Spring water quality assessment of Anantnag district of Kashmir Himalaya: towards understanding the looming threats to spring ecosystem services

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Abstract
This study reports the significance of freshwater springs primarily in meeting drinking water demands besides offering various ecosystem services. We analyzed a total of eighteen hydrochemical quality parameters using standard methods from various representative springs of Anantnag district, Kashmir Himalaya. Groundwater quality profiles were generated in a GIS environment for each parameter. Additionally, statistical methods were employed to understand the interdependence of water quality parameters. Highly variable dissolved oxygen (0.4–9.2 mg L⁻¹) and relatively higher values of nitrate ranging from 57 to 2668 µg L⁻¹ noticed during the study may be mostly related to contamination from agricultural waste. The findings of this study revealed that the springs are predominantly hard water type as the water samples found were calcium-rich and exhibited higher total phosphorus in a few samples owing to limestone lithology in the catchment. Principal Component Analysis (PCA) to the data generated chiefly three components (VF1, VF2, and VF3) having Eigen values of 2.0 or more (2.28–5.37) contributing for 31.63%, 17.99% and 13.44% of the total variance, respectively. The water quality index (WQI) of the samples for drinking purpose ranged from good to excellent. In light of our findings, it is argued that springs offer a potential, although partial, solution to the drinking water demands of a burgeoning population in Indian Himalayan region. However, equally important is to have a thorough investigation of springs to explore the impacts of other forms of pollution, including heavy metals, pesticides and antibiotic wastes, which can diminish much-needed ecosystem services.

Keywords Springs · Drinking water quality · Sustainable development · India · Kashmir valley

Introduction
Water quality issues are a major challenge that humanity is facing in the twenty-first century (UNESCO, UN Water, 2020). Improvements in water resources management and access to water supply and sanitation services is therefore becoming a challenge globally, which underpins the vision that humanity should enjoy uninterrupted, various goods and services that are related with water (WWAP 2019). Water security which has emerged as a prominent challenge (Srinavasan et al. 2017) has initiated dialogue on improving water resource security for the future because of projected water shortages due to climate change (Huntington 2006) and rising water demand across the globe has increased (Burek et al. 2016). Two-thirds of the human population is subjected to severe water scarcity, with 50% of the populations of China and India facing water shortage at least once a year, and 50 million people globally continually short of drinking water (Mekonnen and Hoekstra 2016; Yomo et al. 2019). Presently, maintaining the availability and safeguarding the quality of the freshwater resources on the global horizon are the most pressing of many environmental challenges (Bhat et al. 2022). Goldscheider et al. (2020) report that 15.2% of the global land surface is covered by karstic terrains and freshwater springs are known to supply partially or entirely 25–50% of drinking water to the world’s population (Ford and Williams 2007; Hartmann et al. 2014). United Nations Sustainable Development Goal (SDG) 6 is to ensure access to safe drinking water and sanitation to all by 2030.
physico-chemical conditions that contrast greatly to surface water from its springs has created aquatic habitats with remarkable importance and have been frequently modified (Bhat and Pandit 2018). The springs in the valley are of stable discharge regimes, sometimes low levels of dissolved oxygen and elevated but stable levels of ionic enrichment (calcite dissolution, dedolomitization) and incongruent silicate weathering are the dominant processes controlling the groundwater quality in the south eastern part of the Kashmir Valley. Along Jhelum River in the southern part of Kashmir, the groundwater is controlled by lithology. Despite the role of springs across the world in urban water supply (Petric 2010), little attention has been devoted to research on the economics of spring’s service values (Nabhan 2008; Phillips et al. 2009).

