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A Case Study of Extreme Temperature with Air Pollution and Health Risk in Yazd Province during July 2019

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ABSTRACT

This investigation aims to study synoptic analysis in the dynamic structure accompanied by air pollution of extreme heat during July 2019 in the Yazd province. The time-series data analysis for the yearly surface air temperatures during the past two decades shows a significant peak surface air temperature in July 2019 in Yazd province. The long-term mean and anomalies of the daily basis (2001 to 2019) for the daily mean sea level pressure show a decrease in pressure with a maximum of about 6 hPa and an increase in geopotential height at 500 hPa with a maximum of about 20-30 gpm (geopotential meter), which has led to an increase in the average daily temperature of about 2 to 4 degrees Celsius. Also, showed high values for Ozone mass mixing ratio over the study area mostly over the west with a maximum of ~92 ppb in Yazd province on 1 July 2019. The AIRS (Atmospheric Infrared Sounder on NASA's Aqua satellite) data shows a positive trend (2003- 2019) for the total daytime Ozone column-averaged over the study area during July. Furthermore, the results of this work obtained from OMI satellite observation show a significant increase in the ultraviolet aerosol index (UVAI) during the study period time. This study shows the recent extreme weather changes in the study area which may be necessary for a better future forecast for heat warnings along with poor air quality and health risk when such events may happen in the future.

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INTRODUCTION

Human activities have significantly changed the Earth's atmosphere over the past hundred years (Sha et al 2017; Wang et al 2019). This caused an increase in the concentration of greenhouse gases leading to global warming, resulting in changes in climatic indexes and increasing the intensity and frequency of climatic events (Lucas et al., 2002; López-Moreno et al., 2011; Mirhosseini et al., 2013; Wang et al., 2014; Sadegh et al., 2018; AghaKouchak et al., 2020). At present, climate change and the resulting environmental issues are one of the main scientific, social, and even political issues of the recent century. One of the most important borderlines of climate change events is the temperatures extreme and heat waves, which are of great importance in the economic and social spectrums every year in terms of the frequency of occurrence and the resulting human and financial injuries (Smith et al., 2013; Brown et al., 2015; Fan et al., 2015). Also, the study of the annual mortality rate due to climate hazards shows that extreme temperatures and heat waves cause human health impacts and the highest mortality rate in comparison to other climatic events (Anderson and Bell 2011; Peng et al., 2011; Smith et al., 2013; Shehadeh et al.,

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2014; Schwartz et al., 2015; Connor et al., 2015; Martinez-Austria et al., 2016; Martinez and Bandala 2018). Among air pollutants, in addition to PM10, PM2.5, CO2, CO, SOx, and NOx, the harmful effects of ozone should not be ignored. Although the presence of ozone gas in the upper levels of the atmosphere prevents ultraviolet radiation and has a favorable performance, the presence of ozone on the surface of the earth is a pollutant and causes various respiratory, skin, and plant diseases (Khansalari et al., 2021). Usually, in warm weather and without clouds, the conditions for the photochemical production of ozone are more favorable. Also, low wind speed and downward motions cause this pollutant to be trapped in the surface layer (Zhang et al., 2020; Fazel-Rastgar and Sivakumar 2023). The effect of high temperatures on health depends on factors such as place of residence, health status, and age of individuals (Ibald-Mulli et al., 2001; Schwartz 2015; Van Loenhout 2018). Certainly, children and the elderly are more vulnerable to it, especially heat waves can exacerbate their cardiovascular and respiratory diseases and ultimately lead to death (Kuwali 2008; Sheffield and Landrigan 2011; Ramis and Amengual 2018; Smith 2019). High temperatures increase the heart rate and increase blood flow to the surface of the skin and eventually severe sweating, if the person cannot expel heat in time, the body may face heat stress and tension (Kenney et al., 2014; Wehner et al., 2017). It was reported that the heatwave which happened during in the summer of 2003 in Europe, was the warmest one since 1540 and France was hit significantly. (Beniston et al., 2004; Luterbacher et al., 2004; Schär et al., 2004; Berman et al., 2017). It was reported with a large number in heat-related deaths mostly in France, Germany and Italy (Luterbacher et al., 2004). Also, another study examined the risk of drought-related deaths between 2000 and 2013 in the western United States and found that in the worst-case scenario, this rate increased by 1.5% (Berman et al., 2017). Extreme heat events are more frequent and occur to a lesser extent in Iran. For example, (Yazdanpanah et al., 2015) analyzed the annual correlation between heat stress index and cardiovascular referrals in Bandar Abbas. Their study showed that this trend has increased. Also, in another research by studying the trend of climatic limit indices have estimated different indices related to precipitation and temperature with RClimdex software (Zand et al., 2023). They resulted that the extreme warming index has an increasing trend. However, the cold extreme indices have had a decreasing trend. As mentioned earlier, global warming causes changes in climatic indexes and increases the intensity and frequency of occurrence of climatic events. Therefore, because of heat extremes including heat waves and heat stress, researchers have conducted several studies to investigate this phenomenon. The first and most important part is to study the extreme heat and the consequences on the health of people in the community. Cardiovascular diseases are the most common cause of death in most countries, including Iran, which are effective factors in exacerbating the disease, including weather conditions and its changes, including heat stress. Therefore, the effect of heat extremes on mortality and the recognition of the relationship between them in the field of health prognosis and issuing of the heat warnings by the Meteorological Organization seems to be necessary (Koppe et al., 2004; Andrade et al., 2021). With the clarification of such a connection, it is possible to save by heat warning at many costs, including medical equipment, energy, medicine, etc. At a time when the country is facing economic sanctions, it is possible to save and, most importantly, to save lives. Rescued compatriots with underlying diseases such as cardiovascular disease, asthma, etc. This work aims to understand the weather structure associated with the recent extreme temperatures in Yazd province during July 2019. The results of this research may provide serious information and early warnings to the people who live in climatic vulnerable regions. For example, the study area can be affected more by possible extreme heat events in the future.

MATERIALS AND METHODS

The computations for this research are limited to the summer season with extreme heat. In this study, firstly, the long-term surface air temperatures for the month of July are analyzed.

