

CORRELATION BETWEEN HYDROGEOSEISMOLOGICAL ANOMALIES AND EARTHQUAKES BASED ON DATA FROM THE IOBK BOREHOLE (2002–2024)

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ABSTRACT

This article analyzes earthquakes and their related hydrogeoseismological anomalies recorded between 2002 and 2024, based on data from the IOBK borehole. The results show that earthquakes associated with anomalies were mainly observed in areas located relatively close to the borehole and in the northern direction. At the same time, some earthquakes to the west of the borehole did not exhibit any anomalies. In terms of distance, both nearby and distant earthquakes showed cases where anomalies were present as well as absent. Furthermore, it was noted that anomalies were more frequently associated with stronger seismic events. These findings indicate that the sensitivity of hydrogeoseismological parameters depends on tectonic orientation and hydrogeological conditions, supporting their potential application in seismic prediction systems.

Keywords: *Hydrogeoseismology, Well Data, Earthquakes, Eh, CO₂ Anomalies, Sigma, Background State, Duration, Precursors, Magnitude, Epicenter, Distance*

INTRODUCTION

The chemical, gaseous, microcomponent, radioactive, and isotopic composition of natural waters plays an important role in geological, geochemical, hydrogeological, and, in recent decades, hydrogeoseismological studies.

Observations of Tashkent mineral waters, which began before the 1966 earthquake and have been systematically continued since 1972, indicate that one of the most promising approaches to assessing stress and deformation processes in rocks is the analysis of variations in the gas-chemical composition of groundwater.

Hydrogeochemical anomalies at the Tashkent and Fergana geodynamic polygons are identified through various indicator elements, including carbon dioxide, hydrogen, oxygen, nitrogen, neutral radiogenic gases (helium, argon, radon), and groundwater components such as fluorine, chlorine, boron, and mercury, as well as pH, oxidation–reduction potential (Eh), reservoir and extra-pipe pressure, temperature, and discharge. These anomalies exhibit periodic variations linked to deep tectonic processes. Systematic monitoring of groundwater chemistry and gas composition shows that hydrogeochemical anomalies occur both in epicentral zones and during “transit” earthquakes. Research initiated in Uzbekistan confirms the potential of such studies across other CIS regions and internationally [Kucher *et al.*, 1983].

The main objectives of this study are:

- systematic monitoring of groundwater composition to identify informative parameters;
- establishment of a baseline network of hydrogeoseismological stations in Uzbekistan; and
- validation of results through experimental and analytical approaches.

Currently, continuous monitoring of hydrogeoseismological parameters is carried out in several regions of Uzbekistan, including the Tashkent geodynamic polygon at the Tekstil, IOBK, and Fazilov stations [Anonymous [No date]. This article focuses on the analysis of long-term hydrogeoseismological observations from the Vegetable Research Institute well (IOBK).

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Within the sensitivity zone of the IOBK well, earthquakes of varying magnitudes were recorded during 2003–2023 (Table 1).

Table 1. Earthquakes that occurred within the sensitivity zone of the Vegetable Research Institute well (IOBK) during 2003–2023 [3].

	Date	Latitude	Longitude	Depth	M	R(km)	M/lgR	Epicentr
1	10.11.2003	41,03	67,93	10	5,1	108	2,508085	Kazakhstan
2	08.10.2005	34,53	73,58	26	7,6	852	2,593468	Pakistan
3	08.01.2007	39,80	70,31	16	6	199	2,609997	Tajikistan
4	22.08.2008	41,3	69,4	10	4,8	22	3,575625	Uzbekistan
5	05.10.2008	39,53	73,82	27,4	6,7	445	2,529868	Kyrgyzstan
6	19.07.2011	40,05	71,48	15	6,1	245	2,553192	Kyrgyzstan
7	22.02.2013	41,48	69,11	12,8	4,1	15	3,486124	Kazakhstan
8	24.05.2013	40,93	69,25	13	5,4	48	3,211913	Uzbekistan
9	26.05.2013	40,05	67,44	15	6,1	204	2,641115	Uzbekistan
10	26.10.2015	36,52	70,36	231	7,5	547	2,739238	Afghanistan
11	07.12.2015	38,21	72,77	22	7,2	468	2,696381	Tajikistan
12	08.01.2016	40,94	69,14	10	4,3	45	2,600997	Uzbekistan
13	14.01.2016	41,36	69,24	8,08	4	9	4,191807	Uzbekistan
14	23.01.2018	41,40	68,99	12,29	4,5	14	3,926263	Kazakhstan
15	13.03.2019	41,42	68,97	12	4,6	16	3,820217	Kazakhstan
16	11.09.2021	41,55	68,93	10	4,2	28	2,90224	Uzbekistan
17	05.11.2022	41,57	68,85	13	4,5	34	2,938336	Kazakhstan
18	23.02.2023	38,0	73,22	9	6,9	507	2,550824	Tajikistan

Strong earthquakes: 08.10.2005, Pakistan, **M=7,6**, R=852 км, 26.10.2015, Afghanistan, **M=7,5**, R=547 км, 07.12.2015, Tajikistan, **M=7,2**, R=468 км, 23.02.2023, Tajikistan, **M=6,9**, R=507 км,

