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PATTERNS OF THE INFLUENCE OF SEISMIC ACTIVITY IN THE SHEKI-ZAGATALA ZONE ON THE HYDROGEOCHEMICAL REGIME OF GROUNDWATER (2018–2025)

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Abstract

This article examines the impact of earthquakes in the Sheki-Zagatala seismic zone on the hydrogeochemical characteristics of groundwater. A comparative analysis of seismic events recorded in different years and the results of geochemical monitoring is conducted. It is established that anomalies in hydrogeochemical parameters are formed in conjunction with tectonic processes, and their nature depends on the geological and hydrogeological features of the region. The results of the study demonstrate that long-term and systematic groundwater monitoring is essential for studying seismic processes and holds promise for identifying potential precursors.

***Keywords**:* Greater Caucasus; seismicity; fluid geochemistry; geochemical anomalies; seismic precursors; seismically active zones; stress-strain state.

ŞƏKİ-ZAQATALA ZONASINDA SEYSMİK AKTİVLİYİN YERALTI SULARIN HİDROGEOKİMYƏVİ REJİMİNƏ TƏSİRİ (2018–2025)

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Xülasə

Məqalədə Şəki-Zaqatala seysmik zonasında zəlzələlərin yeraltı suların hidrogeokimyəvi xüsusiyyətlərinə təsiri araşdırılmış, müxtəlif illərdə qeydə alınmış seysmik hadisələr geokimyəvi monitorinqin nəticələri ilə müqayisəli şəkildə təhlil edilmişdir. Müəyyən edilmişdir ki, hidrogeokimyəvi parametrlərdə baş verən anomaliyalar tektonik proseslərlə qarşılıqlı əlaqədə formalaşır və onların xarakteri regionun geoloji-hidrogeoloji xüsusiyyətlərindən asılıdır. Tədqiqat nəticələri göstərir ki, yeraltı suların uzunmüddətli və sistemli monitorinqi seysmik proseslərin öyrənilməsində mühüm əhəmiyyət kəsb edir və mümkün xəbərverici əlamətlərin müəyyənləşdirilməsi baxımından perspektivlidir.

Açar sözlər: Böyük Qafqaz; seysmiklik; flüidogeokimya; geokimyəvi anomaliyalar; seysmik xəbərvericilər; seysmoaktiv zonalar; gərginlik-deformasiya vəziyyəti

ЗАКОНОМЕРНОСТИ ВЛИЯНИЯ СЕЙСМИЧЕСКОЙ АКТИВНОСТИ ШЕКИНСКО–ЗАКАТАЛЬСКОЙ ЗОНЫ НА ГИДРОГЕОХИМИЧЕСКИЙ РЕЖИМ ПОДЗЕМНЫХ ВОД (2018–2025 ГГ.)

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Аннотация

В статье исследовано влияние землетрясений в Шекинско–Закатальской сейсмической зоне на гидрогеохимические характеристики подземных вод, проведён сравнительный анализ сейсмических событий, зарегистрированных в разные годы, и результатов геохимического

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мониторинга. Установлено, что аномалии гидрогеохимических параметров формируются во взаимосвязи с тектоническими процессами, а их характер зависит от геолого-гидрогеологических особенностей региона. Результаты исследования показывают, что долговременный и систематический мониторинг подземных вод имеет важное значение для изучения сейсмических процессов и является перспективным с точки зрения выявления возможных предвестников.

Ключевые слова: Большой Кавказ; сейсмичность; флюидогеохимия; геохимические аномалии; сейсмические предвестники; сейсмоактивные зоны; напряжённо-деформированное состояние.

Introduction

Due to its seismotectonic characteristics, the Azerbaijani part of the Greater Caucasus is included in the list of areas with high seismic risk, and historical sources mention the occurrence of earthquakes with a magnitude of $M \geq 6$ here (Yetirmishli, 2013). The Shamakhi earthquake that occurred in 1902 is considered the beginning of instrumental seismological observations in Azerbaijan (https://seismology.az).