Then the maximum and minimum temperatures in a period of 20 years in the three cities in the Yazd, Bafgh, and Ardakan cities in Yazd province and the days with maximum temperature deviation from the average period, which lasted a few days in the region with heat extreme are determined. Next, the synoptic and dynamical patterns of days with heat extreme in Yazd province during July 2019 are investigated. In this study, July monthly and daily mean data of the temperature parameters (maximum and minimum) of three stations in the Yazd province from the Iran Meteorological Organization were obtained. The length of the statistical period used is from 2001 to 2019. Also, the raw data for the yearly seasonal mean surface air temperature, low-level relative, and specific humidity time series has been used from globally gridded datasets produced and extracted from NOAA/ERSL Physical Sciences Division by the National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP/NCAR). This is through the website (www.ersl.noaa.gov/psd) and it has been analyzed. The NCEP monthly datasets (Kalnay et al., 1996) are available from 1948 onwards. This work also examines the ERA5 hourly data (Rienecker et al., 2011) from the European Centre for Medium-Range Weather Forecasts (ECMWF) including sea level pressure, 500 hPa geopotential altitude, 2m altitude temperature, 1000 hPa and 850 hPa, and relative humidity at 850 hPa were used. This study tests the synoptic analysis for the first day of July 2019 and calculates the long-term average of the same quantities in the period from 2001 to 2019. Here, the variable anomalies have been considered as the departures (monthly climatology) from the long-term (2001-2019). Also, in this work the different atmospheric contaminants obtained from NASA´s Modern-Era Retrospective Analysis for Research and Applications (MERRA-2) model, AIRS (Atmospheric Infrared Sounder on NASA's Aqua satellite), and the Ozone Monitoring Instrument (OMI) onboard NASA's Aura satellite were analyzed and investigated.

STUDY REGION

Figure 1 shows a topographical map of Iran (a) with the wider region of the selected cities (Yazd, Ardakan, and Bafgh) in Yazd province (b). Yazd province locates in arid areas and semi-arid [40] and due to the increase in industrial factories with air pollution, and population growth,

Fig. 1. Topographical map of Iran (a) Iran map and the location of Yazd province, (b) and the selected studied cities in Yazd province.

it has experienced significant climatic anomalies during recent years.

RESULTS AND DISCUSSIONS

Temporal variation of temperature

Figure 2 shows a time series for the yearly surface air temperatures from 1948 to 2019 obtained from NCEP datasets. For each year the data has been averaged in July monthly. This figure illustrates a warming shift mostly around the mid-1990s onward associated with an abnormal pattern with a positive slope. Also, previous research has shown a dramatic warming shift associated with an abnormal pattern with a positive slope initiated nearly from 1994 in surface temperatures long-term trend in Iran (Fazel-Rastgar 2021). This time-series data analysis presents a remarkable recent peak point (red upward arrow) at around 30.8 ℃ in July 2019 during the last three decades. However, there are other high values resulting from the reanalysis model, at around 30.7℃ during 1997, 30.4 ℃ in 2003, 29.7℃ in 2013, and 29.2℃ in 2016 for the averaged July temperature. Figure 3 demonstrates two-time series for the low-level humidity (specific and relative) at a level of 850 hPa from 1948 to 2019 in Yazd province. This figure shows a very slight decrease in low-level humidity over the Yazd province during this time. Also, the relative humidity has been slightly decreased at around 12% during July 2019. However, the specific humidity has not significantly changed for July 2019.HUmidity is one of the key parameters which shows how much water there is holding in the air which can be decreased over the land areas due to global warming. In general, the Yazd province including the Yazd city (the capital) known as a desert capital, has a hot and arid climate with low humidity (Keshtkaran 2011). So, the area experiences a dry climate associated with low humidity normally. The raw data has been extracted from the NOAA site (www.ersl.noaa.gov/psd) and considered annual averaged values for the month of July over Yazd province.

Observational meteorological data analysis

The time series of the minimum and maximum temperatures analysis obtained from the Iran meteorological Organization observation reports for the mentioned stations (Figure 4). As the figure shows the data which were observed from July nearly 3decades before 2019 in Yazd (4a),

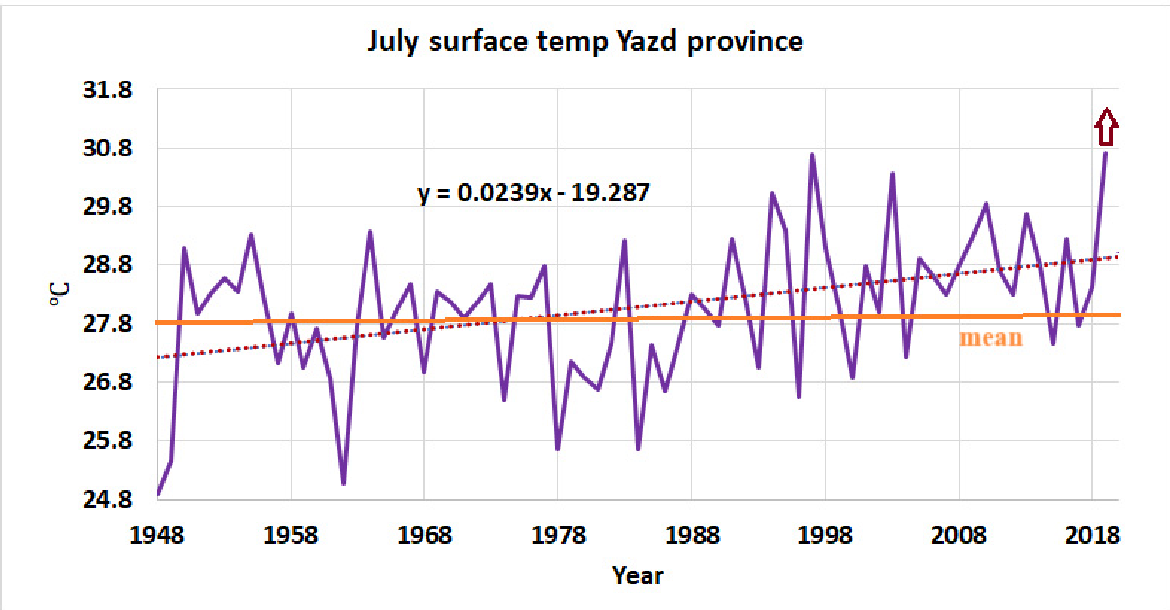

Fig. 2. A time series for the yearly surface air temperature from 1948 to 2019 in Yazd province.

