Hydrogeological and Geophysical Characterization of Kozlupınar and Bentpınarı Water Springs (Denizli, SW Turkey)

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Abstract

This study focusses on describing the hydrodynamic interactions of the Kozlupınar - Bentpınarı springs, aquifer units, groundwater, water table, Babadağ fault zone, and topography, with each other. Due to rapid urbanization and increasing population densities in Denizli, the safe water supply becomes more and more difficult every day. Kozlupınar and Bentpınar springs are historically significant water supply sites for Denizli city. Although the expansion of the city has resulted in the destruction of numerous springs, both springs are still in their natural state, and have great value for urban use in Denizli and vicinity. Kozlupınar's average flow is 0,100 m^3/s; Bentpınarı is 0.130 m^3/s. The average base flows calculated using the Maillet equation (1977-1979) are to 4.75×10^6 m^3/year, and 7.41×10^6 m^3/year respectively. The spring variability estimated as 0.22 for Kozlupınar and 0.12 for Bentpınarı . Recession coefficients, to 0.00199 $days^{-1}$, and 0.00109 $days^{-1}$ respectively. The spring waters emerge from sediments that accumulate on the slopes of the southern mountainous terrain along the Babadağ fault. Hydrologic process of the groundwater, start by the infiltration of precipitation on the high hills on the north side of the Babadağ fault. Almost all aquifers in the region, which feeds springs, and extends to wider areas outside the study area, is heterogeneous and anisotropic due to the different origins and tectonic forces affecting the region. Groundwater flows from south and south-west highland parts of the catchment towards the springs areas in the north and northeast direction.

Keywords: *Kozlupınar, Bentpınarı, Babadağ Fault, Water table map.*

Introduction

Tectonic structures, specifically faults, influence the distribution and movement of groundwater in the geological units and so can be one of the important component of groundwater and hydrogeological processes (Rajabpour at al. 2016). The faulting mechanism and movement type is a significant parameter in the hydrogeological behavior. Normal tension faults have a greater capacity for groundwater flow, compared to reverse faults and strike-slip faults with compressive conditions (Rajabpour at al. 2016; Anderson and Bakker 2008; Dewey and Sengor 1979). Fault zones have the capacity to be hydraulic conduits connecting shallow and deep geological environments, but simultaneously the fault cores of many faults often form effective barriers to flow. The damage zone has secondary structures such as minor faults and fractures extending into the foot wall and hanging wall, which take up the rest of the strain within the fault zone (Bense et al. 2013). Hydrogeological properties are believed to be highly anisotropic in fault zones. Vertical or near-vertical faults are generally may be described as being a barrier in to horizontal flow direction throughout the fault (Rajabpour at al. 2016; Anderson and Bakker 2008). It is well known that groundwater is commonly driven to fault zones from their surroundings. This can be attributed primarily to two factors. One is that the water table (for an unconfined flow system) is roughly a replica of the topography, so that fault zones that occupy valleys and other topographic depressions receive groundwater by topography - driven flow. The second factor is that concentration of stress and fault slip maintains relatively high permeability in an active fault zone and its surroundings. Fault permeability changes of active faults may generate large changes in nearby stream flow, water table and yield of springs (Curewitz and Karson 1997). Many active fault zones receive and transport great volumes of groundwater, often under high fluid overpressure, as is indicated by the common occurrence of springs along fault zones (Curewitz and Karson 1997; Muirwood and King, 1993; Rojstaczer et al. 1995; Leonardi et al. 1998; Melchiorre et al. 1999). As in all metropolises experiencing rapid urban development, sustainable resource management must be implemented in a disciplined manner in the Denizli region as well. To determine aquifer characteristics and hydrodynamic properties for better monitoring, evaluation and estimation of water resources is crucial. This study focusses on describing the hydrodynamic interactions of the aquifer units, groundwater, water table, Babadağ fault zone, topography, and Kozlupınar - Bentpınarı springs with each other.

Material and Methods

The geological study area shown in Figure 1 is located in the of intersection of the Büyük Menderes and Gediz grabens in the Aegean region, one of the most active seismic regions of Turkey. The map area covers an about 20 km^2 (Figure 1). This study is based on geological, geophysical and hydrogeological field data. First, a geological map of the study area was drawn on Google Earth images. The hydrogeological and geophysical survey area covers about 6 km^2 around the springs. A detailed geophysical survey has been carried out in order to trace and analyses those features that might control the hydrogeological behavior of the system, with emphasis on both the lithological and the tectonic discontinuities. The geophysical studies included 2D electrical resistivity survey and ground-penetrating radar (GPR) have been performed to examine the condition of the subsurface and to verify the presence of groundwater. The resistivity parameters were confirmed by the drilling and logging results. In order to provide a basis for hydrogeological interpretations, with resistivity studies, 39 vertical electrical soundings (VES) were made on the hillsides of the southern side where the springs were recharged by groundwater. The cross-sections of a total length of 7900 meters were extracted from the VES records along 11 different resistivity profiles. The GPR profiles with a total length of 1125 meters were taken in the areas nearest to the springs, where the depth of groundwater is estimated to be shallower than 25 meters. The average base flows of Kozlupınar and Bentpınarı springs was calculated using by the Maillet equation. The base flows of spring reserves in the study area was estimated based on the geological structure of the aquifer system and an assumption on the porosity value. In order to verify these estimations, the results were compared to the corresponding values derived by analyzing the hydrographs of springs.

