

# Synoptic Characteristics of Torrential Rains in Southwest and Southeast Iraq: A Case Study

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## Article Info

Received  
02/04/2021

Accepted  
26/05/2021

Published  
20/06/2021

## ABSTRACT

Torrential rains cause many losses in city infrastructure, crops, and deaths in several regions of the world including Iraq as in the case that we will discuss in this work, on January 28 and 29, 2019. Torrential rain caused the flow of torrents in several areas of Iraq and the neighboring areas. This research work aims to identify the synoptic characteristics of torrential rains and the causes of this case. This will be done by analyzing and interpreting the weather maps at different pressure levels with focusing on the troughs and fronts locations, relative vorticity, polar jet stream effect as well as the moisture flux. The Geographic Information System (GIS) was used to analyze the satellite images in order to calculate the Normalized Difference Water Index (NDWI) to confirm the heavy rain case. The weather maps were obtained from the Modern-Era Retrospective analysis for Research and Applications Version 2 (MERRA-2). As for the satellite images we used the satellites imagery from Sentinel-2 and EMUTSAT.

**KEYWORDS:** Torrential Rain; Synoptic characteristics; mid latitude depression; GIS; NDWI.

## الخلاصة

في مناطق متعددة من العالم ومن ضمنها العراق تتسبب الامطار السيلية بالعديد من الخسائر في البنى التحتية للمدن والزراعة والارواح كما في الحالة موضوع الدراسة في هذا العمل والمسجلة بتاريخ 28 و29 كانون الثاني من عام 2019. حيث تسببت الامطار بجريان السيول في بعض مناطق العراق وكذلك المناطق المجاورة للعراق. ان هذا العمل يهدف الى تحديد الخصائص السايونوبتيكية للامطار السيلية وأسباب نشوء الحالة موضوع الدراسة . سيتم هذا من خلال تحليل خرائط الطقس لمستويات ضغطية مختلفة ومتابعة الاخاديد العلوية ومواقع الجبهات السطحية كذلك الدردورية النسبية وتأثير التيار النفاث القطبي وفيض الرطوبة. لقد استخدم نظام المعلومات الجغرافي (GIS) لتحليل صور الأقمار الصناعية حيث تم حساب مؤشر الفروقات المائية المعدل (NDWI) لتحديد حالة الامطار التي تسبب السيول. لقد تم الحصول على الخرائط الطباقية من مشروع إعادة التحليل الحديث للتطبيقات والأبحاث الإصدار الثاني (MERRA-2) ، بينما تم الحصول على صور الأقمار الصناعية من القمر الصناعي سنتينل 2 – (SENTINEL 2) و ايموتسات (EMUTSAT).

## INTRODUCTION

Iraq is located in the Middle East (29.5-37.22 N, 38.45-48.45 E)". According to Bailey classification of moisture index [1] Iraq climate can be classified into three categories: (1) Semi-humid zone in the far north (above 36o N), (2) Semi-dry zone (33o-36o N), and (3) Dry zone in the middle and south of Iraq (under 33o N) [2].

The cumulative average of rainfall graded from 1200 mm in the far north of Iraq to less than 100 mm in the south of Iraq [3]. Some researchers studied the characteristics of rainfall over Iraq, and some of these studies are as follows:

(Al Nassar.et.al 2018) [4] investigate the effect of weather systems on the amount of precipitation in Iraq by measuring variation in precipitation at various time scales and its effect on severe rainfall events.

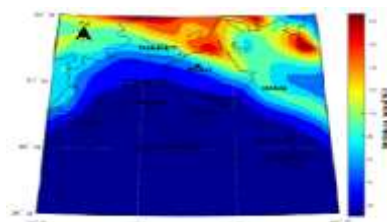


Figure 1. Distribution of Moisture Index Values In Iraq and Surrounding Areas [2].

