# The Detection of IVT Over Iraq and Surrounding Region and the links to Precipitation Over Iraq

*Ahmed Z. AL-Khawaja[1,*], Dheyaa A. Bilal[2] and Asraa k. Abdul kareem[3]*

[1]Department of Regional Meteorological Training Center, Iraqi Meteorological Organization and Seismology, Baghdad, Iraq
[2]Department of Physics, Collage of Education for Pure Science, ThiQar University, Nasiriayh, Iraq
[3]Department of Atmospheric Science, College of Science, Mustansiriyah University, Baghdad, Iraq

**Abstract:** This study examines the impact of low-level vertically integrated moisture flux (IVT) features on precipitation in Iraq and surrounding areas during the rainy season. The study calculates and analyzes the IVT across the region. It identifies the maximum precipitation linked with IVT from January to December (1981-2020). In addition, it determines the IVT threshold for each month using wind component data (u, v) and specific humidity data. The findings reveal that IVT has a greater impact in dry and semi-arid areas, the Mediterranean Sea and the Red Sea are the main sources of IVT. The Red Sea has an impact on Iraq's south and south-central region while the Mediterranean Sea has an impact on Iraq's north and north-central region. The study also finds a strong correlation between IVT and precipitation over Iraq during the rainy season with the amount of precipitation largely influenced by the intensity and direction of IVT. The results suggest that IVT transfer from the Mediterranean and Red Seas has a significant impact on the amount of precipitation over Iraq and the neighboring areas.

## 1 Introduction

The fluctuation of water is a crucial factor for sustaining life, agriculture, and economic development in the countries of the Middle East, specifically Iraq (Zhu et al., 1998; Rutz et al., 2014). Precipitation, a diverse climatic parameter, significantly influences crop growth in the Middle East and Iraq. It refers to the process where water vapor condenses into water droplets and falls to the Earth's surface (Bozkurt et al., 2021; Dezfuli, 2020; Sadeghi et al., 2021). Adequate precipitation relies on the continuous transport of water vapor from external sources into the region (Ralph et al., 2017). This moisture transport, known as the Integrated Vapor Transport (IVT), forms a crucial link between ocean evaporation and continental precipitation, serving as a primary component of the atmospheric water cycle. In recent decades, the frequency and intensity of extreme climatic events such as droughts and floods have increased due to the IVT. They impact both human populations and natural ecosystems in the Middle East, including Iraq (deVries et al., 2018; Akbary et al., 2019). The movement of water vapor in the lower atmosphere guides the dynamics of the tropospheric atmosphere. Particularly, the heat and momentum in the lower troposphere exhibit strong connections with moisture movement in the troposphere. The general circulation of the ocean and atmosphere plays a vital role in the poleward transport of heat and water vapor, influencing their circulation in the lower troposphere (Schneider et al., 1999). Atmospheric moisture flux primarily exists in the form of water vapor, which is transported by atmospheric circulation and plays a crucial role in determining rainfall as part of the hydrological cycle. Water vapor precipitation is sourced from both local evapo-transpiration (ET) and remote moisture transport. They occur where there is a difference in vapor pressure and radiation between different areas (Li et al., 2012). In Iraq, the rain season of 2018/2019 was the wettest, while the previous season of 2017-2018 was the driest, indicating rapid transitions and intensification of extremes potentially due to climate change (Dezfuli et al., 2019). The formation and persistence of precipitation systems depend mainly on the amount of moisture available at lower levels of the troposphere (de Vries et al., 2018). Low-level moisture flux is a useful tool for predicting precipitation. Alijani's study in 1995 reveals that moisture flux from the Mediterranean Sea is the root cause of precipitation across Iraq and surrounding regions. Another study by Dayan and Abramski in 1983 indicates that the subtropical jet current causes warm and moist air to pass through the Middle East in the middle and higher troposphere. Dezfuli's study in 2020 identifies a strong atmospheric river responsible for the record floods in the Middle East. Additionally, the study by Mohammad Darand and Farshadpazhoh in 2019 identifies vertical integrated moisture flux convergence over Iran. According to the study by David Lavers and Martin Ralph et al. in 2015, there is an intensification of horizontal water vapor transport in cmip5 due to climate change. Aqeel Ghazi's 2021 study focuses on the physical and synoptic characteristics of

*Corresponding author E-mail: aliahmedzuhair2009@gmail.com

torrential rains in Iraq and neighboring regions. Hayat Mahdi Aliakbar's 2021 study examines the impact of severe rains on estimating probable maximum precipitation for selected areas in Iraq. This current work aims to calculate and analyze the low-level vertically integrated moisture flux (IVT) across Iraq and its surrounding areas, investigating the source of moisture flux and studying its effects on the area, and explore the impact of IVT on precipitation in Iraq.

## 2 Materials and Methods



**Fig. 1:** Study Area

Figure (1) illustrates that Iraq is situated in Asia and occupies the northeast region of the continent. Iraq shares borders with Turkey, eastern Iran, Syria, and Jordan to the north, and with Kuwait, Saudi Arabia, and the Arabian Gulf to the south.

To assess the historical state of the earth's atmosphere, re-analyses of the atmosphere that incorporate meteorology are considered the most effective approach. In this study, the primary objective is to compute and analyze the IVT using monthly gridded data. To accomplish this, an interactive desktop tool known as Grid Analysis and Display System (GrADS) is utilized to access, manipulate, and visualize earth scientific data quickly. GrADS offers two distinct data models for managing gridded and station data. It supports various data file formats, including binary (stream or sequential).

