Neural Network Forecasting of Earth Globe Seismic Activity Level

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Abstract. In order to develop the scientific and technical foundations of creating an artificial intelligence system for monitoring tectonic origin emergencies, the paper in the results of modeling and forecasting conducted on the basis of neural network technologies, total number of occurrences, with discretion in one month, earthquakes on Earth as one of the main characteristic indicators of the seismic activity of the Earth's globe are presented.

Keywords. emergency, earthquake, tectonic source emergencies monitoring, artificial intelligence system, artificial neural network, neural network simulation, seismic activity level prediction

1 Introduction

The tendency to an abrupt increase in the number and destructive power of natural disasters over the past few decades of the life of society leads to a deterioration of socio-economic and environmental consequences. It indicates the need to develop effective measures to prevent and eliminate emergencies (ES) of various nature on the Globe [1–3].

A promising direction for solving this problem is the development of an effective hazard detection system at the stage of their inception. Also, the causes will be establishing of the occurrence these factors manifestations and effects on them in order to prevent the occurrence of emergencies. This has been implemented on the basis of the classical control loop presented in Fig. 1 [4–7].

This article is part of a planned set of scientific studies aimed at developing a safety system. This eliminates or minimizes losses as much as possible under conditions of manifestation of an emergency. The work is focused on studying the processes of emergence and spreading of emergencies of lithospheric origin, which represent or may pose a serious danger to the life of society [8–12].

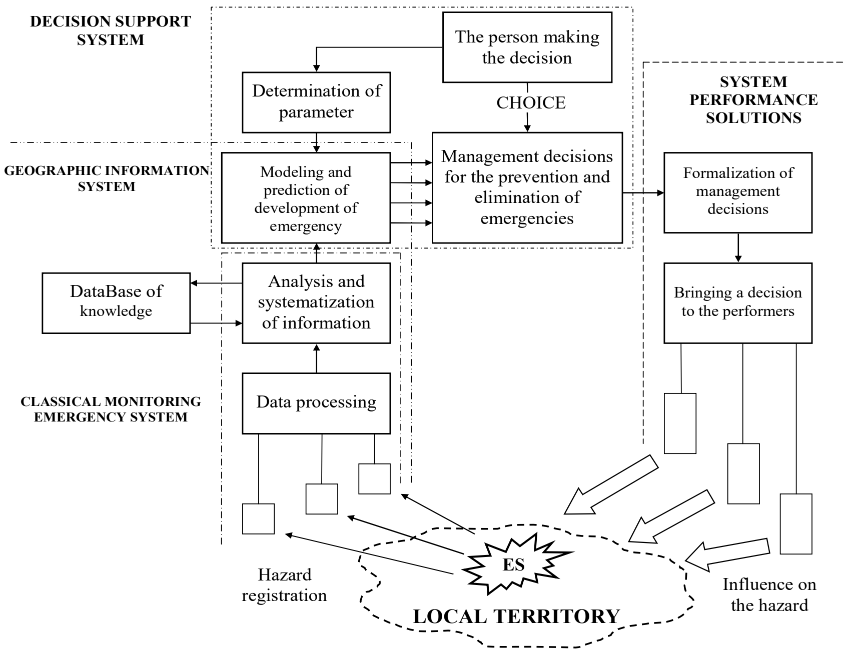

Fig. 1. Diagram of the emergencies monitoring structure as a means of control (Source: author's own elaboration)

When solving the problem of creating an artificial intelligence system for monitoring emergencies of the tectonic nature, there is a need to studying and simulation the processes of occurrence and propagation of the seismic activity level of the local territory under the conditions of seismic activity of the Earth's globe, as an element of the system of nonlinear energy interactions Sun – Earth – Moon.

2 Formal problem statement

Development of scientific and technical bases for creation of artificial intelligence system for monitoring of tectonic origin of the emergency, which is realized by constructing neural network models of forecasting the level of seismic danger of the Earth's territory by the amount and destructive energy of the emergency of tectonic origin.

