Seasonal Dynamics of the Physicochemical and Microbiological Parameters of Selected Thermal Waters in Adjara

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Abstract:

A seasonal investigation was carried out on selected thermal water sources in the Adjara region, specifically in Makhinjauri, Akhalsopeli, and Leghva. The contemporary landscape mosaic surrounding each thermal site was evaluated. Organoleptic and physicochemical parameters of the water samples were measured under field conditions. In laboratory conditions, the ionic composition, along with the concentrations of macroelements and microelements, was analyzed. To assess water quality, the abundance of saprophytic and coliform bacteria was quantified. Furthermore, accompanying gases were examined to determine hydrocarbon composition. The results of this comprehensive study were interpreted in the context of seasonal variation, with the objective of identifying potential avenues for the sustainable utilization of these thermal waters.

Keywords: thermalwaters; fieldmeasurements; physicochemicalparameters; elementalanalysis; biological invasion

I. Introduction

Relevance of the Problem: In the 21st century, amid accelerating global warming, irreversible atmospheric pollution, and the depletion of fossil fuel resources, the identification and development of alternative, renewable, and cost-effective energy sources have become increasingly critical. These efforts are essential for reducing environmental degradation, conserving natural resources, and mitigating the global energy crisis. In addition to solar and wind energy, thermal waters are recognized as a viable alternative energy source. They are considered among the most affordable, environmentally sustainable, stable, and virtually inexhaustible forms of energy. In Georgia, however, most thermal and mineral water resources remain largely unexploited. The therapeutic properties of these waters were well understood by earlier generations, who used them to treat various illnesses. At present, only a limited number of deposits have been studied and are utilized for industrial purposes. Out of approximately 250 identified deposits, only 44 geothermal wells have been officially registered, with temperatures ranging from 30°C to 112°C.

The Adjara–Trialeti fold system is regionally distinguished by highly favorable geothermal conditions, which have resulted in the predominantly thermal nature of groundwater discharge. These waters have historically been utilized for balneological and hygienic purposes since ancient times. Consequently, numerous geothermal water deposits have been identified in the region, and their thermal energy has been applied in balneotherapy as well as across various sectors of the local economy. Western Georgia is notably rich in thermal waters. In general, the deeper the aquifer, the higher the temperature of the discharged water. However, certain sources are characterized by high mineralization, which complicates extraction processes and adversely affects water quality. Georgian thermal waters are recognized for their considerable diversity, ranging from low to highly mineralized types, thus enabling their application across a broad spectrum of consumer and industrial needs. Up until the 1990s, systematic hydrogeological and geological investigations were conducted at officially registered thermal water deposits. These studies were considered essential for the sustainable and effective utilization of geothermal resources. However, following the onset of significant political and socio-economic upheavals in the post-Soviet period, such activities were largely discontinued (Melikadze, G. (2006), Saakashvili et al., 2011).

Geothermal heat is estimated to be five to six times more cost-effective than heat produced through conventional methods, with a relatively short return on investment for appropriately allocated capital. As such, Georgia represents a low-cost and inexhaustible source of deep geothermal energy. Most the country's thermal waters are characterized by therapeutic properties, elevated temperatures, and a diverse chemical composition. Geothermal water reserves are unevenly distributed throughout the country, with approximately 63% located in western Georgia, 24% in the eastern regions, and 13% in the south. These thermal waters exhibit a broad spectrum of chemical compositions, ranging from fresh hydrocarbonate-calcium types to highly mineralized chloride-sodium types. Nearly all categories of therapeutic waters, as defined by balneological classification systems, are present in Georgia. These include thermoradioactive, neutral, carbon dioxide-rich, alkaline-saline, ferruginous, arsenic-containing, and hydrogen sulfide-rich waters. Although Georgia possesses significant potential for the application of geothermal water resources in thermal energy production, this potential remains largely underexploited (Ministry of Environmental Protection and Agriculture of Georgia, 2022). In light of the aforementioned gaps, the present study aimed to conduct a comprehensive analysis of selected thermal waters and their associated gases in the Adjara region, with a focus on seasonal dynamics, to identify potential strategies for the sustainable management and utilization of these natural resources.

The objects of this study were the thermal waters of Makhinjauri (Khelvachauri Municipality), Akhalsopeli (Kobuleti Municipality), and Leghva (Kobuleti Municipality). A review of the limited available literature revealed that no comprehensive investigations have been conducted on these thermal water sources to date. Specifically, organoleptic, physicochemical, and microbiological parameters have not been systematically assessed. Furthermore, neither the ionic composition nor the multi-elemental profile of these waters has been analyzed, and the composition of their accompanying gases, particularly with respect to hydrocarbon content, has not been determined. Consequently, due to the absence of such integrated studies, the potential directions and prospects for the sustainable utilization of these thermal waters remain insufficiently understood.