Various file formats, including GRIB versions 1 and 2, NetCDF, HDF 4 and 5, and BUFR for station data, are utilized in this study. GrADS, which is widely available online and implemented on various operating systems, is a preferred tool. GrADS operates in a five-dimensional data environment with the four standard dimensions (longitude, latitude, vertical level, and time) and an optional fifth dimension for grids, typically used for ensembles. Data descriptor files are employed to position data sets within the 5-D space. GrADS can handle regular, non-linearly spaced, gaussian and variable resolution grids. To calculate specific humidity (q) in g kg$^{-1}$, zonal wind (u) in ms$^{-1}$, and meridional wind (v) in ms$^{-1}$, we use monthly gridded Ecmwf data from ERA5 at eight distinct atmospheric pressure levels (1000-900-800-700-600-500-400-300 hpa), with a 100 hpa spacing between levels. The data that is employed has a spatial resolution of 0.25*0.25 degrees and a temporal resolution of

1981–2020 for 40 years, with an IVT unit of kg m$^{-1}$s$^{-1}$ for monthly mean precipitation data from the Global Precipitation Climatology Project (NCEP.NOAA-GPCP). We analyze the long-term relationship between precipitation and IVT over this 40-year period, using the IVT equation to calculate IVT. Zhu and Newell (1998) develops an algorithm to identify moisture flux in the troposphere using wind and humidity data, employing a Eulerian framework.

$$\text{IVT}= \sqrt{(\tfrac{1}{g}\int_{1000}^{300} qudp)^2 + (\tfrac{1}{g}\int_{1000}^{300} qvdp)^2}$$

where q is the specific humidity (kgkg$^{-1}$). u and v the zonal and meridional components in ((m s$^{-1}$). g is the gravity acceleration and dp is the pressure difference between two adjacent levels. The roots represent the vertical integral of northward water vapor flux and eastward water vapor flux.

First, we determine the source of IVT for each month during the study period and we calculate the precipitation depend on precipitation data and to find the relation between the IVT and precipitation. We take the high month of rate of precipitation and low rate of precipitation and compare it with the IVT.

## 3 Results

The Mediterranean Sea and Red Sea serve as primary sources of moisture feeding, but changes in wind direction can prevent moisture from reaching these regions. The north and north central regions of Iraq are influenced by the Mediterranean Sea while the south- and south-central regions are affected by the Red Sea. Contrary to earlier studies that show high tensile torrential rains, the feeding moisture flux over Iraq originates from both the Mediterranean Sea and Red Sea. Some of the moisture flux from the Mediterranean Sea crosses over the Red Sea, increasing in strength and feeding up. In January, the maximum IVT value over Iraq was 100 kg m$^{-1}$s$^{-1}$, and the threshold was 200 kg m$^{-1}$s$^{-1}$. For February, the maximum value was 100 kg m$^{-1}$s$^{-1}$ and the threshold was 100 kg m$^{-1}$s$^{-1}$. Some IVT transport from the Mediterranean Sea feeds from the Red Sea, resulting in IVT values ranging between 20 and 100 kg m$^{-1}$s$^{-1}$ with a maximum of 100 kg m$^{-1}$s$^{-1}$ over Iraq. In March, the threshold was 200 kg m$^{-1}$s$^{-1}$ and the feeding of moisture flux over Iraq originated from both the Mediterranean Sea and Red Sea. Some of the moisture flux from the Mediterranean Sea crossed over the Red Sea and fed up. As a result, the IVT value ranged between 40-80 kg m$^{-1}$s$^{-1}$, with a maximum of 80 kg m$^{-1}$s$^{-1}$. The threshold for April was 100 kg m$^{-1}$s$^{-1}$ and the majority of the moisture flux over Iraq came from the Mediterranean Sea, with a small amount coming from the Red Sea. The IVT value over Iraq ranges between 40 and 100 kg m$^{-1}$s$^{-1}$, with the highest value being 100 kg m$^{-1}$s$^{-1}$ and a requirement of 200 kg m$^{-1}$s$^{-1}$ for May. The sources of moisture flux over Iraq include the Mediterranean Sea and the Red Sea, with IVT values ranging from 40 to 140 kg m$^{-1}$s$^{-1}$ and a maximum of 140 kg m$^{-1}$s$^{-1}$. The dry season begins in June with a threshold of 400 kg m$^{-}$

$^1s^{-1}$. It is neither the Red Sea nor the Mediterranean Sea transport any moisture. Across the Mediterranean Sea and Red Sea, wind vector direction reversal can be identified at all levels of the lower troposphere with the largest value over Iraq (140 kg m$^{-1}$s$^{-1}$) as compared to the rainy season. The threshold for July is 600 kg m$^{-1}$s$^{-1}$. It is the same as the dry season in June and the highest value is 150 kg m$^{-1}$s$^{-1}$. The threshold remains the same as June and July while the barrier for August is 500 kg m$^{-1}$s$^{-1}$ with a maximum weight of 150 kg m$^{-1}$s$^{-1}$. In September, the threshold is 300 kg m$^{-1}$s$^{-1}$ and the highest point for IVT is 100 kg m$^{-1}$s$^{-1}$. The threshold of October is 200 kg m$^{-1}$s$^{-1}$. Moisture flux from the Red Sea also begins to reverse direction with IVT ranging from 40-80 kg m$^{-1}$s$^{-1}$, and a maximum of 80 kg m$^{-1}$s$^{-1}$, signaling the beginning of the rainy season. The IVT threshold of November is 100 kg m$^{-1}$s$^{-1}$. Additionally, the IVT sources originate from the Mediterranean Sea and the Red Sea which is stronger than the Mediterranean Sea in November with an IVT range of 40 to 100 kg m$^{-1}$s$^{-1}$ with a maximum IVT value of 100 kg m$^{-1}$s$^{-1}$. The IVT threshold of December is 200 kg m$^{-1}$s$^{-1}$. The greatest IVT value was 80 kg m$^{-1}$s$^{-1}$ with moisture transfer from the Mediterranean Sea and the Red Sea ranging from 20 to 80 kg m$^{-1}$s$^{-1}$.