Moderate-magnitude earthquakes (M=5–6,5): 10.11.2003, Kazakhstan, **M=5,1**, R=108 км, 08.01.2007, Tajikistan, **M=6,0**, R=199 км, 05.10.2008, Kyrgyzstan, **M=6,7**, R=445 км, 19.07.2011, Kyrgyzstan, **M=6,1**, R=245 км, 24.05.2013, Uzbekistan, **M=5,4**, R=48 км, 26.05.2013, Uzbekistan, **M=6,1**, R=204 км

Local and small-magnitude earthquakes (M < 5): In 2008, 2013, 2016, 2018, 2019, 2021, and 2022, earthquakes with magnitudes ranging from M = 4.0 to 4.8 were recorded mainly in the territories of Uzbekistan and Kazakhstan. The relationship between earthquake magnitude and the distance between the well and the earthquake epicenter is shown graphically in Figure 1. For the selection of earthquakes, Kurilov's formula (**M/logR**) and Yu.V. Riznichenko's table of source parameters in the Earth's crust were

applied. According to Kurilov's formula ($M/\log R$, where **M** is the magnitude and **R** is the distance from the well to the earthquake epicenter), if the value is greater than or equal to 2.5, the earthquake is considered to have occurred within the sensitivity zone of the well. According to Riznichenko's method, an area ten times larger than the earthquake source dimension is regarded as the sensitivity zone of the well. For the IOBK well, earthquakes that occurred within the sensitivity zone were selected using both approaches.

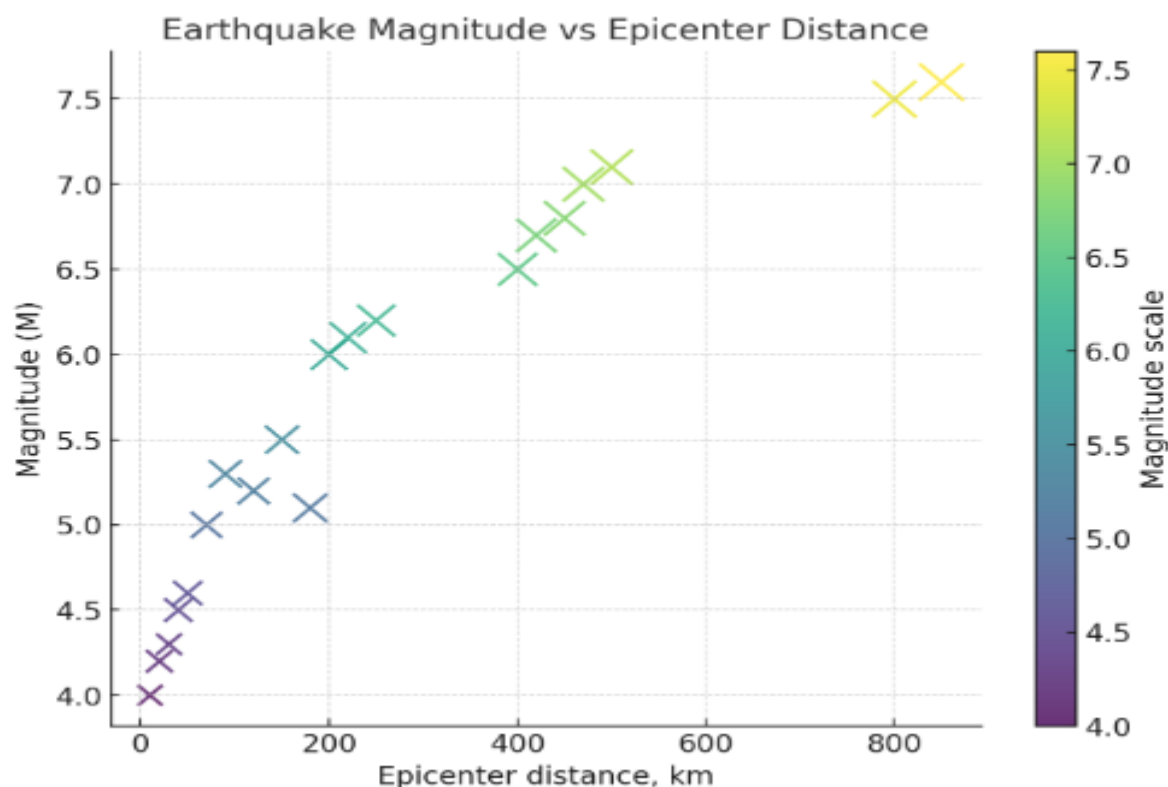


Figure 1: Earthquakes recorded within the sensitivity zone of the Vegetable Research Institute well (IOBK) during 2003–2023.

The distance–magnitude sensitivity model developed for the IOBK well illustrates the degree to which the well can respond to earthquakes occurring at different distances. The graph clearly shows that as the epicentral distance increases, the minimum detectable magnitude also rises. In other words, while weak nearby earthquakes may produce observable variations in the well data, at greater distances only stronger seismic events are likely to be preceded by anomalous changes.

The results of hydrogeoseismological studies conducted at the IOBK well indicate that the most reliable indicators for identifying earthquake-related variations are the Eh and CO₂ parameters. Analysis revealed that deviations of the Eh parameter from its initial background state prior to earthquakes were observed in nearly two-thirds of the events (72%). This highlights the high sensitivity of the Eh parameter and suggests its applicability as a short-term anomalous signal preceding earthquakes.

