

# STUDIES ON SEASONAL VARIATION OF GROUND WATER QUALITY USING MULTIVARIATE ANALYSIS FOR BIDAR URBAN & ITS INDUSTRIAL AREA (KARNATAKA-STATE, INDIA)

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## Abstract

In this study the seasonal variability of groundwater quality parameters in Bidar urban and its industrial area are investigated. Three water samples each from 35 wards were collected and subjected for physico-chemical analysis. Average of the three samples represents each ward data. Analysis was done for pre-monsoon and post-monsoon seasons of the years 2009, 2010 & 2011. Seventeen physico-chemical parameters viz., pH, total hardness, calcium, magnesium, chloride, nitrate, sulfate, total dissolved solids, iron, fluoride, sodium, potassium, alkalinity, manganese, zinc, dissolved oxygen & total solids were analyzed. Factor analysis is applied on the data set to investigate the origin of the water pollution sources. FA yielded three factors for each season (combined pre-monsoon & combined post-monsoon) with 62.8% and 61.6 % total variance respectively; in addition FA identifies anthropogenic factor (i.e., industrial, urban sewage and agricultural drainage) and natural factor (top soil mixture with water and percolation, weathering of ground strata) as latent pollution sources. Hierarchical cluster analysis grouped 35 sampling stations of Bidar urban into three clusters, i.e., relatively less polluted (LP), and moderately polluted (MP) and highly polluted (HP) sites, based on the similarity of water quality characteristics.

**Keywords:** Bidar urban & its industrial area, Ground water quality, Correlation coefficients, Factor analysis, Cluster analysis.

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## 1. INTRODUCTION

Urbanization and industrial development in the developing countries during the last decade have provoked some serious concern for the environment [1]. Human activities such as intensive agriculture around the outskirts of cities, urbanization and industrialization contribute to ground water deterioration [2]. Ground water quality in cities is a matter of serious concern. Ground water due to the percolation of the domestic and industrial wastewater and run-off from agricultural land are among the most vulnerable water bodies to pollution [3]. A groundwater system carrying the one-way of a significant load of matter both natural and anthropogenic sources [4]. Groundwater is heterogeneous at different spatial scale which may be attributed to a number of factors including anthropogenic input, biomass characteristic, weathering of crustal minerals, local environmental conditions, wastewater discharges, and wastewater percolations [5, 6]. Bidar city and its industrial area is located between Latitude 17° 35' N and Longitude 77° 32' E, is the northern most city in Karnataka State, India. Its elevation is about 664 m above the mean sea level. The climate of Bidar and its environs is reported to be pleasant and is relatively cooler when compared to the

temperatures in the neighboring districts of Karnataka. The average annual rainfall as recorded in the previous years is 916.508 mm, 919.630 mm; the monsoon period is over four months i.e. between June to September. The highest rainfall recorded during the above period is 925.05 mm in July month. The average maximum temperature of 43° C is recorded during the period 1963 to 1979 is in the month of May. The maximum temperature however varies from 39° C to 43° C during the months of February to June and falls to 18° C during November and December month. The mean annual maximum humidity observed in the morning was 62.72 % and the minimum observed in the evening was 43.7 %. Humidity will be least during the month of May. During summer the predominant wind direction is westerly, during the monsoon seasons wind blows in Southwesterly directions and during the winter seasons, the predominant wind direction is Southeasterly. Bidar urban plateau is of irregular shape, land stretching about 35.4 Km in length and 19.3 Km in width. The plateau consists of red laterite rocky crust, of a depth varying from 30.5 m to 152.4 m supported on impervious trap base. This has resulted in springs at the cleavages between trap and laterite rocks. Such water springs can be observed in Bidar as Gurunanak Zheera, Narasimha Zheera, Papanasha Shiva

Temple and a few other places. The lands in Bidar and its environs drains into Manjra River (which flows in the region) is a tributary of Godavari River. The major soil types are, Red laterite soil, Black cotton soil and a combination of the above two types. The commonly used building materials (laterite stones) can be easily cut from laterite soil, once they are cut and exposed to the atmosphere, it gets harder. Ground water

levels during pre-monsoon are between 2.81 m to 17.9 m bgl and during post-monsoon between 0.4 m to 13.09 m bgl (Groundwater information booklet 2008). Bidar urban map and its location map are presented in Figure 1 and Figure 2. The study is aimed to identify the natural and anthropogenic factors controlling the variation of ground water quality using factor analysis & cluster analysis.

