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Ground Water Quality Characterisation by using Multi Variation Techniques and ANOVA and T-Test in Visakhapatnam

Dr.P.Pavitra, Assistannt Professor, Dadi Institute of Engineering and Technology, Visakhapatnam, A.P., India

Abstract

Multivariate statistical techniques, cluster analysis, non-parametric tests, and principal component techniques were applied to analyse a water quality to determine the main factors and geo chemical and spatial variation of groundwater quality in the sea water intrusion area, Visakhapatnam. Twenty ground water samples collected and analysed thirteen parameters for 2018 to investigate spatial variations and identify potential pollution sources. The results were obtained and compared regarding standards prescribed by the Bureau of Indian Standards (BIS,2012). The concentrations of TDS, chloride, nitrate, sulphate, and fluoride were above the desired limits. The clustering procedure generated three groups of sites in a very convincing way, as the twenty monitoring sites were divided into low pollution (LP), moderate pollution (MP), and high pollution (HP) types. Principal component revealed that two factors explained around 55 % of the total variance, which water-rock interaction and anthropogenic impact as the dominant factors affecting the groundwater quality. The distribution of factor score one represents high loading for TDS, TH, SO^{2-}_4, Mg^{2+}, Ca^{2+}, Cl^-, K^+, and Na^+High factor loading between these parameters probably indicatesthe dissolution of carbonate rocks, evaporite rocks, and chloride salts, which makes the water slightly salty in some part of the study area. One-way analysis of variance (ANOVA) applied for the data collected, and found that one-way ANOVA was more effective in carrying out water quality analysis. The hypotheses that are drawn using ANOVA were used for water quality analysis.

Key words

Physico chemical parameters, Cluster analysis. Principal component analyses. One-way ANOVA

Introduction

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Groundwater quality deterioration in coastal aquifers is a common problem worldwide and degradation of groundwater quality in coastal region usually occurs due to natural processes such as saline water intrusion, wind driven sea spray and marine vaporisers deposited. Evaporation and groundwater interaction with saline and sedimentary formation cause high salinity even greater than seawater (Allison et al. 1990). Besides, anthropogenic contamination is another major cause of water quality deterioration. Preservation of groundwater quality and its contamination is a serious comprehensive theme of concern today. Groundwater quality differences effect from natural conditions and anthropogenic activities. Natural conditions alter groundwater quality by means of recharge and discharge, mineral dissolution, flow paths, residence times, and mixing fresh groundwater with residential water or intruded seawater. Anthropogenic activities affect groundwater quality through the vadose zone leaching of contaminants due to accidental spillage, leakage, and inappropriate application of chemicals at the land surface; the intrusion of water with high dissolved solids due to groundwater withdrawals(Boniol 1996).

Recently, an extensive number of researchers have shown an increased consciousness in the use of multivariate statistical analysis and geostatistical techniques to achieve a sustainable exploitation of groundwater resources (Babiker et al. 2007; SheikhyNarany et al. 2014). Multivariate statistical analysis such as cluster analysis (CA), analysis of variance (ANOVA) and principal component analysis/factor analysis (PCA/FA) can be used to analyze large groundwater quality datasets without losing important information. They can play the important role of verifying temporal and spatial differences caused by natural and anthropogenic influences (Liu et al. 2011; Dehghanzadeh et al. 2014). In addition, they have been efficiently and widely applied to assessment of ground water quality (Yidana et al. 2008; Koklu et al. 2010; Belkhiri and Mouni 2014), evaluation of the hydro chemical characteristic of groundwater (Cloutier et al. 2008; Papatheodorou et al. 2007; Yidana 2010), identification of groundwater contaminations (Kim et al. 2009; Belkhiri et al. 2010) and design of environmental and water quality monitoring (Khalil et al. 2010; Ou et al. 2012). The combined use of multivariate statistical methods and

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geostatistical modelling might also be capable in the hydro chemical evaluation of aquifers by the spatial variation of characteristics and highlighting the major factors influencing the groundwater quality (Agoubi et al. 2013; Masoud 2014). The present work, therefore, focuses on the use of the multivariate statistical analysis, geostatistical techniques and structural equation modelling of groundwater chemistry data to characterize the groundwater quality evolution process, and to identify the controlling factors, which govern the chemical composition of groundwater.

Study Area

Vishakhapatnam is a coastal port city, often called "The East Coast Jewel", located in Andhra Pradesh, positioned on the east coast of India, settled between the East Ghati hills and across the Gulf of Bengal to the east. It is the administrative headquarters of the Vishakhapatnam district and is also the seat of the Naval Command of the Indian Navy. Geographically the study area is located in between 17° 24' 50.4" N to 17° 29' 31.2" N latitude and 83° 9' 43.2" E to 83° 13' 48" E.Sampling stations represented in table-1

