Interpretation of Groundwater Quality Using Multivariate Statistical Technique in Moradabad City, Western Uttar Pradesh State, India

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Abstract: Groundwater samples from Moradabad city were analyzed for chemical parameters. For present study 58 water samples were collected from different localities on the basis of various land use patterns. The higher values of most of the parameters were found in the area of old settlement, while lower values observed in new settlements. This shows clear impact of land use on groundwater. Water quality data collected from different localities are used in conjunction with multivariate statistical technique to identify key variables. The first four components were chosen for interpretation of the data, which accounts for 77.38% of the total variance in the data set. The maximum number of variables, *i.e.* Cl, Na, TH, TDS, EC and salinity were characterized by first component, while second component is characterized by DO and Mg. The third and fourth components were characterized by Ca, SiO₂, HCO₃ and K respectively. This shows that hydrochemical constituents of the groundwater are mainly controlled by TDS and EC. For cluster analysis single linkage method was used. The findings of the cluster analysis are presented in the form of dendrogram of the sampling stations (cases) as well as hydrochemical variables, which produced four major groupings, suggests that groundwater monitoring can be consolidated.

Keywords: Moradabad, Groundwater, Multivariate analysis, Cluster analysis, Hydrogeochemical

Introduction

Groundwater is the main source of potable water of Moradabad City. A number of people have installed water purifier in their houses in order to get rid off any contamination in water. The main source of groundwater contamination is from domestic and a number of electroplating industries, pulp and paper industry, dairy industry and sugar industry *etc.* These industries pour their effluents directly into open drain, unlined earthen drain and open pits in several places from where polluted water percolates into soil and finally reaches the aquifers. In India, research on the qualitative studies of groundwater specially with reference

to fluoride has been carried out by various workers^{1,2}. Due to limited and confined study of groundwater, interpretations of the quality of groundwater in the area are incomplete for taking any measure for sustainable development³.

The quality of water is depleting rapidly with the change in human life style *i.e.*, massive industrialization, construction activities, utilization of agricultural land and forest land for other developmental purposes. Most of the groundwater studies focus on the assessment of quantitative sources and on the identification recharge processes. These developmental activities generate large quantities of concentrated effluents. These effluents are either dumped into ground or drain into open unlined earthen canals from where they percolate, resulting groundwater pollution.

The rapid industrialization and expansion of cities poses high pressure on water resources including groundwater, results their depletion and contamination. Therefore, it is necessary to monitor and evaluate water quality on regular basis. In present study, at certain places various parameters exceeds the WHO / Indian standards of potable water. Water quality of 58 sampling stations has been statistically researched by using multivariate technique. In this article factor analysis and cluster analysis are used to categorize the spatial variation.

Study area

Moradabad city is also known as Brass City of India having a number of export houses and a number of large and small scale electroplating industries. Moradabad is situated at a distance of 167 km from the national capital, New Delhi (NH 24), on the bank of river Ramganga and located at 28.83° N 78° E. It has an average elevation of 186 meters (610 feet) above sea level. The city of Moradabad is inhabited on the alluvial deposits of quart energy period. The alluvial deposits has been drained and transported from Himalayan ranges by the river Ganga system and specially the River Ramganga. The texture of these deposits is from silt to sandy. These alluvial deposits are of two types; 1. Banger 2. Khaddar. Banger is referred to older alluvium and is found at remote areas from the river valley and at the surface that is loamy. The sand layer of Banger serve as aquifer at various depths from the ground. The Khaddar is newer deposits and found near and along the valley and is inundated every year by floods.

The alluvial loose deposits are laid on hard Paleogene rocks and these rocks are laid on Precambrian basement. The marine Paleogene sediment was deposited in a depression on western U.P. The Neogene sedimentary rocks found under the Ganga valley of nearby areas are totally absent under the quaternary alluvial deposits below Moradabad city. The Paleogene sedimentary rocks are situated at greater depths and much below the reach of general boreholes for tube well purposes in Moradabad city. The rock constitutes a small massif under quaternary deposits and is faulted toward east⁴. The underground water stored in sand layers and aquifers are found above these rocks and are used for all purposes in the city and nearby areas.

