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GEOCHEMICAL CHARACTERISTICS OF NEWLY IDENTIFIED MINERAL WATERS OF THE SHAMAKHI DISTRICT

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Abstract

Mineral waters are an important natural resource whose formation and composition are determined by a combination of geological, hydrogeological, and geochemical factors. The study of geochemical characteristics of mineral waters makes it possible to identify patterns of chemical element migration, conditions of water formation, and their potential practical value. The Shamakhi District of Azerbaijan is characterized by complex geological structure, high tectonic activity, and widespread fault zones, which create favorable conditions for the formation of mineral waters of various genetic types.

This paper presents the results of hydrogeochemical studies of newly identified mineral waters in the Shamakhi District. The chemical and ionic composition, degree of mineralization, acid–base properties, and redox conditions of water formation are examined. The main geochemical processes controlling the formation of mineral water composition are identified, as well as the role of geological structure and tectonic factors.

The study of hydrogeochemical features of these waters is of significant scientific and practical importance for assessing their therapeutic properties and ensuring rational use. The research is based on mineral water investigations conducted at the Shamakhi Geochemical Station from 2001 to 2023 within the Shamakhi District.

Keywords: *mineral waters, hydrogeochemistry, groundwater, trace elements, Shamakhi District*

1. Introduction

The territory of the Shamakhi District has long been known for its mineral waters, which vary widely in ionic–saline, gas, and microcomponent composition (Aliyev, 2000). These waters range from cold bicarbonate–calcium waters of the high-altitude zone to carbonated chloride–bicarbonate calcium–sodium waters and chloride sodium and iodine-bromine waters of the foothill zone.

Previous researchers identified and studied 11 mineral and thermal water sources in this area. As a result of hydrogeochemical survey work conducted in the Shamakhi seismogenic zone, an additional five mineral water sources were identified and investigated (Table 1). Despite these studies, the hydrogeochemical characteristics of mineral water sources in the district remain insufficiently studied.

Table1. Passport Data of the Studied Mineral Water Sources (Azerbaijan, Shamakhi district)

Goshabulag	**Beyuk Yaylag village**	**0.348**	**7.9**	**0**
Archiman	Archiman village	0.494	**7.9**	0
Yaylag	–	0.258	**7.7**	0
Damir-Yolgulu	Kaleybugurd village	0.576	7.7	0
Soyugbulag	3 km southeast of Kaleybugurd village	0.260	–	0

2. Physical-Geographical and Geological Characteristics of the Study Area

The Shamakhi District is located in the southeastern part of the Greater Caucasus and is characterized by mountainous and foothill relief. The climate is moderately continental with pronounced seasonal precipitation, which significantly affects groundwater recharge conditions.

The geological structure of the district is represented by Mesozoic and Cenozoic sedimentary rocks, including limestones, sandstones, and clay shales. The presence of faults and tectonic zones creates favorable conditions for groundwater circulation and the emergence of mineral waters at the surface.

According to occurrence conditions, the studied mineral waters are divided into fissure–unconfined, fissure–confined, and confined types.

The first group ("Goshabulag", "Damir-Yolgulu") is located in the middle-mountain zone (1200–1700 m above sea level), approximately in the central part of the region, and is oriented northwestward. These waters are fissure–unconfined, weakly mineralized (0.3–0.5 g/L), weakly alkaline (pH ≈ 7.9), with no hydrogen sulfide content (H_2S = 0 mg/L).

The second group includes three sources ("Archiman", "Soyugbulag", "Yaylag"), spatially arranged parallel to each other and oriented southeastward.

3. Conditions of Mineral Water Formation

Groundwaters of the Shamakhi District are formed as a result of:

- infiltration recharge by atmospheric precipitation;
- deep circulation along tectonic faults;
- prolonged interaction with carbonate and terrigenous rocks;
- geochemical processes of dissolution, ion exchange, and gas saturation.

The main geochemical processes include dissolution of carbonate and silicate minerals, ion exchange between water and host rocks, and redox reactions. In tectonically disturbed zones, upwelling of deeper, warmer, and more mineralized waters is possible, explaining the presence of warm and thermal springs.

4. Geochemical Characteristics of Mineral Waters

Data presented in Table 2 indicate that the ionic–saline composition of the newly identified mineral water sources belongs to three classes of bicarbonate-type waters:

1. bicarbonate;
2. bicarbonate–sulfate;
3. bicarbonate–chloride.

