Asian Journal of Water, Environment and Pollution, Vol. 14, No. 4 (2017), pp. 61–75.
DOI 10.3233/AJW-170037

Utility of Multivariate Statistical Analysis to Identify Factors Contributing Groundwater Quality in High Altitude Region of Leh-Ladakh, India

Arup Giri, Vijay K. Bharti*, Sahil Kalia, Krishna Kumar, Tilak Raj and Bhuvnesh Kumar

Defence Institute of High Altitude Research (DIHAR), DRDO, Leh-Ladakh, India
✉ vijaykbharti@rediffmail.com

Received August 11, 2017; revised and accepted September 13, 2017

Abstract: Many factors have been found responsible for the groundwater quality like interaction of different water sources, types of soils, other several natural factors, and anthropogenic factors. Therefore, the objectives of the present work were to identify different factors affecting the ground water quality based on multivariate analysis. This study also aimed to determine the usefulness of multivariate statistical techniques to improve our understanding of factors affecting groundwater properties and their interactions. The original matrix consisted of 25 physico-chemical parameters analyzed in 70 number of ground water samples collected from different sites of sampling stations. All the physical and chemical parameters were analyzed by the standard methods of APHA, whereas minerals were determined by ICP-OES method. Thereafter, experimental 70 × 25 matrix was run through the multivariate statistical data analysis which consists of Principal Component Analysis (PCA), R and Q mode Factor Analysis (FA), and Cluster Analysis (CA).

Results showed that physico-chemical factors are important source of variation in the groundwater quality. Interestingly, multivariate analysis revealed that other factors such as dissolution of salts present in the underlying rocks, presence of nutrient load, non-mixing/partial mixing of different types of ground water and moderate type of exchange between river water with adjacent ground water has been found to affect groundwater quality. The study also showed the significant role of multivariate statistical analysis in evaluation and interpretation of the groundwater quality data. The outcome of this study can be used as baseline data to inhospitable and critical areas for future sustainable development and proper management of groundwater system which will ultimately produce good water quality.

Key words: Groundwater, high altitude, multivariate statistical analysis, water quality.

Introduction

Water is essential for the survival of all living organisms. The health of the natural ecosystem depends on the physicochemical and biological characteristics of water (Venkatesharaju et al., 2010). Therefore, management of water resources is important to acquire the good quality of water, or else water systems may cause serious problems in terms of availability and quality (Subba and Rao, 1998). In the present decade, numerous health concerns, mainly in developing countries, are related to access to unsafe water quality and its subsequent domestic utilization, which has become the major issue for the governments of these countries. These countries regularly have one billion or more incidents of diarrhea annually (Mark et al., 2002). It is estimated

*Corresponding Author

that approximately one-third of the world's population use ground water for drinking (WHO, 2002). A total of 80% natural water is waste water type which is unfit for drinking, agriculture, and industry application. In the global scenario, about 1.1 billion people do not have access to improved water supply source. Moreover, two million deaths per annum occur due to diarrhoea. These cases are happening because of the unsafe water supply and improper sanitation (WHO, 2013; Moharir et al., 2002). In India, about 95% of the rural population depends on ground water for their basic domestic uses. But, 70% of the total water resources are seriously polluted. Further, 75% of illness and 80% of the child mortality is attributed to water pollution as quality groundwater has been deteriorated (Dasgupta and Purohit, 2001; Aris, 2009).

Leh district is situated roughly between 32° to 36° North latitude and 75° to 80° East longitude and altitude ranging from 2300 m to 5000 m above mean sea level. This region is covering two important international borders, which has strategic importance for national security. Climatically, this region is characterized by both arctic and desert climate. Therefore Ladakh is often called "Cold Desert". The study area occupies a part of the Indus river valley. The overall drainage system is controlled by the river and many canals which are filled with glacier melted water. In the summer season, irrigation is fully dependent on these canal systems (District Ground Water Information Brochure, 2011). In this region, the rocks are igneous, metamorphic and sedimentary in nature. The Moraine formations consist of boulders and clastics in a matrix of gravel, sand, silt and clay which form the aquifer. Minimum depth of tube well is very shallow as 25 mbgl and is related to river water level, which is often inadequate to provide water. There is rapid growth in human population, industrial formations, establishment of dwelling units, and tourism industry, which ultimately is pushing the demand for fresh water to its limits (Trabelsi et al., 2007; Dolma et al., 2015; Mohapatra et al., 2011).

Several studies indicate that groundwater chemistry is characterized by the complex correlation among a range of the water's physicochemical and biological variables. Therefore, to find the group of factors having the significant contribution to water quality is an important task to evaluate water quality. There is not much literature available on this area which can help in identification of impact of each factor or group of factors on the water quality. Application of multivariate statistical techniques which reveal the relationships using analytical techniques such as the principal component analysis (PCA), factor analysis (FA), and cluster analysis (CA). The execution of the multivariate statistical analysis to large amounts of data, provide a reliable alternative approach for understanding and interpreting the complex system of water quality. Hence, multivariate statistical analysis has been widely used all over the world to determine the groundwater quality at the low altitudinal places (Suk and Lee, 1999; Helena et al., 2000; Adams et al., 2001; Simeonov et al., 2003; Shrestha and Kazama, 2007; Zhang et al., 2009; Jalali, 2010; Hassen et al., 2016; Reghunath et al., 2002).

In different regions of India, numerous studies have been carried out to assess the geochemical characteristics of ground water based on water quality parameters using the multivariate statistical analysis (Sujatha and Reddy, 2003; Laluraj et al., 2005; Jeevanandam et al., 2007; Kumar and Riyazuddin, 2008; Kumar et al., 2009; Aghazadeh and Mogaddam, 2011; Ahmad and Qadi, 2011; Batabyal and Chakraborty, 2015; Choudhary et al., 2016; He et al., 2012). Since all the studies have also been done in arid or semi-arid areas (Wang et al., 2013; Singh et al., 2013). However, no such assessment on groundwater chemistry with the execution of multivariate statistical analysis has so far been made in the high altitude region. Therefore, the objectives of the present study are (1) to evaluate the suitability of ground water in parts of Leh District, Jammu & Kashmir, India; (2) to identify the natural associations among groundwater sampling sites and/or variables; (3) to identify the chances of river water interaction with the ground water, mixing or partial mixing and or non-mixing of different types of water, and (4) to explore and determine the usefulness of multivariate statistical techniques in improving our understanding of groundwater properties and their interactions with the nearby Indus river.

Materials and Methods

Materials

AR grade reagents, distilled water and Borosil glassware were used for the preparation of solutions and sample analysis. For minerals analysis, ICP multi element standard solution IV has been procured from Merck. MacConkey agar and Nutrient agar of Himedia was used for the microbiological study. All the glassware and plastic wares were procured from Borosil and Tarson Company, respectively.

Study Area

This study was conducted in high altitude region of

Leh-Ladakh, an upper Himalayan mountain region at an altitude ranging from 2300 m to 5000 m above mean sea level. The different sample collection sites of all the sampling stations in Leh district have been presented in Figure 1. Average minimum and maximum temperature and humidity data since the year of 2010 to 2015, is shown in the graphical representation (Figure 2). The Indus River in the study area flows throughout the year. Lithologically, the soils of the study area are mainly sandy type followed by silt and clay, respectively. Analysis of soil characteristics was carried out by soil hydrometer (Model No 2151H Soil Hydrometer) according to the method described by Singh et al. (2005). The analyzed data showed that sand is 80.73 %, silt 12.83%, and clay is 6.44%.