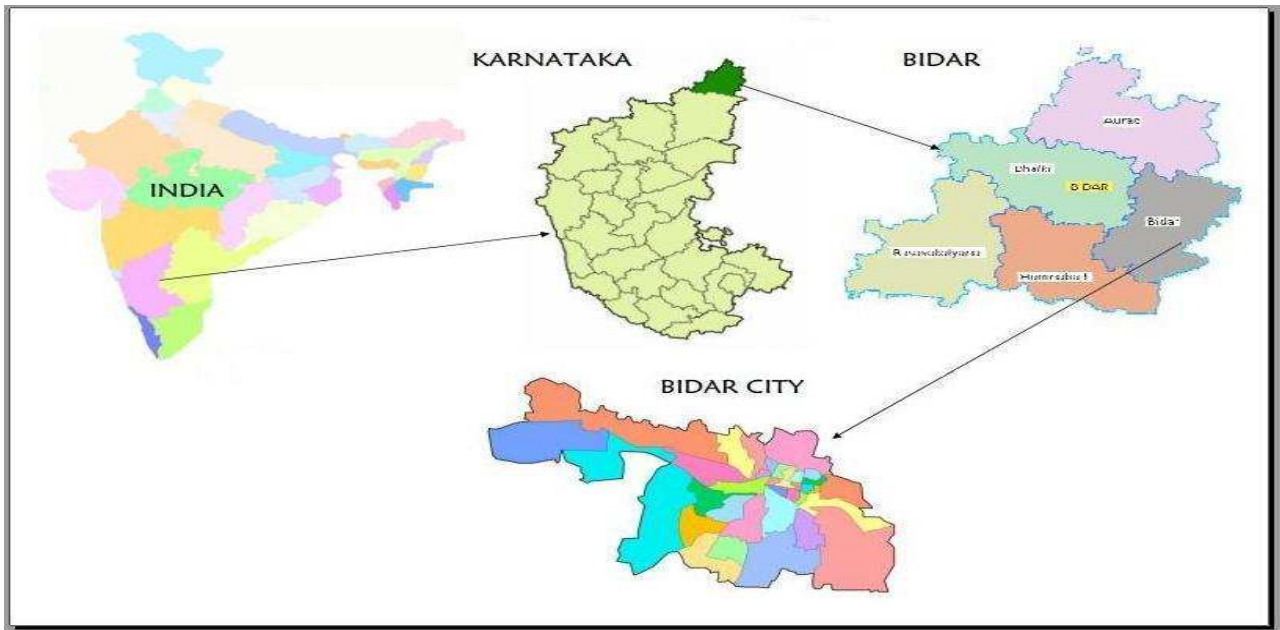


Fig1: Showing the Location of Bidar City

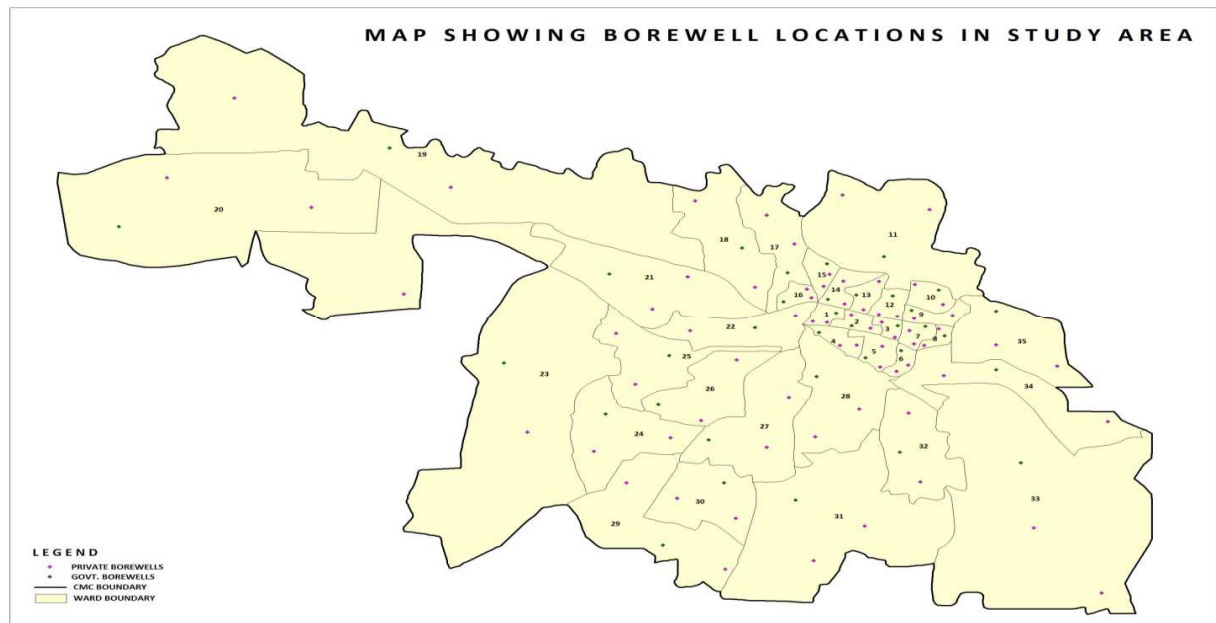


Fig2: Bidar City map showing wards and sampling locations

## 2. MATERIALS AND METHODS

### 2.1 Water Sampling and Analytical Procedures

From each ward 3 samples, one government bore well and two residential owners bore wells water collected and analyzed so as to cover entire ward, afterwards the results average value taken to represent the particular ward. Such 35 wards analyzed covering each season (i.e., pre-monsoon & post-monsoon) for the 3 years during 2009, 2010 & 2012 Total Solids (TS), Total dissolved Solids (TDS) analyzed by gravimetric method, pH by pH meter (Elico Hyderabad Make). Total hardness (TH) and  $\text{Ca}^{2+}$  as  $\text{CaCO}_3$  by using standard EDTA,  $\text{Mg}^{2+}$  was calculated by taking the differential value between TH and  $\text{Ca}^{2+}$  concentrations.  $\text{Na}^+$  and  $\text{K}^+$  was measured using flame photometer. Total alkalinity as  $\text{CaCO}_3$  which is totally  $\text{HCO}_3^-$  as  $\text{CO}_3^{2-}$  is totally absent in the entire Bidar water samples, was estimated by titrating with  $\text{H}_2\text{SO}_4$ .  $\text{Cl}^-$  was determined by titrating with standard  $\text{AgNO}_3$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ , F-, Fe, Manganese (Mn), and Zinc (Zn) were analyzed by Spectrophotometer (Elico Hyderabad Make). Dissolved oxygen (DO) analyzed by Winkler's with azide modification method for statistical analysis MINITAB software is utilized.

### 2.2 Factor Analysis

Factor analysis is a very powerful technique which provides information on the meaningful parameters which describe the whole data set rendering data reduction with minimum loss of information [6]. Factor Analysis is a quantification of the significance of variables that explain the observed grouping and patterns of the inherit properties of the individual objects [7]. Factor Analysis allows the explaining of related parameters by only one factor [6, 7, and 8]. FA exposes the important factor responsible for variation in ground water quality and eventually leads to sources identification of ground water pollution. In this study, FA was applied to extract the most significant factors and to reduce the contribution of less significant variables to simplify even more of the data structure coming from factor analysis. The factors obtained were further subjected to varimax rotation according to well established

rules to maximize differences between the variables and facilitate easy interpretation of the data [3, 4, and 6]. The rotating axis defined by factor analysis generates varimax factor (Factor1, Factor2....) which can further reduce the contribution of variable with minor significance.

