Journal of Modern Technology and Engineering
Vol.8, No.1, 2023, pp.54-62

# THE ROLE OF ARTIFICIAL INTELLIGENCE IN EFFECTIVE EARTHQUAKE FORECASTING

**Ulugbek Turapov**[1], **Fidan Nuriyeva**[2,3*]

[1]Jizzakh Polytechnic Institute, Department of Automation and Management of Production Processes, Jizzakh, Uzbekistan
[2]Dokuz Eylul University, Department of Computer Science, Izmir, Turkiye
[3]Institute of Control Systems of ANAS, Baku, Azerbaijan

**Abstract.** There are enlightened a set of geological and geophysical data on distinguishing the types of the earth's crust is formed in this article. It is known that the method of classifying the earth's crust by species is based on cluster analysis, which allows the computer to create large data sets simultaneously with differentiation algorithms and a comprehensive analysis program.

A comparative and statistical analysis of the preliminary data was carried out, based on the cluster analysis, the problem of solving the problem of classification was revealed. In this study, the capabilities of computers and artificial intelligence were used, which are completely different from the previous method of assessing the potential of strong earthquakes.

Based on the analysis of the relationship of isolated crystal types with earthquakes using the earthquakes detected so far, an algorithm is created that allows predicting similar crystal types. The current tense situation of the earth's crust has been interpreted differently by different authors; the problems that occur in the creation of a catalog of mechanisms of earthquake focus and the study of continuous movement of the focus using mathematical statistics methods and the construction of a mathematical model have been studied.

The problem of field strength reconstruction in two stages, high accuracy of data and in general, as well as the creation of a model for implementation at different values of earthquake magnitude, was raised.

**Keywords**: forecast, cluster analysis, anomaly, classification, mechanism of earthquake focus, reconstruction of stress field.

**Corresponding author:** Fidan, Nuriyeva, Dokuz Eylul University, Department of Computer Science, Izmir, Turkey, e-mail: *nuriyevafidan@gmail.com*

*Received: 23 January 2023; Revised: 19 February 2023; Accepted: 13 March 2023; Published: 30 April 2023.*

## 1 Introduction

As we know, earthquakes - causes as a result of underground tremors and vibrations that occur as a result of a sudden shift, fracture or collapse of the earth's crust or the upper part of the mantle layer and spread over long distances in the form of wave-like vibrations.

- Tectonic;
- Volcano;
- Squealing;

**Tectonic earthquake:** Earthquakes that occur under the influence of natural forces at different depths of the earth's crust are called tectonic earthquakes. They are the product of un-

derground movements and processes, which are the result of the sudden (in 1 min.) expenditure of these processes in the form of kinetic energy.

**Volcanic and earthquakes** occur very rarely in nature; they are equal in strength to the weakest of tectonic earthquakes. The number of earthquakes occurring on the globe can reach several hundred thousand during the year. Most of them are weak earthquakes that can only be detected by seismographs, and only a few thousand can be detected by people.

Earthquakes that damage the national economy can range from several dozen to several hundred. As a result of all the earthquakes that occurred during the year, approximately 0.510 J of kinetic energy is released. Despite the fact that this amount of energy is very large, it is only 0.5% of the total energy released from the processes that take place deep in the earth.

In nature, as a result of strong earthquakes, terrible losses and losses in human life have manifested themselves in different regions in different periods, showing the need for scientists to pay attention and study to this field.

The following earthquakes can be included among the strong earthquakes that have occurred on Earth: Lisbon (1755), California (1906), Ashgabat (1948), Chile (1960), Tokyo (1923), China (1976), Spitak (Armenia, 1988), Zaysan (Kazakhstan) Estonia, 1990), Suusamir (Kyrgyzstan, 1922) and in Uzbekistan – in 838-839 years -Ferghana, in 942 - Bukhara, in 1208-1209 - Urganch, in 1490 - Samarkand, in 1494 - Namangan, in 1620 - Ahsikent, in 1902 - Andijan, in 1921 – 1922 near Bukhara and Samarkand, in 1927 - Namangan, in 1868, 1924, 1938, 1966 - Tashkent, in 1976, 1984 - earthquakes in Gazli (Donish, 1987).

## 2 Literature Review

The first information about earthquakes in Central Asia can be found in manuscripts of the 9th century AD. “In 224 (838-839) there was a strong earthquake in Fergana and many houses were destroyed,” writes Abu-Gardizi - a historian of that time.

