Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Analyses of meteorological drought and its impacts on groundwater fluctuations, a case study: Marand Plain (Iran)

Meteorolojik kuraklık analizi ve yeraltı suyu değişimleri üzerindeki etkileri, Marand Ovası (Iran) örneği

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Received/Geliş Tarihi: 21.08.2018, Accepted/Kabul Tarihi: 14.01.2019 doi: 10.5505/pajes.2019.63600

Research Article/Araştırma Makalesi

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Abstract

Meteorological drought is one specific type of drought that occurs when precipitation is less than the long-term averages in a particular area. One of the hazardous impacts of this phenomenon observed on subsurface waters is the decline of water level in response to droughts. In this study, the climatic and groundwater data were used to analyze their trends in Marand plain, NW Iran, over the past decades to understand the likely relationship between them. To this, groundwater level data were first analyzed and its temporal trends were extracted. Then, the climatic condition of the region studied using the Ombrothermic diagram. Finally, drought analyses were conducted through drought index (SPI). Based on the results of the study, a descending trend was detected in both monthly and annual fluctuations of the groundwater level. It's also found that the region had a partially dry climate with a period of dry months between May and October. The SPI values showed extremely dry periods in 2001 and 2002 and months of July and June during the study period. The joint analysis of groundwater level and SPI values revealed that the impacts of drought were evident on groundwater level changes. Accordingly, the region's groundwater fluctuations found to be mostly under the control of monthly droughts where water level responds to wet and dry months in an expected manner. However, it's also found that the yearly changes in the groundwater level of the study area were not directly correlated to drought periods, suggesting that other factors might be effective in this phenomenon.

Keywords: Groundwater fluctuations, GIS, Drought, Marand plain, Iran

Öz

Meteorolojik kuraklık, spesifik bir kuraklık türü olarak, bir bölgede yağışın uzun vadeli ortalamalardan daha az olması durumunda ortaya çıkmaktadır. Yeraltı sularında gözlemlenen bu olayın tehlikeli etkilerinden biri, kuraklıklara tepki olarak su seviyesinin düşmesidir. Bu çalışmada, iklimsel ve yeraltı suyu verileri, aralarındaki muhtemel ilişkiyi anlamak için son yıllarda kuzeybatı İran'da Marand ovasında yer alan eğilimlerini analiz etmek için kullanılmıştır. Buna göre, ilk olarak yeraltı suyu seviyesi verileri analiz edilmiş ve zamansal eğilimleri çıkarılmıştır. Daha sonra bölgenin iklimsel durumunu anlamak için Ombrotermik diyagramı kullanılmıştır. Son olarak kuraklık indeksi (SPI) ile kuraklık analizleri yapılmıştır. Çalışmadan elde edilen sonuçlara göre, yeraltı suyu seviyesinin hem aylık hem de yıllık değişimlerinde azalış eğilimi tespit edilmiştir. Ayrıca, bölgede Mayıs ve Ekim ayları arasındaki periyodun kurak geçtiği ve bölgenin kısmen kuru bir iklime sahip olduğu da tespit edilmiştir. SPI değerleri bölgenin 2001 ve 2002 yıllarında ve genel olarak Temmuz ve Haziran ayları arasında oldukça kurak dönemler geçirdiğini göstermiştir. Yeraltı suyu seviyesi ve SPI değerlerinin ortak analizi, kuraklığın etkilerinin yeraltı suyu seviyesi değişikliklerinde belirgin olduğunu ortaya çıkarmıştır. Buna göre, bölgenin yeraltı suyu değişimlerinin çoğunlukla aylık kuraklıklarla ilişkili olduğu ve su seviyesinin beklenen şekilde ıslak ve kurak aylara tepki verdiği tespit edilmiştir. Ancak, aynı zamanda, çalışma alanının yeraltı suyu seviyesindeki yıllık değişikliklerinin, kuraklık dönemleriyle doğrudan ilişkili olmadığı ve bu olguda diğer faktörlerin de etkili olabileceği ortaya koymuştur.