Experimental

In order to select suitable sampling sites, a preliminary survey was conducted to determine various land use patterns. On the basis of survey, 58 sampling sites are selected having previously installed jet pumps (we could not install any additional borehole pump due to paucity of funds and limitations with the authors) for groundwater analysis (Table 1). Samples are collected in sterilized polyethylene bottles of one liter and brought to well equipped laboratory for various chemical analysis. The physico-chemical parameters are analyzed with the help of Boush & Lomb Spectrophotometer Spectronic-120, Systronics105,

Hanna Pocket TDS meter, Hanna pocket pH meter, Century Flame Photometer, Century water testing kit and Centaury turbidity meter and conductivity meter. The selected parameters for the estimation of groundwater quality characteristics are: Total Dissolved Solids (TDS), Total Hardness (TH), Electrical Conductivity (EC), Carbon Dioxide (CO₂), Dissolved Oxygen (DO) Hydrogen-ion Concentration (pH), Bicarbonate alkalinity (HCO₃), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Silicate silica (SiO₂-Si), and Salinity (Sal). The parameters are analyzed as given in instrument manual and APHA⁵, Trivedy *et al.*⁶ Golterman *et al.*⁷, Goldman and Horne⁸, Welch⁹ and Weaver *et al.*¹⁰. Before collecting water samples hand pumps and jet pumps were run continuously for some time to avoid any turbidity in water due to presence of fine mud and sand particles.

Table 1. Location of sampling stations (borehole location)

Borehole No.	Location/Area	Borehole No.	Location/Area
1.	Gandhi Nagar	2.	Idhagh
3.	Lajpat Nagar	4.	Kathgargh Beech
5.	Peerzada	6.	Pachpera Mandir
7.	Gospak Ki Zarat	8.	Indra Chowk
9.	Galshaheed Park	10.	Ismaile Road
11.	Gulshan Nagar	12.	Amroha Gate
13.	Mandi Chowk	14.	Bazigaran Guriya Mohalla
15.	Mugalpura Kotwali	16.	Govt. Inter College
17.	Jama Masjid	18.	Barwalan Chowk
19.	Katghar Railway Station	20.	Hafiz Banne Ki Puliya
21.	Langreh Ki Puliya	22.	Asalatpura
23.	Hindu College	24.	Reeti Street
25.	Kath Ki Puliya	26.	Nai Srak Chowk
27.	Savita Sadan	28.	Mufti Tola
29.	Lal Bagh Mandir	30.	Chaurasi Ghanta Mandir
31.	Jhabbu Ka Nala	32.	Nawabpura Sartaj
33.	Kisrol	34.	Nagfani Chowki
35.	Daulat Bagh	36.	Bangla Gaon Chowk
37.	Deputy Ganj	38.	Baradari
39.	Nagar Nigam 1	40.	Nagar Nigam 2
41.	Nagar Nigam 3	42.	Kanjari Sarai
43.	Chiryatola	44.	Linepar
45.	Prem Nagar	46.	Mansarower
47.	Budhi Vihar II	48.	Budhi Vihar I
49.	Court Road	50.	Igar Colony
51.	Jamaa Masjid Chowk	52.	Karula Gali No.1
53.	Karula Gali No.5	54.	Karooli Ki Puliya
55.	Zahid Nagar	56.	Islam Nagar
57.	Rahmat Nagar Gali No. 1	58.	Seta Puri

