Impact of Climate Change on Artificial Recharge System

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ABSTRACT

Does climate change affect the quantity and quality of the wells near the artificial recharge site? Considering the research background, it seems that there has not been a comprehensive study on the impact of climate change and the trend of groundwater quality changes in jafakendeh aquifer. In this study, relation jafakendeh aquifer, climate change in north Iran, evaluated. Therefore, the purpose of this study is to examine trends, changes in groundwater level with some climatic variables of jafakendeh aquifer with the non-parametric Mann-Kendall method and Change-Point Detection with Pettitt's process. The results of the model show that the climate change factor does not affect the groundwater level after the establishment of an artificial recharge system. The results of the research can be used for evaluation Cost-Benefit Analysis of artificial recharge sites after construction.

Keywords: Artificial recharge, Climate change, Trend detection

1.1. Introduction

Ground-water distributed beneath the earth's surface is one of its most valuable sources of freshwater [1]. Groundwater reservoirs receive water and store it in natural or artificial surface-water bodies. They even alleviate its temperature and chemical quality, transporting it from areas of replenishment to areas of need and discharge it to the surface, making up the bulk of the flow in streams in dry climates. A watershed is defined as an area where water enters through precipitation and leaves as evapotranspiration, surface runoff, and subsurface water discharge toward a low topographic area. (Fig. 1) [3]. More than half the world's population now lives within 80kilometers of shoreline. Surface water in the coastal watershed and the island interacts with adjacent underground water. This interaction affects the quantity and quality of water in surface water and below the surface. In the case of a coastal watershed, runoff and subsurface water discharge enter the sea.

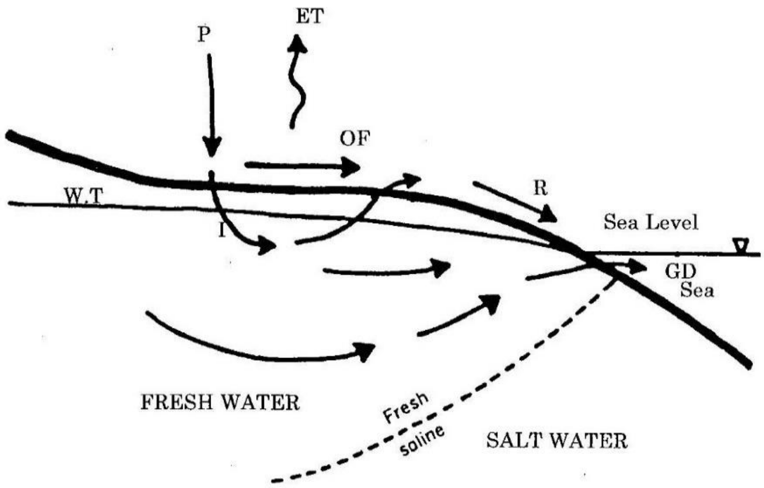

Fig.1 Water balance in coastal watershed [3]

Several studies have been carried out on the changing trend of groundwater levels around the world. The estimate of the groundwater flow to the Gulf of Mexico indicates a complete is the relationship between the coastal aquifer and bay that the surveyed. [4]. Bangladesh Regional Basin water change studies were performed during the 27-year statistical period using the Mann-Kendall test, and it was found that the groundwater level trend is generally increasing and significant [5]. The process of hydrological maximum heights variations was studied using the Mann-Kendall method in 2335 stations in a basin of Turkey [6]. The behavior of the fluctuations of groundwater level in the Regions residential Kuwait and the suburbs according to the information of 6 piezometer wells were studied; the results of the studies showed that the groundwater level has seasonal behavior [7]. The impact of drought on groundwater in northwestern Bangladesh has been studied in recent years. Their results show that groundwater depletion occurs in 42% of the area each year. Hydrograph analysis of groundwater level and rainfall time series showed that increasing groundwater harvesting for irrigation in dry seasons and returning droughts is due to groundwater decrease in this area [8]. In these studies, these questions can be analyzed: Does the sea level affect the quantity and quality of the wells near the artificial recharge site? Does climate change affect the amount and quality of the wells near the artificial recharge site? Do drought, climate change, and increasing potable water demands of a growing population take their toll on water resources? Which is the best method management to store and recharge groundwater reserves? Considering the research background, it seems that there has not been a comprehensive study on the impact of climate change and the trend of groundwater quality changes in jafakendeh aquifer. In this study, the relation of the jafakendeh aquifer and the climate change in the north of Iran investigated. Therefore, the purpose of this study is to examine trends, changes in groundwater level with some climatic variables of jafakendeh aquifer with the non-parametric Mann-Kendall method and Change-Point Detection with Pettitt's process. Parameters used in qualitative calculations include Katium, K^{+}, Na^{+}, Mg^{2+}, Ca^{2+}, TH, SAR Anion, $SO4^{2-}$, Cl^{-}, $HCO3^{-}$, PH, TDS, EC, and Parameters used in climate change Calculations include Precipitation, Humidity, Evaporation, Min, and Max Temperature, Which was used during the statistical period 1989-2017.

2.1. Materials and Methods

2.1.1. Study area and data

The area is located in Golestan province and Gorgan Gulf basin, in the eastern parts of the Alborz Mountains, southeast of the Caspian Sea, at 52˚ 43'-53˚6' 30" Eastern longitude and 53˚32' - 53˚22' North latitude. Gaz Harbor is the closest city in the area. The study site covers the western side of the Jafakende watershed, which is located on the Jafakende River in the Gorgan Gulf catchment area and originates from Alborz highlands (Fig. 2).

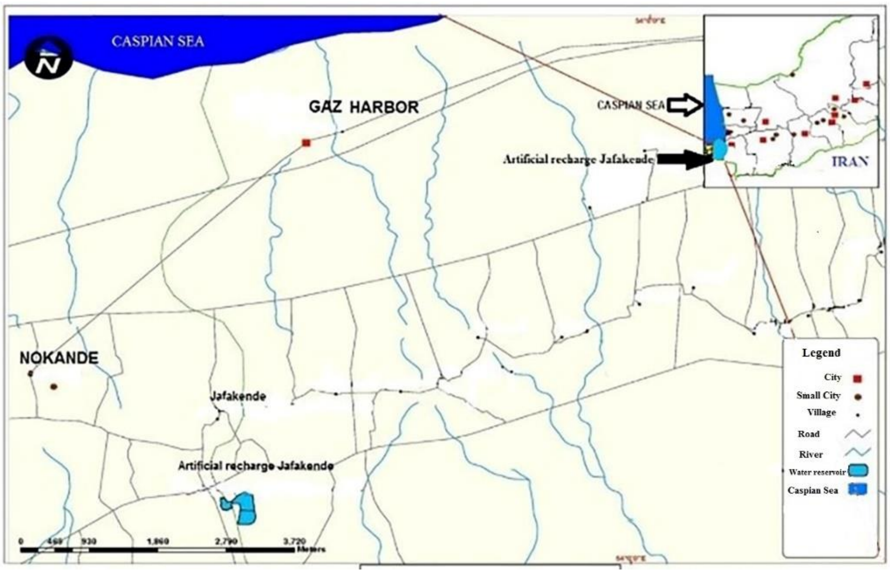

Fig. 2 The study area

The study area has a semi-humid to humid climate with average annual precipitation of 506 mm And 1015 mm. The Caspian Sea influences on the rainfall pattern. Most of the rainfall takes place in the late autumn, and particularly in winter, average monthly precipitation at Jafakende rain gauge station from 1993 to 2017 is shown in Fig. 3.

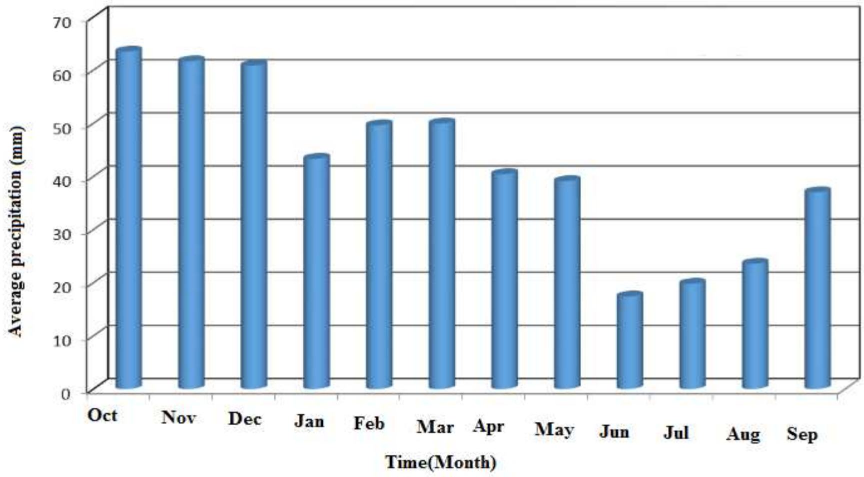

Fig. 3 Average monthly precipitation at Jafakende Rain gauge station

Two rain gauge stations and one evaporation station collect data from the study area.
The Specifications of the meteorological stations are presented in Table 1.