Over the past 20 years, the Kashmir Valley has seen a major shift from agriculture to horticulture related to higher economic returns that, in turn, have resulted in massive increases in the use of fertilizers and pesticides. These compounds also add heavy metals into the aquatic system of the entire Jhelum River basin that flows through the Kashmir Valley. Keeping in mind the importance of spring waters, we conducted an investigation on the physico-chemical characteristics of spring waters in Anantnag district. That groundwater retention in karstic aquifers, such as those underlying the Kashmir Valley, can be very brief making surface contamination quickly transported and exported from the aquifer (Coward et al. 1972; Bhat and Pandit 2018). Thus, the study of pollution in such settings is important for understanding potential impacts to drinking water quality. Development impacts appear to be widespread throughout India, and we hypothesized that changing environmental conditions associated with increased development has increased impacts on Kashmir Valley springs, thereby reducing their sustainability. We sought to determine whether the drinking water quality of springs had deteriorated in relation to other ecosystem goods and services, such as washing, bathing, irrigation, livestock water, and pisciculture. This paper also may offer the policy inputs framing water security plan at District level envisaged under flagshift effort of the Government of India’s National rural drinking water programme (i.e. movement towards ensuring drinking water security) in rural India. We are of this view that this study is in tandem with SDGS (Sustainable development goals) as well as national missions of India like Clean and Healthy India. We include a description of the ecosystem services that springs provide, and report on imminent challenges and threats of various types of pollutants which can undermine the quality and potential of irrigation of fields, especially during drought-ridden periods over the past two decades. Aridity increases the attractiveness of springs for washing, bathing, swimming, and other activities. Some hydro-geochemical research has been conducted on the groundwaters and springs of the Kashmir Valley (Bhat et al. 2010; Bhat and Pandit 2010a, b; Jehangir et al. 2011; Jeelani 2005, 2011, 2014; Hameed et al. 2018) and also in other parts of India (Saxena and Mondal 2003). These studies indicate that congruent carbonate dissolution (calcite dissolution, dedolomitization) and incongruent silicate weathering are the dominant processes controlling the groundwater quality in the south eastern part of the Kashmir Valley. Along Jhelum River in the southern part of Kashmir, the groundwater is controlled by lithology. Despite the role of springs across the world in urban water supply (Petric 2010), little attention has been devoted to research on the economics of spring’s service values (Nabhan 2008; Phillips et al. 2009).

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spring use for ecosystem service providers. The majority of research on Kashmir springs has focused on hydrogeology, while that on ecosystem services and crenobiodiversity is sparse (Lone et al. 2021). In this article, apart from the water quality perspective through physicochemical parameters, we emphasize that an array of water pollution threats are looming over the future of the Kashmir Valley, affecting groundwater, springs, and surface waters. These pollution impacts merit attention and appropriate mitigation to ensure the sustainability of safe drinking water from springs in the region (Bhat et al. 2021). One of the many challenges facing springs in the Kashmir and Indian Himalayan Region is the lack of adequate information for management, as the studies conducted thus far have an academic orientation and were conducted on a small number of springs and for a particular area or district and for a shorter period of time. Such research therefore lacks the required direction and potential to offer clear policy guidance or data the management authorities are looking for at a bigger scale.

Material and methods

Study area

Kashmir valley harbours hundreds of springs that attract the tourists and thereby play an essential role in improving the local economy by providing visitors with an array of services. ‘Anantnag’ literally means ‘innumerable springs’ (Anant means countless and nag means springs in Kashmiri language). It is the southernmost district of Kashmir province lying between 75°03′30″–75°19′29″E longitude and 33°31′07″–33°54′30″N latitude, and covering an area of about 402 km² (Fig. 1). The population of Kashmir valley is about 10,70,114 individuals as per 2011 census. The elevation of the study area varies from 1591 to 2708 m above sea level (m a.s.l). The area receives an average annual precipitation of 1240 mm/yr and has a temperate climate (Rashid et al. 2017). The surficial geology of the valley’s lower plains are dominated by unconsolidated Quaternary alluvium, while Triassic and Permo-Carboniferous strata and
the Panjal volcanic field dominate the central eastern and northern regions, respectively (Fig. 1). Bore and tube wells yields of ~10–20 Ls⁻¹ are sufficient in Triassic strata, but are low to moderate (~5–10 Ls⁻¹) from hand dug and pumped wells in the northern Permo-Carboniferous formations.

