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Spatial and Temporal Assessment of Water Quality Changes in North, Northwest and Southwest Rivers of Iran, Involving Multivariate Statistical Techniques and GIS

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Abstract

Surface water, especially rivers, is one of the most important water resources that play an important role in supplying water for various activities. The purpose of this study was to investigate the temporal and spatial variability of water quality parameters in three different basins, in terms of land use, at 50 hydrometric stations in 9 rivers in the period 1992-2015 by using multivariate and GIS statistical methods. In this study, factor analysis based on 10 qualitative parameters was performed to determine the most important parameters affecting the surface water quality of the study area. The results of Principal component analysis showed that the North, Northwest and Southwest basins have two significant main components with 82.38%, 79.86% and 81.60% of the total variance, respectively. Cluster analysis of hydrometric stations located in northwestern and southwestern regions was divided into two clusters and north into three clusters. In the cluster analysis, some stations in Aji Chay, Atrak and Zayanderood rivers had different water quality characteristics than other stations. These stations are located downstream of the rivers. Based on the pattern of mean water quality parameters in GIS and land use map, station 2 had the lowest values for most parameters.

Keywords: GIS, PCA, Surface Water Quality, WARD.

1. Introduction

Surface waters, especially rivers, are the most important water resources that play an important role in supplying the water needed for various activities such as agriculture, industry, drinking and power generation. On the other hand, these resources are located as a place for the evacuation of sewage, waste water from factories and agricultural drainage. Increasing population, increasing pollution and recent drought, highlights the importance of paying attention to the quality of existing water resources, Surface water quality monitoring is critical to understanding the current state of water resources and the major changes that have occurred over time (Calazans et al., 2018). Therefore, in order to efficiently manage these resources, it is necessary to provide accurate information on the process of changes in river water quality parameters (Barakat et al., 2016). Awareness of the quality of water resources is one of the important requirements in the planning and development of water resources and their conservation and control, especially in developing countries, which has no accurate measurement and monitoring of these resources. Surface water quality impress of natural processes such as precipitation, erosion and weathering of materials, geology, vegetation (Yidana et al., 2008). As well as human factors such as urban, industrial and agricultural activities (Singh et al. and Papatheodorou et al., 2006). Awareness of trends in qualitative changes in rivers at different temporal and spatial will be effective in better control of water resources. Recently, China has also recognized the sustainable use of water resources as a national policy and has made great efforts to develop environmental management strategies (Zhang et al., 2009). Therefore, it is necessary to evaluate the quality of surface water resources, which requires techniques and tools to assess the quality of water in different conditions. Multivariate statistics and mathematical models are commonly used to evaluate surface water quality (Yidana et al., 2008). Multivariate methods such as cluster analysis, factor analysis, principal component analysis and analysis of detection functions through data reduction and clustering are suitable for analysis and decision making. (Helena et al., 2000; Tobiszewski et al., 2010.). In this regard, Principal Component Analysis (PCA) and Cluster Analysis (CA) conducted to identify the characteristics and assess the water quality of The Pearl River Delta area. The results showed that PCA and CA techniques are suitable tools for water quality assessment and water resources management (Fan et al., 2010). Multivariate statistical methods can help water managers to identify factors affecting water quality. Multivariate statistical techniques employed for analyzing and interpreting complex datasets, identifying sources of pollution / factors and understanding spatial variations in water quality, it also confirmed the evaluation and obtaining of better water quality information for the effective management of river water quality (Najafpour et al., 2008; Rezaei and Sayyadi, 2015; Fataei and Shiralipoor, 2011). All quantitative methods investigated for selecting WQM parameters from statistical methods including principal component analysis (PCA), correlation regression (CR) and Decision Analysis (DA). The results showed that PCA as the best method in all studies resulted instability or a decrease in the number of water quality parameters (Nguyen et al., 2019). In a similar study water quality data from 19 Liangjiang New Area (LJJA) rivers, China in April (dry season) and September (wet season) of 2014 and 2015 using multiple statistical techniques Variables such as factor analysis (FA) and cluster analysis (CA) were examined (Luo et al., 2017). Also they studied multivariate techniques such as cluster analysis, factor analysis, principal component analysis and statistical discrimination analysis on 19 parameter data. Qualified at 14 different stations in the Fittsoy Reservoir Basin from 2005 to 2010, Assessing and interpreting the temporal-spatial pattern, surface water quality is essential for the assessment, reconstruction, and conservation of potable water resources (Chow et al., 2016). WQI and PCA used techniques, considering that none of the chemical physical parameters alone are sufficient to provide a complete picture of river water quality. The PCA results indicated the importance of specific environmental parameters for water quality (Mostafaei, 2014). Multivariate statistical techniques used to evaluate water quality parameters were calculated (Vieira et al., 2012; Wang et al., 2013; Zhao et al., 2011). Multivariate methods were applied to determine the spatial and temporal variations of variables and to investigate the impact of natural and anthropogenic factors on water quality (Al-Mutairi et al., 2014; Phung et al., 2015; Voza et al., 2015; Monica and Choi, 2016; Basatnia et al., 2018; Wu et al., 2018; Sahoo and Patra, 2019; Sun et al., 2019).

The results of previous studies reviewed above showed that multivariate statistical methods are useful to evaluate water quality parameters. These methods have been applied for assessing the water quality of rivers, investigating temporal and spatial variations and determining caused by natural or anthropogenic processes. But so far, no comprehensive study has been carried out at different basin levels in terms of different land use conditions, the purpose of this study was to evaluate surface water quality in three different climatic regions of Iran using multivariate statistical methods and GIS. That this study led to the determination of the most important parameters of river water quality in different basins and their comparison, determining the similarities and differences between sampling stations, evaluation of the contribution of qualitative parameters in temporal and spatial variations of surface water quality.

2. Materials and Methods

2.1. Study area

The study was conducted in nine rivers in three different areas of Iran (Figure 1a). The Zayanderood River basin covers an area of 26,917 km^2 has been located between latitudes 31° 15′ and 33° 45′ north and longitudes 50° 02′ and 53° 20′ east in west-central Iran (Rezaei et al., 2013). Another river in the southwest is Karun River. Karun River is the longest river in Iran (Fooladvand et al., 2011). The Karun River basin, with a basin area of 67,000 km^2, is located in the southern part of Iran between longitudes 48°15′ and 52°30′ east, latitude 30°17′and 33°49′ north. (Naddafi et al., 2007). The third river in the south is the Jarahi River. Jarahi River is originated from the Zagros Mountains 2300 meters height by branches as Saqaveh, Lurab, Shour, Charou and Saaq that the basin of the mentioned river is in Khuzestan and Kohgiluyeh and Boyer Ahmad and with an area of approximately 2,750 Km^2 is measured at Idanak hydrometric station (Nohani, 2015). Rivers of Gorganrood, Atrak, Nekarood, and part of Qara Su are located in the north of Iran. The Gorganrood river basin is located in the north-east of Iran and lies between the latitudes of 36° 30′ and 37° 50′ N and the longitudes of 54° 5′ and 56° 30′ E. The total area is 11,888.15 km^2 (Rahmati et al., 2016). The Atrak River Basin is located in the northeast of Iran with an area of about 27,480 km^2 which is part of the Caspian Sea basin (Teymouri and Fathzadeh, 2015). The Nekarood River is derived as a form of small but numerous branches from the southern highlands of Mazandaran province. The area of the Nekarood river basin is about 900 km^2 (Aazami, 2017). The part of Qara Su River Basin in Golestan Province, northern Iran, which is located approximately between 54°02′E and 54°44′E and between 36°37′N and 37°00′N. The river basin covers approximately 1615.28 Km^2, located in the northern slopes of the Alborz Mountains and is close to the southeastern coast of the Caspian Sea (Mehri et al., 2018). Aji Chay, Aharchay and part of Qara Su rivers are in the northwest of Iran. The Aji Chay River 37_240–38_370N, 45_300–47_450E is situated at East Azerbaijan province and east of Urmia Lake, northwest of Iran (Barzegar et al., 2016). The study area of the Aharchay basin is located in the northwest of Iran and is bounded by the latitudes 38.217355 and 38.743466dd N and the longitudes 46.337642 and 47.685697dd E. This river crosses Ahar and Varzeghan cities on its way and finally joins Qara Su River and makes the valley (Ashouri et al., 2015). Qara Su catchment has an area of 14161 Km^2 and it's located in the longitude of 20' 46° to 41' 48° and latitude of 47' 39º to 17' 37º north and comprises 21% of the area of Ardabil and Eastern Azerbaijan province and it is considered to be a part of Aras catchment area and Caspian Sea (Atayi, 2017). Land use map of the basins shown in figure 1b.

2.2. Data collections and analytical methods

The database selected 50 monitoring sites and geographic details about the sampling sites are presented in Table 1. Table 1 summarizes the descriptive statistics for 10 parameters at 50 sampling stations in 9 rivers. 3377 water quality data from 22 hydrometric stations in the north of Iran including Gorganrood, Atrak, Nekarood and part of Qara Su rivers, 1389 water quality data samples from 10 hydrometric stations in northwest Iran including Aji Chay, Aharchai and part of Qara Su rivers. 2846 samples of water quality data were collected from 18 hydrometric stations in the southwest of Iran, including Zayanderood, Karun, and Jarahi rivers.

