Agricultural Water Management 100 (2011) 36–45

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

# Impact of upstream changes in rain-fed agriculture on downstream flow in a semi-arid basin

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ARTICLE INFO

*Article history:*
Received 26 January 2011
Accepted 12 August 2011
Available online 8 September 2011

*Keywords:*
Rainwater harvesting
Irrigation agriculture
SWAT model
Water use
Downstream impact
Stream flow
Karkheh Basin

ABSTRACT

The downstream impacts of increasing water consumption in the upstream rain-fed areas of the Karkheh Basin, Iran are simulated using the semi-distributed SWAT model. Three scenarios are tested at subbasin and basin levels: converting rain-fed areas to irrigation agriculture (S1), improving soil water availability through rainwater harvesting (S2), and a combination of both (S3). The results of these scenarios were compared against the baseline period 1988–2000. The S1 scenario shows a 10% reduction in mean annual flow at the basin level, varying from 8–15% across the subbasins. The reductions in mean monthly flows are in the range of 1–56% at the basin level, with June witnessing the highest flow reduction. Flow reductions are comparatively higher in the upstream parts of the basin, as a result of a relatively higher potential of developing rain-fed areas coupled with comparatively lower amount of available runoff. The impacts of S2 are generally small with reductions of 2–5% and 1–9% in mean annual and mean monthly flows, respectively. The results of S3 are in general similar to those of S1. Although the estimated annual flow reductions remain well within the available water resources development potential, measures needs to be taken to avoid excessive flow reductions in May, June and July. It is recommended that only a limited agricultural area should be converted from rain-fed to irrigated agriculture (about 0.1 million ha), and should practice supplementary irrigation. The supplies should also be augmented through developing additional water storage. Adopting such measures is extremely important for the upper subbasins Gamasiab and Qarasou where comparatively higher flow reductions were estimated.



## 1. Introduction

Improvements of rain-fed agriculture are required to ensure global food security. Improved rain-fed agriculture also contributes to global poverty reduction as the majority of the world's rural poor depend on rain-fed agriculture for livelihoods. It is also beneficial for the environment, e.g., to reduce soil erosion. Yet, a proper understanding of trade-offs resulting from such interventions is essential too (CAWMA, 2007; Rockström et al., 2010).

Wakindiki and Ben-Hur (2002) conducted a field-scale evaluation of indigenous soil and water conservation techniques in a semi-arid rain-fed region of Kenya and concluded that the techniques they investigated, which comprises of building trash lines of various sizes and materials, significantly reduced soil erosion and improved crop yields. The study also noted significant reduction in surface runoff as a result of the applied techniques. Makurira et al. (2010) suggested that the food and livelihood security of the farmers in semi-arid to arid regions could be significantly improved by promoting rainwater harvesting. Their field scale experimentations conducted in the Makanya Basin, Tanzania, demonstrated that the combined use of the conservation agriculture, diversion of runoff to field plots and enhancement of in-field soil moisture through trenching and soil bunding (locally called *fanya juus*) could help in managing erratic distribution and scarce rainfall. The study showed that these methods could significantly increase plant transpiration resulting in higher crop yields and water productivity. Oweis and Hachum (2006, 2009a) reported examples of successful implementation of various water harvesting techniques (e.g. contour ridges, semi-circular and trapezoidal bunds, small runoff basins, terraces, wadi-bed cultivation in the ephemeral streams and farm ponds) from regions of West Asia and North Africa. They reported that the widespread adoption of water harvesting and supplementary irrigation techniques helped improve vegetation growth and raise productivity levels, but also required careful evaluation of factors such as available technical skills at the local level, characterization of climate, water and land use systems, prevailing institutional and policy environment and possible conflicts in the water uses and users among upstream–downstream areas.

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doi:10.1016/j.agwat.2011.08.013