**Sampling and analysis**

We selected thirty representative springs in this study of the Anantnag District for detailed geochemical analysis (Table 1, Fig. 2). We collected water samples in 1 L clean plastic bottles. Before the collection of samples, bottles were carefully washed with distilled water. Each sample was analysed for 18 different physicochemical parameters such as temperature, pH, conductivity, chloride, alkalinity, total hardness, calcium, ammonia, nitrite, nitrate, ortho-phosphorus, total phosphorus, iron, and sulphate (APHA 2005). The temperature of air and water was recorded by using a graduated Celsius thermometer. Electrical conductivity, pH, salinity and total dissolved solids were determined by using a Digital PCS Tester 35 multi-parameter probe. Dissolved oxygen was estimated by Winkler’s titration method. Parameters like free CO₂ and alkalinity were determined by titrimetric methods. Chlorine was estimated by the argentometric method. Total hardness and calcium were measured by a complexometric method. Nitrogen, phosphorus, sulphate, and iron were analysed by spectrophotometric methods. Analysed parameters were interpreted with the cross-plots, their spatial distribution, cluster analysis and principal component analysis (PCA).

A water quality index (WQI) value (Gebrehiwot et al. 2011) was calculated for the thirty selected Anantnag springs, using eight hydro-chemical parameters. WQI values were classified into five types as “excellent water” to “unsuitable for drinking water”. During our survey discussions and interactions with users and relevant stakeholders...
Table 1  General characteristics of the studied springs located in Anantnag district, Kashmir

| Sample | Site name                  | Longitude (in degree E) | Latitude (in degree N) | Average depth (m, bgl) | Immediate catchment/ spring type | Drinking | Irrigation | Washing/Bathing |
|--------|----------------------------|-------------------------|------------------------|-----------------------|----------------------------------|----------|------------|-----------------|
| 1      | Kokernag                   | 75.2978                 | 33.5854                | 0.39                  | Forest/Rheocrene spring          | +++      | +++        | +++             |
| 2      | Verinag                    | 75.2496                 | 33.5353                | 15                    | Forest/Limnocrene spring         | ++       | +++        | +++             |
| 3      | Achabal                    | 75.2217                 | 33.6827                | 0.5                   | Forest/Rheocrene spring          | +++      | +++        | +               |
| 4      | Sherbagh                   | 75.1544                 | 33.7314                | 1.15                  | Forest-cum residential/ Limnocrene spring | ++      | +++        | +++             |
| 5      | Sherbagh Sulphur Spring    | 75.1545                 | 33.7313                | 0.25                  | Forest cum residential/ Limnocrene spring | −       | ++         | +++             |
| 6      | Yashlam                    | 75.0888                 | 33.8319                | 0.20                  | Horticultural cum residential/ Limnocrene spring | +++   | −          | +++             |
| 7      | Baleyaar                   | 75.0938                 | 33.8284                | 0.35                  | Horticultural cum residential/ Rheocrene spring | −       | +++        | +               |
| 8      | TakiyaMaqsood Shah         | 75.1226                 | 33.8271                | 0.10                  | Horticultural cum residential/ Rheocrene spring | +++   | −          | +               |
| 9      | Shalgam                    | 75.1336                 | 33.8347                | 0.30                  | Residential/Limnocrene spring    | +++      | −          | +++             |
| 10     | Sirhama                    | 75.1552                 | 33.8443                | 0.15                  | Residential/Rheocrene spring     | ++       | −          | +++             |
| 11     | KhiramParrayPora           | 75.1724                 | 33.8616                | 0.35                  | Residential/Limnocrene spring    | +++      | −          | +++             |
| 12     | KhiramDegjiPora            | 75.1755                 | 33.8602                | 0.40                  | Horticultural cum Residential/Limnocrene spring | +++   | −          | +               |
| 13     | KhoshroiKalan (Gorwan)     | 75.1588                 | 33.8218                | 0.40                  | Residential/Limnocrene spring    | +++      | ++         | +++             |
| 14     | KhoshroiKalan (Apaarpora)  | 75.1587                 | 33.8210                | 0.25                  | Residential/Rheocrene spring     | +++      | −          | +++             |
| 15     | Katriteng                  | 75.0878                 | 33.8228                | 0.45                  | Agricultural cum Residential/Limnocrene spring | +++ | −          | +++             |
| 16     | Kirkadal                   | 75.1193                 | 33.7983                | 1                     | Residential cum Agriculture/Limnocrene spring | +++ | −          | +               |
| 17     | Gantalipora                | 75.1228                 | 33.7972                | 0.20                  | Agricultural cum residential/Rheocrene spring | −       | +++        | −               |
| 18     | Thajwara                   | 75.1471                 | 33.7942                | 0.15                  | Horticultural cum residential/Limnocrene spring | +++ | −          | −               |
| 19     | Aswara                     | 75.1620                 | 33.7921                | 0.45                  | Horticultural/Limnocrene spring  | ++       | +++        | +               |
| 20     | Pushkreeri                 | 75.1869                 | 33.8009                | 0.40                  | Residential cum Horticulture/Limnocrene spring | +++ | ++        | +++             |
| 21     | Hugam                      | 75.1853                 | 33.8004                | 0.35                  | Residential/Rheocrene spring     | +        | +++        | +++             |
| 22     | Badroo                     | 75.2325                 | 33.8329                | 0.30                  | Residential cum Agriculture/Limnocrene spring | +     | +++        | +++             |
informed us about the services provided by these springs in the study area.