The locations of the 50 monitoring sites are shown in Fig. 1. The dataset used in this study includes 10 water quality parameters in the statistical period of 1999-2015. These parameters are Chloride (Cl), Sulfate (SO_4), Calcium (Ca), Magnesium (Mg), Electrical Conductivity (EC), Bicarbonate (HCO_3), Total Dissolved Solids (TDS), pH, Sodium Adsorption Ratio (SAR) and Sodium (Na).

The frequency of the data was 3377 water quality data samples from 22 hydrometric stations in north of Iran including Gorganrood, Atrak, Nekarood and part of Qara Su rivers and 1389 water quality data samples from 10 hydrometric stations in northwestern Iran including Aji Chay, Aharchay and part of Qara Su rivers, A total of 2846 water quality data samples were collected from 18 hydrometric stations in southwestern Iran including Zayanderood, Karun and Jarahi rivers. The general specifications of the stations are shown in Table 1. Descriptive statistics (minimum, maximum and average) of the water quality parameters were calculated for the monitoring site in Table 2 (a and b).

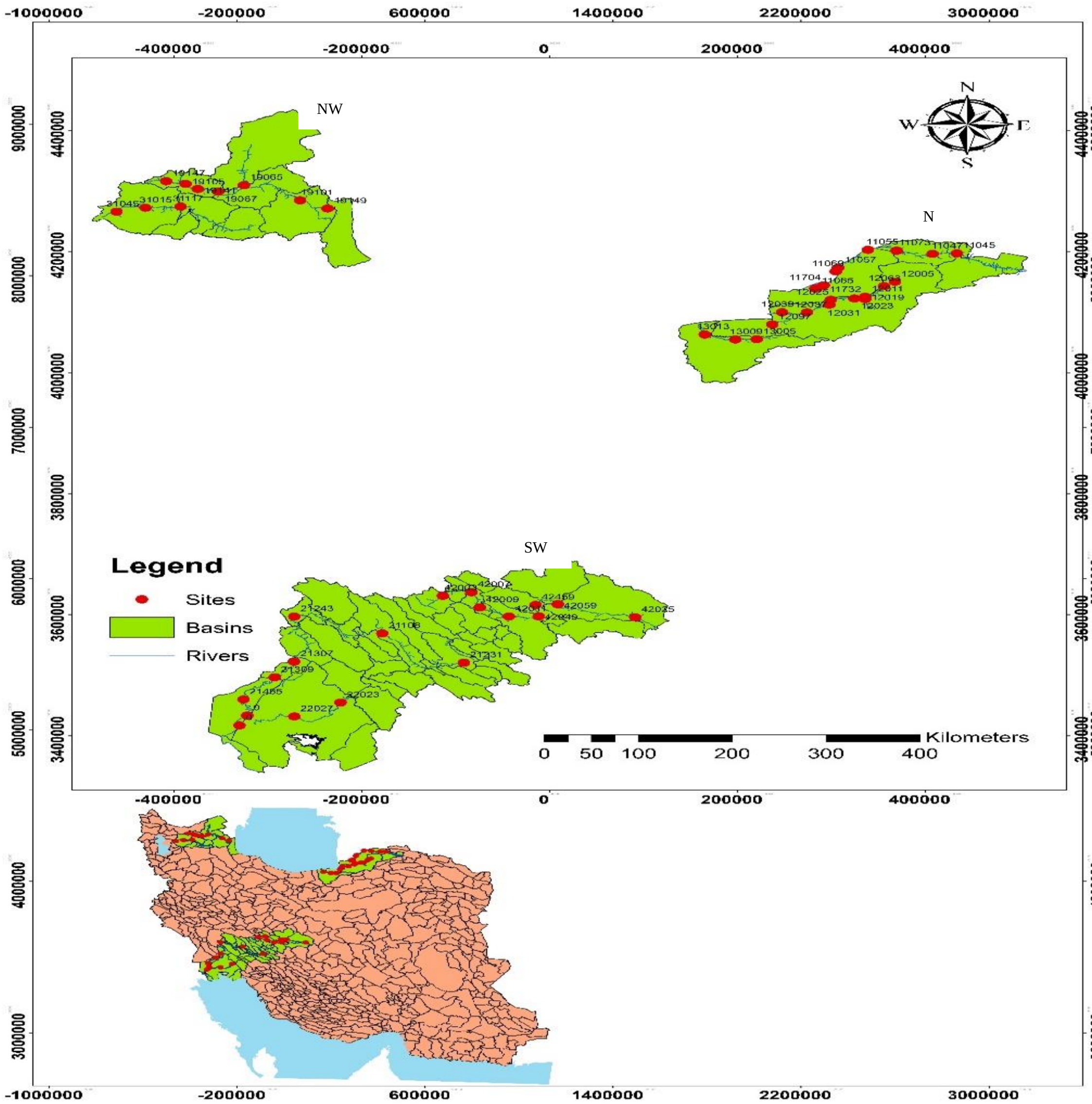


Fig. 1a. The location of case studies.

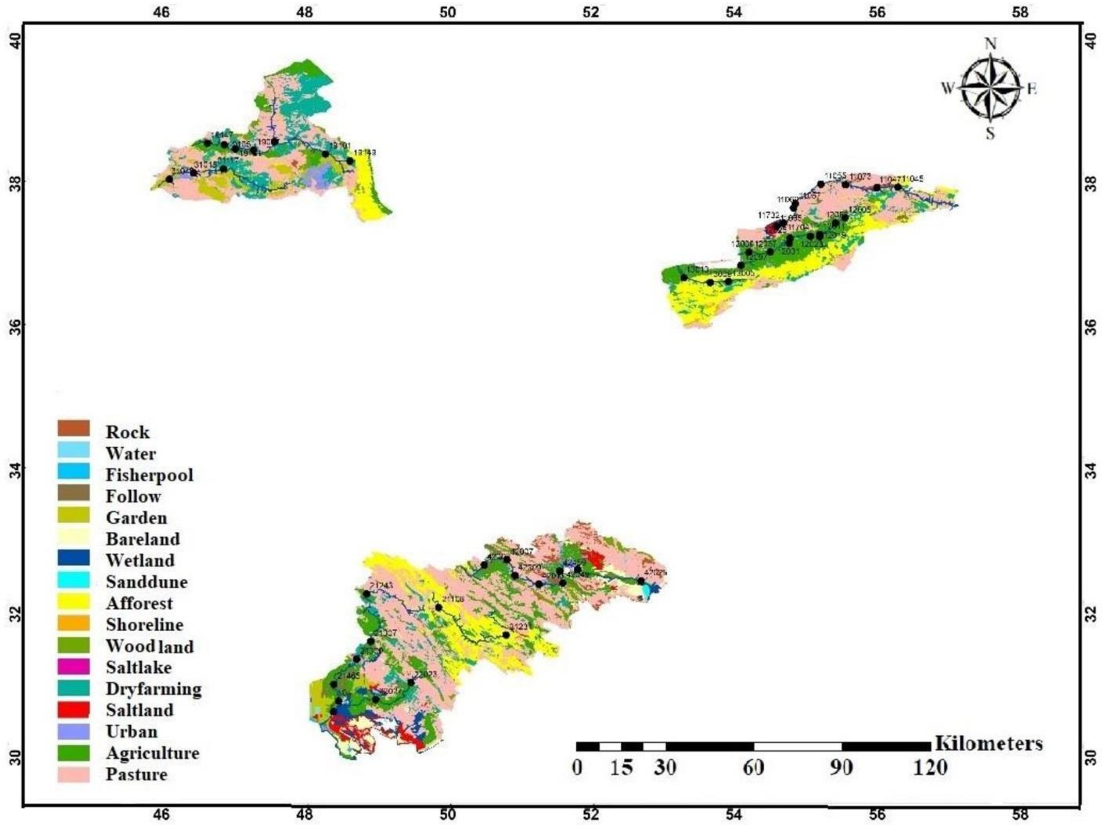


Fig. 2b. Land use of case studies

Table 1- General specifications of river sites

Code of Station	River	Longitude (Geographic)	Latitude (Geographic)
11732	Atrak	54.64	37.41
11704	Atrak	54.65	37.42
11065	Atrak	54.55	37.37
11069	Atrak	54.79	37.63
11057	Atrak	54.81	37.69
11055	Atrak	55.17	37.98
11073	Atrak	55.52	37.95
11047	Atrak	55.95	37.91
11045	Atrak	56.25	37.92
19147	Aharchay	46.6	38.53
19067	Aharchay	47.24	38.43
19141	Aharchay	46.99	38.45
19105	Aharchay	46.84	38.51
31045	Aji Chay	46.06	38.03
31015	Aji Chay	46.41	38.13
31117	Aji Chay	46.82	38.17
22027	Jarahi	48.95	30.77
22023	Jarahi	49.43	31.00
42025	Zayanderood	52.65	32.42
42059	Zayanderood	51.77	32.58
42459	Zayanderood	51.52	32.57
42049	Zayanderood	51.57	32.38
42011	Zayanderood	51.23	32.38
42003	Zayanderood	50.47	32.65
42009	Zayanderood	50.89	32.50
42007	Zayanderood	50.78	32.72
12097	Qara Su	54.05	36.83
12031	Qara Su	54.73	37.14
12019	Qara Su	55.15	37.23
19101	Qara Su	48.25	38.55
19065	Qara Su	47.54	38.38
19149	Qara Su	48.59	38.28
21311	Karun	48.43	30.75
21313	Karun	48.36	30.60
21465	Karun	48.37	30.98

