Planning of water supply infrastructure on the basis of sustainable water resources management in Kayseri Metropolitan City, Central Turkey: a plan for the year 2050

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Abstract

The metropolitan city of Kayseri is an ever growing settlement in central Turkey where the climate is semi-arid. The total population of the metropolitan is about 912 000 by the year 2010. Annually about 57.482.766 million cubicmeter of water for domestic use in the municipality is supplied by the Directorate of Water and Sewage Administration of the Kayseri Metropolitan Municipality, directly from groundwater resources. About one fifth of this amount is provided by a spring while the rest is pumped out through boreholes. The groundwater abstracted for use is of high quality owing to the volcanic rock aquifer. However, the aquifer extends beneath the settlement area of the metropolitan city. All the extraction wells are today surrounded by either houses, apartments and industrial complexes. Abondaned waste disposal sites have been located on the top of the aquifer. Being aware of the risk of groundwater pollution, the increasing demand for high quality water has lead the municipality to make a plan to maintain the high quality and sufficient water supply to the inhabitants for the year 2050. A hydrogeological study to appraise the groundwater resources in the area was conducted and the groundwater system is modeled to provide a sound basis for a sustainable use of the groundwater resources.

A major part of the volcanic rock aquifer is overlain by a moderately thick alluvial deposits which form a secondary aquifer in the region. However, the shallow groundwater in the alluvial aquifer is already contaminated by agrochemicals, fertilizers and waste waters during the period before the sewage system had been constructed. There is a delicate hydraulic balance between the contaminated upper aquifer and the lower volcanic aquifer. The two aquifers are separated by massive but slightly fractured basalt which acts as a semipervious layer. Therefore, it is essential to consider this hydraulic balance and the possible interaction between these two aquifers during exploitation of the volcanic aquifer. This paper demonstrates the efficiency of the use of hydrogeological studies as a basis for an efficient plan of water supply infrasturcture of a metropolitan municipality in a semi-arid region in Turkey.

Key Words : Groundwater pollution, Hydrogeological studies, Alluvial–Deep Aquifer.

Introduction

About 70 % of the total water consumed in Turkey for domestic use is supplied from groundwater resources. It is worthy to note that large cities such as Istanbul, İzmir and Ankara rely on surface water resources which requires treatment before use. Groundwater resources are preferred because they do not need treatment a costly process, as surface waters do. However, this does not mean that the groundwater are exempt of contamination. Stresses on groundwater due to the ever increasing population and industrial development over groundwater catchment areas are theretenead by severe pollution and other adverse consequences. Therefore, it is essential to establish a management strategy based upon a thorough understanding of the recharge-discharge mechanism, hydraulic characteristics, interactions between aquifers. The hydrogeological setting should be considered together with the daily water consumption scheme as the stress on the groundwater reservoir. Restoration of polluted aquifers and cleaning-up of polluted groundwater are very costly and technically very difficult. Due to the very low flow velocity of groundwater, in most cases it takes long time to identify the pollution before the pollutants groundwater in the production or monitoring wells exceed the detection limits. Once the pollutant is detected in the groundwater, it is too late to prevent it, whence the clean and low cost resource may gets out of hand.

Kayseri is a developed industrial city located at the central part of Anatolia having a population of about one million. All domestic and industrial and partly the irrigation water need of the city is supplied from groundwater (Fig.1). The drinking water is supplied from a single orifice spring of a discharge of 300 L/s issuing at the footplain of the Erciyes mountain and from a well field of about 50 boreholes drilled at the plain over which the city takes place. The recharge area of the plain aquifer where the water supply boreholes are located extends to the Erciyes mountain too (Degirmenci at all, 2006). In the year of 2010, the total amount of groundwater that fed the water supply network of the Kayseri Municipality is recorded to be 57,482,766 m^3, excluding the groundwater amount extracted by the private wells and by the irrigation boreholes of the State Hydraulic Works. It is of utmost importance to maintain and manage this groundwater resource in the most efficient way in terms of quality and quantity to assure its sustainability. This, essentially required a detailed hydrogeological study of the aquifers to reveal their extension, thickness, the interactions and their current quality status that enabled us to asses the risk of pollution in the futur.

Performed works

To achieve the objecties outlined a sampling and observation network was established in the area where groundwater is exploited. The network included some 50-75 sampling points of private wells represinting shallow and deep aquifers, springs and rivers (Fig.2). Water samples were collected on monthly basis along one year and analyzed for chemical constituents (Ca, Mg, Na, K, Cl, SO4, HCO3, CO3, F, Br, NH4, NO2, NO3, PO4) Organic Material, microorganisms (Total coliform), heavy metal (Sr, Ni, Fe, Mn, Cu, Pb, Cr, Co, Mn, Rb, Li, Zn) and other trace elements Ag, Al, As, Au, B, Ba, Be, Bi, Br, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, Os, P, Pb, Pd, Pr, Pt, Rb, Re, Rh, Ru, S, Sb, Sc, Se, Si, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr).

