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Research Article/Araştırma Makalesi

Determination of Mardin-Kızıltepe plain groundwater level using geographic information systems and analysis of change between 1985-2019

Mardin-Kızıltepe ovası yeraltı su seviyesinin coğrafi bilgi sistemleri kullanılarak belirlenmesi ve 1985-2019 yılları arasındaki değişimin analizi

Serkan KILIÇASLAN[1*]

[1]Mardin Tarım ve Orman İl Müdürlüğü, Mardin/TÜRKİYE

[1]https://orcid.org/0000-0002-5595-2338

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***Address for Correspondence:**
Serkan KILIÇASLAN
e-mail:
serkankilicaslan@hotmail.com

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ABSTRACT

65% of groundwater resources are used for agricultural irrigation. This situation has made the management and protection of groundwater very important, especially in terms of the protection of natural resources and sustainable agriculture. For this purpose, in the study carried out in the Mardin-Kızıltepe Plain, which is one of the regions with intensive use, groundwater conditions and how they change over time were examined. The 34-year (1985-2019) drilling data of the region were divided into 7 periods and thematic maps of Static Water Level (SWL), Dynamic Water Level (DWL), Well Depth (WD) and Well Yield (WY) data were created and the change rates were analyzed using the reverse distance interpolation technique. While the proportion of the area classified as SWL shallow and normal in Period-1 was 100%, it decreased to 7.5% in Period-7, while the proportion of deep and very deep class, which was 0% in Period-1, reached 92.5%. While the ratio of shallow and normal class was 100% in DWL Period-1, it decreased to 0.2% in Period-7, and the rate of 0% in deep and very deep class in Period-1 reached 99.8% in Period-7. In terms of WD, while 100% of the well depths drilled in Period-1 were in the shallow and normal class, this rate decreased to 0.3% in Period-7, and the rate in the deep and very deep class reached 99.7%. Using the period-7 data, the exploitable groundwater potential of the region was classified and 3.2% of the area was classified as poor (390,78.4 ha), 44% as normal (130,372.3 ha), 36.2% as good (107,295.1 ha), 6.6% as very good (19,465.2 ha). In terms of 14 reference points, the underground SWL fell between 21-149 m, the DWL between 35-193 m, and borehole irrigation well depths of more than 300 m. It is expected that this study will be an important resource in groundwater management and protection in terms of environmental and natural resources protection and sustainable agriculture and will guide future studies on this subject.

Key Words: Groundwater, GIS, Interpolation, IDW

ÖZ

Yeraltı su kaynaklarının %65'i tarımsal sulama için kullanılmaktadır. Bu durum özellikle doğal kaynakların korunması ve sürdürülebilir tarım açısından yeraltı sularının yönetimi ve korunmasını çok önemli hale getirmiştir. Bu amaçla yoğun kullanımın olduğu bölgelerden biri olan Mardin-Kızıltepe Ovası'nda yapılan çalışmada yeraltı suyu koşulları ve zaman içerisinde nasıl değiştiği incelenmiştir. Bölgenin 34 yıllık (1985-2019) sondaj verileri 7 döneme ayrılarak Statik Su Seviyesi (SSS), Dinamik Su Seviyesi (DSS), Kuyu Derinliği (KD) ve Kuyu Verimi (KV) verilerinin tematik haritaları oluşturulmuş ve uzaklığın tersi ile ağırlıklandırma interpolasyon tekniği kullanılarak değişim oranları analiz edilmiştir. Dönem-1'de SSS sığ ve normal olarak sınıflandırılan alanın oranı %100 iken Dönem-7'de %7,5'e düşmüş, Dönem-1'de %0 olan derin ve çok derin sınıfının oranı ise %92,5'e ulaşmıştır. DSS Dönem-1'de sığ ve normal sınıfın oranı %100 iken Dönem-7'de %0,2'ye düşmüş, Dönem-1'de derin ve çok derin sınıfta %0 olan oran Dönem-7'de %99,8'e ulaşmıştır. KD açısından ise Dönem-1'de açılan kuyu derinliklerinin %100'ü sığ ve normal sınıfta yer alırken, Dönem-7'de bu oran %0,3'e düşmüş, derin ve çok derin sınıfta yer alanların oranı ise %99,7'ye ulaşmıştır. Dönem-7 verileri kullanılarak bölgenin işletilebilir yeraltı suyu potansiyeli sınıflandırılmış ve alanın %3,2'si zayıf (390.78,4 ha), %44'ü normal (130.372,3 ha), %36,2'si iyi (107.295,1 ha), %6,6'sı çok iyi (19.465,2 ha) olarak sınıflandırılmıştır. 14 referans noktası açısından, yeraltı SSS 21-149 m arasında, DSS 35-193 m arasında düşmüş ve sondaj sulama kuyu derinlikleri 300 m'den fazla olmuştur. Bu çalışmanın çevre ve doğal kaynakların korunması ve sürdürülebilir tarım açısından yeraltı suyu yönetimi ve korunmasında önemli bir kaynak olması ve bu konuda gelecekte yapılacak çalışmalara yol göstermesi beklenmektedir.

Anahtar Kelimeler: Yeraltı suyu, CBS, İnterpolasyon, IDW

Introduction

When gravity pulls water from the surface and fills the spaces left by porous layers (pebbles, sandstones, etc.) or fractured, cracked rocks (limestone), groundwater is created. Porous rocks or strata need to be connected to the earth for these fluids to form (Anonymous, 2020). After the groundwater seeps down and moves up to the impermeable layer, it is collected in layers called aquifers.

Approximately 3% of the water on earth is freshwater resources, and approximately 31.4% of these resources are groundwater. 65% of these waters are used for agricultural purposes, 25% for drinking and use and 10% for industrial purposes. Groundwater is a natural resource that has been used for a long time, as it generally does not require any treatment process and can be put into operation immediately (Özbay et al., 2011).

The conservation and management of groundwater is the subject of numerous national and international treaties and laws, and the Ministry of Agriculture and Forestry in our nation conducts a number of monitoring and protection initiatives to guard against groundwater pollution and degradation. Agricultural activities are absolutely necessary for human survival. Water is also needed for the continuation of these plant and animal activities. It is very difficult to sustain these activities with only seasonal rainfall, especially for our country, which has a continental climate in many regions. In the cultivation of field and industrial crops, the need for water, which cannot be met by seasonal rainfall, is tried to be met with additional irrigation, and groundwater also plays an important role in this form of production.

In the Mardin-Kızıltepe plain, the rainfall regime in continental climate conditions is in the form of rain rather than snowfall due to changing climatic conditions, and most of these precipitations occur in winter and spring. The plain, with its extremely fertile soils, is typically 600 meters above sea level, with a slope of less than five percent, low drainage density, I and II classes, and a brownish-reddish soil structure. The main agricultural products cultivated in the plain include wheat, legumes, industrial plants, and fodder crops. With the subsidies provided by the Ministry of Agriculture and Forestry, the cultivation areas of strategic crops such as cotton have increased, and the climatic conditions are suitable for mechanization, the cultivation areas of second crop agriculture have expanded considerably (approximately 70 000 ha. as of 2019) (Anonymous). The two crops that need the most water among them are cotton and maize, and boreholes are used to supply this water.

The number of boreholes, which was approximately 500 between 1995 and 2000, has reached nearly 10,000 as of 2019. As a result, the rate of irrigated agriculture in the region has increased, and the yield of the crops that are still cultivated has increased considerably. In a region with such a high density of borehole irrigation wells, the management, use and protection of groundwater is essential.

Since determining the status and conditions of groundwater requires a lot of labor and cost, Geographic Information Systems and Remote Sensing techniques have been used in recent years to reduce this cost and labor requirement (Anbazhagan & Jothibasu, 2016; Aslan, 2019;

Bagyaraj et al., 2013; Balamurugan et al., 2017; Çelik, 2016; Çelik & Hamidi, 2017, 2018; Çelik & Toprak, 2016; Charoenpong et al., 2012; Sener et al., 2005).

In this study, it is aimed to create thematic maps of Static Water Level (SWL), Dynamic Water Level (DWL), Well Depth (WD), and Well Yield (WY) data and analyze the rates of change by collecting 34 years (1985–2019) of borehole data available in Mardin-Kızıltepe Plain with the help of GIS techniques.

Materials and Methods

The Kızıltepe Plain of Mardin Province was designated as the research area. This basin consists of a total area of 296211 ha covering the plain areas of Artuklu, Derik, Kızıltepe, Nusaybin, and Yeşilli Districts. This area is home to 321 villages and hamlets.

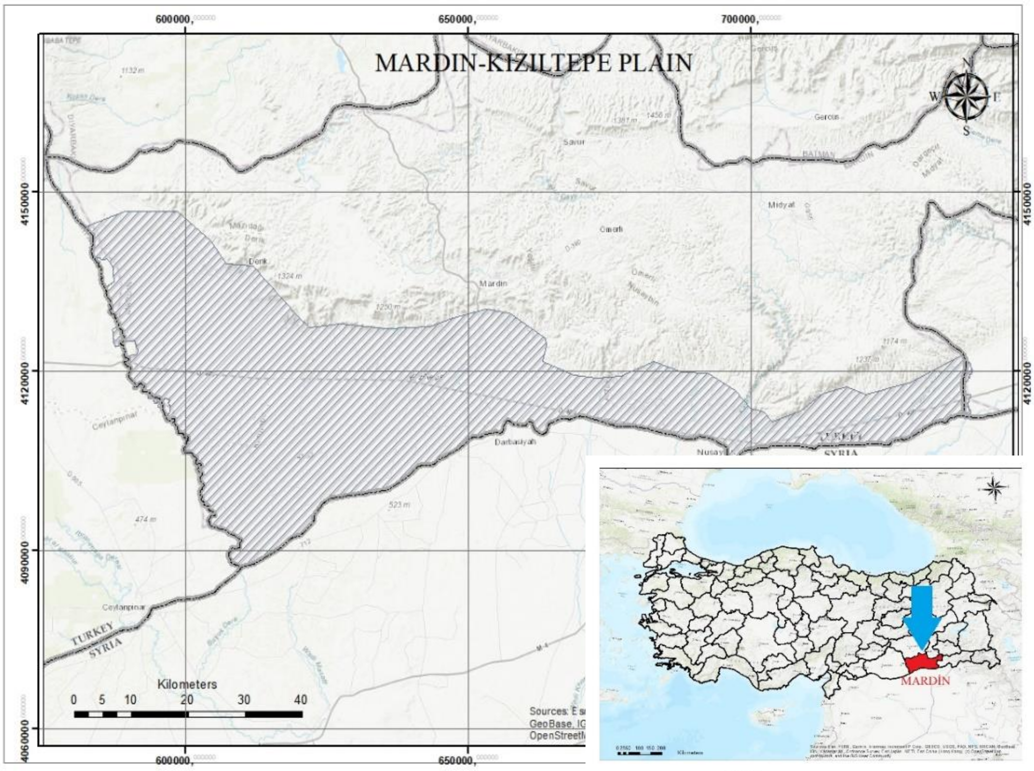


Figure 1. Mardin Kızıltepe Plain

The land is generally flat, with an altitude of 450–650 m. The region's soils have clayey-loamy, silty-loamy, and silty-clayey-loamy structures. Many agricultural products can be grown on these highly fertile soils. The main products grown in the region are wheat, barley, lentils, chickpeas, cotton, and corn. The climate and temperature characteristics of the region allow for the cultivation of cotton as a first and second crop, as well as corn as a second crop. In addition, the yield obtained from wheat increases up to two times under irrigated conditions. Although the temperature characteristics are suitable, the amount and regime of precipitation are insufficient for cotton and corn cultivation and necessitate supplementary irrigation. This water need is largely tried to be met through borehole irrigation wells.