We now calculate monthly the average precipitation for each month and look into the relationship between IVT and precipitation. Utilizing Grads, the rate of precipitation across Iraq in January ranged from 0 to 4 millimeters per day. Furthermore, we observe how precipitation over Iraq is impacted by IVT from the Mediterranean and Red seas. Thus, we can observe how IVT from the Mediterranean and the Red Sea affects precipitation. Over Iraq, the rate of precipitation for March was (0.5-3.5mm/day). We may observe how the Mediterranean Sea's IVT transport affects the precipitation over Iraq. We can observe the effects of IVT movement from the Mediterranean Sea and Red Sea affect on precipitation over Iraq as the rate of precipitation for April was (0.3-2.4mm/day) across Iraq. The rate of precipitation over Iraq in May ranged from 0 to 2 millimeters per day. We can observe the influence of IVT from the Mediterranean and Red Sea on precipitation over Iraq. Due to the absence of IVT transport from the Mediterranean Sea and the Red Sea, the rate of precipitation over Iraq was between 0 and 0.5 mm per day during May and June. Because there is no IVT transport from the Mediterranean Sea and the Red Sea over Iraq in July, August is the same as July and September. IVT starts to transport once more from the Mediterranean Sea and the Red Sea but does not reach Iraq. So, the rate of precipitation over Iraq is (0-0.3mm/day). For the months of October and November, we can observe the impact of IVT transport from the Mediterranean Sea and the Red Sea on the rate of precipitation over Iraq (between 0 and 1 millimeters per day for October and between 0 and 3 millimeters per day for November). We can observe the impact of IVT transit from the Mediterranean Sea and the Arabian Sea on the rate of precipitation over Iraq in December which was 0 to 2 millimeters per day. Figures are shown below.
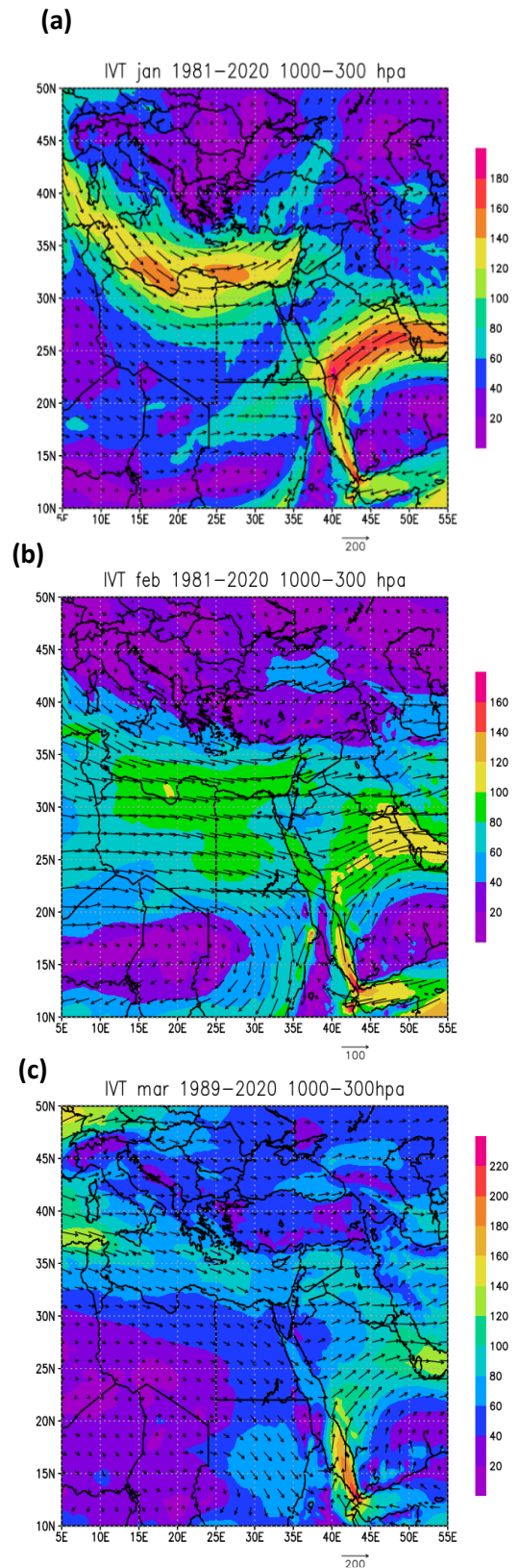
**(a)**