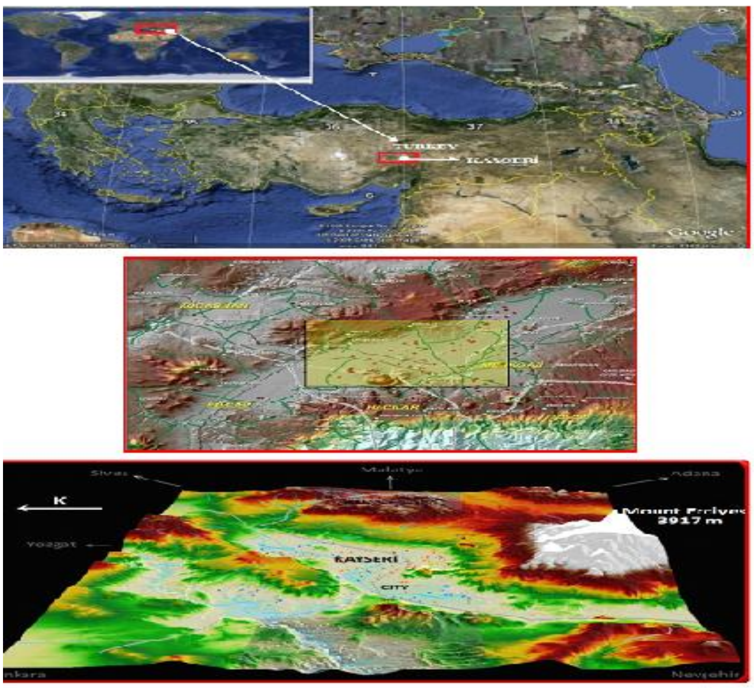


Figure 1. Location Map of the Study Area

In addition to chemical analysis, water samples were collected twice to represent the high water level and low water level seasons respectively and were analysed for environmental isotopes (Oxygen-18, Deuterium and Tritium). During the monthly sampling campaigns, insitu measurements at each sampling point were performed to obtain information of some physico-chemical properties, namely, temperature, electrical conductivity, pH, redox potential, salinity, dissolved oxygen and dissolved carbondioxide. The boreholes in the network (31 ea) were also used to measure the monthly groundwater level by a contact gage. Within the framework of the project, 16 boreholes were drilled with a total of 680 m coring to identify the subsurface extension and thickness of the aquifers in the area. The boreholes were drilled both in the shallow alluvium aquifer and in the deeper volcanic rock aquifer. 12 of the boreholes were drilled as couples, 3-4 meters apart, one tapping the shallow aquifer and the other the deep aquifer. This allowed to quantify the interactions between the shallow and deep aquifers, if any. Falling head permeability tests in alluvium aquifer and lugeon test in deep volcanic aquifer were performed at intervals of 5 meters to determine the hydraulic conductivity of the media.

