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Comparison of formation conditions and contamination of the groundwater of the Shiraz and the Khorramabad basins in Iran by means of factor analysis

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Comparison of formation conditions and contamination of the groundwater of the two large basins using a great number of chemical elements and compounds (10 and more) is a rather complicated task. We have suggested a new method based on applying factor analysis. Using this method gives an opportunity to define the sources of pollution of the groundwater and compare the conditions of their formation on different territories. The method has tested in the study of chemical composition of the groundwater of the Shiraz and the Khorramabad basins of Iran.

[Key words: Iran, Shiraz and the Khorramabad basins, groundwater, chemical composition, contamination, factor analysis]

Introduction

The groundwater of the Shiraz and khorramabad basins are widely used for water supply, industrial needs Agriculture and other purposes. The groundwater of the basin in the drainage zone has mineral concentration of up to 1 g/dm3, and in the discharge zone mineral concentration is reasonably increased which is explained by continental salinity and man-made pollution (fertilizing, chemical industry waste and mine drainage). The groundwater has sulfate-chloride calcium-magnesium composition which corresponds to the drinking water standards. The quality of water in the north-west and south-east of the basin is hydro carbonate calcium-magnesium. The groundwater also contains heavy metals[1, 2].

The geological structure and hydrogeological conditions of the Khorramabad basin were explored by the following Iranian companies[3]. The companies mentioned above have compiled geological and hydrogeological maps, studied the chemical composition of the aquifer reservoir and defined the hydrogeological parameters of the underground reservoir. A major contribution to the study of the hydrogeological conditions of the Khorramabad basin has been made by the department of hydrogeology of the Moscow State University[4].We have applied the method of multivariate statistical analysis (factor analysis) to define the processes and factors that are indeed determinative in the chemical composition formation and contamination of the groundwater in these basins.

Materials and Methods

The chemical composition of groundwater is the end-product of the effect of a complex of natural and technology-related processes (conditions of recharge and discharge, ion exchange, industrial pollution etc). The impact of these processes on the groundwater is reflected in the interconnected alterations in the content of components and the type of bond between them. However, this bond of the components of the groundwater being observed does not remain in pure form. The correlation dependence between the variable values observed is actually the final result of the effect of the complex of these processes. That is why, in order to define the processes and factors that are indeed determinative in the chemical composition formation and contamination of the groundwater in these basins, we have applied the method of multivariate statistical analysis[5, 6].

Statistical methods are some of the most effective ways of identifying patterns in the body of data, since in geology there tends to be no possibility of direct observation and measuring of the processes and factors. They can only be analyzed based on the final results of display of the processes reflected in the values of different characteristics [7, 6].

An important role in the methods of multivariate analyses is played by factor and component analyses. They represent a rather effective medium of data compression by means of transition from the initial values to the new variables – factors (components). Study of the factor structure gives an opportunity to check the existing hypotheses about the reasons creating interconnection between the variables under observation, which provides causal-investigatory interpretation for the obtained results[8].

The method of principal components is used both as an independent one and as an element in all the contemporary schemes of factor analysis. The fundamental difference between component and factor analysis is in the way of searching for factors and the suppositions concerning the nature of the remainders. In component analysis factors are determined in accordance with the maximum test of their contribution to the total dispersion of all the variables. In the factor analysis itself factors are between the variables according to the bond maximization principle. It can be argued that component analysis consists in dispersion study, and factor analysis itself studies correlations between variables. Component analysis supposes all its remainders to be small, while factor analysis makes no such supposition. Accordingly, component analysis considers the bulk dispersion of the variable to be important for the study and connected with the rest of the variables under observation. In factor analysis, on the contrary, it is suggested that the initial data contain a significant share of 'specificity'; thus only the component of the variable that correlates with the other variables is used. Both of the methods suggest that remainders do not correlate with factors. Nevertheless, no suppositions as for correlation between remainders are made, whereas factor analysis also suggests that they do not correlate[5, 7, 9,10, 11].

Factor analysis allows obtaining a minimal number of new variables that are linear combinations of the initial ones, and the new variables contain the same amount of information.

The methods of factor analysis are divided into two large classes: R-modification and Q- modification. The first one is related to the study of correlations between variables and is based on defining the eigenvalues and eigenvectors in the covariance or correlation matrices, and the second one is connected with the study of correlations between the objects and is used for the study of their internal structure with the aim of presenting it in the multidimensional space.