Research Objectives and Methods: A comprehensive review and analysis of relevant literature were conducted as a preliminary step in the study (Ministry of Labour, Health and Social Affairs of Georgia. (2002); Gurgenidze, M. (2019); *Maximum Permissible Discharge (MPD) Norms of Pollutants Discharged with Wastewater into Surface Water Bodies (2020–2025)*; *Conference Proceedings: Regional Development Perspectives – Samtskhe-Javakheti*, 2016); Kiknadze et al., 2018). Three seasonal field expeditions (summer, autumn, and winter) were carried out, during which the organoleptic and physicochemical parameters of the thermal waters were assessed in situ (GOST 23268.1-91. *Mineral Drinking Waters;* GOST 31954-2012. *Drinking Water – Methods for Determining Hardness (ISO 6059:1984, NEQ; ISO 7980:1986, NEQ).* The ionic composition of the water samples was determined (GOST 23268.9-78. *Mineral Drinking Waters;* GOST 23268.8-78. *Mineral Drinking Waters;* GOST 18309-2014. *Water – Methods for Determining Phosphorus-Containing Substances (ISO 6878:2004, NEQ)*, and a multi-element analysis was performed under laboratory conditions using inductively coupled plasma atomic emission spectrometry (ICPE-9820) (Zhen Hao Lee & Qi An Tan; Kiknadze et al., 2018). Microbiological analysis was conducted to assess the microbial purity of the thermal waters (ISO 9308. *Water Quality).* Additionally, the accompanying gases were analyzed to determine their hydrocarbon content using gas–liquid chromatography (*Qualitative and Quantitative Analysis of Multi-Component Hydrocarbon Mixtures by Gas-Liquid Chromatography*). All results were evaluated with consideration of seasonal dynamics (Kiknadze et al., 2018).

Material-Technical Base and Human Resources: The research is being conducted within the framework of a targeted scientific research project funded by Batumi Shota Rustaveli State University (Grant Agreement No. 01-50/157, dated 26.03.2024; Scientific Direction: 1.10 – Interdisciplinary Research). Laboratory analyses are being performed at the Institute of Agrarian and Membrane Technologies, affiliated with Batumi Shota Rustaveli State University (BSU). The research team comprises academic staff from BSU, scientific personnel from the Institute of Agrarian and Membrane Technologies, and students specializing in Ecology, Agrarian Sciences, and Pharmacy who are actively involved in the implementation of the grant project.

II. Results

II.1. Diagnostic Assessment of Landscapes/Habitats Surrounding the Water Locations

Study Site – Makhinjauri.
GPS Coordinates: X 725075.2039; Y 4616596.988.
Elevation: 28.294 m above sea level.

The study site is situated near the Sakalmakhe River and is classified as a transformed ecosystem, located adjacent to a roadway. The area is characterized by an alley of walnut (*Juglans regia*), while plantations of Cryptomeria japonica are present on the nearby slopes. Isolated individuals of the invasive palm species *Trachycarpusfortunei* (Chinese windmill palm) were recorded. Within the shrub layer, both native and invasive species have become established, including *Pueraria hirsuta, Lonicera japonica, Deutzia scabra, Periplocagraeca, Clematis vitalba, Rubus caucasicus, Hedera colchica, Smilax excelsa, and scattered specimens of Hydrangea macrophylla,* among others.

The secondary phytocoenosis, which has been altered by anthropogenic influence, supports a wide range of adventive herbaceous species. These include *Microstegium japonicum, M. imberbe, Anthoxanthum odoratum, Paspalum dilatatum, Oplismenusundulatifolius, Hydrocotyle vulgaris, H. ramiflora, Festuca heterophylla, Polygonum perfoliatum, Achillea nobilis, A. foetida, Cirsium vulgare, Convolvulus arvensis, Falcaria vulgaris, Ophiopogon japonicus, Duchesnea indica, Agropyron repens, Crepisfoetida, Perilla nankinensis,* and others. The vegetation cover has been extensively transformed as a result of human activity. The area is polluted with construction debris, and the living vegetation layer is predominantly secondary, consisting mainly of mesophytic invasive herbaceous species. The mosaic structure of the vegetation is shaped by a combination of factors, including hilly topography, climatic conditions, soil properties, anthropogenic impact, and other environmental variables.

Study Site – Akhalsopeli
GPS Coordinates: X 732420.5559; Y 4333694.242.
Elevation: 8.178 m above sea level.

The study site is situated along the Achkva River. The vegetation exhibits a diverse typological spectrum, with *Alnus barbata* (Caucasian alder) identified as the dominant tree species. Among the mixed arboreal composition, *Pterocaryapterocarpa* (Caucasian wingnut), *Populus canescens* (grey poplar), and *Salix spp.* (willow) are commonly represented, accompanied by scattered individuals of *Juglans regia* (walnut). A high invasive potential of alien plant species has been documented, with abundant populations of *Pueraria lobata* (kudzu vine). Suckering of *Acacia dealbata* (silver wattle) has also been observed. The shrub layer is primarily composed of relict species, including *Rubus caucasicus* (Caucasian blackberry), *Hedera colchica* (Colchic ivy), *Convolvulus arvensis* (field bindweed), *Humulus lupulus* (common hop), and *Sambucus nigra* (black elder), among others. The projective cover of the herbaceous layer is high and predominantly composed of adventive mesophytic species, such as *Ambrosia artemisiifolia, Digitariasanguinalis, Erigeron canadensis, Paspalum digitaria, Perilla nankinensis, Plantago major, Polypogonimberbis, Pteridium tauricum, Setaria glauca, Juncus effusus, Smilax excelsa, Lysimachia vulgaris, Solidago canadensis, Sisyrinchium septentrionale, Hydrocotyle vulgaris*, and others. The natural vegetation cover has been significantly modified by anthropogenic disturbances. The current living vegetation is predominantly secondary and consists largely of mesophytic herbaceous species. The mosaic structure of the plant community is shaped by the interaction of topographic variability, climatic conditions, soil characteristics, anthropogenic impacts, and other environmental factors.