The construction of neural network models for predicting the level of seismic danger in the Earth's globe was performed using the STATISTICA statistical package [13, 14].

3 Literature review

Today, the basis of predictive observations of Earth's seismic activity is knowledge of the physical laws of the earthquake mechanism and control of the physical fields in the seismic zone [15–19]. The basis of these studies is the idea of the absence of external factors affecting the study area that arise in the system of nonlinear energy interactions Sun – Earth – Moon.

The mechanistic approach, which has been developing in various countries for quite some time, has provided answers to many questions about the preparation of the earthquake. Currently, more than a dozen earthquake models have been developed, the most famous of which is following papers [20–22]:

– a model of avalanche-unstable crack formation (AUC), which consists in the rapid growth of the number of cracks, their interaction with each other and eventually the occurrence of a main or main rupture, the shift of which instantly drops the accumulated elastic with the formation elastic waves;

– dilatant diffusion model (DD), in which crack formation also plays a decisive role, but unlike the AUC model, fractures occur and the presence of water in the rocks of the epicentral region is essential;

– consolidation model of earthquake preparation (Dobrovolskiy's model) describes earthquake preparation as a process of emergence and evolution of rigid inhomogeneities in a continuous environment, as well as some other models that emerged as a generalization of the study of stress and fracture processes of solids samples in the laboratory and their subsequent transfer to natural seismic events.

At the same time, the following methods are now used to obtain a comparative assessment of the level of life-threat in the conditions of manifestation of a emergency [23–30]:

– statistical, based on the analysis of emergency statistics on local territories over several years to determine the risk indicators;

– probable, based on the application of mathematical models, which connects the prerequisites for the appearance of emergency with the possibility of their manifestation;

– expert based on expert judgment in combination with fuzzy set theory.

The advantage of the statistical method is objectivity. Probable and expert methods allow to take into account the sources of potential danger, which are rare in the form of emergencies, but the consequences of which are catastrophic. However, the probable method is extremely cumbersome and time-consuming, requiring a large number of outputs, which results in low accuracy of the results obtained. In the absence of tried and tested mathematical models and reliable enough initial data for them, it is advisable to carry out an expert evaluation of the impact on the possibility of implementing large-scale emergencies of a large number of difficultly formalized initial data.

The prospects of using a statistically probabilistic approach to predict earthquakes in a separate Earth globe, without taking into account the external factors (as an element of the Sun – Earth – Moon nonlinear energy interaction system), are given in [31]. This paper presents the results of a study of earthquake prediction in the northwestern area of Vietnam using neural network technologies.

Thus, the use of neural network technologies is one of the promising directions for the development of approaches to predicting earthquakes across the globe into systems of nonlinear Sun – Earth – Moon interactions. This determines the direction of our scientific research in the field of monitoring of the tectonic origin emergencies [8–10, 32–34].

4 Particularities of the processes occurring in the Sun – Earth – Moon system and affecting the level of seismic hazard of the Earth's globe functioning

The dynamics of the physical processes of the Sun – Earth – Moon system affecting the seismic hazard level of the local territory functioning can be schematically represented according to Fig. 2 – 4. This can be characterized by the following spatial constructions within the solar galaxy.

1. The axis of rotation of the Earth in the celestial sphere describes a complex wave-like trajectory. The points of the axis of rotation are at an angular distance of about from the pole ecliptic (Fig. 2). The vertex of the cone coincides with the Earth center. The points of equinoxes and solstices move along the ecliptic towards the sun. Moments of gravitational forces influence on the equatorial bulges and vary depending on the positions of the Moon and the Sun relative to the Earth. When the Moon and the Sun are in the plane of the Earth's equator the moments of forces disappear. If tilts of Moon and Sun are the maximum, then the magnitude of the torque will be greatest. The nutations, owing to fluctuations in the moments of the forces of the axis of rotation of the Earth have been observed by consist of a series of small periodic oscillations. The main nutations have a period of 18.6 years - the time of the orbital nodes of the Moon. Movement with this period occurs on an ellipse. The major axis of the ellipse is perpendicular to the direction of the precessional motion and is equal to; small - parallel to it and equal. Next in magnitude of the amplitude are the components with a period of 0.5 year, 13.7 days., 9.3 years, 1 year, 27.6 days. etc., therefore the trajectory has the form of "thin laces" (shown on the enlarged fragment in the left part of Fig. 2) [35–38].