Table 1- (Continued)

Code of Station	River	Longitude (Geographic)	Latitude (Geographic)
21309	Karun	48.68	31.33
21307	Karun	48.88	31.58
21243	Karun	48.82	32.25
21108	Karun	49.83	32.06
21231	Karun	50.77	31.67
12039	Gorganrood	54.16	37.01
12037	Gorganrood	54.46	37.01
12025	Gorganrood	54.74	37.21
12023	Gorganrood	55.02	37.23
12011	Gorganrood	55.15	37.26
12063	Gorganrood	55.37	37.42
12005	Gorganrood	55.51	37.49
13013	Nekarood	53.25	36.65
13009	Nekarood	53.62	36.59
13005	Nekarood	53.88	36.62

Table 2a- Statistical descriptive (minimum, maximum and average) of the water quality parameters (SC: Station Code, Ave: Average, Max: Maximum and Min: Minimum)

SC	SAR			Na (meq/l)			Mg (meq/l)			Ca (meq/l)			So_4 (meq/l)		
	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min
11045	3.69	7.826	0.909	9.84	28	1.7	8.39	18	2.5	5.74	16	2.1	13.46	29.26	3.4
11047	3.8	9.06	1.271	10.38	34.5	2.8	8.51	18	2.5	6.11	19	2.3	14.25	37.44	1.9
11055	8.52	27.777	2.63	37.04	206	5.64	15.93	80	3.5	13.24	50	2.9	25.78	91.5	5.82
11057	6.05	24.299	2.419	21.54	163	3.9	10.28	50	1.8	10.21	120	2.5	18.47	87.36	2.35
11065	15.96	75.011	2.848	118.67	1104	8.12	**38.03**	**320**	5.1	**27.79**	200	4	**36.74**	153.9	8.32
11069	5.26	20.847	0.038	17.27	136.7	0.1	9.32	48	1.5	9.16	50	2.4	17.22	74.88	0.71
11073	7.36	35.403	1.833	34.05	250	3.33	13.99	80	2.7	11.63	66	2.7	26.51	158.08	4.8
11704	9.67	44.113	3.419	42.72	600	10.92	19.99	280	4.1	13.35	90	5.2	**35.64**	**457**	14.35
11732	8.76	41.378	2.309	39.15	424	8.7	17.8	150	4.4	13.36	100	4.6	32.49	219.5	11.64
12005	4.18	18.516	0.827	10.56	120	1.32	5.78	60	1.5	3.9	24	1.45	6.53	70.7	0.94
12011	6.64	26.088	0.575	23.14	175	0.89	11.63	50	1.1	7.6	40	1.8	15.15	74.88	0.96
12019	3.35	11.19	0.204	7.25	48	0.25	4.13	24	0.7	3.56	12.8	1.6	4.04	33.28	0.31
12023	5.06	18.112	0.47	14.21	81	0.63	7.01	32.5	1.5	5.24	23	1.4	8.93	47.9	0.81
12025	5.8	19.317	0.733	17.61	117.5	1.27	9.33	57	2	6.37	33	2.3	12.3	83.2	1.87
12031	10.51	26.062	0.155	52.4	156	0.6	**26.62**	76	2	14.69	66	2.5	**44.32**	139	1.5
12037	9.18	22.114	0.26	40.63	142	0.39	20.63	100	2.2	11.67	38	1.8	32.81	145.6	1.53
12039	8.03	27.835	0.286	32.83	217.4	0.42	16.42	88	1.9	9.32	36	1.9	24.61	104	1.58
12063	8.22	40.566	1.265	37.88	420.6	2.04	18.24	140	2	12.65	75	1.5	24.01	113.15	1.05
12097	2.83	16.586	0.191	7.08	119.6	0.29	5.17	74	1.1	4.61	30	1.9	5.01	25.79	0.37
13005	0.74	2.194	0.135	1.19	3.8	0.2	2.03	3.4	0.8	3.28	5.8	0.7	1.08	3.80	0.1
13009	0.41	1.416	0.065	0.58	2.1	0.1	1.55	3.1	0.6	2.49	4.5	1	0.48	2.2	0.1
13013	0.41	1.556	0.08	0.56	2.2	0.1	1.49	2.7	0.4	2.27	6.2	0.6	0.43	2.1	0.1
19065	3.82	9.76	0.678	6.35	18.9	0.83	2.18	7	0.3	3.63	10.1	1	5.24	19.4	0.2
19067	2.51	4.29	0.785	4.9	7.22	1.36	2.72	6	1.01	4.94	8.8	1.7	4.66	8.5	0.83
19101	3.73	8.891	0.132	6.72	15.4	0.2	2.48	5.1	0.4	3.91	9.6	0.8	5.3	11.4	0.1
19105	1.79	4.386	0.497	2.33	5.22	0.5	1.12	2.2	0.24	2.21	3.4	0.56	0.61	2.3	0.02
19141	2.81	4.704	0.905	4.57	8.8	1.2	2.53	4.4	0.6	2.7	4.6	1.34	3.03	8.54	0.05
19147	1.32	3.385	0.278	1.65	4.2	0.34	0.94	2.7	0.3	2.13	4	0.3	0.32	5.42	0.01
19149	0.53	5.226	**0**	0.43	6.4	**0**	0.41	1.2	**0.1**	0.77	2.5	**0.2**	0.24	4.6	**0**
21108	1.9	4.333	0.253	2.78	6.74	0.38	1.39	3.91	0.25	2.84	6.5	1.2	0.94	4.69	0.03
21231	1.43	2.838	0.121	2.08	4.03	0.21	1.61	4.3	0.6	2.65	4.2	1.3	0.71	1.9	0.1
21243	3.72	11.215	0.963	6.37	21.44	1.66	1.53	6.18	0.35	4.16	9.69	1.58	2.73	10.3	0.03
21307	4.79	9.633	1.538	10.26	22.24	2.21	3.26	7.18	0.81	5.8	29.14	2.3	6.04	19.14	1.2
21309	4.91	9.231	1.786	10.87	23.8	2.83	3.47	6.5	0.64	5.98	15.6	2.6	6.51	15.51	1.3

Table 2a- (Continued)

SC	SAR			Na (meq/l)			Mg (meq/l)			Ca (meq/l)			So_4 (meq/l)		
	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min
21311	6.21	13.411	2.095	14.83	38.25	3.54	4.34	9.83	1.03	6.53	15.65	3.2	7.65	16.23	0.09
21313	6.53	13.819	2.02	16.11	40.9	3.12	4.77	9.58	0.27	6.7	15.4	2.68	8.22	17.2	1.57
21465	4.99	10.068	1.883	11.17	25.04	3.02	3.63	7.77	0.34	6.09	17.4	2.74	6.81	18.3	1.58
22023	4.39	11.514	0.802	12.36	35.8	1.27	4.01	12.85	0.65	11.95	26.16	2.4	13.64	29.11	2.02
22027	6.46	16.26	1.034	20.88	74.9	3.22	6.45	33.55	1.1	13.2	23.42	4.42	17.05	58.22	5.53
31015	**49.7**	121.326	0.679	**266.09**	1193.9	1.56	17.23	160	0.38	**28.24**	**1250**	1.38	26.28	11.4	1.1
31045	15.86	71.487	4.103	40.78	178	8.8	5.1	11.6	1.4	7.37	26	2	6.17	74.45	0.3
31117	**46.54**	**350.526**	4.234	**257.96**	**3500**	6.7	11.87	70.4	1.12	21.05	129	3.2	19.99	146	1.72
42003	0.35	1.989	0.056	0.45	3.8	0.1	0.8	2.5	0.2	2.44	5.2	1	0.46	3.2	0.01
42007	0.29	4.583	0.068	0.36	7.1	0.1	0.72	2.1	0.1	2.33	3	1.4	0.45	2.3	0.01
42009	0.32	1.997	0.072	0.4	3.4	0.1	0.76	1.9	0.1	2.39	3.9	1.2	0.56	3.33	0.01
42011	0.63	4.819	0.071	0.86	6.9	0.1	0.88	2.1	0.3	2.65	4	1.5	1.06	7.1	0.01
42025	**27.2**	123.443	0.636	**164.92**	800	0.9	**36.19**	140	1.8	**29.77**	112	2.2	25.98	156.4	0.5
42049	1.73	4.734	0.064	3.03	11	0.1	1.42	4.9	0.3	3.88	8.6	1.3	2.74	8.74	0.11
42059	1.94	4.111	0.221	3.28	7	0.3	1.74	4.2	0.3	3.66	5.7	1.7	2.47	5.9	0.1
42459	1.4	4.102	0.065	2.22	8.1	0.1	1.29	3.1	**0.1**	3.33	6.8	1.3	2.17	7.7	0.11

