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Impacts of Geological Formations on Quality of Groundwater

Case study:centeral iran

Kh. Shafiei Motlagh

Assist Prof, Department of civil Engineering, Dehdasht Branch, Islamic Azad University, Dehdasht, Iran

(Corresponding Author):Kh_shafieimotlaq@yahoo.com

Abstract

Sedimentary environment and impacts of geological formations on quality of groundwater in Navizak, Taleghan was studied. To examine sedimentary environment, we sampled formations and examined the samples at both microscopic and macroscopic scales. For hydrogeochemical analysis of water we used Piper, Stiff, Shuler, Wilcox, star, and composite diagrams. Saturation indices were analyzed using PHREEQC codes. The results indicate that hydrogeochemistry of groundwater at confined aquifers and aquitards is affected by geological formations of the region. At the north and northeast areas, aquitards are predominantly calcium bicarbonate layers. This layer is fed by Karaj formation and the quality observed in this zone is because the layer is located above the upper red formation (URF). The central and southern zones have waters of calcium-sulfate type with acceptable quality for drinking. This is the result of significantly thick layers of clay and marl which reduce hydraulic conductivity, improve water retention, and therefore, increase the amount of salts in groundwater. Although alluvial confined aquifers with layers of salt and gypsum lower the quality of groundwater, however, their undesirable effects can be neglected due to the narrow range of their presence.

Keywords: Hydrogeochemistry; Upper Red Formation; Clay/Marl Layers

Introduction

Chemical properties of groundwater in a region are affected by sediments, evaporation, transpiration, topographical profile of the region, and drought and wetness periods (Anderson *et al.*, 1988). In addition to lithology of aquifers, that controls chemical properties of groundwater, hydreogeological parameters, such as permeability and flow rate, may also play a role in controlling water-rock reactions through changing water sustainability. Lower rates of water flow increases the time period during which water is in contact with rocks, thereby enriching water in salt (Anderson *et al.*, 1988). Quality of groundwater is the result of processes and reactions that occur from water condensation in atmosphere to the time when water rises from wells or springs. Chemical composition, biology, amount of substances dissolved in water, and temperature are among the factors that determine quality of water, its origin, and its path (Alley, 1993).

Type of rocks in an aquifer significantly affects quality of groundwater. Waters rising from lime and dolomite rocks typically have calcium, magnesium, and bicarbonates solved in them. Sulfate is formed through oxidization of pyrite and gypsum. Lime rocks typically become weathered faster than igneous rocks. This is why water found in lime rocks has more substances solved in them. Evaporative rocks are easily weathered and therefore contain extremely salty water. Sulfate and chlorine are dominant anions while sodium and chlorine are dominant cations (Davis and Dewiest, 1966). The more minerals are dissolved in groundwater flowing to discharge point, the higher will be total dissolved solids (TDS) (Hounslow, 1995).

Groundwater is used for drinking, irrigation, and industrial applications. Therefore, required quality of water depends on criteria and standards defined for specific applications. Since most people in Navizak use groundwater for drinking, it is extremely important to determine quality of this water. The present study aims to determine qualitative and quantitative characteristics of groundwater in Navizak, Taleghan and examine the effects of geological formations on the groundwater.

Area

The area studied here covers 11.7 km^2 and is located 120 km north of Tehran at 482000 to 485000 longitude and 400300 to 4010500 latitude. In the state divisions, Navizak basin is located at Mian Taleghan Hamlet, Savojbalagh Town. With an average precipitation of 627.7 mm and average annual temperature of 9.5℃, the area is considered a humid, cold and semi-humid area. The basin is a tree-canal sub-basin of Sefidrud. Topographically, water in this area flows in north-south direction to Shahrud River - the major river in the region. Geomorphologically, the area consists of mountains, floodplains, and hills.

Geology

Navizak basin is a part of Alborz Zone, and therefore its geology and structure is similar to tectonic features of Alborz. The formations in the area are typically in east-west direction. These formations, including Karaj Formation, URF, and Quaternary alluviums, belong to Cenozoic era (Fig. 1).

Karaj Formation consists of two separate parts: one part contains volcanic rocks (intermediate-basic magma) mostly andesite rocks that form a border between mountains and hills (Figs. 2 and 3). The other part is predominated by basanites (with large analcime crystals) found in the form of parallel layers of sill and lopolith between layers of igneous rocks (Tehran Agricultural Jihad, 2001).