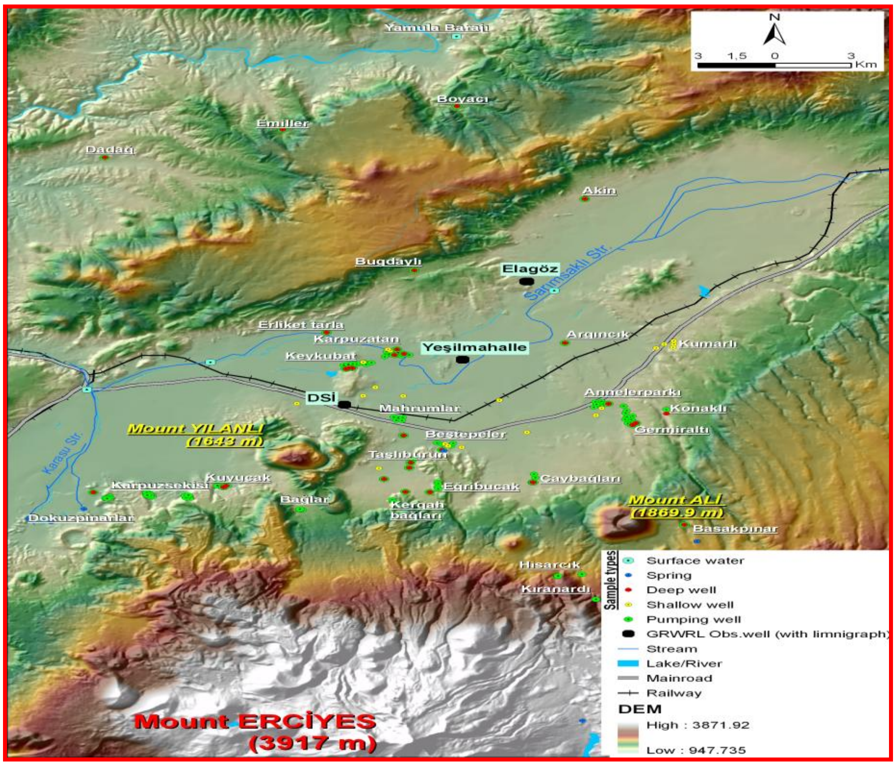


Figure 2. Location Map of The Sampling Point and Groundwater Pumping Well

Definition of aquifer units

Two aquifers were diffrentiated at the Kayseri City groundwater basin. The volcanic rock confined lower aquifer which is recharged from remote areas on the highlands of the Erciyes mountain, defined as the main aquifer and the upper shallow alluvium unconfined aquifer (Fig.3). The volcanic rock series that constitutes the lower aquifer are the products of the Erciyes volcanism that started in Neogene and lasted at Quaternary. The Quaternary alluvium that overlies the volcanic rock aquifer forms the secon (upper) aquifer.The volcanic rock series is composed of volcanic slug, basalt, andesite, tuff and agglomerates. The series thus includes litological units having both intergranular and fracture porosities. In some places the upper parts of the basalt and the andesite are massif and unfractued forming a confining layer overlying the main aquifer, making it confined or leaky. The continuity of this confining layer is not easy to determine, partly because the heterogeneity of volcanic rocks. This massif layer functions as a protective cover for the confined aquifer against pollution. The Beştepeler spring and the area underlying the Abandoed Waste Disposal Site exhibit the best example for the confined aquifer under protection. In areas where this layer is lacking the aquifer is much more vulnerable to pollution. The groundwater in the deep confined aquifer is proved to be still clean owing to the protective cover overlying the aquifer.

Recharge-Discharge mechanism of the aquifers

The main aquifer which is utilized in supplying water for domestic use in the region is mainly recharged from precipitation falling on the high elevations of the Erciyes mountain, particularly in the form of snow. The contribution of local rainfall is almost negligable

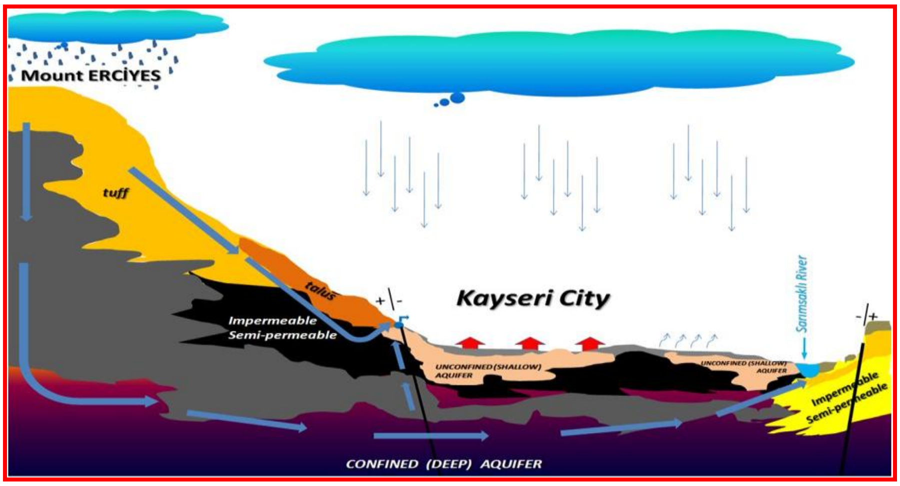


Figure 3. Shematic Hydrogeological section of The Study Area

to the recharge of the main aquifer. The average annual precipitation is calculated from a record of 72 year long data recorded at the Kayseri meteorological station. The annual potential evapotranspiration (ETP) is calculated as 496,9 mm, and the actual evapotranspiration (ETa) is 315.4 mm. These figures suggest that the effective precipitation is 374,6-315,4=59,2 mm. Assuming that all effective precipitation is infiltrated (although some is known to form runoff and taking the catchment area of the wells and springs tapping the aquifer as 190 190 km^2 the total potential recharge is calculated as 190.10^6 x 0,0592 = **11.248.000 m^3/year.** And as noted above, in 2010 the water that was delivered to the water supply network by KASKI was about five folds **(57.482.766 m^3/year)** of this amount. There are three large scale troughs (glacier trough valleys) in northern and northeastern sides of the Erciyes mountain peak (Fig.4). A 700 m long, 200 m wide and 20 to 50 m thick glacier occupies one of these troughs. These troughs are filled with snow every winter and as air temperature rises this snow pack melts slowly for long part of the year. The melt water infiltrates and feeds the aquifer underlying the Kayseri city. The outflow from the aquifer occurs through springs and wells that are utilized by KASKI for supplying water to the city. The groundwater flow direction in the area where the KASKI well field is located is depicted in Figure 5. The map reveals that the recharge of the system is from Erciyes mountain in general and the groundwater flow direction is from south-southeast to north to northwest. As depicted in Figure 5, the Keykubat and Karpuzatan well fields (with 17 wells producing 27 % of the total abstracted amount) are located at the lowest part of the groundwater system.