2. The pressure from the solid inner core and the surrounding melt (outer core) onto the mantle arises as a result of the eccentric revolution of the Earth's shell around the displaced inner core, which squeezes the shell from the inside. The forces compressing the shell of the sphere (planet) and drawing it inward to the core arise in other parts of the planet. This process has two components: impact at the expense of the annual displacement of the center nucleus relative to the center of the globe (Fig. 2 – 4); impact at the expense of eccentric circulation of the core relative to the lower mantle, when due to the difference in angular rotation velocity of the core and lower mantle (ω_1 – angular velocity of rotation of the mantle; ω_2 – angular velocity of rotation of the outer core; ω_3 – angular velocity of rotation of the inner core;

$\Delta\omega = \omega_2 - \omega_1$ – angular velocity of rotation of the outer core relative to mantle ("western drift")), therefore, there are zones of high pressure and vacuum ($P_1 \neq P_2$ where P_1 and P_2 are indicators of pressure of the inner core of the globe on its surface), affecting the level of seismic activity of the surface of the Earth (Fig. 3). As long as there is a difference in the angular velocity of rotation and displacement of the nucleus, the appearance of such zones will be maintained [39, 40].

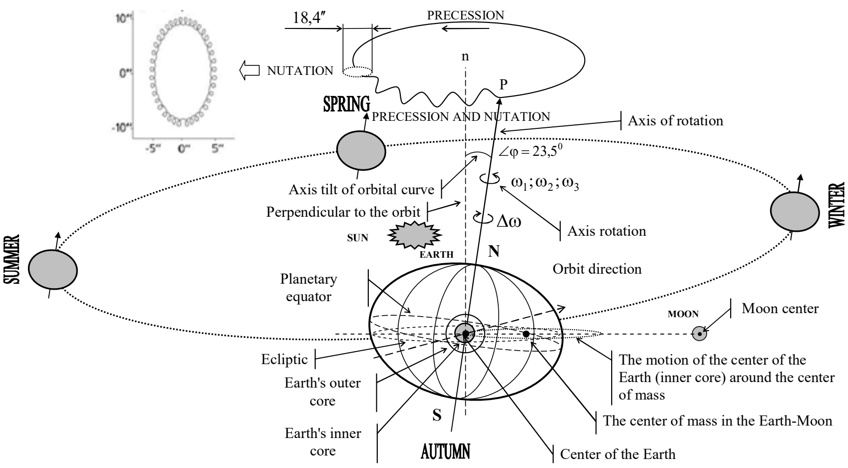

Fig. 2. Motion diagram of the inner core of the Earth in the Sun–Earth–Moon system (Source: author's own elaboration)

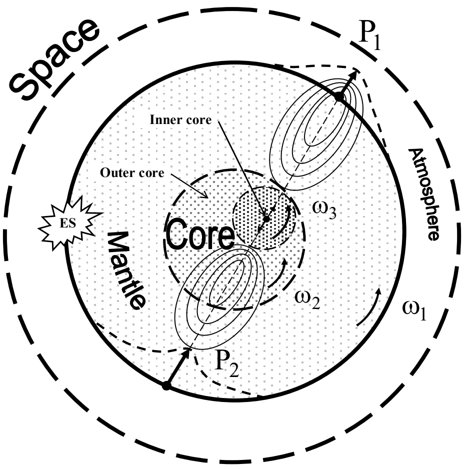

Fig. 3. Influence diagram of internal core oscillations on seismic activity (Source: author's own elaboration)

