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Assessment of groundwater quality in semi-urban and urban settings of Baddi tehsil of Solan district: A case study

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Abstract
This study assessed the quality of groundwater for domestic purposes in the Baddi tehsil of Solan district in terms of spatial variations in the physico-chemical characteristics. The monitoring was done for the post-monsoon session 2011 and considering eleven water quality parameters. The mean pH, electrical conductivity, total alkalinity, total hardness, chloride, sulphate, potassium, sodium, bicarbonate, magnesium and calcium in the forty sampling locations were found in the range of 7.45-8.35, 0.484-0.99 mS/cm, 134.2-289.5 mg/l, 127-320 mg/l, 15.4-100 mg/l, 28.6-59.1 mg/l, 3.48-11.83 mg/l, 6.37-32.78 mg/l, 81.9-176.6 mg/l, 18.25-38.46 mg/l, 33.6-127.4 mg/l respectively. The obtained results are compared with BIS standard limits. The results revealed higher values of total hardness and bicarbonate at most of the groundwater sampling locations. The study of physico-chemical characteristics of these groundwater samples suggest that the evaluation of water quality parameters as well as water quality management practices should be carried out periodically to protect the water resources. Principal component analysis was used to identify the possible sources of contamination and to examine the spatial changes of groundwater quality of semi-urban and urban settings of Baddi tehsil.

Keywords: groundwater quality, physico-chemical, correlation analysis, principal component analysis, biplot

Introduction
General
Groundwater is an important natural and limited reservoir of our earth hence, cannot be looked upon in isolation. Variation in groundwater quality is a function of physico-chemical characteristics of the area influenced by natural and anthropogenic activities (Subramani *et al*., 2005) [1]. Natural sources, more particularly the geogenic sources are responsible for the variation in physico-chemical composition of groundwater which changes with space and time (Zahid *et al*., 2008; Vikas *et al*., 2009; Gunduz *et al*., 2009; Mamatha and Rao, 2009; Brindha *et al*., 2011, Sahoo and Rout, 2012) [2, 3, 4, 5, 6, 7]. Assessment of groundwater quality on drinking water standards have been carried out by several researchers (Howari *et al*., 2005; Rao *et al*., 2005; Raju 2007; Haritash *et al*., 2008; Umar *et al*., 2009; Gupta *et al*., 2009; Dar *et al*., 2011, Rout and Sharma, 2011; Rout and Rani, 2013; Rout and Rani, 2013; Rout and Attree, 2016; Rout and Attree, 2016; Rout *et al*., 2016; Rout *et al*., 2017; Khawaja *et al*., 2017) [8-22]. Nowadays growing population, rapid urbanization, accelerating pace of industrialization and intensification of agriculture has exerted heavy pressure on our vast but limited fresh water resources (Sahoo *et al*., 2009, Patra *et al*., 2009; Rout *et al*., 2011; Rani *et al*., 2012; Rout, 2017) [23-27]. Therefore qualitative analyses of different types of water quality parameters can be used to assess the pollution status. The study attempt to estimate the physico-chemical parameters like pH, electrical conductivity, total alkalinity, total hardness, chloride, sulphate, potassium, sodium, bicarbonate, magnesium and calcium content at selected locations of semi-urban and urban setting of Baddi region of Solan district, Himachal Pradesh.

Materials and methods
Description of the study sites
Baddi tehsil of Solan district is located between the latitude 30° 57′ 28″ N and longitude 76° 47′ 28″ E. Dominated mainly by pharmaceutical units, the town has emerged as one of the leading industrial areas of the region, thus also attracting many ancillary units and gradually exerting pressure on the natural resources including groundwater.

The investigation was carried out at 40 designated sampling locations selected on the basis of occurrence of industries which are responsible for source of contamination. The sampling sites were identified after reconnaissance of the subject area, so as to represent the whole area. All the sampling locations of the study area is shown in Table no. 1.