Geological Settings

Regional Tectonics and Geology

The West Anatolian Horst-Graben System extends from the Aegean Sea to central Anatolia and it is one of the most rapidly deforming regions in the world (Jackson and McKenzie 1984; Eyidogan and Jackson 1985; Sengor 1987; Dewey and Sengor 1979; Le Pichon and Angelier 1979; Taymaz et al. 1991; Seyitoglu and Scott 1991; Taymaz and Price 1992; Westaway 1994; Seyitoglu and Scott 1996; Alessio and Martel 2004). It is characterized mainly by E–W trending major horsts and grabens, and NW–SE to NE–SW oriented relatively short and locally suspended cross-grabens (Bozkurt 2003), contained within the major E–W trending horsts. The tectonic origin, age and structural development of these structures and direction of extension in the region are hot issues in the international literature.

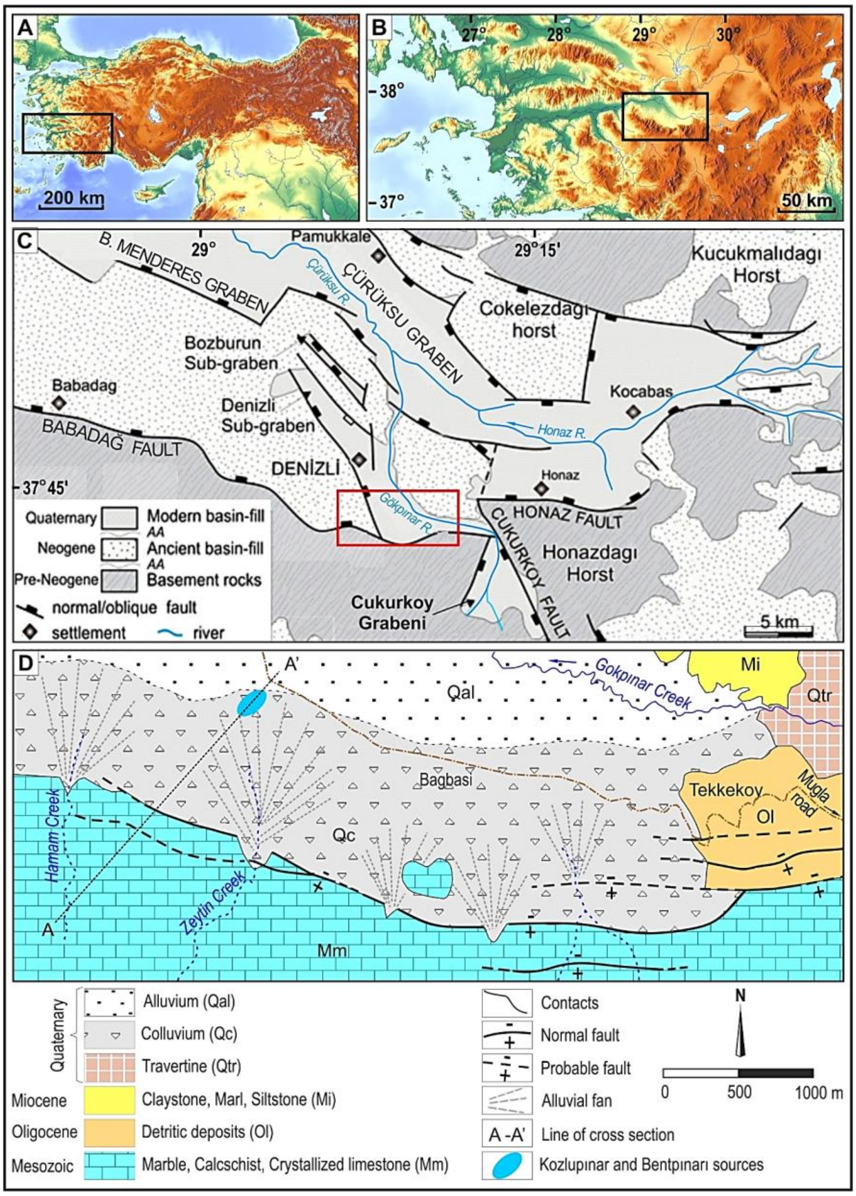

Fig 1. Location of the study area. A) Relief map of Turkey. B) Location of Denizli Basin in SW Turkey. C) Simplified map showing the major active basins in the Denizli Basin (compiled from Koçyiğit, 2005). Box shows position of study area. D) Geological map of study area.

The west Anatolia basins are very well defined by horst-graben morphology that may reach up to 200 km in length, where the main peaks of the horsts may reach up to 2 km in height, while the graben floors lie at about sea level. The Denizli Graben is situated in an area where three major E–W grabens approach at their eastern ends. The Denizli Basin as a whole is bounded in the north by the Cokelezdag Horst and in the south by the Babadağ and Honazdag Horsts. It is a NW–SW elongated basin approximately 50 km long and 25 km wide, and comprises two

Quaternary sub-basins, namely the Curuksu Graben in the north and the Laodikia Graben in the south, separated by a large basin-parallel topographical high along which Late Miocene–Pliocene fluvio-lacustrine deposits are exposed (Kaymakcı 2006).

