Assessment of groundwater/surface water interaction using statistical analysis

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ABSTRACT
Hydrologic interaction between surface water (SW) and ground water (GW) in arid regions when the surface water contains pollutants is an important issue in water resources management. The interaction of GW/SW along Gharachai River, central part of Iran, was investigated. Results of cluster analysis showed that corresponding SW and GW stations (stations close to each other) were classified with the same trend, which could be an indication of the interaction of SW and GW. Analysis of variance of the data showed that changing the source of water (GW or SW), location of sampling, and the interaction of these two had significant effect on measured nitrate concentration. In case of electrical conductivity (EC) and total dissolved solids (TDS) only the source of water (GW or SW) and location of sampling had significant effect on measured values. In case of Cl only the location of sampling has a significant effect on measured Cl concentration.

RÉSUMÉ
L'interaction hydrologique entre l'eau de surface (SW) et l'eau souterraine (GW) dans les régions aridecontines quand l'eau de surface contient des polluants sont un problème important dans la direction de ressources d'eau. L'interaction de GW/SW le long de la Rivière de Gharachai, la partie centrale d'Iran, a été examiné. Les résultats d'analyse de Groupe ont montré que correspondant les stations de SW et GW (les stations ferment à chaque autre) ont été classifié avec la même tendance, qui pourrait indiquer l'interaction de SW et GW. L'analyse de variance des données montrées que changeant la source d'eau (GW ou SW), l'emplacement d'essaie, et l'interaction de ces deux effet significatif eu sur la concentration de nitrate mesurée. En cas de la conductivité électrique (CE) et total a dissous des solides (TDS) seulement la source d'eau (GW ou SW) et l'emplacement d'essaie l'effet significatif eu sur les valeurs mesurées. En cas de Cl seulement l'emplacement d'essaie a un effet significatif sur la concentration de Cl mesurée.

1 INTRODUCTION

About 98 percent of the world’s water is salt water. Out of the remaining 2% freshwater, 87% is frozen, forming the polar ice caps, glaciers, and icebergs. So there remains about 0.2 percent available fresh water contained in springs, rivers, lakes, groundwater, etc (Loftas, 1995). Population growth and industrial development have resulted in increasing demand for water on one hand and pollution of water resources on the other hand. Therefore, to achieve a sustainable development it is necessary to have an appropriate management system to protect the existing water resources.

Groundwater (GW) and surface water (SW) are not isolated components of the hydrologic system but instead interact. Thus, it is important to acquire knowledge of the processes that play a role in the interaction between groundwater and surface water when dealing with water resources management in an area. In arid regions where the main water source is ground water, the interaction of surface and ground water when the surface water contains considerable amount of pollution becomes an important issue (Loftas, 1995).

Surface water bodies are hydraulically connected to ground water in most types of landscapes. Even if a surface water body is separated from the ground-water system by an unsaturated zone, seepage from the surface water may recharge ground water. Hydrologic interactions between surface and subsurface waters occur by subsurface lateral flow through the unsaturated soil and by infiltration into or ex-filtration from the saturated zones (Figure 1). The larger-scale hydrologic exchange of GW and SW in a landscape is controlled by (1) the distribution and magnitude of hydraulic conductivities; (2) the relation of stream stage to the adjacent groundwater level; and (3) the geometry of the stream channel within the plain.

For hydraulically connected stream–aquifer systems, the resulting exchange flow is a function of the difference between the river stage and aquifer head. A simple approach to estimate flow is to consider that flow is a direct function of the hydraulic conductivity and head difference, based on Darcy’s law.

In general, subsurface flow through porous media is sluggish and much slower than SW. As a result the rate of contaminant transport is much slower compared to SW. However, when contaminated it takes more time and money to clean up GW. As mentioned, one source of pollution of GW could be its interaction with contaminated

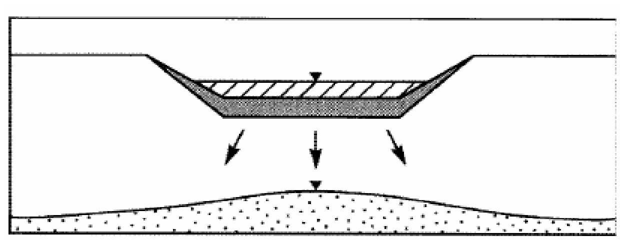

Figure 1: Interaction of GW and SW

SW, which could be an important issue in arid and semi arid regions.