Table 1: Sampling locations of the study area

	Sampling locations				
Coordinates in degree (°)	**S1**	**S2**	**S3**	**S4**	**S5**
N	30.94022	30.95022	30.96678	30.96847	30.97042
E	76.77825	76.77481	76.75016	76.75803	76.75892
	S6	S7	S8	S9	S10
N	30.98339	30.99186	30.99231	30.99203	30.99589
E	76.75119	76.74667	76.746	76.74808	76.74514
	S11	S12	S13	S14	S15
N	30.99722	30.96219	30.97647	30.99161	30.98969
E	76.74567	76.76111	76.77097	76.77456	76.76622
	S16	S17	S18	S19	S20
N	30.98733	30.98772	30.99483	31.00119	31.00475
E	76.75547	76.75122	76.74756	76.76003	76.77206
	S21	S22	S23	S24	S25
N	31.01247	31.00806	31.00586	31.0045	30.98125
E	76.77492	76.76872	76.78025	76.779	76.78169
	S26	S27	S28	S29	S30
N	30.97386	30.97647	30.97608	30.96575	30.97322
E	76.77344	76.78781	76.7915	76.78944	76.79575
	S31	S32	S33	S34	S35
N	30.95908	30.95603	30.94853	30.94994	30.93917
E	76.81175	76.81117	76.80447	76.80789	76.79817
	S36	S37	S38	S39	S40
N	30.94847	30.94703	30.95881	30.95825	30.92661
E	76.7935	76.78708	76.79239	76.78533	76.79561

Collection and characterization of groundwater samples

Groundwater samples were collected from 40 selected locations in 1-L airtight sampling bottles and thereafter stored at 4 °C prior to processing and analysis. Groundwater samples were collected directly from the tube wells, hand pumps and open wells after running the water for about 3-5 minutes. All the parameters were analyzed according to the standard methods (APHA, 2003) [28]. Analytical reagent (AR) grade chemicals were used throughout the study without any further purification. Distilled water was used for experimental purpose. A comparison of water quality parameters of the Baddi tehsil as observed with drinking water quality standards (BIS) is shown in Table 2. In the subsequent sub-headings, a brief discussion of parameters like pH, electrical conductivity (EC), total alkalinity (TA), total hardness (TH), chloride (Cl^-), sulphate (SO_4^{2-}), potassium (K^+), sodium (Na^+), bicarbonate (HCO_3^-), magnesium (Mg^{2+}) and calcium (Ca^{2+}) is being presented.

Table 2: Comparison of water quality parameters of groundwater of Baddi region with drinking water quality standard (Bureau of Indian Standards)

Parameters	**Observed Range of Samples**		**Indian Standards (BIS)**	
	Minimum	**Maximum**	**Desirable limit**	**Maximum limit**
pH	7.45	8.35	6.5-8.5	No Relaxation
EC	0.484	0.99	-	-
TA	134.2	289.5	200	600
TH	127.1	320.7	200	600
Cl^-	15.4	100	250	1000
SO_4^{--}	28.6	59.1	200	400
K^+	3.48	11.83	-	-
Na^+	6.37	32.78	-	-
HCO_3^-	81.9	176.6	30	-
Mg^{2+}	18.25	38.46	30	100
Ca^{2+}	33.6	127.4	75	200

*Units of all parameters are in mg/l except EC (mS/cm) and pH

Principal component analysis (PCA)

PCA is widely used to investigate the processes which influence the groundwater quality by examining chemical associations defined by one or more variable loadings on factors (Chen *et al*., 2007; Kuppusamy and Giridhar, 2006) [29, 30]. Simplification of data is done using linear combinations of the variables of the original matrix, which allow adequate visualization of the results that are grouped according to their similarities. This way, the chemical species are combined according to their provenance in the formation environment in a matrix of geochemical data (Hu *et al*., 2013) [31]. PCA takes the data from the original 11-dimensional space (pH, EC, TA, TH, Cl^-, SO_4^{2-}, K^+. Na^+, HCO_3^-, Mg^{2+} and Ca^{2+}) and project them onto a two-dimensional plane. The vector along which the 11-dimensional data is most variable is called the first principal axis (PC1). The position of a data point on a principal axis is called a principal component. The PC is expressed as (Singh *et al*., 2005) [32]:

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \ldots\ldots\ldots + a_{im}x_{mj} \ldots\ldots(1)$$

Where a is the component loading, **z** the component score, x the measured value of a variable, i the component number, j the sample number, and m the total number of variables.

