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Research Article

The evaluation of artificial recharge performance in a historic flooding in southern Iran

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ABSTRACT- The water crisis is a major challenge for water resources managers in semi-arid regions of Iran. Most of the policies to deal with this crisis have been to contain surface water behind dams. Changing the national approach from dam construction to watershed management is inevitable to conserve groundwater resources in Iran. The effects of flood water spreading (FWS) and artificial recharge of groundwater (ARG) were investigated in a large area in southern Iran during the 151 hours of historic flooding in 2017. The study area was two basins in the Gareh Bygone Plain (GBP) including the Bisheh Zard Basin (192 km^2) and Tchah Qootch Basin (171 km^2). The water budget equation was used to evaluate the inflow and outflow of the flood spreading system. Six installed piezometers in the GBP measured the water recession level. The inflow and outflow were continuously measured by a water-level recorder and five broad-crested weirs, respectively. The soil water content of 30 m depth was recorded by the Time Domain Reflectometry (TDR) sensors. The total volume of water retained by the system on 17 January 2017 was 19,160,951 m^3. Net replenishment of the aquifer was 6,677,301 m^3. The total recharge of the ARG was 8,332,916 m^3 in the study duration. The flood water system retained 70% of the total diverted flow to the system and increased the water level wells in the study area from 1.03 to 2.74 m. Therefore, it can be concluded that FWS and ARG restrained the rare flood event in Iran .Consequently; they can be the logical processes to avoid flood damage and conserve groundwater resources.

INTRODUCTION

Iran has encountered with serious water crisis in recent years because of the mismanagement of water resources. Unsustainable policies ignoring the capacity of our land and water, and the effects of world wars, the Iraq-Iran war, and sanctions have weakened Iran's natural resources.

The total area of coarse-grained and deep alluvium in Iran from which ephemeral rivers flow is about 15 million hectares. Most of the rain-fed farmland (6 million ha) is underlain with deep coarse-grained alluvium, i.e., potential aquifers (Mesbah et al., 2016). Several factors have drastically disturbed groundwater (GW) resources in Iran. Some of these factors reported to be the modernization due to the Agrarian Reform Law in1960s, policies for self-sufficiency in wheat and red meat in the 1980s, and highly subsidized electricity for pumping water for agricultural development in the 1990s, (Rahnemaei et al., 2013). Despite these factors, floodwater spreading (FWS), a simple appropriate technology, which could be practiced on a very large scale, is a solution to achieve a balance between the supply and demand of water resources. The ancient Persians had discovered that their home was the land of flood and drought. They further discovered that evaporation is one of the most reasons for decreasing surface water flow. Therefore, they stored water in potential aquifers tby implementing the FWS activities to deliver it to Qanats (Kowsar, 1991).

The importance of FWS on spate irrigation (SI) and its influence on the artificial recharge of groundwater (ARG) has been studied (Kowsar, 1991; Kowsar, 2005; Kowsar, 2008; Hashemi et al., 2012; Hashemi et al., 2014; Ghahari et al., 2014; Mesbah et al., 2016; Pakparvar et al., 2016; Pakparvar et al., 2018). Politicians prefer dams to ARG because of the invisibility of the ARG's final effects. It would take years to monitor historic flooding to prove the merits of FWS, particularly for the ARG.

The infiltration rate and its trend in recharge basins have been assessed by numerous methods such as using pressure sensors, single-ring infiltrometers, soil moisture sensors, and observation (Ganot et al., 2017). Another technique is measuring soil moisture dynamic parameters instead of the tracer technic that provides in situ estimates of the soil infiltration rate (Barquero et al., 2019). The potential of recharge has been studied in a river catchment based on the lysimeter infiltration monitoring, monitoring of GW drainage by a gallery, river discharge hydrograph, and GW fluctuation (Stako et al., 2012). The spatial and temporal distribution of recharge has been assessed using the BALSEQ model to obtain daily sequential estimates of water balance in Brazil (Souza et al., 2019).

During the exceptional flooding of 12 to 19 February 2017 at the Kowsar station (Floodwater Spreading and Aquifer Management Research, Training and Extension Station) a rare opportunity was provided to measure the inflow and outflow of the FWS systems in the Gareh Bygone Plain (GBP), a desert in southern Iran. The general aim of this study was to mobilize the general public to demand better water management from the government. The specific objectives were to provide a balance sheet for a historic floodwater harvesting event and evaluate the effects of FWS and ARG.

MATERIALS AND METHODS

Study site

The Study Area, Gareh Bygone Plain is located in southern Iran, 200 km southeast of Shiraz at 28° 35′ N, 53° 53′ E, 1140 m above mean sea level with the arid climate condition. (Fig. 1). The Agha-Jari is the major formation in the study region. The GBA is a small part of the main aquifer named Shib-Kooh Aquifer (SKA). According to the iso-potential groundwater map of SKA, the groundwater flow trend in the entire GBA is mainly from north to south and southwest. Two basins contribute floodwater to the ARG systems including the Bisheh Zard Basin (BZ) with an area of 192 km^2, and the Tchah Qootch Basin with an area of 171 km^2. The runoffs of the two basins are spread on 1591 and 441 ha, respectively. There is not any hydrometric station in the Tchah Qootch basin. The visual surveys during FWS events since December 1984, have assured us that the Tchah Qootch ARG systems receive almost the same floodwater as the Bisheh Zard systems. Therefore, about 27% of Bisheh Zard ARG systems are assigned to the Tchah Qootch ARG system.

Six piezometers (Ps) have been installed in the GBP from 1988 to 2009 (Fig. 2). P1 and P4 were located in the out, P2, P5, and P6 in the middle, and P3 immediately downstream of the ARG systems, respectively. Observation wells 5 and 6 were installed in 2005 to study the water recession level from 2005 to 2018 (Fig. 2).

