



Evaluating the impact of watershed management on the environmental sustainability of the Taftan watershed in arid areas of southeast Iran

Moien Jahantigh¹ · Mansour Jahantigh²

Received: 18 September 2022 / Accepted: 22 April 2023 / Published online: 18 May 2023
© Saudi Society for Geosciences and Springer Nature Switzerland AG 2023

Abstract

Soil and water conservation are the most requested natural resources, especially in the dryland region. Watershed management is the key to solving such problems and creating a stable environment for sustainable development in natural ecosystems. Therefore, to identify the appropriate solution to improve these conditions, it is necessary to conduct applied research. This research aimed to evaluate the impacts of watershed management activities on environmental sustainability in the Taftan watershed. To do this research, field visits were made to the study area where watershed management was implemented. Also, the locations of check dams and their numbers were determined. Moreover, field visits were made to the watershed, and the dimensions of the built check dams were estimated. To measure the flood volumes, graduated scales were installed in the reservoirs and outlets of the watershed, and the volume of the flood was measured for each rainfall event. As well as water flow duration was estimated before and after watershed management activities. To determine the infiltration rate, used the double-ring method. Also, by using satellite images, the effect of watershed management operations on the agricultural land area was investigated. The data was analyzed with SPSS18. Data indicated that the volume of structural operations is 145,744 m³. According to field observation, check dam reservoirs were filled up with sediments, and many of them were ineffective. During the research, an amount of 883,139 m³ of flood was created, of which 433,095 m³ was controlled in check dam reservoirs and 450,044 m³ (51%) caused runoff. According to the data, watershed management operation reduces floods (49%), improves water quantity, and increases occupation and environmental sustainability.

Keywords Soil and water conservation · Natural ecosystem · Environmental sustainability · Check dam

Introduction

Increasing the population and improving the level of social welfare and demand for food needs are effective factors in the destruction of ecosystems and environmental damage. Inefficient utilization of resources in watersheds causes this destruction, which has results such as the occurrence of

heavy floods and environmental degradation. A large part of Iran is located in the arid region, so its rainfall is about one-third of the world. In recent decades, a large part of Iran has been exposed to severe floods, and over time, the volume of losses of life and property and environmental damage has increased (Jahantigh and Jahantigh 2020). Consequences of such circumstances are including lack of water infiltration into groundwater aquifers and reduction of water available for agriculture and reduction of income, increase the irregular migration due to lack of income, and destruction of the environment (Foster and Chilton 2003; Cotti et al. 2022; Yu et al. 2022). Therefore, optimal control and use of existing floods is a basic need of natural ecosystems. Human activities in natural ecosystems have a great impact on floods and flooding. With urban development, due to the increase in impermeable surfaces, the volume and also occurrence of floods increase (Ghafouri 1996; Li and Xu 2002; Abiye 2022). Floods are one of the most important causes of

Responsible Editor: Amjad Kallel

✉ Moien Jahantigh
moienja23@yahoo.com

¹ Department of Watershed Management Engineering, Faculty of Agriculture & Natural Resources, University of Gorgan, Gorgan, Iran

² Soil Conservation and Watershed Management Research Department, Sistan Agriculture and Natural Resources Research and Education Center, AREEO, Zabol, Iran

environmental degradation. This phenomenon destroys soil and transfers into the rivers and canals and causes them to be blocked. Such a situation creates a basis that subsequent floods, due to the lack of suitable drainage channels, cause the destruction of natural ecosystems and ultimately cause climate change and environmental crises (Yang et al 2003; Arnell and Gosling 2016). Runoff control is possible in different ways, as the use of each method depends

on the environmental conditions and socio-economic and environmental effects on the ecosystem (Bailey and Ayres 1936; Brooks et al. 1991; Amini et al. 2013). Various factors and methods have been studied to reduce floods and prevent them worldwide, one of which is the use of small consecutive dams (Jons 2000; Wang et al. 2021).

Pawar (1998) reported that with the implementation of watershed management operations such as the construction