Anahtar kelimeler: Yeraltısuyu değişimleri, CBS, Kuraklık, Marand ovası, Iran

1 Introduction

As an unpleasant phenomenon that afflicts both environment and human well-being, "Drought is considered by many to be the most complex but least understood of all natural hazards affecting more people than any other hazard" [1]. The most well-known characteristic of different types of drought (Meteorological, Agricultural, Hydrological and Socio-economic droughts) is water deficit during some periods. Among drought types, a meteorological drought is known as a phenomenon in which the amount of precipitation rate is lower than its mean long-term records in a given area, which originates from changes in climate patterns. In the case of meteorological drought, the impacts on surface water resources are much more sensible and faster than subsurface resources. During such periods, groundwater aquifers serve as a pivotal reservoir in many parts of the world mainly in arid and semi-arid regions, which rely extremely on groundwater resources in supplying their water needs.

The existence and long-term replenishment of groundwater resources is under the control of climatic conditions. [2] believes that climate change will, therefore, have a great impact on the world's groundwater resources. A longstanding drought may result in groundwater level decline in aquifers. [3] have suggested that in a drought-stricken aquifer, groundwater recharge rates are diminished at the first stage and then groundwater level and discharge are decreased in consequence. In many porous and karstic aquifers of the world, groundwater levels are a strong function of recharge from infiltration. Thus, when drought conditions start to prevail in the surface, it, sooner or later, influence the water levels below ground [4]. The global climate change and associated drought impacts on surface and subsurface water resources have been the subject of several studies around the world. [5] have studied the influence of climate change on shallow groundwater resources in an alluvial aquifer in western Turkey. They have observed a constant declining pattern in the groundwater levels of a surficial aquifer in Western Anatolia, which was highly depleted by anthropogenic withdrawals. [6] have analyzed the correlation between precipitation and groundwater levels in an alluvial plain in northwestern Turkey. They have filled in missing precipitation records by correlating with atmospheric meteorological parameters and associated the completed precipitation records with groundwater level measurements. [7] studied the effects of drought on groundwater resources in Alashtar Plain in Iran. They analyzed the relationship of SPI (Standardized Precipitation Index) and GRI (Groundwater Resource Index) on a monthly and yearly basis during 1991-2010 and found that the trend of meteorological and groundwater drought is negative and consistent with winter and autumn, respectively. [8] used four drought indices (the standardized precipitation index, China-Z index, modified CZI and Z-Score) for monitoring meteorological drought in Salt Lake Basin, Iran. Their results suggested that drought indices are very sensitive to precipitation rates but had spatial and temporal variations. They found that the modified CZI and Z-Score indices could be used as good meteorological drought predictors in Iran. [9] did drought analyses in Awash River Basin, Ethiopia using GIS and found that severest drought events occurred in the study area during May 1988 to June 1988 and April 1998 to May 1998 based on hydrological drought analysis. [10] applied Remote Sensing and GIS techniques to assess agricultural drought in East Shewa Zone, Ethiopia. They used Water Requirement Satisfaction Index (WRSI), Standard Precipitation Index (SPI) and Normalized Difference Vegetation Index (NDVI) to assess agricultural drought conditions and found out a reduction of grain yield during the cropping seasons between 2000 and 2005. They suggested that agricultural drought risk mapping can be used to guide decision-making processes in drought monitoring. [11] used the MODFLOW model for prediction of groundwater table under drought scenarios in Garbaygan Plain, Iran. They used four scenarios (wet conditions and, normal, moderate and severe drought conditions) in the study and concluded that based on forecasted water budget, groundwater level is likely to fluctuate under different precipitation conditions (from wet conditions to severe drought conditions) so that locations with high densities of wells experience a larger decline in groundwater levels. [12] studied groundwater fluctuations under different climate conditions in Neyshabour Plain, Iran. Applying SPI, they found that long term (42 Months) SPI had the greatest correlation (0.519) with the groundwater level. [13] applied SPI, GRI and SECI to analyze drought impacts on groundwater in Fasa Aquifer in Iran and found that groundwater drought has occurred in the area in 2003, 2008 and 2009. They also reached a high level of significance between SPI with groundwater level, GRI and SECI values in the 49 months that indicated that groundwater of the area was directly influenced by drought. [14] studied the drought impacts on groundwater quality and level in Khois Plain, SE Iran. They used Hydrograph and Kymograph diagrams and performed spatial analyses in GIS and concluded that the recent droughts had a significant impact on groundwater quality and quantity degradation.