Fig 3 Upper red formation touches volcanic rocks of Karaj Formation at north Segran, northeast view,(courtesy of Tehran Agricultural Jihad, 2001)

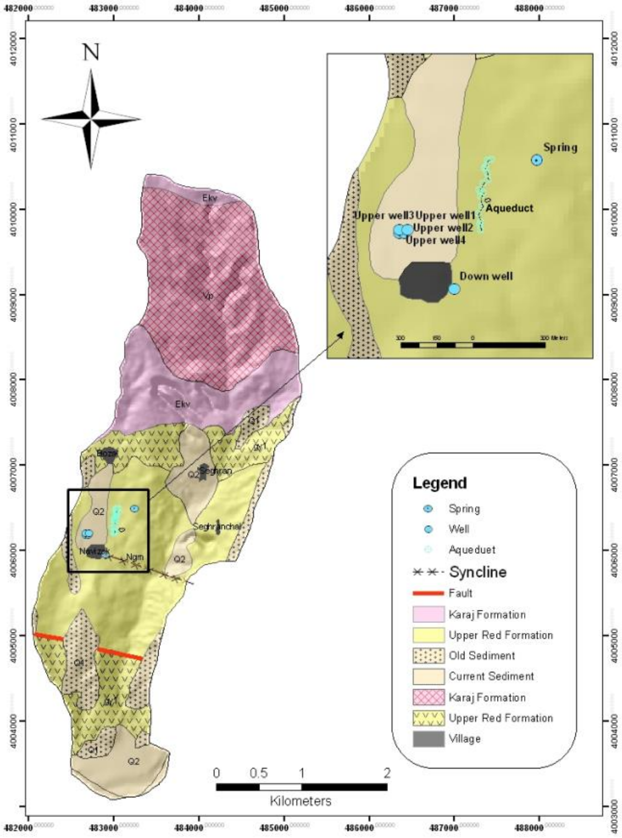


Fig 1 Location of water resources in Navizak on geological map

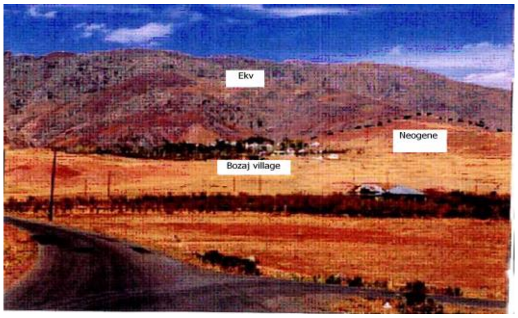


Fig 2 A northward view of volcanic rocks in Karaj Formation (Eocene) with east-west bedding and southward slope (courtesy of Tehran Agricultural Jihad, 2001)

At the southern parts, after Eocene igneous rocks, there are series of Neogene sedimentary rocks (URF). This formation in Navizak basin consists of Ngm and gy_1. Lithologically, Ngm in this area ranges from mudstone, siltstone, marl, lime marl, and limestones to interlayers of gypsum between the layers of marls in the formation (Fig. 4). Gy_1 is composed of mudstone, siltstone, red and gray gypsum from Neogene. At the time when these formations were formed in the salt lake, the water contained high amounts of dissolved salts and gypsum (Tehran Agricultural Jihad, 2001).

Quaternary sediments outcropped at southern and central parts of the area can be divided into two groups: Q_1: old sediments that include sand and coarse sediments, and Q2: current sediments that include alluvial, floodplain, and alluvial fan sediments (Tehran Agricultural Jihad, 2001).

Hydrogeologically, Karaj Formation has a high to average discharge while Quaternary sedimentations have average discharge. The aquifers mainly consist of these formations. URF, that covers a vast area, has low permeability and poor discharge (Fig. 5).

Fig 4 URF marl and mudstone outcrops (Ngm) at southern Navizak (a); dry farming lands spread over URF (Ngm), southern Navizak (b)

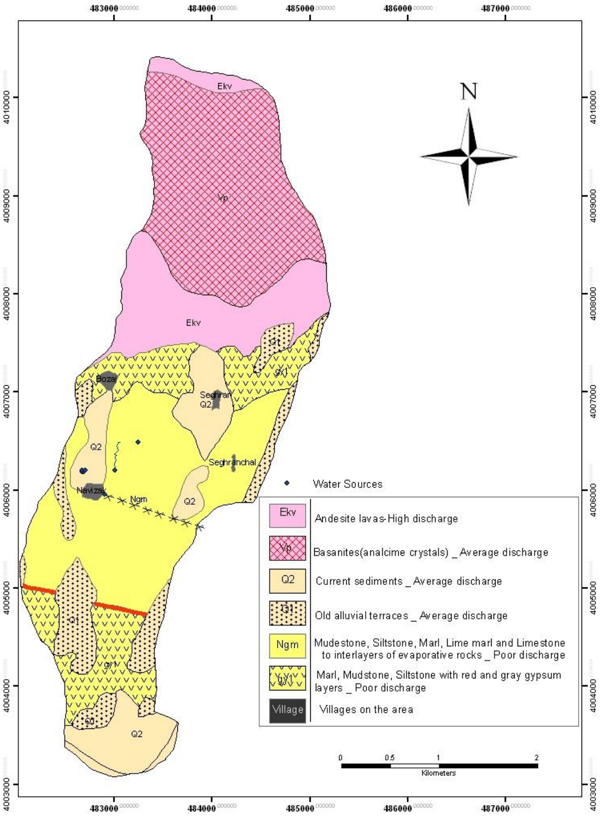


Fig 5 Hydrogeological map of Navizak, Taleghan

Methodology

To examine the sedimentary environment of the area, we conducted geological, geomorphological, and stratigraphic studies on formations in the area. We sampled formations and examined these samples both microscopically and macroscopically. Three marl samples were selected for XRD. Fig. 7 shows the samples picked manually and Fig. 8 depicts their thin sections. Chemical analysis (XRF) was performed on one mudstone sample and one marl sample (Table 1).