Experimental Design and Sampling

All the hand pumps used in the present study are located in the vicinity of the communities. The criterion of including a hand pump in this study mainly depended on the number of people in the community (population mentioned in the study area) that use the well water for their daily and domestic activities. An on-site personal interview in the study area confirmed this observation. All the water samples were collected in acid pre-cleaned polyethylene (Polylab) containers for analysis in the laboratory during the summer season. The quality control measures were applied using blank samples such as field/equipment blanks and method blanks. The quality of analytical methods and measured values were verified by analyzing a blank sample and standards in triplicate in each series of analysis. Total 70 groundwater samples (ten from each sampling stations) were collected in August 2015 from seven different sites around the Leh district, state of Jammu & Kashmir, India.

In the study, local populaces are very small and sparsely distributed. In every village, we counted the number of the hand pump and found average 12 hand pump per village. Statistically, it has been standardized that sampling should be ≥20% of the population (Singh et al., 2008). To absolutely rectify the Type-II error in our study, we have sampled 83% of the sample from the population. GPS readings were taken to identify the sampling locations with the help of Garmin GPS 72H. Location of sample collection

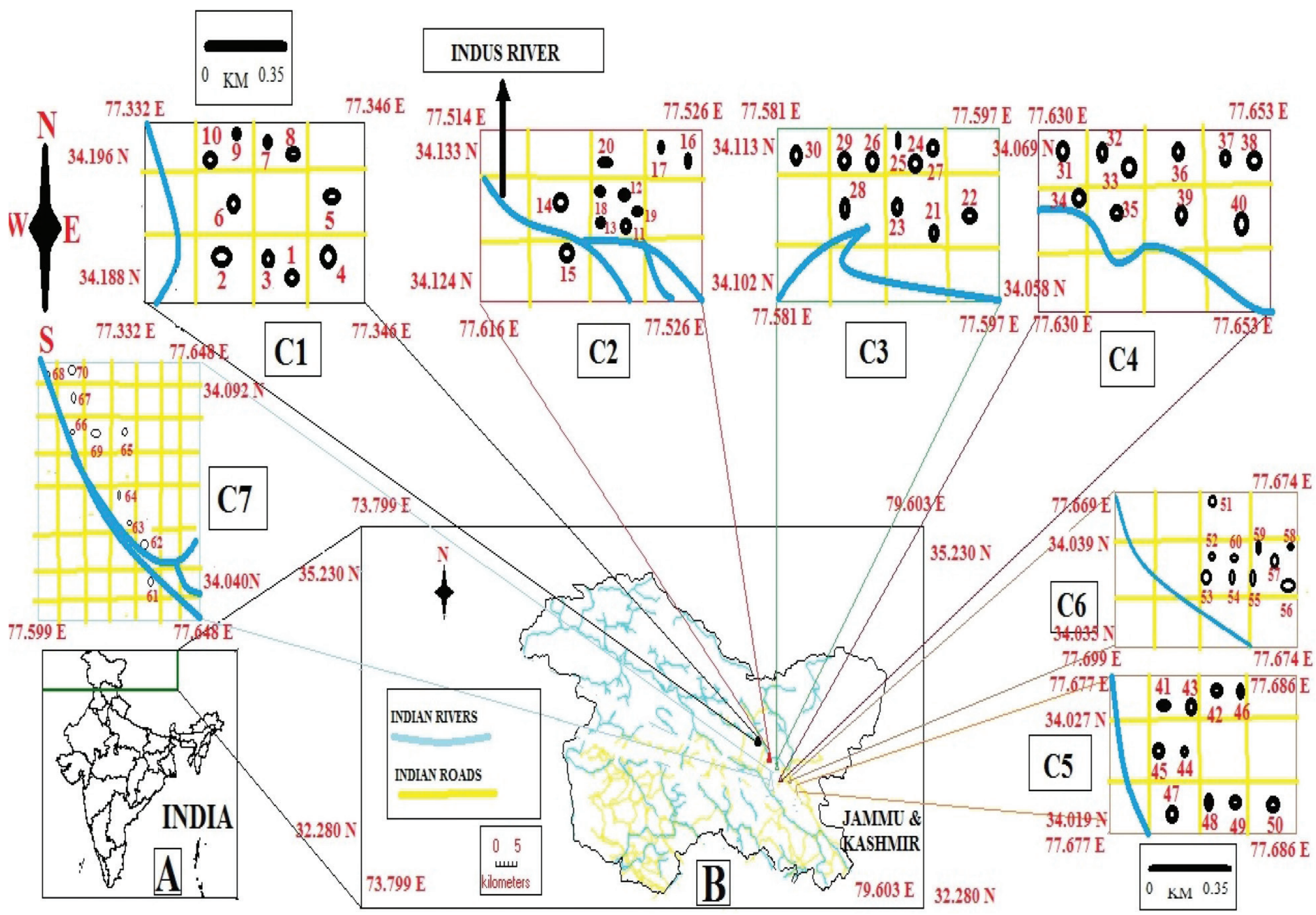

Figure 1: Location of groundwater sampling sites (seven sampling stations) in Leh district.

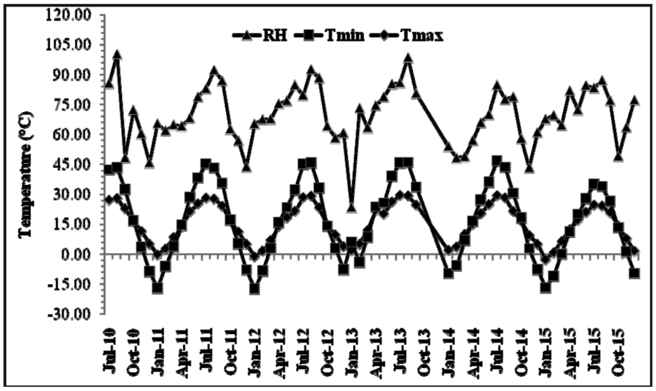

Figure 2: Variation of relative humidity (RH%), maximum temperature (Tmax), and minimum temperature (Tmin) of six consecutive years (2010 - 2015) at Leh-Ladakh, Kashmir (Giri et al., 2017).

was made by QGIS 2.12 software after the use of taken coordinates (Figure 1). Samples were collected from shallow hand-pumps (average depth 25 metres) after flushing water for 10–15 min to remove the stagnant water (Isa et al., 2012). The sampling was manually performed and the collection was made within 11 a.m. of the sampling period.

Sample Treatment and Sample Analysis

The sampling was done in two 500 mL polypropylene bottles. The sampling containers were washed, rinsed with distilled water and dried before use. One bottle containing water samples was preserved with toluene for the analysis of physicochemical parameters analysis. In another bottle, samples were filtered through a 0.45 µm pore size cellulose acetate membrane. After filtration, water samples for minerals analysis were acidified with 65% trace metal-grade nitric acid solution to a pH $\leq$ 2.0 (Singh et al., 2005). For bacteriological studies, water samples were collected under aseptic conditions into sterilized falcon tubes and analyzed for indicator and pathogenic micro organism within 24 h. The methods of sampling and collection were in accordance with Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1985). All samples were immediately transported to the laboratory under low-temperature conditions.

In situ parameters such as temperature (TEMP), pH, electrical conductivity (EC), salinity, total dissolved solid (TDS) and dissolved oxygen (DO) were analyzed by using HACH sensION156 (American Public Health Association, 1998). Turbidity (TUR) was measured by using HACH portable turbidity meter (2100Q01) (American Public Health Association, 1998). All these parameters were recorded in the field during sample collection. Major anions such as carbonate (CO_3), and bicarbonate (HCO_3^-) were immediately analyzed by titrimetric method (Singh et al., 2005). Hardness was measured by the titrimetric method (American Public Health Association, 2012). Level of chloride (Cl^-) was detected by Mohr's Method (American Public Health Association, 2012). Among other anions sulphate (SO_4^{2-}), nitrate (NO^{3-}) and orthophosphate (PO_4^{3-}) were analyzed through the protocol as described in American Public Health Association (2012). All the parameters, units, analytical method, instruments and references are mentioned in Table 1.

