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# *Spatial and Temporal Evaluation of Water Quality in the Kashkan River*

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***ABSTRACT***

The Kashkan River basin is one of the most important watersheds in the west of Iran, where major urban, agricultural and livestock regions are located in its catchment area. The aim of the study reported here is to evaluate the spatial and long temporal variations of surface water quality in the Kashkan River by using Water Quality Index, which aggregates different parameters and their dimensions into a single score. This study was conducted by using the variations of concentration of nine physicochemical parameters which periodically were measured (from 1974 to 2009) at 10 sampling stations. Chemical data were analyzed using both the principal component analyses and cluster analyses, which quantify the relations between variables by computing the matrix of correlations and classifying the monitoring stations, respectively. The present study demonstrated the ability of Water Quality Index developed by Canadian Council of Ministers of Environment for interpretation of the historical water quality data in the Kashkan River, Iran. This study has also highlighted that among the 10 sub-basins in the watershed, Jelhool sub-basin has the worst water quality. Moreover, water quality in the Kashkan River has been slightly deteriorated since 2000. However, the Kashkan River water has had fair quality for general uses.

***Keywords***

Water quality, Physicochemical parameters, indices, Kashkan river

## 1. Introduction

Given the public skepticism about the availability of freshwater quality in the near future, great interest has been increased among developing countries and countries with transition economies to monitor water quality during the past decades in order to manage their water resources (Debels et al. 2005; Babaei et al. 2011a). However, the chemical properties of rivers are complex and depend on inputs from the atmosphere, from the geology through which it travels and the inputs from man's activities (Bricker and Jones 1995; Shrestha et al. 2008; Ghadimi and Ghomi 2012). Karamouz et al. (2006) also noted that, as a whole, in Iran different kinds of environmental problems–caused by a disordered economic growth and the excessive water use associated with those–have been generally affecting both the availability and the quality of freshwater.

The Kashkan River, located in the west of Iran, drains an important agricultural

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watershed. In addition, considerable amount of water is exploited from it to be used for irrigation and to produce drinking water for nearby cities, such as Aleshtar, Poledokhtar, and Jogolvandi. The river in its particular length also receives the cities' urban waste water, which–until recently–was discharged without any primary treatment. The aim of this study is to assess surface water quality in the Kashkan River to optimize the management of the quality of water in the river. In fact, the effective long-term management of rivers requires a fundamental understanding of hydro-morphological, chemical, and biological characteristics (Shrestha et al. 2008). Besides, water quality may be spatially or temporally assessed (Rosemond et al. 2009). However, to assess water quality, two components are required: (a) measurement of water quality variables, and (b) comparison of measures with benchmarks, guidelines, or objectives to assess water quality. In Iran, some water quality guidelines have been developed to compare water quality for general use (Tajreshi et al. 2002; Babaei et al. 2011b).

Traditionally, single variable with trend analysis has been frequently used on a site-to-site basis to report the status of the watershed. These methods are now onerous, simply put, time consuming and furthermore, may not provide an integrated or easily interpreted assessment of water quality. So, effective tools to assess the water quality are needed to communicate the health of water to multiple users (Lumb et al. 2006; Rosemond et al. 2009). More recently, effective methods such as multivariate statistical techniques and Water Quality Index (WQI)—to reach an overall and integral management of water quality—are used extensively.

Multivariate statistical techniques, such as cluster analysis (CA), factor analysis (FA), and principal component analysis (PCA) are tools that were applied for the evaluation of variations and the interpretation of a large complex water quality data (Liou et al. 2004; Sojka et al. 2008; Bhardwa et al. 2010; Chitmanat and Traichaiyaporn 2010; Cieszynska et al. 2012). The multivariate analysis is widely used to characterize and evaluate the river water quality and it is a useful tool for evidencing variations caused by natural and anthropogenic processes (Quadir et al. 2007; Satheeshkumar and Khan 2011). In this regard, Pejman et al. (2009) evaluated spatial and seasonal variations of water quality in Haraz River Basin using multivariate statistical techniques, such as cluster analysis, principal component analysis and factor analysis and mentioned that a parameter, which can be significant in contribution to water quality variations in river for one period, may not be significant for another period. Similarly, Zare et al. (2011) investigated seasonal variations of chemical characteristics of surface water for the Chehelchay Watershed in the Northeast of Iran by applying various multivariate statistical techniques and demonstrated the usefulness of multivariate statistical approaches for analysis and interpretation of water quality data. In addition, Noori et al. (2011) noted that analyzing water quality data collected from Gorganrud River by using PCA revealed that all monitoring stations are important in explaining the annual variation of data set. Fataei (2011) used multivariate statistical techniques for analyzing the quality of water and monitoring the variables affecting water quality in Gharasou River–in Ardabil province–in the Northwest of Iran, and discussed the effectiveness of these techniques to obtain better information about the water quality and design the network of monitoring for effective management of water resources.

On the other hand, water quality indices are intended as a simple, readily understandable tool for managers and decision makers to transmit information on the quality and potential uses of a given water body based on various criteria (Stambuk-Giljanovic 2003; Sedeno-Diaz and Lopez-Lopez 2006; Babaei et al. 2011a). Some water quality indices, which have been developed in public domain for the purpose of water quality assessment in some countries, include the National Sanitation Foundation Water Quality Index (NSFWQI) (Ott, 1978), British Columbia Water Quality Index (BCWQI) (Ott, 1978), Canadian Council of Ministers of Environment Water Quality Index (CCME WQI)(CCME, 2001), and Oregon Water Quality index (OWQI) (Cude, 2001). No national WQI has yet been developed in Iran territory; nonetheless, CCME WQI was chosen to apply in the present study.

CCME WQI was based on the concept of British Columbia Water Quality Index (BCWQI); instead of the conventional Delphi approach, the CCME WQI employed three variances: scope, frequency, and amplitude, each of which has been scaled between 0 and 100. The CCME WQI mathematically combines these variances to produce a single dimensionless number that represents overall water quality at a site relative to the selected objective (e.g. general use). The result of CCME WQI is a single dimensionless number from 0 to 100, where a score of 100 indicates that all variables are below the chosen guideline. The selection of appropriate guidelines and/or objectives is crucial to calculate representative and accurate water quality indices (CCME 2001; Khan et al. 2003). CCME WQI allows the user to define local standards, which are taken into account during index computation, and to specify water quality objectives/standards, which are determined by the user (Sargaonkar et al. 2008; Rosemond et al. 2009). Furthermore, another advantage of the CCME WQI is its ability to combine various parameters with variety of measurement units in a single metric (CCME 2001); these abilities allow researchers to use a variety of variables in various regions, and all of these features of the CCME WQI persuaded the author to apply it in the present study.

