JAES
Journal of Anatolian Environmental and Animal Sciences
(*Anadolu Çevre ve Hayvancılık Bilimleri Dergisi*)
DOI: https://doi.org/10.35229/jaes.1201454
Year: 8, No: 1, 2023 (16-27)
AÇEH
Yıl: 8, Sayı: 1, 2023 (16-27)
ARAŞTIRMA MAKALESİ RESEARCH PAPER

Bozova Groundwater Quality Modeling and Evaluation Using Fuzzy AHP Method Based on GIS Technique

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Received: *08.11.2022* ***Accepted:*** *19.02.2023* ***Puplished:*** *31.03.2023*

How to cite: **Aslan, V. (2023).** Bozova Groundwater Quality Modeling and Evaluation Using Fuzzy Ahp Method Based on Gıs Technique. *J. Anatolian Env. and Anim. Sciences*, ***8***(1), 16-27. https://doi.org/10.35229/jaes.1201454
Atıf yapmak için: **Aslan, V. (2023).** Bozova Yeraltısuyu Kalitesinin CBS Tekniğine Dayalı Fuzzy AHP Yöntemiyle Modellenmesi ve Değerlendirilmesi. *Anadolu Çev. ve Hay. Dergisi*, ***8***(1), 16-27. https://doi.org/10.35229/jaes.1201454

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Abstract: One of the most important elements of economic growth and sustainable development in ecological balance is water. However, today, water, unlike the important natural resources of all periods, is in a state of international crisis; population is increasing on the other hand, water resources are decreasing and our planet is experiencing an increasingly dry period. People have already begun to feel the concern that they will not find water in the future and to take their precautions. In addition to the ever-increasing need for water in our country, the control and prevention of groundwater pollution are also gaining importance. In this study, samples taken from well waters consumed as drinking, irrigation and utility water in Bozova basin were analyzed according to the criteria specified in the Regulation on Water Intended for Human Consumption. It is aimed to establish a model for the groundwater quality of the site and to identify areas with high water quality. Water samples from 16 separate wells were obtained for this, and the results were then assessed using the F-AHP approach, one of the GIS supported MCDM methods. Groundwater quality maps were first classified by raster and then by reclassify in the ArcMap environment. Afterwards, a groundwater pollution map was created by weighting the parameters in the F-AHP application. Finally, these parameters were interpreted and suggestions were made.

Keywords: Groundwater, MCDM, GIS, Fuzzy AHP method.

Bozova Yeraltısuyu Kalitesinin CBS Tekniğine Dayalı Fuzzy AHP Yöntemiyle Modellenmesi ve Değerlendirilmesi

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Öz: Ekolojik denge içinde ekonomik büyümenin ve sürdürülebilir kalkınmanın en önde gelen unsurlarından biri sudur. Fakat, günümüzde su bütün dönemlerin önemli doğal kaynaklarından farklı olarak uluslararası kriz durumundadır; nüfus artmakta buna karşılık su kaynakları azalmakta ve Gezegenimiz giderek kurak bir dönemi yaşamaktadır. İnsanlar gelecekte su bulamayacaklarının endişesini şimdiden duymaya ve önlemlerini almaya başlamışlardır. Ülkemizde giderek artan su ihtiyacının yanısıra yeraltı suyunun kirliliğinin kontrolü ve önlenmesi çalışmaları da önem kazanmaktadır. Bu çalışmada, Bozova havzası içme, sulama ve kullanma suyu olarak tüketilen kuyu sularından alınan örneklerin İnsani Tüketim Amaçlı Sular Hakkındaki Yönetmelikte belirtilen kriterlere göre kalite analizi yapılmıştır. Sahanın yeraltı su kalitesi için bir model oluşturma ve yüksek su kalitesine sahip alanları belirleme amaçlanmıştır. Bunun için 16 farklı kuyudan su örnekleri toplanmış ve veriler CBS destekli ÇKKV yöntemlerinden F- AHP tekniğiyle değerlendirilmiştir. Yeraltı suyu kalite haritaları ArcMap ortamında önce raster, sonrada reclassify ile sınıflandırılmıştır. Daha sonra da parametreler F-AHP uygulamasında ağırlıklarındırılarak yeraltı suyu kirliliği haritası oluşturulmuştur. Son olarak da bu parametreler yorumlanıp öneriler yapılmıştır.

Anahtar kelimeler: Yeraltı suyu, ÇKKV, CBS, bulanık AHP yöntemi.

INTRODUCTION

The need for clean, high-quality water resources is rising quickly today as a result of expanding agriculture, industry, tourism, and economic activity as well as a rapidly expanding population. However, due to anthropogenic and natural forces, clean water supplies, which are fairly scarce, are increasingly losing their useable qualities. The use of poor quality water can put the ecology and people at risk for diseases that threaten their lives (Germolec et al., 1989; Sadat-Noori et al., 2014). The inadequacy of resources suitable for drinking, use and irrigation in arid and semi-arid regions necessitates the use of less qualified resources in these regions.

Depending on the intended purpose of the water, water quality is a measure of its fitness for use, taking into consideration a number of physical, chemical, and biological factors (Cordy, 2015; Taylor, 1981). Water quality can change negatively as a result of ecological interactions (Bordalo et al., 2001; Diersing, 2009). Important variables that directly impact water quality include dissolved minerals, organic matter content, and heavy metals (Taylor, 1981). Determining the parameters controlling the water quality is very important for the protection of the ecosystem (Marjani & Jamali, 2014).

Many criteria and standards have been determined by different organizations in order to protect water resources and prevent quality loss in terms of compliance with usage characteristics (WHO/UNICEF, 2012). Water quality criteria will not only enable the classification of water resources according to their intended use, but also they are used in determining the regions where water pollution is most intense and in determining the priorities of the measures to be taken (Chapra, 2008). The process of evaluating water quality is made more difficult by the abundance of water quality criteria and the evolution of many standards for these criteria. Various water quality classifications may arise for different criteria representing the same water sample (Sume & Verep, 2021).

Planned construction and land use are important in order to maintain the ecological balance and ensure sustainable water management in groundwater aquifers. In order to be able to design, plan and implement in the basins, first of all, the specific physical characteristics of the basin should be determined. By considering these features, point and diffuse pollution source that can cause water pollution; Planning studies should be carried out for population growth, settlement areas, land use patterns, regulation of socio-economic and socio-cultural activities. The physical properties of the basin are spatial data, and the choice of settlement in the basins is a spatial decision problem. The evaluation of multiple spatial data together is a multi-criteria spatial decision problem (Chang, 1996).

In this context, the integration of the Fuzzy AHP method, one of the multi-criteria decision-making methods, and the spatial analysis tools of the Geographical Information System (GIS) are effective in solving spatial decision problems.