Taking into account the key role of Marand aquifer (Iran) in provision of used water for both human and agriculture in one hand and the possible effects of the recent droughts in the region on the other hand, this study is aimed at unearthing the temporal trends in the aquifer's water storage and the general climatic stance of Marand city as well as determining the dry periods in an effort to assess the recent drought impacts on groundwater-level variations to see the possible relations between monthly and yearly drought phenomenon and groundwater level fluctuations in the study area in order to define at what extent droughts affect the plain's groundwater level changes.

2 Materials & Methods

2.1 Study area

Marand region is located in the north-west of provincial capital Tabriz, northwest of Iran, between the longitudes of 45-15 to 46-50 East and the altitudes of 38-18 to 38-46 North. With an area of 662 Km^2, Marand Plain is located in the southern parts of the county. The region is a part of the catchment area in the Caspian Sea in northwest Iran [15]. It has a semi-arid climate and the average annual rainfall is 236 mm [16]. Most of the region's population lives in the plain and relies on the region's agriculture-based economy [17]. Almost all water needs of the region are provided from groundwater resources. Based on the reports of the Regional Water Organization, Marand Palin is among the six critical regions in East Azerbaijan province, in which, any exploitation of groundwater resources is prohibited due to a severe decline in water level in recent decades [18]. The location of the study area is shown in Figure (1).

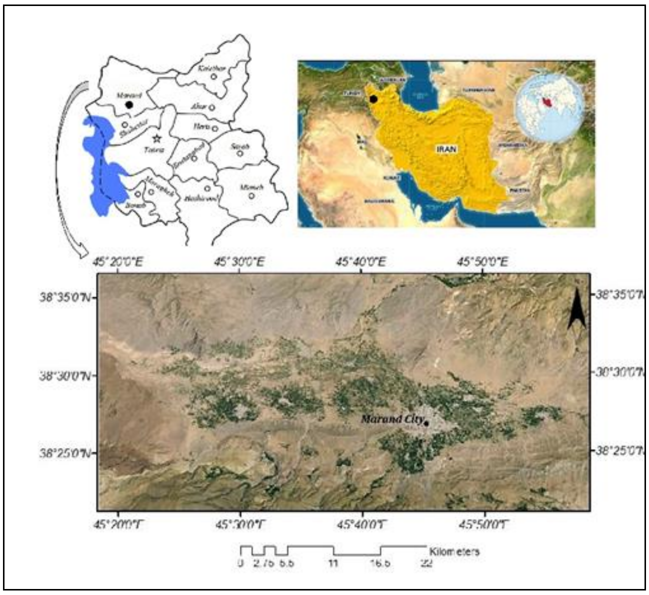

Figure 1: Geographic location of Marand plain in East Azerbaijan Province, NW Iran.

2.2 Data gathering

In the present research, the required data were collected from official resources. The Regional Water Company of East Azerbaijan branch provided the groundwater data of the region's piezometric wells and the monthly records of climatic data (rainfall and temperature) were obtained from the Weather Office of Maran County. Table 1 illustrates the meteorological stations located in Marand County. Analyzing and managing the available datasets of the region, a suitable database of the same temporal range was collected to perform the analyses.

2.3 Groundwater level fluctuations

To study the recent changes in groundwater level, the hydrograph of the region's aquifer was drawn. Hydrographs are used to demonstrate groundwater level trends plotting the converted water level readings below ground surface against corresponding time periods [19]. Since the available piezometric wells did not cover up all the study area, the Thiessen Polygons method was applied on 20 wells to fit them to Marand Plain. This method partitions the given area applying the geometric distance to determine neighborhoods [20] and is one of the most accurate tools to draw hydrographs of groundwater aquifers. .The Thiessen network was created using ArcGIS software. The locations of wells and their corresponding Thiessen network are shown in Table 2 and Figure 2, respectively.

2.4 Analyses of climatic data

Climate has a pivotal role in water resources especially groundwater aquifers. Groundwater resources and their long-term replenishment are controlled by long-term climate conditions [2]. Air temperature and rainfall are the key elements describing the climate of a given region. For analyzing climate of the study area, the available datasets of mean temperature and rainfall for the last 15 years (2000-2014) of Marand Synoptic Station were used in the study.

Table 1: The meteorological stations of Marand county used in the study.