The lithostratigraphic units that outcrop in the study area range in age from upper Palaeozoic to the Holocene. The basement rocks are represented by metamorphic rocks, Mesozoic marine carbonate sequences of the Lycian Nappes, ophiolitic mélange and Oligocene continental sedimentary rocks. Graben fill consists mainly the alluvial-colluvial fan, fluvial deposits and travertines, overlies the Neogene ancient graben fill (Koçyiğit 2005). The river deposits of the graben are covered with large-scale alluvial fans. Units within the work area near the springs; Menderes massive metamorphic rocks, Oligocene-Middle Miocene conglomerate, Upper Miocene-Lower Pliocene aged marl, conglomerate, sandstone, claystone and mudstone, Quaternary colluvial and alluvial units.

Hydrogeology

The drainage basin of Kozlupınar and Bentpınar springs have five geological units in terms of lithology, origin and hydrogeology: Mesozoic Marble, Calcschist, Crystallized limestone (Mm), Oligocene Detritic deposits (Ol), Miocene Claystone, Marl, Siltstone (Mi), Quaternary Travertine (Qtr), Colluvium (Qc), and Alluvium (Qal) (Figure 1). These units which involve heterogeneous and anisotropic characteristics, weak zones and discontinuities have been formed by the tectonic stresses over time. Hydrogeologically, these discontinuities indicate secondary porosity and high permeability and they contribute significantly to the groundwater movement, especially near the main faults. The geological and geophysical studies have shown that the groundwater movement in the basin and the spring yield depend on the size and location of the tectonic discontinuities rather than the primary porosity of the units. Kozlupınar and Bentpınarı springs located in the Gökpınar Dam basin are included in the "tectonic springs" class and their waters flow into Gökpınar Stream. Apart from these two springs, there are many springs in several sizes along the slopes of mountainous areas within the basin. Some of these springs outside the study area flow all seasons. Yields of springs are in m^3/s: Gökpınar 0.849; Derindere 0.362; Yukarısantral 0.04; Pınarbaşı 1.131; Mesut Pınarı 0.012; Gökçen Pınarı 0.030, Turgut Pınarı 0.070. Others dry in summer months depending on natural and artificial reasons (TUBITAK 2012; Bense et al. 2013).

Brittle fault zones are discontinuities that may act as conduits, barriers or combined conduit–barrier systems that enhance or impede fluid flow (Antonellini and Aydin 1994; Newman and Mitra 1994; Goddard and Evans, 1995; Caine et al., 1996; Bense et al., 2003a). Structural and hydrogeological field evidences are needed to understand the influence of fault zones on aquifer characteristics and the hydrogeological behavior of these zones. Structural evidence includes the displacement of the aquifer bedrock and water-bearing layers, and also variation in the saturated thickness of the aquifer across the fault (Bense et al. 2013). The influence of the Babadağ fault on the geological structure and hydrogeological properties of the aquifer units in the spring zone was investigated by the interpretation of the VES and GPR profiles. There is an unconfined aquifers system, consists of accumulations of Mesozoic metamorfic units and Quaternary alluvial fan deposits throughout the area, on hanging wall of Babadağ fault, as seen in all of the VES and GPR profiles (Figure 1, 3). The footwall on the south side consists of Mesozoic metamorphic rocks with structural discontinuities due to intense tectonism. The Babadağ, Honaz and Çukurköy faults controlled by the tectonic features of the region have different inclination and relatively high permeability. The media is very suitable for accumulation and movement of groundwater because of the tectonic discontinuities, geometric and hydraulic parameters of vadose and phreatic zone. Because hydraulic gradients in the area develop parallel to the inferred fault zones, the faults also tend to collect groundwater. That is why the ground waters are transported towards the topographic depressions (Gökpınar gorge) along the margins of these faults. The most important springs of the region are located at this junction and its vicinity. The Kozlupınar and Bentpınarı springs on the Babadağ fault are also in this system although they are not very close to the intersection (Figure 2, 3). Babadağ fault, location and boundaries put forward in detail with the geophysical profiles, forms the southern boundary of the Büyük Menderes Graben. This fault in the east-west direction brought the aquifers and impermeable units to the same level and formed the most efficient springs of the region. The ground waters of all the sedimentary formations in the plain north of the Babadağ fault recharge by the ground waters of the mountainous regions in the south of fault.

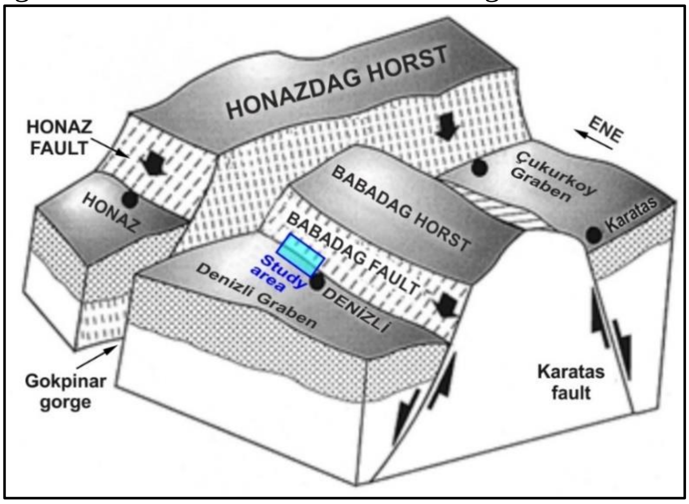

Figure 2. Sketched block diagram depicting geometrical relationship among the Denizli Graben, the Çukurköy Graben and their margin bounding major faults (modified) [28].