Multivariate analysis

The data were prepared and processed in SPSS 11.0 and Statistica software in window XP. Descriptive statistics and Factor analysis were processed in SPSS where cluster analysis was prepared in statistica software. Factor analysis was used to understand the correlation structure of collected data and identified most important factors contributing the data structure¹¹⁻¹³. For factor analysis Varimax and Kaiser Normalization rotation method was used¹⁴ and also used to find association between parameters so that the number of measured variable can be reduced. After obtaining correlation matrix and eigen values, factor loading were used to measure the correlation between variables and factors. These variables were then rotated by Varimax rotation technique to obtain new variability which is easy to interpret. Cluster analysis is also another data reduction method that was used to classify entities with similar properties. Multivariate statistical method encompassing cluster analysis, factor analysis, principal component analysis and discriminate analysis have been successfully used in hydrochemistry for many years¹⁵⁻¹⁷. Factor analysis was also used to find association between parameters so that the number of measured parameters can be reduced. Known associations were then used to predict unmeasured water quality parameters¹⁸. The method divides a large number of homogenous groups on the basis of their correlation structure. For cluster analysis single linkage method was used. In this method the distance between the clusters was determined by the distance of the two closest objects (nearest neighbor) in the different clusters.

Results and Discussion

The descriptive statistics of the analyzed water quality parameters are depicted in Table 2. Higher values of TDS, EC, Na, Cl, SiO₂ and Salinity is recorded in sampling station (SS) 31, while hardness and HCO₃ is found higher in SS 17 and other parameter like, CO₂, Ca and pH is higher in SS 45,05 and 46, respectively. The lowest value of HCO₃, Cl, Na, TDS, EC and salinity is observed in SS 47. It is interesting to note that higher values of most of the parameters are found in the area of old settlement, while lower values observed in new settlement (Table 3). This shows clear impact of land-use on groundwater.

Table 2. Descriptive statistics of groundwater

Parameters	Unit	No. Of Samples	Minimum	Maximum	Mean	St. Error	SD	Variance
DO	mg/L	58	2.40	6.50	4.51	0.13	1.036	1.07
CO ₂	mg/L	58	2.00	48.00	18.24	1.10	8.419	70.88
HCO ₃	mg/L	58	98.00	630.00	307.48	16.04	122.18	14928.07
Cl	mg/L	58	14.20	256.70	107.39	8.67	66.05	4363.78
Hardness	mg/L	58	136.50	836.00	350.29	24.07	183.34	33615.05
Ca	mg/L	58	11.80	166.50	48.85	4.61	35.11	1233.31
Mg	mg/L	58	5.60	156.80	51.59	4.58	34.95	1221.90
Na	mg/L	58	28.00	140.00	76.17	3.10	23.63	558.39
K	mg/L	58	3.00	43.00	9.96	0.85	6.48	42.01
SiO ₂	mg/L	58	10.00	20.00	17.03	0.31	2.39	5.71
TDS	mg/L	58	292.00	1898.00	902.53	50.17	382.14	146031.90
EC	μS/cm	58	372.00	2112.00	1086.03	57.65	439.11	192823.12
pH	-	58	6.80	7.90	7.32	0.03	0.25	0.06
Salinity	mg/L	58	0.17	1.07	0.52	0.0302	0.22978	0.053

Table 3. Chemical composition of groundwater from different localities of Moradabad city