Study Site – Leghva

GPS Coordinates: X 7424338.613; Y 4638118.757

Elevation: 83.4 m above sea level

The study site is located on a flat plain intersected by the Skura River. A narrow strip of riparian tree vegetation extends along the river valley, primarily composed of *Alnus barbata* (Caucasian alder). Among the mixed arboreal species, *Pterocaryapterocarpa* (Caucasian wingnut) is frequently encountered. The surrounding landscape includes a maize (*Zea mays*) field and a *Corylus avellana* (hazelnut) plantation, with the site situated adjacent to a roadway. The herbaceous layer within these agrocoenoses is characterized by a high frequency of adventive species and a heterogeneous floristic composition, comprising both native and alien taxa. Documented species include *Hydrocotyleramiflora*, *Poa annua*, *Lespedeza striata*, *Trifolium diffusum*, *Pteridium tauricum*, *Paspalum thunbergii*, *P. paspalodes*, *Polygonum thunbergii*, *Cyperus esculentus*, *C. longus*, *C. badius*, *Solidago virgaurea*, *Ajuga reptans*, *Ambrosia artemisiifolia*, *Asplenium scolopendrium*, *Miscanthus sinensis*, *Oxalis violacea*, *Perilla nankinensis*, *Setaria glauca*, *Cynodondactylon*, and others. The area surrounding the thermal water source has been transformed into agrocoenosis and remains under constant anthropogenic influence. The site is fenced and safeguarded by livestock and other external disturbances. It is positioned alongside the Skura River valley and adjacent to a road. The vegetation cover is marked by a high invasion potential of alien plant species.

II.2. Results of Field Measurements

Organoleptic parameters assessed under field conditions indicated that the thermal waters were generally colorless. An exception was recorded in June at the Leghva site, where the water exhibited a yellowish hue, attributed to the presence of abundant clay particles on the surface (Table 1). The thermal water at Makhinjauri was characterized by a pronounced odor indicative of hydrogen sulfide, whereas the water at Akhalsopeli emitted a distinct gasoline-like smell. Taste evaluations showed varying degrees of salinity: the water at Makhinjauri was slightly saline, that at Akhalsopeli moderately saline, and the water at Leghva highly saline. In terms of transparency, the waters at Makhinjauri and Akhalsopeli were classified as clear, while the water at Leghva was slightly turbid.

Table1

Organoleptic Characteristics of Thermal Waters – First Expedition (June)

Parameter	Location	Description
Color	Makhinjauri	A colorless liquid
	Akhalsopeli	A colorless liquid
	Leghva	Yellowish liquid

Odor	Makhinjauri	Characterized by a typical hydrogen sulfide odor
	Akhalsopeli	A distinctive gasoline-like smell
	Leghva	Indicative of a complex mixture of dissolved substances in the water
Taste	Makhinjauri	Slight saline
	Akhalsopeli	Moderate saline
	Leghva	High saline
Appearance	Makhinjauri	Clear, free of suspended particles
	Akhalsopeli	Clear, free of suspended particles
	Leghva	clay particles visible on the water surface
Appearance	Makhinjauri	Transparent
	Akhalsopeli	Transparent
	Leghva	Slight turbid

Second expedition (October)

Parameter	Location	Description
Color	Makhinjauri	A colorless liquid
	Akhalsopeli	A colorless liquid
	Leghva	A colorless liquid
Odor	Makhinjauri	Characterized by a typical hydrogen sulfide odor
	Akhalsopeli	A distinctive gasoline-like smell
	Leghva	Indicative of a complex mixture of dissolved substances in the water
Taste	Makhinjauri	Slight saline
	Akhalsopeli	Moderate saline
	Leghva	High saline
Appearance	Makhinjauri	Clear, free of suspended particles
	Akhalsopeli	Clear, free of suspended particles
	Leghva	clay particles visible on the water surface
Appearance	Makhinjauri	Transparent
	Akhalsopeli	Transparent
	Leghva	Slight turbid

Third expedition (December)

Parameter	Location	Description
Color	Makhinjauri	A colorless liquid
	Akhalsopeli	A colorless liquid
	Leghva	A colorless liquid
Odor	Makhinjauri	Characterized by a typical hydrogen sulfide odor
	Akhalsopeli	A distinctive gasoline-like smell
	Leghva	Indicative of a complex mixture of dissolved substances in the water
Taste	Makhinjauri	Slight saline
	Akhalsopeli	Moderate saline
	Leghva	High saline
Appearance	Makhinjauri	Clear, free of suspended particles
	Akhalsopeli	Clear, free of suspended particles
	Leghva	clay particles visible on the water surface
Appearance	Makhinjauri	Transparent
	Akhalsopeli	Transparent
	Leghva	Slight turbid