In our hydrogeochemical experiments in September 2010, we sampled water from four resources: one spring, one aqueduct, and two wells. We then evaluated electrical conductivity, TDS, pH, concentration of calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, fluoride, nitrate, nitrite, and phosphate ions at Laboratory of Tehran Water & Wastewater Authority (Table 3). Using Excel and AqOa, we represented and analyzed the data on Piper, Stiff, Shuler, and Wilcox diagrams. PHREEQC was used to determine saturation indices for calcite, dolomite, and gypsum, in order to identify geochemical processes in the area. During the field inspections, we determined depth of groundwater and flow direction by observing level of water at wells. Fig. 6 illustrates the flowchart of our study.

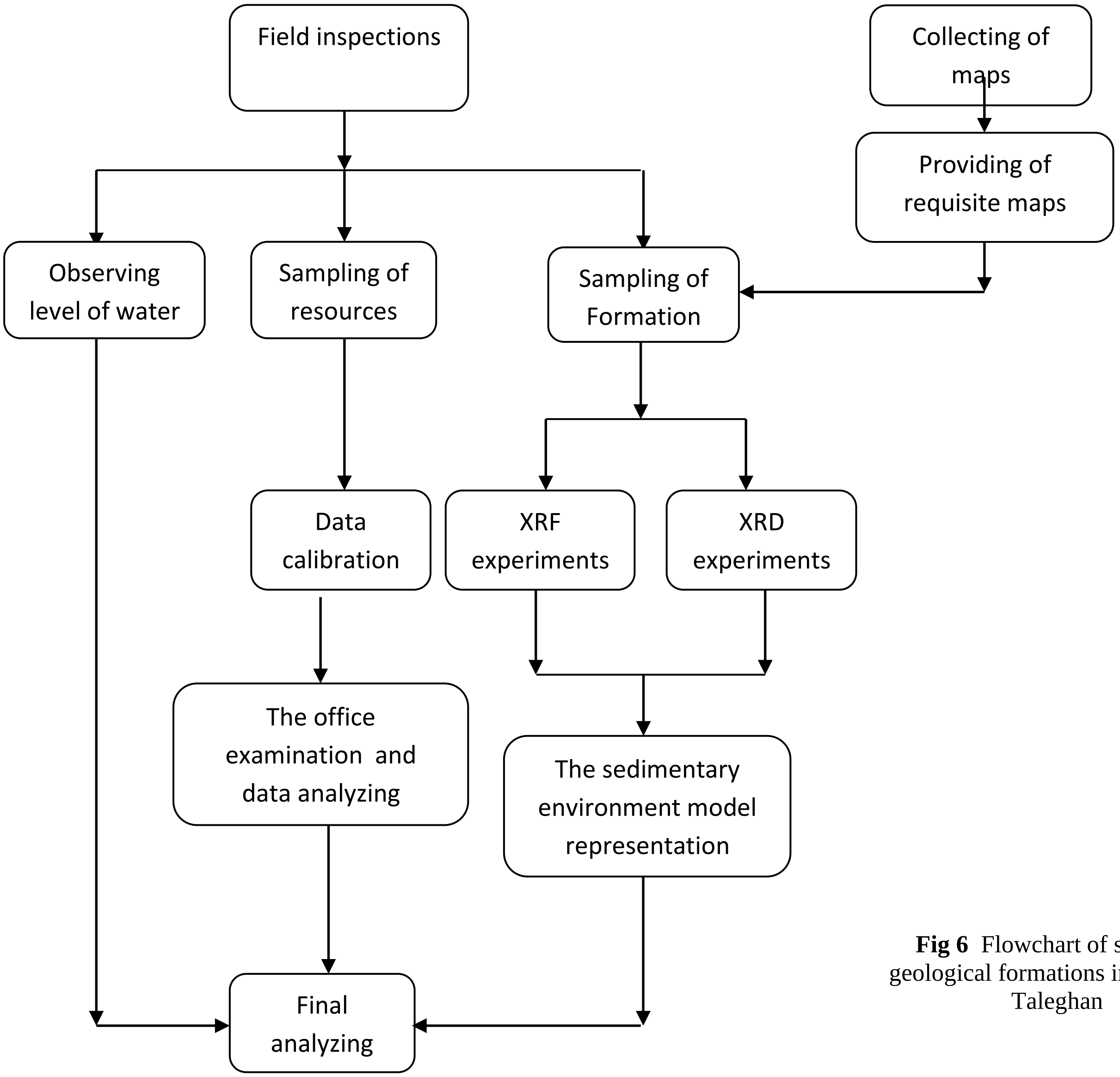


Fig 6 Flowchart of study on geological formations in Navizak, Taleghan

Fig 7 Sampled picked manually from the area, packstone to floatstone (a); marl to lime mudstone (b); gypsum and anhydrite (c)

