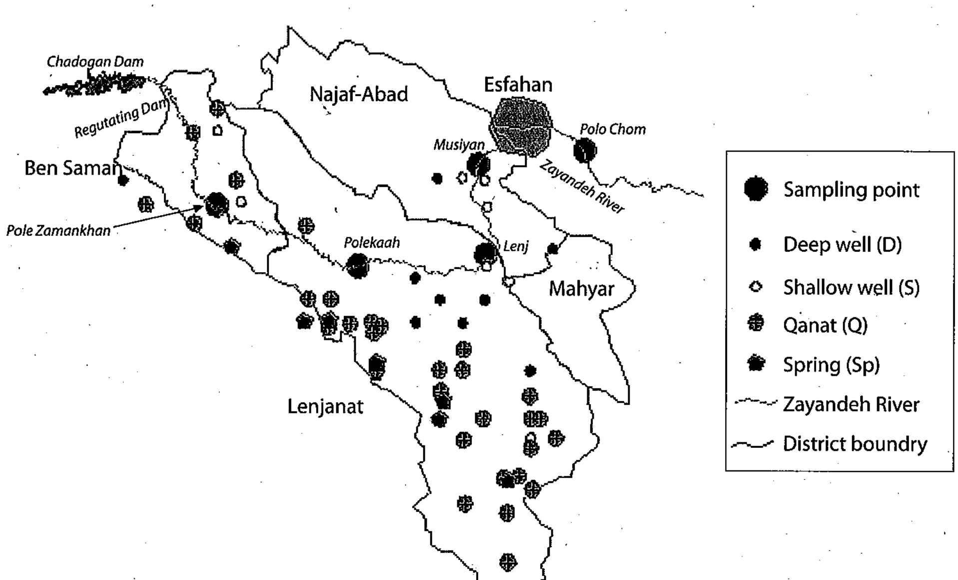
4.9. Variations in groundwater chemistry to identify source of groundwater

A. Gieske, M. Miranzadeh and A. Mamanpoush

Groundwater plays an important role as an additional source of water when surface water supplies become stressed, and the Zayandeh Rud is no exception. The domestic and industrial water supply for Esfahan is augmented with groundwater in summer. In the irrigation command areas, many farmers operate wells close to the irrigation channels, and during the 2000-2001 drought, groundwater was the only significant source of irrigation water. Further away from the irrigated areas, groundwater plays a dominant role in providing drinking water to small villages and small-scale irrigation schemes. Traditionally, the groundwater was tapped by kanats and hand-dug wells. However, in recent years, many deep tube wells have been drilled that have lowered water tables substantially in both irrigated and non-irrigated areas. In recognizing both the potential of groundwater and the possibility of it being over-exploited, the Ministry of Energy has monitored water levels and quality in the entire Esfahan Province since the early 1980s (Raeisi 1995). The total number of wells monitored exceeds 700, scattered throughout the province.

In view of the large amount of hydrochemical data available, it was decided to make an exploratory study of the Lenjanat sub-catchment along the Zayandeh Rud to see if it was possible to identify the extent to which groundwater is largely recharged from the Zayandeh Rud or if it was derived from other sources (figure 4.29.). The Lenjanat sub-catchment was selected because it is upstream of the major irrigation systems and thus represents a situation reflecting the overall hydrogeology of the basin.

Figure 4.29. Location of ground and surface-water sampling points in Lenjanat sub-catchment.

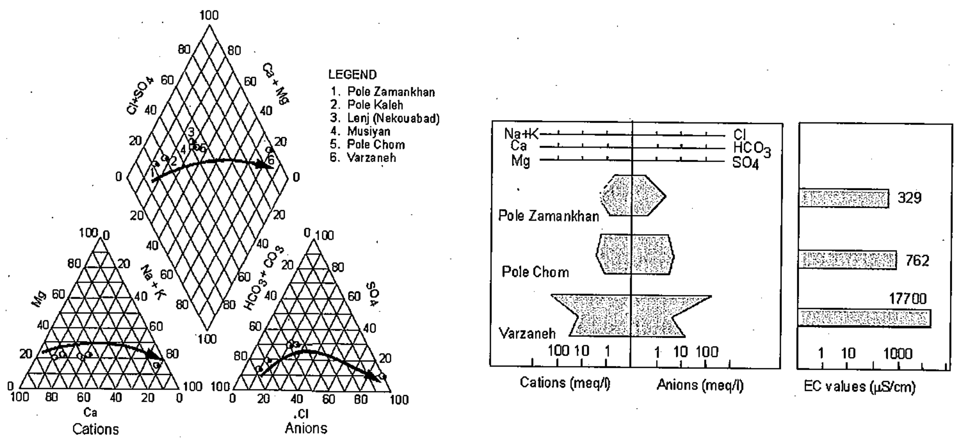


4.9.1. Surface water composition

Average EC values for three stations along the Zayandeh Rud at Pol-e-Zamankhan, Pol-e-Chom and Varzaneh show significant differences—from the first station (close to the Chadegan Dam) to the second (downstream of Esfahan) there is an increase in EC from 0.33 to 0.76 dS m^{-1}, while from the second to the third station (close to Gavkhouni Swamp) the EC increases to 1.7 dS m^{-1}. Therefore the largest increase in EC occurs well beyond Esfahan. While flowing through the Lenjanat District the electrical conductivity of the Zayandeh River water increases only from 0.3 to about 0.6 dS m^{-1}.