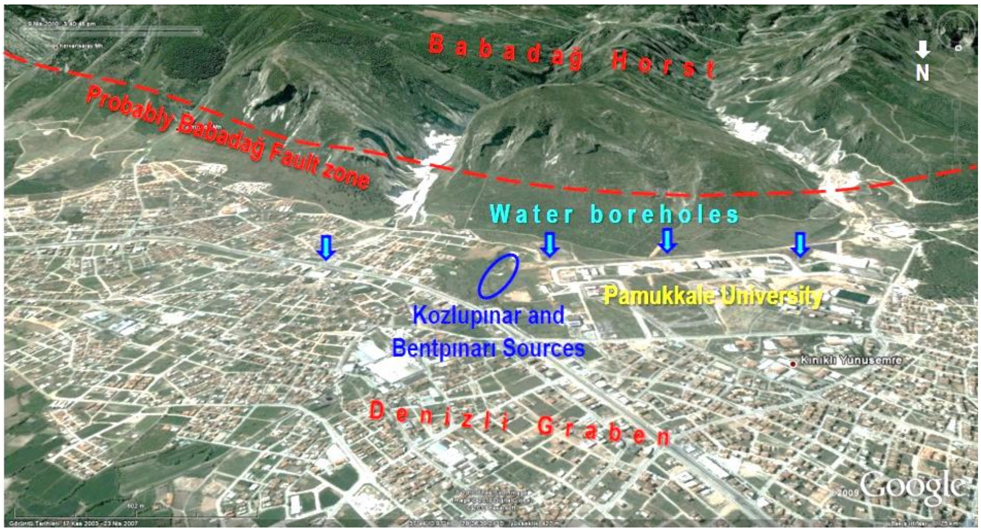

Figure 3. Position of Kozlupınar, Bentpınarı springs and Babadağ fault zone on Google Earth image.

Topography is a major factor which has to be considered for delineating the recharge and discharge zone; high land areas are an indicator of recharge areas. The divergence and convergence of vector flow lines is an indicator of the recharge and discharge areas respectively in general (Fetter 2001). The flow line on a flow net tends to diverge from recharge areas and converges towards to discharge areas (Fetter 2001). Often groundwater hydrologists need to be opportunists in the study of fault zones as groundwater monitoring networks are designed to characterize the hydrodynamics of aquifers as a whole without any specific focus on fault zones. Hence, closely spaced arrays of boreholes over fault zones are rare. However, the shape of the hydraulic head profile that might show steps or inflections in hydraulic gradient at fault zones can be used to infer the directions and rate of fluid flow at the fault zone (Haneberg 1995; Bense et al. 2003b; Anderson and Bakker 2008) and provide an indication of the hydrogeological behavior of a fault zone as a barrier or a conduit). In the light of data obtained from geological, geophysical and hydrogeological field studies, a water table map has been prepared for the surroundings of the Kozlupınar and Bentpınarı springs. the main recharge and discharge areas and routes of the springs have been determined on this map (Figure 4, 5, 6). Both water springs are part of a dynamic groundwater flow system. The groundwater flows from south and south-west highland parts of the catchment towards the springs areas in the north and northeast direction (Figure 6). The curves showing the location and movement of underground water are shaped by the position and characteristics of buried faults. The depth of groundwater table ranges from about 5 m to the northeast to more than 40 m to the southwest (Figure 8). The groundwater development in the aquifer and the spring yields depend on the size, frequency and location of the tectonic discontinuities such as cracks, fissures and joints in the geological units rather than the primary porosity of the units. That is, the groundwater in the region is largely controlled by the Babadağ fault associated with secondary and minor faults. Kozlupınar and Bentpınarı springs are located where groundwater level is closest to the surface, in other words where the surface and the water table intersect naturally (Figure 7, 8). Groundwater-level fluctuations due to aquifer storage changes involve the extraction of water from the aquifer, both through natural means and human involvement.