Table 1 Specification of the existing meteorological stations

STATION	Type	Height (m)	UTM	
			X	Y
Jafakende	Rain gauge station	30	228941	4069303
Vatana	Rain gauge station	100	229122	4067740
Kordkoy	Evaporation Station	140	243359	4072714

In investigating the exchange of underground flow between the Jafakende aquifer and the Caspian Sea, four observation piezometer wells were used. The characteristics of these wells are presented in Table 2.

Table 2 Observation wells are studied

Piezometer Wells	UTM		Height (m)	Distance well from the Caspian sea (km)
	X	Y		
P2	227473	4075185	-21.63	0.40
P3	224602	4068109	38.58	7.26
P6	227145	4070728	19.57	4.68
P10	228430	4069821	21.02	5.92

Jafakende is the river in the study area with an area of 41 square kilometers, the upper mountain catchment (Alborz heights) originates (Figure 4). This river flows along the plain and the main inflow of surface water to the plain. It is estimated that each year, on average, approximately 1.64 MCM of floodwater is diverted from the river to the floodwater distribution system for artificial recharge of groundwater.

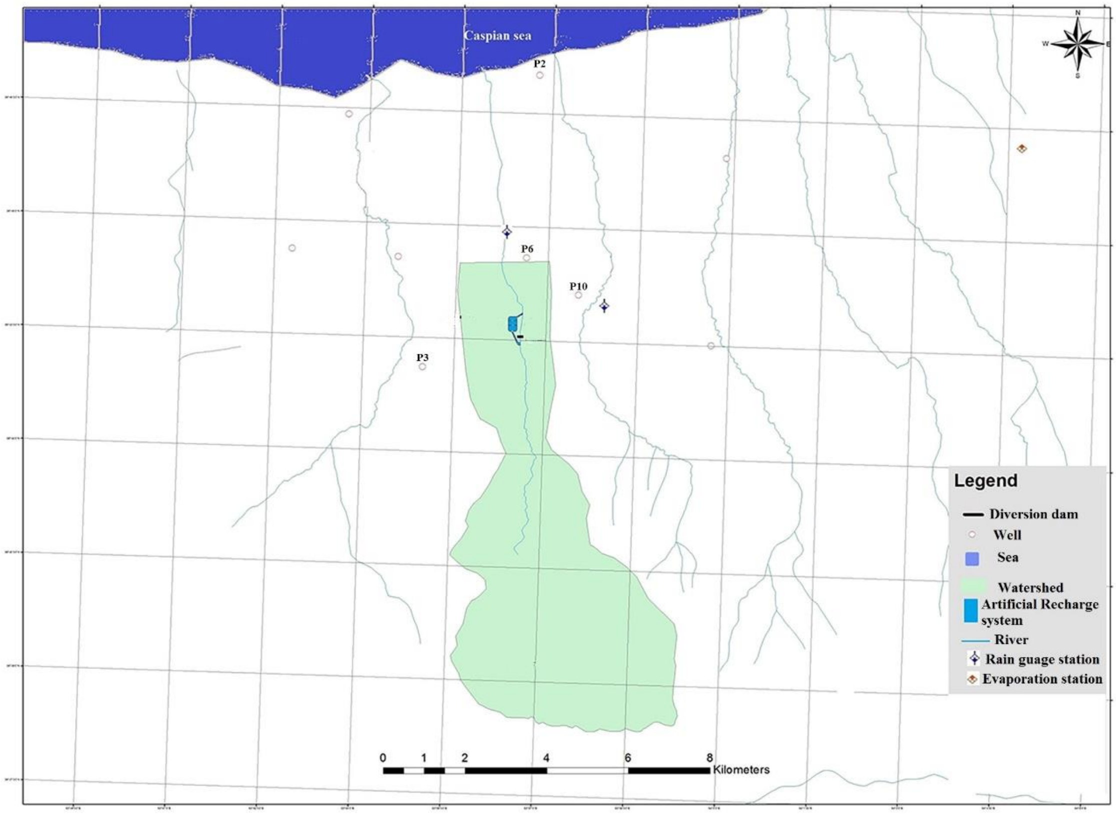

Fig.4 The meteorological stations and piezometer wells in Jafakende watershed

This study will be beneficial in limiting floods and flood damage, but it is the most excellent value is in reducing the dissipation of quality water. In the upper reaches of the basin, it is possible to control the water and prevent the occurrence of floods and waste, water and soil erosion, and reduce soil fertility as part of watershed management. Since floods can't always be controlled at the upstream, flood control and land nutrition are controlled by flood spreading at the basin outlet and downstream [9, 10]**.** Ground-water shortage and water crisis due to climate change is a threatening global concern. The economic impacts of drought are massive and multifaceted as it can be discussed at several levels, including the shift in land use, rain-fed agriculture, and water resource management (Fig. 5) [11].

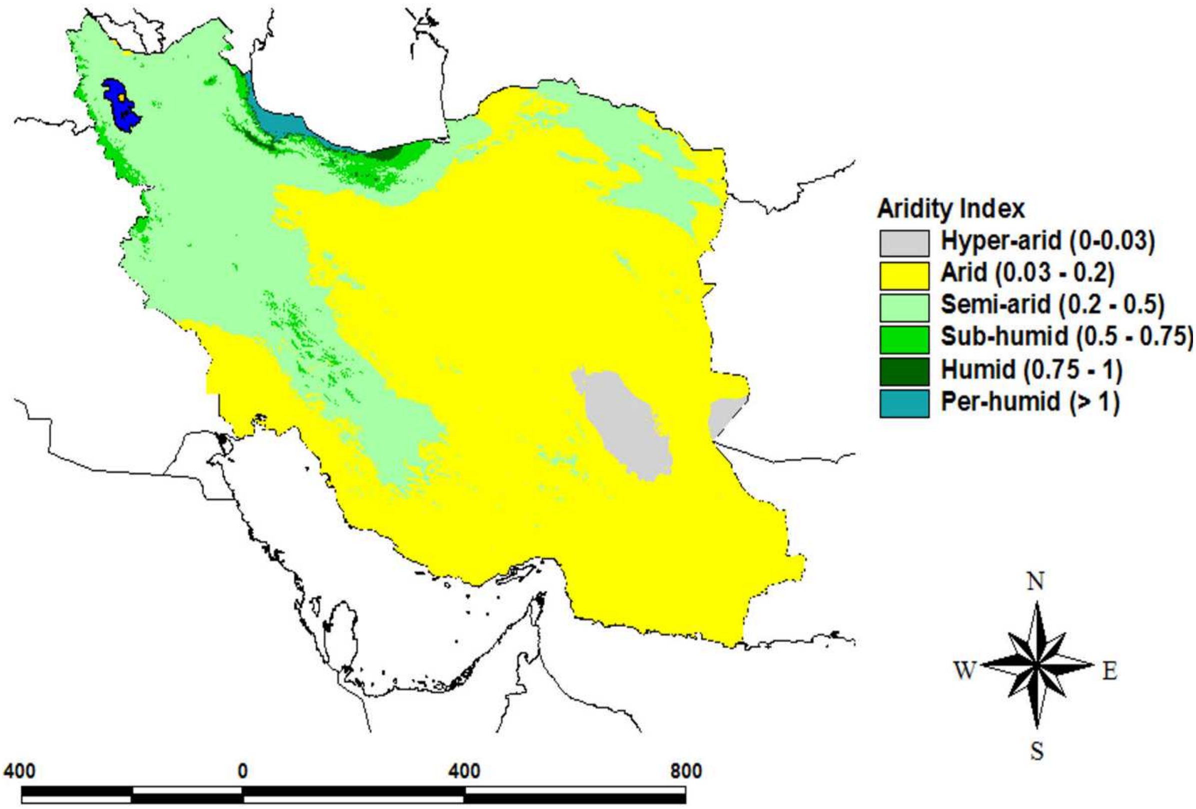

Fig. 5 Aridity classes in Iran [11]

Groundwater depletion is a growing global concern. The increasing water demand as a result of climate change has intensified the water crisis. Artificial recharge techniques are traditional solutions to problems caused by infrequent precipitation in arid regions. Artificial recharge experts are interested in searching for new methods of floodwater spreading and artificial recharge in arid and semi-arid areas [12]. Artificial recharge is a practice where floodwater is distributed over or into the ground to augment underground aquifers. Artificial recharge plans and flood spreading helped mitigate droughts, as well as in controlling floods, in several arid and semi-arid regions of the world. The United States and Europe began to artificially recharge groundwater as early as the nineteenth century, setting up facilities for that purpose. Over time, several methods were devised for artificial feeding. Today, a substantial part of the drinking water is supplied from artificially-fed groundwater in many developed countries, including Germany, Sweden, and the Netherlands. In recent years, much attention has been given to recharging groundwater reservoirs using excess surface water [1]. There are reports that artificial recharging was successfully used in Oman to raise the water table in arid areas [13]. Flood spreading plans are the best options for preventing land subsidence and reducing the effects of saltwater intrusion on groundwater quality. The relationship between groundwater level and the impact of rainfall collected in Taiwan was investigated. Floods that spread across the basin provide aquifers and affect groundwater levels [19]. An investigation into some watersheds in India, where rainwater harvesting is practiced, showed that this operation saved 27–34% of the annual average rainfall in the groundwater form. In the Jin-Jiang district of China, surveys have shown the Effect of flood spreading coupled with the artificial recharge of aquifers in arid and semi-arid regions to be the best option for storing water in dry areas, taking into account its beneficial ramifications [13]. The use of aquifers to store the excess surface water through artificial recharge is increasing (Fig. 6).

