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Research article

# Impact of climate variation on hydrometeorology in Iran

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ABSTRACT

Results confirm that Iran like many countries is affected by high climate variability, which has influenced hydroclimatological variables such as temperature, evaporation, precipitation, runoff, and radiation. This study uses Global Land Data Assimilation System (GLDAS) data to assess hydrological cycle changes in Iran during a long period (Jan1948-Jan2017). Results show that hydrometeorological variables have significant changes ($p$-value < .01) during the period of 2010–2017 relative to the baseline period (2004–2009). Most extreme values of these variables including temperature, evaporation, precipitation, wind, and downward longwave radiation occurred recently (in 2015 to 2017). The average temperature of Iran has an upward trend in most months particularly in summer and winter followed by a significant increase of evaporation since 1948 ($p$-value < .01). Furthermore, the results show significant changes in downward longwave and shortwave radiation, which can be caused by changes in temperature and cloud types. Climate variation has influenced extreme hydrometeorological variables particularly precipitation. The analysis of the results in this study can provide insight into this highly interconnected hydrometeorological changes.

## 1. Introduction

Climate has been changing globally. Iran like most countries has been experiencing high climate variation, which can change magnitude and trend of hydrometeorological variables. The results of this change like heavy rain, storm, drought, and increase in temperature have been occurring (Tabari et al., 2014). Changes differ from region to region over the country. Abbaspour et al. (2009) used the Soil and Water Assessment Tool (SWAT) model to assess the impact of climate change on Iran's water resources. The results revealed that the southern and eastern regions of the country will be at higher risk of drought while the northern and western regions will be threatened by the floods. Climate variation can affect other sectors such as agriculture and energy directly or indirectly. For instance, the impact of climate variation on the hydrologic cycle can influence hydropower. Jamali et al. (2013) showed that lack of adaptation to climate change leads to considerably decrease of efficiency in the Iran's Karkheh Hydropower in future.

Insufficient climate assessment studies and improper managements lead to environmental degradation and ecosystem/resources (e.g., land, water, air) destruction in Iran. Groundwater depletion in many regions particularly in Northeastern Iran caused subsidence and saltwater intrusion (Motagh et al., 2007). Most lakes in Iran are drying including Lake Urmia, the largest lake in the Middle East and the home of different species (Tourian et al., 2015; Delju et al., 2013; Zarghami, 2011). Dried lake causes sand and dust storm around the lake and affects ecosystem functioning and human health. Dust storm over western Iran has disrupted people's lives (Naimabadi et al., 2016; Najafi et al., 2014). Ecosystem degradation such as coral reef bleaching has been occurring in Persian Gulf (Shinn, 1976; Mostafavi et al., 2007). These issues indicate the necessity of implementing sustainable adaptation and mitigation plans considering possible climate changes.

An increase in temperature variability is predicted by climate models (Bathiany et al., 2018). Higher temperature yields more evaporation and thus increases atmospheric water vapor. Water vapor can produce a wide variety of cloud types with different albedo. Different clouds show varied feedbacks in the energy balance system. For instance, low clouds can block incoming shortwave radiation and decrease surface temperature (negative feedback). On the other hand, high cloud can trap outgoing longwave radiation (positive feedback) and increase surface temperature (Dessler, 2010). Note that the feedbacks of the water vapor and precipitation are very uncertain because precipitation is a highly complex and nonlinear process. Any change in radiation and energy balance (Eq. (1)) affects components of the water cycle (Eq. (2)).

$$R_n = R_S^{\downarrow} - R_S^{\uparrow} + R_L^{\downarrow} - R_L^{\uparrow} \quad (1)$$

and

$$P - Q - G - ET = \Delta S \quad (2)$$

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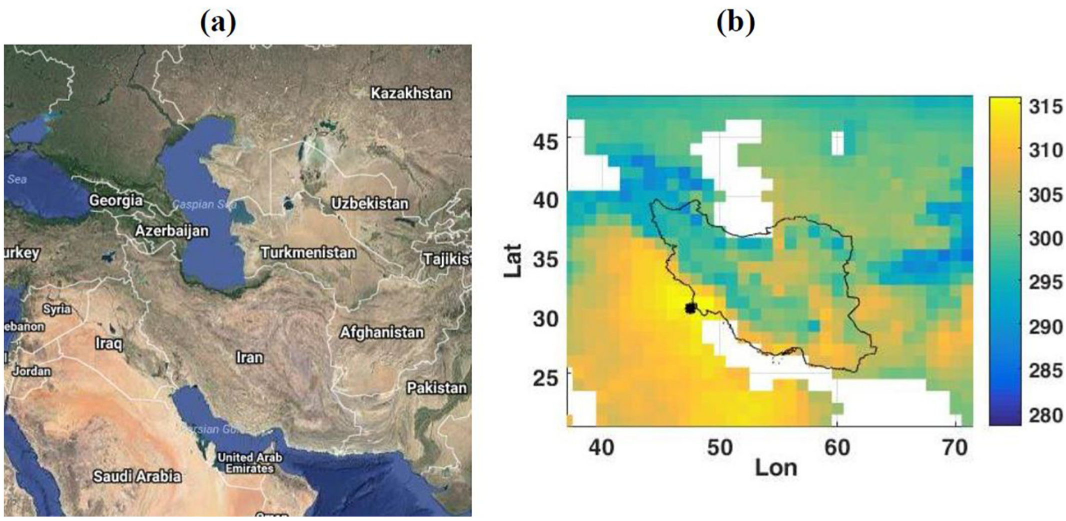