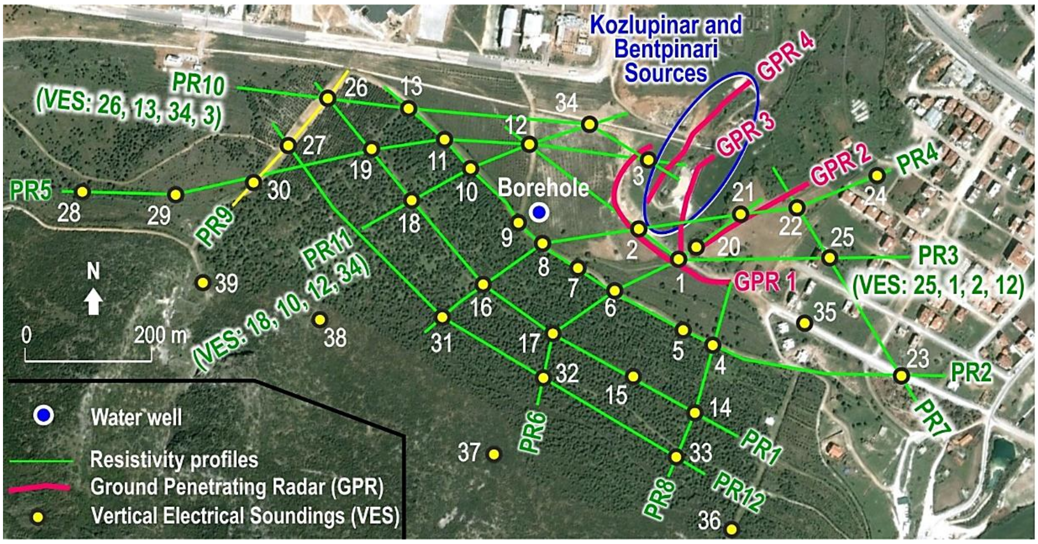

Figure 4. Location map of VES points, VES profiles (blue) and GPR profiles (red).

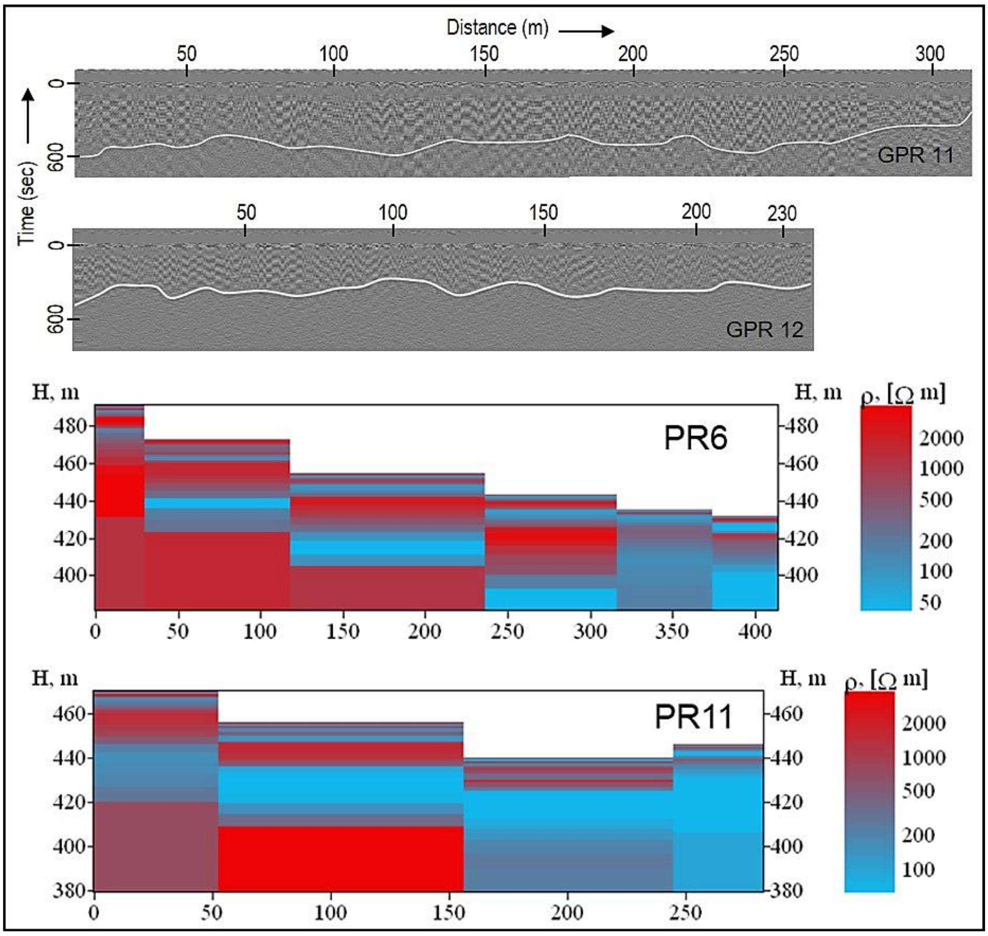

Figure 5. Isobath map of the groundwater (May 2010).

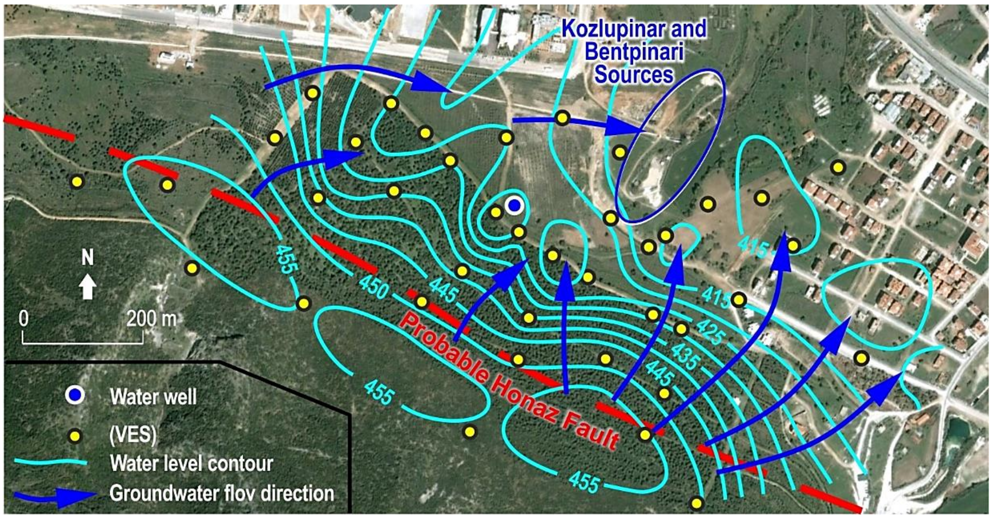

Figure 6. Water table contour map (May 2010).

