This manuscript is submitted for publication in *Water Resources Research*

A critical appraisal of the status and hydrogeochemical characteristics of freshwater springs in Kashmir Valley

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Key Points

- **This study integrated Physico-chemical, biological, and geological dataset to characterize the springs**
- **Hydro-chemical facies indicated that silicate weathering and rock-water interaction are important factors governing spring water chemistry**
- **Presence of coliform in some samples suggests contamination of aquifers by sewage**

Abstract

With growing water scarcity, jeopardized by climate change, and population growth, springs are likely to play an important role in meeting the domestic water demand in future. In the Kashmir valley, springs play an important role in meeting drinking water demand via both an organized and unorganized supply chain. This paper examines the water quality of Kashmir Valley springs during the last 11 years in relation to their geographical location, regional hydrogeological conditions, anthropogenic activities and climate change. We analyzed data for 258 springs using Geographic Information System (GIS) and Water Quality Index (WQI) techniques from the whole Kashmir Valley. WQI ranged from 23 (excellent water) to 537 (water unsuitable for drinking). The WQI indicated that 39.5% of the springs had excellent waters, 47.7% had good water, 5% had poor water, 1.6% had very poor water, and 6.2% of the samples had water unsuitable for drinking purposes. Coliform bacteria in some of the sampled springs provided evidence of organic (mainly human) pollution of shallow aquifers. Principal component analysis (PCA) yielded four principal components explaining a cumulative variance of 31%, 49%, 59%, and 67% respectively. The chemical relationships in Piper diagram identified Ca–Mg–HCO_3 as the most predominant water type, whereas a Gibbs diagrams revealed that the spring water of the study region was mainly controlled by rock weathering dominance. Our findings therefore suggest that springs have the potential to offer viable solution to the rising demand and therefore merit an attention for their protection and management.

Keywords: Gibbs Diagram; Geology; Hydrochemistry; Kashmir Himalaya; Piper trilinear; Springs

1. Introduction

Water scarcity in many parts of the world has become an unpleasant reality (Taloor et al. 2020). Freshwater has become a stressed resource and its availability has become increasingly limited (Misra 2014; Odhiambo 2017). With the fast pace of urbanization and industrialization, climate change and rising temperatures, and a marked decline in rainfall, the problem of water scarcity is being increasingly felt across the globe (Okello et al., 2015; Pandey 2021). The water economy is under huge stress and supplying safe drinking water to a growing global population is one of the major challenges for water resource managers (Koop and van Leeuwen 2017). River and stream systems may not be able to meet the water demands for industrial, agricultural, and domestic uses in the coming decades, due to unscientific and improper use of water which has led to acute shortage of water supply in many parts of the world (Ojha et al., 2020). Due to unavailability or inadequate quality, demand for drinking water has increased over the years, especially in densely populated, arid and semi-areas regions of the world (Chen et al., 2019; Jasrotia et al., 2019). As a result, 40% and 20% of the world population is now facing severe and high-water stress respectively (Guppy and Anderson, 2017). Additionally, the increasing demands for water resources has exaggerated conflicts between nations, thus increasing the probability of a third world war. Water from freshwater springs may help alleviate this situation. Worldwide, $1/4^{th}$ of the consumption of water relies on underground sources, which contributes 36% to drinking, 27% to industrial, and 42% to irrigation (Döll et al., 2012). During the last few years freshwater springs have gained increased status and recognition because of the vital role they perform in meeting the increasing demands for drinking water (Bhat et al., 2020). They have been the source of freshwater supplies for populations around the world, guaranteeing domestic water of rural and urban residents, supporting social and economic development, and maintaining ecological balance. India has approximately 5 million springs, including nearly 3 million in the Indian Himalayan Region (IHR) alone (Gupta and Kulkarni 2018). These springs are a source of fresh water for over 200 million people. An estimated 80-90% of the population in the Himalayas depends on springs for their daily use (Scott et al., 2019). The existence of springs is not restricted to rocks of any specific type or age group or any particular topographic or geological setting. They occur wherever groundwater emerges naturally from soil, sediment, or rock into a water body or onto the earth's surface (Pitts and Alfaro, 2001). Therefore, the diversity of springs is suggestive of the wide range of hydrologic and geologic settings which lead to their occurrence (LaMoreaux and Tanner, 2001). Water quality of freshwater springs varies both in time and space based on the source of aquifers, rock formations, mineral dissolution, ion exchange, intermingling together with pollutants (Tlili-Zrelli et al., 2018). Utilization of springs whether indirect or direct provides a wide variety of benefits to human societies, but this resource has been associated with substantial costs to the environment, including biodiversity loss, and deterioration of water quality (Barquin and Scarsbrook, 2008). The quality of water is regularly declining from the effects of overutilization (Singh and Singh 2018), mixing of pollutants (Sharma and Bhattacharya 2017), land-use-land-cover changes (Dar et al., 2020a) and mining activities (Pophare et al., 2014; Selvakumar et al., 2014). As a result, spring water resources are severely diminishing in quality and quantity in several parts of the world, especially in arid and semi-arid regions (Simiyu et al., 2009; Cantonati et al., 2021). Despite their critical importance, springs have received little recognition in terms of management and conservation (Cantonati et al., 2021). Over the past few decades, freshwater springs have been declining in quantity and quality throughout the world due to overexploitation, population growth, lack of rainfall, and climate change (Thakur et al., 2018; Cantonati et al., 2021).

In Kashmir Himalaya, spring water plays an irreplaceable role in supplying water, especially in far-flung backward areas that are sparsely populated and relatively short of surface-water resources. Freshwater springs have been used by people since time immemorial to meet the basic needs of households, livestock, and irrigation (Bhat and Pandit 2018; Bhat and Pandit 2020). Despite the huge importance of springs, little attention has been paid to their management and conservation (Bhat et al., 2020; Cantonati et al., 2021). During the last few decades, the freshwater springs of the Kashmir valley have been under increasing risk of depletion due to anthropogenic activities and changing climate (Jeelani et al., 2018). Large scale land use changes, massive deforestation in catchment areas, and infrastructural development have largely disrupted the hillslope hydrology in the Kashmir valley. This has led to depletion, flow reduction and drying up of natural freshwater springs. Although the national government has established a new Jal Shakti Ministry, which focusses on the immediate need to restore the health of springs. Kashmir Valley springs have not received their due attention and many are drying up (Jeelani et al., 2014). The negative social, economic, and environmental impacts of the degradation of spring water quality is alarming, especially in uphill rural areas where there are no other sources of drinking water. Scientific knowledge of Kashmir Valley springs is incomplete, due to insufficient surveys, investigations, and absence of synthesis of current information in grey and published literature. Given this state of knowledge, the present article aims to provide a comprehensive overview of the environmental status of Kashmir Valley springs including their underlying geology, geographical distribution, and water quality.

2. Materials and Methods

2.1 Study area

Kashmir valley covering an area of 15948 km^2, is located on the northwestern part of the IHR, between 36° 58'–32° 17' N latitudes and 80° 30'–73° 26' E longitudes (Fig. 1). The elevation of the valley varies from 1080 m to 5260 m above mean sea level. The valley has a distinctive continental climate, with a marked seasonality characteristic of the sub-continent of India (Hussain, 2005). Based on the overall physical characteristics of local weather, the valley has four weather seasons spring, summer, autumn, and winter. The mean annual precipitation of the valley is ~1240 mm $year^{-1}$, and the monthly temperature varies from -5°C to more than 30°C. The Kashmir Himalaya region supports a rich diversity of flora and fauna (Dar and Khuroo 2020) in association with its unique geographical position, varied terrain and temperate climate. The abundance and diversity of water resources and associated biodiversity in the Kashmir valley, including glaciers, lakes, rivers, streams, springs, ponds, and wetlands, is unmatched in the entire Himalayan region. In the Kashmir valley, freshwater springs occur widely, including in both high-altitude areas and plains (Fig. 3). Across the valley, numerous springs provide freshwater year-round. In Kashmir Himalaya, the human population is experiencing a massive growth rate and providing sufficient potable water is a challenge for water resource managers. As per Census (2011), Kashmir valley has a population of 6,888,475 persons which is projected to reach 7,405,717 persons by the year 2021 (Census Projections, 2001). This large human population increase, together with unprecedented urbanization, is severely damaging the fragile ecosystems of the Kashmir Himalayan region with grave consequences for the long-term sustainability of water resources. A large human population has led to an increasing demand for water supplies, and as a result, many areas are facing the threat of acute water crisis, including the drying and diminishing of wells and springs in many villages.

2.2 Regional geology

Geologically, the Kashmir valley has rocks of all ages, from recent alluvium to the old Archean, and preserves a chronological record of volcanism, tectonics, and sedimentation that accompanied the Himalayan orogeny (Singh 1971). Bounded by the Pir Panjal Range to the south-west and the Greater Himalayan Range to the north-east, the valley has a record of tectonic activity and the consequent evolution of landscapes in the form of several tectonic and sedimentary structures. Quarternary (Karewa), Triassic (carbonate), Palaeozoic (silicate and carbonate), and Recent (alluvium) rock deposits are the main geographical components in the Kashmir valley (Fig. 2). Tectonic-geomorphological studies in the Kashmir valley support the existence of a vast lake (often called Karewa Lake) that once occurred in the present Kashmir valley (Lydekar, 1883), as indicated by extensive lacustrine deposits from the Udars or Karewas plateau. The sedimentation in Lake Karewa occurred during two phases (Lower and Upper Karewa) in the Pliocene epoch, as indicated by the Hirpur and Nagum formations, respectively (Singh 1982). The Karewa region is 12 to 25 km wide in the southwest, and extends about 80 km from south (Shopian) to north (Baramulla). Karst in Kashmir is widespread due to the wide distribution of carbonate rocks, particularly towards the southern fringe of the region. The Kashmir Valley is characterized by diverse karst features, including not only diverse cold and warm springs, but also sinkholes, caverns, conduits, shafts, karren fields and pits that are most developed in Triassic limestone located in the southern part of the valley.