Table 1. Mardin Province Field Crops Production Information (Source: Tüik data)

	1993		**2019**	
	Planted Area (ha)	**Yield (kg/ha)**	**Planted Area (ha)**	**Yield (kg/ha)**
Wheat	113467	2059	173209	3640
Barley	84300	2447	28360	2530
Lentil	107789	1066	27702	1460
Chickpea	7517	1382	7559	1560
Vetch	750	1049	1235	1540
Maize	11	9455	44442	9480
Cotton	13230	1032	13016	1860
Alfalfa	3	2666*	500	12000*

*: Green grass

Table 2. Artuklu-Derik-Kızıltepe-Nusaybin Districts Field Crops Production Information (Source: Tüik data)

	2004		**2019**	
	Planted Area (ha)	**Yield (kg/ha)**	**Planted Area (ha)**	**Yield (kg/ha)**
Wheat	102569	3480	143127	3610
Barley	45246	3157	12974	2675
Lentil	41657	1213	16943	1400
Chickpea	450	1167	3043	1678
Maize	12856	7373	43313	9065
Cotton	15733	2373	11458	2865
Alfalfa	0	0	500	12000*

*: Green grass

As can be understood from Table 1, the cultivation areas of barley and lentil plants, which do not need much water, decreased by approximately 136000 ha in 2019 compared to 1993, while the cultivation of wheat and corn crops, which can be irrigated or cultivated as a second crop, increased by 100000 ha. In addition, the yield per hectare of all crops has increased.

Similarly, as can be seen in Table 2, based on the cultivation areas of the districts in the study area, barley and lentil cultivation areas decreased by approximately 57000 ha compared to 2004, wheat and corn cultivation areas increased by 71000 ha, wheat, lentil, chickpea, corn and cotton products yielded increased per hectare, and alfalfa (green grass) plant, which was not cultivated in 2004, had 500 hectares of cultivation.

In Mardin Province, irrigated agricultural land was 17.6% with 67926.5 ha and 317552.2 ha was 82.4% in 2000, while irrigated agricultural land increased to 47.7% with 150000 ha and dry agricultural land decreased to 52.3% with 164503 ha in 2019 (Mardin Provincial Directorate of Agriculture and Forestry, 2001-2019). The biggest reason for this increase in irrigated agricultural lands has been the newly drilled borehole irrigation wells.

The region has a continental climate with hot and dry summers and mild and rainy winters. According to the data obtained from the General Directorate of Meteorology (MGM), the average annual temperature is 16.1 °C. The average annual precipitation is 667 mm, and precipitation is usually in the form of rain. The highest temperature is 42.5 °C, and the lowest temperature is -14 °C (MGM, 2022). Table 3 shows the meteorological data table for this period.

Table 3. Meteorological data

Mardin	**Avr. Temp (°C)**	**Avr. Sunshine Duration (hours)**	**Avr. Number of Rainy Days**	**Avr. Monthly Total Rainfall (mm)**	**Highest Temp (°C)**	**Lowest Temp (°C)**
January	3.1	4.5	12	116.7	19.4	-13.4
February	4.2	5.1	10.6	103.7	19.5	-14
Mart	8	6	11.5	96.4	27.5	-11.7
April	13.5	7.3	10.3	82	33.6	-5.3
May	19.5	9.7	7.3	45.8	35.4	2.6
June	25.7	12.2	1.5	4.5	40	5
July	30	12.4	0.5	1.3	42.5	11.8
August	29.7	11.5	0.2	0.5	42	12.8
September	25.2	10.3	0.7	1.9	39.3	8
October	18.4	7.7	5.1	33.2	35.6	-2.5
November	10.9	5.9	7.6	71.1	26.1	-9.5
December	5.3	4.3	10.8	110.7	24.1	-11.9
Annual	16.1	96.9	78.1	667.8		

The average annual temperature, which was 15.5 °C in the 1940s, approached 17 °C in the 2020s, whereas the average annual precipitation, which was around 750 mm, dropped below 600 mm (MGM, 2022). This situation has also significantly affected the groundwater potential.

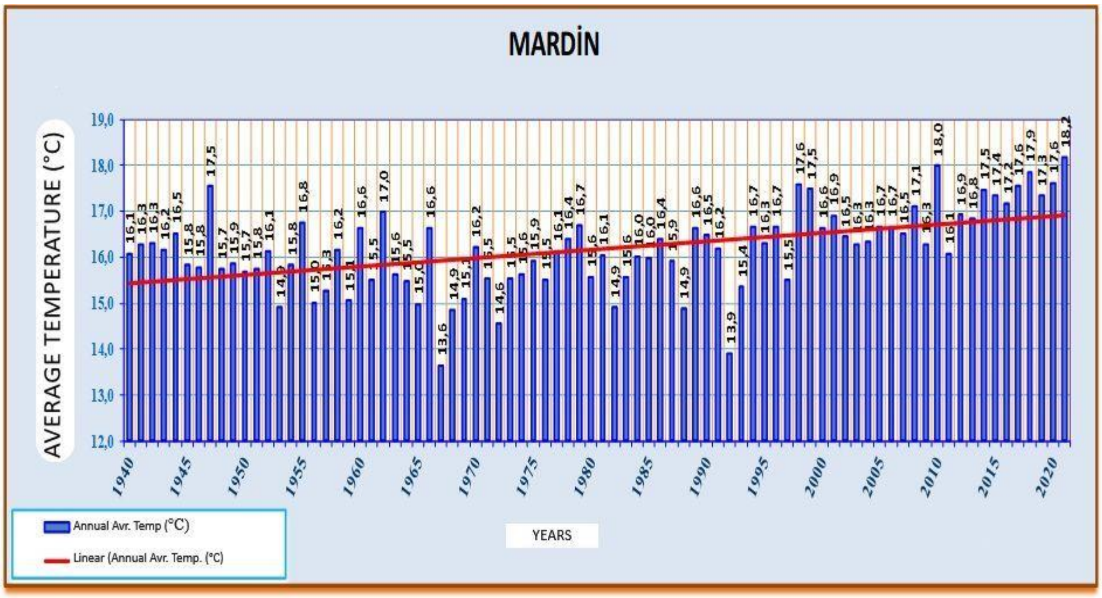


Figure 2. Annual Average and Trend of Monthly Average Temperature Values

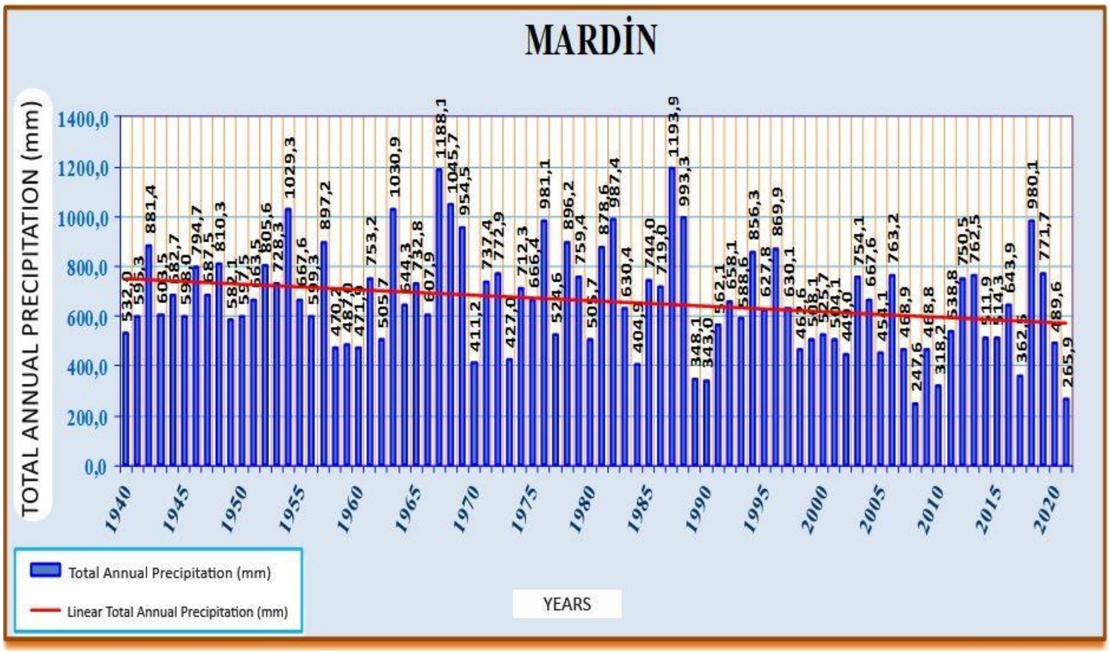


Figure 3. Distribution and Trend of Annual Total Precipitation Data

In this study, information on 34 years (1985–2019) of boreholes in Mardin-Kızıltepe Plain was obtained from the DSİ Regional Directorate. This information includes the owner of the well, administrative location of the land where the well is located at the province/district/village level, point coordinates of the borehole, date of drilling, SWL (m) and DWL (m), WY (lt/sec) WD (m). The 2567 remaining points were categorized into 5-year periods using the following criteria: Period-1 (1985-1990), Period-2 (1991-2005), Period-3 (1996-2000), Period-4 (2001-2005), Period-5 (2006-2010), Period-6 (2011-2015), and Period-7 (2016-2019), after eliminating points with incorrect or incomplete information. Statistical information of the data used in the study is given in Table 4 and spatial information is given in Figure 4.

