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Original Research

Drinking Water Quality of a Rice Land in Turkey by Statistical and GIS Perspectives

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Abstract

This study was carried out to determine the drinking water quality of İpsala District, known as "Rice Land" in Turkey. Water samples were collected from 23 stations, including all the residential areas in winter 2013. Some physical, chemical, and microbiological water quality parameters (temperature, dissolved oxygen, pH, conductivity, turbidity, nitrite, nitrate, ammonium, sulfate, phosphate, chloride, fluoride, and biological oxygen demand) were determined and some multi-statistical methods were applied to detected data. The geographic information system was also used in order to make a visual explanation by presenting distribution maps of investigated parameters, and groundwater samples were assessed according to national and international quality criteria. According to data observed, although the investigated parameter levels in ground water of İpsala District did not exceed the limit values for drinking, the region has class II-III (Turkish Regulations) groundwater quality in terms of nitrite and nitrate parameters in general.

Keywords: İpsala District, drinking water quality, multivariate statistical techniques, ArcGIS

Introduction

Environmental pollution that has nearly become a limiting factor for mankind gets top attention all over the globe today. Many reasons have been mentioned by the scientific community, focusing especially on rapid growth of world population, and extreme developments of industry and technology. The effects of almost all the anthropogenic threats on the environment can be minimized if the necessary measures are taken. But in order to take measures, legal sanctions are not enough every time, especially in a society away from spiritual values, where environmental awareness has not been established. Therefore, one of the most important fundamentals of this global problem is no environmental awareness in society.

One of the most affected components of the environment is limited freshwater resources of the world, and pollution caused by anthropogenic activities decreases the quality and potential of limited freshwater [1]. It is known that only 2.8% of water is fresh and suitable for human consumption on the world, and 30.1% of this freshwater is under ground. It was also calculated that 50% of total groundwater were allocated for drinking, 20% for industrial supplies, 15% for agricultural activities, 10% for municipal supplies, and 5% for other applications [2]. Groundwater is the most important source of drinking water for numbers of human communities. But a large variety of organic and inorganic materials have been identified as contaminants found in groundwater and negatively effective on human health. Previous studies have shown that land use in rural areas, especially agricultural applications, can contribute nitrogen and phosphorus compounds to groundwater [3-5]. Therefore, monitoring groundwater quality has a critical importance both for human health and also for ecosystem health, especially in rural areas.

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Table 1. Location properties of select stations.

Station Number	Location	Coordinates		Structural information of water resources [6]	
		North	South	Capacity (L/sec)	Source Type (wells)
S1	İpsala District	40.91883	26.38262	-	-
S2	Sarıcaali Village	40.99130	26.38327	15	Drilling
S3	Sultan Town	41.02951	26.45334	-	-
S4	Balabancık Village	41.03702	26.40355	4	Drilling
S5	Tevfikiye Village	41.06900	26.49451	-	Drilling
S6	Karaağaç Village	41.06499	26.53095	-	Drilling
S7	İbriktepe Town	41.01300	26.50279	-	-
S8	Hacı Town	40.98249	26.55032	40	Drilling
S9	Pazardere Village	40.97980	26.58013	40	Drilling
S10	Turpçular Village	40.94334	26.43567	10	Catchment
S11	Hıdırköy Village	40.91715	26.46215	-	Drilling
S12	Sarpdere Village	40.88983	26.43266	39	Drilling
S13	Korucu Village	40.90164	26.49781	-	Drilling
S14	Esetçe Town	40.87251	26.44253	15	Drilling
S15	AliçoPehlivan Village	40.84245	26.44142	-	-
S16	Kocahıdır Town	40.81180	26.40614	-	-
S17	Küçükdoğanca Village	40.80848	26.42683	1	Drilling
S18	Yapıldak Village	40.79068	26.44150	8	Drilling
S19	Koyuntepe Village	40.76936	26.34409	4	Caisson
S20	Ahır Village	40.89655	26.37366	4	Catchment
S21	Kumdere Village	40.86491	26.36770	10	Drilling
S22	Paşaköy Village	40.85287	26.32058	6	Drilling
S23	Yenikarpuzlu Town	40.83346	26.29405	-	-

İpsala District can be described as an agricultural city containing large and productive agricultural lands, including the most important paddy fields of Turkey. 35% of total Turkish rice production is being supplied from İpsala Plain [6, 7]. The aim of this study was to evaluate the drinking water quality of İpsala District by a statistical approach and present the investigated parameters visually using GIS maps.

Material and Method

Study Area and Collection of Samples

İpsala District, with 753 km^2 land area, is located in the Marmara Region of Turkey in Edirne Province, and the total population of the district is about 30,000, including the rural and the urban areas. İpsala Plain, located in the Meriç Valley and irrigated mainly by the Meriç River, includes most of the soil of İpsala District. It is the largest plain and one of the most productive agricultural areas of the province [6, 7].

In this study groundwater samples were collected in winter 2013 from 23 stations from the drill fountains of the villages located in İpsala District. Groundwater with a volume of three wells was purged before sampling. Drinking water samples were then collected at the outflow of drillpump in polyethylene bottles. Coordinate information and locations of select stations were given in Table 1, and a map of İpsala District was given in Fig. 1. Also, some structural information about the drinking water sources of İpsala District and connected villages were given in Table 1.