### 2.3 Cluster Analysis

Cluster analysis is a major technique for classifying a mountain of information into manageable meaningful piles. It is a data reduction tool that creates subgroups that are more manageable than individual datum. In cluster analysis there is no prior knowledge about which elements belong to which clusters. The grouping or clusters are defined through an analysis of the data. Hierarchical CA, the most common approach, starts with each case in a separate cluster and joins the clusters together step by step until only one cluster remains [19, 20]. The Euclidean distance usually gives the similarity between two samples, and a distance can be represented by the difference between transformed values of the samples [21].

There are four basic cluster analysis steps:

1. Data collection and selection of the variables for analysis
2. Generation of a similarity matrix
3. Decision about number of clusters and interpretation
4. Validation of cluster solution

## 3. RESULTS AND DISCUSSIONS

Summary of physico-chemical analysis of ground water of the study area for the combined pre-monsoon and post-monsoon 2009, 2010 & 2011 values are presented in the Tables 1 & 2. Also correlation coefficients for combined pre-monsoon and post-monsoon are worked out and presented in Tables 3 & 4. From the correlation table of pre-monsoon season, it is evident that a positive correlation ( $> 0.67$ ) existed between Ca-TH, Mg-TH, Na-pH, & TS- $\text{SO}_4$  such waters have permanent hardness and solubility of minerals. During post-monsoon season, positive correlation existed between Mg-TH, Na-TH & TS- $\text{SO}_4$  which indicates only permanent hardness.

**Table 1:** Summary of combined season-wise physico- chemical composition of groundwater samples collected from the study area (covering all the 35 wards)

Chemical constituents	Combined Pre-monsoon of 2009, 2010 & 2011				
	Min	Max	Mean	$\sigma$	CV
pH	7.31	7.94	7.61	0.156	2.05
TH	101	120	108.77	4.685	4.27
$\text{Ca}^{2+}$	80.9	92.1	85.91	2.643	3.076
$\text{Mg}^{2+}$	18.35	28.25	22.87	2.63	11.5
$\text{Cl}^-$	52.85	176.2	154.73	20.848	13.47
TDS	230.5	504.5	427.43	47.77	11.17
Fe+	0.152	0.415	0.30	0.57	19.0
F-	0.29	0.52	0.38	0.049	12.89
$\text{NO}_3^-$	16.3	24.6	20.91	1.688	8.07
$\text{SO}_4^{2-}$	21.7	34.5	27.33	4.456	18.3

Na+	95.5	114.1	102.22	5.647	5.51
K+	20.75	34.1	23.22	2.854	12.29
HCO <sub>3</sub> <sup>-</sup>	63.95	91.7	84.62	7.96	9.406
Mn	0.026	0.148	0.09	0.026	2.88
Zn	2.14	3.15	2.42	0.211	8.72
DO	5.4	5.9	5.71	0.138	2.42
TS	440.5	618.8	532.42	56.835	10.67