Table 4. Statistical information of the borehole irrigation wells used in the study

Period		Number of Well	Min	Max	Median	Mean	Standard Deviation	CV (%)
1985-1990	SWL	4	10	27	19.0	18.8	8.5	45.3
	DWL	4	27	58	46.0	44.3	14.0	31.7
	WD	4	46	167	82.0	94.3	53.4	56.7
	WY	4	2	10	3.8	4.9	3.8	77.8
1991-1995	SWL	12	11	90	62.5	57.0	22.2	39.0
	DWL	12	27	115	87.5	78.3	28.1	35.9
	WD	12	65	200	155.0	145.2	43.3	29.8
	WY	12	5	20	20.0	17.3	4.4	25.2
1996-2000	SWL	497	10,3	182	86.0	87.4	25.2	28.8
	DWL	497	32,7	200	111.0	112.6	27.1	24.0
	WD	497	40	350	185.0	176.1	42.9	24.3
	WY	497	6	40	14.0	14.3	4.4	31.0
2001-2005	SWL	123	12	210	96.0	103.7	31.4	30.3
	DWL	123	30	250	140.0	146.6	33.6	22.9
	WD	123	50	500	280.0	286.0	85.1	29.8
	WY	123	1,8	50	15.0	15.9	7.3	46.0
2006-2010	SWL	445	12	290	115.0	137.6	59.2	43.0
	DWL	445	21	340	175.0	186.1	61.6	33.1
	WD	445	40	610	370.0	330.4	89.5	27.1
	WY	445	0,5	58	22.0	21.3	9.6	45.3
2011-2015	SWL	468	19	310	188.0	175.8	54.9	31.2
	DWL	468	70	380	230.0	221.9	54.5	24.6
	WD	468	81	648	500.0	455.6	94.5	20.7
	WY	468	0,5	55	17.0	18.6	10.8	57.9
2016-2019	SWL	1018	15	310	128.0	129.6	41.9	32.3
	DWL	1018	40	620	440.0	400.2	102.9	25.7
	WD	1018	30	350	195.0	200.2	50.0	25.0
	WY	1018	1	61	27.0	25.3	9.6	37.8

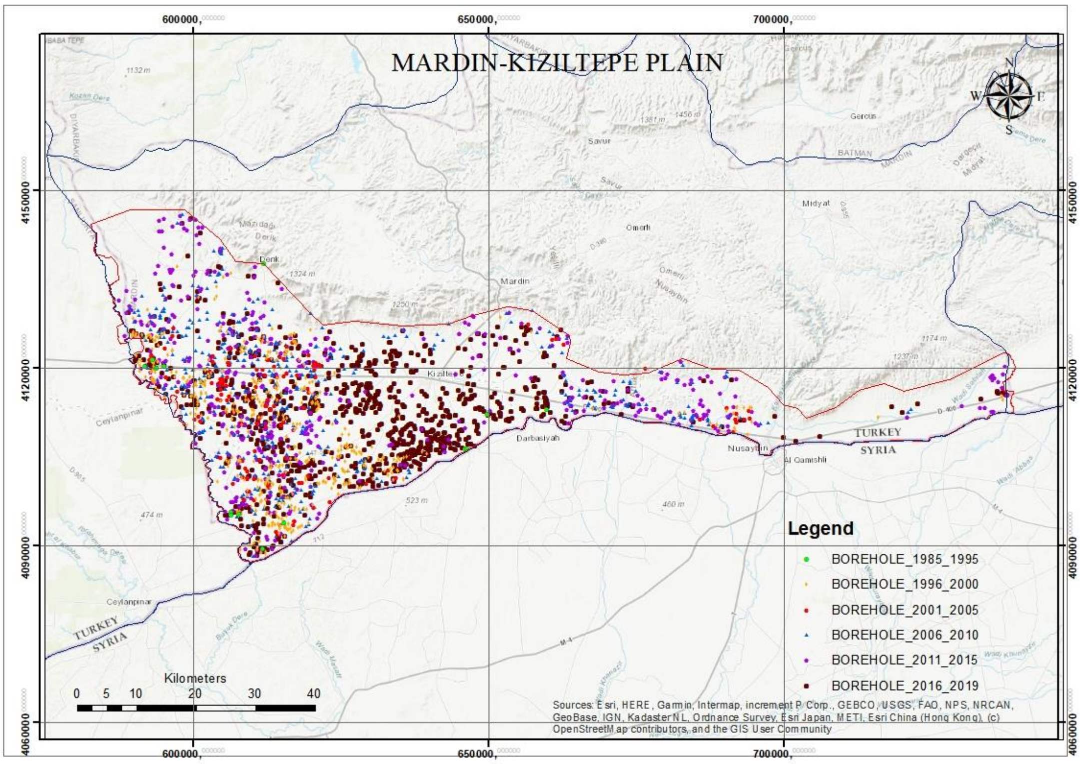


Figure 4. Representation of borehole points classified by year

In the study, point information was organized and sorted using the Microsoft Office Excel (Microsoft, Washington, United States of America) program, and points with missing and incorrect information were removed. After that, the well point location data was digitized and entered into the ArcGIS environment (Esri, Southern California, United States). Interpolation analyses were then run on the point data, and maps were generated.

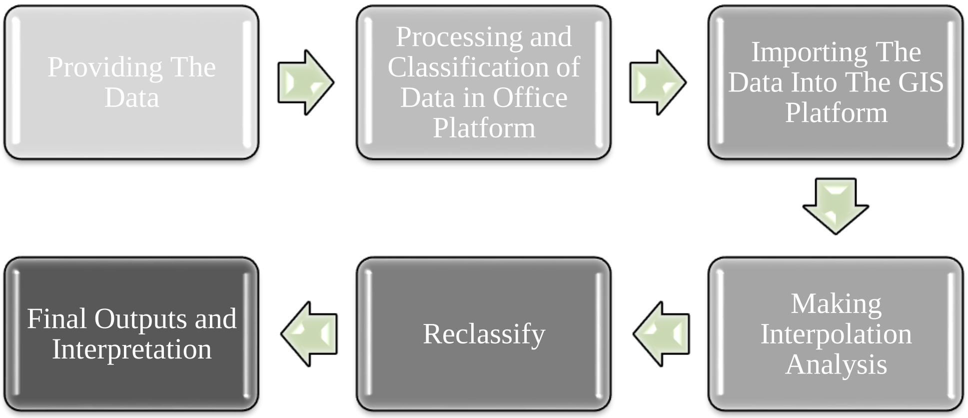


Figure 5. Work Flow Chart

Spatial interpolation can be defined as the process of estimating the values of unknown points based on known points with defined locations and values. Spatial interpolation results in the use of distance-based spatial estimation methods to convert discrete data defined on point data into continuous data (Bakiş et al., 2012). It is an interpolation method that takes into account all sample points based on the principle that when calculating the value of a point, nearby points have a more significant influence based on their distances to that point, while distant points have a lesser effect (Konuk, 2011). The IDW formula is given in the following equation.

$$Z = [(\Sigma_{i=1}^{n}(Z_i/di^m)/\Sigma_i^n =)(1/di^m)] \qquad (1)$$

Z: Estimated value, Z_i: at known point, di: distance between the point whose value is to be estimated and point i, m: force of gravity.

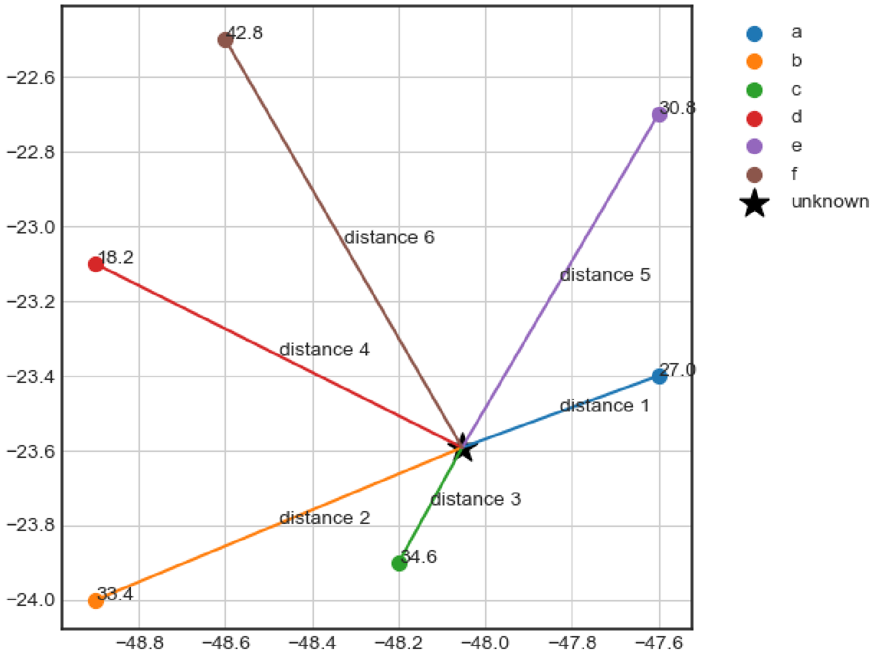


Figure 5. Weighting with the Inverse of Distance (http-2)

The data were analyzed according to the IDW technique, one of the interpolation methods, and the weighting method according to the inverse of the distance. Analysis parameters; Output cell size: 100 m, Search Radius: Variable, Number of Points: 12, Power: 2.

In order to make the obtained analysis raster maps more visually meaningful and to enable better observation and interpretation of the data, they were subjected to a reclassify process and period thematic maps were produced. The parameters related to SWL, DWL, WD and WY used in this process are given in Table 5.

Table 5. Parameters related to SWL, DWL, WS and CV water level classes

SWL	**Class**	**m**
	Shallow	0-50
	Normal	51-100
	Deep	101-200
	Very Deep	200->
DWL	**Class**	**m**
	Shallow	0-50
	Normal	51-100
	Deep	101-200
	Very Deep	200->
WD	**Class**	**m**
	Shallow	0-100
	Normal	101-200
	Deep	201-300
	Very Deep	300->
WY	**Class**	**lt/sec**
	Less Efficient	0-10
	Normal	11-20
	Efficient	20-30
	Very Efficient	30->

Results and Discussion

The borehole data in Mardin-Kızıltepe plain, which was selected as the study area, were processed, classified according to years, transferred to the map environment, spatial interpolation analysis (IDW method) was performed, existing well data were evaluated, areas with missing data were calculated and point data were converted into raster data. In the last step, in order to better interpret the data visually, groundwater SWL, DWL, WD and WY thematic maps and areal distribution tables were produced by years by reclassify the data and thus the change in groundwater level by years was tried to be determined.