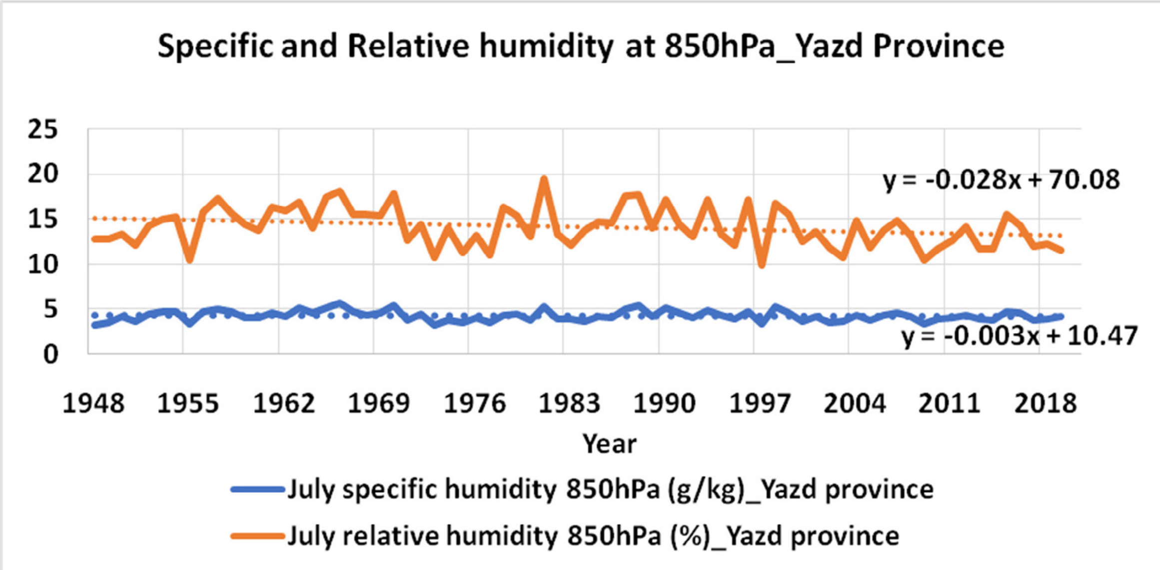

Fig. 3. Two time series for the low-level humidity (specific and relative) at 850hPa from 1948 to 2019in Yazd province.

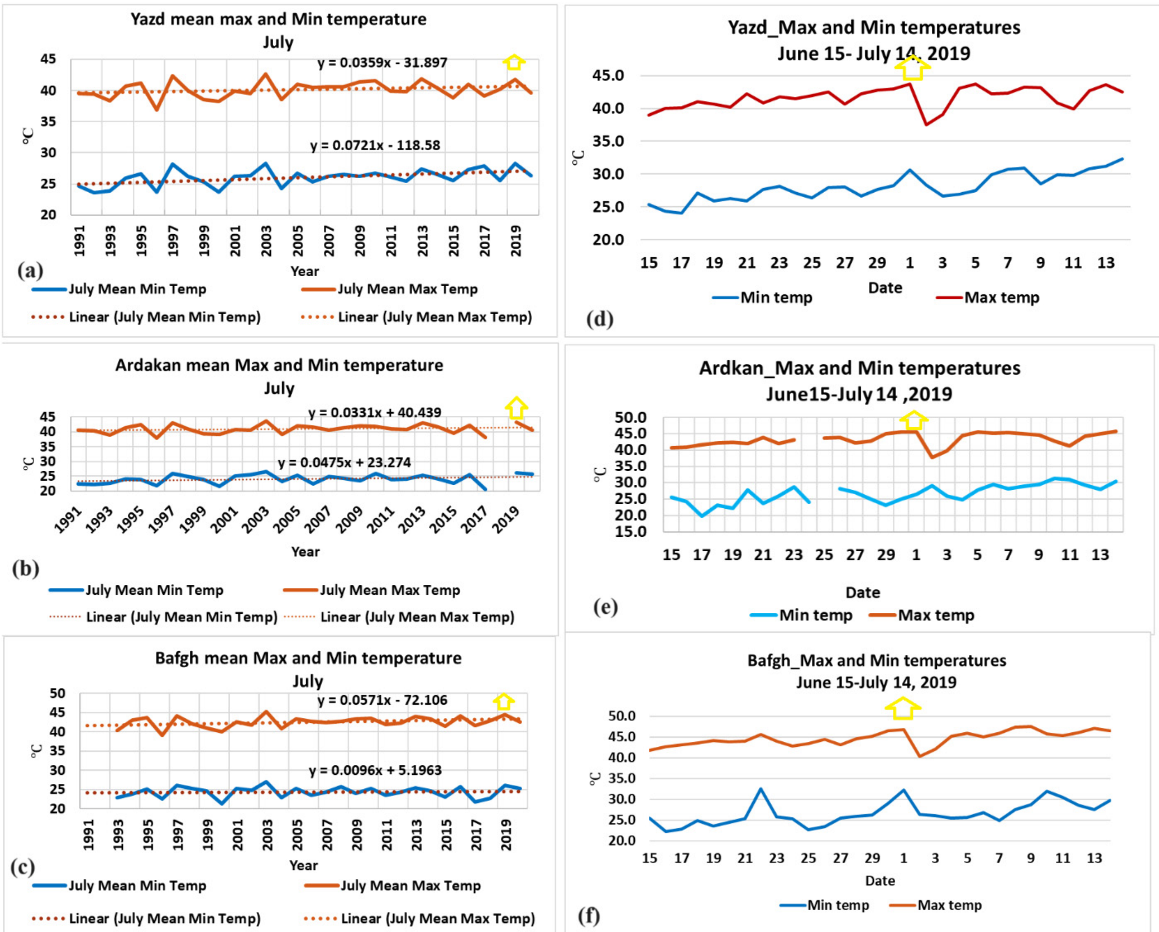

Fig.4. July mean values for maximum and minimum temperatures for Yazd (a), Ardakan (b), and Bafgh(c) for nearly 3 decades before 2019. Daily mean maximum and mean for Yazd (d), Ardakan (e), and Bafgh(f) during June15- July 14 in 2019.