**Table 2:** Summary of combined season-wise physico- chemical composition of groundwater samples collected from the study area (covering all the 35 wards)

Chemical constituents	Combined Post-monsoon of 2009, 2010 & 2011				
	Min	Max	Mean	$\sigma$	CV
pH	7.44	7.84	7.71	0.117	15.17
TH	111.7	128.8	121.0	5.260	4.35
Ca <sup>2+</sup>	85.15	96.2	91.7	2.013	2.19
Mg <sup>2+</sup>	21.5	36.6	29.29	4.288	14.64
Cl <sup>-</sup>	72.0	184.0	164.08	19.36	11.79
TDS	411.1	528	457.93	29.751	6.49
Fe <sup>+</sup>	0.2	0.48	0.35	0.057	16.28
F <sup>-</sup>	0.33	0.56	0.42	0.051	12.14
NO <sub>3</sub> <sup>-</sup>	17.6	28	23.28	2.076	8.92
SO <sub>4</sub> <sup>2-</sup>	24.5	36.1	29.38	4.072	13.80
Na <sup>+</sup>	98.8	121.8	110.68	5.143	4.64
K <sup>+</sup>	22.85	30.7	25.34	2.828	11.16
HCO <sub>3</sub> <sup>-</sup>	66	98.3	88.49	8.167	9.22
Mn	0.041	0.193	0.11	0.034	30.9
Zn	2.29	3.33	2.71	0.310	11.44
DO	5.3	5.8	5.73	0.12	2.09
TS	490	648.5	568.14	46.727	8.21

### 3.1 Water Pollution Sources Identification

Factor Analysis was applied on the data set to identify the spatial sources of pollution in groundwater. According to Eigen value criterion, only factors with Eigen value greater than one are considered essential and important. Additional factors provide marginally less explanatory capability and were not examined further. In statistics, Kaiser-Meyer-Olkin's (KMO) measure of sampling adequacy: This is an index used to examine the appropriateness of Factor Analysis. High values of F1, F2... (0.5 to 1.0) indicates FA is appropriate. Below (< 0.5) implies Factor Analysis as inappropriate. According to the Kaiser criterion, only the first three factor groups could be used, because subsequent Eigen values are less than 1. Three factors were obtained with Eigen value greater than one with total variance of 62.8% & 61.6%; these are considered

responsible for the variation in the ground water system. Scree plot is graph of Eigen values against Y-axis versus Factor numbers against X-axis. Here Factor numbers with Eigen values less than 1 value are discarded and above 1 value are only considered. Scree plots for factor analysis are given in Fig No. 3 & Fig No. 4 (Data of combined Pre-monsoon & Post-monsoon seasons of years 2009, 2010 & 2011). Table 5 & Table 6 (Data of combined Pre-monsoon & Post-monsoon seasons of years 2009, 2010 & 2011) presents the factor analysis of the 17 physico-chemical parameters which constituted three factors explaining about 62.8% & 61.6% of the total variance respectively. The classification of the factor loading as 'strong', 'moderate' and 'weak' corresponds to absolute loading of > 0.75, 0.75-0.50 and 0.50-0.30, respectively [22].

**Table 3:** Correlation coefficients for the season wise combined physico-chemical composition of groundwater samples collected from the study area (covering all the 35 Wards) for the Pre-Monsoon periods of years 2009, 2010 & 2011

	pH	TH	Ca	Mg	Cl	TDS	Fe	F	NO3	SO4	Na	K	Alk	Mn	Zn	DO	T S
pH	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TH	0.533	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ca	0.469	0.857	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mg	0.470	0.905	0.562	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cl	0.065	0.217	0.125	0.262	--	--	--	--	--	--	--	--	--	--	--	--	--
TDS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.275	0.052	0.036	0.093	0.020	--	--	--	--	--	--	--	--	--	--	--	--
Fe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.417	0.103	0.243	0.030	0.297	0.252	--	--	--	--	--	--	--	--	--	--	--
F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.260	0.357	0.174	0.428	0.515	0.321	0.458	--	--	--	--	--	--	--	--	--	--
NO3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.666	0.444	0.297	0.480	0.380	0.322	0.061	0.510	--	--	--	--	--	--	--	--	--
SO4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.549	0.311	0.273	0.286	0.560	0.147	0.312	0.401	0.487	--	--	--	--	--	--	--	--
Na	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.672	0.620	0.441	0.631	0.461	0.260	0.023	0.552	0.639	0.641	--	--	--	--	--	--	--
K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.454	0.207	0.226	0.141	0.418	0.009	0.205	0.276	0.351	0.521	0.629	--	--	--	--	--	--
Alk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.324	0.053	0.030	0.054	0.312	0.345	0.035	0.523	0.527	0.324	0.182	0.256	--	--	--	--	--
Mn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.176	0.096	0.087	0.090	0.121	0.208	0.126	0.008	0.092	0.037	0.146	0.124	0.254	--	--	--	--
Zn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.006	0.235	0.036	0.343	0.148	0.329	0.318	0.280	0.214	0.062	0.086	0.289	0.053	0.241	--	--	--
DO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.277	0.182	0.170	0.155	0.324	0.122	0.204	0.442	0.229	0.587	0.456	0.649	0.151	0.118	0.153	--	--
TS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.399	0.375	0.429	0.252	0.538	0.259	0.156	0.367	0.332	0.741	0.599	0.641	0.098	0.063	0.178	0.627	--

