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Correlation Study and Regression Analysis of Drinking Water Quality in Kashan City, Iran

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Abstract

Chemical and statistical regression analysis on drinking water samples at five fields (21 sampling wells) with hot and dry climate in Kashan city, central Iran was carried out. Samples were collected during October 2006 to May 2007 (25 - 30 °C). Comparing the results with drinking water quality standards issued by World Health Organization (WHO), it is found that some of the water samples are not potable. Hydrochemical facies using a Piper diagram indicate that in most parts of the city, the chemical character of water is dominated by NaCl. All samples showed sulfate and sodium ion higher and K^+ and F^- content lower than the permissible limit. A strongly positive correlation is observed between TDS and EC (R = 0.995) and Ca^{2+} and TH (R = 0.948). The results showed that regression relations have the same correlation coefficients: (I) pH -TH, EC -TH (R = 0.520), (II) NO_3^- -pH, TH-pH (R = 0.520), (III) Ca^{2+}-SO_4^{2-}, TH-SO_4^{2-}, Cl^- -SO_4^{2-} (R = 0.630). The results revealed that systematic calculations of correlation coefficients between water parameters and regression analysis provide a useful means for rapid monitoring of water quality.

Keywords: Kashan, water quality parameters, regression equation, correlation coefficient, Piper diagram

Introduction

Water is the elixir of life. It is an important component to human survival. Although three-quarters of the earth is surrounded by water only a small portion of it can be used for drinking. The physical and chemical parameters of water play a significant role in classifying and assessing water quality. It is the basic duty of every individual to conserve water resources [1]. Drinking water quality is affected by the presence of different soluble salts [2]. As the population increases, the water demand for industrial, domestic and agricultural uses increases too. When these demands exceed the naturally renewable supply, water shortage occurs in the area [3]. According to the World Health Organization drinking water must be free of chemicals and microbial contaminations which are a risk to human health. Good drinking water quality is essential for the well being of all people. The natural water analysis for physical, chemical properties including trace element contents are very important for public health studies [4].

Investigations of the quality of drinking water samples have been continuously performed by researchers around the world. Therefore water quality control is very important. These studies are also a main part of pollution studies in the environment [5-6]. The data sets contain rich information about the behavior of the water resources. The classification, modelling and interpretation of monitoring data are the most important steps in the assessment of water quality.

Kashan is one of the biggest cities in the province of Isfahan, in central Iran. Kashan is located 258 km (160 miles) south of Tehran. It had an estimated population of 290,000 in 2007 living on an area of 2,100 hectares. The Kashan is located between 33° 45' and 34° 23' latitude, and 51° 05' and 51° 54' longitude and is located at an altitude of 1,600 m above sea level (**Figure 1**).

This city is located between the Karkas mountain slope and Iran central desert, part of which constitutes Salt Lake [3]. As we get nearer to the central desert of Iran and sand hills and high grounds from the north and east, the climate is hot and dry. In this region there is no permanent river but there are some dry streams which lead to floods in the neighboring mountains to the salt lake. Increasing water demands associated with the rapid urban development and expansion of agricultural lands has led to overexploitation of water in this city. As water withdrawal continues, water shortage crises will happen in this area. According to the obtained data, about 86 % of groundwater is for agricultural uses [3]. During the last two decades, Erode has gone through rapid industrialization and population growth, though it is an agricultural based area. The area under study (the Kashan city) has only been studied by a few researchers. The study area according to an iso-precipitation map, is located between lines of 100 to 150 mm (mean of 130 mm) and the area's atmosphere temperature with respect to the annual isotherm map, is between 17.5 - 23 °C. Annual mean evaporation of Kashan city is 2,205.5 m.

The main sources of water supply in the area are groundwater, rainfall and water from underground springs and the Qanats. The precipitation, which is the sole source of ground water and recharges the study area, is very low due to low average rainfall. Underground water is the only source of water for the areas of Kashan. The average thickness of the aquifer is 86 m. The aquifer storage coefficient is estimated at about 4 percent. Transmissivity varies between 100 and 900 m^2/day.