Table-1 Geological coordinates of Coastal belt of the study areas

S.No.	Sampling station	Code of the sample	Latitude	Longitude
1	Sagar Nagar (BW)	SWI1	17.464 N	83.215 E
2	Park Hotel (Bw)	SWI2	17.431 N	83.201 E
3	Jodugulapalem (BW)	SWI3	17.450 N	83.205 E
4	Madhura Wada(BW)	SWI4	17.492 N	83.210 E
5	PeddaRushikonda (BW)	SWI5	17.475 N	83.225 E
6	ChinnaRushikonda (BW)	SWI6	17.452 N	83.230 E
7	Kalimata Temple (BW)	SWI7	17.421 N	83.200 E
8	Ins Kalinga (BW)	SWI8	17.425 N	83.201 E
9	Kapuluppada (BW)	SWI9	17.441 N	83.204 E
10	Kapuluppada (DW)	SWI10	17.491 N	83.222 E
11	Boyapalem (BW)	SWI11	17.441 N	83.162 E

12	Yendada (BW)	SWI12	17.465 N	83.212 E
13	Chepaluppada (BW)	SWI13	17.443 N	83.213 E
14	Chepaluppada (DW)	SWI14	17.464 N	83.222 E
15	Appugahr (BW)	SWI15	17.441 N	83.205 E
16	Muvvalapalem.Colony (BW)	SWI16	17.446 N	83.202 E
17	Lawsons Bay Colony (BW)	SWI17	17.441 N	83.202 E
18	Vuda Park Road(BW)	SWI18	17.435 N	83.202 E
19	Jalaripeta(BW)	SWI19	17.437 N	83.204 E
20	Fishing Harbour(BW)	SWI20	17.414 N	83.180 E

Material and Methodology

Twenty bore well water samples were collected in sterilized plastic bottles, all the sampling containers were washed and rinsed thoroughly with the groundwater to be taken and analysed physico chemical characteristics according to theprocedure Prescribed by APHA (2005) inchemistry laboratory. p^H analysed by using p^Hmeter of ELICO L1615 Model and conductivityof the water samples were determined by usingdigital in the laboratory. The classical methodof examination applied for estimation of totalhardness by using EDTA and EBT indicator,calcium, magnesium, carbonate, bicarbonate bymethyl orange and phenolphthalein and chloridedetermined by an argent metric method. Totaldissolved solids (TDS) were estimated fromcation and anion content by calculation method(Hem 1991). Sulphate, Phosphate, and nitrate ofthe water samples were estimated by UV, visiblespectrophotometer, SHIMAD2U UV-1800Model. Na^+, K^+ were determined by using aflame photometer, ELICO CM-378 Model.Heavy metals like Iron, Chromium, Copper,Zinc, and Lead analysed by using AtomicAbsorption Spectra photometer AA-400 model.

3.1 Data Treatment and Multivariate Statistical technique

Recently, multivariate statistical studies have been applied extensively to investigate environmental phenomena (Yidana et al. 2008). Multivariate statistical techniques can help to shortened and establish large data set to provide meaningful vision. In the present study, three multivariate statistical techniques were applied to assess groundwater quality in the study area.

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3.1.1 Cluster Analysis
Cluster analysis is an exploratory data analysis tool that purposes at categorisation varies objects into groups in a way that the degree of resemblance within the matters is utmost if they belong to the same group (Guzman-Guzman 1989). To carry out the cluster study, EC and concentrations for Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO^{-}_3 and NO_3^{-}, were used as variables. The dataset was treated by the Ward's method of linkage with Euclidean distance as measure of comparison.

3.1.2 Principal Component Analysisis extensively applied to analyse interrelationship among different sets of groundwater hydro chemical data to extract the most considerable issues and to diminish the data with minimum loss of information (Mustapha and Aris 2012; Schaefer and Einax 2010). In this investigation, PCA is suitable tool to hydro chemical data from the origins to extract the principal factors corresponding to the different sources of variation in the data and to identifying the spatial basis of contamination in the study area.

3.1.3 Analysis of Variance One way between subject effect analysis of variance (one-way ANOVA) compares the variance between the different sets with the changeability within each of the group. A one-way ANOVA between group examines was conducted to explore the mean variances between the bunch groups recognized in the last steps as outlined using multivariate statistical analysis by pollution source.

4 Results and Discussion
4.1 Cluster Analysis
The resulted dendrogram (Fig. 3) grouped all the eighteen sampling wells into two statistically significant clusters. The clustering procedure generated three groups of sites in a very convincing way, as the sites. Group A comprised sites Sagar Nagar,Jodugulapalem, Madhura Wada, PeddaRushikonda, ChinnaRushikonda,Appugahr, MuvvalapalemColony, Lawsons Bay Colony, Jalaripeta, which corresponds to 50 % of all the sample wellsOn the basis of overall chemical composition, characterized by ion abundances $Na^{+}>Ca^{2+}> Mg^{2+}> K^{+}$ and $HCO_3^{-}> Cl^{-}>SO_4^{2-}> NO_3^{-}$ (meq/l) (Fig. 4). Bicarbonate and calcium are the dominate ions in this group, the concentration

