Assessing Temporal and Spatial Variations of Groundwater Quality (A case study: Kohpayeh-Segzi)

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Abstract. Assessing the quality of groundwater is important to ensure the sustainable safe use of these resources. However, describing the overall water quality condition is difficult due to the spatial variability of multiple contaminants and the wide range of indicators (chemical, physical and biological) that could be measured. Therefore, in this case study, some water quality parameters including Na, Mg, Cl, K, and pH, SAR, TDS, Th, Co3, HCo3, So4, Ca and EC of 34 wells and 16 qanats have been monitored and analyzed in a 15 year period. After collecting data, the main affecting factors on water quality of wells and qantas were determined separately by factor analysis test. Zoning maps were generated in Arc GIS on the basis of most important effective factors. Dry and wet years were determined based on rainfall data and 7-year moving average. Finally, the temporal trend of principal factors was depicted and water quality variations of wells and qantas were compared. Believing that sodium and chlorine are the most important parameters for water quality of wells and qanats, water quality of wells during dry years is downgraded as the results show. In initial wet year period, water quality is extremely improved but thereafter it is degraded. Results also show that water quality variation in qanats is negligible.

Keywords: Ground water quality, Factor Analysis, GIS, Kohpayeh-Segzi.

Introduction

Almost 97.5% of all waters on Earth are salty leaving only 2.5% as fresh water. Fresh water is one of the basic necessities for life sustenance, human consumption, habitat support and maintaining the quality base flow of rivers. Nearly 70% of fresh water is frozen in the icecaps of Antarctica and Greenland and only 1% of world's fresh water (~0.007% of all water on earth) is accessible for direct human uses. This is the water found in lakes, rivers, reservoirs and those underground sources that are shallow enough to be tapped at an affordable cost (Alizadeh, 2006).

Ground water has become an essential resource over the past few decades due to the increase in its usage for drinking, irrigation and industrial uses, etc. The quality of ground water is equally important as its quantity (Skidmore 1997). They are usually of excellent quality. Being naturally filtered in their passage through the ground, they are usually clear, colorless, and free from microbial contamination and require the minimal treatment. Unfortunately, these valuable resources are now posed by an ever-increasing number of soluble chemicals from urban and industrial activities and from modern agricultural practices. Landslides, fires and some effective surface processes may also affect the quality of shallow groundwater Babiker *et al.* (2007).

The chemical composition of groundwater is a measurement of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other purposes. Therefore, different uses require different standards of water quality Babiker *et al.* (2007). The chemistry of groundwater reflects inputs from the atmosphere, soil and water-rock reactions as well as from pollutant sources such as mining, land clearance, agriculture, acid precipitation, domestic and industrial wastes.

The assessment of vulnerability degree of groundwater is one of the most important and interesting subjects but many uncertainties are associated with the aquifer vulnerability assessment due to insufficient representation of key factors such as soil media Robins *et al.* (1994), net recharge (Rosen, 1994) and hydraulic conductivity estimates Aller *et al.* (1987), lack of knowledge concerning the physical and chemical properties and attenuation processes of pollutants Barber *et al.* (1993) which require the vulnerability estimates to be validated by accurate field testing.

Many different water quality parameters determine the ground water suitability for any water usages. Therefore, the cost of a monitoring program to assess all of them would be prohibitive, so resources should be used only for assessing key contaminants necessary for the local environment or for a specific water use Babiker *et al.* (2007). For this purpose, multivariate and factor analyses are effective applicable methods for selecting the major contamination variables.

Describing the overall water quality condition is difficult due to the spatial variability of multiple contaminants and wide range of indicators that could be measured. Geographical Information System (GIS) can be an effective and powerful tool for mapping, monitoring, modeling and assessing water quality, detecting environmental change, determining water availability, preventing flooding and managing water resources on a local or regional scale (Ledi Tjandra 2003). GIS can be utilized in various ground water assessments, e.g. for assessing the ground water resource hazard Masoudi *et al.* (2009), generating the groundwater contamination risk map (Ducci 1997) preparation the spatial variation map of groundwater quality (Anbazhagan and Nair 2004), relating the ground water quality variations to spatial variation of some environmental variables (topography, geology, land use and pollution sources) (Hong and Chon 1999), etc.