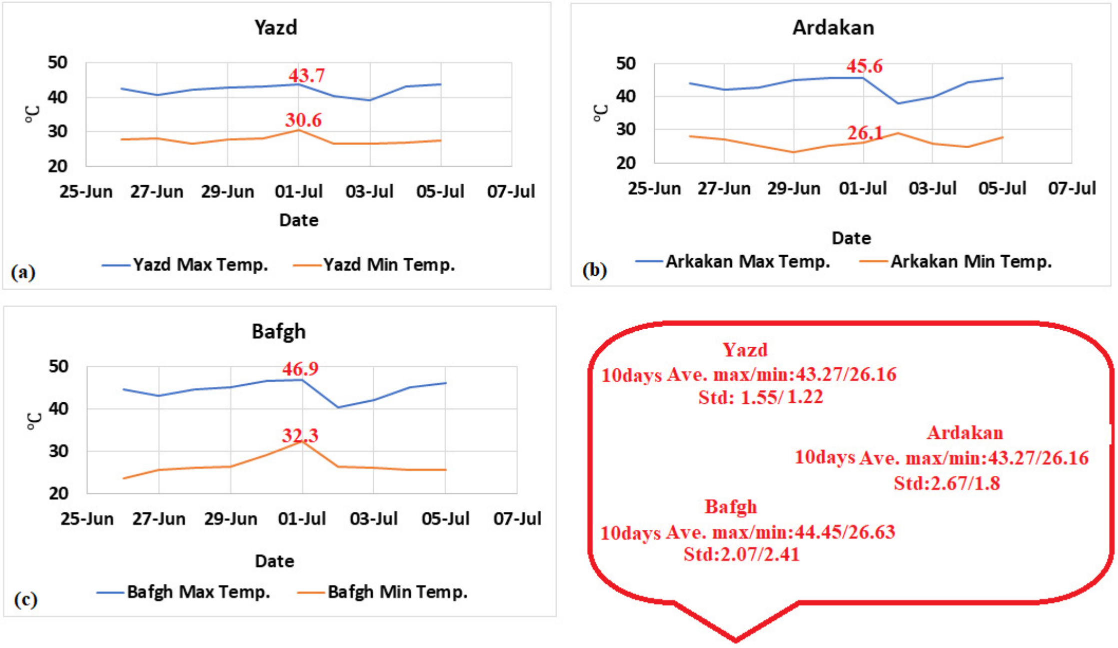

Fig. 5. Time series from 26 June to 5 July 2019 with the comparison of the extreme maximum and minimum temperatures during these 10 days averaged for Yazd (a), Ardakan (b), and Bafgh (c).

Ardakan (4b), and Bafgh (4c) cities, clearly shows the peak points for all mentioned cities in July in, 2003, 2013, 2016 and for the specific case study period during 2019 which has shown with the yellow arrows. This case study focused on the extremely high temperatures on 1 July 2019. So, the daily analysis for June 15- July 14, 2019, for these cities have been depicted in figures 4d (Yazd), 4e (Ardakan), and 4f (Bafgh) showing the peak day (yellow arrows) on the first of July. Also, the daily time series from 26 June to 5 July 2019 with the comparison of the extreme maximum and minimum temperatures with these 10 days interval averaged for mentioned cities have been brought in Figure 5 (a: Yazd, b: Ardakan and c: Bafgh). The observational data for the July monthly changes in 2019 for the surface relative humidity has been brought in Figure 6 for the cities of Yazd (a) and Bafgh (b). This figure shows the peak points for July 2, 2019, the day after the peak day of the extreme temperatures for these cities. When the air gets warm, more molecules can go from the liquid phase to the gas phase. So, there could be more water molecules in the air and the warmer air can hold more water vapor. So, it seems the increase in the air humidity happened shortly after the extremely warm temperatures in the study areas which happened on the first day of July 2019. It can be noted that when the extreme heat can result heath-related problem, the humidity can have extra severity (Russo et al., 2017; Li et al., 2019). The relative humidity was not reported for the city of Ardakan during the study time. The observational data has been reported by the Iran Meteorological Organization for the mentioned synoptic and climate meteorological stations.

Weather system analysis during first day of July in 2019 during extreme heat

Figure 7a shows the pattern of the average daily sea-level pressure (red isobaric lines) on the first day of July in 2019 and its departures (shades colors) compared to the average from 2001 to 2019 which is superimposed on the isobaric map. As it shows, the low pressure has extended into Iran from low latitudes, and it displays two closed low isobaric centers (~ 995 hectopascals) in the Yazd province. The average daily basis (from 2001 to 2019) of the sea level pressure indicates a decrease in the surface pressure with a maximum of about 6 hectopascals

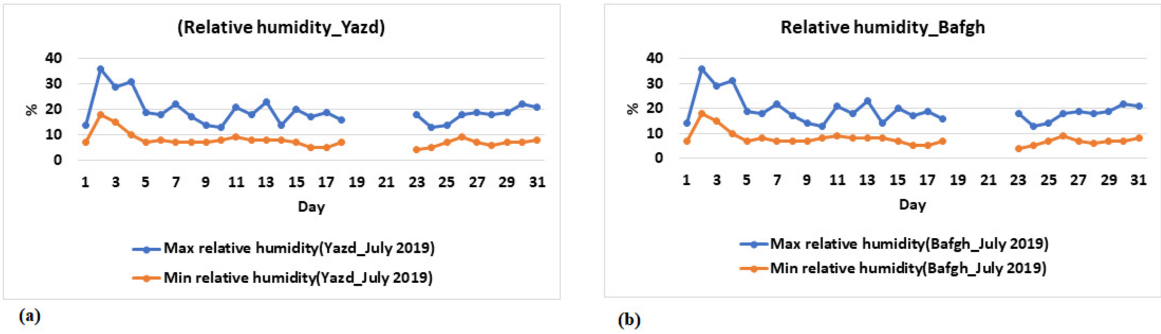

Fig. 6. The observational data for the July monthly changes in 2019 for the surface relative humidity inthe cities of Yazd (a) and Bafgh (b).