Studies of the interaction between groundwater and streams have been developed through different approaches. Langhoff et al. (2006) considered stream–aquifer interactions from a hydrological, geophysical and geomorphological point of view. Nemeth and Solo-Gabriele (2003) evaluated a method to quantify water exchange based on the reach transmissivity concept. Keery et al. (2007) explored a method of utilizing temperature time series to calculate vertical water fluxes across riverbed sediments. Moran and Brabets (2005) investigated the water quality and GW/SW Interactions along the John River near Anaktuvuk Pass, Alaska, during 2002–2003. GW/SW interaction of the upper John River was studied by a numerical groundwater flow model of the headwater area of the John River. Oxtobee and Novakowski (2002) analyzed groundwater–surface water interaction by considering mainly electrical conductivity, temperature surveys, isotopic analysis and mixing calculations, together with hydraulic head and discharge measurements. Mencio and Mas-Pla (2008) employed multivariate analysis in a hydrological study to determine surface water origin and its interaction with groundwater in Mediterranean streams. Principal component analysis (PCA) and cluster analysis of the PCA results showed the significance of the interaction between streams and aquifers.

One way of quantifying the interaction between a groundwater flow system, and stream environment is to conduct field investigations to measure the exchange. Detailed measurements of stream discharge and water quality parameters along with statistical analysis of the collected data can be used to assess GW/SW interaction. Statistical analysis techniques such as cluster analysis have been widely used in environmental studies to reduce the complexity of large scale data sets. These techniques identify structure in the data set, and reveal relationships between the data components, so that important information may be retained, while noise is discarded.

In the present work, the interaction of GW/SW along Gharachai River, central part of Iran, was investigated using field measurement and statistical analysis of the collected data.

2 MATERIALS AND METHODS

Gharachai River is located in the central province of Markazi, Iran, and is the main receiving water body for discharges from municipal as well as industrial effluents of the region. Since ground water is the main source of water in the region it was decided to investigate the interaction of this river's water with ground water from qualitative aspect, especially during the low flow conditions, where the pollution load of the river is at its maximum levels. Samples were collected both from river water and groundwater and analyzed for common quality parameters such as NO_3, EC, TDS, and Cl.

Results were compared using statistical analysis to investigate the interaction of the groundwater and surface water. The water quality of GharaChai River at upstream is such that it is suitable for irrigation purposes. As the water moves along its path toward downstream the quality of water degrades due to discharge of a variety of pollutants.

To achieve the objectives of this research samples from river water at 10 stations and groundwater from 10 wells along the river were collected every two months and analyzed for EC, TDS, NO_3, and Cl for a period of one year. EC and TDS were measured on site using portable equipment. The samples were collected in plastic containers and transferred to laboratory for the analysis of Cl and NO_3 according to Standard Methods (APHA, 2005). The location and coordinates of the sampling points are presented in Figure 2 and Table 1.

Table 1. UTM Coordinates (zone 39) of sampling points

	SW Station Coordinates		GW Station Coordinates	
1	369199	3748522	368178	3747628
2	366496	3749391	351773	3754788
3	360895	3757606	351891	3756048
4	350839	3758883	351891	3756048
5	347968	3767686	342026	3767954
6	348893	3772091	348007	3768271
7	346996	3788111	348112	3768467
8	345905	3794138	347476	3784127
9	338041	3802952	342680	3794708
10	330438	3810822	329585	3810748

3 RESULTS AND DISCUSSIONS

As mentioned the GW flow is slow and as such it takes a considerable amount of time for contaminants to move compared to SW. Thus, for some parameters such as BOD, which could be changing through time the concentrations in GW and its trend could be different from SW. For this reason parameters such as NO_3, EC, TDS, and Cl were chosen in this research.

SPSS software was used to analyze the results using Cluster analysis. Cluster analysis, using Ward method, was conducted for average values (average of 6 sampling events) for river stations, GW wells and qualitative parameters. Based on similarities of the collected data, presented by Euclidean distance, they are classified in different groups. The results are presented in Figures 3 and 4.

As it can be seen from Figure 3, river stations 2, 3, 4, 6, and 7 are grouped together and are different from other stations. These stations are located in the same region and the variations of the concentrations are similar. Stations 1 and 5 are grouped together next to the previous group. These two stations are located at the upstream points and hence show similar trends. Stations 8, 9 and 10 are located downstream of discharge points of agricultural and domestic wastewaters and have similar quality as they are grouped together.