E. coli in water samples were identified by the pour plate method as described in the Medical Laboratory Manual for Tropical Countries (Cheesbrough, 1984). One mL of each of the water samples was aliquoted onto sterile MacConkey agar plates and uniformly spread over the entire surface of the agar and incubated at 44°C for 48 hrs. The total number of colonies for *E. coli* was counted and mean value of three replicates was calculated (MacConkey, 1905).

For minerals analysis, all the water samples were digested on mass to weight basis, using metal grade 69% nitric acid (HNO_3), 60% perchloric acid ($HClO_4$) and 35.40% hydrochloric acid (HCl). Samples were digested on 42 blocks Automated Hot Bock digestion system (Questron Technologies Inc, Canada). Thereafter, all the minerals were estimated in the digested water samples by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) (Perkin-Elmer Analyst, Optima 7000 DV) (Charan, 2013). Plasma conditions of ICP-OES method were standardised as follows: plasma flow 15 Lt/min, auxiliary gas flow 0.2 Lt/min, nebulizer gas flow 0.8 Lt/min, RF power 1300 wat, and pump flow rate 1.5 ml/min.

Data Treatment and Statistical Analysis

All the mathematical and statistical computations were made using Microsoft Office Excel 2007, Statistical Package for Social Sciences (SPSS) version 22, and Minitab 17 statistical packages. All the data have been standardized by using standard statistical procedures. Principal Component Analysis (PCA) is used to explain the variance-covariance structure of a set of variables. Hence, all the data were subjected to principal component analysis (PCA) to reduce the dimensionality of the data by explaining the correlations among a large number of variables in terms of a smaller number of underlying factors (principal components

Table 1: Physico-chemical parameters determined and analytical techniques used

Sl. No.	*Parameter*	*Abbreviation*	*Unit*	*Method/Equipment used*	*Reference*
01	Temperature	TEMP	°C	HACH Instrumental method	APHA, 1998
02	pH	pH	--------	HACH Ion selective instrumental method	APHA, 1998
03	Electrical conductivity	EC	µS/cm	HACH Ion selective instrumental method	APHA, 1998
04	Total dissolved solids	TDS	mg/L	HACH Ion selective instrumental method	APHA, 1998
05	Salinity	SAL	ppt	HACH Ion selective instrumental method	APHA, 1998
06	Turbidity	TUR	NTU	Nephlometric method by Turbidity meter	APHA, 1998
07	Total hardness	TH	mg/L	EDTA Titrimetric Method	APHA, 2012
08	Chloride	Cl	mg/L	Mohr's Method	APHA, 2012
09	Dissolved oxygen	DO	mg/L	HACH Ion selective instrumental method	Manivasakam, 1997
10	Carbonate & bicarbonate	CO_3, HCO_3	mg/L	Titrimetric method	Singh et al., 2005
11	Alkalinity	ALK	mg/L	Titrimetric method	APHA, 2012
12	Sulphates	SO_4	mg/L	U.V. visible spectro-photometric method	APHA, 2012
13	Nitrate	NO_3	mg/L	U.V. visible spectro-photometric method	APHA, 2012
14	Phosphate	PO_4	mg/L	U.V. visible spectro-photometric method	APHA, 2012
15	Minerals (sodium, potassium, calcium, magnesium, manganese, phosphorus, iron, zinc, copper, silica)	Na, K, Ca, Mg, Mn, P, Fe, Zn, Cu, Si	mg/L	ICP-OES Instrumental method	Charan, 2014
16	E. coli	*E. coli*	CFU/mL	Plate Count method	Cheesbrough, 1984

or PCs). Thereafter, R & Q mode varimax rotation was analyzed for finding more clearly defined factors called varifactors (VFs) after running the Factor analysis (FA) that facilitate interpretation of the data (Helena, 2000; Reghunath, 2002). At last, Q-mode cluster analysis (CA) has been done to identify the similarity among all the samples (Reghunath, 2002). Cluster analysis is used to construct smaller groups with similar properties from a large set of heterogeneous data.

Results and Discussion

Identify the Exchange between River and Ground Water Using Q-mode FA and Q-mode CA

To identify the exchange between the river water with adjacent ground water, the entire seventy water samples were subjected to the Q-mode FA and Q-mode CA. Meanwhile, the general descriptive statistics have been tabulated in Table 2. The analysis of Q-mode FA has generated two factors which together account for 95.93% of the variance. The first factors (which constitute for 49.40% of the variance) are considered as representative of the factor model and have been taken for interpretation as the first factor taken into account to interpret the data (Wang et al., 2013). The rotated loadings, eigenvalues, the percentage of variance and cumulative percentage of variance of the two factors are given in Table 3.

The first factor which accounted for 49.4% of the variance consists of high loadings of samples 2, 6, 10, 11, 13-15, 21, 23-25, 29, 30, 31, 33, 34, 39-41, 43-45, 47, 48, 51-55, 60 and 63-70. The second factor which accounted for 46.53% of the variance consists of high loadings of rest of the samples. A higher number of samples within factor 1 fall on the nearby side of the Indus River but the variance percentage is only 49.4%

Table 2: Descriptive statistics of the physico-chemical parameters

Parameters	*Mean ± SE*	*Median*	*Minimum*	*Maximum*	*Skewness*	*Kurtosis*
TEMP	17.24 ± 0.14	17.20	14.90	19.60	0.49	0.05
pH	7.70 ± 0.04	7.61	7.13	8.58	0.70	-0.30
COND	488.74 ± 19.77	494.00	139.00	1143.00	0.88	3.57
TDS	238.50 ± 9.87	238.50	66.40	563.00	0.87	3.36
SAL	0.21 ± 0.01	0.20	0.00	0.60	1.34	5.12
TUR	24.74 ± 7.88	8.05	0.35	524.00	6.65	49.27
DO	10.03 ± 0.04	10.00	9.27	10.65	-0.21	-0.46
Cl	22.74 ± 0.86	24.13	10.81	39.24	-0.06	-0.89
ALK	494.49 ± 13.85	496.00	202.00	696.00	-0.29	-0.21
HARD	235.99 ± 13.87	211.89	81.25	837.11	2.26	9.20
CO_3	0.93 ± 0.05	0.90	0.00	1.94	0.13	-0.11
HCO_3	28.23 ± 0.91	27.60	9.48	54.50	0.68	1.92
SO_4	0.46 ± 0.01	0.44	0.21	0.71	0.09	0.05
PO_4	0.04 ± 0.00	0.03	0.01	0.17	1.71	3.35
Na	234.49 ± 6.92	233.28	100.00	420.00	1.23	3.83
K	24.76 ± 0.77	27.19	10.05	36.88	-1.01	0.05
Ca	60.92 ± 2.59	60.59	25.00	123.80	0.51	0.25
Mg	40.75 ± 1.58	42.61	14.26	68.43	-0.18	-0.52
Mn	0.61 ± 0.04	0.80	0.01	0.99	-0.83	-1.21
P	0.46 ± 0.04	0.35	0.02	2.02	1.70	3.91
Fe	1.95 ± 0.08	2.09	1.01	5.01	1.21	4.15
Zn	0.89 ± 0.10	0.60	0.07	3.67	1.41	1.62
Cu	0.01 ± 0.00	0.01	0.00	0.06	2.90	11.58
Si	5.95 ±	5.96	2.98	10.44	0.52	1.27
E. coli	1.47 ±	0.00	0.00	17.00	3.02	9.98

out of 95.93% where the second factor stands for 46.53%. From this result, it indicates that there is the interaction between adjacent Indus River water and ground water. In the second factor, all the sites are moreover located at not a great far distance from the river. This might be the reason for showing 46.53% of variance percentage (Reghunath et al., 2002). This finding was related with the findings of Reghunath et al. (2002). In that study, it has been found that the majority of the samples within factor 1 fall on either side of the main course of the river system. This strongly suggests that there is an exchange between the river water and adjacent groundwater. The high variance of this factor (89.9% out of 99.1%) suggests that this exchange between river water and groundwater plays a dominant role in the hydrochemical evolution of groundwater in that study area. Therefore, in our study, it has been found that the moderate variance existed between the two factors. Hence, it may be concluded that moderate type of exchange between Indus River water and ground water was present or may be a lateral flow of Indus River with the study area plays a role in the hydrochemical evolution of ground water in the Leh district (Reghunath et al., 2002; Huang et al., 2013).