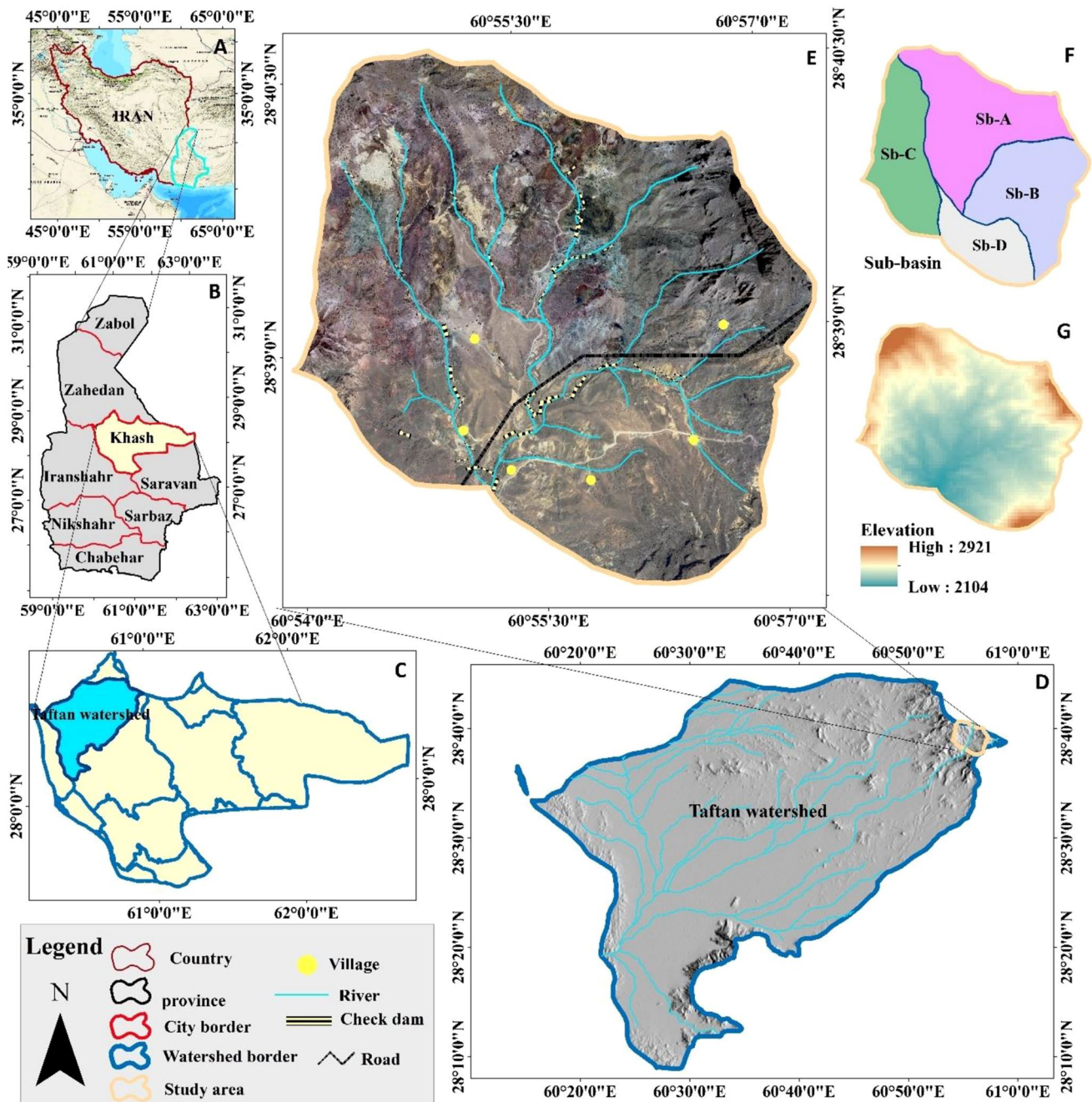


Fig. 1 Location map of the study area. **A** map of Iran, **B** the location of Sistan and Baluchestan Province in Iran, **C** the location of the Taftan watershed in Khash County, **D** location of the studied area in

Taftan watershed, **E** Google Earth image for the study area includes check dams, river, and basin boundary, **F** digital elevation model (DEM), and **G** sub-basin map of the study area

of small dams, the survival rate of vegetation in the Maharashtra watershed in India, areas with shallow foothills and semi-deep soils, has increased to 23 and 47%, respectively. Also, the occurrence and volume of floods have been reduced, which has led to a decrease in the erosion rates in the mountains and highlands area from 42.68 to 12.79%. The results of researches on the impacts of watershed management activities on floods showed that the occurrence and volume of floods were significantly reduced by performing mechanical and biological activities (Ranade and Gupta 1996; Sarka 2022). The other study in the Megalia watershed of India demonstrated that with the implementation of watershed management, sediment production has decreased to 0.16218 hectares per square kilometer, which has improved environmental indicators including rainfall reserves and vegetation (Rymbai and Jha 2012). Moreover, some report shows that rangeland management based on watershed management activities in US watersheds has led to increase vegetation and soil moisture storage and also reduce runoff and sediment volume (Wine et al 2012). Delayed structures, in addition to preventing runoff junction at upstream, by storing flood flows in their reservoir and reducing the flow velocity of runoff, cause a lag time to reach runoff to its maximum outflow in the basin. Moreover, these structures can reduce the maximum flood discharge with a return period of 1000 years to the equivalent discharge with the occurrence of floods with a return period of 25 years, after control and penetration into soil. Reference studies showed that small structures play an important role in increasing infiltration and reducing sediment and runoff in mountainous areas. About 87 million hectares of Iran are mountainous areas where there is a field of watershed

management operation. To succeed in the implementation of watershed management programs, various factors such as the importance of the environment, sustainable development, improving crop and livestock production, and socio-economic development by improving the living conditions of stakeholders in watersheds are considered. Therefore, in this study, the performance of watershed management measures and their environmental impact in the Taftan watershed were studied.

Materials and methods

Study area

The study area is about 30 km northwest of Khash city (in the Taftan watershed) with an area of 1100 ha (with coordinates of 60° 46' 11"–60° 57' 17" east longitude and 28° 31' 40"–28° 40' 40" north latitude) that is located at an average altitude of 2301 m above sea level (Fig. 1). The watershed has a dry climate with critical ecological conditions. The average annual temperature of the watershed is 15.7 °C, and the warmest and coldest months of the year are August (36.2) and February (1–1.1), respectively. The average annual precipitation of this region is 174.9 mm, most of which occurs in winter. This area has a high evaporation rate and low humidity. The plant community of the study area includes 264 species and belonged to 47 families, and vegetation condition ranges from poor to good. There are three types of plants in this watershed. Annual and perennial plants account for 62.4% and 37.6% of the flora list, respectively. Investigation of vegetative form of plant species also