Results and Discussion

pH: The pH of the groundwater samples of the study area varied from a minimum value of 7.45 at sampling station 8 to a maximum value of 8.35 at sampling station 3 (Figure 1a). The average pH value of the region was 7.743 with standard deviation of 0.169 and is positively skewed (Table 3). The results shows that groundwater collected from forty different sampling stations were moderately alkaline (pH 7.45-8.35) and were within the permissible limit (pH 6.5-8.5) of drinking water quality standards as recommended by BIS (Table 2).

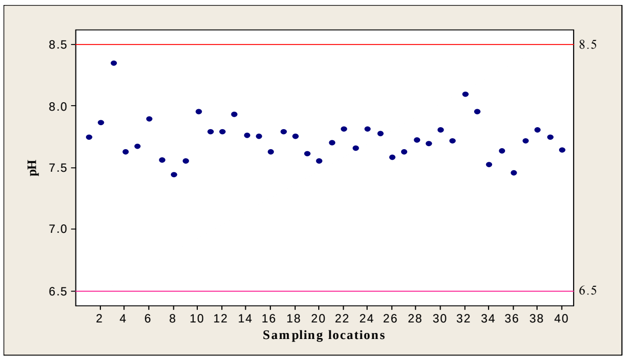

Fig 1a

Electrical conductivity (EC): The Electrical conductivity of the analysed groundwater samples varied from a minimum value of 0.484 mS/cm at sampling station 32 to a maximum value of 0.99 mS/cm at sampling station 11 (Figure 1b). The average EC value of the region was 0.673 mS/cm with standard deviation and error of 0.118 and 0.018, which is positively skewed (Table 3).

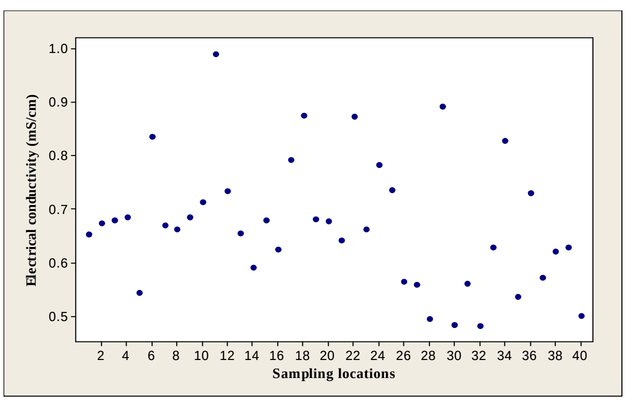

Fig 1b

Total alkalinity (TA): The total alkalinity of the groundwater samples varied from a minimum value of 134.2 mg/l at sampling station 30 to a maximum value of 289.5 mg/l at sampling station 10 (Figure 1c). The overall results showed that the total alkalinity level of groundwater was well within the permissible limit (200-600 mg/l) of drinking water quality standards as prescribed by BIS (Table 2). The average TA value of the region was 237.26 mg/l with standard deviation and error of 38.35 and 6.064, and having skewness value of -0.708 (Table 3).

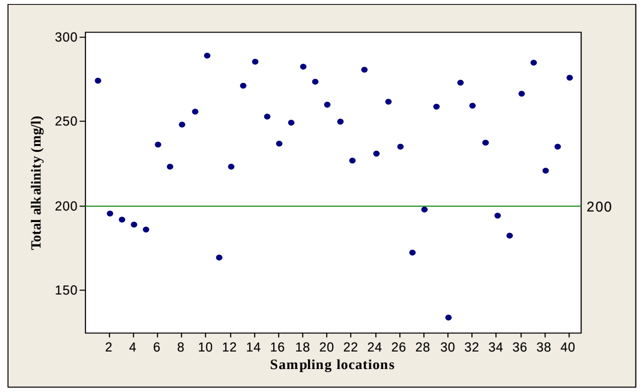

Fig 1c

Total hardness (TH): The total hardness of groundwater varied from a minimum value of 127.1 at sampling station 20 to a maximum value of 320.7 at sampling station 9 (Figure 1d). The average TH value of the region was 201.15 mg/l with standard deviation and error of 48.23 and 7.626, which is positively skewed (Table 3). The results shows that collected groundwater samples were well within the maximum permissible limit (600 mg/l) of drinking water quality standards as prescribed by BIS (Table 2).