The first step in both modifications of factor analysis is transformation of the initial data matrix into a square symmetric matrix that expresses either the degree relation between variables (R-modification), or that between the objects these values are defined on (Q-modification). This is done by means of multiplying the data on the left or right of the matrix by the matrix transposed to the latter. The data matrix consists of *N* rows of observations and *M* columns of variables. Multiplying the data matrix [*x*] on the left by the matrix [*x*]'transposed to it, we get the square matrix *R* (*R*= [*x*]'*[*x*]) that has the order *M x M.* The elements of the matrix *R* consist of the sum of squares of the pairing products of *M* variables represented in the initial matrix, i.e.:(1)

$$r_{ik} = \sum_{i=1}^{n} x_{ij} x_{ik} \,, \qquad k, j = 1 \ldots m$$

Where: j and K are numbers of columns of the data matrix. If the data are standardized, i.e. each variable has zero mean and standard deviation that equals 1, the matrix R will be the correlation matrix of M variables.

Multiplying the data matrix [x] on the right by the matrix [x]'transposed to it results in the square matrix Q (Q = [x] *[x]') with the order N x N.

If the data matrix [x] contains unprocessed observations, the matrix Q contains squares and pairing products of all the pairs of objects summed over the variables.

In most studies more objects than variables are used, which results in the matrix Q having a higher order than that of the matrix R, though they are both drawn up based on the initial data matrix [x].

Applying factor analysis in geology is based on defining the eigenvalues and eigenvectors either for matrix R or for matrix Q. Close connection between them is obvious since they both originate from the same data set.

Analysis starts with calculating the correlation between the given number N of the measured variables. The matrix of the correlation coefficients is processed in accordance with the method of principal components (R-modification) of factor analysis. The result is a certain number of significant factors that can 'explain' the variability of the sampling in terms of the new variables or factors. Factor loadings express the 'composition' of factors through the initial variables. Since these factors are difficult to be interpreted, it is common to use rotation of the axes obtained at the first stage (using Varimax method) to increase the roles of variables influencing the factor significantly, and to diminish the role of those with insignificant effect.

Each of the numbers in the fixed column of the matrix of factor loadings stands for the contribution of a certain variable to the composition of the factor; i.e. it can be suggested that each column represents a factor equation where loadings are coefficients with correspondent initial variables.

a) Initial data matrix X is normalized i.e. standardized according to the formula: (2)

$$X_k^s = \frac{x_{k_i} - \bar{x}_k}{\sigma_k},$$

Where: X_{ki} –value of the k^{th} case of the i^{th} row, $\bar{X}_k$ – mean of the k^{th} case, σ_k – standard deviation of the k^{th} case, k –column number, i – row number of the data matrix;

b) Based on the normalized matrix X^s the correlation matrix *R* is calculated by multiplying it on the left by the matrix transposed to it;

c) Eigenvectors (*Z)* of matrix *R*, that is the principal components, is found ;(3)

$$Z_j = \sum_{i=1}^{p} A_{ji} X_{ji}^s \qquad j = 1 \ldots P,$$

Where P – the number of principal components (equals the number of parameters in the initial matrix; A_{ji} – weight of the jth component in the ith variable (or vice versa) ;

d) An orthogonal matrix, that combines cases and factors, is constructed based on the eigenvectors. Factor loadings are correlation coefficients between cases and factors;

e) Factors are ranked by decreasing of dispersion. The obtained matrix of factor loading is the basis for hydrogeological interpretation;

f) To evaluate the intensity of manifestation of different factors on different sites (e.g., to define the intensity of development of different natural and industrial processes in different parts of the valleys) a matrix of factor scores is calculated for the sites (wells, springs) :(4)

$$F_{ij} = \frac{\sum_{k=1}^{M} f_{jk} \times X^s{}_{ik}}{\lambda_j},$$

Where: F_{ij} –value of the jth factor in the ith point, f_{jk} – factor loading of the jth factor upon the

k^{th} variable, X_{ik}^s – value of the k^{th} variable in the i^{th} point, *л*$_j$ – eigenvalue vector of the correlation matrix, or the sum of squares of factor loadings of the j^{th} factor, *M* – the number of variables.

The data of chemical composition of the groundwater of the Shiraz and Khorramabad intermountain basins were processed according to the program pack of factor analysis.

To realize this method the data of chemical analyses of the groundwater in different parts of the Shiraz and Khorramabad intermountain basins were used (Tables 1and 2). They are characterized by 18 chemical elements and compounds.

The initial data matrix contains the information about chemical composition of the groundwater for 61 wells and springs. The results of chemical composition of the groundwater given in the table will be assembled as a matrix and factor analysis will be realized.

To evaluate the bond strength between separate indices of chemical composition of the groundwater without taking into account the influence of the rest of the variables, we have analyzed correlation analysis. Analysis of the matrix of pairing coefficients of correlation showed the following: significant positive relation was determined for Ca and HCO_3, Cu and Fe and negative relation was determined for Na and Cr, Ba and Fe. There is no strong dependence of Cl, SO_4, fluorine, potassium, cadmium and zinc on the rest of the elements.