Station Name	Station Sort	UTM (X)	UTM (Y)	Elevation (m)
Marand	Synoptic	562607.2	4246742	1720
Payam	Pluviometic	569903.3	4244952	1802
KoshkSaray	Pluviometic	549446.5	4255897	1150
Miyab	Pluviometic	569597.8	4280091	2200
Harzandat	Pluviometic	559461.7	4278159	1470
Yekanat	Pluviometic	539157.6	4278034	1405
Zonooz	Pluviometic	572564.9	4272719	1678

Table 2: Piezometric data of marand plain used in the study.

Number	Location	Well ID	UTM (X)	UTM (Y)	Thiessen Area (Km^2)
1	Abarghan	W_1	579250	4257600	32.77
2	Asadaghi	W_2	575050	4257700	42.95
3	Bahraam	W_3	562400	4254600	29.13
4	Charchar	W_4	563650	4267000	29.27
5	Dolat Abad	W_5	569500	4258750	48.60
6	Galleban	W_6	548012	4264039	46.05
7	Dizaj Hossein	W_7	554550	4257200	23.16
8	Kondlaj	W_8	564700	4249400	25.82
9	KoshkSaray	W_9	549050	4254650	32.32
10	Markid	W_{10}	554500	4260400	22.66
11	Qamish Aghol	W_{11}	541550	4265450	42.82
12	Qaraje Mohamad	W_{12}	548150	4261850	12.39
13	Qaraje Mohamad	W_{13}	548150	4260750	26.73
14	Qirkhlar	W_{14}	534200	4262650	57.80
15	Gazafar	W_{15}	536500	4258800	38.08
16	Saritapeh	W_{16}	570550	4261450	20.23
17	Marand	W_{17}	560050	4256500	26.63
18	Qirmizi Qishlaq	W_{18}	540100	4257400	47.68
19	Yalquz Aghaj	W_{19}	557850	4260050	19.83
20	Yamchi	W_{20}	557700	4262700	37.91

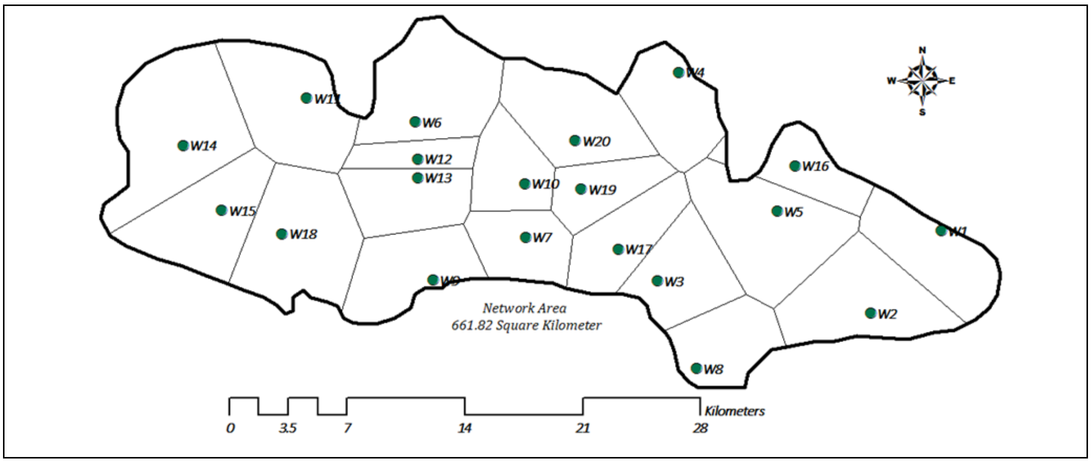

Figure 2: Thiessen network of marand plain accompanied by piezometric wells.

2.4.1 Estimation of missing data

Climate data are not always complete due to technical or anthropogenic errors thus it is vital to fill in the data gaps prior to performing data analyses. The Normal Ration method was used to estimate the missing rainfall data. This method, which was recommended by [21], is used to estimate the missing data of a station (dependent) based on the data of a nearby station (independent) using the following equation:

$$P_A = \frac{Pi_A}{Pi_B} \times P_B \tag{1}$$

Where P_A represents rain data for a dependent station (A), P_B represents mean rain for an independent station (B), Pi_A and Pi_B represent the mean rainfall data in shared periods for the stations A and B respectively [22].