Principal Component Analysis (PCA) and geostatistical techniques were employed in a case study in east Coast of India. Based on PCA, salinity and nutrient were very predominant contaminants in that shallow coastal aquifer. Thereafter, spatial correlations of these two factors were assessed and the spatial variation map was generated for salinity in study area but spatiality was not meaningful for nutrient factor (Satyaji Rao 2010). Similar research was conducted in Bajo Andarax, Spain by Sânchez-Martos *et al.* (2001). The major variables were presented by PCA, and their spatial variation was performed through the experimental and theoretical variograms and ordinary block Kriging method. The researchers declared that this methodology describes the spatial and temporal variations of principal physico-chemical processes associated with the major variables.

An interesting study was performed in Sarchahan plain, Iran for the assessment of ground water quality by cluster and factor analyses. Water resources were classified in two groups by cluster analysis. Cluster analysis also revealed that the main effecting factors are the concentration of gypsum and halite. Factor analysis revealed that 98.9 % of water quality variability is defined by five factors and calcium, magnesium and sodium sulphate concentrations in alluvial materials were the main ground water contaminants Ghayomian *et al.* (2005).

This case study tries to assess the temporal and spatial variations of ground water quality in Kohpayeh-Segzi plain by statistical analysis and GIS.

Study Area

The study area is located in 35° 52' to 36° 6' N and 50° 39' to 51° 05' E, 25 kilometers of eastern Esfahan city, Iran. The watershed area is 1601 km2. The mean annual rainfall is 118.6 mm and the mean air temperature is about 23°C. The general elevation ranges from 1490 m to 1720 m above sea level. Slope is between 0-2 percent. The mean yearly evaporation is 2593.8 mm.

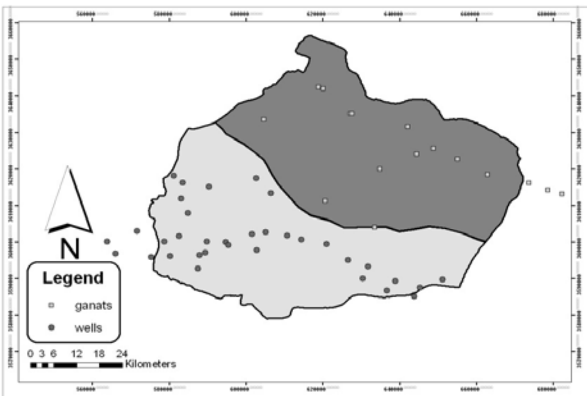

Fig. 1. Sampling Point Position in Kohpayeh-Segzi Plain

Methodology

Water of 34 wells and 16 qantas were sampled (Fig. 1) and their quality was analyzed. Factor Analysis was used to select the main effecting factors on wells and qantas. Selected parameters were Na, Mg, Cl, K, and pH, SAR, TDS, Th, Co3, HCo3, So4, Ca and EC. Normality of data was checked by Kolmogrove-Smirnov statistics and homogeneity of variance was checked by Levene statistics. According to K-S test, data are normally distributed with 95% or higher data confidence and variance is homogeneous, too.

Spatial distribution map was generated by Geostatistics methods in Arc GIS software. Kriging, IDW (Inverse Distance Weighting) and various RBF (Radial Basis Function) methods were used to analyze the spatial variation of main factor values and to generate the contour map of key water quality factors. The best geostatistical methods were selected by RMSE and MBE indices and the final contour maps were generated using these indices.7-year moving average was used to classify dry and wet years. Finally, the temporal trend of principal factors was depicted and thereby, water quality variations of wells and qantas were compared.

Results and Discussion

(Table 1), shows the special values and variance percentage for the assessed parameters of 34 wells. As it is shown, only value of three factors is above 1 percent. These three factors encompass 83.9 percent of variation, i.e. 57.74, 17.05 and 8.89 percent of the variances could be defined by sodium, calcium and carbonate, respectively. Only 16.32 percent of total variance cannot be justified by these three factors.

