IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

SPATIAL AND SEASONAL VARIATION IN GROUND WATER QUALITY OF RIVER PALAR BASIN USING MULTIVARIATE TECHNIQUES

L.Sankar*, K.Bala Kumar
Department of Environmental Engineering, C.Abdul Hakeem College of Engineering and Technology, Vellore, Tamil Nadu, India.
Assistant Professor in Department of Civil Engineering in C Abdul Hakeem College of Engineering & Technology, Melvisharam, Vellore-632509, Tamil Nadu, India.

DOI:

ABSTRACT
In this study, spatial and seasonal variation in ground water quality of palar river basin using multivariate statistical techniques, such as cluster analysis, principle component analysis and factor analysis. water quality data collected from 8 sampling station in river during monsoon(October,November,december) and post monsoon(January,February,march) were analyzed for 13 parameters(pH, turbidity, Electrical conductivity (EC), total solid(TS),Total Dissolved solids (TDS), Total Hardness, calcium, magnesium, chlorides, Sulphates, alkalinity, dissolved oxygen, ammonia). Cluster analysis grouped eight sampling stations into three clusters of similar water quality features and thereupon the whole river basin may be categorized into three zones, i.e. low, moderate and high pollution. The principle component analysis/factor analysis assisted to extract and recognize the factors or origins responsible for water quality variations in each month. The inorganic parameters total solid,total dissolved solid,total hardness,electrical conductivity were the most significant parameter contributing variations in all month.

KEYWORDS: Cluster analysis; Factor analysis; Principal component analysis; River.

INTRODUCTION
Ground water is an important source of drinking water for many people around the world. It plays an important role in groundwater protection and quality conservation. The resource in several places becomes contaminated from natural sources or numerous human activities. Residential, municipal, commercial, industrial and agricultural activities can affect ground water quality. It is well known that occurrence of ground water and its availability for various uses is controlled by the nature of rock formation in which it occurs as well as geological structures, geomorphologic and hydrological setting and hydro-meteorological conditions. Contamination of groundwater results leads to poor drinking water quality, loss of water supply, high cleanup costs, high costs alternative supplies and potential health problems. As the inadequate quantity of surface water does not fulfill the needs of the people, the search for and exploitation of groundwater is a must and it is the main source for agricultural, industrial, drinking and domestic purposes.

Therefore, the effective, long-term management of rivers requires a fundamental understanding of hydro-morphological, chemical and biological characteristics (Shrestha and Kazama, 2007). However, due to spatial and temporal variations in water quality (which are often difficult to interpret), a monitoring program, providing a representative and reliable estimation of the quality of ground waters is necessary. The application of different multivariate statistical techniques, such as cluster analysis (CA), principal component analysis (PCA) and factor analysis (FA) helps in the interpretation of complex data matrices to better understand the water quality and ecological status of the studied systems, allows the identification of possible factors sources that influence water systems and offers a valuable tool for reliable management of water resources, as well as rapid solution to pollution problems. Also in recent years, the PCA and FA methods have been exerted for a variety of environmental applications, containing evaluation of ground water monitoring wells and hydrographs, examination of spatial and temporal patterns of surface water quality, identification of chemical species related to hydrological conditions and assessment of environmental quality indicators.

The aim of this study is to analyze the 13 parameters of water in 8 sampling stations of palar River for monsoon(October,November,december) and post monsoon(January,February,march) seasons. The obtained data set is subjected to the multivariate statistical methods (i.e. CA, PCA and FA) to evaluate information about similarities and dissimilarities between sampling stations, to recognize water quality variables for seasonal variations in river water quality and the affect of pollution sources on the water quality parameters of the palar River Basin.

MATERIALS AND METHODS

STUDY AREA

Palar river basin which is flowing through the North Arcot district of Tamil Nadu state lies between 12° 28' 0" N latitude and 80° 10' 0" E longitude. River Palar is the major drainage system in the district, which rises near Nandhidurg in Karnataka and enters the district about 7 km west of Vaniyambadi. During pre-monsoon, this area experiences high temperature of around 44°C and minimum of around 20°C during post-monsoon. The major source of rainfall is northeast monsoon (October to December). The annual recharge of ground water is 127822 ha-m and the present extraction works out to be 94076 ha-m. The total annual rainfall in this area is 800 mm/year. It is an industrial area which exports around 70% of the leather goods from India. Tanneries are mainly small scale industries located in Vaniyambadi, Ambur and Ranipet which are discharging huge amount of salts and heavy metals like chromium that affect the quality of water and soil. Ranipet in Palar basin has been identified as one of the top ten dirtiest and polluted cities in the world according to the New York-based Blacksmith Institute. Tanneries discharging their effluents directly or indirectly into the Palar river. Water quality analysis of the untreated effluent shows that the Total Dissolved Solids (TDS) is in the range of 20000- 30000mg/l. Other major constituents of pollution are sodium, chloride, magnesium, sulphate and chromium. Due to high permeable sand along the river course, there exist many tanneries along the river course with good groundwater.