In our country and in the world, GIS and related techniques are used successfully in modeling studies related to the potential status and pollution of surface and underground water resources, as in many areas (Yavuz, 2017). Celik (2007) investigated the groundwaters of Diyarbakır Plain and modeled them with GIS. At the same time, he observed the changes in static water level by considering the negative effects of population growth in the plain, misuse of groundwater for agricultural purposes, and irregularity in precipitation due to climate change, on the groundwater potential of the basin. Aslan and Celik used the GIS supported Fuzzy AHP method in their modeling studies on the underground water potential and pollution of the Şanlıurfa Harran Plain. Very low, low, medium and high and very high groundwater potential pollution zones of the GWPI map were determined by making hydrogeological, hydrological and geological evaluations (Celik, 2007; Aslan & Celik, 2021).

In this study, in order to determine the geographical information system of groundwater quality and change in the Bozova basin, in the first stage, 10 parameters related to pollution were transferred to ArcMap environment and thematic maps were obtained. With the method of determining weight ratios, thematic maps showing groundwater level changes and classification were produced. In the second stage, 10 parameters used for groundwater pollution in the Bozova basin were calculated by weighting according to their effects on water quality in the F-AHP technique, one of the MCDM methods. Groundwater pollution area distribution map was created with the values found in fuzzy AHP. In the third stage, this groundwater pollution area distribution map was analyzed and interpreted. In the fourth stage, the result of the whole study was evaluated and then the necessary recommendations were made.

MATERIAL AND METHOD

Material: Geological map (1/25000 scale) of the study area was prepared by contact tracing in the field. The water available in the plain has been identified (drilling, common wells and springs) has been mapped. Drilling wells and required ordinary wells and sources were coded and their static levels and flow rates were observed. Water samples were taken and analyzed at various locations.

Geophysical points were made with the Wenner electrode expansion system in various parts of the plain in the study area. The aim of the geophysical study is to determine the depth of the existing Pliocene formation in the plain and to determine the ceiling of the Paleocene marls located under the Eocene limestone. In order to determine the hydrogeological coefficients of the aquifer, a pump experiment was carried out in Bozova well no 4416.

Study Area: Bozava Plain is located within the borders of Sanliurfa province in the Southeastern Anatolia Region, within the 10º-43' latitude circles and 12º-58' longitude circles of the Sanliurfa N 40 map. It is located 100 km northwest of Sanliurfa with a drainage area of 1246.1 km². Bozova plain is within the boundaries of a plateau showing different surface shapes. In Bozova, Baziki-Kepirce-Kılıçören regions form a plain, while other regions are hilly. According to meteorological observations, the annual average is 427.1 mm.

Figure 1. Bozova Plain Location Map.

The geological formations in the study area consist of dendritic materials consisting of Quaternary aged sand, clay, pebbles and Pliocene aged basalts at the top. At the bottom, there are Eocene aged limestones, Paleocene aged marls and clayey limestones. They were formed by the filling of the depression formed in the south by the NW-SE directional fault formed along Yaslıca-Arıkök in the northeast. There are asphalt and stabilized roads connecting the settlements. Summer and winter transportation is provided to all parts of the study area. The main streams are the stream formed by the Pınarbaşı spring and the stream formed by the kahniğ spring in the west. They discharge the waters of the study area from both sources.

Bozova Plain is within the boundaries of a plateau showing different surface shapes. While the plain has an altitude of 700-750 m in the South, this height decreases to 500 m towards the North. In Bozova, Baziki-Kepirce-Kılıçoren regions form a plain, while other regions are hilly (DSI, 2012).

Climate: The typical Southeastern Anatolian climate is seen in the Bozova-Yaylak plain. Winters are cold and rainy, Summers are dry and quite hot. Precipitation is usually in the form of rain between November and April. The average is 427.1 mm per year. There are 6 meteorological observation stations on the plain. The average annual precipitation value for Bozova-Yaylak plain was calculated by considering the area affected by these 6 observation stations. (The average is calculated by taking into account the area affected by the observation station.) The annual averages of the meteorological stations are shown in the table below.

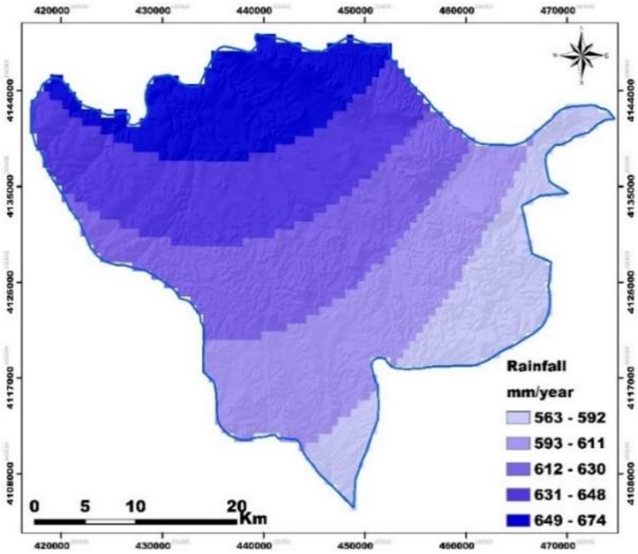

Figure 2. Precipitation Map of Bozova Plain.

SI (State Hydraulic Works) study and planning department, observations branch directorate, Observation table directorate, Station name Bozova İŞLT. Administration DMI altitude 618 station no 17944 region Southeast province and district Şanlıurfa latitude-longitude 37° 22' – 38° 31' observation type monthly total precipitation (mm) is given as a year.

Here Business Administration is BA, State Meteorology Station is SMS, Province And Distribution is PD, Observation Type is OT, January is JNRY, February is FBRY, March is MRCH, April is APRL, August is AGST, September is SPTMR, Oktober is OCTR, November is NVBR, December is DCBR and Yearly is YRLY.

Geology of the Basin: The study area consists of Mesozoic and Quaternary formations. There are also magmatic rocks around Karapınar and Karacaören villages. Sedimentary rocks from old to young

Paleocene: This unit outcropping on the northern and eastern borders of the plain consists of clayey limestone and marl. No fossils were found in this macroscopic examination. This formation has been accepted as Paleocene due to its lithological features.

Table 1. Observation Values of Bozova Plain.