SS	DO	CO ₂	CO ₃	Cl	TH	Ca	Mg	Na	K	SiO ₂	TDS	EC
1	6.06	12.00	366.00	76.60	298.80	116.1	23.90	67.00	18.0	18.00	789.00	1064.0
2	2.42	12.00	272.00	153.2	284.00	75.70	5.600	97.00	12.0	16.00	848.00	1169.0
3	5.25	14.00	348.00	66.70	138.00	55.50	44.30	72.00	12.0	18.00	689.00	958.00
4	4.44	14.00	226.00	116.3	218.40	87.50	18.90	62.00	11.0	16.00	665.00	908.00
5	4.84	12.00	290.00	170.2	415.80	166.5	35.20	92.00	14.0	12.00	1184.0	1729.0
6	4.44	32.00	504.00	146.1	344.40	137.9	45.80	94.00	11.0	18.00	1190.0	1624.0
7	5.25	18.00	248.00	256.7	407.40	163.2	46.00	82.00	11.0	18.00	1265.0	1702.0
8	6.46	6.000	216.00	92.19	154.40	62.20	31.40	67.00	12.0	18.00	671.00	896.00
9	5.65	20.00	294.00	170.2	273.00	109.3	56.40	99.00	10.0	14.00	1182.0	1563.0
10	4.84	20.00	406.00	165.5	310.00	124.5	52.00	80.00	12.0	16.00	1094.0	1470.0
11	6.06	14.00	436.00	120.1	172.20	68.90	68.30	93.00	12.0	12.00	1040.0	1402.0
12	4.84	24.00	214.00	59.60	136.50	54.70	42.80	95.00	12.0	14.00	708.00	858.00
13	5.70	26.00	374.00	82.30	476.00	25.20	100.8	93.00	11.0	20.00	923.00	1104.0
14	4.80	30.00	272.00	107.8	514.00	56.30	91.00	94.00	7.00	19.00	1066.0	1326.0
15	6.50	24.00	250.00	171.6	836.00	77.40	156.8	90.00	5.00	18.00	1404.0	1705.0
16	5.60	16.00	442.00	97.80	526.00	37.80	105.3	88.00	9.00	19.00	940.00	1142.0
17	4.80	18.00	630.00	76.60	562.00	42.00	111.5	90.00	38.0	18.00	1202.0	1139.0
18	6.06	18.00	616.00	163.1	712.00	29.40	155.8	116.0	10.0	18.00	1335.0	785.00
19	5.30	20.00	410.00	63.80	490.00	26.90	103.1	81.00	6.00	19.00	864.00	1625.0
20	5.60	24.00	224.00	180.1	700.00	60.60	133.9	107.0	10.0	20.00	1384.0	1046.0
21	6.50	26.00	396.00	177.3	504.00	31.90	103.5	126.0	17.0	20.00	1202.0	1670.0
22	4.80	16.00	352.00	56.70	412.00	18.50	89.30	86.00	8.00	18.00	790.00	958.00
23	6.50	14.00	320.00	44.00	292.00	35.50	49.80	75.00	10.0	16.00	639.00	876.00
24	3.20	12.00	230.00	87.93	356.00	35.30	35.30	75.00	6.00	18.00	866.00	997.00
25	2.40	16.00	334.00	80.84	300.00	23.60	23.60	74.00	7.00	20.00	773.00	878.00
26	4.00	24.00	264.00	234.0	748.00	52.10	52.10	97.00	10.0	20.00	1732.0	1938.0
27	4.80	26.00	328.00	209.9	712.00	43.70	43.70	83.00	8.00	16.00	1631.0	1860.0
28	3.60	26.00	292.00	222.7	744.00	37.00	37.00	91.00	7.00	18.00	1612.0	1860.0
29	3.20	12.00	344.00	52.50	260.00	42.00	42.00	48.00	6.00	16.00	549.00	642.00
30	4.80	24.00	312.00	255.3	568.00	68.90	68.90	109.0	7.00	16.00	1563.0	1761.0
31	4.00	28.00	520.00	248.2	588.00	33.60	33.60	140.0	10.0	18.00	1898.0	2112.0
32	4.80	12.00	256.00	35.50	224.00	48.80	48.80	93.00	8.00	20.00	475.00	573.00
33	3.20	24.00	348.00	219.8	500.00	43.70	43.70	65.00	8.00	20.00	1371.0	1582.0
34	3.60	8.000	252.00	21.30	208.00	16.80	16.80	32.00	3.00	18.00	422.00	516.00
35	4.40	26.00	328.00	80.80	328.00	25.20	25.20	63.00	6.00	18.00	724.00	848.00
36	4.00	12.00	292.00	31.20	200.00	28.60	28.60	62.00	6.00	20.00	514.00	610.00
37	4.00	42.00	528.00	106.3	416.00	16.80	16.80	110.0	8.00	19.00	1154.0	1332.0
38	4.80	12.00	320.00	85.10	380.00	11.80	11.80	77.00	6.00	18.00	894.00	1047.0
39	4.40	6.000	116.00	24.80	180.00	45.40	45.40	43.00	6.00	16.00	385.00	497.00
40	4.04	6.000	120.00	53.10	188.00	37.00	37.00	59.00	7.00	20.00	512.00	648.00
41	3.20	14.00	160.00	56.70	320.00	43.70	43.70	71.00	8.00	12.00	685.00	852.00
42	4.80	20.00	170.00	53.10	296.00	23.50	23.50	64.00	10.0	14.00	694.00	880.00
43	4.80	18.00	170.00	28.30	140.00	37.00	37.00	63.00	10.0	10.00	599.00	755.00
44	4.00	24.00	150.00	116.3	340.00	63.90	63.90	65.00	6.00	16.00	784.00	983.00