Khan (CCME 2004) compared CCME WQI with French WQI and concluded that the ninety percent results from both WQIs are correlated in trend of index values. However, CCME WQI values are consistently lower than those of the French WQI. Lumb et al. (2006) used CCME WQI to monitor the water quality in the Mackhenzie River basin in Canada and strongly recommended to use the site-specific objectives/standards. Rosemond et al. (2009) pointed that the application of the region-specific objectives to the CCME WQI allows the index to become a more effective communicative tool but its limits hinder it in usefulness in rating absolute water quality relative to ideals for uses such as drinking water.

The purpose of this study was mainly to develop an effective water quality management in the Kashkan River with applying CCME WQI, using periodically collected water quality measured data from 1974 to 2009. Only the limited constitute of water quality (such as; EC (Electrical Conductivity), $CO_3^{2-}$, $HCO_3^{-}$, $Cl^{-}$, $SO_4^{2-}$, $Ca^{2+}$, $Mg^{2+}$,$Na^{+}$, $K^{+}$, and pH) have been measured along 35 years. We determined the level of quality at different locations along the Kashkan River based on those chemical data, which were retrieved from the Water Resource Management Company (WRMC) data bank.

## 2. Materials and Methods

### 2.1. Study Area and Sampling point

The Kashkan River (Fig.1), which is located in Lorestan province in the west of Iran (33◦05'–34◦ 02' N and 47◦12'–48◦59' E), is one of the longest rivers with a length of 900 km, a drainage area of 9.236 $km^2$, an average rainfall of 562 mm/year in the catchments area, and an annual runoff of 2.02 billion cubic meters. The headwaters of the Kashkan River are in the Zagrus Mountains at an altitude of about 3140 meter above sea level (m.a.s.l). The four major perennial tributaries of the Kashkan River include Doab, Khorramabad, Jehlool, and Madianrud. Numerous intermittent and ephemeral streams discharge to the Kashkan River only during periods of intense rainfall and (or) heavy snowmelt. Some towns such as Aleshtar, Poledokhtar, Jogolvandi, and Koohdasht are situated along the Kashkan River on which their untreated sewage water is dumped into the river.

Basic especially geological, hydrological information of the Kashkan River basin and its sub-basins district is given in Table 1. The surface area is geologically composed mainly of shale, marl, conglomerate, limestone, and Quaternary alluvium at different ages consisting of clay, silt, sand, and gravel mixed in varied proportions. Land uses in the study area are predominantly agriculture (covers 41%), forest (covers 39%), and pasture (covers 20%). All of the ten monitoring stations, which were considered for assessment, were numbered from 1 to 10 (Fig. 1).

### 2.2. Application PCA and CCME WQI for Kashkan River

In addition, The PCA was applied based on the dataset of the mean annual values of 10 water quality parameters at 10 monitoring stations. PCA was also used as a data exploratory method and not as a tool for strict statistical inference and hypothesis testing. This study assesses spatial and long temporal variations in water quality over 36 years (from 1974 to 2009). The surface water quality parameters only included EC, $CO_3^{2-}$, $HCO_3^{-}$, $Cl^{-}$, $SO_4^{2-}$, $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, and pH. These data for 10 water quality monitoring stations in which monitored periodically and stored over thirty-six years, were retrieved from Iranian WRMC.

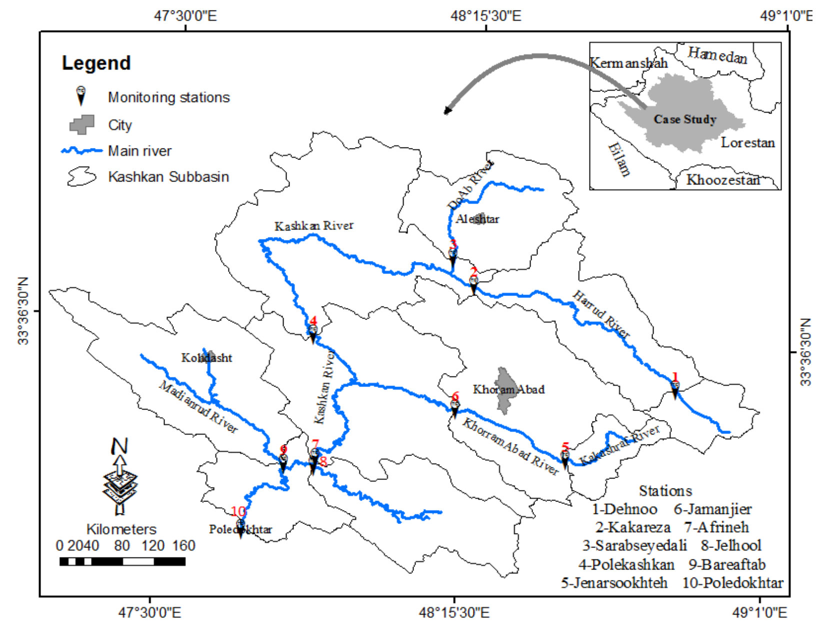


Fig. 1 Map of study area, monitoring stations located on tributary of Khashkan River, Iran.

Table 1. Basic information of KR watershed

| Station No. | Station/ subbasin name | Basin area ($Km^2$) | Mean discharge ($m^3$/sec) | Subbasin area ($Km^2$) | Geology and land use characteristic (cover %) |
|---|---|---|---|---|---|
| 1 | Dehnoo | 266 | 2.44 | 266 | Limestone (37%), Conglomerate (17%), Alluvium (46%), *Dryfar-modpas. (32%) |
| 2 | Kakareza | 1145 | 14.97 | 880 | Shale, Marl (5%), Limestone (54%), Conglomerate (6%), Alluvium (35%), *Dryfar-modpas. (40%) |
| 3 | Sarabseyedali | 777 | 8.32 | 777 | Shale and marl (4%), Limestone (59%), Alluvium (37%), Moderate pasture (25%) |
| 4 | polekashkan | 3448 | 22.25 | 1526 | Shale, Marl (29%), Limestone (19%), Conglomerate (26%), Alluvium (26%), Afforestation (38%) |
| 5 | Jenarsookhteh | 242 | 1.49 | 242 | Shale, Marl (29%), Limestone (17%), Conglomerate (10%), Alluvium (44%), *Dryfar-modpas. (60%) |
| 6 | Jamanjier | 1656 | 11.56 | 1414 | Shale, Marl (14%), Limestone (43%), Conglomerate (8%), Alluvium (35%), * dryfar-modpas. (45%) |
| 7 | Afrineh | 6803 | 54.32 | 1699 | Shale, Marl (32%), Limestone (36%), Alluvium (32%), Afforestation (23%) |
| 8 | Jelhool | 817 | 4.69 | 817 | Shale, Marl (39%), Limestone (35%), Conglomerate(16), Alluvium (10%), Afforestation (35%) |
| 9 | Bareaftab | 1132 | 1.39 | 1132 | Shale, Marl (41%), Limestone (27%), Alluvium (32%), *Dryfar-modpas. (60%) |
| 10 | Poledokhtar | 9235 | 64.06 | 482 | Shale, Marl (41%), Limestone (32%), Conglomerate (6%), Alluvium (20%), Afforestation (47%) |

*Dry farming with moderate pasture

On the other hand, CCME WQI—which was originally formed in 1997 as the Canadian Water Quality Index-comprises of three factors: Scope ($F_1$), Frequency ($F_2$), and Amplitude ($F_3$) (CCME, 2001), which are calculated as Eq. 1 through Eq. 6.