STATION NAME		BOZOVA			BA			SMS		ALTITUDE		618
STATION NO		17944			REGION				SOUTH EAST			
PD		SANLIURFA		LATITUDE-LONGITUDE					37° 22'- 38° 31'			
OT		TOTAL MONTHLY RAIN (mm)										
YEAR	**JNRY**	**FBRY**	**MRCH**	**APRL**	**MAY**	**JUN**	**JULY**	**AGST**	**SPTMR**	**OCTR**	**NVBR**	**DCBR**	**YRLY**
1957	-	-	-	-	-	.	.	.	.	3.1	35.6	35.1	-
1958	119.4	19.4	28.3	8.4	5.8	56.3	.	.	.	1.0	26.4	76.5	341.5
1959	59.0	42.7	12.9	37.7	12.1	17.6	.	.	.	28.9	11.7	24.6	247.2
1960	160.6	10.7	58.3	33.5	9.4	0.5	.	.	.	4.9	29.2	21.4	328.5
1961	55.7	66.4	42.1	12.1	35.6	14.5	.	.	.	15.4	96.3	77.3	415.4
1962	47.4	81.6	6.3	25.3	16.0	.	.	.	.	2.7	6.1	79.6	265.0
1963	69.8	47.0	46.7	80.5	129.1	.	5.9		16.4	31.0	0.7	54.5	481.6
1964	19.5	94.1	102.2	7.0	6.3	10.0	1.0	4.0	.	.	80.2	85.6	409.9
1965	61.1	122.3	71.5	30.9	5.0	.	.	0.0	0.0	90.8	18.6	58.7	458.9
1966	83.9	22.5	48.0	25.9	8.2	.	.	.	10.5	8.6	43.8	64.6	316.0
1967	72.0	108.1	116.8	49.2	97.1	2.0	1.0	.	3.0	98.5	42.9	79.4	670.0
1968	113.0	70.0	29.7	13.5	66.9	3.7	.	0.0	.	46.9	55.0	108.5	507.2
1969	174.9	60.4	112.7	74.5	32.8	.	.	.	0.0	68.3	30.5	36.5	590.6
1970	31.8	26.4	111.4	9.9	2.0	.	5.5	.	.	2.8	25.6	43.6	259.0
1971	4.1	30.3	56.6	190.4	4.8	0.2	.	2.3	.	35.0	48.6	80.6	452.9
1972	40.7	25.1	74.8	108.3	75.3	26.6	.	0.0	19.4	20.8	17.2	0.0	408.2
1973	32.3	20.1	34.3	24.2	10.0	3.3	.	.	.	16.1	68.9	45.5	254.7
1974	95.0	22.3	102.5	36.5	0.0	0.0	.	.	0.3	2.0	25.5	45.8	329.9
1975	18.6	95.9	9.1	69.1	46.9	1.5	.	.	0.0	4.0	56.7	76.6	378.4
1976	94.4	74.4	67.6	95.0	61.7	4.0	.	.	.	100.6	16.0	106.4	620.1
1977	22.3	62.9	60.0	31.7	30.4	4.0	-	-	-	-	-	-	-
1978	-	-	-	-	-	-	-	-	-	-	-	-	-
1981	-	-	-	-	2.8	3.7	.	.	0.0	27.4	40.1	53.7	-
1982	30.5	22.6	29.4	66.5	67.1	11.8	.	.	6.3	45.7	38.6	42.4	360.9
1983	72.3	34.5	73.2	71.3	35.2	4.8	.	.	.	4.9	90.8	43.9	430.9
1984	73.2	22.6	52.6	35.6	4.2	0.6	.	.	.	27.0	80.4	43.7	339.9
1985	65.1	69.9	24.7	60.7	5.5	.	.	.	.	15.9	45.6	68.9	356.3
1986	38.2	71.0	34.0	36.0	22.8	23.2	.	.	0.6	15.7	31.4	43.0	315.9
1987	110.7	29.6	64.1	5.7	0.0	1.6	3.2	.	.	88.0	69.9	104.9	477.7
1988	82.6	39.8	101.9	126.8	16.9	5.8	.	.	.	116.7	40.3	66.8	597.6
1989	.	12.4	74.2	8.3	.	.	.	2.8	.	70.1	52.3	39.0	259.1
1990	70.7	91.6	5.7	38.5	0.3	1.7	.	.	.	3.6	49.6	28.5	290.2
1991	49.9	55.1	83.0	30.8	22.7	.	.	.	0.0	11.0	25.8	69.2	347.5
1992	17.7	80.6	9.5	5.7	29.0	37.2	.	.	3.5	3.5	34.1	33.6	254.4
1993	65.4	45.9	26.3	48.8	180.4	12.3	0.0	.	.	0.0	48.2	17.3	444.6
1994	80.4	60.0	23.4	32.1	14.7	1.5	.	.	4.6	26.1	104.7	53.6	401.1
1995	54.7	40.7	25.6	43.7	34.1	11.1	0.0	.	.	21.6	67.9	8.1	307.5
1996	-	-	-	-	-	-	-	-	-	-	-	-	-
1997	-	-	-	-	-	-	-	-	8.5	66.8	44.0	71.3	-
1998	39.4	22.5	.	57.2	34.3	7.2	.	.	.	2.5	37.3	69.0	269.4
1999	19.8	50.3	62.9	38.6	0.0	24.7	.	0.5	.	10.0	0.5	39.3	246.6
2000	70.7	49.3	22.0	38.3	4.6	.	.	4.3	10.0	28.6	43.0	67.6	338.4
2001	15.9	59.3	83.2	55.3	56.8	.	.	.	.	33.1	36.3	142.6	482.5
2002	34.3	35.9	94.7	54.9	16.9	6.0	7.3	4.8	7.6	1.0	26.0	34.4	323.8
2003	82.1	119.6	114.8	31.9	4.2	4.7	.	.	4.1	28.3	45.4	67.1	502.2
2004	96.9	29.5	1.6	60.1	30.5	5.2	.	.	.	7.4	191.4	9.3	431.9
2005	66.1	66.7	41.0	29.4	30.2	30.2	.	.	.	24.5	31.6	23.2	342.9
2006	88.9	52.6	25.7	68.0	6.6	.	.	.	.	67.7	76.4	23.4	409.3
2007	53.8	44.6	56.4	39.6	8.6	3.4	.	.	.	16.6	12.5	59.4	294.9
2008	44.1	35.6	12.5	3.5	29.6	16.7	.	.	38.8	14.4	19.7	36.2	251.1
2009	36.5	64.6	63.6	10.5	18.0	2.3	1.6	.	21.2	58.5	35.2	59.0	371.0
2010	75.6	15.5	32.4	42.6	2.2	1.7	.	.	2.2	33.5	.	66.4	272.1
2011	81.5	25.7	23.2	164.7	29.1	1.1	25.2	0.0	21.8	20.2	45.2	44.4	482.1
2012	120.3	84.9	17.8	34.6	14.8	0.2							272.6
2013													0.0
2014													0.0
2015													0.0
Average	**63.2**	**50.8**	**50.9**	**47.6**	**28.3**	**7.6**	**1.1**	**0.4**	**3.6**	**29.2**	**44.3**	**54.7**	**381.6**

Eocene: Eocene limestones form a large part of our study area. These limestones break off from place to place, have abundant melting spaces, and are hard crystalline. Great karst events occurred. (For example: They are located above a large cave reaching Koçhisar and Taşalan villages.) This unit, which sits concordantly on top of the Paleocene, contains lamellar branches and numulites as fossils. The presence of lamellar branches indicates the frequency of the deposition environment. Although the layers are massive in places, they have grown very well in some places. The stratifications have developed as cm in some places and as m in some places. These Eocene limestones have collapsed due to a fault that occurred along Arıkök-Dutluca in the north. Later, this place was filled with detrital materials in the Quaternary.