Based on these general conclusions, the subsequent analysis focuses on the variations of **Eh** and **CO₂** parameters prior to earthquakes, presented in graphical form. The graphs not only demonstrate the temporal dynamics of these parameters but also allow for the determination of the duration and amplitude of deviations relative to the background state. In this way, the degree of correlation between each parameter and seismic events can be visually assessed, thereby further elucidating their prognostic significance.

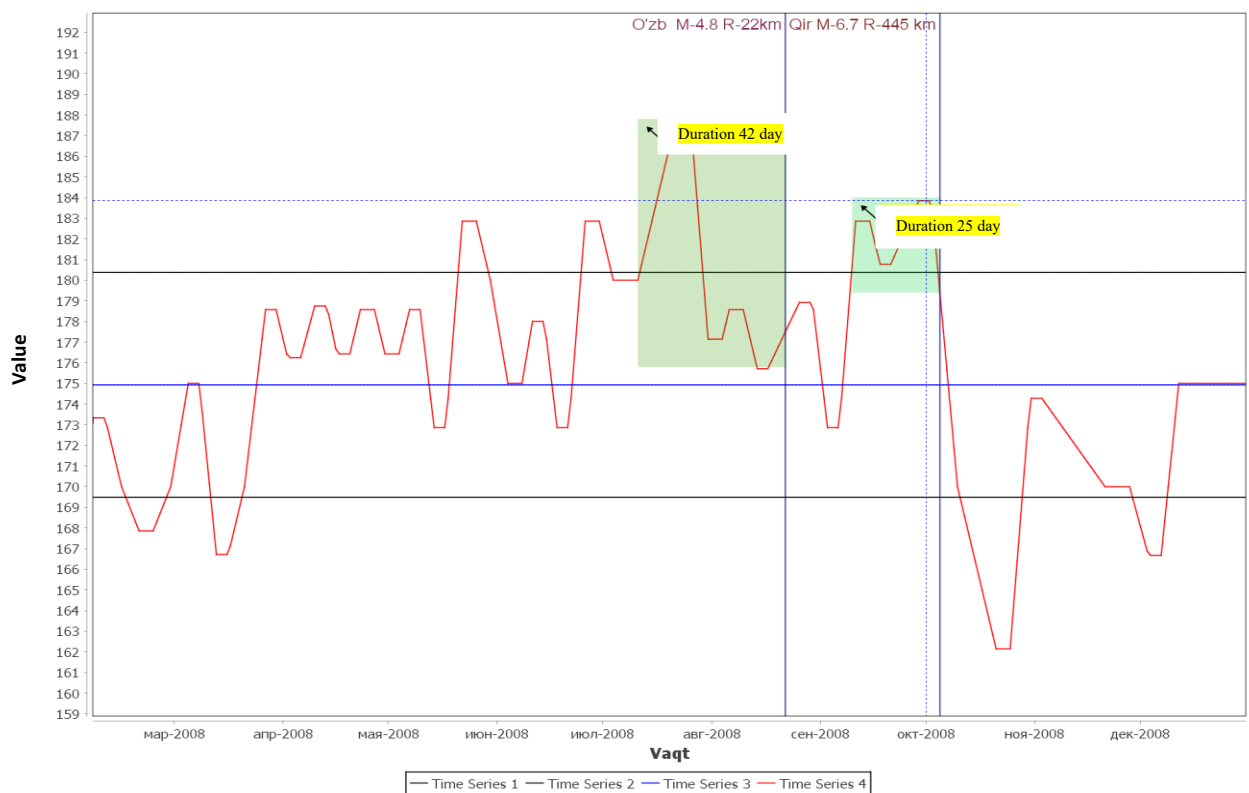


Figure 2. Graph of Eh variations in groundwater at the IOBK well during 2008–2009.

The graph illustrates the temporal variations of hydrogeoseismological parameters and their relation to the background state. As a statistical criterion, one standard deviation ($\pm 1\sigma$) was adopted as the background state, with the $\pm\sigma$ range defining the limits of natural variability. As seen in the data, parameter values at certain time intervals exceeded the background boundaries, appearing as anomalous processes.

In July–August 2008, a long-lasting anomalous interval of approximately 42 days was recorded, during which the parameter values deviated from the background range and exhibited significant changes. Subsequently, in September, an earthquake of $M = 4.8$ occurred in the territory of Uzbekistan, which is marked by a vertical line on the graph. This indicates that the anomalous interval had developed prior to the earthquake.

In September–October, another anomalous interval was recorded, lasting approximately 25 days. During this period, the parameter values again deviated from the background state, exhibiting sharp variations. Following this anomalous interval, in October, an earthquake of $M = 6.7$ occurred in the territory of Kyrgyzstan, which is indicated by a vertical line on the graph. On the graph, anomalous intervals are highlighted in different colors, with their duration, onset, and termination points clearly marked. The portions remaining within the background range represent the natural state of the parameter, while the excursions beyond this range reflect anomalous conditions in hydrogeoseismological parameters associated with seismic processes.