Chemical and Physicochemical Analysis

Temperature, dissolved oxygen, pH, and conductivity parameters were determined using a "Hach Lange HQ40D Multiparameter" device during field studies; turbidity parameter was determined using a Hach Lange 2100Q Portable Turbiditymeter device during field studies; nitrite, nitrate, ammonium, sulphate, phosphate, chlorine, and fluorine parameters were determined using a Hach Lange DR3900

Spectrophotometer device during the laboratory studies; and BOD (biological oxygen demand) was determined using a Hach Lange BOD Trak II device during laboratory studies.

Statistical Analysis and ArcGIS

Cluster analysis (CA) was applied to the results by using the "Past" package program. Pearson correlation index (PCI) and factor analysis (FA) were applied to the results using the SPSS 17 package program. The distribution maps (CIS Maps) of parameters were made by using the ArcGIS package program.

Results

Results of detected parameters in İpsala District with minimum, maximum, and mean values and some national and international water quality standards were given in Table 2. GIS-based distribution maps were given in Figs. 2, 3, and 4.

As a result of the present study, although some parameters recorded in some villages of İpsala District were determined as quite close to the limit values, all investigated parameters in the drinking water resources of the region have been found to be in the range of drinking and human consumption standards specified by the Turkish Standards Institute [9], European Communities [10], and the World Health Organization [11]. However, it was also determined that, according to Water Pollution Control Regulation [12], İpsala District has quite low groundwater quality in terms of especially nitrite and nitrate concentrations.

According to the Water Pollution Control Regulation criteria in Turkey [12], the region has class I water quality in terms of pH, dissolved oxygen, ammonium, sulphate, and fluorine parameters; it also is class I water quality in terms of BOD parameter, except Pazardere Village (S9 has class II water quality); it has class II water quality in terms of the chlorine parameter. As stated before, nitrate and nitrite accumulations in drinking water resources of İpsala District were found to be quite high. S5, S6, S7, S14, S15, S17, S19, and S23 stations have class II and S9 station has class III (limit of class IV is 20 mg/L and detected value in S9 was 19.3 mg/L) water quality in terms of nitrate parameter, and all the region has class II-III water quality in terms of nitrite parameter. According to another, the water quality classification specified by Uslu and Türkman [13], the ground water of the investigated region has class II-III water quality in terms of phosphate concentrations.

Pearson Correlation Index (PCI)

The relations between the levels of investigated parameters in drinking water resources of İpsala District and connected villages were determined using Pearson correla-

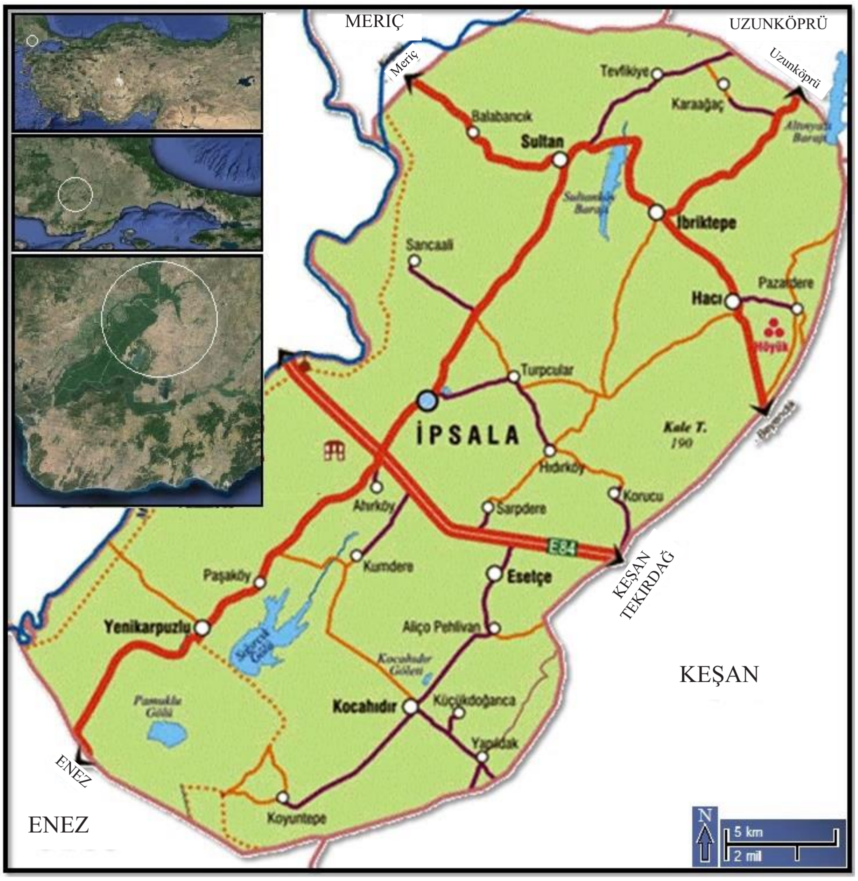

Fig. 1. Map of İpsala District (modified from Anonymous, 2012) [8].

tion index (PCI) (n = 23 for all parameters) and results of PCI were given in Table 3.