SAMPLE COLLECTION

Water samples were collected from 8 stations (Vaniyambadi, Ambur, Pallikonda, Vellore, Arcot, Walaja, Kaveripakam, Kanchipuram) for monsoon and post monsoon season. Then, collected samples were kept in a 2 litter polyethylene plastic bottle cleaned with metal free soap, rinsed many times with distilled water and finally soaked in 10 % nitric acid for 24 hours, finally rinsed with ultrapure water. All water samples were stored in insulated cooler containing ice and delivered on the same day to laboratory and all samples were kept at 4 °C until processing and analysis.

ANALYTICAL METHODS

In the present investigation, water samples were collected from 8 stations in 6 different month(monsoon and post monsoon). The selected water quality parameters include pH, turbidity, Electrical conductivity (EC), total solid(TS),Total Dissolved solids (TDS), Total Hardness, calcium, magnesium, chlorides, Sulphates, alkalinity, dissolved oxygen, ammonia.

The pH, turbidity, electrical conductivity concentration of the water was measured by the pH, turbidity and electrical conductivity meter. Total dissolved solid, total solid were determined by gravimetric method at 105-110ºC. Total Hardness, calcium, magnesium, chlorides were determined by titration method. Sulphate and ammonia concentration measured by spectrometric method. Dissolved oxygen is determined by winkler method. The water quality parameters, their units and methods of analysis are summarized in Table 1.

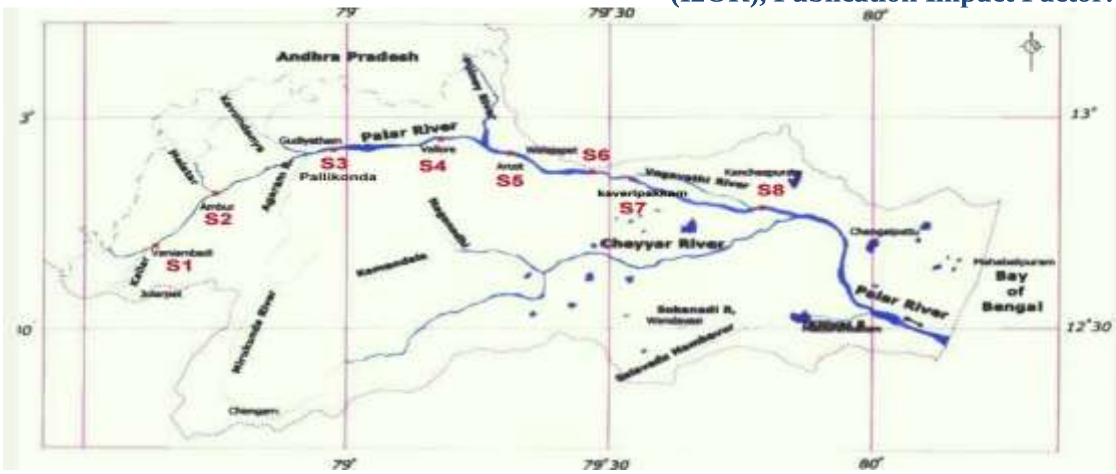


Fig 1: Map of the study area and sampling location

STATISTICAL METHODS

All mathematical and statistical calculations were implemented using STATISTICA 8 and Microsoft Office Excel 2007.

Cluster analysis

Cluster analysis is a group of multivariate techniques whose primary purpose is to assemble objects based on the characteristics they possess (Shrestha and Kazama, 2007). The Euclidean distance usually gives the similarity between two samples and a distance can be represented by the difference between analytical values from the samples (Otto, 1998). In this study, hierarchical agglomerative CA was performed on the raw data set by means of the Ward's method, using squared Euclidean distances as a measure of similarity. The spatial variability of water quality in the whole river basin was determined from CA, using the linkage distance, reported as Dlink/Dmax, which represents the quotient between the linkage distances for a particular case divided by the maximal linkage distance. The quotient is then multiplied by 100 as a way to standardize the linkage distance (Simeonov et al., 2003; Wunderlin et al., 2001). Cluster analysis was used in the present investigation because a visual summary of intra-relationship amongst variations parameters can lead to a better understanding of governing factors.