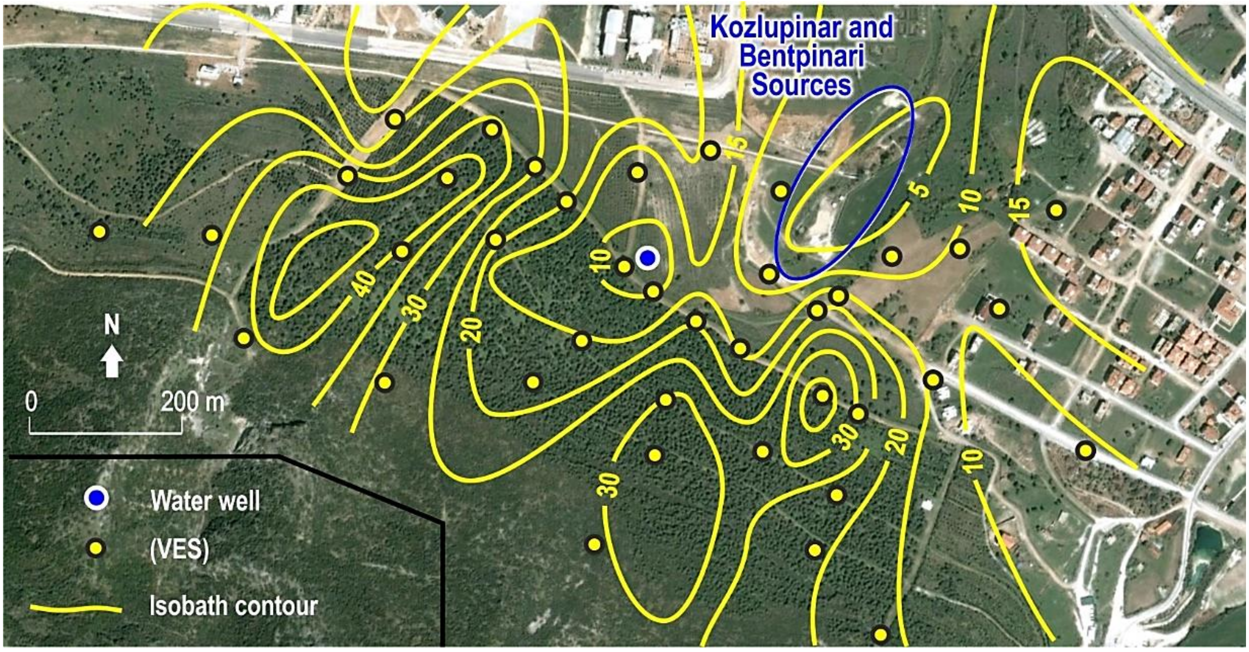

Figure 7. Isobath map of the groundwater (May 2010).

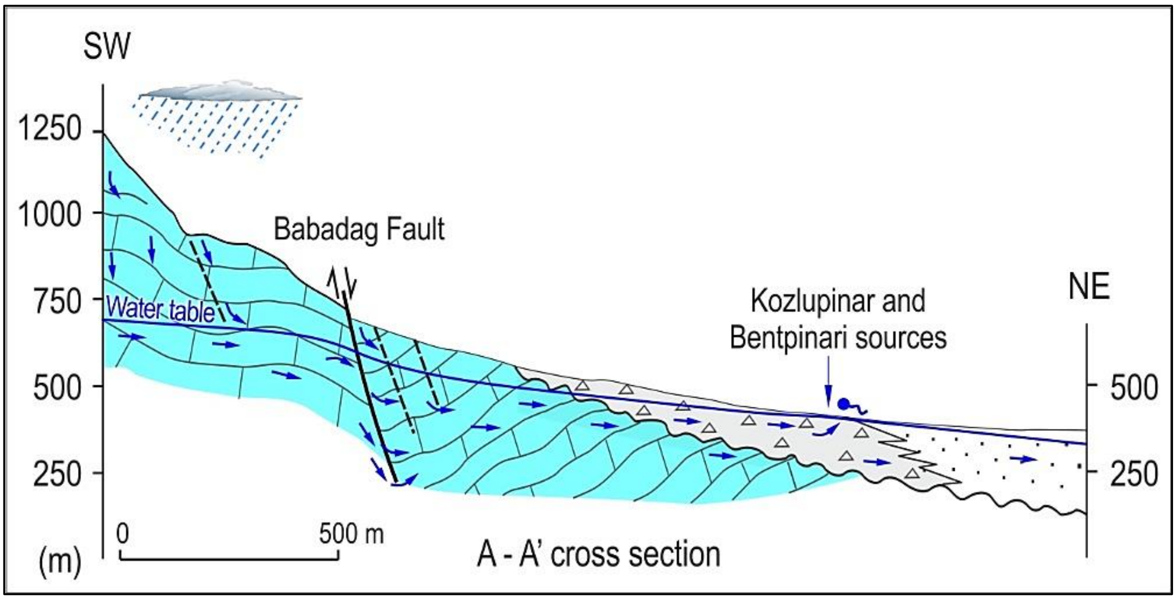

Figure 8. The hydrogeological A – A' cross section of the springs area (Figure 1) prepared according to the geophysical VES data.