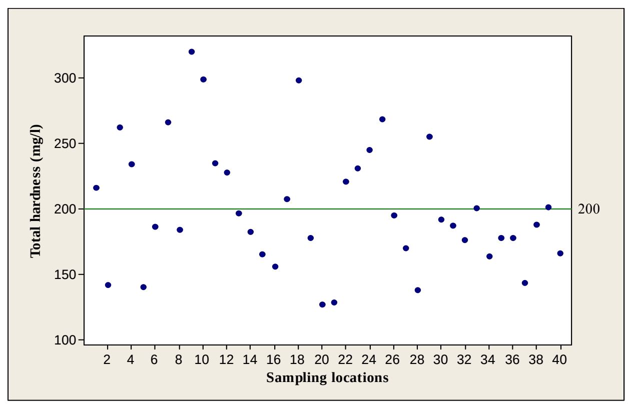

Fig 1d

Chloride (Cl^-): The Cl^- content of the groundwater samples of the study area varied from a minimum value of 15.4 at sampling station 21 to a maximum value of 100 at sampling station 29 (Figure 1e). The average chloride values of the region was 38.83 mg/l with standard deviation of 17.85, and is positively skewed (Table 3). The results shows that groundwater collected from different sampling stations well within the permissible limit (200-1000 mg/l) of drinking water quality standards as recommended by BIS (Table 2).

Table 3: Statistical analysis of groundwater of Baddi region

	pH	EC	TA	TH	Cl^-	SO_4^{2-}	K^+	Na^+	HCO_3^-	Mg^{2+}	Ca^{2+}

N	40	40	40	40	40	40	40	40	40	40	40
Min.	7.45	0.484	134.2	127.1	15.4	28.6	3.48	6.37	81.9	18.25	33.6
Max.	8.35	0.99	289.5	320.7	100	59.1	11.83	32.78	176.6	38.46	127.4
Mean	7.743	0.673	237.26	201.15	38.83	46.62	8.09	14.11	144.74	29.13	72.12
Std. error	0.027	0.018	6.064	7.626	2.823	1.289	0.272	0.982	3.699	0.83	3.42
Variance	0.028	0.014	1471	2326	319	66.52	2.97	38.6	547.29	27.35	467.34
Stand. Dev.	0.169	0.118	38.35	48.23	17.85	8.156	1.723	6.213	23.39	5.23	21.62
Median	7.74	0.668	243.45	190	33	47.15	7.955	11.86	148.5	29.12	67.9
Skewness	1.189	0.584	-0.708	0.645	1.535	-0.455	-0.26	1.568	-0.708	-0.021	0.676
Kurtosis	3.212	0.205	-0.173	-0.098	2.819	-0.435	0.895	2.158	-0.176	-0.676	0.129
Geom.Mean	7.742	0.663	233.9	195.76	35.58	45.86	7.88	13.06	142.69	28.65	69.07