The changing ionic composition of the Zayandeh water is shown in a Piper diagram and in three Stiff diagrams (figure 4.30). The Piper diagram clearly shows that the initial composition plots as Ca^{++}-$HCO3^{-}$ type water, as is expected in a limestone/dolomite environment with relatively high recharge. The Stiff diagram for Pol-e-Zamankhan shows the typical diamond shape of this type of water (Journel 1989). Further downstream, past Esfahan at Pol-e-Chom, the ionic concentrations of sodium, chloride, magnesium and sulphate have increased relative to those of calcium and bicarbonate, and water quality declines sharply. This leads to a more rectangular shape of the Stiff diagram. The Piper diagram shows that the further the sampling points are downstream of Chadegan Dam, the further they plot to the right, following the direction of the three arrows towards the right-hand corners of the rhombus and the two triangles. Finally, in Varzaneh, the ionic composition of the water is dominated by Na^{+}, K^{+}, Cl^{-} and SO_4^{--} and the points are plotted in the far-right corners of the triangles and rhombus. The Stiff diagram for Varzaneh attains the typical hourglass shape, characterizing this highly saline brine. The convex shape of the arrows in the Piper diagram suggests that cation exchange processes are involved. Hence, interaction between surface water and groundwater needs to be examined.

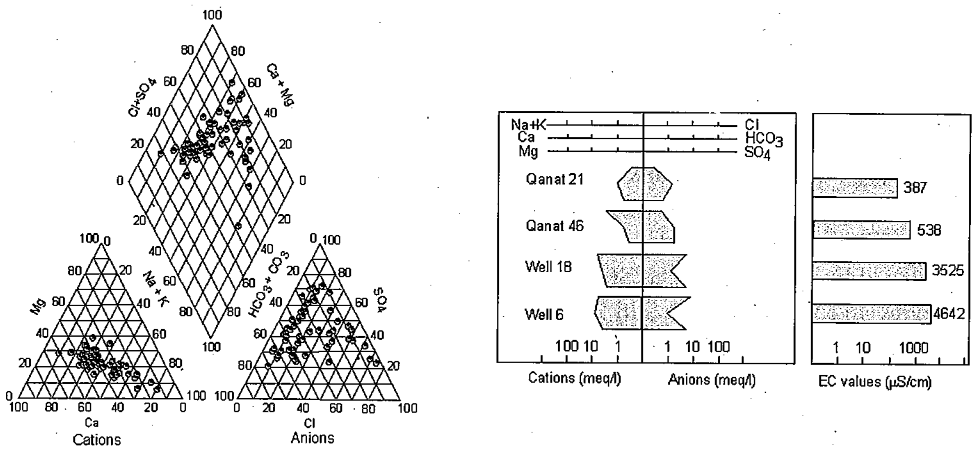
Figure 4.30. Piper and Stiff diagrams showing water composition along the Zayandeh Rud.



4.9.2. Groundwater composition

The ionic content and associated hydrochemical changes of the groundwater in the Lenjanat District are less easily understood, as is illustrated by figure 4.31. The points are scattered over the diagram, while the Stiff diagrams show the presence of different types of water. The program WATEVAL (Hounslow 1995) was used to calculate the Langelier saturation index for calcite and several other indices such as $Na^+/(Na^++Cl^-)$, $Ca^{++}/(Ca^{++}+SO_4^{--})$, $Mg^{++}/(Ca^{++}+Mg^{++})$, $(Ca^{++}+Mg^{++})/SO_4^{--}$ and HCO_3^-/(sum anions).

Figure 4.31. Piper and Stiff diagrams showing water composition of groundwater in the Lenjanat sub-catchment.



The hydrochemistry of the Lenjanat District points clearly at groundwater recharge in carbonate rocks of the southern mountain range. On its way northward towards the Zayandeh Rud, the groundwater may come in contact with gypsum deposits. If it does, gypsum is dissolved and water quality deteriorates. The Piper diagram reveals this pattern. Fresh Ca^{++}-$HCO3^-$ water from the southern mountain range is plotted in the left corner of the rhombus. As the groundwater flows northward, it comes into contact with gypsum deposits. The Ca^{2+} and SO_4^{2-} contents then increase and the composition plots more to the right in the Piper diagram.