Currently, seismic observations in Azerbaijan are carried out continuously and systematically by the Republican Seismic Survey Center. The Center conducts operational registration of earthquakes occurring in seismically active zones through a network of seismic stations operating throughout the country and determines their main parameters (magnitude, epicenter, focal depth, etc.).

In the 1980s–1990s, a network of stationary geochemical and geophysical stations covering the main seismogenic zones was formed in the territory of the Republic, and systematic research of geophysical and geochemical parameters in areas close to the epicentral zones was initiated. During this period, methodological approaches were developed to assess the stress-strain state of seismogenic zones, as well as to determine the relationship between anomalous changes observed in geophysical and geochemical field parameters and seismic processes (https://seismology.az).

The reflection of seismic processes not only in geophysical, but also in geochemical parameters has necessitated special research in this direction. For this purpose, fluidogeochemical research has been conducted within the center since 1979 in the “Complex Geochemical Research” department. One of the most important issues of these studies is the search for earthquake precursors and the assessment of seismic hazard. In solving the above issues, extensive observations conducted in underground mineral and fresh water basins of self-flowing springs and wells in seismically active regions of Azerbaijan - Absheron, Siyazan, Khachmaz, Shamakhi, Sheki - are of great importance (Keramova, 2004).

During earthquakes, elastic waves arising in the earth's crust and water-saturated rocks affect the stress-strain state, intensifying physicochemical processes, accelerating fluid flows and gas migration. As a result, groundwater is enriched with micro- and macroelements and short-term anomalous changes in geochemical fields are formed. The nature and scale of these changes are closely related to the earthquake strength, focal depth, epicentral distance, focal mechanism, and tectonic structure of the region (Kopylova, 2006; Skelton, 2014).

Fluidogeochemical observations conducted in recent years show that changes in the level, temperature, flow volume, and color of groundwater before an earthquake serve as an important source of information in assessing seismic hazard. In particular, changes in the permeability of rocks during earthquakes, such as compression and expansion, cause fluctuations in the level of groundwater, such as rises and falls, and such changes have been studied by many researchers as a geochemical indicator (Kopylova, 2020; Yusupov, 2020).

Against the background of these general patterns, data for 2018–2025 were analyzed in order to assess seismic activity on the southern slope of the Greater Caucasus and its possible impact on groundwater.

Seismicity of the Sheki-Zagatala economic region

The Sheki-Zagatala economic region is located on the southern slope of the Greater Caucasus and has a complex tectonic structure. The area is characterized by intense faulting and thrust-type fault zones, which are characterized by moderate to high seismic activity. These types of faults, i.e. thrust zones formed by the movement of rocks over each other, cause stress accumulation in the region and, as a result, earthquakes. The region is also characterized by compressional processes and active fault lines, as a result of which earthquakes of various magnitudes occur from time to time and the seismic hazard remains high (Ismail Zadeh, 2020).

According to the data of the "Earthquake Research Bureau" of the RSSC, during the research period, a total of 29 earthquakes with a magnitude of 3.0 and greater, with a focal depth ranging from H=4–45 km, were recorded in the Sheki–Zagatala economic region - Balaken, Gakh, Gabala, Oghuz, Sheki and Zagatala regions (Fig. 1, Table 1). Four of these seismic events had a magnitude of 3.0 or greater, with a focal depth ranging from H=4–10 km, and the epicenters were located in the Zagatala region. We have tried to show the analysis of changes in the composition of groundwater during these earthquakes based on geochemical monitoring of fluids conducted in the "Complex Geochemical Research" department during 2018-2025.