He confirmed that most of the heavy rain events are associated with cut-off low systems which are effective in Iraq between October and November. The cold southeast winds advect over the warm surface of the Red Sea. The advection cools the saturated surface air on the Red Sea. This moist air rushed toward Iraq to participate in the heavy rain event. as for the researcher (Hassan and others) [5] estimated the amounts of extreme rain, as well as calculating the climatology mean of rain in Baghdad city. They identified the positive and negative anomaly of rain over Baghdad city. As for the researchers (Jafaar.I and Kadhum.H 2019) [6] , analyze the dynamics of the torrential rains over Iraq , They found that the jet stream trajectory is associated with troughs at 500 mb level. (Shaghatai, 2020) [7] tried to study Severe Rainfalls over Iraq, He indicated that the intermediate depression's effect on Iraq, with two fronts, warm and cold. The aim of this work is to find out the synoptic characteristics and causes of the torrential rains event on 28-29 January 2019. According to the authors knowledge, the importance of this work is coming from, it is considered the first case study focusing on the issue of torrent rains in Iraq.

## MATERIALS AND METHODOLOGY

It is possible to determine the flow of torrents on the ground using satellite images. The Normalized Difference Water Index (NDWI) designed by McFeeters [8] was used in this work to identify open areas that were exposed to rain. The purpose of NDWI was to: (1) Amplifying the reflection of water in the green band  $B_{GREEN}$ . (2) Minimize water reflection in the near infrared band  $B_{NIR}$ , McFeeters's NDWI calculated as:

$$DWI = \frac{B_{GREEN} - B_{NIR}}{B_{GREEN} + B_{NIR}} \quad (1)$$

For sentinel - 2  $B_{GREEN} = B_3$  and  $B_{NIR} = B_8$  , so we can calculate NDWI directly as follow:

$$NDWI = \frac{B_3 - B_8}{B_3 + B_8} \quad (2)$$

Then, by subtracting NDWI images of the same area before and after the rains, we will get an image that is characterized by a clear change in the water body, as it represents the areas of torrential flow. With regard to the synoptic case, according to Mohsin, 2019 [9] The polar jet has a major influence on the low pressure value at the surface. The polar jet stream occurred as a result of the temperature gradient between the tropical

air and the polar air. The jet stream blows from west to east, and is characterized by fluctuating speed and frequent meandering [10].

The subtropical current arises as a result of the flow of winds from the top of the Hadley cell towards the north above the Ferrel cell, where the winds are affected by both the Coriolis force and the angular momentum to push the jet stream from the west towards the east. It is characterized by being more regular in its flow than the polar and less meandering [10]. For that, a jet stream over the Iraq region must be followed when a case of torrential rain occurs. wind speed and streamline maps at a level of (300 mb) are important for determining the location of the polar jet stream and the subtropical jet stream.

To monitor how the case responds vertically we must determine the location of the trough. The identification of the trough will be easy at the pressure level of 500 mb. the trough can be defined as a meandering of cold polar air (low geopotential surface) towards the tropics warmer air (high geopotential surface), troughs usually associated with low pressure and bad weather, the region of instability is always located at the center of low pressure that forms in the transition zone between the trough and the ridge[10].

According to (Still, 2015) the rotation of an air column in counterclockwise direction in a moving weather system is known as positive vorticity. There are several types of vorticity: relative vorticity, absolute vorticity, and potential vorticity. Relative vorticity is defined as a rotation of a local air column relative to the observer's position and Earth's rotation and it can be calculated as follows:

$$\zeta_r = \frac{\pm 2M}{R} \quad (3)$$

Where M represents the tangential velocity and R represents the radius of a trough or ridge.

Surface fronts are the boundaries separating the different air masses. It is characterized by a large horizontal slope in temperature, humidity and wind. It is a region where clouds and rain form and it can be identified on maps by the apparent change in temperature while the forehead moves [10] It can also be identified by satellite images where two types of clouds accompanying the cold front are observed on satellite images. A band of cloud formed as a result of warm moist air rising through a deep layer of the atmosphere towards the cold side in front and is undermined by the

descent of the cold dry air [11]. According to (PAUL, 2007) in mid latitude depression, increase in sea surface temperature leads to increase in rain rate as well, the Increased in moisture amounts will contribute to cyclogenesis of the mid-latitude depression. [12] Therefore, it is appropriate to follow up the sources of moisture prepared for the depression to find out the causes of the torrent rains that accompanied the case.