Table 2b-Statistical descriptive (minimum, maximum and average) of the water quality parameters (SC: Station Code, Ave: Average, Max: Maximum and Min: Minimum)

SC	Cl (meq/l)			Hco_3 (meq/l)			pH			EC (µS/cm)			TDS (µS/cm)		
	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min
11045	6.22	21	0.9	4.4	6.9	2.55	7.83	8.51	6.9	2265.54	5375	831	1402.79	2956	522
11047	6.51	29	1.5	4.36	6.8	2.6	7.82	8.44	6.9	2364.46	5960	936	1460.42	3511	579
11055	36.81	235	3.3	3.82	6.6	2	8.02	6.4	6.7	6163.54	29700	1326	3813.86	17800	853
11057	19.01	170	3.1	3.77	6.2	1.6	7.76	8.44	6.9	3860.14	22000	921	2392.07	14731	607
11065	145.39	1490	5.9	2.95	4.5	1.7	7.52	8.72	**4.63**	16589.97	141800	1912	10254.31	85050	1063
11069	14.85	146	0.7	3.76	6.3	1.4	7.68	8.24	6.9	3387.42	20280	638	2094.27	11892	401
11073	29.42	243	1.2	3.9	6.4	2.1	7.8	8.43	6.83	5505.67	31985	930	3408.41	19800	598
11704	37.25	510	9.6	3.71	9.6	1.7	7.62	8.58	6.61	7004.52	69400	2610	4340.01	38170	1551
11732	34.96	600	6.8	3.14	6.1	1.1	7.65	8.92	6.6	6562.7	59500	2119	4047.58	35700	1300
12005	9.34	130	1	4.42	6.5	2.4	7.87	8.42	6.9	1945.95	17960	558	1211.79	10586	356
12011	21.67	185	1	**5.61**	10.2	3	7.73	9.47	6.7	3982.35	24100	458	2468.21	14164	297
12019	6.35	47.2	0.3	4.62	10.8	**0.1**	7.75	8.86	6.6	1428.29	8010	301	895.17	4966	187
12023	12.84	78.7	0.6	4.81	8.7	2.6	7.77	8.34	6.8	2517.37	12100	410	1565.67	7058	260
12025	16.64	108	1.1	4.45	7	2.1	7.72	8.79	6.9	3125.25	16485	722	1951.9	10320	455
12031	43.89	134	2.1	**5.64**	9.4	2.7	7.8	8.65	6.7	8701.63	24215	698	5453.82	16247	449
12037	34.97	120	0.7	5	7.6	3	7.74	8.32	7.8	6827.53	25700	457	4249.62	16705	289
12039	29.38	230	0.6	4.75	9.9	2.6	7.75	8.36	6.8	5472.14	29550	450	3400.89	20655	286
12063	40.72	520	1.4	4.07	5.9	2.4	7.79	8.78	6.8	6368.92	57300	655	3953.07	32451	415
12097	7.04	1.94	0.4	4.94	7.7	1.9	7.65	8.41	6.5	1610.22	20700	332	1011.36	12627	215
13005	0.98	2.4	0.2	4.33	6.3	1	8.03	10.3	7.5	662.29	980	253	430.5	658	153
13009	0.51	1.5	0.1	3.51	5.1	1.1	**8.06**	9.3	7.4	475.73	708	229	306.02	467	144
13013	0.49	2	0.2	3.29	8.2	1.2	**8.07**	9.5	7.5	443.67	939	218	288.76	679	137
19065	2.83	11.8	0.1	4.22	8	1.3	7.69	8.6	6.3	1217.02	2940	140	821.34	1742	185
19067	2.6	7.5	0.68	**5.32**	7.4	1.25	7.92	9.2	7.1	1269.14	2120	513	825.12	1398	308
19101	3.95	9	0.3	4.07	7.3	0.2	7.55	8.21	6.57	1335.71	2270	272	919.48	1589	166
19105	0.77	2.12	0.21	4.24	6.95	0.9	7.97	8.7	6.7	576.4	943	177	371.71	625	116
19141	1.88	4.5	0.5	4.91	7.06	1.9	7.99	8.65	7.1	989.92	1580	367	638.2	1063	235

Table 2b- (Continued)

SC	Cl (meq/l)			Hco3 (meq/l)			pH			EC (µS/cm)			TDS (µS/cm)		
	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min
19147	0.59	4.3	0.14	3.79	6.65	0.8	**8.11**	9.4	7.11	483.97	1200	156	309	793	107
19149	0.36	2.9	**0.1**	1.09	4	0.3	7.6	8.77	6	171.23	952	**64**	111.73	666	**42**
21108	3	6.7	0.86	2.94	4	1.42	7.94	8.6	7	741	1184	379	426.47	805	228
21231	2.48	4.2	0.3	3.13	6	1.1	7.97	8.4	7.68	633.84	900	397	413.35	642	251
21243	6.58	19.79	1.75	2.66	4.58	1.2	7.92	8.7	7	1198.78	2700	515	764.01	1730	333
21307	10.05	22.1	2.2	3.18	**33.9**	0.58	7.85	8.7	6.9	1884.87	3670	600	1204.3	2125	384
21309	10.54	24.5	2.9	3.13	4.39	0.64	7.82	8.7	6.7	1980.67	3570	763	1255.04	2271	458
21311	14.66	36.81	3.2	3.13	4.32	1.73	7.77	8.6	6.9	2492.4	4891	752	1591	2990	482
21313	16.07	39.37	3.23	3.24	5.6	1.02	7.68	8.6	6.5	2683.46	5228	735	1715.11	3342	472
21465	10.81	26.8	3.15	3.14	4.51	1.18	7.82	8.8	6.01	2034.2	3980	752	1293.48	2473	461
22023	12.1	30.96	1.37	2.48	5.24	1.02	7.74	8.3	6.5	2659.67	5984	480	1791.34	3830	307
22027	20.89	76.65	2.81	2.45	4.62	0.35	7.72	8.5	7	3949.23	29100	1616	2474.62	6918	1035
31015	**282.49**	1250	1.38	3.27	11.4	1.1	7.75	8.7	6.88	**29988.65**	148000	964	**19328.42**	96251	627
31045	42.35	146	9.87	**5.48**	11.5	2.85	7.71	8.9	6.59	5366.52	21000	1720	3465.99	13750	1118
31117	**269.05**	**3600**	5.45	2.99	5.2	0.88	7.86	8.6	6.9	**23328.58**	**207000**	1179	**15084.92**	**134550**	766.35
42003	0.58	3.5	0.1	2.71	6.4	1.1	7.75	8.8	6	351.64	1045	211	226.41	732	137
42007	0.46	7.6	0.1	2.56	3.7	0.27	7.78	8.5	6.9	322.64	1229	242	207.3	798.9	128
42009	0.46	1.3	0.2	2.58	4.6	1	7.86	8.6	6.7	335.78	918	218	218.15	597	141.7
42011	0.62	3.8	0.2	2.79	4.2	1.7	7.84	8.6	6.8	419.07	1219	252	272.55	792	164
42025	**202.01**	725	0.7	3.57	6.3	1.5	7.64	8.5	6.8	**21788.04**	80500	459	**15050.12**	56350	298
42049	2.48	8.4	0.6	3.2	5.2	1.2	7.82	8.9	6.8	808.3	2010	378	534.65	1407	245.7
42059	2.5	5.8	0.3	3.99	8.6	1.4	7.65	**10.3**	6.6	893.51	1550	364	588.16	1085	236.6
42459	1.82	5.9	0.5	2.96	5.3	0.7	7.85	9.1	6.9	669.07	1574	363	444.42	1083	236

2.3. Statistical analyses

Multivariate analysis of the water quality dataset of nine rivers was performed using hierarchical cluster analysis (CA) and principal component analysis (PCA). CA and PCA were used to appraise the temporal and spatial patterns of water quality dataset. Cluster analysis is utilized to classify the objects of the system into categories or clusters based on their nearness or similarity (as mentioned by Vega et al., 1998). The similarity between two samples is usually measured by Euclidean distance which can be demonstrated by the difference between analytical values derived from the samples (as mentioned by Otto, 1998). In this study, the hierarchical Ward method was used for clustering. This method was performed to gather objects into groups based on independent variables. These clusters represent homogeneity within the clusters and heterogeneity between the clusters (McKenna, 2003). The dendrogram obtained from the CA helps to explain the patterns in the set of observations. Principal component analysis (PCA) is one of the multivariate statistical techniques. The main purpose is to reduce the lower-dimensional linear structure from the data sets (as mentioned by Helena et al. 2000). PCA is a technique that identifies pattern, this method tries to illustrate the variance of a large set of correlated variables by converting them into a smaller set of independent variables (as mentioned by Simeonov et al., 2003; Singh et al., 2005). Before the multivariate statistical analysis Kaiser–Meyer–Olkin (KMO) statistics, and Bartlett's test were applied to evaluate and treat the dataset used in this study The KMO statistics and Bartlett's test were calculated to investigate the suitability of the dataset for PCA.