The earthquake-prone East Anatolian Fault System is part of a tectonic triple junction where the Anatolian, Arabian, and African plates touch each other. Since 1970, only 3 earthquakes of magnitude 6 or higher have occurred in the region, so scientists did not expect this to be the last terrible earthquake in Turkey. Terrible earthquakes that occurred in the south-eastern part of Turkey and in the north of Syria showed how such a natural disaster can happen unexpectedly (Bachmanov et al., 2017).

Earthquake specialist V.V. Belousov (1954) expresses his opinion as follows: Proposed the principle of ”Seismic Zoning” mapping of earthquake sites, suggesting that strong earthquakes that have occurred in the past should be based on the assumption that they are likely to recur somewhere. In addition, he emphasized the conditions of occurrence of earthquakes, their connection with the structure of the earth’s crust and tectonic movements (Belousov & Pavlenkova, 1985).

It is known that the tectonic activity of the region is determined by a set of geological and geophysical indicators, and their unique combination determines its ”Seismo tectonic potential”. In this regard, V.V. Belousov said, that ”First of all, it is necessary to raise the issue of distinguishing the types of the earth’s crust according to their structure (Belousov & Pavlenkova, 1985).

But if distinct types of the earth’s crust are chosen, they reflect different stages of development of the earth’s crust. That is, various endogenous regimes allow us to assess what processes are taking place in it, not only the modern structure of the crust, but also the laws of its development. In addition, he noted that ”it would be very important to use the characteristics of the deep structure of the earth’s crust in order to determine the relationship between the processes in the earth’s crust.” Based on this, in 1980, G. I. Reisnyer proposed the method of creating a ”Seismo tectonic potential” map (Reisner, 1980).

For example, Chinese scientists say that with the help of such algorithms, earthquakes can

be predicted in advance by the irregularities in the movement of electrons in the magnetic field above the fault zone in a certain area (Liu et al., 2006; Ai et al., 2020).

And the Chinese scientists are hoping for data that can be collected from the ionosphere. In 2018, the country launched a seism-electromagnetic satellite into space to detect anomalies in the Earth's ionosphere. Chinese scientists reported that they discovered a decrease in electron density in the ionosphere a few weeks before the May 2021 and January 2022 earthquakes (Li et al., 2022).

Also, scientists have mentioned that although they are studying satellite data, their findings are far from being able to predict earthquakes in advance. It is difficult to know exactly where earthquakes occur.

The reason is that large earthquakes cause waves in the region far from their epicenter. This makes it difficult to find the exact location. Various other signals are also hoped for. For example, Japanese scientists suggest the possibility of forecasting it 1 month in advance, depending on the changes in the water vapor rising from the earthquake zones. Tests have shown that this method is 70 percent accurate.

However, despite so many tests, no one has been able to predict exactly when and where an earthquake will occur. Even if the forecasts improve, it is still questionable whether it is possible to create a method, algorithm and program based on the analysis of the data obtained with them.

Evacuating entire cities or asking people to stay out of buildings when their homes are at risk of collapse can be expensive until forecasting accuracy improves.

More than fifty thousand people died and more than hundred thousand people were injured and left homeless in Turkey and Syria due to 2 unexpected and terrible earthquakes that occurred at February 6, 2023. The first 7.7-magnitude devastating earthquake destroyed the houses of sleeping people in an instant. A few hours later, another 7.6-magnitude strong earthquake occurred (AFAD, 2023).

In this case, the studied area is divided into cells of equal size, and data from the maps compiled on the basis of observations are entered into each cell. The geological-geophysical indicators to be selected in solving the given problem are characterized by their relation to seismo tectonics. The problem was characterized by a certain sum of traditional units corresponding to different levels of "Seismo tectonic potential" in each cell. Then, the obtained map was compared with the map of epicenters of strong earthquakes (Riznichenko, 1985).

The division of the earth's crust into types opens wide opportunities in the study of endogenous processes, in particular, up to seismic zoning and geodynamics. It is necessary to establish connections between types of earth's crusts and to determine their place in the general system. Unlike all of the above, the method of dividing the earth's crust (Reisner, 1980; Reisner et al., 1993; Reisner & Reisner, 1987) into homogeneous regions is based on a clearly structured and justified physical model - the geodynamic concept of V.V. Belousov (Belousov & Pavlenkova, 1985).