## DATASET

In this work, the data was obtained from the following sources:

- Satellite imagery which is used to calculate NDWI obtained from Sentinel - 2, the images include 13 bands: band number 3 (the green band) and band number 8 (near infrared. NIR) were used, and their characteristics are as follows:

**Table 1.** Green and near infrared. NIR bands information.

Band name	Band Number	Spatial Resolution (m)	Central Wavelength (nm)	Band width (nm)
the green band	B3	10	560	35
the NIR b	B8	10	842	115

- Weather maps which are used in synoptic analysis obtained from Model projects: Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA -2 ) [13]
- With regard to information related to torrential rains and the resulting local damages, we have adopted the reports of the Joint Coordination and Monitoring Center (JCMC), which is an Iraqi government institute that deals with disasters and risks.

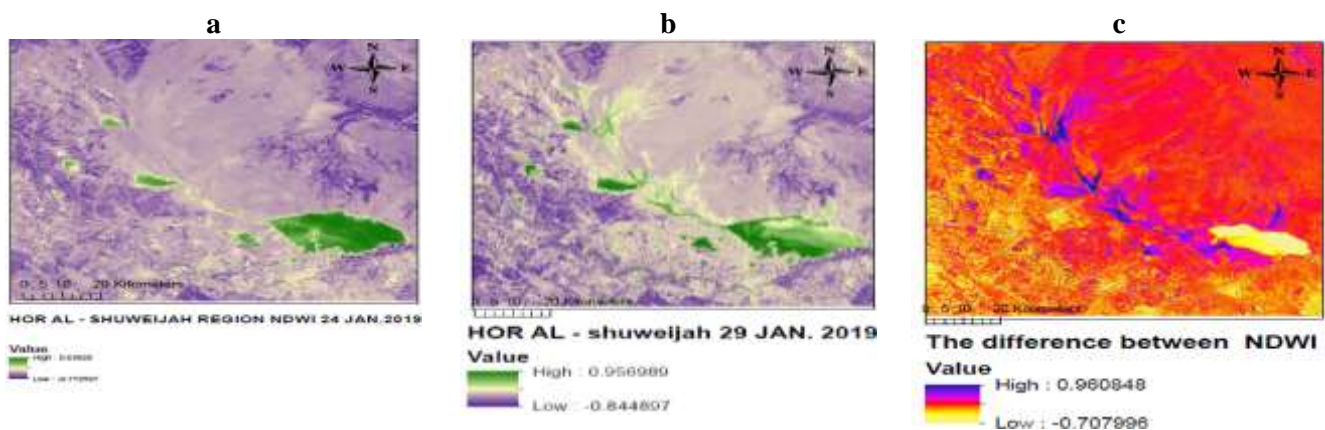
## RESULTS AND DISCUSSION

### Case study

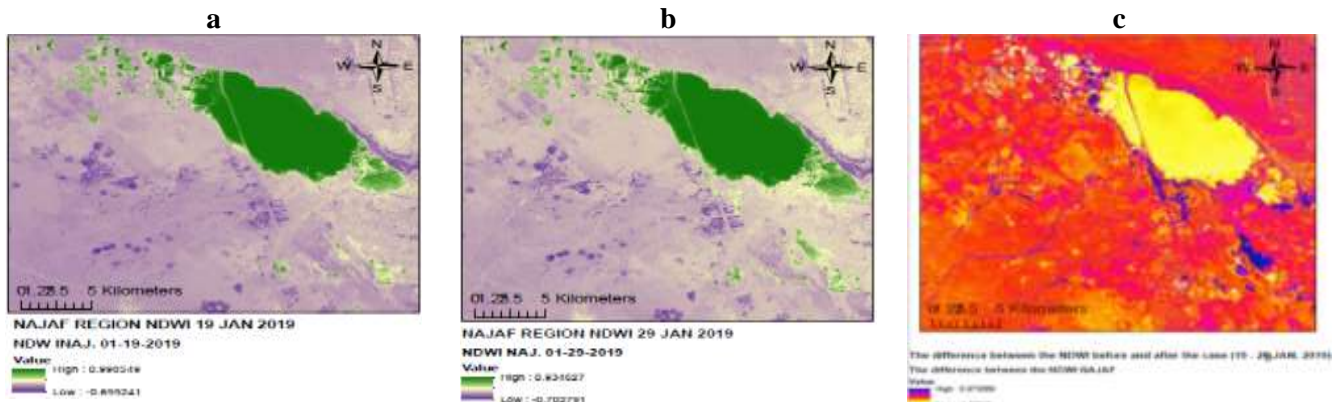
The government reports issued by JCMC indicated that rainfall was recorded, including heavy rains on 27 and 28 January 2019, followed by a wave of torrent in several areas of South West and South East of Iraq. The storm moved in a direction  $256^{\circ}$  (from the west towards eastern Iraq), as the path of the storm passed over the Bahr Al-Najaf in South West of Iraq and Hor Al-Shweijah in Southeast of Iraq regions, respectively.

Kuwait, Iran and parts of Saudi Arabia also were affected by the heavy rainfall. JCMC reports indicated that 42 mm rainfall was recorded within 12 hours over Najaf city at southwestern Iraq.