According to the results of PCI, the relations between temperature – dissolved oxygen (-); dissolved oxygen – pH (+); conductivity – nitrite (+), sulphate (+), chlorine (+) and fluorine (+); turbidity – sulphate (+); nitrate – chlorine (+) and BOD (+); and sulphate – chlorine (+) levels were directly proportional at the 0.01 significance level. It was also found that the relations between temperature – dissolved oxygen (-) and sulphate (-); dissolved oxygen – ammonium (+); pH – fluorine (+); nitrate – ammonium (+) and sulphate (+); ammonium – BOD (+); and sulphate – fluorine (+) and BOD (+) levels were directly proportional at the 0.05 significance level.

Factor Analysis (FA)

Factor Analysis (FA) that facilitates the interpretation of large data sets is widely used in water quality assessment studies and is one of the most powerful multivariate statistical methods [14-18].

In the present application, FA was used to detect the effective varifactors on drinking water resources of İpsala District by using correlated variables. Uncorrelated variables (turbidity, phosphate, and nitrite) were removed from the data set in order to make the applied FA more reliable. A total of ten variables were used to detect the varifactors (n = 23 for all parameters).

The result of the Kaiser-Meyer-Olkin (KMO) test that presents the measure of sampling adequacy was 0.605, which means that the sampling adequacy was enough for the present application (>0.5) [14].

Eigenvalues higher than one were taken as criterion for assessing the principal components that are required to explain the sources of variance in the data. According to rotated cumulative percentage variance, three factors explained 74.867% of total variance (Table 4).

The factor loadings were classified according to loading values as “strong (>0.75),” “moderate (0.75-0.50),” and “weak (0.50-0.30)” [14]. All the factor loadings after rotation for three components were given in Fig. 5 and component plot in rotated space that shows the related variables of three factors were given in Fig. 6.

The first factor (F1), named as “Ionic Factor,” explained 30.19% of total variance and it was related to the variables of conductivity, sulphate, chlorine, and fluorine parameters. Conductivity, sulphate, and chlorine parameters were strong; the fluorine parameter was moderately positively loaded with this factor (Figs. 5 and 6).

The second factor (F2), named as “Agricultural Factor,” explained 22.9% of total variance and it was related to the variables of ammonium, BOD, and nitrate parameters. All parameters were strongly positively loaded with this factor (Figs. 5 and 6).

Third factor (F3), named as “pH Factor,” explained 21.77% of total variance and it was related to the variables of pH, dissolved oxygen, and temperature parameters. pH and dissolved oxygen parameters were strong; temperature parameter was strongly negatively loaded with this factor (Figs. 5 and 6).

Table 2. Results of detected parameters and some limit values.

Limit values and the results of the present study		Parameters											
		Temp (ºC)	pH	DO (mg/L)	Cl^- (mg/L)	SO_4 (mg/L)	NH_4 (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)	BOD (mg/L)	F^- (mg/L)	EC (mS/cm)	Tur (NTU)
Water quality classes [12]	Class I (very clean)	25	6.5-8.5	8	25	200	0.2	0.002	5	4	1	-	-
	Class II (less contaminated)	25	6.5-8.5	6	200	200	1	0.01	10	8	1.5	-	-
	Class III (much contaminated)	30	6.0-9.0	3	400	400	2	0.05	20	20	2	-	-
	Class IV (extremely contaminated)	>30	Out of 6.0-9.0	<3	>400	>400	>2	>0.05	>20	>20	>2	-	-
Drinking water standards	TS266 [9]	-	6.5-9.5	-	250	250	0.5	0.5	50	-	1.5	2500	5
	EC [10]	-	6.5-9.5	-	250	250	0.3	0.5	50	-	1.5	2500	-
	WHO [11]	-	-	-	-	-	-	0.2	50	-	1.5	-	-
İpsala District	Minimum	10.60	6.58	7.84	41.30	13.00	0.006	0.006	0.42	0.60	0.22	437	0.11
	Maximum	19.20	7.90	11.52	113.00	65.20	0.025	0.018	19.30	6.80	0.63	1023	9.28
	Mean	13.52	7.46	9.58	75.87	32.13	0.014	0.010	4.93	1.61	0.38	688	0.91
	SD	2.35	0.29	0.97	19.05	13.36	0.005	0.002	4.48	1.25	0.10	168	1.85

Temp – Temperature, DO – Dissolved oxygen, Tur – Turbidity, TS266 – Turkish Standards Institute, EC – European Communities, WHO – World Health Organization