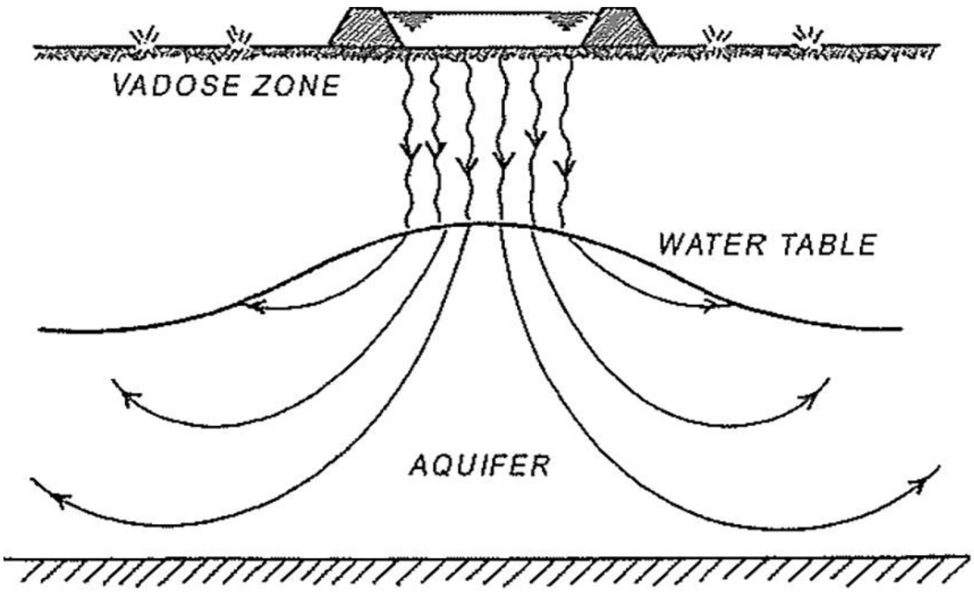

Fig. 6 Cross-section view of a typical groundwater recharge system [2]

2.1.2. Flood and Drought management

A severe and fundamental issue currently faced by most countries is the limited water and soil resources arising from the exploitation of these resources and the destruction of the environment by humans. The circulating water is mainly introduced to the plain via precipitation. In large parts of the direct, most of the rainfall runs over the ground, causing floods and not giving the earth enough time to absorb much water (Fig. 7). In the upper reaches of the basin, known as the watershed, the water can be controlled to prevent floods, water dissipations, and the erosion of the soil, which reduces soil fertility. Because water cannot be retained entirely upstream, floods can be controlled by aquifers that are amplified by artificial charging and flood spreading at the mouth of the basin.

Fig. 7 (a) Flash flood **(b)** Land subsidence

2.1.3. Artificial recharge as the best option

Artificial recharge can be defined as a human-made process that facilitates the transfer of surface water into aquifers. Several methods make the transmission of the surface water toward the subsurface formations. Purposes for artificial recharge include groundwater (well field) management, preventing land subsidence, wastewater reclamation**,** and improving groundwater quality during periods of sharp reductions in surface water flow and floods. Artificial recharge projects also help save water. A successful artificial recharge project consists of two critical elements, namely a reliable supply of quality water and understanding the subsurface geological and hydrological conditions. When integrated into a basin management program, artificial recharge can substantially enhance the availability of water. In principle, Floodwater Spreading systems operate by infiltration the water into aquifers for augmenting groundwater and serve as experimental plots for improving the ground conditions, moving-sand stabilization, and reforestation (Fig. 8) [10]**.**

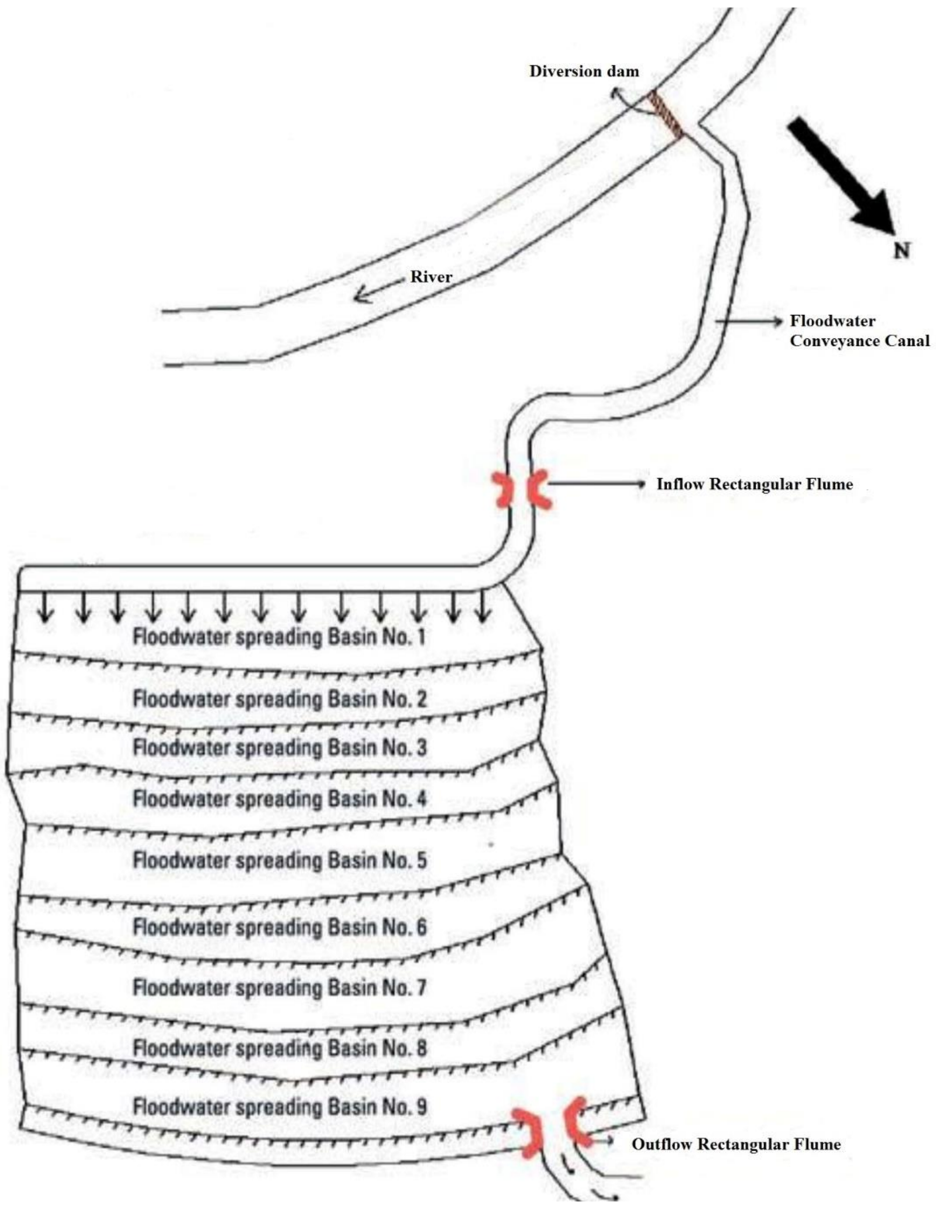

Fig. 8 Artificial recharge system

Artificial recharging techniques have been employed to add water to aquifers. Recharging aquifers by infiltration of surface water take place when the water table is below the water surface of a stream, and the streambed is permeable. The rate of penetration depends on the surface-water temperature, the permeability of the streambed and the aquifer, the streambed thickness, depth of the stream, and the water table. Data on groundwater runoff can help estimate the extent of aquifer recharge. However, it must be noted that, in many watersheds, not all the surface runoff can be diverted into the aquifer (Fig. 9).

Fig .9 (a) Floodwater spreading system **b)** diversion dam

3.1. Non-Parametric Trend and Change-Point Detection Tests

Awareness of the process of changes in the quantity and quality of groundwater in aquifers management is of great importance. The Mann-Kendall Test and Pettitt's test are used for trend and change point detection analysis.