The storm was followed by torrents coming from the Iraqi- Saudi Arabia border area, in the same case the areas of southeastern Iraq received up to 45 mm within 12 hours. It was followed by torrents coming from the Iraqi-Iranian border area, reaching to  $1000 \text{ m}^3 / \text{hour}$ . NDWI was calculated using satellite imagery processing using Geographic Information System (GIS) software from the ARC GIS Foundation to prove the torrents as we see in Figures 2 and 3. The image of the difference between the NDWI value before and after the rains fall, where the regions appeared in blue, is representing the areas that witnessed major changes in the volume of water. They form lines where torrents flow



**Figure 2.** Torrents are caused by rain in the (Hor Al-Shuweijah) region a- NDWI before rain falls in (Hor Al-Shuweijah) and the surrounding area. b - NDWI after rain fell in (Hor Al-Shuweijah) and the surrounding areas. C – The difference in the NDWI before and after rain falls in the (Hor Shuweijah) area and the surrounding areas, where the torrent appears in blue color.

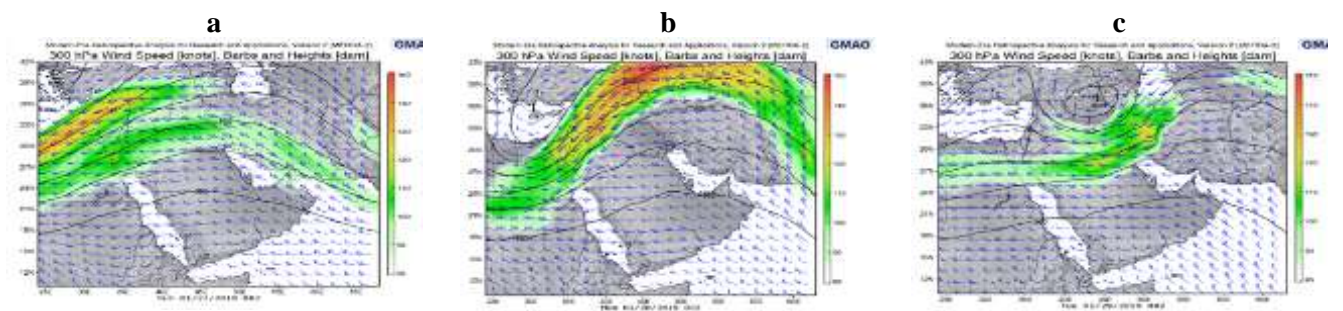


**Figure 3.** Torrent caused by rain in the (Bahr Al-Najaf) region a- NDWI before rain falls in (Bahr Al-Najaf) and the surrounding areas b - NDWI after rain fell in (Bahr Al-Najaf) and the surrounding areasd - The difference in the NDWI before and after rain falls in the (Bahr Al-Najaf) area and the surrounding areas, where the torrent appears in blue color.