3. Results and Discussion

3.1. Principal Component Analysis

The KMO statistics and Bartlett's test were calculated to examine the dataset's suitability for PCA. KMO value must be more than 0.5; otherwise, the data set would not be appropriate for the PCA. In this study, the KMO statistics results for the north, northwest, and southwest were 0.66, 0.71 and

0.65, respectively. The significant results of this study also represent that there were significant relationships among the water quality parameters. The correlation matrix was computed in order to recognize the relationship of different water quality parameters in the three studied areas. The correlation matrix of the water quality parameters in the three studied areas obtained from the PCA is shown in Tables 3, 4 and 5. The correlation coefficient of 0.5–0.75 is considered a moderate correlation between two variables (Montgomery and Runger, 1999). In the three areas, the lowest correlation is observed for pH and Hco_3 parameters. The highest correlation coefficient in the north area is between SAR and TDS (0.912), SAR and EC (0.912), Na and EC (0.992), EC and Mg (0.967), Ca and EC (0.957), So_4 and EC (0.723), Cl and EC (0.977) and TDS and EC (0.977). The highest Correlation coefficient in the northwest area is between Na and SAR (0.952), Na and Cl (0.998), Mg and So_4, (0.902), Ca and TDS (0.921), So_4 and EC (0.578), Cl and TDS (0.942), TDS and EC (0.974). The highest Correlation coefficient between water quality parameters in southwest area are Na and SAR (0.955), Na and Cl (0.990), Mg and EC (0.920), Ca and EC (0.873), So_4 and EC (0.621), So_4 and TDS (0.621), Cl and EC (0.988), TDS and EC (0.985). Also, except for pH and Hco3, other parameters had a positive correlation. The results in the first stage of PCA indicate that there is a high correlation between most of the parameters. This confirms the suitability of the data available for PCA entry to determine the most important water quality parameters.

In order to determine the most important parameters affecting surface water quality, the Varimax method was used among the ten parameters studied in three study areas. The basis for selecting agents is more than one eigenvalue to determine the most important parameters affecting surface water quality. The results of this analysis are shown in Table 6. Parameters that have the most factor loading (positive or negative) are the best representative for describing that component.

Table 3- Correlation coefficients between water quality input parameters in the northern

	SAR	Na	Mg	Ca	So_4	Cl	Hco_3	pH	EC	TDS
SAR	1									
Na	0.900	1								
Mg	0.865	0.946	1							
Ca	0.856	0.932	0.923	1						
So_4	0.802	0.683	0.777	0.731	1					
Cl	0.0840	0.986	0.927	0.924	0.570	1				
Hco_3	**0.027**	**-0.028**	**0.041**	**-0.030**	**0.061**	**-0.048**	1			
pH	**-0.086**	**-0.061**	**-0.058**	**-0.072**	**-0.065**	**-0.055**	**-0.010**	1		
EC	**0.912**	**0.992**	**0.967**	**0.957**	**0.723**	**0.977**	**-0.016**	**-0.065**	1	
TDS	**0.912**	0.987	0.964	0.956	0.720	0.973	**-0.017**	**-0.067**	**0.997**	1

Table 4- Correlation coefficients between water quality input parameters in the northwest

	SAR	Na	Mg	Ca	So_4	Cl	Hco_3	pH	EC	TDS
SAR	1									
Na	**0.952**	1								
Mg	0.492	0.509	1							
Ca	0.828	0.829	0.741	1						
So_4	0.500	0.503	**0.902**	0.707	1					
Cl	0.951	**0.998**	0.500	0.835	0.476	1				
Hco_3	**-0.100**	**-0.119**	**0.284**	**0.034**	**0.250**	**-0.130**	1			
pH	**-0.062**	**-0.070**	**-0.028**	**-0.073**	**-0.025**	**-0.071**	**0.016**	1		
EC	0.920	0.930	0.607	0.916	**0.578**	0.935	**-0.080**	**-0.079**	1	
TDS	0.933	0.937	0.606	**0.921**	0.570	**0.942**	**-0.086**	**-0.080**	**0.974**	1

Table 5. Correlation coefficients between water quality input parameters in the southwest

	SAR	Na	Mg	Ca	So_4	Cl	Hco_3	pH	EC	TDS
SAR	1									
Na	**0.955**	1								
Mg	0.838	0.886	1							
Ca	0.802	0.833	0.821	1						
So_4	0.669	0.599	0.613	0.687	1					
Cl	0.930	**0.990**	0.912	0.852	0.533	1				
Hco_3	**0.095**	**0.061**	**0.072**	**0.018**	**-0.006**	**0.058**	1			
pH	**-0.184**	**-0.155**	**-0.162**	**-0.245**	**-0.222**	**-0.151**	**-0.200**	1		
EC	0.947	0.988	**0.920**	**0.873**	**0.621**	**0.988**	**0.063**	**-0.174**	1	
TDS	0.942	0.980	0.913	0.863	**0.621**	0.979	**0.066**	**-0.163**	**0.985**	1

According to the results of the study area, with a total of 79.86% of the total variance, there are two significant components. The first component, accounting for 57.57% of the total variance, includes SAR, Na, Ca, Cl, EC, and TDS as the most important parameters affecting surface water quality changes in the region, with Cl (0.968) having the highest factor load. (Table 6). The second component, accounting for 22.28 of the total variances, contains the parameters Mg, So4, and Hco3. Among the parameters studied, the pH parameter in the first two components (-0.107) and the second (0.042) is not an effective element in changes in surface water quality in the area. The results show that the rivers of the southwest region with 81.60% of total variance have two significant main components. The first component accounts for 69.21% of the total variance, including the parameters SAR, Na, Mg, Ca, So4, Cl, EC and TDS as the most important factors affecting surface water quality changes. The EC parameter (0.988) has the highest factor loading. The second component, accounting for 12.38% of the total variance, contains the parameter Hco3. The parameters of this component represent the ions and suspended substances in the rivers of the study area. Among the investigated parameters, the first and second components, respectively, Hco3 (-0.011) and pH (-0.756), are not effective elements in changes in surface water quality.

Includes Hco3 and pH parameters, which indicate the acidity of surface water. According to the results, the study area of the north, with 82.38% of the total variance, has two significant components. The first component, accounting for 72% of the total variance, includes SAR, Na, Mg, Ca, So4, Cl, EC, and TDS as the most important parameters affecting surface water quality changes. The EC parameter (0.995) has the highest factor load (Table 6).

Table 6- Factor loadings for each of the principal components with the normalized Varimax period, eigenvalues and percentages of variance in the North, Northwest, and Southwest

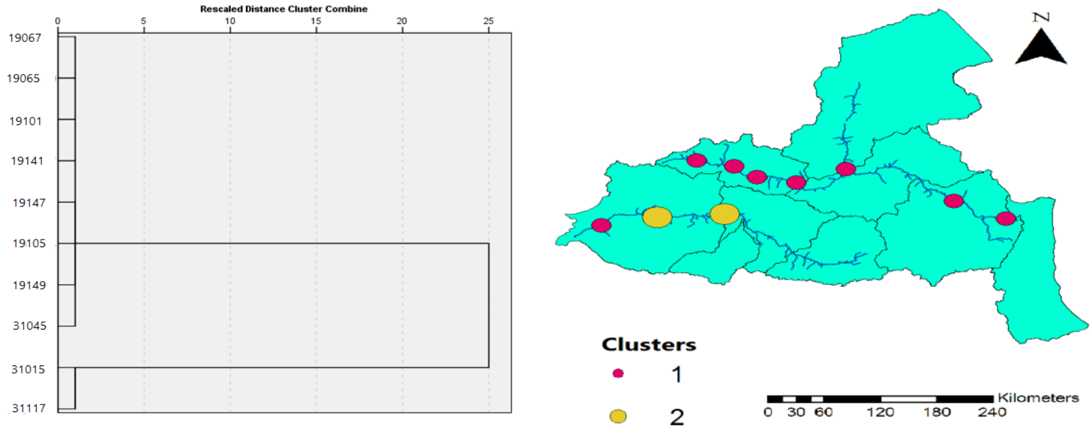
Parameter	North		Northwest		Southwest	
	Components		Components		Components	
	1	2	1	2	1	2
SAR	**0.930**	0.096	**0.949**	0.148	**0.950**	0.100
Na	**0.984**	-0.020	**0.963**	0.142	**0.977**	0.05٠
Mg	**0.970**	0.078	0.443	**0.819**	**0.929**	0.070
Ca	**0.962**	0.011	0.839	0.448	**0.899**	0.100
So_4	0.776	0.171	0.431	**0.802**	**0.694**	0.113
Cl	0.958	-0.042	0.968	0.123	**0.974**	0.042
Hco_3	-0.045	**0.900**	-0.312	**0.729**	-0.011	**0.785**
pH	-0.061	-0.426	-0.107	0.042	-0.143	**-0.756**
EC	**0.995**	0.017	**0.945**	0.251	**0.988**	0.065
TDS	**0.993**	0.017	**0.951**	0.243	**0.983**	0.060
Eigen value	7.20	1.04	5.76	2.23	6.92	1.24
% Total variance	**72.00**	10.39	**57.57**	22.28	**69.21**	12.38
Cumulative %	72.00	**82.38**	57.57	**79.86**	69.21	**81.60**

The parameters of this component represent the ions and suspended substances in the rivers of the study area. The second component, accounting for 10.39 of the total variances, contains the parameter Hco3. Among the investigated parameters, the pH parameter in the first two components (-0.061) and the second one (-0.426) is not an effective element in changes in surface water quality. In Prioritization (PCA) the principal components indicate the importance of each parameter in the contamination, it puts the most important parameters in the first component and the least important ones in the next component.

