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# EXPLORING SPRINGS IN KISHTWAR FOR HYDRO-GEOCHEMISTRY VIA MULTI-FACTOR ANALYSIS

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**Abstract**

Springs in Kishtwar, Jammu and Kashmir, serve as vital water sources in this Himalayan region, yet their hydrogeochemical profiles remain underexplored. This study applies multi-factor analysis, including principal component analysis (PCA) and Piper trilinear diagrams, to assess water quality from selected geothermal and non-geothermal springs like Kiyar, Tatapani Padder, Godresh, Vimal. Temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), turbidity, hardness, chlorides, sulphates, and nitrates were all measured in situ and in the lab using APHA 23rd-edition protocols on twenty-four composite water samples that were collected between May and July. Results reveal rock-water interaction as the dominant control, with hot springs showing elevated mineralization, elevated electrical conductivity, high total dissolved solids, slightly alkaline $p^H$ and elevated temperatures. Hot springs show enhanced chemistry promising its therapeutic and ecotourism applications. Since these hot springs exhibits lower DO and higher organic and mineral content requires attention for careful monitoring if used for drinking. On the other hand, cold springs viz. Godresh and Vimal displayed lower organic loading, greater DO, and colder temperature. All physico-chemical parameters stayed within the BIS, APHA and WHO drinking water guideline levels, suggesting their broad acceptability.

**Keywords**: Hot and Cold Springs, Hydrogeochemical Dynamics, Kishtwar, Sustainable Management, Water Quality Index (WQI).

**Introduction**: Known as the Third Pole, the Himalayan region is one of the planet's most important fresh water reservoirs. Major river systems including the Indus, Ganges and Brahmaputra provide water to roughly 1.9 billion people in south Asia. The subcontinent snowfield, glaciers and springs serve as natural reservoirs that nourish perennial rivers and support hydropower agriculture and wild life.[1,2,3,4] Particularly in Indian Himalayan areas like