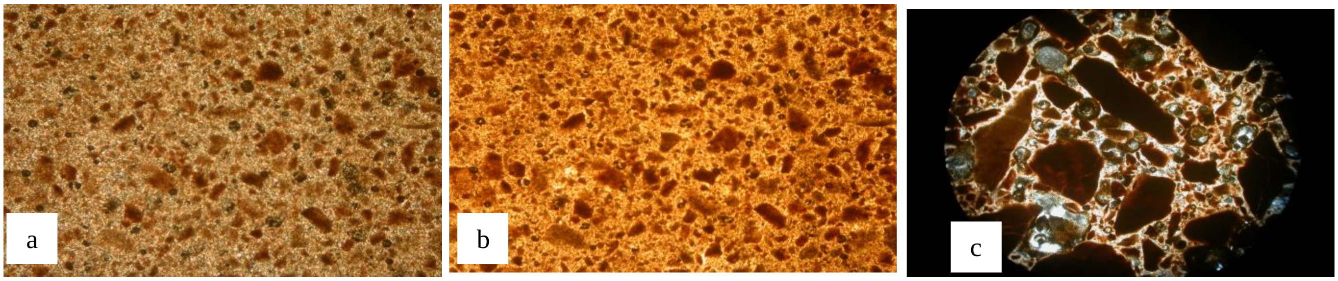


Fig 8 Thin sections (in polarized light), marl to lime mudstone (a); packstone (b); floatstone (c)

Table 1 Chemical analysis (MAGIX-P) XRF for unconsolidated samples

Ngm Unit Oxides	subsurface sample (red), mudstone	Surface sample (white), marl
SiO_2	54.02	48.02
Al_2O_3	15.82	10.77
Fe_2O_3	8.98	3.98
CaO	4.82	14.32
MgO	4.14	3.44
Na_2O	1.25	0.53
K_2O	2.45	2.52
SO_3	0.34	0.95
P_2O_5	0.74	0.18
MnO	0.20	0.13
TiO_2	1.36	0.53
SrO	0.10	0.11
L.O.I*	5.68	14.40

*****Lost of ignation

Discussion

In this study, we examined sedimentary and hydrogechemical environment of Navizak.

Sedimentary depositional environment

Characteristics of the samples taken from Navizak Valley (Table 2) indicate a decrease in environment energy as we move from base of Ngm to the higher elevations since in temporal and spatial sequence, the rocks are ordered as packstone, floatstone, marl, lime mudstone, and evaporative rocks (gypsum and anhydrite). As we move from the base upward, matrix percentage in the rocks increases. This reflects decrease in energy in the environment.

In the sedimentary sequence in Navizak, as we move upward from the base, first we observe carbonated hematized rocks which indicate a marine environment. Then, we find detrital deposits followed by marl and lime mudstones. This means that the environment has become more confined leading to formation of evaporative deposits and rocks. Therefore, sedimentary environment for URF has been a salt lake covered by rocks of Karaj Formation at bottom.

XRF analysis of two unconsolidated samples (Table 1) indicates changes in some oxides such as calcium, iron, and aluminum oxides. Changes in CaO level in the two samples may be attributed to surface and subsurface profiles. However, high concentrations of Fe_2O_3 and Al_2O_3 in the mudstone are the result of climate and environmental conditions. Expanded mudstone depositions and silts can be attributed to existence of floodplains. According to the log of wells drilled in Navizak, there are bands of sands with a thickness of 1 to 2 m (aquifers) between floodplain mudstone depositions. This fine-grained sand-stone facies is the crevasse depositions of meandering river. And this justifies the presence of floodplain, crevasse sediments, and existence of meandering and playa rivers at a lake environment.

Our examinations revealed that in the sedimentary environment, URF is a bedrock on which meandering river has formed floodplains, alluvial terraces, and alluvial deposits with interlayers of evaporative rocks.

Table 2 Thin sections and samples taken from URF at Navizak

#	Relative ratio of main components	Matrix	Cement type	Texture	Structure	Dunham classification	aggregates	Type & size of lithoclast
A	Calcite: 60-70% Hematite: 2-3% Clay minerals: 25-35% Quartz: 5-10%	Clay and micrite (with crystals smaller than 4 µ)	Micrite	Mud-supported	Indeterminate lamination	Marl to lime mudstone	-	-
B	Calcite: 70-80% Hematite: 5-10% Clay minerals: 20-30% Quartz: 2-3%	Clay and micrite (with crystals smaller than 20 µ)	Micrite	Grain-supported	Indeterminate lamination with iron	Packstone	No micrite in lime	Pellet (hematized lime), silt-like
C	Calcite: 70-80% Hematite: 10-15% Clay minerals: 20-30% Quartz: 2%	Micrite and clay (rich in clay)	Micrite	Mud-supported	Indeterminate lamination with iron	Floatstone	No micrite in lime	Inter-clast (hematized lime), sand-like

Hydrogeochemistry

For chemical analysis of water, a well (W_1), a spring (Sp), an aqueduct (Aq) were selected from a low-permeability layer (URF) as well as a well (W_2) formed by a number of wells linked to each other (Fig. 1). Table III shows some of chemical parameters measured for groundwater in the area.