According to this concept, the main source of tectonic movements is the differentiation of the mantle substance, as a result of which its soluble content enters the earth's crust along with a large amount of deep heat, causing physical and chemical changes of various velocities in it. This, in turn, manifests itself in surface structures and affects one or another intensity of tectonic activity.

The study of modern endogenous regimes is based on the classification of the earth's crust into types with the help of geological-geophysical data that determine the current state and structure. In this case, the initial geological-geophysical data should be evenly distributed over the entire studied area. The main thing is that the selection of initial data should be in accordance with the intended purpose.

Seismo tectonics of strong earthquake focus was studied on the basis of the complex of geological and geophysical data, and its connection with modern endogenous regimes was determined

(Junga, 1990). In this approach, the method of dividing the earth's crust into types was used. As a result of their work, the regions where strong earthquakes may occur in accordance with Mmax have been allocated. Considering the above methodology, it is appropriate to use the following complex of geological and geophysical data when dividing the earth's crust into types:

1. Heat flux density.
2. The thickness of the Earth's crust.
3. Heights of the modern relief.
4. Isostatic gravity anomalies.
5. Depth of consolidated Paleozoic foundation.
6. $\Delta$T magnetic anomalies.
7. Density of ground cracks.
8. Amplitude of neo tectonic movements.

"When we study earthquakes in the laboratory, we study whether small cracks or defects appear in a certain area before an earthquake. It is in the complexity of the earth's fault system that crosses the whole world. In addition, there are many seismic sounds - the earth is constantly making high and low sounds. It is mixed with anthropogenic sounds created by mankind: traffic sounds, construction noises and makes it difficult to receive clear signals.

But there are such uncertainties in nature that we often cannot see and predict the signs of a strong earthquake," said Chris Marone, a professor at Sapienza University in Italy. They develop "Maps of dangerous areas" based on earth faults. It calculates the probability of earthquakes in the regions in the next few years.

Unfortunately, such calculations cannot help people living in earthquake-prone areas to evacuate or move to safe shelters. But it can serve as a guideline for building buildings in such areas based on earthquake-resistant standards.

On the other hand, not everyone who lives in dangerous areas can afford infrastructure that can withstand strong tremors. Marone said that in the 1970s and 1980s, the Western world began to set its own seismic standards and has been following them. But building and retrofitting buildings to earthquake-resistant seismic standards is costly.

## 3 Methodology

Earthquakes and other natural disasters pose a great threat to the development progress of any country. Management of the risk of natural disasters, taking into account protection from natural disasters, also shows that it is a supporter of a proactive approach to the socio-economic development of Uzbekistan (Tukhtasinov et al., 2021a,b; Ibragimov et al., 2002; Bezrodnyj & Tujchiev, 1987; Rebeckij et al., 2020; Artikov et al., 2017).

Earthquakes are more common in regions with the most tectonically active mountain ranges in the world. These places are referred to as belt (regional) fault areas of the earth's surface in the geological term (Rebeckij, 2007). Regions of the globe where strong earthquakes occur can be divided into two main regions depending on their seismic activity; the first, in the direction of geographic latitude, the Alps, Carpathians, Caucasus, Kopetdog, Tienshan, Pamir, Himalayas, and the second, in the meridional direction - along the two coasts of the Pacific Ocean and partially in the land region (Rebetsky & Kuzikov , 2016).

Such seismically active areas include South America to Antarctica, the northern part of Europe and Asia, Central and West Africa, Australia and other regions. Therefore, Central

Asia belongs to the seismically active region due to its seismically active Kopetdog, Tianshan, and Pamir mountains (Rebeckij, 1997). A specific volume in the earth's crust or upper mantle where an earthquake occurred is the epicenter of the earthquake, and the point considered to be its center is called the hypocenter, and the projection of the hypocenter on the surface of the earth is called the epicenter of the earthquake (Ulomov, 1997). The distance between the epicenter and the hypocenter indicates the depth of the earthquake. In most cases, the hypocenter of the earthquake in the territory of Central Asia is located at a depth of 5-50 km from the surface of the earth. In certain regions of the globe, the center of earthquakes can be at a depth of 200-300, even 700 km.