Principal component analysis/factor analysis

PCA is designed to transmute the original variables into new, uncorrelated variables (axes), called the principal components, which are linear combinations of the original variables (Shrestha and Kazama, 2007). PCA provides information on the most meaningful parameters which describe the whole data set interpretation, data reduction and to summarize the statistical correlation among constituent in the water with minimum loss of original information (Helena *et al.*, 2000). FA follows PCA which is a linear combination of observable water quality variables, whereas FA can include unobservable, hypothetical, latent variables (Helena *et al.*, 2000; Vega *et al.*, 1998). PCA of the normalized variables was executed to extract significant principal components (PCs) and to further reduce the contribution of variables with minor significance; these PCs were subjected to varimax rotation (raw) generating factors (Abdul-Wahab *et al.*, 2005; Love *et al.*, 2004; Shrestha and Kazama, 2007; Singh *et al.*, 2004, 2005). The main applications of factor analytic techniques are 1) to lessen the number of variables and 2) to discover structure in the relationships between variables, that is to classify variables.

RESULTS AND DISCUSSION

The results of water quality parameters from 8 stations in 6 month of palar river are represented in Table 2.

Cluster analysis of water quality

Cluster analysis was applied to find out the similarity groups between the sampling stations. Based on 13 variables cluster analysis classified 8 sampling location into 3 distinct cluster at $(D_{link}/D_{max})X100 < 50$, (Fig 2) represented by less pollution, moderate pollution, high pollution levels. Cluster 1 formed by station 1,3,5,7,8; cluster 2 by station 4 and 6 , cluster 3 by station 2.

Cluster 1 station were located in headwater with green cover and no industrial activity thus the water quality was optimal, site 4 and 6 of cluster 2 were having moderate pollution level because of direct discharge of domestic sewage into the palar river. The water of least quality located in station 2. This result demonstrated the influence of untreated tannery waste water discharge in palar river. The results exhibit that the CA technique is useful in present accredited classification of ground waters in the whole river basin, hence, the number of sampling sites and respective cost in the future monitoring plans can be lessen.

Table 1: Water quality parameters, abbreviations, units and methods used for water sample of palar River

Parameter	Abbreviation	Units	Analytic methods
pH	pH	ph unit	pH meter
Turbidity	Turbidity	NTU	Turbidity meter
Electrical conductivity	EC	Ohm	Conductivity meter
Hardness	Harness	mg/L	EDTA Titration method
Calcium	Ca	mg/L	Titration method
Magnesium	Mg	mg/L	Titration method
Alkalinity	Alkalinity	mg/L	Titration method
Total solid	TS	mg/L	Gravimetric method
Total dissolved solid	TDS	mg/L	Gravimetric method
Chloride	cl^-	mg/L	Argentometric method
Sulphate	So_4^-	mg/L	Spectrometric method
Dissolved oxygen	DO	mg/L	Winker azide method
Ammonia	Ammonia	mg/L	Spectrometric method

Table 2: Results of water quality parameters from eight sampling stations of palar River in six month

Station	pH	Turbidity	EC	TS	TDS	Alkalinity	hardness	Ca	Mg	Cl^-	So_4^-	Ammonia	DO
Month- October 2015													
1	8.1	1.5	2200	2900	2200	705	1245	300	945	474	97	0.23	0.4
2	7.77	2.3	5800	7100	6700	490	3700	2200	1500	1680	195	0.49	0.3
3	7.65	2.1	1700	3200	2500	510	1515	100	1415	527	141	0.19	0.2
4	7.19	1	3900	5100	3700	670	2200	1000	1200	1182	214	0.16	0.4
5	7.74	2.7	3300	4000	3600	651	1250	400	850	1085	171	0.37	0.3
6	7.4	0.7	4100	3900	3500	491	1335	475	860	1329	221	0.42	0.5
7	7.97	2.3	1400	2100	1900	780	800	185	615	654	300	0.15	0.5
8	7.45	2.8	1200	2000	1700	610	604	450	154	200	220	0.2	0.6
Month- November 2015													
1	7.83	4	2100	3000	2100	410	1055	500	555	532	158	0.33	2
2	7.42	4.5	4000	5500	4500	300	2800	2000	800	1500	180	0.42	2.2
3	7.3	2.7	1066	2500	1500	240	570	300	270	242	126	0.15	2.1
4	7.02	2.7	3100	4000	2800	385	1200	800	400	779	200	0.12	2
5	7.2	3	1423	3000	2000	135	610	310	300	444	123	0.33	1.2
6	7.23	2.8	2900	3700	3000	165	1030	600	430	1082	213	0.24	2.4
7	7.46	2.5	1300	2000	1700	180	745	310	435	504	144	0.12	1.6
8	7.05	3	1000	1800	1500	300	500	300	200	180	200	0.19	1.8
Month – December 2015													
1	7.7	4.2	2300	3000	2000	300	805	500	305	550	206	0.29	2.1
2	7.32	4.7	5000	5600	4500	250	2015	1600	415	1400	226	0.36	2.3
3	7.22	3	1200	2500	1400	210	508	300	208	230	185	0.12	2.4