Jammu & Kashmir, Himachal Pradesh, and Uttarakhand, springs are very important for rural and mountainous inhabitants. These springs, which are frequently found in places with little or no access to groundwater or piped water supplies, are the main sources of drinking water, irrigation, and everyday household needs.[5,6] However, anthropogenic pressures, deforestation, uncontrolled tourism, climate change, and unpredictable rainfall patterns have all contributed to the depletion and deterioration of spring water sources in recent decades.[7,8,9] The Himalayan region's water sources are especially susceptible to pollution and seasonal fluctuations due to the region's complicated hydrogeology and geologically delicate terrain.[10,11,12] Public health and ecological sustainability are seriously threatened by surface and spring water contamination brought on by increased urbanization and land-use change in hill regions. Furthermore, the recharging of aquifers that supply these springs is being directly impacted by the swift retreat of glaciers and decreased snow cover brought on by global warming.[13,14] In this regard, physico-chemical monitoring of Himalayan springs becomes crucial for understanding the current state of water quality as well as for developing suitable conservation, sustainable management, and safe drinking water access policies for the local population.[15,16,17] Particularly in understudied regions like Kishtwar in Jammu and Kashmir, systematic investigations on water quality indicators offer important insights into the origins of pollution, seasonal patterns, and the general health of freshwater ecosystems. In rural and hilly areas, water springs are essential lifelines that supply fresh water for home usage, irrigation, and drinking. Springs are frequently the main and most accessible supply of water in areas like Kishtwar, which are known for their rough terrain and inadequate infrastructure. For rural populations' health and well-being, it is crucial to guarantee the sustainability and safety of these sources.[18,19,20] Both natural and man-made variables affect the quality of spring water. The chemical composition is influenced by geology, soil type, and seasonal change, and contamination may result from human activities including agriculture, open defecation, and uncontrolled construction.[21,22,23] In contrast to urban regions with centralized water treatment systems, rural residents frequently drink untreated water straight from springs, making them more susceptible to long-term health problems, heavy metal exposure, and waterborne illnesses.[24,25,26] In addition, spring flow dynamics, groundwater recharge, and precipitation patterns are all changing due to climate change. Because of this, it is crucial to continuously monitor physico-chemical parameters in order to comprehend how water quality evolves over time and to develop adaptable techniques for managing water resources.[27, 28] In many rural civilizations, springs also have ecological and cultural value. In addition to public health emergencies, their degradation can lead to the loss of traditional knowledge and community identity.[29, 30] As a result, scientific research on the quality of spring water contributes to the development of infrastructure, conservation initiatives, and policy, especially in rural areas where access to clean water is still a developmental challenge.[31,32,33] The Union Territory of Jammu and Kashmir's District Kishtwar, which is situated in the eastern portion of the Jammu area, is renowned for its abundant natural resources, distinctive topography, and essential freshwater systems. Kishtwar, which is surrounded by Doda, Anantnag, and the Chenab River valley, is distinguished by its rugged landscape, thick forests, and glacial-fed springs that provide the local population with their main supply of irrigation and drinking water. The area undergoes a variety of meteorological circumstances that affect the hydrochemical composition of its water bodies due to its altitudes, which range from 1,500 to nearly 6,000 meters above sea level.[34, 35, 36] Due to the lack of piped water delivery infrastructure, most of Kishtwar's rural and hilly people rely on natural springs for their daily water needs. Snowmelt and rainfall infiltration through fractured bedrock and wooded catchments feed these springs, many of which are perennial and found in isolated locations. Concern over the decline in spring water quality, particularly in terms of physico-chemical features, is growing due to the region's increased anthropogenic pressures, including road development, deforestation, and uncontrolled garbage disposal.[37,38] Variations in the water's flavour, clarity, and flow patterns in Kishtwar's springs have been noted in a number of field observations and local surveys conducted in recent years. A thorough scientific evaluation is required since these changes point to potential changes in the hydrogeochemical environment of aquifers and adjacent ecosystems. Additionally, these natural springs are more vulnerable due to climate change-related effects such decreased snowfall and altered precipitation patterns. There is little scientific literature on the thorough physico-chemical profiling of Kishtwar's springs, despite the vital reliance on these sources. Concerns about water quality in various Chenab Valley regions have been brought to light by a few recent studies, but there has not been much focus on high-altitude rural springs in Kishtwar. In order to guarantee safe drinking water and to comprehend the long-term sustainability of these water sources, it is crucial to assess physico-chemical parameters including pH, electrical conductivity, dissolved oxygen, total dissolved solids, and ionic concentrations.[39,40,41] Furthermore, if untreated spring water is tainted by chemical or microbiological pollutants, it may be dangerous for public health. Because of this, routine water quality monitoring is essential, particularly in a district with limited access to state-of-the-art water treatment and testing facilities. By evaluating specific physico-chemical characteristics of springs at different places in District Kishtwar, this study seeks to close the information gap and further our understanding of hydrogeological behaviour and water safety in Himalayan regions.[42,43] The water quality problems in Jammu and Kashmir, notably the comparatively understudied area of District Kishtwar, have been the subject of numerous research and reports in recent years. Despite the abundance of freshwater springs in the area, many of which are essential for domestic and drinking needs in rural and isolated settlements, thorough physico-chemical analyses are still rare. Nonetheless, there have been a few notable but isolated contributions that shed light on the hydro-geochemical state of the water sources in the Chenab Valley, where Kishtwar is located. In one such study, Hussain *et al.* assessed the seasonal variation in water quality parameters of natural springs in parts of Kishtwar and noted that the concentration of some ions, like calcium and magnesium, occasionally exceeded allowable limits, possibly as a result of anthropogenic influences and local geological formations. In a different study, Sharma and Raina examined the groundwater in the neighboring districts of Doda and Kishtwar. They found problems with turbidity and bacterial pollution, particularly during the monsoon season.[44,45] Several water bodies in the area, including springs, were classified under Class B and C water quality categories in a report released by the Jammu and Kashmir Pollution Control Committee in 2022. This indicates that the water bodies are suitable for outdoor bathing and drinking after conventional treatment, but they are not always directly potable. Additionally, Singh et al. reported considerable seasonal and regional variation in physico-chemical parameters including TDS, EC, and nitrate content in their comparative evaluation of water quality in rural and urban water sources in the Chenab basin, including parts of Kishtwar.[46,47,48] The growing impact of uncontrolled land use changes and inadequate waste management close to spring recharge zones was highlighted in another thorough hydrochemical investigation on Himalayan Spring systems by Kaul and colleagues, which included reference data from Kishtwar. More recently, a 2024 environmental monitoring survey carried out as part of a DST-funded project examined the water quality of certain springs in Kishtwar and expressed worries over rising levels of sulphate and chloride, which were attributed to increased runoff from erosion and human activity. In order to provide safe drinking water and to guide conservation efforts in this environmentally delicate Himalayan district, these studies collectively highlight the increasing necessity for routine, standardized, and comprehensive monitoring of spring water sources in Kishtwar.