Contd...

45	2.40	48.00	224.00	76.60	340.00	21.90	21.90	77.00	10.0	16.00	875.00	1105.0
46	3.20	2.000	108.00	17.00	168.00	16.80	16.80	33.00	8.00	12.00	328.00	425.00
47	4.80	4.000	98.000	14.20	160.00	31.90	19.56	28.00	6.00	16.00	292.00	372.00
48	4.00	16.00	140.00	57.00	268.00	25.20	50.00	52.00	8.00	18.00	542.00	693.00
49	4.80	18.00	220.00	35.50	232.00	21.00	43.80	30.00	6.00	20.00	444.00	530.00
50	4.40	12.00	256.00	49.60	248.00	29.43	42.60	38.00	7.00	18.00	463.00	781.00
51	4.20	16.00	560.00	106.4	440.00	26.90	90.90	75.00	43.0	16.00	1323.0	1483.0
52	3.20	16.00	324.00	156.0	180.00	57.20	85.00	64.00	8.00	18.00	815.00	955.00
53	4.80	22.00	412.00	141.8	256.00	18.50	51.20	77.00	12.0	16.00	1146.0	1124.0
54	3.20	12.00	272.00	53.90	168.00	35.30	19.50	49.00	7.00	18.00	530.00	633.00
55	4.40	12.00	244.00	92.20	168.00	25.20	25.60	56.00	10.0	16.00	554.00	686.00
56	3.60	24.00	412.00	56.80	160.00	33.60	18.50	47.00	5.00	14.00	493.00	526.00
57	4.00	18.00	380.00	140.4	172.00	25.20	26.60	78.00	9.00	16.00	896.00	964.00
58	4.00	16.00	244.00	113.5	184.00	23.50	30.50	84.00	9.00	16.00	735.00	823.00

SS- Sampling Stations; DO - Dissolved Oxygen; TH- Total Hardness as CaCO₃; TDS - Total Dissolved Solids; EC - Electrical Conductivity, All parameters are in mg/L except pH and EC ($\mu\text{S/cm}$)

Table 4 represents the initial eigen value, percent of variance and cumulative percent of total variance of groundwater data. From table 4, it is inferred that the first four components together account for 77.38% of the total variance in which the first component accounts for 40.66% of the total variance.

Table 4. Rotated component matrix, eigen value, percentage of total variance and cumulative percentage of groundwater

Variables	Components			
	1	2	3	4
DO	6.677E-02	0.865	-0.133	0.109
CO ₂	0.653	-0.232	0.407	0.111
HCO ₃	0.371	0.138	0.238	0.711
Cl	0.922	8.296E-02	-0.149	-4.861E-02
Hardness	0.759	0.341	0.344	3.442E-02
Ca	0.401	0.220	-0.719	-7.556E-02
Mg	0.287	0.739	0.328	0.237
Na	0.752	0.240	0.109	0.252
K	8.360E-02	0.136	-0.176	0.881
SiO ₂	0.140	0.303	0.620	-0.182
TDS	0.943	0.138	4.432E-02	0.195
EC	0.925	0.106	-0.121	0.123
pH	-0.589	-1.422E-02	-0.511	-0.244
Salinity	0.879	0.182	-5.646E-02	0.277
Eigenvalue	6.539	1.625	1.521	1.148
% Total variance	40.663	12.646	12.236	11.839
Cumulative %	40.663	53.309	65.545	77.384

The second component explains 12.64%, the third component 12.23% and fourth component exhibit 11.83% of the total variance. Guidelines have been developed for determining the number of factors to be used and ignored¹⁹⁻²². For interpreting of the data the method of Kaiser Criterion²³, is followed which retains only those factors having eigen values greater than 1. The first four factors having an eigen value greater than 1 has been used for further interpretation.