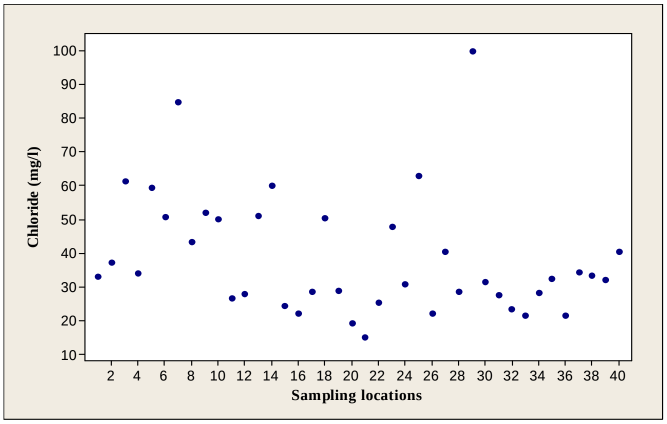

Fig 1e

Sulphate (SO_4^{2-}): The sulphate content of the groundwater samples of the study area varied from a minimum value of 28.6 at sampling station 1 to a maximum value of 59.1 at sampling station 5 (Figure 1f). The average sulphate content of the region was 46.62 mg/l with standard deviation and variance of 8.156 and 66.52, and is negatively skewed (Table 3). The results (Figure 1) shows that groundwater quality of the study area were falls within the permissible limit (200-400 mg/l) of drinking water quality standards as prescribed by BIS (Table 2).

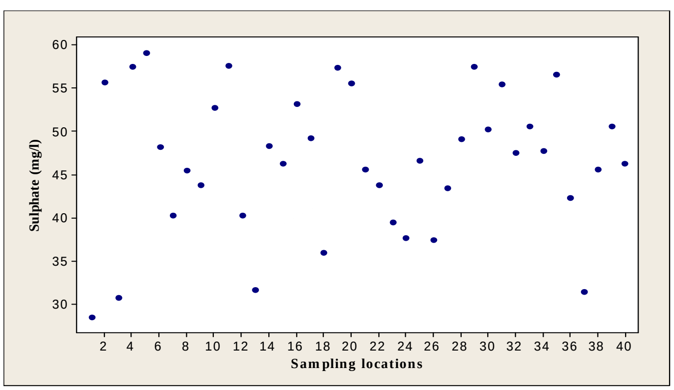

Fig 1f

Potassium (K^+) and Sodium (Na^+): The potassium of the groundwater samples of the study area varied from a minimum value of 3.48 at sampling station 7 to a maximum value of 11.83 at sampling station 34 and the sodium content of the groundwater samples of the study area varied from minimum 6.37 at sampling station 1 to maximum 32.78 at sampling station 18 (Figure 1g and h). The average content of K^+ was 8.09 mg/l with Kurtosis value of 0.895. Similarly the average content of Na^+ was 14.11 mg/l with Kurtosis value of 2.158 and having median value of 11.86 (Table 3).

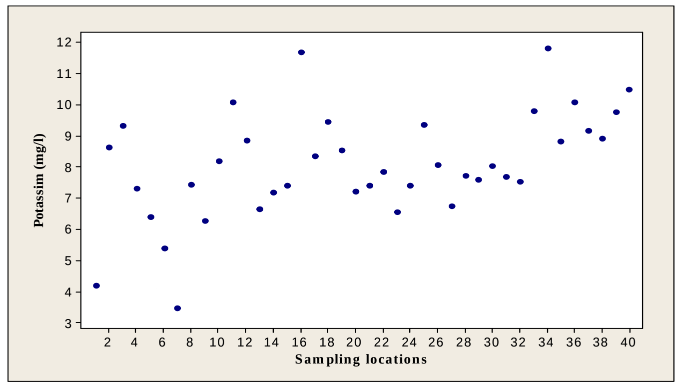

Fig 1g

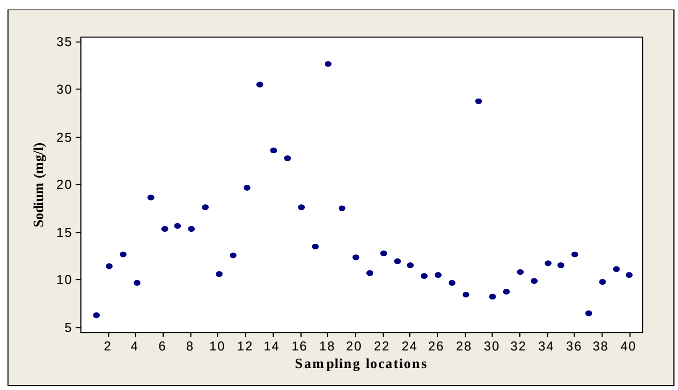

Fig 1h

Bicarbonate (HCO_3^-): The HCO_3^- of the groundwater samples of the study area varied from a minimum value of 81.9 at sampling station 30 to a maximum value of 176.6 at sampling station 28 (Figure 1i). The mean HCO_3^- content of the region was 144.74 mg/l with standard deviation and error of 23.39 and 3.699, and is negative skewness value of -0.708 (Table 3).