Table 2. Geochemical Characteristics of the Studied Mineral Water Sources (Azerbaijan, Shamakhi District)

No.	Source name	Ionic composition formula (Kurlov formula)	Total dissolved solids (g/L)	pH	H_2S (mg/L)
1.	Goshabulag	$M_{0.3}\ HCO_3(89)\ Ca_7\ Mg_{15}\ (Na+K)_{14}$	0.348	7.9	0
2.	Archiman	$M_{0.5}\ HCO_3(19)\ SO_4{}_{16}\ Ca_{58}\ Mg_{15}\ (Na+K)_{30}$	0.494	7.9	0

No.	Source name	Ionic composition formula (Kurlov formula)	Total dissolved solids (g/L)	pH	H_2S (mg/L)
3.	Yaylag	$M_{0.2}\ HCO_3(73)\ SO_4{}_{23}\ Ca_{62}\ (Na+K)_{20}\ Mg_{12}$	0.258	7.7	0
4.	Damir-Yolgulu	$M_{0.6}\ HCO_3(75)\ SO_4{}_{19}\ (Na+K)_{63}\ Ca_{24}\ Mg_{13}$	0.576	7.7	0
5.	Soyugbulag	$M_{0.2}\ HCO_3(67)\ SO_4{}_{22}\ Cl_{11}\ Ca_{59}\ (Na+K)_{34}$	0.260	7.5	0

The bicarbonate class is further subdivided based on dominant cation composition (Na^+, Ca^{2+}, Mg^{2+}).

- Bicarbonate–calcium waters are typical of fresh and weakly mineralized sources.
- Bicarbonate–chloride waters indicate prolonged interaction with saline strata and magmatic formations.
- Bicarbonate–sulfate waters form due to interaction with sulfur-bearing minerals in groundwater circulation zones.

Elevated sulfate and chloride concentrations indicate the influence of deep groundwater components.

5. Trace Element Composition

The trace element composition (Table 3) varies among the studied waters. Saline waters contain mainly Ti, Cu, and Sr, whereas hydrogen sulfide waters are characterized by a more diverse trace element assemblage, including Mn, Ni, and Br.

Table 3. *Trace Element Content in the Studied Mineral Water Sources (Azerbaijan, Shamakhi District)*

No.	Source / well name	Ionic composition type	Ba (mg/L)	Sr (mg/L)	Mn (mg/L)	Ni (mg/L)	Ti (mg/L)	Cu (mg/L)	Br (mg/L)
1.	Goshabulag spring	HCO_3–Ca–Mg–Na	6.96	0.30	0.30	0	1.74	0.03	69.6
2.	Archiman spring	HCO_3–SO_4–Ca–Na–Mg	9.88	0	9.88	0.49	1.48	0.05	49.4
3.	Yaylag spring	HCO_3–SO_4–Ca–Na–Mg	0	0	<0.26	0.52	0.26	0.03	7.74
4.	Damir-Yolgulu spring	HCO_3–SO_4–Na–Ca–Mg	17.28	0	0	0	1.73	0	57.6
5.	Soyugbulag spring	HCO_3–SO_4–Ca––Na	5.20	0.26	0.78	<0.25	0.52	0.13	7.8

The spatial distribution of trace elements corresponds to Pleistoseist zones of strong and perceptible earthquakes, indicating a relationship between hydrogeochemistry and tectonic activity.

6. Objects and Research Methods

The objects of study were natural mineral water sources of the Shamakhi District: Goshabulag, Archiman, Yaylag, Damir-Yolgulu, and Soyugbulag. Sampling was carried out daily, five times per week, in accordance with standard hydrogeochemical methodologies.

Laboratory analyses included determination of major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^+, SO_4^{2+}, Cl^+), pH, Eh, and total mineralization. Analytical methods included colorimetric, titrimetric, helium analysis (INGEM-1), and calculation methods. Data processing utilized Excel, HydroGeo, and related software.

7. Comparative Analysis and Regional Features

Comparative analysis showed that mineral water sources of the Shamakhi District exhibit similar hydrogeochemical characteristics but differ in mineralization degree and ionic ratios. These differences are controlled by local geological conditions, deep water circulation, and tectonic activity intensity.

8. Conclusion

The Shamakhi District is a перспективный (promising) region for mineral water exploration and utilization due to:

1. Complex tectonic and geological structure facilitating groundwater circulation;
2. Diversity of aquifers from alluvial to deep sedimentary horizons;
3. High mineralization potential controlled by geochemical processes;
4. Seismic activity influencing fracture development and groundwater systems.

Comprehensive studies of five newly identified mineral water sources were conducted, revealing key patterns of their distribution and formation within different geological structures and enabling the development of a new mineral water classification.

The dominant water types are weakly to moderately mineralized bicarbonate calcium and sodium waters. Their chemical composition results from long-term water–rock interaction, tectonic influence, and dynamic fluid processes.

Based on hydrogeochemical characteristics, it is recommended to conduct regime monitoring at the “Soyugbulag” and “Archiman” sources for inclusion in the regional seismogeochemical monitoring network, as these waters reflect deep circulation with minimal infiltration influence.

Practical Significance

The results identify new перспективные (prospective) mineral water resources and provide a balneological assessment of their therapeutic potential. Sulfate mineral waters with mineralization of 2–5 g/dm³ identified in the Shamakhi District are recommended for expanding the range of bottled local mineral waters.

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