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of Na^+ and HCO_3^- varied from 35 mg/l to 250mg/l and from 80 mg/l to430 mg/l with a mean concentration of 102.6 and 294.77 mg/l, respectively (Table 1). The source of bicarbonate is attributed to natural processes such as dissolution of carbonate minerals in the presence of soil group B comprised Park Hotel (SWI-2), Kalimata Temple (SWI-7), Ins Kalinga (SWI-8), Boyapalem (SWI-11), Yendada (SWI-12), Vuda Park Road (SWI-18)made one group as cluster 2, which corresponds to 28 % of all the sample wells, the order of abundance of major ions in this cluster is Ca^{2+}> Na^+>Mg^{2+}> K^+ and Cl^-> HCO_3^-> SO_4^{2-}> NO_3^- (meq/l). Magnesium and sulphate are the dominate ions in this group, which shows spatial variation in north, east, and north-eastern side of the plain. The concentration of Calcium ranged from 22 to 120 mg/l and these samples exceeded the BIS guideline limit of 75 mg/l (BIS, 2012). The value of Chloride ranged between 80 and 440 mg/l. All samples exceeded the desirable limit of Chloride (250 mg/l) (BIS,2012). group C comprise Kapuluppada, Chepaluppada(BW and DW), Fishing Harbour. Sampling stations in group C are highly contaminated compared to Group A class. The clustering procedure generated three groups of sites in a very convincing way, as the sites. the first eigenvalue is 5.449 which accounts for 54.49 % of the total variance and this constitutes the first and main factor. The second and third eigenvalues are 1.609 and 1.06 and these accounts for 16.09 and 9.97 %, respectively, of the total variance Principle component analysis was applied on the dataset to categorising the spatial source of pollution in the study area. Two factors with eigenvalues more than one were extracted from varimax-rotated analysis. The eigenvalue is the variance explained by a factor, the higher the value, the more variance they have taken (Awadallah and Yousry 2012). Factor loadings were classified as "strong" loading value >0.75, "moderate" loading value between 0.75 and 0.5, and "weak" loading value between 0.5 and 0.3. The first-factor loading attributed to TDS, TH, SO^{2-}_4, Mg^{2+}, Ca^{2+}, Cl^-, K^+, and Na^+, which explained 54.5 % of the total variability of the studies' groundwater quality. High factor loading between these parameters probably indicates the dissolution of carbonate rocks, evaporite rocks, and chloride salts, which makes the water slightly salty in some part of the study area, where wells belong to cluster one is located. The results of first-factor loading indicate the natural factor impact in the study

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area. The second-factor loading explained 16.09 % of the total variance. The factor shows strong positive loading for TA, TH, Ca^{2+}, NO^{-}_{3}, SO^{2-}_{4}. The results of factor loading show clear evidence of anthropogenic influence in the study area.

ANOVA performed for sampling stations for three years as shown in the Table- 4.28, 4.29, 4.30 respectively. These tables provide important expressive statistics like the standard deviation, mean, and 95% confidence intervals for each set in a dependent time. The results of ANOVA revealed that all of the stations demonstrated significant variation (p value ≤ 0.05) from one sampling station to another sampling stations for three years in the study area. The physicochemical parameters shown different distribution patterns along the water samples. The p value of these parameters p^H, EC, TDS, TH, Mg^{2+}, Cl^- and SO_4^{2-} and EC, EC, TDS, TA, Mg^{2+}, K^+ Cl^- and SO_4^{2-} were less than a value of 0.05. The existing study types of water were constrained to three different types in pre monsoon. Most of the water samples (30%) are strategized in the Na+-Ca2+-Mg2+-Cl--HCO3--SO42- field. Fifty percent showed Na+-Ca2+-Mg2+-Cl--HCO3-type. In Post-monsoon period, 20% showed Na+-Ca2+-Mg2+-Cl--HCO3--SO42- type, 32 % showed Na+-Ca2+-Cl--HCO3--SO42- type and 10 % showed Na+-Ca2+-Mg2+-Cl- type.This might be due to alkali salts leaching through rainfall and closure of minerals.

The minimum conductivity of520µS/cm was observed at Park hotel (BW)(2) during post-monsoon in the year 2015 and the extreme conductivity of 3500 µS/cm was detected fishing harbor (BW)(20) in pre-monsoon during the year 2014. A higher concentration of EC due to water drained from municipal wastewater, runoff water, and groundwater seepage and it depends on temperature.
The physico-chemical characteristics of groundwater in the area of investigation are given in table-3. SWI-10,SWI-11,SWI-12,SWI-17,SWI-20 sampling stations showed higher concentration of EC due to septic system landfills, nature of soil hazardous waste landfills dissolved minerals. Higher TDS concentration showed in all sampling stations due to dissolution of salt and industrial discharge by rain water which mainly consists of calcium carbonate, bicarbonate, magnesium

carbonate, and sodium. Dissolved inorganic salts, small amounts of organic matter and gases contributed. SWI 3, SWI 5, SWI 6, SWI 9, SWI 13, SWI 17, SWI 20 sampling stations showed higher concentration of alkalinity due to landfills Hazardous waste landfills, Fertilizers Industrial wastes Minerals, seawater sampling stations. SWI 1, SWI 3, SWI 9, SWI 10, SWI 15, SWI 17, SWI 20 sampling stations showed higher concentration of hardness is due to leaching of carbonate and bicarbonate salts. Water from sites SWI 4, SWI 14, SWI20 are high concentration of chloride due to Irrigation drainage, brine produced during drilling of oil and gas, Fertilizers, industrial waste, and landfills. High values of Ca hardness at SWI-1, SWI-3 site due to dissolution of $CaCO_3$ by water recharge. Fluoride and bromide concentrations in all sampling stations showed below the permissible limi. Higer iron concentration in sampling stations SWI 3, SWI 5, SWI 6, and SWI 17 due to Leaching of cast iron pipes in water distribution systems.

