American Journal of Water Resources, 2016, Vol. 4, No. 6, 121-129
Available online at http://pubs.sciepub.com/ajwr/4/6/1

DOI:10.12691/ajwr-4-6-1

Identification of Critical Water Quality Parameters Derived from Principal Component Analysis: Case Study from NOIDA Area in India

Virendra Bahadur Singh[1,2], Jayant Nath Tripathi[1,*]

[1]Department of Earth and Planetary Sciences, Nehru Science Centre Building, Faculty of Science, University of Allahabad, Allahabad, India
[2]Department of Petroleum Engineering, Graphics Era University, Dehradun, India
*Corresponding author: jntripathi@gmail.com

Abstract Factor analysis is applied to 18 hydrochemical variables of groundwater quality for 33 groundwater samples to interpret the relationships with specific processes that control the quality of groundwater in Noida area which is a part of the National Capital Region (NCR) of Delhi in the river basin of Yamuna. The three factor model for this area explains 79.30% of total variance. Factor 1, which explains 47.25% of the total variance, has strong positive loadings on Mg^{2+}, Cl^{-}, SO_4^{2-}, TH, EC, TDS, Na^{+}.Factor 2 explains 16.75 % of the total variance with moderate positive loadings on K^{+}, HCO_3, CIA, and Ca^{2+}. Factor 3 explains 15.30 % of the total variance with strong positive loadings on Na % and SAR. Factor 1, 2 and 3 can be interpreted as salinity, alkalinity and pollution respectively.The geographical distribution of the factor scores at individual bore wells delineated boundaries, which define where groundwater is affected by salinization, alkalinity and pollution. In this study multivariate analysis reveals that the over-pumping and pollution caused differences in terms of water quality and hence for proper management of groundwater requires rainwater harvesting and water softening techniques to reduce the salinity.Thus, this study shows the effectiveness of multivariate statistical technique factor analysis for analysis and interpretation in the groundwater quality problem.

Keywords: *factor analysis, groundwater quality, noida area, uttar pradesh*

Cite This Article: Virendra Bahadur Singh, and Jayant Nath Tripathi, "Identification of Critical Water Quality Parameters Derived from Principal Component Analysis: Case Study from NOIDA Area in India." *American Journal of Water Resources*, vol. 4, no. 6 (2016): 121-129. doi: 10.12691/ajwr-4-6-1.

1. Introduction

Water is one of the basic necessities of life,second only to oxygen as ranked by experts. Safe water must be provided to all. Providing safe drinking-water to the people of an area can result in tangible benefits to health. Drinking unsafe water causes many significant risks to health over a lifetime of consumption, including different sensitivities that may occur between life stages. Groundwater is an important source of water throughout the world, and its protection is necessary, from the socio-economic point of view. Groundwater contains dissolved substances, which result from either natural processes or anthropogenic. These substances are often called contaminants, especially when the amounts present are at possibly harmful or problematic levels. The important natural processes contributing to pollution in groundwater are rock-water interactions, dissolution, precipitation, sorption and geochemical reactions. Anthropogenic activities such as waste disposals, leaching of salts, fertilizers, pesticide from the agricultural fields and salt intrusion due to over exploitation contribute to groundwater pollution. Groundwater contamination has increased particularly in urban area due to rapid urbanization, industrialization and improper disposal of various kinds of waste and excessive use of agrochemicals in agriculture (e.g. [1-7]). Subsurface leaching of contaminants from land causes severe degradation of the groundwater quality in urban areas. With the fast growth and development of NOIDA area, which is a part of the National Capital Region (NCR) of Delhi in the river basin of Yamuna in Gautam Budh Nagar Uttar Pradesh, vast stretch of agriculture land is converted into residential, industrial and commercial uses. Understanding of the impacts of land use activities on the quality of groundwater is one of the important aspects of developing a better policy in legislative or regulatory mechanism for providing clean and safe drinking water to the people of this urban area. A variety of methods are being used to reveal the information concealed in the quality variables as obtained from a water-quality monitoring network. Mostly, these approaches are statistical. When the number of variables is greater than two, application of multivariate analysis techniques gives simpler and more easily interpretable results for the evaluation of the observed quality data (e.g. [8]). Studies show that these techniques allow the identification of the possible sources that influence water systems and offer a valuable tool for reliable management of water resources as well as rapid solution for pollution problems (e.g. [9,10]). So in this study multivariate statistical technique, factor analysis is applied to hydrochemical variables of groundwater quality to determine the sources of the groundwater quality inputs and to group monitoring stations.

2. Study Area

The present study area lies between $28^{0}32'$ and $28^{0}36'$N latitudes and $77^{0}18'$ and $77^{0}22'$E longitudes (Figure 1) with a mean altitude of 190 m above mean sea level and is a part of National Capital Region (NCR) located in NOIDA, at the outer fringe of Delhi. NOIDA is a well- developed and fast growing area located in Gautam Budh Nagar district of Uttar Pradesh. It is bound on the west and south-west by the Yamuna River, on the north and north-west by the city of Delhi, on the north-east by the cities of Delhi and Ghaziabad and on the north-east, east and south-east by the Hindon River. NOIDA falls under the catchment area of the Yamuna-river, and is located on the old river bed. The soil is loamy and fertile in nature. Land use pattern of thestudy area based on satellite imagery is given in Figure 2. The study area is underlain by alluvial deposits which gently slopes towards south, are of Pleistocene to Recent age (e.g. [11]). Of these Older Alluviums, believed to be Middle to Upper Pleistocene in age (e.g. [11]) consisting of predominantly clay and kankar mixed with fine to medium sand (e.g. [12]) is not touched by the highest flood level because it forms the high ground. The Newer Alluvium, which in general occupies the areas of lower altitude, consisting of clay and sand mixed with gravel of medium size is restricted to the present flood plains along river channels believed to be Upper Pleistocene to Recent age (e.g. [13]). Silt stone, Claystone, Girt, Sandstone, Shale, Conglomerate, Limestone, including intrusive (Andaman)—moderately thick and regionally extensive confined/unconfined aquifers down to 150 m (e.g. [14]). Besides rainfall, the main source of groundwater recharge is Yamuna river and associated Okhala reservoir (e.g. [12]).