3. Internal elastic stresses arise in the process of moving lithospheric plates (Fig. 4), which are energy sources of earthquakes. The occurrence depth of elastic stresses depends on the nature of a movement plates. The relative motion of lithospheric plates leads to the emergence of shallow (not deeper than 20–25 km) earthquake sources and dipping of lithospheric plates into the mantle initiates the appearance of sources of deep (exceeding 70 km) earthquakes. The probability of elastic stresses - sources of earthquakes decreases with increasing distance from the interface of the lithospheric separation plates.

4. Surface and bulk seismic waves are the propagation factors of earthquake hazards Z_0, that can cause secondary earthquakes [41, 42].

5. The probability of mutual amplification or weakening of bulk seismic waves increases in the process of spatial-vibrational movement of the Earth's internal core and its effect on the external core. Consequently, the possibility of secondary earthquakes Z' increases also [43].

7. The territorial-temporal changes in the intensity of the natural electromagnetic field pulses of the Earth initiating anomalous processes in the atmosphere occur due to the movement of the Earth's inner core has been established [44–46].

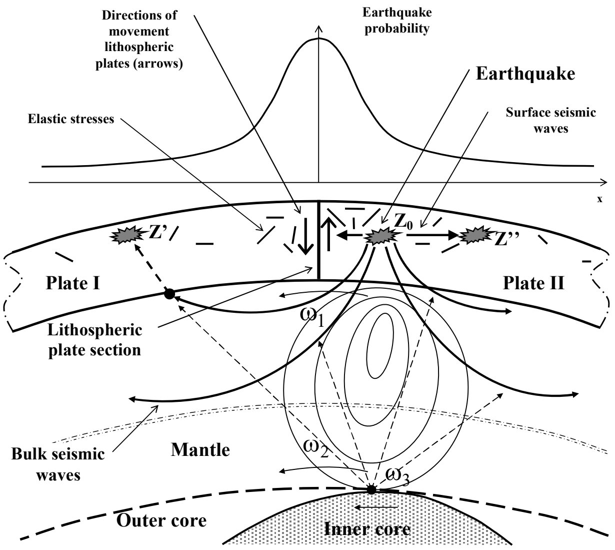

Fig. 4. Process diagram of earthquake and the spread of seismic activity (Source: author's own elaboration)

Thus, combining the analysis results of the impact dynamics and energy of the internal physicochemical processes of the Earth on the origin generating tectonic processes allowed to formulate an approach to studying the nature of seismic phenomen. It is an important tool for analyzing the results of civil defense research on the development of models for the development of ES tectonic nature.

5 Experiments and results of neural network prediction of the level of seismic activity of the Earth

According to the purpose of the research, the solution of the scientific problem in the work is ensured by constructing an artificial neural network (ANN) model – a model for predicting the level of seismic activity of the planet from the conditions of the system functioning of nonlinear energy interactions Sun – Earth – Moon. This is a time series model, where the initial indicator, according to Fig. 5, is the total number of earthquakes in the world $N_{\Sigma}(t)$ (provided that $M \geq 5$ the magnitude of the earthquake), depending on the current time of analysis (t), as well as the distance of the Earth's inner core from the center of the planet $\Omega(t)$ and the change in the length of day $LOD(t) = S(t) - 86400s$ (where $S(t) = \frac{r_0}{r(t)} 86400s$ – the length of day, $r_0 = 7{,}292115 \cdot 10^{-5}$ rad/s – constant (average) angular velocity of the Earth's own rotation).

For the development presented in Fig. 5 models have a multilayer perception (MLP) selected. The input parameters of this model are the results of the analysis of the monthly dynamics of indicators, $N_{\Sigma}(t)$, $\Omega(t)$ and $LOD(t)$ for $2009 - 2018$, which are presented in [8–10, 32–34] and Fig. 6.