Conclusion

Multivariate statistical analysis, geostatistical techniques and structural equation modeling were applied to assess the spatial variability of groundwater quality and to identify the main factors and sources of contamination. Cluster analysis defined two major clusters, reflecting different hydrochemical processes. Application of principal component analysis reveals that natural and anthropogenic factors as the source of groundwater contamination, which explained more than 85 % of the total variance. Natural process such as dissolution of evaporite and carbonate rocks mostly affected western and eastern sides, which was differentiated by high loading for EC, Na, K, Ca, Mg, and SO_4. Anthropogenic contamination was spatially distributed in the central and southern sides of the plain, where agricultural activities imposed high concentrations of NO_3, NO_2, NH_4, and CO_2 in to groundwater. The one-way ANOVA test revealed that there aren't significant mean differences between NO_3, NO_2, NH_4, COD, and HCO_3 at p SEM reviled good fit indices, confirming that the spatial variation in groundwater quality is by these parameters SO_4, Mg, Ca, Cl, K, and Na. This study provides a new technique of confirming exploratory data analysis using structural equation modeling in groundwater quality.

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Analysis of samples clearly reveals that water from sites SWI 3, SWI 5, SWI 6, SWI 9, SWI 13, SWI 17, SWI 20 highly polluted, Other sites such as SWI-10,SWI-11,SWI-12, SWI 4, SWI 14, are moderately polluted; From the above results continuous groundwater monitoring is required by establishing a planned monitoring network in the study area for regular assessment will be useful for the proper management of the water resources and it require proper treatment like filtration and disinfection and management to make its suitability for household uses.

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Table- 2:One-way analysis of variance (ANOVA) for parameters during pre-monsoon and post monsoon in 2018

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Parameter		Pre-monsoon					Post-monsoon				
		Sum of Squares	df	Mean Square	F	Sig.	Sum of Squares	df	Mean Square	F	Sig.
p^{+}	Between Groups	0.376	11	0.034	0.938	0.551	0.341	12	0.028	1.067	0.437
	Within Groups	0.292	8	0.036			0.187	7	0.027		
	Total	0.668	19				0.528	19			
E.C	Between Groups	1722703	11	156609	0.968	0.533	1564467	12	130372	1.62	0.026
	Within Groups	1294792	8	161849			564333	7	80619		
	Total	3017495	19				2128800	19			
TDS	Between Groups	779863	11	70897	0.99	0.52	693387	12	57782	1.54	0.029
	Within Groups	573192	8	71649			262133	7	37448		
	Total	1353055	19				955520	19			
TH	Between Groups	18646	11	1695	1.248	0.038	18722	12	1560	2.17	0.015
	Within Groups	10862	8	1358			5032	7	719		
	Total	29508	19				23754	19			
Cl-	Between Groups	23205	11	2110	1.043	0.048	14762	12	1230	1.06	0.491
	Within Groups	16175	8	2154			8133	7	1162		
	Total	39380	19				22895	19			
SO_4^{2-}	Between Groups	3493	11	318	3.5	0.045	2131	12	178	3.97	0.038
	Within Groups	726	8	91			313	7	45		
	Total	4219	19				2444	19			
HCO_3^-	Between Groups	24163	11	2197	19.708	0	13497	12	1125	1.18	0.43
	Within Groups	892	8	111			6683	7	955		
	Total	25055	19				20180	19			
Na^-	Between Groups	15807	11	1437	3.066	0.061	14404	12	1200	3.16	0.068
	Within Groups	3750	8	469			2663	7	380		
	Total	19557	19				17067	19			
Ca^{2+}	Between Groups	1334	11	121	0.718	0.701	1459	12	122	1.27	0.038
	Within Groups	1351	8	169			669	7	96		
	Total	2685	19				2128	19			
Mg^{2+}	Between Groups	2784	13	214	4.28	0.042	3169	13	244	5	0.029
	Within Groups	301	6	50			293	6	49		
	Total	3084	19				3463	19			

Table-3: **Site wise One-way analysis of variance (ANOVA) for Salt water intrusion area during pre an post monsoon in 2016**