3.1.1. Mann-Kendall Trend detection Test

This method has been extensively used to assess the significance of trend exist in hydro-metrological data such as temperature, streamflow, precipitation, and groundwater level. HA, is that the data follow an identical pattern in the alternative hypothesis, and H0 is that the data come from a population with independent realizations and are identically distributed in the null hypothesis. If the number of data time series is **n** within the study period, the statistic **S** is calculated by Eqs. (1) and (2), [14, 15].

$$\mathbf{S} = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathbf{Sgn}\,(\mathbf{X_j} - \mathbf{X_k}) \qquad \textbf{(1)}$$

With

$$\text{Sgn}(X) = \begin{cases} +1 & \text{if } X > 0 \\ 0 & \text{if } X = 0 \\ -1 & \text{if } X < 0 \end{cases} \tag{2}$$

Under the hypothesis of independent and randomly distributed random variables, when **n ≥ 8**, the statistic ***S*** has a normal distribution, where it's mean, and variance is calculated as Eq. (3)
The mean of is **E[s] = 0,** and the variance σ^2

$$\sigma^2 = \{n(n-1)(2n+5) - f(z) = \sum_{j=1}^{p} t_j\ (t_j - 1)(2t_j + 5)\}/18 \tag{3}$$

Where **p** is the number of the tied groups in the data set and t_j is the number of data points in the j_{th} tied group. The statistic **S** is approximately regular distributed provided that the following Z-transformation is employed, and the extraction of Z statistic is according to Eq. (4).

$$Z = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases} \tag{4}$$

It follows that the hypothesis that there is no trend is rejected when the Z value computed by the equation above is higher in absolute value than the critical value *Z*α, at a chosen level of significant α [16].

3.1.2. Pettitt's change-point detection

One of the non-parametric tests is for detecting the change point in a time series. In the present study, this statistic was used to find a sudden change in the quantity and quality of groundwater data. First, $U_{t,T}$ the time series is obtained Eq. (5), [17].

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \text{sgn}\ (X_i - X_j) \tag{5}$$

In this equation, **t** is the period length, and **T** is the number of data in the statistical series. Also, $\text{sgn}\ (X_i - X_j)$ Calculated as in Eq. (2).

By calculating the value of **k** using Eq. (6) and replacing it in Eq. (7), the ***p*** statistic is obtained:

$$K_T = \max |U_{t,T}| \tag{6}$$

$$p \text{ ' } 2 \exp\left(\frac{-6\, K_T^2}{T^3 + T^2}\right) \tag{7}$$

4.1. Results and Discussion

4.1.1. Trend analysis, quantity, and quality of groundwater time series for the wells research

In this test, H0 indicates the homogeneous data, and H1 represents failure occurrence in the researched time series. If the calculated p-value is less than α or a significance level of 0.05, then this change point is considered to be statistically significant. In tying the error, and when the error is less than 5%, the change will be regarded as substantial (Table 3). The values of the Z statistic of Mann–Kendall test for years and annual quantity and quality of groundwater time series for the piezometer wells studied are given in Table 4, 5. If the Z statistic is positive, the trend is increasing, and, if negative, the pattern will be decreasing [18]. The table shows that significant positive trends in the quantity and quality of wells groundwater data are observed in the year between1989 to 2017 at the piezometer wells around the artificial recharge site of Jafakendeh. In general, four wells were tested that only p6 well, is located in the artificial recharge site, and the P2 piezometer well is located near the Caspian Sea. The results show that wells P2, P3, P10 have a decreasing trend in the groundwater level. Still, the right direction of increasing the level of pisometer p6 in the groundwater level has occurred after the construction of the artificial charging site. Also, the results of studies show that the groundwater quality variables in the P6 piezometer well have a steady trend between 2006 and 2017 (after the construction of the artificial charging site).

Table 3 The *P* values (*α=0.05)* of the Mann–Kendall test for change in annual Quality wells

Variable	P-value/P2-well	P-value/P3-well	P-value/P6-well	P-value/P10-well
TH	0.867	0.222	0.051	< 0.0001
SAR	< 0.0001	0.001	0.781	0.002
Kation	< 0.0001	0.031	0.378	< 0.0001
K^{+}	0.349	0.074	0.449	< 0.0001
Na^{+}	< 0.0001	0.002	0.377	0.00
Mg^{2+}	0.011	0.037	0.749	< 0.0001
Ca^{2+}	0.014	0.995	0.00	0.002
Anion	< 0.0001	0.041	0.339	< 0.0001
$SO4^{2-}$	0.002	0.792	0.005	< 0.0001
Cl^{-}	< 0.0001	0.028	0.721	< 0.0001
$HCO3^{-}$	0.038	0.002	0.012	0.001
PH	0.985	0.023	0. 408	0.025
TDS	< 0.0001	0.599	0.574	< 0.0001
EC	< 0.0001	0.468	0.565	< 0.0001

Table 4 The *Z* values of the Mann–Kendall test for change in the annual quality wells

Variable	Z-p2	Z-p3	Z-p6	Z-p10
TH	0.0	-0.82	1.95	0.0
SAR	4.502	-3.21	0.28	3.11
Kation	5.590	-2.16	0.88	4.41
K^{+}	-0.936	-1.79	0.76	4.21
Na^{+}	5.594	-3.15	0.88	3.53
Mg^{2+}	2.55	-2.08	-0.32	4.62
Ca^{2+}	2.459	0.06	3.61	3.15
Anion	5.50	-2.05	0.96	4.41
$SO4^{2-}$	-3.172	0.26	-2.84	4.02
Cl^{-}	5.595	-2.19	0.36	4.32
$HCO3^{-}$	2.076	-3.12	2.52	3.33
PH	-0.018	2.28	0.83	-2.23
TDS	5.317	-0.53	0.56	4.30
EC	5.354	-0.73	0.58	4.30

Table 5 Results Mann-Kendall trend test / climatic variable and groundwater table

Variable	Kendall tau	S	Var(S)	Z	Trend	p-value (Two-tailed)	slope
Precipitation	-0.040	-12	0.00	0.0	no	0.80	-0.127
Humidity	-0.247	-74	0.00	0.0	no	0.089	-0.342
Evaporation	0.073	22	0.00	0.0	no	0.628	0.068
Min-Temperature	0.571	171	1832.333	4.02	+	< 0.0001	0.093
Max-Temperature	0.32	96	1832.333	2.27	+	0.026	0.069
Groundwater level(P2)	1.00	406	0.0	0.0	0.0	< 0.0001	0.351
Groundwater level(P3)	0.236	96	0.00	0.0	no	0.075	0.587
Groundwater level(P6)	0.46	185	2841	3.45	+	0.001	0.766
Ground-water level(P10)	0.429	174	0.00	0.0	0.0	0.001	1.771

4.1.2. Changepoint detection, quantity and quality of groundwater time series for the wells rsearch

The Pettitt test was used to detect changepoint of years and the annual quantity and quality of piezometer well groundwater data during the period 1989–2017. The results of applying the Pettitt test on annual quantity and quality of piezometer wells groundwater data are given in Table 6, 7. On a yearly time scale, 3 of the four selected wells had significant change points in groundwater level (excepted P2), and all of the piezometer wells faced a positive jump (increased groundwater level). As well as an annual time scale, 3 of the four selected piezometer wells had significant change points in quality groundwater. The results show P6 piezometer has very few changes in a number of the variable of quality groundwater. Best-applied Effect for these Studies that P6 well has the highest frequency increasing groundwater level and constant of the Quality variable after built artificial recharge site of occurrence of the change point was found to be (Fig. 10).

Table 6 The results of the Pettitt test for detecting the quality Of groundwater data change point

Variable	**t-P2** **(**Year of the beginning of the detection)	**t-P3** **(**Year of the beginning of the detection)	**t-P6** **(**Year of the beginning of the detection)	**t-P10** **(**Year of the beginning of the detection)
TH	-	-	-	2000
SAR	2005	1999	-	2004
Kation	2001	1998	-	2004
K^+	-	-	-	2004
Na^+	2005	1999	-	2004
Mg^{2+}	1999	1996	-	2004
Ca^{2+}	2000	-	1997	1999
Anion	2001	1998	-	2000
$SO4^{2-}$	2002	-	2001	2000
Cl^-	2001	1998	-	2000
$HCO3^-$	-	2003	2004	2001
PH	-	-	-	2001
TDS	2001	-	-	2004
EC	2001	-	-	2004

Table 7 Results Pettitt test / climatic variable and Ground-water table.

Variable	**K**	**t** **(**Year of the beginning of the detection)	**p-value** **(Two-tailed)**	**mu1** (Before the year of occurrence of the detection)	**mu2** (Before the year of occurrence of the detection)
Precipitation	42	-	0.749	-	-
Humidity	122	2007	0.001	84.241	74.830
Evaporation	76	-	0.143	-	-
Min-Temperature	118	2009	0.003	11.886	13.019
Max-Temperature	78	-	0.1165	-	-
Groundwater level(P2)	210	2002	< 0.0001	20.670	26.644
Groundwater level(P3)	118	1999	0.031	129.799	142.861
Groundwater level(P6)	165	2007	0.00	36.675	49.740
Groundwater	172	1999	0.00	119.769	151.891

level(P10)					