2.4.2 Ombrothermic diagram

[23] have defined a dry month as a period of time when the total precipitation in mm is as same as or less than double the mean temperature in degrees Celsius ($P \leq 2T$). An Ombrothermic diagram is used to study monthly drought and shows long term periods of dryness and wetness of a study area. To obtain the climate status of the study area, an Ombrothermic diagram was drawn using mean temperature and precipitation of Marand Station.

2.4.3 Standardized precipitation index

Standardized Precipitation Index (SPI) offers an index using rainfall probability distribution function to show the actual rainfall as a standardized departure and hence it has gained importance in recent years as a drought indicator permitting temporal as well as spatial comparisons [19]. SPI is based on the probability of the amount of precipitation for any time scale which is then transformed into an index. The climatic condition can be defined by SPI values in which negative SPI below -1 indicates dryness while wetness is expressed by positive values. According to the changes in SPI values droughts are distinguished so that when SPI reaches -1.0 the drought starts and ends when SPI becomes positive again [24]. Table 3 illustrates the SPI classification. For this study, the SPI values were computed based on all the meteorological stations of Marand County by using Drought Indices Package (DIP) software. This package is a program written by Iran Water Resources Company (http://www.wrm.or.ir/research) as the outcome of the project WRE1-79489 entitled "design of Tehran drought monitoring system".

Table 3: Drought classification [25].

Index Value	Description
2.0+	Extremely Wet
1.5 to 1.99	Very Wet
1 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Very Dry
-2 and less	Extremely Dry

It is aimed to calculate a number of drought indices that are more concerned in drought monitoring in a friendly environment and different time scales. The package can convert monthly data time series to the moving average time series with 3 to 48-month lag. The drought indices that the package calculates are CZI (China Z Index), MCZI (Modified China Z Index), SPI (Standardized Precipitation Index), ZSI (Z Score Index), DI (Drought Index), PNI (Percent of Normal Index) and EDI (Effective Drought Index). Input file for all the indices is monthly precipitation data, excluding EDI which requires daily data.

3 Results and discussion

3.1 The climate of the region

The Ombrothermic diagram of Marand station (Figure 3) was drawn using mean temperature and precipitation data for a 15-year period (2000-2014), the only available dataset of the study area. The figure shows that Marand region has 5 severe dry months ranging from May to October while the wet period of the study area ranges from January to May (very wet) and October to December (moderately wet).

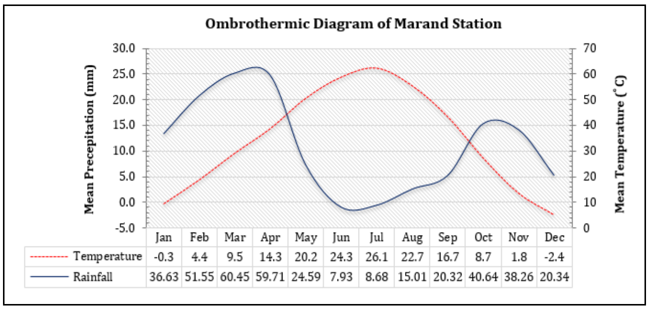

Figure 3: The ombrothermic diagram of marand synoptic station (2000-2014).

3.2 SPI results

SPI values in monthly and yearly time-scale were calculated through DIP analyzes. This package can calculate monthly, moving average SPI with a lag time of 1, 3, 6, 9, 12, 18, 24 and 48 months. The monthly precipitation data were introduced to the package and the program was run for 1-month and 12-month time scales to obtain the results. The monthly SPI results indicate that the region has two months categorized in very dry class in June and July and three months of moderately wet climate from Feb to Mar.

The study area has normal SPI for the remaining months (7months) including Jan, May, Aug, Sep, Oct, Nov, and Dec. Yearly SPI values show that the study area has suffered severe droughts in 2001 and 2002 having estimated SPI values of -2.02 and -2.22 respectively. The drought situation of the region was near normal for years 2003-2007 and 2010-2014. In the years 2008 and 2009, there were moderate levels of dryness and wetness respectively. The monthly and annual classification of meteorological drought (2000 to 2014) of the study area is shown in Tables 4 and 5 respectively.