Table 1 Precipitation data of the studied watershed in 2010

Event	Hour	Month	0–3	3–6	6–9	9–12	12–15	15–18	18–21	21–24	Total
1	13.00	May	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2
2	5.00	August	0.0	0.0	0.0	0.0	3.2	0.4	0.0	0.0	3.6
3	7.00	November	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5
4	28.00	January	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5
5	29.00	January	0.2	1.8	1.3	2.4	2.5	2.5	4.6	3.0	18.3
6	30.00	February	1	0.5	0.0	0.6	0.0	0.0	0.0	0.0	2.1
7	13.00	February	0.0	0.0	0.1	0.2	8.3	13.3	11.4	12.3	45.6
8	14.00	February	4.4	26.6	5.0	0.0	0.0	0.0	0.0	0.0	36.0
9	20.00	February	1.6	2.0	2.9	1.5	3.2	2.4	1.6	6.8	22.0
10	21.00	February	0.0	0.3	0.1	3.5	9.3	0.1	8.4	1.4	23.1
11	22.00	February	0.0	0.0	4.5	1.0	0.0	0.0	1.2	12.5	19.2
12	23.00	February	12.5	2.0	0.4	0.1	0.0	0.0	0.0	0.0	15.0
13	28.00	February	0.0	0.0	0.0	0.0	0.2	0.2	2.7	0.0	3.1
14	9.00	March	1.5	0.0	0.3	0.0	0.0	0.8	0.3	0.0	2.9
15	10.00	March	0.2	5.5	1.5	0.7	0.0	0.0	5.5	0.2	13.6
16	11.00	March	0.0	1.4	0.0	0.0	1.0	0.0	0.0	0.0	2.4
Total	-	-	21.4	40.1	16.1	10.0	28.4	19.7	35.7	36.7	208.1

Table 2 The extent of flood control through the reservoirs of structures

Date	Duration of precipitation (min)	Precipitation (mm)	Precipitation volume in the watershed (m ³)	Flood volume (m ³)	Volume of flood reservoirs (m ³)	Outflow volume (m ³)
2010–5-26	540.00	14.00	278,040.0	75,070.00	75,070.00	-
2011–1-19	600.00	18.3	363,438.0	98,128.00	98,128.00	-
2011–2-2	600.00	45.6	905,616.0	135,842.0	123,330.0	12,512.00
2011–2-3	540.00	36.00	714,960.0	142,992.0	57,197.00	85,795.00
2011–2-8	660.00	22.00	436,920.0	117,968.0	60,393.00	57,575.00
2011–2-9	600.00	23.00	456,780.0	114,195.0	34,431.00	79,764.00
2011–2-10	360.00	19.00	377,340.0	101,881.0	49,974.00	51,907.00
2011–2-11	480.00	15.00	297,900.0	80,433.00	47,451.00	32,982.00
2011–3-1	36.00	13.6	270,096.0	72,925.00	72,925.00	-
2011–3-15	660.00	45.00	893,700.0	241,299.0	38,574.00	82,130.00
2011–3-16	450.00	13.4	266,134.0	71,856.00	38,574.00	153,877.0
2011–3-17	240.00	22.7	450,822.0	121,722.0	88,221.00	33,501.00
2011–3-27	360.00	10.5	208,530.0	56,303.00	56,303.00	-
Total	-	-	592,0276	1,430,614	840,571.0	590,043.0

shows that the highest frequency is related to herbaceous plants, and the lowest is related to quasi-grasses. Geologically, this watershed is located in the flash zone of eastern Iran (Jahantigh 2013, 2017).

Methodology

To conduct this research, the basic field reports were studied. Field visits were made to the watershed, and the dimensions of check dams constructed were estimated. Rainfall and flood flows were measured at the required time. To measure the flood volume, graduated scales were installed at the reservoirs and the outlets of the watershed. The volume of the flood was measured for each rainfall event (Merz et al. 2006; Shope et al. 2013). The infiltration rate was estimated in the check dam reservoir using a double-ring method (Ronnqvist 2018). As well as flow duration was tested before and after watershed

management operation using the direct measurement method (Pawar et al. 2023). Also, by employing satellite image, the effect of watershed management operation on the agricultural land area was investigated. To achieve this purpose, first high-resolution images related to the years before (2004) and after (2017) watershed management operations were taken from the Google Earth imagery using Elshayal Smart GIS software. Images mosaic was performed by using Global Mapper software. After that, by the visual interpretation method, agricultural land use was determined, and the area of this land use was calculated for the study period by using GIS software (Hegazy and Kaloop 2015; Malarvizhi et al. 2016). Additionally, hydrological analysis (analyzing flood discharge, surface runoff, and its correlation with runoff infiltration), soil erosion control (determine sediment transport), and land use changes (changes in agriculture area) were employed to reveal the environmental effects of watershed management operation by

Fig. 2 Comparison of runoff volume before and after watershed management operation

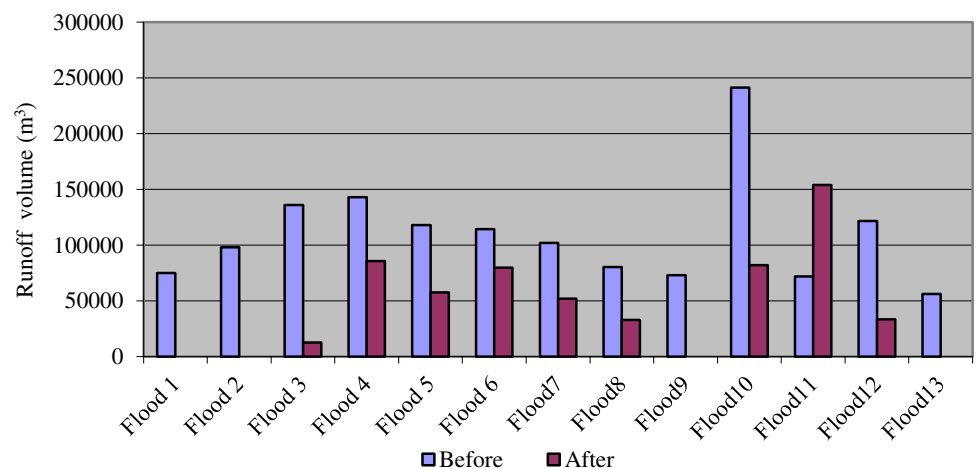


Table 3 Result of comparison volume of runoff before and after watershed management