Sampling Sites		Pre monsoon Sum of Squares	df	Mean Square	F	Sig.	Post monsoon Sum of Squares	df	Mean Square	F	Sig.
SWI 1	Between Groups	1053629	10	131704	21	0.002	674294	10	67429	18	0.003
	Within Groups	30839	5	6168			19217	5	3843		
	Total	1084468	15				693511	15			
SWI 2	Between Groups	2014677	10	251835	35	0.001	846872	10	84687	22	0.002
	Within Groups	36019	5	7204			19257	5	3851		
	Total	2050697	15				866129	15			
SWI 3	Between Groups	1806976	10	225872	31	0.001	1003389	10	100339	22	0.002
	Within Groups	36475	5	7295			22808	5	4562		
	Total	1843451	15				1026197	15			
SWI 4	Between Groups	4487939	10	560995	183	0.000	2741762	10	274176	114	0.000
	Within Groups	17157	5	3431			12065	5	2413		
	Total	4505116	15				2753828	15			
SWI 5	Between Groups	4343048	10	542881	100	0.0000	2178256	10	217826	58	0.000
	Within Groups	27141	5	5428			18880	5	3776		
	Total	4370189	15				2197136	15			
SWI 6	Between Groups	3443143	10	430393	86	0.000	1705316	10	170532	69	0.000
	Within Groups	24993	5	4999			12273	5	2455		
	Total	3468135	15				1717588	15			
SWI 7	Between Groups	1808146	10	226018	53	0.000	864753	10	86475	34	0.001
	Within Groups	21187	5	4237			12534	5	2507		
	Total	1829334	15				877287	15			
SWI 8	Between Groups	2015638	10	251955	54	0.000	719328	10	71933	32	0.001
	Within Groups	23499	5	4700			11305	5	2261		
	Total	2039137	15				730633	15			
SWI 9	Between Groups	2157885	10	269736	31	0.001	1092933	10	109293	19	0.002
	Within Groups	43285	5	8657			23487	5	5697		
	Total	2201170	15				1121420	15			
SWI 10	Between Groups	4193904	10	524238	75	0.000	2380143	10	238014	65	0.000
	Within Groups	35064	5	7013			18325	5	3665		
	Total	4228968	15				2398468	15			
SWI 11	Between Groups	4718284	10	589786	109	0.000	2828314	10	282831	109	0.000
	Within Groups	27109	5	5422			12939	5	2588		
	Total	4745393	15				2841754	15			
SWI 12	Between Groups	3869227	10	483653	136	0.000	2586611	10	258661	181	0.000
	Within Groups	17741	5	3548			7145	5	1429		
	Total	3886968	15				2593756	15			
SWI 13	Between Groups	3068097	10	383512	63	0.000	1697796	10	169780	48	0.000
	Within Groups	30449	5	6090			17577	5	3515		
	Total	3098547	15				1715373	15			
SWI 14	Between Groups	4023208	10	502901	60	0.000	2175083	10	217508	59	0.000
	Within Groups	41669	5	8334			18380	5	3676		
	Total	4064878	15				2193463	15			
SWI 15	Between Groups	2720217	10	340027	69	0.000	1125767	10	112577	35	0.001
	Within Groups	24536	5	4907			15978	5	3196		
	Total	2744753	15				1141745	15			
SWI 16	Between Groups	2279076	10	284885	64	0.000	1307026	10	130703	56	0.000
	Within Groups	22183	5	4437			11667	5	2333		
	Total	2301259	15				1318693	15			
SWI 17	Between Groups	4565690	10	570711	43	0.000	3692648	10	369265	48	0.000
	Within Groups	66991	5	13398			38549	5	7710		
	Total	4632681	15				3731197	15			
SWI 18	Between Groups	3054104	10	381763	51	0.000	2442625	10	244263	55	0.00000
	Within Groups	37651	5	7530			22029	5	4406		
	Total	3091755	15				2464655	15			
SWI 19	Between Groups	4115719	10	514465	144	0.000	1700252	10	170025	79	0.000
	Within Groups	17920	5	3584			10815	5	2163		
	Total	4133639	15				1711067	15			
SWI 20	Between Groups	9111975	10	1138997	226	0.000	4681610	10	468161	172	0.000
	Within Groups	25247	5	5049			13629	5	2726		
	Total	9137222	15				4695239	15			

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Table-3: Ionic ratios forboth seasons

Selected stations	Na+/Cl-		Ca2+/Mg2+ Cl-/TA		Cl-/TA		Ca2+/SO42- +HCO-3	
	Pre-M	Post-M	Pre-M	Post-M	Pre-M	Post-M	Pre-M	Post-M
SWI1	0.50	0.49	4.10	5.38	1.00	1.15	0.32	0.35
SWI2	0.42	0.45	2.91	3.20	0.86	0.94	0.28	0.26
SWI3	0.52	0.55	3.20	3.50	0.89	0.96	0.27	0.25
SWI4	0.65	0.67	1.96	1.58	1.08	1.11	0.18	0.15
SWI5	0.63	0.71	2.40	3.00	0.73	0.67	0.18	0.17
SWI6	0.69	0.69	1.71	2.33	0.62	0.68	0.16	0.18
SWI7	0.51	0.51	4.00	5.78	0.81	0.93	0.30	0.34
SWI8	0.53	0.47	2.75	6.00	0.85	1.07	0.25	0.30
SWI9	0.61	0.64	1.49	1.44	0.76	0.79	0.18	0.17
SWI10	0.50	0.45	2.06	2.08	1.00	1.29	0.24	0.23
SWI11	0.40	0.36	1.75	1.84	0.94	1.08	0.28	0.28
SWI12	0.51	0.59	2.26	2.25	0.72	0.75	0.22	0.20
SWI13	0.61	0.58	2.56	2.67	0.93	1.05	0.21	0.20
SWI14	0.60	0.76	2.43	2.71	0.93	1.00	0.24	0.20
SWI15	0.64	0.59	3.04	3.19	0.88	0.90	0.27	0.24
SWI16	0.57	0.69	2.43	2.80	0.92	0.83	0.23	0.23
SWI17	0.53	0.54	2.40	2.67	0.52	0.52	0.22	0.22
SWI18	0.49	0.58	3.05	3.19	0.68	0.63	0.25	0.25
SWI19	0.60	0.72	4.40	5.89	1.04	0.91	0.26	0.29
SWI20	0.52	0.57	2.69	2.68	1.19	1.21	0.24	0.22