4	6.95	3.2	3200	4200	2600	305	804	600	204	760	266	0.1	2.2
5	7.05	4.5	1600	3200	1900	95	508	310	198	434	165	0.3	1.8
6	7.09	3.5	3000	3900	2800	120	805	605	200	1068	285	0.2	2.3
7	7.35	2.9	1400	2500	1600	135	606	405	201	490	226	0.1	1.4
8	6.93	3.6	1200	2000	1300	225	400	300	100	170	264	0.15	1.8
Month – January 2016													
1	7.42	3.6	2100	2800	1800	315	1015	720	295	609	164	0.3	2.1
2	7.15	3.5	4800	5500	4200	260	2220	1805	415	1503	152	0.38	2.2
3	7.02	2.1	1100	2300	1200	225	600	408	192	258	168	0.14	2.1
4	6.89	2	3000	4000	2300	315	1020	820	200	806	184	0.12	2.4
5	6.95	3.5	1400	3000	1700	105	615	500	115	500	135	0.35	2.3
6	7.01	3	2800	3800	2700	140	1000	705	295	1112	212	0.25	1.9
7	7.05	2.2	1200	3400	1500	155	820	600	220	608	164	0.13	1.3
8	6.86	2.6	1000	1800	1100	240	600	420	180	222	208	0.17	1.9
Month – February 2016													
1	7.4	3.8	2200	3000	1900	350	1150	900	250	802	170	0.32	1.8
2	7.1	3.9	4400	5700	4400	280	2950	2200	750	1608	142	0.4	1.7
3	7.02	2.8	1400	2400	1500	255	650	556	94	307	145	0.15	1.3
4	6.85	2.6	3500	4200	2400	330	1300	925	375	708	178	0.14	2
5	6.92	3.9	1700	3300	1900	125	730	615	115	402	110	0.37	1.9
6	6.98	3.4	3200	4000	2900	165	1150	804	344	1024	202	0.29	1.8
7	7.02	2.6	1500	3600	1600	175	800	710	90	622	150	0.14	1.6
8	6.84	2.9	1300	2000	1200	260	600	505	95	234	195	0.18	1.3
Month – March 2016													
1	7.56	3.2	2000	3100	2000	400	1000	720	280	906	180	0.32	2
2	7.23	3.3	4000	5800	4500	320	2600	1840	760	1684	156	0.41	2.1
3	6.97	2.4	1300	2600	1600	290	500	315	185	364	167	0.16	1.9
4	7.12	2.2	3300	4200	2600	365	1100	808	292	770	195	0.16	1.8
5	7.14	3.1	1600	3400	1900	175	550	464	86	446	126	0.39	1.6
6	7.2	3.2	3000	4100	2800	205	950	754	196	1064	209	0.3	1.4
7	7.32	2.2	1400	3200	1700	225	705	600	105	646	171	0.15	1.8
8	7.02	2.6	1200	2200	1400	280	440	365	75	247	209	0.2	1.9

Seasonal variations of water quality parameters

Box and whisker plots represent seasonal trends in Fig.3. The average pH is higher in the October and its gradually decreasing after monsoon season. The variation in the turbidity is approximately similar in all month in that December month having highest average value. Total solid, total dissolved solid, electrical conductivity average value is higher in the October month due to industrial (tannery) activity near the palar river and its reduced after the rain during November, December due to dilution. Similarly hardness average value is high in the October month. Chloride, sulphate, ammonia average value is higher in the October month due to more agricultural activity during that month. Dissolved oxygen value is high in the November and December month.

Principal component analysis/factor analysis was executed on 13 variables for the eight different sampling stations in six month, in order that is identified important seasonal water quality parameters. An eigenvalue gives a measure of the significance of the factor. The factors with the highest eigen values are the most significant. Eigen values of 1.0 or greater are considered significant (Shrestha and Kazama, 2007). Classification of factor loading is thus 'strong', 'moderate' and 'weak', corresponding to absolute loading values of > 0.75, 0.75-0.50 and 0.50-0.30, respectively (Liu et al., 2003). Corresponding, variable loadings and explained variance are presented in Table 3 and strong loading values have been highlighted. The two factors of PCA/FA include totally more than 79 % of the total variance in each season respecting water quality data sets. Each water quality parameter with an strong correlation coefficient value (> 75 %) was considered to be an significant parameter contributing to seasonal variations of the water quality in palar River.