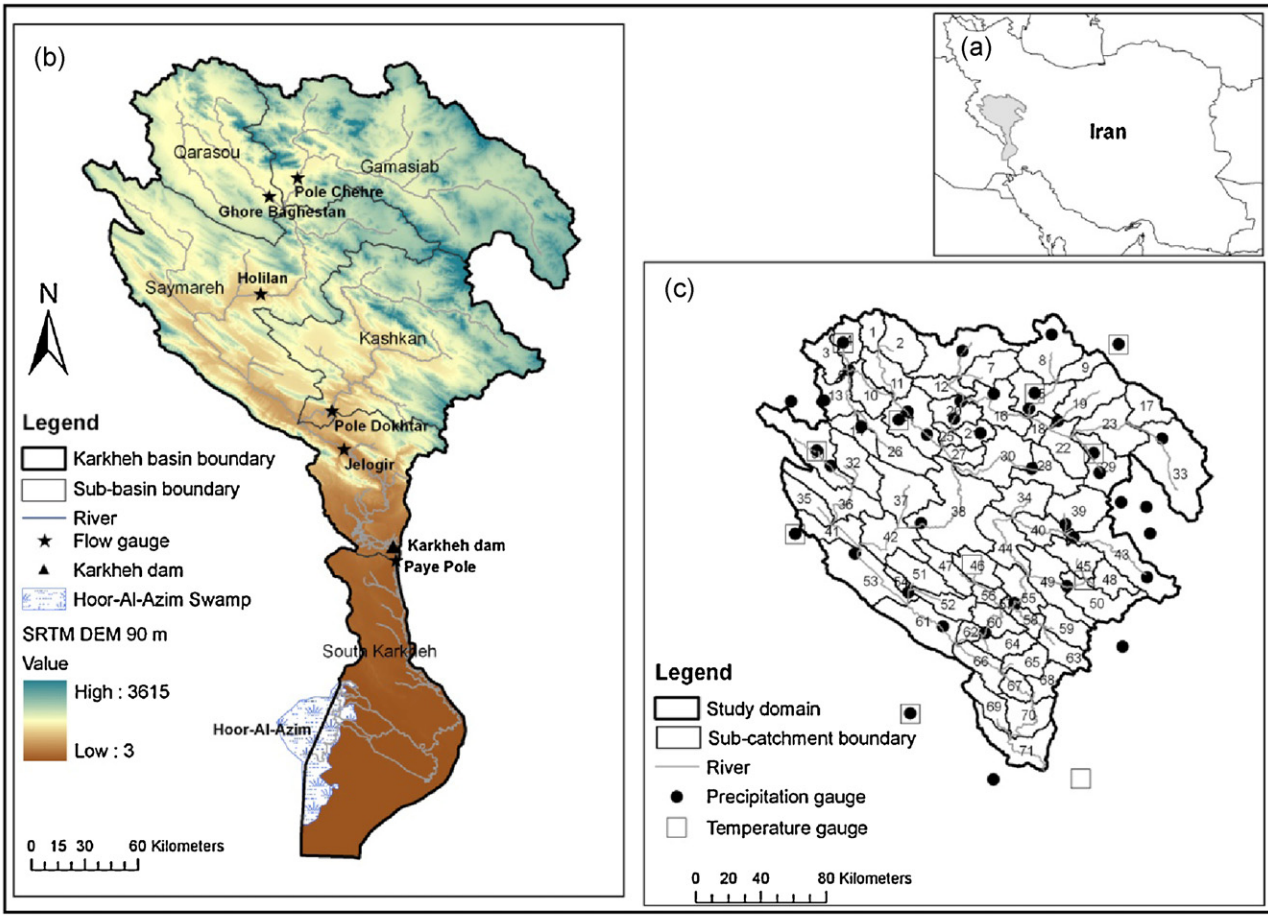


**Fig. 1.** The Karkheh Basin: (a) location in Iran, (b) salient features and locations of stream flow gauges, (c) modeling domain and subbasins. The gauge names and corresponding river reach identification number (ID) on the mainstream rivers are Pole Chehre (20), Ghore Baghestan (24), Holilan (38), Pole Dokhtar (60), Jelogir (66), Paye Pole (71). More information about these gauges is given in Table 1.

Xiubin et al. (2003) compared the observed runoff and precipitation records for two periods, representing hydrological conditions without implementation of soil and water management interventions (1959–1969) and the period (1990–1995) with interventions in three subbasins of the Yellow River Basin, China. They noted a reduction of about 50% in the mean annual runoff, which was mainly attributed to various interventions, such as building earth dams, planting trees or grass, terraces, and irrigation projects. They highlighted that the benefits of increased food production and reduced soil erosion realized from the above-mentioned interventions came at the cost of reduced downstream flow. Lacombe et al. (2008) investigated the impact of water and soil conservation works (WSCW), mainly contour ridges and hillside reservoirs, on runoff response of the Merguellil Basin (1183 km$^2$) in Tunisia. The observed rainfall and runoff records over 1981–2005 were used to investigate changes in the runoff regime. The study indicated runoff reduction of 28–32% at the basin scale due to the WSCW. They further noted that the harvested soil moisture and stored water in the small dams were not efficiently used for the benefit of increased crop production, and argued that the WSCW contributed to the loss of water through enhanced (non-beneficial) evapotranspiration in the region.

The brief review of the recent studies presented above shows the need for much better understanding of the impact of upgrading rain-fed agriculture on hydrology and water availability at subbasin to basin scales. The main objective of this paper is to investigate such impacts in the semi-arid Karkheh Basin, Iran. More specifically, this study aims to (a) investigate the potential for converting rain-fed agriculture to irrigated agriculture and the associated impacts on stream flow, (b) evaluate the impact of soil and water conservation on stream flow, and (c) assess the predictive uncertainty of the model used and its implications.

## 2. Materials and methods

### 2.1. Brief description of the study basin

The Karkheh Basin is located in the western part of Iran and drains an area of 50,764 km$^2$ (Fig. 1a and b). About 80% of the basin area is part of the Zagros mountain ranges, from where almost all of the basin runoff is generated. Hydrologically, it is divided into five subbasins (catchments), namely Gamasiab, Qarasou, Saymareh, Kashkan and South Karkheh. The Karkheh River eventually terminates in the Hoor-Al-Azim swamp, a large transboundary wetland shared with Iraq, which is connected to the Euphrates-Tigris system. A brief discussion on the study area is presented below. Further details of the study area can be found in JAMAB (1999), Ahmad et al. (2009), Marjanizadeh et al. (2009) and Masih et al. (2009, 2010, 2011a, 2011b).

The climate is semi-arid in the mountainous region (north) and arid in the lower plains (south). The mean annual precipitation is about 450 mm/year (yr), ranging from 150 mm/yr in the lower part to 750 mm/yr in the upper part of the basin. Most of the precipitation (about 65%) falls during December to March (winter) and almost no precipitation is observed during June to September (summer). In the mountainous area, the winter precipitation falls as