This study's main goal is to evaluate the physico-chemical properties of a few water springs in District Kishtwar in order to determine whether or not they are suitable for household and drinking use. Understanding the quality of water springs is essential for maintaining public health and sustainable water resource management because they are an essential source of freshwater for rural and semi-urban communities in this hilly area. The study's justification is based on growing worries about environmental changes, an increase in human activity, and irregular monitoring, all of which could worsen the quality of the water. As a part of the ecologically delicate Himalayan region, Kishtwar is distinguished by a variety of geological formations, a range of climates, and dispersed human settlements that mostly rely on natural springs for their daily water needs. Despite their importance, these water sources are frequently still little understood, and there is a dearth of thorough scientific information regarding their physico-chemical state. Therefore, this study aims to close that gap by offering a thorough analysis of important water quality parameters, identifying possible contaminants or deviations from standard norms, and producing baseline data that can educate communities, policymakers, and local authorities about the state of these vital water resources and the steps that must be taken to protect them.

## Material And Methods / Experimental Details / Methodology

### Description of the Study Area

The study was carried out in the Indian Union Territory of Jammu and Kashmir's District Kishtwar, which is situated in the Jammu region. At an average elevation of roughly 1,590 meters above sea level, Kishtwar is known for its mountainous landscape, thick forests, and abundance of natural water springs. The district's temperate climate, which features chilly winters and mild summers, affects the hydrological properties of its springs. Kishtwar's coordinates are roughly 33.3° N latitude and 75.8° E longitude.

Based on accessibility, local significance, and representativeness of the water quality in the area, four well-known natural spring locations were chosen for this study. As indicated in Table 1, four sample springs, two sources of low-temperature drinking water, and two geothermal springs were selected to capture lithological and altitudinal variations.