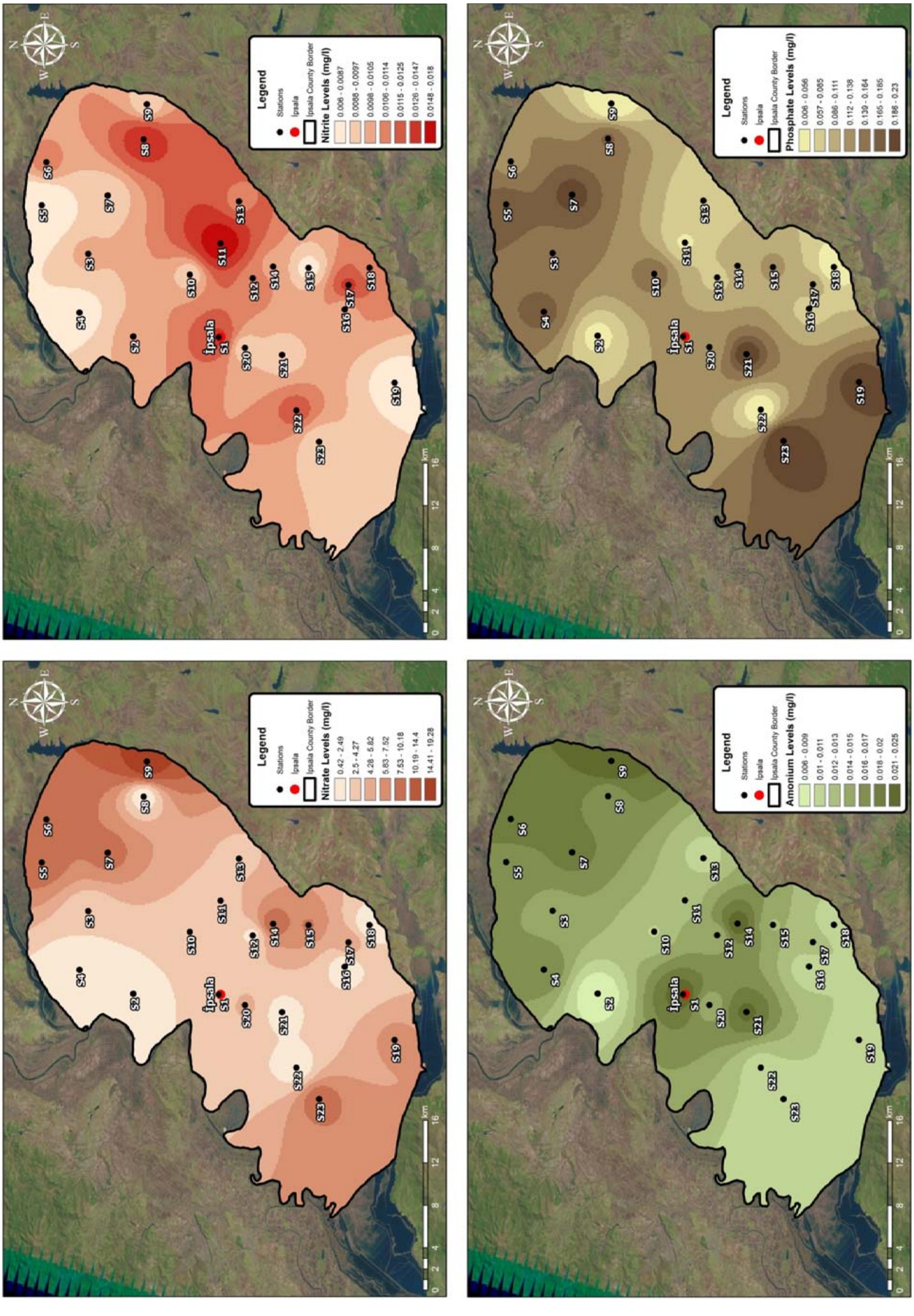

Fig. 2. Nitrate, nitrite, ammonium, and phosphate distributions.