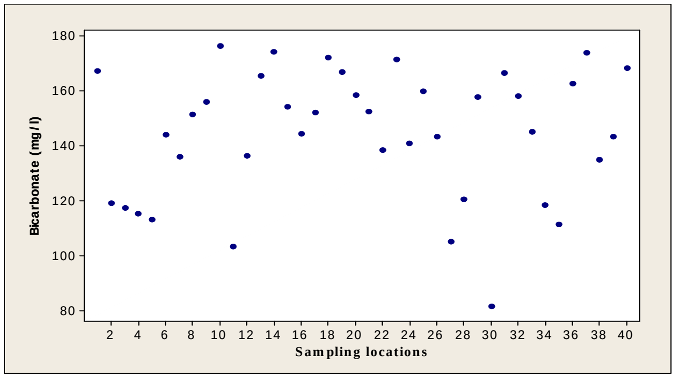

Fig 1i

Magnesium (Mg^{2+}) and Calcium (Ca^{2+}): The magnesium content of the groundwater samples of the study area varied from a minimum value of 18.25 at sampling station 17 to a maximum value of 38.46 at sampling station 38. The calcium content of the groundwater samples of the study area varied from a minimum value of 33.6 at sampling station 7 to a maximum value of 127.4 at sampling station 22 (Figure 1 j and k). The results shows that magnesium content groundwater collected from different sampling locations were within the permissible limit (30-100 mg/l) of drinking water quality standards of BIS (Table 2). Similarly the calcium content of groundwater collected from different sampling locations was within the permissible limits (75-200 mg/l) of drinking water quality standards of BIS (Table 2).

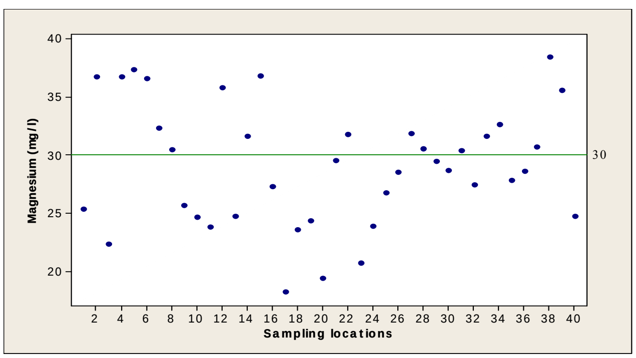

Fig 1j

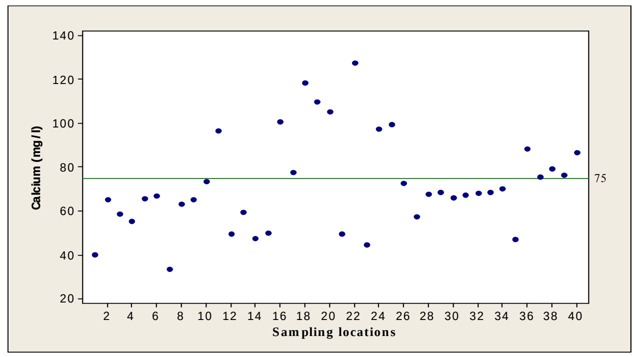

Fig 1k

Correlation matrix analysis

Correlation matrix analysis was prepared (Rout and Sharma, 2011; Rout and Bhatia, 2015; Rout *et al*., 2015) [15, 33, 34] to find out the relationship between different water quality parameters and is presented in Table 4. The highest positive correlation is observed between total alkalinity (TA) and bicarbonate (HCO_3^-) is 0.98. The highest negative correlation is observed between potassium and chloride (Cl^-) is -0.37. There is also positive correlation exists between other physico-chemical parameters shown in Table 4.