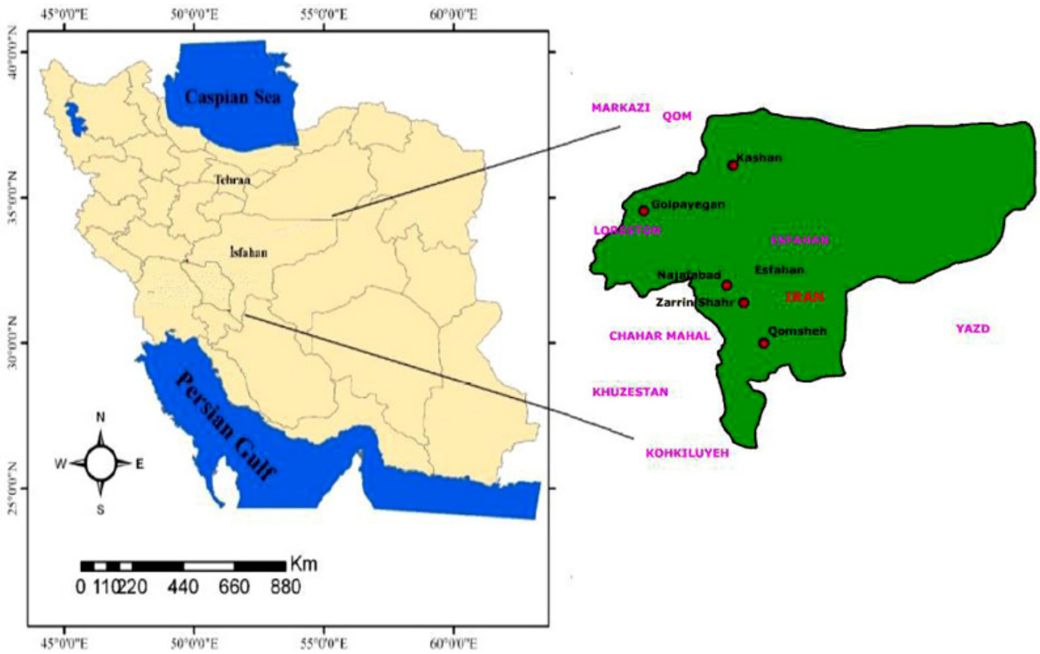

Figure 1 The location of Kashan city in Iran.

21 samples were collected during October 2006 to May 2007 [7-9]. This paper is a new study on water quality parameters using the correlation coefficient and regression method in analyzing the Kashan drinking water.

Materials and methods

Drinking water quality data

Water samples were collected in clean polyethylene bottles from different sources viz. tube wells, hand pumps, open wells and other sources [10].

The drinking water quality depends on many physicochemical parameters and their concentrations, which are derived from laboratory tests on water samples.

21 Samples were collected during October 2006 to May 2007. Drinking water samples were collected from five different fields in Kashan city namely: (a) Kashan-North (3 wells), (b) Kashan-South (4 wells), (c) Kashan-West (5 wells), (d) Kashan-East (4 wells) and (e) Kashan-Center (5 wells) and analyzed during 2006 - 2007 at local water and sewage authority laboratories according to standard methods (**Table 1**).

Twelve parameters for the estimation of drinking water characteristics were adopted including pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH) calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfate (SO_4^{2-}), chloride (Cl^-), nitrate (NO_3^-), Sodium (Na^+), Potassium (K^+) and fluoride (F^-) by using standard techniques [11-13]. The temperature of the water samples was in the range 25 - 30 °C.

The important physicochemical characteristics of analyzed water samples viz., Mean, Standard Deviation (SD), Standard Error (SE) and Coefficient of Variation (CV) are presented in **Table 2** and the values are compared with standard parameters in **Table 3**.

The Coefficient of Variation observed for Mg^{2+} and NO_3^- values found to be 54.83 and 67.88 % respectively. The observed CV for Mg^{2+} and NO_3^- are very high. The CV for pH, TDS, EC, Cl^-, SO_4^{2-}, F^-, Ca^{2+}, Na^+, K^+ and TH found to be 3.18, 20.33, 21.42, 34.34, 24.0, 11.09, 32.73, 32.36, 14.30 and 28.54 %. It shows that variation in these parameters among its measured values at different locations is not high and variation range is very narrow (**Table 2**).