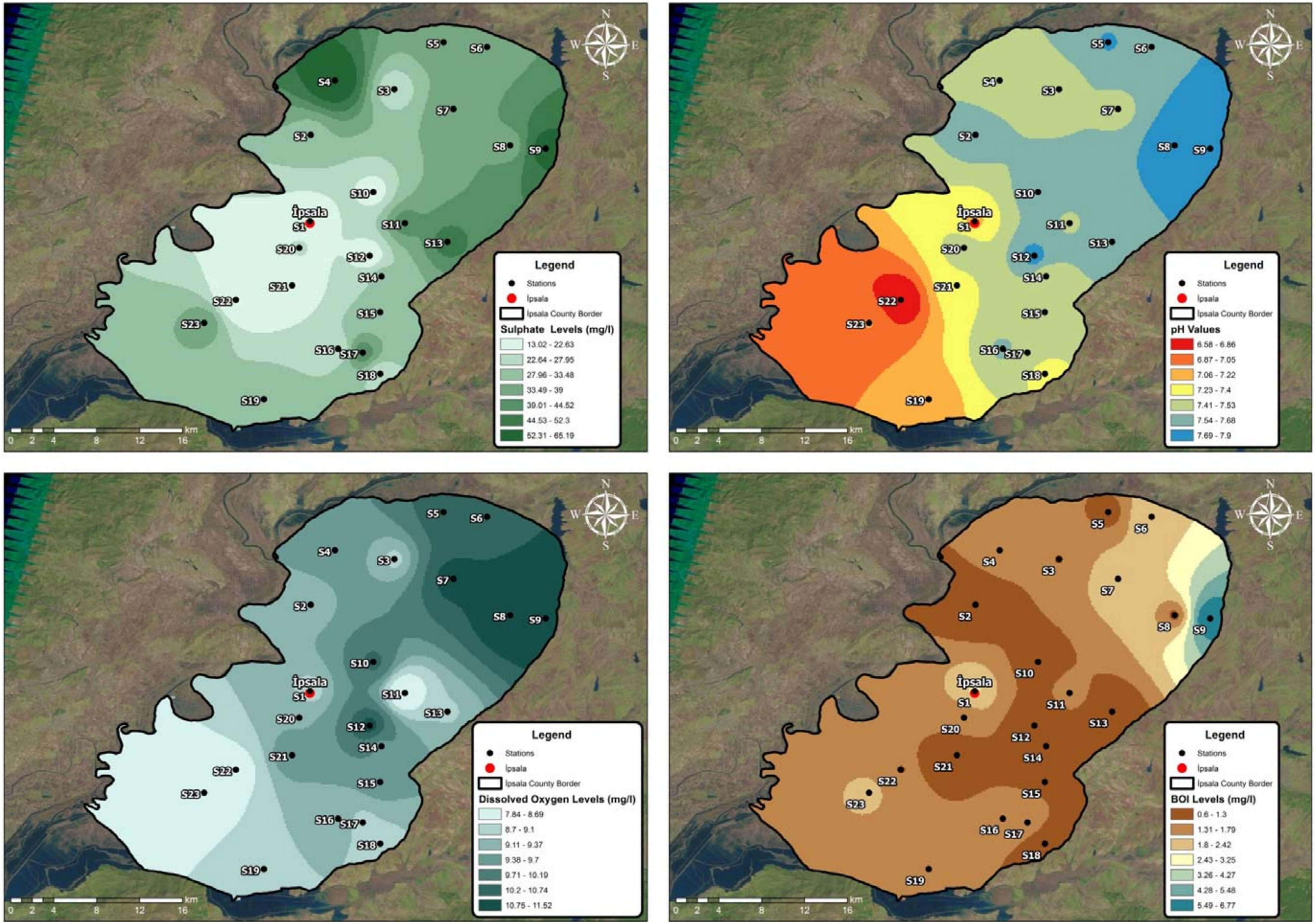

Fig. 3. Sulphate, pH, dissolved oxygen, and BOD distributions.

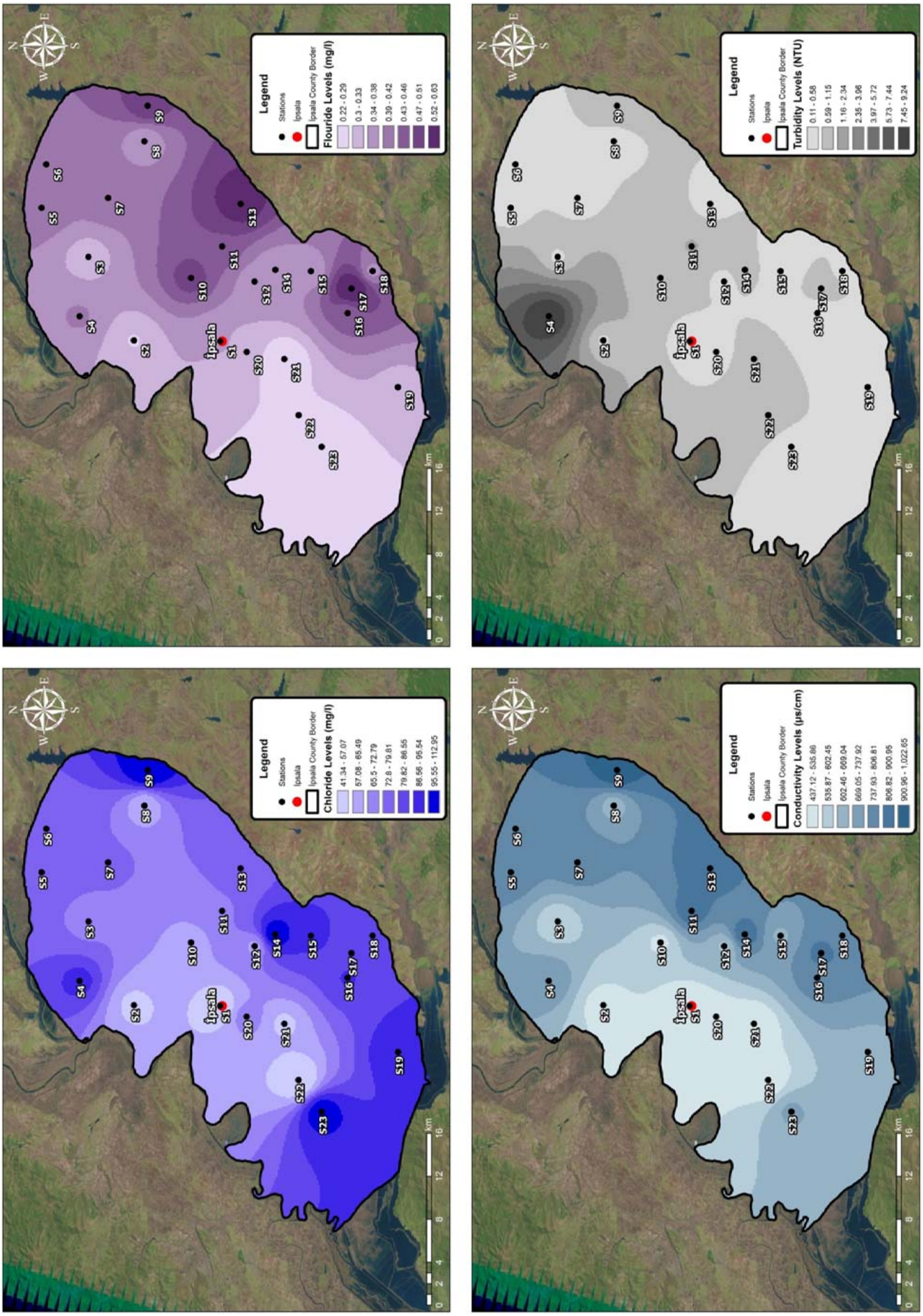

Fig. 4. Chloride, fluoride, conductivity, and turbidity distributions.

Table 3. PCI coefficients.