(Table 2) shows the special values and variance percent of assessed parameters for 16 qantas. Accordingly, value of four factors is above 1 percent. These four factors justify 96.32 percent of data variations, i.e. 65.17, 12.99, 10.27 and 7.89 percent of variances could be justified by chloride, carbonate, SAR and bicarbonate, respectively. This means that only 0.68 percent of total variance could not be justified by these four factors.

Table 1. Special Values and Variance Percentage for Assessed Parameters of 34 Wells

Component	Initial Eigen values			Rotation Sums of Squared Loadings		
	Special values	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.506	57.741	57.741	6.715	51.656	51.656
2	2.217	17.057	74.798	2.093	16.103	67.759
3	1.156	8.893	83.691	2.071	15.932	83.691
4	0.808	6.218	-			
5	0.707	5.438	-			
6	0.312	2.397	-			
7	0.144	1.109	-			
8	0.129	0.995	-			
9	0.018	0.136	-			
10	0.002	0.016	-			

Table 2. Special Values and Variance Percentage for Assessed Parameters of 16 Qantas

Component	Initial Eigen values			Rotation Sums of Squared Loadings		
	Special values	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.472	65.169	65.169	6.894	53.032	53.032
2	1.689	12.991	78.160	2.132	16.401	69.433
3	1.336	10.277	88.437	1.842	14.166	83.598
4	1.026	7.890	96.327	1.655	12.729	96.327
5	0.332	2.553	-			
6	0.110	0.844	-			
7	0.022	0.169	-			
8	0.011	0.087	-			
9	0.003	0.019	-			
10	9.33E-005	0.001	-			

To determine three major affective factors on well water quality, Rotation Varimax is used (Table 3). Maximum weight (0.961) in the first-parameter column is shown by sodium, so this parameter is considered as the most important parameter influencing the water well quality in the study area. So, the highest weight in the second and third parameter columns are related to calcium (0.766) and carbonate (0.931), respectively. Therefore, three captions (sodium, calcium and carbonate) are the most important variables influencing in the water quality of wells.

Table 3. Rotated Component Matrix in Wells

	Component		
	1	2	3
K	0.749	-0.156	0.436
Na	0.961	0.141	-0.114
Mg	0.890	0.277	0.132
Ca	0.538	0.766	-0.091
So4	0.417	0.335	-0.328
Cl	0.921	0.336	0.011
Hco 3	-0.009	-0.755	0.101
Co3	0.024	0.026	0.931
Ph	-0.041	-0.179	0.907
Tds	0.937	0.331	-0.072
Ec	0.937	0.331	-0.072
Th	0.793	0.555	0.022
Sar	0.860	-0.176	-0.155

The Varimax rotation in a Principal Component Analysis is also implemented to determine four important influencing factors on water quality of qanats (Table 4). Maximum weight in the first-parameter column (0.981) is related to chlorine, so this parameter is considered as the main parameter influencing the water quality in qanats. Also, the highest weight in the second, third and fourth-parameter columns is dedicated to carbon (0.918), SAR (0.869) and Bicarbonate (0.954), respectively. Therefore, these four parameters (chloride, carbonate, SAR and bicarbonate) are the most important variables that affect water quality of qanats in the studied area.

As a whole, the most effective parameters affecting water quality in wells are cations and those effecting qanats are anions. These changes can be related to main geological formations in the studied area.

Table 4. Rotated Component Matrix in Qanats

	Component			
	1	2	3	4
K	0.508	0.360	-0.109	0.660
Na	0.854	0.198	0.479	-0.001
Mg	0.923	0.213	0.029	0.280
Ca	0.929	0.318	0.106	0.023
So4	0.009	0.423	0.766	0.396
Cl	0.981	0.138	0.086	-0.090
Hco 3	-0.074	-0.088	0.185	0.954
Co3	-0.321	-0.918	-0.160	0.063
Ph	-0.608	-0.757	0.004	-0.206
Tds	0.925	0.234	0.296	0.034
Ec	0.927	0.233	0.292	0.034
Th	0.939	0.282	0.077	0.123
Sar	0.393	-0.086	0.869	-0.030

Considering the results of factor analysis, sodium and chlorine are the most important parameters influencing water quality in qanats and wells, respectively. Therefore, spatial and temporal variations of these two parameters in drought and wet years and general trends of them in 1993-2008 are considered. This selection provides general data to get a good management pattern by minimum time and charges. 7-year Moving Average for the years 1993 to 2008 illustrates drought years before 2002-2003 and thereafter, wet years are dominate (Fig. 2).