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) \times 100 \quad (1)$$

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of variables}}\right) \times 100 \quad (2)$$

$$\text{excursion}_i = \left(\frac{\text{Failed Test Value}_i}{\text{Objective}_j}\right) - 1 \quad (3)$$

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{number of tests}} \quad (4)$$

$$F_3 = \left(\frac{nse}{0.01\text{nse} + 0.01}\right) - 1 \quad (5)$$

$$CCWQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^3}}{1.732}\right) \quad (6)$$

The last formula, i. e. Eq. (6), produces a value between 0 and 100 and gives a numerical value to the state of water quality. The water quality is ranked in the five categories;
(1) Excellent (CCME WQI values 95–100),
(2) Good (CCME WQI values 80–94),
(3) Fair (CCME WQI values 60–79),
(4) Marginal (CCME WQI values 45–59),
(5) Poor (CCME WQI values 0–44).

## 3. Results and Discussion

The summarized basic statistics of dataset (19,600 observations) are given in Table 2. Water samples generally were collected periodically from 1974 to 2009. Analyses and statistical parameters of the chemical constituents of the Kashkan River at different stations are represented in Table 2. Annual means, minimum, maximum, and standard deviations were calculated for each parameter. All statistical analyses were performed using SPSS statistical software.

From 1974 to 2009, the water in the catchment of Kashkan River shows a normal range of pH (ranging from 6.8 to 7.9). Other constituents vary viz. sulfate from 14.5 to 278.2 mg/l; calcium from 43 to 120 mg/l, magnesium from 12.2 to 49.1 mg/l, bicarbonate from 142.6 to 271.7 mg/l (elevated concentrations were observed). The high concentration of $HCO_3^-$—above 271 mg/l—maybe associated with a very low discharge here.

### 3.1. PCA Analysis

Principal Component Analysis was conducted to see which parameters that are going to be included in the CCME WQI calculations are correlated and which are responsible for most of the variance observed in the water quality data. Correlation matrix of the PCA (shown on Table 3) shows the significant values (α=0.05 and α=0.01) of correlation between particular parameters. The significant positive correlation obtained between parameters indicates a good consistency between the results.

In Table 3, good correlations are seen between some pairs of variables such as: $Na^+$ and $SO_4^{2-}$; $Ca^{2+}$ and $Cl^-$; EC and $Ca^{2+}$, $Na^+$, $Cl^-$, $Mg^{2+}$, $SO_4^{2-}$; $Mg^{2+}$and $K^+$; $SO_4^{2-}$ and $Ca^{2+}$. All of the parameters have positive correlation. The data sets that are highly correlated can imply a natural origin of those components in the water of the Kashkan catchment; they have been probably released from limestone and shale-marl formations, which cover approximately 35% and 21% of the land surface, respectively.

Table 2. Statistical description of water quality parameters at different stations