Table 1 Physicochemical parameters of drinking water at studied wells for Kashan city.

Code No.	Name of well	pH	TDS (mg/l)	EC (μmhos/cm)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	F^- (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	TH (mg/l)
1	Kashan-North 1	7.38	1592	2209	306	476	35.14	0.91	213	55	244	7.122	713
2	Kashan-North 2	7.41	1288	1779	297	375	8.31	0.91	172	30	216	6.921	516
3	Kashan-North 3	7.41	1511	2076	350	473	10.22	0.90	188	32	262	6.864	582
4	Kashan-South 1	7.92	2066	2975	674	676	46.27	0.76	212	67	382	8.74	805
5	Kashan-South 2	7.53	1748	2381	165	568	35.12	0.73	181	46	354	8.66	629
6	Kashan-South 3	7.14	1208	1629	287	433	14.38	0.70	88	31	288	8.85	244
7	Kashan-South 4	7.35	1258	1751	384	470	12.61	0.76	96	29	317	8.61	344
8	Kashan-West 1	7.32	1042	1407	188	292	16.35	0.70	126	31	127	7.85	471
9	Kashan-West 2	7.42	1027	1383	259	284	24.16	0.91	123	26	99	8.07	434
10	Kashan-West 3	7.14	950	1322	210	301	10.12	0.90	122	24	160	7.53	419
11	Kashan-West 4	7.78	1155	1579	364	407	52.12	0.92	162	43	272	7.35	530
12	Kashan-West 5	7.41	1103	1499	271	361	18.15	0.91	140	0.38	217	7.22	499
13	Kashan-East 1	7.82	1536	2039	389	379	31.25	0.71	118	0.41	264	9.925	442
14	Kashan-East 2	7.16	1428	1980	510	482	6.22	0.65	107	27	446	9.851	373
15	Kashan-East 3	7.16	1613	2215	439	415	16.13	0.70	119	24	315	10.06	436
16	Kashan-East 4	7.51	1307	1860	412	454	22.14	0.78	106	27	342	10.23	357
17	Kashan-Center 1	7.36	1040	1454	458	568	42.63	0.78	244	31	295	7.15	703
18	Kashan-Center 2	7.75	1476	2098	433	545	0.51	0.81	259	0.33	287	6.96	746
19	Kashan-Center 3	7.24	1394	1907	313	571	17.25	0.76	207	29	250	7.554	653
20	Kashan-Center 4	7.52	1306	1750	325	419	10.35	0.80	128	42	212	7.142	490
21	Kashan-Center 5	7.12	1199	1621	233	300	10.12	0.75	119	29	160	6.934	438

Table 2 Statistical analysis of drinking water samples for Kashan city.

Parameters	Max	Min	Range	Mean	SD	SE	CV %
pH	7.92	7.12	0.80	7.421	0.236	0.036	3.18
TDS	2066	950	1116	1345	273.50	42.20	20.33
EC	2975	1322	1653	1853	396.90	61.24	21.42
Cl^-	674	165	509	346	118.80	18.34	34.34
SO_4^{2-}	676	284	392	440.40	105.70	16.31	24.0
NO_3^-	52.12	0.51	51.61	20.93	14.21	2.192	67.88
F^-	0.92	0.65	0.27	0.798	0.088	0.014	11.09
Ca^{2+}	259	88	171	153.8	50.33	7.767	32.73
Mg^{2+}	67	0.33	66.67	29.72	16.30	2.514	54.83
Na^+	446	99	347	262.30	84.90	13.10	32.36
K^+	10.23	6.864	3.366	8.076	1.155	0.178	14.30
TH	805	244	561	515.40	147.10	22.70	28.54

In the present study the pH ranges from 7.12 - 7.92, which lies in the range prescribed by WHO [14]. All the samples show higher EC values than the permissible limit. All water samples showed sulfate and sodium ion higher than the permissible limit. All the water samples contained K^+ and F^- content lower than the permissible limit**.** Only 2 % of samples had a NO_3^- concentration higher than the limit (**Table 3**). Total hardness was higher in 26 % samples whereas 74 % samples contained TH within the optimum limit (**Table 3**). The level of TDS is one of the characteristics, which decides the quality of drinking water. The analyzed data show that 29 % samples had more than the maximum permissible limit. In this study area, the chloride values of drinking water were in the range of 165 - 674, indicating salty water. In the present study, magnesium content for all samples has high values but within the WHO standards limit. Calcium content shows that 24 % samples had more than the maximum permissible limit.