3.2. Cluster analysis

3.2.1. Northwest Basin

In this study, the cluster analysis method was applied to identify similar stations of temporal and spatial variations. CA in the northwest has generated a dendrogram into two clusters. Homogeneous clusters were determined based on the Ward method and Euclidean distance. The first cluster comprises eight stations in the Aharchay River, the upstream station of Aji Chay and part of the Qara Su River in this area, and the two stations downstream of the Aji Chay River are located in a separate cluster (Fig. 2-b). According to the cluster diagram, the stations in each cluster have similar water quality characteristics. The results show that upstream-downstream in the northwest, except for two downstream stations of the Aji Chay River, surface water quality variables have similar characteristics, and regarding the land use map (figure 1b), it clearly shows the impact of urban and its pollution on water quality.



a

b

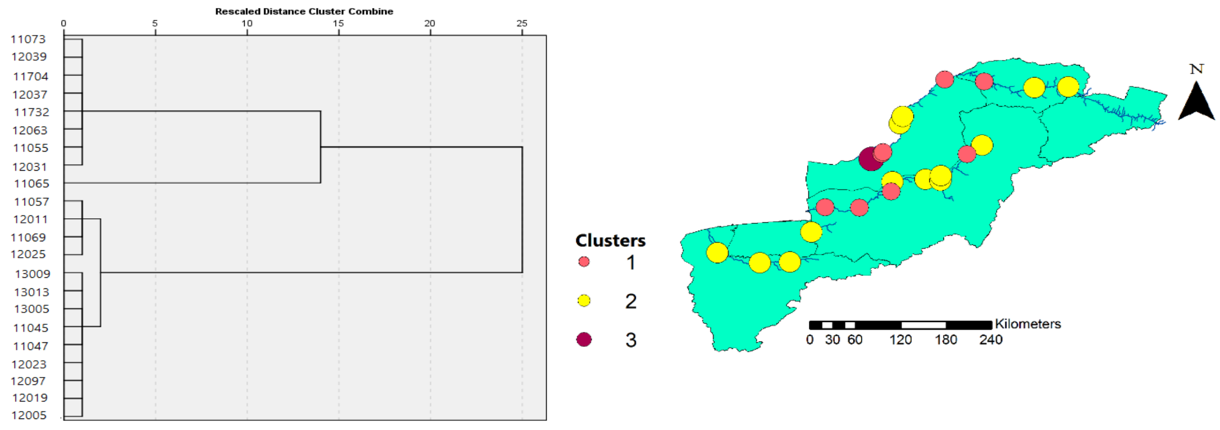
Fig. 2a. The dendrogram of clustering, b: Clusters from the northwestern region by the Ward method

3.2.2. North Basin

Based on Figure 3a, the hydrometric stations understudy in the northern area are divided into three homogeneous clusters. The results showed that the upstream rivers and the three stations in the Nekarood River have similar water quality characteristics. The middle and downstream stations of the Atrak and Gorganrood rivers, except for station No. 11065, have similar characteristics. Station number 11065 is located on the Atrak River in the third cluster, which has different water quality characteristics than other stations. This difference, according to the land use map (figure 1b), is due to the salinity of the area. Figure 3b shows the clusters of the Ward method.

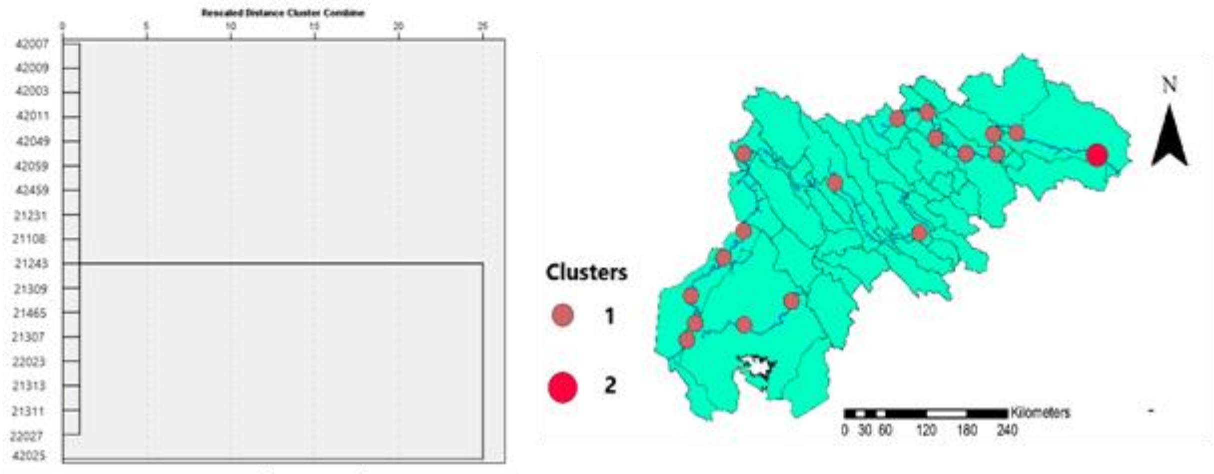
3.2.3. Southwest Basin

According to the dendrogram results of the southwest study area, two clusters were obtained (Fig. 6). The first cluster consisted of 17 stations with similar water quality characteristics and only one station with code 42025 was placed downstream of the Zayanderood River in the second cluster, so that the water quality characteristics of this station were inconsistent with the stations in the northwest. Due to being located at the outlet of the basin and upstream erosion is the most polluted.



a b

Fig. 3a. The dendrogram of clustering, b: Clusters from the northwestern region by the Ward method.



a b

Fig. 4a. The dendrogram of clustering, b: Clusters from the northwestern region by the Ward method.

3.3. Total study areas

In this study, clustering of all 50 stations in the mentioned study areas was performed simultaneously. Based on the results of the dendrogram of the total study area, the stations were divided into two clusters (Figure 5). The results showed that the clustering of the whole region was consistent with the clustering of individual regions critical stations, in this case, are also in the second cluster and have similarities (Fig. 6).

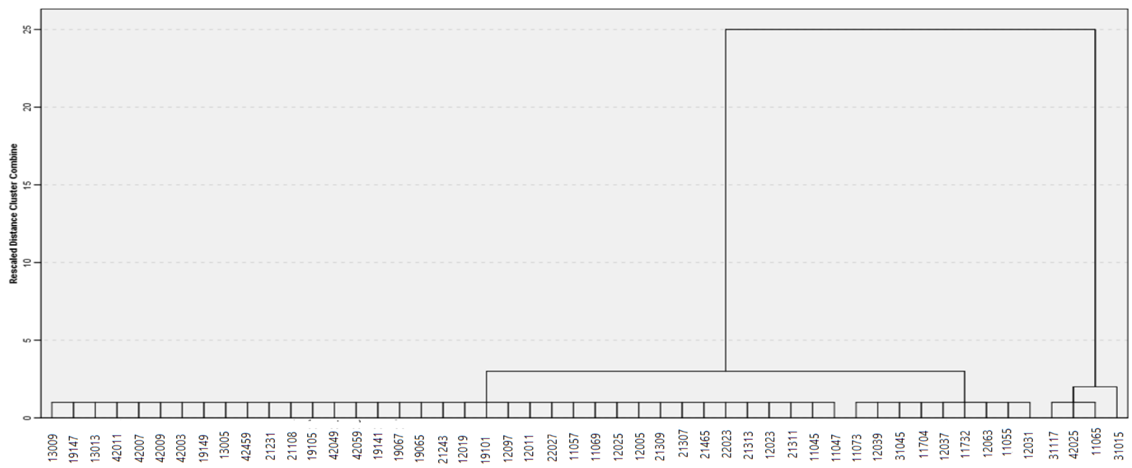


Fig. 5. Dendrograms for clustering the whole study area by Ward method

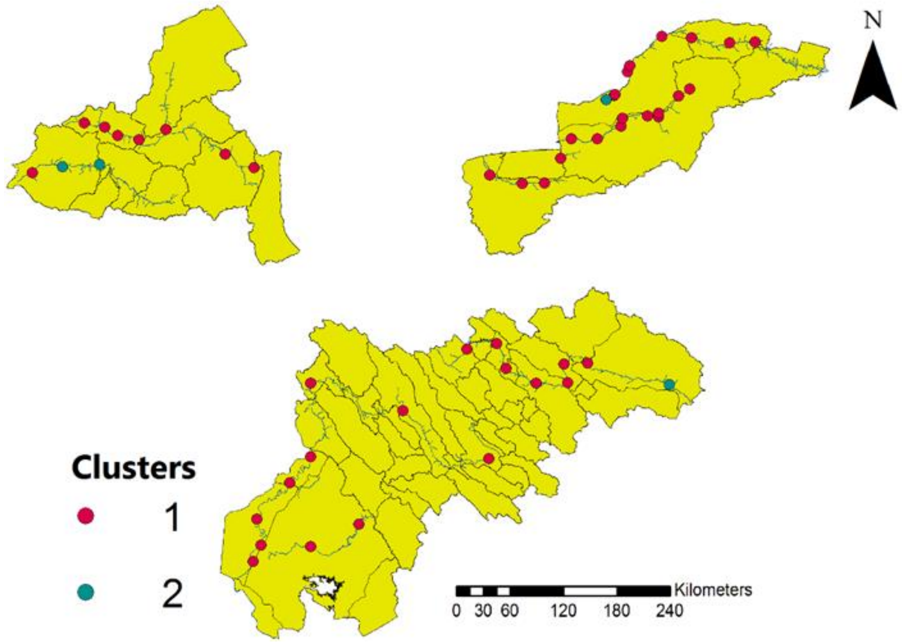


Fig. 6. Clusters from the entire study area of the Ward method

Cluster analysis is a good tool for classifying parameters and showing the relationship between them, it can be said that the parameters that are in a cluster are more dependent on each other.

