Assessment of the surface water quality in Tajan river basin, Iran

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Abstract: In the research, multivariate statistical techniques, such as cluster analysis (CA), principal component analysis (PCA) and factor analysis (FA) were used to identify characteristics of water quality and to assess spatial and seasonal variations of water quality in Tajan River Basin. Water quality data collected from ten sampling stations in river during Six years were analyzed for 14 parameters. Cluster analysis grouped stations into three clusters and the characteristic of clusters was agreed to the spatial pattern human activities in the Tajan river basin. In this investigation, cluster three (station 10) matches to highly polluted sites. The principal component analysis/factor analysis helped to extract and recognize the factors or origins responsible for water quality variations in four seasons. The temperature (natural parameter), BOD_5, COD, FC, NO_3^- and PO_4 (anthropogenic activities) were the most significant parameters contributing to water quality variations for all seasons.
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1. Introduction

It is well-known that river play an important role in population development, supplying water for humans, agriculture, and industrial consumption (Simeonov et al., 2003; Nouri et al., 2008). The natural processes (such as precipitation inputs, weathering and erosion) and anthropogenic activities (such as mining, agriculture, residential and industrial wastes), discharge dissolved compounds and suspended matter into the rivers, decreasing water quality significantly (Carpenter et al., 1998; Ouyang et al., 2006). On the other hands, rivers play a major role in assimilating or carrying off municipal and industrial wastewater and runoff from farm land (Singh et al., 2004). River water quality is one important factor directly concerning with health of human and aquatic life (Kazi et al., 2009). In recent decades, river water quality monitoring by measurement of various water quality parameters has been increasing. However, due to spatial and temporal variations in water quality a monitoring program that will provides representative and reliable estimation is necessary (Shrestha and Kazama, 2007). In this study, for the physico-chemical parameters of rivers, the usual method of water quality evaluation is to measure multiple parameters of pollutants in different monitoring at periodic times in a watershed with varying topographical conditions. Multivariate statistical methods have been widely used in the interpretation of complex data set to evaluate the water quality and a variety of environmental phenomen (Ouyang, 2006; Bouza-Deano et al., 2008). Also, multivariate statistical techniques are useful in verifying temporal and spatial variations caused by natural and anthropogenic factors linked to seasonality (Parinet et al., 2004; Simeonov et al., 2004; Wu et al., 2010). In this study, a large data matrix obtained during the 6-yr (2004~2010) monitoring program subjected to different multivariate statistical techniques. The goal of this paper is to delineate the characteristics of the water quality of Tajan Rivers and to identify water quality variables for seasonal variations in river water quality.

2. Material and Methods

Study area

The location of the study area is on the Mazandaran Province in the north of Iran. Tajan River basin from Tizabad Mountain and after receiving many other small rivers (e.g., Lajim, Garmab-rood and Farim River) passes through the city of Sari and then enters the Caspian Sea through Farahabad city. It is about 170 km long and its catchment area is about 4000 km^2 with an annual average water flow of 207.4 km^2 (Kalantari and Ebadi, 2006). Pollution sources that threaten the quality of water in Tajan river are Mazandaran wood and pulp, Paksar dairy products and Sari Antibiotic production factories, Sari municipal wastewater and agriculture activities (Mehrdadi et al., 2006).