**(b)**

**(c)**

**Fig. 2:** a to c. the IVT over Iraq and surrounding regions and sources of IVT for January, February, march.

**(a)** IVT apr 1981-2020 1000-300 hpa

**(b)** IVT may 1981-2020 1000-300 hpa

**(c)** IVT jun 1981-2020 1000-300 hpa

**(d)** IVT jull 1981-2020 1000-300 hpa

**(e)** IVT aug 1981-2020 1000-300 hpa

**(f)** IVT sep 1981-2020 1000-300 hpa

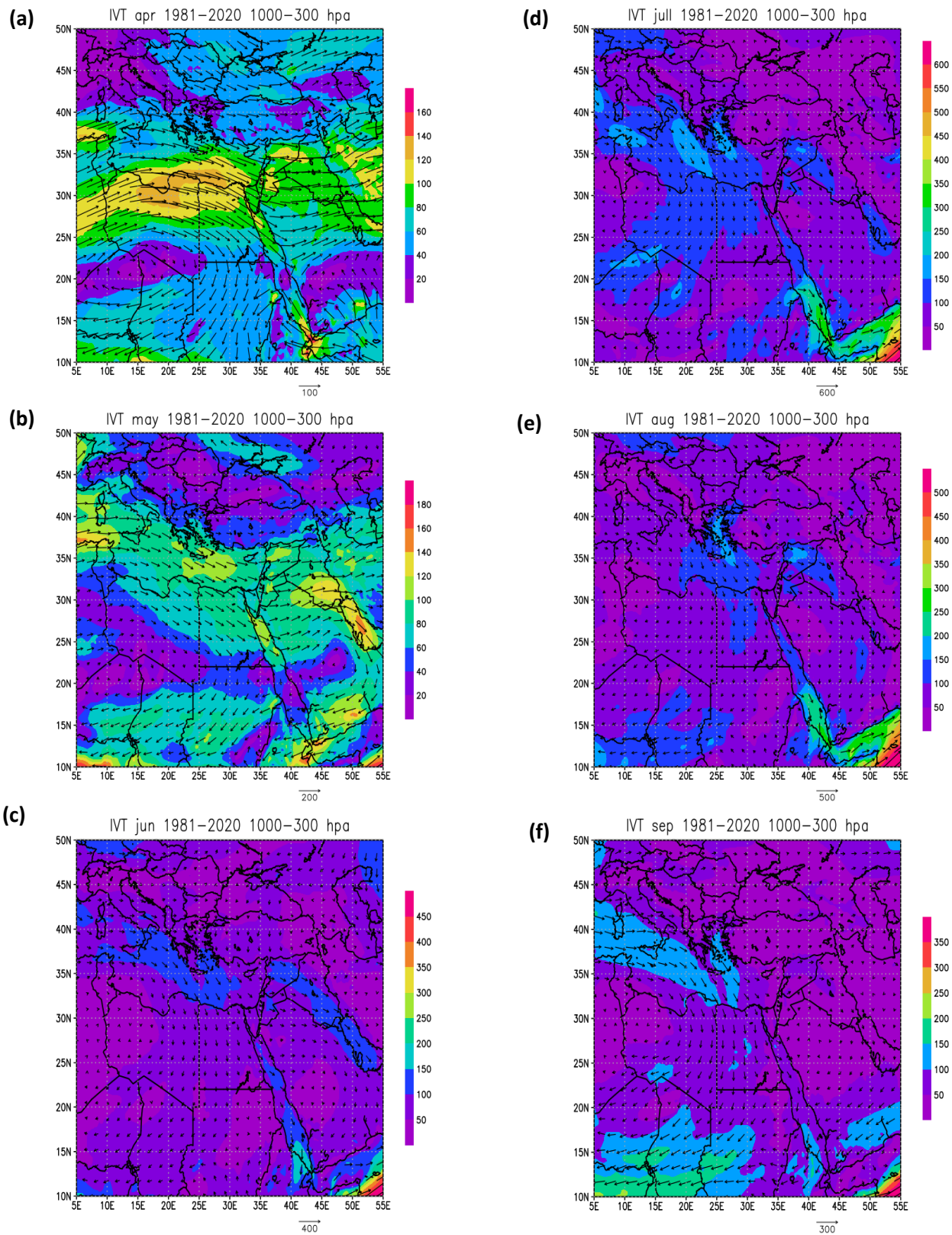**Fig. 3:** a to f. IVT over Iraq surrounding regions and sources of IVT for April, may, June, July, august, September.