Figure 4 shows that GW wells located in the same region are not necessarily classified in the same group. While wells 3, 4, 5 and 6 of groundwater which are at the same zone of the river and groundwater are grouped together, wells 1, 7 and 9 or wells 2, 8 and 10 are classified in the same group. This could be due to the fact

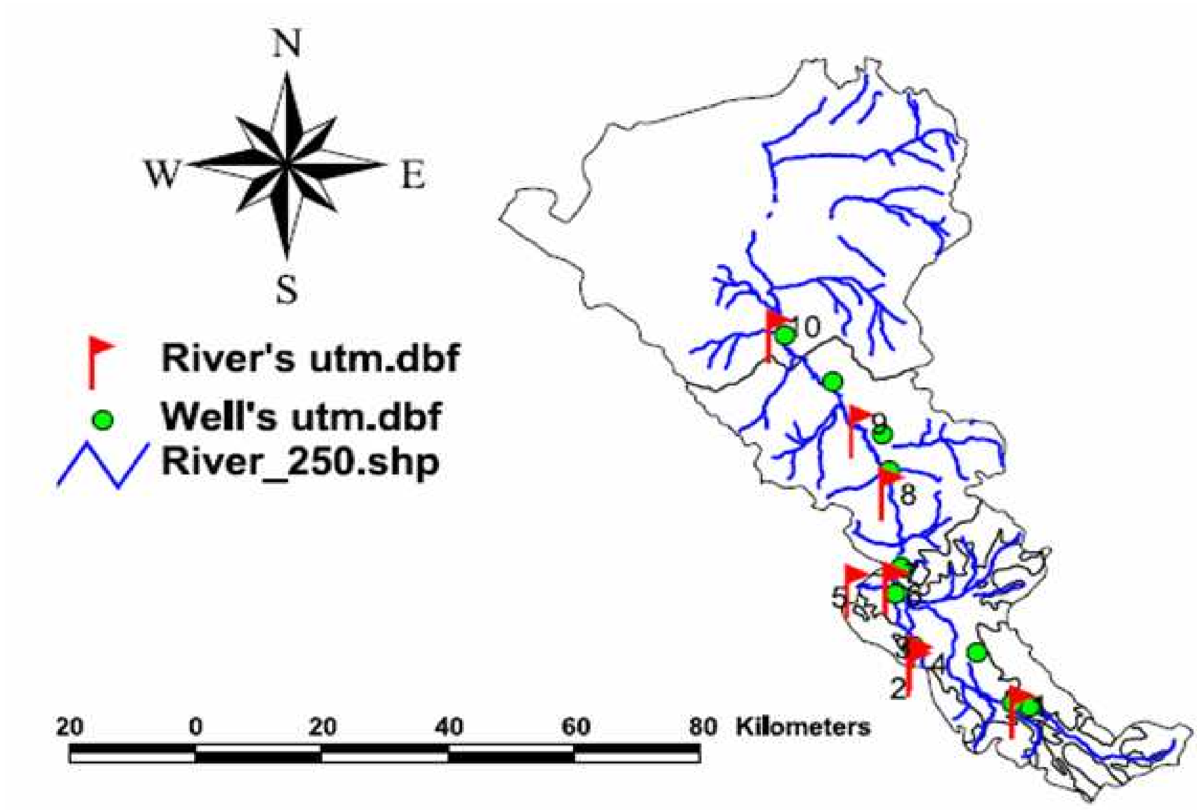

Figure 2: Location of sampling points

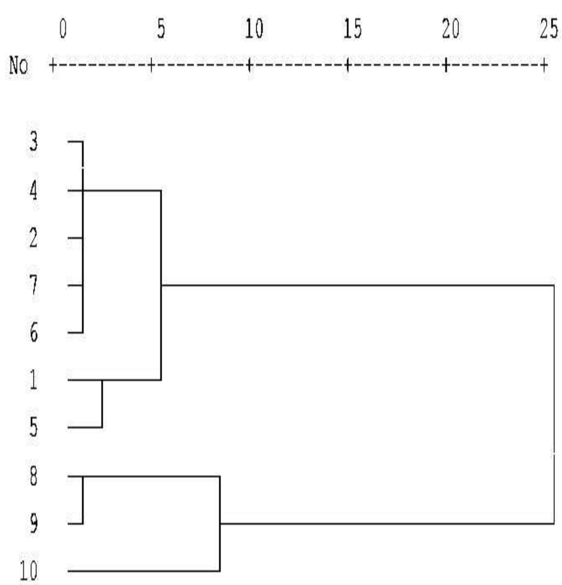

Figure 3: Results of Cluster Analysis for River Stations

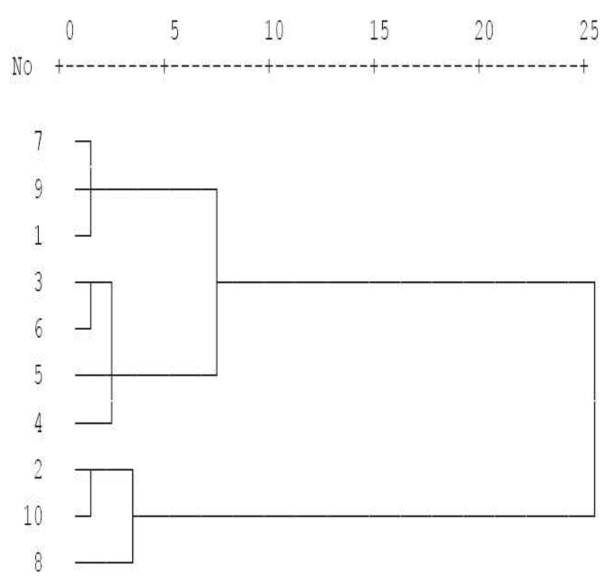

Figure 4: Results of Cluster Analysis for GW Wells

that as water moves through subsurface over longer periods of time its quality will change. Nevertheless, corresponding SW and GW stations (SW and GW stations close to each other) are more or less classified in the same manner, which could be an indication of the interaction of SW and GW.

Correlation matrix of the collected data (average values) are presented in Tables 2 and 3. Smaller values of Euclidean distance show better similarities. The results are the same as cluster analysis.

Analysis of variance (ANOVA) was also conducted using SAS software to evaluate the variations observed in collected data. The results for nitrate are presented in Table 4. They show that changing the source of water (GW or SW), location of sampling, and the interaction of these two parameters have significant effect on measured nitrate concentration. The results of ANOVA for EC are presented in Table 5. They show that changing the source of water (GW or SW) and location of sampling have significant effect on measured EC concentration, but the interaction of these two parameters has no significant effect on measured EC concentration. The results for TDS were similar to EC as expected, see Table 6. In case of Cl, see Table 7, only the location of sampling has a significant effect on measured Cl concentration.

4 CONCLUSIONS

Results of Cluster analysis showed that corresponding SW and GW stations (stations close to each other) were classified with the same trend. This could be an indication of the interaction of SW and GW. Analysis of variance of the collected data showed that changing the source of water (GW or SW), location of sampling, and the interaction of these two parameters had significant effect on measured nitrate concentration. In case of EC and TDS only the source of water (GW or SW) and location of sampling had significant effect on measured values. In case of Cl only the location of sampling has a significant effect on measured Cl concentration.