3.3 Hydrography results

Groundwater heads of Marand Plain were analyzed for monthly and annual records. The monthly hydrograph diagram shows that the overall monthly fluctuations of groundwater of the region follow an overall decreasing trend with a total decline of 5.7 m during the last 15 years. According to the diagram, the groundwater trend was ascending from January to March and from June to July so that the highest level occurred in March with 1156 m while the major descending trends were observed from March to June and from July to September so that the lowest level was observed in June with about 1099 m. It was also found that the groundwater had slight fluctuations from September to December.

On the other hand, yearly groundwater trends of the region were also descending with about 53m fall in 15 years, which corresponded to about 3.5m per year decline head in Marand Plain groundwater decreased. The annual hydrograph also showed significant groundwater declines in 2001, 2003, 2007 and 2012, in which the groundwater heads were extremely critical in the years 2007 and 2012 with values of 1036 m and 1050 m, respectively. On the opposite extreme, the highest levels of groundwater occurred in 2005 and 2011 with values of 1170 m and 1163 m, respectively. The monthly and yearly hydrographs are given in Figures 4 and 5.

Table 4: Monthly drought (1.SPI) classification.

Drought Class	SPI	Month
Near Normal	0.44	Jan
Moderately Wet	1.05	Feb
Moderately Wet	1.33	Mar
Moderately Wet	1.39	Apr
Near Normal	-0.22	May
Very Dry	-1.64	Jun
Very Dry	-1.57	Jul
Near Normal	-0.91	Aug
Near Normal	-0.49	Sep
Near Normal	0.59	Oct
Near Normal	0.48	Nov
Near Normal	-0.43	Dec

Table 5: Annual drought (12.SPI) classification.

Drought Class	SPI	Year
Extremely Dry	-2.02	2000
Extremely Dry	-2.22	2001
Near Normal	0.99	2002
Near Normal	0.95	2003
Near Normal	0.50	2004
Near Normal	0.02	2005
Near Normal	-0.22	2006
Near Normal	0.04	2007
Moderately Dry	-1.03	2008
Moderately Wet	1.18	2009
Near Normal	0.4	2010
Near Normal	0.11	2011
Near Normal	0.91	2012
Near Normal	-0.15	2013
Near Normal	0.55	2014

3.4 The Impact of Drought on Groundwater

To find out the relationship between meteorological drought and groundwater fluctuations in the study area, the temporal variations of groundwater levels were plotted together with SPI values as shown in Figure 6. Accordingly, it was found that groundwater levels of Marand aquifer were affected mostly by monthly droughts, in which, monthly wetness and dryness cause apparent groundwater fluctuations. For instance, the groundwater level increased from January to March and from September to October. On the other hand, it declined from March to June, from July to September and from October to December, which precisely followed SPI values (Figure 6). Although the groundwater levels of the study area are under control of monthly or seasonal droughts, the annual fluctuations of groundwater are slightly affected by yearly drought conditions. Based on Figure 7, groundwater levels of the region were affected by the dry periods of 2000-2001 and 2006-2007 and showed a declining pattern. On the other hand, groundwater levels increased from 2013 to 2014 despite the negative SPI values representing drought conditions. This might be related to a specific lag in groundwater response to precipitation events. In some periods, however, no rational relation between drought index and groundwater level was observed as in the case of the years 2003, 2008, 2011 and 2013. This finding proposes that there can be other effective influences such as differences in pumping rates caused by over-cultivation of agricultural products in those periods which is a typical characteristic of the region's agricultural activities.

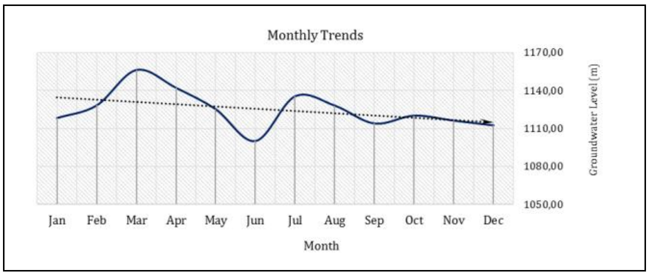

Figure 4: Monthly Fluctuations of Marand Plain's Groundwater Level (2000-2014).