| Station no. | | EC | pH | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $HCO_3^{-}$ | $CO_3^{2-}$ | $Cl^{-}$ | $SO_4^{2-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **min** | 180 | 6.6 | 20 | 3.6 | 0.46 | 0.01 | 76.25 | 0.01 | 3.55 | 0.01 |
| | **max** | 675 | 8.3 | 89.8 | 44.4 | 18.4 | 9.75 | 353.8 | 18 | 30.17 | 179.52 |
| **1** | **mean** | 371.86 | 7.8 | 48.26 | 14.34 | 4.78 | 2.48 | 186.66 | 1.37 | 10.12 | 21.48 |
| | **S.D.** | 106.54 | 0.4 | 0.76 | 0.63 | 0.13 | 0.04 | 0.94 | 0.1 | 0.12 | 0.45 |
| | **Count** | 164 | 164 | 164 | 164 | 164 | 62 | 164 | 91 | 164 | 161 |
| | **min** | 178 | 5.2 | 18 | 1.2 | 0.69 | 0.78 | 64.05 | 0.01 | 2.84 | 0.48 |
| | **max** | 700 | 8.3 | 72 | 42 | 23 | 18.33 | 305 | 18 | 39.05 | 89.28 |
| **2** | **mean** | 332.33 | 7.8 | 44.14 | 12.19 | 4.66 | 2.54 | 169.37 | 2.144 | 9.49 | 16.87 |
| | **S.D.** | 91.77 | 0.4 | 0.73 | 0.5 | 0.13 | 0.05 | 0.76 | 0.12 | 0.14 | 0.3 |
| | **Count** | 205 | 205 | 205 | 205 | 205 | 68 | 205 | 110 | 205 | 200 |
| | **min** | 190 | 6.4 | 20 | 1.08 | 0.69 | 1.17 | 54.9 | 0.01 | 3.55 | 0.48 |
| | **max** | 630 | 8.5 | 78 | 45.6 | 23.46 | 12.87 | 298.9 | 15 | 24.85 | 79.68 |
| **3** | **mean** | 350.17 | 7.8 | 46.04 | 12.57 | 5.17 | 3.19 | 179.89 | 1.81 | 11.57 | 14.52 |
| | **S.D.** | 99.09 | 0.37 | 0.76 | 0.55 | 0.12 | 0.05 | 0.85 | 0.11 | 0.11 | 0.27 |
| | **Count** | 218 | 217 | 218 | 218 | 218 | 69 | 218 | 107 | 218 | 211 |
| | **min** | 210 | 6 | 19 | 3 | 1.38 | 1.17 | 76.25 | 0.01 | 5.33 | 0.01 |
| | **max** | 1600 | 8.3 | 258 | 42 | 32.43 | 13.65 | 289.75 | 30 | 92.3 | 597.6 |
| **4** | **mean** | 363.91 | 7.8 | 43.73 | 14.28 | 7.93 | 3.79 | 170.39 | 2.18 | 14.11 | 23.65 |
| | **S.D.** | 135 | 0.42 | 1.05 | 0.5 | 0.17 | 0.06 | 0.67 | 0.14 | 0.27 | 0.98 |
| | **Count** | 204 | 204 | 204 | 204 | 204 | 59 | 205 | 99 | 204 | 201 |
| | **min** | 370 | 6.6 | 32 | 4.8 | 1.84 | 0.01 | 140.3 | 0.01 | 7.1 | 0.48 |
| | **max** | 820 | 8.4 | 72 | 61.2 | 34.96 | 49.92 | 384.3 | 21 | 35.5 | 104.16 |
| **5** | **mean** | 576.31 | 7.6 | 54.47 | 30.81 | 9.06 | 5.3 | 271.66 | 1.36 | 20.4 | 30.52 |
| | **S.D.** | 110.31 | 0.47 | 0.51 | 0.93 | 0.32 | 0.18 | 0.86 | 0.15 | 0.18 | 0.61 |
| | **Count** | 59 | 59 | 59 | 59 | 59 | 53 | 59 | 58 | 59 | 59 |
| | **min** | 260 | 6 | 19 | 6 | 1.38 | 0.01 | 76.25 | 0.01 | 3.55 | 0.01 |
| | **max** | 1020 | 8.4 | 98 | 68.4 | 43.47 | 42.12 | 378.2 | 42 | 71 | 132.96 |
| **6** | **mean** | 529.97 | 7.7 | 55.74 | 21.45 | 18.65 | 4.83 | 230.64 | 2.86 | 36.53 | 25.87 |
| | **S.D.** | 126.9 | 0.49 | 0.9 | 0.69 | 0.38 | 0.1 | 1.04 | 0.19 | 0.31 | 0.44 |
| | **Count** | 268 | 268 | 268 | 268 | 268 | 126 | 268 | 172 | 268 | 266 |
| | **min** | 285 | 6.8 | 23 | 1.8 | 2.8 | 2 | 76.3 | 0.01 | 12.4 | 0.01 |
| | **max** | 1300 | 8.4 | 82 | 74.4 | 78.2 | 27.3 | 292.8 | 21 | 152.7 | 182.4 |
| **7** | **mean** | 521.4 | 7.8 | 47.2 | 19.3 | 27.9 | 5.2 | 182.7 | 3 | 49.1 | 37.5 |
| | **S.D.** | 139 | 0.35 | 0.69 | 0.72 | 0.69 | 0.1 | 0.7 | 0.16 | 0.66 | 0.56 |
| | **Count** | 223 | 222 | 223 | 223 | 223 | 67 | 223 | 120 | 223 | 222 |
| | **min** | 365 | 6.4 | 24 | 3.84 | 2.3 | 1.95 | 54.9 | 0.01 | 7.1 | 6.24 |
| | **max** | 2010 | 8.5 | 330 | 94.8 | 209.3 | 31.2 | 436.15 | 36 | 216.6 | 757.44 |
| **8** | **mean** | 1134.3 | 7.7 | 120.6 | 34.45 | 57.04 | 5.57 | 142.57 | 1.46 | 112.8 | 278.19 |
| | **S.D.** | 236.01 | 0.42 | 2.27 | 0.89 | 1.38 | 0.1 | 0.62 | 0.18 | 1.04 | 2.26 |
| | **Count** | 361 | 360 | 361 | 361 | 361 | 141 | 361 | 204 | 361 | 361 |
| | **min** | 319 | 6.4 | 22 | 11.4 | 4.83 | 1.95 | 67.1 | 0.01 | 17.75 | 0.96 |
| | **max** | 2000 | 8.8 | 230 | 81.6 | 186.3 | 25.74 | 530.7 | 42 | 184.6 | 511.2 |
| **9** | **mean** | 836.01 | 7.9 | 66.38 | 40.11 | 39.08 | 5.68 | 235.19 | 6.98 | 48.8 | 140.5 |
| | **S.D.** | 235.67 | 0.39 | 1.75 | 0.81 | 0.85 | 0.1 | 1.14 | 0.3 | 0.76 | 1.67 |
| | **Count** | 211 | 210 | 211 | 211 | 211 | 77 | 211 | 135 | 211 | 211 |
| | **min** | 330 | 6.4 | 27 | 1.8 | 2.07 | 1.95 | 91.5 | 0.01 | 7.1 | 0.01 |
| | **max** | 1400 | 8.5 | 254 | 61.2 | 78.2 | 28.47 | 384.3 | 42 | 181.1 | 543.36 |
| **10** | **mean** | 622.49 | 7.8 | 56.85 | 24.36 | 30.03 | 5.41 | 188.73 | 2.03 | 61.25 | 64.36 |
| | **S.D.** | 141.14 | 0.41 | 1.01 | 0.85 | 0.77 | 0.08 | 0.72 | 0.16 | 0.79 | 0.96 |
| | **Count** | 277 | 276 | 277 | 277 | 277 | 120 | 277 | 166 | 277 | 277 |

[*] All the water quality parameters are expressed in milligram/liter, except pH, EC (μS/cm), S.D.: Standard deviation

Table 3. Correlation matrix of water quality variables of PCA

| | EC | pH | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $HCO_3^-$ | $CO_3^{2-}$ | $Cl^-$ | $SO_4^{2-}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **EC** | 1 | | | | | | | | | |
| **pH** | -0.181 | 1 | | | | | | | | |
| **$Ca^{2+}$** | 0.928** | -0.280 | 1 | | | | | | | |
| **$Mg^{2+}$** | 0.827** | -0.232 | 0.606 | 1 | | | | | | |
| **$Na^{+}$** | 0.917** | 0.116 | 0.836** | 0.638* | 1 | | | | | |
| **$K^{+}$** | 0.716* | -0.255 | 0.466 | 0.824** | 0.662* | 1 | | | | |
| **$HCO_3^-$** | -0.116 | -0.383 | -0.334 | 0.421 | -0.365 | 0.334 | 1 | | | |
| **$CO_3^{2-}$** | 0.266 | 0.701* | 0.000 | 0.444 | 0.383 | 0.343 | 0.155 | 1 | | |
| **$Cl^-$** | 0.898** | -0.079 | 0.884** | 0.547 | 0.963** | 0.628 | -0.429 | 0.128 | 1 | |
| **$SO_4^{2-}$** | 0.949** | -0.053 | 0.964** | 0.650* | 0.909** | 0.493 | -0.383 | 0.210 | 0.898** | 1 |

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

According to the eigenvalue criterion (eigenvalues >1), the three first eigenvalues were taken into account. The cumulative variance for the first three principal components is 95.52% of the total variance of the original dataset (Table 4 and Fig. 2). These first three principal components were later rotated according to varimax rotation in order to make an easy interpretation (Table 4).

In this table, communalities show that all parameters have been described to an acceptable component which loaded higher than 0.8 may be taken into consideration for the interpretation of the PCA. As can be seen in Table 4 eigenvalues of the first, second, and third principal components (PC) were 5.802, 1.974, and 1.776, respectively, and the respective contributions were 58.02%, 19.7% and 17.76%. On the first PC, the factor loadings of EC, calcium, sodium, chloride, and sulfate show a positive relation. However, on the other hand, in the second PC, bicarbonate, magnesium, and potassium are significant, while carbonate and pH have high factor loadings on the third PC (Table 4).

This suggests that all parameters of combination of variety from three principal components are effective to analyze the degree of water quality in the Kashkan River watershed and may be included in CCME WQI.