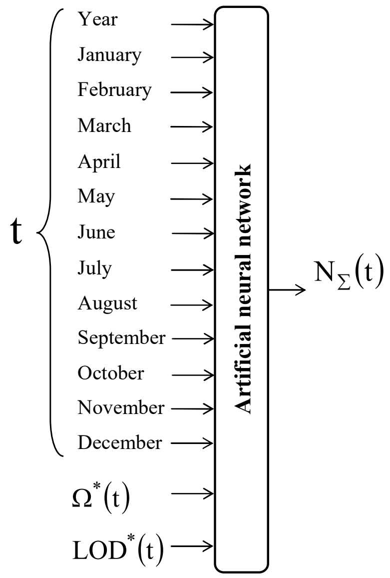

Fig. 5. Scheme of the ANN time series model for the monthly forecasting of the Earth's number of earthquakes, depending on the indices of the remoteness of the Earth's inner core from the center of the planet and changes in the length of day (Source: author's own elaboration)

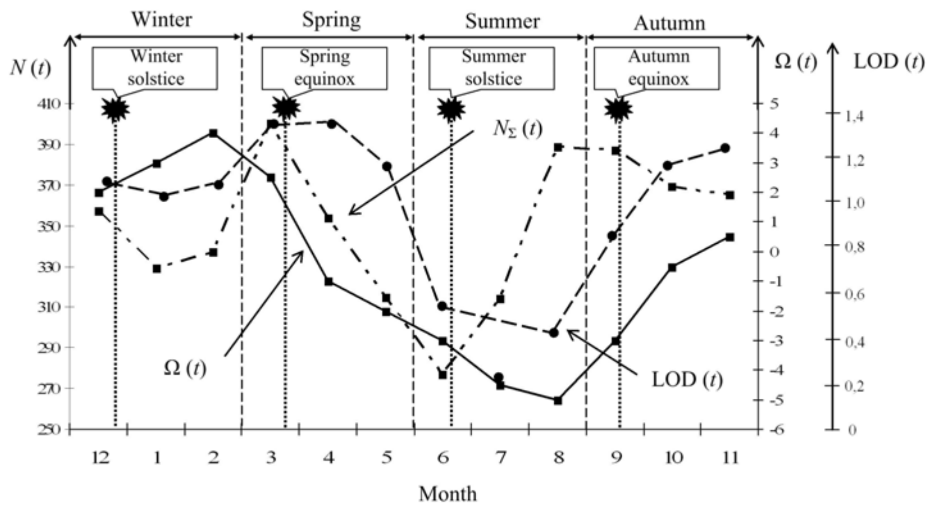

Fig. 6. Monthly dynamics of the variations in the rate of variation of the Earth's axial rotation ($\mathrm{LOD}(t)$), the distance of the inner core from the center of the Earth ($\Omega(t)$) and the total seismic activity ($N_{\sum}(t)$) with magnitude during 2009 – 2018 are summarized on the Globe (Source: author's own elaboration)

When developing a mathematical model for predicting the level of seismic activity of the Earth ball, based on the decision parameter $N_{\sum}(t)$ on the complexity of the MLP architecture, it was based on five analyzes of the learning results of networks, which accidentally included five hundred neural networks. The criterion for choosing the optimal network was the relationship between the forecast error and the complexity of the architecture. The results of the analysis are presented in Table 1.

Table 1. Statistical characteristics of the three-layer perceptions suggested by the "decision-maker" as the best for neural network time series analysis of the forecast of the monthly dynamics of the Earth's seismic activity ($N_{\sum}(t)$)

№	Architecture	Study productivity	Control productivity	Test productivity	Activation hidden layer	Activation of yield
1.	MLP 15-199-1	0,944	0,859	0,976	Exp.	Logistic
2.	MLP 15-233-1	0,935	0,634	0,964	Identity	Exp.
3.	MLP 15-243-1	0,939	0,859	0,986	Exp.	Logistic
4.	MLP 15-187-1	0,938	0,884	0,985	Exp.	Logistic
5.	MLP 15-12-1	0,967	0,727	0,668	Tanh	Identity

For neural network training, all observations were divided into three samples. By default, random sampling was performed between samples to avoid retraining the network and to ensure quality generalization (forecasting). The first sample (Educational – 50% of observations) was used to train the network; the second (Control – 25% of observations) – for cross-validation of the learning algorithm during its operation; third (Test – 25% of observations) – for the final independent testing of a trained neural network. The training was done with speed $\eta = 0{,}01$.