Water use and regional groundwater level fluctuation

The annual water amount that has been abstracted and distributed to the city by the KASKI water supply network between 1998 and 2010 is shown on the graph in Figure 6, depicted together with the energy consumption and the energy cost. The shares of different springs and wells in the total consumed amount is plotted as percentage in Figure 7. It is also known that

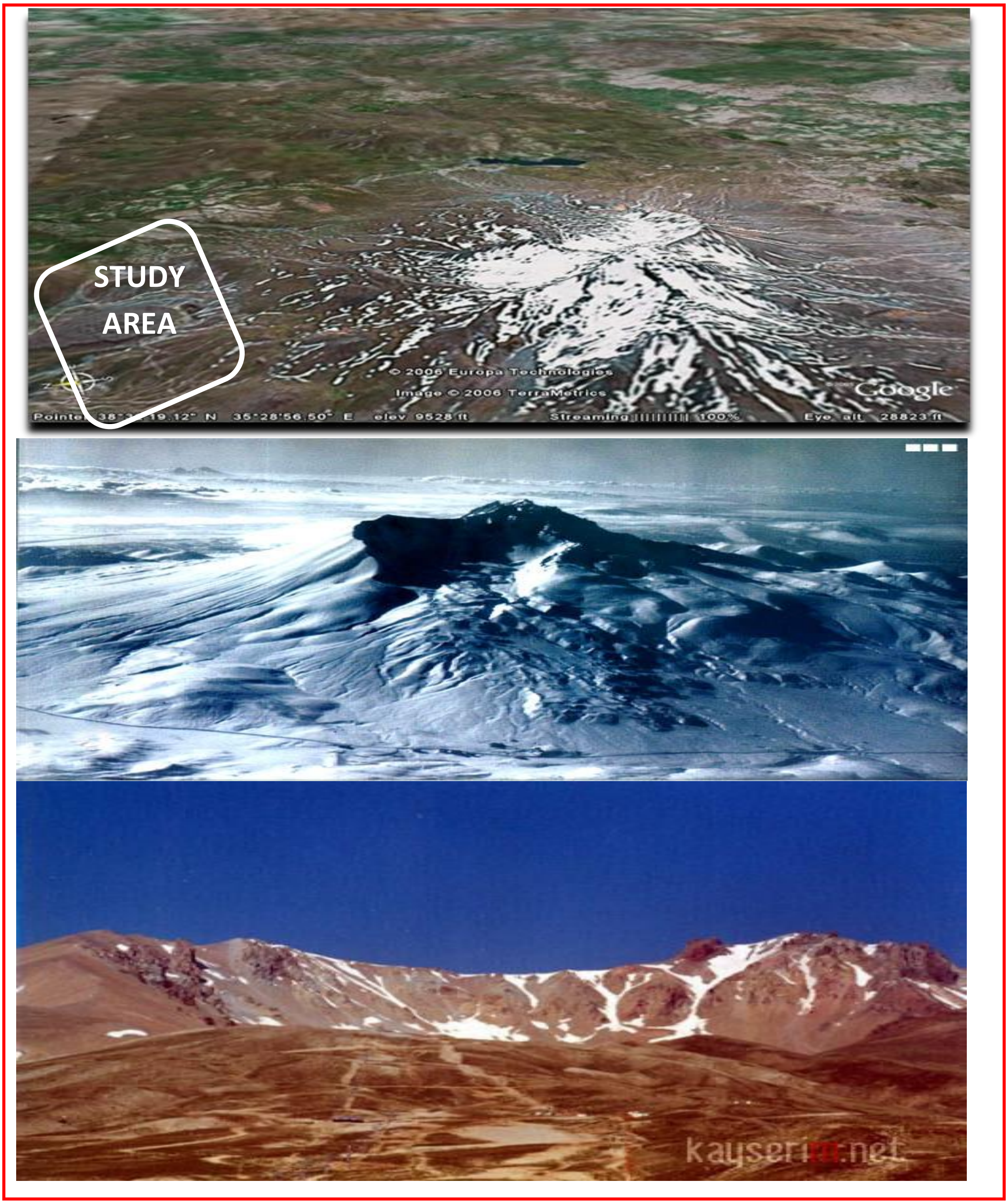


Figure 4. The views of the the Erciyes Mountain Peak *(There are large scale troughs (glacier trough valleys) with important functions in the main aquifer feeding)*

groundwater is abstracted in certain amounts through wells drilled by people in and region and by the State Hydraulic Works. As seen from the graph given in Figure 8 where the drawdowns due to these abstractions are depicted, the drawdown in the Mahrumlar well field is 1 m and 1.5 m at the Yeşilmahalle well field for the first 7 years after 1967; for period of 24 years between 1973 and 1997, on the other hand, is only 0.75 m in the Yeşilmahalle well field and 0.2 m in the Mahrumlar well field. Significant drawdowns in the order of 1.5-2 m, occured after 1998.

Apparently, the deep aquifer that provides water to the Kayseri city has a very high recharge rate. In the Beştepeler groundwater production field there exists one spring of 300 L/s discharge rate and three production boreholes in a circle of 130 m diameter; each of which has a pumping rate of 83 L/s. The dynamic level with a drawdown of only 10 cm in these wells is attained in 1 minute after pumping starts. The Beştepeler spring issues where a deep subvertical fracture connects the 50-55 m deep confined aquifer to the surface. The spring water is conveyed to storage tanks by three pumps. The shallow alluvium aquifer is of low yield because their extension and particularly thier thickness are small.