Measurements

The inflow was continuously measured by a water-level recorder installed upstream of the inundation canals. The outflow was measured intermittently (usually on a 2-hour basis) at five broad-crested weirs, which drained the surcharge of the ARG systems (Fig. 3). Water table level was monitored in six piezometers by water level sensors. Soil water content was recorded to a depth of 30 m by the TDR sensors installed in the wells. The subsurface outflow was estimated based on Hashemi et al. (2012).

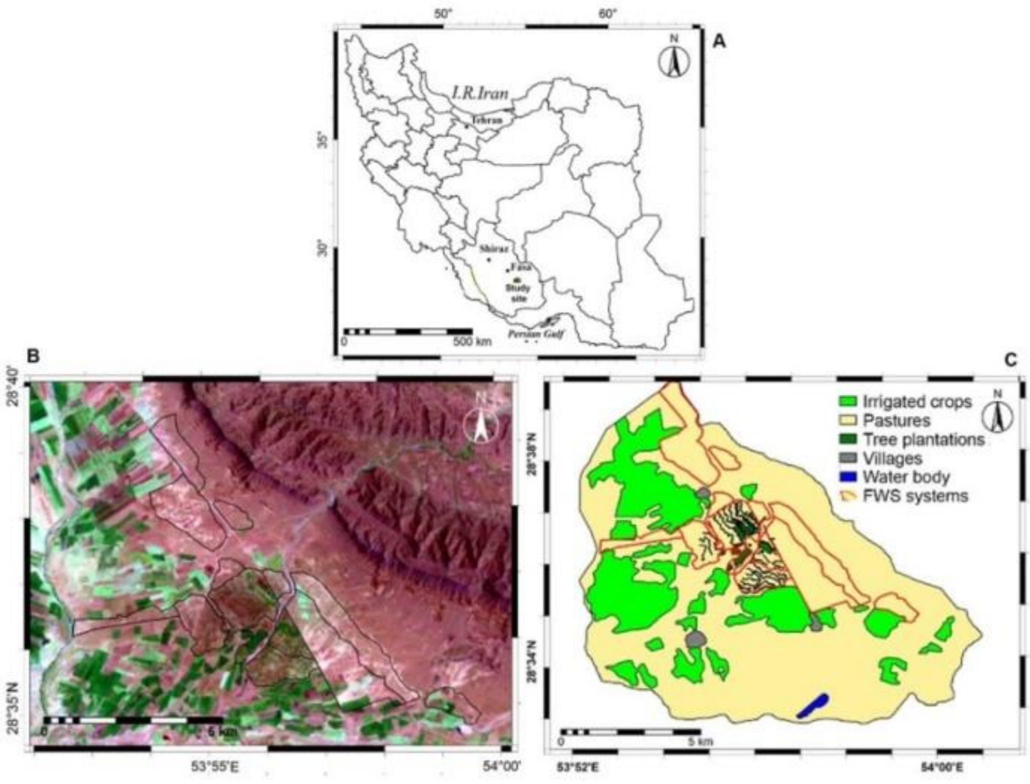

Fig. 1. Location of the study site in Iran (A), the landscape of the Gareh Bygone Plain with location of the floodwater spreading (FWS) project (RGB$_{742}$ Landsat TM5) (B), simplified map of main land uses (C). The scale bar is accurate for maps B and C. Map A is modified based on a published map on the internet (retrieved from Pakparvar, 2015).

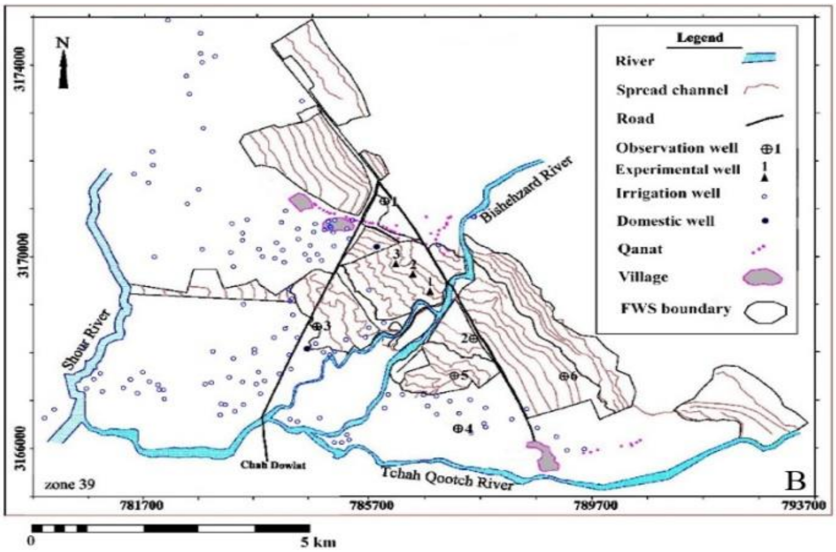

Fig. 2. Detailed map of the floodwater spreading (FWS) systems, observation wells, experimental wells, and distribution of some of the important operational wells in the Gareh Bygone Plain. Observation wells 2, 4, 5, and 6 are located inside and the others are outside the FWS systems (retrieved from Pakparvar et al., 2016).