**Table 4:** Correlation coefficients for the season wise combined physico-chemical composition of groundwater samples collected from the study area (covering all the 35 Wards) for the Post-Monsoon periods of years 2009, 2010 & 2011

	pH	TH	Ca	Mg	Cl	TDS	Fe	F	NO3	SO4	Na	K	Alk	Mn	Zn	DO	TS
pH	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TH	0.468	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ca	0.463	0.610	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mg	0.353	0.938	0.297	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cl	0.154	0.072	0.131	0.040	--	--	--	--	--	--	--	--	--	--	--	--	--
TDS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.152	0.186	0.001	0.222	0.011	--	--	--	--	--	--	--	--	--	--	--	--
Fe	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.413	0.052	0.337	0.093	0.340	0.123	--	--	--	--	--	--	--	--	--	--	--
F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.207	0.294	0.058	0.330	0.479	0.341	0.509	--	--	--	--	--	--	--	--	--	--
NO3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.600	0.531	0.436	0.446	0.323	0.347	0.037	0.449	--	--	--	--	--	--	--	--	--
SO4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.529	0.181	0.388	0.048	0.505	0.232	0.279	0.349	0.393	--	--	--	--	--	--	--	--
Na	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.631	0.701	0.423	0.657	0.228	0.431	0.057	0.506	0.723	0.401	--	--	--	--	--	--	--
K	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.427	0.120	0.324	0.005	0.423	0.020	0.166	0.221	0.192	0.462	0.335	--	--	--	--	--	--
Alk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.450	0.071	0.054	0.056	0.415	-	0.061	0.479	0.567	0.403	0.373	0.277	--	--	--	--	--

						0.280												
Mn	0.118	-	-	0.041	-	0.003	0.183	0.172	0.123	0.046	0.121	0.005	-	0.036	0.265	--	--	--
Zn	0.050	-	-	0.506	0.142	0.367	0.300	0.248	0.291	-	0.011	0.337	0.383	0.014	0.326	--	--	--
DO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.07	-	-
	0.300	0.102	0.076	0.088	0.200	0.065	0.160	0.370	0.136	0.412	0.222	0.532	0.199	0.194	0.16	0.43	--	
TS	0.491	0.199	0.439	0.050	0.538	0.033	0.007	0.411	0.222	0.727	0.367	0.629	0.242	0.106	1	5	--	

Scree Plot of C1-C17

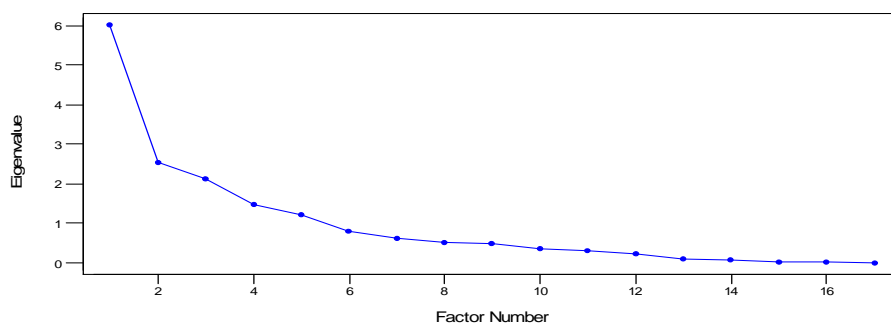


Fig3: Screen Plot for the combined data of pre-monsoon 2009, 2010 & 2011

Table 5: Factor Analysis (for Combined Data of Pre-Monsoon 2009, 2010 & 2011) (Rotated Factor Loadings and Communalities Varimax Rotation)

Variable	Factor 1	Factor 2	Factor 3	Communality
pH	0.429	0.656	-0.001	0.694
TH	0.161	0.930	0.031	0.892
Ca2+	0.168	0.799	-0.198	0.706
Mg2+	0.125	0.842	0.206	0.767
Cl-	0.666	0.001	0.317	0.543
TDS	0.044	-0.145	-0.661	0.459
Fe+	-0.157	-0.218	0.737	0.616
F-	0.511	0.198	0.683	0.767
NO3-	0.463	0.468	0.457	0.643
SO42-	0.806	0.259	0.019	0.718
Na+	0.623	0.600	0.214	0.794
K+	0.793	0.131	-0.110	0.659
HCO3-	0.446	-0.057	0.494	0.446
Mn	0.149	-0.270	-0.177	0.127
Zn	0.345	-0.353	-0.563	0.561
DO	-0.771	-0.050	0.127	0.613
TS	0.808	0.251	-0.197	0.754
Eigen Value	6.1	2.5	2.2	--
% Variance	26.2	21.6	15.0	--
Cumulative % of Variance	26.2	47.8	62.8	--