Variable	Mean	Std. deviation	T-test		
			t	df	sig
Runoff before (m ³)	110047.23	47634.226	4.181	12	0.001
Runoff after (m ³)	45387.92	46315.5987			

descriptive and inferential analysis (Jahantigh and Jahantigh 2020; Pramudiya et al. 2022). Statistical analyses were performed using (by compare mean *t*-test) the SPSS 18 software.

Results

Forty-five check dams in this watershed were surveyed, of which 87.5% and 12.5% of them are loose rock-cement and gabion, respectively. The aim of constructing these structures was to ecologically stabilize the relevant watershed by controlling floods and sediment and storing it to meet the water required for agriculture and the environmental sustainability of the region. Most of these structures are based on scientific construction methods, and each of them has a spillway, wing, and stilling basin. The size of these structures is different and adequate for their specific site. The smallest and largest constructed dams in this watershed are 10 and 42 m long, respectively. The base width of some check dams reaches 3.5 m. But the upper width is usually 1 m, and their maximum height reaches 6.7 m. The spillway of check dams has made in different dimensions; their height is about 1 m, and their length varies and is dependent on runoff volume. In 2010, during the autumn season, several traces of rain occurred, but from 20 to 23 February, 79.3 mm of rain occurred, which led to create effective floods and also sediment production in the study area. Moreover, in March of the mentioned year, the rain onset from the ninth day and continued until the eleventh day and the total rainfall was

18.9 mm during 3 days. Although the occurrence of this rainfall did not cause flooding, it increased the base flows of the main waterway (Table 1). The average rainfall in 2011 was 68.5 mm. The highest precipitation occurred on 26 June and 5 February (about 11.6 mm), which had no runoff. The average reservoir volume and the total capacity of each check dams were estimated at 3239 and 145,744 m³, respectively. During the study period, rainfall events caused 883,139 m³ of floods, of which 433,095 m³ (49%) has stored in check dams reservoirs so that 0.044 was formed by flood sediments. Hence, during the study period, 1947.8 m³ of sediments were deposited in the reservoirs of constructed dams. According to the measurements, 450,044 m³ of flood volume (51%) has left the basin (Table 2). Watershed management operation has provided good conditions for rainwater harvesting and infiltration at upstream of the study area. While before the implementation of watershed management, all flood flows were out of reach after a short time. During the study period, 5,920,276 m³ of rainfall has occurred in the region, which has led to the creation of 1,430,614 m³ of runoff. Meanwhile, watershed management operation has caused storage and infiltration of 840,571 m³ of flood volume in the reservoirs of structures, and only 590,043 m³ of it has left the basin. On the other hand, if the studied structures were not built in this basin, 1,430,614 m³ of runoff volume not only was leaving the basin, but also was increasing the destructive power of flood flows. This shows that watershed management operations are efficient in rainwater harvesting and controlling soil loss. A comparison of runoff volume before and after watershed management is shown in Fig. 2. According to the results, there is a significantly different between the volume of runoff before and after watershed management operation (Table 3). After watershed management operation, the runoff enters the reservoirs of the constructed dams, and after filling them, it flows to downstream. Structures act as regulators of stream flow and increase runoff continuity. In addition, the peak discharge volume greatly decreases due to mechanical and biological

Fig. 3 5-h rainfall flood hydro-graph in this basin

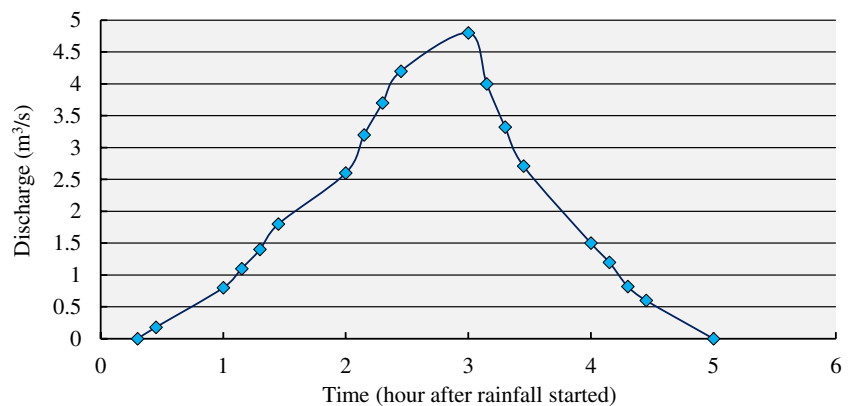
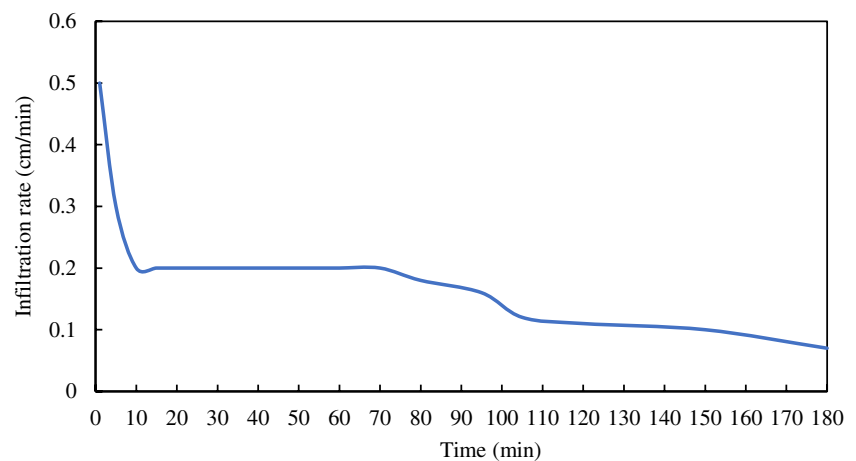