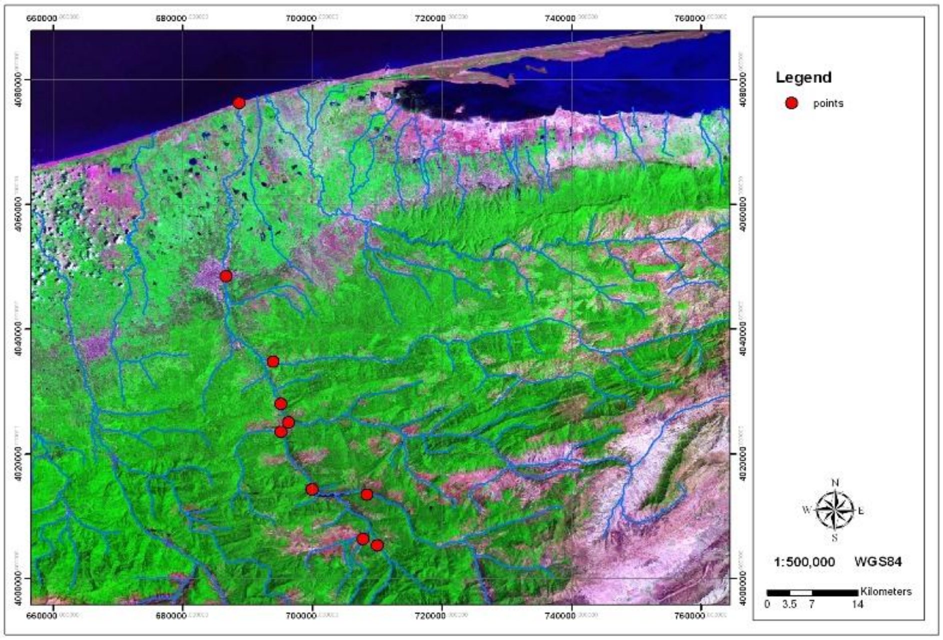

Figure 1 map of study area and surface water quality monitoring stations in the Tajan river basin.

Monitored parameters and analytical methods

From 2004 to 2010, data (14 parameters for water quality assessment) have been collected from ten water quality monitoring stations along Tajan River. The selected water quality parameters includes discharge, temperature, dissolved oxygen, 5-day biochemical oxygen demand, chemical oxygen demand, pH, total dissolved solids, electrical conductivity, hardness, chloride ion, total coliforms, NO_3^-, SO_4^{2-} and PO_4. The methods of analysis are shown in Table 1. The water quality data are shown in Table 2, with mean and deviation to monitor the distribution of data.

Table 1: water quality parameters and analytical methods used during 2004-2010 for surface water of the Tajan river basin

No.	Parameters	Units	Analytical methods
1	Temperature	WT (℃)	Thermometer
2	Discharge	Q (m3/s)	Current meter
3	dissolved oxygen	DO(mg l-1)	DO meter
4	biochemical oxygen demand	BOD5(mg l-1)	Winkler azide method
5	chemical oxygen demand	COD(mg l-1)	Potassium permanganate
6	pH	pH unit	pH meter
7	total dissolved solids	TDS(mg l-1)	Gravimetrically at 103-105 ℃
8	electrical conductivity	EC(µS cm-1)	Electrometric
9	hardness	T-har(mg l-1)	Titrimeter
10	chloride ion	Cl(mg l-1)	Spectrophotometric
11	total coliforms	FC (CFU/100 ML)	The membrane filter technique
12	Nitrate	NO3- (mg l-1)	Spectrophotometer
13	Solphate	SO42- (mg l-1)	Ion chromatographic
14	Total phosphate	PO4 (mg l-1)	Spectrophotometer

Statistical methods

In the present study, statistical calculation was using STATISTICA 5 software. Before the multivariate analysis, *z*-scale transformation was applied to the raw water quality dataset to avoid miss classification because of wide differences in data dimensionality to eliminate the influence of different units of measurements and to render the data dimensionless (Liu et al., 2003; Shrestha and Kazama, 2007). Also, to examine the suitability of the data for Principal component analysis/factor analysis, Kaiser-Meyer-Olkin (KMO) and Bartlett's test was performed. High value (close to 1) shows that Principal component analysis/factor analysis may be useful. In this study, KMO is 0.81. Bartlett's test shows whether correlation matrix is an identity matrix, which would shows variables are unrelated (Shrestha and Kazama, 2007; Zhao et al., 2009). The significant level was 0.05 in this study, shows that there are significant relationships among variables.