Nevertheless, the determined peculiarities of distribution of pair bonding of the components of the groundwater do not give enough grounds to determine the factors forming the chemical composition or the character of contamination or the quantitative role of each of them.

Table 1 — The chemical composition of groundwater Shiraz basin (mg/dm3)

Source type	Cd	Co	Ba	Cu	Mo	Ni	Pb	Zn	Fe	PH	Cl	HCO_3	SO_4	Ca	Mg	Na	Tds	ECμm
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Pirbona.w	0.007	0.00001	0.001	0.014	0.00001	0.01	0.00001	0.393	0.032	8.3	43	165	202	68	50	28	530	740
Pol-berenji.spr	0.007	0.00001	0.028	0.015	0.017	0.004	0.00001	0.425	0.214	8.3	391	195	79	72	28	201	940	1670
Babahaji.w	0.004	0.005	0.001	0.003	0.008	0.03	0.001	0.145	0.027	8.3	53	185	231	78	50	41	580	937
Pol-fasa.w	0.008	0.00001	0.002	0.019	0.00001	0.02	0.00001	0.398	0.038	8.2	58	201	210	74	51	38	605	904
Barmedade.spr	0.004	0.011	0.003	0.014	0.00001	0.01	0.00001	0.388	0.039	7.8	56	238	189	72	54	36	617	873
Kaftarak.w	0.005	0.013	0.005	0.005	0.005	0.015	0.023	0.039	0.038	8.2	57	256	192	74	54	33	630	869
Barmedelak.spr	0.008	0.015	0.004	0.006	0.006	0.014	0.026	0.04	0.037	7.8	57	305	154	82	55	33	640	869
Barmetaer.spr	0.008	0.015	0.004	0.006	0.006	0.014	0.026	0.04	0.037	7.5	184.9	305	205	104	67	378	1571	2290
Barmeshoor.w	0.006	0.01	0.001	0.01	0.014	0.016	0.007	0.244	0.162	7.9	185	305	230	117	77	548	1974	3050
Barmekhan.spr	0.006	0.03	0.015	0.377	0.051	0.044	0.046	0.122	1.472	8.3	1018	244	255	120	80	718	2380	3810
Brmebaboonak.spr	0.002	0.01	0.014	0.012	0.007	0.004	0.023	0.04	0.12	8.3	1206	244	264	160	61	856	2700	4346
Soltanabad.w	0.002	0.012	0.035	0.006	0.014	0.01	0.016	0.018	0.096	8.2	85	194	283	94	64	58	760	1132
Shapoor.w	0.002	0.015	0.03	0.017	0.048	0.004	0.23	0.057	0.298	8	85	180	283	98	43	50	665	1035
Krooni.w	0.006	0.01	0.025	0.024	0.059	0.087	0.041	0.315	1.391	8.5	92	207	288	118	58	57	700	1170
Jarestan.w	0.007	0.02	0.006	0.009	0.005	0.009	0.002	0.196	0.203	8	71	195	264	90	52	45	686	1000
Ghachi.w	0.004	0.018	0.004	0.015	0.012	0.039	0.032	0.051	0.099	7.4	64	220	231	98	47	40	665	936
Mahmudabad.w	0.005	0.015	0.023	0.021	0.056	0.085	0.038	0.305	1.384	8.2	64	220	250	94	47	40	677	918
Pir-mohammad.w	0.007	0.00001	0.029	0.016	0.018	0.005	0.00001	0.429	0.218	7.9	185	225.5	154	71	39	25	518	703
Khatoonak.w	0.006	0.009	0.024	0.017	0.017	0.082	0.027	0.025	0.047	7.88	184.9	225.52	107	58	36	17	435	509
Moinabad.w	0.006	0.005	0.001	0.013	0.00001	0.00001	0.039	0.13	0.054	7.3	21	214	59	46	33	10	351	486
Khabir.w	0.006	0.004	0.016	0.011	0.00001	0.021	0.024	0.147	0.002	7.6	18	232	62	60	28	13	376	520
Shams.w	0.002	0.003	0.018	0.035	0.008	0.004	0.016	0.063	0.046	7.3	25	299	106	84	34	21	501	695
Mansoorabad.w	0.01	0.014	0.004	0.018	0.032	0.019	0.042	0.065	0.219	7.4	21	226	67	56	27	13	367	537
Mohammad.w	0.004	0.036	0.037	0.036	0.025	0.049	0.045	0.092	0.264	7.6	25	226	73	52	30	19	384	545
Ghasrgushe.w	0.007	0.027	0.043	0.039	0.012	0.036	0.019	0.09	0.128	7.8	333	226	1047	349	27	213	2130	2950
Saadi.w	0.00001	0.01	0.001	0.011	0.003	0.019	0.02	0.173	0.295	7.4	142	232	744	221	61	171	1327	2280
Abkhan.w	0.00001	0.017	0.038	0.039	0.095	0.038	0.023	0.146	1.338	8.1	301	275	288	94	75	201	1190	1820
Aliabad.w	0.006	0.02	0.005	0.019	0.016	0.04	0.036	0.065	0.01	7.3	50	281	180	80	49	32	624	854
Bahram.w	0.00001	0.021	0.013	0.027	0.018	0.00001	0.027	0.073	0.047	8	234	238	317	92	90	133	1715	2500