This graph illustrates the variations of hydrogeoseismological parameters recorded at the IOBK well between 2015 and 2016. The red line represents the temporal dynamics of the measured parameter, while the horizontal black and blue lines indicate the background state and its statistical boundaries ($\pm\sigma$ level). Throughout 2015, the parameter mostly fluctuated around the background state, with occasional sharp increases in the range of 220–240; however, these rises were relatively short-lived. At the beginning of 2016, a more pronounced and longer-lasting anomaly was recorded. This anomaly, highlighted with a green

shade on the graph, persisted for **18 days**. During this period, the parameter values significantly exceeded the background range and remained consistently elevated.

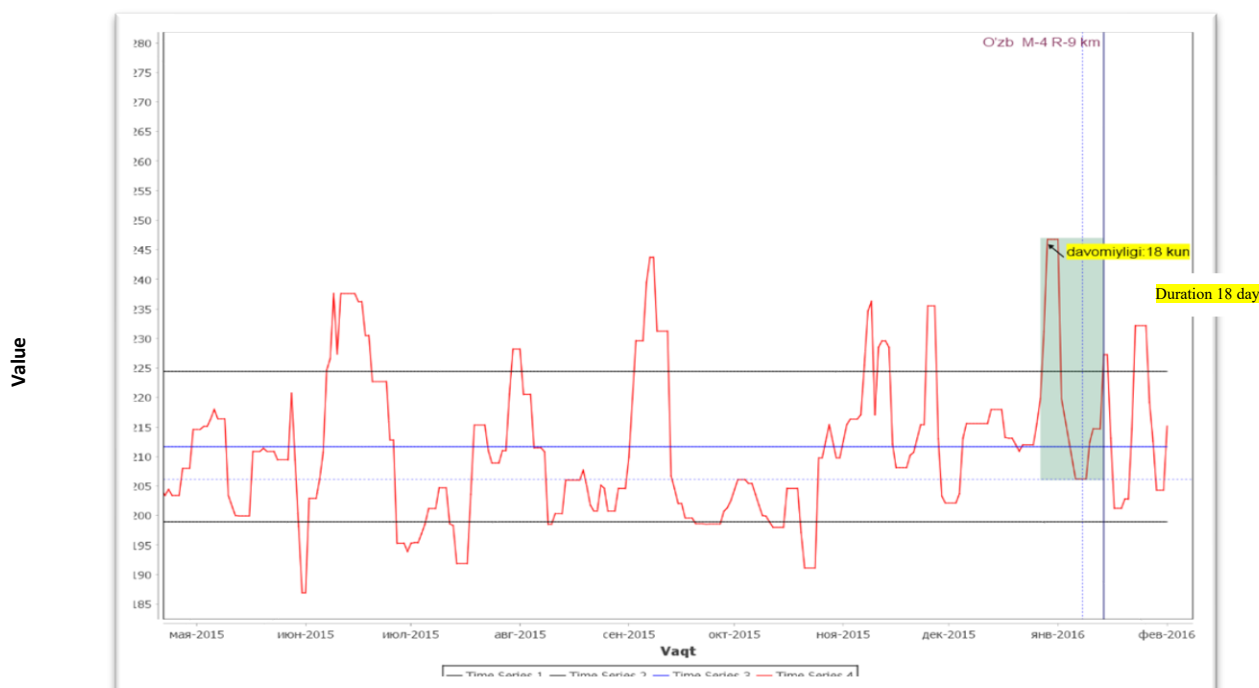


Figure 3. Graph of Eh variations in groundwater at the IOBK well during 2015–2016. Shortly after the anomaly ended, the parameter values declined, and by **late January 2016**, an earthquake of magnitude **M = 4** with an epicentral distance of 9 km occurred.

