VIBRATION FORECAST IN EUROPE FROM THE RESULTS OF GROUNDWATER MONITORING ON THE TERRITORY OF UKRAINE

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The article provides theoretical and practical arguments regarding the possibility of predicting local and strong distant earthquakes around the world, based on the detection of anomalous behavior of the groundwater physical properties in the Earth's tectonically stressed zones before local and strong earthquakes. The authors suggest that many strong and major events can be predicted at least a few months before they occur. The theoretical positions of the authors are confirmed by the successful prediction of an earthquake that occurred in Ukraine on January 21, 2022.

KEYWORDS

Trend of the amplitude, forecast model, shocks environment criticality.

1 INTRODUCTION

Earthquakes are the terrible natural disasters that strike without prior notice and cause loss of life and damage to residential and industrial infrastructure. For many centuries, mankind all over the world has been looking for ways and possibilities to predict strong earthquakes. At the same time, earthquake prediction includes an early determination of the occurrence time, location and magnitude of a future earthquake and offers specific information about the corresponding magnitude range and space-time window [Geller 1997, Ismail-Zadeh 2013]. Despite the scientists' different attitudes towards earthquake predictions, attempts to predict the time and location of its occurrence still continue. Earthquake prediction research is based on methods for detecting the presence of preliminary changes (anomalies) in the observed geophysical or geochemical parameters when seismic activity changes in a particular region. These parameters include electric and magnetic fields, water level and temperature, gas emissions from the ground and the appearance of springs, surface temperature and surface deformations of the daytime relief, seismicity [Rikitake 1975, Cicerone 2009]. Changes in the ionosphere are also being investigated for earthquake prediction or early warning [Chen 2004, Kunitsyn 2014, Lin 2015, Ulukavak 2020, Nekrasov 2020].

As a rule, different research methods are carried out in seismically active zones or near them. Regular monitoring and various types of research in countries located in seismically active zones are carried out in order to reduce the consequences of the impact of strong earthquakes on the technosphere [Roeloffs 1988, Skelton 2014, Martinelli 2015, Huang 2017].

Long-term and numerous studies by seismologists and hydrogeologists have shown that stresses caused by earthquakes are accompanied by hydrological and hydrogeological reactions. The physicochemical groundwater attributes are considered to be one of the most promising prognostic parameters and often used among the various earthquake's precursors [Wang 2016, Nahornyi 2020]. Earthquake observation and prediction research using groundwater monitoring data is called earthquake hydrology or hydroseismology and is conducted in seismically active zones in the United States [Merifield 1984, Roeloffs 1988], China [Huang 2017], Japan [Koizumi 2013], Taiwan [Song 2003, Yeh 2015], India [Kumar 2009] and Russia [Kopylova 2021].

The groundwater response to earthquakes is the result of a complex interplay of various factors such as earthquake magnitude, distance from the epicenter, hydrogeological conditions, and controlled well design; hydrogeological conditions include the aquifer types, bedrock, and the presence of large faults in the observation vicinity [Macala 2009].

In addition, studies of the change precursors occurrence, including seismicity, surface deformation, geoelectromagnetism, and subsurface fluids, have shown that change precursors do not occur before every earthquake [Yue 2005]. Preliminary changes in groundwater are thought to be related to changes in volumetric deformation of the earth's crust [Roeloffs 1988] or changes in static and dynamic stress. These deformations are indirectly estimated from the change in water level recorded in observed deep wells [Wang 2010, Pigulevskiy 2010].

In this context, several researches have suggested that the timing, variation pattern, extent and spatial changes distribution in water level and quality can help predict the timing, location, and magnitude of earthquakes [Rikitake 1979, Igarashi 1992, Kingsley 2001, Cicerone 2009, Hwang 2020]. The groundwater response to earthquakes is the result of a complex interplay of various factors such as earthquake magnitude, distance from the epicenter, hydrogeological conditions, and monitoring well design; hydrogeological conditions include aquifer types, bedrock and the presence of large faults in the observation vicinity. Preliminary changes in groundwater are considered to be related to changes in volumetric deformation of the Earth's crust [Brodsky 2003] or changes in static and dynamic stress. These deformations are indirectly estimated from the change in water level recorded in observed deep wells [Wang 2010, Pigulevskiy 2010 & 2011a,b].