Visuals related to the change in static water level are presented in Figures 6 a-b-c-d-e-f-g, and the spatial distribution is provided in Table 6. In the SWL spatial distribution, the ratio of shallow and normal classes decreased from 100% in Period-1 to 7.5% in Period-7, whereas the ratio of deep and very deep classes increased from 0% in Period-1 to 92.5% in Period-7.

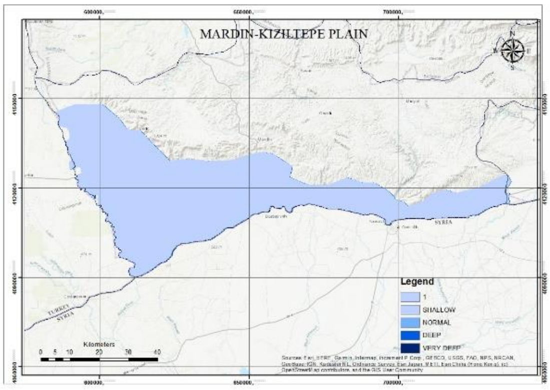


Figure 6-a Thematic map of Period-1 SWL

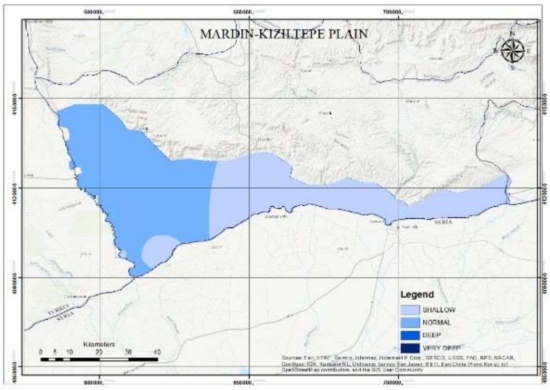


Figure 6-b Thematic map of Period-2 SWL

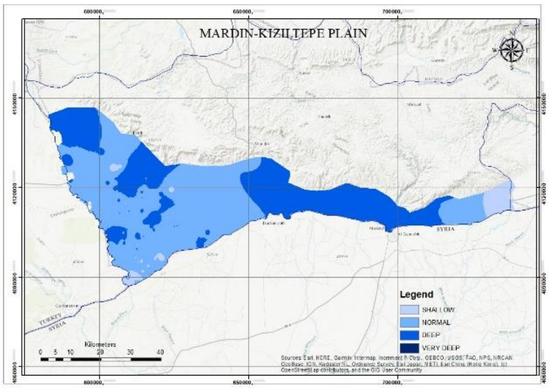


Figure 6-c Thematic map of Period-3 SWL

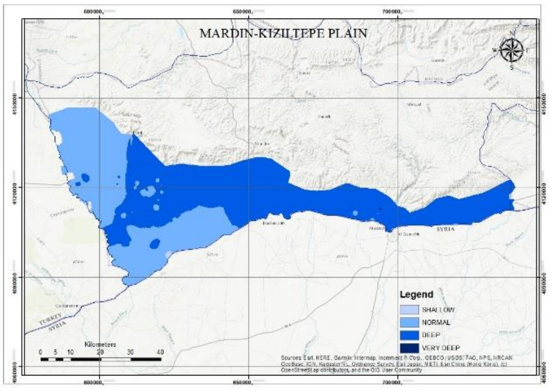


Figure 6-d Thematic map of Period-4 SWL

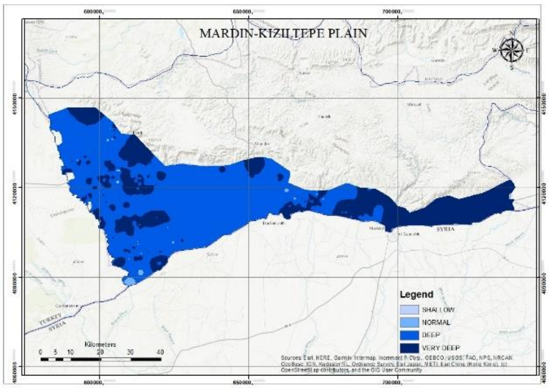


Figure 6-e Thematic map of Period-5 SWL

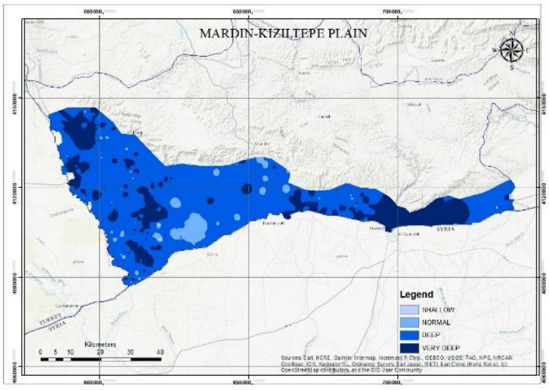


Figure 6-f Thematic map of Period-6 SWL

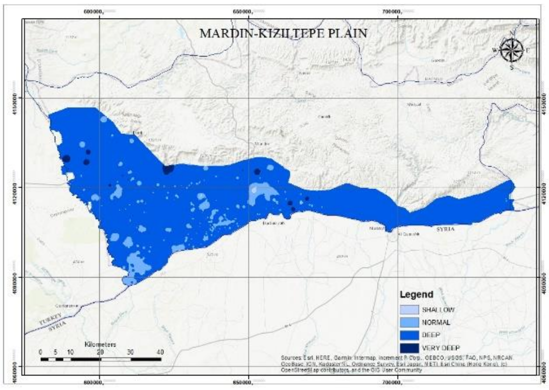


Figure 6-g Thematic map of Period-7 SWL

Table 6. SWL areal distribution table in 7 periods

	Distribution (%)						
Class	**Period-1**	**Period-2**	**Period-3**	**Period-4**	**Period-5**	**Period-6**	**Period-7**
Shallow	100	44.5	4.2	0.1	0.0	0.0	0.1
Normal	0.0	55.5	56.7	40.5	0.5	4.8	7.4
Deep	0.0	0.0	39.1	59.7	67.9	72.7	91.5
Very	0.0	0.0	0.0	0.0	31.5	22.5	1.0

Visuals related to the changes in dynamic water levels are presented in Figures 7 a-b-c-d-e-f-g, and the spatial distribution is provided in Table 7. In the areal distribution of DWL, the ratio of shallow and normal classes decreased from 100% in Period-1 to 0.2% in Period-7, whereas the ratio of deep and very deep classes increased from 0% in Period-1 to 99.8% in Period-7.