**3.2 Governing Factors Of Groundwater Quality By Factor Analysis (For Combined Data Of Pre-Monsoon 2009, 2010 & 2011) (Rotated Factor Loadings And Communalities Varimax Rotation):**

**Factor1:**

Having Eigen value with 6.1 and 26.2% of the variance, has high loadings on SO<sub>4</sub>, K & TS, moderate loadings on Cl, F & Na and low loadings on pH, NO<sub>3</sub>, HCO<sub>3</sub> & Zn.

(1) **High loading:** It suggests that the quality of ground water is mainly controlled by high loading parameters. The high SO<sub>4</sub> is related to the long-history of evaporation process, the high value of K suggests pollution from application of potash fertilizers to agricultural lands (Cain et al., 1989) and high loading on TS accounts for low mixing of overlying soft soil after percolation due to monsoon runoff/pollution.

(2) **Moderate loading:** Gentle slope and sluggish-drainage conditions supporting longer-residence time of groundwater, more water-rock interaction and higher solubility of minerals mark mostly saline water and enrichment of Na and Cl. F indicates weathering of country rocks.

(3) **Low loading:** The combination of pH, NO<sub>3</sub>, Zn & HCO<sub>3</sub> indicates weathering of country rocks.

**Factor 2:**

Having Eigen value with 2.5 and 21.6% of the variance, has high loadings of TH, Ca & Mg, moderate loadings on pH & Na and low loadings on NO<sub>3</sub>.

(1) **High loading:** The combination of TH, Ca & Mg represents permanent hardness.

(2) **Moderate loading:** Na with pH represents solubility of minerals.

(3) **Low loading:** Presence of NO<sub>3</sub> indicates mild pollution

**Factor 3:**

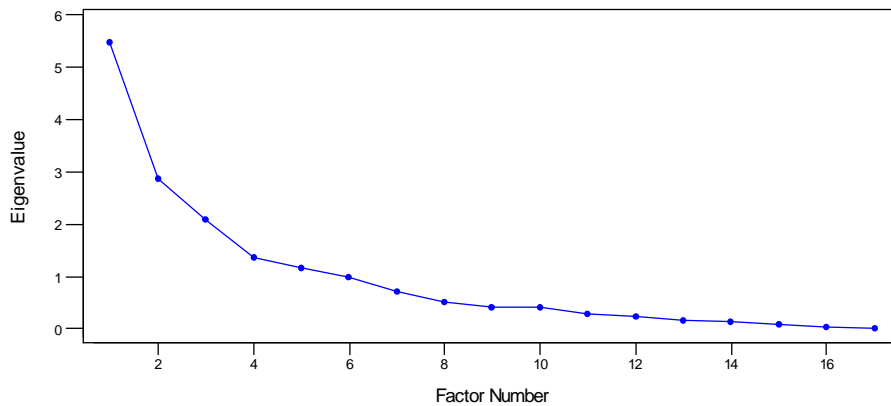
Having Eigen value with 2.2 and 15.0% of variance, has no high loadings, moderate loadings on Fe & F, and low loadings on HCO<sub>3</sub> & NO<sub>3</sub>.

(1) **High loading:** No loading at all

(2) **Moderate loading:** Fe & F indicates weathering of country rocks.

(3) **Low loading:** Presence of HCO<sub>3</sub> & NO<sub>3</sub> weathering of country rocks

Scree Plot of C1-C17



**Fig4:** Screen Plot for the combined data of pre-monsoon 2009, 2010 & 2011

**Table 6:** Factor Analysis (for Combined Data of Post-Monsoon 2009, 2010 & 2011) (Rotated Factor Loadings and Communalities Varimax Rotation)

Variable	Factor 1	Factor 2	Factor 3	Communality
pH	0.569	-0.582	0.252	0.725
TH	0.922	-0.023	0.058	0.854
Ca2+	0.592	-0.320	0.383	0.600
Mg2+	0.848	0.112	-0.103	0.742
Cl-	-0.010	-0.615	-0.487	0.615

TDS	-0.405	-0.022	0.398	0.323
Fe+	-0.089	0.222	-0.860	0.796
F-	0.317	-0.385	-0.735	0.789
NO3-	0.700	-0.335	-0.204	0.644
SO42-	0.255	-0.756	-0.24	0.652
Na+	0.814	-0.321	-0.203	0.806
K+	0.056	-0.781	0.086	0.620
Alk(HCO3-)	0.186	-0.525	-0.392	0.464
Mn	-0.118	-0.281	0.075	0.098
Zn	-0.604	-0.441	0.349	0.682
DO	-0.066	0.596	0.036	0.360
TS	0.144	-0.813	-0.057	0.684
Eigen Value	5.5	2.9	2.0	--
% Variance	24.6	23.6	13.4	--
Cumulative % of Variance	24.6	48.2	61.6	--

