probability	λ=0.38, 60-years %	λ=0.53, 30-years %	λ=0.38, 60-years, %	λ=0.53, 30-years, %	λ=0.38, 60-years, %	λ=0.53, 30-years, %	λ=0.38, 60-years, %	λ=0.53, 30-years, %	λ=0.38, 60-years, %	λ=0.53, 30-years, %
P(n=0)	68.2	58.7	46.5	34.4	31.7	20.2	21.6	11.8	14.7	6.9
P(n>=1)	31.8	41.3	53.5	65.6	68.3	79.8	78.4	88.2	85.3	93.1
P(n=1)	26.13	31.29	35.62	36.71	36.41	32.30	33.09	25.27	28.19	18.53
P(n=2)	5.01	8.34	13.65	19.58	20.94	25.84	25.37	26.95	27.02	24.71
P(n=3)	0.64	1.48	3.49	6.96	8.03	13.78	12.97	19.17	17.26	21.96
P(n=4)	0.06	0.20	0.67	1.86	2.31	5.51	4.97	10.22	8.27	14.64
P(n=5)	0.00	0.02	0.10	0.40	0.10	1.76	1.52	4.36	3.17	7.81

Table 3 Calculated Poisson Distribution for the Periods 1964–2024 and 1995-2024 (Ml>=3.5)

from Fig 7, the earthquake recurrence *b*-value=0.880, degree of earthquake activity a=2.7 and coefficient of determination R^2=0.9964. This high R^2 value (0.9964) indicates a strong linear correlation, which is consistent with the Gutenberg–Richter law. The slope of the regression line (b-value ≈ 0.89) suggests a relatively frequent occurrence of large-magnitude earthquakes in the region.

Based on the above results, used formula (5) and (6), the Poisson distribution was calculated using data on earthquakes with magnitudes of 3.5 or greater that occurred during the periods 1964–2024 (see t*able 3*).

2. Results of the Analysis of the Poisson Distribution and Seismic Probability

First, we have shown Probability of no earthquake (Ml>=3.5) occurring during 1 year.

For shown Table 2, since there were 23 earthquakes over 60 years, the average yearly rate is:

$$\lambda = \frac{23}{60} = 0.3833 \text{ then } P(0) = e^{-\lambda} = e^{-0.3833} = 0.6815$$

The probability that no earthquake occurs during 1 year is approximately **68.2%**.

The probability of **at least one earthquake** occurring in 1 year is given by:

$$P(\geq 1) = 1 - P(0) \text{ then}$$

$$P(\geq 1) = 1 - 0.6815 = 0.3185$$

The probability of an earthquake occurring in 1 year is approximately **31.9%**.

2. Results of the Analysis of the Poisson Distribution and Seismic Probability

Second, let us calculate the probability of no earthquake occurring during a 5-year period.

23 earthquakes occurred Ml>=3.5 over 60 years:

$$\lambda = \frac{23}{60} = 0.3833 \text{ then}$$

Average number of earthquakes over 5 years:

$$\lambda = 5\ x\ 0.3833 = 1.9165$$

Using the Poisson distribution:

$$P(0) = e^{-\lambda} = e^{-1.9165} = 0.1479$$

The probability of **no earthquake occurring during a 5-year period** is approximately **14.8%**.

Probability of at least one earthquake occurring during a 5-year period:

$$P(\geq 1) = 1 - P(0) = 1 - 0.1479 = 0.8521$$

The probability of an earthquake occurring over 5 years is approximately **85.2%**.

For the period from 1964 to 2024, the annual occurrence rates of earthquakes with magnitudes greater than 3.5 were calculated for both 60-year and 30-year intervals. Using the Poisson distribution functions (Equations 3 and 4), the probability of observing *k* earthquakes with magnitudes greater than 3.5 in a single year was estimated (*Table 3*, *Fig 8*).