As CA was used to detect similar groups between the sampling sites, CA using Ward's method was applied to the average data of the study period years using squared Euclidian distance as a similarity measure. The results were illustrated in Fig. 3 where the observation points can be roughly assigned to three clusters. Cluster 1 included Station 8 as it is distinctly more polluted than the other stations, cluster 2 included Station 9 which has moderate quality, and cluster 3 included the rest stations–Stations 1, 2, 3, 4, 5, 6, 7, and 10– which are duly affected by similar sources and are approximately referred to relatively cleaner areas.

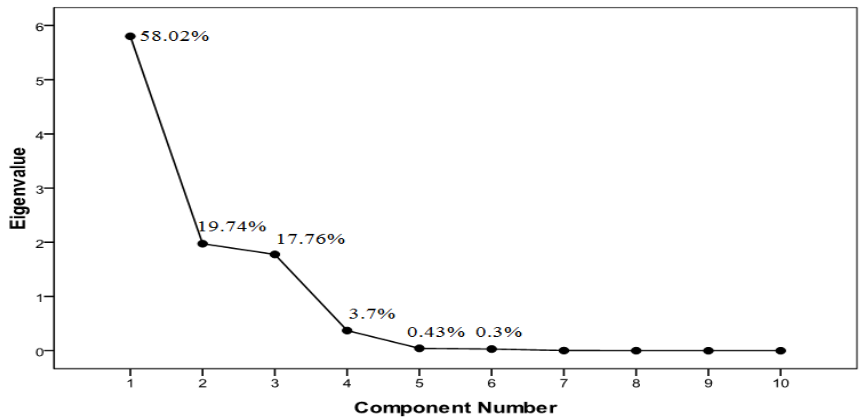


Fig. 2. Screen-plot for the PCA of the water quality parameters from case study monitoring stations

Table 4. Variances explained by rotated components

| **PC** | **1** | **2** | **3** | |
|---|---|---|---|---|
| **Percent variance %** | **58.02** | **19.738** | **17.763** | |
| **Cumulative variance %** | **58.02** | **77.75** | **95.519** | |
| | **Rotated loadings** | | | **Communalities** |
| EC | 0.946 | 0.309 | 0.020 | 0.990 |
| pH | -0.095 | -0.359 | 0.925 | 0.993 |
| $Ca^{2+}$ | 0.956 | 0.026 | -0.188 | 0.950 |
| $Mg^{2+}$ | 0.605 | 0.762 | 0.099 | 0.956 |
| $Na^{+}$ | 0.951 | 0.083 | 0.254 | 0.976 |
| $K^{+}$ | 0.567 | 0.711 | 0.059 | 0.830 |
| $HCO_3^{-}$ | -0.422 | 0.887 | -0.113 | 0.979 |
| $CO_3^{2-}$ | 0.141 | 0.346 | 0.916 | 0.979 |
| $Cl^{-}$ | 0.972 | -0.003 | 0.013 | 0.946 |
| $SO_4^{2-}$ | 0.974 | 0.021 | 0.051 | 0.953 |

```
Dendrogram using Ward Method
                                        Rescaled Distance Cluster Combine

           C A S E                0         5        10        15        20        25
 Label                     Num   +---------+---------+---------+---------+---------+

 (3)  SayabSeyAli            3    -+
 (4)  Polekhashkan           4    -+-----------------+
 (1)  Dehnoo                 1    -+                 |
 (2)  KakaReza               2    -+                 +-----------------------------+
 (7)  Afrine                 7    -+                 |                             |
 (10)  PoleDokhtar          10    -+-------+         |                             |
 (6)  JamAnjir               6    -+       +---------+                             |
 (5)  Jenarsookhte           5    ---------+                                       |
 (8)  Jehlool                8    ---------------------------+---------------------+
 (9)  BareAftab              9    ---------------------------+
```

Fig. 3. Dendrogram showing clustering of monitoring stations.

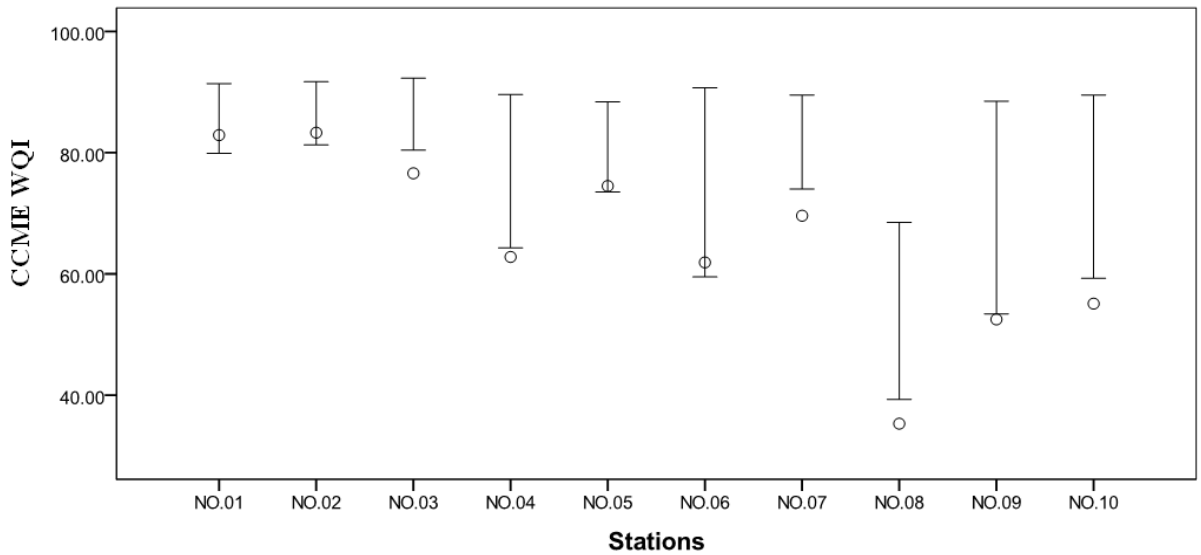


Fig. 4. Spatial variation of mean CCME WQI scores for monitoring station in case study from 1974 to 2009. The bar denotes ± SD and circle symbol in graph represents WQI based on total number of test (the last row of Table 5)

**3.2. CCME WQI**

Even as the minimum, maximum, mean values of CCME WQI score for each monitoring station in the whole period studied are provided in Table 5, the spatial and temporal mean variation of WQI scores are shown in Figs. 4 and 5, respectively. At first glance, we see that temporal change in water quality from 1974 to 1999 is incidental although afterwards begins to decline, but no statistically significant differences in index values could be temporally detected for all ten stations located on the tributaries. On the other hand, spatial variation of water quality is considerable along the entire river course. Especially in the lower part of the watershed–downstream of station 7–water quality in the main course begins to deteriorate slightly.