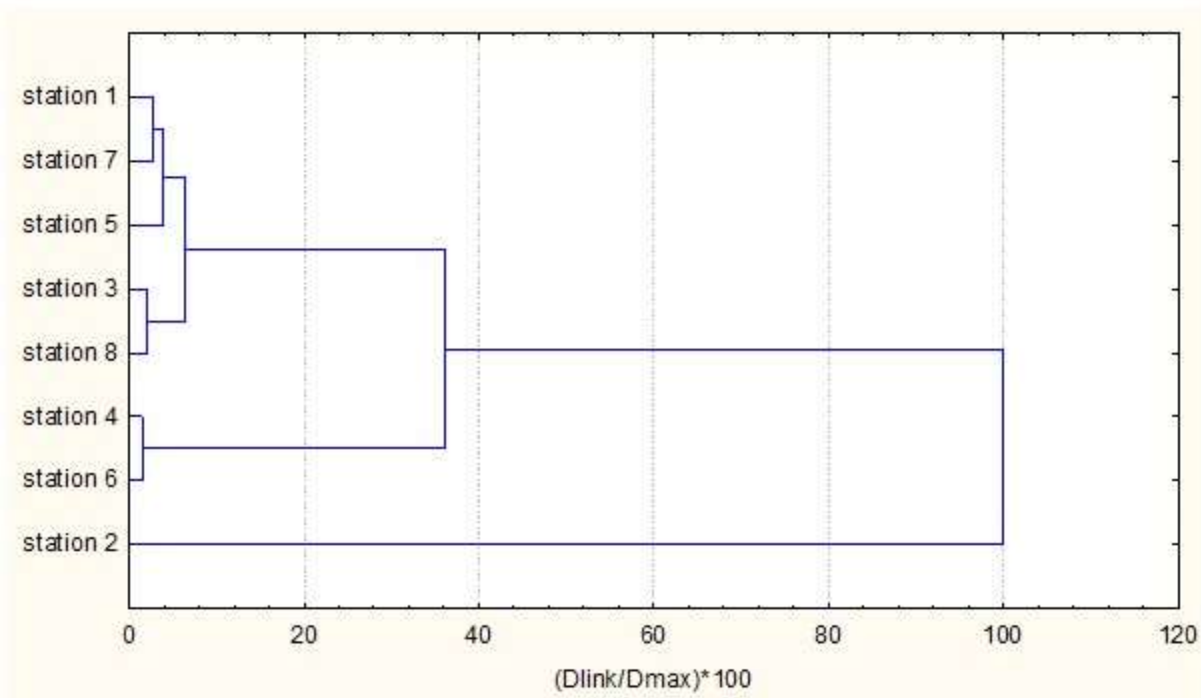
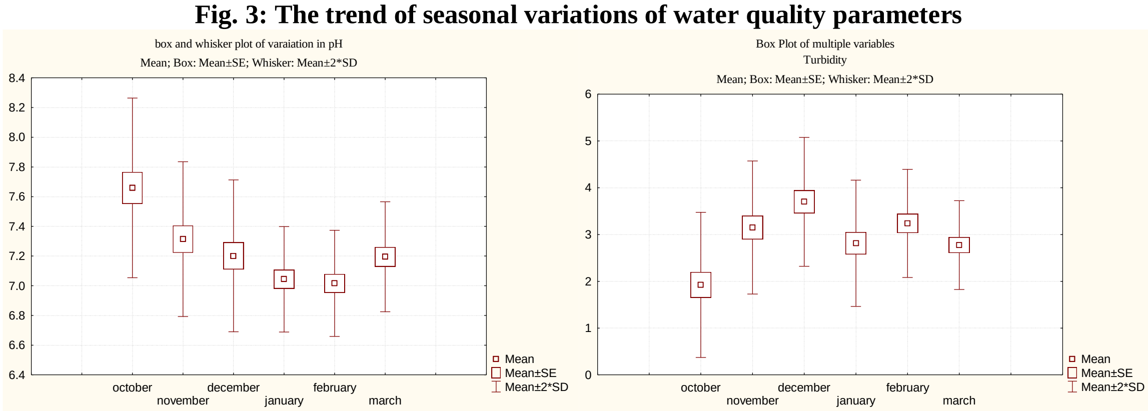


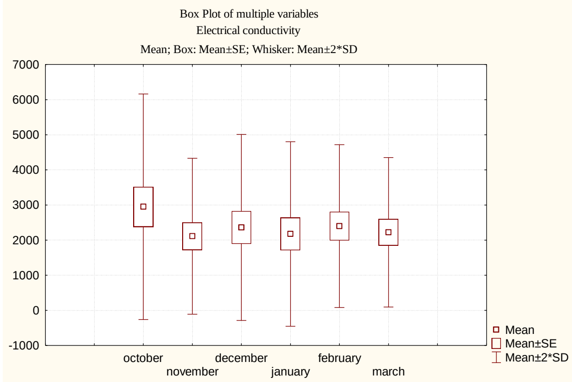
Fig. 2: Dendrogram of cluster analysis for sampling stations according to ground water quality parameters of the palar River Basin