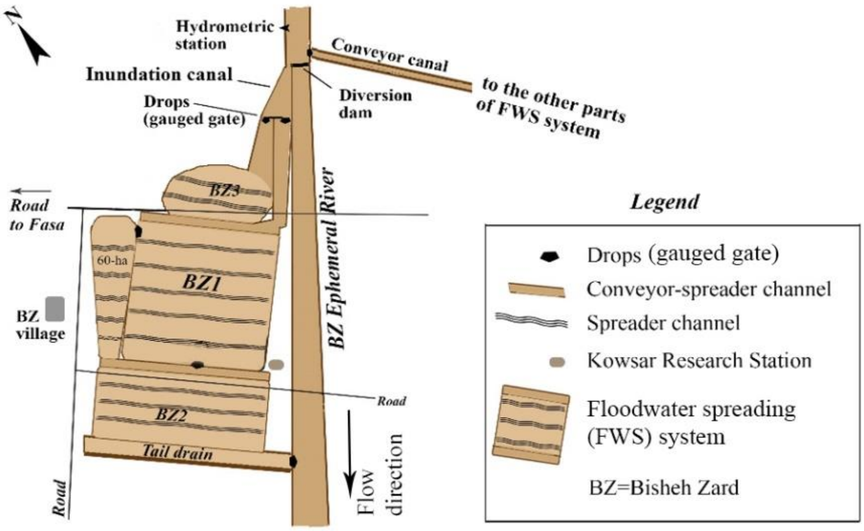

Fig. 3. Schematic map of Bisheh Zard BZ1, BZ2 and BZ3 floodwater spreading (FWS) systems and location of gauged gates for flow measurements. Dimensions are not to scale (retrieved from Pakparvar, 2015).

By measuring the inflows, the volumes of floodwater which were gathered by the Bisheh Zard (BZ) 1 to BZ 3 (local names for every individual FWS system) were calculated for all floods (Fig. 3). This was the typical measurement of the FWS systems. Similarly, the incoming and departure flow-rate of the FWS systems was determined in the study area. Hence, the volume of retained water in the individual FWS systems and the entire project was calculated. To avoid mentioning unnecessary particulars, the other parts of the FWS systems are not described at this point.

The operation of the floodwater spreading system

An archetypal FWS system is drowned in Fig. 4 to exemplify its important constituents (Pakparvar, 2015). The system begins with a diversion dam which is width wisely built on a bed of a river (normally an ephemeral stream) with a spillway to steer a pre-defined part of the flow to an inlet opening. Diverted water sequentially, goes to the beginning of the FWS system via a conveyor canal. This canal performs concurrently a role as a sedimentation sink so it is called an inundation canal. The floodwater without sediment subsequently arrives at the conveyor-spreader waterway. This transfer water to the top of the spreading area distributes onto the whole basin steadily to the downslope bank. The weirs alongside the banks, facilitate the arrival of water into the further channel, called the level-silled channel, which acts as spreader sinks. This process is repeated in several successive basins and channels until reaching to a canal called a tail drain which diverts the excess water to the main river (Fig. 4). More details of the system can be found in Mesbah et al. (2016) and Pakparvar (2015).

Water Budget in the Saturated Zone

There are several approaches to quantifying surface and groundwater recharge. Scanlon et al. (2002) considered three techniques in the unsaturated zone, saturated zone and surface water to determine recharge. The techniques of saturated zone measurements are subdivided into Darcy’s law, tracing, numerical modeling, water table fluctuation (WTF), and water budget methods. As illustrated in Fig. 5, the change in GW storage, ΔS, is the main concept of the saturated zone water budget.

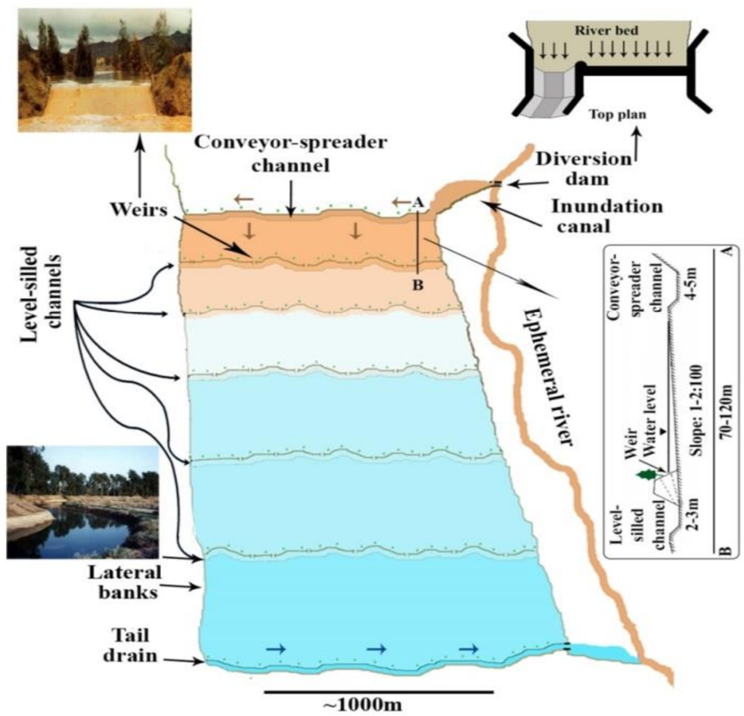

Fig. 4. Generalized diagram of atypical floodwater spreading system. The scales are approximate (retrieved from Pakparvar, 2015)