More complete information was obtained with the help of the method of principal components or R-modification of factor analysis. The results obtained are reflected in Table 3.

Analyzing the data of this table, the following can be established:

1. There are a number of factors that are responsible for 100% of total impact on the studied indices of chemical composition of the groundwater. A significant contribution is made by four factors the weight of which amounts 10% after rotation of the matrix.

2. The first factor (weight – 25.730%) with positive bond strength of more than 0.5 includes: copper, magnesium, natrium, chlorine, Tds and ECμmo. The most characteristic elements of the first factor are copper, chlorine, magnesium, natrium, Tds and ECμmo.

3. The second factor (weight – 17.534%) with positive bond strength of more than 0.5 includes: barium, molybdenum, nickel, Fe .The main elements characterizing this factor are bromine, molybdenum and Fe.

4. The third factor (weight – 14.039%) with positive bond strength of more than 0.5 includes: SO_4 and calcium. The main elements characterizing the third factor are SO_4 and calcium.

5. The fourth factor (weight – 11.998%) with positive bond strength of more than 0.5 includes: cobalt, HCO_3. The elements characteristic for the fourth factor are: zinc, PH, cobalt and HCO_3.

To analyze the distribution of the marked four factors on the territory of the Shiraz and Khorramabad basins, loadings of each of the factors for all the wells and springs were defined. With this end in view we have applied Q-modification of factor analysis. The results of this analysis are reflected in the Tables 4 and 5 and the Figures 1 and 2.

Results and Discussion

Shiraz basin

The distribution of factor loadings upon the wells and springs on the territory of the Shiraz intermountain basin is given in the Table 3 and the

Table 2. — The chemical composition of groundwater Khoramabad basin (mg/dm3)