2 METHODOLOGY

The measurement results processing in control wells consists in organizing the collection, storage, replenishment, and presentation of observational data using computer tools and in highlighting useful signals against the interference background [Cooper 1965, Panda 2013, 2014, 2016, 2019 and 2021, Valicek 2016 & 2017, Pandova 2018, Bozek 2021]. Hydrogeo-seismic variations in the water level are considered as useful signals. Collection, storage, and visualization of measurement results is carried out using information systems specially developed for this purpose. Hydrogeoseismic variations form numerical series compiled with a certain time step, reflecting the dynamics of water level variations in the control well.

An important principle here is an individual approach to the processing of each time series. This is due to the formation peculiarities of the control well hydrodynamic regime, taking into account the experience gained over its operation period. This experience takes into account the peculiarities of water level changes under the influence of the regime-forming complex factors, the possibility of distinguishing hydrogeoseismic variations, the degree of time series noisiness due to the influence of non-seismic factors, as well as sensitivity to water level registration intervals.

To determine the relationship between the hydrogeological precursors and local or remote strong earthquakes, monitoring observations of groundwater level fluctuations in a well in Kryvyi Rig (Fig. 1) with a depth of 815.0 m are carried out at a static water level of -106.0 m from the day surface [Pigulevskiy 2011a,b and 2012].

Figure 1. Observing well location map in the central part of Ukraine: 1 – Kryvyi Rig. The well coordinates is follow: N: 47.91°, E: 33.39°;

It is located within the Kryvyi Rig iron ore structure in the central part of the Ukrainian Shield (USh) of the East European Platform. Well monitoring, starting from December 2007, is carried out using stand-alone groundwater level sensors MiniDiver-10 manufactured by Schlumberger-Eijkelkamp with a time interval of 6 minutes [Hyun 2021]. Continuous monitoring and analysis of the changes results in groundwater associated with regional changes in stress and deformation in the earth's crust shows the associated short-term and long-term fluctuations in the level of groundwater in the well (Fig. 2).

The largest Precambrian iron ore basin in Europe is located within the Kryvyi Rig iron ore structure. In tectonic terms, the structure is located in the eastern part of the Ingulets-Kryvyi Rig-Kremenchug suture zone. The zone crosses USh in the meridional direction and has a length of more than 300 km and a width of 10 km. At present, it is the source of modern seismicity in the central part of the USh, as our observations show [Pihulevskyi 2021].

According to the results of seismic observations, the Kryvyi Rig-Kremenchug fault has a westerly dip. It passes through the entire earth's crust with fall turns from 75-80° (basement surface) to 45-55° (at the bottom of the earth's crust). Also, younger large tectonic faults of the sub latitudinal direction were traced in the earth's crust. An analysis of regional gravimetric and magneto metric maps [Svistun 2021] shows that in the southern direction it continues in the Black Sea, and in the northern direction it continues through the Dnipro-Donetsk aulacogen in the Voronezh crystalline massif.

The Kryvyi Rig iron ore basin (Kryvbass) has been actively developed since the middle of the 19th century. The greatest intensity of ore mining fell on 80-90 years of the last century. The main tool in the extraction of iron ore is powerful blasting, which is carried out in quarries and mines. And at the same time, large volumes of masses are redistributed from depth to the surface. Together they affect the elastic-deformation state of the Kryvbass rock mass, which is the cause of man-made and natural seismic events. Local seismic events that occur in tectonically weakened zones of central Ukraine with a high level of technogenic load have, for the most part, an insignificant magnitude.

Monitoring of these zones makes it possible to reveal the presence of elastic-deformation changes in the tectonic zone and the precursors associated with them, which begin to behave anomalously before strong events, while the size of these areas can be different [Nahornyi 2020, Elshin 2021].

Over time, monitoring results form a time series describing the change in water level over the observation period. This series is approximated [Nagornyi 2018, Krenicky 2021] by the model (1) during predicting an earthquake. Model parameter T_{for}, coinciding in value with the estimated earthquake time is determined as a result of minimizing the "discrepancy" (2) of the water level trend $A_0(t_i)$ and the forecast model graph A_{mod} (2), one of its parameters T_{for} is determined, which numerically coincides with the earthquake sought time

$$A_{mod} = A\cdot\left[1+\alpha\cdot\left(\frac{t_i - t_0}{T_{for} - t_i}\right)^{\beta}\right], \qquad (1)$$

$$U = \sum_{j=1}^{m}\left(A_0 - A_{mod}\right)^2 \Rightarrow \min . \qquad (2)$$

where: T_{for} – earthquake time forecasting; A, α, β – model parameters determined in the minimizing the "discrepancy"; t_0, t_i – calendar time at the water level registration for the first and subsequent measurements cases, respectively.

3 RESULTS

The initial data for the analysis were registered from January 24, 2021, to February 9, 2022) in three observing wells as shown in Fig. 1.