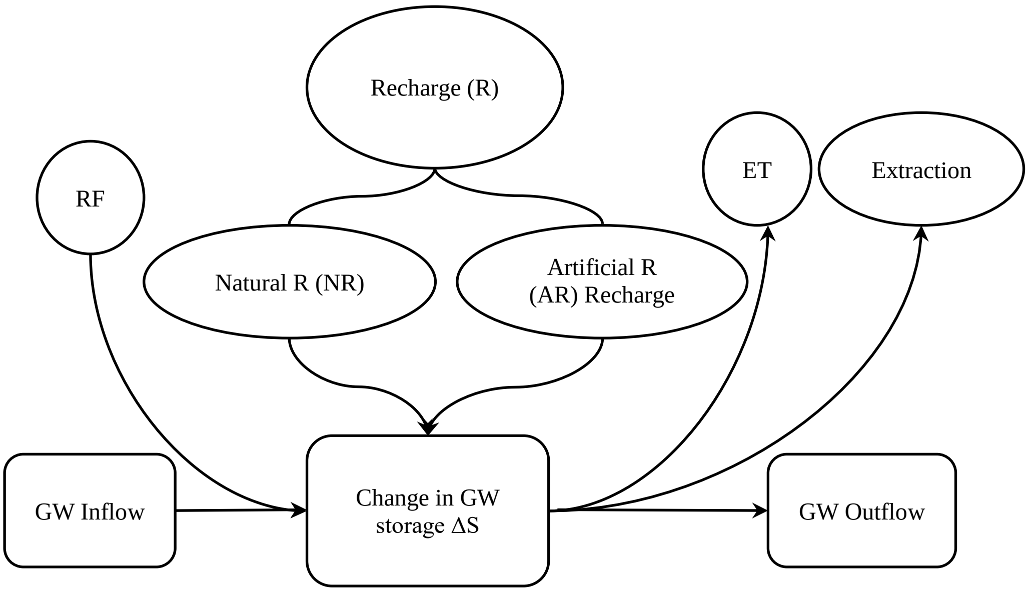

Fig. 5. The schematic of the water budget for the saturated zone. Extraction is any type of direct withdrawal of groundwater; e.g. pumping. ET is evapotranspiration and RF is agricultural return flow (retrieved from Pakparvar 2015).

A general budget equation for the saturated zone (Hoque et al., 2007) is shown as Equation (Eq.) 1.

$$\Delta S = NR + AR + RF + Q_{in}^{gw} - Q_{out}^{gw} - ET^{gw} - E$$ Eq. (1)

where ΔS is the change in GW storage (or change in saturated pore volume), NR and AR are the natural and artificial recharge of GW, respectively, RF is the agricultural return flow, Q_{in}^{gw} and Q_{out}^{gw} are subsurface inflow and outflow, respectively, E is the extraction from the aquifer and ET^{gw} is the evapotranspiration from the GW. ET^{gw} can be neglected as the deep water tables in arid regions do not allow direct ET from the aquifer unless deep roots take up the water from the GW table. Natural recharge pertains to diffusion from upland and water infiltration in river beds whereas artificial recharge is influenced by an engineered structure to generate or intensify the recharge of GW.

By knowing ΔS, the specific yield can be determined as Eq. 2 (Scanlon et al., 2002)

$$S_y = \frac{\Delta S}{\Delta h}\Delta t$$ Eq. (2)

where S_y is the specific yield, h is the water-table height, and t is the time (Scanlon et al., 2002). Recharge can be natural or artificial. Natural recharge pertains to diffusion from upland and adjacent aquifers and water infiltration in river beds, whilst artificial recharge is that influenced by an engineered structure to generate or intensify the recharge of GW. The budget equation (Eq. 1) was used from 18 February to 21 April 2017 when the measurable vadose zone drainage was terminated.

Natural Recharge of the River

The Bisheh Zard ephemeral river is separated into two branches at a junction and the FWS systems are surrounded by these two branches. The geometry of the branches including the length and width were measured by drawing the river vector based on visual interpretation on a Google Earth screen. The time of inundation of each branch was recorded during the events. Then the recharge of the river was measured using inundation time, river geometry, and hydraulic conductivity of the river bed.

The river bed and its banks are strewn with coarse-grained alluvium (very high infiltration rate). However, the settlement of some suspended load onto the inundated area substantially decreases the infiltration rate (IR). The instantaneous infiltration rate (q) was determined as Eq. 3 (Bouwer, 1986).

$$q = q_0 - (v\varphi \propto I)$$ Eq. (3)

where, q_0 is the initial infiltration rate (m Day^{-1}), v is the sediment concentration (g l^{-1}), φ is the fraction of retained suspended mater, I is the cumulative height infiltrated water, and $\propto$ is the clogging coefficient that was determined by Eq. 4.

$$\propto = 0.32 \times (q_0^{0.48} \times (v\varphi)^{-0.26})$$ Eq. (4)

The Philip equation (Eq. 5) was applied to calculate vertical infiltration (Bouwer, 1986) as below.

$$I_t = S_i t^{0.5} + At$$ Eq. (5)

where I_t is the cumulative infiltration, t is the cumulative time, S_i is the Sorptivity coefficient and A is a factor related to the soil permeability. Unidentified parameters A and S_i were estimated by using the least squares method. The derivative of Eq. (6) was employed as Eq (6) to calculate i, the infiltration rate, for any given time:

$$i = 0.5\, S_i t^{-0.5} + A$$ (1) Eq. (6)

The river recharge of the Bishe Zard branches was determined using the cumulative infiltrated water to the aquifer.

$$R_r = K_{fs} tA/24$$ Eq. (7)

where R_r is river recharge (m^3), t is the inundation time (hr), and A is the riverbed size of the area (m^2).

The field saturated hydraulic conductivity (K_{fs}) was determined by Wooding's equation (Radcliffe and Ŝimùnek, 2010) as below.

$$K_{fs} = i_s/[1 + \left(\frac{4\lambda_c}{\pi r}\right)]$$ Eq. (8)

where i_s is the steady state infiltration rate, r is the radius of the ring, and λ_c is the microscopic capillary length. The λ_c was assigned to the river bed material based on the tabular guidelines presented by Elrick and Reynolds (1992).

Effective rainfall and aquifer recharge

Effective precipitation (P_{eff}) was calculated as proposed by Ali (2017) for the rainfall amount equal to or more than 250 mm as Eq. (9).

$$P_{eff} = 125 \text{ mm} + 0.1P \text{ for } P \geq 250 \text{ mm}$$ Eq. (9)

The aquifer recharge as induced by direct rainfall (R_p) was calculated as Eq. (10).

$$R_p = P_{eff} A$$ Eq. (10)

RESULTS AND DISCUSSION

The temporal trend of rainfall, groundwater hydrograph, and number of wells in the region are given in Fig 6. The generalized hydrograph shows an increase in water level from 1993 to 1997, a steep decrease from 1997 to 2004, and a gradual decrease from 2005 to 2012. The difference between the initial and final GW levels was about 6 m. The annual trend of rainfall during the study period revealed some irregularity, though a general declining trend can be perceived. As inferred from Fig. 6, the number of irrigation wells started to increase from the beginning of construction of the FWS systems in 1983, but an expedited increase is shown from 1989 to 1994 (72 wells in 5 years). The number of wells continued to increase until 2005, after which it remained stable up to 2012. The recession trend in GW from 1997 to 2004 coincided with recurrent droughts and an increase in the number of irrigation wells. The increase in the amount of annual rainfall from 2000 to 2005 slowed down the rate of decrease in water level. The recent drought from 2005 to 2012 increased the rate of drop in water level again.