The thermal waters of Makhinjauri (34.9–37.62 °C) and Akhalsopeli (35.0–37.62 °C) are classified as warm, where as the water at Leghva is categorized as cool, with temperature sranging from 13.5 to 18.34 °C. Atmospheric pressure at the Makhinjauri site was measured at 1014.2 mbar in summer, 1018.9 mbar in autumn, and 1013.8 mbar in winter (Table 2). At the Akhalsopeli site, values were recorded at 1016.0 mbar in summer, 1023.5 mbar in autumn, and 1018.8 mbar in winter. Atmospheric pressure at the Leghva site was measured at 1012.4 mbar in summer, 1017.8 mbar in autumn, and 1011.9 mbar in winter. The pH levels of the Makhinjauri (9.5–8.86) and Akhalsopeli (8.0–8.56) waters indicate moderate alkalinity, where as the Leghva water is classified as weakly alkaline (7.80–8.17). The highest electrical conductivity was recorded in the Leghva water (11,450–11,530 µS/cm), while the lowest values were observed at Makhinjauri (495–561 µS/cm). Correspondingly, salinity was found to be highest at the Leghva site (5,725–5,765 mg/L) and lowest at the Makhinjauri site (247–281 mg/L).

Table 2

Assessment of Physicochemical Parameters of Thermal Waters Under Field Conditions

First Expedition (June)

Location	Physical and Chemical Parameters				
	Temperature, °C	*Atmospheric Pressure, mbar*	*pH*	*Electrical Conductivity, µS/Sm*	*Salinity, mg/l*
Makhinjauri	37.62	1014.2	9.5	495	247
Akhalsopeli	37.63	1016.0	8.56	10650	5325
Leghva	18.34	1012.4	8.17	11498	5749

Second expedition (October)

Location	Physical and Chemical Parameters				
	Temperature, °C	*Atmospheric Pressure, mbar*	*pH*	*Electrical Conductivity, µS/Sm*	*Salinity, mg/l*
Makhinjauri	37.20	1018.9	9.0	518	259
Akhalsopeli	37.20	1023.5	8.50	9060	4530
Leghva	15.63	1017.8	7.86	11450	5725

Third expedition (December)

Location	Physical and Chemical Parameters				
	Temperature, °C	*Atmospheric Pressure, mbar*	*pH*	*Electrical Conductivity, µS/Sm*	*Salinity, mg/l*
Makhinjauri	34.9	1013.8	8.86	561	281
Akhalsopeli	35.0	1018.8	8.0	10700	5350
Leghva	13.5	1011.9	7.80	11530	5765

III. Laboratory Studies

III.1. Ionic Composition of Thermal Waters

The waters of Makhinjauri (pH 9.5–8.86) and Akhalsopeli (pH 8.0–8.56) are classified as moderately alkaline, while the water at Leghva is considered weakly alkaline (pH 7.80–8.17). A direct correlation between pH and alkalinity was observed; as pH increased, alkalinity also increased, as indicated by elevated concentrations of bicarbonate ions (HCO_3^-) across all study sites (Table 3). Chloride and sodium ions were found to play a leading role in the salinization process. In the thermal waters of Akhalsopeli and Leghva, chloride was identified as the dominant anion, with its concentration decreasing during the winter season. The total hardness of the Leghva thermal water exceeded established permissible limits by a factor of 3 to 4. In contrast, the hardness of the Akhalsopeli water remained within acceptable limits, while the Makhinjauri water was characterized as soft. The concentrations of nitrates, nitrites, ammonium ions, phosphates, and sulfates confirmed that the thermal waters were not chemically contaminated. A general decline in the concentrations of these ions was observed with decreasing temperature. Although the concentration of silicon in the thermal waters exceeded the maximum permissible concentration (MPC), the waters were not classified as siliceous, as the balneological threshold for this biologically active element is a minimum of 50 mg/L. Iron concentrations were found to be negligible; therefore, the waters were not classified as ferruginous. In the thermal water at Akhalsopeli, the fluoride concentration exceeded the permissible limits during all three seasons. The Makhinjauri thermal water is characterized by a sulfide composition rich in hydrogen sulfide. The Akhalsopeli thermal water is presumed to be of the chloride-sodium ionic type and exhibited elevated levels of both fluoride and boron. Based on temperature measurements (34.9–37.62 °C), the thermal water at Makhinjauri is not classified as mineral water. In contrast, the Akhalsopeli water is categorized as mineral-thermal (35.0–37.63 °C), with a mineralization level exceeding 1 g/L. The Leghva water is classified as highly mineralized, with mineral content ranging from 7.400 to 7.540 g/L.

