

APPLICATION OF HYDROGEOCHEMICAL DIAGRAMS AND GEOTHERMOMETRY TO CHARACTERIZE THE SAMTSKHE-JAVAKHETI GEOTHERMAL SYSTEM, GEORGIA

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Abstract. The Samtskhe–Javakheti region of southern Georgia hosts significant geothermal resources associated with volcanic and tectonic activity. This study applies a combined hydrogeochemical and geothermometric approach to characterize the chemical evolution and thermal regime of thermal waters in the area. Major cation and anion analyses were interpreted using Piper, Durov, diamond grid, Ludwig–Langelier, and Schoeller diagrams to classify water types, evaluate mixing processes, and assess fluid–rock interactions. Reservoir temperatures were estimated using silica geothermometers and the Giggenbach Na–K–Mg triangle, distinguishing between immature and fully equilibrated fluids.

Results indicate that thermal waters range from calcium–sulfate and mixed alkaline–bicarbonate types to sodium–potassium–chloride and alkaline–chloride–sulfate types, reflecting diverse geochemical evolution. Temperatures derived from silica geothermometers and the Giggenbach triangle range from 70 to 122 °C, consistent with medium–enthalpy geothermal reservoirs. The study demonstrates that Samtskhe–Javakheti thermal waters comprise a heterogeneous mixture of immature and equilibrated fluids, providing a comprehensive understanding of water evolution and thermal characteristics. These findings support future geothermal exploration and sustainable utilization of the region’s resources.

Key words: Samtskhe–Javakheti, geothermal system, hydrogeochemistry, geothermometry, Piper diagram, Durov diagram, Giggenbach triangle, reservoir temperature.

Introduction

The Samtskhe–Javakheti region of southern Georgia, part of the Lesser Caucasus volcanic arc, hosts significant geothermal resources. The area features Neogene–Quaternary volcanism, including lava plateaus, volcanic cones, and pyroclastic deposits, primarily of basaltic to andesitic composition [1-2]. Fractured volcanic rocks and interbedded sediments facilitate hydrothermal circulation, generating numerous thermal springs [3-4].

Despite its potential, systematic hydrogeochemical and geothermometric studies are limited. The application of hydrochemical diagrams (Piper, Durov, diamond grid, Ludwig–Langelier, Schoeller) and chemical geothermometers provides insights into water evolution, reservoir temperatures, and fluid–rock interaction, supporting geothermal resource assessment.

Geological setting of the study area

The Samtskhe–Javakheti region is situated within the Lesser Caucasus volcanic arc, influenced by the convergence of the Arabian and Eurasian plates. Neogene–Quaternary volcanic activity formed extensive lava plateaus, volcanic cones, and pyroclastic deposits, which are interlayered with sedimentary formations [1-2]. Tectonic fracturing and volcanic structures create hydrothermal pathways, facilitating the circulation of thermal waters. Thermal springs are mainly associated with fractured volcanic rocks, tuffs, and sedimentary interbeds, which serve as aquifers [3-4].

Methods

Water samples were collected from 10 thermal springs and wells across the study area. Major cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+}) and anions (Cl^- , SO_4^{2-} , HCO_3^-) were analyzed following standard procedures. Hydrochemical facies were determined using Piper and Durov diagrams [5-6].

Further hydrochemical classification employed the diamond grid diagram [7-8], Ludwig–Langelier diagram [9], and semi-logarithmic Schoeller diagram [10] to evaluate water types and chemical evolution.

Reservoir temperatures were estimated using the Giggenbach Na–K–Mg triangle [11] and silica geothermometers [12]. Cation geothermometers were applied selectively for higher-temperature samples. These methods provided constraints on fluid–rock interaction, water maturation, and reservoir temperatures.

Results and Discussion

Water samples from ten thermal springs in the Samtskhe–Javakheti region (Table 1) were collected and subjected to chemical and physicochemical analyses.

Table 1. Sampled thermal water points: location, site name, temperature, and pH

ID	Location	pH	Outlet temperature °C
JA1	Tsinubani	9.68	38.2
JA10	Corchali	8.69	25
JA11	Didi Smada	9.59	27.6
JA2	Tsinubani 2	9.94	25.2
JA27	Vardzia	7.03	41.3
JA34	Aspindza	9.24	37.5
JA71	Nakalakevi	7.43	35.5
JA72	Tmogvi	7.12	60.9
JA73	Vardzia 2	7.63	54.3
JA98	Akhalsike	6.9	39.5

Hydrochemical Classification

The Durov diagram (Fig. 1a) reveals three zones [8]: JA71, JA72, JA73 (Zone 5): No dominant anions, indicating mixing or dilution; JA2 (Zone 6): SO_4 -dominant with Na as the major cation, reflecting probable mixing influences; JA98 (Zone 9): Cl^- and Na-dominated, characteristic of older, evolved waters.