The results of spatial analysis showed that IDW (with power =2) and Kriging methods had minimum errors and are found as the best interpolator methods for showing the spatial variations in chlorine and sodium parameters, respectively (Table 5). Spatial variation map of and water quality of wells and qanats based on the main effecting parameter is depicted in Figs. 3 and 4.

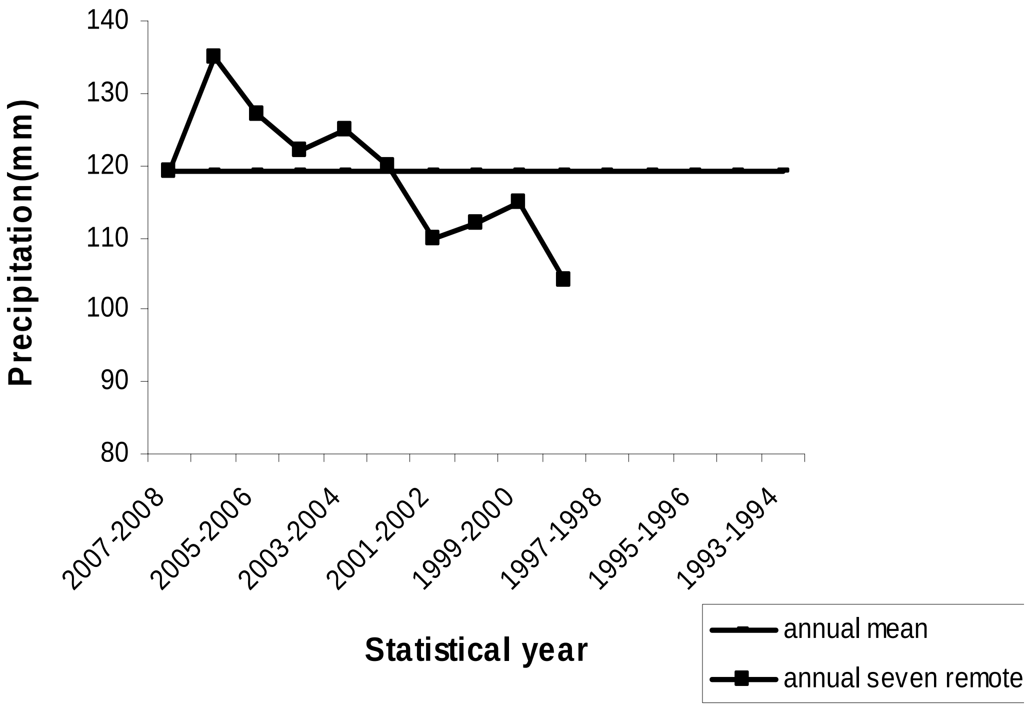

Fig. 2. 7 Year Moving Average

Table 5. Comparison of Interpolation Methods

Interpolation method / Error criteria	Thin Plate Spline	Inverse Multiquadric	Multiquadric	Spline with Tension	Regularized Spline	Kriging	IDW (power =4)	IDW (power =3)	IDW (power =2)	IDW (power =1)	Water resource
RMSE	40.86	26.33	26.59	26.31	26.27	26.52	28.58	27.04	25.68	26.27	Qant
MBE	6.32	-1.38	2.053	-1.04	-0.86	-0.65	2.51	1.91	0.61	-1.56	
RMSE	9.36	6.33	6.78	6.38	6.51	6.18	6.78	6.72	6.68	6.68	Well
MBE	-1.76	-1.54	-1.11	-1.31	-1.48	-1.11	-2.28	-2.27	-2.16	-1.71	