Table 3 Chemical parameters for groundwater (Sp: spring, Gh (aqueduct), W_1 and W_2: wells)

Water sources	**PH**	**Ec(µ mhos/cm)**	**TDS (mg/l)**	**TH (mg/l as $CaCO_3$)**	**Anions (mg/l)**								**Cations (mg/l)**			
					F^-	**Cl^-**	**SO_4^{2-}**	**CO_3^{2-}**	**HCO_3^-**	**NO_3^-**	**NO_2^-**	**PO_4^{-3}**	**Ca^{2}+**	**Mg^{2+}**	**Na^+**	**K^+**
Sp	8.31	349	209	173	0.1	9	5	0	195	5	0.001	0	42	17	10	0.5
Aq	8.31	722	433	307	0.1	28	40	0	315	20	0.006	0	80	26	30	4.5
W_1	7.45	1210	726	490	0.1	60	288	0	278	5	0.001	0	127	42	54	3.3
W_2	7.71	1140	684	484	0.1	50	140	0	434	5	0.001	0	118	46	45	3.1

Facies are classified based on qunatity of major cations and anions (in meq/l) in groundwater (Sikdar *et al.*, 2001). Concentration of major cations and anions, TDS, and ionic ratios are among the most important parameters commonly used to identify groundwater type (Saleh *el al.*, 2001). A comparison between total number of major cations and anions in Collins diagrams (Fig. 10) shows that the highest error is that of aqueduct while the lowest error is observed in W_2. The diagrams have almost equal cation ratios for the water resources. Among these cations, calcium ion has the highest concentration, leading to formation of calcic facies. However, anion concentrations vary from one resource to another. The highest concentration at the spring is that of bicarbonate, the lowest being measured for chlorine and sulfate. As we move to the aqueduct, W_2, and W_1, the concentration of chlorine and sulfate ions gradually increases; in W_1, sulfate ions outnumber carbonate ions and change water type from bicarbonate to sulfate type.

