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Research papers

Effect of Dam operation on monthly and annual trends of flow discharge in the Qom Rood Watershed, Iran

Hiva Yaghmaei [a], Seyed Hamidreza Sadeghi [a,*], Hamidreza Moradi [a], Mehdi Gholamalifard [b]

[a] Department of Watershed Management Engineering, Faculty of Natural Resources, Tarbiat Modares University, Iran
[b] Department of Environment, Faculty of Natural Resources, Tarbiat Modares University, Iran

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A B S T R A C T

Trends in flow discharge, temperature and rainfall from the Qom Rood Watershed, Iran, for a period of 1979–2016 were analyzed at monthly and annual time scales. Trend analyses were conducted using the Mann-Kendall test, the double-mass curve of mean annual discharge versus rainfall, and rainfall-runoff relationship before and after the 15 Khordad Dam operation. Multiple regression of flow discharge against rainfall and temperature was used to determine the residual trend at four meteorological and hydrological stations located upstream and downstream of the Qom Rood Watershed. Results showed that the temperature at the upstream and downstream stations did not have any significant trend, but a significant decreasing trend ($P < .05$) in rainfall was detected only in May ($z = -1.66$) at the downstream stations. There was a significant positive trend ($P < .05$) in rainfall in February ($z = 2.22$) and July ($z = 2.15$) at the upstream stations, and in October ($z = 2.3$) and November ($z = 1.8$) at the downstream stations. However, there was a noticeable decrease in monthly and annual flow discharge, and residual trend at 99% significance level at the downstream stations. At the upstream stations, the flow discharges had significant ($P < .05$) declining trend in all months, but annual flow discharge did not change significantly. Analysis of double mass curve between runoff and rainfall at the downstream stations showed an inconsistency in the line slope concordant with the time of 15 Khordad Dam operation. Annual mean discharge at the upstream stations did not show a significant change before and after 15 Khordad Dam operation. However, annual flow magnitude decreased significantly by 87.5 and 81.7% in Shad Abad and KoohSefid, respectively. These results confirmed that natural driving forces did not affect flow discharge changes and the observed decreasing tendency in flow discharge at the downstream stations was due to 15 Khordad Dam, and at the upstream stations due to diversion/storage dams. These findings highlighted the role of human interference in changing the hydrologic regime in the study area based on which appropriate adaptive decisions can be made.

1. Introduction

Anthropogenic forces, including economic development, demands of growing population, and intensive urbanization, compounded by climate change, are posing a serious challenge to soil and water resources management in many developing countries (Sadeghi et al., 2009; Biemans et al., 2011; Davudirad et al., 2016; Hazbavi and Sadeghi, 2016). Precipitation and temperature are two of the most important climate variables affecting the hydrological regime. Trends in these variables can be used to assess the impact of climate change on the hydrological system (Liang et al., 2011; Tabari and HosseinzadehTalaee, 2011; Zhou and Huang, 2012; Sharma et al., 2014; Fatichi et al., 2015; Zhang et al., 2015; Chen et al., 2016; Lin et al., 2017). Partal and Kahya (2006), Modarres and Silva (2007), Xu et al. (2007), Hao et al. (2008), Hu et al. (2011), Wu et al. (2012), Žganec (2012), Milano et al. (2015), Gajbhiye et al. (2016), Nepal (2016), and Lin et al. (2017) identified temporal variations in the hydrological series of different rivers from around the world that occurred in response to climate change. In some arid and semi-arid areas, anthropogenic driving forces have intensified and have overtaken climate change impacts on the natural hydrological cycle (Milliman et al., 2008; Heath and Plater, 2010; Wang et al., 2012, 2017; Zhao et al., 2012; Mei et al., 2015; Davudirad et al., 2016; Lin et al., 2017; Serago and Vogel, 2018).

* Corresponding author.
E-mail addresses: hiva.yaghmaei@modares.ac.ir (H. Yaghmaei), sadeghi@modares.ac.ir (S.H. Sadeghi), hrmoradi@modares.ac.ir (H. Moradi), m.gholamalifard@modares.ac.ir (M. Gholamalifard).

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Construction and operation of dams are one of the important anthropogenic forces (Poff et al., 2007; MacManamy et al., 2012). Nearly 45,000 large dams have been constructed around the world since the 1930s, creating artificial flow regimes (WCD, 2000). In arid regions, which cover almost one third of the Earth's land surface and have more than 20% of the world population (Martínez-Granados et al., 2011; Massuel et al., 2014), storage dams have been constructed for multipurposes. Although hydropower and flood control are the common main dam function in these regions, many dams operate as storage to supply irrigation and/or drinking water when needed (Petts, 1984; Casado et al., 2016). Despite their ability to mitigate floods and droughts, dams may compound the interaction between ocean, river, and the physical environment of the estuary by altering the natural water cycle (Le et al., 2007; Morais et al., 2009, Zhang et al., 2011; Rasanen et al., 2017). The magnitude of their impacts depends on local climate, and purposes and policies for operation of dams (Molle et al., 2004; Richter and Thomas, 2007). Zhao et al. (2012), Lu et al. (2014), El Bastawesy et al. (2015), Aguiar et al. (2016) and Alrajoula et al. (2017) found that the construction of hydraulic structures (reservoir and dams) across different parts of the globe altered the natural hydrological regime. In some watersheds, the impact of dam construction, combined with climate change, has led to different degrees of impact (Richter and Thomas, 2007; Xu et al., 2010; Wu et al., 2012; Gao et al., 2013; Santos et al., 2014; Zhao et al., 2015; Yang et al., 2015, Chen et al., 2016; Li et al., 2016; Lin et al., 2017; Vicente-Serrano et al., 2017; Serago and Vogel, 2018). A major challenge for dam management is the determination of the acceptable alteration degree without impairing ecological health and ecosystem services. Accordingly, the best option for the management of downstream flows is mimicking natural conditions as much as possible (Shirangi et al., 2008; Fantin-Cruz et al., 2015). For water managers and decision makers, it is necessary to know the role of climate and anthropogenic forces in flow discharge.