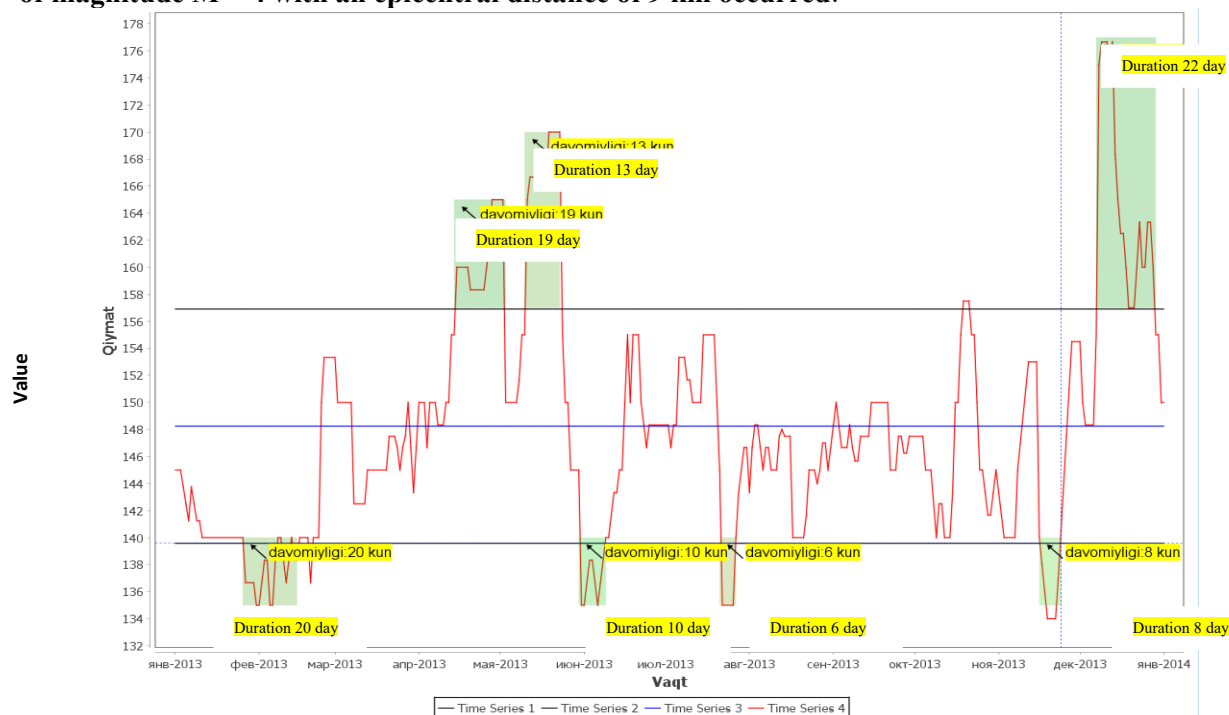


Figure 4. Graph of Eh variations in groundwater at the IOBK well during 2013.

Although the graph shows multiple deviations from the background state lasting days to weeks, it is important to emphasize that these anomalies were not always associated with earthquakes. This indicates that seismic precursors are not universal signals and that their sensitivity and diagnostic capability are limited. While statistically significant, such deviations may arise from various factors, including hydrological influences (seasonal changes, rainfall, groundwater dynamics), technical noise or instrument drift, human activity, or local geomechanical processes. Therefore, each anomaly requires independent verification to confirm its seismic significance.

In presenting the research results, it is essential to explicitly acknowledge that in many cases deviations from the background did not coincide with earthquakes. Such transparency ensures the reliability of the findings and provides a basis for future improvements in monitoring systems, particularly in filtering signals and enhancing the signal-to-noise ratio.

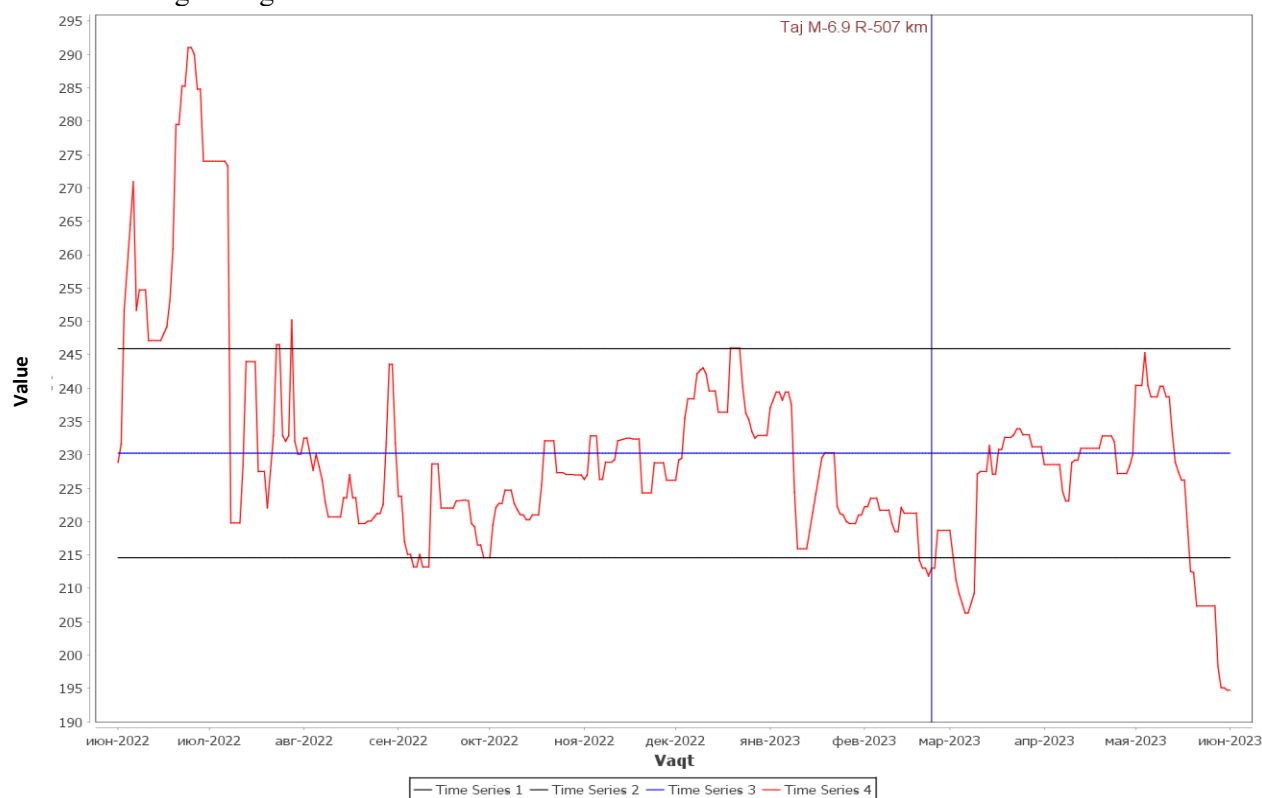


Figure 5. Graph of Eh variations in groundwater at the IOBK well during 2023.