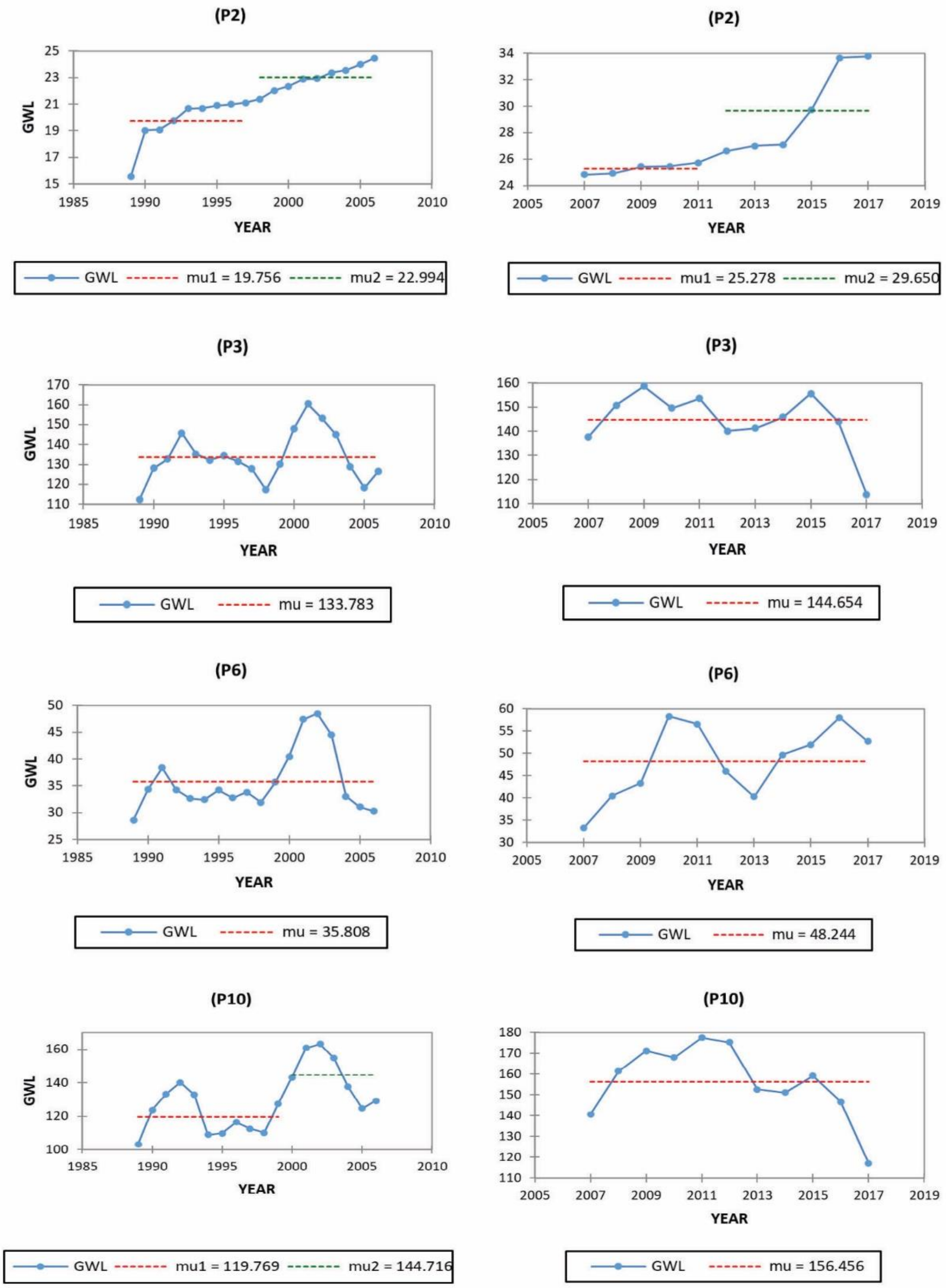

Fig.10 Trend and change point detection, piezometers (P1, P2, P6, P10) before (mu1) and after (mu2)

Site construct

4.1.3. Impact of artificial recharge system according to test results

The results of the recorded statistics of wells before the construction of the artificial charging site showed that, in general, the behavior of piezometric wells to reduce the depth of groundwater indicates the unfavorable condition of the aquifer. But the results of field visits and recorded statistics of piezometric wells and according to the obtained results from the present research showed that the trend of the changes in the regional groundwater level is increasing after building an artificial recharge site. In all piezometers, wells have a positive jump and increased groundwater level even in the years when climate change has occurred.

4.1.4. Suggestion to improve the efficiency results and future research

1- Determining the existence of climate change based on the calculation and Analysis of rainfall-runoff time series, then compare the impact of climate change on groundwater changes in different places.
2- Investigating the impact of climate change on water quality.
3- Investigation of time delays 1 and 2 on the impact of climate change (precipitation-temperature) and runoff on groundwater level and quality.
4- Spatial discussion P1, P2 in cases 1, 2, 3, and study of the impact of atmospheric rivers or ARS in terms of space and time.
5- Finally, using other methods such as Wavelet, etc. in calculations and Analysis.

5.1. Conclusion

The results of the model show that the groundwater level of the piezometer (P2/well) near the Caspian Sea does not affect the groundwater level (P6/well) of the artificial recharge site. The results of the model show that the quality of the piezometer (P2/well) near the Caspian Sea does not affect the quality groundwater well (p6/well) near the artificial recharge site. The overall result is that in this study, wells near the sea do not modify the quantity and quality of wells near the artificial recharge site. Thus they will not be considered in the modeling. However, further studies were needed to address more groundwater characteristics as well as other climate variables and the impact of climate change there. Therefore, in these studies, the effects climate change factors on the decrease and increase of groundwater levels before and after the establishment of an artificial recharge system in the aquifer are studied; the results are as follows. The results of the model show that the climate change factor does not affect the groundwater level after the establishment of an artificial recharge system. Implementing artificial recharge and flood spreading sites in many areas has helped mitigate droughts and even neutralize its Effect in some cases. Studies in areas with flood distribution programs show a trend in usefulness as recorded points and water tables in piezometers and wells are increasing at most stations. The results of the research can be used for evaluation Cost-Benefit Analysis of artificial recharge sites after construction. According to the results of this research, it is necessary to control groundwater exploitation, and the groundwater level will be increased by increasing agricultural water efficiency and artificial recharge.

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Declarations

Availability of data and material
All data generated or analyzed during this study are within the submitted manuscript.
Competing interests
The authors declare they have no competing interests.
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Figures

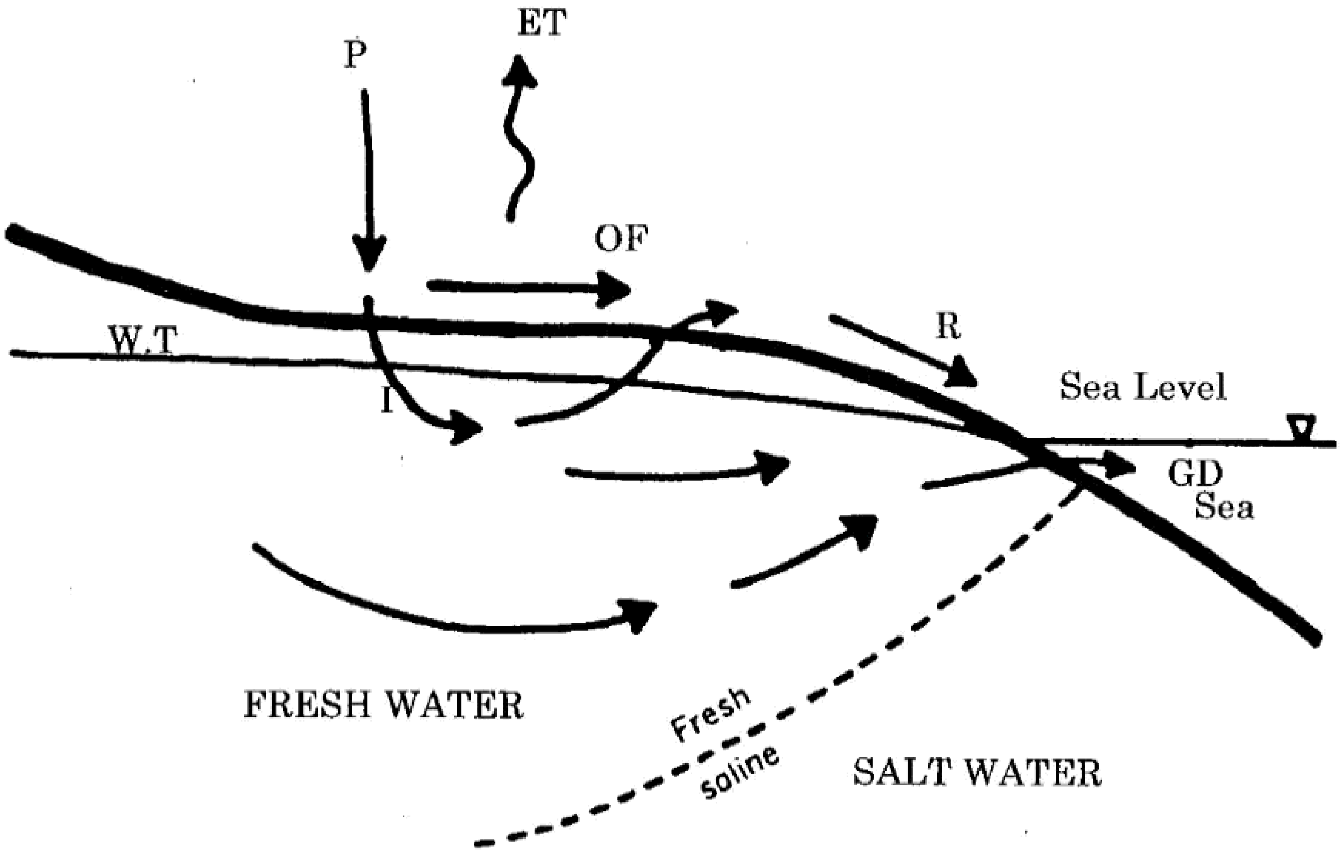

Figure 1

Water balance in coastal watershed [3]