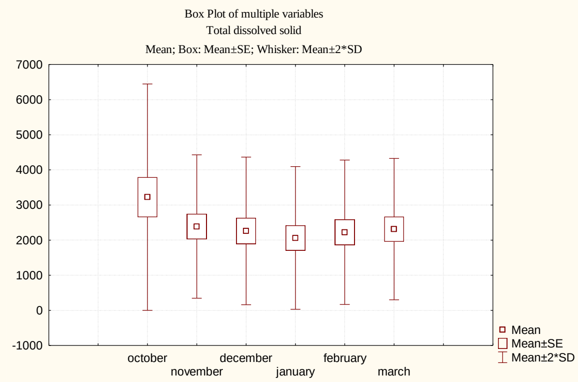
The most significant water quality parameters that can contribute to evaluate seasonal variations of water quality are signalized in Table 4. Total solid, total dissolved solid, electrical conductivity, hardness are the most significant parameters contributing to the variation all the 6 month of palar river. The main reason for this is the discharge of the tannery effluent into the palar river. Ammonia and sulphate as the most significant parameter contributing the variation in two and four month respectively because of agricultural activity near the palar river basin.

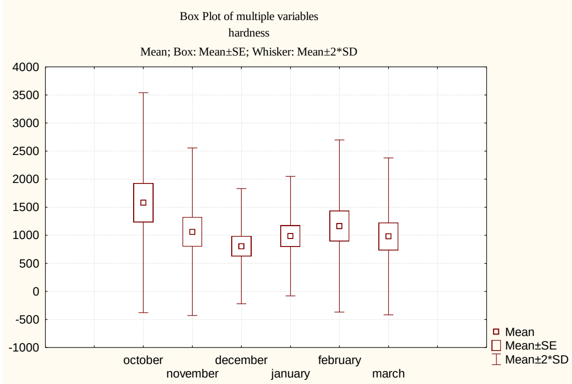
Fig. 3: The trend of seasonal variations of water quality parameters

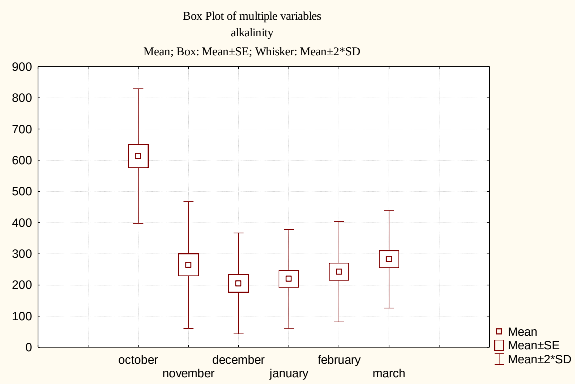


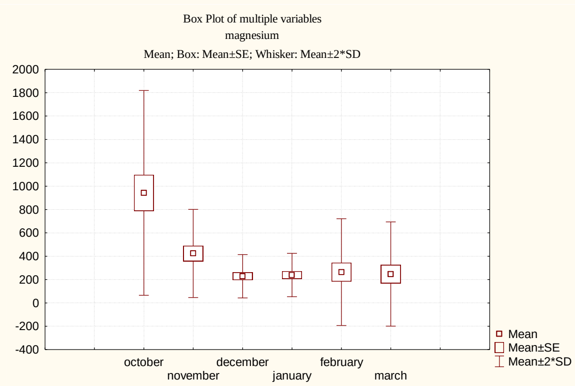
ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