Plio-quaternary: As stated above, the south of the mentioned villages has collapsed due to a NE-SE directional fault that occurred along Arıkök-Yaslıca-Dutluca. This collapsed part was filled with detrital materials in Quaternary. Detritic materials consist of clay, sand and gravel grains. The upper part of these detrital materials generally consists of sand and gravel. It was formed by a clay and sandy clay material up to 15-30 m thick with the lower part of the same detrital material. This detrital material can reach a thickness of 70 m in some places.

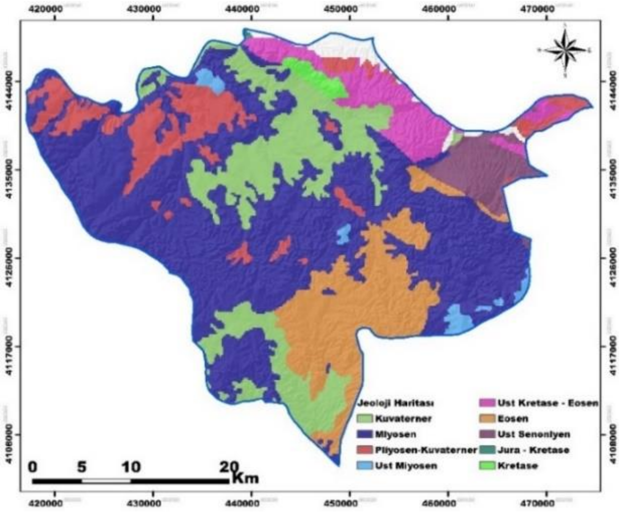

Figure 3. Geological Map of Bozova Plain.

General Condition of Aquifers and Groundwater of Bozova Basin: In the research region, there are two aquifers. One of them is the detrital materials, which is the Tünek aquifer, and the other is the Eocene limestones.

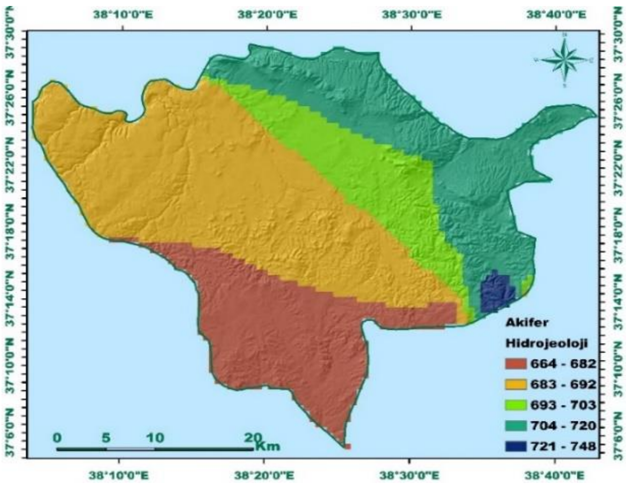

Figure 4. Aquifer Map (Hydrogeology) Map.

Groundwater in detrital materials is fed by falling rains and cannot discharge its waters to the outside. The discharge is by evaporation and drinking and watering the animals. However, the waters of this aquifer are negligible, so they can be neglected. It is salty in places.

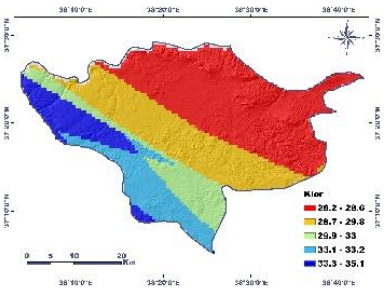

Figure 5.a Bozova Basin Chlorine (C**l)**

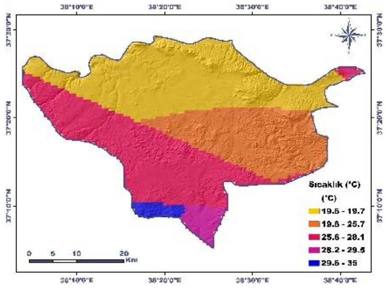

Figure 5.b Temperature (ºC) Map

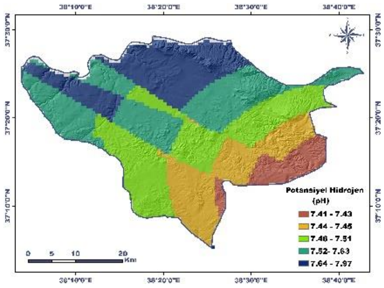

Figure 5.c pH Map

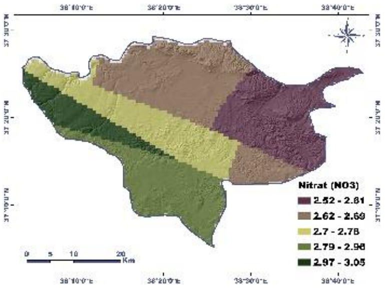

Figure 5.d Nitrate (NO_3) Map

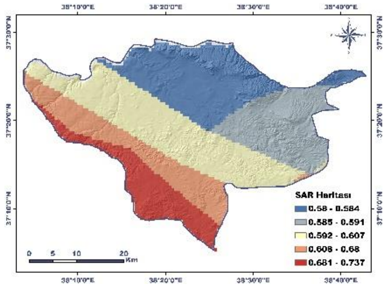

Figure 5.e SAR Map

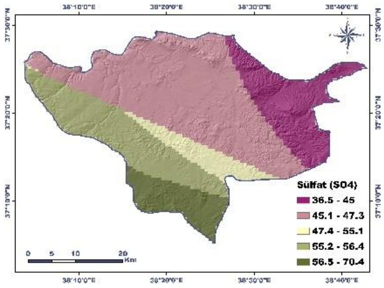

Figure 5.f Sulphate (SO4) Map

Method

Analysis Methods of Water Samples:

Determination of Physical Properties:

Temperature (°C): The temperature is determined by a portable oxygen meter that measures temperatures between -5 °C and +45 °C with an accuracy of 1°C.

Dissolved Oxygen (mg/lt): The dissolved oxygen value was determined using a portable oxygen meter that measures 0.2 ppm precision.

pH Determination: pH measurements were determined by a field type pH meter with a measurement range of 0-14 with a sensitivity of 0.01.

Nitrite Determination: It was made by sulfanilic acid method. Nitrate Determination: The nitrate amount was determined by measuring the optical density of the colored complex formed by the nitrate ion interacting with phenol disulfanic acid to form a yellow complex at a wavelength of 41O milli-micron.

Determination of Water Chemistry Properties: Chemical analysis of 15 of the 21 boreholes drilled for the purpose of supplying drinking and irrigation water in the plain could be made. In addition, some ordinary village wells drilled in the limestones in the study area and the water samples of some springs from the limestones were subjected to chemical analysis.

Resources: Water samples were taken from both ordinary village wells drilled in the limestones and some ordinary wells drilled in the whole aquifer and analyzed. However, sodium content could not be determined during these chemical analyzes due to the insufficiency of the laboratory.