Presently Iran suffers from many soil and water-related issues. Although studies (e.g., Abbaspour et al., 2009; Gorjian and Ghobadian, 2015; ShahniDanesh et al., 2016) have reported that water crisis in Iran is mainly caused by climatic factors, Kousari and AsadiZarch (2011) found that the trend in rainfall in semi-arid regions of Iran did not significantly change. In addition, Abtahi and Safe (2014) did not discern any trend in rainfall in the Namak Lake Basin. Other researchers (i.e., KhalighiSigaroodi and Ebrahimi, 2010; Hosseini et al., 2012; Hosseini and Ashraf, 2015; Zeinoddini et al., 2015; Madani et al., 2016; Rahmati et al., 2016) found that anthropogenic factors caused hydrological imbalances in Iran. These disparities call for a comprehensive evaluation of the hydrologic regimes countrywide with high spatial and temporal resolutions.

Literature shows that the relationship between natural and regulated flow regimes in arid areas is challenging. To ascertain the role of climate change and anthropogenic forces is therefore essential for better management of water at the watershed scale. Hence, the objective of this study was to discriminate the effects of dam construction and climate changes on the alternation in streamflow at monthly and annual bases. The Qom Rood Watershed, with many important cities, industries and endangering ecosystems, was selected for the study. Human interventions in natural resources have markedly intensified in recent decades in this watershed. Spatial and temporal variations of temperature, rainfall, and flow discharge were analyzed using data from 1979 to 2016. Despite many studies on changes in climatic variables worldwide as well as in Iran, debate on the role of climate change in hydrological behavior has continued. This study therefore attempted to quantify the role of climate change and anthropogenic influence in the alternation of streamflow, which may help formulate regional strategies for water resources management, which has not been undertaken in central Iran. The present study is different from other studies in that it considers the effect of dam construction in changing flow discharge at different time scales. Four different methods of Mann–Kendall test, double-mass curve of mean annual discharge versus rainfall, and rainfall-runoff relationship pre- and post-Dam operation, and residual trend were applied. The findings of this study will provide insights into the linkage between climate change and hydrological cycle.

2. Materials and methods

2.1. Study area

The Qom Rood Watershed was chosen as a study area because of increasing water-related issues and the availability of quality data for pre- and post- dam construction. The Qom Rood Watershed (32° 50′–34° 50′ N and 49° 30′–51° 20′ E) with an area of some 16,000 km^2 is located in central Iran. The study watershed and geographical positions of the selected stations are presented in Fig. 1.

The watershed with rainfall from 126.5 to 506.9 mm and an average of 200 mm is characterized by arid (BW) and semi-arid (BS) climates based on the De-Marton climate classification. For this study, we divided the watershed into two sections, viz. the upstream of the 15 Khordad Dam, and the downstream area between the 15 Khordad Dam and the Namak Lake Estuary is a habitat for many endangered fauna and flora species (Hajirostamloo, 2009). Human activities and climate change have disturbed the hydrological behavior of the Qom Rood Watershed. Hence, it has become as one of the most fragile watersheds in Iran (Ghorbani, 2013). We tried to dissect the impacts of 15 Khordad Dam construction and climate factors on river flow in the Qom Rood Watershed at different time scales.

2.2. Datasets

The maximum available and common datasets of temperature, rainfall and flow discharge with a record length of 456 months (or 38 years from 1979 to 2016) were utilized at monthly and annual scales. The datasets included 21 years since the 15 Khordad Dam came into operation. It may be noted that 1995 was the time when 15 Khordad Dam with 96.8 m height, 2×10^8 m^3 storage capacity and 1.3×10^4 m^2 surface area with the maximum level was impounded. The amount of water, which is annually released, evaporates and drains from 15 Khordad Dam, is 54.8×10^6, 12.2×10^6 and 3.4×10^6 m^3, respectively. The data were obtained from Ministry of Energy of Iran, collected at four hydrological and meteorological stations throughout the Qom Rood Watershed (Fig. 1). Two of the hydrological stations (i.e., Bagher Abad and Doodehak) and meteorological stations (i.e., Ahmad Abad and Hossein Abad) are located upstream of the dam, and the other two hydrological stations (i.e., Shad Abad and KoohSefid) and meteorological stations (i.e., Salarieh and Massileh) are located downstream of the dam.

2.3. Time series analyses

Trend analysis was applied to determine temporal alternations (i.e., increasing or decreasing) of temperature, rainfall and flow discharge (Delvi and Goswami, 2015). Since most of the hydrological and meteorological series in arid and semi-arid areas are expected to have significant skew, the non-parametric Mann-Kendall (M-K) test (Mann, 1945; Kendall, 1975) was applied to analyze trends (Jhajharia et al., 2012, 2014; Niazi et al., 2014; Sadeghi and Hazbavi, 2015; Gajbhiye et al., 2016). This test has been widely used to detect trends in various environmental, meteorological,