**Results and discussion**

**Descriptive analysis**

Safeguarding groundwater quality from an ever-increasing enrichment and diversity of environmental contaminants is a large challenge (Damania et al. 2019). Reports regarding the rise in groundwater temperature and the widening of seasonal thermal variations in response to atmospheric temperature changes, besides their roles in ecosystem acknowledged in the research community (Kurylyk 2014; De Stasio et al. 2009). From the water temperature data records, all the 30 springs were found to be cold water springs having temperatures lower than the ambient air temperature. A perusal of the results indicated related to range of temperature in the studies springs from 9.5 to 20.0 °C (Fig. 3a). Only springs 5–7, 15, 17, 21, and 25 were warm springs (temperature range 16–20 °C), indicating that the groundwater had travelled through longer circulation paths having some hydrothermal activity (Nathenson et al. 2003). Some recent reports on more than 300 springs have shown the temperature range of spring waters between 18 and 22 °C. In one of the study on spring water temperatures authors have reported an increase of approximately 2 °C in the period from 2002 to 2017 (Kurylyk 2014). The maximum temperature (20 °C) was observed at Baleyar village (S-7). Water was found slightly acidic to alkaline (pH range: 6.8–8.3), with an average value of 7.4. The pH of most springs is basic in nature, which can be attributed to limestone-rich lithology of Kashmir valley (Al-Jiburi and Al-Basrawi 2013; Barakat et al. 2018). The value of dissolved oxygen (DO) concentration varied from 0.4 to 9.2 mg L⁻¹, with an average of 3.7 mg L⁻¹ (Fig. 3b). Variation in the concentration of DO is due to differences in water temperature (Singh et al. 2014), as DO concentration is inversely related to water temperature. A similar trend was observed in all springs, with S-5 showing the lowest DO level (0.5 mg L⁻¹) at the temperature of 18 °C. Besides high temperature, another cause for such low levels of DO can be ascribed to the relatively higher amount of sulphur present in the spring under question (Bhat 2015). The highest values of DO were observed at S-1 (Kokernag), S2 (Verinag) and S3 (Achabal) which had low temperature. The presence of relatively high oxygen at these sites seems to be a function of oxygen producing periphytic algal population found very much visible during the survey in these springs. It is important to mention here that the dissolved oxygen is normally not a primary water quality parameter considered by regulatory agencies, but is negatively related to BOD and COD, and therefore offer insight into the status of water quality. At the same time, DO plays a significant role in aesthetics and ecosystem functioning (Chen et al. 2019). In our study about 77% of the springs recorded DO levels less than 5 mg L⁻¹, however this does not affect the potability of water of these springs, as it normally does not have any harmful impacts on the human system. The springs, in general, were rich in CO₂ (Fig. 3b) because of the dissolution of carbonates from the catchment in addition to inputs from bacterial respiration.