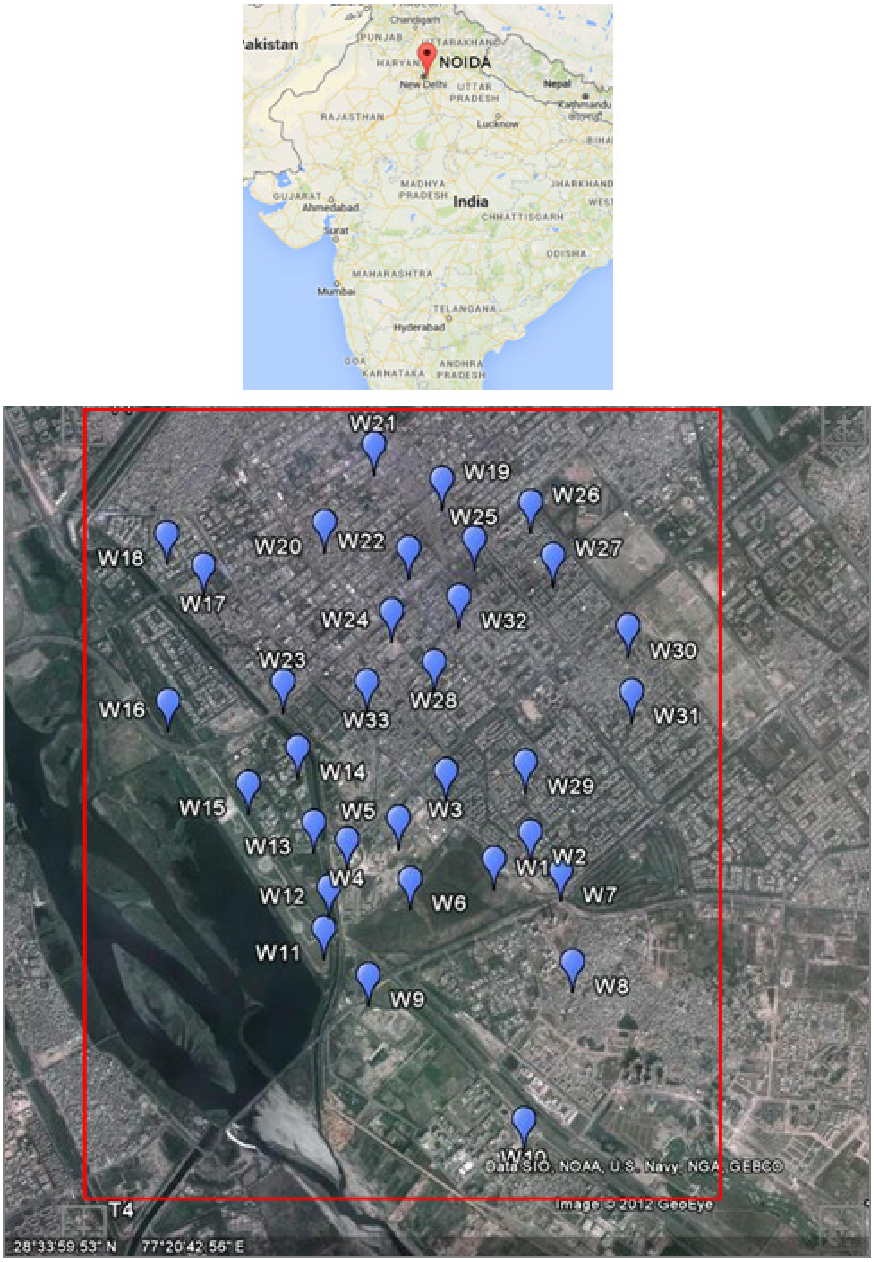

Figure 1. Google earth image of the study area shown in red border and location of the 33 groundwater bore well (W_1 to W_{33})

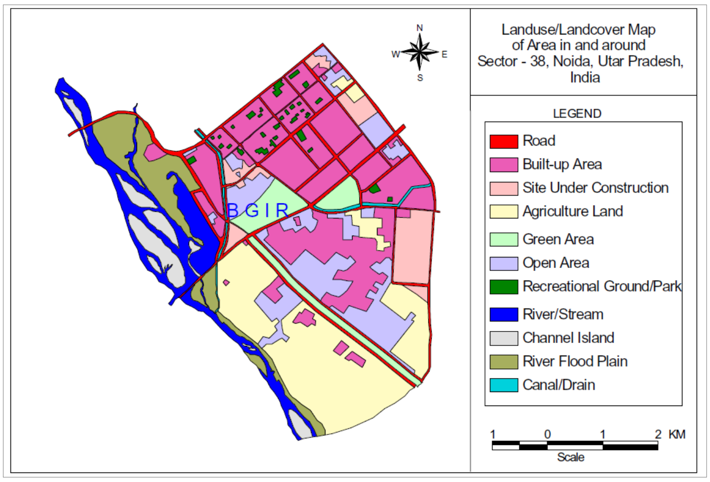

Figure 2. Land use map of the study area (e.g. [12])

Table 1. Chemical analysis data of groundwater in parts of NOIDA area in India (e.g. [12])