Source type	Cd	Co	Ba	Cu	Mo	Ni	Pb	Zn	Fe	PH	Cl	HCO_3	SO_4	Ca	Mg	Na	Tds	ECμmo
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Rashidi-darai.w	0.0005	0.004	0.015	0.003	0.00001	0.0004	0.0008	0.005	0.048	7.28	80	300	60	230	170	13	384	600
Malekshahi.w	0.00008	0.0008	0.074	0.048	0.00001	0.001	0.005	0.00001	0.11	7.02	30	510	57	350	240	6	441	690
Naservand.w	0.00009	0.001	0.066	0.004	0.0004	0.0013	0.0005	0.007	0.00001	7.41	60	400	157	280	220	108	364	570
Dehbagher.w	0.00005	0.001	0.01	0.002	0.004	0.0016	0.0008	0.0009	0.059	7.21	130	570	3	390	280	29	643	990
Borjali.spr	0.0001	0.001	0.192	0.001	0.001	0.003	0.0002	0.014	0.04	7.41	20	320	20	180	200	1	236	370
Sorkhedeh.spr	0.00008	0.003	0.2	0.001	0.001	0.003	0.0001	0.008	0.056	7.83	330	390	178	340	240	290	650	1000
Robatnamaki.w	0.00009	0.001	0.17	0.001	0.001	0.003	0.0005	0.004	0.021	7.71	160	460	55	350	300	20	507	780
Kalmekhub.spr	0.0002	0.002	0.21	0.003	0.00002	0.005	0.001	0.0008	0.11	7.4	80	530	143	360	250	108	409	640
Cheshmebid.spr	0.0001	0.002	0.23	0.003	0.0005	0.005	0.003	0.019	0.04	7.38	40	350	14	390	10	4	188	450
Sarabe-sgha.spr	0.0002	0.003	0.09	0.002	0.00001	0.0034	0.0007	0.004	0.07	7.5	40	530	92	430	200	26	416	650
Ghale-joghd.spr	9.0001	0.001	0.08	0.0009	0.0009	0.003	0.0002	0.006	0.016	7.32	20	360	5	330	50	6	294	460
Cheshme- cheragh.spr	0.0002	0.001	0.2	0.002	0.00002	0.002	0.004	0.004	0.001	7.23	70	430	11	330	110	65	371	580
Saboor.w	0.00009	0.008	0.08	0.046	0.00001	0.002	0.005	0.005	0.9	7.54	40	380	52	340	110	18	294	460
Cheshme- sorkhe.spr	0.00008	0.0014	0.01	0.002	0.003	0.0017	0.0009	0.0009	0.06	7.97	70	330	71	300	110	39	275	430
Navekesh.spr	0.00001	0.002	0.08	0.005	0.0006	0.002	0.006	0.008	0.1	7.18	30	390	24	360	80	3	326	510
Gilooran.w	0.00005	0.003	0.015	0.003	0.00001	0.0005	0.0008	0.005	0.04	7.26	120	490	5	390	200	24	624	960
Sarabe- yas.spr	0.00007	0.004	0.01	0.005	0.00002	0.0004	0.00007	0.005	0.04	7.34	70	490	127	370	210	90	435	680
Kahriz.spr	0.00008	0.003	0.015	0.006	0.00001	0.004	0.0007	0.004	0.049	7.64	30	270	98	250	8	56	224	350
Ali-abad.w	0.0001	0.0013	0.01	0.02	0.00004	0.004	0.00001	0.007	0.098	7.52	50	340	142	290	160	73	313	490
Chogharushi.w	0.00001	0.0013	0.07	0.005	0.0005	0.002	0.006	0.008	0.1	7.16	70	690	64	210	510	95	494	760
Sarnamak.w	0.0001	0.002	0.19	0.003	0.0003	0.003	0.0006	0.015	0.04	7.18	160	600	65	450	360	16	669	1030
Changai.spr	0.00009	0.008	0.08	0.04	0.00003	0.001	0.04	0.05	0.09	7.23	80	470	9	380	160	16	468	720
Chamgharg.w	0.0001	0.0008	0.08	0.04	3E-06	0.001	0.00005	0.05	0.09	7.18	160	600	65	450	360	16	669	1030
Charkal.w	0.00008	0.002	0.1	0.001	0.001	0.003	0.00001	0.008	0.05	7.47	285	810	193	260	440	600	838	1270
Dore.spr	0.00005	0.001	0.08	0.006	0.0008	0.002	0.00007	0.009	0.15	7.02	30	610	57	350	240	96	441	690
Gooshe.spr	0.00008	0.0007	0.07	0.04	0.00001	0.001	0.004	0.004	0.09	7.66	10	290	90	350	40	1	236	370
Gerdabsangi.spr	0.0002	0.001	0.1	0.002	0.00007	0.004	0.0001	0.0008	0.09	7.38	40	350	14	390	10	4	288	450
Kiv.spr	0.00002	0.001	0.1	0.002	0.00005	0.003	0.001	0.0007	0.098	7.56	20	380	1	290	8	2	294	4650
Cheshme-tala.spr	0.00002	0.002	0.2	0.04	0.00001	0.003	0.004	0.003	0.053	8.16	60	450	9	350	150	9	345	540
Sarabe-ghoorchi.spr	0.0002	0.003	0.08	0.05	0.00001	0.0035	0.005	0.005	0.09	7.41	60	400	157	280	220	108	364	570
Darband.w	0.002	0.001	0.06	0.007	0.0001	0.002	0.0008	0.0006	0.004	7.54	70	370	106	320	170	63	342	523
Balilvand.w	0.004	0.004	0.015	0.003	0.00005	0.0004	0.093	0.006	0.05	7.4	60	530	143	360	250	108	409	640

Figure 1. Based on the position of contour line of these factors on the territory of the basin, the following conclusions can be drawn 1.

The first factor has positive loading and is distributed in the western part of the basin and can only be locally marked in its north-western and western parts with the max. Value of loading (more than +1.0) upon the area of the springs Barmekhan(3.25), Barmebaboonak (2.57) and w. Barmeshoor (157). W. Abkhan (0.71), Bahram (0.87) and spr. Barmetaer (0.87) also have positive loadings from 0.5 to 1.0.

Since all these wells have negative loading of less than 1, they will not be taken into consideration hereinafter.

2. The second factor has positive loading upon a wide zone that stretches from the west to the north-east in the central part of the basin and locally upon the south-west. It has the max. Loading upon w. Krooni (2.08) and Shapoor (1.42), Abkhan (2.10), Mohammad (1.20) and spr. Barmekhan (1.72). Positive loadings from 0.5 to 1.0 are also upon w. Khatoonak (0.61).

3. The third factor has positive values in the northern part of the basin and in a small part in its south-western zone. Its max. Positive values are confined to w. Abkhan (2.37), Mohammad (1.24), Shams (1.16) and spr. Barmetaer (1.22).

