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An Assessment of the Unprecedented Extreme Precipitation Events over Iran: From Satellite Perspective

A Report by the Center for Hydrometeorology and Remote Sensing (CHRS), University of California, Irvine

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Highlights and summary of findings

1. **Total rainfall accumulation from March 20th to April 21st, 2019 for the Western part of Iran was close to 40% of the mean annual rainfall from 2003 to 2018**.
2. The rainfall accumulation for the western cities of Shiraz, Khorram Abad, Ahvaz, and Shahre Kord is 78%, 71%, 52%, and 49% of the mean annual rainfall from 2003 to 2018 for each city, respectively.
3. **The total amount of rainfall in five days (March 24th-25th and March 30th-April 1st) were responsible for 40 to 65 percent of total accumulation for the major cities over the Western part of Iran** during the entire month (March 20th to April 21st).
4. Based on our 35-year record of satellite observations (PERSIANN-CDR) **the total amount of precipitation for the entire 30 days period of March 20th to April 21st (Month of Farvardin, 1398) represents the highest ever recorded**.
5. Our high resolution (4-kilometer, half-hour accumulation) data also shows that **the city of Poldokhtar in Lorestan Province received 33 mm of rainfall in an hour** (at 6:00 am local time), which intensified the engulfment of the city by flood water and turned some roads into a river.

Takeaways

1. This is another in a series of wake-up calls about the future of global climate norms and a clear example of the consequences of climate change on the intensification of the hydrologic cycle of our planet, **which is resulting in global record-breaking extremes (both floods and droughts)**.
2. After almost a decade of persistent drought**, it only took a small number of back-to-back atmospheric rivers (ARs) to be favorably positioned by atmospheric circulations to bring unprecedented amounts of record rainfall and eliminate hydrometeorological droughts in a very short time**.
3. **Similar situations have been experienced globally** and with respect to the United States, the recent (2018-2019) extreme rainy seasons in California and Texas are good examples.
4. The main take-home message is that **the need for adaptation policies and mobilization to cope with the consequences of such extremes and their associated hazards is greater than ever**.

Background

A series of devastating floods and flash floods have deluged large parts of Iran following the unprecedented rainfall events from March 17th to April 20th. Moisture-loaded atmospheric river (AR) events targeted northern regions on the shores of the Caspian Sea started in Golestan Province in northeast Iran, followed by several extreme events impacted 25 out of 31 provinces of the country, and major cities including Tabriz, Tehran, Shiraz, Khorram Abad, Shahre Kord, Mashhad, Kerman, Ahvaz, and Gorgan. The hardest-hit city was Shiraz with a population of 1.8 million. Shiraz is about 100 miles inland with a Mediterranean climate, averaging 48.5 mm of rain in March, according to the World Meteorological Organization (https://public.wmo.int/en). These recent torrential downpours in Iran can be attributed to a large-scale meteorological phenomenon that originates from the Middle East and Europe. The narrow high-pressure jet streams traveling through two primary corridors over Europe and northern Africa hit the cloudy regions with low-pressure system near the Mediterranean region. As a result, they expelled the clouds to the Middle East region and generated heavy and persistent rainfalls over Iran, Iraq, and Afghanistan. The heavy storms coincided with the seasonal melting of snow cover over the mountainous regions, which caused unprecedented flooding in many parts of Iran. At the time of this writing, at least 76 people have been reported dead, along with hundreds of injured and millions forced to relocate. The damage is expected to cost around $2.5 billion dollars and as official Iranian News Agency (IRNA) reports, more than 14,000 kilometers of roadways and 10,900 infrastructures including bridges, channels, and culverts have been destroyed (http://www.irna.ir/fa/news/83278793).