**Synoptic analysis**

Figure 4 shows the evolution of the meandering of the jet stream during the case study. While the polar jet stream is meandering, towards the south a trough is developing over northwestern Iraq.

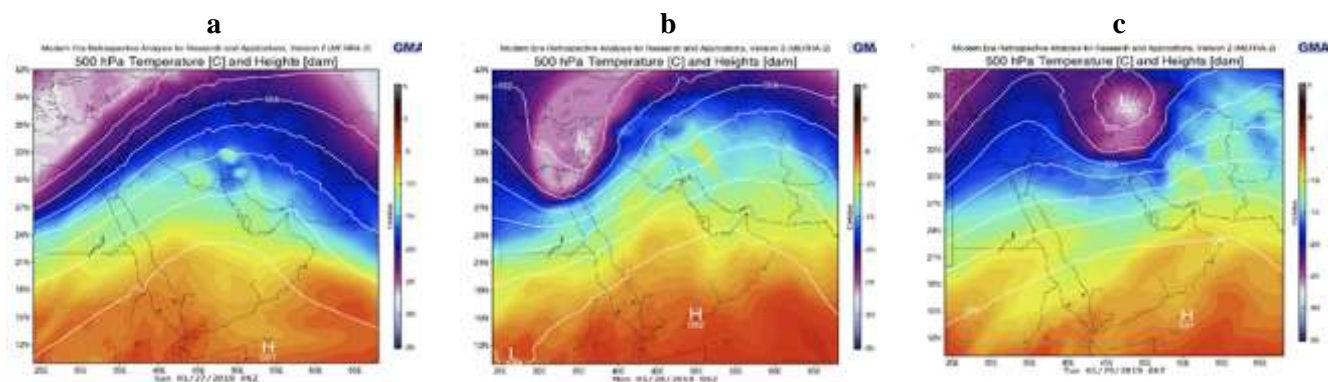
This makes the atmosphere unstable, which is considered a beginning of the mid-latitude depression formation. The positioning of the subtropical jet stream over central Iraq enhances the moisture feeding from the tropics.



**Figure 4.** The evolution of the jet stream during the case study.

As the trough develops the depression deepens, as we can see in the figure 5 which represents the temperature at the level of 500 mb. It is clear that the colder air (trough) is located in northwestern

Iraq and penetrates south in the middle of warmer air areas. The trough moves from west to east towards central Iraq, which enhances instability and the possibility of cloud formation.



**Figure 5.** The temperature at the level of 500 mb.

The main reason for the formation of vorticity is the horizontal shear of the winds in the jet stream. Figure 6 shows that the positive relative vorticity is located in the transitional areas between the

trough and ridge (south and east of trough) which is considered a zone of positive vorticity advection PVA, and the center of trough.