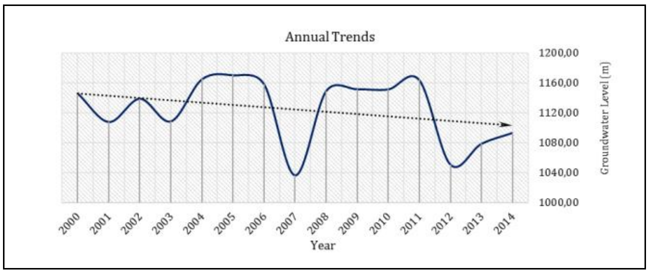

Figure 5: Annual Fluctuations of Marand Plain's Groundwater Level (2000-2014).

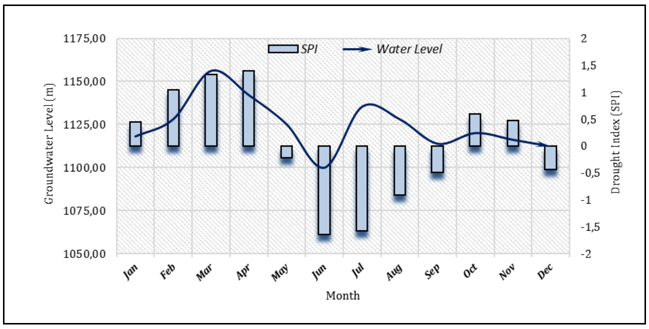

Figure 6: Impacts of drought on groundwater monthly fluctuations.

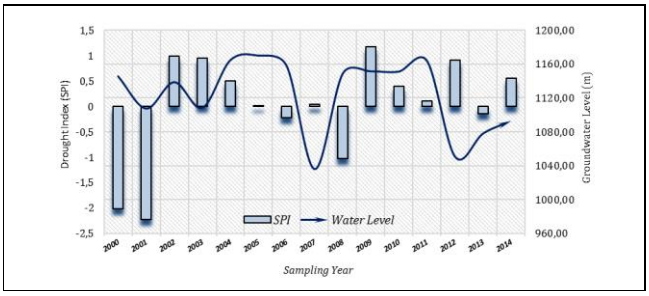

Figure 7: Impacts of drought on groundwater annual fluctuations.

4 Conclusion

Iran is located in a drought-prone region of the world. Most of the country suffers from water shortage as well as water mismanagement. On the other hand, the recent effects of global warming and climate change have caused a tremendous decline in precipitation amounts. These factors accompanied by the growing population were deemed to play the main role in the groundwater crisis in the country. Almost all of the groundwater aquifers of the country have been facing severe water shortages in recent years and some of them have totally dried up as a result of meteorological drought and other anthropogenic factors. Since droughts are inevitable phenomena and considering the pivotal importance of groundwater resources in human life, it seems vital to bring these resources under a regular monitoring practice, which offers a comprehensive view of their stance over time.

In the present study, the objective was to analyze the meteorological drought and to understand its impacts on groundwater in Marand Plain where its aquifer is in a critical situation. According to of the Ombrothermic diagram, Marand Plain experiences severe droughts from May to October while the wet period ranges from January to May (very wet) and October to December (slightly wet). SPI outcomes showed a relative similarity between the climate of the region and monthly SPI values where June and July are the driest months based on precipitation records. The yearly SPI values indicate that Marand Plain has suffered extreme droughts during 2000 and 2001 and a moderate drought in 2008 while in the remaining years the condition is near normal. Putting the groundwater hydrographs into account, it was found that the groundwater fluctuations of the Plain is mostly under the control of monthly droughts, which coincides with the findings of the similar study done by [26] through which they investigated the effect meteorological and hydrological drought on groundwater quantity and quality and also found that the negative trend in groundwater level of Marand plain is affected by monthly droughts with 5 month delay. While the yearly droughts have had significant impacts on groundwater levels in some periods for example from 2001 to 2006 groundwater fluctuations were influenced directly by yearly droughts though in the remaining periods there is no obvious relation between drought and groundwater level changes. This can be transpired by other causative factors such as variations in water exploitations etc.

Since the region is closely dependent on agriculture, it is clear that preserving its socio-economical stance is tightly linked to the effective management of groundwater resources. From this perspective, analyzing climatic data can indeed be a beneficial tool to organize conservative plans as well as taking drastic measures to tackle droughts in order to assuage their harsh impacts on groundwaters of the study area.

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