Earthquakes caused by earthquakes are measured in points. The tremors are strongest at the epicenter, and the strength decreases as you move away from it. The area (level) within the line marking the strongest tremors around the epicenter and where they intersect is called the Pleistocene region. When an earthquake occurs, longitudinal and transverse seismic waves spread from its center. Longitudinal waves are denoted by the letter R (first wave), transverse waves are denoted by the letter S (second wave). In addition, there are surface waves L that appear on the surface of the earth.

Although these waves are considered basic, complex waves are formed due to the fact that transverse and longitudinal waves are refracted and reflected on the earth's surface and internal layers. Waves travel at different speeds. The fastest-propagating wave is a longitudinal wave, and in the environment, most people in the building can feel it. Appliances in the house come into action. The building and furniture shake. The sleepers will wake up. Everyone notices. Many people are in a hurry to get out, some things fall from their place.

In some houses, people move. Buildings are damaged, brick walls are cracked. Some houses built of raw bricks and straw are destroyed, sometimes rocks move in the mountains. Buildings will be severely damaged, landslides will occur in the mountains. Houses made of brick and concrete are completely or partially destroyed, underground pipes are cut off. Rocks fall, hills are moved, and cracks in the ground are up to 10 cm wide.

Large cracks (up to 1 m wide) appear on the surface of the earth. Dams and embankments will fail, railways will bend.

New lakes will appear. Wide and deep ravines form on the surface of the earth, the earth shakes in vertical and horizontal direction. Rocks will topple in the mountains, bridges, dams, railways will be completely destroyed. The shape and relief of the earth will change. The surface of the earth is bent, high rocks are overturned, and rivers change their course.

Transverse waves travel at an average speed of 5 km/s, and surface waves travel at the slowest speed. The farther the seismic station that records earthquake waves is from the epicenter of the earthquake, the greater the time difference between the waves reaching the station. This condition makes it possible to determine the distance from the epicenter of the earthquake to the radius of propagation based on the record of recorded waves. For this purpose, the dependence of the time between transverse and longitudinal waves on the epicenter distance is studied for different regions.

This relationship is in the form of a plot, called a hodograph, and is important in the processing and study of earthquake data. The total power of earthquake waves is determined by magnitude (M).

It is a conditional number and corresponds to the displacement amplitude of the particles of the environment at the ground level. This value is determined from records - seismograms recorded by seismic stages. The magnitude marked with the letter A is called the intensity class of an earthquake. For example, 1012 J of energy is released from the center of an earthquake with a magnitude equal to 5 (M q5), that is, K q 12. Various seismic scales have been proposed to express the power of an earthquake.

One of them is the 12 - items Mercalli – Kankani - Zybyerg scale adopted by the International Seismic Association, which is still used in several European countries, which is accepted in 1917.

The second is offered by Wood and Newman in the USA in 1931. The Mercalli scale is a slightly improved 12 - items MM scale. The third is the 12 - items scale developed by S. V. Medvedev in Russia.

The MShKq 12 - point scale recommended at the 1964 UNESCO international meeting on seismology and earthquake-resistant construction in Paris was compiled by S. V. Medvedev (Moscow), V. Schonheuer (Jena, Germany) and V. Karniklar (Prague).

There are many ways and signs to determine the strength of an earthquake. Although the manifestation of the Pekin (Beijing) earthquake on the earth is determined in points, the points do not represent the exact power of the earthquake.

Therefore, the size that shows the real power of an earthquake is the magnitude. At the beginning of 1940s the American researchers Ch. Richter and B. Gutenberg and is expressed as follows:

$$M = LogA(\mu m) + 1.32LogX(km)$$

Here, $A$ is the seismic wave amplitude or displacement in $\mu m$, $X$ is the distance from the location of the seismograph to the epicenter of the earthquake (km).

In international data, the magnitude of an earthquake is measured on the Richter scale. The magnitude of the strongest earthquake can reach 9. Earthquake energy (E) is measured in Joules. The relationship between earthquake power and magnitude is expressed as follows:

$$M1 = LogE–\alpha.M + V$$

Here, $\alpha = 1.8$ and $V = 11$ for weak earthquakes; $\alpha = 1.5$ and $V = 12$ for strong earthquakes.

The line connecting the points of the earthquake with the same strength on the earth's surface is called the isoseist line, and the set of isoseists showing the distribution of the earthquake force in the area is called the isoseist map.