2.3 Water Quality Evaluation

Review of Literature

During the last ten years, investigations were conducted by the Aquatic Ecology Laboratory, Department of Environmental Science, University of Kashmir, in the plains, basins, and karst areas, which are the main hydrogeologic regions for spring water development and utilization, covering all the 10 districts of Kashmir Valley. Based on an extensive bibliometric analysis covering the time period between 2010 and 2020, we identified 10 research publications and 6 dissertations on spring water in the Kashmir valley that we could use (Bhat and Pandit 2009; Bhat and Pandit, 2010a, b, c; Bhat et al., 2010a, b; Ifra and Tanveer 2014; Bhat and Lone 2015; Bhat and Pandit 2018; Hameed et al., 2018; Bhat and Pandit 2020; Bhat et al., 2020; Lone et al., 2020; Sheikh and Bhat 2020; Shabir and Bhat 2020; Dar and Bhat 2020;).

Spatial distribution maps

Sampling sites were located using a hand-held Global Positioning System (GPS, Garmin having an accuracy of 3 m). The geographical coordinates recorded at different springs were imported into a Geographic Information System (GIS) platform. The GIS-based analysis of spatiotemporal behaviour of the water quality in the study area was executed with the assistance of the spatial analyst module and Natural Neighbor interpolation technique (Dar et al., 2020b) in ArcGIS 10.1 software.

Water Quality Index

WQI has been widely used to evaluate the water quality for drinking purposes in various regions of the world (Dar et al., 2021). The water quality parameters were assigned different weights from 1 to 5 based on their critical health effects. The maximum weight of 5 was assigned to parameters such as NO_3 and Fe, due to their major importance in water quality evaluation, and least value of 1 was given to Na^+, and K^+. The water quality index was computed by the following equations:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad \textbf{(1)}$$

where W_i is the relative weight, w_i is the weight of each water quality parameter, and n is the number of parameters. Then, for each parameter, a quality rating was determined as follows:

$$Q_i = \frac{C_i}{S_i} \times 100 \qquad \textbf{(2)}$$

where Q_i represents the quality rating, C_i is the concentration of each water quality parameter, Si is the recommended standard value for each chemical parameter. Thereafter, to calculate WQI, the first sub-index (S_i) was determined as:

$$S_i = W_i \times Q_i \qquad \textbf{(3)}$$

where S_i symbolizes the sub-index of the ith parameter, and W_i and Q_i indicate the relative weight and quality rating of the ith parameter, respectively.

$$SWQI = \sum_{i=0}^{n} S_i \qquad \textbf{(4)}$$

Principal Components Analysis

PCA converts various measured interconnected parameters into few orthogonal (uncorrelated) parameters known as principal components (PCs). The technique works with a relationship matrix and thus imitates the statistical relationships between parameters. Although the measured physico-chemical water quality parameters that are evaluated are correlated, the calculated parameters (PCs) are uncorrelated and are obtained as a linear combination of the observable water quality parameters. The correlation coefficients obtained between the original parameters and PCs are the factor loadings, which quantify the weights of influence of each original variable on each PC. The PC can be expressed as:

$$z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + \cdots + a_{im}x_{mj} \qquad \textbf{(5)}$$

where 'z' is the component score, 'a' the component loading, 'x' the measured value of parameter, 'i' the component number, 'j' the sample number and 'm' the total number of parameters (Juahir et al., 2011).

Piper diagram

For the identification of water types, the chemical analysis data of the spring water samples were plotted on a Piper diagram, using Origin 8.0 software.

Gibbs diagram

Gibbs (1970) proposed two diagrams to understand the natural mechanisms of surface water chemistry. These diagrams have been used widely to study the principal mechanisms governing the chemistry of groundwater (Lone et al., 2020). Gibbs diagrams depend on two ratios which are computed by the following equations:

$$Gibbs\ ratio - I = \frac{Cl^-}{Cl^- + HCO_3^-} \qquad \textbf{(6)}$$

$$Gibbs\ ratio - II = \frac{Na^+ + K^+}{Na^+ + K^+ + Ca^{2+}} \qquad \textbf{(7)}$$

3 Water Quality

Evaluating the quality of spring water is essential for determining its fitness for drinking purposes in the study area. The various physical, chemical, and biological parameters of spring waters were compared with drinking water quality standards set by WHO (2017). The concentration values of various water quality parameters are given in Table 1. The pH is a fundamental property describes the acidity and alkalinity of water samples. The chemical characteristics show that the spring water samples are acidic to alkaline in nature with a pH value ranging from 5.5-11. The spatial distribution of pH in the study area is shown in Fig. 4a. Among the investigated samples, 95% of the samples had pH values within the desirable limits: 3% had pH values in the acidic range, and 2% had pH values above the permissible limits (WHO, 2017). The acidic character at some places is related to the presence of organic acids and high carbon dioxide content (Bhat et al., 2010a), whereas the high alkaline nature is related to the limestone-rich lithology of the study area (Hameed et al., 2018). Ionic concentrations, estimated as electrical conductivity (EC), ranged from 90-2710 μS cm^{-1}. The spatial distribution of EC in the study area is shown in Fig. 4b. It was found that 99.6% of the samples had EC values within the permissible limits and thus only 0.4% had EC values beyond the permissible limits set by WHO (2017). High EC values are due to contamination of aquifers by inorganic fertilizers and inputs of domestic sewage from adjoining catchment areas (Bhat and Pandit 2010a, b). The concentration of total dissolved solids (TDS) signifying the various types of dissolved minerals present in the water samples varied between 64-682 mg L^{-1}. The spatial distribution of TDS in the study area is shown in Fig. 4c. About 16.3% of the samples show TDS contents above the WHO (2017) desirable standard value. Davis and De Wiest (1966) classified TDS values into four categories (i) TDS < 500 mg L^{-1} as desirable for drinking, (ii) TDS between 500 - 1000 mg L^{-1} as permissible for drinking, (iii) TDS between 1000 – 3000 mg L^{-1} as useful for irrigation, and (iv) TDS > 3000 mg L^{-1} as unfit for drinking and irrigation. According to this classification, about 84% of the samples in the study area were desirable and 16% of the samples were within permissible limits (Table 2). Water quality evaluation of the springs in the study area also indicated that the waters are soft to very hard. The concentration of total hardness (TH) generally caused by the compounds of calcium, magnesium, and other metals in the study area ranged from 48-344 mg L^{-1} (Fig. 5a), well below the maximum permissible limit of 500 mg L^{-1} set by WHO (2017). Furthermore, 25% of the samples were hard and 4% very hard, following the classification by Sawyer and McCartly (1967) (Table 2). The concentration of calcium in the study area varied between 6-289 mg L^{-1}. The spatial distribution of calcium in the study area is shown in Fig. 5b. We found that 4% of the samples had concentrations above the permissible limits set by WHO (2017). The concentration of magnesium varied between 1-150 mg L^{-1} (Fig. 5c). The concentration of magnesium in 60.5% of the samples was within the desirable limits, the concentration in 38.8% samples was within the permissible limits, and 0.8% samples had concentrations above the permissible limits set forth by WHO (2017). Bicarbonate alkalinity in the study area ranged from 2 to 424 mg L^{-1} (Fig. 5d). The predominant source of bicarbonates (alkalinity), total hardness, and calcium ions in the study area is the carbonate lithology which indicates the intense dissolution and chemical weathering of calcite minerals, whereas the magnesium values indicate contribution through dissolution of pyroxenes, dolomites, and amphiboles (Mir and Lone 2020). The concentration of nitrate in the spring water samples varied between 10-3844 μg L^{-1} (Fig. 6a) and was within the desirable limits set by WHO (2017). The concentration of the SO_4^{2-} varied between 1-53 mg L^{-1}. The spatial distribution of SO_4^{2-} is shown in Fig. 6b. SO_4^{2-} concentrations are all within the desirable limit of 200 mg L^{-1} set by WHO (2017). The possible sources of sulfates and nitrates in the study area reveal intense leaching and surface runoff from soils and agricultural fields, leakages from septic tanks and surface drains, and domestic sewage (Lone et al., 2020). Iron concentrations in the study area ranged from 0.008 to 764 μg L^{-1} (Fig. 6c). Chloride concentrations varied between 3-66 mg L^{-1} (Fig. 6d), well within the desirable limits set by WHO (2017). The sources of chloride in the study area are related to the dissolution of soil salts, finer detrital sediments comprising silt/sandy-silt/clay and sandy clay. Fairly low chloride concentrations reveal low background levels from the lithological foundations in the area. However, higher chloride concentrations–observed in some areas are indicative of the increasing anthropogenic pressures in the form of sewage and domestic wastes, surface runoff from agricultural fields, and evaporation from lakes and wetlands. The concentration of total phosphorus (TP) in the study area ranged from 16-13252 μg L^{-1}. The higher concentrations were found in the south of the Kashmir valley (Fig. 7a). Based on concentration of TP, only 66.7% of the samples were suitable for drinking purposes and 33.3% of the samples were not suitable for drinking purposes as per the Environmental Quality Standards for Surface Water of the People's Republic of China (GB3838-2002) (Zuo et al., 2013) (Table 2). In the study area, the presence of Coliform bacteria occurred in 5.4% of the investigated samples and the value ranged from 3-28/100 ml (Fig. 7d). According to WHO (2017), coliform should not be present in any of the samples for drinking purposes, therefore, the presence of coliform bacteria in some of the samples indicates the contamination of aquifers by septic tanks.