The extracted components explain nearly 77.38% of the variability in the original 14 variables. The number of eigen values can be estimated from a scree plot demonstrated in Figure 1. As shown in this figure, the eigen value sharply decrease within the first four components and then slowly stabilize for the remaining ones.

Figure 1. Scree plot of groundwater

The regression analysis between TDS-Salinity; TDS-EC; TDS – hardness; TDS – Cl; TDS – Na shows strong positive relationship as $r = 0.93, 0.91, 0.83, 0.89$ and 0.77 , respectively, and moderate positive correlation with Na ions ($r = 0.77$) and very low positive correlation ($r = 0.29 - 0.56$) with Ca, Mg, CO_2 and HCO_3 suggesting the aquifer chemistry to be mainly controlled by TDS, Hardness, EC, Cl and Salinity (Table 5 and Figure 2-5).

Figure 2. Correlation between total and dissolved solids (TDS and EC)

Table 5. Correlation coefficient matrix of hydrochemical data of groundwater.

	DO	CO ₂	HCO ₃	Cl	TH	Ca	Mg	Na	K	SiO ₂	TDS	EC	pH	Salinity
DO	0.000													
CO ₂	-0.038	0.000												
HCO ₃	0.203	0.357	0.000											
Cl	0.110	0.428	0.319	0.000										
TH	0.234	0.471	0.370	0.648	0.000									
Ca	0.255	0.006	0.021	0.448	0.076	0.000								
Mg	0.536	0.191	0.376	0.262	0.616	0.039	0.000							
Na	0.318	0.534	0.533	0.661	0.610	0.230	0.447	0.000						
K	0.175	0.015	0.496	0.090	0.132	0.130	0.261	0.234	0.000					
SiO ₂	0.062	0.158	0.214	0.137	0.356	-0.179	0.268	0.161	-0.074	0.000				
TDS	0.187	0.558	0.516	0.894	0.823	0.282	0.415	0.778	0.274	0.168	0.000			
EC	0.208	0.528	0.423	0.844	0.700	0.432	0.290	0.713	0.232	0.103	0.909	0.000		
pH	-0.064	-0.650	-0.431	-0.405	-0.605	0.037	-0.459	-0.536	-0.143	-0.198	-0.565	-0.478	0.000	
Salinity	0.201	0.467	0.484	0.837	0.763	0.346	0.460	0.683	0.393	0.109	0.934	0.868	-0.513	0.000

Figure 3. Correlation between total dissolved solids and total hardness

Figure 4. Correlation between total dissolved solids and chloride.

Figure 5. Correlation between total dissolved solids and sodium

Table 4 represents the factor loading which were used to measure the correlation between variable and factors. Component loading higher than 0.6 is taken into consideration as suggested by Mahloch²⁴ and Mazlum and Mazlum²⁵. The components with larger variance are more desirable since they give more information about the data. The highest factor loading of TDS and EC is 0.943 and 0.925, respectively indicating the strong relationship between these two variables (Table 4), which is further supported by regression analysis as $r = 0.91$ and cluster analysis (Dendrogram) as shown in Figure 7.