Table 2. Classification of Factors Affecting Potential Groundwater Zones

Sequence No	Parameters	Rating	Sub Parameters	Land Coverage	Range (%)	Groundwater View	Degree
1	**Chlorine (Cl)**	5	28.2-28.6	393	0.09	Very Good	8
			28.7-29.8	522	0.12	Good	6
			29.9 - 33	486	0.11	Moderate	5
			33.1-33.2	1105	0.25	Weak	4
			33.3-35.1	1863	0.43	Very Weak	3
2	**Temperature (ºC)**	4	19.6 – 19.7	64	0.02	Very Good	9
			19,8 – 25.7	114	0.03	Very Good	8
			25.8- - 28.1	1130	0.32	Good	7
			28.2- 29.5	837	2.24	Moderate	5
			29.6 - 35	1379	0.39	Weak	3
3	**Potential Hydrogen (pH)**	6	7.41-7.43	893	0.20	Very Good	7
			7.44-7.45	1194	0.27	Good	6
			7.46-7.51	1146	0.26	Moderate	5
			7.52-7.63	792	0.18	Weak	4
			7.64-7.97	344	0.08	Very Weak	3
4	**Nitrate (NO^-_3)**	9	2.52 – 2.61	393	0.10	Very Poor	3
			2.62– 2.69	832	0.19	Poor	4
			2.70 – 2.78	841	0.21	Moderate	5
			2.79 – 2.86	1328	0.32	Good	7
			2.87 – 3.05	975	0.23	Very Good	8
5	**Specific Absorption Rate (SAR)**	7	0.58 – 0.584	1085	0.25	Very Weak	4
			0.585 – 0.591	776	0.18	Weak	5
			0.592 – 0.607	1275	0.29	Moderate	6
			0.608– 0.680	683	0.16	Good	7
			0.681 - 0.737	550	0.13	Very Good	8
6	**Sulfate (SO_4)**	8	36.5-45.0	333	0.09	Very Good	6
			45.1-47.3	705	0.20	Good	5
			47.4-55.1	237	0.07	Moderate	4
			55.2-56.4	1640	0.47	Weak	3
			56.5-70.4	609	0.17	Very Weak	2

Table 3. Chemical analysis results of water samples taken from existing sources in the study area

Where the Sample Was Taken	PH	ECX10^6	Cations (meq/l)				Anions (meq/l)				% Na	SAO SAR	Class of Water	Hardness
			Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4				
Kucukgol	8.0	300	0,2	0,03	2,5	0,4	0.0	2,59	0,2	0,11	6	0,16	C_2S_1	19
Kahnik	8.0	310	0,2	0,02	2,6	0,6	0.0	2,89	0,22	0,2	6	0,16	C_2S_1	20
Inbasi	7,3	300	0,17	0,02	2,7	0,34	0.0	2,74	0,2	0,15	5	0,14	C_2S_1	19,5
Cavsak	7,8	335	0,14	0,02	3,1	0,3	0.0	3,19	0,2	0,08	4	0,11	C_2S_1	19
Pinarbasi	7,5	315	0,17	0,03	2,9	0,4	0.0	3,04	0,2	0,05	5	0,13	C_2S_1	20

These waters, whose analysis results are given in the table above and whose properties are shown in the logarithmic diagram (Seller diagram), are typical compact limestone waters results of very good quality. It can be used in all kinds of irrigation.

Common features seen in spring waters:

PH 7 is generally acceptable as basic.

EC X106 = moderate

$CO^=_3 + HCO^-_3\ Cl^-$

$SO^=_4\ Cl^-$

$Ca^{++} + Mg^{++}\ Na^+ + K^+$

They are medium salty and low sodium waters.

Shallow Wells: Water samples were taken from both ordinary village wells drilled in the limestones and some ordinary wells drilled in the whole aquifer and analyzed. However, sodium content could not be determined during these chemical analyzes due to the insufficiency of the laboratory.

The analysis results of some ordinary village wells drilled in the limestones and shallow wells drilled in the perch aquifer are shown in the table.

Common features seen in shallow wells drilled in limestones:

PH 7 is acidic,

EC X 106 = Moderate

$CO^=_3 + HCO^-_3\ Cl^-$

Since Sodium, Potassium and Sulfate values cannot be measured, it is not possible to say anything about this issue. However, there is no harm in using all these waters for irrigation purposes.

Ordinary village wells drilled in the upper aquifer are generally divided into 2. Some of them belong to brackish and salty water, and the other part belongs to fresh water. The results of the analyzes made in 2 different wells drilled in the center of the Baziki region and in the shallow wells drilled in Hacılar Kepirce and Saf villages are given in the table below.

As can be seen in the table above, some waters have very high ECX106 values. This high value is due to the excess amount of salt in it. However, since the amounts of Na, K and SO4 cannot be determined, it is difficult to tell the type of this salt.

Table 4. Chemical Analysis Results of Shallow Wells in the Upper Aquifer.

Where the Sample Was Taken	pH	$ECX10^6$	Cations (meq/l)				Anions (meq/l)				% Na	SAO SAR	Hardness
			Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4			
Baziki I village	6,7	606,6	-	-	3,6	0,8	0	3,5	0,7	-			22
Baziki II village	6,6	1777	-	-	9,9	3,3	0	4,2	4,4	-			21
Hacılar village	6,9	6257	-	-	39,1	4,9	0	13,3	13,4	-			220
Kepirce village	6,9	2095	-	-	12,0	8,2	0	3,8	5,4	-			100
Arıkok village	7,1	677	-	-	4,3	3,0	0	5,2	1,4	-			36

Drilling Wells:

According to the results of these chemical analyzes made during the drilling of the wells; Wells 4416,4417,3431 and 3009 have PH 7, basic waters. All other boreholes have a PH of 7. In well 3009, ECX106 = 5600. Apart from this, ECX106 values in all other boreholes are between 280-540.

Hardness in all boreholes generally ranges from 11-16 Fr°.

The amounts of Cl^- and $SO^{=4}$ ions in the waters are generally below 3.0 mek/lt except the 3009 borehole.

The amount of chloride in the water is usually more or equal to the amount of sulfate.

The chemical properties of the water in which some wells are located are shown in the table below. In order to compare the quality of these waters with each other, a Schoeller diagram was drawn. However, since Ca and Mg valences are given together, we do not have the opportunity to compare them.

The results of the water analysis of the boreholes are given in the table. The water of the boreholes only looks bad in well no. 3009. In all other wells, the water is generally of good quality and can be used as drinking and utility water (Yesilnacar & Gulluoglu, 2008).

Table 5. Chemical Analysis Results of Some Drilling Well Waters.

Well No of Sample Taken	PH	$EOX10^6$	Cations (meq/lt)				Anions (meq/lt)				% Na	SAO SAR	Class of Water	Hardness
			Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4				
3009	8,3	5600	21,1	0,25	4,7	29,6	0,84	4,92	17,3	34,4	40,3	6,6	C_5S_1	
3431	7,8	430	1,2	0,05		3,1	0	3,37	0,4	0,6	27,9	0,97	C_2S_1	13
4416	8,3	330	0,33	0,06		2,9	0,24	2,44	0,38	0,23	10,0	0,27	C_2S_1	
4417	8,1	350	0,26	0,07		3,1	0,12	2,53	0,2	0,58	7,58	0,2	C_2S_1	

Table 6. National International Standards for Consumptive Waters (Anonymous, 2005).