WQI

WQI ranged from 23 (excellent water) to 537 (water unsuitable for drinking) (Table 3). The WQI indicates that 87% of the samples have waters between good to excellent water and are fit for drinking purposes without any treatment. Approximately 7% of the samples have water quality ranging from poor to very poor and require minimal treatments before being used for drinking purposes. 6.2% of the samples have water unsuitable for drinking purposes. WQI indicated that the majority of the springs have excellent to good water, whereas few springs have very poor-quality waters.

PCA

PCA was executed on 14 water quality parameters with 258 sampling sites to identify variation in water quality. The variable loadings and variance (%) for the four components derived from the dataset is given in Table 4. This analysis led to the cumulative explanation of 31%, 49%, 59%, and 67% of the variance. The PC1 explained 31.08% of the total variance and had strong loading of TH, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3-N, Cl^-, and TP. The PC2 explained 18.08% of the total variance and had strong loading of EC, TDS, and Salinity. The PC3 explained 9.2% of the total variance and had strong positive loadings of pH, bicarbonates, and SO_4^{2-}. The PC4 explained 8.1% of total variance with strong positive loading for Coliform concentration.

Piper trilinear and Gibbs diagram

Statistical distribution diagrams such as Piper Trilinear were used not only to gain better insights into the hydrochemical processes operating in the water system, but also to characterize the water types present in the area (Fig. 8). Since Ca–HCO_3, Mg– HCO_3, Ca–Mg–HCO_3, and Na–HCO_3 are the most common hydrochemical facies, it is likely that lithology and anthropogenic activities have played an important role in controlling the spring water chemistry in the Kashmir Valley. The Gibbs diagram also highlights that rock dominance is factor affecting water chemistry in the study area (Fig. 9).

Piper Trilinear and the Gibbs diagram suggest that silicate weathering and rock-water interaction are important factors in increasing the concentration of major ions in the spring water. The chemical composition in spring water is the product of long-term interaction between groundwater and the environment and human activities. A large number of anthropogenic activities (agricultural, horticultural and grazing activities) also affected the chemical compositions of spring water. The spring water in the study area is dominated by Ca-Mg-HCO_3 and Ca-Mg-Cl, which indicate that the major hydrochemical facies is weathering-solubilization. The formation of spring water type is mainly the result of water that recharges the aquifer, type of rock with which groundwater is in contact, rate of flow and length of flow path, residence time and, the dissolution of minerals in the study area.

4. Climate change and role of springs in Kashmir valley

Like many regions of the world, the Kashmir valley is moderately to highly susceptible to climate change (ENVIS, 2015). Climate change impacts are likely to be felt through changing precipitation patterns, water availability, floods and drought (OECD, 2013). Assessment and monitoring of hydro-geochemical and physico-chemical properties of natural springs, which supply water for thousands of people, is crucial and provides information about sustainable use of springs in the context of climate change scenarios (Rani et al., 2020). Climate change and growing population have jeopardized the water resource base and availability (Okello et al., 2015a). Population growth will lead to an overall increase in water demand (per capita increase) and pressure on freshwater resources (Okello et al., 2015b). Reports indicate that the instances of springs drying is increasing in the Kashmir valley (Down to Earth, 2005). This has been attributed to glacier retreat, pollution, blocking of feeding channels and forest denudation (Down to Earth, 2005; Tambe et al., 2012). Although once known as a surplus water state with low population densities, the Kashmir Valley has recently seen a significant increase in population and water demand (Ahmed and Ahmed, 2013). The combined effect of climate change and population growth is likely to challenge the future freshwater availability (Schleich and Hillenbrand, 2009). According to the Census of India (2011), the current Kashmir population is 6.89 million and the projected population by the year 2051 is 14.41 million (Fig. 10). Based on per capita per day consumption (135 liters/day) estimates of Public Health Engineering Department (PHED, 2021), future demand was forecasted. The current total domestic demand is estimated to be 235 billion liters per year and is projected to reach 850 billion liters per year by 2050 (Fig. 11). With growing water scarcity, exacerbated by climate change and population growth, springs are likely to play an important role in meeting the domestic water demand in future. Proper management and conservation of spring water resources in the face of climate change require knowledge of their potential, demand, availability, quality and recharge.

5. Conclusions

Hydro-chemical analysis of spring water samples in the Kashmir Valley exhibit that Ca and Mg are dominant followed by the Na^+ and K^+ among cations. The bicarbonate is one of the most dominant anions followed by the Cl and NO_3. Analysis of hydro-chemical facies reveals two dominant facies on the Piper Trilinear diagram: Ca–Mg– HCO_3^- and Ca–Mg– HCO_3^- – SO_4^{2-} type, thus showing that the water chemistry is dominated by the alkaline earth (Ca^{2+}+Mg^{2+}) and weak acids (HCO_3^-). The Gibbs plot shows that total dissolved solids, point towards rock (dolomite, calcite and silicate) dominance and suggests congruent dissolution of carbonate lithology. The high values of HCO_3^- in spring water samples illustrate the dissolution of carbonate rocks in the recharge area due to the acidic precipitation (CO_2–rich) and ionic enrichment. The water quality index indicated that 95% of the springs have excellent to good category which means that most of the springs are a source of fresh drinking water for the population in the study area.

Acknowledgements

The authors would like to thank the Department of Environmental Science, University of Kashmir for providing different kinds of facilities. The authors would also like to thank Prof.

Douglas Glazier, Juniata College, Huntingdon USA for revising the earlier draft of the manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest

Data availability statement

Datasets for this research are included in this paper

Funding

No funding was received during the course of the study

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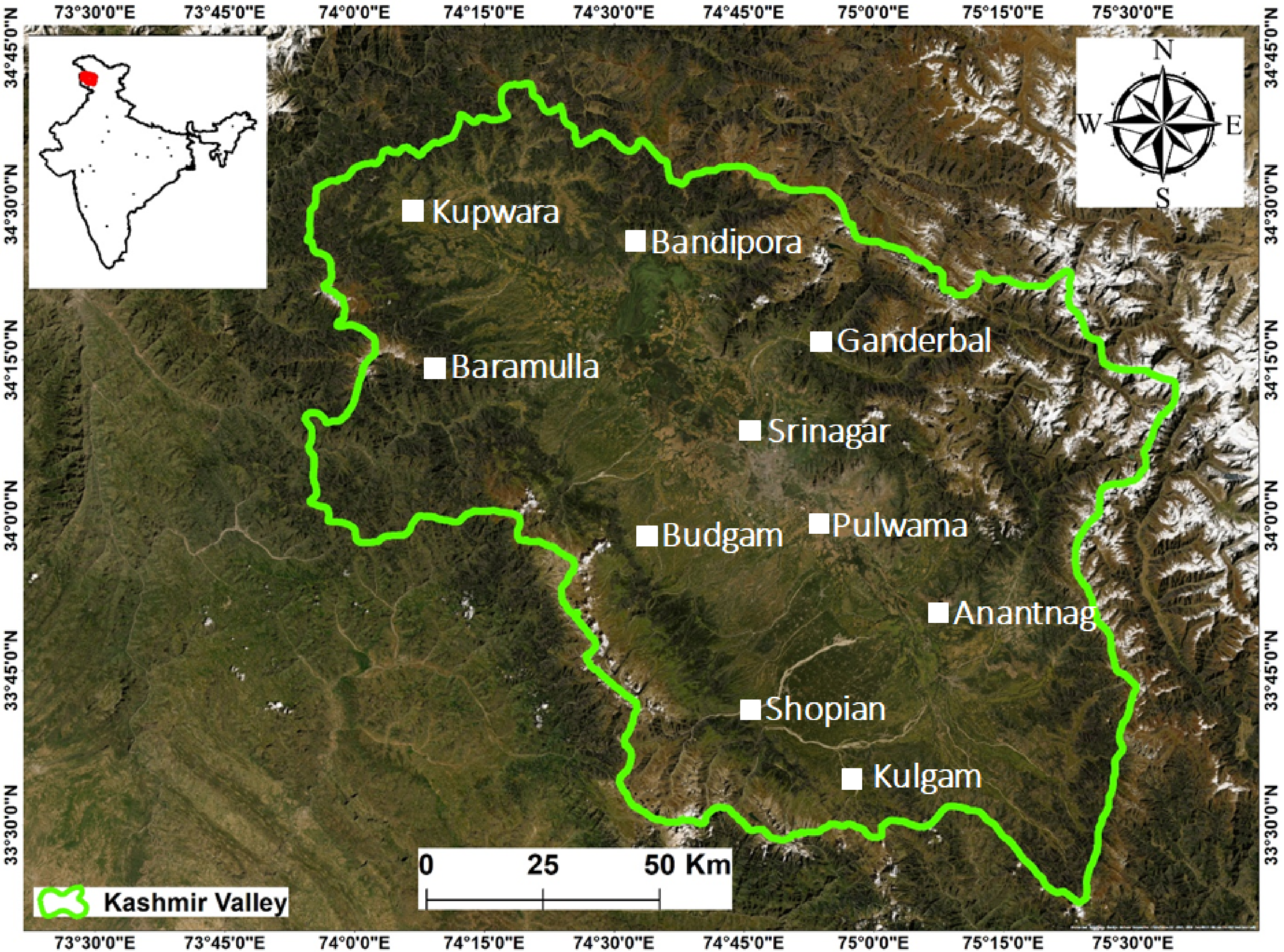
Figure 1. Location map of the study area.