Evaluation of Aquifer Recession Hydrographs:

The volume of stored water in the saturated zone above the outflow spring level is termed the dynamic volume of the spring (Mangin 1975; Ford and Williams 1994). A number of authors have used equation to describe the discharge hydrograph of an aquifer and identify its transportation and storage characteristics (Castany 1967; Schôeller 1967; Atkinson 1977; Korkmaz 1990; Karanjac and Altug 1980; Drogue 1972; Bonacci 1987; Bonacci & Jelin, 1988; Soulios 1991). Studying hydrograph recession curves of springs may provide hydrogeological information especially where fracture or conduit flows are significant. This approach is preferred over other geological and geophysical methods (Dreiss 1982; Bakalowicz 2005) because the spring drains water from large areas of aquifer, so the discharge is governed by accumulative effect from the flow systems that exist in the aquifer. This contrasts with other geological and geophysical methods that only represent the aquifer locally at the investigation points.

Quantitative analysis of the hydrograph recession curves of Kozlupınar and Bentpınarı springs was conducted through Maillet's equation (1).

The first interpretation of the base-flow analysis was carried out by Maillet (1905) and was based on the drainage of a simple reservoir. Maillet assumes that the discharge Q_t at time t of a spring is a function of the volume of water held in storage:

$Q_t = Q_0 \cdot e^{-\alpha t}$ (1)

where Q_t in m^3/s is the discharge at time t; Q_0 in m^3/s, the discharge from storage at the beginning of the recession; t is the time elapsed between Q_0 and Q_t; and α is termed the recession (discharge) coefficient; this value is a function of aquifer transmissivity, storage coefficient and catchment geometry.

If the spring discharge is plotted as a function of time, the dynamic reserves (Vs) at any time t is equal to the area under the curve bounded between the time t and the time when discharge reaches zero. By integrating Maillet's equation (1) and allowing for units, the dynamic reserves may be estimated by equation (Steiakakis 2018):

$Vs = Q_0 \cdot c/\alpha$ (2)

Where c is the unit conversion factor (days to seconds), equal to 86400 when Q_0 is the flow rate at the beginning of recession in m^3/s and α in $days^{-1}$.

The recession coefficient can be defined as (Steiakakis 2018):

$\alpha = (\log Q_0 - \log Q_t)/0.4343t$ (3)

Variability of spring (Korkmaz 1989):

$Qv = (Q_0 - Q_t) / Q_0$ (4)

where Qv in % is the variability between minimum and maximum spring flow.

Base flow (Korkmaz 1989):

$Qb = [(Vs1 - Vs2) / t] \times T$ (5)

where Qb is the base flow (m3/year); Vs1 is the dynamic reserve at the beginning of the recession; Vs2 is the dynamic reserve at the end of the recession; t is the time elapsed between Vs1 and Vs2; T is a year (365 day).

The hydrograph data of the Kozlupınar and Bentpınarı springs were analyzed for the years between 1977 and 1979, by the best fit of the observed curves with the Maillet's equation. Monthly flow measurements of the springs by DSI (General Directorate of State Hydraulic Work) have been implemented since 1977. The spring flow measurements were manually recorded by measuring the time taken for a specific amount of water to come out of the spring. In 1980, two water box were built on the springs for ensure that the rate of flow was reliable during all seasons of the year and isolate it from contaminated surface runoff. Since 1980, all of the water of both sources has been used to provide reliable urban water continuously. However, little amount of spring water continues to flow out to earth surface naturally except for the water supplied to the main pipes. The reliable flow measurement cannot be done after the water boxes. That's why, the measurements of the first three years were employed in the calculations.

In detail, the hydrograph data of the springs were plotted on semi-logarithmic graphs and the recession coefficients (α) were estimated by Equation (3). The results referring to the representative years are presented in Figure 9.