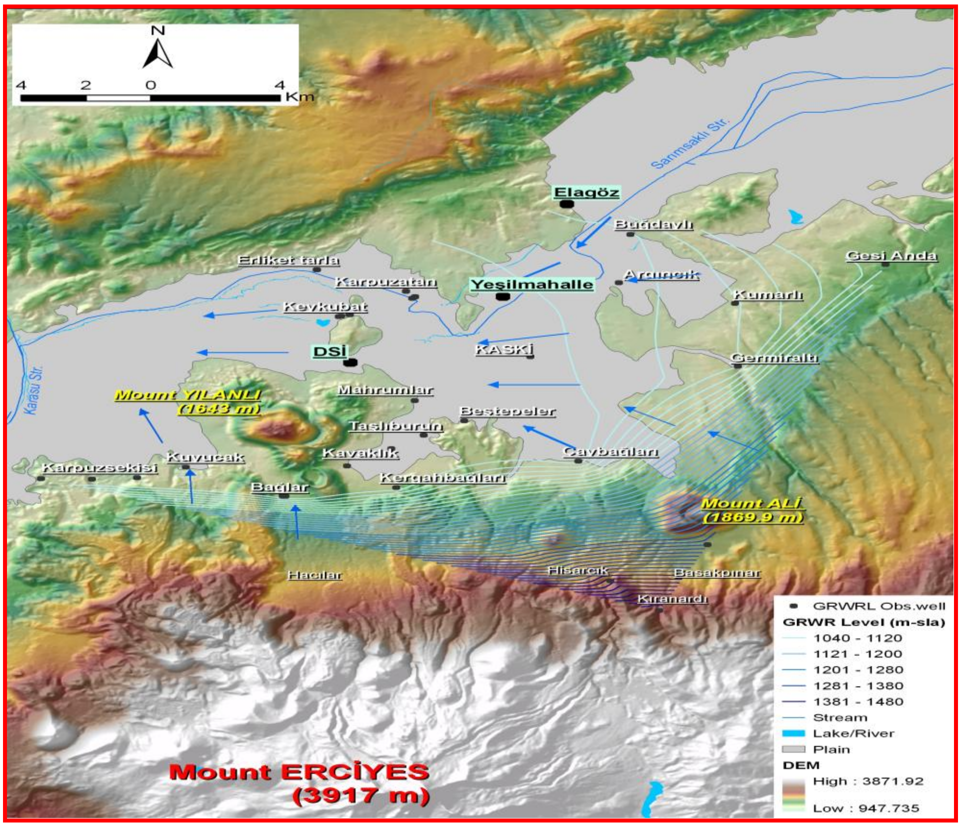


Figure 5. Groundwater Level Map of The Kayseri Metropolitan City Drinking Water Basin

Water quality and pollution risk

The total dissolved solid content (EC 150-450 μS/cm), and therefore hardness (6-14 F) of the groundwater in the lower, deep aquifer because of the low solubility of the volcanik rock units that compose the aquifer. These properties make the groundwater in the volcanic rock aquifer is of high quality. Whereas, the shallow unconfined alluvium aquifer is directly exposed to several pollution sources of urbanisation and agriculture. As a consequence the groundwater of this shallow aquifer has varying and higher dissolved solids (400 -3000 μS/cm) with a high risk of pollution. The nitrate content of the groundwater of the upper alluvium aqufer is 240 mg/L, due to the seepage from the abandoned waste disposal site. The chloride is recorded to be as high as 705 mg/L. Similar pollution problem in the alluvium aquifer is encountered in the Karpuzatan well field where uncontrolled and unplanned urbanisation. The upper aquifer is polluted by cesspools and waste water seepages to a great extent during the periods when the infrastructure of the city was far from adequate.

The deep volcanic rock aquifer is protected against pollution because the massif-unfractured uppler confining layer forms a barrier to pollutant movement. For instace, the Beştepeler well field and the spring which supplies 18 % of the total water abstraction, no trace of pollution was detected although the abandoned waste disposal site is located only 500 m upstream.