Presented in Table. 1 networks are characterized by a more effective balance between modeling error and architecture complexity for time series analysis of the forecast of the monthly dynamics of Earth's seismic activity ($N_{\Sigma}(t)$). This was the basis for further construction of the three-layer MLP 15-12-1 network, which has fifteen inputs (Fig. 5), 12 elements in the hidden layer and one logical output function of thirteen inputs, presented in Fig. 7.

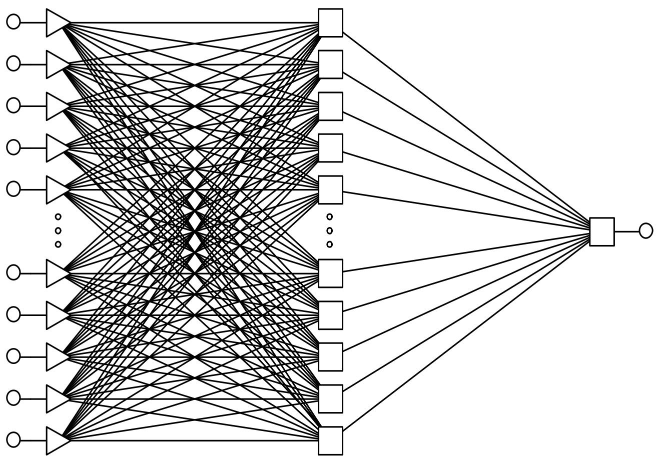

Fig. 7. MLP 15-12-1 Three-Layer Perceptron Architecture with Logical Signal Transmission for Time Series Prediction of Globe Seismic Monthly Dynamics ($N_{\Sigma}(t)$) (Source: author's own elaboration)

In this case, the use of logical activation functions, with scaling parameters, was based on a given fraction of span of a logical function equal $0{,}9$ (respectively range $[0{,}05; 0{,}95]$) to the range of training of the neural network. The function of activating the hidden layer of the perceptron MLP 13-10-1 is hyperbolic tangent. This allows for a slight extrapolation of the data. In addition, the use of logical functions stabilizes learning.

The results of checking the adequate prognostic performance of MLP 15-12-1 network are presented in Fig. 8, where the dependence observed ($N^{*}_{\Sigma}(t)$) statistic the values of the Earth's seismic activity indicator via predicted ($N_{\Sigma}(t)$) values. The coefficient of correlation between these indicators on the results of the training "Educational Choice" is equal $r^2_{N^*_\Sigma(t)N_\Sigma(t)} \approx 0{,}967$.

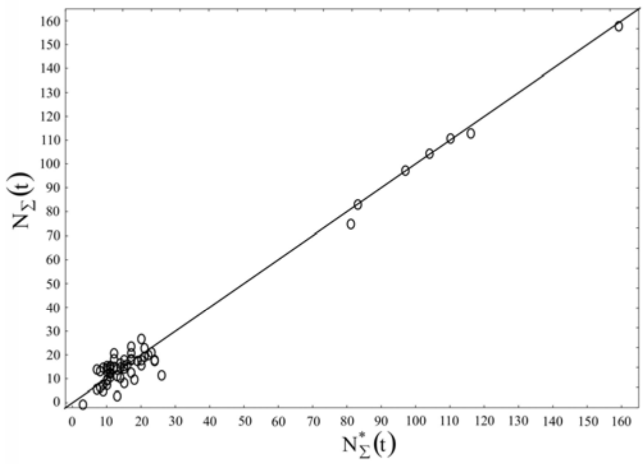

Fig. 8. Dependence of observed ($N^*_\Sigma(t)$) statistic values of the Earth's seismic activity indicator by via predicted values ($N_\Sigma(t)$) by MLP Network 15-12-1 (Source: author's own elaboration)