Table 4: Correlation matrix among physico-chemical parameters of groundwater

	pH	EC	TA	TH	Cl^-	SO_4^{2-}	HCO_3^-	K^+	Na^+	Mg^{2+}	Ca^{2+}
pH	1										
EC	0.022*	1									
TA	-0.066	0.065*	1								
TH	0.21*	0.471*	0.153*	1							
Cl^-	0.083*	0.191*	0.105*	**0.506****	1						
SO_4^{2-}	-0.203	0.011*	-0.284	-0.243	-0.064	1					
HCO_3^-	-0.066	0.065*	**0.98****	0.153*	0.105*	-0.284	1				
K^+	0.031*	0.112*	-0.091	-0.149	**-0.37**	0.204*	-0.091	1			
Na^+	0.002*	0.368*	0.278*	0.259*	0.463*	-0.047	0.278*	-0.071	1		
Mg^{2+}	-0.082	-0.147	-0.336	-0.287	0.015*	0.215*	-0.336	-0.066	-0.033	1	
Ca^{2+}	-0.043	0.392*	0.141*	0.06*	-0.245	0.159*	0.141*	0.497*	0.076*	-0.3	1

*Correlation is significant at the 0.05 level & **Correlation is significant at the 0.01 level

Principal component analysis

PCA was performed using MATLAB (Rout *et al*., 2016; Rout *et al*., 2017; Lavaniya *et al*., 2015; Lavaniya *et al*., 2015) [20, 21, 35, 36] and the results of analysis are shown in Table 5 and Figure 2. Here, PCA is performed on covariance correlation matrix data, such that the considered data set can be explained. While analyzing the results (Table 5), the cumulative percent variance of PC1 and PC2 is more than 84% and from the third component the cumulative percentage variance is more than 94% therefore, PC1 and PC2 has taken for consideration. The loading values >0.75 signifies "strong", the loading with values in between 0.5-0.75 indicate "moderate" while loading values between 0.3-0.50 denote as "weak" (Liu *et al*., 2003) [37]. Using the above classification, only one variable in component 1 have strong positive loading. Considering the first two components, higher coefficient is for total hardness (TH) with 0.841 and total alkalinity (TA) with 0.732. The coefficient for other parameters is very less. Biplots of all the physico-chemical parameters are shown in Figure 2. The two biplots of TA and TH are falls in different coordinate (Figure 2) which indicates similar trend will not follow between them. Hence the quality of ground water can be well differentiated by taking the first two parameters having higher coefficients, i.e., TA, & TH. The PC1, contains a negative loading on SO_4^{2-}, K^+ and Mg^{2+} and positive loading on the EC, TA, TH, Cl^-, Na^+, HCO_3^- and Ca^{2+}. The PC2, contains positive loading on TA, K^+, Na^+, HCO_3^-, and Ca^{2+} and negative loading on the pH, EC, TH, Cl^-, SO_4^{2-} and Mg^{2+}. In other words, PC1 shows the inverse relationship between SO_4^{2-}, K^+, Mg^{2+} and the eight other variables, with higher PC1 and PC2 values indicating that concerned parameters (TH & TA) are responsible for development of poor water quality in the study area. The results shows that out of 40 groundwater samples 17 and 30 groundwater samples exceeding the desirable limit of TH and TA, i.e., 200mg/l., as prescribe by BIS (Figure 1. iii and iv). Hence the ground water quality of the study area is not in a good state. The reason for poor ground water quality is due to disposal sewage and industrial effluents into the ground without proper treatment.