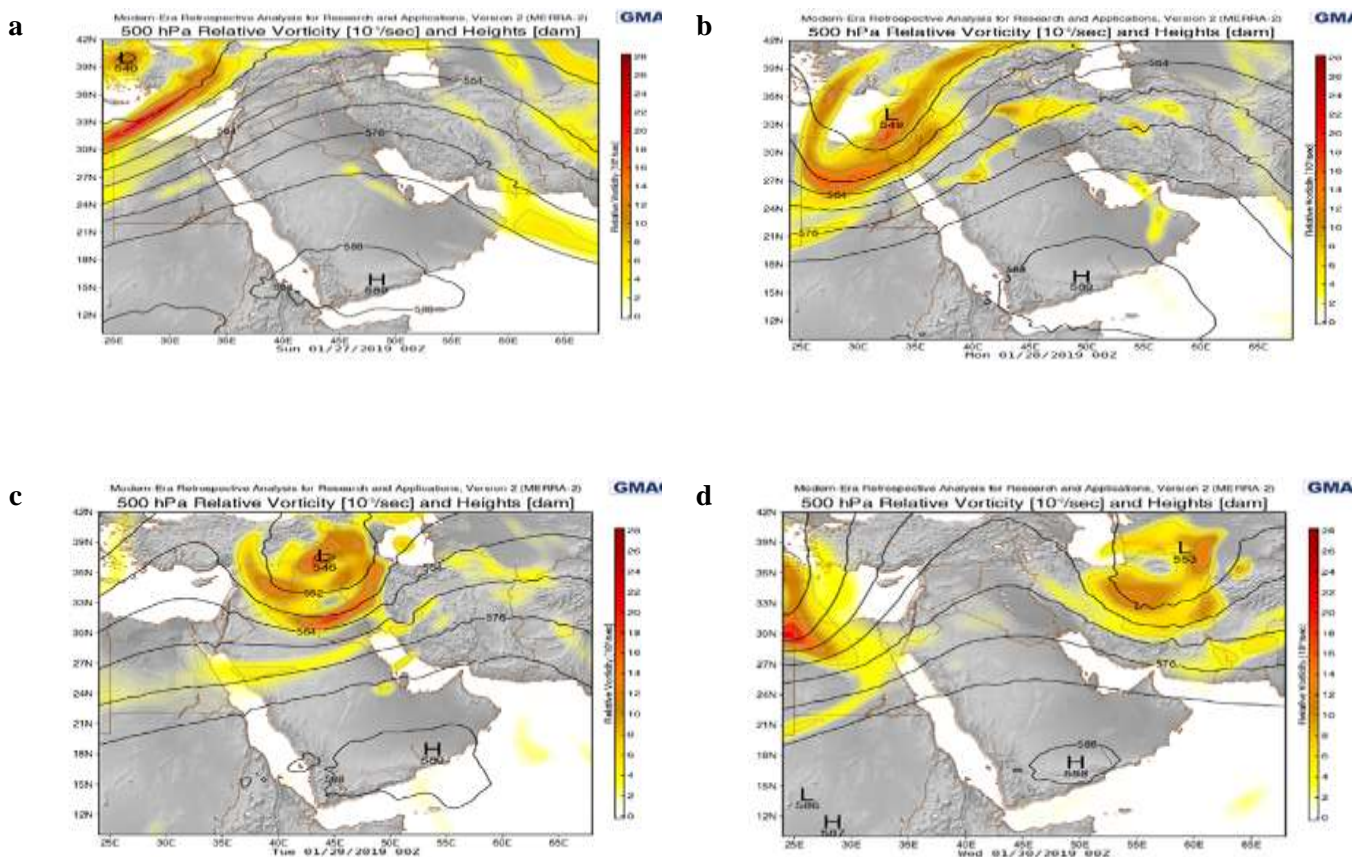


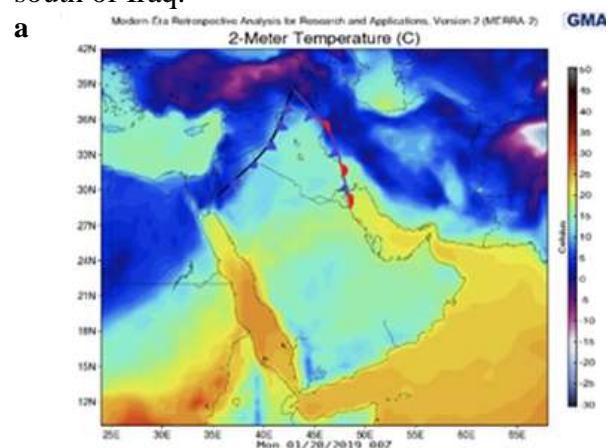
Figure 6. 500 mb relative vorticity [ $10^5/\text{sec}$ ] and height.