Bore Well	pH	EC	TDS	F	Cl^-	HCO_3	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	TH	Na %	RSC	MH	SAR	PI	CIA
W_1	7.35	2570	1698	0.6	508	217	393	211	99	257	12.7	934	38.1	-5.8	43.7	3.7	46.7	0.2
W_2	7.85	2690	1852	0.6	585	310	358	249	133	204	13.3	1169	28.3	-6.7	46.9	2.6	69.4	0.44
W_3	7.35	3930	2949	0.7	948	283	837	236	137	496	11.1	1151	48.7	-6.9	48.9	6.4	63.8	0.18
W_4	7.9	1135	1027	0.23	177	505	34	149	36	116	5.4	519	33.3	2.2	28.4	3.1	51.4	-0.04
W_5	7.6	1093	963	0.17	159	485	30	140	33	108	5.2	484	33.3	3.1	27.8	2.1	52.3	-0.08
W_6	7.75	1622	1388	1.25	184	451	297	69	32	347	6.5	304	71.5	4.4	43.4	8.6	84	-1.94
W_7	7.55	3920	2789	0.5	909	270	767	225	132	474	12.5	1102	48.7	-6.7	49.1	6.2	57.8	0.18
W_8	7.1	2750	1999	0.2	493	628	252	200	62	311	34.5	755	48.9	2.7	33.9	4.9	61.8	-0.04
W_9	7.34	2210	1580	1	447	438	228	176	57	215	10.7	672	41.8	0.4	34.6	3.6	62	0.24
W_{10}	7.65	1104	882	0.7	80	279	273	86	37	122	6	367	42.6	0.9	41.6	2.8	58	-1.43
W_{11}	7.46	1264	935	0.5	174	398	99	98	30	127	9.2	365	44.2	2.9	33.2	2.9	54.6	-0.18
W_{12}	7.56	1736	1372	1.3	236	442	287	131	51	216	7.9	538	47.1	1.9	39	4	52.3	-0.44
W_{13}	7.43	878	596	0.9	50	312	49	96	28	53	8.1	355	26.2	1.6	32.7	1.2	84.2	-0.79
W_{14}	7.34	677	507	1.2	58	270	25	68	18	60	8.1	243	36.5	2	29.6	1.7	65	-0.71
W_{15}	7.7	716	647	0.9	64	389	27	76	18	63	8.7	264	35.9	3.7	28.3	1.7	63.3	-0.64
W_{16}	7.88	764	570	0.8	40	329	23	69	33	68	8.4	307	34.1	2.3	44.1	1.7	43.8	-1.83
W_{17}	7.86	690	551	2.2	42	310	52	55	29	55	6.8	255	33.5	2.5	46.3	1.5	53.2	-1.18
W_{18}	7.67	589	531	2.3	24	341	11	76	32	40	5	321	22.7	2.4	40.6	1	53.3	-1.77
W_{19}	7.68	2730	2017	1.7	475	345	504	160	91	432	8.6	774	55.2	-2.1	48.4	6.8	58.5	-0.42
W_{20}	7.4	1713	1396	1.7	197	562	203	124	56	244	5.7	539	49.9	3.8	42.6	4.6	52.8	-0.93
W_{21}	7.58	1846	1440	1.2	305	345	315	183	72	200	7.7	753	37.2	-1.9	39.3	3.2	58.9	-0.03
W_{22}	7.86	2800	1667	1.5	397	535	97	176	93	357	10.3	824	48.9	0.5	46.6	5.4	63	-0.41
W_{23}	7.66	1383	1084	0.9	155	420	186	125	45	146	7	498	39.5	1.9	37.5	2.8	70	-0.49
W_{24}	7.63	849	692	1.4	78	319	83	85	34	82	7.9	354	34.7	1.7	39.9	1.9	59	-0.71
W_{25}	7.75	1477	1261	1.2	197	438	226	114	58	213	14.9	524	48	1.9	45.9	4	62.6	-0.74
W_{26}	7.59	2630	1831	0.7	430	504	249	194	76	366	9.6	797	50.4	0.3	39.1	5.6	56.9	-0.33
W_{27}	7.54	1926	1529	1	334	381	289	192	63	252	10.9	741	43.2	-1.2	35.2	4	55	-0.2
W_{28}	7.63	1367	1078	1.3	196	372	157	87	40	218	7.3	380	56	2.3	42.8	4.9	59.9	-0.75
W_{29}	7.15	3800	2818	0.5	970	257	792	214	133	439	10.5	1082	47.2	-6.7	50.7	5.8	59.7	0.29
W_{30}	7.7	2720	1815	0.4	536	363	316	112	96	382	9.8	674	55.6	-0.8	58.6	6.4	65.6	-0.12
W_{31}	7.85	2780	1918	0.8	572	195	519	109	89	425	10.1	636	59.6	-3.2	57.3	7.3	63.1	-0.16
W_{32}	7.5	3200	2528	0.5	646	482	566	269	112	437	12.5	1129	46.1	-3.4	40.6	5.7	52	-0.06
W_{33}	7.66	693	553	0.9	49	248	82	73	26	68	5.9	290	34.9	1.2	36.9	1.7	52.5	-1.25

Units: Ionic concentration in mg l^{-1}, except pH, EC (mS cm^{-1}), SAR (meq l^{-1}), RSC (meq l^{-1}), PI (meq l^{-1}), CIA (meq l^{-1}) and MH (%). MH= Magnesium Hazard, RSC=Residual sodium carbonate, SAR: Sodium absorption ratio, PI= Permeability index, CIA: Chloro - alkaline indices, TH: Total Hardness.

3. Materials and Method

Water quality parameters namely pH, EC, TDS, F, Cl, HCO_3, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, TH, Na %, RSC, MH, SAR, PI, CIA of 33 bore wells (Table 1) included in this study have been taken from [12] in part of NOIDA area. Factor analysis is a statistical data reduction technique whose general objective is to analyze interrelationship among a large number of variables and to explain these variables in terms of their common underlying factor. Factor analysis is capable of dealing with raw data consisting of hundreds or thousands of measurements and observations and resolves these into distinct patterns with a minimum loss of original information (e.g. [15,16,17]). It is a method for investigating whether a number of variables of interest Y1, Y2, : : :, Yl, are linearly related to a smaller number of unobservable factors F1, F2, : : :, Fk . There are three stages in the factor analysis, (a) generation of a correlation matrix for all the variables, (b) extraction of factors from the correlation matrix based on the correlation coefficients of the variables, and (c) rotation of these factors to maximize the relation between them and other variables (e.g. [18]). In practice, the first two or three factors are taken, which explain the reasonable percent of variance. In the present study, first three factors have been utilized which explains 79.30% of total variance. The interpretation of the Factors can be simplified by rotation of the factors. In the present study, correlation matrix of variables generated in the factor analysis is shown in Table 2. The varimax rotation of [19] was applied to obtain a simple structure with scores. Table 4 shows the rotated factor matrix of the three factors. The factor loadings correlate the factors and the variables. They represent the most important information on which the interpretation of factors is based. The contribution of each factor at every bore well (factor scores) is computed. Factor scores are projections of data onto corresponding eigenvectors. Factor scores can be thought of as the actual values of each well on the underlying factors. Factor scores were calculated using SPSS software for all 33 monitoring bore wells (Table 5).