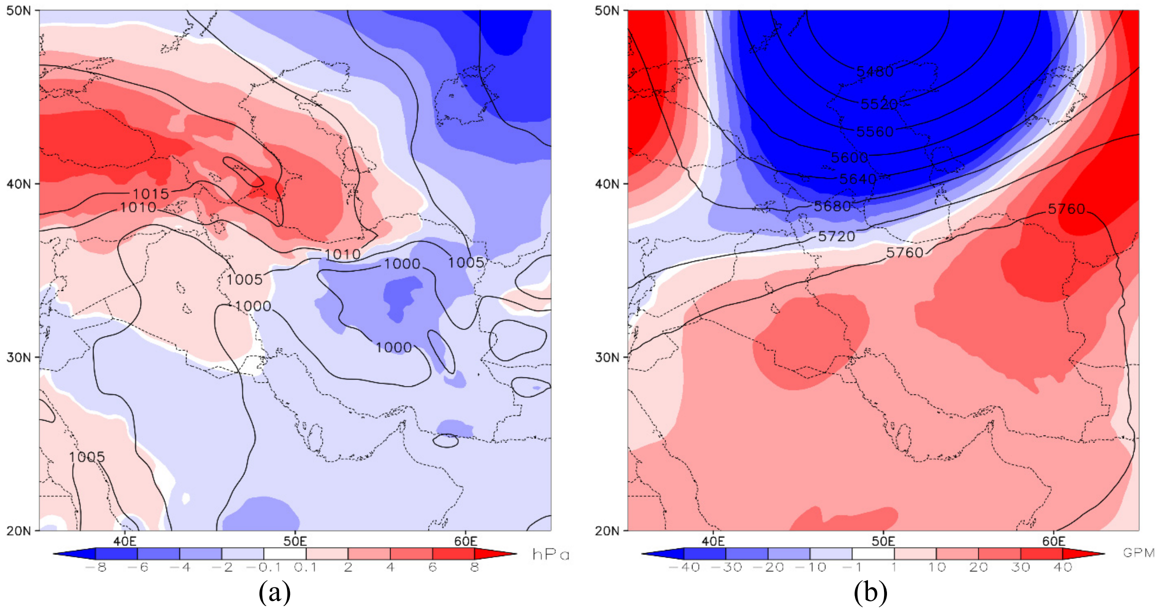

Fig.7. (a) Daily average of the mean sea level pressure in hPa on 1 July 2019 (black contours), anomaly of mean sea level pressure on this day compared to the average from 2001 to 2019 in hpa (shaded areas), (b) Daily average of geopotential height in gpm at 500 hPa on 1 July 2019 (black contours) and anomaly of geopotential height on this day compared to the average from 2001 to 2019 in gpm (shaded areas).

(hPa). This shows heat-low intensification during the extreme heat in the study area in 2019. The daily average of the geopotential height (red color contours) at the level of 500 hPa on the first day of July 2019 and its anomaly values compared to the mean values from 2001 to 2019 (shade colors) are shown in Figure 7b. On this specific day, the subtropical high has been stretched into Iran. This chart also shows that the height of the 500hPa geopotential in northeastern Iran and Yazd province has a significant increase to around 20 to 30 geopotential meters in comparison to the long-term average (2001-2019). Therefore, the map analysis of the surface level (Fig. 7a) associated with rather lower pressure and mid-tropospheric level controlled by higher values (Fig. 7b) has resulted in an increase in air column thickness linked to an increase in air temperature in Yazd province.

Figure 8 shows the low-level temperature pattern along with the superimposed long-term

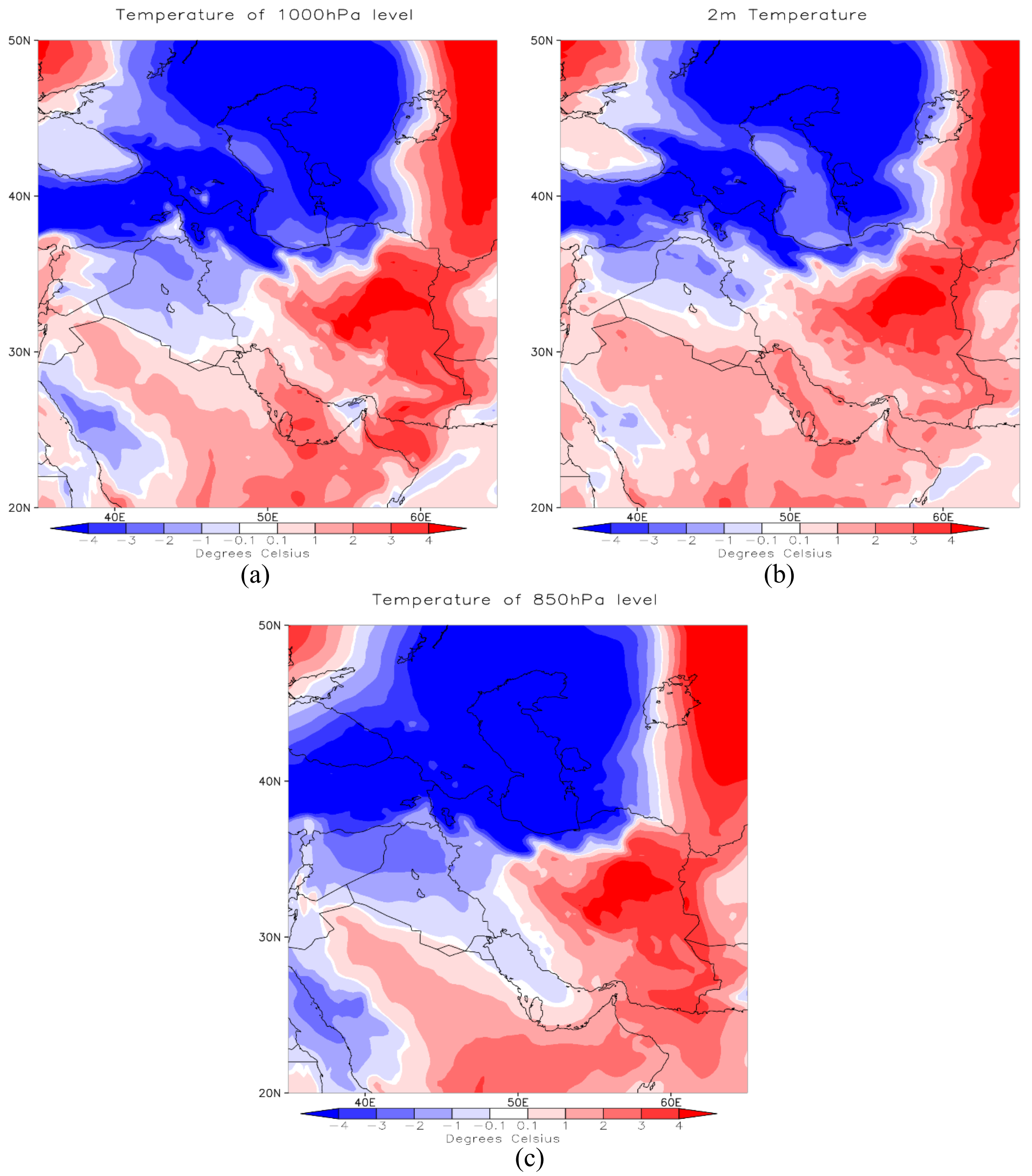

Fig.8. Anomaly of the daily average temperature on1 July 2019 compared to the average from 2001 to 2019: (a) at 1000hpa, (b) at the height of 2 meters, (c) at 850hpa.