Fig. 4 Showing Horton's infiltration curve at various times



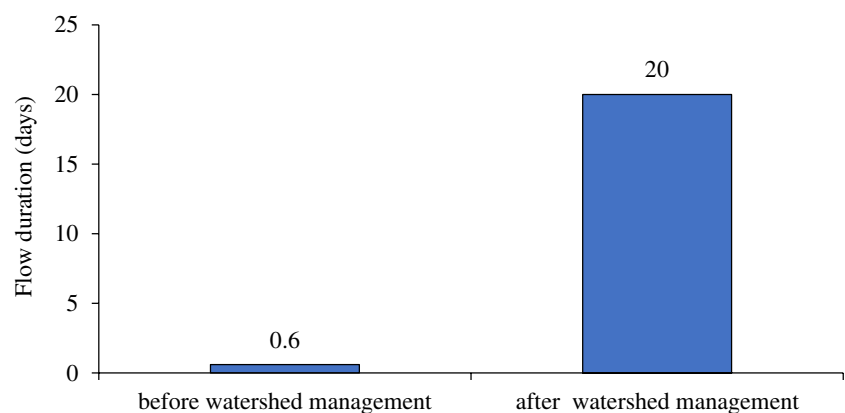
barriers. For example, a 5-h flood hydrograph in this basin, which has a base flow, shows that with the onset of rainfall, its outflow significantly increased, while after the cessation of rainfall, discharge gradually decreased (Fig. 3). Findings indicate that at 1, 2, 5, 10, 15, 20, 20, 25, and 30 min, the penetration rate was equivalent to 5, 3, 3, 2, 2, 2, 2, 2, and 2 mm, respectively. Also, investigation of penetration speed at different times shows that in 150 and 180 min, penetration speeds were 0.7 and 0.6 (mm/min), respectively (Fig. 4). Examination of flow duration after rainfall events in the study area shows that, before the implementation of watershed management, with a rainfall of 10 mm per hour, flood was producing, and after rainfall cessation, up to 6 h later, flood was stopping. Whereas, after the implementation of watershed management operations, rainfall of more than 30 mm per hour was producing runoff at the basin outlet. However, its flow duration increased to 10 and 20 days after rainfall, at a height of 10 and 20 cm, respectively (Fig. 5). As depicted in Figs. 6 and 7, after watershed management operation (2017), the area of flood farming in sub-basins A, B, C, and D compare to non-implementation conditions (2004) increased to 55.36%, 54.7%, 61.3%, and 69.4%, respectively. Also, the results

show that the garden area compare to non-implementation conditions significantly increased (72.1%, 16.7%, 66.1%, and 77.5%, respectively).

Discussion

Precipitation drainage into the main river in the watershed causes flood flow, which has strong destructive powers (Koem et al. 2019; Al Habib et al. 2020). These floods cause soil erosion and destroy potential agricultural lands along rivers. When the capacity of channels is low, the flood speed and its destructive power increase (Maryono 2018; Emily et al. 2020; Krätzschmar et al. 2022). Hence, the implementation of watershed management operations, especially in arid areas, is one of the basic needs to stabilize the ecosystem and use available resources optimally for sustainability and development in these regions. Accordingly, this operation requires a well-planned, so that, in addition to high performance, it is economically viable too. In this regard, the construction of check dams in waterways, based on the scientific principles of watershed management, decreases flood

Fig. 5 Flow duration before and after watershed management



risk in upstream waterways. So, these structures prevent to runoff junction of waterways in upper and also reduce runoff volume. Such a mechanism mitigates the velocity of concentrated flood flows and contributes to improve runoff infiltration at the upstream regions. In other words, check dams construction by reducing peak flow discharges and runoff volumes significantly increased the runoff infiltration in the upstream regions. So that finding represented that the effect of check dams contributed 2.4 times to decrease runoff volume during the study period.