The Zagatala seismic zone is located on the northwestern edge of the part of the Greater Caucasus that falls within the territory of Azerbaijan. In the north, west and south directions, this zone comes into contact with areas of Southern Dagestan and Western Georgia characterized by high seismic activity. The area of the Zagatala seismically active zone in Azerbaijan is approximately 3500 km². The first historical data on earthquakes in this zone date back to 1853. The epicenters of seismic events are mainly concentrated on three parallel lines extending in the transverse direction. Strong earthquakes with a maximum intensity of 7 points are observed in the northernmost part of these epicentral lines (Yetirmishli, 2023).

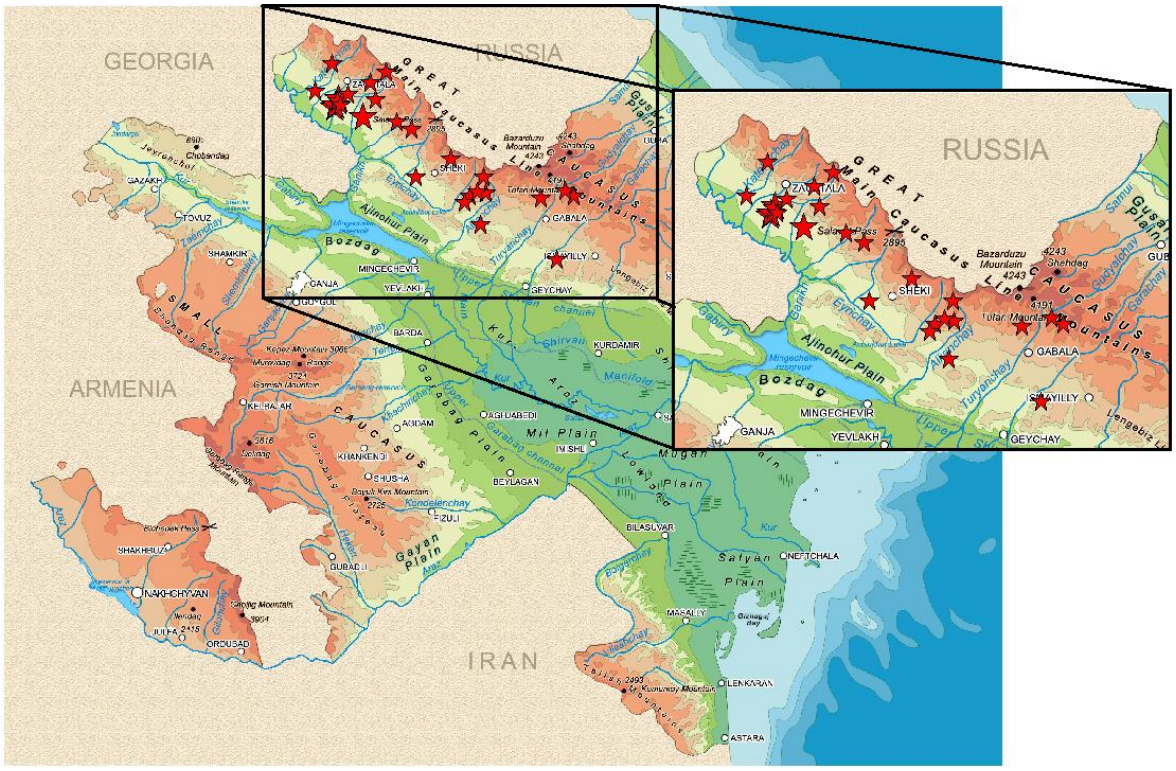

Fig. 1. Earthquake sources with ml≥3.0 in the Sheki-Zagatala economic region in 2018-2025

Table 1.