anomaly (2001-2019) structures over the study areas. This figure displays around 1-4 degrees increase in the air temperatures at levels of 1000 hPa. (Fig. 8a), at two meters height (Fig. 8b), and 850 hPa (Fig. 8c) The higher temperatures are associated with a rather warmer atmosphere due to rather intensive heat low centered over the central part of Iran. This is associated with the extreme heat event in the study area during the study period.

Figure 9a shows the mean wind vectors during 2001-2020 for July at 200hPa level and figure 9b displays the daily average of wind vectors on 1 July 2019. A comparison of these two figures clearly indicates a stronger (41m/s with respect to 35m/s) and a wavy subtropical jet in 1 July

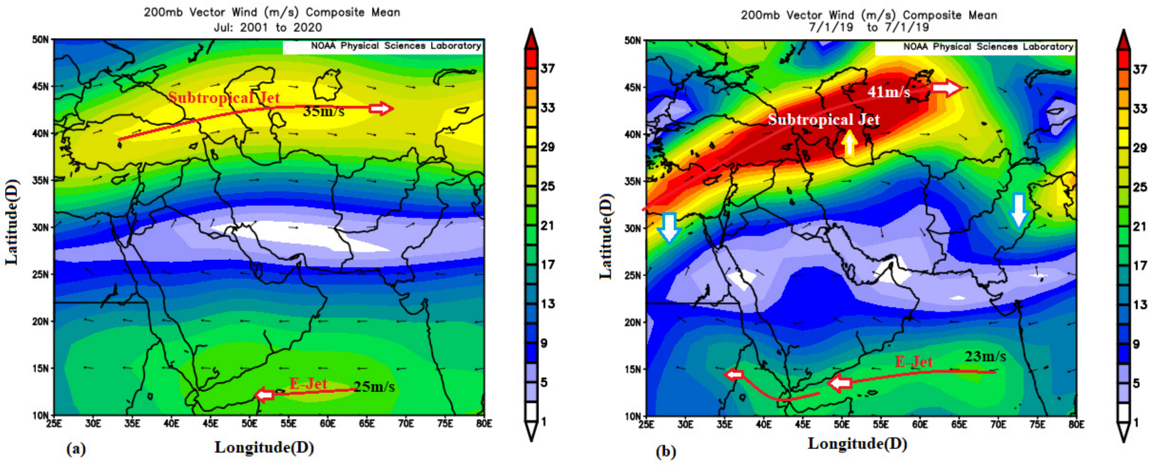

Fig. 9. (a) Mean wind vectors during 2001-2020 for July at 200 hPa level and, (b) daily average of wind vectorsat 200 hPa level on 1 July 2019.

2019 with respect to the long-term average. The jet core for the long-term average (Fig. 9a) is stretching zonally from the west to east nearly at around 37-42ºN (core) and has changed from a nearly westerly axis to the south easterlies and shifted into the north during (see the yellow arrow in Fig. 9b) the extreme event (Fig. 9b). So, the northward shift of the subtropic jet has been caused to an increase in the temperature over the study area. Jet streams play a substantial role in controlling the weather since they normally cause breaking the warmer and colder air. Jet streams affect normally forcing the air masses across and transporting the weather systems to the new regions and impact them to stop if they have relocated too far away. Also, the position of the jet streams is very significant since it controls the northern and southern limits of the main wet and dry belts on the surface. For example, when the subtropical jet stream which marks the edge of the subtropics with warmer air mass moves poleward that indicates the shift of the warmer air into the higher latitudes. Studies have shown that the tropics are expanding at around 0.5degrees per decade based on observations (Staten et al., 2018; Grise et al., 2019). However, despite the poleward tropic extension, the latitude trends of the subtropical jet are smaller than 0.5° per decade (Maher et al., 2020).

Observational air quality and pollution data analysis

Figure 10 displays a high-resolution map (0.25degree) obtained from the MERRA-2 (Rienecker et al., 2011) database for the time average map of the Ozone mass mixing ratio over the study area. This figure presents the high values mostly over the west with a maximum of ~92 ppb in Yazd province on 1 July 2019. Almost most parts of the Yazd province have over 80ppb of Ozone with an unhealthy situation of Ozone pollution. From, 1971, the EPA (U.S. Environmental Protection Agency) has stated the national air quality standards for ozone. The current national air quality standard for ozone is 80 parts per billion (ppb) averaged over 8 hours[1]. Ozone and fine particulate matter are important pollutants regulated under the Clean Air Act by EPA. Low level Ozone is associated with health risk outcomes. Recent study shows that the low-level Ozone can impact on heath and even on mortality (Di et al., 2017).

Figure 11 shows a time series for the ultraviolet aerosol index (UVAI) over the study area from 2005 to 2019 (data availability from 2005). This figure clearly shows a significant increase in the UVAI with high values in 2019 with respect to the past decade. The ultraviolet aerosol index (UVAI) is a method of finding aerosol absorption using satellite measurements. The UVAI

1. https://www.federalregister.gov/documents/2020/12/31/2020-28871/review-of-the-ozone-national-ambient-air-quality-standards