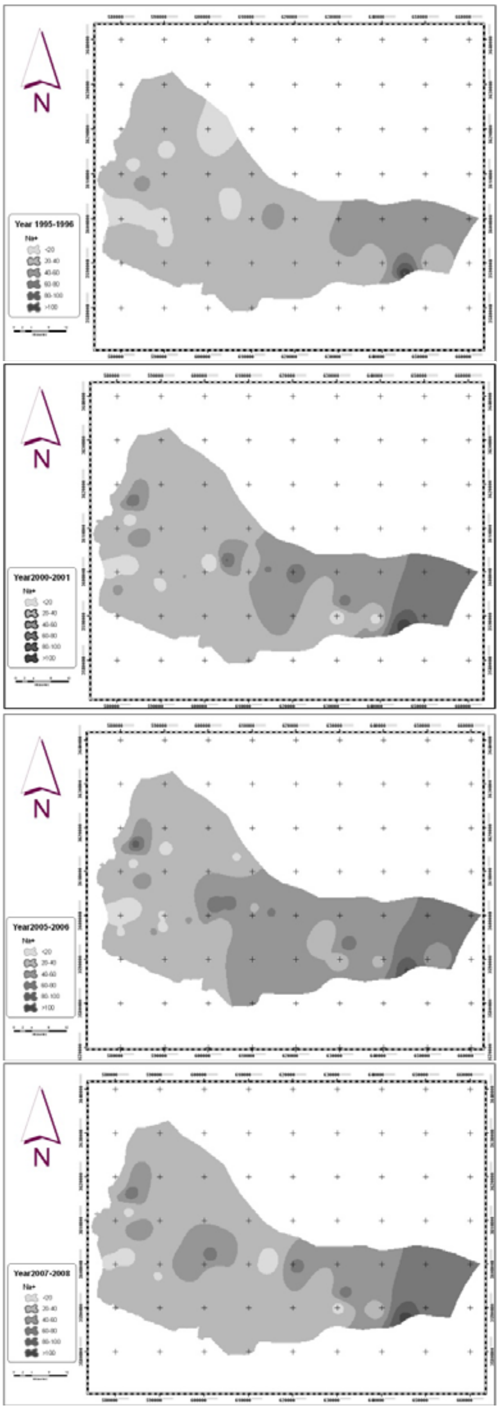

Fig. 3. Well Water Quality Variations Based on Na^+

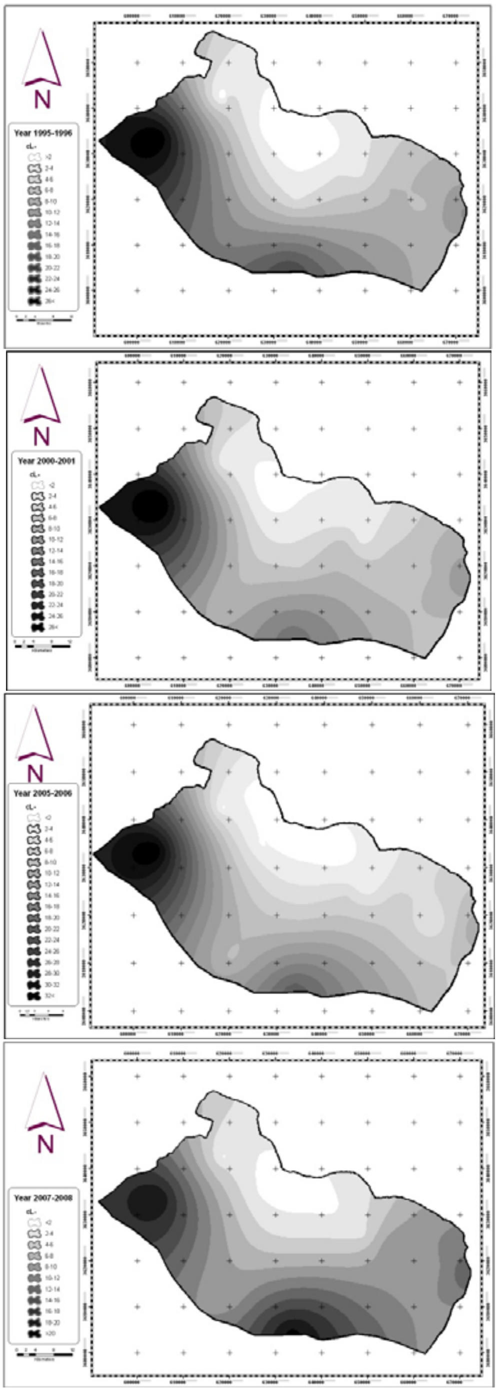

Fig. 4. Qanats Water Quality Variations Based on cL^-

As (Fig. 2) shows, 1995-1996 to 2001-2002 are drought years and after 2002-2003, wet years were started. Temporal variations of this parameter show that water quality during drought year is degraded and in wet year, it is extremely improved initially but thereafter, it is degraded. But water quality variation in qanats assessed by the most affecting factor i.e. chlorine, shows the minimum variations.