Table 3 — Factor loadings after rotation (R-modification)

No	Elements	Factors				
		1	2	3	4	5
1	Cd	-0.152464	-0.179923	-0.254280	-0.262346	0.152656
2	Co	0.215674	0.439273	0.244002	0.586797	0.099643
3	Ba	-0.107729	0.633333	0.407664	-0.018868	0.197076
4	Cu	0.606839	0.399788	-0.099645	0.059385	0.039815
5	Mo	0.181376	0.900517	-0.055956	0.033718	-0.007036
6	Ni	-0.087461	0.695690	0.007161	-0.043157	0.039815
7	Pb	-0.147891	0.438509	0.074375	0.372325	-0.007031
8	Zn	-0.057275	-0.011887	-0.108763	-0.849100	-0.147891
9	Fe	0.347570	0.840151	-0.054852	-0.165320	-0.007035
10	pH	0.360133	0.347771	0.037337	-0.680965	-0.179923
11	Cl	0.851826	0.094154	0.192076	-0.062660	-0.188639
12	HCO_3	0.357849	-0.188634	-0.193964	0.597823	0.244301
13	SO_4	0.131074	0.039815	0.928334	0.026640	0.362825
14	Ca	0.258270	-0.007035	0.923378	0.068206	0.236260
15	Mg	0.710536	0.063549	-0.090143	0.083032	0.074375
16	Na	0.932648	-0.049452	0.152056	0.046384	0.029814
17	Tds	0.871545	-0.043911	0.451051	0.097694	-0.007331
18	ECμmo	0.890944	-0.036467	0.421982	0.061672	-0.149891
Total dispersion		4.631433	3.156244	2.526969	2.159754	2.019744
Weights of factors, %		25.7302	17.5347	14.0387	11.9986	9.8641

Positive loadings from 0.5 to 1.0 are also upon w. Bahram (0.73), Mansoorabad (0.65), Gachi (0.93), Shapoor (0.90) and spr. Barmedelak (0.99).

4. The fourth factor has positive values of more than 1.0 in w. Kasrgoshe (4.27) and Saadi (1.82). W. Shapoor (0.64), Soltanabad (0.54) and spr. Barmebabunak (0.84) also have positive loadings from 0.5 to 1.0.

Analyzing the joint distribution of all the four factors on the territory of the Shiraz basin, it is possible to single out several zones affected by two or more factors.

For example, the area of w. Khabir is simultaneously affected by the first, second and third factors. The same phenomenon can be observed in the area of w. Barmekhan. This gives evidence of similar recharge conditions and possibly of their contamination.

The second and the third factors are active in the area of w. Mohammad. A similar situation can be observed in the area of w. Shapoor too. This gives evidence of similar conditions.

Khorramabad basin

The distribution of factor loadings upon the wells and springs on the territory of the Khorramabad basin is given in the Table 4 and the Figure 2.

Based on the position of contour line of these factors on the territory of the basin, the following conclusions can be drawn:

1. The first factor has positive loading and is distributed in the southern part of the basin and can only be locally marked in its north-western, northern and north-eastern parts with the max. Value of loading (more than 1.0) upon the area of w. Charkal (3.54), Chamgharg (1.04) and Sarnamak (1.02) and spr. Sorkhe de. W. Chogha Horushi (0.94), Belilvand (0.53) and spr. Kalmekhub (0.54) also have positive loadings from 0.5 to 1.0.

2. The second factor has positive loading upon a wide zone that stretches from the west to the north of the basin, as well as upon the south-west, central part and south. It has the max. loading (more than 1.0) upon w. Sabur (34.8) and spr. Changai (2.15) and Sarabe Gorchi (1.12). There are also positive loadings from 0.5 to 1.0 upon w. Belilvand (0.82),

Table 4. — Factor loadings upon wells and springs after rotationin the Shiraz basin (Q-modification)