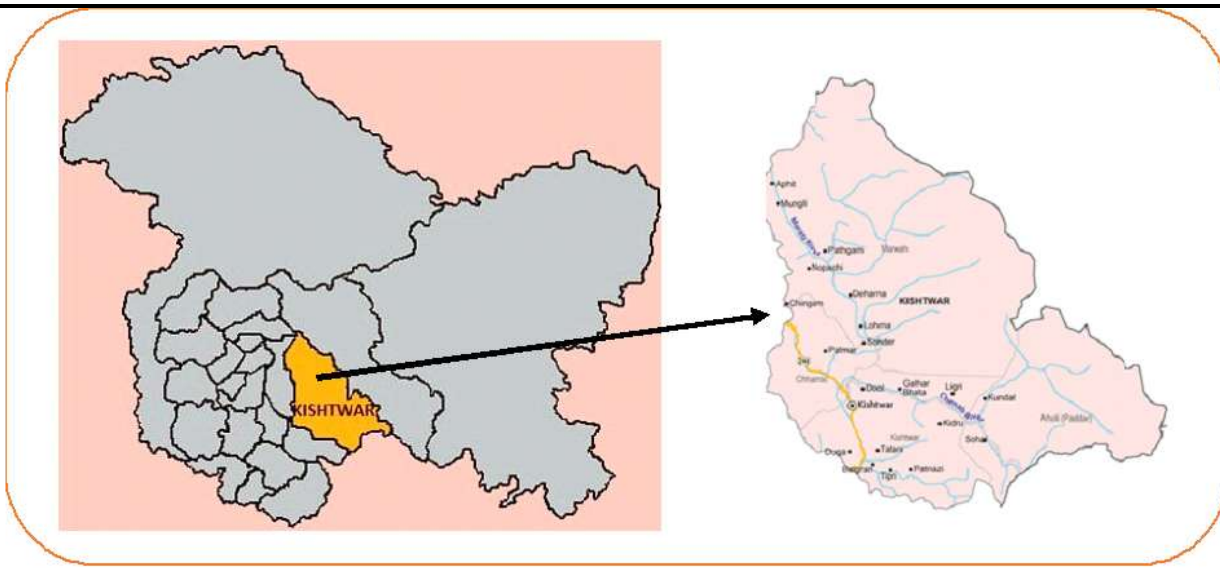


**Figure 1: Jammu and Kashmir map indicating Kishtwar**

**Table 1: Lithological and altitudinal variability of four prominent natural spring sites**

| Site code | Local name & setting | Latitude (N) | Longitude (E) |
|---|---|---|---|
| 1. | Kiyar | 33.5684° | 75.8177° |
| 2. | Tatapani Padder | 33.2245° | 75.8562° |
| 3. | Godresh | 33.3138° | 75.7891° |
| 4. | Vimal | 33.3116° | 75.7662° |

**Sampling Technique:** During the pre-monsoon (May-July2025), six grab samples were taken from each site, resulting in a total of 24 water samples. Pre-rinsed with site water, sterile 0.5-liter high-density polyethylene bottles were utilized. Temperature, pH, EC, TDS, DO, and other in-situ parameters were recorded right away. The bottles were then put in an ice chest at 4 ± 1 °C and brought to the lab. While samples for BOD were incubated for 24 hours, samples for nutritional analysis were refrigerated at 4°C and analyzed within 48–60 hours. Triplicate samples (10% of total) and field blanks ensured quality control.

**Computational Techniques**

Every decision was made in accordance with APHA's "Standard Methods for the Examination of Water & Wastewater," 23rd ed. (2017), and the outcomes were compared to BIS IS 10500:2012 and WHO drinking-water criteria from 2022.

**Table 2: WHO cum APHA benchmark for examination of water**

| Parameter | Method & instrument | APHA section | Detection limit |
|---|---|---|---|
| BOD | Incubation (20 °C, 5 d) & DO difference | 5210 B | 0.1 mg $L^{-1}$ |
| COD | Closed-reflux dichromate; Hach DRB200 & DR6000 | 5220 D | 1 mg $L^{-1}$ |
| DO | Winkler titrimetric (azide modification) | 4500-O C | 0.05 mg $L^{-1}$ |
| EC / TDS | Multi-probe (Hach HQ40d) | 2510 B | 0.1 µS $cm^{-1}$ / 1 mg $L^{-1}$ |
| pH | Portable meter (Hanna HI98190; 3-point calibration) | 4500-$H^+$ | 0.01 pH |
| Temperature | Digital stem thermometer (Hanna HI145-20) | – | 0.1 °C |
| Turbidity | Nephelometer (Eutech TN-100) | 2130 B | 0.01 NTU |
| Total hardness, $Ca^{2+}$, $Mg^{2+}$ | EDTA titration | 2340 C | 1 mg $L^{-1}$ as $CaCO_3$ |
| Chloride | Argentometric titration | 4500-$Cl^-$ B | 0.2 mg $L^{-1}$ |
| Nitrate | UV spectrophotometry; 220/275 nm | 4500-$NO_3^-$ B | 0.01 mg $L^{-1}$ |
| Sulphate | Turbidimetric ($BaCl_2$); 420 nm | 4500-$SO_4^{2-}$ E | 0.5 mg $L^{-1}$ |

Certified standards were used to create calibration curves (R2 > 0.998), with precision across triplicates of less than 5% RSD. Every day, the performance of the instrument was evaluated using reagent blanks and quality-control standards.

## RESULTS AND DISCUSSION

To investigate the regional and seasonal variability of physico-chemical indices, descriptive statistics, Pearson correlations, and one-way ANOVA ($\alpha = 0.05$) were calculated in SPSS v29 and Microsoft Excel 365. To find regulating factors and categorize sampling locations with comparable water-quality characteristics, multivariate techniques (PCA and hierarchical clustering) were used. Table 3 displays the physico-chemical data for the four chosen springs in both tabular and graphical form.