The output of the Q-mode cluster analysis is given as a dendrogram (Figure 3). The dendrogram contains two major clusters as shown in Figure 3. Clusters 1 and 2 correspond to the factors 1 and 2, respectively, of the Q-mode factor analysis for seventy water samples. The similarity of the Q-mode cluster analysis to the Q-mode factor analysis confirms the interpretation made using the Q-mode factor analysis (Reghunath et al., 2002).

Determination of Water Pollution Source and Presence of Non-mixing/Partial Mixing of Different Types of Water Using R-mode FA and R-mode CA after PCA Analysis

All the 25 variables were run through the PCA analysis which extracted 10 variables based on the eigenvalues (>1). Extracted variables and non-extracted variables

Table 3: Varimax rotated Q-mode factor loading matrix

Sample No.	*Fator 1*	*Factor 2*	*Sample No.*	*Factor 1*	*Factor 2*
30	.846	.510	2	.691	.670
67	.843	.521	12	.517	.840
68	.842	.527	1	.488	.834
69	.842	.501	3	.521	.832
31	.839	.527	18	.501	.828
45	.838	.525	50	.550	.826
40	.833	.532	16	.499	.825
39	.829	.553	5	.511	.823
65	.828	.545	19	.478	.820
24	.826	.549	7	.546	.810
60	.824	.548	17	.524	.810
66	.822	.561	20	.529	.804
53	.821	.561	46	.551	.804
55	.818	.561	35	.572	.799
6	.818	.557	36	.572	.797
47	.817	.558	9	.564	.795
54	.812	.566	59	.591	.793
23	.812	.571	26	.577	.790
51	.811	.568	4	.507	.789
43	.810	.554	38	.599	.785
41	.804	.564	37	.589	.785
29	.803	.571	8	.591	.781
52	.799	.562	22	.580	.779
63	.797	.570	42	.594	.776
10	.797	.586	28	.589	.770
44	.795	.594	57	.609	.768
70	.795	.587	27	.588	.763
21	.795	.585	61	.599	.761
64	.794	.582	56	.612	.760
25	.781	.590	58	.629	.760
48	.773	.586	62	.621	.759
34	.765	.602	49	.603	.737
15	.761	.600	32	.631	.726
33	.747	.633	Eigenvalues	34.58	32.57
11	.730	.650	Total % of variance	49.4	46.5
13	.727	.654	Cumulative %	49.4	95.9
14	.705	.661			

are presented in Table 4 and scree plot presented in Figure 4.

R-mode factor analysis of all the parameters/variables of water samples has been carried out. The analysis generated 10 factors which together account for 76.66% of the variance. The rotated loadings, eigenvalues, the percentage of variance and cumulative percentage of variance of all the 10 factors are given in Table 5.

The first eigenvalue is 4.12 which accounts for 16.48% of the total variance and these constitute the

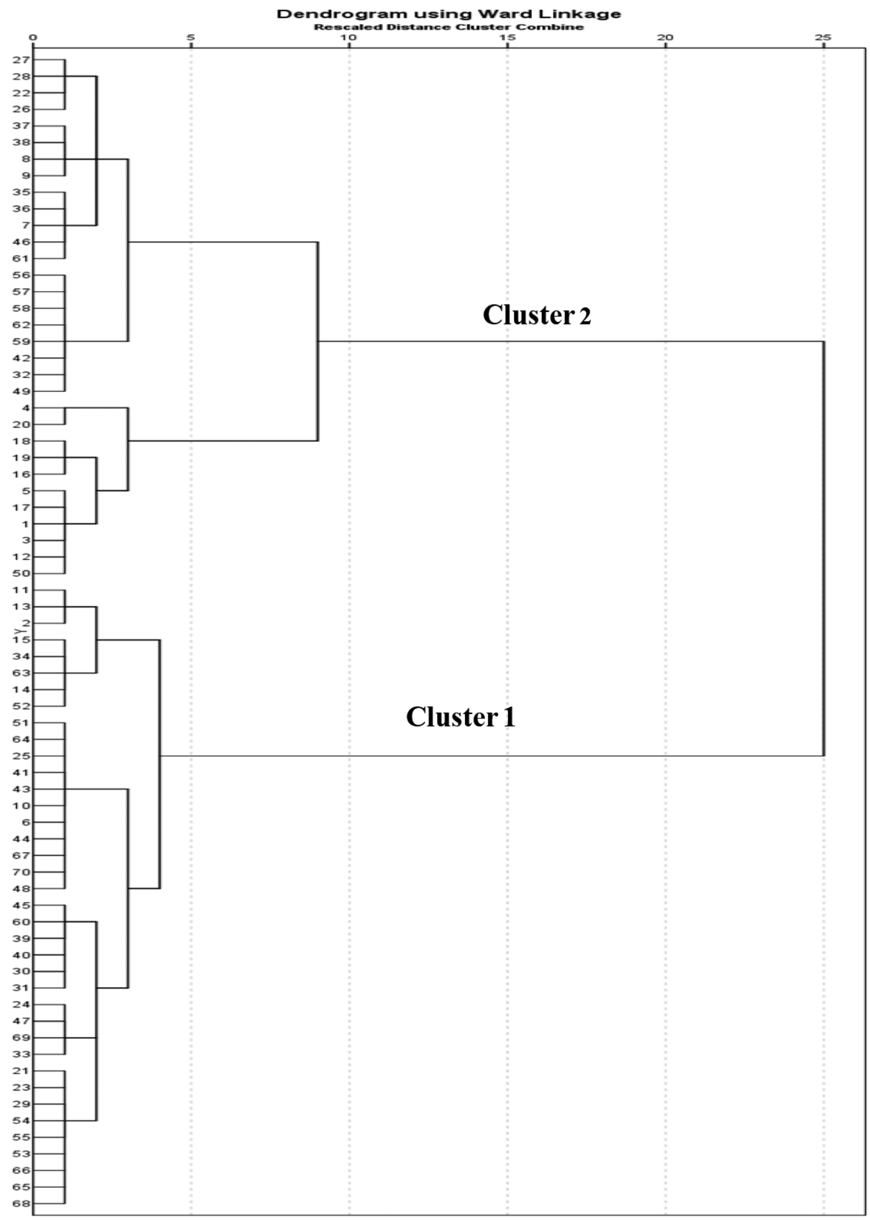

Figure 3: Dendrogram of the Q-mode cluster analysis (The axis shown at the below indicates the relative similarity of different cluster groups. Lesser the distance, greater the similarity between objects).

first and main factor. The rest of the eigenvalues each constitute less than 10% of the total variance.