As well, results showed that the system of check dams, by storing floods, substantially increased runoff infiltration (59%). The reason for this mechanism is related to the soil characteristics of the study area. Because the soil texture at the upper section of the study area is light with high pore, consequently, most of the runoff volume due to heavy rainfall in these control points gradually infiltrates the groundwater. Roughani et al. (2011) have also achieved such results by studying the Bardeh watershed in the southwest Iran. They reported that, with

Fig. 6 Classification of flood farming and garden land area before (I) and after (II) watershed management operation in study area

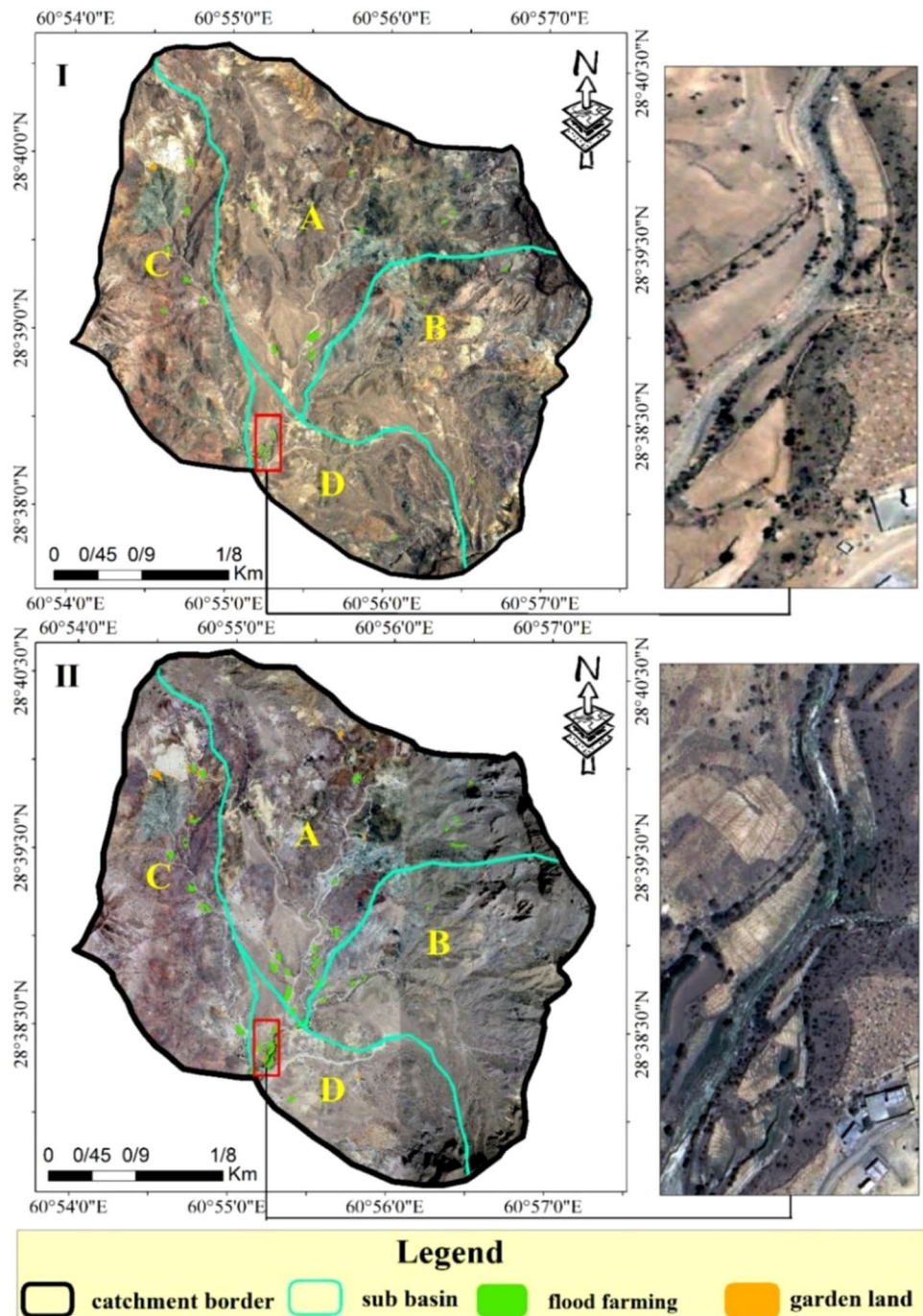
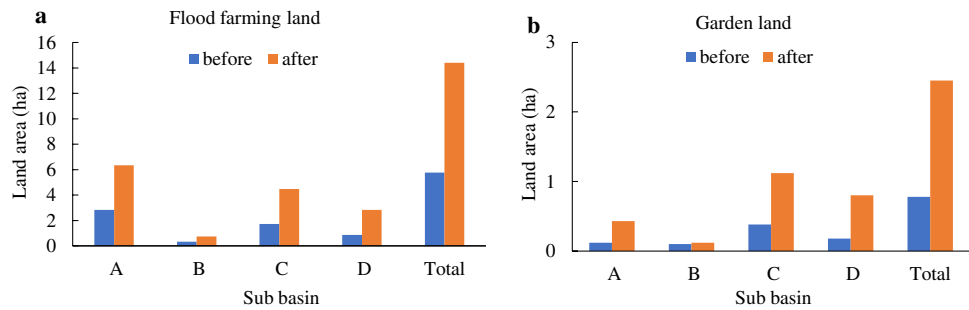