Parameters of earthquakes with ml≥3.0 in the Sheki-Zagatala economic region in 2018-2025

Years	*Day/Month*	*φ*	*λ*	*ml*	*H (km)*	*Earthquake sources*
2018	21.04	40,96	47,39	3,4	28	Oguz district
	03.05	41,20	46,98	3,0	18	Sheki district
	05.06	41,50	46,64	5,5	10	Zaqatala district
	22.06	41,11	47,42	3,3	6	Oguz district
	24.06	41,10	47,32	3,2	12	Oguz district
	23.10	41,10	47,98	3,1	9	Qabala district
	26.10	41,08	47,98	3,1	13	Qabala district
2019	05.06	41,66	46,69	3,0	25	Zaqatala district
	15.07	41,43	46,95	3,3	36	Qakh district
	08.08	41,63	46,34	3,0	7	Balaken district
	10.08	41,55	46,46	4,9	5	Zaqatala district
	10.08	41,58	46,48	3,4	11	Zaqatala district
	10.08	41,59	46,48	3,7	9	Zaqatala district
	11.08	41,56	46,47	4,4	6	Zaqatala district
	02.09	41,11	47,92	3,2	13	Qabala district
	01.12	41,61	46,55	3,8	15	Zaqatala district
2021	28.09	41,64	46,61	3,1	11	Zaqatala district
	07.12	41,71	46,79	3,5	42	Zaqatala district
2022	01.03	41.59	46.49	4,2	9	Zaqatala district
	15.04	41.58	46.72	3,9	23	Zaqatala district
	23.07	41.76	46.45	3,1	7	Balaken district
2023	24.04	41.56	46.50	3.8	7	Zaqatala district
	25.06	41.28	47.20	3.0	16	Sheki district
	21.07	41.08	47.77	3.3	7	Qabala district
	30.07	41.19	47.41	3.0	18	Oguz district
	31.08	41.07	47.29	3.0	26	Sheki district
	19.12	41.12	47.37	3.0	25	Oguz district
2025	27.02	40.78	47.87	3.3	45	Ismayilli-Qabala border
	27.06	41.47	46.86	3.3	19	Qakh-Zaqatala border

During 2018, 7 earthquakes with ml ≥ 3.0, H=6-28 km occurred in the territory of Sheki-Zagatala regions. The strongest one was recorded on 05.06.2018 at 22:40 local time, with a magnitude of 5.5 and a focal depth of H=10 km in Zagatala region. As a result of the conducted hydrogeochemical monitoring, noticeable anomalies in the composition of groundwater were identified at our observation sites before and after the earthquake. The recorded changes were mainly manifested in the sites located in Shamakhi, Sheki and Absheron regions. Thus, an increase in the concentration of HCO_3^- ion was recorded at the "Shamakhi-8" site of Shamakhi region from the beginning of May, and this increase continued until mid-July. Similar dynamics were observed in the groundwater of the "Surakhani" site of Absheron region; here the concentration of Mg^{2+} ion increased by 14.05. An increase was observed starting from 12 July and was fluctuating until 12 July (Fig. 2). According to the results of monitoring conducted at the "Food Combine" and "Heating" facilities of the Sheki region, a decrease in the concentration of Σ (Na+ K+) and HCO_3^- ions was recorded in groundwater before the earthquake.

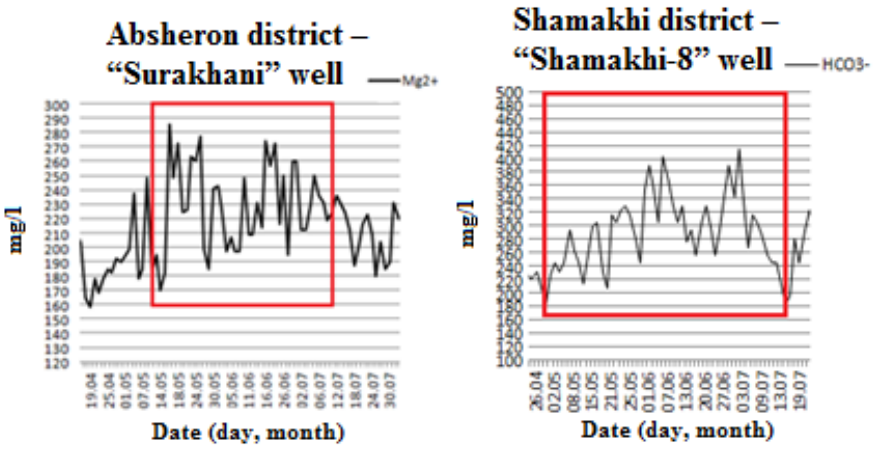

Fig. 2. Variation in the concentration of Mg^{2+} ions in the "Surakhani" well and HCO_3^- ions in the Shamakhi-8 well before the earthquake