3.4. Checking the parameters

The patterns of average water quality parameters are shown as a series of maps across north, northwest and southwest Iran basins. The pattern of 10 parameters is presented in figure 7 (SAR, Na, Mg and Ca) parameters are presented, in figure 8 (So_4, Cl, Hco_3 and pH) and in figure 9 (EC and TDS). Sodium Adsorption Ratio (SAR) is one of the determinants of water quality for agricultural purposes. SAR is used to detect soil water permeability problems. The average SAR variation in the 50 study stations ranged from 0.29 to 49.7, the lowest value belongs to the 42007 stations in the Zayanderood River in the southwest basin that located in upstream and the highest value related to the 31015 at downstream Aji Chai River Station in the northwest basin. For the Na parameter, lots of amounts of Na value in combination with chloride give the taste of water salinity. The variation of Na in the study stations is between 0.36 and 266.09, with the lowest Na value belongs to 42007 on the Zayanderood River in the southwest basin and the highest value at 31015 at the Ajay Chai River Station in the north basin. As per the classification in Figure 1, the stations 31015 and 31117 on the Aji Chay River have SAR and Na values of more than 46 and 164, respectively, with 4% of the stations being in the fifth category. Calcium and magnesium are essential nutrients and drinking water can be a good source of these nutrients. Magnesium is a common element in water that forms soluble salts in water. The lowest Mg value of 0.41 was for the 19149 stations of the Qara Su River in northwest basin and the highest was for the Atrak River at 38.03 at the 11065 stations in north basin. The results showed that the two stations 11065 and 42025 located on the Atrak and Zayanderood rivers, Mg value have more than 36. Therefore, 4% of the stations were in the fifth category (Figure 7.). Calcium is also found in most natural waters and depends on the type of rock that passes through it. The lowest Ca value was found at station 19149 at 0.77 in Gharre Soo River and the highest at station 42025 at 29.77 at Zayanderood River. As can be seen from the figure, the four stations 31117, 31015, 11065 and 42025 on the Aji Chay, Atrak and Zayanderood rivers have Ca values greater than 21, Therefore, 8% of the studied stations were in the fifth category.

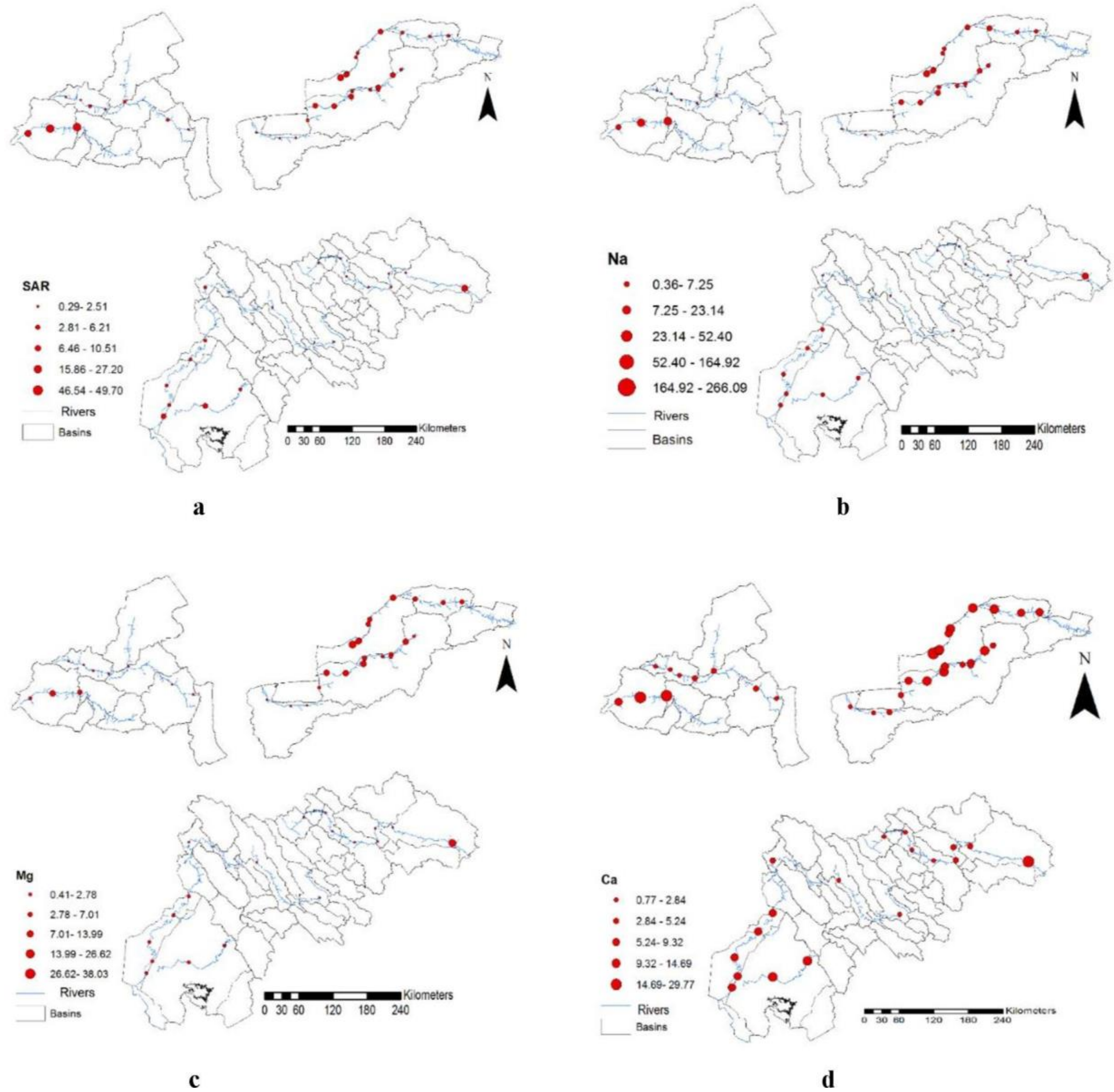


Fig. 7. Distribution map of the parameters a: SAR, b: Na, c: Mg and d: Ca in the study areas

The range of SO_4 variations in the 50 study stations ranged from 0.24 to 44.32, with the lowest and highest occurrences being in 19149 and 12031 Qara Su River, respectively. Also, stations 12063, 12039 and 12037 in Gorganrood and stations 11055, 11073, 11732, 11704 and 11065 in Atrak River and stations 42025, 31015 and 12031 in Zayanderood, Aji Chay, and Qara Su have SO4 content greater than 24%. The studied SO4 stations were classified in the fifth category. The lowest Cl value was 0.36 for station 19149 of Qara Su River in northwest basin and the highest value was for 282.49 at station 31015 of Aji Chay River. Cl will be toxic to plant growth if it is high in water. According to Figure 8, the four stations 11065 and 42025 in the Atrak, Zayanderood and 31117 and 31015 rivers on the Aji Chay River have Cl values greater than 145, with 8% of the stations being in the fifth category. The minimum Hco_3 value of 1.09 is for the 19149 stations at the Qara Su River and its maximum value at 12031 is 5.64 at the Qara Su River. According to the figure .8. 19141 and 19067 stations on the Aharchay River, 12097 and 12031 on the Qara Su River, 12037 and 12011 on the Gorganrood River, and 31045 on the Aji Chay River have Hco3 content exceeding 4.9 and 14% of the stations studied in the category Fifth category. There are relatively uniform pH values for all stations in three basins, with the average pH of the stations being between 7.52 and 8.11 that are shown in Table 2b. The minimum and maximum pH values for station 11065 are 7.52 in the Atrak River in the north basin and station 19147 are 8.11 in Aharchay River in the northwest. As can be seen from Figure 8, 11055 on the Atrak River, 19147 on the

Aharchay River, and the 13005, 13009 and 13013 on the Nekarood have a pH value greater than 8 and 10% of the studied stations were in the fifth category of map.