The first factor (which accounts for 16.48% of the total variance) is characterized by very high loadings of TDS, COND and SAL with negative moderate loadings of pH followed by moderate loadings of ALK. A high loading of TDS, COND and SAL are revealed with the physicochemical sources of variability (Varrol and Sen, 2009). Higher loading of salinity might be due to the dissolution of salts from the underlying rocks, evaporate dissolution, and return flow from irrigation water and also depth of the well (Bennetts et al., 2006; Ghabayen et al., 2006). Negative moderate loading of pH might indicate the increase in dissolved organic carbon (DOC) from the runoff and leached from soil (Dinka, 2010). One of the previous studies at this study area on the soil had estimated that the soil alkalinity level is high (Charan et al., 2013). The present study has shown moderate loading of alkalinity in the ground water (Bharti et al., 2017). This property of the ground water only comes from the leaching process in the soil. These loading factors are definitely indicators of the leaching process going on in the study area.

Table 4: Extracted components based on eigenvalue after PCA analysis

	Initial Eigenvalues			*Extraction sums of squared loadings*		
Component	*Total*	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*
1	4.889	19.556	19.556	4.889	19.556	19.556
2	2.949	11.795	31.351	2.949	11.795	31.351
3	2.002	8.009	39.360	2.002	8.009	39.360
4	1.783	7.133	46.494	1.783	7.133	46.494
5	1.605	6.421	52.915	1.605	6.421	52.915
6	1.424	5.698	58.612	1.424	5.698	58.612
7	1.282	5.128	63.741	1.282	5.128	63.741
8	1.160	4.639	68.380	1.160	4.639	68.380
9	1.068	4.273	72.652	1.068	4.273	72.652
10	1.001	4.005	76.657	1.001	4.005	76.657
11	.879	3.515	80.172			
12	.746	2.984	83.156			
13	.708	2.833	85.989			
14	.664	2.657	88.645			
15	.541	2.163	90.808			
16	.516	2.063	92.871			
17	.394	1.578	94.449			
18	.338	1.352	95.801			
19	.287	1.149	96.951			
20	.242	.967	97.917			
21	.180	.719	98.637			
22	.169	.678	99.314			
23	.094	.376	99.691			
24	.061	.245	99.936			
25	.016	.064	100.000			

The second factor (which accounts for the 8.62% of the total variance) is characterized by very high loadings of chloride with moderate negative loadings of P and TEMP. High loadings of chloride might be due to the dissolution of salts and leaching process of soil (Sarin et al., 1989; Datta and Tyagi, 1996; Liang et al., 2016). The factor also authenticates the leaching process made after the factor 1 data interpretation. However, moderate negative loadings of P and TEMP may be due to the existence of agricultural runoff and natural or weather factor, respectively (Varrol and Sen, 2009; Nelson, 2002; Grift et al., 2016).

In the present result, the third factor (which accounts for the 8.43% of the total variance) is characterized by high loadings of Fe and Mn followed by moderate loading of Mg. This may be due to influence from non-point sources such as agricultural runoff or atmospheric deposition (Huang et al., 2013; Boutron

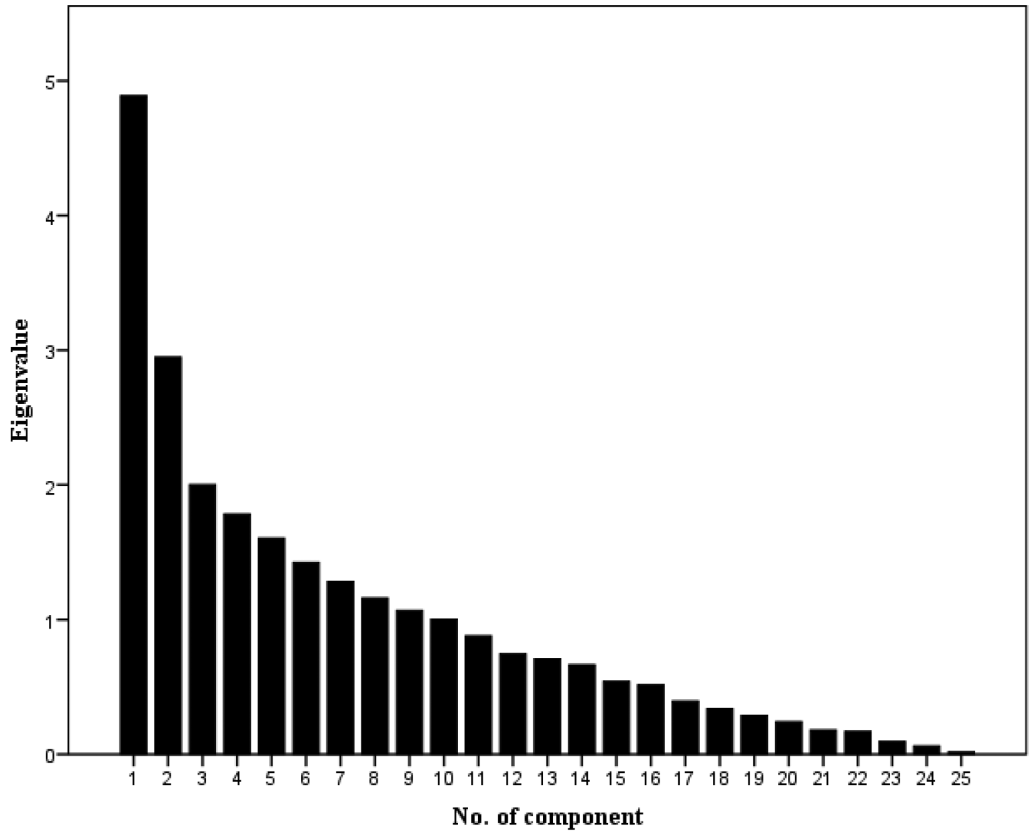

Figure 4: Scree plot of eigenvalues of physico-chemical variables of groundwater in Leh, Jammu & Kashmir, India.

et al., 1991; Bohlke et al., 2007). In the study area, chemical fertilizers were used by the farmers (Mann, 2002; Acharya et al., 2012). The agricultural runoff or atmospheric deposition may initiate or enhance the ground water pH; ion exchange and oxidation-reduction (redox) conditions all affect the mobility of trace elements (Bohlke et al., 2007; Seiler, 2003). In this way, our finding of nutrient loading in the study area through agricultural runoff or atmospheric deposition may be possible (Huang et al., 2013).

Factors 4-9 are characterized by the dominance of only one variable each, such as Si (factor-4), carbonate (factor 5), hardness (factor 6), dissolved oxygen (factor 7), zinc (factor 8) and potassium (factor 9). All these factors account for 37.77% of the total variance. The single dominance of variables in each factor indicates non-mixing or partial mixing of different types of water. The present results were in accordance with the study of Reghunath et al. (2002). In their study, it has been found that Factors 3–8 are characterized by the dominance of only one variable each, such as Mg in factor 3, K in factor 4, NO_3^- in factor 5, CO_3 in factor 6, pH in factor 7, and SO_4^- in factor 8 and together these six factors account for 34.7% of the total variance. The results of this study strongly accorded with our study. Therefore, it might be strongly indicated that non-mixing/partial mixing of different types of water has been present in the study area.

Factor 10 is characterized by moderate loading of *E. coli* and sodium. This might be due to the moderate effects of anthropogenic activity in which *E. coli* has moderate effects (Affum et al., 2015). In this area, sanitation septic wastage is loaded in open land. This has the causal effect to increase in soil salinity (high level of Na) and bacterial presence (Anonymous, 2009). Water stewardship information series (2007) has been documented that infiltration of domestic or wild animal fecal matter may act as a source of *E. coli* in groundwater resources. River sites are highly affected by the presence of wild and domestic animals in this area. As earlier, it was stated that if there was an exchange between river water and ground water, it has great chances for the presence of *E. coli* in the ground water.