However, not all the news is bad. Water levels in Lake Urmia, the second-largest saltwater lake in the Middle East, rose by 62 cm compared to spring 2018. This lake is located in northwestern Iran and has shrunk by 80% in the last three decades due to drought and high water demands on the lake. The torrential rains have replenished the water levels of this aquatic gem and expanded its volume nearly two-fold from a year ago from intense rains and the seasonal melting of snow cover in the mountains (https://earthobservatory.nasa.gov/images/144848/reviving-the-shriveled-lake-urmia).

The ground-based observations from gauge networks and weather radars suffer from a poor distribution over Iran and the data is not easy to access. Moreover, they cannot provide a full image of the meteorological phenomena that roots from hundreds of miles away and expands to a large spatial domain that impacts several countries. Satellite-based precipitation products provide valuable information on the spatial characteristics and the temporal evolution of the extreme precipitation events such as the ones that hit Iran, recently. Precipitation Estimation from Remotely Sensed Information using Artificial Neural Network-Cloud Classification System (PERSIANN-CCS) is a satellite-based operational product that provides half-hourly rainfall estimates at 0.04°x0.04° (approximately 4 km) spatial resolution (Hong et al. 2004). It uses the infrared (IR) imagery from the geostationary satellites and extracts the cloud features such as coldness, geometry, and texture to estimate rainfall. PERSIANN-CCS is a useful tool for monitoring and analyzing extreme precipitation events in near-real-time at a quasi-global scale (60°N to 60°S).

PERSIANN-CCS estimates of the recent extreme events

The PERSIANN-CCS product is used to track and monitor the recent extreme rainfall events that impacted major parts of Iran during March and April 2019 and yielded close to 346.65 billion cubic meters of rainfall over Iran. Daily accumulated precipitation estimates by PERSIANN-CCS over Iran from March 20th to April 21st, 2019, is displayed in Figure 1. **Daily accumulated figures demonstrate the initiation of two major extreme precipitation events from west and south-west of Iran and their propagation toward the central and eastern regions of Iran.** Figures 1a and 1b present the magnitude of daily extreme precipitation event hitting western and southwestern parts of Iran on March 24th and March 25th with highest precipitation value of 171 and 201 mm, respectively. Subsequently, another extreme precipitation event impacted the same regions on March 31st and April 1st with highest precipitation value of 143 and 141 mm, respectively (Figure 1c and 1d).

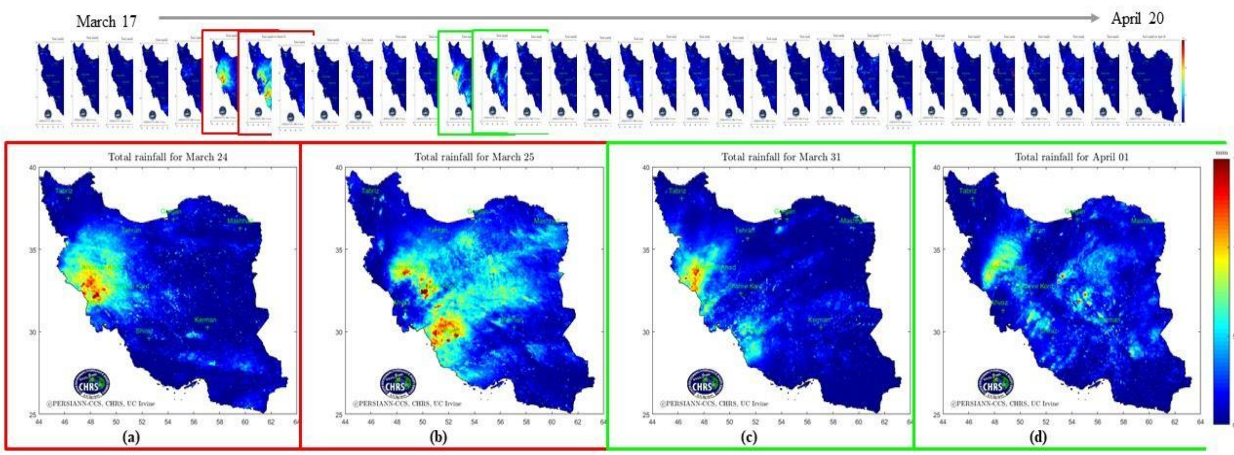

Figure 1. The spatial distribution of daily precipitation from PERSIANN-CCS (03-17-2019 to 04-01-2019); (a) daily rainfall on 24 March; (b) daily rainfall on 25 March; (c) daily rainfall on 31 March; (d) daily rainfall on 1 April.