**(a)**



**(b)**



**(c)**
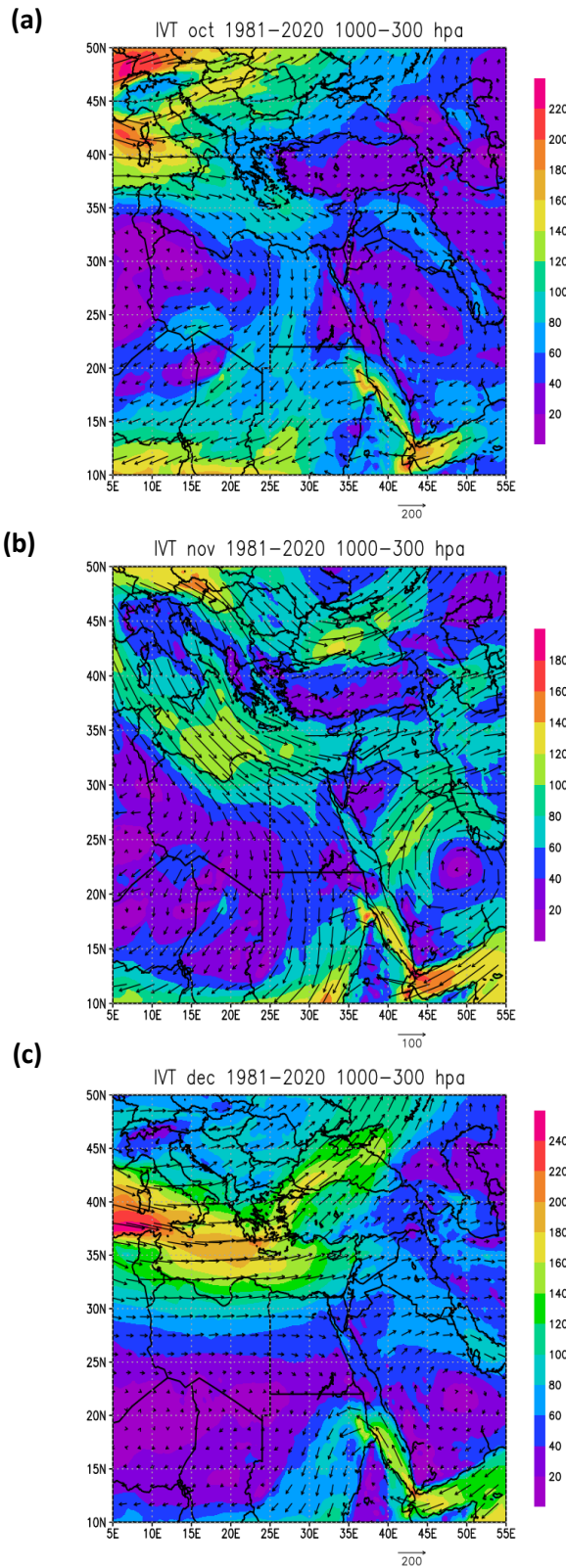


**Fig. 4:** a to c.  IVT over Iraq surrounding regions and sources of IVT for October, November, December.

Now we take one case for one month with high rate of precipitation over Iraq and another case of low rate of precipitation over Iraq in rainy season. It finds the effect of IVT on precipitation over Iraq. It has been shown that in January was the high rate of precipitation over Iraq in 40 years and the lower amount of precipitation was in October when the  change from the dry season to wet season. The moisture transport  from Mediterranean sea being to reversal direction and also from Red sea start reversal direction  to start change to wet season. The IVT was strong. In January, the rate of precipitation was high while  in October IVT was not too strong and rate of precipitation was low.
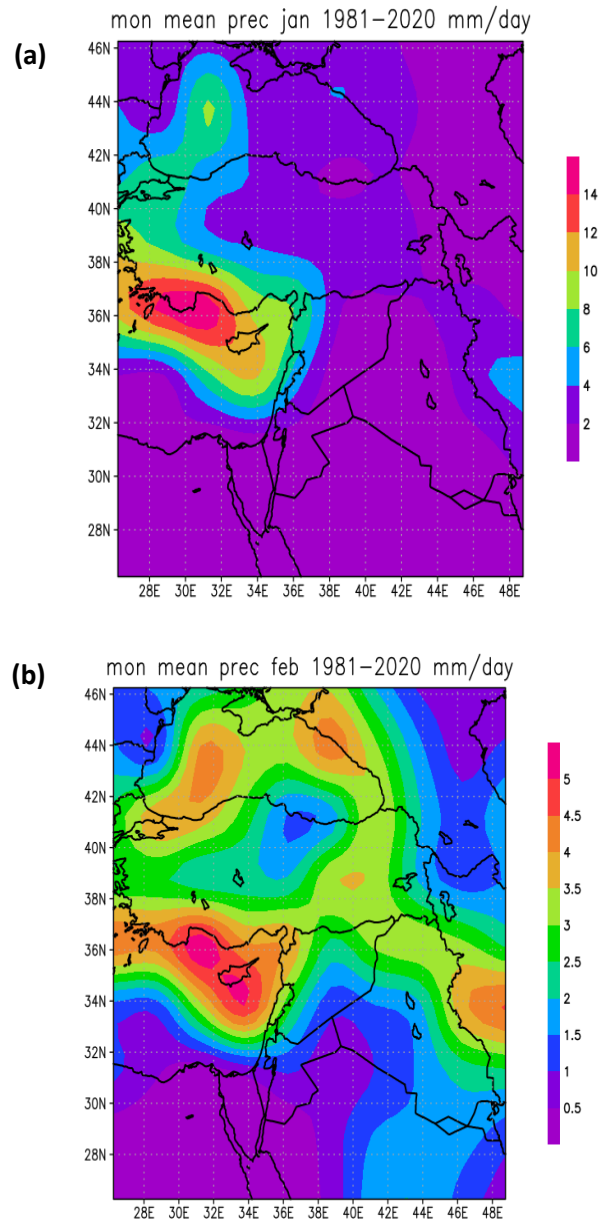
**(a)**