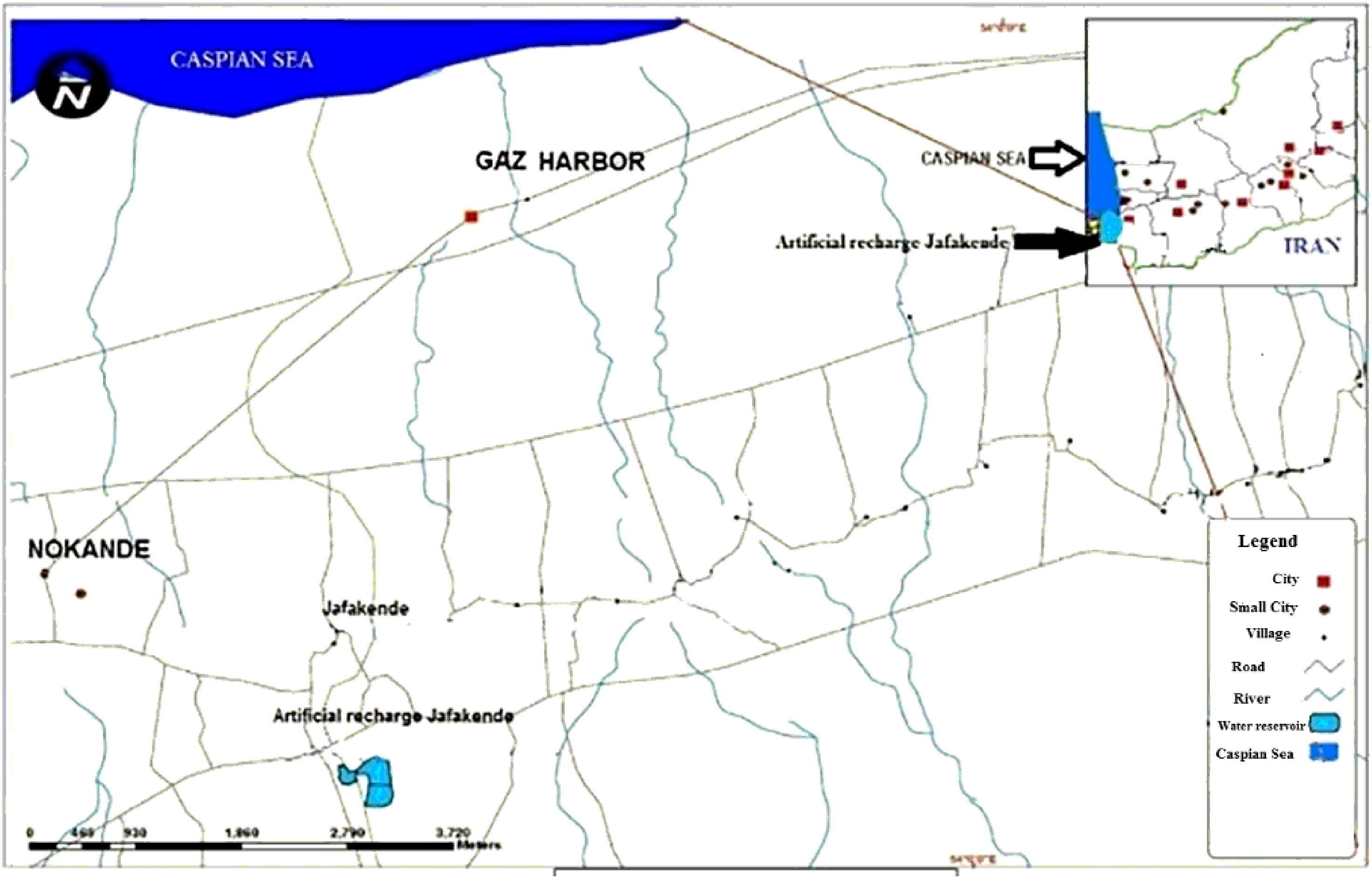

Figure 2

The study area

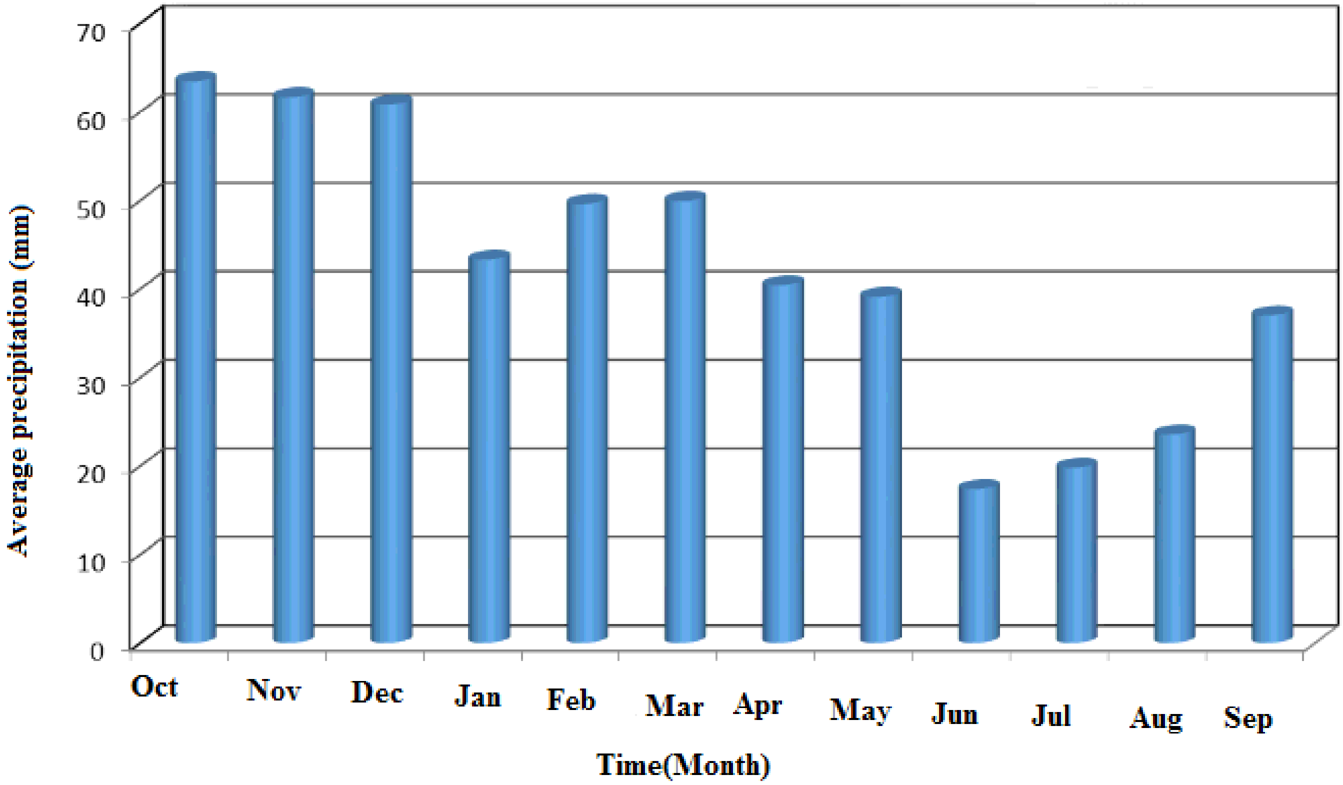

Figure 3

Average monthly precipitation at Jafakende Rain gauge station

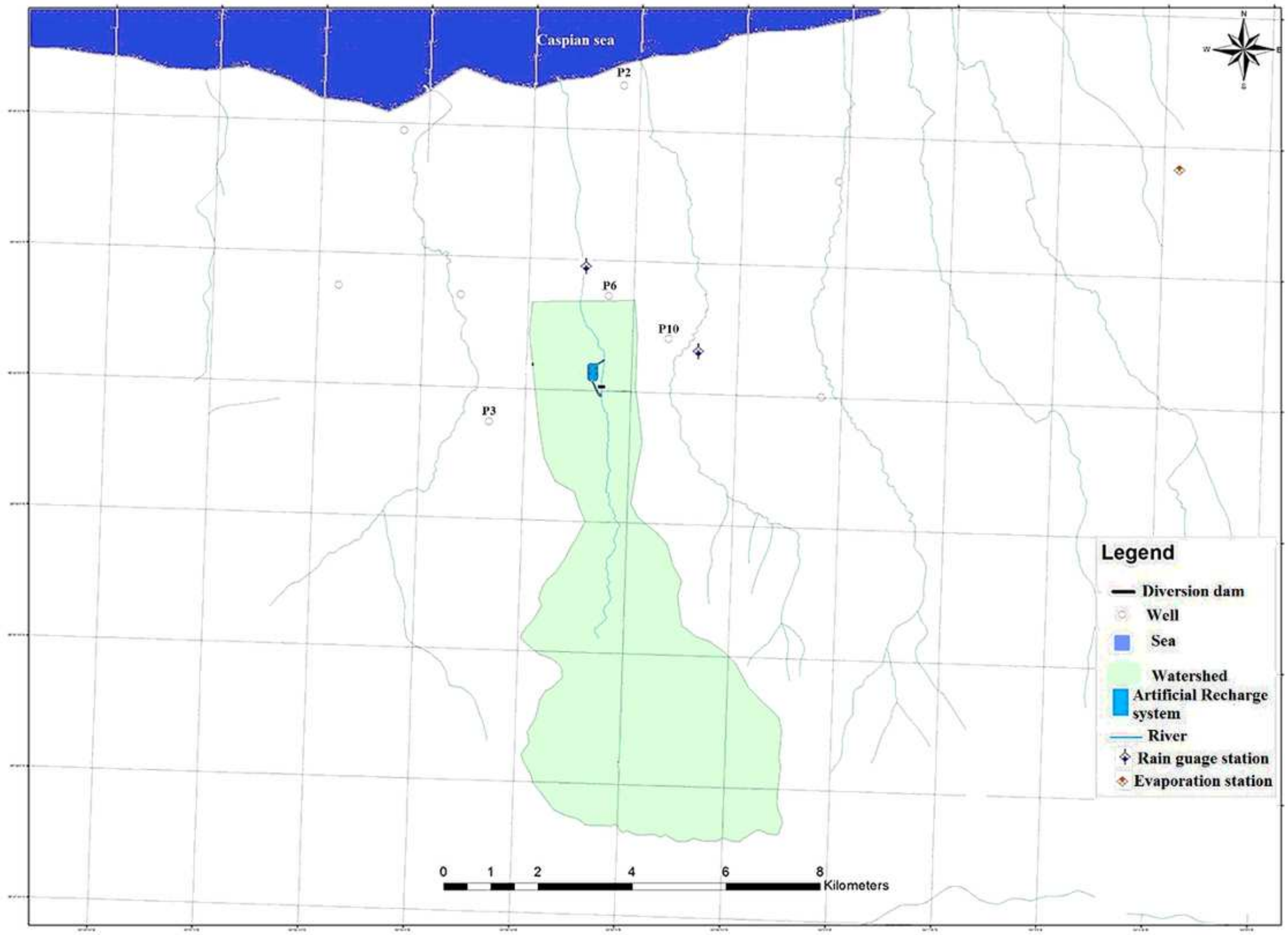

Figure 4