Mean daily precipitation values from March 21st to April 20th for nine major cities of Iran, namely Tehran, Tabriz, Shiraz, Khorram Abad, Shahre Kord, Mashhad, Kerman, Ahvaz, and Gorgan, are summarized in Figure 2. Succinctly, **the highest amount of daily precipitation estimated by PERSIANN-CCS is 93 and 124 mm for Khorram Abad and Shiraz on March 24th and March 25th, respectively.**

Figure 3a displays the spatial pattern of the cumulative rainfall for the period from March 21st to April 20th over Iran. **As seen, cities of Khorram Abad, Shahre Kord, and Shiraz are the places that experienced the highest cumulative rainfall during a short period (March 21st to April 20th). These cities are also among the places that experienced massive and destructive floods subsequently after the consecutive intense rainfall events.** Additionally, following the heavy and persistent rainfalls over the western and southwestern Iran, the city of Ahvaz—located downstream of Khorram Abad and Shahre Kord—experienced devastating floods.

In order to understand the significance of the recent rainfall events in terms of total rainfall, the cumulative precipitation map for 2018 (Figure 3b) and the mean annual precipitation between 2003 to 2018 (Figure 3c) is presented. According to these figures, the cities of Khorram Abad, Shahre Kord, and Shiraz received between 50% - 80% of their mean annual rainfall during this short period. Furthermore, **there are significant rainfall accumulations over the northwestern part of Iran near the city of Tabriz which has brought a considerable volume of water to the shriveled Lake Urmia and contributed to the restoration of the lake that had been suffering from long-term desiccation. Comparison with the gauge data**