Water Quality Parameters	Water Quality Classes	Area Covered	
		Area	
Effective Factors	Factor Classes	km²	%
Hydrogeological Environments	Low permeability	42.3	86.33
	very permeable	6.7	13.67
Chlorine mg/l (Cl)	Very good quality waters (< -180)	48.70	99.39
	Good quality waters (180.01 - >)	0.30	0.61
Hydrogen Ion Concentration mg/l (pH)	III. quality water (< -8.5)	47.50	96.94
	IV. quality water (8.5- >)	1.50	3.06
Sodium mg/l (Na)	I.-II. Quality water (< -6.25)	35.4	72.24
	III. quality water (6.25-12.5)	13.5	27.55
	IV. quality water (12.5- >)	0.1	0.20
Magnesium mg/l (Mg)	IV. quality water (< -5)	45.6	45.6
	III. quality water (5.01- >)	93.06	93.06
Sulfate mg/l (SO4)	IV. quality water (< -3)	48.5	98.98
	III. quality water (3.01- >)	0.50	1.02
Nitrate mg/l (NO_3)	<22	25	50
	22-44		
	44-89		
	>89		
Specific Absorption Rate mg/l (SAR)	0-5		
	5-10		
	10-18		
	18-26		
	>26		

Fuzzy AHP Method: In a matrix with n entries, (nxn-1)/2 comparisons are performed using the F – AHP method. Since a criterion will be expressed as 1 when compared to itself, the diagonal values of the matrix must all be 1. After the pairwise comparisons are completed, it is necessary to determine the relative importance, namely the priority, of each element being compared, which Saaty (1980) sees as the 'synthesis' part. Saaty (1980) acknowledged that locating the primary eigenvector of matrix A can be used to determine the relative importance of the criterion . When compared to the fuzzy AHP approach, the interval values used instead of simple net numbers limit how well the AHP method can capture the expert's knowledge based on perception or preference. The hierarchical fuzzy multi-criteria decision making problems are therefore solved using the fuzzy AHP approach (Saaty, 1980; Lee et al. 2013). Triangular fuzzy numbers are used in the fuzzy AHP approach to 23pplied the field experts' binary comparison of the decision elements (TFN).

The work flow diagram for 23ppl study is given in Figure 2, and maps of 6 hydrogeological parameters such as chlorine, temperature, pH, nitrate, SAR, sulfate were created to evaluate the groundwater pollution and potential distribution as shown in the figure. Table 1 displays the scale for the fuzzy AHP method's pairwise comparison of one feature with another (Tseng et al., 2008). Instead of classical numbers, the numbers 2/3, 1, 3/2, 2, 5/2, 3, 7/2, 4 and 9/2 are used as fuzzy scaling ratios. Preferring one element over another (Lee et al., 2013). Pairwise comparisons of the parameters were performed using the fuzzy scale.

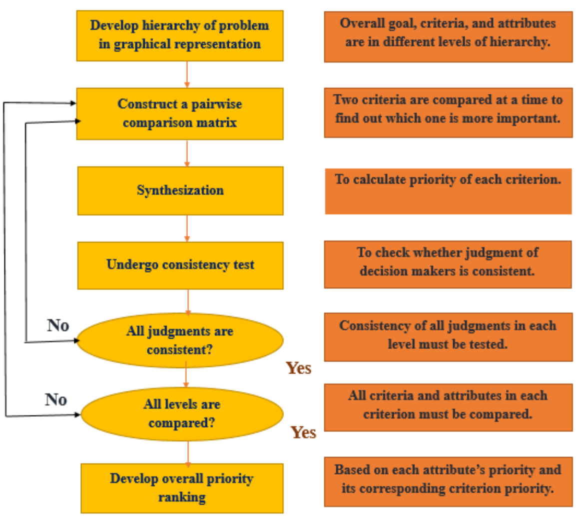

Figure 5. Flow-chart methodology adapted for the present work.

According to Chang's measure analysis, the steps of calculating the relative weights of the criteria using fuzzy AHP Kahraman et al. (2004) was 23 pplied (Kahraman et al., 2004).

First stage: the value of the fuzzy synthetic coverage relative to the object is defined as;

$$S_i = \sum_{j=1}^{n} M_{gi}^{j} x \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (1)$$

In order to obtain the $\sum_{j=1}^{m} M_{gi}^{j}$ value in the formula, the m order analysis value is as seen in equation 2.

Fuzzy addition is applied.

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} I_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad (2)$$

and $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$ to get $M_{gi}^{j}(j, 2, 3, \cdots, m)'$ (j, 2, 3, $\cdots\cdots, m)'$ fuzzy addition operation values are as follow carried out.

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = (\sum_{i=1}^{n} I_i \sum_{j=1}^{m} m_i \sum_{i=1}^{n} u_i \quad (3)$$

and obtaining the inverse of the vector in equation 3:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_1}, \frac{1}{\sum_{i=1}^{n} m_1}, \frac{1}{\sum_{i=1}^{n} I_1}\right) \quad (4)$$

Second stage:

$M_2 = (I_2, m_2, u_2) \geq M_1 = (I_1, m_1, u_1)$ probability degree is defined as:

$V(M_2 \geq M_1 = sup_y \geq$ $[\min(\mu_{M1}(x), \mu_{M2}(y)]$ **(5)** and can be equivalently expressed as:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M2}(d)$$

$$\begin{cases} 1, & if \ m_2 \geq m_1, \\ 0, & if \ m_2 \geq m_1, \\ \frac{I_1 - u_2}{(m_2 - u_2) - (m_1 - u_2)} & \end{cases} \text{otherwise,} \quad (6)$$

Third stage: The probability of the degree of convex fuzzy number being greater than k convex fuzzy number

$M_i(i = 1, 2, 3, \cdots\cdots, k)$, $V(M \geq M_1, M_2, M_3, \cdots\cdots, M_k)$, $V[(M \geq M_1)\ ile\ (M \geq M_2)\ ve\ (M \geq M_k)]$ can be determined with the help of where d is the coordinate of D, which is the highest point of intersection between μ_{M1} and μ_{M2}. The values of $V(M_1 \geq M_2)\ ve\ V(M_2 \geq M_1)$ were needed to compare M1 and M2. Third stage: The probability of the degree of convex fuzzy number being greater than k convex fuzzy number

$M_i(i = 1, 2, 3, \cdots\cdots, k)$, $V(M \geq M_1, M_2, M_3, \cdots\cdots, M_k$ V[It can be determined using $V[(M \geq M_1)\ ile\ (M \geq M_2)\ ve\ (M \geq M_k)]$.

$$min\ V(M \geq M_i),\ i = 1, 2, 3, .., k \quad (7)$$

let's admit

$$d^1(A_1) = min\, V(S_1 \geq S_k) \quad \textbf{(8)}$$

k=1,2,3,…,n;The weight vector for k≠i can be given,

$$W^{\iota} = (d^{\iota}(A_1), d^{\iota}(A_2), d^{\iota}(A_3), d^{\iota}(A_n))^T \quad \textbf{(9)}$$

where A_i $(i = 1, 2, 3, \ldots\ldots\ldots, n)$ is n elements.