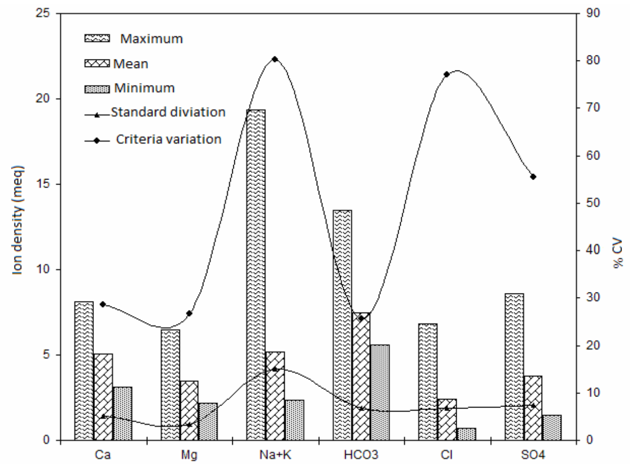

Fig. 5. Coefficient of Variation (CV) in Studied Parameters of Wells

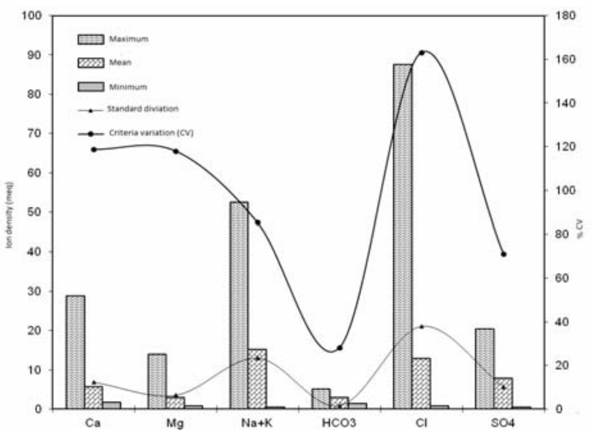

Fig. 6. Coefficient of Variation (CV) in Studied Parameters of Qanats

Conclusion

Travertine formation and mineral spring as the major geological factors increased salts in the north part of study area that directly affects the quality of ground water resources.

When water flows in the north part of study area toward the center, it is affected by geological changes. Marls extremely changes chemical characteristics of ground water and they clearly cause water quality degradation by increasing deep and semi-deep wells in this area.

In other hand, marshy areas which are stretched from north (Barkhowar) to south of Segzi (near Kohpayeh) are other effective parameters. Salinity in Kohpayeh-Segzi increases from northwest to southeast as it is noticeable in Segzi plain. It is resulted from compaction of clay and salt formations (create relatively impervious lands) and very high water levels (causing severe evaporation). As a whole, by going toward the east of studied area, high and very high salinity values are observed.

Sulphatic water of qanats which is detected as a small area of studied aquifer between carbonate waters is related to pyrite schist formations. It also seems that Sodic water is resulted from the effects of compact and saline clays that cover a large part of studied area. This formation is probably related to lake formations after Miocene Period. Recharging water from available lake deposits of clay and marl (after Miocene Period) increases salts, especially in Cl and Na in ground water of adjacent area. Salt values are commonly increased from west to the east of studied area.

(Figs. 5 and 6) shows, the coefficient of variation (CV) in the studied parameters of wells *and qanats, respectively. According to these Figures, maximum coefficient of* variation *in* wells and qanats is dedicated to sodium and chlorine, respectively. This finding confirms the important role of sodium and chlorine concentrations in the study area as the results of factor analysis.

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