**Table 3: Average Physico-Chemical Parameters of Water Samples from Selected Springs of District Kishtwar (May-July 2025)**

| Parameter | Kiyar | Tatapani Padder | Godresh | Vimal |
|---|---|---|---|---|
| BOD (mg/L) | 3.9 | 3.7 | 1.9 | 2.6 |
| COD (mg/L) | 14.7 | 14.1 | 9.7 | 9.8 |
| DO (mg/L) | 5.8 | 5.6 | 7.4 | 7.8 |

| | | | | |
|---|---|---|---|---|
| EC (µS/cm) | 519 | 512 | 387 | 415 |
| TDS (mg/L) | 343 | 339 | 238 | 274 |
| pH | 7.3 | 7.6 | 6.8 | 7.1 |
| Temperature (°C) | 59.7 | 67.5 | 18.2 | 14.3 |
| Turbidity (NTU) | 3.6 | 3.3 | 2.2 | 2.5 |
| Total Hardness (mg/L) | 217 | 198 | 128 | 153 |
| Chlorides (mg/L) | 63 | 58 | 28 | 37 |
| Nitrates (mg/L) | 4.8 | 4.6 | 3.3 | 3.2 |
| Sulphates (mg/L) | 33 | 37 | 19 | 18 |

The graphical representation of physico-chemical parameters of mentioned four springs is shown in Figure **2** and **3**.