The normalized weight vectors represent normalization's last stage.

$$W = (d(A_1), d(A_2), d(A_3),\ d(A_n))^T \quad \textbf{(10)}$$

where W is a non-fuzzy number.

The scale we used in our study for fuzzy AHP is given in Table 6.

The groundwater potential region map for the Bozova basin was created by combining the six thematic layers using a weighted thrust analysis method on the GIS platform.

$$\text{GWPZ} = \sum_{i=1}^{n} (X_A \times Y_B) \quad \textbf{(11)}$$

The applied of the weighting (W) of the applied fuzzy AHP algorithms on the thematic layers and the normalized (NW) weights are provided in Table 10 using the data from Tables 8 and 9.

Table 7. Fuzzy scale (Chang, 1996)

Language scale for importance	Triangular fuzzy scale	Triangle fuzzy mutual scale
Just equal	(1, 1, 1)	(1, 1, 1)
Equally important	(1/2, 1, 3/2)	(2/3, 1, 2)
Weakly more important	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly more important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Much more strongly important	(2, 5/2, 3)	(1/3, 2/5, 1/2)
It matters much, much more strongly.	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
Definitely more important	(3, 7/2, 9/2)	(2/9, 1/5, 1/3)

Table 8. Six thematic data were selected for the current research using the pairwise comparison matrix table

Criteria	Assigned Weight	Chlorine	Temperature	pH	Nitrat	SAR	Sulfate	Geometric Mean	Normalized weight
Chlorine	**5**	**5/5**	5/4	5/6	5/9	5/8	5/7	0.1283	0.76982
Temperature	**4**	4/5	4/4	4/6	4/9	4/8	4/7	0.1026	0.61586
pH	**6**	6/5	6/4	6/6	6/9	6/8	6/7	0.1540	0.92379
Nitrate	**9**	9/5	9/4	9/6	9/9	9/8	9/7	0.2310	1.38568
SAR	**8**	8/5	8/4	8/6	8/9	8/8	8/7	0.2053	1.23172
Sulfate	**7**	7/5	7/4	7/6	7/9	7/8	7/7	0.1796	1.07775
Total		**7.80**	**9.75**	**6.50**	**4.33**	**4.875**	**5.57**		

$$\text{Average } \lambda_{max} = \frac{\sum(\text{Normalzed weight})/(\text{Geometrik mean})}{8} = 6.00462$$

$$\text{Consistency Index (CI)} = \frac{6.00462-6}{5} = 0.000924$$

CR=CI/RI= 0.000924/1.20=0.00077< 0.1 →Since the CR value is less than 0.1, it is within the limits of consistency.

Table 9. Six parameters' significance weights and comparison matrix values.

	Chlorine	Temperature	pH	Nitrate	SAR	Sulfate	FGM
Chlorine	1 , 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2 ,2, 5/2	2, 5/2, 3	5/2, 3, 7/2	1.58, 2.00, 2.42
Temperature	½, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	2, 5/2, 3	1.25, 1.51, 2.00
pH	2/5, ½, 2/3	1/3, 2/3, 1	1, 1, 1	1, 3/2 ,2	3/2, 2, 5/2	3/2, 2, 5/2	0.96, 1.28, 1.61
Nitrate	2/5, ½, 2/3	2/5, ½, 2/3	½, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	0.74, 1.03, 1.31
SAR	1/3, 2/5, ½	2/5, ½, 2/3	2/5, ½, 2/3	½, 2/3, 1	1, 1, 1	1, 3/2, 2	1.16, 0.83, 1.72
Sulfate	2/7, 1/3, 2/5	1/3, 2/5, ½	2/5, ½, 2/3	2/5, ½, 2/3	½, 2/3, 1	1, 1, 1	0.65, 0.57, 0.71

Table 10. Weights for thematic layers using Fuzzy-AHP techniques.

	Chlorine	Temperature	pH	Nitrate	SAR	Sulfate	FGM	Fuzzy weights Wi	Wi	NW
Chlorine	1 , 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2 ,2, 5/2	2, 5/2, 3	5/2, 3, 7/2	1.49, 1.88, 2.27	0.19, 0.29, 0.43	0.303	0.3063
Temperature	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	3/2, 2, 5/2	2, 5/2, 3	1.15, 1.47, 1.83	0.14, 0.22, 0.35	0.237	0.2396
pH	2/5, 1/2, 2/3	1/3, 2/3, 1	1, 1, 1	1, 3/2 ,2	3/2, 2, 5/2	3/2, 2, 5/2	0.92, 1.12, 1.27	0.11, 0.17, 0.24	0.173	0.1749
Nitrate	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	3/2, 2, 5/2	0.71, 0.89, 1.14	0.09, 0.14, 0.22	0.157	0.1587
SAR	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 1, 1	1, 3/2, 2	0.55, 0.68, 0.87	0.07, 0.10, 0.16	0.110	0.1112
Sulfate	2/7, 1/3, 2/5	1/3, 2/5, 1/2	2/5, 1/2, 2/3	2/5, 1/2, 2/3	1/2, 2/3, 1	1, 1, 1	0.45, 0.53, 0.67	0.06, 0.08, 0.13	0.009	0.0091
Total									**0.989**	**0.3064**

CONCLUSİON AND RECOMMENDATİONS

It has been observed that the chlorine value in the groundwater in Bozova basin varies between 28.2 and 35.1, the temperature is between 19.5 °C and 35 °C, the pH value is between 7.41 and 7.97, the nitrate values are between 2.52 - 3.05 mg/lt, the SAR values are between 0.58 - 0.74 and the sulfate values are between 36.5 – 70.4. The concentration of these parameters in the city is mostly seen in the south-west of the basin. These regions are the regions where agriculture is mostly done. It can be said that the use of fertilizers and pesticides of agricultural origin cause especially high nitrate and sulfate levels in the groundwaters of these regions.

Another reason for their concentration in these regions can be taken into account that the sewerage and drainage systems are not built regularly. It can even be considered that domestic and industrial wastewater may also cause it.

The study is likely to conclude that changes in groundwater level are controlled by three key factors;

First; climate change and the consequent variation in precipitation, which in turn affects groundwater recharge. It can be said that the average precipitation in the Bozova Basin has decreased by about 6% in the last twenty years. This factor is very important on the south-west side of the basin, where groundwater is not used for irrigation.