3. Result and Discussion

Spatial similarity with cluster analysis

Cluster analysis (CA) technique is an useful tool that offers reliable classification of surface water and makes possible adequately to serve for spatial assessment in an optimal manner in the basin (Vega et al., 1998; Wu et al., 2010). To survey anthropogenic and natural influences on characteristics of water quality in monitoring stations, CA was used to classify these stations based on results of Principal component analysis (PCA) (Fan et al., 2010). In this study, hierarchical agglomerative CA was performed on the normalized data set using the Ward' s method, using squared Euclidean distances as a measure of similarity. The spatial variability of water quality in the river basin was determined from CA, using the linkage distance, reported as Dlink/Dmax, which represents the quotient among the linkage distances for a particular case divided by the maximal linkage distances. The quotient is then multiplied by 100 as a way to standardize the linkage distance (Simeonov et al., 2003; Pejman et al., 2009).

The results were illustrated in Fig.2, where three main groups at (Dlink/Dmax)*100<70 are visible. The cluster 1 (stations 1, 2, 3, 4, 5, 6, 7 and 8) relatively less polluted sites. These stations located upstream of the Tajan river, receives pollution mostly from rural wastewater. This result suggests the self-purification and assimilative capacity of the river. Cluster two consisted of one station (9) with moderate pollution of river water. This station receives pollution from agricultural activities, wastewater of municipal and timber & paper industry. Cluster three (station 10) correspond to highly polluted sites. Discharge of domestic wastewater, agriculture runoff and Sari Antibiotic production factories are principal reasons of pollution increase. This station located downstream that self-purification capability of Tajan River is weak. The some characteristics are also reported by other researchers (Wnderlin et al., 2001; Singh et al., 2004; Kim et al; 2005; Shrestha and Kazama, 2007).

Table 2: range, mean and S.D of water quality parameters at different locations of the Tajan river basin during 2004-2010

parameters		Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station 10
Q (m^3/s)	Mean	7.81	5.01	5.29	6.08	4.97	4.06	4.66	2.41	0.31	0.35
	S.D	0.99	0.84	1.10	1.99	1.34	1.29	2.49	1.54	0.38	0.01
WT (℃)	Mean	8.36	8.59	8.66	8.61	8.7	8.7	8.93	8.97	10.36	18.15
	S.D	1.16	1.09	1.13	1.10	0.98	0.93	1.01	0.94	1.25	1.02
DO (mg l^{-1})	Mean	7.74	7.66	7.56	7.56	7.25	7.24	7.17	6.20	5.15	4.04
	S.D	0.38	0.28	0.19	0.17	0.20	0.20	0.15	0.16	0.17	0.17
BOD_5 (mg l^{-1})	Mean	1.55	2.08	2.51	3.31	5.51	4.36	5.33	5.34	8.34	31.34
	S.D	0.50	0.44	0.50	0.50	0.50	1.15	1.13	1.15	1.15	1.15
COD (mg l^{-1})	Mean	2.40	3.33	3.84	5.93	9.58	7.27	8.88	8.91	14.23	55.70
	S.D	0.70	1.04	1.04	1.03	2.01	2.19	1.98	2.01	2.05	5.88
TDS (mg l^{-1})	Mean	78	185	190	194	234	286	317	333	508	737
	S.D	45.56	12.91	69.66	42.57	64.52	36.18	52.42	22.89	99.72	105.13
EC (µS cm^{-1})	Mean	291	260	484	422	460	509	652	694	627	870
	S.D	67.11	195.28	105.29	45.63	105.40	57.32	81.08	40.39	172.44	324.49
pH	Mean	7.87	7.85	7.87	7.87	7.87	7.88	7.89	7.78	7.88	7.84
	S.D	0.09	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.09	0.08
Cl (mg l^{-1})	Mean	0.44	0.99	0.72	0.59	2.46	0.43	1.21	0.42	0.64	2.18
	S.D	0.11	0.65	0.48	0.13	0.75	0.11	0.49	0.07	1.00	1.90
SO_4^{2-} (mg l^{-1})	Mean	0.47	2.10	1.22	1.59	1.31	0.47	1.56	0.38	0.50	1.40
	S.D	0.17	1.46	0.45	0.30	0.49	0.19	0.53	0.12	0.43	0.68
Hard	Mean	2.14	3.19	2.45	2.69	2.51	2.24	2.52	2.16	2.20	2.97
	S.D	0.29	0.75	0.37	0.22	0.28	0.25	0.31	0.18	0.42	0.73
FC (CFU/100 ML)	Mean	1	1	1	1	2	2	2	4	13	46
	S.D	0.31	0.44	0.37	0.46	0.96	0.50	1.27	0.96	1.20	9.14
NO_3^- (mg l^{-1})	Mean	0.00	0.01	0.00	0.33	0.45	0.54	0.56	0.58	0.65	0.90
	S.D	0.00	0.00	0.01	0.06	0.06	0.08	0.08	0.08	0.08	0.08
PO_4 (mg l^{-1})	Mean	0.01	0.01	0.01	0.41	0.54	0.65	0.72	0.78	0.79	1.01
	S.D	0.00	0.00	0.00	0.10	0.10	0.09	0.09	0.09	0.09	0.26