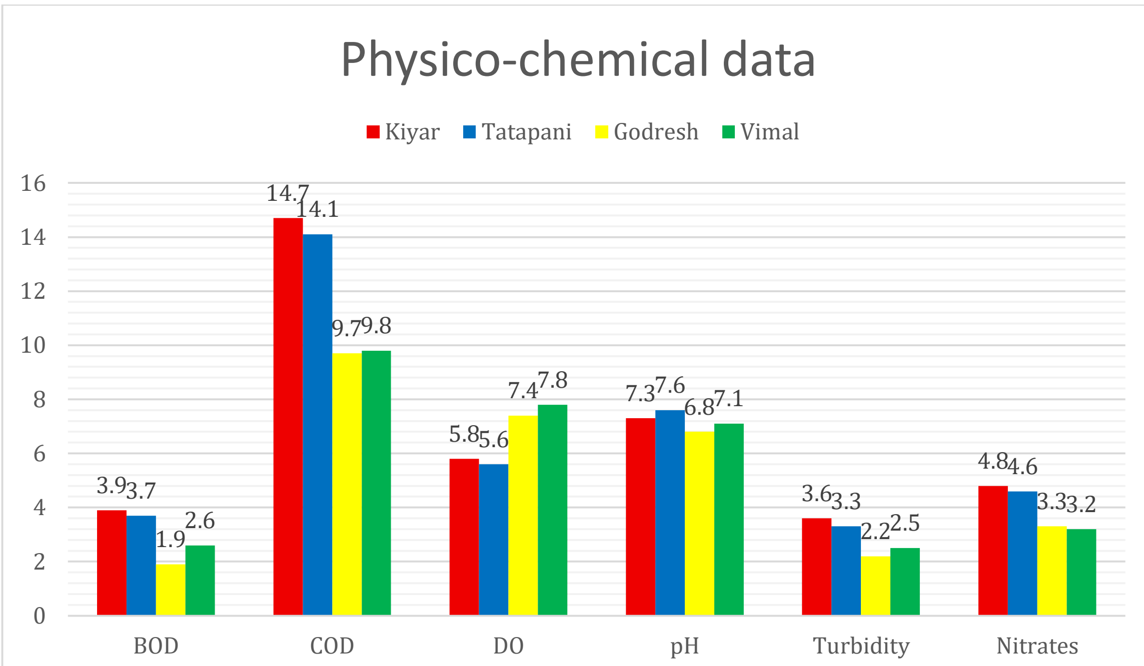


**Figure 2: Comparison of selected physico-chemical parameters of four springs**.

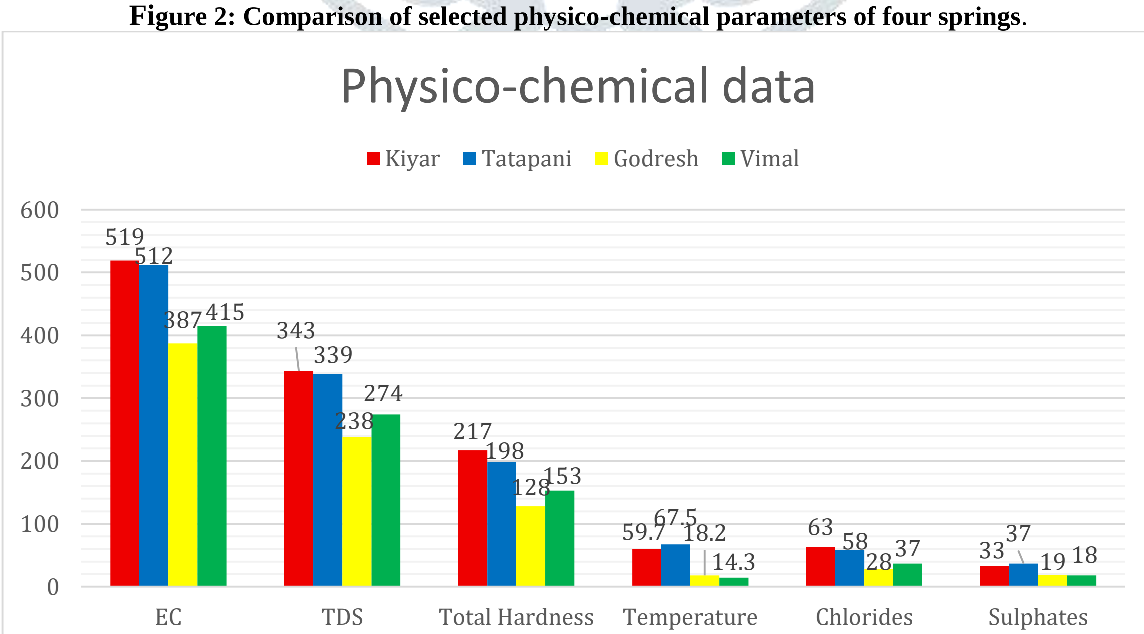


**Figure 3: Comparison of selected physico-chemical parameters of four springs**

**Notes:**

- As soon as the sample was taken, the site's temperature and pH were measured.
- In accordance with APHA and BIS guidelines, spectrophotometric techniques and calibrated digital meters were used to measure EC, TDS, DO, BOD, and COD.
- A portable turbidimeter was used to measure the turbidity.
- Standard titrimetric and spectrophotometric techniques were used to measure hardness, chlorides, sulphates, and nitrates.

Significant spatial variation in water quality parameters, reflecting both geological and environmental influences, is revealed by the physico-chemical analysis of spring water samples taken from four different locations in District Kishtwar between May and July: Kiyar, Tatapani Padder, Godresh and Vimal. The temperature of the spring water varied greatly; two hot springs in the Kishtwar region, Kiyar and Tatapani Padder had high temperatures of 59.7°C and 67.5°C, respectively, which are suggestive of geothermal activity in these regions. The springs at Godresh and Vimal, which are located in comparatively temperate regions, displayed significantly lower temperatures of 18.2°C and 14.3°C, respectively.

The pH readings were within the typical acceptable ranges for drinking water, ranging from slightly acidic to pleasantly alkaline. Kiyar and Tatapani Padder had slightly higher pH values of 7.3 and 7.6, indicating a more alkaline character, perhaps as a result of the action of geothermal minerals, while Godresh and Vimal reported pH values of 6.8 and 7.1 respectively.

The increased dissolved solids content was correlated with an increasing trend in electrical conductivity (EC), a measure of ion concentration, from Godresh (387 µS/cm) and Vimal (415 µS/cm) to the hot springs of Kiyar (519 µS/cm) and Tatapani Padder (512 µS/cm). With values ranging from 274 mg/L at Vimal to 343 mg/L at Kiyar, total dissolved solids (TDS) showed a similar pattern, suggesting that the thermal springs had more mineralisation.

Godresh (7.4 mg/L) and Vimal (7.8 mg/L) had the greatest dissolved oxygen (DO) levels, indicating comparatively clean and cooler water conditions. Kiyar (5.8 mg/L) and Tatapani Padder (5.6 mg/L) had lower DO values, perhaps as a result of higher temperatures decreasing oxygen solubility. Accordingly, the hot springs had higher levels of biodegradable organic matter than Vimal (2.6 mg/L BOD, 9.8 mg/L COD) and Godresh (1.9 mg/L BOD, 9.7 mg/L COD). Kiyar recorded BOD and COD levels of 3.9 mg/L and 14.7 mg/L, respectively, while Tatapani Padder reported 3.7 mg/L and 14.1 mg/L, respectively.