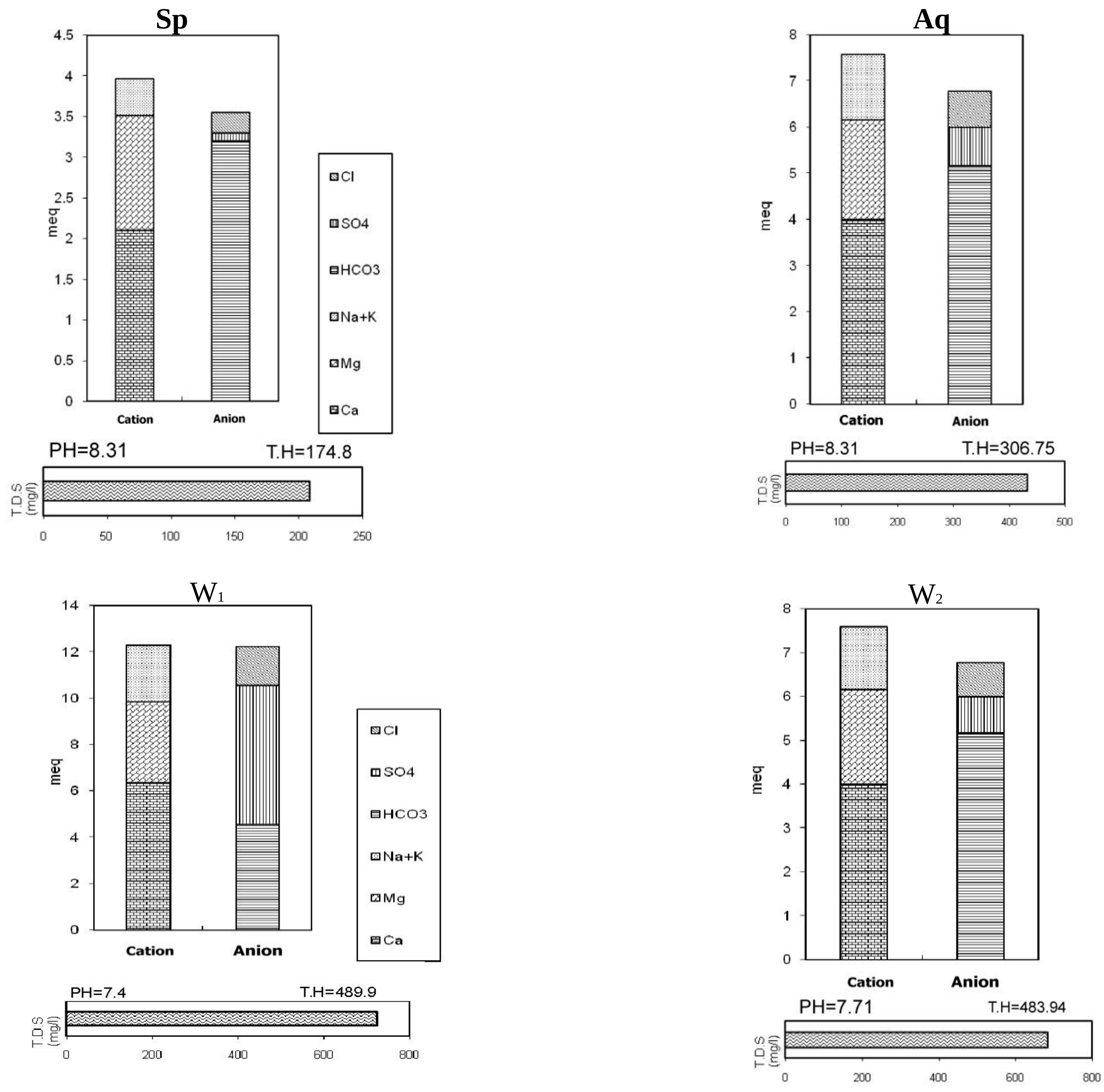


Fig 10 Collins diagram for water resources of the area (September 2010)

In the Piper diagram (Fig. 11), samples taken from the spring (S), the aqueduct (Gh), and W_2 fall in Region 5. This is characteristic of shallow and fresh waters with temporary hardness. while the sample from W_1 falls into Region 9.

No cation or anion predominate this region, showing different types of water are mixed here. Therefore, the area is mostly covered by fresh and nonevaporable water.

The star diagrams clearly show the changes in type of water as we move from spring to W$_1$ (Fig. 12). An investigation of Piper, Collins, and star diagrams indicates two types of water: bicarbonate and sulfate water types. However, the predominant type is bicarbonate water, with sulfate type seen in smaller amounts mostly at central and southern Navizak. The presence of this type may be caused by clay and marl layers fed by Gypsum horizons and interlayers (Neogene evaporative deposits). Bicarbonate type is typically found at northern parts fed by Karaj Foundation. Variations in water type reflect the effects of geological formations on quality of groundwater.

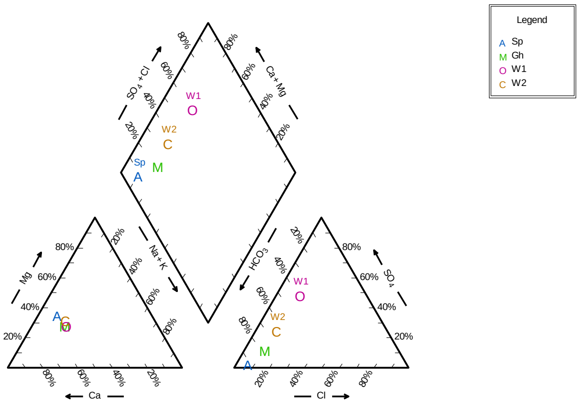
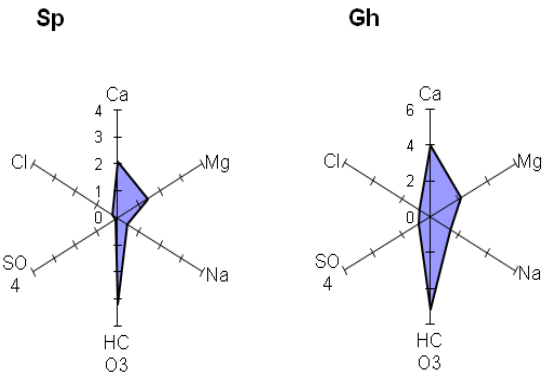


Fig 11 Piper diagram for water resources of Navizak (September 2010)



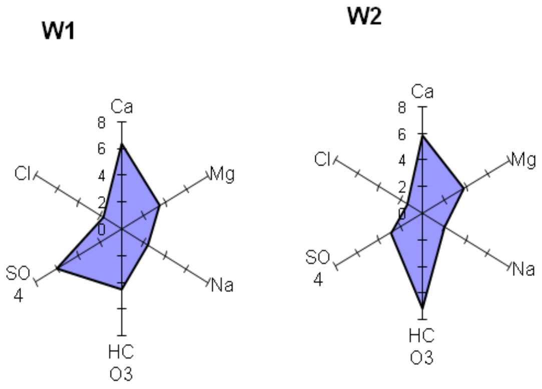


Fig 12 Star diagram for water resources of Navizak (September 2010)

Given the overall shape obtained from Stiff diagrams, one can determine the environment (rocks and deposits) from which water originated. Fig. 13 shows samples originated from different environments (Hounslow, 1995).

As seen in Stiff diagram for water resources of Navizak (Fig. 14), groundwater is of good quality in the covering of spring area. The water originates from andesites in Karaj Formation as well as lime marls. These shapes together with chemical composition of water at aqueduct and W_2 shows limestone and lime marl as origin. These resources have water with lower quality compared to the spring. The shape found in the diagram and water composition at W_1 is totally different from other resources. Since W1 is located at the middle part, Neogene unit with evaporative interlayer has water with poor quality. These characteristics are similar to