The meteorological stations and piezometer wells in Jafakende watershed

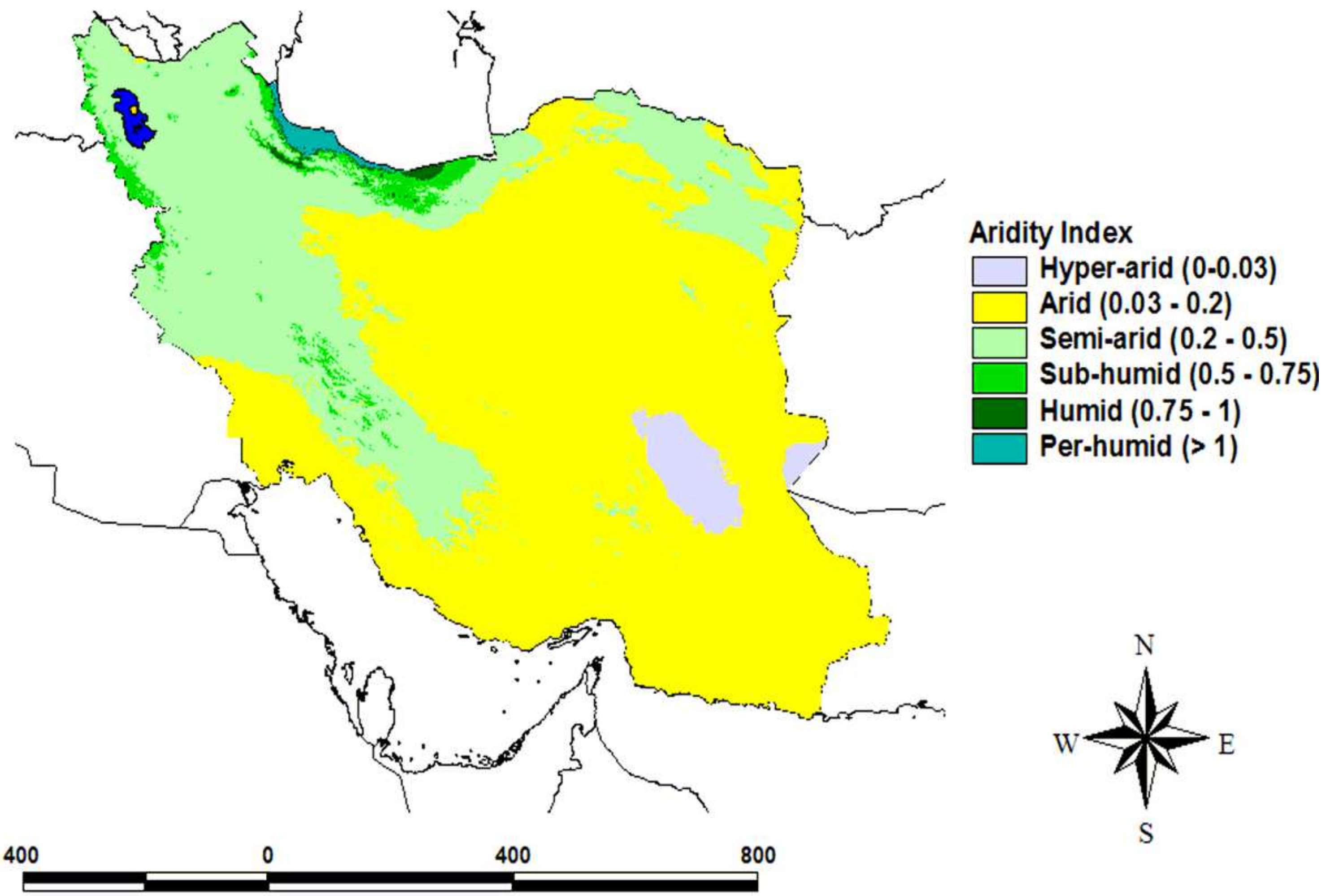

Figure 5

Aridity classes in Iran [11]

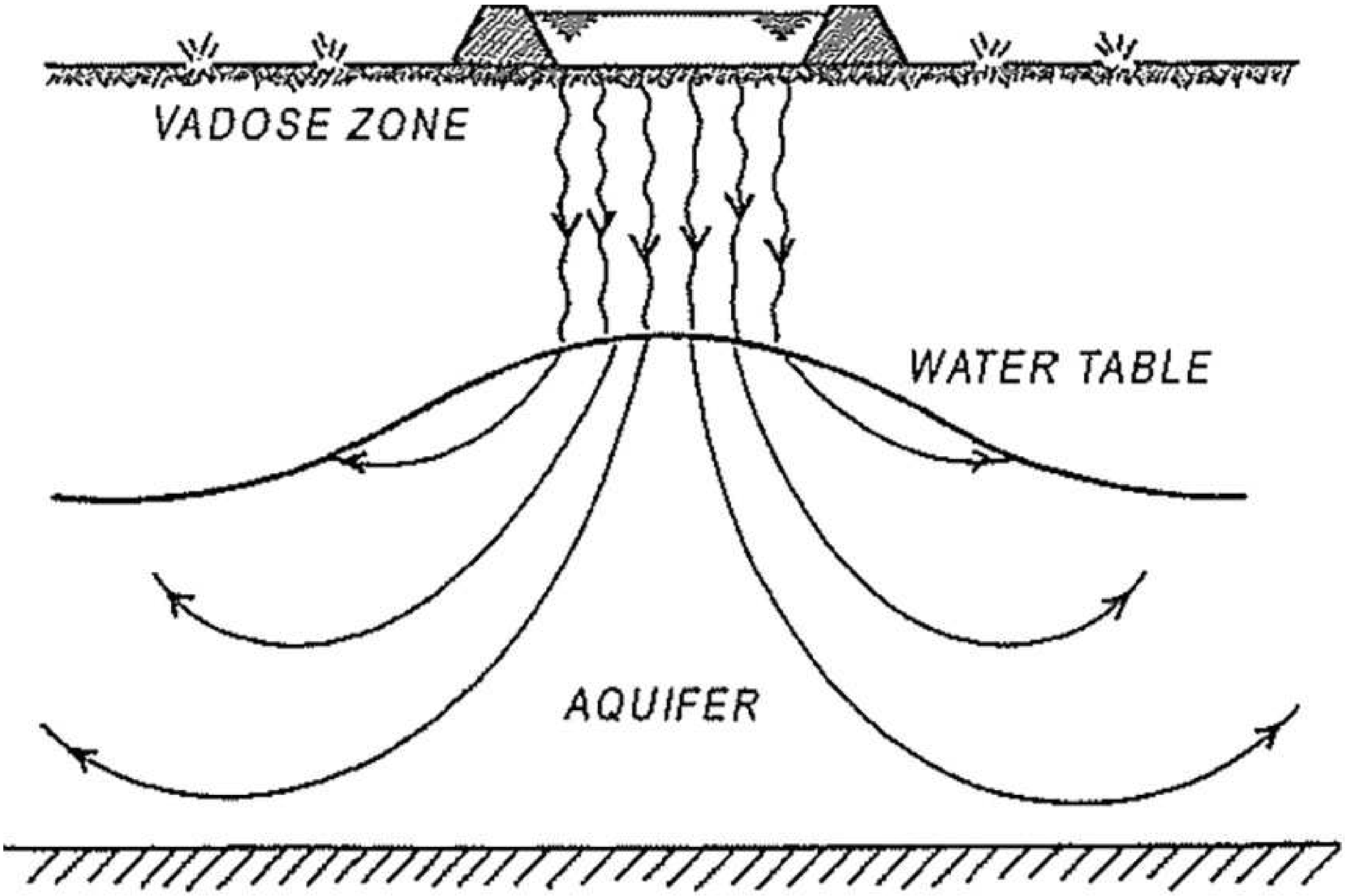

Figure 6

Cross-section view of a typical groundwater recharge system [2]