73°30'0"E
73°45'0"E
74°0'0"E
74°15'0"E
74°30'0"E
74°45'0"E
75°0'0"E
75°15'0"E
75°30'0"E
34°45'0"N
34°30'0"N
34°15'0"N
34°0'0"N
33°45'0"N
33°30'0"N
N
W
E
S
Kupwara
Bandipora
Ganderbal
Baramulla
Srinagar
Budgam
Pulwama
Anantnag
Shopian
Kulgam
0
25
50 Km
Kashmir Valley

Figure 2. Geological map of the study area.

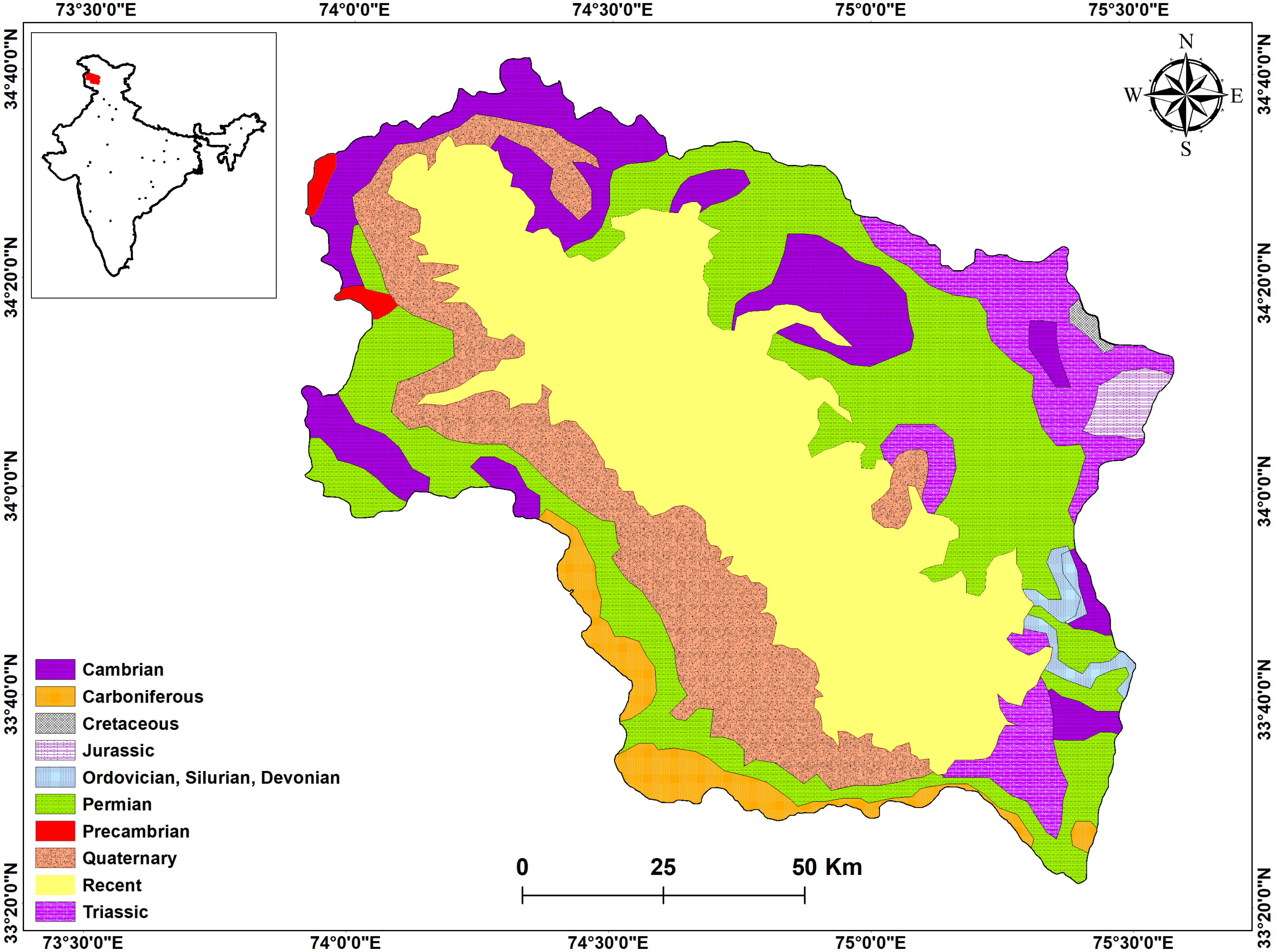
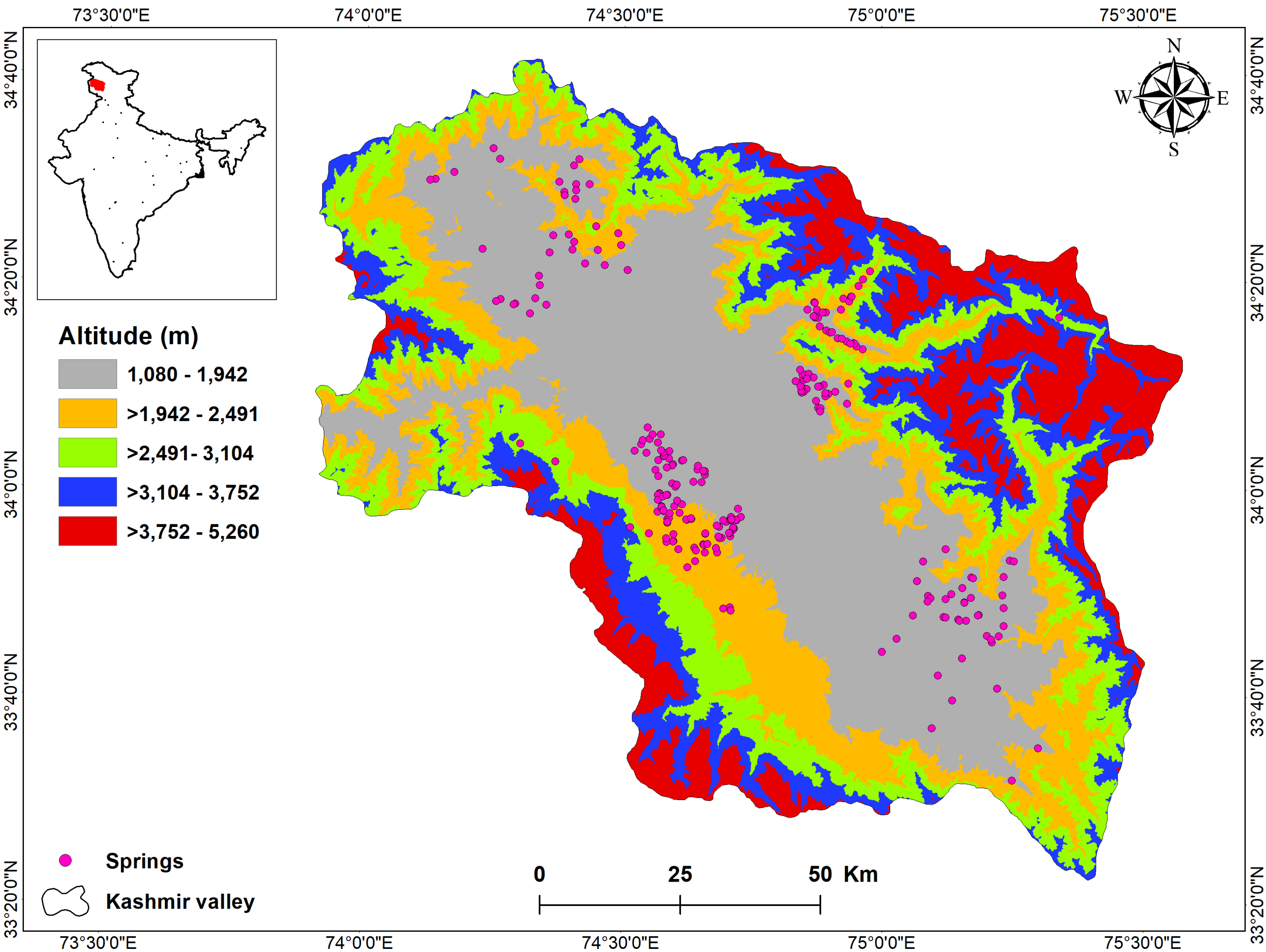

73°30'0"E
74°0'0"E
74°30'0"E
75°0'0"E
75°30'0"E
34°40'0"N
34°20'0"N
34°0'0"N
33°40'0"N
33°20'0"N
N
S
E
W
Cambrian
Carboniferous
Cretaceous
Jurassic
Ordovician, Silurian, Devonian
Permian
Precambrian
Quaternary
Recent
Triassic
0
25
50 Km

Figure 3. Map showing location of freshwater springs in the Kashmir Himalaya.