The forecasting results are presented in Figs. 2 and 3, Table 1 and in the «Protocol ...».

Fig. 2 shows a graph of the change in the water level in the control well from January 24, 2021, to February 9, 2022.

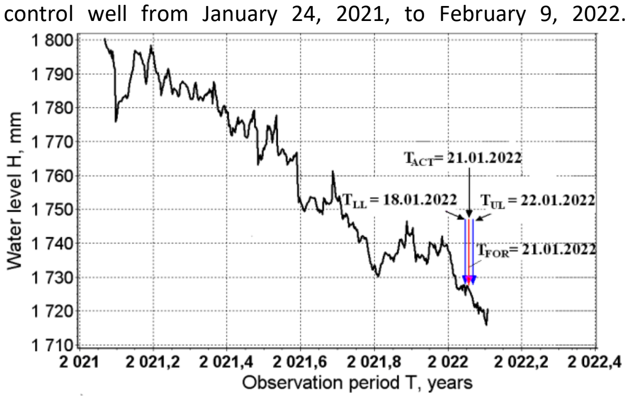

Figure 2. Change in water level in the control well during the year of observations

In Fig. 2, the arrows also mark the actual date of the earthquake (T_{ACT}), the value of the forecast (T_{FOR}), and its confidence (lower T_{LL} and upper T_{UL}) limits.

The results of the short-term forecast are given in Table 1.

Table. 1 Earthquake forecast (actual date of the earthquake 21.1.2022)

Date of predicting	6.12.2021	21.12.2021	6.1.2022	21.1.2022
Forecast date of the earthquake	24.1.2022	22.1.2022	20.1.2022	21.1.2022
Deviation of the forecast from the actual date	0.7 %	0.4 %	- 0.2 %	- 0.1 %
Deviation forecast from actual dates in days	2.85	1.38	-0.71	- 0.36

The change in the forecast over the observation period is shown in Fig.3.

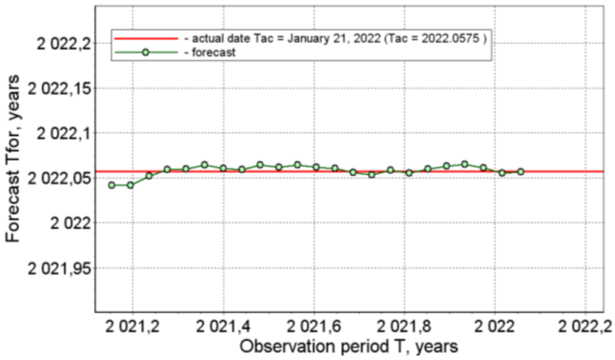

Figure 3. Change during the year of the earthquake time forecasting

Below is the " Forecast Protocol..."

PROTOCOL

earthquake forecast

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|| **Forecast date:** ||

|| **20.1.2022 year** ||

==========================

FORECAST:

forecast quality: - good

The forecast of the most probable date of the earthquake is: 21.1.2022

and changes with a confidence probability P=0.95 within the following limits:

from 18.1.2022 to 22.1.2022

4 DISCUSSION

The water levels, depending on the well, varied from 1800 to 1720 mm (Fig. 2).

As shown by the short-term forecast (Table 1), the deviation of the average value of the forecast from the actual date of the earthquake (January 21, 2022) in the period from December 6, 2021, to January 21, 2022, decreased from less than three days to 9 hours. At the same time, the confidence limits of the forecast change in the range of 4 days, being in the interval of January 18-22, 2022 (Fig. 2, “Forecast protocol").

In a similar range, the long-term forecast also changed throughout the entire period of observation of the variation in the water level in the well (Fig. 3).

Monitoring measurements in the Krivyi Rig well recorded fluctuations in the relative water level from 1800 to 1720 mm (Fig. 2). The performed short-term prediction (Table 1) showed the deviation of its average value from the actual date of the earthquake (January 21, 2022) in the period from December 6, 2021, to January 21, 2022, decreased from less than three days to 9 hours.

5 CONCLUSIONS

The research results show the effectiveness of both long-term and short-term earthquake prediction based on the results of monitoring water level fluctuations in a control well.

Based on the results, the authors suggest that many strong and major events can be predicted at least a few months before they occur. The theoretical positions of the authors are confirmed by the successful prediction of an earthquake that occurred in Ukraine on January 21, 2022, provided that function (2) is used as a forecast model. On this base, time-dimension for a forecast accuracy is proven to be significantly improved.

Authors plan to continue in the improvement of the model and its predictive abilities on the base of the analytic work with data acquired from another important events.

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