Compared to 2018, an increase in the number of earthquakes with ml ≥ 3.0 was observed in 2019. Thus, the most active year within the research years was 2019. The largest recorded earthquake with a magnitude of ml = 4.9; focal depth H=5 km occurred on August 10 at 11:35 local time, 18 km southwest of the Zagatala station, in the Zagatala region. On the same day, between 14:00 and 15:22, weaker earthquakes were also recorded in the Zagatala region: the magnitude was around 3.4–3.7, the focal depth was located at a depth of H=9–11 km, and the intensity near the epicenter was 3–4 points. 20 hours later, on August 11, 2019, at 07:29 local time, another earthquake occurred 16 km southwest of the Zagatala station - a magnitude 4.4 earthquake with a focal depth of H=6 km. The earthquake sources were mainly located in the impact zone of the Vandam and Sharur-Zagatala deep faults. (Yetirmishli, 2019).

During these consecutive earthquakes, hydrogeochemical changes in the composition of groundwater were recorded mainly at the "Arzag Kombinat" facility in Sheki region; "Shamakhi-8", "Chukhuryurd-49" in Shamakhi region; "Arik-baghi" facility in Khachmaz region; "Shikhov-2" facility in Absheron region. Thus, a decrease in the concentration of Σ (Na+ K+) ions and the degree of total mineralization was observed in the "Arzag Kombinat" well 25 days before the earthquake. At the same time, 23 days before the earthquake, a decrease in the concentration of Mg^{2+} ions and the pH indicator characterizing acid-base balance was recorded in the "Shamakhi-8" well; 20 days before, a decrease in the concentration of HCO_3^- ions was recorded in the "Arik-baghi" well. A decrease in the concentration of Ca^{2+} ions and the total degree of mineralization was observed in the "Shikhov-2" facility in the Absheron region, and an increase in the concentration of HCO_3^- ions was recorded.

In 2022, weak seismicity was observed in the economic region. On March 1, 2022, at 14:34 local time, an earthquake with a magnitude of 4.2 and a focal depth of H = 9 km was recorded approximately 14 km southwest of the epicenter in the Zagatala region. The value of the displacement in the focus indicates that the left-lateral displacement of the fault-uplift type of movement predominates and is consistent with the Kakheti transverse fault. Later, on April 15, 2022, at 17:02 local time, an earthquake with a magnitude of 3.9 and a focal depth of H = 23 km occurred in the region. The value of the displacement in the focus indicates that the fault-uplift type of movement predominates and is consistent with the Shambul-Ismayilli fault (Kazimova, 2022).

Since earthquakes differ in depth, mechanism of occurrence and fault lines, when considering the spatial and temporal variations of hydrogeochemical parameters of groundwater, we will encounter a similar picture. In other words, the anomalous changes in geochemical parameters during both earthquakes were different. The changes in the water of the "Isitme" spring in the Sheki region can be cited as an example of this difference (Fig. 3).