Table 3

Ionic Composition of Thermal Waters

First Expedition (June)

Parameter, Unit of Measurement	Locaion			*Permissible limit*
	Makhinjauri	*Akhalsopeli*	*Leghva*	
pH	9.5	8.56	8.17	**6.5-8.5**
HCO_3^-, mg/l	73.2	54.9	30.5	**400**
Hardness,mg.eq./l	0.3	6.8	30.0	**7-10**
Ca^{2+}, mg/l	4.0	132.3	420.8	**140**
Mg^{2+}, mg/l	1.22	2.4	109.5	**85**
Cl^-, mg/l	63.65	1570.5	1638.4	**250**
NH_4^+, mg/l	0.028	0.098	1.283	**2.0**
NO_2^-, mg/l	0.135	0.133	0.189	**0.2**
NO_3^-, mg/l	4.31	2.1	2.25	**50**
PO_4^{3-}, mg/l	0.078	0.045	0.0066	**3.5**
F^-, mg/l	0.639	2.967	-	**0.7**
H_2S, mg/l	6.8	-	-	**0.03**
Dry residue, mg/l (mineralization)	280	1224	7540	1000

Second expedition (October)

Parameter, Unit of Measurement	Locaion			*Permissible limit*
	Makhinjauri	*Akhalsopeli*	*Leghva*	
pH	9.0	8.50	7.86	**6.5-8.5**
HCO_3^-, mg/l	64.6	51.7	26.8	**400**
Hardness, mg.eq./l	0.3	5.2	25.875	**7-10**
Ca^{2+}, mg/l	4.6	113.0	380.5	**140**
Mg^{2+}, mg/l	0.3	1.66	93.74	**85**
Cl^-, mg/l	56.7	1530.6	1560.8	**250**
NH_4^+, mg/l	0.016	0.091	1.344	**2.0**
NO_2^-, mg/l	0.134	0.110	0.170	**0.2**
NO_3^-, mg/l	1.78	0.85	1.04	**50**
PO_4^{3-}, mg/l	0.069	0.034	0.049	**3.5**
F^-, mg/l	0.40	2.62	0.04	**0.7**
H_2S, mg/l	5.98	-	-	**0.03**
Dry residue, mg/l	268	1165	7486	**1000**

Third expedition (December)

Parameter, Unit of Measurement	Locaion			*Permissible limit*
	Makhinjauri	*Akhalsopeli*	*Leghva*	
pH	8.86	8.0	7.80	**6.5-8.5**
HCO_3^-, mg/l	61.0	48.8	25.7	**400**
Hardness, mg.eq./l	0.275	5.0	23.0	**7-10**
Ca^{2+}, mg/l	3.27	94.49	372.0	**140.0**
Mg^{2+}, mg/l	0.1	0.5	87.6	**85.0**
Cl^-, mg/l	40.0	1475.0	1500.0	**250**
NH_4^+, mg/l	-	-	0.093	**2.0**
NO_2^-, mg/l	0.027	0.022	0.034	**0.2**
NO_3^-, mg/l	-	-	-	**50**
PO_4^{3-}, mg/l	0.039	0.027	0.045	**3.5**
F^-, mg/l	0.414	1.147	0.5472	**0.7**
H_2S, mg/l	5.112	-	-	**0.03**
Dry residue, mg/l	254	1100	7400	**1000**

III.2. Multi-Element Analysis of Thermal Waters by Plasma Atomic Emission Spectrometry

A multi-element analysis of thermal waters, conducted using plasma atomic emission spectrometry, indicated that among the macroelements, aluminum concentrations were elevated at all three study sites. Additionally, silicon concentrations were found to increase during the winter season (Table 4). In the thermal waters of Akhalsopeli and Leghva, the concentrations of potassium, and especially sodium, exceeded established permissible limits. These elevated ion levels were found to contribute significantly to the degree of salinization at both locations. At the Akhalsopeli site, sodium concentrations exceeded the maximum permissible concentration (MPC) of 200 mg/L by a factor of 16 to 30, while at the Leghva site, exceedances ranged from 12 to 20 times above standard. Magnesium concentrations in the thermal waters at Leghva also surpassed the permissible threshold during all three seasons, with exceeding factors ranging approximately from 1.03 to 1.29.

Table 4

Multi-Element Analysis of Thermal Waters by Plasma Atomic Emission Spectrometry

Macroelements (mg/L). First Expedition (June)

Locaion	Al	Fe	K	Ca	Mg	Na	P	Si
Makhinjauri	1.42	-0.0103	12.1	4.0	1.22	194	0.0775	18.2
Akhalsopeli	18.6	-0.0104	98.4	132.3	2.4	5976	0.0484	7.52
Leghva	24.9	0.162	93	420.8	109.5	3998	0.0861	12.38
MPC	**0.5**	**0.3**	**20.0**	**140**	**85**	**200**	**3.5**	**10**

Second expedition (October)

Locaion	Al	Fe	K	Ca	Mg	Na	P	Si
Makhinjauri	1.71	-0.086	4.99	4.6	0.3	87.1	0.0314	21.8
Akhalsopeli	23.3	-0.083	33.5	113	1.66	3180	0.0341	9.97

Leghva	33.4	0.062	29.9	380.5	93.74	2580	0.0093	15.7
MPC	**0.5**	**0.3**	**20.0**	**140**	**85**	**200**	**3.5**	**10**

Third expedition (December)