**(b)**



**Fig. 5:** a  to  b.  precipitation  over  Iraq  for  January, February.

**(a)**

mon mean prec mar 1981−2020 mm/day

**(b)**

mon mean prec apr 1981−2020 mm/day

**(c)**

mon mean prec may 1981−2020 mm/day

**(d)**

mon mean prec jun 1981−2020 mm/day

**(e)**

mon mean prec jul 1981−2020 mm/day
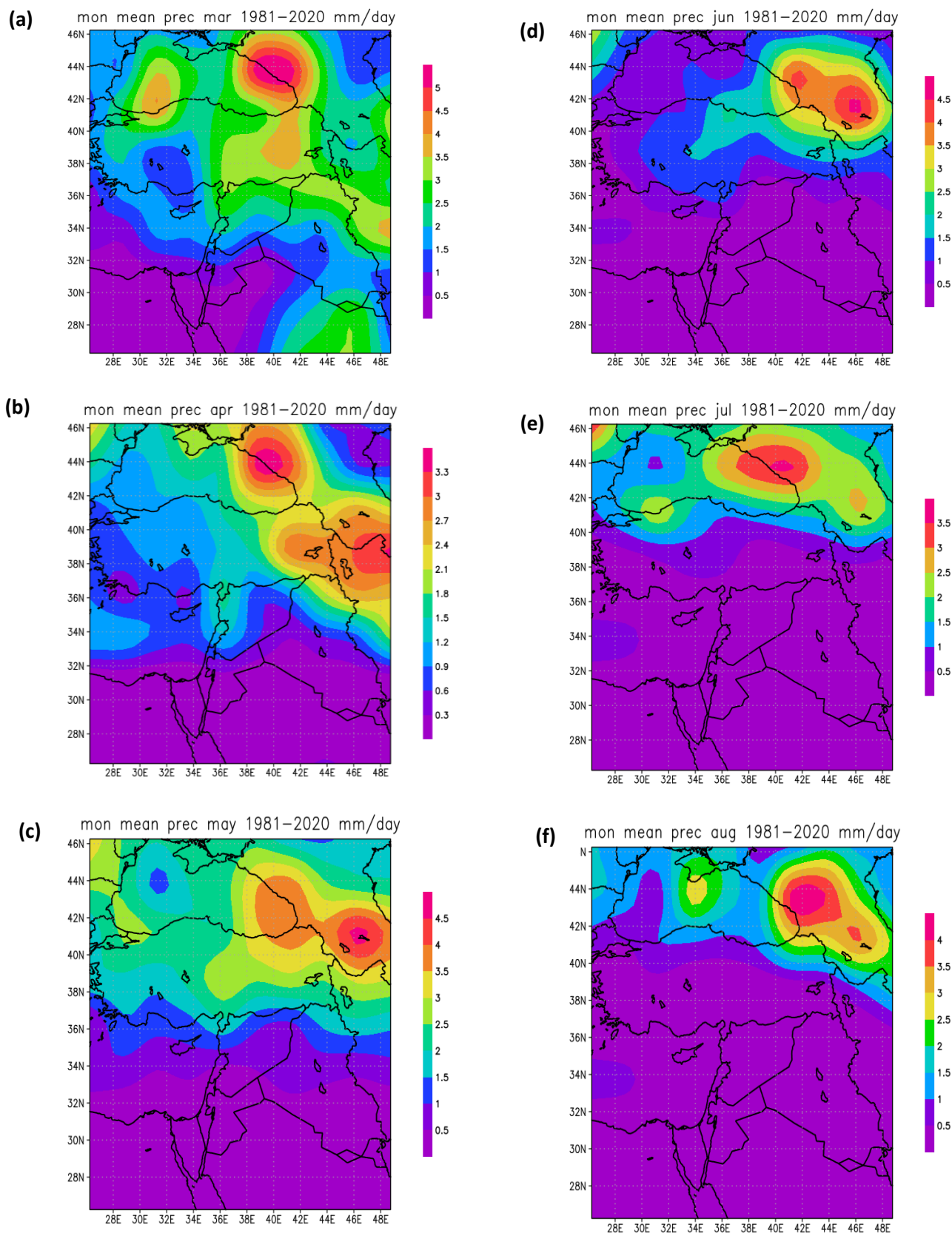
**(f)**