The decreasing trend in the GW level cannot be statistically described to the temporal trend of rainfall. However, the timely influence of rainy years on the GW hydrograph can be implied. For instance, the increase in GW level during the period 1993–1997 was concurrent with large storms in 1993 and 1995. A drought period from 1996 to 2000 coincided with a severe recession in the GW level as described by Pakparvar et al. (2017) and Ghahari & Mesbah (2018).

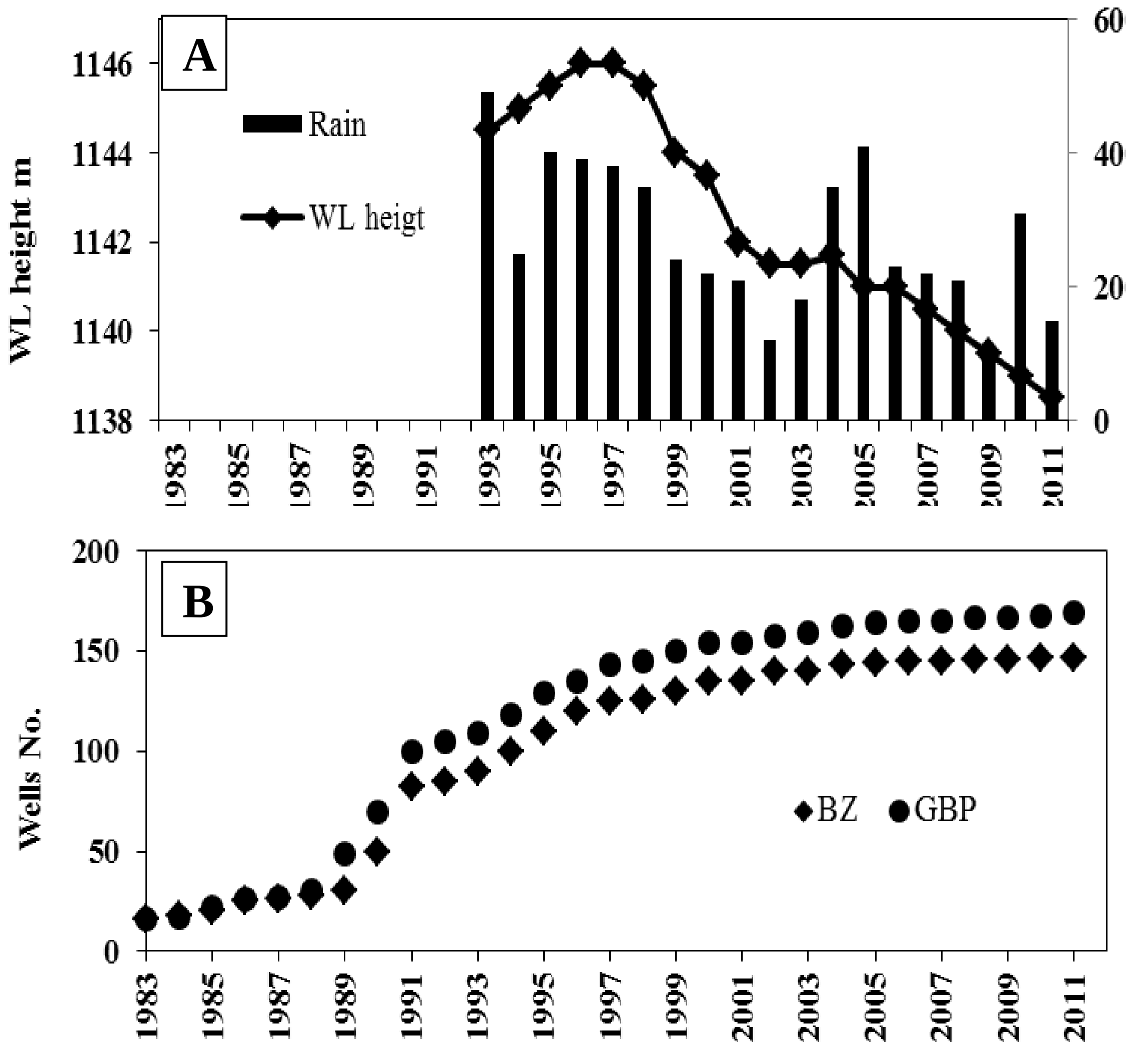

Fig. 6. Temporal trend of rainfall, and groundwater hydrograph (A). The number of wells in the region (B). GBP is the whole Gareh Bygone Plain. BZ is the Bisheh Zard aquifer. WL is groundwater level height.

Historic Flooding Evaluation

A two-week-old front arrived in Iran on 31 January 2017. It was so cold that the thermometer registered the unheard-of 5 °C at Bandar Abbas, one of the hottest places around the Persian Gulf. A few days before the unprecedented rainfall, the Madden-Julian Oscillation (MJO) was very strong in phases 7 and 8. A very humid and warm front advanced from southeast above the Oman Sea, which covered the southwestern region of Iran, and to a lower degree a front originated on the northern Indian Ocean and converged on the southern and central part of the country. Simultaneously, another front, which had originated in the Atlantic Ocean and the Mediterranean Sea advanced towards northwest of the Iran and the western part of the Persian Gulf. The combination of high humidity and low pressure led to the inundation of southwestern Iran for 6 days.