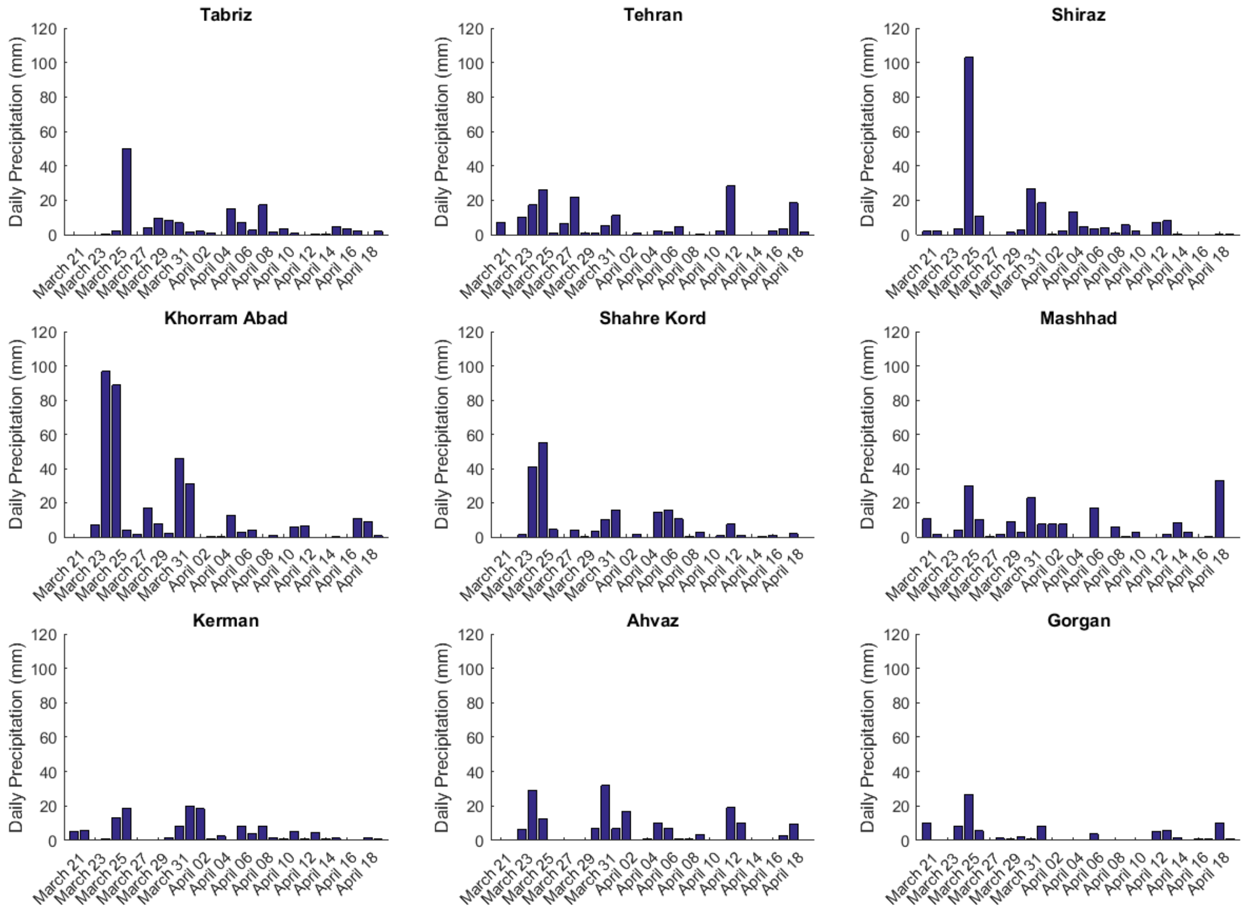

Figure 2. Daily precipitation data estimated by PERSIANN-CCS for Tabriz, Tehran, Shiraz, Khorram Abad, Shahre Kord, Mashhad, Kerman, Ahvaz, and Gorgan.

Cumulative rainfall estimates for a similar period (March 21st to April 20th, 2019) from a number of gauge stations, provided by the Khuzestan Water and Power Authority (KWPA), that are located in the western and southwestern Iran are displayed in Figure 4a. According to this figure, the spatial pattern of the cumulative rainfall from the limited gauges in that area is consistent with the PERSIANN-CCS estimates (Figure 4a), where the areas near the cities of Khorram Abad and Shahre Kord show the highest total accumulations. In terms of total rainfall amount, the PERSIANN-CCS estimates are comparable with the gauge-based observations.

Aside from the total rainfall estimates, the performance of PERSIANN-CCS in capturing the extreme rainfall events throughout their evolution has been evaluated using the gauge-based observations. Figure 5 presents the time series of precipitation from the gauge stations that recorded intense rainfall (i.e. >300 mm) from March 21st to April 20th compared with the PERSIANN-CCS estimates in the same pixels. It could be inferred that the patterns in both rain gauges and the satellite-retrieved precipitation are in agreement specifically for the occurrence time and magnitude of peak values.