Table 5: Loadings of experimental variables on the ten PCs

	Components										
Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
pH	0	-0.001	0	-0.001	-0.004	0	-0.001	0.013	0.999	0.051	0.005
EC	0.001	-0.001	0.002	0.001	0.000	0.006	0.000	-0.002	-0.051	0.998	-0.025
TA	0.430	0.732	-0.065	-0.026	0.051	-0.017	0.027	0.002	0.004	-0.013	-0.521
TH	0.841	-0.499	0.070	-0.184	0.064	0.017	0.023	0.000	-0.001	-0.001	0
Cl^-	0.176	-0.100	-0.357	0.881	-0.126	-0.199	0.022	0.026	0	0.001	0
SO_4^{2-}	-0.052	-0.022	0.069	0.169	0.973	-0.039	-0.122	-0.018	0.004	0	0
K^+	-0.006	0.001	0.042	-0.004	0.017	0.021	-0.001	0.999	-0.013	0.001	-0.003
Na^+	0.044	0.013	-0.021	0.200	-0.029	0.936	-0.283	-0.017	0.001	-0.006	0
HCO_3^-	0.262	0.446	-0.040	-0.016	0.031	-0.010	0.018	0.005	-0.005	0.021	0.853
Mg^{2+}	-0.039	-0.019	-0.064	0.039	0.125	0.283	0.947	-0.004	0.002	-0.001	-0.001
Ca^{2+}	0.048	0.070	0.923	0.346	-0.114	-0.038	0.077	-0.035	0.001	-0.002	0
Eigenvalue	2640.1	1831.9	502.3	197.5	53.0	26.9	19.3	2.0	0	0	0
% Variance	50.069	34.74	9.527	3.746	1.005	0.51	0.366	0.037	0	0	0
Cumulative % Var.	50.069	84.809	94.336	98.081	99.086	99.596	99.962	99.999	100	100	100

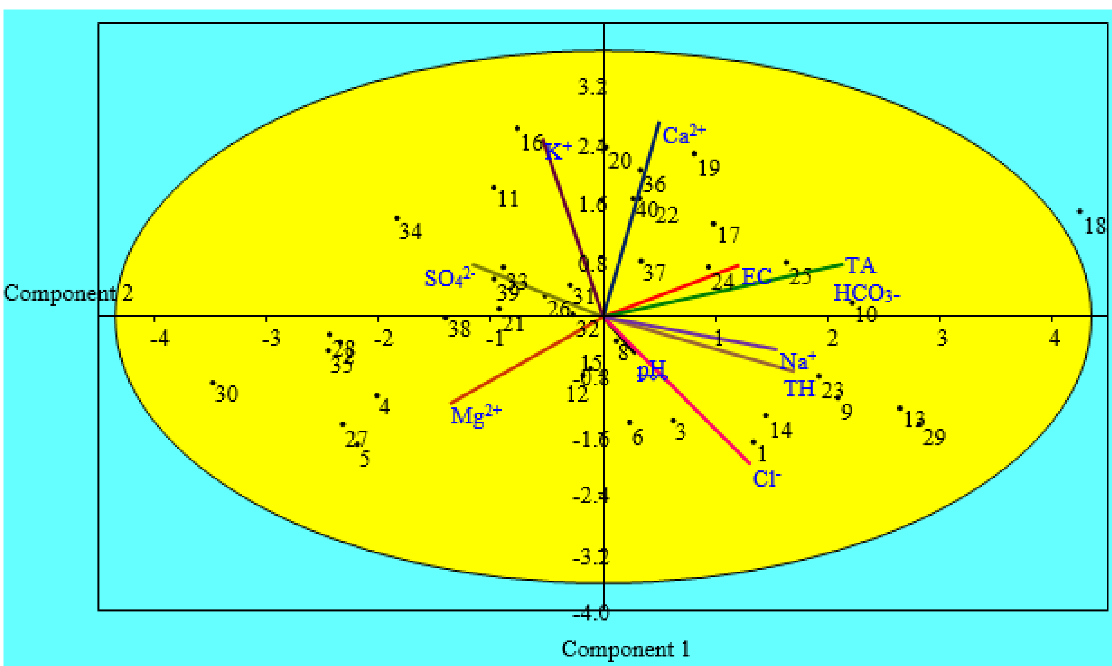

Fig 2: Scatter plot of the principal component analysis of groundwater

Conclusions

Water quality data set of the semi-urban and urban setting for Baddi tehsil in Solan district of Himachal Pradesh was analyzed using PCA. PCA plot showed strong positive correlation between parameters like HCO_3^- and total alkalinity. Analyzing the eleven parameters of water sample, the results indicate that ground water quality from the selected sampling sites can be used for domestic and industrial purposes after treatment. The parameter HCO_3^- was not within the permissible limits for drinking water quality as recommended by BIS. If the ground water will directly be used for domestic purposes, it may lead to various health problems. This study recommends removal of HCO_3^- ions before the water is being used for domestic and industrial purposes.

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