4. Results and Discussion

The problem in the ground water quality study in an area for monitoring purpose is to reach a conclusion analyzing a large number of measured variables (e.g. [20]). Therefore, in this study, hydrochemical variables of ground water quality have been analyzed employing factor analysis. The correlation matrix of variables generated in the factor analysis is shown in Table 2. The eigenvalue, the percentage of variance, and the cumulative percentage of variance associated with each factor is given in Table 3, which shows that the first three factors explain approximately 79.30%of total variance. Table 4 shows the loadings of varimax rotated factor matrix for three factors.

[21] classified the factor loadings as "strong", "moderate", and "weak", corresponding to the absolute loading values of >0.75, 0.75-0.50 and 0.50-0.30, respectively. Factor 1, which explains 47.25 % of the total variance (Table 3), has strong positive loadings on Mg^{2+}, Cl^-, SO_4^{2-}, TH, EC, TDS, andNa^+, moderate loadings on Ca^{2+}, MH, CIA, and SAR. High positive loadings indicated strong linear correlation between the factors and parameters. The association of EC, TDS, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+} and Na^+ reflects the influence of salinity in the area and Factor 1 can be interpreted as a salinity factor because salinity is a measure of the amount of dissolved particles and ions (e.g. Na^+, Cl^- Mg^{2+},SO_4^{2-}) in water. The other frequently used measures of salinity are Total Dissolved Solids (TDS) and Electrical Conductivity (EC). Electrical conductivity is the ability of an electric current to pass through water is proportional to the amount of dissolved salts in the water – specifically, the amount of charged (ionic) particles. The Table 2 shows the correlation coefficient between EC and TDS is 0.986. The Figure 3 shows the distribution of score of Factor 1 and Figure 4 shows the distribution of TDS spatially, which are quite similar. Since TDS also shows a close positive relationship with Na^+, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^+ and TH parameters (Table 2), the variation in the TDS of the groundwater samples can be used to discuss the regional influence of salinity factor and its modifications locally by the specific field setting of the samples. The Table 5 shows the high Factor 1 score at borewells W_1, W_2, W_3, W_7, W_{29}, W_{31}, W_{32}, indicate severe groundwater salinization at these bore wells. Comparison of Figure 1 and Figure 2 (Landuse map) of the area reveal that high salinity bore wells are situated closed to or in built-up area and green area. This indicates that Irrigation return flows and anthropogenic activities such as over pumping are the main contributors of ions, especially Na^+, Cl^-, SO_4^{2-} and Mg^+, to the groundwater body in the study area. Semi-arid climate, gentle slope and occurrence of clay in the study area lead to sluggish drainage conditions, reflecting a longer residence time of water, and consequently, more effective water-rock interaction and higher solubility of mineral occur, such hydrological environments are the additional sources of salt in the groundwater. As the salinity process of Factor 1 is controlled by water-rock interaction and anthropogenic activity, Factor 1 is considered as lithogenic & anthropogenic controlled factors.

Table 2. Matrix of correlation coefficient for hydochemical variables of groundwater quality in parts of NOIDA area in India

	pH	EC	TDS	F	Cl^-	HCO_3	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	TH	Na%	RSC	MH	SAR	PI	CIA
pH	1.000	-0.335	-0.359	0.259	-0.371	-0.065	-0.342	-0.370	-0.198	-0.224	-0.451	-0.297	-0.055	0.211	0.211	-0.091	-0.024	-0.379
EC		1.000	0.986	-0.366	0.976	-0.011	0.892	0.832	0.944	0.937	0.450	0.925	0.502	-0.799	0.574	0.759	0.062	0.677
TDS			1.000	-0.371	0.972	0.023	0.923	0.839	0.924	0.940	0.433	0.918	0.519	-0.777	0.531	0.773	0.047	0.659
F				1.000	-0.412	-0.059	-0.286	-0.443	-0.301	-0.250	-0.371	-0.387	-0.067	0.316	0.138	-0.167	0.002	-0.553
Cl^-					1.000	-0.135	0.918	0.821	0.945	0.880	0.415	0.920	0.403	-0.859	0.549	0.678	0.033	0.714
HCO_3						1.000	-0.289	0.145	-0.170	0.055	0.300	-0.012	0.198	0.505	-0.372	0.141	-0.008	0.030
SO_4^{2-}							1.000	0.691	0.870	0.861	0.268	0.813	0.478	-0.840	0.603	0.705	0.060	0.521
Ca^{2+}								1.000	0.840	0.668	0.462	0.960	0.108	-0.757	0.177	0.416	-0.097	0.785
Mg^{2+}									1.000	0.831	0.338	0.959	0.304	-0.909	0.647	0.606	0.006	0.667
Na^+										1.000	0.350	0.781	0.735	-0.639	0.630	0.925	0.117	0.488
K^+											1.000	0.417	0.183	-0.204	0.053	0.246	0.074	0.392
TH												1.000	0.214	-0.868	0.428	0.531	-0.047	0.756
Na%													1.000	-0.076	0.489	0.914	0.244	0.051
RSC														1.000	-0.545	-0.383	0.045	-0.645
MH															1.000	0.597	0.063	0.068
SAR																1.000	0.236	0.270
PI																	1.000	-0.042
CIA																		1.000

Table 3. Eigenvalues, percent of variance, cumulative eigenvalue for the factor analysis of hydrochemical variables of groundwater

Factor	Eigenvalue	Percent of variance	Cumulative percent of variance
1	9.92200	55.12300	55.12
2	2.39100	13.28200	68.41
3	1.96100	10.89600	79.30
4	1.03000	5.72300	85.02
5	0.80300	4.46200	89.49
6	0.70000	3.88900	93.37
7	0.59500	3.30700	96.68
8	0.26200	1.45600	98.14
9	0.16800	0.93200	99.07
10	0.07474	0.41500	99.48
11	0.05194	0.28900	99.77
12	0.01782	0.09899	99.87
13	0.01212	0.06732	99.94
14	0.00716	0.03976	99.98
15	0.00342	0.01900	100.00
16	0.00043	0.00238	100.00
17	0.00001	0.00006	100.00
18	0.00001	0.00003	100.00