Locaion	**Al**	**Fe**	**K**	**Ca**	**Mg**	**Na**	**P**	**Si**
Makhinjauri	1.66	-0.082	1.798	3.27	0.1	85.5	0.0201	22.5
Akhalsopeli	22.7	-0.080	32.9	94.49	0.5	4060	0.0153	10.53
Leghva	32.8	0.0097	29.1	372.0	87.6	2490	0.0077	16.0
MPC	**0.5**	**0.3**	**20.0**	**140**	**85**	**200**	**3.5**	**10**

The concentrations of the following microelements were not detected in the thermal waters during any of the three seasons: Co, Cr, Cu, Mo, Ni, Zn, Sb, Se, Ti, Tl, V, Be, Hg, Pb, As, and Cd (Table 5). Boron was consistently detected at both the Akhalsopeli and Leghva sites throughout all sampling periods. Particularly at Akhalsopeli, the concentration of boron exceeded the maximum permissible concentration (MPC) by a factor of 30 to 35, indicating a potentially significant environmental and health concern. Elevated concentrations of lithium and manganese were also recorded in the Leghva thermal waters across all three seasons. The concentration of barium, a known toxic element, remained below the maximum permissible concentration in all thermal water samples.

Table 5

Multi-Element Analysis of Thermal Waters by Plasma Atomic Emission Spectrometry Microelements (mg/L). First Expedition (June)

Locaion	**B**	**Mn**	**Ba**	**Li**	**Sb**
Makhinjauri	0.17	-	-	-	-
Akhalsopeli	14.8 H	0.0058	0.0093	-	-
Leghva	2.75	0.236	0.0003	0.1538	<0.00170
MPC	**0.5**	**0.05-0.1**	**0.1**	**<0.03**	**0.005**

Second expedition (October)

Locaion	**B**	**Mn**	**Li**	**Sb**	**Ba**
Makhinjauri	0.14	-0.0002	-0.0369	-0.0237	-0.0001
Akhalsopeli	17.4 H	0.0062	-0.430	-0.0064	0.0071
Leghva	3.19	0.0615	0.214	<0.0031	0.0006
MPC	**0.5**	**0.05-0.1**	**<0.03**	**0.005**	**0.1**

Third expedition (December)

Locaion	**B**	**Mn**	**Li**	**Sb**	**Ba**

Makhinjauri	0.099	0.0004	-0.011	-0.0149	-0.0901
Akhalsopeli	16.5 H	0.0042	-0.400	-0.0118	0.007
Leghva	3.12	0.165	0.24	<0.0029	0.0006
MPC	**0.5**	**0.05-0.1**	**<0.03**	**0.005**	**0.1**

III.3. Assessment of Thermal Water Purity

Thermal water samples were evaluated for fecal contamination, revealing that during the summer season, the number of saprophytic microorganisms per milliliter was as follows: Makhinjauri, 8 CFU/mL; Akhalsopeli, 18 CFU/mL; and Leghva, 12 CFU/mL (with the permissible limit set at ≤100 CFU/mL). In the autumn season, a marked decrease in saprophytic microorganism counts was recorded at the Akhalsopeli and Leghva sites, while no saprophytes were detected in the Makhinjauri samples (Table 6). During the winter season, all three sites were found to be free of saprophytic microorganisms. The abundance of saprophytic anaerobic microorganisms is closely correlated with the presence of readily biodegradable organic compounds in oligotrophic environments such as freshwater systems. Variations in their abundance serve as sensitive indicators of eutrophication processes, commonly manifested as algal blooms, driven by anaerobic microbial activity and accompanied by the deterioration of organoleptic properties such as odor and taste. Across all sampling sites and seasons, the concentration of lactose-positive coliform bacteria, a key indicator of fecal contamination, remained below 300 CFU/L, staying within acceptable hygienic and sanitary standards.

Table 6

Microbiological Analysis of Thermal Waters

First Expedition (June)

Parameter, Unit of Measurement	Location			*Permissible limit*
	Makhinjauri	*Akhalsopeli*	*Leghva*	
Total Number of Saprophytic Microorganisms (*CFU/mL)	8	12	18	nomore100/1ml
Count of Lactose-Positive Coliform Bacteria (CFU/L)	< 300	< 300	< 300	nomore 300/1L

Second expedition (October)

Parameter, Unit of Measurement	Location			*Permissible limit*
	Makhinjauri	*Akhalsopeli*	*Leghva*	
Total Number of Saprophytic Microorganisms (*CFU/mL)	-	2	6	nomore100/1ml
Count of Lactose-Positive Coliform Bacteria (CFU/L)	< 300	< 300	< 300	nomore 300/1L

Third expedition (December)

Parameter, Unit of Measurement	Location	*Permissible limit*

	Makhinjauri	*Akhalsopeli*	*Leghva*	
Total Number of Saprophytic Microorganisms (*CFU/mL)	-	-	-	nomore100/1ml
Count of Lactose-Positive Coliform Bacteria (CFU/L)	< 300	< 300	< 300	nomore 300/1L

III.4. Analysis of Hydrocarbon Content in Gases Accompanying Thermal Waters

Methane was identified as the dominant hydrocarbon component in the accompanying gases, based on retention time determined through gas analysis. At all three study sites, the hydrocarbon composition of the associated gases consisted exclusively of methane, with a methane yield of 100% (Figures 1, 2, and 3). During the summer season, methane concentrations, estimated from peak area measurements, increased across sites in the following ascending order: Makhinjauri<Leghva<Akhalsopeli. In the autumn and winter seasons, a decline in methane content was observed in the gases accompanying thermal waters. It is noteworthy that, due to the already low methane concentration in the Makhinjauri thermal water during the summer, methane could not be detected at this site during the autumn and winter sampling periods.