mon mean prec aug 1981−2020 mm/day

**Fig. 6:** a to f.  precipitation over Iraq for march, April, may, June, July, august.

**(a)**



**(b)**



**(c)**
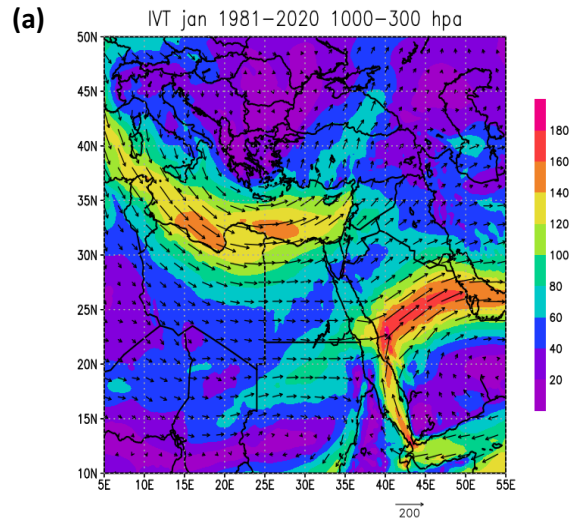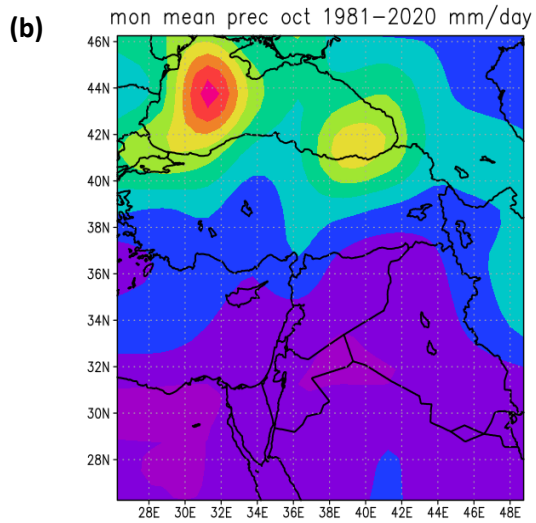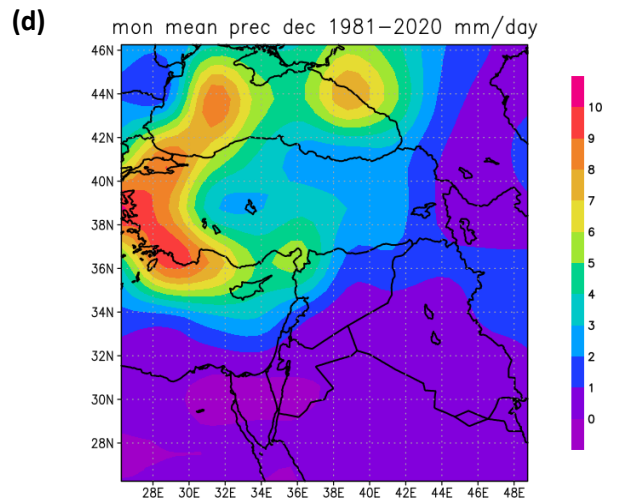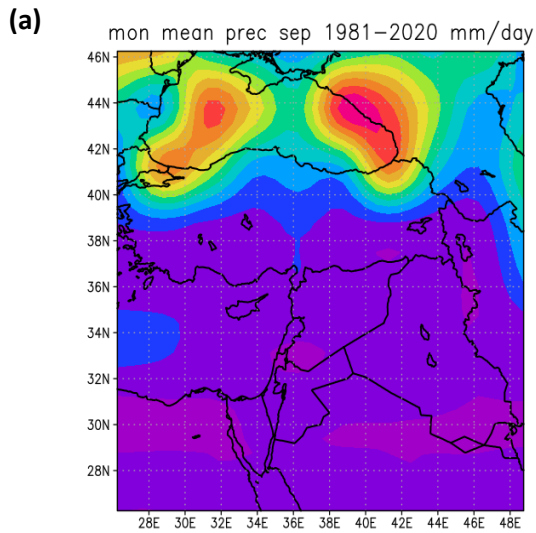