| Sample | Site name            | Longitude (in degree E) | Latitude (in degree N) | Average depth (m, bgl) | Immediate catchment/ spring type | Drinking | Irrigation | Washing/Bathing |
|--------|----------------------|-------------------------|------------------------|------------------------|----------------------------------|----------|------------|-----------------|
| 23     | Kathsoo 75.2346      | 33.8620                 | 0.38                   | Agriculture/Limnocrene spring | −       | +++        | −               |
| 24     | Sallar 75.2468       | 33.8887                 | 0.10                   | Residential cum agriculture/Holocrene spring | −       | +++        | −               |
| 25     | Dalseer 75.2542      | 33.8870                 | 0.5                    | Residential/Limnocrene spring | +       | −          | +++             |
| 26     | Akad 75.2343         | 33.8122                 | 0.8                    | Residential/Limnocrene spring | +++     | ++         | +++             |
| 27     | Seer 75.2342         | 33.7836                 | 1                      | Residential/Limnocrene spring | +++     | −          | +++             |
| 28     | Hutmura 75.2248      | 33.7670                 | 0.4                    | Residential/Limnocrene spring | +++     | −          | +++             |
| 29     | Mattan 75.2119       | 33.7570                 | 2                      | Residential cum Forest/ Limnocrene spring | +++     | +++        | ++              |
| 30     | SheikhuAalam Spring Manznoo 75.2025 | 33.7678 | 1.5 | Residential/Limnocrene spring | +++     | −          | +++             |
Fig. 3 Cross-plots between various water quality parameters of the spring waters at different study sites. 

a) Water temperature (°C) and pH  
b) CO₂ (mg L⁻¹) and DO (mg L⁻¹)  
c) TDS (mg L⁻¹) and Conductivity (µS cm⁻¹)  
d) Sulphate (mg L⁻¹) and Chloride (mg L⁻¹)  
e) Total hardness (mg L⁻¹) and Calcium content (mg L⁻¹)  
f) Total phosphorus (µg L⁻¹) and Orthophosphorous (µg L⁻¹)  
g) Nitrate (µg L⁻¹) and Ammonia (µg L⁻¹)
and organic matter decomposition (Maas and Wicks 2017). Electrical conductivity (EC) was found to lie in the range of 168–855 μS cm⁻¹, indicating low to moderate mineral content (Fig. 3c), with contamination by inorganic fertilizers and domestic sewage potentially responsible for higher levels of conductivity (> 700 μS cm⁻¹) (Kumar et al. 1996) found in the springs like 13, 17, 19, 27 and 28. The overall higher conductivity of springs is also likely attributed to the high residence time of water in the aquifer, which prolongs its interaction with host rock (Jeelani 2010). Broadly, springs having water temperature from 9.5–12 like 1, 2 and 3 were usually found to have the lower EC values, with the notable exception of springs like 21, 25 and 26. As EC and TDS are strongly correlated (Abdul Wahid 2013), the values of TDS were found in proportion with EC. The concentration of salinity is directly related to the aquifer geology and its chemical characteristics (Al-Naeem 2015).

The anions of the spring waters revealed the dominance of Cl⁻ ions over other ions with usual ionic progression as Cl⁻ > SO₄²⁻. The Cl⁻ and SO₄²⁻ values ranged from
Table 2 Ranges of the various physico-chemical parameters of the spring waters collected from Anantnag district, Kashmir