Table-4. Sampling site wise T-Test for ionic ratios

Sampling sites						
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
SWI1	2.61	7	0.04	1.10	0.10	2.09
SWI2	1.88	7	0.10	1.92	-0.50	4.34
SWI3	2.92	7	0.02	1.02	0.19	1.84
SWI4	4.01	7	0.01	0.60	0.25	0.95
SWI5	2.56	7	0.04	0.96	0.07	1.84
SWI6	2.73	7	0.03	0.87	0.12	1.63
SWI7	2.58	7	0.03	1.49	0.18	2.80
SWI8	2.38	7	0.05	1.38	0.01	2.75
SWI9	4.09	7	0.01	0.54	0.23	0.86
SWI10	4.02	7	0.01	0.62	0.26	0.99
SWI11	3.70	7	0.01	0.54	0.19	0.88
SWI12	2.68	7	0.03	0.85	0.10	1.61
SWI13	3.00	7	0.02	0.96	0.20	1.72
SWI14	3.34	7	0.01	0.84	0.24	1.43
SWI15	2.29	7	0.06	1.30	-0.04	2.65
SWI16	2.00	7	0.09	1.71	-0.31	3.72
SWI17	2.34	7	0.05	1.19	-0.01	2.39
SWI18	2.21	7	0.06	1.63	-0.11	3.38
SWI19	2.65	7	0.03	1.10	0.12	2.07
SWI20	2.71	7	0.03	1.46	0.19	2.74

Table-5. PCA results summarized the rotated component matrix of standardized water quality data and the eigenvalues of each PC for premonsoon and post monsoon for average values

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Parameters	Pre monsoon Factor loadings			Post monsoon Factor Loadings		
	F1	F2	F3	F1	F2	F3
E.C	0.691	-0.655	-0.217	0.642	-0.374	0.573
TDS	0.687	-0.657	-0.221	0.682	-0.454	0.523
T.A	0.670	0.111	0.205	0.773	-0.182	-0.435
TH	0.842	0.364	0.257	0.785	-0.223	-0.379
Ca^{2+}	0.555	0.701	-0.364	0.855	0.294	-0.220
Mg^{2+}	0.652	-0.118	0.698	0.512	0.778	-0.032
Na^{+}	0.743	-0.126	-0.108	0.735	-0.292	-0.294
Cl^{-}	0.886	-0.019	0.059	0.730	0.007	0.232
SO_4^{2-}	0.869	0.203	0.010	0.367	0.513	0.584
NO_3^{-}	0.719	0.202	-0.398	0.867	0.024	-0.030
Eigenvalue	5.449	1.609	0.998	5.728	1.538	1.467
Variability (%)	54.491	16.090	9.979	52.071	13.978	13.332
Cumulative %	54.491	70.581	80.561	52.071	66.048	79.380

Class	1	2	3
Objects	9	6	5
Sum of weights	9	6	5
Within-class variance	102067.388	119651.148	261873.257
Minimum distance to centroid	49.736	73.167	38.180
Average distance to centroid	265.567	281.654	356.156
Maximum distance to centroid	506.047	526.938	866.458

Figure 2. Dendrogram showing spatial similarities of monitoring sites produced by cluster analysis