Table 4. Eigenvalues, percent of variance, cumulative eigenvalue for the factor analysis of hydrochemical variables of groundwater

Variable	Factor 1 (loadings)	Factor 2 (loadings)	Factor 3 (loadings)
pH	-0.175	-0.615	0.044
EC	**0.880**	0.325	0.322
TDS	**0.864**	0.347	0.340
F	-0.270	-0.593	0.103
Cl^-	**0.919**	0.303	0.192
HCO_3	-0.419	**0.607**	0.420
SO_4^{2-}	**0.908**	0.098	0.244
Ca^{2+}	**0.744**	**0.577**	-0.046
Mg^{2+}	**0.956**	0.172	0.113
Na^+	**0.773**	0.191	0.583
K^+	0.194	**0.681**	0.193
TH	**0.885**	0.392	0.035
Na%	0.256	0.000	**0.912**
RSC	-0.970	-0.039	0.190
MH	0.676	-0.471	0.382
SAR	0.548	0.076	**0.808**
PI	-0.051	-0.028	0.403
CIA	0.620	**0.587**	-0.166
Eigenvalue	8.51	3.02	2.76
Percent of variance	47.25	16.75	15.30
Cumulative percent	47.25	64.00	79.30

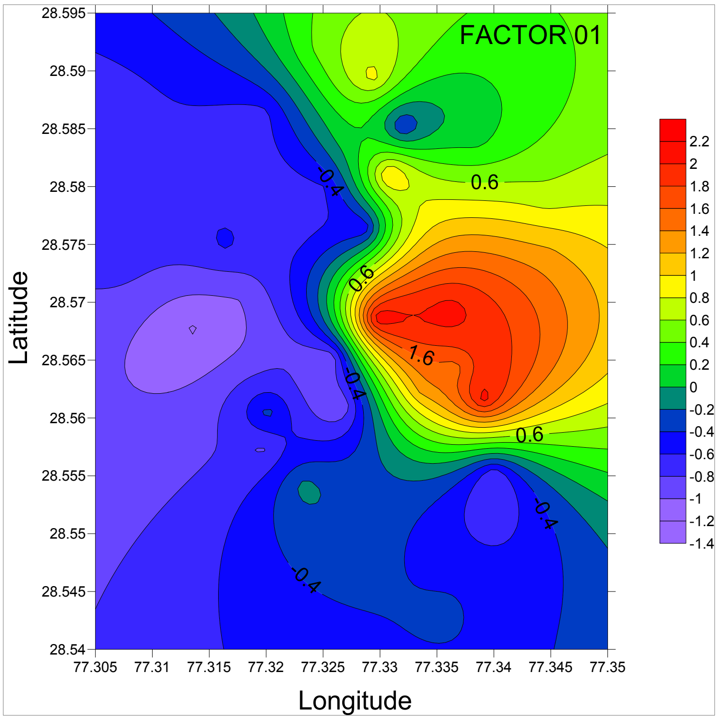

Figure 3. Spatial distribution of scores of Factor 1, using Surfer Golden Software

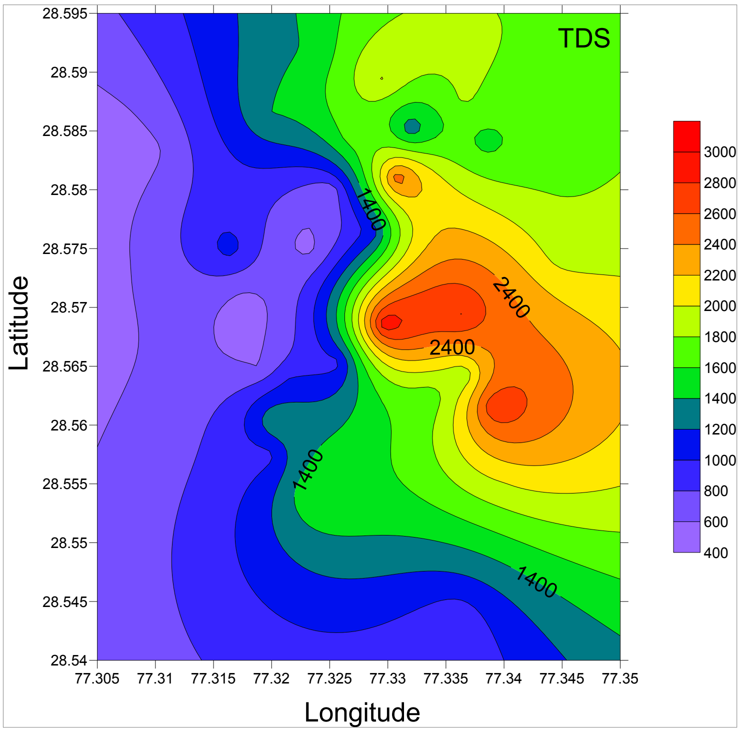

Figure 4. Spatial distribution of Total Dissolved Solid (TDS)