Figure 7

(a) Flash flood (b) Land subsidence

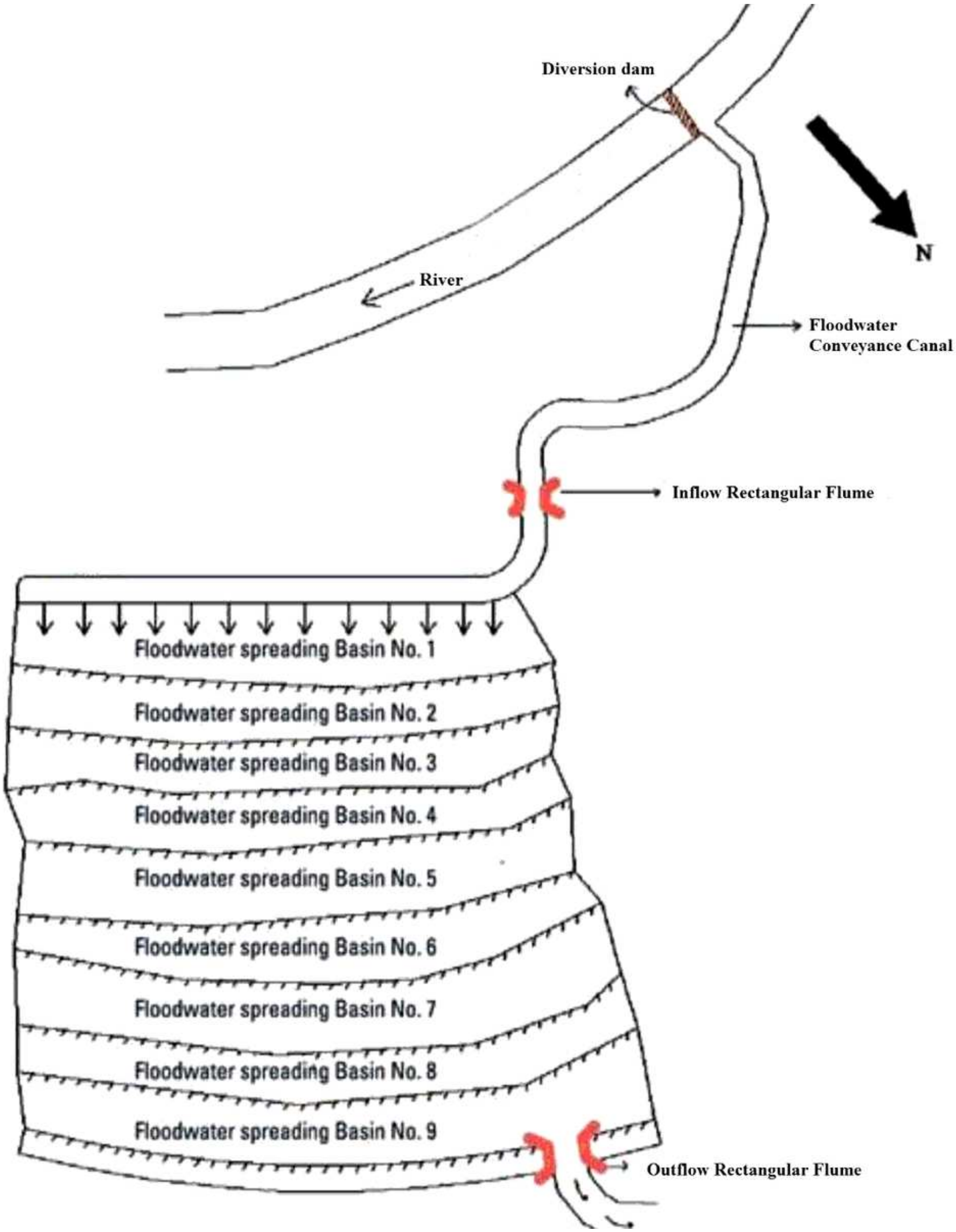

Figure 8

Artificial recharge system

Figure 9

(a) Floodwater spreading system b) diversion dam

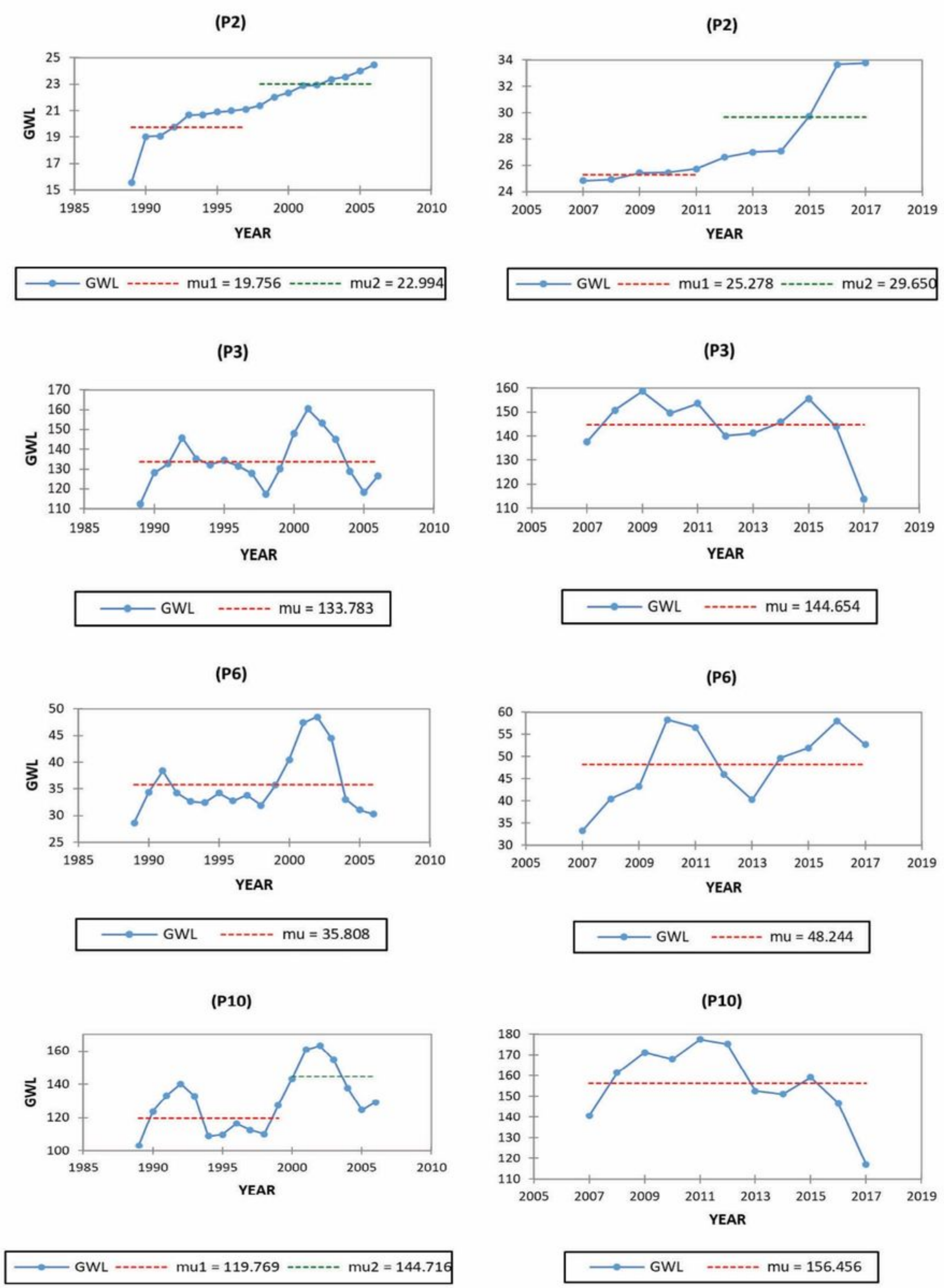

Figure 10

Trend and change point detection, piezometers (P1, P2, P6, P10) before (mu1) and after (mu2) Site construct