### 3.3 Governing Factors Of Groundwater Quality By Factor Analysis (For Combined Data Of Post-Monsoon 2009, 2010 & 2011) (Rotated Factor Loadings And Communalities Varimax Rotation):

#### Factor1:

Having Eigen value with 5.5 and 24.6% of the variance, has high loadings on TH, Mg & Na, moderate loadings on Ca, pH & NO<sub>3</sub> and low loadings on F.

(1) **High loading:** It suggests that the quality of ground water is mainly controlled by high loading parameters. The high loadings on TH, Mg & Na shows the permanent hardness of groundwater

(2) **Moderate loading:** The combination of pH, NO<sub>3</sub> & HCO<sub>3</sub> indicates weathering of country rocks.

(3) **Low loading:** F indicates weathering of country rocks.

#### Factor 2:

Having Eigen value with 2.9 and 23.6% of the variance, has no high loadings at all, moderate loadings on DO and no low loadings too

(1) **High loading:** No loading at all

(2) **Moderate loading:** DO indicate mild reaeration/mixing of rain water.

(3) **Low loading:** No loading at all

#### Factor 3:

Having Eigen value with 2.0 and 13.4% of variance, has no high loadings, no moderate loadings and low loadings on Ca, TDS & Zn

(1) **High loading:** No loading at all

(2) **Moderate loading:** No loading at all

(3) **Low loading:** Presence of Ca indicates weathering of country rocks, whereas TDS & Zn indicates mild pollution

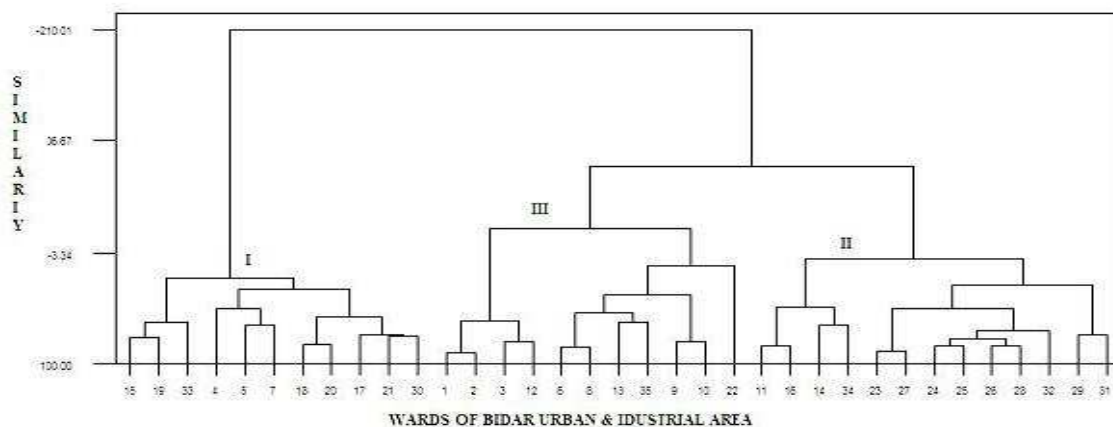
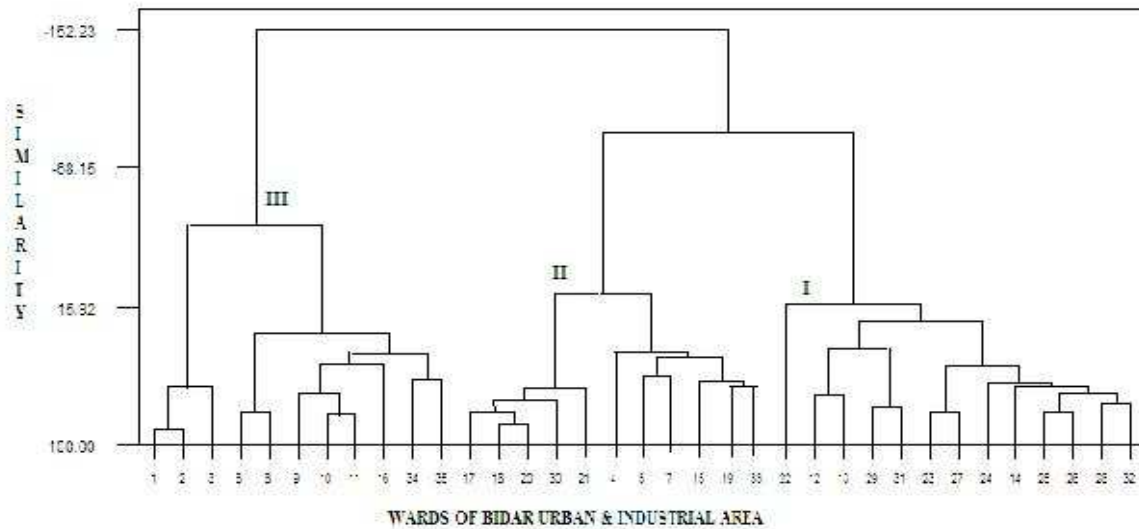