The output of the R-mode cluster analysis is given as a dendrogram (Figure 5). The dendrogram contains three major clusters as shown in Figure 3. Clusters 1, 2 and 3 have been showing the interrelationship among

Table 5: Varimax rotated R-mode factor loading matrix

	Rotated component matrix									
	VF 1	*VF 2*	*VF 3*	*VF 4*	*VF 5*	*VF 6*	*VF 7*	*VF 8*	*VF 9*	*VF 10*
TDS	**.950**	.117	.040	.027	-.066	-.039	-.082	.046	.048	-.014
COND	**.948**	.120	.044	.042	-.063	-.031	-.085	.001	.082	-.004
SAL	**.919**	.152	.046	-.026	-.027	.046	-.202	.003	.040	-.025
pH	-.699	-.139	.178	-.293	.021	.021	.113	-.052	.294	-.320
ALK	**.632**	.359	.111	.187	.287	.050	.235	.018	.097	-.058
Cl	.233	**.841**	.061	-.079	-.079	.056	.165	.052	-.017	.064
TEMP	-.318	**-.717**	.012	-.008	.160	-.057	.133	.099	.039	-.019
P	-.071	**-.527**	-.240	-.190	-.133	.074	.004	.267	-.331	.222
Fe	.086	.100	**.795**	.086	-.072	-.029	.025	.193	-.059	.083
Mn	.007	.074	**.764**	.235	.134	.128	-.005	-.140	.177	-.139
Mg	-.095	-.183	**.551**	.246	.325	.064	.458	.126	-.073	.042
Si	.051	.019	.130	**.797**	.015	-.042	-.101	.225	-.063	-.044
PO_4	.396	.042	.279	**.700**	-.039	.056	.070	-.124	.189	-.017
SO_4	.054	.475	-.126	**-.544**	.092	-.167	-.373	.183	-.182	.091
CO_3	-.057	-.008	-.005	.074	**.805**	.103	.083	.022	-.282	.256
HCO_3	.016	-.152	.115	-.158	**.745**	-.036	-.136	-.171	.141	-.327
HARD	.041	-.056	-.018	.037	.074	**.830**	-.228	-.211	.071	-.065
TUR	.059	-.102	-.135	.017	.021	**-.675**	-.297	-.111	.170	.045
DO	-.217	.045	.032	-.047	-.030	-.031	**.823**	.061	-.025	-.009
Zn	-.012	-.089	-.023	.130	.027	-.198	.141	**.799**	.130	.021
Cu	-.167	-.028	-.356	.047	.323	-.293	.116	-.627	-.033	.035
K	-.087	.029	-.058	-.027	.160	.085	.023	-.130	**-.774**	-.258
Ca	-.021	.359	-.413	.222	.130	.405	-.087	.242	.484	-.141
E coli	.268	-.030	-.100	-.281	-.003	-.058	.136	-.086	.087	**.699**
Na	-.288	.036	.153	.167	.030	-.118	-.225	.099	.237	**.619**
Eigenvalues	4.12	2.16	2.11	1.92	1.64	1.55	1.49	1.48	1.38	1.34
Total % of variance	16.5	8.6	8.4	7.7	6.5	6.2	5.9	5.9	5.5	5.4
Cumulative %	16.5	25.1	33.5	41.2	47.8	53.9	59.9	65.8	71.3	76.7

the variables. Cluster 2 shows the compact relationship among the salinity, TDS and EC which is found in Factor 1 of the R-mode factor analysis. This dendrogram is giving the confirmation about the interpretation made in the R-mode factor analysis (Reghunath et al., 2002).

Conclusions

Water-quality monitoring programmes generate complex multidimensional data that need appropriate analysis and data mining to identify useful variables and factors influencing water quality. This study elucidated usefulness of multivariate statistical treatment for their analysis and interpretation of the underlying information to identify factors contributing groundwater quality in high altitude region of Leh-Ladakh. Further, this study revealed that hierarchical cluster analysis grouped the sampling sites into three clusters of similar characteristics reflecting the water quality characteristics. The extracted grouping information can be used in reducing the number of sampling sites without missing much information of factors and variables. Interestingly, ten varifactors obtained from factor analysis indicate that the parameters responsible for water-quality variations are mainly related to leaching from soil, soluble salts (natural), the presence of respiration of organic matter and nutrients loadings (anthropogenic). Among rest of the factors, 'single dominance' nature of one variable were found which may be due to the non-mixing/partial mixing of different types of ground water. Q mode factor and Q-mode cluster analysis altogether determine that there is the existence of an interaction between the river water and the nearest ground water. Thus, this study presents usefulness of multivariate statistical techniques in water quality assessment, reducing the sampling sites, and identification of pollution sources/factors with a view to obtaining better information about the water quality

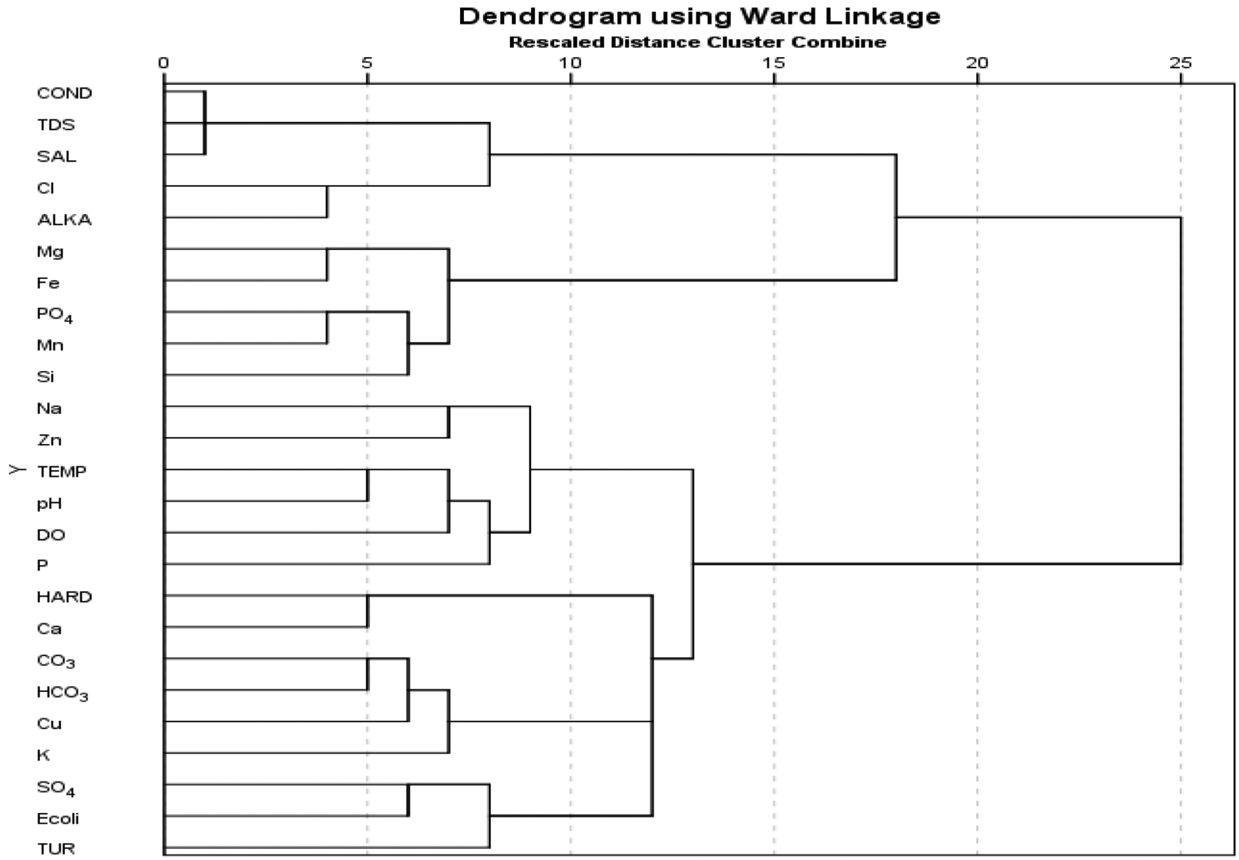

Figure 5: Dendrogram of the R-mode cluster analysis (The axis shown at the below indicates the relative similarity of different cluster groups. Lesser the distance, greater the similarity between objects).

and design of monitoring network/strategy for effective management of water resources.