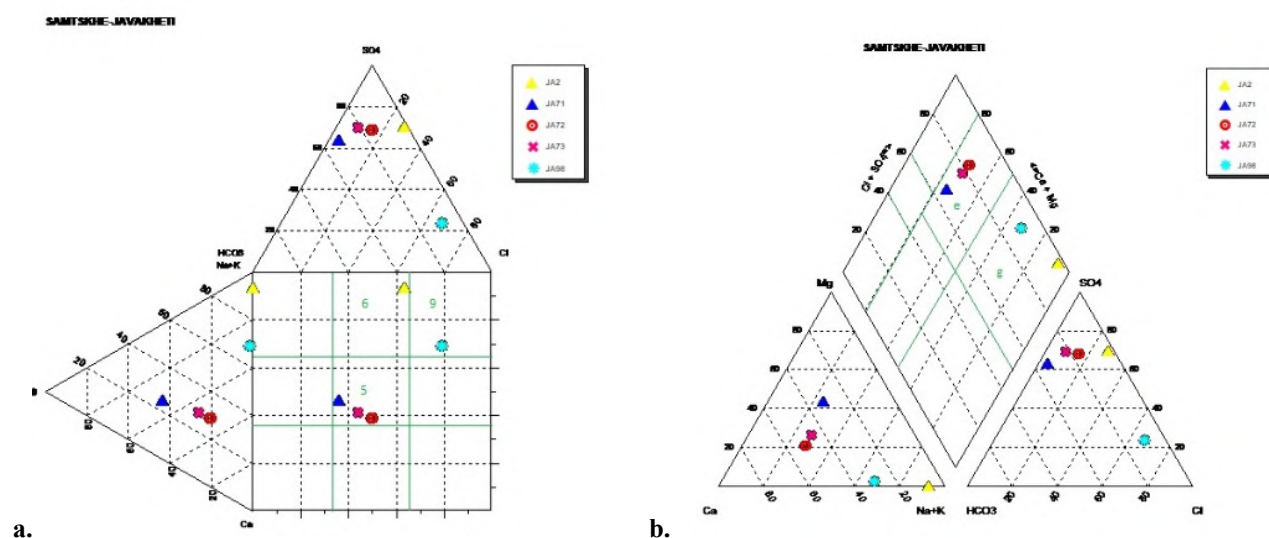


Fig. 1. Durov diagram (a) showing the hydrochemical classification of thermal water samples from the Samtskhe–Javakheti region. Piper diagram (b) illustrating the chemical facies of thermal water samples, highlighting sodium–potassium–chloride and calcium–sulfate types.

On the Piper diagram (Fig. 1b), JA2 and JA98 are classified as sodium–potassium–chloride type, while the remaining samples are calcium–sulfate type. The diamond grid diagram [7] identifies JA71, JA72, and JA73 as waters of increased alkalinity with elevated sulfate and chloride, whereas JA98 and JA2 are alkaline waters dominated by sulfate and chloride.

The Ludwig–Langelier diagram (Fig. 2a) further classifies JA71, JA72, and JA73 as mixed alkaline–bicarbonate waters (upper-left quadrant) and JA98, JA2 as alkaline–chloride–sulfate waters (upper-right quadrant).

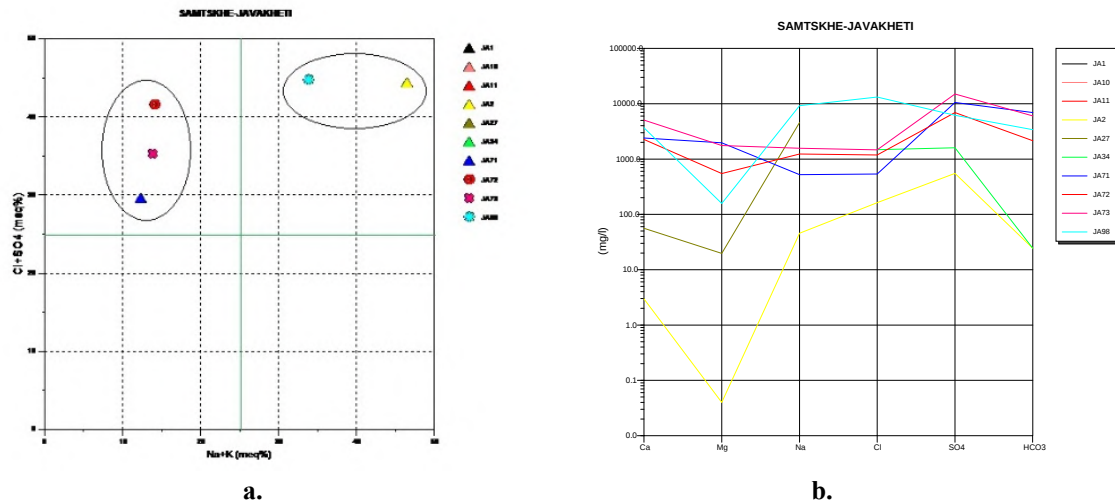


Fig. 2. Ludwig–Langelier diagram (a) showing the distribution of thermal waters according to alkaline–bicarbonate and alkaline–chloride–sulfate types. Semi-logarithmic Schoeller diagram (b) displaying major cation and anion compositions of the sampled thermal waters.