1= Ali Abad 2=Karcha 3=Parvarich Abad 4=Solayman Abad 5=Varand 6=Vastan
7=Rigcheshme 8=Garmrood 9= pol-e-tajan 10=farhabad

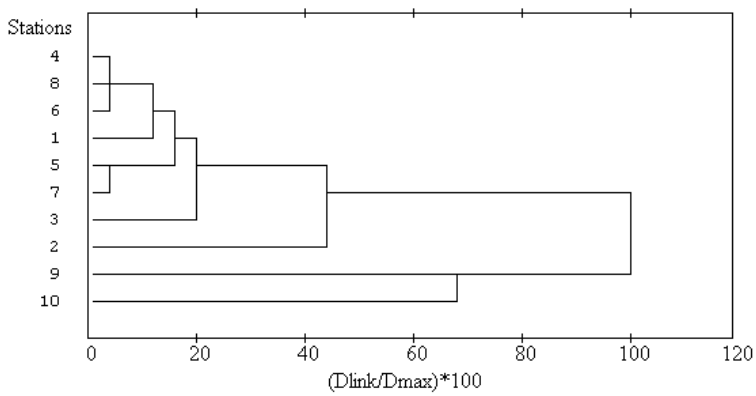

Figure 2 Dendrogram showing clustering of sampling site according to surface water quality characteristics of the Tajan river basin

Seasonal variations of water quality parameters

Principal component analysis/factor analysis was executed on 14 variables for the 10 different sampling stations in four seasons, 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 eigenvalues are the most significant. Eigenvalues of 1.0 or greater are considered significant (Shrestha and Kazama, 2007; Pejman et al., 2009). Table 3 shows the eigenvalue representing factors, the factor loading (>0.4) which was classified as strong, moderate and week corresponding to absolute loading values of >0.75, 0.75~0.50 and <0.4, and the proportion of total variance explained by the factors for the raw data (Liu et al., 2003). The PCA and FA factors include totally more than 88% of the total variance in each season respecting water quality data sets.

Table3 : the factor loadings value and explained variance of water quality parameters in four seasons