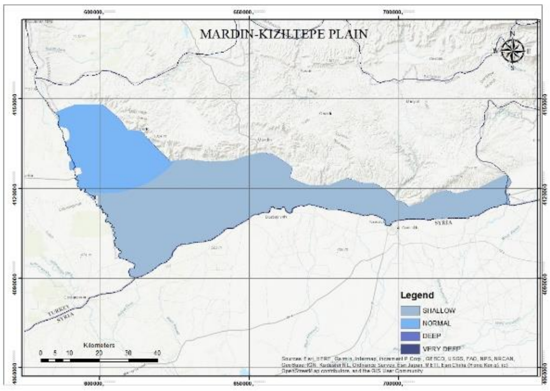


Figure 7-a Thematic map of Period-1 DWL

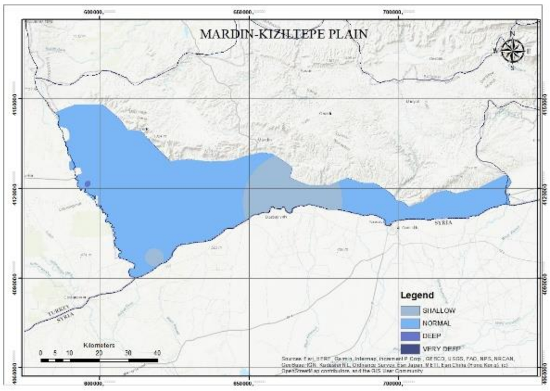


Figure 7-b Thematic map of Period-2 DWL

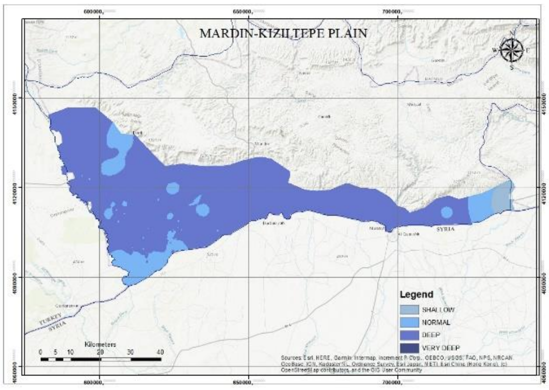


Figure 7-c Thematic map of Period-3 DWL

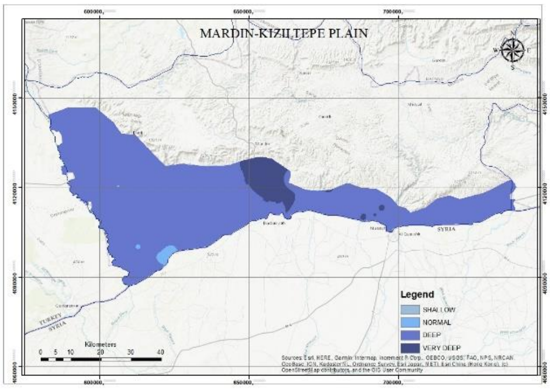


Figure 7-d Thematic map of Period-4 DWL

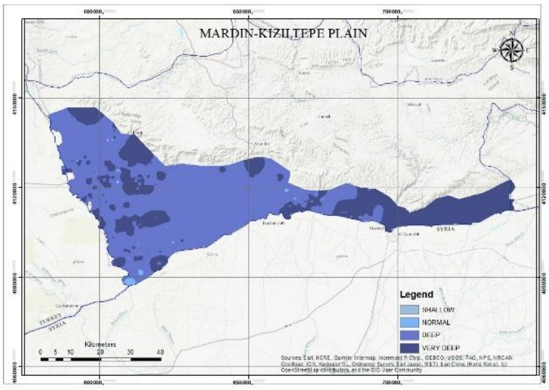


Figure 7-e Thematic map of Period-5 DWL

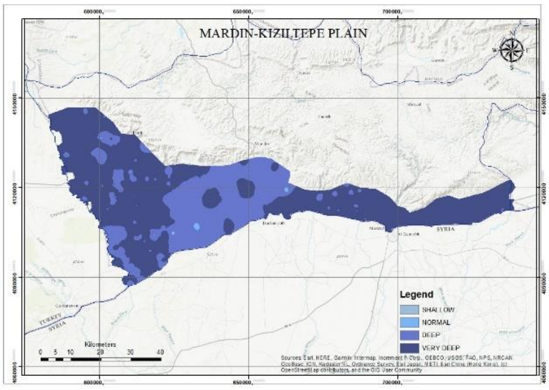


Figure 7-f Thematic map of Period-6 DWL

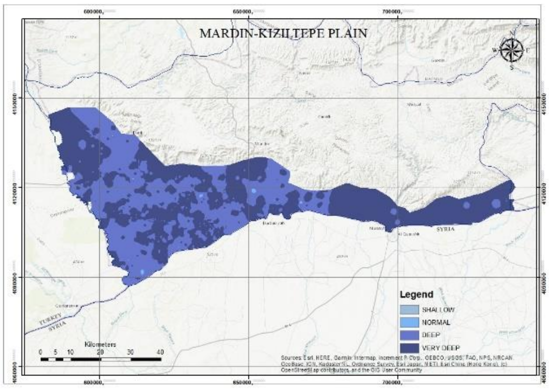


Figure 7-g Thematic map of Period-7 DWL

Table 7. DWL areal distribution table in 7 periods

	Distribution (%)						
Class	**Period-1**	**Period-2**	**Period-3**	**Period-4**	**Period-5**	**Period-6**	**Period-7**
Shallow	74.3	14.4	2.1	0.0	0.0	0.0	0.0
Normal	25.7	85.5	13.4	0.9	0.5	0.2	0.2
Deep	0.0	0.1	84.5	92.4	67.9	32.5	42.9
Very	0.0	0.0	0.0	6.7	31.5	67.3	56.9

The visuals related to the change in well depth are presented in Figures 8 a-b-c-d-e-f-g, and the spatial distribution is provided in Table 8. In the areal distribution of WD, shallow and normal class ratios decreased from 100% in Period-1 to 0.3% in Period-7, whereas deep and very deep class ratios increased from 0% in Period-1 to 94.7% in Period-7.

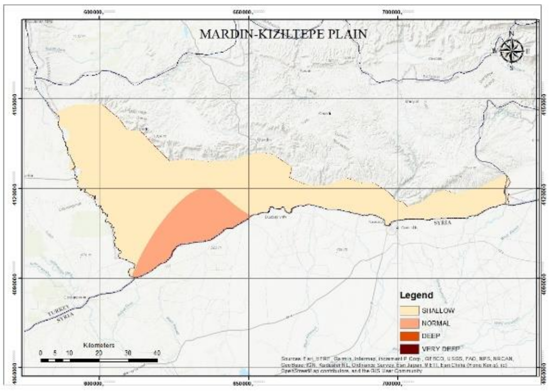


Figure 8-a Thematic map of Period-1 WD

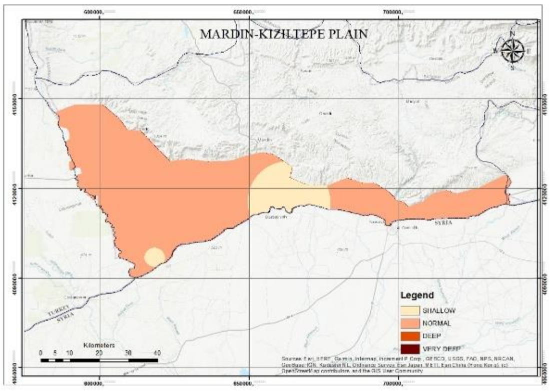


Figure 8-b Thematic map of Period-2 WD

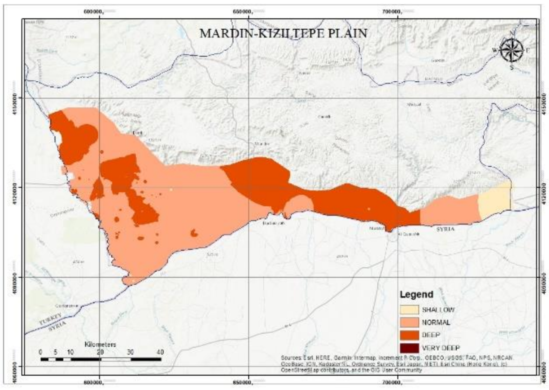


Figure 8-c Thematic map of Period-3 WD

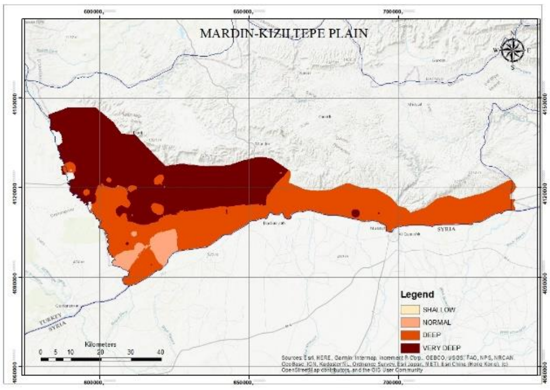


Figure 8-d Thematic map of Period-4 WD

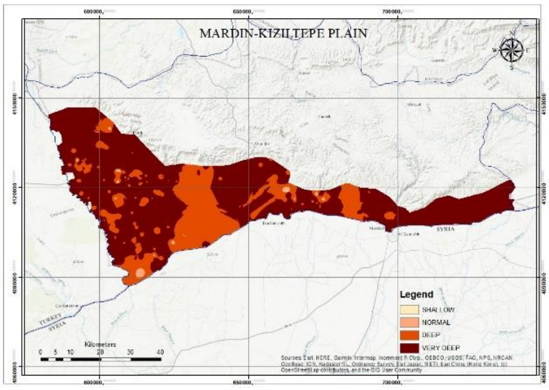


Figure 8-d Thematic map of Period-4 WD

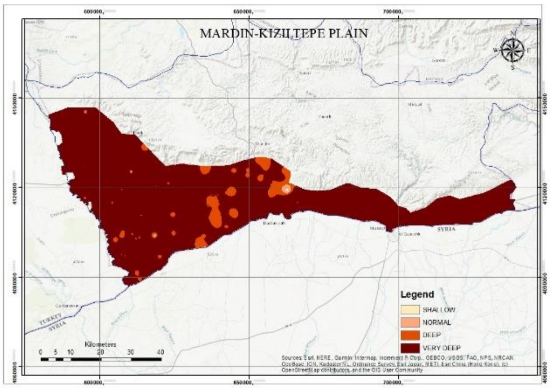


Figure 8-f Thematic map of Period-6 WD

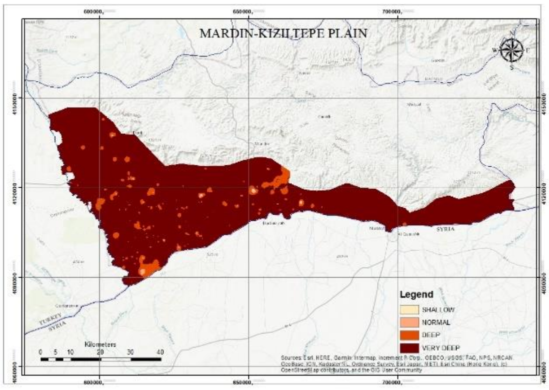


Figure 8-g Thematic map of Period-7 WD

Table 8. WD areal distribution table in 6 periods

	Distribution (%)						
Class	**Period-1**	**Period-2**	**Period-3**	**Period-4**	**Period-5**	**Period-6**	**Period-7**
Shallow	83.7	11.6	3.5	0.0	0.0	0.0	0.0
Normal	16.3	88.4	62.3	4.3	0.7	0.2	0.3
Deep	0.0	0.0	34.2	48.2	26.3	5.5	5.0
Very Deep	0.0	0.0	0.0	47.4	73.0	94.3	94.7

The visuals related to the change in well yield are presented in Figures 9 a-b-c-d-e-f-g, and the spatial distribution is provided in Table 9. In terms of WY area distribution, the ratio of less productive and normal classes decreased from 100% in Period-1 to 21.7% in Period-7, whereas the ratio of productive and very productive classes increased from 0% in Period-1 to 78.3% in Period-7.