**Fig. 1.** (a) Map of Iran and Neighbors (obtained from Google Map), (b) Average temperature in August 2015 over Iran and neighboring countries. The black circle shows the place with the maximum temperature.

where $R_n$ is net radiation, $R_S{}^{\downarrow}$ is downwelling shortwave, $R_S{}^{\uparrow}$ is upwelling shortwave, $R_L{}^{\downarrow}$ is downwelling longwave, and $R_L{}^{\uparrow}$ is upwelling longwave radiation. For further details in Eq. (1), the reader is referred to Moghim et al. (2015). $P$, $Q$, $G$, $ET$, and $\Delta S$ refer to precipitation, runoff, groundwater, evapotranspiration, and storage changes, respectively. Different cloud types with varied features (e.g. albedo, thickness) play a critical role in net radiation changes, which can lead to different precipitation patterns. Increase (decrease) in precipitation can increase (decrease) runoff and soil moisture, which directly influences extreme hydrological events such as flood (drought).

This study focuses on Iran extending from 25°N to 40°N latitude and from 44°E to 64°E longitude (Fig. 1). Iran, the second-largest country in the Middle East, has diverse climate (from arid and semi-arid to humid climate). This country has different land covers such as forest, pasture, agriculture, bare land, desert, and also two main landforms including mountain ranges and seas in north and south. Iran like many other countries in Middle East and North Africa has been experiencing natural and human-induced climate variation, which causes extreme hydrological events such as droughts and floods. While those regions lack climate studies and impact assessments to evaluate current issues and report the results.

Evidence indicates that damages and economic losses from natural disasters are increasing significantly in Iran. For instance, strong storm hit Iran in 2015 that had serious impacts on different provinces. Damages caused by heavy rains in southern Iran costed about 60 million dollars. Floods had severe damages on many houses (at least 900), infrastructure, water and power supply (FloodList, 2008). Iranian Red Crescent reported strong floods and landslides in northwest of Iran that caused loss of life (at least 42) and significant property damages in 2017 (FloodList, 2008). The National Drought Warning and Monitoring Center (NDWMC) reported a 50% decrease in annual precipitation over 40 years in Sistan and Baluchestan Province in southeast of Iran (Financial Tribune, 2015). This reduction leads to severe droughts that influence food quality and quantity, economy, health, and people's livelihood (Provincial Disaster Management Authority, PDMA Balochistan, 2012).

Evidence indicates that Iran is facing more frequent and severe natural disasters and extreme weather events. Communities need to adapt to changes and mitigate damages. This study can provide an integrated assessment of climate variability and its impact on the hydrological cycle in Iran. Section 2 describes methods and data that are used in this work. Changes in the water and energy budget are explained in sections 3 and 4, respectively. Different patterns of hydrometeorological changes are discussed in section 5, followed by their interconnection changes in sections 6. Discussion and concluding remarks are pointed out in Section 7.

## 2. Methods and data

Climate studies require long-term datasets, which are usually limited in the Middle East. Lack of observed data in Iran affects climate research, impact assessments, and policy-making processes. To reduce the risk of loss and damage from climate change and protect ecosystem and natural resources, we need to use available data and evidence to assess current and projected changes. This study aims to analyze the hydrometeorological variables to clarify connections between climate variations, hydrometeorological changes, and extreme weather events that most regions like Iran have been facing. The analysis of these linkages clarifies how hydrometeorological variables change mutually through the water cycle and energy budget. For the analysis of hydrometeorological variation, reliable climate data are needed. Many studies have used GCMs to analyze climate changes (e.g Trenberth, 2011; Kharin et al., 2007; Liepert and Previdi, 2009, among many others). The large uncertainty associated with the GCMs for climate studies is of great concern (e.g. Deser et al., 2012; Dobler et al., 2012; Solomon et al., 2007, among many others). Thus, this study uses GLDAS product to analyze and assess climate variation over one of the regions in the Middle East (Iran) that has been experiencing many environmental issues due to lack of climate studies. For instance, Lake Urmia in northwest Iran, which was once the second largest saline lake in the world, has been drying fast.

Global Land Data Assimilation System (GLDAS-2.0 and 2.1) product can provide optimal fields of fluxes and water cycle components (Rodell et al., 2004). GLDAS uses data assimilation techniques and integrates satellite data and ground observations into the advanced land surface models (LSMs) including Catchment, Noah, the Community Land Model (CLM), and the Variable Infiltration Capacity (VIC). GLDAS-2.0 is forced by the Princeton meteorological forcing data (Sheffield et al., 2006) and GLDAS-2.1 is forced by the National Oceanic and Atmospheric Administration (NOAA), Global Data Assimilation System (GDAS) atmospheric analysis fields (Derber et al., 1991), the disaggregated Global Precipitation Climatology Project (GPCP) precipitation fields (Adler et al., 2003), and the Air Force Weather Agency's AGRicultural METeorological modeling system (AGRMET) radiation. GLDAS provides a long-term global (excluding Antarctic) dataset extending from 1948 to present at 3-hourly and monthly resolution.