Table 3 Comparison of drinking water quality with drinking water standards.

Parameters	WHO	USPH	European standard	ISIRI1053	Present study report
pH	6.9 - 9.2	6.0 - 8.5	6.5 - 8.5	6.5 - 9.0	7.12 - 7.92
TDS	500 - 1500 mg/l	500	500	1500	950 - 2066
EC	300 µmhos/cm	300	400	300	1322 - 2975
Cl^-	200 - 600 mg/l	250	250	250	165 - 674
SO_4^{2-}	200 - 250 mg/l	250	-	250	284 - 676
NO_3^-	40 - 50 mg/l	-	-	50	0.51 - 52.12
F^-	1 - 1.5 ppm	-	-	1.50	0.65 - 0.92
Ca^{2+}	75 - 200 mg/l	100	100	300	88 - 259
Mg^{2+}	30 - 150 mg/l	30	-	30	0.33 - 67
Na^+	50 - 60 mg/l	-	-	200	99 - 446
K^+	20 mg/l	-	-	20	6.86 - 10.23
TH	100 - 500 mg/l	500	-	500	244 - 805

USPH - United States Public Drinking water Standard
WHO - World Health Organization
ISIRI1053 - Institute of Standards and Industrial Research of Iran, Drinking water

According to **Table 1**, the hydrochemical facies of waters in most area of this city was of a sodium-chloride type. The Piper diagram of these sampling waters is shown in **Figure 2**. According to this diagram, the dominant anion is chloride, which dominates the concentration of sulfate and bicarbonate in more than 60 % sampling samples (reported by Jamshidzadeh and Mirbagheri [3]).

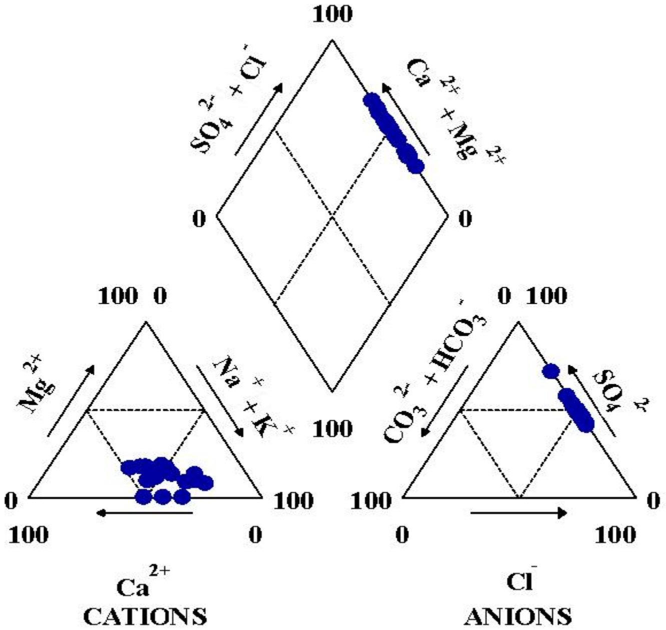

Figure 2 Piper diagram of 21 drinking water samples.

Linear regression model

The mathematical models used to estimate water quality require two parameters to describe realistic water situations. Correlation analysis measures the closeness of the relationship between chosen independent and dependent variables. If the correlation coefficient is nearer to +1 or –1, it shows the probability of the linear relationship between the variables x and y. The correlation between the parameters is characterized as strong, when it is in the range of +0.8 to 1.0 and –0.8 to –1.0, moderate when it's value is in the range of +0.5 to 0.8 and –0.5 to –0.8, weak when it is in the range of +0.0 to 0.5 and –0.0 to –0.5 [15]. This analysis attempts to establish the nature of the relationship between the variables and thereby provides a mechanism for prediction or forecasting [16].