Second; Population growth creates extreme trends in groundwater for drinking and use. Drinking water projects have relatively reduced the demand for groundwater. However, the use of groundwater in landscape irrigation is very important in the district, and the demand for groundwater among rural residents is also quite high.

Third; Irrigation of crops and gardens in agriculture is done through wells. Especially around Kabacık and Taşlıdere villages, and in Kılçık, Yavuz Selim villages, the demand for many wells is quite high to meet the need for agricultural irrigation, which poses a threat to groundwater.

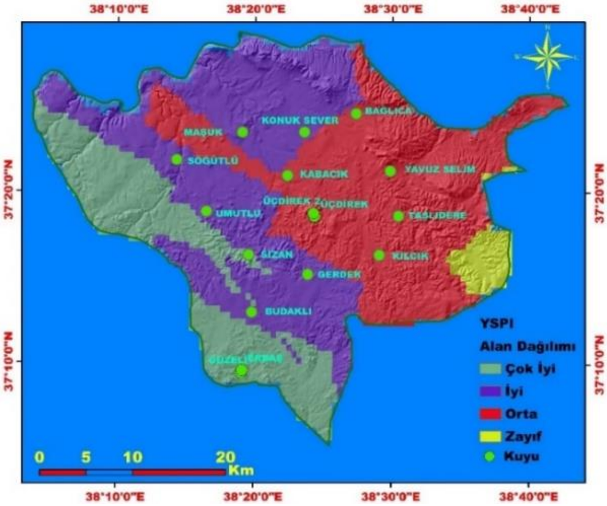

Figure 6. Groundwater Pollution Potential Index Distribution Map.

Table 11. Bozova Plain WWPI Area Classification

GWPI	Describing	Ratio (%)	Area (1550 km^2)
675	Weak	20	310
1249	Moderate	37	573.5
1299	Good	39	604.5
101	Very Good	3	34.5

Table 12. Bozova Plain Groundwater Pollution Result Values.

							Quenching Formations			Statıc Water Level		Pumping Test Result			
												Flow Rate (l/sn)			
Purpose of opening	**Well Number**	**WELL NAME**	**Coordinate No.**	**Year Opened**	**Floor Level (m)**	**Depth (m)**	**Floor to Ceiling depth (m)**	**Thickness (m)**	**Lithology**	**Measurement Date (month)**	**Water level relative to the ground (m)**	**Artesian**	**Pump**	**Drawdown (m)**	**Specific Capacity (Lt/sn/m)**
Drinking	3009	Kilicoren	41-32	2002	524	152	100	51	Limestone	8	65		0,5	25	0,02
Drinking	3431	Kepirce	44-40	2003	511	208	64	14	Limestone	8	62		2,5	10	
Research	4416	Baziki	41-37	2003	92	245	115	94	Limestone	8	39,85		8,1	0,7	
Drinking	4417	Hacilar	36-34	2003	519	209	60	120	Limestone	8	52,10		8,1	2,3	
Drinking	4426	Bozova	58-35	2003	565	337	-	-	Limestone	-	-		-	-	
Drinking	4428	Seyitoren	63-27	2003	-	120	10	23	Limestone	8	52,01		0,2	12	
Drinking	7236	Turkmen veren	27-32	2006	525	83	10	83	Limestone	8	42		4,2	10	
Drinking	7735	Arikok	50-40	2003	560	150	50	10	Clay Sand	7	6		2,2	9,9	
Drinking	7839	Kanli avsar	38-19	2003	640	200	5	85	Limestone	8	50		0,6	30	
Drinking	7880	Alimerdan	33-25	2003	566	92	5	87	Limestone	9	65		2	1	
Drinking	7928	Cakmakli	51-37	2003	580	136	5	131	Limestone	7	79		2,7	13	
Drinking	8025	Umutlu	36-29	2003	544	200	0	200	Limestone	8	62		0,4	68	
Drinking	8092	Kochisar	29-35	2003	515	122	0	122	Limestone	10	50,4		8	4,5	
Drinking	7574	Asagı Goklu	13-31	2003	575	151	11	119	Limestone	8	77,8		3,2	2,2	
Drinking	7841	Yukarı Goklu	10-33	2003	-	250	7	233	Limestone	7	61,5		2,7	33	
Drinking	9602	Gunece	18-22	2008	568	114	1	113	Limestone	4	19,35		15	0,4	
Drinking	9604	Kurugul	13-34	2008	610	227	118	109	Limestone	3	91,50		2	13	
Drinking	8529	Yukari Goklu	12-33	2012	-	200	102	49	Limestone	8	71,40		6,5	10	
Drinking	8027	Hubabi	22-13	2012	670	150	1	24	Limestone	10	30,70		0,5	29	
Drinking	8028	Ekenek	26-10	2012	715	135	1	134	Limestone	9	33		5,7	27	
Drinking	9598	Asman	35-10	2018	610	130	7	7	Sand, gravel	4	3,2		10	1,4	

Therefore, it is obvious that groundwater levels have decreased in the use of water for irrigation purposes in this arid Bozova plain. There is a great demand for groundwater, especially for irrigation of the southeastern part of the Basin. There is a large gap in terms of water budget between seed scattering, spraying and groundwater consumption in the crop area. In order to prevent the situation in the basin from getting worse, groundwater quality and efficiency in water use need to be increased. Since the field irrigation has not increased in the plain, the creation of efficient irrigation systems based on drinking water, soil and climatic conditions should be considered. Especially people in Bozova district need to be educated on how to use groundwater and natural resources in the best way in order to increase their quality of life and make their welfare level better. The use of groundwater for irrigation purposes in the district should be reduced by approximately 50% and groundwater usage should be kept at an acceptable level. Although the increase in the population of the district can meet the need for drinking water from the existing water network without adversely affecting the groundwater level, precautions should be taken without threatening the groundwater potential of the basin due to climate change and increasing water use demand.

Eocene limestones are the main aquifer for water boreholes. While the well is being constructed, the well must be well sealed from the top to the main aquifer.

It is important to establish a good drainage system for the water returning from irrigation.

In order to prevent salinity, it is necessary to ensure that the appropriate plant pattern is grown.

In order to prevent the rise of the ground water level, flood irrigation should be abandoned and sprinkler and drip irrigation should be expanded in the plain.

In addition, with the work presented here

With a GIS supported F-AHP method, it has been shown that the time to reach any receiving environment of groundwater pollution in an irrigation and drinking water basin can be obtained in a short time and with easily obtainable data without resorting to complex mathematical models. An example application is shown for an important water basin in Bozova district. However, such a study can easily be repeated for other important water basins of the country when necessary.

Studies using MCDA and especially its integration with FAHP, will provide an improvement in the accuracy of groundwater potential maps due to the flexibility of fuzzy membership functions. In this context, the present article applied the integrated approach of Fuzzy-AHP and GIS to the development of thematic data layers to describe the Bozova basin GWPZ. Recognition of the sensitive factors affecting the identification of potential groundwater regions and demonstration of the capabilities of GIS technology in groundwater mapping emerge using the fuzzy AHP MCDA method.

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