Physical and chemical processes are also activated in the part of the Earth where tectonic movements are activated and around it. For example, the density of rocks, electrical conductivity, magnetic properties, and properties of electromagnetic wave propagation, vertical and horizontal position of the earth's surface can change. The amount of oil, gas, and water obtained through the existing boreholes in these regions changes dramatically, the chemical composition of underground water, the amount of microelements, and gases also change.

These listed factors can be considered as harbingers of an earthquake, which change dramatically and in large quantities on the eve of an earthquake. They are very important in solving the problem of earthquake prediction. In this regard, non-stop research is being conducted in all seismically active regions of the globe on the basis of international and national programs of many years.

The following 3 pieces of information are necessary for effective forecasting of the earthquake that is happening in front of scientists today:

– to determine the area of the earthquake;

– predicting the time of earthquake;

– to determine how high the earthquake will be.

It must be admitted that forecasting earthquakes in advance is a very difficult scientific field. Although it is possible to detect minute signals from seismic data after an earthquake occurs, it is much more difficult to predict what will happen in advance.

While modern science is progressing and humanity is flying in space, scientists are still unable to accurately predict the 3 requirements of earthquakes. According to scientists, the main reason for this is the complex structure of the earth.

Another process that will require artificial intelligence is the creation of an earthquake prediction algorithm. Chinese university professors have developed such tools. These tools assess post-disaster damage through satellite imagery. It is predicted that the wide application of artificial intelligence and ICT in this field will solve this problem.

It is hoped that computer algorithms will be able to detect the aftershocks of the main earthquake. In this, the buildings damaged by the main earthquake and which may pose a danger to people will be identified and they will be relocated. This alone can be of great benefit to the safety of rescuers and earthquake survivors.

Currently, the intensive penetration of IT technologies into all fields and their integration with the field are conducting research, expressing their thoughts and opinions about creating an opportunity for scientists to detect earthquakes in advance as much as possible. As we know, field researchers are using seismic data signals to study the behavior of animals in the moments before an earthquake occurs, from disturbances in the movement of electrons in the upper atmosphere.

Artificial intelligence is also becoming more likely to identify informational signs that people miss. In these cases, the methods, algorithms, and programs that should be created to predict future earthquakes by creating accurate sensors and computer analysis of the data from the earthquakes can help.

## 4 Conclusion

In conclusion, it is necessary to develop a disaster resilience program, that is, to identify, prioritize and plan disaster preparedness measures (including a crisis management system), as well as to implement seismic risk reduction:

* increasing the scientific potential for natural disaster risk management;
* to help identify risks for the strengthening of buildings and structures under construction;
* strengthening crisis management systems through disaster preparedness;
* managing the financial consequences of natural disasters and promoting economic opportunities.

Seismo tectonics of strong earthquake focus is studied on the basis of geological-geophysical data set, its connection with modern endogenous regimes is determined, and the method of dividing the earth's crust into types is used, and the regions where possible strong earthquakes can occur are separated.

Probability of predicting an earthquake requires the use of artificial intelligence tools and the devoloping of an algorithm. Chinese university professors have developed such tools. These tools assess post-disaster damage through satellite imagery. It is predicted that the widespread use of artificial intelligence and ICT in this field will solve this problem.

Taking into account the above mentioned approach, it is appropriate to use the following complex of geological-geophysical data (heat flow density, thickness of the earth's crust, heights of the modern relief, isotactic anomalies of gravity, depth of consolidation of the Paleozoic foundation) when dividing the earth's crust into types. $\Delta$T magnetic anomalies, the density of earth faults, the amplitude of neo tectonic movements, the study of the spectral spatial characteristics of seismicity, that is, the study of the characteristic dimensions of seismically active regions and the determination of their measurement levels.

Studying the reasons why strong earthquakes occur mostly at night may be thought.

Studying of the spectral temporal characteristics of seismicity, which is, determining the characteristic activation time of seismically active areas and determining the nature of the relationship between spatial and temporal characteristics may be obtained.

Studying the distribution and redistribution of elastic stresses both in the earth's crust and in its deeper parts, considering taking into account the specified spatio-temporal characteristics may be goaled.

Comparison of the obtained results with existing hypotheses about the nature of seismicity and seismogenic stresses will be studied.

## References

AFAD. (2023). Kahramanmaraş Earthquakes Evaluation Report. Disaster and Emergency Management Presidency (Report) (in Turkish).