2. Results of the Analysis of the Poisson Distribution and Seismic Probability

Calculated Poisson Distribution for the Periods 1964–2024 and 1995-2024 (Ml>=3.5)										
Time period	**1 year**		**2 year**		**3 year**		**4 year**		**5 year**	
Probability	λ=0.38, 60-years %	λ=0.53, 30-years %	λ=0.38, 60-years, %	λ=0.53, 30-years, %	λ=0.38, 60-years, %	λ=0.53, 30-years, %	λ=0.38, 60-years, %	λ=0.53, 30-years, %	λ=0.38, 60-years, %	λ=0.53, 30-years, %
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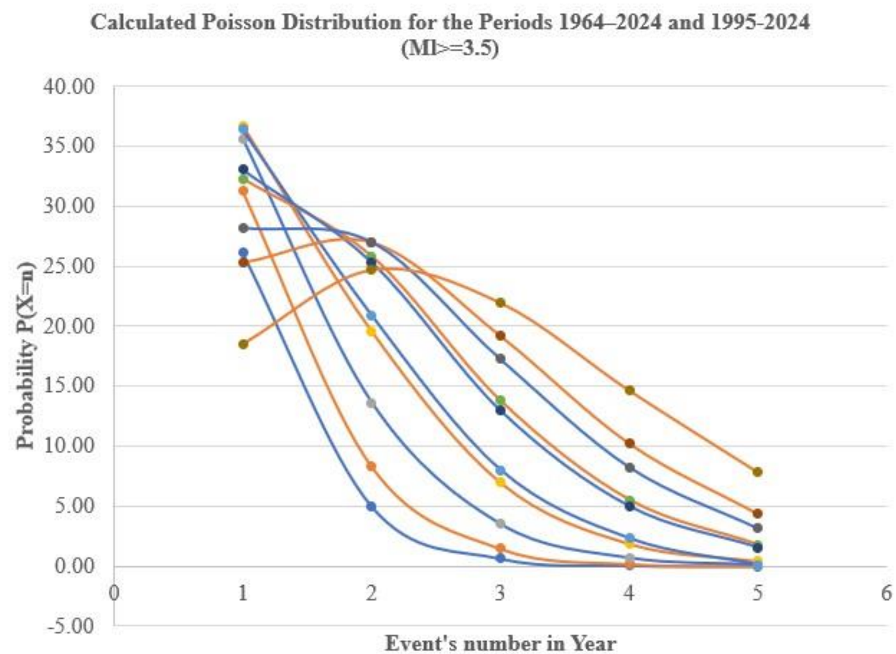

Fig 8 Seismic Probability Estimation based on the Poisson Distribution (Ml>=3.5, period of Years: 60 and 27)

2. Results of the Analysis of the Poisson Distribution and Seismic Probability

According to the results based on the Poisson distribution, during the periods of 60 years (1964–2024) and 27 years (1998–2024), the probability of earthquakes with a magnitude of ≥5.0 occurring once or twice per year is the highest.

In Table 3 and Fig 8, it was found that there is a 31.8% probability that an earthquake with magnitude greater than 3.5 will occur more than once in 1 year, and a 26.1 probability that it will occur more than twice in 1 year.

Specifically, the probability of one earthquake occurring per year is the most prominent, as indicated by the peaks of several distribution curves. In contrast, the probability of more than two occurrences decreases gradually, and the likelihood of three or more earthquakes per year is significantly low.

CONCLUSION

- In this study, the seismic characteristics of the mountainous Altai region in western Mongolia were investigated to assess the current state of seismic activity, the frequency of earthquake recurrence, and the level of seismic hazard in the region.
- The research was conducted using earthquake data from the National Data Center of the Institute of Astronomy and Geophysics, Mongolian Academy of Sciences. The dataset includes historical moderate-to-strong earthquakes that occurred between 1900 and 1963, as well as instrumental data from 1964 to 2024 for earthquakes with magnitudes greater than 0.5.

  - ✓ Seismic activity and recurrence patterns in the region were analyzed. The key parameters describing the seismic behavior — the a and b values — were estimated using the Gutenberg–Richter law. Additionally, the statistical probability of earthquake occurrence over 60-year and 30-year periods was calculated using the Poisson distribution.

  - ✓ From 1964 to 2024, Mongolia seismic network stations recorded more than 6713 earthquakes with magnitude from 0.5 to 4.8 in Har-Us-Nuur fault zona.

CONCLUSION

- These results suggest that in the studied region, the occurrence of large-magnitude earthquakes multiple times per year is unlikely, while the probability of having one significant event per year is relatively high.
- This analysis provides important insights into the seismic frequency, risk assessment, and future planning for disaster preparedness and management in the western region of Mongolia.
- The probability of a strong earthquake occurring every year is relatively low. Due to the relatively small number of strong earthquakes, it cannot be ruled out that there is a small error in the calculation of the Poisson distribution.

In the future, the seismic situation in the western region can be studied in connection with seismic activity along active faults, which may provide an opportunity to forecast the probability of strong earthquakes.

THANK YOU FOR ATTENTION