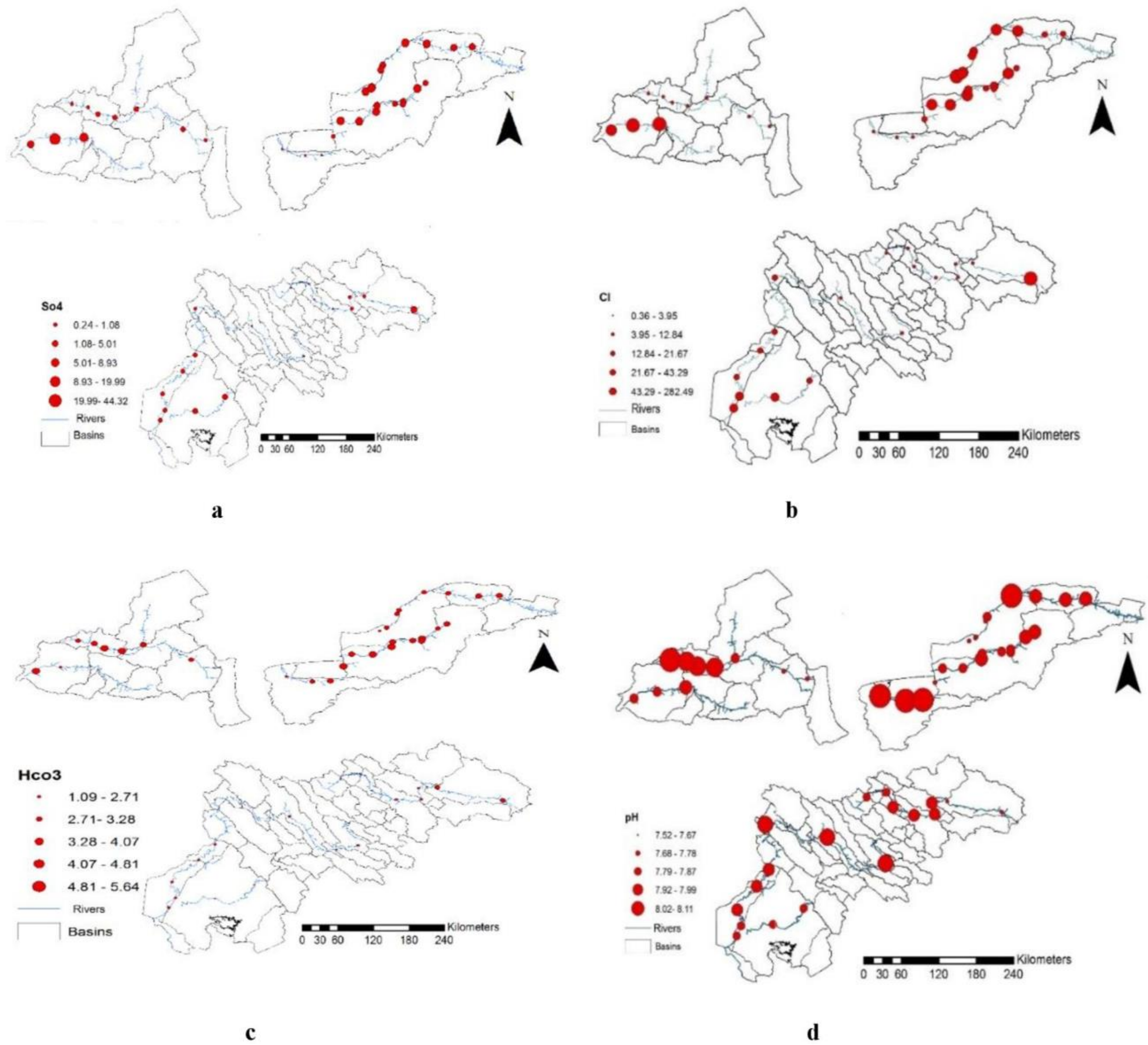
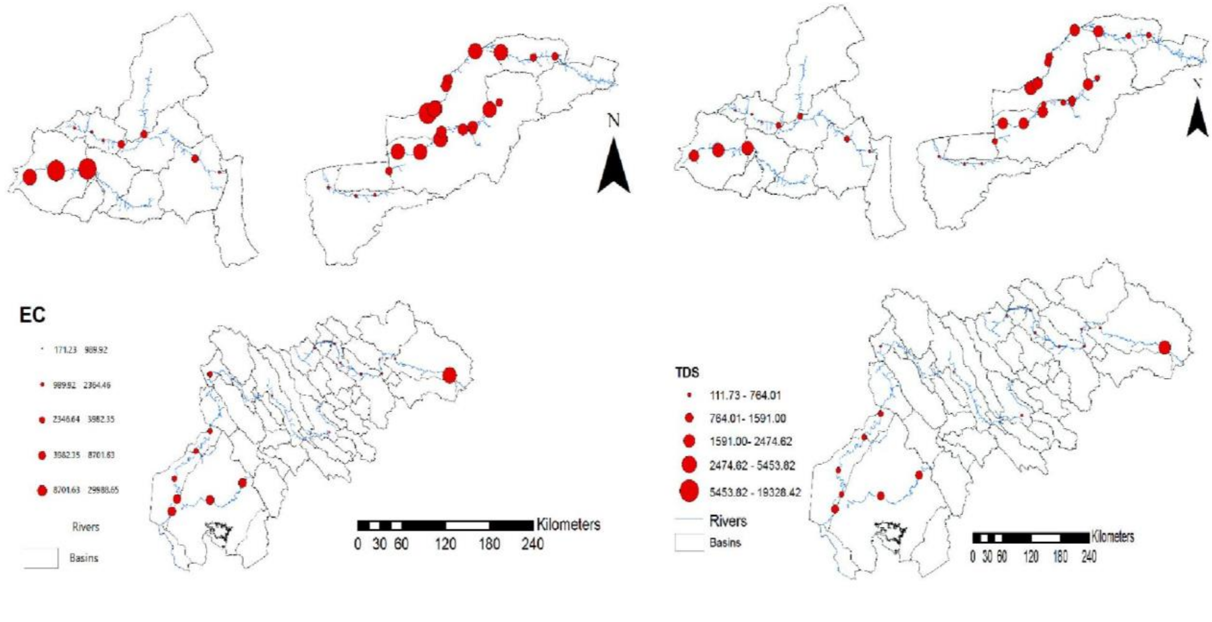


Fig. 8. Distribution map of the parameters a: So_4, b: Cl, c: Hco_3 and d: pH in the study areas

The lowest EC and TDS values in the study area were 0.41 and 111.73 for the 19149 stations of the Gharu Soo River and the highest values were 38.03 and 19328.42 for the Ajay Tea River Station 31015, respectively. As can be seen from the figure, 4 stations 11065 and 42025 on the Atrak and Zayanderood rivers and 31117 and 31015 on the Aji Chay River have EC values of more than 16500 and TDS of 10250 respectively, of which 8% are in the study area. They came in the fifth category.



a b

Fig. 9. Distribution map of the parameters a: EC and b: TDS in the study areas

4. Conclusion

In this study, the spatial variability of water quality parameters in three ranges in 50 hydrometric stations located on 9 rivers during the period 1999-2015 was studied by multivariate statistical method and GIS. In this study, factor analysis based on 10 qualitative parameters was performed to determine the most important parameters affecting the surface water quality of the study area. The results of PCA showed that the north, northwest and southwest basin respectively with 82.38%, 79.86% and 81.60% of total variance have two significant main components. CA was used to determine homogeneous areas in terms of water quality parameters in the study area. CA of hydrometric stations located in northwestern and southwestern regions was divided into two clusters and north into three clusters. In cluster analysis of stations in the study areas, the four stations 31015, 31117, 11065 and 42025 in Aji Chay, Atrak and Zayanderood rivers had different water quality characteristics than the other stations. The water quality characteristics of these stations were inconsistent with other stations. The use of PCA/CA in determining the main parameters of river water quality in Iran has been used in researches, such as Khaledian et al. (2018) and Noori et al. (2018). The patterns of average water quality parameters are shown in GIS. Based on the land use map (figure 1b) of these patterns, it was investigated that station 19149 located on the river Qara Su in the northwestern basin had the lowest values in most parameters for water quality and 31015, 31117, 11065 and 42025 stations in downstream had the highest values in most parameters. The results showed that stations located in river upstream with different land use in three basins had better water quality, but stations in downstream rivers with different land uses had poor water quality. In a similar study, Rezai and Sayadi (2015) concluded that river water quality is better in upstream. Therefore, using multivariate statistical methods, a large amount of river water quality data can be processed, and the most important water quality parameters can be obtained. Because the methods reduce sampling costs and target monitoring and identifying homogeneous areas plays an important role in the integrated management of biota and watersheds. Lack of sufficient information about all parameters of surface water quality, to accurately diagnose the changes that may occur as a result of a potential problem over a long period of time. Also, the lack of number of stations and sampling periods in some areas was one of the limitations that we faced in this study.

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6. Disclosure statement

No potential conflict of interest was reported by the authors

7. References

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