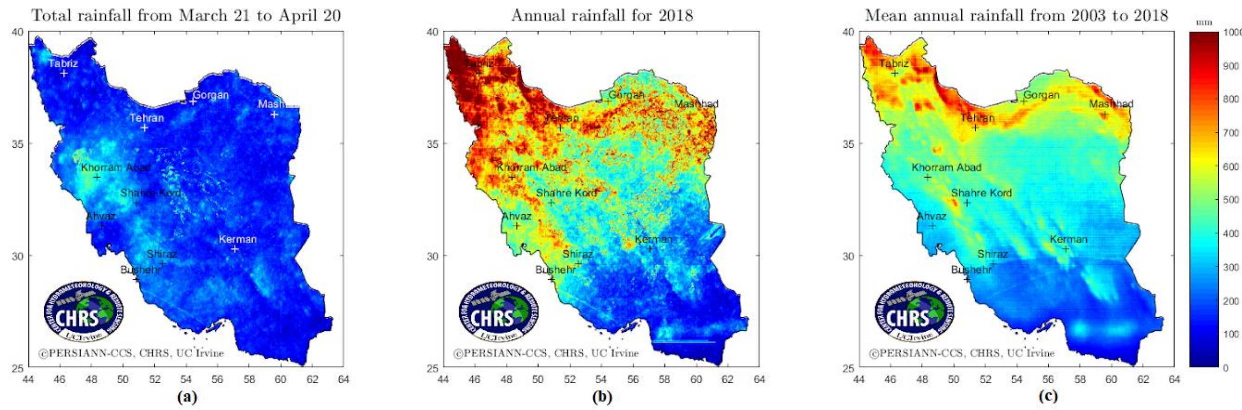

Figure 3. Spatial distribution of (a) accumulated rainfall during the period of March 21 to April 20, (b) accumulated rainfall for 2018, and (c) mean annual rainfall from 2003 to 2018 for the entire country of Iran.

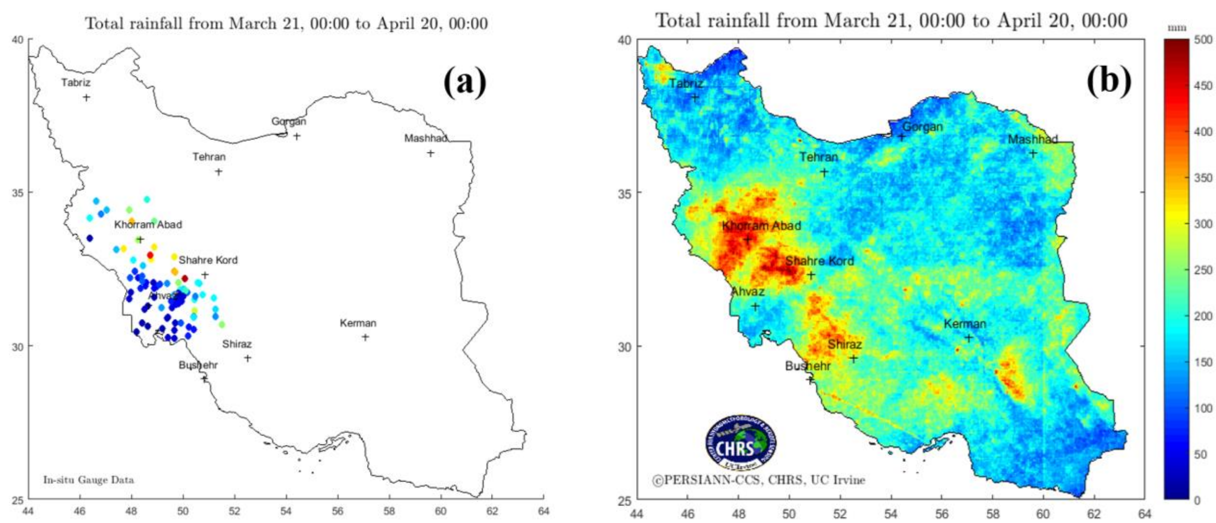

Figure 4. (a) Spatial distribution and the total rainfall amount of rain gauges; and (b) PERSIANN-CCS estimates for the same period over Iran.

The impact of recent rainfall events on Lake Urmia

The bright side of the torrential rainfall events was their contribution to the replenishment of Lake Urmia, the second-largest saltwater lake in the Middle East. As depicted in Figure 6, the Lake Urmia basin has received a considerable amount of rainfall in 2018 compared to the preceding years. As a result, many of the reservoirs have been at their near full capacity at the beginning of 2019 (https://www.farsnews.com/azarbaijan-gharbi/news/13971228000507). **Following the extreme precipitation events in the first months of 2019, which in terms of accumulated value is roughly equivalent to the mean annual precipitation of the preceding years, led to a massive release of water from some of the reservoirs in the basin. Consequently, the lake has revived its volume by almost a factor of two compared to spring 2018.** As stated by a local official, the size of Lake Urmia had expanded by 593 square kilometers, taking it to around 3,000 square kilometers. Its depth increased by 62 cm in the rains. (https://en.mehrnews.com/news/144155).