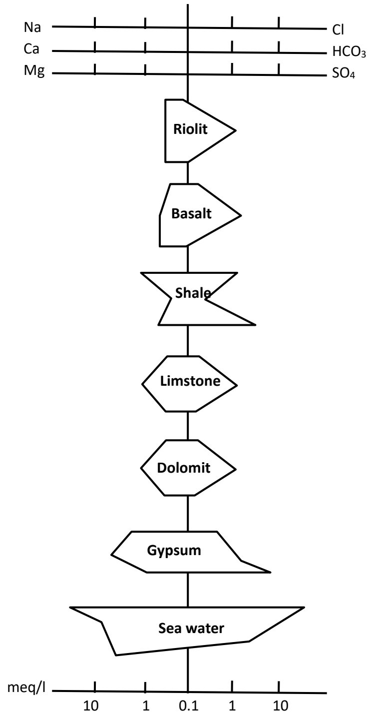


Fig 13 Overall shape of Stiff diagram for samples taken from different environments (Hounslow, 1995)

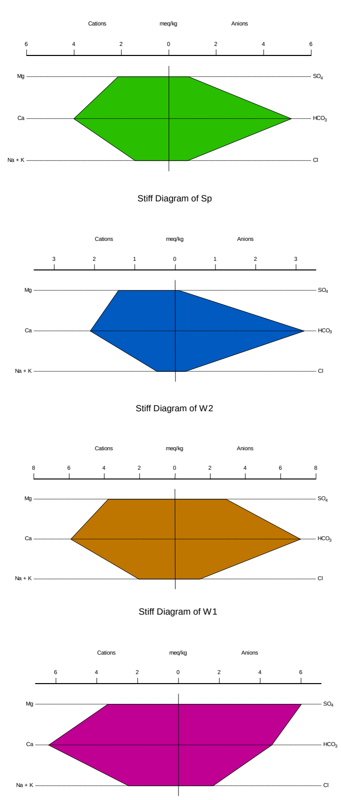


Fig 14 Stiff diagram for water resources in Navizak

For hydrogeochemical study of groundwater in the area, saturation indices were obtained for calcite, dolomite, and gypsum using PHREEQC (Parkhurst and Appelo, 1999). A positive saturated index indicates deposition and when the index is negative, dissolution is expected. Our findings show oversaturation for calcite and dolomite, while negative index for gypsum indicates undersaturation of this mineral in water. This suggests the importance of the effects of carbonated minerals on the chemistry of groundwater. Therefore, in September, sedimentation of calcite and dolomite is expected. Negative index for gypsum indicates continued dissolution of this mineral in water. The dissolution increases as we move from the spring to W_1 because of increased number of evaporative layers. Saturation indices for calcite and dolomite are controlled by calcium, magnesium, and bicarbonate ions. Increased concentration of these ions results in oversaturation of water in calcite and dolomite, thereby deposition of these minerals (Aq). As concentration of sulfate increases, saturation indices for calcite and dolomite slightly decrease. At the central parts of the area (W_1), this creates oversaturated water in calcite and dolomite (Fig. 15).

To determine chemical evolution of groundwater in aquitards and aquifers of Navizak, we examined variations in hardness and partial pressure of CO_2. Figure 16 shows hardness versus the ratio of partial volume of CO_2 dissolved in water to partial value of CO_2 in the atmosphere. The plot indicates chemical evolution of groundwater found in different layers of the area. As seen in the plot, hardness increases as more CO_2 is available for dissolution of limestone in water.

Chemically, groundwater in the area covers a range that starts at average harness and concentration in the spring and ends at it upper limit in W_1. Increase in CO_2 concentration occurs along increased hardness in the path of water flow. Fig.17 depicts total dissolved ions (TDI) versus other major ions in the water resources examined in this study. Given the stability of chlorine ions and their low affinity in chemical reactions, we also provided a graph showing concentration of chlorine ions versus concentration of sodium ions. As TDI increases in the area, so do concentrations of sodium, chlorine, and sulfate ions, indicating dissolution of evaporative minerals (gypsum and halite) in the groundwater. Since the deposits in the middle area have fine grains, groundwater is shallow, and level of evaporation and transpiration is higher compared to other parts of the area, therefore TDI and water-dissolved ions have higher concentrations here. In addition, relative ratio of Na/Cl ions concentration ranges from 1.31 to 1.71. Meyback (1987) believes that ratios higher than one may indicate increased concentration of sodium caused by silicate weathering. If we accept that silicate weathering can potentially contribute to increase in sodium ion concentration, then bicarbonate must be the predominant anion in the waters studied here (Rogers, 1989). Using measurements of depth of water in the well network of Navizak, we examined average depth of groundwater in September 2010. The depth reaches its maximum (20 m) at northeasters Navizak at the last aqueduct shaft (head well) while the shallowest part is observed in southeastern Navizak in a region close to Neogene Formation (less than 5 m). Measurements of groundwater depth at several points indicate that maximum depth is found at foothills while the minimum depth is observed at areas with low permeability. In general, groundwater in Navizak flows from north to south toward Taleghan River.