In this study, the relationship of water quality parameters on each other in data of water analyzed was determined by calculating Karl Pearson's correlation coefficient, R, by using the formula given below:

$$R = \frac{\sum (X - \overline{X})(Y - \overline{Y})}{\sqrt{\sum (X - \overline{X})^2 \sum (Y - \overline{Y})^2}} \tag{1}$$

where, x (x = values of x-variable, $\overline{x}$ = average values x) and y (y = values of y-variable, $\overline{y}$ = average values y) represents two different water quality parameters. If the values of the correlation coefficient, R between two variables X and Y are fairly large, it implies that these two variables are highly correlated.

To determine the straight linear regression, the following equation can be used:

$$Y = a + bX \tag{2}$$

where, x and y are the dependent and independent variable, respectively, as a is the slope of line and b is the intercept on the y axis. The value of empirical parameters 'a' and 'b' are calculated with the help of the following equation:

$$b = \frac{\sum XY - \overline{X}\sum Y}{\sum X^2 - \overline{X}\sum X} \tag{3}$$

$$a = \overline{Y} - b\overline{X} \tag{4}$$

In statistics, correlation is a broad class of statistical relationship between two or more variables. The correlation study is useful to find a predictable relationship which can be exploited in practice. It is used for the measurement of the strength and statistical significance of the relationship between two or more water quality parameters [17]. To study the correlation between various water quality parameters, the regression analysis was carried out using computer software SPSS, version –7.5.

Results and discussion

The systematic calculation of correlation coefficient between water quality variables and regression analysis provide indirect means for rapid monitoring of water quality. The correlation coefficient measures the degree of association that exists between two variables, one taken as a dependent variable. The greater the value of the regression coefficient, the better is the fit and more useful the regression variables [16]. Correlation is the mutual relationship between two variables. Direct correlation exists when increase or decrease in the value of one parameter is associated with a corresponding increase or decrease in the value of other parameter [18]. In this study, the numerical values of the correlation coefficient, R for the twelve water quality parameters are tabulated in **Table 4**.

Table 4 Correlation coefficients among various water quality parameters.

Parameters	pH	TDS	EC	Cl^-	SO_4^{2-}	NO_3^-	F^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	TH
pH	1											
TDS	0.455	1										
EC	0.466	0.995	1									
Cl^-	0.423	0.528	0.576	1								
SO_4^{2-}	0.379	0.692	0.724	0.630	1							
NO_3^-	0.520	0.249	0.254	0.248	0.340	1						
F^-	0.179	-0.287	-0.265	-0.249	-0.246	0.121	1					
Ca^{2+}	0.407	0.347	0.380	0.265	0.630	0.306	0.290	1				
Mg^{2+}	0.100	0.400	0.417	0.168	0.392	0.510	0.034	0.190	1			
Na^+	0.216	0.628	0.649	0.686	0.751	0.195	-0.473	0.127	0.205	1		
K^+	0.021	0.330	0.319	0.364	0.107	0.089	-0.647	-0.518	-0.077	0.556	1	
TH	0.520	0.492	0.520	0.304	0.630	0.412	0.249	0.948	0.325	0.126	-0.449	1

Strong 2 Moderate 16 Weak 39 Negative 9

In **Table 4** it is shown that the idea of bearing a single parameter analyzed has a relationship with other parameters. A highly positive correlation is observed between TDS and EC (R = 0.995) (**Figure 3**) and between Ca^{2+} and TH (R = 0.948) (**Figure 4**). Hardness plays a role in heart diseases in humans. Hardness above approximately 200 mg/l may cause scales in water pipes and distribution systems. According to this table, drinking water in this city is hard for all samples. The TDS concentrations more than 1,000 mg/l can make scales in water pipes, heaters, boilers and household appliances.