No	Well (spring)	Factors			
		1	2	3	4
1	2	3	4	5	6
1	Pirbona w.	-0.353791	-0.75265	-2.01828	-0.282473
2	Pole Berenji spr.	0.068046	-0.27636	-2.03876	-0.085501
3	Babahaji w.	-0.343500	-0.41065	-0.89190	-0.119954
4	Polefasa w.	-0.217185	-0.76212	-1.73186	-0.389261
5	Barmedade spr.	-0.180478	-0.76508	-0.56951	-0.419671
6	Kaftarak w.	-0.161650	-0.45554	0.32813	-0.455622
7	Barmedelak spr.	-0.082286	-0.66431	0.99987	-0.790479
8	Barmetaer spr.	0.869834	-1.03430	1.22364	-0.439387
9	Barmeshur w.	1.572496	-1.04629	0.12085	-0.353454
10	Barmekhan spr.	3.257177	1.72258	0.18312	-0.763217
11	Barmebabunak spr.	2.566158	-1.02819	-0.15355	0.840410
12	Soltanabad. w	-0.351905	0.15420	-0.06014	0.535128
13	Shapoor w.	-0.977612	1.42434	0.90634	0.648162
14	Krooni w.	-0.175925	2.08464	-1.39674	0.013842
15	Jarestan w.	-0.295752	-0.39402	-0.41573	0.025784
16	Gachi w.	-0.561400	-0.13900	0.93379	-0.011651
17	Mahmudabad w.	-0.375449	2.02210	-0.82149	-0.168912
18	Pir mohammad w.	-0.450839	-0.24053	-1.40796	-0.247836
19	Khatoonak w.	-0.773432	0.60600	0.21379	-0.395586
20	Moina bad w.	-0.766594	-0.85339	0.36936	-0.780966
21	Khabir w.	-0.845751	-0.49343	0.04994	-0.492036
22	Shams w	-0.536607	-0.65376	1.16288	-0.470584
23	Mansoorabad w.	-0.798168	-0.03053	0.64968	-0.864068
24	Mohammad w.	-0.998615	1.20217	1.24011	-0.172677
25	Kasrgoshe w.	-0.303517	0.04094	0.18048	4.267164
26	Saadi w.	0.039571	-0.82594	0.36955	1.927690
27	Abkhan w.	0.712310	2.10194	2.37246	-0.211658
28	Aliabad w.	-0.410197	-0.20116	1.46671	-0.558552
29	Bahram w.	0.875061	-0.33167	0.73521	-0.215364

Chamgarg (0.52) and spr. Cheshmeh Tala (0.82), Gooshe (0.59).

3. The third factor has positive values in the part of the basin that stretches from its central part in the north-western direction, as well as in a narrow zone in the western part of the basin. Its max. positive values (more than 1.0) are confined to w. Chamgharg (2.63) and Sarnamak (1.18). Positive loadings from 0.5 to 1.0 are also upon w Giluran (0.89), Malek Shahi (0.74) and spr. Doreh (0.71), Cheshmeh Cherag (0.59), Cheshmeh Bid (0.82).

4. The fourth factor has positive values of more than 1.0 in w. Belilvand (2.38) and Rashidi-Dar (1.37), Sarabeyas (1.2), Dehbagher (1.17). W. Chogharooshi (0.93), Giluran (0.99) and spr. Cheshmeh Sorkhe (0.62), Doreh (0.53), Changai (0.94) also have positive loadings from 0.5 to 1.0.

Analyzing the joint distribution of all the four factors on the territory of the Khorramabad basin, it is possible to single out several zones affected by two or more factors. For example, the area of spr. Doreh. is simultaneously affected by the first, second and third factors. The same phenomenon can be observed in the area of w. Chamgharg and spr. Changai, w. Malek Shahi and Robate Namaki, as well as in the area of spr. Sarabesaqqa and Kalmekhub. This gives evidence of similar recharge conditions and possibly of their contamination.

Table 5. — Factor loadings upon wells and springs after rotation in the Khorramabad basin (Q-modification)

No	Well (spring)	Factors 1	2	3	4
1	2	3	4	5	6
1	Rashidi-Dar w.	-0,45117	-0,02537	-0,72861	1,36800
2	Malek Shahi w.	-0,20449	0,14227	0,74256	0,83310
3	Naservand w.	0,14818	-0,38843	-0,99033	0,60311
4	Dehbagher w.	0,44033	-2,01958	-0,81605	1,17385
5	Borjali spr.	-0,82226	-0,61100	-0,42290	-0,55630
6	Sorkhe de spr.	1,95296	0,28252	-1,08768	-1,61482
7	Robate Namaki w.	0,45527	-0,63176	0,10205	1,02355
8	Kalmekhub spr.	0,54452	0,17496	-0,20788	-1,63980
9	Cheshmeh Bid spr.	-1,04144	0,07964	0,82037	-1,96270
10	Sarabesaqqa spr.	0,00820	0,12134	0,30340	-0,47178
11	Qaleh Joghd spr.	-1,55544	-1,65444	0,42819	-0,10687
12	Cheshmeh Cherag spr.	-0,42416	-0,54465	0,53526	-0,59101
13	Saboor w.	-0,53582	3,40421	-0,31507	0,09455
14	Cheshmeh Sorkhi spr.	-0,59117	-0,90608	-1,49902	0,62273
15	Navekesh spr.	-0,81633	-0,28876	0,46459	0,34905
16	Giluran w.	0,15093	-0,43109	0,88855	0,99360
17	Sarabeyas spr.	0,28213	0,15967	-0,26433	1,19949
18	Kahriz spr.	-0,92510	0,31010	-1,62062	-0,10971
19	Aliabad w.	-0,26838	0,31147	-1,19310	-0,07714
20	Chogha rushi w.	0,93549	-0,73139	0,01780	0,93093
21	Sarnamak w.	1,02587	-0,34205	1,80790	-0,96777
22	Changai spr.	0,05003	2,15174	-1,95618	0,94223
23	Chamgharg w.	1,04586	0,51671	2,63447	0,11154
24	Charkal w.	3,54745	-0,44263	-1,22248	-0,34338
25	Doreh spr.	0,16490	-0,62352	0,70798	0,52615
26	Gooshe spr.	-1,04311	0,59518	-0,56632	0,24874
27	Gardabsangi spr.	-1,06905	-0,30942	0,19861	-0,82846
28	Kiv spr.	-1,04707	-0,77620	0,02230	-0,75297
29	Cheshmeh Tala spr.	-0,43825	0,82534	-0,09178	-1,57115
30	Sarabe Gorchi spr.	0,18953	1,12963	-0,91009	-0,16016
31	Darband w.	-0,23787	-0,30265	-0,80631	0,17897
32	Belilvand w.	0,52947	0,82423	-0,51973	2,38778