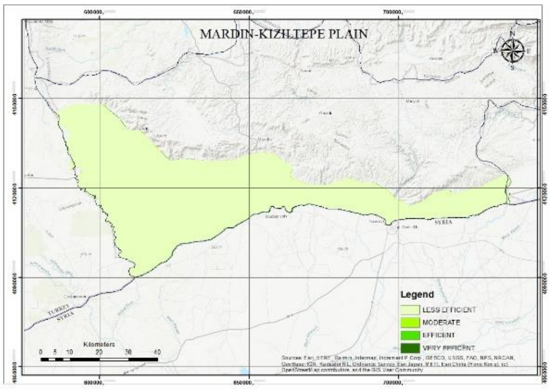


Figure 9-a Thematic map of Period-1 WY

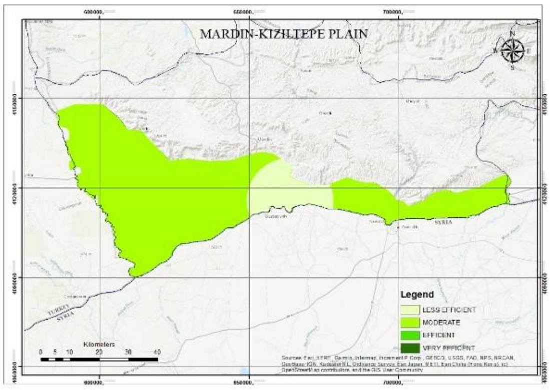


Figure 9-b Thematic map of Period-2 WY

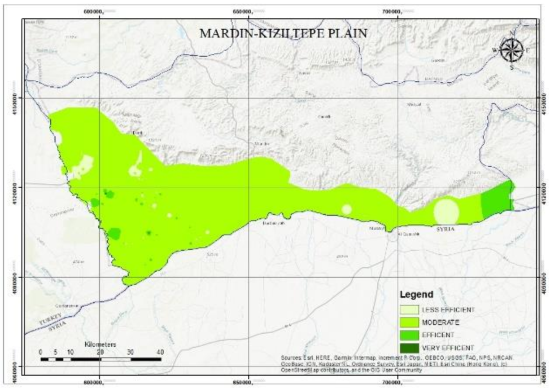


Figure 9-c Thematic map of Period-3 WY

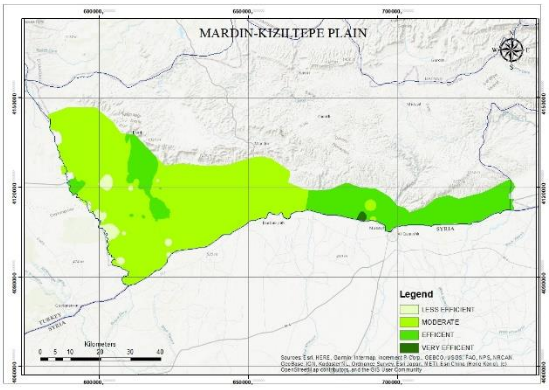


Figure 9-d Thematic map of Period-4 WY

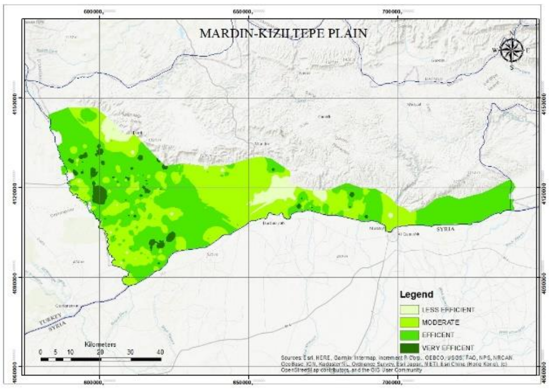


Figure 9-e Thematic map of Period-5 WY

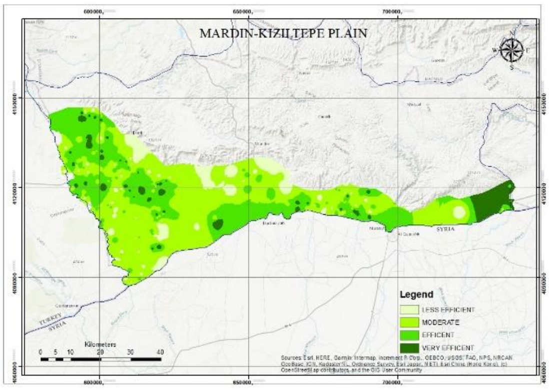


Figure 9-f Thematic map of Period-6 WY

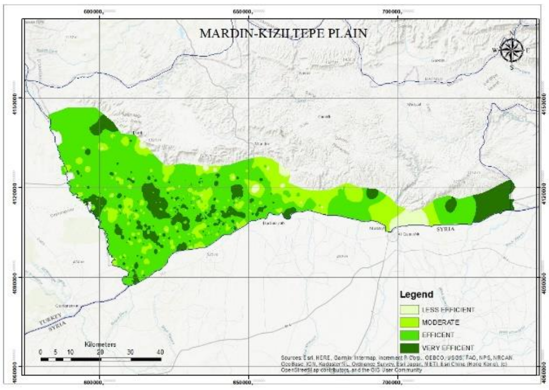


Figure 9-g Thematic map of Period-7 WY

Table 9. WY areal distribution table in 6 periods

	Distribution (%)						
Class	**Period-1**	**Period-2**	**Period-3**	**Period-4**	**Period-5**	**Period-6**	**Period-7**
Shallow	100	11.2	4.3	2.4	5.3	9.2	3.0
Normal	0.0	88.8	91.3	71.4	40.0	52.2	18.7
Deep	0.0	0.0	4.4	25.9	51.5	32.5	63.1
Very Deep	0.0	0.0	0.0	0.2	3.1	6.1	15.3

In terms of SWL, DWL, WD, and WY, the distributions of the classes in Period-1 and Period-7 were compared, and these values are given in Table 7.

Table 10. Comparison of Period-1 and Period-7 values in terms of groundwater values

		Period-1	**Period-7**
SWL	**Class**	**Distribution (%)**	**Distribution (%)**
	Shallow	100	0.1
	Normal	0.0	7.4
	Deep	0.0	91.5
	Very Deep	0.0	1.0
DWL	**Class**	**Distribution (%)**	**Distribution (%)**
	Shallow	74.3	0.0
	Normal	25.7	0.2
	Deep	0.0	42.9
	Very Deep	0.0	56.9
WD	**Class**	**Distribution (%)**	**Distribution (%)**
	Shallow	83.7	0.0
	Normal	16.3	0.3
	Deep	0.0	5.0
	Very Deep	0.0	94.7
WY	**Class**	**Distribution (%)**	**Distribution (%)**
	Less Efficient	100	3.0
	Moderate	0.0	18.7
	Efficient	0.0	63.1
	Very Efficient	0.0	15.3

The SWL shallow class ratio, which had been 100% in Period-1, decreased to 0.1% in Period-7, whereas the deep class ratio, which had been 0.0% in Period-1, increased to 91.5% in Period-7. The DWL shallow and normal class ratios, which had been 74.3% and 25.7% in Period-1, decreased to 0% and 0.2% in Period-7, respectively, whereas the deep and very deep class ratios, which had been 0% in Period-1, increased to 42.9% and 56.9% in Period-7.

While the WD shallow class rate was 83.7% and the normal class rate was 16.3% in Period-1, these values decreased to 0% and 0.3% in Period-7, respectively, whereas the WD deep and very deep class rates were 0% in Period-1, these rates became 5.0% and 94.7% in Period-7, respectively.

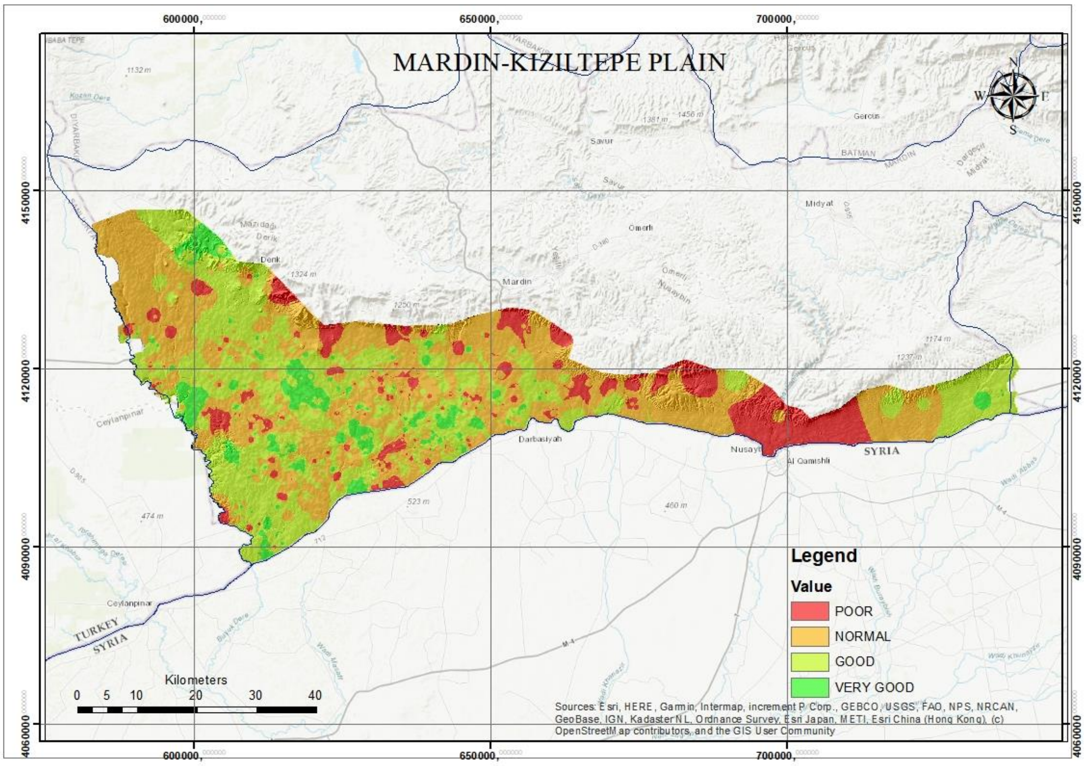
While the low-productivity class rate, which was 100% in Period-1, decreased to 3.0% in Period-7, the productive and very productive class rates, which were 0% in Period-1, increased to 63.1% and 15.3% in Period-7, respectively.

Accordingly, while the SWL shallow class area ratio in the whole Plain was 100% in Period-1, it decreased to 7.4% in Period-7, whereas the deep and very deep class ratio, which was 0% in Period-1, became 92.5%. While the ratio of shallow and normal classes was 99.9% in DWL Period-1, it decreased to 0.2% in Period-7, and the ratio of 0.1% in deep and very deep classes in Period-1 increased to 99.8% in Period-7. In terms of WD, while 100% of the well depths drilled in Period-1 were in the shallow and normal class, this rate decreased to 0.3% in Period-7, and the deep and very deep class rate increased to 99.7%. In other words, water levels have been falling over the years and well depths have been increasing.

It is understood from this that the static and dynamic water levels of groundwater have been decreasing over the years and the depths of wells have been increasing. Thus, it costs more to dig deeper wells, and more energy and labor is spent to extract water from such a deep distance. This is reflected in product costs, increasing product prices and limiting the cultivation areas of some crops such as cotton. In addition, the increasing need for energy brings along some social and economic problems.

With the increasing number of wells, irrigated agriculture opportunities have increased in the region, yield increases in the crops grown, and second crop agriculture opportunities have emerged (Table 1 and Table 2). This has led to more water use, and with the addition of climate change and irregularities in the precipitation regime, increase in average temperatures (Figure 2) and decrease in average precipitation (Figure 3), groundwater levels have decreased.

Using the Period-7 (2016-2019) data, SWL was weighted as 20%, DWL as 30%, and WY as 50%, and a groundwater map was obtained in terms of operation (Figure 10).



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 10. Thematic map of groundwater

Accordingly, 13.2% of the area is classified as poor (39,078.4 ha), 44% as normal (130,372.3 ha), 36.2% as good (107,295.1 ha) and 6.6% as very good (19,465.2 ha) in terms of groundwater management.

Most of the region (approximately 237,667 ha) is classified as normal and good. However, when evaluated together with other data, studies are required for the protection and management of groundwater in the basin. This is an urgent issue in the plain where there are nearly 10,000 borehole irrigation wells together with unlicensed wells.

Fourteen reference well points drilled in Period-3 (1996–2000) were selected from different regions, and the change in static and dynamic water levels was calculated in a GIS environment and presented graphically. Figure 11 shows where these reference points are located.