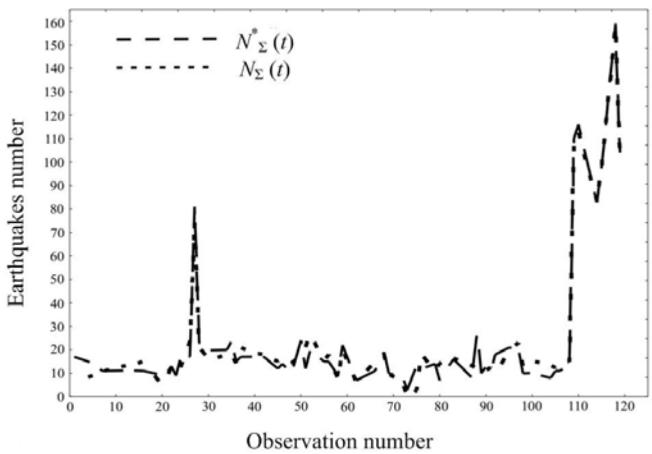

Fig. 9. Graph of the time dependence (of observation number) where the dependence observed ($N^*_\Sigma(t)$) statistic the values of the Earth's seismic activity indicator via predicted ($N_\Sigma(t)$) values by MLP network 15-12-1 (Source: author's own elaboration)

The graph of time dependence (from observation number), with the appropriate level of prognostic adequacy, where the dependence observed ($N_{\Sigma}^{*}(t)$) statistic the values of the Earth's seismic activity indicator via predicted ($N_{\Sigma}(t)$) values by the MLP 15-12-1 network is presented in Fig. 9.

According to the data analysis Table 2 it is necessary to state that obtained within the limits of the ideas about the dynamics of physical processes that occur in the system Sun – Earth – Moon and affect the level of seismic danger of functioning of the local territory of the planet (see Fig. 2 – 4), the MLP neural network 15-12-1 and the results of its forecast allow us to ascertain the adequacy, in accordance with the data of Figs. 8 and the $r^2_{N_{\Sigma}^{*}(t)N_{\Sigma}(t)} \approx 0{,}967$ parameter figure presented in Fig. 5 models for predicting the level of seismic activity of the globe.

Table 2. The result of the prediction by the MLP network 15-12-1 level of seismic activity-those of the Globe

t	2019											
	01	02	03	04	05	06	07	08	09	10	11	12
$\Omega^{*}(t)$	3,00	4,00	2,50	-1,00	-2,00	-3,00	-4,50	-5,00	-3,00	-0,50	0,50	2,00
$LOD^{*}(t)$	0,81	1,00	0,96	0,98	0,70	0,19	0,01	0,05	0,17	0,27	0,37	0,24
$N_{\Sigma}^{*}(t)$	120	104	118	113	93	103	117	127	131	137	138	123
$N_{\Sigma}(t)$	116	113	132	120	83	97	125	141	144	124	147	138
$\delta_{N_{\Sigma}(t)}$,%	3	9	11	6	10	6	7	11	9	9	7	12

6 Conclusion

The paper presents a neural network model of the time series for the monthly forecasting of earthquakes with magnitude $M \geq 5$. The obtained neural network allows us to predict the level of seismic activity of the globe with adequacy at the level $r^2_{N_{\Sigma}^{*}(t)N_{\Sigma}(t)} \approx 0{,}967$.

The results obtained are the basis for the development of scientific and technical bases for the creation of a system of artificial intelligence for the performance of tasks of monitoring of tectonic origin.

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