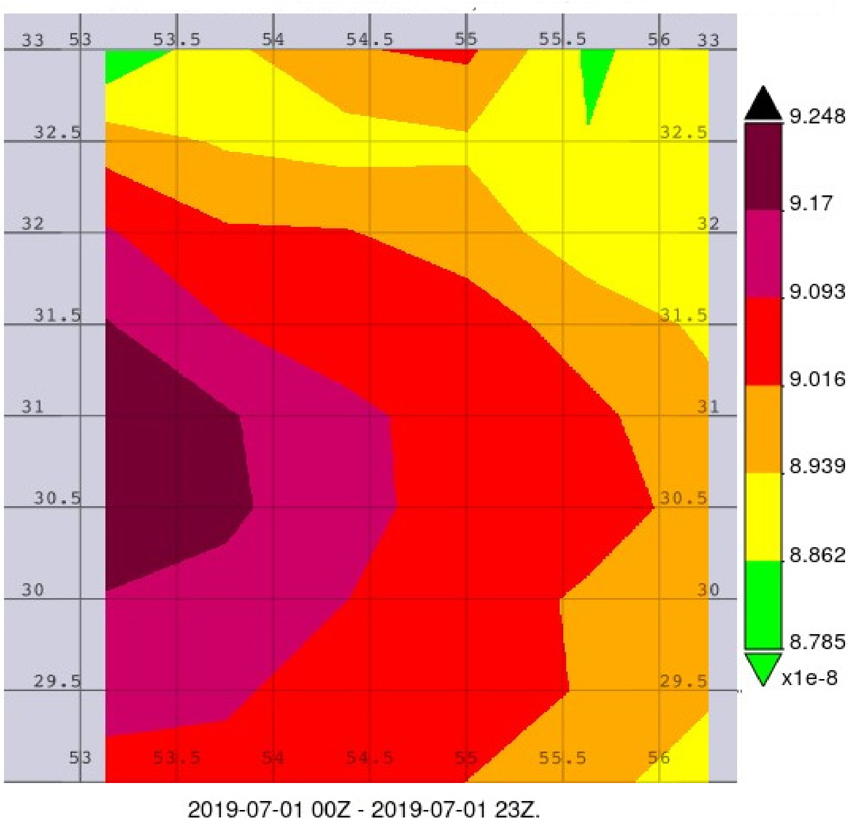

Fig. 10. Time average map of the Ozone mass mixing ratio (10ppb) at 700hPaover Yazd province on 1 July 2019 (obtained from the MERRA-2).

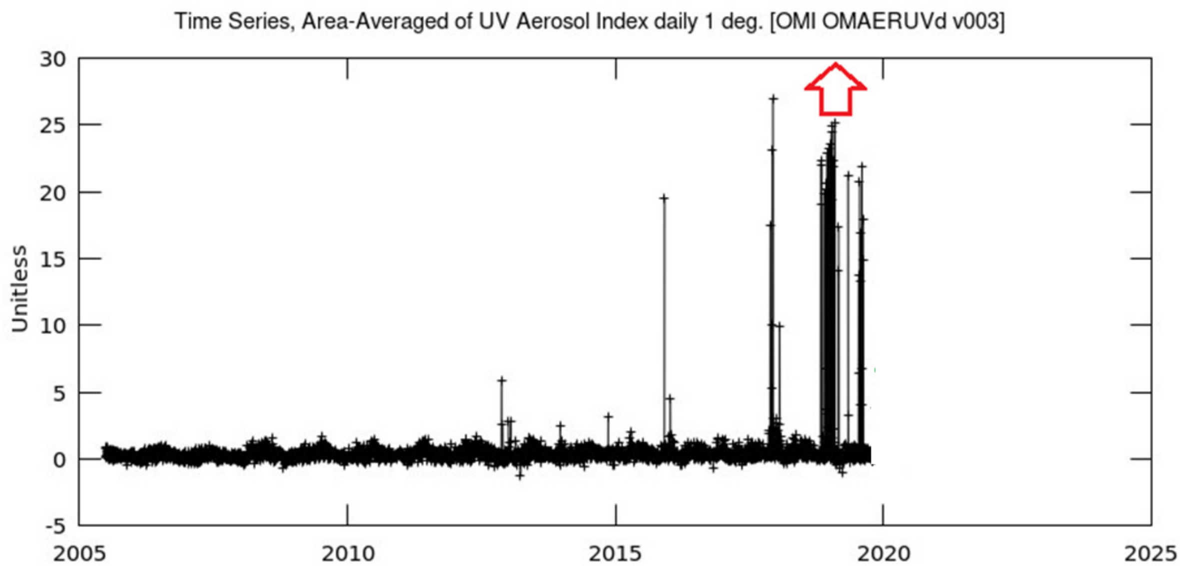

Fig.11. A time series for the ultraviolet aerosol index (UVAI) over the study area from 2005 to 2019.

is computed by breaking the spectral contrast of radiances due to aerosol impacts from those because of Rayleigh scattering at two wavelengths in the near-UV region (Herman et al., 1997; Torres et al., 1998; Torres et al.,2007). The numerical models along with observational data show that the ultraviolet scattering and absorption particles in the boundary layer can accelerate the photochemical reactions which has major implications in the air pollution controlling

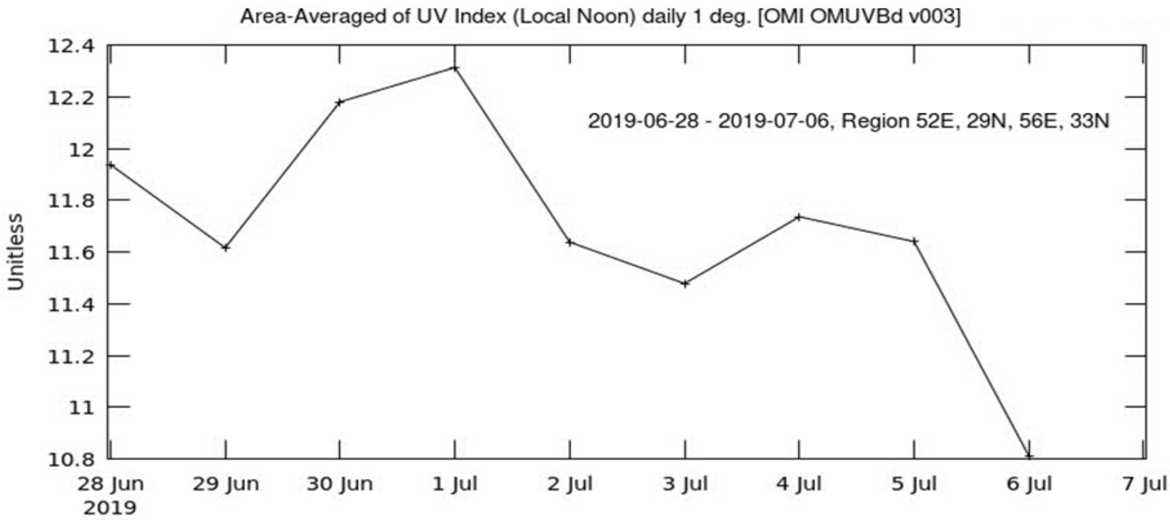

Fig.12. A time series for the UV index (from 28 June to 6July 2019) averaged over the study area.