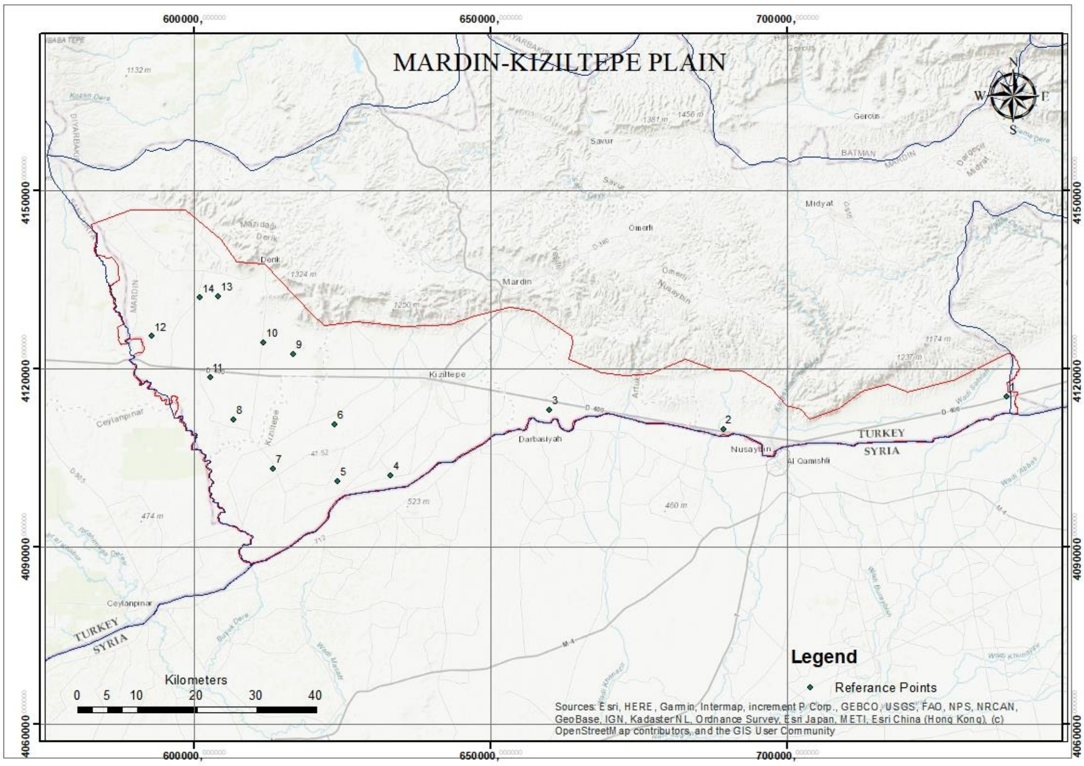


Figure 11. Location map of reference points

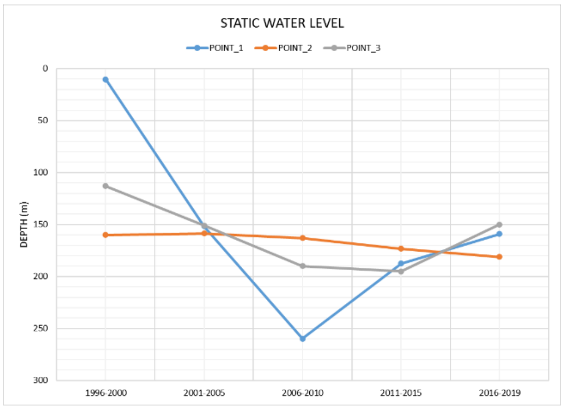


Figure 12-a SWL change at reference points 1-2-3

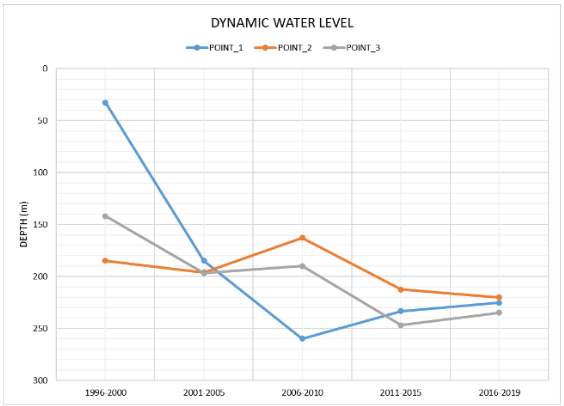


Figure 12-b DWL change at reference points 1-2-3

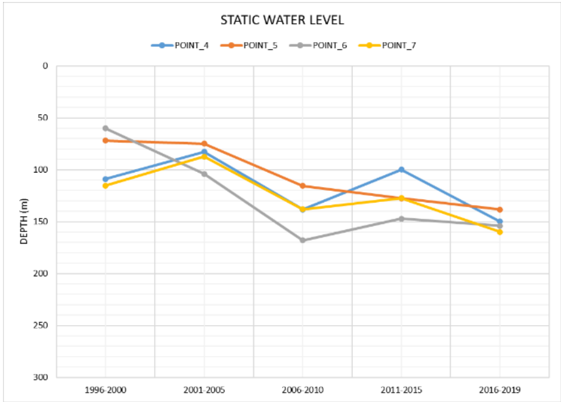


Figure 12-c SWL change at reference points 4-5-6-7

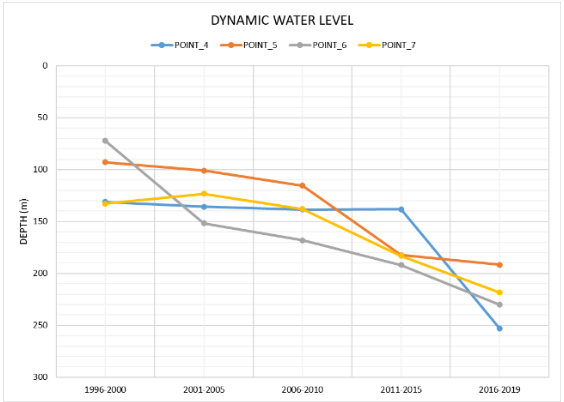


Figure 12-d DWL change at reference points 4-5-6-7

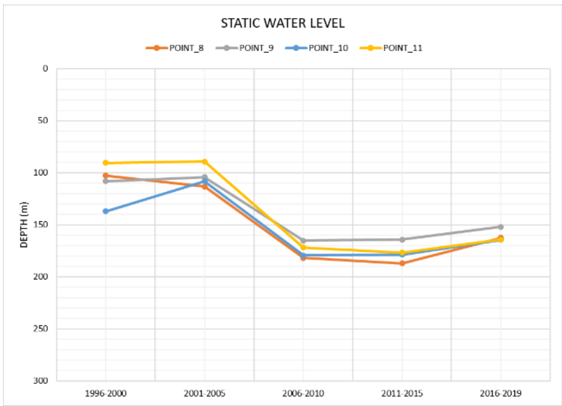


Figure 12-e SWL change at reference points 8-9-10-11

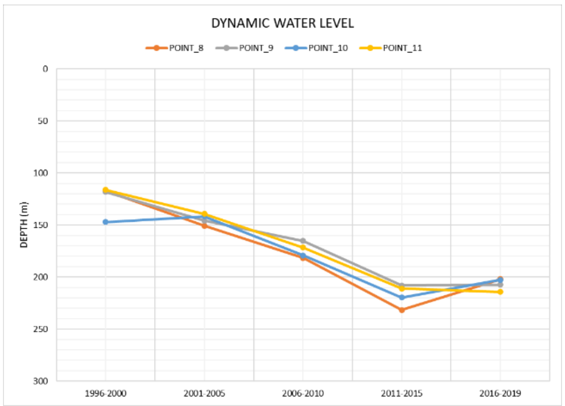


Figure 12-f DWL change at reference points 8-9-10-11

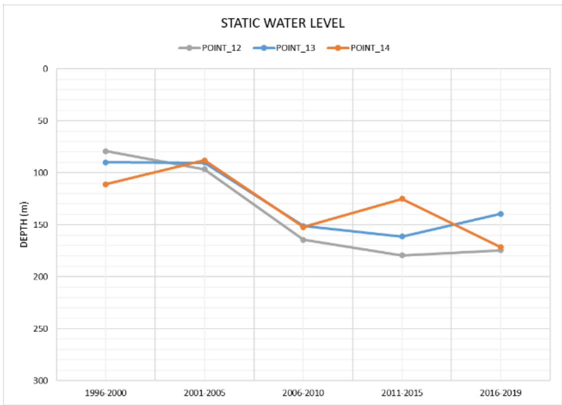


Figure 12-g SWL change at reference points 12-13-14

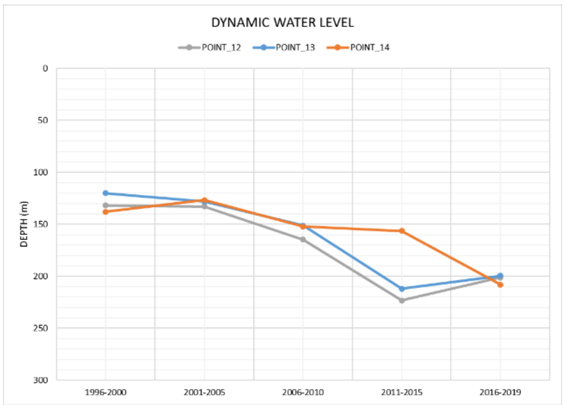


Figure 12-h DWL change at reference points 12-13-14

Table 11. Period-3 and Period-7 change table for Reference Points

Point Name	**SWL (m)**			**DWL (m)**		
	Period-2	**Period-7**	**Difference**	**Period-2**	**Period-7**	**Difference**
1	10	159	149	33	225	193
2	160	181	21	185	220	35
3	113	150	37	142	235	93
4	109	150	41	131	253	122
5	72	138	67	93	192	99
6	60	154	94	72	230	158
7	115	160	45	133	218	85
8	103	163	60	117	202	85
9	108	152	44	118	208	89
10	137	164	28	147	203	56
11	90	164	74	116	214	98
12	79	175	95	132	201	69
13	90	139	49	120	199	79
14	111	172	61	138	208	70

SWL is 21-149 m at points 1-2-3 in the eastern and southern parts of the plain (Nusaybin and Artuklu), 41-94 m at points 4-5-6-7 in the southwestern part of the plain (Kızıltepe), and 28-74 m at points 8-9-10-11 in the western part of the plain (Kızıltepe-Derik). In the northwestern parts of the plain (Derik), it was observed that there was a decrease between 49-61 m in points 12-13-14, 35-193 m in points 1-2-3, 85-158 m in points 4-5-6-7, 56-98 m in points 8-9-10-11, and 69-79 m in points 12-13-14.