| Parameters                                | Observed ranges | WHO and BIS Standards |
|-------------------------------------------|-----------------|-----------------------|
| pH                                        | 6.8–8.3         | 6.5–8.5               | 6.0–9.0               |
| Conductivity (µS cm⁻¹)                    | 168–855         | 750                   | 1,400                 |
| Salinity (mg L⁻¹)                         | 77–399          | –                     | –                     |
| Total Dissolved Solids (mg L⁻¹)           | 120–608         | 600                   | 2,000                 |
| Dissolved Oxygen (mg L⁻¹)                 | 0.4–9.2         | –                     | –                     |
| CO₂ (mg L⁻¹)                              | 10–36           | –                     | –                     |
| Total Alkalinity (mg L⁻¹)                 | 70–280          | 300                   | 600                   |
| Chloride (mg L⁻¹)                         | 5–40            | 250                   | 500                   |
| Total Hardness (mg L⁻¹)                   | 72–340          | 300                   | 600                   |
| Calcium (mg L⁻¹)                          | 36–289          | 75                    | 200                   |
| Magnesium (mg L⁻¹)                        | 19–112          | 30                    | 100                   |
| Sulphate (mg L⁻¹)                         | 1–33            | 200                   | 400                   |
| Iron (µg L⁻¹)                             | 1–764           | 300                   | 1,000                 |
| Nitrate (µg L⁻¹)                          | 57–2668         | 45,000                | 10,000                |
| Nitrite (µg L⁻¹)                          | 1–495           | 10,000                | –                     |
| Ammonia (µg L⁻¹)                          | 2–16            | –                     | –                     |
| Ortho-phosphorus (µg L⁻¹)                 | 7–401           | –                     | –                     |
| Total phosphorus (µg L⁻¹)                 | 44–2837         | –                     | –                     |

5–40 mg L⁻¹ and 1–33 mg L⁻¹, respectively, in the study area (Fig. 3d). Differences in SO₄²⁻ values may be due to prevailing land-use type and the extent of impregnation of the aquifer bedrock with CaSO₄ (Cole 1983). Relatively low concentration of chloride can indicate negligible impact on springs, as compared to studies conducted elsewhere reporting the increased concentration due to entry of sewage directly or indirectly in the springs (Paramvisam and Srinavasan 1981; Bhat and Pandit 2018). Higher concentrations of alkalinity at some springs are chiefly contributed by the presence of bicarbonates (Reda 2015). The permissible limit for drinking water of alkalinity and chloride prescribed by WHO (2011) is given as 200 mg L⁻¹ and 250 mg L⁻¹, respectively (Table 2). The majority of the springs studied fall into hard and very hard water categories.

The concentration of iron varied from 1–764 µg L⁻¹ with an overall mean of 76 µg L⁻¹, well below the permissible limit (1000 µg L⁻¹) of drinking water (WHO 2011). The maximum value of 764 µg L⁻¹ was obtained at S-3 (Achabal). In addition to enrichment by organic wastes, the source of iron (Fe) may be due to the presence of iron rich minerals in the catchment of these springs (Rao 2007). During the investigation, we could see the concentrations of orthophosphorus and total phosphorus fluctuated from 7–401 and 44–2837 µg L⁻¹, respectively (Fig. 3f). Source of phosphates can be artificial or anthropogenic, depending on human activities in the area. The slightly higher concentration of phosphates in some springs provides clear evidence of the direct influence of agricultural and horticultural activities being undertaken in the catchment of these springs where there is heavy use of phosphate fertilizers (Kipngetich et al. 2013). Since, the Jhelum basin receives phosphate loading through agriculture and horticulture, which sustain the livelihood of the major portion of the population in Kashmir. This pollution jeopardizes the ecosystem services of springs on a long-term basis (Charlton et al. 2018). Further, rocks in the whole Panjal traps are calcium-rich in combination with phosphate, which on dissolution releases exceedingly high concentrations of phosphorus in spring waters in the area. Almost 20% of the springs located in the northwestern portion of the District displayed higher concentrations of orthophosphorus and total phosphorus, whereas the rest of the 80% springs showed the concentrations which have been reported by few earlier works as well (Jeelani et al. 2001, 2014; Bhat and Pandit 2018; Bhat et al. 2021).

Nitrogen in the form of nitrate (NO₃⁻), nitrite (NO₂⁻), and ammonia (NH₃⁺) present in natural water evoke great interest because of their nutrient values, thereby being limiting factors for many bio-chemical processes. Nitrate concentration in the present study varied from 57 µg L⁻¹ to 2668 µg L⁻¹ at S-5 to S-19 (Fig. 3g). A higher concentration of nitrate in groundwater is due to the excessive use of fertilizers and the addition of animal and human waste (Mondal et al. 2008; Bhat and Pandit 2010a, b). Lower nitrate concentrations in some springs are due to minimum agriculture activities in the immediate catchment. Decomposition of organic matter is also reported as an important source of nitrate in the springs. However, there is emerging evidence, that the threshold of 10 mg L⁻¹ may be too high, as the
Nitrate levels of 3.87 mg L$^{-1}$ have been reported to be associated with colorectal cancer (Schullehner et al. 2018).