Spring					Summer			
Parameters	PC1	PC2	PC3	PC4	PC1	PC2	PC3	
Q	-0.122	-0.047	-0.088	0.945	-0.208	-0.032	0.781	
WT	0.852	0.319	-0.222	-0.191	0.849	0.363	-0.089	
TDS	0.256	0.049	-0.043	-0.067	0.330	0.023	-0.041	
EC	-0.081	-0.037	0.901	-0.091	0.337	0.921	-0.051	
pH	0.254	0.951	-0.030	-0.078	-0.111	-0.058	-0.669	
Cl	0.369	0.795	0.002	-0.026	0.423	0.765	-0.097	
SO_4	-0.132	0.844	-0.021	0.108	-0.082	0.862	0.193	
Hard	0.099	0.927	-0.057	-0.107	0.106	0.928	0.008	
DO	-0.932	-0.016	0.062	0.171	-0.924	-0.144	0.162	
BOD_5	0.905	0.296	-0.171	-0.126	0.889	0.387	-0.065	
COD	0.897	0.308	-0.166	-0.133	0.888	0.385	-0.066	
FC	0.864	0.275	-0.230	-0.154	0.834	0.421	-0.073	
NO_3	0.882	0.006	0.267	0.150	0.888	-0.010	0.053	
PO_4	0.848	-0.031	0.302	0.186	0.833	-0.045	0.101	
Total variance %	41.26	31.23	8.22	7.96	41.47	32.31	8.34	
Autumn					Winter			
Parameters	PC1	PC2	PC3		PC1	PC2	PC3	PC4
Q	-0.155	0.084	0.675		-0.086	-0.038	-0.117	0.858
WT	0.915	0.138	-0.145		0.963	-0.029	-0.093	-0.049
TDS	0.096	0.976	-0.002		-0.023	0.977	-0.011	0.042
EC	0.092	0.981	-0.018		-0.040	0.991	-0.119	0.006
pH	0.021	-0.032	0.745		-0.199	-0.044	0.607	-0.283
Cl	0.163	0.743	0.110		-0.024	0.712	0.143	0.362
SO_4	-0.167	0.825	0.087		-0.074	0.894	-0.150	-0.101
Hard	-0.008	0.907	-0.114		-0.035	0.888	-0.122	-0.212
DO	-0.930	0.055	0.091		-0.895	0.159	-0.198	0.084
BOD_5	0.957	0.154	-0.096		0.984	-0.003	-0.042	-0.013
COD	0.950	0.147	-0.096		0.977	0.023	-0.031	-0.009
FC	0.919	0.122	-0.150		0.954	-0.003	-0.111	-0.047
NO_3	0.863	-0.092	0.129		0.751	-0.102	0.549	0.162
PO_4	0.824	-0.137	0.176		0.640	-0.109	0.641	0.203
Total variance %	41.98	29.18	8.29		39.93	29.17	8.68	7.74

In this study, PC1 explained 41.26% (spring), 41.27%(summer), 41.98%(autumn) and 39.93%(winter) of the total variance and was highly contributed to by variables of temperature, biochemical oxygen demand, chemical oxygen demand, fecal coliform, nitrate and phosphate, but was negatively influenced by DO. Biochemical oxygen demand, chemical oxygen demand and fecal coliform with strong factor loadings are the most important parameters in water quality variations for four seasons of year. It showed that the component was related to organic pollutants from domestic and industrial wastewater. Nitrate and phosphate with positive strong loading value as the most significant parameters contributed to water quality variations in four seasons, it has this meaning that considerable amount of inorganic nutrients due to excessive influx of orchard and agriculture activities. In PC2, the Cl, SO_4 and hardness are the most significant parameters contributing to water quality variations for all four seasons. This component was mainly associated with geological source. In the Tajan River region, basing on PCs score station 9 and 10 had got the highest scores among all the stations. These stations are located in downstream of river and near from rural and cities. In this region river were seriously polluted by all kinds of pollutants (domestic and industrial wastewater, agriculture activities). There are other reports similar approach has successfully been applied to water quality (Singh et al., 2005; Shrestha and Kazama, 2007; Pejman et al., 2009).

5. Conclusions

In this study, surface water quality data for the Tajan River (in north Iran) were evaluated by PCA and CA multivariate techniques. Cluster analysis divided ten stations into three clusters (low, moderate and high pollution) of water quality characteristics. The results of clusters of the Tajan River water quality agreed of human activities. It recommends that CA was an effective method for the reliable classification of surface water. Also, the results of the PCA showed parameters responsible for water quality variations in Tajan River stations that were related to temperature (natural parameter), BOD_5, COD_{Mn}, FC, NO_3 and PO_4 (anthropogenic parameters: agriculture runoff, domestic and industrial wastewater) in four seasons of years. Evidently Principal component analysis/factor analysis is useful for the analysis of complex data and identification and assessment of pollution sources and variations in water quality for effective river water quality management.

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