The Schoeller diagram (Fig. 2b) confirms these trends: JA71, JA72, JA73: $\text{Ca} > \text{Na} > \text{Mg}$; $\text{SO}_4 > \text{HCO}_3 > \text{Cl}$; JA2, JA27: $\text{Na} > \text{Ca} > \text{Mg}$; $\text{SO}_4 > \text{Cl} > \text{HCO}_3$; JA98: $\text{Na} > \text{Ca} > \text{Mg}$; $\text{Cl} > \text{SO}_4 > \text{HCO}_3$.

These results collectively indicate diverse geochemical evolution, mixing processes, and water maturity within the system.

Geothermometry

The Giggenbach Na–K–Mg triangle (Fig. 3) shows JA71, JA72, and JA73 in the “immature” water zone, indicating mixing with cold waters or conductive cooling, whereas JA2, JA27, and JA98 plot in the equilibrium zone, reflecting chemical equilibration with host rocks.

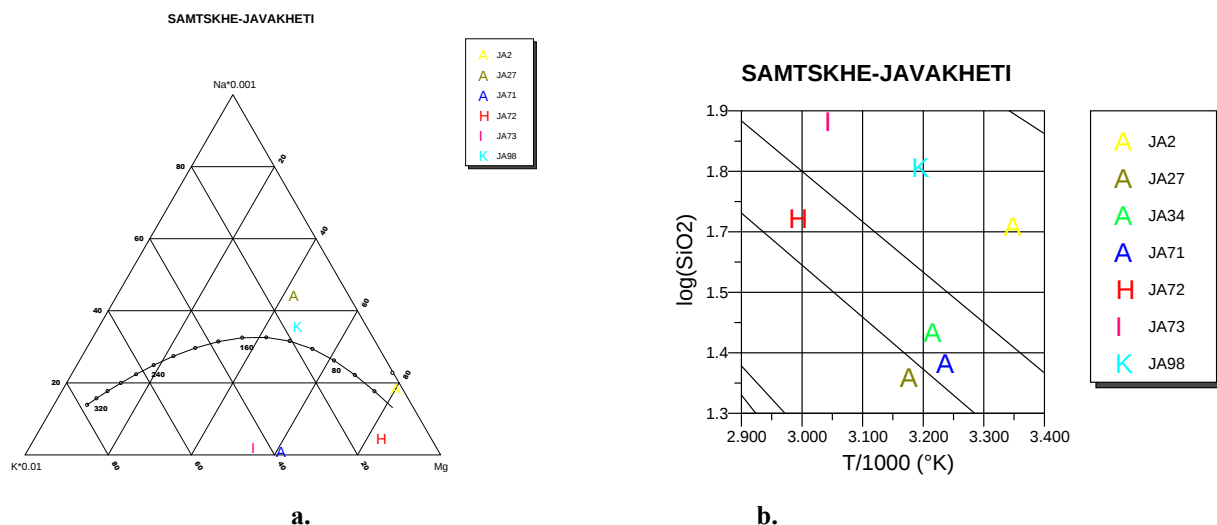


Fig. 3. Giggenbach Na–K–Mg triangle (a) depicting the equilibrium status of thermal waters, distinguishing between immature and equilibrated fluids; Reservoir temperatures of Samtskhe–Javakheti thermal waters estimated using silica geothermometers (quartz and chalcedony), showing the range of thermal conditions across sampled sites (b).

Reservoir temperatures derived from the Giggenbach triangle range from 70–90°C, while silica geothermometers provide slightly higher values of 70–122°C, consistent with the triangle results. Cation geothermometers were not applied to the low-temperature immature waters due to unreliability.

These findings, combined with hydrochemical diagram results, indicate the presence of both immature and fully equilibrated fluids, highlighting the heterogeneous nature of the Samtskhe–Javakheti geothermal system.

Conclusion

The integrated hydrogeochemical and geothermometric study demonstrates that the Samtskhe–Javakheti thermal waters comprise a mixture of immature and equilibrated fluids. Water types range from calcium–sulfate and mixed alkaline–bicarbonate to sodium–potassium–chloride and alkaline–chloride–sulfate, reflecting variable water–rock interaction, mixing, and thermal maturation. Reservoir temperatures of 70–122°C indicate medium-enthalpy geothermal potential, suitable for direct-use applications. The combined use of hydrochemical diagrams and geothermometers provides a robust framework for evaluating geothermal resources and guiding sustainable utilization in the region.

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