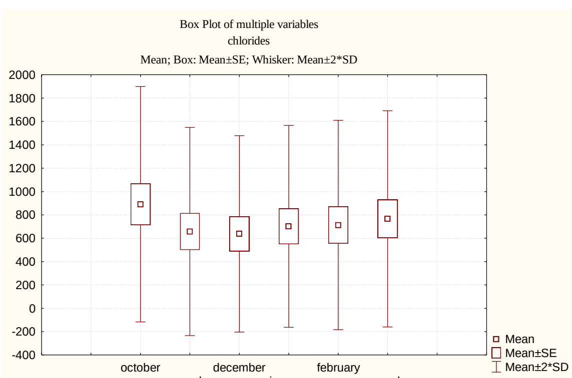


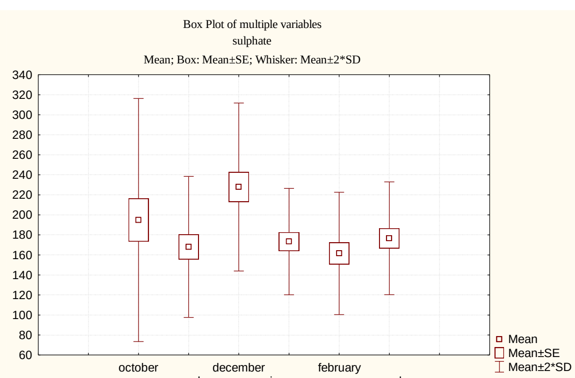


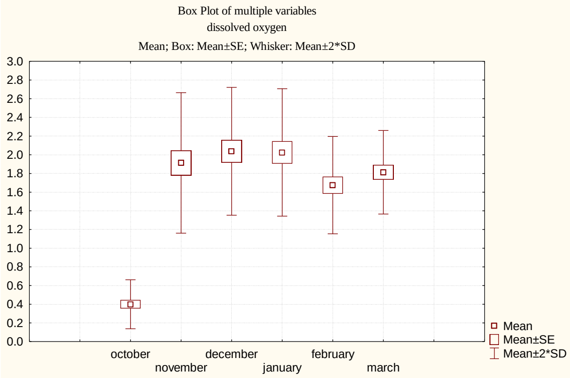












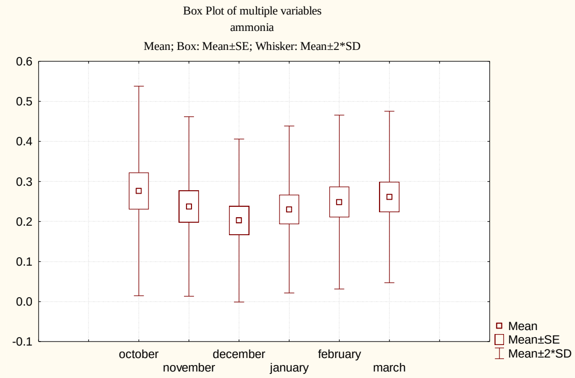


Table 3: The factor loadings value and explained variance of water quality parameters in six months

Variables	Factor 1	Factor 2
pH	0.188545	0.590824
Turbidity	0.231732	0.239796
EC	-0.957062	-0.202317
TS	-0.981372	-0.037873
TDS	-0.977805	-0.063948
Alkalinity	0.619001	-0.011684
Hardness	-0.944464	0.069199
Calcium	-0.859398	-0.203353
Magnesium	-0.766186	0.473231
Chloride	-0.903970	-0.267933
Sulphate	0.151935	-0.786789
Ammonia	-0.757165	-0.092438
DO	0.515329	-0.761715

For October

Variables	Factor 1	Factor 2
pH	-0.254599	0.767202
Turbidity	-0.785691	0.487512
EC	-0.938963	-0.260776
TS	-0.937844	-0.117075
TDS	-0.966629	-0.151632
Alkalinity	-0.335886	-0.022655
Hardness	-0.970575	0.047265
Calcium	-0.953845	-0.029136
Magnesium	-0.916267	0.276816
Chloride	-0.932217	-0.172456
Sulphate	-0.402308	-0.749910
Ammonia	-0.665855	0.544481
DO	-0.549919	-0.438843

For November

ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

Variables	Factor 1	Factor 2
pH	-0.282710	0.619436
Turbidity	-0.645687	0.540162
EC	-0.962655	-0.253468
TS	-0.939732	-0.212742
TDS	-0.972573	-0.176878
Alkalinity	-0.316625	-0.162013
Hardness	-0.969183	-0.021108
Calcium	-0.957809	-0.094673
Magnesium	-0.895932	0.323245
Chloride	-0.912040	-0.258561
Sulphate	-0.094546	-0.866526
Ammonia	-0.708362	0.582611
DO	-0.510603	-0.254746

For December

Variables	Factor 1	Factor 2
pH	0.449446	0.429680
Turbidity	0.565979	0.730466
EC	0.954060	-0.242306
TS	0.895395	-0.226334
TDS	0.967297	-0.154772
Alkalinity	0.260882	-0.330757
Hardness	0.968858	-0.147978
Calcium	0.963150	-0.136052
Magnesium	0.870912	-0.186926
Chloride	0.929907	-0.204056
Sulphate	-0.258777	-0.665151
Ammonia	0.682895	0.675848
DO	0.309774	0.182654

For January

Variables	Factor 1	Factor 2
pH	-0.330375	-0.277200
Turbidity	-0.600834	-0.693885
EC	-0.918001	0.309291
TS	-0.917511	0.100252
TDS	-0.970909	0.072753
Alkalinity	-0.225138	0.551171
Hardness	-0.961464	0.135274
Calcium	-0.944791	0.092508
Magnesium	-0.964894	0.232336
Chloride	-0.961979	0.104401
Sulphate	0.108011	0.702686
Ammonia	-0.693347	-0.643930
DO	-0.503134	-0.162690