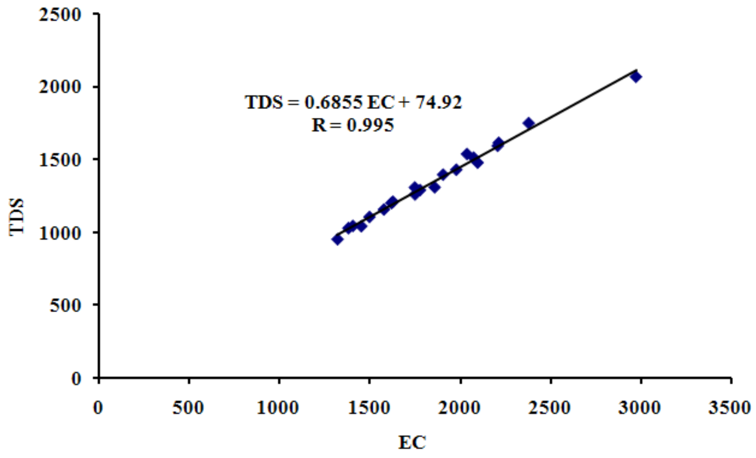

Figure 3 Correlation between total dissolved solids, TDS and electrical conductivity, EC

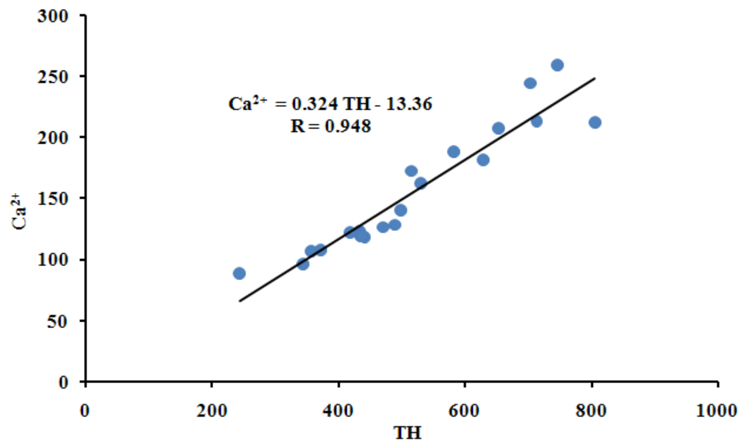

Figure 4 Correlation between calcium, Ca^{2+} and total hardness, TH.

No significant correlation among most of the parameters was observed in the water of Kashan city. However, some of the parameters having correlation coefficients with $p < 0.05$ are detailed in **Table 5**. However, some very poor correlation was observed between F^- and Mg^{2+} (0.034) so that F^- is weakly dependent on Mg^{2+}. Meanwhile, a low negative correlation is observed between K^+ and Mg^{2+} (–0.077).

The linear regression analyses have been carried out for the water quality parameters which are found to have better and higher levels of significance in their correlation coefficient ($R > 0.50$). The regression equations obtained from the analysis are given in **Table 5**. The different dependent characteristics of water quality were calculated using the regression equation and by substituting the values for the independent parameters in the equations.

These correlations suggested that the heavy and trace metals behave independently of physical parameters, anions and major cations in the water of Kashan city while some of the major cations, anions and physical parameters were found interrelated.

Table 5 Linear correlation coefficient R and regression equation for some pairs of parameters which have significant value of correlation.