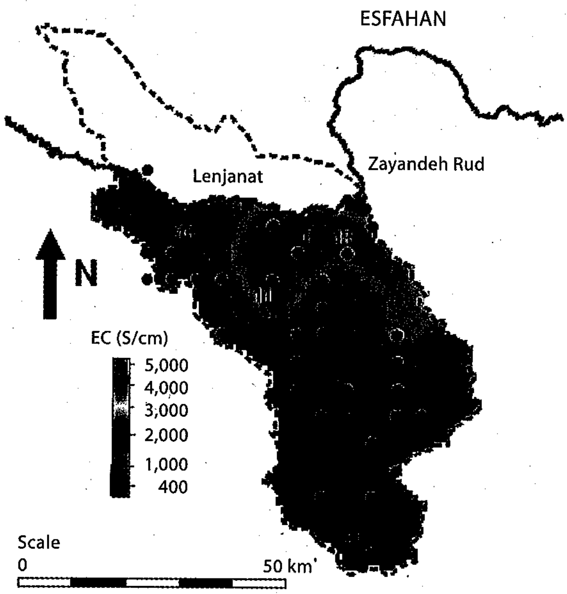
The scattered distribution in the anion triangle may be explained by the fact that gypsum deposits are not equally distributed over the area. If large quantities of gypsum are dissolved, the evolution will be towards the top of the anion triangle, whereas if the presence of gypsum is less strong, the groundwater evolution will be more towards the right-hand apex of the anion triangle with a relatively higher Cl^- content. The variety in Stiff diagrams may be explained similarly.

4.9.3. Analysis of EC values of groundwater

The spatial distribution of the EC values in the Lenjanat District was determined by means of Kriging, using the ILWIS GIS package. A clear picture emerges where groundwater recharge predominantly takes place in the southern mountain range, and where the groundwater becomes more mineralized as it flows northward (figure 4.32.). The high EC values around wells 11, 6 and 18 may have three additional causes:

- The presence of point pollution sources, for example, industry
- The extensive use of groundwater for irrigation in the area around the wells
- The possibility that the deep wells are drilled in a deeper, more saline aquifer

Figure 4.32. EC of groundwater in the Lenjanat sub-catchment estimated through kriging of water quality sample data.



4.9.4. Using chemical analyses to estimate surface and groundwater recharge

Because it seems likely that both groundwater and irrigation return flow reach the Zayandeh Rud and then mix with the fresh river water, it is instructive to make a simple conceptual model of the situation. We consider the stretch of river between Pol-e-Kaleh and Lenj (Nekouabad) as a single cell, as was discussed in Droogers et al. (2000). Five components can be distinguished (as illustrated in figure 4.33.), and their indicative values for flow rates and concentrations are summarized in table 4.12

- River inflow I with concentration c_i
- River outflow O at Lenj with concentration c_o (combining the flow through the river with the irrigation offtake at the diversion weir)

- Groundwater seepage S with concentration c_s
- Irrigation and urban abstraction G with concentration c_g (according to Droogers et al. 2000, this is about 9.5 m³/s on average)
- Return flow R with concentration c_r (10 percent salt sequestration is assumed)

Figure 4.33. Components of Surface and Groundwater Interactions.

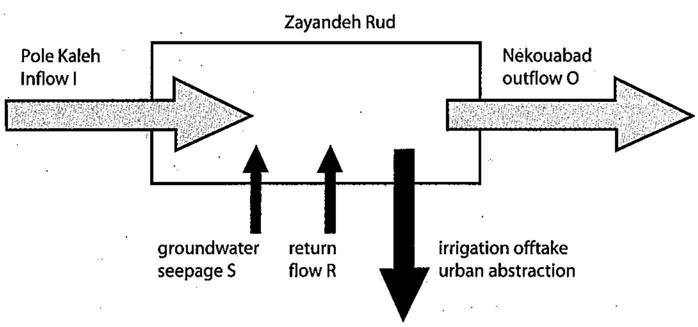


Table 4.12. Concentrations and flow rates of the five component conceptual model.

Flow component		Q (m³/s)	EC (mδS/cm)	TDS
Pol-e-Kaleh inflow	I	54.0	366	256
Nekouabad outflow	O	50.0	575	403
Groundwater seepage	S	?	3,000	2,100
Irrigation/urban	G	9.5	471	330
Return flow	R	?	2,120	1,484

There are two balance equations for the 5 components, resulting from water and solute mass balance conservation. They may be written as:

$$I+S+R=G+O$$
$$C_iI+c_sS+c_rR=c_gG+c_oO$$

Solution yields the following values for return flow R and groundwater seepage S: R = 3.4 m^3s^{-1} and S = 2.1 m^3s^{-1}. Thus, the irrigation return flow percentage becomes: 100*(R/G) = 36%, fully consistent with the results of Droogers et al. (2000a).