73°30'0"E
74°0'0"E
74°30'0"E
75°0'0"E
75°30'0"E
34°40'0"N
34°20'0"N
34°0'0"N
33°40'0"N
33°20'0"N
N
S
E
W
Altitude (m)
1,080 - 1,942
>1,942 - 2,491
>2,491- 3,104
>3,104 - 3,752
>3,752 - 5,260
Springs
Kashmir valley
0
25
50 Km

Figure 4. Spatial distribution of (a) pH, (b) electrical conductivity (?S cm-1), total dissolved solids (mg L-1), and (d) salinity (mg L-1) in the study area.

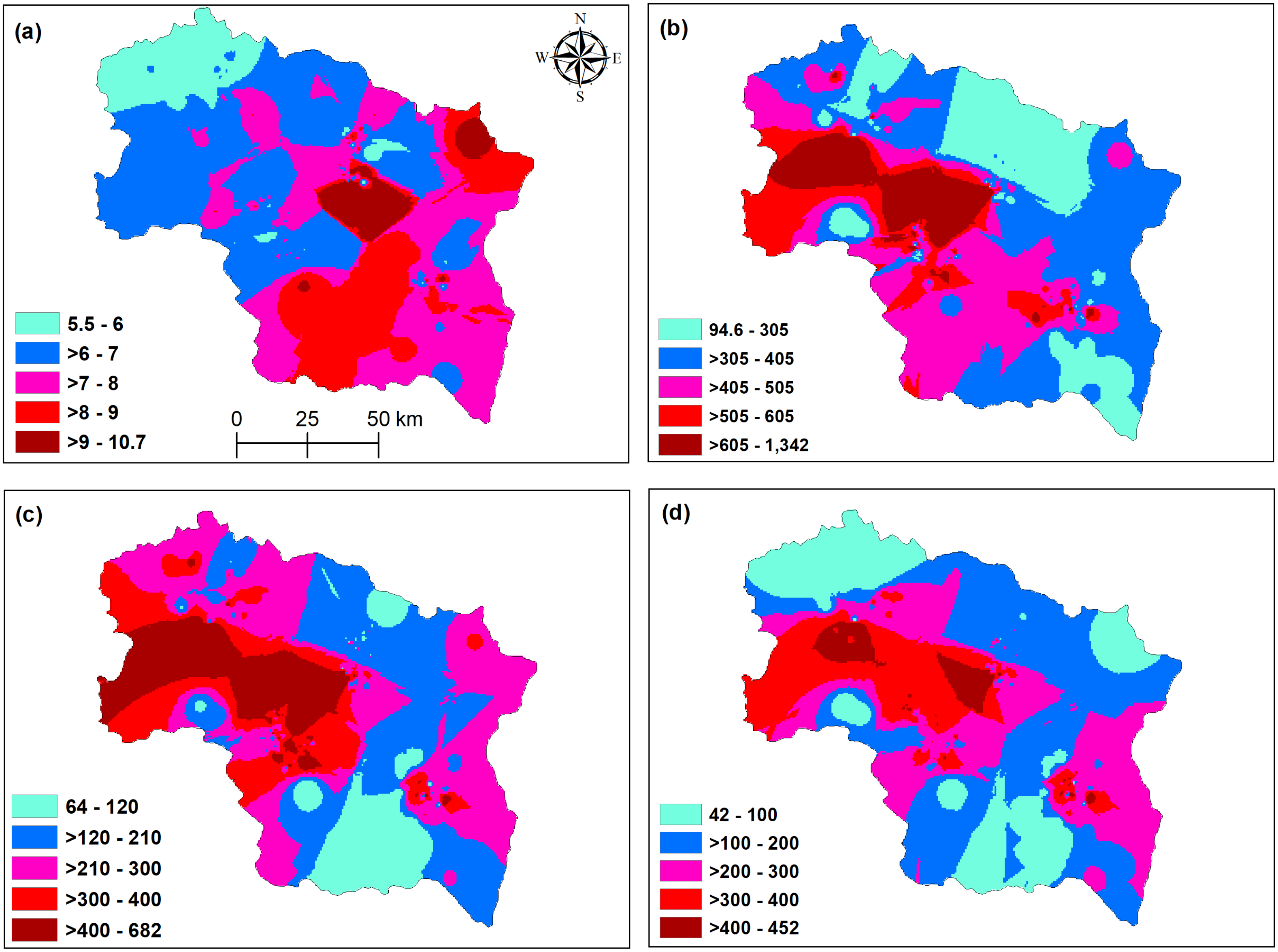

(a)
N
W
E
S
5.5 - 6
>6 - 7
>7 - 8
>8 - 9
>9 - 10.7
0
25
50 km
(b)
94.6 - 305
>305 - 405
>405 - 505
>505 - 605
>605 - 1,342
(c)
64 - 120
>120 - 210
>210 - 300
>300 - 400
>400 - 682
(d)
42 - 100
>100 - 200
>200 - 300
>300 - 400
>400 - 452

Figure 5. Spatial distribution in the study area (a) total hardness (mg L-1), (b) calcium (mg L-1), and (c) magnesium (mg L-1), and (d) bicarbonate alkalinity (mg L-1).

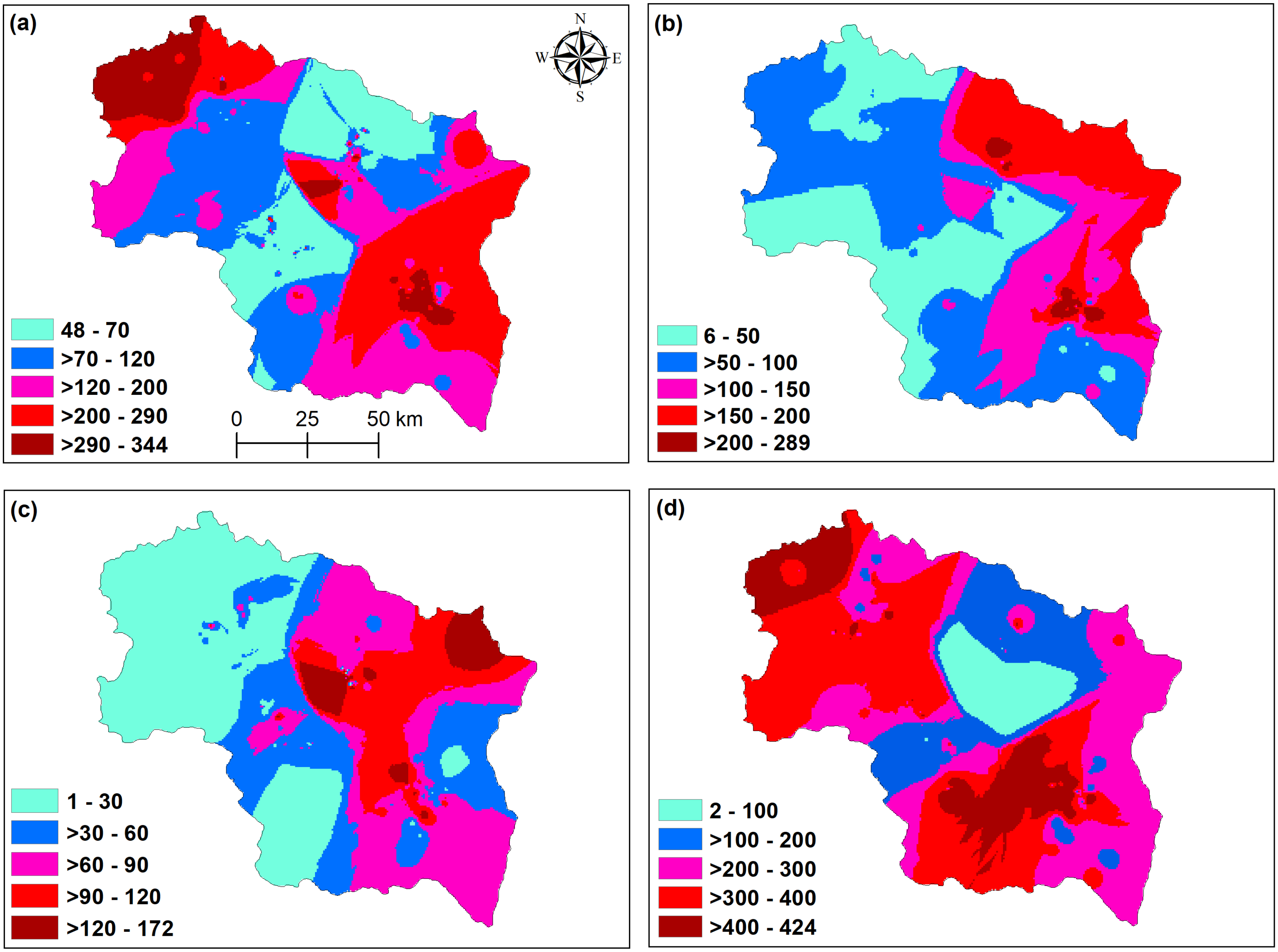
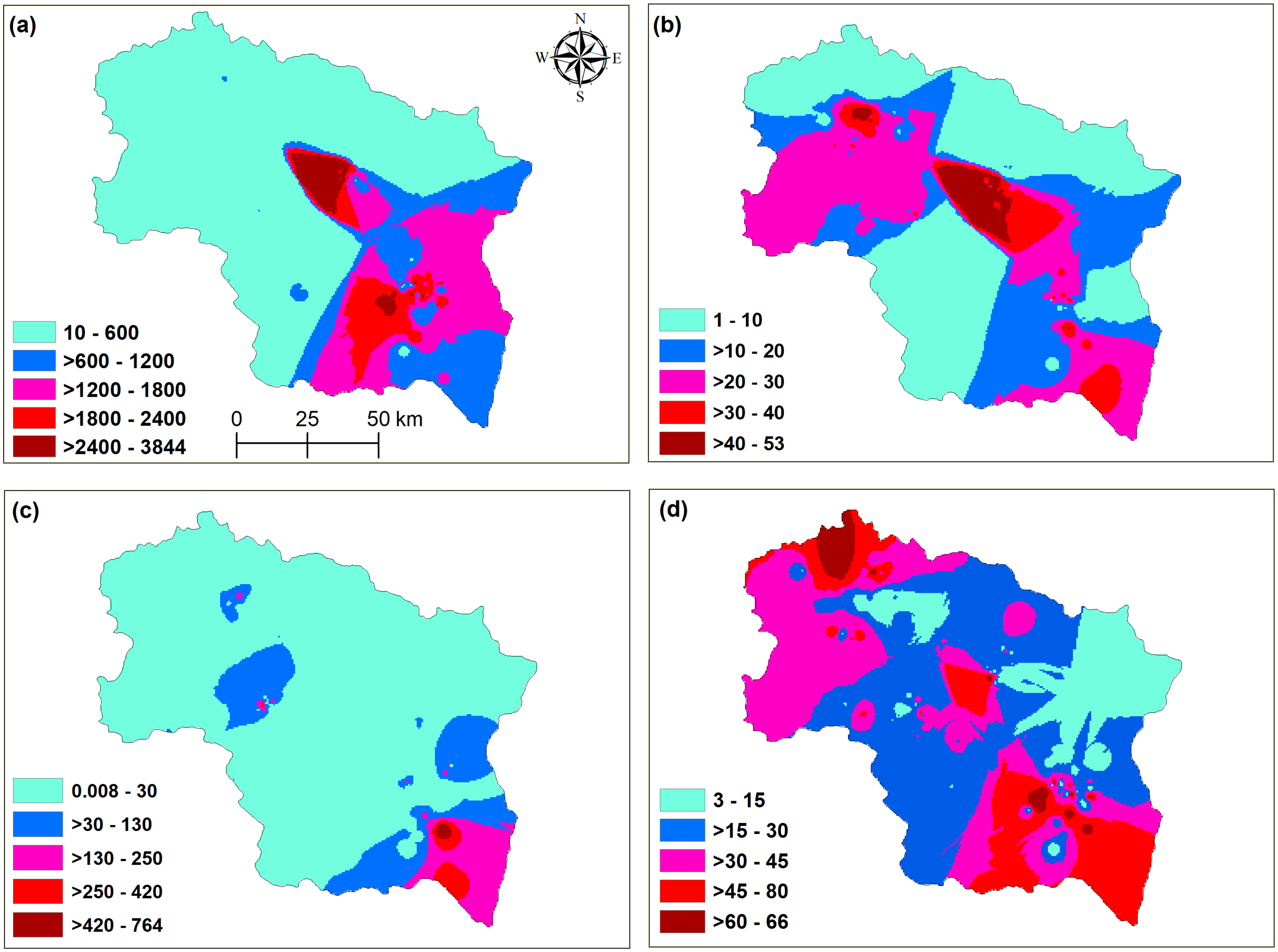