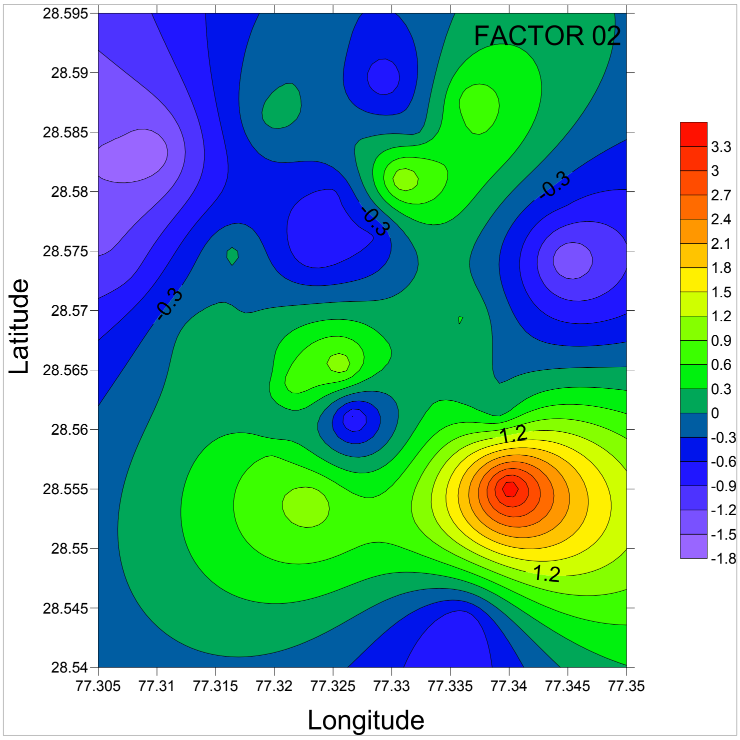

Figure 5. Spatial distribution of scores of Factor 2

Factor 2 explains 16.75 % of the total variance (Table 2) with moderate positive loadings on K^+, HCO_3, CIA and Ca^{2+}. Factor 2 can be identified with the processes of alkalinity due to agricultural and domestic pollution. Potassium is an important fertilizer, held by clay particles in soil and leaches into the groundwater through the soil profile. Potassium is also common in many rocks. Many of these rocks are relatively soluble and potassium concentrations in groundwater increase with time. The bicarbonates are derived mainly from the dissolution of carbonates and/or silicate minerals by carbonic acid and from the soil zone CO_2. The soil zone in the subsurface environments contains elevated CO_2 pressures (produced as a result of decay of organic matter and root respiration), which in turn combines with rainwater to form bicarbonate. During recharge, the waters absorb large amounts of CO_2, which converts to HCO_3 in the weathering reactions (e.g. [22]). Such reaction can lead to enhance the pH of ground water. The pH of the analyzed samples in the study area varies from 7.1 to 7.9 indicating alkaline nature of the water. Here, soils appear to play a major role on the process of alkalinity and hence, Factor 2 is considered as a lithogenic controlled factor. Alkalinity was mainly contributed by bicarbonate ions which range from 195 mg/l to 628 mg/l in the studied samples. [23] reported that concentration of bicarbonates more than 200 mg/l is common to groundwater. However, relatively higher concentration (>300mg/l) at certain sites can be attributed tothe dissolution of carbonates due to carbonic acid formed as a result of infiltrating carbon dioxide. The high Factor 2 score at wells W_5, W_8, W_9, W_{32}, indicate influence of alkalinity at these wells. The Figure 5 shows the distribution of score of Factor 2 and Figure 6 shows the distribution of HCO_3 spatially, which are quite similar. The correlation of Figure 5 with the Figure 2 (Landuse map) of the area shows that these wells are situated in built up area and open area.