The Kowsar Station received rainfall of 265 mm, which surpassed its 20-year mean annual precipitation by 222 mm. The maximum flow i.e. 330.8 m^3s^{-1} was recorded at 16:30 on 18 February for the Bisheh Zard River. The highest determined flow in the 35 years of the life of the Station had been 300 m^3s^{-1} that had occurred on 3 December 1986. It is interesting to note that while the maximum flow depth and velocity at the gauging station were 176.0 cm and 3.0 m s^{-1}, respectively, the mean flow discharge from the floodwater spreading channels was 8.0 cm with a mean velocity of 2.0 ms^{-1}. The erosive power of such flow at the ARG systems was practically near zero. The daily values of rainfall and flow rate in the event are shown in Fig. 7. The flood water hydrograph from 12 to 19 Feb. 2017 in cumulative time is given in Fig. 8. Pakparvar et al. (2018) used a water balance equation and modeling approaches in a multi-layered vadose zone. The soil water balance was calculated for the top 4.0 m of layers after the flooding event on 16 January to 23 July 2011 in the study area. The maximum flow depth at the gauging station was 145.0 cm for that particular event.

Fig. 9 shows the hydrographs of the six wells (W1, OW1, OW3, OW4, OW5, and OW6) before the event to five months after it (from 28 Dec. 2016 to 30 July 2017) in the GBP. During this period, the water level increased due to the artificial recharge. In this period, a greater increase in GW level was observed relative to the previous period 1997 to 2004 as reported by Ghahari & Mesbah (2018). FWS increased the water level in amount of 1.03 and 2.74 m in OW5 and W1, respectively.

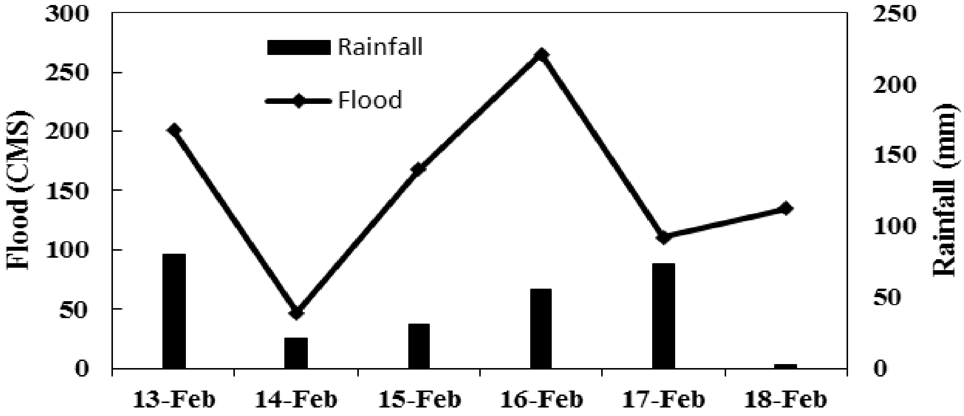

Fig. 7. The values of rainfall and flow rate from 12 to 19 February 2017 in Gareh Bygone Plain

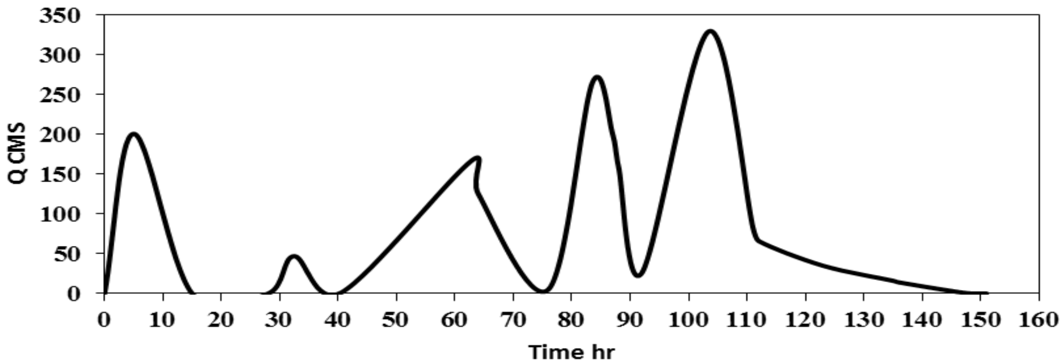

Fig. 8. Flood hydrograph from 12 February 2017 (Time = 0 hr) to 18 February 2017 (Time = 150 hr) in Gareh Bygone Plain.

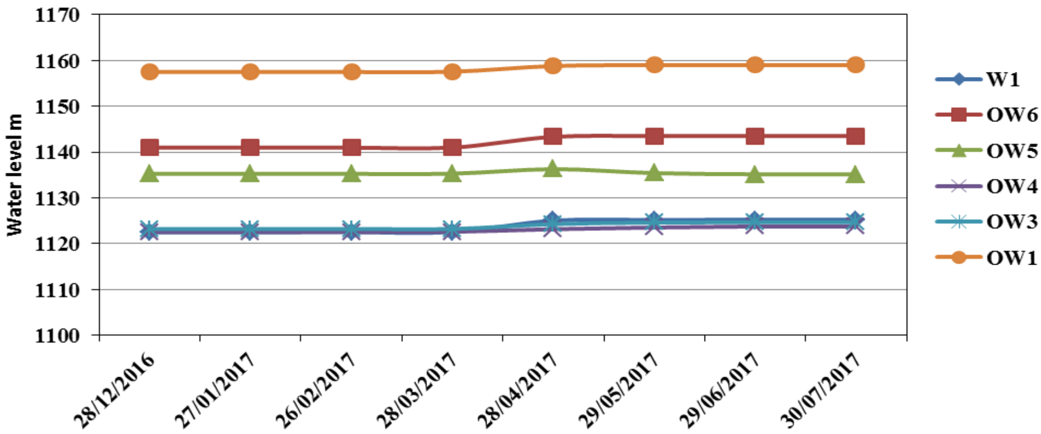

Fig. 9. Water level changes in the wells from 28 Dec. 2016 to 30 July 2017 in the GBP.