Fig. 7 Comparison changes of flood farming land (a) and garden land (b) before (2004) and after (2017) watershed management operation in the study area



the implementation of these structures, in addition to the runoff infiltration at upstream, soil stabilization has also taken place. This process influences the hydrological response of the watershed and effectively mitigates flood processes in this area. Yuan et al. (2022) reported that the construction of check dams substantially decreased the runoff coefficient and by increasing the capacity of storing floods has promoted runoff infiltration. This mechanism effectively reduces sediment transport. As a result, during the study period, 1947.8 m³ of sediment was deposited in the reservoirs of constructed dams. The results of Li et al. (2017) also showed that the implementation of check dams by modifying the hydrological responses in the catchment reduces flooding risk and sediment transport. Research results showed that the construction of check dams as an engineering structure is useful for soil and water conservation and achieves to sustainability and ecosystem development in the watershed basin (Roughani et al. 2011; Zhao et al. 2016; Tang et al. 2020). In accordance with the results, constructing different check dams in the studied watershed has efficiently contributed to control and storage surface runoff. This process is a suitable

solution to meet an important part of the water required for farmers and ranchers. Based on the results, after watershed management operation, due to the increase in water available resources to crop production and livestock, the area of garden and flood farming lands significantly increased. Palanisami and Kumar (2009) have found that watershed management activities have major effects on biophysical, environmental, and socio-economic development. So increasing agricultural lands is one of the effects of mechanical structures in this region (Fig. 7). Also, some reports show that watershed management operation has played an important role in controlling surface runoff and increasing yields in watersheds (Karbowski 1993; Zhu et al. 2004; Bombino et al. 2009; Jahantigh 2017).

Overall, implementation of watershed management operations by check dams construction in the Taftan watershed has contributed to control surface runoff and effectively promoted the runoff infiltration and groundwater table that consequently caused farmland for agricultural production has increased. This process has played an important role in soil and water conservation and also environmental sustainability in this area (Fig. 8).

Fig. 8 View of impacts of watershed management activities on environmental and agricultural condition in the Taftan watershed



Conclusions

In this research, the impact of watershed management operations on flood reduction and environmental sustainability in the Taftan watershed was studied. The results showed that during the implementation of this research, 840,571 m³ of flood volume was stored in the reservoir of check dams, and the amount of runoff infiltration in these control points was increased by 59%. In addition, during the study period, 1947.8 m³ of sediment was deposited in the reservoirs of constructed dams which caused the sediment transport extremely reduced. This process, consequently, caused the area of garden and flood farming lands significantly increased. Therefore, it is concluded that implementation of watershed management operations such as check dams construction, by modifying the hydrological responses in the watershed, not only has effects on the hydrology process, but also has positive ecological and environmental effects to achieve sustainability and ecosystem development in watersheds. Hence, to maintain the ecosystem functions of watersheds, especially in arid areas, training and management based on watershed management approaches can create important synergies to improve the socio-economic condition and environmental services in watershed basins.

To obtain satisfactory results from watershed management operations in the Taftan watershed, it is necessary to take into account maintenance requirements for the stability of structural measures, expansion, and also promotion of watershed management activities in other sub-basins.

Data Availability Data is available on https://sistan.areeo.ac.ir/fa-IR/sistan.areeo.ac/26669/page/_sistan/address.

Declarations

Conflict of interest The authors declare no competing interests.

References

- Abiye W (2022) Soil and water conservation nexus agricultural productivity in Ethiopia. *Adv Inagric* 1:1–10
- Al Habib AH, Firdaus P, Pangestu D (2020) Analysis of atmospheric physical conditions during flash floods and flood prediction using the rainfall runoff inundation model in the greater Jakarta area. *Natl Seminar Geogr* 1(1):72–82
- Amini A, Taherei Ghazvinei M, Javan M, Saghafian B (2013) The results derived from field observation and HEC–HMS model showed that the practices had significant impacts on the runoff storage and peak flow reduction. *Arab J Geosci* 7(8):1–10
- Arnell NW, Gosling SN (2016) The impacts of climate change on river flood risk at the global scale. *Clim Change* 134:387–401
- Bailey R, Ayres AW (1936) Watershed approach in improving the socio-economic status of tribal area. A case study. *J Rural Dev Hyderabad*: 107–116
- Bombino G, Gurnell AM, Tamburino V, Zema DA, Zimbone SM (2009) Adjustments in channel form, sediment calibre and vegetation around checkdams in the headwater reaches of mountain torrents, Calabria, Italy. *Earth Surf Proc Landforms* 34(7):1011–1021. <https://doi.org/10.1002/esp.1791>
- Brooks KN, Ffolliott PF, Gregersen HM, Thames JL (1991) *Hydrology and the management of watershed*, vol 1. Iowa State University, p 220
- Cotti D, Harb M, Hadri A, Aboufirass M, Chaham KR, Libertino A, Campo L, Trasforini E, Krätzschar E, Bellert F, Hagenlocher M (2022) An integrated multi-risk assessment for floods and drought in the Marrakech-Safi Region (Morocco). *Front Water* 4:1–17
- Emily C, Donnell O, Colin Thorne R (2020) Drivers of future urban flood risk. *J Wires Water* 8(6):1–23
- Foster SSD, Chilton PJ (2003) Groundwater: the processes and global significance of aquifer degradation. *Philos Trans* 29:1957–1972. <https://doi.org/10.1098/rstb.2003.1380>
- Ghafari RA (1996) Deterministic analysis and simulation of runoff in urban catchment. Ph.D. Thesis, Wollongong University, Wollongong, NSW, Australia, p 365
- Hegazy I, Kaloop MR (2015) Monitoring urban growth and land use change detection with GIS and remote sensing techniques in Daqahlia Governorate Egypt. *Int J Sustain Built Environ* 22:12–22. <https://doi.org/10.1016/j.ijbsbe.2015.02.005>
- Jahantigh M (2017) Study effect of watershed management on sediment control in dryland region (Case Study Taftan). *Iranian J Watershed Manag Sci Eng* 10(35):81–89
- Jahantigh M, Jahantigh M (2020) Investigating of land use change effect on some soil physical chemistry characteristics and Erosion in arid areas (case study: Hirmand of Sistan). *Quart J Environ Erosion Res* 36:92–118
- Jahantigh M (2013) Studying and recognition of characteristics of erosion rivers in Sistan region. *Soil Conserv Watershed Manag Inst* 51. <https://sistan.areeo.ac.ir/fa>
- Jons JAA (2000) The physical causes and characteristics of floods. *Floods* 2:93–112
- Karbowski A (1993) Optimal flood control in multi-reservoir cascade systems with deterministic inflow forecasts. *Water Resour Manag* 7:207–223
- Koem S, Akase N, Muis I (2019) Community capacity building in reducing disaster risk in Bandung Rejo Village, Gorontalo Regency, Axiologiya. *J Commun Serv* 3(2):176–184
- Krätzschar E, Bellert F, Hagenlocher M (2022) An integrated multi-risk assessment for floods and drought in the Marrakech-Safi region (Morocco). *Front Water* 4:1–17
- Li Z, Xu C (2002) Rainfall collection and water-saving irrigation project and ecological water for small watershed soil and water conservation in semi-arid and extremely water deficient region 12th ISCO Conference, Beijing
- Li EH, Mu X, Zhao G et al (2017) Effects of check dams on runoff and sediment load in a semi-arid river basin of the Yellow River. *Stoch Env Res Risk Assess* 31(7):1791–1803. <https://doi.org/10.1007/s00477-016-1333-4>
- Malarvizhi K, Vasantha Kumar S, Porchelvan P (2016) Use of high resolution Google Earth satellite imagery in landuse map preparation for urban related applications. *Procedia Technol* 24:1835–1842
- Maryono A (2018) *Water resources management reform*. UGM Press, Yogyakarta
- Merz R, Blöschl G, Parajka J (2006) Spatio-temporal variability of event runoff coefficients in Austria. *J Hydrol* 331:591–604
- Palanisami K, Kumar D (2009) Impacts of watershed development programs experiences and evidence from Tamil Nadu. *Agric Econ Res Rev* 22:387–396
- Pawar PB (1998) Prospect and problems in use of vetiver for watershed management in sub-mountain and scarcity zones (Maharashtra,