The analysis of this graph shows that prior to the $M = 6.9$ earthquake, which occurred in March 2023 in the territory of Tajikistan at a distance of 507 km, no significant deviations from the background state were observed in the hydrogeodynamic parameters. Although short-term and minor fluctuations were recorded during the observation period, they cannot be regarded as statistically significant anomalies. The stability of the parameter and its persistence within the background range throughout the entire period indicate that in this case no reliable precursory signals were detected. This finding demonstrates that hydrogeoseismological parameters do not always manifest as precursors of seismic processes, and their sensitivity and universality are limited. Therefore, relying on a single parameter for prediction is insufficient; instead, it is necessary to jointly analyze multiple independent parameters and apply multifaceted filtering techniques. This result highlights an important aspect of hydrogeodynamic monitoring: even when a stable background state is maintained, strong seismic events may still occur.

Accordingly, for the period 2002–2024, annual graphs, yearly background states, the number of deviations from the background, and pre-earthquake variations were calculated (Table 2).

Well of the Institute of Vegetable Growing

Table 2

№	Data	M	R(km)	Sensitivity zone of the well (km)	M/lgR	Duration of deviation from the background state (day)	Value of deviation from the background state (mV) (Eh)	Magnitude of deviation from the background state (%)	Epicentr
1	10.11.2003	5.1	108	83	2,508085	38	6	17	Kazakhstan
2	08.10.2005	7.6	852	1300	2,593468	-	-	-	Pakistan
3	08.01.2007	6	199	250	2,609997	44	17	31	Tadjikistan
4	22.08.2008	4.8	22	57	3,575625	41	6	54	Uzbekistan
5	05.10.2008	6.7	445	440	2,529868	25	4	36	Kyrgyzstan
6	19.07.2011	6.1	245	250	2,553192	-	-	-	Kyrgyzstan
7	22.02.2013	4.1	15	27	3,486124	-	-	-	Kazakhstan
8	24.05.2013	5.4	48	83	3,211913	43	17	53	Uzbekistan
9	26.05.2013	6.1	204	250	2,641115	45	18	56	Uzbekistan
10	26.10.2015	7.5	547	750	2,739238	8	10	40	Afghanistan
11	07.12.2015	7.2	468	750	2,696381	13	11	44	Tadjikistan
12	08.01.2016	4.3	45	57	2,600997	12	23	88	Uzbekistan
13	14.01.2016	4	9	27	4,191807	18	23	88	Uzbekistan
14	23.01.2018	4.5	14	57	3,926263	115	28	73	Kazakhstan
15	13.03.2019	4.6	16	57	3,820217	11	10	45	Kazakhstan
16	11.09.2021	4.2	28	57	2,90224	9	13	25	Uzbekistan
17	05.11.2022	4.5	34	57	2,938336	-	-	-	Kazakhstan
18	23.02.2023	6.9	507	440	2,550824	-	-	-	Tadjikistan

Total number of earthquakes (units)	Number of earthquakes with observed deviation from the background state	Number of earthquakes without observed deviation from the background state	Average duration of deviation from the background state (days)	Average magnitude of deviation from the background state (mV)	Average magnitude of deviation from the background state (%)	Total number of deviations from the background state (units)	Proportion of earthquakes relative to the total deviations from the background state (%)
18	13 (72.2%)	5 (27.8%)	31	14	50	89	15.7

According to the analysis of the table data, a total of 18 earthquakes were recorded during the period 2003–2023. Among them, deviations from the background state were observed in 13 cases (72.2%), while no such changes were detected in 5 cases (27.8%). This indicates that hydrogeodynamic parameters often exhibit significant anomalous variations prior to earthquakes; however, this phenomenon is not always observed.

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The average duration of deviations from the background state was 31 days, suggesting that anomalous processes preceding earthquakes are generally sustained for about one month. The average amplitude of deviations was 14 mV, with the relative value of the difference from the background state amounting to 50%. These figures demonstrate that the anomalous variations are substantial and statistically significant. A total of 89 deviations from the background state were recorded, of which only 15.7% were directly associated with earthquakes. The analysis shows that although deviations from the background state are often observed prior to earthquakes, they are not universal. This highlights the necessity of a multiparameter approach in hydrogeoseismological studies, meaning that anomalies should be confirmed by their duration, amplitude, and synchronous variations across several indicators (gas, radon, chemical composition, groundwater level).

In the case of the CO₂ parameter, the observed **variations prior to earthquakes were mostly long-lasting and stable anomalous states**. Approximately half of these cases coincided with earthquakes, indicating that when using this parameter in forecasting, particular attention should be paid to its dynamics and duration. Therefore, **the CO₂ parameter may serve as a medium- to long-term signal**, rather than a short-term one (Table 3).