The hot springs in Kiyar and Tatapani Padder had greater turbidity levels of 3.6 and 3.3 NTU, perhaps as a result of mineral precipitates and suspended particles typical of geothermal waters, while Godresh (2.2 NTU) and Vimal (2.5 NTU) had the lowest turbidity values, indicating clearer water.

While Godresh and Vimal reported lower hardness values of 128 mg/L and 153 mg/L, Kiyar and Tatapani Padder registered 217 mg/L and 198 mg/L, respectively, indicating a discernible rise in overall hardness in thermal springs.

The hot springs also had the highest levels of chloride, 63 mg/L at Kiyar and 58 mg/L at Tatapani Padder, as opposed to 37 mg/L at Vimal and 28 mg/L at Godresh. This suggests that saline groundwater intrusion is more common in geothermal locations.

Kiyar (33 mg/L) and Tatapani Padder (37 mg/L) had equally high sulphate concentrations, although Godresh and Vimal had lower levels (19 mg/L and 18 mg/L). The hot springs' nitrate levels were likewise marginally higher—4.8 mg/L in Kiyar and 4.6 mg/L in Tatapani Padder, compared to 3.3 mg/L in Godresh and 3.2 mg/L in Vimal, but they were all still within permissible bounds for drinkable water.

All things considered, the comparison shows that the thermal springs' water quality is very different from the cold springs', particularly with regard to temperature, mineral content, and organic load. The geological conditions, especially the Marwah region's geothermal nature, which enriches the water with dissolved minerals but may also lower oxygen levels, are mainly responsible for these differences. Comprehending these site-specific features is essential for assessing these springs' viability for various applications and for the sustainable management of local water supplies.

**Results**; Spring water samples from four locations—Kishtwar, Vimal, Godresh, Kiyar Marwah Hot Spring, and Tatapani Padder were physico-chemically analysed. The results showed significant geographical heterogeneity influenced by both geological and environmental factors. In comparison to the temperate springs of Godresh and Vimal, the hot springs of Kiyar and Tatapani Padder showed noticeably higher temperatures (59.7°C and 67.5°C). Kiyar and Tatapani Padder exhibited increased electrical conductivity, total dissolved solids, mineral content (hardness, chlorides, and sulphates), and slightly alkaline pH levels in accordance with their geothermal nature. While the hot springs showed lower DO levels because of heat impacts, the colder springs showed increased dissolved oxygen, indicating improved oxygenation. The geothermal springs had comparatively higher BOD and COD levels, indicating a higher organic load. Turbidity was higher in hot springs, probably because to mineral suspensions, even though it was within allowable limits in all samples. There were notable differences between thermal and non-thermal sources, but all measured parameters, including nitrate concentrations, stayed within permissible bounds for drinking water.

## 4. CONCLUSION

The study comes to the conclusion that there are significant differences in spring water quality between geothermal and non-geothermal sources in District Kishtwar. Because of the geothermal activity in the area, the hot springs of Kiyar and Tatapani Padder have higher temperatures, more mineralisation, and more organic matter. Godresh and Vimal springs, on the other hand, have water profiles that are cooler, clearer, and more oxygen-rich. Although all springs are currently safe for general use, their characteristics should be taken into account before recommending them for particular uses like drinking, bathing, or medicinal usage. These findings highlight the significance of geological features in determining water chemistry. In order to make sure the springs stay within safe health and environmental requirements, the statistics also confirm the necessity of routine monitoring.

**Future Work:**

To further understand temporal dynamics, future research should concentrate on seasonal changes in water quality over a wider timescale. To supplement the existing physico-chemical analysis and offer a more thorough assessment of water safety, thorough hydrogeological and microbiological analyses are advised. Additionally, if sustainable resource management techniques are closely followed, investigating the medicinal potential of geothermal waters in the Marwah region may create opportunities for ecotourism and local development. Decision-making for the preservation and best use of spring water resources in Kishtwar can be further improved by incorporating GIS-based mapping and long-term monitoring systems.

**CONSENT (WHERE EVER APPLICABLE)**

As this research work deals with study of properties water and hence involves no medical procedures or involvement of patients. Hence no such consent is required for this manuscript.

**Disclaimer**

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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