	Temp	DO	pH	EC	Tur	NO_2	NO_3	NH_4	SO_4	PO_4	Cl^-	F^-	BOD
Temp	1												
DO	**-0.417***	1											
pH	**-0.554****	**0.659****	1										
EC	-0.286	0.127	0.398	1									
Tur	-0.199	-0.054	-0.038	0.077	1								
NO_2	-0.020	-0.284	-0.014	0.071	-0.117	1							
NO_3	-0.167	0.293	0.248	**0.587****	-0.223	-0.306	1						
NH_4	0.046	**0.435***	0.233	0.210	0.137	-0.072	**0.504***	1					
SO_4	**-0.422***	0.105	0.359	**0.710****	**0.541****	-0.033	**0.432***	0.182	1				
PO_4	0.012	0.177	-0.094	-0.266	0.120	-0.413	0.011	0.145	0.011	1			
Cl^-	-0.032	-0.004	0.170	**0.731****	0.124	-0.344	**0.662****	0.163	**0.570****	0.039	1		
F^-	-0.220	0.128	**0.454***	**0.646****	0.043	0.237	0.256	0.021	**0.503***	-0.334	0.225	1	
BOD	-0.108	0.260	0.220	0.406	0.009	-0.053	**0.728****	**0.518***	**0.450***	-0.199	0.393	0.267	1

Temp – Temperature, DO – Dissolved oxygen, Cond – Conductivity, Tur – Turbidity
*Correlation is significant at the 0.05 level ($p<0.05$)
**Correlation is significant at the 0.01 level ($p<0.01$)
Bold means the statistically significant correlation coefficients.

Cluster Analysis (CA)

Cluster Analysis (CA) that enables us to classify objects according to similar characteristics is also a multivariate statistical technique being used widely in water quality assessment studies [1, 19-22].

In the present application, CA was used to classify the stations according to physicochemical characteristics. The diagram of CA calculated by using all detected parameters of drinking water resources of İpsala District and connected villages are given in Fig. 7, and similarity coefficients of investigated stations are given in Table 5.

According to results of CA, eight statistically significant clusters (C) were formed:

Cluster 1 (C1) corresponded to S20, S2, S3, and S10 stations
Cluster 2 (C2) corresponded to S21, S1, and S22 stations
Cluster 3 (C3) corresponded to S9 station
Cluster 4 (C4) corresponded to S8 and S12 stations
Cluster 5 (C5) corresponded to S15, S19, and S23 stations
Cluster 6 (C6) corresponded to S5, S7, S6, S16, and S18 stations
Cluster 7 (C7) corresponded to S11, S13, S17, and S14 stations
Cluster 8 (C8) corresponded to S4 station (Fig. 7)

Maximum similarities were observed between S5-S6; S11-S13; and S16-S18 stations at the 0.99 level. Minimum similarities were observed between S9-S1 and S21 stations at the 0.60 level (Table 5).

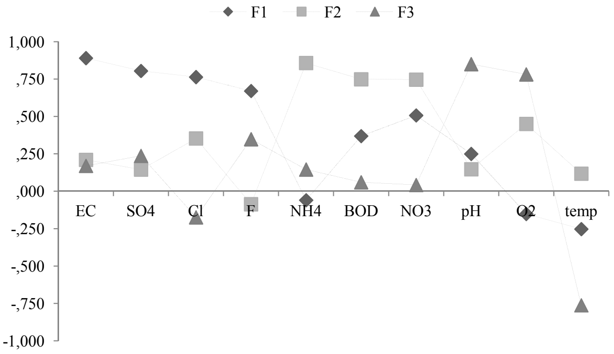

Fig. 5. Rotated component matrix.

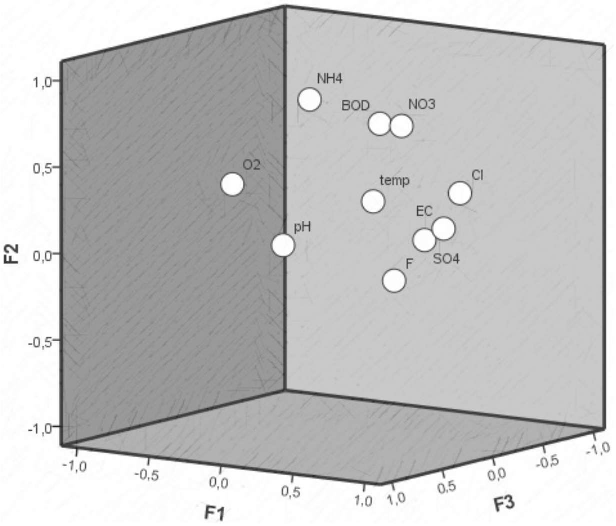

Fig. 6. Spatial component plot.

Table 4. Total variances explained in FA.