Pairs of parameters	R value (n = 21)	Coefficient regression		Regression equation
		a	b	
pH - TH	0.520	0.0008	7.0064	pH = 0.0008 (TH) + 7.0064
TDS - EC	0.995	0.6855	74.92	TDS = 0.6855 (EC) + 74.92
TDS - Cl^-	0.528	1.2147	924.75	TDS = 1.2147 (Cl^-) + 924.75
TDS - SO_4^{2-}	0.692	1.7897	556.84	TDS = 1.7897 (SO_4^{2-}) + 556.84
TDS - Na^+	0.628	2.0237	814.22	TDS = 2.0237 (Na^+) + 814.22
EC - Cl^-	0.576	1.9242	1187.20	EC = 1.9242 (Cl^-) + 1187.20
EC - SO_4^{2-}	0.724	2.7185	655.76	EC = 2.7185 (SO_4^{2-}) + 655.76
EC - Na^+	0.649	3.0353	1056.80	EC = 3.0353 (Na^+) + 1056.80
EC - TH	0.520	1.404	1129.40	EC = 1.404 (TH) + 1129.40
Cl^- - SO_4^{2-}	0.630	0.7032	36.322	Cl^- = 0.7032 (SO_4^{2-}) + 36.322
Cl^- - Na^+	0.686	0.9607	94.027	Cl^- = 0.9607 (Na^+) + 94.027
SO_4^{2-} - Ca^{2+}	0.630	1.3336	235.32	SO_4^{2-} = 1.3336 (Ca^{2+}) + 235.32
Na^+ - SO_4^{2-}	0.751	0.6029	-3.2171	Na^+ = 0.6029 (SO_4^{2-}) - 3.2171
TH - SO_4^{2-}	0.630	0.8874	124.59	TH = 0.8874 (SO_4^{2-}) + 124.59
Mg^{2+} - NO_3^-	0.510	0.7532	17.723	Mg^{2+} = 0.5732 (NO_3^-) + 17.723
F^- - K^+	-0.647	-0.0495	1.1977	F^- = -0.0495 (K^+) + 1.1977
Ca^{2+} - K^+	-0.518	-22.583	336.19	Ca^{2+} = -22.583 (K^+) + 336.19
Ca^{2+} - TH	0.948	0.3243	-13.360	Ca^{2+} = 0.3243 (TH) - 13.360
K^+ - Na^+	0.556	0.0076	6.0916	K^+ = 0.0076 (Na^+) + 6.0916
NO_3^- - pH	0.520	31.586	-213.480	NO_3^- = 31.586 (pH) - 213.480

In current study, it is evident that the distribution of sodium (Na^+), electrical conductivity (EC), total dissolved solids (TDS), sulfate (SO_4^{2-}) and chloride (Cl^-), were significantly correlated (R > 0.6). NO_3^- and pH are positively correlated with all of the water parameters and F^- is negatively correlated with most of the water parameters. Highly negative correlation coefficient is found between F^- and K^+ (R = –0.647) and Ca^{2+} and K^+ (R = –0.518).

The results showed that regression relations have the same correlation coefficients, as: (I) pH and TH, EC and TH (R = 0.520), (II) NO_3^- and pH, TH and pH (R = 0.520), (III) Ca^{2+} and SO_4^{2-}, TH and SO_4^{2-}, Cl^- and SO_4^{2-} (R = 0.630).

Interrelationship studies between different variables are very helpful tools in promoting research and opening new frontiers of knowledge. The study of correlation reduces the range of uncertainty associated with decision making [19]. This result agrees with the results obtained by Jothivenkatachalam *et al.* [1] and Daraigan *et al.* [20].

Finally, it can be concluded that the correlation studies of the water quality parameters have great significance in the study of water resources. According to these results, in most parts of this city, these values exceeded the prescribed limit of WHO. The main concern about the chemical analysis of water is about low concentrations of fluoride and high concentrations of sulfate, which were in agreement with the obtained results by Miranzadeh *et al*. [21].

Conclusions

Iran is one of the developing countries suffering from water pollution. The correlation coefficient is a helpful tool for the promotion of research in water pollution problems. Drinking water is most essential for livelihoods and for other consumptions in Kashan city with a hot and dry climate. 21 samples were collected during October 2006 to May 2007. A new study was carried out on water quality parameters using the correlation coefficient and regression method in analyzing Kashan drinking water. The concentrations of most of the investigated parameters in the drinking water samples were within the permissible limits of the World Health Organization drinking water quality guidelines.

Hydrochemical facies using a Piper diagram indicate that in most part of this city, the chemical character of water is dominated by NaCl. The statistical analysis of the experimentally estimated water quality parameters on water samples yielded the range of the variation, mean, standard deviation and coefficient of variation. Since the correlation coefficient gives the interrelationship between the parameters, correlation coefficients were calculated. In the correlation regression study, we can conclude that with most of the parameters are more or less correlated with each other. Highly positive correlation is observed between TDS-EC and Ca^{2+}-TH. The results showed that regression relations have the same correlation coefficients, pH and TH, EC and TH, NO_3^- and pH, TH and pH, Ca^{2+} and SO_4^{2-}, TH and SO_4^{2-}, Cl^- and SO_4^{2-}. All samples showed sulfate and sodium ions higher and K^+ and F^- content lower than the permissible limit.

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