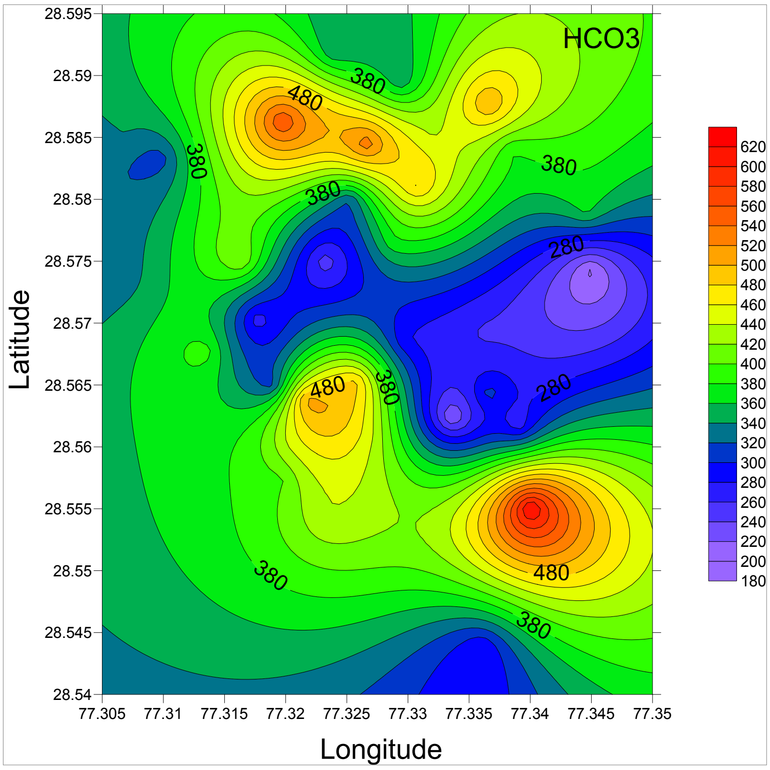

Figure 6. Spatial distribution of HCO_3

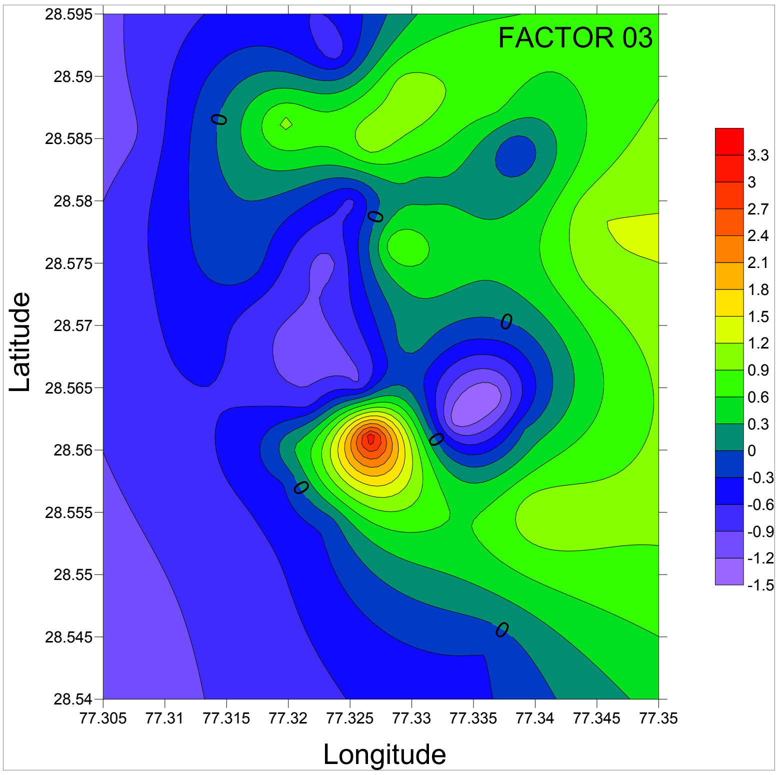

Figure 7. Spatial distribution of scores of Factor 3

Factor 3 explains 15.30 % of the total variance (Table 2) with strong positive loadings on Na% and SAR, moderate loadings on Na^+. Factor 3 is related to the modified recharge through anthropogenic activity of sewage pollution. The correlation coefficient between Na% and SAR is 0.914 and that of Na% and Na^+ is 0.735, between SAR and Na^+ is .925. The Factor 3 shows high factor score at bore wells W_6, W_8, W_{19}, W_{20}, W_{22}, W_{30}, W_{31}which record an increase in sodium (Table 1) in groundwater above ambient or natural levels may indicate pollution from point or non-point source. All groundwater contains some sodium because most rocks and soils contain sodium compounds from which sodium is easily dissolved. There are many important anthropogenic sources for elevated sodium levels in groundwater (e.g. Erosion of salt deposits and sodium bearing rock minerals, groundwater pollution by sewage effluent, irrigation and precipitation leaching through soils high in sodium, infiltration of leachate from landfills or industrial sites, infiltration of surface water contaminated by road salt, etc). The Figure 7 shows the distribution of score of Factor 3 and Figure 8 shows the distribution of Na % spatially, which are quite similar. The comparison of Figure 7 with the Figure 2 (Landuse map) of the area shows that these wells are situated in built up area. This indicates that sodium may reach groundwater as a result of residential, commercial and industrial activity. Since Sodium is more mobile in soil than potassium and so it is used often as an indicator of human impacts to shallow ground water. Since there is no lithological impact on the pollution activity, Factor 3 is considered as anthropogenic controlled factor.

Table 5. Factor score matrix of three factors

Bore Well	Factor 1 (Score)	Factor 2 (Score)	Factor 3 (Score)
W_1	**1.270**	0.293	-1.445
W_2	**1.500**	0.114	-1.466
W_3	**2.148**	0.200	0.170
W_4	-0.774	0.790	-0.761
W_5	-0.914	**1.109**	-0.932
W_6	-0.968	-0.966	**3.322**
W_7	**2.086**	0.058	0.016
W_8	-0.803	**3.599**	**1.154**
W_9	-0.131	**1.104**	-0.190
W_{10}	-0.369	-0.918	-0.293
W_{11}	-0.838	0.690	-0.291
W_{12}	-0.324	0.082	0.253
W_{13}	-0.915	0.079	-0.811
W_{14}	-1.002	-0.035	-0.795
W_{15}	-1.221	0.202	-0.499
W_{16}	-0.677	-1.098	-0.751
W_{17}	-0.605	-1.736	-0.573
W_{18}	-0.748	-1.425	-1.033
W_{19}	0.869	-0.845	**1.059**
W_{20}	-0.668	0.121	0.998
W_{21}	0.373	-0.013	-0.766
W_{22}	0.111	-0.024	**1.108**
W_{23}	-0.565	0.057	-0.038
W_{24}	-0.601	-0.634	-0.693
W_{25}	-0.423	-0.133	0.738
W_{26}	0.074	0.792	0.752
W_{27}	0.131	0.530	-0.323
W_{28}	-0.535	-0.607	0.913
W_{29}	**2.099**	0.326	-0.206
W_{30}	0.701	-0.559	**1.181**
W_{31}	**1.241**	-1.481	**1.072**
W_{32}	**1.078**	**1.207**	0.167
W_{33}	-0.601	-0.880	-1.037