The nitrite values of springs were recorded in the range of 1–495 µg L$^{-1}$ with an average of 30 µg L$^{-1}$. The higher variation in the nitrite–nitrogen in groundwater may be due to the leaching of domestic sewage through soil stratum, as reported by Sheikh et al. (2013). Ammonia values in most of sites were recorded in a range of 2–16 µg L$^{-1}$ (Fig. 3g). It is more or less negatively correlated with nitrate concentrations of spring water samples with correlation coefficient of

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**Fig. 4** Spatial distribution of **a** TDS, **b** DO, **c** Iron, and **d** Total phosphorus of the spring waters from a part of Anantnag district, Kashmir Himalaya, India
– 0.26. In general, agricultural sources seem to be the main source of nitrogen in these springs, as well as decomposition of organic matter and domestic sewage.

**Spatial distribution of the selective hydro chemical constituents**

We prepared spatial distribution maps of the selective hydrochemical parameters of the spring waters to assess its
appropriateness for drinking water practices using kriging technique. TDS values varied from 120 to 608 mg L$^{-1}$ with a mean of 315 mg L$^{-1}$, which are less than the desirable limit for drinking water use (Fig. 4a). It was observed more than exceeding the permissible limit (> 500 mg L$^{-1}$, WHO 2011) at the Springs S-13, 19, 27 and 28, which are located in central-eastern and western parts. The DO varied from 0.4–9.2 mg L$^{-1}$, although it has been noted that > 5.0 mg L$^{-1}$ of DO (in about 33% springs) have better impacts on aquatic ecosystem health. It had been found in half the portion of the study are located in the south and also at the springs S-11, 18 and 24 in the northern part (Fig. 4b). The spatial distribution map of Fe content had been prepared as is shown in Fig. 4c. Values of iron varied from 1 to 764 µg L$^{-1}$. Here, we could find that except for Achabal Spring all values were within desirable and permissible limits of drinking water quality. It was only here Achabal spring wherein concentration was exceeding the desirable limit of 300 µg L$^{-1}$ but still well within the permissible limit of 1000 µg L$^{-1}$ (Table 2). On the other hand, we observed total phosphorus concentration in the range of 44–2837 µg L$^{-1}$ and its spatial distribution depicted in Fig. 4d. It shows that a comparatively higher value were encountered in the N-W of the area, where rocks are calcium-rich within Panjal traps which bound phosphate.

**Statistical analysis**

Cluster analysis and principal component analysis (PCA)/factor analysis

The cluster analysis is a useful method for finding homogeneity groups within data from chemical spring water analysis. Spring waters were grouped into three distinct classes by cluster analysis (Fig. 5). Cluster 1 corresponds to four sites (S-6, 10, 12 and 14), Cluster 2 contains eleven sites (S-1, 5, 7, 8, 11, 15, 18, 21, 26, 29 and 30), and Cluster 3 contains fifteen sites (S-2, 3, 4, 9, 13, 16, 17, 19, 22, 23, 24, 25, 27, 20 and 28). From cluster analysis, the variability of hydrochemistry was mainly related to rock-water interaction, dissolution of carbonates, and likely influences of anthropogenic activities (agricultural and horticultural) in the spring catchment area.

We carried out the PCA to extract the most important factor which showed similarity between the different sampling
sites. This analysis identified a reduced number of 3 vari-
factors (i.e., VF1, VF2, and VF3), indicating that 63% of 
temporal and spatial changes in water quality of springs 
(Fig. 6). VF1 elucidated 31.63% of the total change with 
strong positive loading on parameters like water tempera-
ture, pH, electrical conductivity, CO₂, alkalinity, chloride, 
TH, Ca²⁺ and Mg²⁺, nitrate, nitrite, orthophosphorous and 
total phosphorus (Fig. 7a). On the other hand, negative loads 
were detected for the DO, Fe and ammonia. VF2 explained 
about 17.99% of total variance of electrical conductance, 
CO₂, DO, alkalinity, chloride, Mg²⁺, orthophosphorous and 
total phosphorus, Fe, SO₄²⁻, nitrate and ammonia (Fig. 7b). 
The VF3 described about 13.44% of the total variance had 
a strong positive loading only on the spring water tempera-
ture, CO₂, orthophosphorous, total phosphorus, sulphate and 
nitrite (Fig. 7c), but others had negative loadings.