Figure 1.

Hydrocarbon Composition of Gases Accompanying Thermal Waters, June

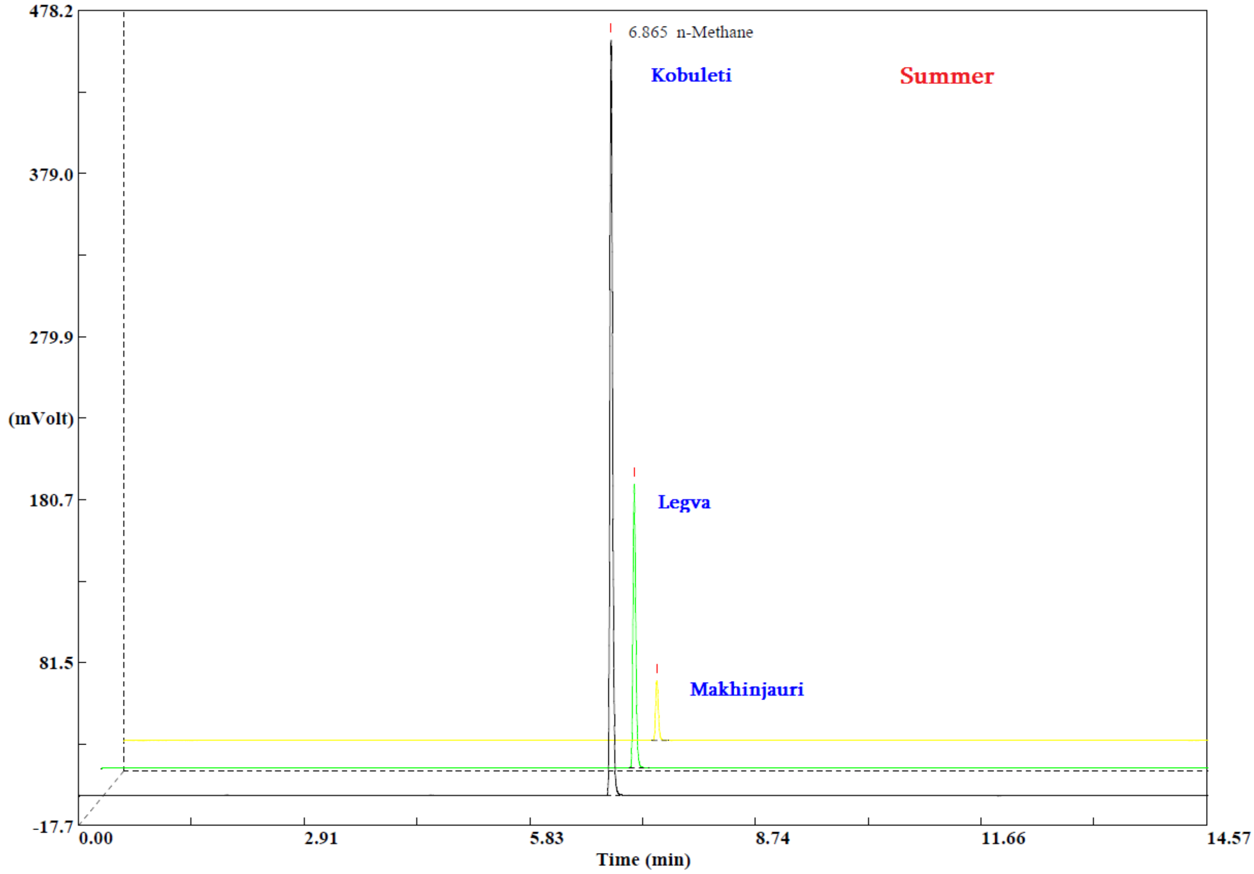


Figure2.