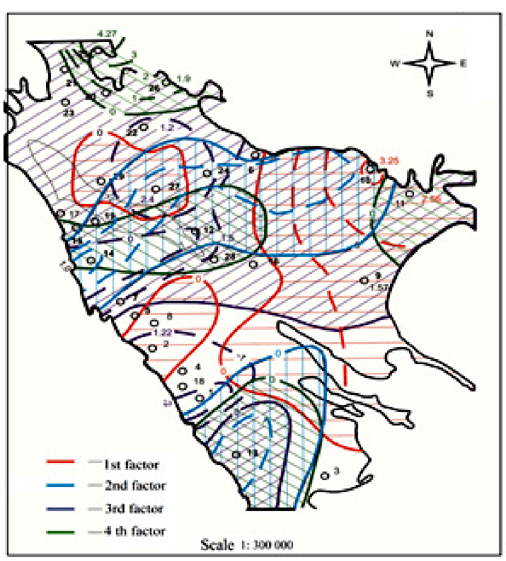

Fig.1 — schematic map of factor analysis the wells and spring off the Shiraz basin

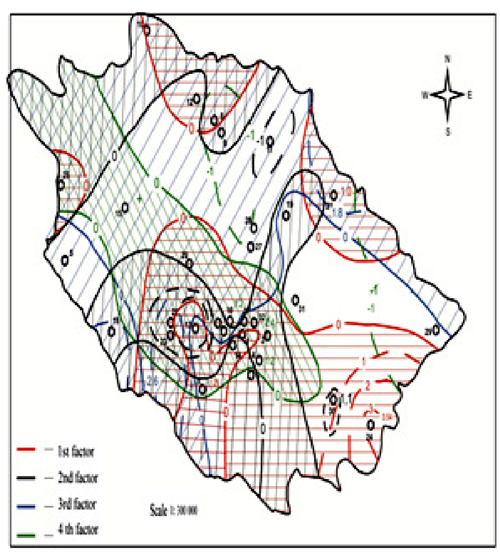

Fig.2 — schematic map of factor analysis the wells and spring off the Khorramabad basin

Conclusion

Comparing the maps of distribution of factor loadings for the groundwater in the Shiraz and the Khorramabad basins (Fig. 1 and 2), it can be argued that these basins contain several sites affected by two or even three identical factors.

For example, the groundwater in the area of w. Khabir and Barmekhan in the Shiraz basin, affected by the first, second and third factors simultaneously, corresponds strictly to the groundwater in the area of spr. Doreh, Changai, Sarabesaqqa and Kalmekhub and w. Chamgharg, Malek Shahi and Robate Namaki in the Khorramabad basin, affected by the same factors. The groundwater in the area of w. Mohammad and Shapoor in the Shiraz basin, affected by the second and third factors, also corresponds strictly to the groundwater in the area of w. Belilvand, Sarabeyas, Naservand, Dehbagher and spr. Doreh, affected by the same two factors.

Taking into account the fact that the second and third factors include Tds and ECμmo, characterizing the total contamination of the groundwater of the Shiraz and the Khorramabad basins, it is possible to make an assumption about similarity of conditions of contamination of the groundwater in these valleys.

The analysis mentioned above gives grounds to conclude that in case any contamination in one of the wells or springs has been detected, let us say in the Shiraz basin, it will be possible to make a forecast as for the probable contamination of wells and springs of the Khorramabad basin using the map of distribution of factor loadings.

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