The concentration of salinity, Cl, TDS and EC show high positive loading (0.879 – 0.943) and the concentration of CO₂, Na and hardness have moderate positive loading (0.653 -0.759) in the first component. The second component contain high positive loading of DO and Mg. The third component is governed by Ca and SiO₂ whereas fourth component exhibit only K ions. On the basis of the factor loading the first component can be established as “salt factor” as it contains EC and some important inorganic salts along with salinity¹⁵. The first component is associated with a combination of various hydrogeochemical processes that contribute to enrich more mineralized water (high value of TDS), as suggested by Rao *et al.*³ and Hem²⁶. The enrichment of Na and Cl ions in groundwater is due to the interaction of water with rocks and secondly the association of TDS with higher concentrations of Na and Cl ions. This indicates anthropogenic activities such as discharge of sewage in open unlined earthen canals and pits, which support the sewage to percolate and finally mixes with groundwater. It can be understood that domestic wastes percolate into soil from where it mixes with groundwater. Component first supports the contamination in groundwater from human and animal wastes. Similar observations have also been reported by Chettri and Smith²⁷, Fisher and Mullican²⁸, Rao *et al.*³. The concentration of HCO₃ in the groundwater is the result of the reaction of soil CO₂ with the dissolution of silicate minerals. According to Rao *et al.*³ the mineral dissolution during water-soil and water-rock interactions depends upon the amount of CO₂ which originates from H₂CO₃. The negative loading of pH suggest that the decrease of $p\text{CO}_2$ and H₂CO₃ values during out gassing of CO₂ results in an increase of pH, when the level of CO₂ decreases there is sharp rise in pH value which shift the water towards alkaline side and the concentration of HCO₃ increases. Minerals of the bed rock are subjected to weathering and subsequently affected by leaching, which contribute

dissolved salts to groundwater, resulting in an increase in TDS, EC and hence water salinity³. Second component show high positive loading of DO and Mg. High loading of Mg ions is related to the weathering of ferro magnesium mineral and anthropogenic sources as also suggested by Rao *et.al.*³; Hem²⁶; Zhang *et al.*²⁹ and Satyanarayana and Periakali³⁰. Third component is controlled by Ca and SiO₂ relates to weathering of feldspar and silicate rocks. Fourth component shows association between HCO₃ and K. It is interesting to note that the eigen values for the second and third components are approximately same (1.62 and 1.52), indicating that their relative effects are similar.

Figure 6. Dendrogram of the location of 58 cases using single linkage

Figure 7. Dendrogram of the 12 chemical parameters of 58 cases.

The dendrogram of sampling stations produced four major groupings (Figure 6). The dendrogram shows that the association between cases (sampling stations) 41-42; 27-28; 36-54; 34-59; 46-47; 40-48; 13-16; 52-57 and 5-7 is more significant. The first cluster group shows close association between 41 and 42 with bonds to station 58, 12, 8, and 4 and to a lesser degree, station 3. Second group of association is between SS 27 and 28 which bound with SS 26 and 30 with lesser degree of association. There is a close association between 34 and 49 which resembles with SS 36 and 54, and this cluster constitute third group. The fourth group marked by the association between sampling station 25 and 35, showing affinity with group first. Sampling station 18, 19, 20 and 31 shows association with rest of the sampling stations at lesser degree as linkage distance is from 300 to 500.

Another dendrogram of the 12 indexes based on the cluster analysis is depicted in Fig 7. On the basis of dendrogram of all 12 indexes can be grouped into four main clusters. First cluster group shows close association between SiO₂, CO₂, K and DO. This group is further associated with group second to a lesser degree, having Na, Mg and Ca indexes. Group third and fourth shows the close association between hardness-bicarbonate and EC –TDS. These indexes have high values in most of the sampling stations. These findings corroborates with the results of correlation analysis and cluster analysis.

Conclusion

In general the groundwater of the Moradabad city is alkaline in nature and hard, but at some places the water is relatively soft and falls within the safety limits as prescribed by WHO and Indian Standards. The concentration of TDS, EC, TH, Ca, Mg, Na, HCO₃ and Cl at most of the sampling stations exceeds the safety limits for drinking water. Computational analysis of the data set of hydrochemical constituents in the groundwater suggests that the aquifer (TDS) is mainly controlled by Cl, TH, Na, salinity and EC. There is a strong positive relationship between TDS-EC; TDS-Cl; TDS-TH and TDS-Na. The data were analyzed for factor analysis and first four components are chosen, which contribute 77.38% of the total variance. Dendrogram of the 58 cases and 12 variables are plotted and grouped into four main clusters.

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