In this case study, we focus on long-term variations (over a thirty-six-year period) when WQI had the lowest variation in 1984 (vary from 68.5 at Station 8 to 91.4 at Station 1) and the highest variation in 2004 with varying from 39.3 at Station 8 to 87.1 at Station 1 (Fig 5). Station 8 in 2004 had the lowest WQI score (39.3) and station 3 in 1983 had the highest one (92.3) (Table 5).

Figure 6 shows the water quality map based on CCME WQI scores in a bar plot in the whole watershed, and Fig. 7 shows CCME WQI scores along the main course in correlation with the volume of discharge. The bar graph in Fig 7 represents WQI score and the line graph represents volume of surface water at the stations. Generally, water quality deteriorates along the main course whereas it can be clearly seen from Fig.7 that WQI at Station 7(Afrine) is higher than WQI at station 4 (Polekashkan)—Station 7 located about 57 km downstream of Station 4. This may indicate the entrance of considerable water (about 23.7 MCM) with suitable quality to the main course after station 4 (Polekashkan) and before station 7 (Afrine)

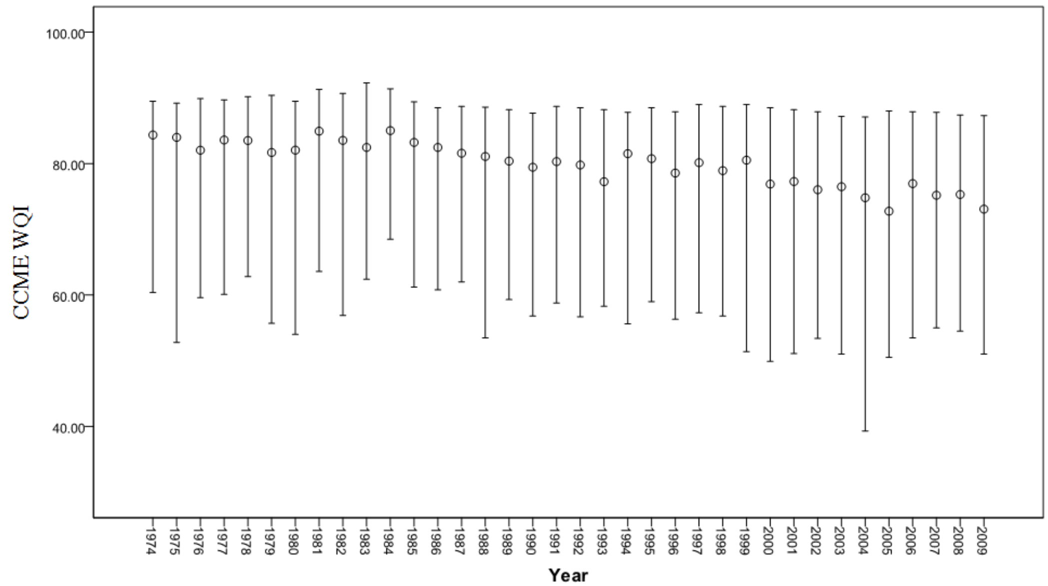


Fig. 5. Temporal variation of the mean WQI scores for the 10 monitoring stations in case study, the bar denotes ± SD

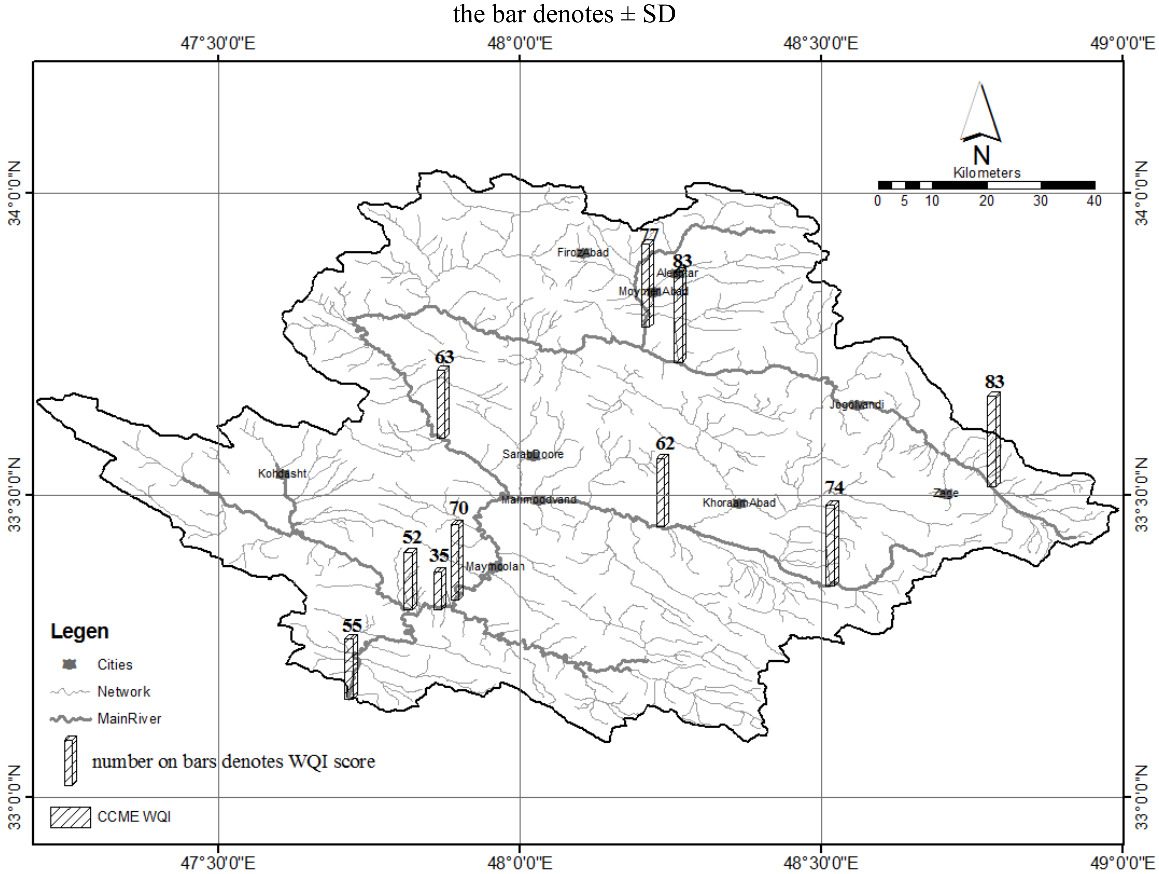


Fig. 6. Bar plot of CCME WQI scores for each monitoring station of the Kashkan River watershed from 1974 to 2009, number on the bars denotes WQI score.