Declaration of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Acknowledgements

The Authors are thankful to Defence Research and Developmental Organization (DRDO), New Delhi, India, for financial support and Director, DIHAR for providing research facility and guidance. We are also thankful to technical staffs and Mr. Sahil Kapoor, SRF and Mr. Avilekh, SRF for their technical assistance.

References

Acharya, S., Singh, N., Katiyar, A.K., Maurya, S.B. and R.B. Srivastava (2012). Improving soil health status of cold desert Ladakh region. Defence Institute of High Altitude Research (DIHAR), Defence Research & Development Organisation (DRDO), Extension Bulletin No. 24.

Adams, S., Titus, R., Pietesen, K., Tredoux, G. and C. Harris (2001). Hydrochemical characteristic of aquifers near Sutherland in the Western Karoo, South Africa. *Journal of Hydrology*, **241:** 91-103.

Affum, A.O., Osae, S.D., Nyarko, B.J.B., Afful, S., Fianko, J.R., Akiti, T.T., Adomako, D., Acquaah, S.O., Dorleku, M., Antoh, E., Barnes, F. and E.A. Affum (2015). Total coliforms, arsenic and cadmium exposure through drinking water in the Western Region of Ghana: Application of multivariate statistical technique to groundwater quality. *Environmental Monitoring Assessment*, **187:** 1-23.

Aghazadeh, N. and A. Mogaddam (2011). Investigation of hydrochemical characteristics of groundwater in the Harzandat aquifer, northwest of Iran. *Environmental Monitoring and Assessment*, **176:** 183-195.

Ahmad, Z. and A. Qadi (2011). Source evaluation of physicochemically contaminated groundwater of Dera Ismail Khan area, Pakistan. *Environmental Monitoring and Assessment*, **175:** 9-21.

American Public Health Association (APHA) (1985). American Water Works Association (AWWA) and Water

Environment Federation (WEF). Standard methods for the examination of water and waste water. American Public Health Association, USA, 10th ed., Washington DC. Link: https://goo.gl/Q9YZb5

American Public Health Association (APHA) (1998). American Water Works Association (AWWA) and Water Environment Federation (WEF). Standard methods for the examination of water and waste water. American Public Health Association, USA, 20th ed., Washington DC.

American Public Health Association (APHA) (2012). American Water Works Association (AWWA) and Water Environment Federation (WEF). Standard methods for the examination of water and waste water. American Public Health Association, USA, 20th ed., Washington DC.

Anonymous (2009). Ground Water Information Booklet of Leh District, Jammu and Kashmir State. North Western Himalayan Region, Central Ground Water Board Jammu, Unpub. Report, 16.

Aris, A.Z., Abdullah, M.H., Woong, K.K. and S.M. Praveena (2009). Hydrochemical changes in small tropical island's aquifer: Manukan Island, Sabah, Malaysia. *Environmental Geology*, **56:** 1721-1732.

Basavarajappa, H.T. and M.C. Manjunatha (2015). Groundwater Quality Analysis in Precambrian Rocks of Chitradurga District, Karnataka, India using Geo-informatics. *Technique Aquatic Procedia*, **4:** 1354-1365.

Batabyal, A.K. and S. Chakraborty (2015). Hydrogeochemistry and Water Quality Index in the Assessment of Groundwater Quality for Drinking Uses. *Water Environment Research*, 8**7:** 607-617.

Bennetts, D.A., Webb, J.A., Stone, D.J.M. and D.M. Hill (2006). Understanding the salinisation processes for groundwater in an area of southeastern Australia, using hydrochemical and isotopic evidence. *Journal of Hydrology*, **323:** 178-192.

Bharti, V.K., Giri, A. and K. Kumar (2017). Evaluation of Physico-Chemical Parameters and Minerals Status of Different Water Sources at High Altitude. *Peertechz Journal of Environmental Science and Toxicology*, **2:** 10-18.

Bohlke, J.K., Verstraeten, I.M. and T.F. Kraemer (2007). Effects of surface-water irrigation on sources, fluxes, and residence times of water, nitrate, and uranium in an alluvial aquifer. *Applied Geochemistry*, **22:** 152-174.

Boutron, C.F., Gorlach, U., Candelone, J.P., Bolshov, M.A. and R.J. Delmas (1991). Decrease in anthropogenic lead, cadmium and zinc in Greenland snows since the late 1960s. *Nature*, **353:** 153-156.

Charan, G. (2013). Studies on certain essential minerals status and heavy metals presents in soil, plant, water and animal at high altitude cold arid environment. Ph.D. Thesis, JAYPEE University of Information Technology, Waknaghat, Solan, India. Link: https://goo.gl/v7xkQ5

Charan, G., Bharti, V.K., Jadhav, S.E., Kumar, S., Acharya, S., Kumar, P., Gogoi, D. and R.B. Srivastava (2013). Altitudinal variations in soil physico-chemical properties at cold desert high altitude. *Journal of Soil Science and Plant Nutrition*, **13:** 267-277.

Cheesbrough, M. (1984). Medical laboratory manual for tropical countries, Fakenham. *Tropical Health Technology*, **II:** 206-222.

Choudhary, S., Ramteke, S., Rajhans, P.K., Sahu, K.P., Chakradhari, S., Patel, S.K. and L. Matin (2016). Assessment of Groundwater Quality in Central India. *Journal of Water Resource and Protection*, **8:** 12-19.

Dasgupta, A. and K.M. Purohit (2001). Status of the surface water quality of Mandiakudal. *Pollutant Research*, **20:** 103-110.

Datta, P.S. and S.K. Tyagi (1996). Major ion chemistry of groundwater in Delhi area: Chemical weathering processes and groundwater flow regime. *Journal of Geological Society of India*, **47:** 179-188.

Dinka, M.O. (2010). Analyzing the Extents of Basaka Lake Expansion and Soil and Water Quality Status of Matahara Irrigation Scheme, Awash Basin (Ethiopia), Vienna, Austria. Ph.D. dissertation, University of Natural Resources and Applied Life Sciences.

District Ground Water Information Brochure, Leh district (2011). Ground water information brochure of Leh district Jammu and Kashmir State. Link: https://goo.gl/qeuAj0

Dolma, K., Rishi, S.M. and R. Lata (2015). An Appraisal of Centralized Waste Water Treatment Plant with Respect to Leh Town. *International Journal of Science and Research*, **4:** 754-759.

Ghabayen, S.M.S., McKee, M. and M. Kemblowski (2006). Ionic and isotopic ratios for identification of salinity sources and missing data in the Gaza aquifer. *Journal of Hydrology*, **318:** 360-373.

Giri, A., Bharti, V.K., Sahil, K., Vineeth, R., Puneet, R., Tilak, R. and K. Bhuvnesh (2017). Seasonal changes in hematological and biochemical profile of dairy cows at high altitude cold desert. *Indian Journal of Animal Sciences*, **87:** 723-727.

Grift, V.D.B., Broers, P.H., Berendrecht, W., Rozemeijer, J., Osté, L. and J. Griffioen (2016). High-frequency monitoring reveals nutrient sources and transport processes in an agriculture-dominated lowland water system. *Hydrology and Earth System Sciences*, **20:** 1851-1868.

Hassen, I., Hamzaoui-Azaza, F. and R. Bouhlila (2016). Application of multivariate statistical analysis and hydrochemical and isotopic investigations for evaluation of groundwater quality and its suitability for drinking and agriculture purposes: Case of Oum Ali-Thelepte aquifer, central Tunisia. *Environmental Monitoring Assessment*, **188:** 135.