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.219	42.189	42.189	4.219	42.189	42.189	3.019	30.191	30.191
2	1.734	17.345	59.534	1.734	17.345	59.534	2.290	22.901	53.092
3	1.533	15.333	74.867	1.533	15.333	74.867	2.177	21.774	74.867
4	0.743	7.433	82.300						
5	0.587	5.868	88.167						
6	0.445	4.451	92.618						
7	0.295	2.946	95.564						
8	0.230	2.295	97.860						
9	0.136	1.364	99.224						
10	0.078	0.776	100.000						

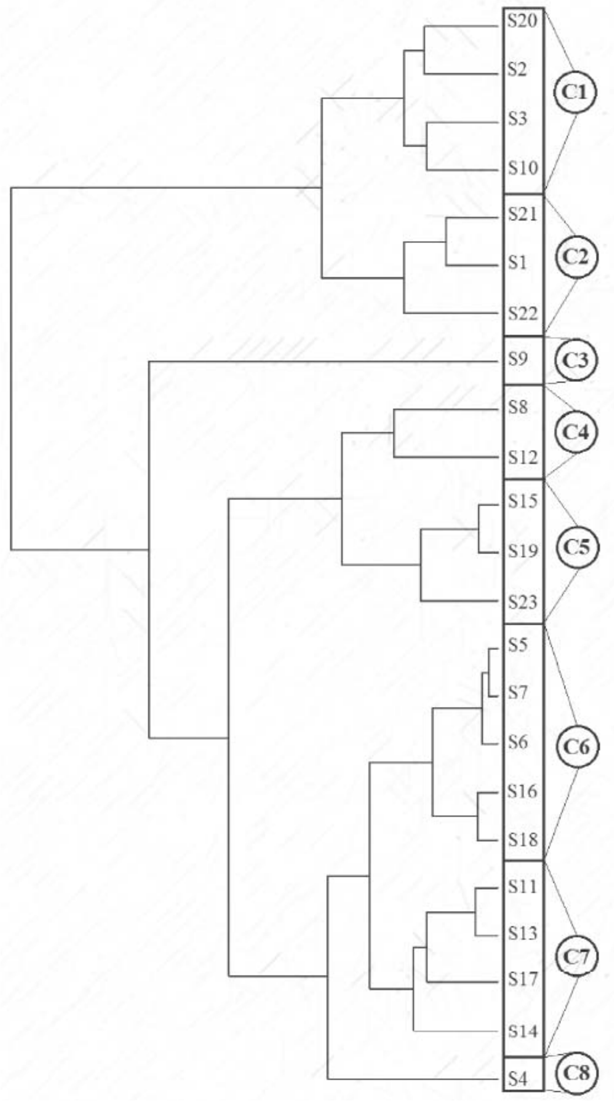

Fig. 7. CA diagram of stations.

Discussion

Although almost all investigated parameters in İpsala District were within the normal values and did not exceed the drinking water limits, organic contents of groundwater, including primarily the nitrate parameter, were detected in hazardous levels. Nitrate is a naturally occurring form of nitrogen found in the earth's crust. Although it is a common nitrogenous compound due to natural processes of the nitrogen cycle, anthropogenic sources like agricultural applications have extremely increased the nitrate levels in the environment in especially rural areas [23, 24]. Nitrate can also leach into groundwater due to its high mobility. Although it may occur naturally in some groundwater ecosystems, the main sources of nitrate in groundwater are anthropogenic activities, including particularly: nitrogen-rich fertilizers, which are being used intensively in İpsala District in order to reduce the effects of monoculture farming ongoing for many years (particularly paddy cultivation); animal feedlots which are also common in the investigated area; and municipal wastewater, sludge, and septic tanks that are being used virtually anywhere in İpsala District [25]. Livestock waste is also one of the most important sources of bacteria and nitrates for groundwater, when especially many animals are located in small barns that have improper drainage systems. If the ponds used to conserve the animal wastes in farms leak underground or if the water table of the region is too close to the land surface exactly as in the İpsala District, groundwater resources can be significantly affected [26].

One the most adverse effects of nitrate on humans is methemoglobinemia, which is known as blue baby syndrome and found especially in newborn infants less than 6-months old. The stomach acid of a newborn infant is not as strong as in older children and adults, which causes a significant increase of bacteria that convert nitrate to nitrite. Pregnant women and adults with reduced stomach acidity and people deficient in the methemoglobin-reducing

Table 5. Similarity coefficients of stations.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23
S1	1.00																						
S2	0.92	1.00																					
S3	0.89	0.94	1.00																				
S4	0.73	0.79	0.83	1.00																			
S5	0.72	0.78	0.82	0.93	1.00																		
S6	0.72	0.79	0.83	0.94	**0.99**	1.00																	
S7	0.72	0.78	0.82	0.93	1.00	0.99	1.00																
S8	0.82	0.89	0.91	0.89	0.88	0.89	0.88	1.00															
S9	**0.60**	0.66	0.70	0.84	0.87	0.86	0.87	0.75	1.00														
S10	0.91	0.97	0.97	0.80	0.80	0.80	0.80	0.90	0.67	1.00													
S11	0.68	0.75	0.79	0.90	0.95	0.94	0.95	0.84	0.90	0.76	1.00												
S12	0.86	0.91	0.95	0.86	0.85	0.85	0.85	0.95	0.72	0.94	0.81	1.00											
S13	0.68	0.74	0.78	0.90	0.95	0.94	0.95	0.84	0.91	0.75	**0.99**	0.80	1.00										
S14	0.67	0.73	0.77	0.88	0.93	0.93	0.93	0.82	0.92	0.74	0.96	0.79	0.97	1.00									
S15	0.80	0.86	0.90	0.92	0.90	0.91	0.90	0.95	0.78	0.87	0.85	0.92	0.85	0.86	1.00								
S16	0.73	0.78	0.83	0.94	0.97	0.98	0.97	0.88	0.85	0.80	0.93	0.86	0.93	0.93	0.91	1.00							
S17	0.70	0.76	0.80	0.92	0.97	0.96	0.97	0.86	0.89	0.77	0.97	0.82	0.97	0.95	0.89	0.96	1.00						
S18	0.74	0.79	0.84	0.95	0.97	0.97	0.96	0.89	0.84	0.81	0.93	0.86	0.92	0.92	0.92	**0.99**	0.95	1.00					
S19	0.80	0.86	0.90	0.92	0.90	0.90	0.89	0.95	0.78	0.87	0.85	0.92	0.85	0.86	0.99	0.91	0.88	0.91	1.00				
S20	0.93	0.97	0.95	0.79	0.78	0.79	0.78	0.87	0.66	0.96	0.75	0.91	0.74	0.73	0.86	0.79	0.76	0.80	0.86	1.00			
S21	0.98	0.93	0.89	0.73	0.72	0.72	0.72	0.82	**0.60**	0.91	0.68	0.86	0.68	0.67	0.80	0.73	0.70	0.74	0.80	0.93	1.00		
S22	0.96	0.94	0.90	0.74	0.73	0.73	0.73	0.84	0.61	0.93	0.70	0.88	0.69	0.68	0.81	0.75	0.71	0.75	0.81	0.94	0.95	1.00	
S23	0.77	0.83	0.87	0.94	0.92	0.92	0.91	0.93	0.82	0.84	0.87	0.89	0.87	0.88	0.96	0.92	0.90	0.92	0.97	0.83	0.76	0.78	1.00