**(d)**
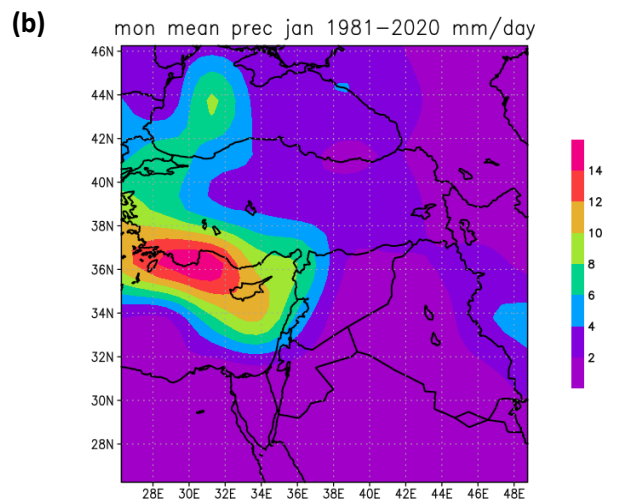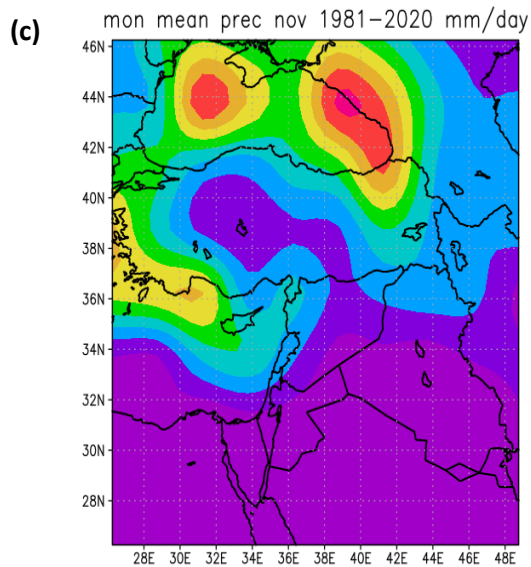


**Fig. 7:** a to d. precipitation over Iraq for September, October, November, December.

**(a)**



**(b)**



**Fig. 8:** a to b correlation between IVT and precipitation over Iraq for January
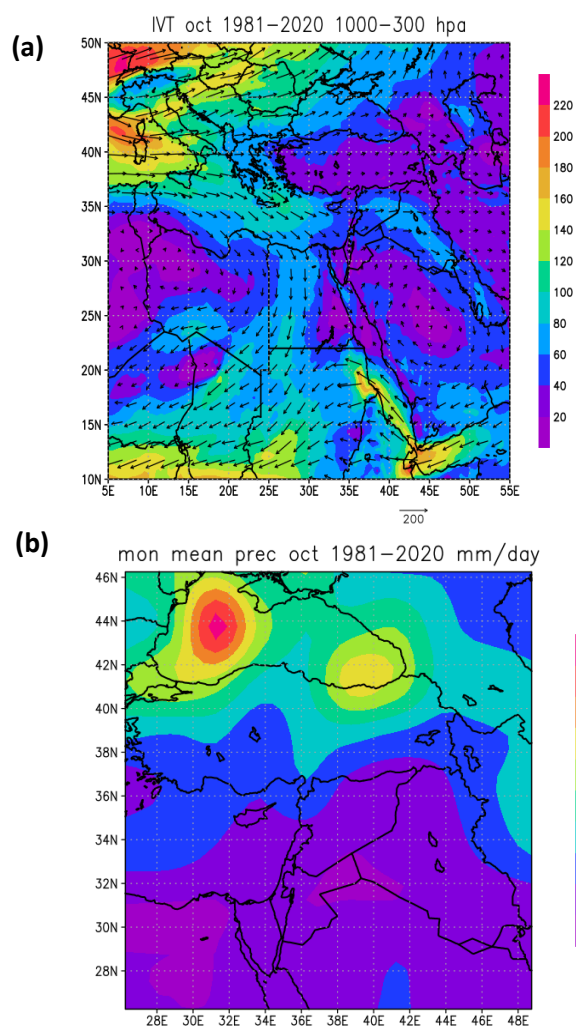
**(a)**

**(b)**

**Fig. 9:** a to b correlation between IVT and precipitation over Iraq for October.

## 4 Conclusion

This study aims to identify IVT over Iraq and its surrounding areas, track its sources, and examine its effects on precipitation using monthly means from 1981 to 2020. The study also investigates the relationship between IVT transport and monthly precipitation means over 40 years for each month in Iraq. The results reveal a connection between IVT and precipitation during the rainy season. The highest and lowest precipitation rates during the rainy season were selected for analysis. The size and direction of IVT had a significant impact on precipitation in the study area. There was a strong correlation between IVT readings and rainfall intensity. The study concludes that IVT transport from the Mediterranean Sea and Red Sea influences precipitation in the region of interest. Moreover, the change from the dry to the wet season affects Iraq and its surrounding areas by altering the course of the Mediterranean Sea and Red Sea. By analyzing moisture flux transport and its sources and

examining its correlation with precipitation, the study sheds light on the impact of IVT on the region's precipitation patterns.

## References

[1] M. Akbary, S. Salimi, S. A. Hosseini, and M. Hosseini, "Spatio-temporal changes of atmospheric rivers in the Middle East and North Africa region," International Journal of Climatology, vol. 39, pp. 3976-3986, 2019.

[2] S. Brands, J. M. Gutiérrez, and D. San-Martín, "Twentieth-century atmospheric river activity along the west coasts of Europe and North America: algorithm formulation, reanalysis uncertainty and links to atmospheric circulation patterns," Climate Dynamics, vol. 48, pp. 2771-2795, 2017.

[3] J. M. Cordeira, F. M. Ralph, and B. J. Moore, "The development and evolution of two atmospheric rivers in proximity to western North Pacific tropical cyclones in October 2010," Monthly Weather Review, vol. 141, pp. 4234-4255, 2013.

[4] A. Dezfuli, "Rare atmospheric river caused record floods across the Middle East," Bulletin of the American Meteorological Society, vol. 101, pp. E394-E400, 2020.

[5] A. K. Dezfuli, B. F. Zaitchik, H. S. Badr, J. Evans, and C. D. Peters-Lidard, "The role of low-level, terrain-induced jets in rainfall variability in Tigris–Euphrates headwaters," Journal of hydrometeorology, vol. 18, pp. 819-835, 2017.

[6] D. L. Douluri, "Heavy Precipitation and Flooding Associated with Atmospheric Rivers over the Indian Region," IIT Kharagpur, 2020.

[7] N. Esfandiari and H. Lashkari, "The effect of atmospheric rivers on cold-season heavy precipitation events in Iran," Journal of Water and Climate Change, vol. 12, pp. 596-611, 2021.

[8] N. Forsythe, H. J. Fowler, X.-F. Li, S. Blenkinsop, and D. Pritchard, "Karakoram temperature and glacial melt driven by regional atmospheric circulation variability," Nature Climate Change, vol. 7, pp. 664-670, 2017.

[9] B. Guan and D. E. Waliser, "Detection of atmospheric rivers: Evaluation and application of an algorithm for global studies," Journal of Geophysical Research: Atmospheres, vol. 120, pp. 12514-12535, 2015.

[10] X. Li, Z. Wen, W. Zhou, and D. Wang, "Atmospheric water vapor transport associated with two decadal rainfall shifts over East China," Journal of the Meteorological Society of Japan. Ser. II, vol. 90, pp. 587-602, 2012.

[11] D. Yihui and J. C. Chan, "The East Asian summer monsoon: an overview," Meteorology and

Atmospheric Physics, vol. 89, pp. 117-142, 2005.

[12] F. Zereini and H. Hötzl, Climatic changes and water resources in the Middle East and North Africa: Springer, 2008.

[13] Y. Zhu and R. E. Newell, "A proposed algorithm for moisture fluxes from atmospheric rivers," Monthly weather review, vol. 126, pp. 725-735, 1998.

[14] D. Loudyi and S. A. Kantoush, "Flood risk management in the Middle East and North Africa (MENA) region," vol. 17, pp.379-380, 2020.

[15] P. H. Gleick, "Water, drought, climate change, and conflict in Syria," Weather, climate, and society, vol. 6, pp. 331-340, 2014.