He, J.H., Ma, J.Z., Zhang, P., Tian, L.M., Zhu, G.F. and W.M. Edmunds (2012). Groundwaters recharge environments and hydrogeochemical evolution in the Jiuquan Basin, Northwest China. *Applied Geochemistry*, **27:** 866-878.

Helena, B., Pardo, R., Vega, M., Barrado, E., Fernandez, J.M. and I. Fernandez (2000). Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga river, Spain) by principal component analysis. *Water Research*, **34:** 807-816.

Huang, G., Sun, J., Zhang, Y., Chen, Z. and F. Liu (2013). Impact of anthropogenic and natural processes on the evolution of groundwater chemistry in a rapidly urbanized coastal area, South China. *Science of the Total Environment*, 463-464. http://dx.doi.org/10.1016/j.scitotenv.2013.05.078

Isa, N.M., Aris, A.Z. and W.N.A. Sulaiman (2012). Extent and severity of groundwater contamination based on hydrochemistry mechanism of sandy tropical coastal aquifer. *Science of the Total Environment*, **438:** 414-425.

Jalali, M. (2010). Application of Multivariate analysis to study water chemistry of groundwater in a semi-arid aquifer, Malayer, Western Iran. *Desalination Water Treatment*, **19:** 307-317.

Jeevanandam, M., Kannan, R., Srinivasalu, S. and V. Rammohan (2007). Hydrogeochemistry and groundwater quality assessment of lower part of the Ponnaiyar river basin, Cuddalore district, South India. *Environmental Monitoring and Assessment*, **132:** 263-274.

Kumar, A.R. and P. Riyazuddin (2008). Application of chemometric techniques in the assessment of groundwater pollution in a suburban area of Chennai city, India. *Current Science,* **94:** 1012-1022.

Kumar, M., Ramanathan, AL. and A.K. Keshari (2009). Understanding the extent of interactions between groundwater and surface water through major ion chemistry and multivariate statistical techniques. *Hydrology Process*, **23:** 297-310.

Laluraj, C.M., Gopinath, G. and P.K. Dineshkumar (2005). Groundwater chemistry of shallow aquifers in the coastal zones of Cochin, India. *Applied Ecology and Environmental Research*, **3:** 133-139.

Liang, J., Fang, H. and G. Hao (2016). Effect of Plant Roots on Soil Nutrient Distributions in Shanghai Urban Landscapes. *American Journal of Plant Science*, **7:** 296-305.

MacConkey, A.T. (1905). Lactose-fermenting bacteria in faeces. *Journal of Hygiene (London)*, **5:** 333.

Mann, S.R. (2002). Ladakh, Then and Now: Cultural, Ecological and Political. 1st ed., Mittal Publications.

Mark, W.R., Ximing, C. and A.C. Sarah (2002). World Water and Food to 2025: Dealing with security. International Food Policy Research Institute, NY. Washington DC, USA.

Mohapatra, P., Vijay, R., Pujari, P., Sundaray, S. and B. Mohanty (2011). Determination of processes affecting groundwater quality in the coastal aquifer beneath Puri city, India: A multivariate statistical approach. *Water Science and Technology*, 6**4:** 809-817.

Moharir, A., Ramteke, D.S., Moghe, C.A., Wate, S.R. and R. Sarin (2002). Surface and ground water quality assessment in Bina region. *Indian Journal of Environmental Protection*, **22:** 961-969.

Nelson, D. (2002). Natural varieties in the composition of groundwater, drinking water programme, Oregon Department of Human Services. Springfield, USA.

Reghunath, R., T.R.S. Murthy and B.R. Raghavan (2002). The utility of multivariate statistical techniques in hydrogeochemical studies: An example from Karnataka, India. *Water Research*, **36:** 2437-2442.

Sarin, M.M., Krishnaswami, S., Dill, K., Somayajulu, B.L.K. and W.S. Moore (1989). Major ion chemistry of the Ganga-Brahmaputra river system: Weathering processes and fluxes to the Bay of Bengal. *Geochimica Et Cosmochimica Acta*, **53:** 997-1009.

Seiler, R.L., Skorupa, J.P., Naftz, D.L. and B.T. Nolan (2003). Irrigation-Induced Contamination of Water, Sediment, and Biota in the Western United States—Synthesis of Data from the National Irrigation Water Quality Program.

Shrestha, S. and F. Kazama (2007). Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. *Environmental Modelling and Software*, **22:** 464-475.

Simeonov, V., Stratis, J.A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., Sofoniou, M. and T. Kouimtzis (2003). Assessment of the surface water quality in northern Greece. *Water Research*, **37:** 4119-4124.

Singh, D., Chhonkar, P.K. and B.S. Dwivedi (2005). Manual on Soil, Plant and Water Analysis. Westville Publishing House, New Delhi.

Singh, E.J.K., Gupta, A. and N.R. Singh (2013). Groundwater quality in Imphal West district, Manipur, India, with multivariate statistical analysis of data. *Environmental Science and Pollution Research*, **20:** 2421-2434.

Singh, S., Bansal, M.L., Singh, T.P. and R. Kumar (2008). Statistical Methods for Research Workers. Kalyani Publishers, Kolkata.

Subba, R.C. and N.V.S. Rao (1995). Ground water quality in residential colony. *Indian Journal of Environmental Health*, **37:** 295-300.

Sujatha, D. and B.R. Reddy (2003). Quality Characterization of groundwater in the south-eastern part of the Ranga Reddy District, Andhra Pradesh, India. *Environmental Geology*, **44:** 579-586.

Suk, H. and K.K. Lee (1999). Characterization of a ground water hydrochemical system through multivariate analysis: Clustering into ground water zones. *Ground Water*, **37:** 358-366.

Trabelsi, R., Zairi, M. and H.B. Dhia (2007). Groundwater salinization of the Sfax superficial aquifer, Tunisia. *Hydrogeololgy Journal*, **15:** 1341-1355.

Varrol, M. and B. Sen (2009). Assessment of surface water quality using multivariate statistical techniques: A case study of Behrimaz Stream Turkey. *Environmental Monitoring and Assessment*, **159:** 543-553.

Venkatesharaju, K., Ravikumar, P., Somashekar, R.K. and K.L. Prakash (2010). Physico-chemical and Bacteriological Investigation on the river Cauvery of Kollegal Stretch in Karnataka. *Journal of Science, Engineering and Technology*, **6:** 50-59.

Wang, P., Yu, J.J., Zhang, Y.C. and C.M. Liu (2013). Groundwater recharge and hydrogeochemical evolution in the Ejina Basin, northwest China. *Journal of Hydrology*, **476:** 72-86.

Water stewardship information series. Total, Fecal & E. coli Bacteria in Groundwater. (2007) 1-2. http://webcache.googleusercontent.com/search?q=cache:9dtVokUmtAwJ:www.env.gov.bc.ca/wsd/planprotect_sustain/groundwater/library/ground_fact_sheets/pdfs/coliform(020715)_fin2.pdf+&cd =1&hl=en&ct=clnk&gl=in

WHO (2002). World Health Report: Reducing risks—promoting healthy life. Geneva.

WHO (2013). Water sanitation and health: Facts and figures on water quality and health. World Health Organization, Switzerland. Available from http://www.who.int/water_sanitation_health/facts figures/en/. Accessed 10 July 2013.

Zhang, Q., Li, Z., Zeng, G., Li, J., Fang, Y., Yuan, Q., Wang, Y. and F. Ye (2009). Assessment of surface water quality using multivariate statistical techniques in red soil hilly region: A case study of Xianjiang watershed, China. *Environmental Monitoring and Assessment*, **152:** 123-131.