Table 3

IOBK 2002-2024 y. M-4.0 Lg(R) ≥2.5.					41.35	69.14
№	Date	M	CO ₂ % об.			
			anomaly	period		
1	10.11.2003	5,1	+	140	41,03	67,93
2	22.08.2008	4,8	+	110	41,3	69,4
3	05.10.2008	6,7	+	110	39,53	73,82
4	19.07.2011	6,1	+	205	40,05	71,48
5	26.10.2015	7,5	+	150	36,52	70,36
6	07.12.2015	7,2	+	160	38,21	72,77
7	08.01.2016	4,3	+	100	40,94	69,14
8	14.01.2016	4	+	170	41,36	69,24
9	23.01.2018	4,5	+	60	41,40	68,99
			9	50%		
IOBK 2002-2024 y. M-4.0 Lg(R) ≥2.5.					41.35	69.14
№	Date	M	CO ₂ % об.			
			anomaly	period		
1	08.10.2005	7,6	-	-	34,53	73,58
2	08.01.2007	6	-	-	39,80	70,31

3	22.02.2013	4,1	-	-	41,48	69,11
4	24.05.2013	5,4	-	-	40,93	69,25
5	26.05.2013	6,1	-	-	40,05	67,44
6	13.03.2019	4,6	-	-	41,42	68,97
7	11.09.2021	4,2	-	-	41,55	68,93
8	05.11.2022	4,5	-	-	41,57	68,85
9	23.02.2023	6,9	-	-	38,05	73,22
			9	50%		

Analyzing the table data, during the period 2002–2024, among the 18 earthquakes ($M \geq 4.0$, $Lg(R) \geq 2.5$) recorded at the IOBK borehole, anomalous changes in CO_2 concentration were observed in half of the cases (50%), while in the other half (50%) no such changes were recorded.

The total number of cases with anomalies amounted to 9, which were mainly characterized by lasting for a certain period before the earthquakes (ranging from 60 to 205 days). For example, prior to the $M=5.1$ earthquake on November 10, 2003, the anomalous period in CO_2 concentration lasted for 140 days, while before the $M=6.1$ earthquake on July 19, 2011, it extended to 205 days. Similarly, before the $M=4.0$ earthquake on January 14, 2016, a 170-day anomalous interval was observed. Such long-lasting CO_2 variations strengthen the likelihood of their association with seismic processes.

Earthquakes at IOBK borehole, CO_2 anomalies and epicenter distance (2002–2024)

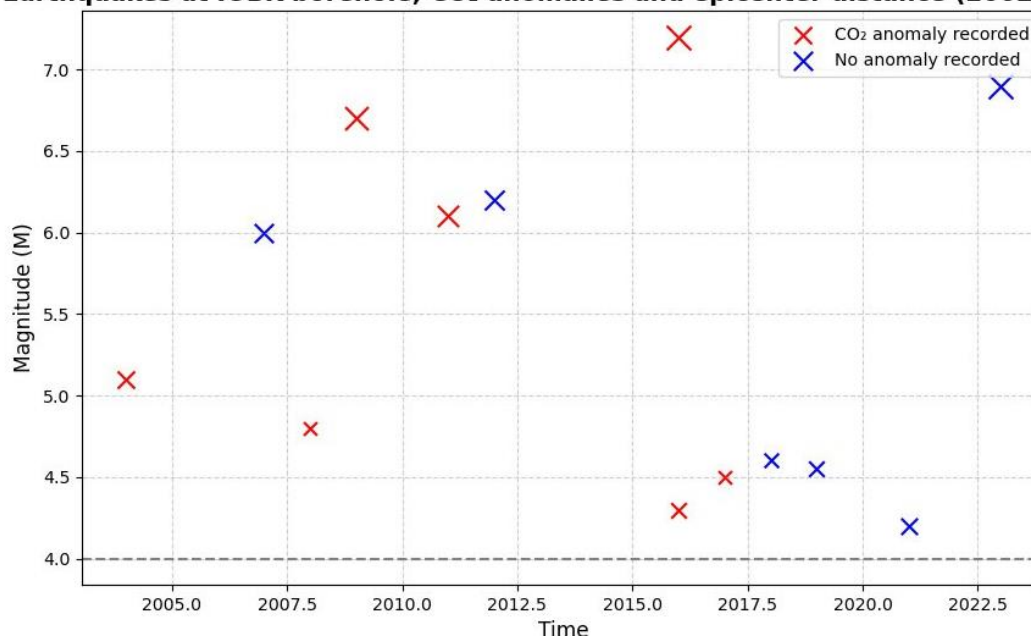


Figure 6. Earthquakes with and without CO_2 anomalies at the IOBK borehole during 2002–2024.

- Red dots – earthquakes with recorded CO_2 anomalies,
- Blue dots – cases without anomalies,
- Dot size – proportional to the epicentral distance.

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The 9 cases in which no anomaly was observed indicate that changes in CO₂ concentration do not always manifest in direct association with earthquakes. For example, no CO₂ variations were recorded prior to the M=7.6 earthquake on October 8, 2005 (Pakistan), the M=6.0 earthquake on January 8, 2007 (Tajikistan), and the M=6.9 earthquake on February 23, 2023 (Tajikistan). This shows that although the CO₂ parameter demonstrates high sensitivity as a seismic precursor, its universality and specificity are limited.

During the period 2002–2024, anomalous changes in CO₂ concentration were observed in 50% of the 18 recorded earthquakes with M ≥ 4.0 at the IOBK borehole. Their duration ranged from 60 to 205 days and was especially evident before strong and nearby earthquakes. However, in the remaining 50% of cases, no such changes were recorded, which indicates that although the CO₂ parameter has high sensitivity as a seismic precursor, its universality remains limited.