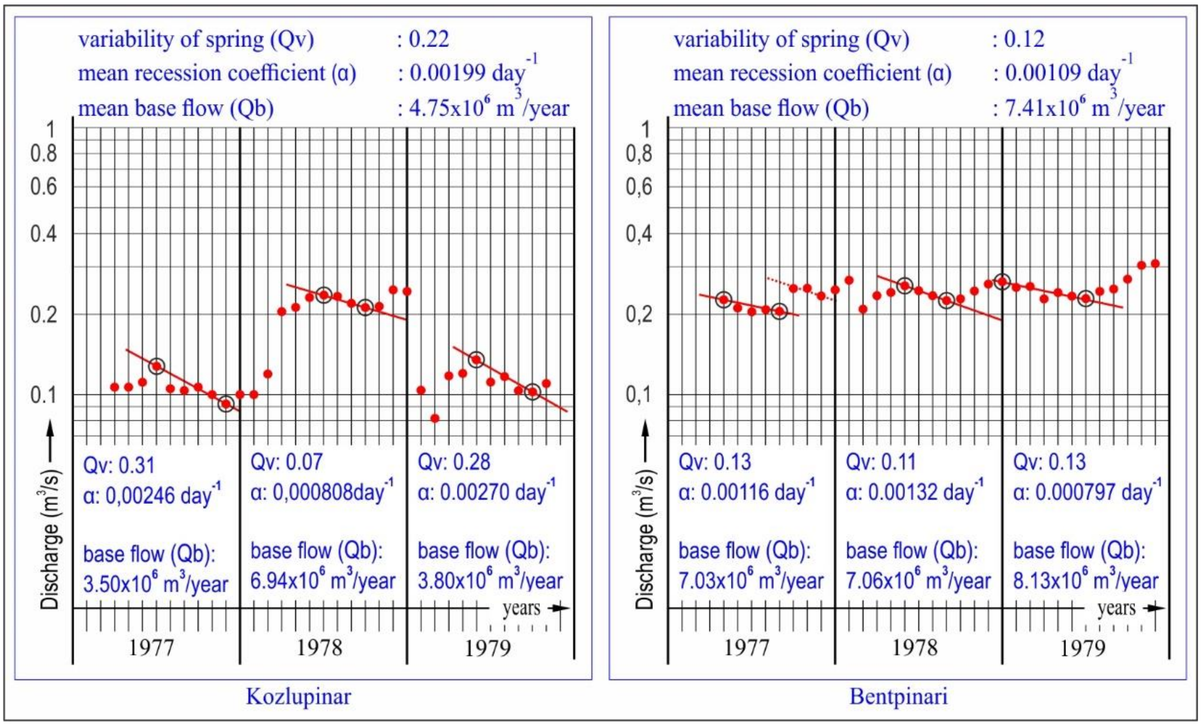

Figure 9. The average base flows of Kozlupinar and Bentpinari springs, calculated using the Maillet equation (1977-1979).

The derived data from the recession analysis presented above suggest that the mean values of recession coefficients of the Kozlupınar and the Bentpınarı springs, to 0.00199 days^{-1}, and 0.00109 days^{-1} respectively. The recession coefficient of Kozlupınar is relatively large compared to Bentpınarı. The possible cause of this difference may be that the Kozlupınar is closer to the Babadağ fault zone. The magnitude of the discharge coefficient indicates that the flow of groundwater depends on primarily through tectonic discontinuities such as faults, joints and fissures. The spring variability estimated by the ratio of maximum and minimum discharges is 0.22 for Kozlupınar and 0.12 for Bentpınarı. According to the classification presented in Table 1, this values indicates that discharge of the springs is described as "moderate variable" (Korkmaz 1991). The discharges and base flows variability of such springs are parallel to the values in the "cumulative deviation from mean precipitation" analysis. The estimated average annual base flow of the Kozlupınar source (Figure 9) was calculated as 4.75×10^6 m^3/year and the Bentpınarı source as 7.41×10^6 m^3/year.

The estimated mean annual base flow of the aquifer (Figure 9) is calculated at about $4{,}75\times10^{6}$ m^{3}, equivalent to the mean annual spring discharge.

Table 1. Classification of water springs based on the limits of recession coefficients (Korkmaz 1991).

	α (recession coefficient)	Qd (variability of water
1 (poorly variable)	0,00035 day^{-1} and/or ≤ 0,00035 day^{-1}	≤ 6%
2 (moderate	0,00035 day^{-1} - 0,00175 day^{-1}	6% - 27%
3 (high variable)	0,00175 day^{-1} and/or 0,00175 day^{-1} -	27% and/or 27% -92%
4 (very high	0,00126 day^{-1} and/or ≥ 0,00126 day^{-1}	≥ 92%

6. CONCLUSİONS

Babadağ, Honaz and Çukurköy fault zones, which have a relatively high permeability and a tendency to collect underground water, are well suited for the existence and movement of groundwater. As hydraulic gradients in the region develop parallel to faults zones, the groundwater is transported towards the intersection of these faults (Gökpınar gorge). The most important springs of the region are located at this intersection and its vicinity. The Kozlupınar and Bentpınarı springs on the Babadağ fault are also in this system although they are not very close to the intersection. The Babadağ fault zone is located along the eastern part of the Menderes Massif and bounds the southern margin of the Denizli Graben.

This paper has shown that lithologic units in the study area crop out consist of metamorphic and sedimentary rocks ranging in age from Mesozoic to Quaternary. Units with aquifer properties are of Mesozoic limestone, Quaternary Travertine, Colluvium and Alluvium. Aquifers have a large storage capacity, and the flow of groundwater is primarily through joints and fissures. Geological and geophysical studies have shown that the groundwater movement in the basin and the spring yields depend on the size and location of the tectonic discontinuities rather than the primary porosity of the units. The flow regimes of the springs reflect of the dynamic character of the groundwater systems in the region. The groundwater dynamics are controlled by faulting and little amount of karstification. Both springs are in the tectonic source class. Babadağ Fault, which its location and boundaries determined in detail with the geophysical profiles, forms the southern boundary of the Büyük Menderes Graben. The ground waters of all the sedimentary formations in the plain areas to the north of the Fault are recharged from ground waters of the high mountains in the south. Diverging groundwater flow lines are suited in southern highlands (Babadağ horst) towards the discharging zones (springs region) in the northern part of the study area.

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