Highest and lowest similarities are given in bold enzyme are all susceptible to methemoglobinemia. Nitrite is absorbed in blood cells and hemoglobin is converted to methemoglobin, which cause an efficiency of carrying oxygen [25]. EPA maximum contaminant level (MCL) of 10 mg/L nitrate may cause methemoglobinemia in newborn infants and methemoglobin-sensitive adults [27].

Kaçaroğlu and Günay [28] observed the nitrate contents of drinking water in urban areas of Eskişehir, Turkey. In this research the average nitrate concentration in groundwater was recorded as 40.0 mg/L and it was also indicated that 34.2% of the nitrate concentrations of the study area were above the limits in drinking water. Nas and Berktay [29] evaluated the nitrate concentrations in groundwater of Konya, Turkey, using GIS. According to the GIS maps produced in the study, nitrate contents tend to increase in the city center in general and the average nitrate levels were recorded as 2.2 mg/L in 1998 and 16.1 mg/L in 2001. In a macroscopic point of view, although the nitrate accumulations in drinking water of İpsala District were not as high as detected in groundwater of the urban side of Eskişehir Province, the recorded nitrate values in the present study were approximately the same levels in Konya Province.

In a study performed in the USA, nitrate levels were investigated in drinking water of rural areas in New York state. As a result of the mentioned study, nitrate levels in 15.7% of investigated wells had exceeded the critical limit of 10 mg/L [30]. In another study that investigated nitrate in Ontario, Canada, 14% of farmstead domestic wells contained nitrate above the 10 mg/L limit [31]. In the present study, nitrate contents in 23% of investigated stations including Tevfikiye, Karaağaç, and İbriktepe, which have formed a separate cluster (C6) in Cluster Analysis (CA), and Esetçe stations were recorded as quite close to the EPA maximum contaminant level (MCL) of 10 mg/L (8.840 mg/L, 9.160 mg/L, 8.410 mg/L and 9.730 mg/L respectively), and also nitrate concentrations recorded in Pazardere station, which has formed a separate cluster (C3) in CA, has exceeded the MCL limit two times (19.3 mg/L).

It is known that biological oxygen demand (BOD) is an important microbiological parameter that expresses the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down the organic contents [23, 24]. According to a report by Environment Canada [32], BOD levels in drinking water sources should be less than 3 mg/L, and BOD levels greater than 10 mg/L are declared as polluted water. BOD concentrations detected in Karaağaç and İbriktepe stations were two of the highest BOD levels recorded in the region (2.35 mg/L and 2.31 mg/L, respectively). But the highest BOD level was recorded in Pazardere station as 6.80 mg/L. According to the results of Factor Analysis (FA), ammonium, BOD, and nitrate parameters were strongly positively loaded with an agricultural factor that explained 22.9% of total variance.

Conclusions

In the present study drinking water quality of İpsala District and connected villages, known as “Rice Land” in Turkey, were investigated and some multistatistical methods were applied to detected data in order to evaluate the results properly.

According to data observed and statistical evaluation, organic contents in drinking water resources of İpsala District were detected in quite high levels. According to results of FA, three effective factors on groundwater quality of the İpsala District were identified using a large number of physico-chemical water quality data. According to results of CA, eight clusters of similar water quality characteristic were identified for the region.

Nitrate is an important plant nutrient and may limit the growth of agricultural crops, but it may also cause significant health problems in plants, animals, and humans, if exposed to it in large amounts. Therefore, necessary measures should be taken as soon as possible in order to increase the water quality in the region and decrease the nitrate accumulations in drinking water. Groundwater quality of İpsala District should be monitored on a regular basis and an attentive and careful agricultural and sewage management focusing on especially fertilizer applications in the region may reduce the nitrate concentrations in groundwater of İpsala District. Also, proper siting of livestock barns, regular cleaning, and avoiding overloading can preclude groundwater pollution caused by animal husbandry.

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