The earthquakes with observed anomalies were mainly recorded to the north of the IOBK borehole and in nearby areas. This may indicate that the sensitivity zone of the borehole is closely related to the northern tectonic directions. At the same time, the absence of anomalies for earthquakes that occurred to the west, closer to the borehole, demonstrates the sensitivity of hydrogeoseismological parameters to local geological and hydrogeodynamic conditions (Figure 7).

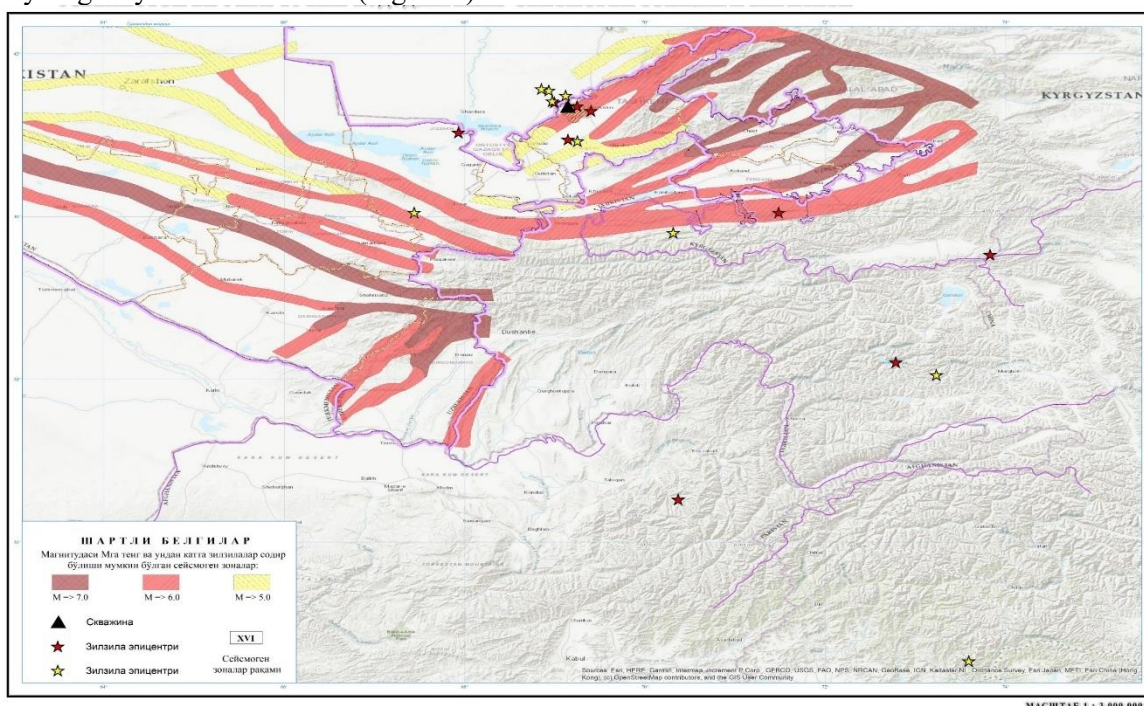


Figure 7. Map of seismogenic zones of Uzbekistan and adjacent territories (Ibragimov R.S., Sodiqov Yu.M., Nurmatov U.A., 2020)

At greater distances from the borehole, both cases with anomalies and without anomalies have been recorded. This indicates that distance is not the decisive factor; rather, the occurrence of anomalies is more closely related to tectonic orientation, the hydrogeological structure of aquifers, and the local characteristics of seismogenic processes. Therefore, when assessing the relationship between anomalies and earthquakes, not only distance but also geodynamic orientation and the properties of the hydrogeological environment must be taken into account [Last Quake (No date); Martinelli, 2015; . Martinelli *et al.*, 2015, 2021; Matsumoto *et al.*, 2007; Matsumoto N, Koizumi, 2013; . Nakagawa *et al.*, 2020; Namvaran, Negarestani (2015); Negarestani *et al.*, 2002, 2014].

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Conclusion. The analysis of hydrogeoseismological observations carried out at the IOBK borehole during 2002–2024 revealed that anomalous changes in groundwater parameters were, in certain cases, recorded prior to earthquakes. In particular, deviations from the baseline in the **Eh indicator** were observed in advance of most earthquakes, manifesting as short-term and reliable signals. This demonstrates the potential of using the Eh parameter as a sensitive indicator before earthquakes.

The CO₂ indicator, on the other hand, was characterized by longer-term and more persistent anomalous intervals. The changes recorded in this parameter were especially significant prior to strong earthquakes located relatively close to the borehole. At the same time, it was found that in some cases, even strong earthquakes were not preceded by anomalous changes. This indicates that hydrogeoseismological parameters are not universal and that their prognostic sensitivity and specificity are limited.

Based on the obtained results, it can be concluded that for hydrogeoseismological indicators to be applied as effective forecasting tools, they must be evaluated within a multiparametric analysis — that is, in combination with gas, chemical, hydrodynamic, and radiogeochemical data. Furthermore, the dependence of anomalous variations on tectonic orientation, hydrogeological structure, and local geodynamic processes indicates that they should be analyzed within a comprehensive approach.

Thus, the research findings justify the scientific and practical significance of hydrogeoseismological parameters, their potential application in improving the national seismic forecasting system, and the necessity of integrating them with other geophysical and geochemical methods to enhance forecasting accuracy in the future.

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