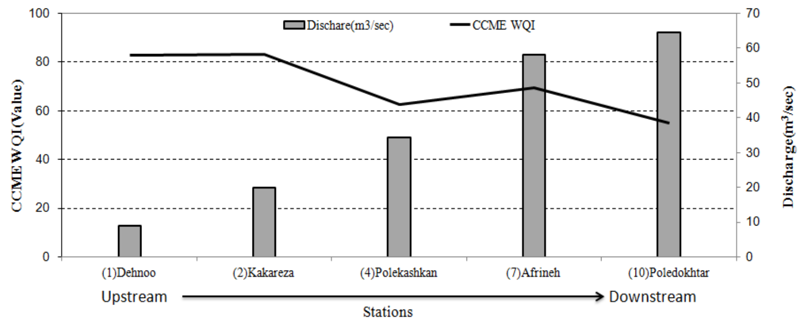


Fig. 7. Graph of CCME Score and discharge of river along main course river

Table 5. CCME WQI scores of the stations of the Kashkan River during the study period

| Year \ Stations | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Min | Max | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1974 | 88.8 | 89.3 | 89.0 | 88.8 | NA* | 89.1 | 75.9 | 60.4 | 88.5 | 89.5 | 60.4 | 89.5 | 10.0 |
| 1975 | 88.9 | 89.2 | 89.0 | 89.0 | NA | 87.1 | 89.0 | 52.8 | 88.5 | 82.5 | 52.8 | 89.2 | 11.9 |
| 1976 | 89.9 | 89.4 | 89.3 | 89.2 | NA | 87.9 | 88.8 | 59.6 | 74.8 | 69.5 | 59.6 | 89.9 | 11.3 |
| 1977 | 89.7 | 89.4 | 89.2 | 89.6 | NA | 88.4 | 89.5 | 60.1 | 73.3 | 83.2 | 60.1 | 89.7 | 10.3 |
| 1978 | 90.1 | 90.2 | 89.5 | 89.5 | NA | 88.3 | 89.0 | 62.8 | 68.8 | 83.5 | 62.8 | 90.2 | 10.4 |
| 1979 | 88.9 | 89.7 | 90.4 | 89.5 | NA | 88.3 | 89.3 | 55.7 | 60.5 | 83.0 | 55.7 | 90.4 | 13.6 |
| 1980 | 89.1 | 89.5 | 89.3 | 89.2 | NA | 88.3 | 89.0 | 54.0 | 67.0 | 83.1 | 54 | 89.5 | 12.8 |
| 1981 | 91.3 | 89.2 | 89.5 | 89.1 | NA | 89.0 | 89.2 | 63.6 | 74.9 | 88.7 | 63.6 | 91.3 | 9.4 |
| 1982 | 89.3 | 90.7 | 90.7 | 89.5 | NA | 89.6 | 88.9 | 56.9 | 82.5 | 73.8 | 56.9 | 90.7 | 11.4 |
| 1983 | 89.7 | 91.7 | 92.3 | 89.3 | NA | 90.7 | 83.6 | 62.4 | 67.8 | 74.7 | 62.4 | 92.3 | 11.3 |
| 1984 | 91.4 | 89.5 | 89.8 | 89.0 | NA | 89.4 | 89.2 | 68.5 | 77.1 | 81.4 | 68.5 | 91.4 | 7.8 |
| 1985 | 87.3 | 88.6 | 89.4 | 87.5 | NA | 88.9 | 86.9 | 61.2 | 71.1 | 88.2 | 61.2 | 89.4 | 10.0 |
| 1986 | 87.9 | 87.4 | 88.5 | 88.0 | NA | 87.1 | 88.2 | 60.8 | 72.4 | 81.9 | 60.8 | 88.5 | 9.7 |
| 1987 | 88.6 | 87.9 | 88.6 | 83.3 | NA | 87.1 | 88.7 | 62.0 | 65.7 | 82.4 | 62 | 88.7 | 10.4 |
| 1988 | 87.6 | 88.6 | 88.3 | 87.9 | NA | 87.9 | 81.1 | 53.5 | 73.2 | 81.7 | 53.5 | 88.6 | 11.6 |
| 1989 | 87.2 | 88.2 | 87.8 | 88.0 | NA | 88.2 | 81.4 | 59.3 | 70.7 | 72.7 | 59.3 | 88.2 | 10.5 |
| 1990 | 79.9 | 86.9 | 87.7 | 87.2 | NA | 85.3 | 87.1 | 56.8 | 62.5 | 81.7 | 56.8 | 87.7 | 11.6 |
| 1991 | 86.3 | 88.0 | 86.6 | 88.7 | NA | 80.2 | 88.4 | 58.8 | 63.8 | 82.0 | 58.8 | 88.7 | 11.2 |
| 1992 | 87.1 | 88.5 | 87.7 | 81.5 | NA | 85.7 | 87.8 | 56.7 | 69.6 | 73.6 | 56.7 | 88.5 | 11.0 |
| 1993 | 86.9 | 87.7 | 86.5 | 88.2 | NA | 73.8 | 81.9 | 58.3 | 59.1 | 72.9 | 58.3 | 88.2 | 12.0 |
| 1994 | 87.5 | 87.8 | 87.3 | 87.8 | 86.8 | 85.6 | 87.3 | 55.6 | 69.4 | 80.1 | 55.6 | 87.8 | 10.8 |
| 1995 | 87.8 | 88.0 | 87.2 | 88.5 | 88.4 | 85.2 | 81.1 | 59.0 | 67.6 | 74.8 | 59 | 88.5 | 10.3 |
| 1996 | 87.9 | 82.0 | 86.8 | 81.8 | 87.7 | 80.6 | 87.8 | 56.3 | 59.7 | 75.1 | 56.3 | 87.9 | 11.6 |
| 1997 | 89.0 | 88.6 | 87.7 | 88.7 | 86.6 | 74.7 | 88.5 | 57.3 | 58.4 | 82.0 | 57.3 | 89 | 12.6 |
| 1998 | 88.4 | 88.3 | 88.6 | 88.7 | 80.7 | 81.2 | 88.0 | 56.8 | 60.3 | 68.4 | 56.8 | 88.7 | 12.5 |
| 1999 | 89.0 | 88.3 | 87.9 | 88.3 | 79.9 | 87.7 | 88.1 | 51.4 | 68.8 | 75.9 | 51.4 | 89 | 12.3 |
| 2000 | 87.8 | 88.5 | 87.9 | 88.5 | 80.5 | 80.9 | 74.6 | 49.9 | 56.0 | 74.3 | 49.9 | 88.5 | 13.8 |
| 2001 | 87.3 | 87.9 | 87.5 | 88.2 | 79.8 | 80.4 | 87.3 | 51.1 | 54.7 | 68.6 | 51.1 | 88.2 | 14.2 |
| 2002 | 86.7 | 87.9 | 87.2 | 86.5 | 73.5 | 73.2 | 87.0 | 58.1 | 53.4 | 66.8 | 53.4 | 87.9 | 13.1 |
| 2003 | 87.0 | 87.2 | 86.8 | 87.2 | 84.3 | 79.8 | 74.6 | 51.0 | 66.3 | 60.7 | 51 | 87.2 | 13.0 |
| 2004 | 87.1 | 87.1 | 86.0 | 87.0 | 85.5 | 66.6 | 74.0 | 39.3 | 60.1 | 75.4 | 39.3 | 87.1 | 15.8 |
| 2005 | 86.6 | 87.4 | 80.4 | 88.0 | 84.8 | 59.5 | 74.4 | 50.5 | 56.1 | 60.0 | 50.5 | 88 | 14.7 |
| 2006 | 87.2 | 87.5 | 86.7 | 80.4 | 80.1 | 72.3 | 87.9 | 53.5 | 59.9 | 74.1 | 53.5 | 87.9 | 12.1 |
| 2007 | 87.0 | 81.3 | 80.8 | 66.9 | 79.4 | 73.5 | 87.8 | 58.6 | 55.0 | 81.6 | 55 | 87.8 | 11.5 |
| 2008 | 80.5 | 86.6 | 87.1 | 87.4 | 78.9 | 72.2 | 81.4 | 54.6 | 54.5 | 69.9 | 54.5 | 87.4 | 12.4 |
| 2009 | 87.1 | 87.3 | 80.4 | 64.3 | 77.6 | 80.6 | 78.3 | 51.0 | 64.9 | 59.3 | 51 | 87.3 | 12.4 |
| **Min** | 79.9 | 81.3 | 80.4 | 64.3 | 73.5 | 59.5 | 74.0 | 39.3 | 53.4 | 59.3 | 39.3 | 81.3 | 13.8 |
| **Max** | 91.4 | 91.7 | 92.3 | 89.6 | 88.4 | 90.7 | 89.5 | 68.5 | 88.5 | 89.5 | 68.5 | 92.3 | 7.0 |
| **Average** | 87.8 | 88.1 | 87.6 | 86.4 | 82.2 | 82.6 | 85.0 | 56.6 | 66.6 | 76.6 | 56.6 | 88.1 | 10.5 |
| **SD** | 2.26 | 1.93 | 2.55 | 5.61 | 4.22 | 7.50 | 5.12 | 5.19 | 8.99 | 7.76 | 1.93 | 8.99 | 2.4 |
| **1974-2009** | 82.9 | 83.3 | 76.6 | 62.8 | 74.5* | 61.9 | 69.6 | 35.3 | 52.5 | 55.1 | 35.3 | 83.3 | 15.6 |