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Table 2: Correlation matrix for river stations based on Euclidean distance

Station	Euclidean Distance									
	1	2	3	4	5	6	7	8	9	10
1	.000									
2	63.599	.000								
3	53.090	10.544	.000							
4	53.943	9.697	1.261	.000						
5	34.057	30.303	19.969	20.681	.000					
6	66.939	3.931	13.986	13.132	33.423	.000				
7	61.019	4.425	8.559	7.577	27.581	7.328	.000			
8	176.136	112.671	123.171	122.366	142.863	109.458	115.606	.000		
9	172.780	109.379	119.879	119.072	139.568	106.184	112.394	5.011	.000	
10	301.773	239.276	249.612	248.863	268.975	235.912	242.597	129.380	132.023	.000

Table 3: Correlation matrix for GW stations based on Euclidean distance

Well	Euclidean Distance									
	1	2	3	4	5	6	7	8	9	10
1	.000									
2	179.013	.000								
3	86.899	252.830	.000							
4	118.370	286.640	33.932	.000						
5	35.391	210.375	54.164	84.265	.000					
6	64.394	226.531	26.347	60.232	35.945	.000				
7	19.056	163.873	105.290	136.725	52.848	82.357	.000			
8	237.079	85.230	319.648	353.026	271.297	293.837	219.534	.000		
9	35.910	148.291	121.800	153.591	69.777	98.177	17.230	202.476	.000	
10	197.913	19.483	272.034	305.813	229.429	245.738	182.510	73.111	166.709	.000

Table 4: Results of ANOVA for nitrate

Source of Variation	Mean Square	Degrees of Freedom	F
Water Source (WS)	227.16645	1	0.0161
Location (L)	80.50211	9	0.0341
WS x L	89.12424	9	0.0189
Error	37.90261	100	

Table 5: Results of ANOVA for EC

Source of Variation	Mean Square	Degrees of Freedom	F
Water Source (WS)	269354.35	1	<0.0001
Location (L)	57702.48	9	0.0005
WS x L	28134.65	9	0.0748
Error	15512.89	100	

Table 6: Results of ANOVA for TDS

Source of Variation	Mean Square	Degrees of Freedom	F
Water Source (WS)	11009.41	1	<0.0001
Location (L)	13215.56	9	0.0005
WS x L	5603.79	9	0.0748
Error	7810.69	100	

Table 7: Results of ANOVA for Cl

Source of Variation	Mean Square	Degrees of Freedom	F
Water Source (WS)	0.3185	1	0.9283
Location (L)	95.94	9	0.0147
WS x L	48.37	9	0.2820
Error	39.14	100	

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