This amount of increase for the OW1 well, which was located in the upper parts of the FWS, was equal to 1.26 meters (according to Fig. 9 from 1157.55 to 1158.81 m). According to Hashemi (2014), it can be stated that the fault that starts from Koghar Mountain and continues along this well, can be the reason for the feeding of this part of the aquifer, and the increase of the water table in this area. This is while the drinking water well of the station i.e. W1 showed an increase of 2.74 m (according to Fig. 9 from 1122.30 to 1125.04 m). OW3 well, despite being at the end of flood distribution and being affected by all systems, increased by 1.07 m (according to Fig. 9 from1123.22 to1124.29 m). This was also true for OW4 well. The reason for the low increase in the water level of these wells can be stated due to the location of the aforementioned wells in the agricultural area of the region and the existence of exploitation wells around them. OW5 well showed an increase in the water level of 1.03 m (according to Fig. 9 from 1135.25 to 1136.28 m) despite being inside the flood distribution networks. The reason for the low increase in this area could be attributed to its location in the range of pasture and forest with dense bush and tree cover (Ghahari & Mesbah, 2018).

Natural Recharge

Considering the q_0 as 2.5 (Pakparvar, 2015) for the identical material to the river bed, v as 8.1 g l^{-1} as averaged measured data of 4 floodwater samples, φ as 0.2 and I as 2.25 as measured previously (unpublished data), the adjusted hydraulic conductivity was calculated. Using Eq. (7), the volume of water obtained from the infiltration rate into the left and right branches of the Bisheh Zard river (K_{fs}=0.917) is shown in Table 1.

Artificial Recharge

The inflow to the Bisheh Zard ARG systems (with an aquifer area of 32,326,913 m^2) consisted of effective rainfall (Smith, 1992), infiltration into the river bed and its banks (Berend, 1967), and the floodwater diverted into the systems. The system output consisted of evapotranspiration (ET) of the flood-irrigated in 1140 ha of afforested plots and rangeland, ET of 205 ha of irrigated wheat and barley, the residual water in the vadose zone, the surcharge of the ARG systems drained into the Bisheh Zard River, the rise in the water table level and the subsurface flow out of the aquifer towards the Shour River of Jahrom.

From 21 March 2017 to 21 April 2017 wheat and barley were cultivated in 150 and 50 ha, respectively. An irrigated barley plot with an area of 5 ha, was assumed as a representative to estimate the volume of pumped water from the fields. The representative field was irrigated with 11 l s^{-1} every seven days. The area of 50 ha of barley and 150 ha of wheat received 73,183 (one irrigation) and 399,180 m^3 irrigation water (two irrigation), respectively. According to Pakparvar (2015), 16.3 % of the retained water is consumed by the trees and the improved rangeland.

The effective radius, thickness, and infiltration rate of the aquifer were 15,216 m, 0.5 m, and 0.005 mm d^{-1}, respectively. Based on these values, the subsurface flow towards the Shour River of Jahrom was determined.

The retained water in the vadose zone was 48.9% of total water which was calculated as 9,362,737 m^3 which was 25.8 cm on the aquifer (Pakparvar, 2015). ARG system increased the volume and depth of the aquifer by 6,677,301 m3 and 31.4 cm, respectively. The results of artificial recharge in the ARG system are shown in Table 2.

Pakparvar et al. (2017) reported a total volume of 6,920,000 m^3 of diverted flood water in the BZ in the event of 28 January to 2 February 2011. In this period, FWS retained the volume of 4,840,000 m^3 flood water. These events ponded the entire FWS systems of 2,033 ha and resulted in an average depth of 0.34 m on the FWS surface. The ratio of artificial recharge to the depth of ponded water (0.24 and 0.34, respectively) was 0.7. Similarly, during the current study, the artificial recharge and depth of ponded water were 0.52 and 0.74, respectively, and the ratio was 0.7. Hendrickx et al. (1991) reported similar values (0.6 to 0.8) for an alluvial stony fan resembling the GBP study site.

Of the 34.64 cm extracted water from the aquifer, 0.24 cm and 25.8 cm was estimated as the irrigation withdrawal and retaining in the vadose zone, respectively, which was assumed to return to the aquifer. The return flow was 24.8% of the irrigation-applied water. This percentage is close to the values reported for the main crops in the dry states of the USA (15–55%; average 24%) (Sabol et al. 1987). The value of 24% has been also reported by Jafari et al. (2012) for a similar environment and management settings to the current study area. There is uncertainty about the specific time when the return flow reaches the GW. However, the continuation of farming activities in successive years guarantees a permanent irrigation return volume of what is calculated for a particular year (Pakparvar et al., 2017).

Table 1. Natural recharge of the Bisheh Zard river in the flood event

	Left branch	Right branch	Total
Recharge m^3	1,273,617	353,781	1,627,398

Table 2. The values of retained water by the artificial recharge in the study area.

	Volume m^3	Depth cm
Diverted flood water	20,035,114	74.1
Surcharged flood water	5,755,527	21.3
Retained flood water	14,279,587	52.8
Effective rainfall	4,881,364	15.1
Total retained flood	19,160,951	70.8
Irrigation water withdrawal	472,363	0.24
Trees consumption	3,120,912	8.6
Retained water in the vadose zone	9,362,737	25.8

Outflow, Subsurface Flow Towards the Shour River of Jahrom

The effective radius, thickness, and infiltration rate of the aquifer were 15,216 m, 0.5 m, and 0.005 mm d-1, respectively. Based on these values, the subsurface flow towards the Shour River of Jahrom was determined to be 27,769 m-3 in 73 days of the study period. The total recharge was calculated to be 8,332,916 m3. There was an anomaly in the amount of rainfall and the volume of the flood, in that the extent of rainfall and its subsurface flow. Some higher rainfall resulted in a lower volume of subsurface flow. The reason for this diversity was the disparity in the location of rainfall. When the rainfall covered both the high land basins as well as the GBP, maximum runoff occurred and the volume of the resulting flood flow was relatively high. In contrast, when the rainfall was limited to within the plain, the resulting flow in the ephemeral rivers was not enough to produce extreme flooding. The season of flood occurrence was the other source of variation. In the summertime, when the soil surface is barren due to drought, runoff is much higher than in the winter. It has been reported that in spite of the low rainfall during the study period, numerous flooding events occurred and the FWS systems were operating (Pakparvar et al., 2017; Kowsar, 2005).