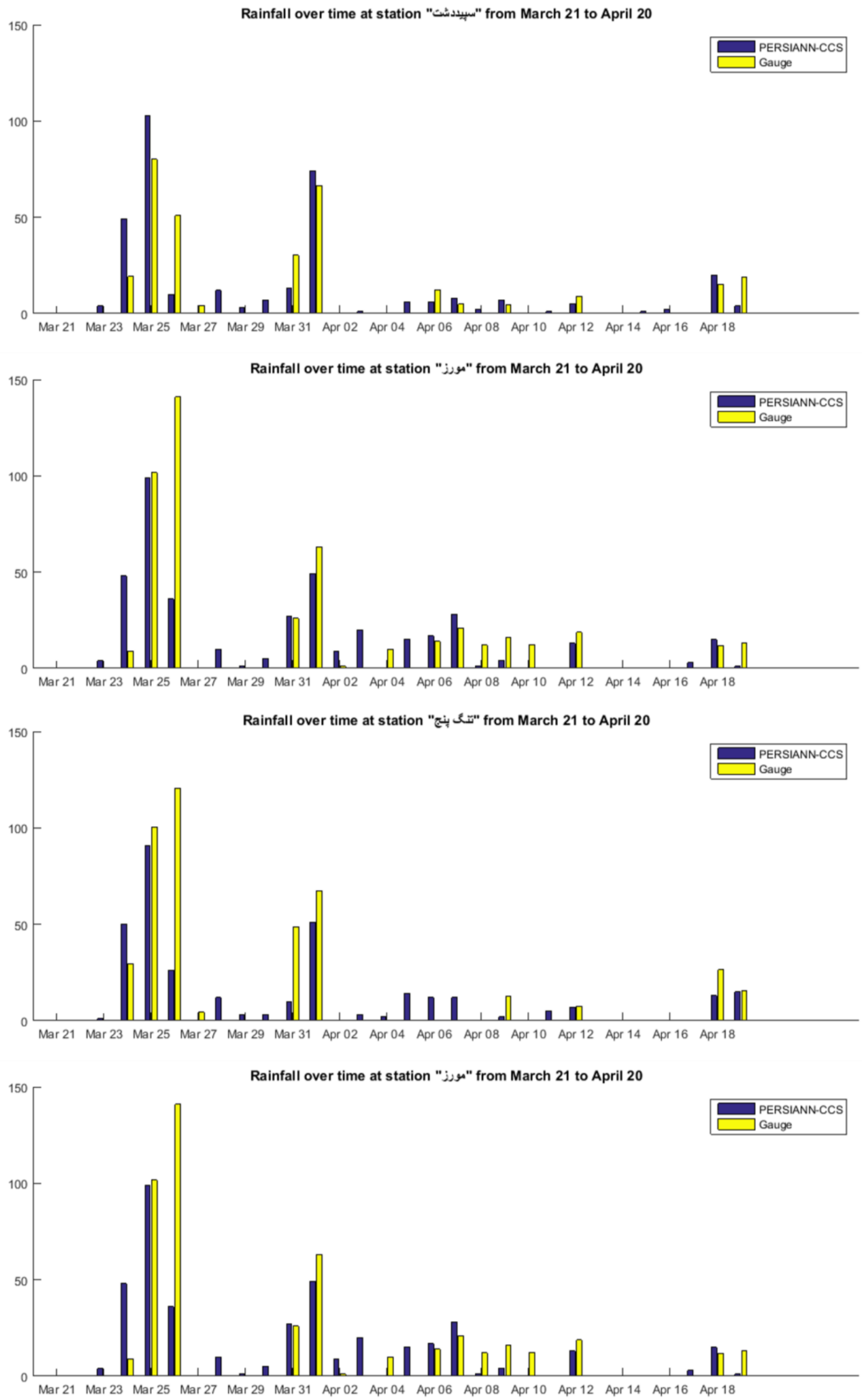

Figure 5. Comparison of rainfall time series for PERSIANN-CCS and gauge data in selected stations with accumulated rainfall of 300 mm or more.

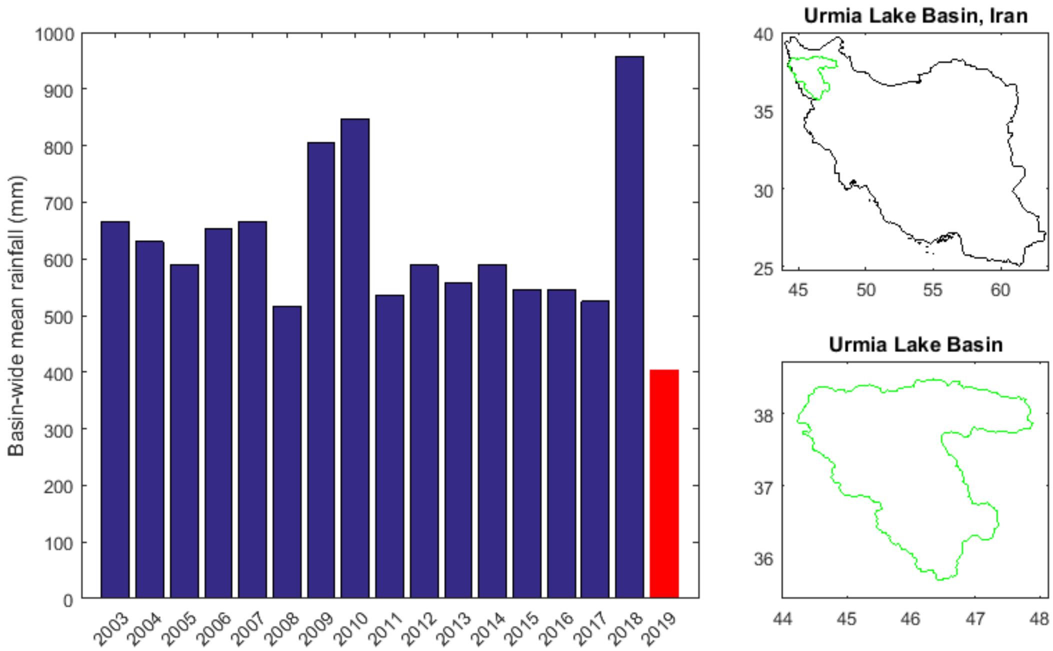

Figure 6. Lake Urmia basin location and the mean rainfall for the region from 2003 to 2018 and first 4 months of 2019.

More information and the next steps

Near real-time PERSIANN-CCS data can be visualized and manipulated using various GIS tools for monitoring and analyzing extreme precipitation events via CHRS iRain (http://irain.eng.uci.edu). Additionally, the PERSIANN-CCS product is freely available and can be downloaded from the CHRS Data Portal (https://chrsdata.eng.uci.edu). It provides access to real-time precipitation information across the world, which is of interest to engineers and water resources managers. This information is useful for monitoring and managing natural hazards such as flash floods and landslides, managing the early warning systems, and reservoir operation and management. More information on the development of this product and its performance across various climatic conditions can be found in Hsu et al. (1997), Sorooshian et al. (2000), and Nguyen et al. (2018 and 2019).

More information about the recent extreme rainfall events over Iran from the eye of satellites can be accessed from the CHRS website (https://chrs.web.uci.edu).

CHRS Homepage

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