(a)
N
W
E
S
48 - 70
>70 - 120
>120 - 200
>200 - 290
>290 - 344
0
25
50 km
(b)
6 - 50
>50 - 100
>100 - 150
>150 - 200
>200 - 289
(c)
1 - 30
>30 - 60
>60 - 90
>90 - 120
>120 - 172
(d)
2 - 100
>100 - 200
>200 - 300
>300 - 400
>400 - 424

Figure 6. Spatial distribution in the study area (a) nitrate (?g L-1), (b) sulphate (mg L-1), and (c) iron (?g L-1), and (d) chloride (mg L-1).



(a)
N
W
E
S
10 - 600
>600 - 1200
>1200 - 1800
>1800 - 2400
>2400 - 3844
0
25
50 km
(b)
1 - 10
>10 - 20
>20 - 30
>30 - 40
>40 - 53
(c)
0.008 - 30
>30 - 130
>130 - 250
>250 - 420
>420 - 764
(d)
3 - 15
>15 - 30
>30 - 45
>45 - 80
>60 - 66

Figure 7. Spatial distribution in the study area (a) total phosphorus (?g L-1), (b) sodium (mg L-1), and (c) potassium (mg L-1), and (d) coliform.

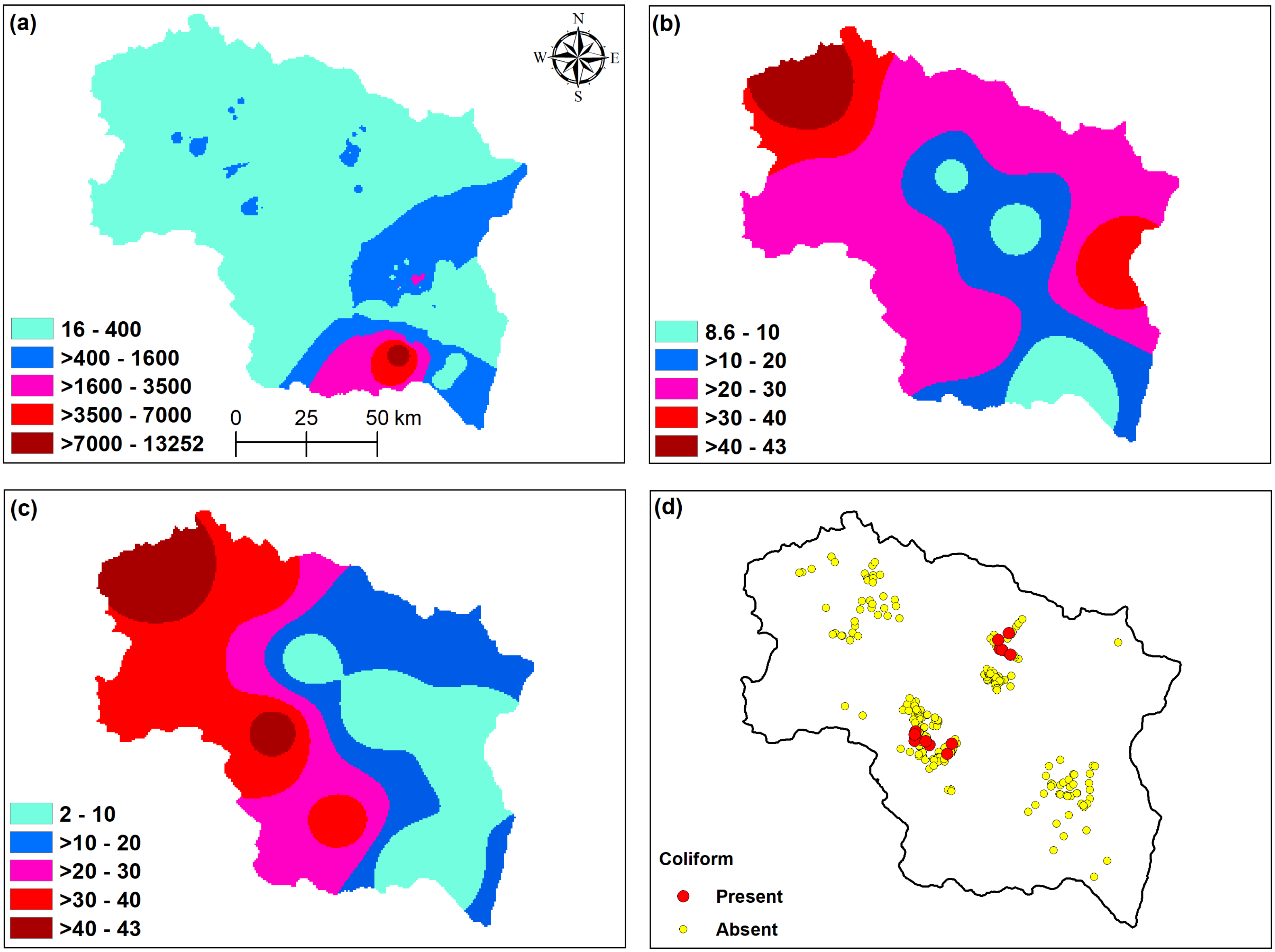
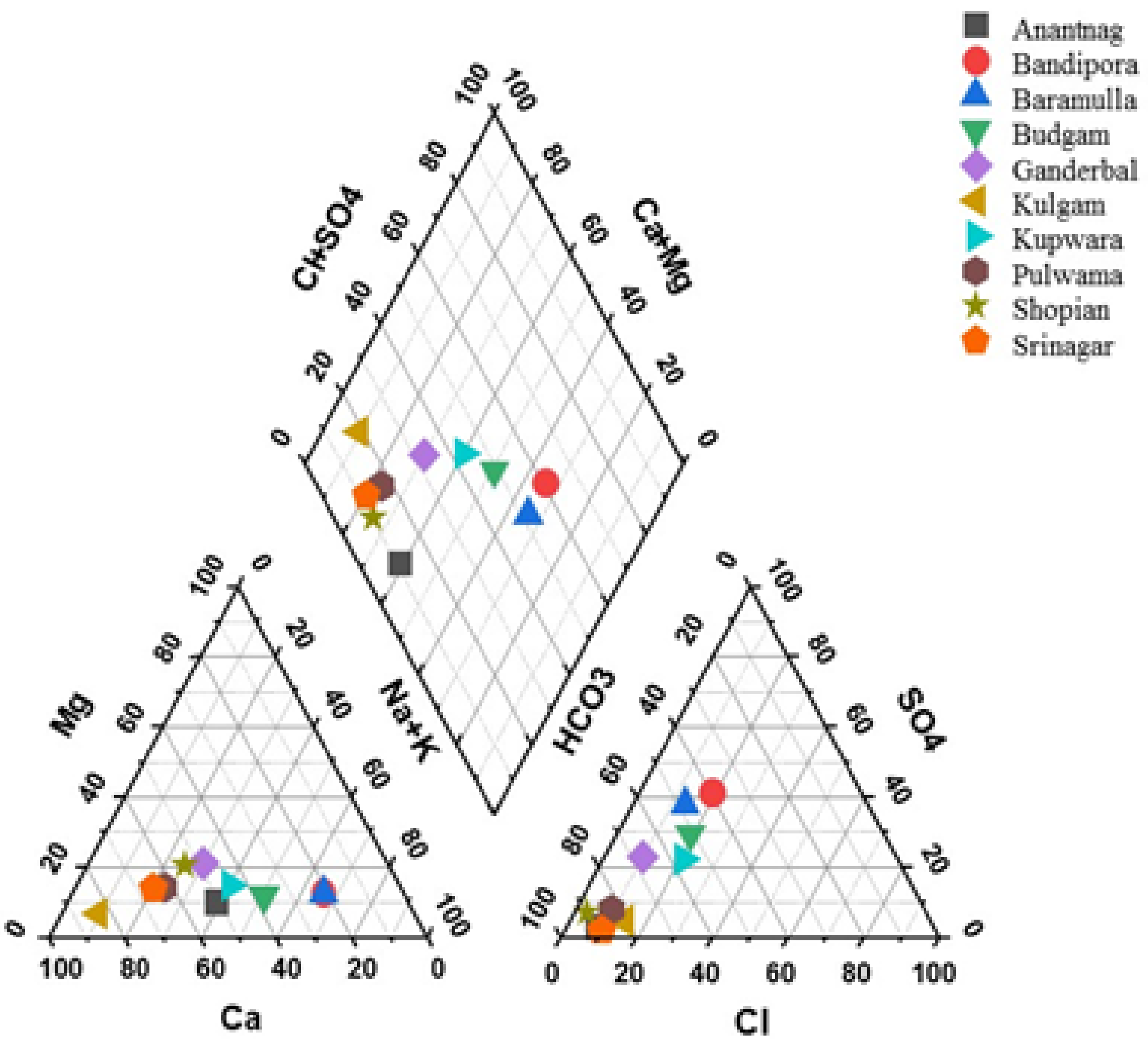
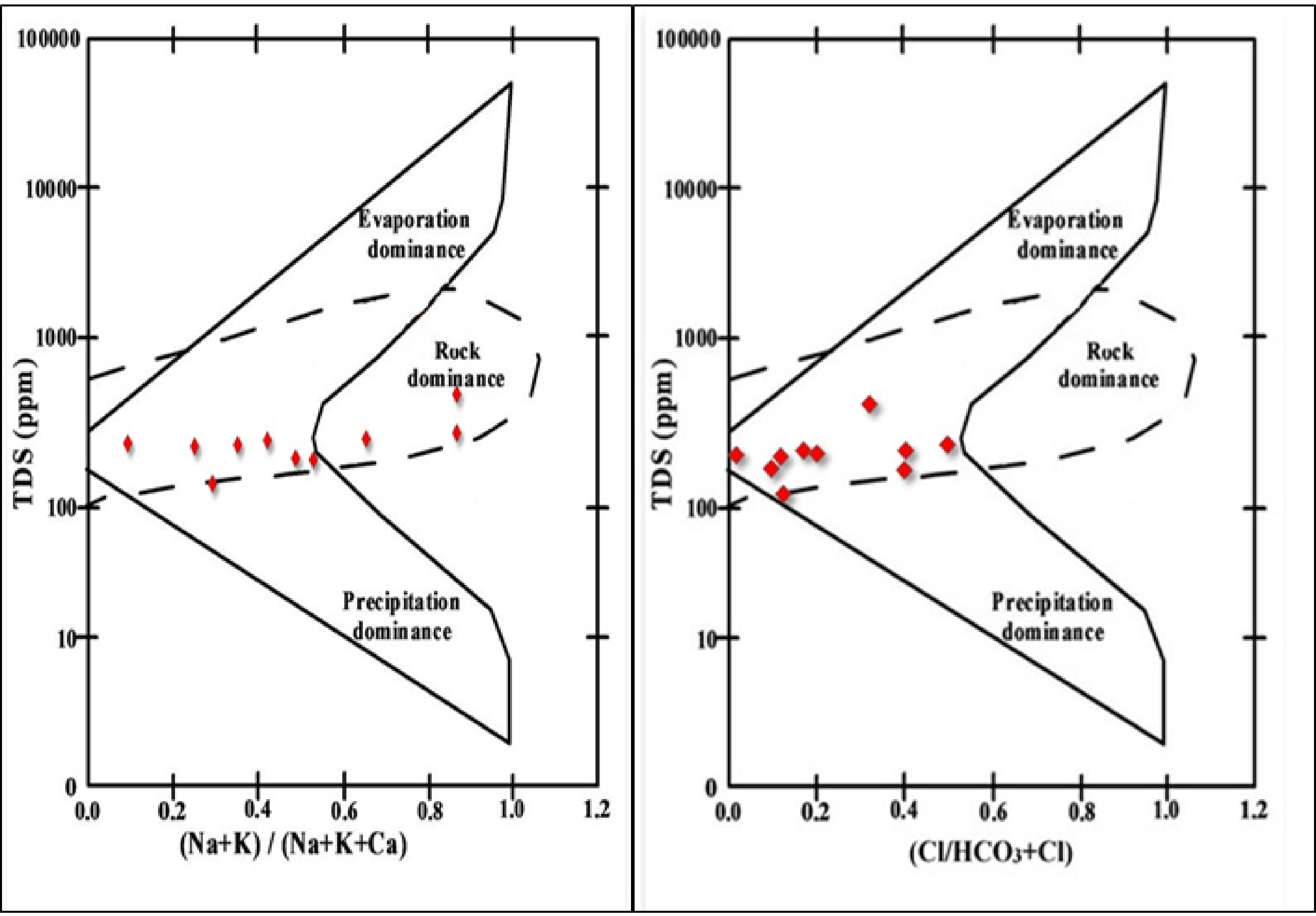

(a)
N
W
E
S
16 - 400
>400 - 1600
>1600 - 3500
>3500 - 7000
>7000 - 13252
0
25
50 km
(b)
8.6 - 10
>10 - 20
>20 - 30
>30 - 40
>40 - 43
(c)
2 - 10
>10 - 20
>20 - 30
>30 - 40
>40 - 43
(d)
Coliform
Present
Absent

Figure 8. Piper trilinear diagram of the spring water chemistry.



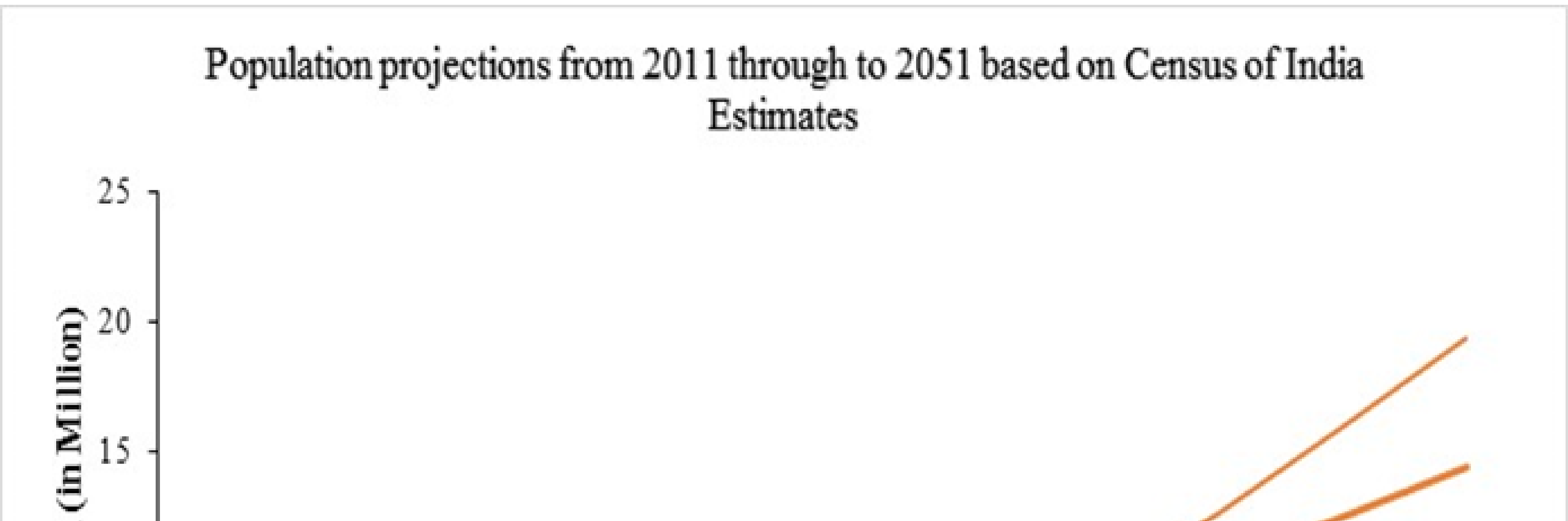
Anantnag
Bandipora
Baramulla
Budgam
Ganderbal
Kulgam
Kupwara
Pulwama
Shopian
Srinagar
Cl+SO4
Ca+Mg
Mg
Na+K
HCO3
SO4
Ca
Cl
0
20
40
60
80
100

Figure 9. Controlling mechanism for spring water chemistry (Gibbs, 1970).