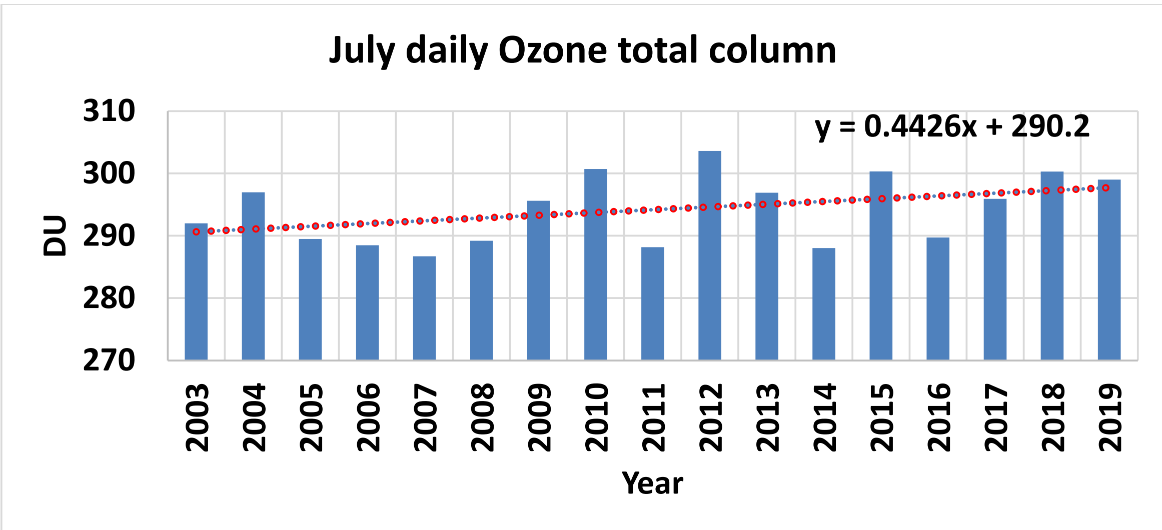

Fig.13. A histogram of the total daytime (2003- 2019) Ozone column-averaged over the study area during month of July

(Dickerson ET AL., 1997).

Figure 12 shows a time series for the UV index (from 28 June to 6 July 2019) averaged over the study area obtained from the Ozone Monitoring Instrument (OMI) onboard NASA's Aura satellite. This figure expresses a peak value on 1 July 2019 (~ 12.3) over the study area. Following 1 July, the UV index peaked, with a second recorded high of 12.2 on 30 June. Subsequently, on 29 June and 2 July, the index was relatively high, registering at 11.6.

Figure 13 shows a positive trend from 2003 to 2019 (data is available only from 2003) histogram of the total daytime Ozone column-averaged over the study area during the month of July. The data was obtained from AIRS (Atmospheric Infrared Sounder on NASA's Aqua satellite) and shows a total ozone column of around 299Dobson unit (DU) in July 2019 covering the Yazd province. Also, this figure clearly shows a positive trend for the past 2 decades associate with an increase in Ozone pollution over the study area.

SUMMARY AND CONCLUSIONS

This study has used multiple datasets including the observational and reanalysis model results to understand the weather structure accompanied by air pollution of extreme heat during July 2019 in the Yazd province. The time-series data analysis has shown a significant peak surface air temperature in July 2019 during the last three decades. Besides, the time series of the monthly and daily minimum and maximum temperatures observed from July 2001 to 2019 in Yazd, Ardakan, and Bafgh cities in Yazd province clearly indicated the peak values for maximum temperature points for all mentioned cities on the first day of July 2019. The composite mean maps during the study period along with the anomalies for the mean sea level pressure display rather more intense heat low and mid-tropospheric ridge at a level of 500 hPa rather than long-term normal value. This is associated with rather lower pressure and higher thickness of the mid-tropospheric air column connected to an increase in air temperature in Yazd province. The low-level temperature forms along with the long-term anomaly structures over the study areas have displayed an increase of 1-4 degrees in the air temperatures at low atmospheric levels of 1000 hPa, 850 hPa, and at two meters of air respectively. The results for the different atmospheric contaminants analysis obtained from AIRS (Atmospheric Infrared Sounder on NASA's Aqua satellite) showed a positive trend (2003- 2019) for the total daytime Ozone column averaged over the study area during the month of July. The data showed a total ozone column of around 299 DU in July 2019 over Yazd province. Also, a time series for the ultraviolet aerosol index (UVAI) over the study area from July 1, 2005, to the end of 2019, shows a substantial increase in the UVAI with high values in 2019 with respect to the past decade. Also, this research showed high values for Ozone mass mixing ratio over the study area mostly over the west with a maximum of ~92 ppb in Yazd province on July 1, 2019.

This research has revealed the existence of the showed poor air quality during the recent extreme heat event over the study area. The results of this study show the recent extreme weather along with poor air quality and health risks in the study area which may possibly be necessary for a better future forecast for heat warning when such events may happen in the future.

For further work, a more thorough identification of different climate and air pollution variables in shorter time scales (sub-daily) would be recommended. However, there is some observational limitation in many regions like the central part of Iran. Also, future work needs to access the healthcare claims data to understand specific rates of cardiovascular admissions, respiratory admissions, and deaths among different age groups. This will give a perspective on the percentage change in health risks when extreme temperatures happen in the study area.

ABBREVIATIONS

NASA: National Aeronautics and Space Administration
AIRS: Atmospheric Infrared Sounder on NASA's Aqua satellite
UVAI: Ultraviolet Aerosol Index
NOAA: National Oceanic and Atmospheric Administration
ERSL: Earth System Research Laboratories
NCEP: National Centers for Environmental Prediction
NCAR: National Center for Atmospheric Research
ECMWF: European Centre for Medium-Range Weather Forecasts
ERA5: Fifth generation ECMWF atmospheric reanalysis of the global climate
MERRA-2: Modern Era Retrospective analysis for Research and Applications, Version 2
OMI: Ozone Monitoring Instrument
EPA: U.S. Environmental Protection Agency
DU: Dobson unit (unit measurement for trace gas measurement in a vertical column through

the Earth's atmosphere)

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GRANT SUPPORT DETAILS

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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