When the reference point regions are analyzed, in the Artuklu and Nusaybin areas in the southern and southeastern parts of the plain, SWL decreased between approximately 21 and 149 m and DWL decreased between approximately 35 and 193 m in the reference regions numbered 1, 2, and 3.

In Kızıltepe lands in the southwestern parts of the plain, SWL decreased between approximately 41 and 94 m and DWL between approximately 85 and 158 m in reference zones 4-5-6-7.

In Kızıltepe and Derik lands in the western parts of the plain, SWL decreased between approximately 28 and 74 m and DWL decreased between approximately 56 and 98 m in reference zones 8-9-10-11.

In Derik lands in the northwestern part of the plain, SWL decreased between approximately 49 and 61 m and DWL decreased between approximately 69 and 79 m in reference zones 12–13–14.

This indicates that the DWL has dropped by 95 m and the average subterranean SWL has dropped by roughly 62 m in the last 34 years in the area. The primary cause of this significant drop is the drilling of boreholes for irrigation.

The crops cultivated in the basin, mainly cotton and maize, require a large amount of water during the vegetation period (about 700–1500 mm), and since it is not possible to meet this water demand with the drought and low rainfall (average 58 mm) in the summer months, farmers intensively use these wells to obtain high yields. Wild irrigation techniques, which are gradually decreasing but still in use, disrupt the soil's structure, increase energy costs, and contribute to the excessive use of water.

Climate change is another factor. The region's precipitation regime is changing, with gradually decreasing snowfall being replaced by heavy rainfall in a short period of time. In this type of precipitation regime, rainwater cannot reach the lower layers of the soil and is lost through surface runoff. The average annual temperature, which was 15.5 °C in the 1940s, approached 17 °C in the 2020s, while the average annual precipitation, which was around 750 mm, fell below 600 mm. With increasing summer temperature averages, the rate of transpiration and evapotranspiration increases; thus, more and faster water is lost per unit time, and more frequent and more frequent irrigation is needed to replace this water that evaporates into the air.

One of the consequences of this decline in groundwater levels is the drying up of natural spring waters in the more mountainous and hilly areas in the north of the region. Especially in the last 10 years, many natural springs have either dried up completely or dried up in the summer months, and the flow rate of the remaining waters has decreased considerably.

(Charoenpong et al., 2012), examined the accuracy of interpolation techniques (IDW, Kriging and Splines) in determining groundwater potential using borehole data drilled between 1995 and 2011 in Phuket province, Thailand and reported that the IDW method was more accurate than the other two. In the study conducted by (Anbazhagan & Jothibasu, 2016) in the Amaravati River Basin, Southeast India, geoinformatics effects were evaluated for mapping sustainable groundwater potential areas using electrical resistivity, linearity and geomorphology parameters at depths of 25, 50, 75 and 100 m. They stated that boreholes at depths below 75 m are not suitable for sustainable groundwater potential. In two separate studies conducted in Diyarbakır city center and Çınar District, borehole irrigation well data were classified in periods and analyzed with the Spatial Analyzed Kriging method, and a decrease of 10-84.5 m in the city center and 8-50 m in Çınar District was determined in the static water level at the determined reference points (Çelik, 2016; Çelik & Toprak, 2016). In two similar studies conducted in Şanlıurfa Harran Plain and Diyarbakır Silvan District, borehole data were interpolated by IDW method, and thematic maps showing static water level, dynamic water level and well yields were created by reclassify (Çelik et al., 2017; Çelik & Hamidi, 2018). In a study conducted in Amhara region, Ethiopia, groundwater potential areas were classified using remote sensing data and interpolation techniques (IDW), and as a result, 6.5% of the area was classified as very good, 22.1% as good, 51.2% as moderate, 18.4% as low and 1.8% as very low (Bagyaraj et al., 2013). Our findings parallel with those of the above studies.

Conclusions and Recommendations

As a result, the proportion of the area classified as SWL shallow and normal decreased from 100% in Period-1 to 7.5% in Period-7, while the proportion of deep and very deep class, which was approximately 0.0% in Period-1, became 92.5%. While the ratio of shallow and normal class was 100% in DWL Period-1, it decreased to 0.2% in Period-7, and the ratio of 0% in deep and very deep class in Period-1 increased to 99.8% in Period-7. In terms of VA, while 100% of the well depths drilled in Period-1 were in the shallow and normal class, this rate decreased to 0.3% in Period-7, and the deep and very deep class rate increased to 99.7%.

In terms of groundwater potential, 13.2% of the area is classified as poor (39,078.4 ha), 44% as normal (130,372.3 ha), 36.2% as good (107,295.1 ha), 6.6% as very good (19,465.2 ha).

Underground SWL in the region decreased between 21-149 m (average 62 m), DWL between 35-193 m (average 95 m), and borehole irrigation well depths exceeded 300 meters.

The number of boreholes, which was approximately 500 until 2000, approached 10,000 as of 2019. Thus, irrigated agriculture opportunities have increased in the region, and the average yield of second crop agriculture and crops under culture has increased. This has led to more water use, and groundwater levels have decreased due to changes and irregularities in the precipitation regime, increase in average monthly temperatures, and decrease in precipitation. As the SWL and DWL declined over the years, the cost of drilling and using wells increased, requiring intensive use of energy and labor.

As a solution, as seen in this study, if the current crop cultivation techniques continue, the groundwater level will drop even further, and much greater costs will be required for its extraction and utilization. Therefore, the use of groundwater in such basins is very important and needs to be controlled and regulated. One of the biggest steps of the solution is to urgently complete the GAP and reduce irrigation from boreholes. Thus, the use of boreholes will decrease, water use energy and labor costs will decrease, which will lead to a decrease in overall production costs.

The GAP Mardin irrigation canal project started in 2009 but has still not been finalized. Prolonged bureaucratic procedures, various disputes and ongoing lawsuits, mistakes in consolidation, uncertainties in the selection of canal and pond locations, etc. are among the reasons why the project has not been completed.

Within the scope of product support payments, the Ministry of Agriculture and Forestry has introduced some regulations such as reducing wild irrigation, encouraging pressurized irrigation, and 3-year alternation requirement in some crops, which has reduced the amount of water use to some extent. In addition to the continuation of such practices, it is very important to carry out educational activities to create awareness against over-irrigation as a society.

In addition, it is recommended that various demonstration studies be carried out to grow crops that are more compatible with the region and changing climatic conditions and that require less water, and that producers be trained and supported in the cultivation of such crops.

This study is expected to be an important resource in groundwater management and protection in terms of environmental and natural resources protection and sustainable agriculture and to guide future studies on this subject.

Declaration

The author declares that there is no conflict of interest.

Author Contribution

S.K.: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration

REFERENCES

Anbazhagan, S., & Jothibasu, A. (2016). Geoinformatics in groundwater potential mapping and sustainable development: A case study from southern India.

Hydrological Sciences Journal, *61*(6), 1109–1123. https://doi.org/10.1080/02626667.2014.990966

Anonymous. (2020). Yeraltı Suları Nasıl Oluşur? Suder. https://suder.org.tr/ambalajli-su/yeralti-sulari-nasil-olusur/

Aslan, V. (2019). *Harran Ovasi Yeralti Suyu Potansiyeli Ve Kalitesinin Coğrafi Bilgi Sistemi Destekli Çok Kriterli Karar Verme Yöntemi İle Modellenmesi*. (Yayımlanmamış doktora tezi). Dicle Üniversitesi Fen Bilimleri Enstitüsü, Diyarbakır

Bagyaraj, M., Ramkumar, T., Venkatramanan, S., & Gurugnanam, B. (2013). Application of remote sensing and GIS analysis for identifying groundwater potential zone in parts of Kodaikanal Taluk, South India. *Frontiers of Earth Science*, *7*(1), 65–75. https://doi.org/10.1007/s11707-012-0347-6

Bakiş, R., Bayazit, Y., & UyguçgiL, H. (2012). *SEYDİSUYU HAVZASINDAKİ YAĞIŞ, SICAKLIK VE BUHARLAŞMA DAĞILIMLARININ UZAKLIĞA BAĞLI TAHMİNLEME YÖNTEMLERİ İLE HARİTALANMASI*.

Balamurugan, G., Seshan, K., & Bera, S. (2017). Frequency ratio model for groundwater potential mapping and its sustainable management in cold desert, India. *Journal of King Saud University - Science*, *29*(3), 333–347. https://doi.org/10.1016/j.jksus.2016.08.003

Çelik, R. (2016). Diyarbakır Çınar Tarımsal Alanlarının Yıllara Göre Yeraltı Suyu Seviye Haritalarının Coğrafik Bilgi Sistemi (CBS) İle Tespiti. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, *7*(2), Article 2.

Sener, E., Davraz, A., & Ozcelik, M. (2005). An integration of GIS and remote sensing in groundwater investigations: A case study in Burdur, Turkey. *Hydrogeology Journal*, *13*(5–6), 826–834. https://doi.org/10.1007/s10040-004-0378-5

Çeli̇k, R., Aslan, V., & Akyıldız, M. H. (2017). Harran Ovası'nın yeraltısuyu potansiyelinin coğrafi bilgi sistemi ile modellenmesi. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, *8*(1), 53–64.

Çelik, R., & Hamidi, N. (2018). Ergani İlçesi Ovasının yeraltısuyu potansiyelinin Coğrafi Bilgi Sistemi ile belirlenmesi. Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi, 9(2), 999-1007.

Çeli̇k, R., & Hami̇di̇, N. (2018). Silvan İlçesi Ovası yeraltı suyu potansiyeli ve tematik haritalarının Coğrafi Bilgi Sistemi ile belirlenmesi. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, *9*(2), 929–937.

Çeli̇k, R., & Toprak, Z. F. (2016). Küresel İklim Değişikliğinin Diyarbakır Kent Merkezi Yeraltı Suyu Seviyesine Etkisi. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi, 7*(2), 279–290.

Charoenpong, S., Suwanprasit, C., & Thongchumnum, P. (2012). Impacts Of Interpolatıon Techniques On Groundwater Potentıal Modelıng Usıng Gıs In Phuket Provınce, Thaıland. *In Proceeding the 33rd Asian Conference of Remote Sensing*, 1–7.

Konuk, A. (2011). Coğrafi Bilgi Sistemleri İçin Temel İstatistik içinde (s. 168-172), Eskişehir, Anadolu Üniversitesi Yayınları

Özbay, Ö., Yıldız, Dursun, & Kırmıztaş, Hasan. (2011). *Görünmez Stratejik kaynak: Sınıraşan Yeraltı Suları*. Ortadoğu Stratejik Araştırmalar Merkezi.