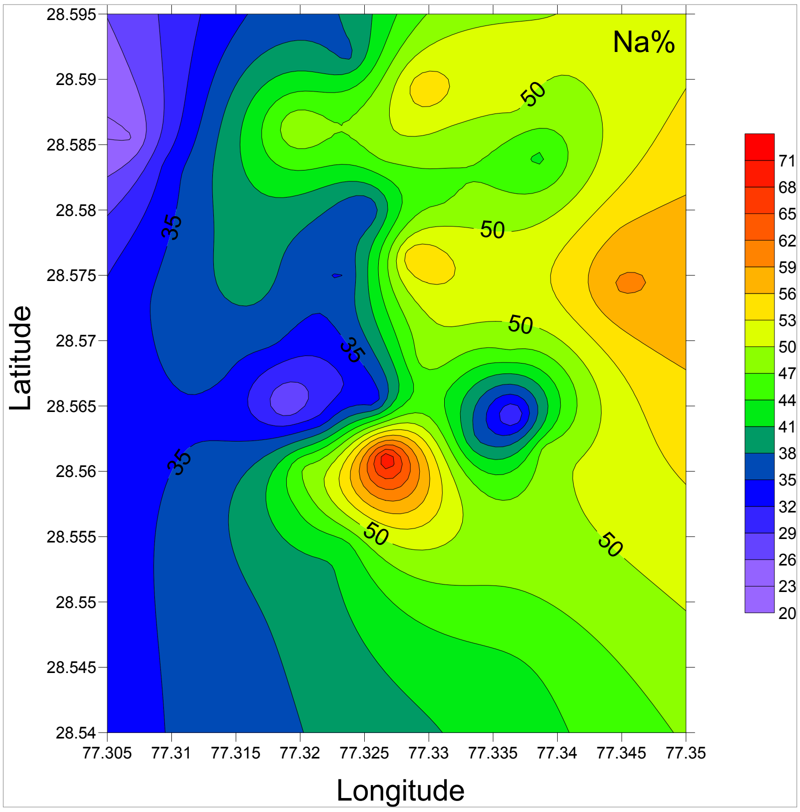

Figure 8. Spatial distribution of Na %

5. Conclusion

Factor analysis techniques can be effectively used for manipulating, interpreting, and representing data concerning groundwater contaminants. This statistical technique is an effective way of delineating grouping in the data and knowing the main factors (e.g. environmental or anthropogenic) influencing the groundwater quality. Factor analysis was applied to groundwater samples from an area of NOIDA. The extraction of three factors explains 79.30 % of the total variance in the groundwater quality data set. Factor 1 is identified as salinity, Factor 2 as alkalinity and Factor 3 as pollution processes. The Factor 1, 2 and 3 are described as lithogenic & anthropogenic controlled factor, lithogenic controlled factor and anthropogenic controlled factor, respectively. The geographical distribution of the factor scores at individual bore wells delineated boundaries, which define where groundwater is affected by salinization, alkalinity and pollution and inferred that Factor1 may be related to the regional flow system of groundwater. The over-pumping of groundwater causes land subsidence and gradual salinization of the local groundwater. The Over extraction of groundwater is the major cause of groundwater salinization, Factor 2 may be related to the pathways of recharge through soil zones, and Factor 3 may be related to the modified recharge through soil anthropogenic activity of the agricultural and urban waste. This study suggests that salinity and pollution are the main factors affecting the quality of groundwater in this area. Hence for proper management of groundwater requires rainwater harvesting and water softening techniques to reduce the salinity. The pollution to the groundwater can be minimized by making proper drainage in the area. The methodology adopted in this study can be successfully applied in other areas for groundwater quality studies for scientific planning of groundwater resources.

References

[1] Subramanian, V., *Water: quantity-quality perspectives in South Asia*, Kingston International Publishers, Surrey, 2000.

[2] Kumarsen, M., Riyazddin, P., "Major ion chemistry of environmental samples around sub-urban of Chenai city," *Current Science*, 9, 1668-1677, 2006.

[3] Mohan, R., Singh, A.K., Tripathi, J.K., Chaudhary, G.C., "Hydrochemistry and quality assessment of groundwater in Naini industrial area, District Allahabad, Uttar Pradesh," *Jour. Geol. Soc. India*, 55, 77-89, 2000.

[4] Kumar, M., Ramanathan, A.L., Rao, M., Kumar, B., "Identification and evaluation of hydrogeochemical processes in the groundwater environment of Delhi, India," *Environ. Geol.*, 50, 1025-1039, 2006.

[5] Ramesh, R., Shivkumar, K., Eswaramoorthi, S., Puryaja, G.R., "Migration and contamination of major and trace element in groundwater of Madras city," *India. Environ. Geol.*, 25, 126-136, 1995.

[6] Singh, A.K., Mondal, G.C., Singh, P.K., Singh, S., Singh, T.B., Tewary B.K., "Hydrochemistry of reservoirs of Damodar River basin, India: weathering processes and water quality assessment," *Environ. Geol.*, 8, 1014-1028, 2005.

[7] Singh, A.K., Mondal, G.C., Singh, S., Singh, P.K., Singh, T.B., Tewary, B.K., Sinha, A.K., "Aquatic Geochemistry of Dhanbad District, Coal City of India: Source Evaluation and Quality Assessment," *Jour. Geol. Soc. India*, 69, 1088-1102., 2007.

[8] Mazlum, N., Ozer A., Mazlum, S., "Interpretation of water quality data by principal components analysis," *Turkish Jour. Engg. Environ. Sci.*, 23, 19-26, 1999.

[9] Reghunath, R., Murthy, T.R.S., Raghavan, B.R., "The utility of multivariate statistical techniques in hydrochemical studies: an example from Karnataka, India," *Water Res.*, 36, 2437-2442, 2002.

[10] Kazi, T.C., Arain, M.B., Jamali, M.K., Jalbani, N., Afridi, H.I., Sarfraz, R.A., Baig, J.A., Shah, A.Q., "Assessment of water quality of polluted lake using multivariate statistical techniques: A case study," *Ecotoxicology and Environmental Safety*, 72(2), 301-309, 2009.

[11] Wadia, D.N., *Geology of India*, Macmillan, London, 1980.

[12] Singh, A.K., Tewary, B.K., Sinha, A., "Hydrochemistry and Quality Assessment of Groundwater in Part of NOIDA Metropolitan City, Uttar Pradesh," *Journal Geological Society of India,* 78, 523-540, 2011.

[13] Krishana, M.S. *Geology of India and Burma.Madras*, CBS Publishers and Distributors, Delhi, 1982.

[14] Ramakrishnan, M., Vaidyanadhan, R., *Geology of India,* Geological Society of India, Bangalore, 2008.

[15] Hair, J.F., Anderson, R.E., Tatham, R.L., *Multivariate Data Analysis,* 3rd edition., Macmillan, New York, 1992.

[16] Helena, B., Pardo, R., Vega, M., Barrado, E., Fernandez, J.M., Fernandez, L., "Temporal evolution of groundwater composition in an alluvial aquifer (Pisuerga River, Spain) by principal component analysis," *Water Research,* 34, 807-816, 2000.

[17] Shrestha, S., Kazama, F., "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, 2007.

[18] Gupta, A.K., Gupta, S.K., Patil R.S., "Statistical analyses of coastal water quality for a port and harbour region in India," *Environ. Monit. Asses.,* 102, 179-200, 2005.

[19] Kaiser, H.F., "The varimax criteria for analytical rotation in factor analysis," Psychometrika 23(3), 187-200, 1958.

[20] Saffran, N.K., Cash, K., Hallard, K., *Canadian water quality guidelines for the protection of aquatic life. CCME water quality Index 1.0. User Manual*, Canadian, 2001.

[21] Liu, C.W., Lin, K.H., Kuo, Y.M., "Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan," Science of the Total Environment, 313, 77-89, 2003.

[22] Jacks, G., "Chemistry of groundwater in a district in Southern India," *Journal of Hydrology*, 18, 185-200, 1973.

[23] Matthess, G., *The properties of groundwater,* Wiley, New York, 1982.