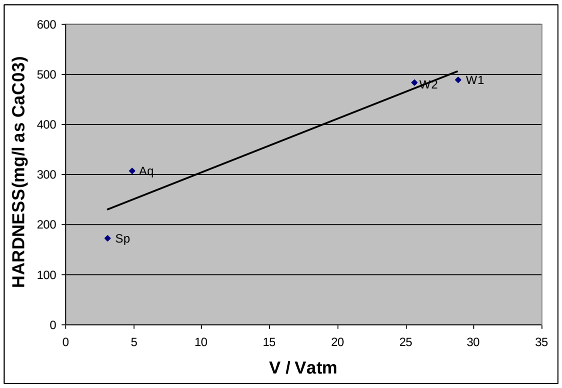
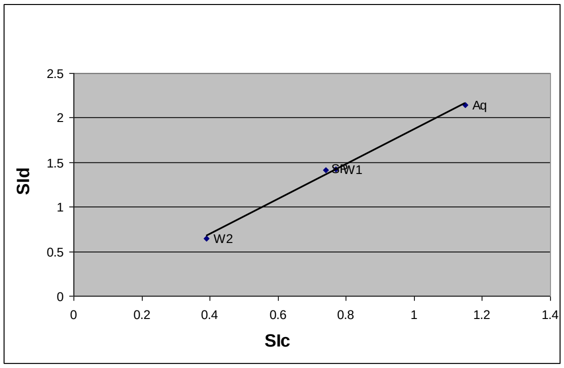


Fig 16 Hardness – ratio pressure of plot for water resources in Navizak, Taleghan (September 2010)



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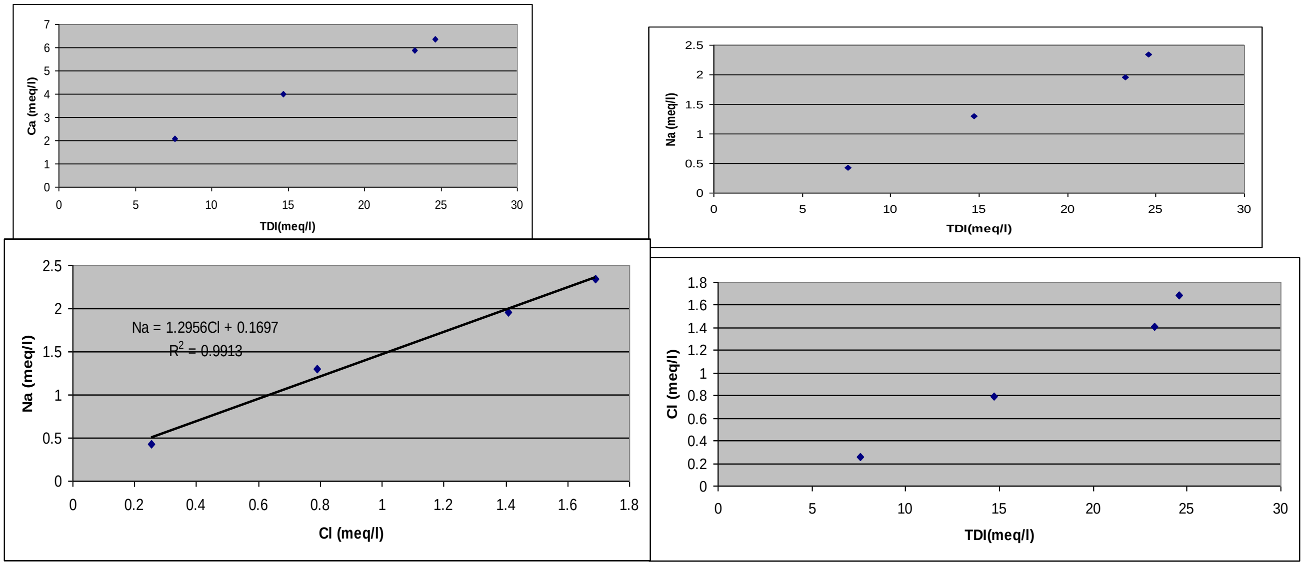

Fig 17 Composite diagrams for water resources in Navizak,Taleghan (September 2010)

Conclusion

According to the findings of XRD analysis, marlstones in Navizak usually tend to become carbonated rather than forming detrital deposits. This is confirmed by the presence of limestone in the area. XRF results show that diagenetic processes and climatic conditions contribute to formation of red deposits (usually mudstone). It can be said that in the sedimentary depositional environment of this area, Neogene deposits have been formed in a salt lake environment with Karaj Formation as its bed. This layer has been then covered by deposits from meandering and playa rivers. In the floodplain of the area, bands of sand (1-2m thick) are observed within mudstone depositions, forming major aquifers in the area. Groundwater in Navizak is, in general, calcium bicarbonate type with calcium sulfate type in smaller amounts. Variations in groundwater type in Navizak indicate the effects of geological formations and shows that the groundwater resources in this area are fed by Karaj Formation. Geochemical nature of aquifers and aquitards in the area ranges from calcium bicarbonate in north and northeastern Navizak to calcium sulfate in central and southern Navizak, along the general direction of groundwater flows. Given the vastness of the area, the upper red formation lowers the quality of groundwater because marl and clay layers together with fine-grain depositions with significant thickness reduce hydraulic conductivity and increase groundwater retention. On the other hand, Quaternary deposits, with their salt and gypsum interlayers, degrade quality of water. However, since these layers are present only in limited parts of the area, their detrimental effects can be neglected.

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