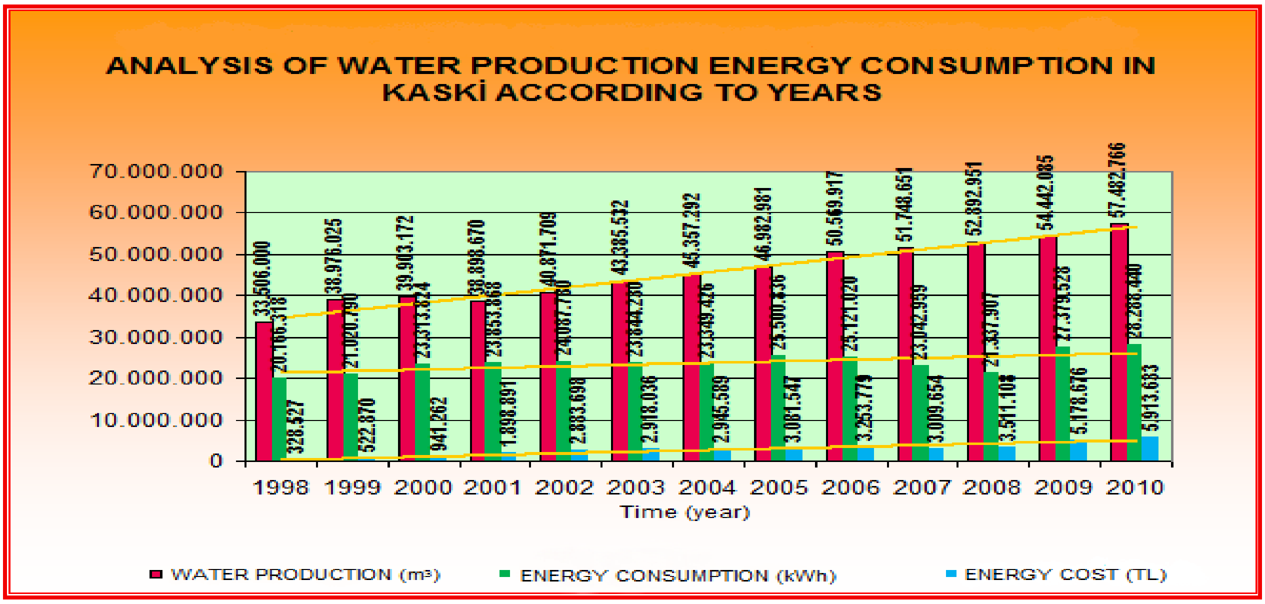


Figure 6. The Annual Amount of Water Production, Energy Consumption and Energy Cost *(KASKİ Drinking Water Department)*

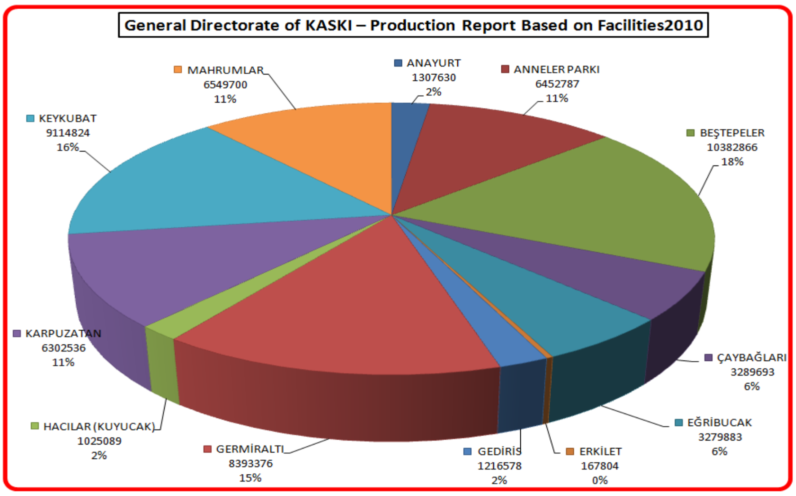


Figure 7. The Annual Water Amount Supply from Different Well Groups in 2010 by KASKİ

However, this impermeable upper layer is not extensive over the whole area and is lacking in some places. In areas where the alluvium rests directly on the volcanic aquifer without the barrier layer in between the pollution risk is high. It is also the case where the upper layer is fractured to some extent forming an aquitard, particularly when the piezometric level of the lower aquifer is lowered below the water table of the upper alluvium aquifer (Fig. 9).

There exist 17 production wells of KASKI at the Keykubat and Karpuzatan well fields in the area where the groundwater level is measured to be very shallow (1.5-4.5 m). These wells produce about 27 % of the total abstracted groundwater. These areas are under higher risk of groundwater pollution. A total of 8 boreholes, 4 in the Keykubat area (SK-1AL, SK-2, SK-3AL, SK-4), and 4 in the Karpuzatan area (SK-5, SK-7AL, SK-6, SK-8AL) were drilled to elucidate the hydraulic relations between the alluvium aquifer and the deep volcanic rock aquifer. All boreholes were also cored, sampled and tested for two years. Figure 10 depicts some results of these studies. The boreholes were drilled in couples and each couple were drilled about 5-10 m far from the KASKI production wells. Groundwater level measurements were made when production wells stopped pumping. As can be noticed in the figure, the piezometric level of the lower aquifer is only 15-20 cm higher than the water table of the upper aquifer. This hydraulic condition assures the upward flow and therefore no leakage from the polluted upper aquifer occurs to pollute the lower aquifer. However, when pumping particularly in the Karpuzatan well field causes a drawdown that lowers the piezometric level down to the water table (about 115 cm) the polluted water of the upper aquifer seeps downward to pollute thelower aquifer whose water is utilized for drinking purposes. Therefore, it is essential to strcitly control pumping rates in this area.