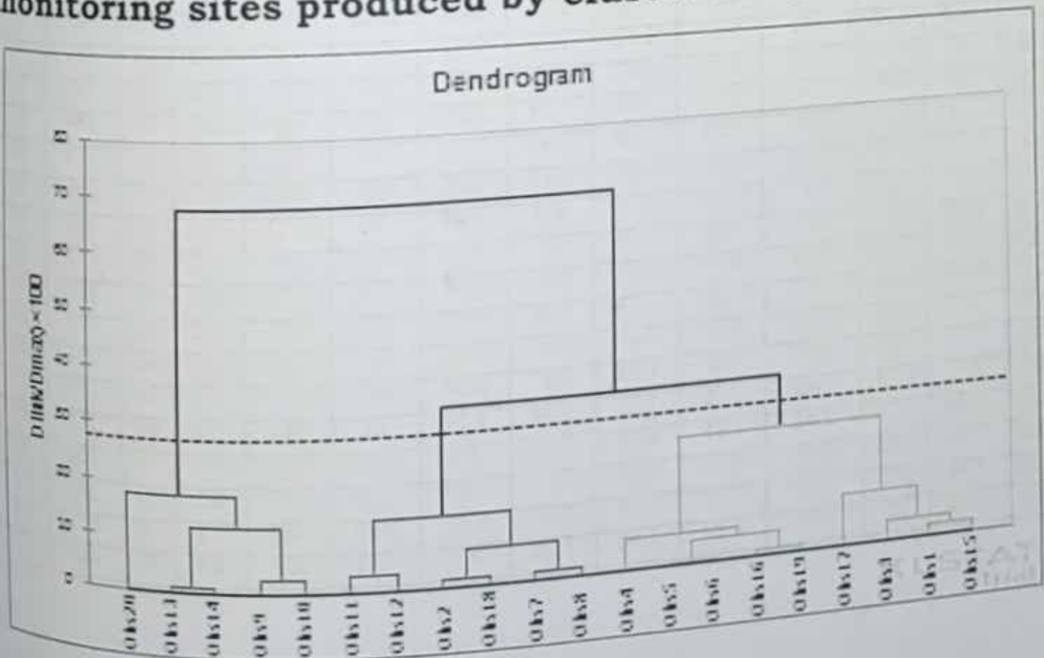

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Table-6. various parameter assessed during pre-monsoon period of 2018 by the Nemerows pollution index

Sampling station	p^H	EC	Cl^-	TDS	TH	Ca^{2+}	Mg^{+2}	Na^+	K^+	SO_4^{2-}	NO_3^-	Hco^-_3	Fe^{2+}	F^-
SWI1	0.92	0.78	0.86	1.52	1.41	1.09	0.63	0.65	0.95	0.36	0.17	1.22	0.67	0.43
SWI2	0.91	0.78	0.77	1.54	1.14	0.77	0.70	0.47	1.65	0.17	0.12	1.00	0.80	0.35
SWI3	0.86	0.81	0.97	1.61	1.38	0.99	0.73	0.72	1.20	0.41	0.23	1.10	1.13	0.6
SWI4	0.91	1.28	1.07	2.51	1.16	0.55	1.03	0.92	0.40	0.32	0.13	1.04	0.87	0.28
SWI5	0.92	1.20	0.73	2.37	0.92	0.61	0.53	0.70	0.60	0.26	0.15	1.12	1.40	0.37
SWI6	0.92	1.13	0.66	2.24	1.00	0.61	0.67	0.62	0.75	0.27	0.14	1.12	1.50	0.45
SWI7	0.82	0.72	0.72	1.43	1.11	0.80	0.57	0.55	0.70	0.26	0.14	0.65	0.50	0.4
SWI8	0.86	0.82	0.79	1.62	1.03	0.73	0.53	0.52	0.80	0.22	0.12	0.80	0.93	0.23
SWI9	0.88	1.03	1.07	2.03	1.61	0.69	1.53	0.65	0.60	0.42	0.15	1.39	0.73	0.21
SWI10	0.87	1.20	1.07	2.36	1.70	0.85	1.43	0.61	0.60	0.38	0.14	1.19	0.97	0.24
SWI11	0.91	1.21	0.75	2.37	1.18	0.64	0.93	0.43	0.50	0.22	0.16	0.90	0.70	0.26
SWI12	0.91	1.08	0.41	2.14	0.90	0.57	0.57	0.35	0.75	0.19	0.14	0.85	0.90	0.43
SWI13	0.92	1.11	1.21	2.20	1.44	0.92	0.93	0.90	0.95	0.36	0.17	1.47	0.83	0.36
SWI14	0.94	1.27	1.31	2.49	1.57	0.99	1.07	0.89	1.30	0.38	0.31	1.34	0.57	0.32
SWI15	0.89	1.05	0.77	2.07	1.40	1.08	0.63	0.63	0.70	0.39	0.22	1.07	1.03	0.46
SWI16	0.92	0.95	0.80	1.87	1.09	0.76	0.57	0.70	0.50	0.34	0.09	0.92	0.57	0.7
SWI17	0.89	1.14	0.62	2.26	1.45	0.96	0.87	0.47	0.85	0.27	0.25	1.25	1.20	0.4
SWI18	0.88	0.88	0.65	1.75	1.20	0.85	0.63	0.51	0.55	0.26	0.10	0.92	0.63	0.28
SWI19	0.91	1.15	0.80	2.28	1.11	0.76	0.63	0.79	0.75	0.35	0.14	1.00	0.73	0.35
SWI20	0.91	1.75	1.56	3.45	1.66	1.11	0.97	0.90	2.65	0.49	0.26	1.04	0.70	0.57