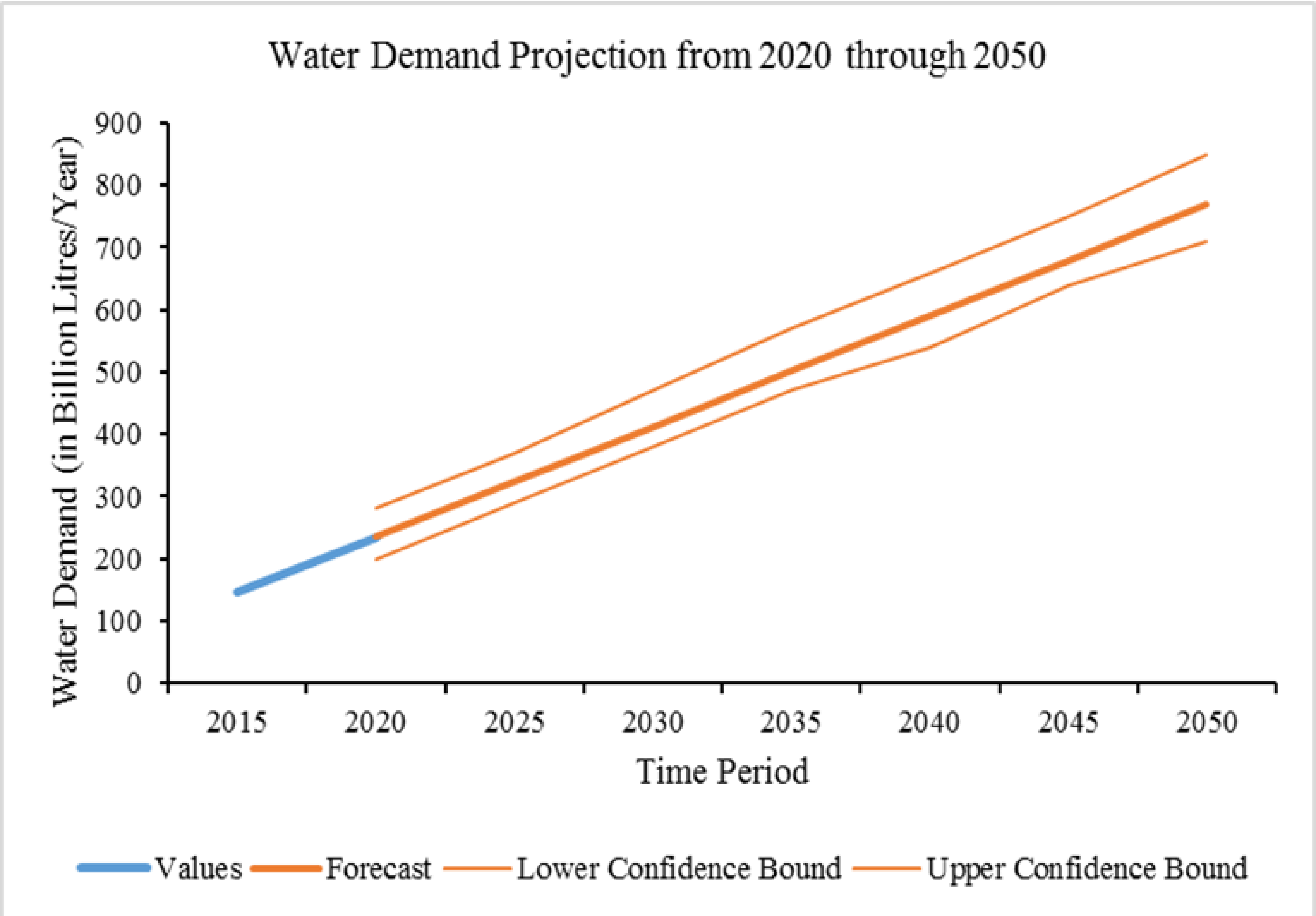
100000
10000
1000
100
10
0
TDS (ppm)
Evaporation dominance
Rock dominance
Precipitation dominance
0.0
0.2
0.4
0.6
0.8
1.0
1.2
(Na+K) / (Na+K+Ca)
(Cl/HCO3+Cl)

Figure 10. Population projection for Kashmir Valley from 2011 through 2051 based on Census of India estimates.



Population projections from 2011 through to 2051 based on Census of India Estimates
25
20
15
10
5
0
Population (in Million)
1951
1961
1971
1981
1991
2001
2011
2021
2031
2041
2051
Time Period
Values
Forecast(Values)
Lower Confidence Bound(Values)
Upper Confidence Bound(Values)

Figure 11. Total domestic water demand projection for Kashmir Valley from 2021 through 2050 based on PHE estimates.



Water Demand Projection from 2020 through 2050
Water Demand (in Billion Litres/Year)
900
800
700
600
500
400
300
200
100
0
2015
2020
2025
2030
2035
2040
2045
2050
Time Period
Values
Forecast
Lower Confidence Bound
Upper Confidence Bound

List of Tables

Table 1 Comparison of Spring water quality of study area with WHO, (2017) for drinking purposes

S. No.	WQ Parameters	Concentration in study area	WHO 2017	
			HDL	MPL
1.	pH	5.5 - 11	7.0	8.5
2.	Conductivity (µS cm^{-1})	90 - 2710	-	1500
3.	TDS (mg L^{-1})	64 - 682	500	1500
4.	Salinity (mg L^{-1})			
5.	TH as $CaCO_3$ (mgL^{-1})	48 - 344	100	500
6.	Ca (mg L^{-1})	6 - 289	75	200
7.	Mg (mg L^{-1})	1 - 150	30	150
8.	Bicarbonate alkalinity (mg L^{-1})	2 - 424	-	-
9.	Chloride (mg L^{-1})	3 - 66	200	600
10.	Sulphate (mg L^{-1})	1 - 53	200	400
11.	Nitrate (µg L^{-1})	10 - 3844	45	-
12.	Iron (µg L^{-1})	0.008 - 764	-	-
13.	Total phosphorus (µg L^{-1})	16 - 13252	-	-
14.	Coliform (per 100 mL)	3 - 28	0	-

Table 2 Classification of spring waters for drinking purposes based on TDS (Davis and DeWiest, 1966), Total hardness (Sawyer and McCarthy, 1967) and Total Phosphorus (People's Republic of China), Zuo et al. 2013.

S. No.	**TDS mg/l**	**Classification**	**No. of samples**
1.	<500	Desirable for drinking	218
2.	500-1000	Permissible for drinking	40
3.	1000-3000	Useful for irrigation	-
4.	>3000	Unfit for drinking and irrigation	-
	Total Hardness mg/l		
5.	<75	Soft	115
6.	75-150	Moderately hard	69
7.	150-300	Hard	64
8.	>300	Very hard	10
	Total Phosphorus		
9.	≤ 20-200	Used for drinking purposes, fishing and recreation	172
10.	≤ 300	Used for industry and irrigation	20
11.	≤ 400	Cannot be used by any sector	66

Table 3 WQI in the study area

S. No.	Water Quality	Range	No. of Samples in the study area
1.	Excellent	0 - 50	102
2.	Very good	>50 - 100	123
3.	Poor water	>100 - 200	13
4.	Very poor water	>200 - 300	4
5.	Water unsuitable for drinking purposes	>300	16

Table 4 Principal component loadings for water quality parameters for the entire data set

Variables	PC 1	PC 2	PC 3	PC 4
pH	0.15427	0.076356	-0.51888	0.18402
EC	0.098336	0.47796	0.28338	0.05421
TDS	0.080293	0.53928	0.27254	0.03938
Salinity	0.15019	0.53533	0.055602	0.09310
TA	0.29559	-0.23499	0.41152	-0.18001
TH	0.39778	-0.20081	0.16679	0.08179
Ca	0.3928	-0.08587	0.12751	0.17237
Mg	0.41172	0.0045516	-0.18806	0.10313
SO_4	0.28709	0.13756	-0.3891	-0.18398
Fe	0.094955	-0.020059	0.015793	-0.67759
NO_3-N	0.34849	0.053942	-0.32108	0.02736
Cl	0.37085	-0.081688	0.17548	-0.23818
TP	0.12545	-0.15436	0.082936	0.26556
Coliform	0.044337	-0.18069	0.17856	0.50256
Eigen values	4.3100	2.6100	1.3000	1.1400
% Variance	31.0840	18.6980	9.2900	8.1660
Cumulative % variance	31.0840	49.7820	59.0730	67.2390