Artikov, T.U., Ibragimov, R.S., Ibragimova, T.L., & Mirzaev, M.A. (2017). *Synoptic long-term forecast of places of expected seismic activity on the territory of Uzbekistan.* Georisk, *2*, 20–28.(In Russian)

Bachmanov, D.M., Kojurin, A.I., & Trifonov, V.G. (2017). Database of active faults in Eurasia. *Geodynamics and Tectonophysics, 8*(4), 711–736.

Belousov, V.V., Pavlenkova, N.I. (1985). Earth's crust types. *Geoteknika,* 1, 3-14. (In Russian)

Bezrodnyj, E.M., Tujchiev, H.A. (1987). *Focal mechanisms of strong earthquakes in Uzbekistan.* Tashkent: FAN, 144 p.

Earthquakes in Central Asia and Kazakhstan. Dushanbe: Donish. (1979-1988).

Rebetsky, Yu.L., Kuzikov, S.I. (2016). Active faults of the northyern Tien Shan: tectonophysical zoning of seismic risk. *Russian Geology and Geophysics, 57*(6), 967–983.

Rebeckij, Ju.L. (2007). Stress state favorable for large-scale brittle fracture of rocks. *Dokl. RAN, 416*(5), 106–109.

Rebeckij, Ju.L. (1997). Reconstruction of tectonic stresses and seismotectonic deformations: methodological foundations, poles of modern stresses in Southeast Asia and Oceania. *Dokl. RAN, 354*(1), 101–104.(In Russian).

Rebeckij, Ju.L., Ibragimova, T.L., Ibragimov, R.S., & Mirzaev, M.A. (2020). Stress state of seismically active regions of Uzbekistan. *Issues of Engineering Seismology, 47*(3), 28–52.

Rebeckij, Ju.L., Sycheva, N.A., Sychev, V.N., Kuzikov, S.I., & Marinin A.V. (2016). Stress state of the crust of the Northern Tien Shan according to the KNET seismic network. *Geology and geophysics*, *57*(3), 496–520.(In Russian).

Reisner, G.I. (1980). *Spatial distribution of seismic hazards.* Nedra (In Russian).

Reisner, G.I., Johanson, L.I., Reisner, M.G., Baranov, Y.E. (1993). Typification of the earth's crust and modern geological processes.(In Russian).

Reisner, G.I, Reisner M.G. (1987). *Modern Endogenous Regimes.* AS USSR.(In Russian).

Riznichenko, Y.V. (1985). *Selected works. Problems of seismology.* Publishing of AS of USSR, 408p.(In Russian).

Tukhtasinov, A. Kh., Khusanbayev, D.D., & Atabayev, D.Kh. (2021a). Classification of the earth crust of uzbekistan according to geological - geophysical data. *Science and Innovative Development*, 5, 44-54.

Tukhtasinov, A., Khusanbayev, D., Atabayev, D., & Mukhammedrakhimov, C. (2021b). Modern endogenous regimes and evolution of the earth's crust of Uzbekistan. *An International Multidisciplinary Research Journal, 11*(12), 940-949.

Khusanbayev, D.D. (1991). Modern endogenous regimes and seismotectonic features of strong earthquake foci (on the example of Uzbekistan). Ph.D. Thesis, Uzbekistan.

Junga, S.L., (1990). *Methods and results of studying seismotectonic deformations.* Moscow, Nauka, 190p. (In Russian).

Ulomov, V.I. (1974). *Dynamics of the Earth's Crust in Central Asia and Earthquake Forecast.* Tashkent: FAN, 216p. (In Russian).

Ibragimov, R.N., Nurmatov, U.O., & Ibragimov O.R. (2002). Seismotectonic method for assessing seismic hazard and issues of seismic zoning. Tashkent: Gidroingeo, 59–74.(In Russian).

Li, M., Wang, H., Liu, J., & Shen, X. (2022). Two Large Earthquakes Registered by the CSES Satellite during Its Earthquake Prediction Practice in China. *Atmosphere, 13*(5), 751p.

Liu, T.Y., Li, G.Z., Liu, Y., Wu, G.F., & Wang, W. (2006). Estimation of the Future Earthquake Situation by Using Neural Networks Ensemble. *International Symposium on Neural Networks, Advances in Neural Networks,* 1231–1236.

Ai, Y., Wang, X. A., Yong, S. S., & Sun, C. (2020, August). An earthquake prediction model based on precursor window detection. *Journal of Physics: Conference Series, 1601*(5). IOP Publishing.