**Water quality index (WQI), socioeconomic 
and governance aspects**

A significant parameter, WQI is mainly adopted for assessing 
spring water quality and its fitness for drinking purposes 
(Gorde and Jadhav 2013). Weighted quality index method 
classifies water quality according to degrees of purity using 
the methods of Brown et al. (1972) and Ahmad (2014). 
Being an effective tool to examine the extent of water, it 
can be used well in the execution of water quality upgrad-
ing programmes. It is one of the collective indices that have 
been acknowledged as a rating that reflects the composite 
influence on the overall quality of information of specific 
water quality data (Das et al. 2013).

Values of WQI were calculated for the spring sam-
ples and the resultant index thus generated varied from 
35 to 82 with an average of 56. As we know that WQI 
values are grouped into 5 types for drinking purpose in

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**Fig. 8** Water quality map of the studied springs in a part of Anantnag district, Kashmir
ranges of 0–50, 50–100, 100–200, 200–300 and > 300 for the excellent, very good, poor, very poor and unsuitable drinking waters, respectively. The analysis revealed that all the physico-chemical water parameters are well within the highest desirable limit or maximum permissible limit prescribed by the WHO (2011) (Table 3). From the analysis of the above results, it has been found that the overall water quality of 30 springs falls within the excellent (12 spring sites) to very good (18 spring sites) category of water quality class based on water quality index values which is suitable for both irrigation and drinking use (Fig. 8) as reported here and elsewhere (Bhat et al. 2020; Bhat and Pandit 2020; Lone et al. 2020). Given the type of water quality and other ecosystem services these springs provide (Fig. 9) and the corresponding threats operating at various levels and magnitudes (Bhat et al. 2021), it is prayed to have the in-depth investigation and monitoring programs are needed on the looming threats to protect and safeguard the quality and character of these spring ecosystems.

### Table 3 Related weight ($W_i$) of physical and chemical parameters

| Quality parameter | WHO (2011) standards | Weight ($w_i$) | Relative weight ($w_i$) |
|-------------------|----------------------|---------------|-------------------------|
| pH                | 6.5                  | 4             | 0.190                   |
| Conductivity      | 750                  | 2             | 0.095                   |
| Chloride (mg L$^{-1}$) | 250                | 3             | 0.143                   |
| Alkalinity (mg L$^{-1}$) | 200                | 2             | 0.095                   |
| Total hardness (mg L$^{-1}$) | 300                | 2             | 0.095                   |
| Calcium (mg L$^{-1}$) | 75                  | 2             | 0.095                   |
| Magnesium (mg L$^{-1}$) | 30                  | 1             | 0.048                   |
| Nitrate-nitrogen (mg L$^{-1}$) | 10                  | 5             | 0.238                   |
| $\Sigma w_i$ = 21 |                      |               | 1.000                   |

### Conclusion

Hydrochemical signatures of spring have important roles in evaluation of drinking water quality. We could get the excellent water quality impression from our data purely based on physico-chemical parameters being used through the Water Quality index. However, the
concentration of phosphorus level raise some genuine concern regarding the potential to trigger eutrophication in spring ecosystems which has not been worked out in these systems till now. This may also impede the services of springs like economic, ecosystem and social services of the spring ecosystems. Therefore, we suggest that regular monitoring of selected springs is needed to facilitate rapid responses to various threats, like nutrient enrichment and pollution from heavy metals, pesticides and micro plastics. We also argue that the costs involved in treating the drinking water from other sources can be saved if springs are tapped, connected to water supply schemes, and managed properly. However, ecological integrity of spring ecosystems in this process should be protected and safeguarded.

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Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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