Table-7. WQI of sampling stations during pre-monsoon period in the year

Parameters	P^H	TA	TDS	TH	Ca^{++}	Mg^{++}	Cl^-	No_3^-	SO_4^{--}	Fe^{++}	F^-	ΣQ.W.	WQI
SWI1 q_iw_i	9.84	0.8	0.33	0.7	1.28	2.35	0.3	0.02	0.16	244	40	300	66
SWI2 q_iW_i	9.3	0.57	0.39	0.35	1.21	1.88	0.31	0.09	0.12	255	12	281	62
SWI3 q_iW_i	9.1	0.5	0.4	0.62	1.18	1.98	0.38	0.09	0.19	333	70	417	92
SWI4 q_iW_i	10.6	0.73	0.59	0.75	0.62	3.77	0.44	0.18	0.14	266	30	313	69
SWI5 q_iW_i	10.6	0.68	0.42	0.37	0.62	1.23	0.24	0.11	0.11	278	60	352	77
SWI6 q_iW_i	9.97	0.75	0.47	0.42	0.62	1.7	0.25	0.11	0.11	278	50	342	75
SWI7 q_iW_i	4.66	0.48	0.3	0.7	1.21	1.79	0.29	0.06	0.09	255	30	294	65
SWI8 q_iW_i	1.4	0.53	0.4	0.32	1.04	1.41	0.3	0.07	0.1	266	40	311	68
SWI9 q_iW_i	5.92	0.68	0.44	0.95	0.76	5.19	0.43	0.07	0.23	300	50	363	80
SWI10 q_iW_i	6.12	0.93	0.47	0.92	1.11	4.9	0.46	0.1	0.23	300	80	394	87
SWI11 q_iW_i	9.98	0.88	0.48	0.6	0.73	3.3	0.34	0.06	266	0.1	90	372	82
SWI12 q_iW_i	9.31	0.55	0.44	0.35	0.83	2.07	0.14	0.11	278	0.1	41	332	73
SWI13 q_iW_i	9.98	1.08	0.57	0.8	1.59	3.68	0.59	0.1	255	0.2	42	315	69
SWI14 q_iW_i	11.3	0.98	0.62	0.84	1.47	4.05	0.54	0.1	122	0.2	80	221	49
SWI15 q_iW_i	9.31	0.83	0.52	0.6	1.58	2.17	0.34	0.12	167	0.2	50	231	51
SWI16 q_iW_i	9.51	0.73	0.42	0.75	1.17	0.94	0.34	0.1	144	0.2	60	218	48
SWI17 q_iW_i	8.64	0.73	0.48	1.18	1.39	2.26	0.2	0.1	122	0.1	70	206	45
SWI18 q_iW_i	7.98	0.65	0.29	0.75	1.53	1.7	0.19	0.1	167	0.2	90	269	59
SWI19 q_iW_i	9.98	0.75	0.4	0.62	1.09	2.07	0.32	0.10	189	0.2	70	273	60
SWI20 q_iW_i	11.3	0.7	0.9	1.12	2.08	3.02	0.7	0.11	133	0.4	60	212	47

Table-8. WQI of sampling stations during post-monsoon period

Parameters	P^H	TA	TDS	TH	Ca^{++}	Mg^{++}	Cl^-	No_3^-	SO_4^{--}	Fe^{++}	F^-	ΣQ.Wi	WQI
SW1 q.wi	4.66	0.68	0.3	0.8	1.04	1.89	0.29	0.03	0.13	211	20	240	53
SW2 q.wi	7.12	0.58	0.4	0.77	1.49	0.94	0.29	0.06	0.09	200	10	221	49
SW3 q.wi	4.32	0.53	0.37	1	1.04	4.53	0.36	0.06	0.16	244	30	286	63
SW4 q.wi	10.3	0.6	0.59	0.75	0.41	3.02	0.42	0.12	0.13	222	20	258	57
SW5 q.wi	6.65	0.58	0.37	0.88	0.38	0.85	0.22	0.09	0.1	244	40	294	65
SW6 q.wi	3.92	0.6	0.32	0.52	0.52	1.13	0.26	0.08	0.11	233	20	260	57
SW7 q.wi	3.33	0.45	0.3	0.71	1.18	1.51	0.27	0.06	0.1	200	10	217	48
SW8 q.wi	4.66	0.56	0.31	0.48	0.9	1.23	0.29	0.06	0.06	189	20	217	48
SW9 q.wi	4.99	0.7	0.32	1.03	0.66	4.53	0.4	0.05	0.22	211	30	253	56
SW10 q.wi	5.32	0.88	0.42	0.85	1.07	4.71	0.4	0.09	0.22	255	40	309	68
SW11 q.wi	3.99	0.78	0.36	0.68	0.52	2.83	0.3	0.04	0.12	222	60	291	64
SW12 q.wi	2	0.5	0.27	0.45	0.71	1.6	0.1	0.09	0.07	200	20	225	50
SW13 q.wi	8.31	1.12	0.76	0.88	1.4	3.39	0.7	0.09	0.2	177	30	224	49
SW14 q.wi	8.98	0.9	0.54	0.85	1.25	3.87	0.5	0.1	0.18	110	50	178	39
SW15 q.wi	7.12	0.75	0.32	0.58	1.25	1.79	0.3	0.05	0.2	132	20	165	36
SW16 q.wi	6.18	0.63	0.43	0.8	0.97	1.32	0.3	0.08	0.12	120	30	152	33
SW17 q.wi	10.3	0.68	0.4	0.95	1.23	1.79	0.3	0.08	0.09	124	40	144	32
SW18 q.wi	10.97	0.63	0.4	0.53	1.25	1.32	0.16	0.04	0.12	164	70	185	41
SW19 q.wi	3.92	0.65	0.38	0.63	0.94	1.7	0.28	0.05	0.17	87	40	126	28
SW20 q.wi	8.65	0.62	0.64	0.88	1.84	2.55	0.31	0.09	0.33	92	30	134	30