- India). *Newslett Vetiver Netw* 19:33–35. https://www.vetiver.org/INR_watershed.htm
- Pawar AP, Sarkar S, Saha SK (2023) Three-dimensional study of flow past blunt headed cylinder at low Reynolds numbers. *Int J Therm Sci* 189:108256. <https://doi.org/10.1016/j.ijthermalsci.2023.108256>
- Pramudiya A, Suripin M, Robert J, Kodoatie N (2022) Water storage for controlling surface runoff in upstream watershed. *Webology* 19(1):5674–5694
- Ranade DH, Gupta RK (1996) Predicting runoff from vertisols of Malwa region (India). *Crop Res* 11:9–16. <https://www.cse.iitb.ac.in/~pocra>
- Ronnqvist H (2018) Double-ring infiltrometer for in-situ permeability determination of dam material. *Engineering* 10:320–328
- Roughani M, Tabatabaie M, Shadfar S (2011) Evaluate watershed management operations and introduce a method in determining flood control structures, Iran. *Watershed Manag Sci Eng* 4(13):51–60
- Rymbai PN, Jha LK (2012) Estimation of the sediment production rate of the Umbaniun Micro-watershed, Meghalaya, India. *J Geogr Reg Plan* 5(11):893–897
- Sarka S (2022) Drought and flood dynamics of Godavari basin, India: a geospatial perspective. *Arab J Geosci* 15(77):1–15
- Shope CL, Bartsch S, Kim K, Kim B, Tenhunen J, Peiffer S, Park J, Fleckenstein OSY, Koellner JT (2013) A weighted, multi-method approach for accurate basin-wide streamflow estimation in an ungauged watershed. *J Hydrol* 494:72–82
- Tang H, Pan H, Ran Q (2020) Impacts of filled check dams with different deployment strategies on the flood and sediment transport processes in a Loess Plateau catchment. *Water* 12(5):1319. <https://doi.org/10.3390/w12051319>
- Wang T, Lu Y, Liu T, Zhang Y, Yan Y, Liu Y (2021) The determinants affecting the intention of urban residents to prevent flooding in China. *Nat Hazard* 22:2185–2199
- Wine M, Zou C, Bradford J, Gunter S (2012) Runoff and sediment responses to grazing native and introduced species on highly erodible Southern Great Plains soil. *J Hydrol* 450–451:336–341
- Yang D, Kanae S, Oki T, Koike T, Musiak K (2003) Global potential soil erosion with reference to land use and climate changes, Japan. *Soc Hydrol Water Resour* 17(14):2913–2928
- Yu Q, Wang Y, Li N (2022) Extreme flood disasters: comprehensive impact and assessment. *Water* 1211:1–14
- Yuan S, Li Z, Chen L, Li P, Zhang Z, Zhang J, Wang A (2022) Effects of a check dam system on the runoff generation and concentration processes of a catchment on the Loess Plateau. *Int Soil Water Conserv Res* 10(1):86–98. <https://doi.org/10.1016/j.iswcr.2021.06.007>
- Zhao GJ, Mu XM, Jiao JY, An ZF, Klik A, Wang F, Jiao F, Yue XL, Gao P, Sun WY (2016) Evidence and causes of spatiotemporal changes in runoff and sediment yield on the chinese loess plateau. *Land Degrad Dev* 1–15. <https://doi.org/10.1002/ldr.2534>
- Zhu Y et al (2004) A survey: obstacles and strategies for the development of ground- water resources in arid inland river catchments of western China". *J Arid Environ* 59(2):351–436

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.