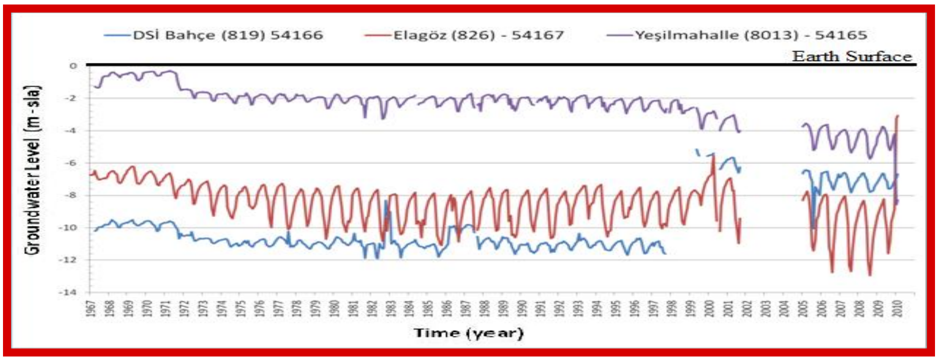


Figure 8. Annual Groundwater Level Variation in The Kayseri Metropolitan City Drinking Water Basin *(DSİ Groundwater Level Observation Wells, with limnigraph)*

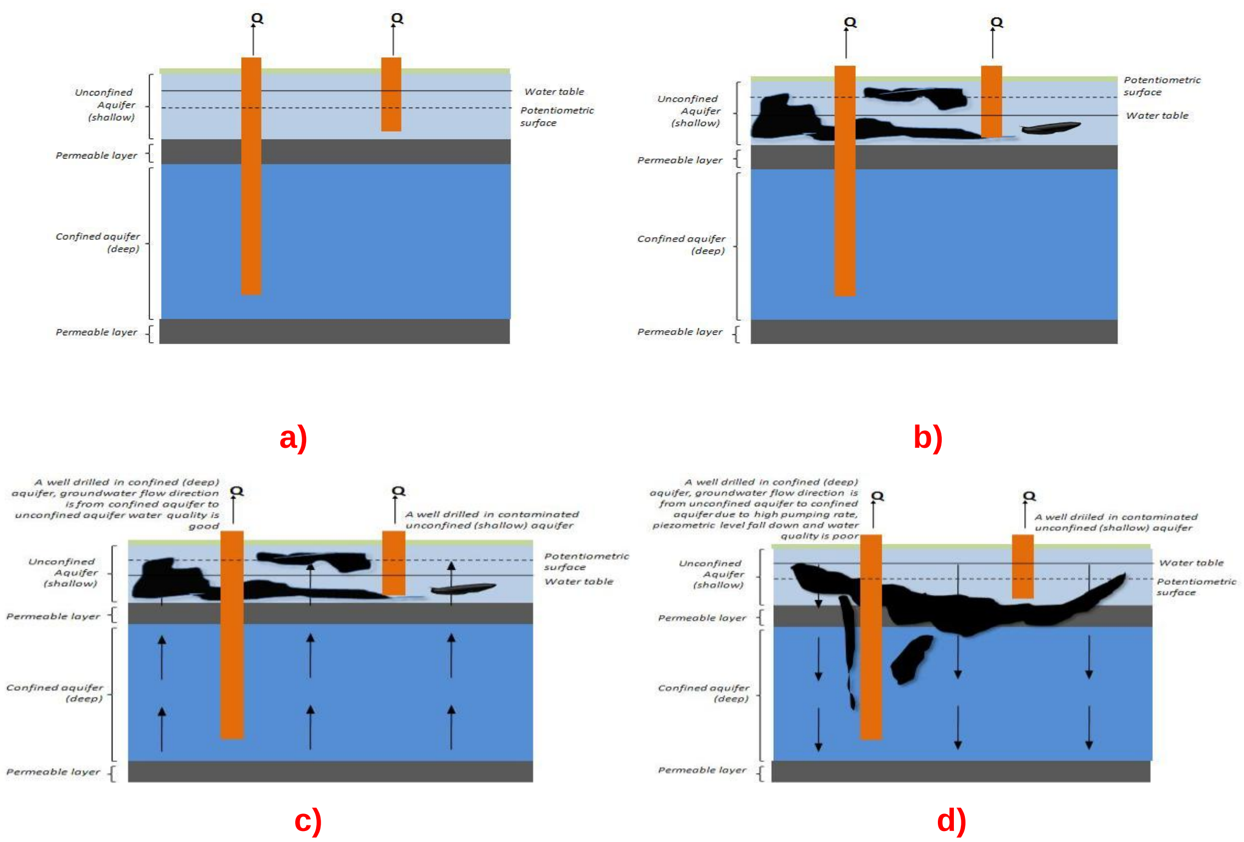
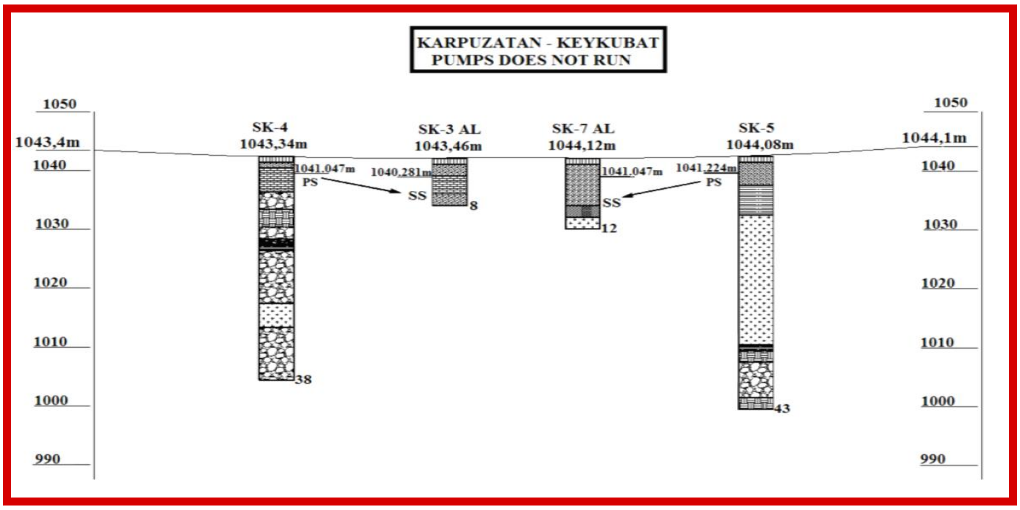