Fig5: Dendograms of hierarchical cluster analysis for combined pre-monsoon 2009, 2010 & 2011



**Fig6:** Dendograms of hierarchical cluster analysis for combined post-monsoon 2009, 2010 & 2011

### 3.4 Cluster Analysis:

In this study, sampling site classification as performed by the use of cluster analysis. Hierarchical Cluster Analysis was performed on the factor scores obtained from factor analysis using Ward’s method with squared Euclidean distances as a measure of similarity. The linkage method that will determine how the distance between two clusters is defined. Choices include Single, Average, Centroid, Complete, McQuitty, Median, and Ward [23]. Cluster analysis from factor scores of stations reduce the clustering error caused by data error or multicollinearity. Ward’s method uses analysis of variance (ANOVA) to calculate the distances between clusters to minimize the sum of squares of any two possible clusters at each step. Results of cluster analysis are represented using dendrogram. In the dendograms of Bidar city water sampling stations are classified into three clusters as shown in Fig.5 & 6.

On the basis of Cluster analysis, wards of Bidar urban are divided as follows (Combined pre-monsoon 2009, 2010 & 2011): Cluster-I(Ward4,5,7,15,17,18,19,20,21,30 & 33), Cluster-II (Ward 11,14,16,23,24,25,26,27,28,29,31 & 32), Cluster-III (Ward 1,2,3,6,8,9,10,12,13 & 35).

And on the basis of Cluster analysis, wards of Bidar urban are divided as follows (Combined post-monsoon 2009, 2010 & 2011):

Cluster-I	(Ward 12,13,14,22,23,24,25,26,27,28,29,31,32),
Cluster-II	(Ward 4,5,7,15,17,18,19,20,21,30,33),
Cluster-III	(Ward 1,2,3,6,8,9,10,11,16,34,35).

Wards of same clusters have the similar pattern of the groundwater quality.

Combined pre-monsoon 2009, 2010 & 2011: Wards of Cluster-I are more polluted, here major contributors in ground water pollution are SO<sub>4</sub>, K & TS. Wards of Cluster-II are less polluted areas. These wards have higher loading in TH, Ca, and Mg which indicates permanent hardness. Wards of Cluster-III are moderately polluted. Pollution in these wards is mainly by Fe & F which is generally by weathering of country rocks.

Combined post-monsoon 2009, 2010 & 2011: Wards of Cluster-I are more polluted, here TH, Mg & Na are having higher contribution. Wards of Cluster-II which are less polluted areas also here mild reaeration is taking place. Wards of Cluster-III are moderately polluted. Pollution in these wards is mainly due to Ca, Zn and TDS. Ca & Zn indicates weathering of country rocks. TDS may be by percolation of runoff and soft overlying soil during monsoon.

### CONCLUSIONS

Factor analysis was successfully applied to identify the sources of pollution in Bidar urban and its industrial area. The results reveal that among the variables studied TH, Ca, Mg, are statistically the most significant parameters that bring variation in water quality in the area. During pre-monsoon period of analysis, TH, Ca, & Mg are dominants, TS & K are present moderately. SO<sub>4</sub> also present in low. Whereas during post-monsoon period of analysis, again TH & Mg are dominants but remaining parameters viz., K, TS, SO<sub>4</sub> & TDS have low loadings. This may be due to dilution of ground water during monsoon season. The contribution of anthropogenic activities through discharge of domestic waste water/industrial effluent into the groundwater is very less as is identified by Factor Analysis. To restore the ecological stability and aesthetic

quality of ground water, there is need to empower local environmental agency to enforce regular compliance to the standard guidelines to the various industries located around the area and safe disposal of domestic waste water. Cluster analysis through factor scores and by dendograms, identified low, medium and high polluted wards during both pre-monsoon and post-monsoon periods of the study area. It has been revealed that hardness is more during pre-monsoon studies and little less during post-monsoon studies. In pre-monsoon period, SO<sub>4</sub> is major contributor, TH, Ca & Mg present mildly high showing permanent hardness to water whereas Fe & F which are moderately present which is generally by weathering of country rocks. In post-monsoon period, TH, Mg & Na are major contributors. Ca, Zn and TDS are moderately present. Ca & Zn indicates weathering of country rocks. TDS may be by percolation of runoff and soft overlying soil during monsoon. DO is present in few wards which indicates mild reaeration by percolated water during monsoon. In all since factors scores are less than 0.35 value pollution is less in the entire Bidar urban.

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