Hydrocarbon Composition of Gases Accompanying Thermal Waters, October

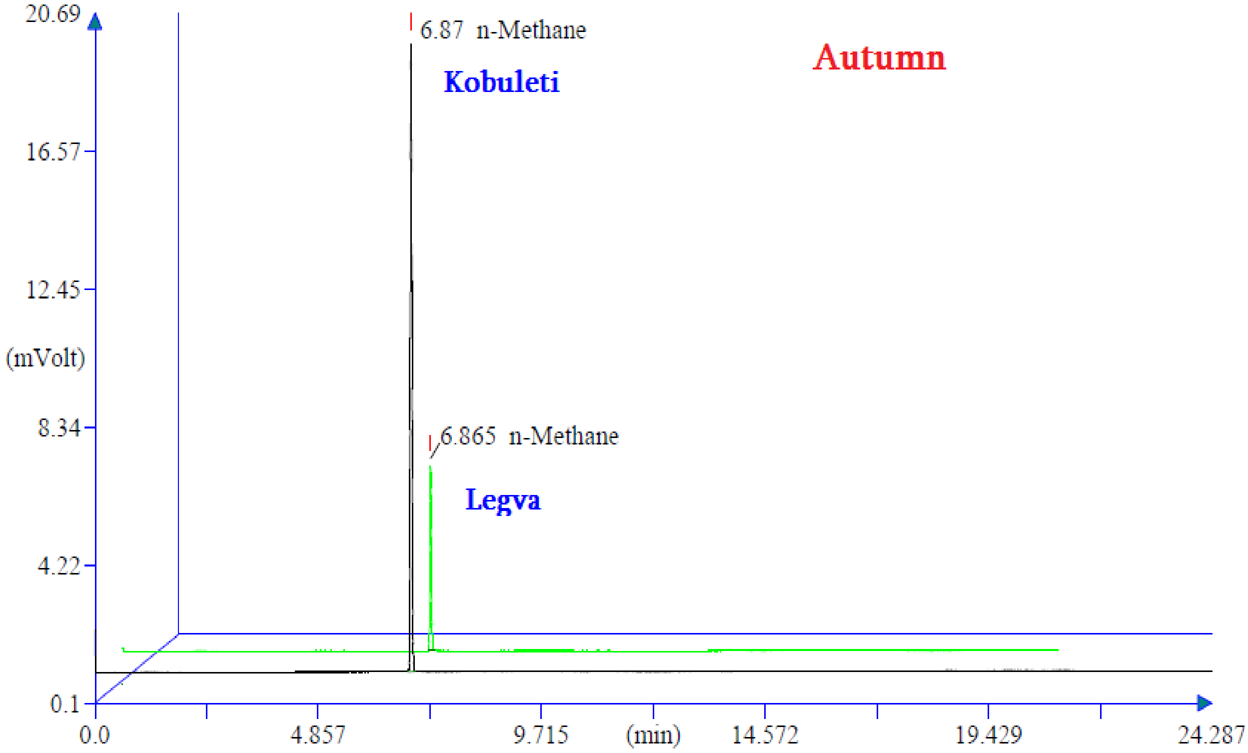
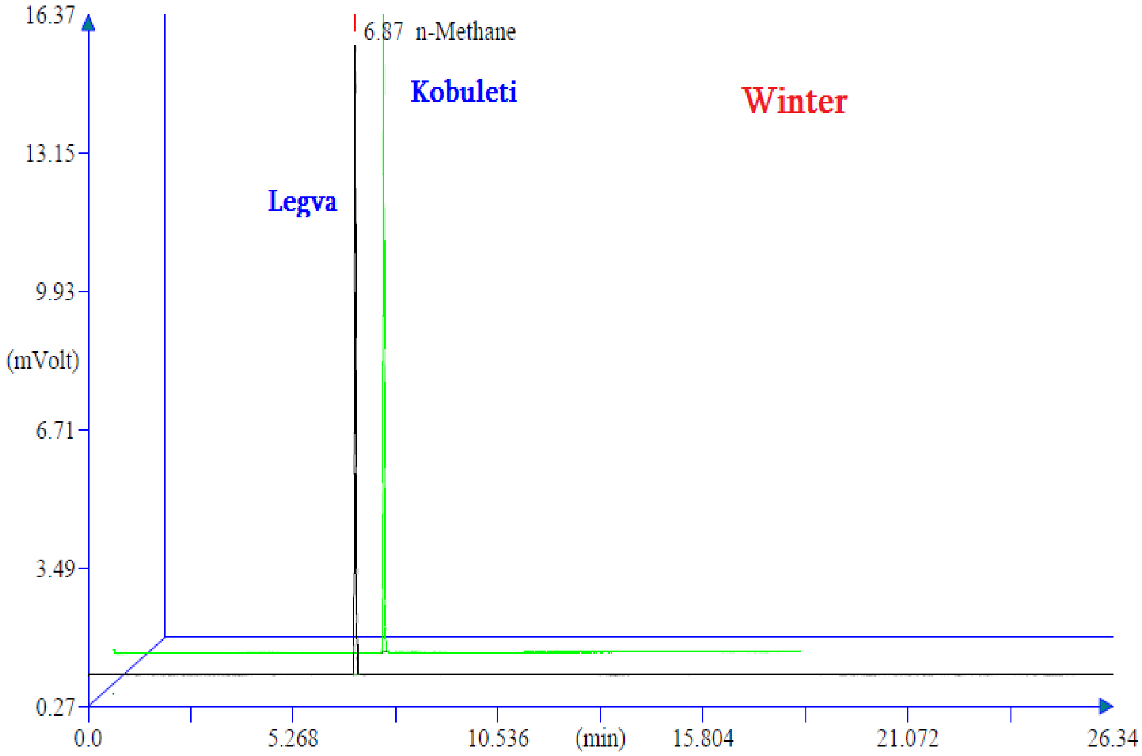


Figure3.

Hydrocarbon Composition of Gases Accompanying Thermal Waters, December



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