Figure 9. Hydrodynamic Structural Effect on pollutant transport: **a)** *uncontaminated aquifer system, **b)** contaminated aquifer system, **c)** Groundwater Flow Direction is from confined aquifer to unconfined aquifer, water quality is good **d)** Groundwater Flow Direction is from unconfined aquifer to confined aquifer, water quality is poor*



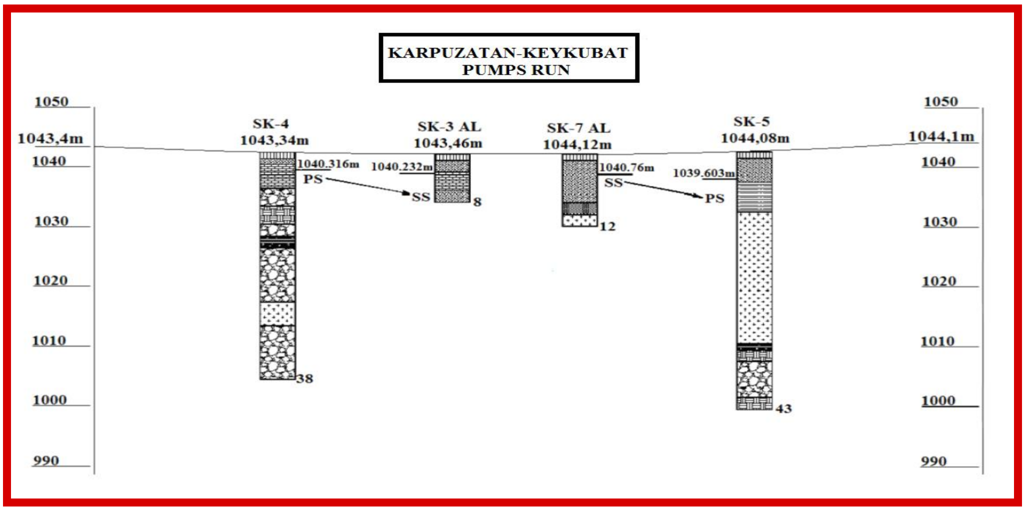


Figure 10. Borehole logs and measured water table and piezometric level in the the shallow and deep wells in Keykubat and Karpuzatan well fields

Water use scheme

In addition to the ever increasing demand for water due to the incresing population, adverse effects of climate change on water resources lead KASKI to search for new water resources for the projected future needs. In this framework, KASKI has initiated a project in 2009 entitled "The Dokuzpınarlar Drinking Water Project". A total of 24 boreholes were drilled at the Dokuzpınarlar area with a capacity of 60 l/sec each. The new well field is located about 10 km to the west of the city and construction of pipeline taht will connect the well field to the existing water suplly network still continues. KASKI has installed a SCADA by which the groundwater abstraction scheme from 50 wells with the most efficient energy consumption. Pumps are replaced by the new technology pumps to minimize energy costs and maximize the yield (Fig.6).

Conclusions

The hydrogeological studies that we conducted in the area revealed that the upper shallow aquifer is already polluted particularly in the Keykubat and Karpuzatan sites, the lowest area in th region; and that the head difference of 15-20 cm between the piezometric level of the lower aquifer and the water table of the upper aquifer is critical in terms of pollution risk of the lower aquifer. The stress of the aquifer in these sites should be reduced gradually by introducing new alternative sources. Furthermore, the impact of climate change is projected to cause a change in the type of pricipitation if not the amount. A significant portion of the snow fall is projected to turn into rainfall. This will reduce the recharge to the deep aquifer. Increase in rainfall will cause rise in the water table of the polluted upper aquifer, which consequently increase the risk of pollution of the lower aquifer.

Arsenic content of the groundwater, a common problem in volcanic rock aquifers is another issue that should be taken in consideration. Currently, this problem is not addressed in the Kayseri city water supply case. However, detailed research should be conducted in the new well field to assure that the groundwater does not contain arsenic above the allowable limits. Well construction may require a special attential in this regard.

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