In Iran, there are 647 dams built, 146 under construction, and 537 dams under the different study phases. Changing the national approach from dam construction to watershed management is inevitable to conserve groundwater resources in Iran. A way to increase scarce water resources in arid and semiarid areas is to use artificial recharge of surface water to the groundwater. Artificial recharge of groundwater as the supply supporter is the first ring in a long chain of groundwater management. Due to very small freshwater resources in the Gareh Bygone Plain, a floodwater spreading system has been established since 1983. The system improved groundwater quantity and quality. After 40 years of operation, there has been getting an evaluation of the function of the recharge system or aquifer characteristics. The Kowsar Station in GBP was in a unique position in Iran to report a successful water harvesting event from a historic deluge (Hashemi et al. 2012; Pakparvar et al., 2015; Pakparvar et al. 2017).

Flooding is considered the number one disaster in the world. It surpasses even earthquakes in causing damage and casualties. Flood water spreading and artificial recharge of groundwater contained the rare flood event in Iran. The same event caused damage to 2500 hectares of gardens and agricultural land in a suburb of the City of Jahrom, 60 km to the west of the study area. The financial damage was estimated to be 25 million US dollars in these lands (Jahrom governorate news report, 2018, unpublished information). Fortunately, the implemented evacuation activities prevented any loss of life. This event in GBP proved that Flood Water Spreading (FWS) is a logical process to avoid flood damages and conserve groundwater resources.

CONCLUSIONS

The flooding of February 2017 offered the lifetime opportunity in securing solid pieces of evidence that FWS, particularly for ARG, is a logical alternative solution to prevent water resources from decreasing in Iran. There were no accurate measurements in a similar event in December 1986, because of the lacking tools to monitor the water level, inflow, and outflow (Hashemi et al., 2012; Hashemi et al., 2014). However, in the present study it was found that at the maximum flow, 330.8 m3s-1 water entered five ARG systems with a total area of 1140 ha, and 92.8 m3s-1 water drained from the five crested weirs; thus 290.1 l s-1 ha-1 water was retained by the systems. The mean infiltration rate of systems at the maximum flow rate was 104.4 mm hr-1. During the 151 hours of the flooding, 14,279,587 m3 of floodwater diverted from the Bisheh Zard was retained by 5 ARG systems. The total retained water was 17,834,075 m3 in 1765 ha of GBP. The contribution of natural and artificial recharge groundwater from total retained water was 0.08 and 71%, respectively. The contribution results of NR, AR, and extraction were close to similar studies (Sabol et al., 1987; Jafari et al., 2012; Hashemi et al., 2012; Pakparvar et al., 2017). FWS increased the water level wells in the study area from 1.03 to 2.74 m.

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مقاله علمی- پژوهشی

ارزیابی عملکرد تغذیه مصنوعی در یک سیل تاریخی در جنوب ایران

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دشت گره بایگان

چکیده -بحران آب چالش بزرگی برای مدیران منابع آب در مناطق نیمه خشک ایران است. بیشتر سیاست‌ها برای مقابله با این بحران، مهار آب‌های سطحی پشت سدها بوده است. تغییر رویکرد ملی از سدسازی به آبخیزداری برای حفظ منابع آب‌های زیرزمینی ایران اجتناب ناپذیر است. تأثیر پخش سیلاب و تغذیه مصنوعی آب‌های زیرزمینی در منطقه وسیعی در جنوب ایران طی ۱۵۱ ساعت سیل تاریخی در سال ۱۳۹۵ بررسی شد. منطقه مورد مطالعه دو حوضه در دشت گره بایگان شامل حوضه بیشه زرد (۱۹۲ کیلومتر مربع) و حوضه چاه قوچ (۱۷۱ کیلومتر مربع) بود. معادله بودجه آب برای ارزیابی آب ورودی و خروجی سیستم پخش سیلاب استفاده شد. شش پیزومتر نصب شده در دشت گره بایگان، سطح رکود آب را اندازه گیری کردند. جریان ورودی و خروجی به ترتیب با یک ثبات سطح آب و پنج سرریز تاج پهن اندازه گیری شدند. محتوای آب خاک تا عمق ۳۰ متری توسط سنسورهای دستگاه رطوبت سنج براساس بازتاب سنجی دامنه زمانی (Time Domain Reflectometry, TDR) ثبت شد. حجم کل آب حفظ شده توسط سیستم در ۲۹ بهمن ۱۳۹۵، ۱۹۱۶۰۹۵۱ متر مکعب بود. تغذیه خالص آبخوان ۶۶۷۷۳۰۱ مترمکعب بود. کل تغذیه ناشی از تغذیه مصنوعی در مدت مطالعه ۸۳۳۲۹۱۶ متر مکعب بود. سیستم پخش سیلاب، ۷۰ درصد سیلاب انحرافی را مهار نمود و سطح آب چاه‌های منطقه را از ۱/۰۳ تا ۲/۷۴ متر بالا برد. بنابراین میتوان نتیجه گیری کرد که پخش سیلاب و تغذیه مصنوعی، رویداد سیل نادر در ایران را مهار کردند. در نتیجه، آنها می توانند فرآیندهای منطقی برای جلوگیری از خسارات سیل و حفظ منابع آب‌های زیرزمینی باشند.