**NA**: Not available; **S.D**: Standard deviation; *from1994 to 2009

The ranking and classification of water at investigative stations are shown in Table 6; Stations 1 and 2 belong to “Good” category, stations 3, 4, 5, 6, and 7 belong to “Fair”, and Stations 9 and 10 fall to “Marginal”, and finally Station 8 belongs to “Poor” category of water quality. According to the CCME water quality index, most tributaries of Kashkan River have low ranking level in water quality throughout the years in which Station 8 has the poor quality and Station 2 has the best water quality in the Kashkan watershed. Therefore, the main tributaries such as Sarabseyedali, Jamanjir, and Bareaftab River have fair and Jehlool, another tributary, has poor surface water quality.

Table 6. Classifying Stations according to CCME score base on all data (1974 through 2009)

| Station | Total No. of tests | CCME WQI score | Rank | Water quality status (linguistic) |
|---|---|---|---|---|
| 8-Jelhool | 361 | 35.29 | 10 | Poor |
| 9-Bareaftab | 211 | 52.49 | 9 | Marginal |
| 10-Poledokhtar | 277 | 55.14 | 8 | |
| 6-Jamanjier | 268 | 61.93 | 7 | Fair |
| 4-Polekashkan | 204 | 62.82 | 6 | |
| 7-Afrineh | 223 | 69.58 | 5 | |
| 5-Jenarsookhteh | 59 | 74.46 | 4 | |
| 3-Sarabseyedali | 218 | 76.63 | 3 | |
| 1-Dehnoo | 164 | 82.95 | 2 | Good |
| 2-Kakareza | 205 | 83.25 | 1 | |

WQI values in stations upstream reflected better quality in comparison to stations located downstream. This could be due to erosion by tributary inflow and can also be caused by moderate and low contributions of land use and population density, respectively. This agrees with Keshtkar et al. (2011) who tried to relate land use with major chemical ions of stream waters in the central plateau of Iran and demonstrated that Na, Ca, SAR (Sodium Adsorption Ratio), and $SO_4$ associate with urban, forested and agriculture land use and similarly K, Mg and pH with pasture and bare land uses.

## 4. Conclusions

WQI integrates the results of the environmental parameters into a single score in time and space, which allows water quality to be viewed in terms of a numerical value that qualifies possible water uses. PCA, on the other hand, points out the importance of certain environmental parameters for water quality. None of the physicochemical parameters by itself (used as analytical values) is sufficient to give a full picture of the water quality of a river. The paper presents water-quality evaluation based on a 36-year monitoring plan in the Kashkan River. The studies were carried out from 1974 to 2009 by surface water analysis at 10 various stations.

Unfortunately, so far there are no WQIs in Iran nationally, therefore, CCME WQI based on its advantages can be preferentially used. The mean WQI score—checked against the general rating scale for water quality—indicates that Kashkan River water is suitable to be considered as public water supply system. It requires no extensive treatments for most industries or crop usages, and is suitable for irrigation. Not only did the CA results correspond well with the CCME WQI results, but also PCA highlighted that all of the parameters included in CCME directly affect water quality and are effective to analyze the degree of water quality in the Kashkan River watershed. The mean spatial variation of WQI score along the Kashkan River showed that water quality deteriorates along the main course from upstream to downstream normally; however, in the middle portion it improves and after that gets worse again in the lower portion of the river. Improving causes by reaching about 32.02 MCM (Million Cubic Meters) with good quality from Afrine sub-basin. This pattern may be associated with rock-water interaction and major land uses along the Afrine sub-basin. This finding of the current study is consistent with those of Sorinejad et al. (2002) who found that major differences in stream chemistry among sub–basins of the Kashkan River were closely related to land use. Water quality in the Kashkan River –especially at monitoring stations 1, 2, 3, or 6 which an improvement in water quality could be displayed–was affected by land use more than by point discharges, because these stations not only are associated with agricultural areas but also are situated far away from large population centers. On the other hand, temporally, from 1974 to 1999, mean WQI score was more than 81(means good quality), but in the last 10 years (2000-2009) the CCME WQI was 75.5, and fell from good quality to fair quality in CCME classification. Anyway, mean CCME WQI scores stayed above 70, which means fair quality of water for most uses.

Ideally, water quality should be assessed with properly analyzed physical, chemical and biological parameters whereas the surface water quality monitoring program in Iran covers routinely only ten chemical parameters that we have obtained in this study. Nonetheless, the results confirmed the ability of CCME WQI to evaluate the water quality in the Khashkan River.

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