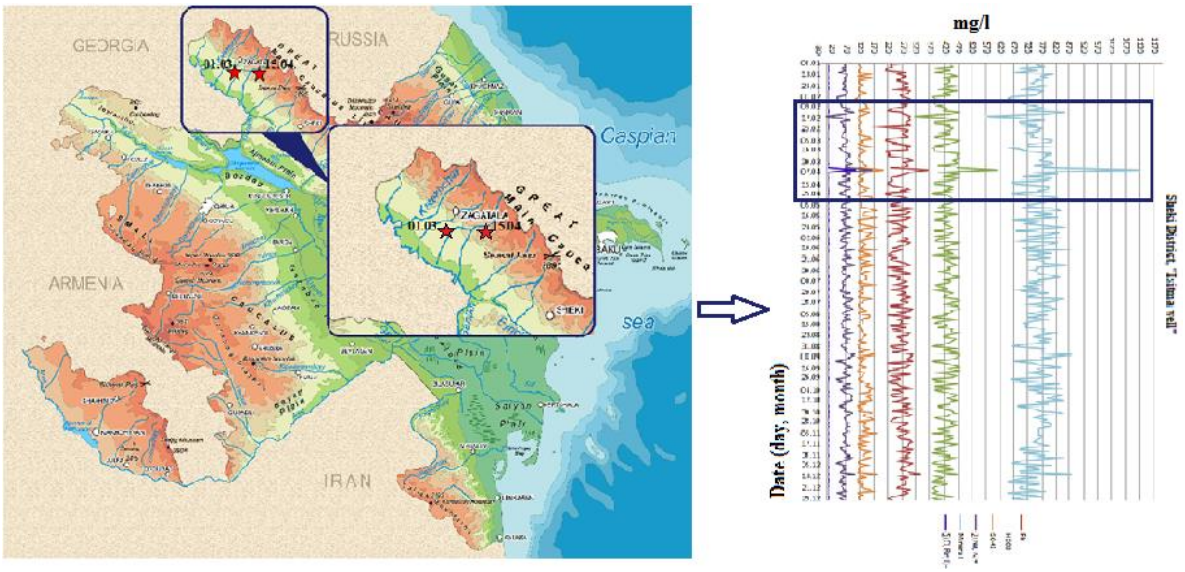

Fig. 3. Variations in geochemical parameters before the 2022 Zagatala earthquakes

During the Zagatala earthquake of 15.04.2022, a stronger anomalous change was observed in the spring water of the Sheki region. This may seem paradoxical at first glance, since the magnitude of that earthquake was small and the depth of the focus was large. The explanation for this paradoxical appearance may be related to several factors.

The effect of the type and direction of the fault: The earthquake that occurred on the Shambul-Ismayilli fault favors uplift-type displacement and is consistent with longitudinal faulting. Vertical movement can directly affect groundwater sources, causing sudden changes in water level and intensification of geochemical anomalies.

Geographical proximity: The Sheki region is located closer to the Shambul-Ismayilli fault than to the Kakheti fault. Proximity to the fault increases the transfer of earthquake energy to the groundwater system, and therefore the amplitude of the observed anomalies may also increase.

Hydrogeological conditions: Since the springs and groundwater systems are located in areas rich in cracks and porosity, the vertical tectonic stress caused by the earthquake directly affects the hydrodynamics and chemical composition of water. This can lead to the intensification of water anomalies even in deep-seated and relatively low-magnitude earthquakes.

It should be noted that during the study years of 2020 and 2024, no earthquakes with ml $\geq$ 3.0 were recorded in the territory of the Sheki-Zagatala region. In other years, seismic activity did not exceed the background level.

Conclusion

There is a mutual relationship between the behavior of groundwater and seismic activity. Earthquakes cause changes in the level, temperature, chemical composition and amount of gas components of groundwater; the dynamics of these hydrogeochemical parameters, in turn, can act as an indicator of tectonic processes and seismic activity. The conducted studies show that the changes recorded in the physicochemical properties of groundwater are closely related to the increase in tectonic stress and are of great importance in assessing the geodynamic processes occurring in the region.

Thus, systematic and continuous conduct of geochemical and hydrogeodynamic monitoring, as well as expanding the scope of application of these methods, is considered necessary for more accurate monitoring and assessment of seismic processes.

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