For February

Variables	Factor 1	Factor 2
pH	0.354957	0.026598
Turbidity	0.592201	-0.557899
EC	0.885351	0.069160
TS	0.932736	-0.100959
TDS	0.969063	-0.041085
Alkalinity	0.323662	0.807733
Hardness	0.979882	0.123502
Calcium	0.979184	0.078567
Magnesium	0.952059	0.217056
Chloride	0.965948	-0.009035
Sulphate	-0.178439	0.471028
Ammonia	0.658907	-0.613926
DO	0.332676	0.676225

For March

Table 4: The most significant parameters that contribute to water quality variations in each month

Month	Parameters with strong positive factor loadings	Parameters with strong negative factor loadings
October	EC,TDS,TS,hardness,Ammonia,sulphate	-
November	EC,TDS,TS,hardness,sulphate	pH
December	EC,TDS,TS,hardness,sulphate	sulphate
January	-	EC,TDS,TS,hardness,cl, turbidity
February	EC,TDS,TS,hardness,	sulphate
March	EC,TDS,TS,hardness,	EC,TDS,TS,hardness, alkalinty

CONCLUSION

In this study, various multivariate exploratory techniques were utilized to evaluate variations in ground water quality palar River Basin. Cluster analysis grouped eight sampling stations into three clusters of similar water quality features and thereupon can be allocated whole river basin into three zones i.e. low, moderate and high pollution. According to acquired information, it is possible to plan for coming events, optimum sampling strategy, that can be lessened the number of sampling stations and affiliated recurring costs. The principle component analysis and factor analysis assisted to extract and recognize the factors or origins responsible for water quality variations in four seasons of year. The inorganic parameter total solid, total dissolved solid, hardness were the most significant parameters contributing to water quality variations for all month. Result of PCA/FA evinced that, a parameter that can be significant in contribution to water quality variations in river for one season, may less or not be significant for another one. Accordingly it is required that, when selecting water quality parameters for implementing environmental monitoring plans in river basins, the seasonal variations of parameters in assessment of water quality must be consider.

ACKNOWLEDGEMENTS
I express our deep and sincere to our honorable principal Dr. A.RAJESH, to avail the required facilities for the successful completion of this project work.

I express sincere gratitude to our Head of the Department Mr.T.SANKAR, M.Tech, who have paved the way to start our project and very helpful to complete the project.

I take this immense opportunity with pride and pleasure in expressing my deep sense of gratitude and in-doubtless to my guide Mr.K.BALAKUMAR M.E.

I also thank Mr.J.SHARPUDIN M.E and Mr.N.BABU M.E for their ideas, which enable for successful completion of this project.

I also express my thanks to all teaching and non-teaching staffs of civil engineering department for their timely suggestion and help rendered in connection with the project.

Last but not least i extend my gratitude to my friends for their assistance during our project work.

REFERENCES
[1] H. Pejman; G. R. Nabi Bidhendi; A. R. Karbassi; N. Mehrdadi; M. Esmaeili Bidhendi. Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques
[2] Abdul-Wahab, S. A.; Bakheit, C. S.; Al-Alawi, S. M., (2005). Principal component and multiple regression analysis in modelling of ground-level ozone and factors affecting its concentrations.
[3] Shrestha, S.; Kazama. F., (2007). Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. Environ. Model. Software, 22 (4), 464-475.
[4] Simeonov, V.; Stratis, J. A.; Samara, C.; Zachariadis, G.; Voutsa, D.; Anthemidis, A.; Sofoniou, M.; Kouimtzis, T., (2003). Assessment of the surface water quality in Northern Greece. Water Res., 37 (17), 4119-4124
[5] Wunderlin, D. A.; Diaz, M. P.; Ame, M. V.; Pesce, S. F.; Hued, A.C.; Bistoni, M. A., (2001). Pattern recognition techniques for the evaluation of patial and temporal variations in water quality. A case study: Suquia river basin (Cordoba, Argentina). Water Res., 35 (12), 2881-2894
[6] Tamilarasi; V Murugesan .S; and Vishwanathan .B. Groundwater Quality Monitoring in Walajah Block, in Palar river basin at Vellore District, Tamilnadu, India
[7] K. Venkatesharaju; R. K. Somashekar and K. L. Prakash. Study of seasonal and spatial variation in surface water quality of Cauvery river stretch in Karnataka
[8] Ishaq S. Eneji; Agada P; Onuche; Rufus Sha'Ato. Spatial and Temporal Variation in Water Quality of River Benue, Nigeria
[9] HongmeiBu; XiangTan; SiyueLia; QuanfaZhang. Temporal and spatial variations of water quality in the Jinshui River of the South Qinling Mts.,China
[10] Bengraine, K.; Marhaba, T. F., (2003). Using principal component analysis to monitor spatial and temporal changes in water quality. J. Hazard. Mater., 100 (1-3), 179-195.