Under the PVA zone on the surface, a convergence zone formed that caused air to ascend towards the top that is the reason the rainy cloud was formed in this case. Wind maps at the level of 850 indicate a clear change in wind direction in the axis of the trough. Whereas the winds change from western direction in western of Iraq to the southwest direction in eastern of Iraq, We notice the formation of a low-altitude jet stream at the wind turning axis. All these details show the progress of a surface cold front, the front zone location can be determined using surface temperature maps as shown in Figure 7.

Figure 8 shows that the location of the cold front matches the satellite images captured at the same time.

The process of occlusion between the cold front and the warm front at the eastern regions of Iraq It Appears clearly in Figure 7-b, cold front moved rapidly from northwestern Iraq towards the southeast, then the cold air covered most of Iraq region within 24 hours, with a temperature difference about 10 Celsius degrees. This process was accompanied by torrential rains, which

caused the flow of torrents in several areas of Iraq and neighboring areas such as Kuwait City, to the south of Iraq.



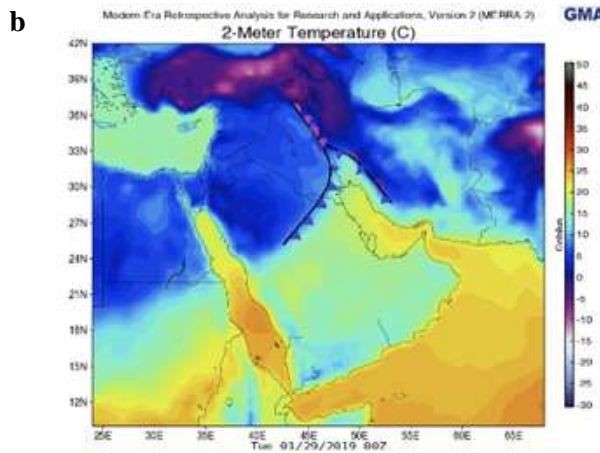


Figure 7. The fronts zone

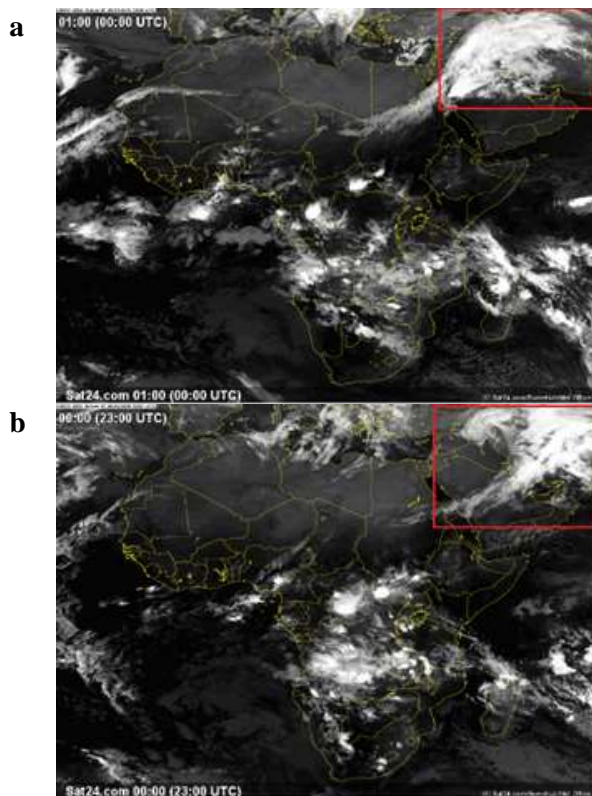


Figure 7. Cloud formation associated with fronts zone.

**Moisture Feeding**

Maps and satellite images indicate that the moisture was feeding from the tropical regions of West Africa and the Red Sea region (East Africa) towards the Middle East and towards the point of winds convergence in northwestern Iraq and in front of the cold front. The presented figure 8 shows that the winds in the med troposphere (at 700 mb level) are similar in direction to the direction of moisture flux. The infrared images from the satellite also show a thin line of clouds extending from West Africa at the Sahel region and strengthening over the Red Sea region all the

way to central Iraq and its neighboring regions and along an advanced cold front line.

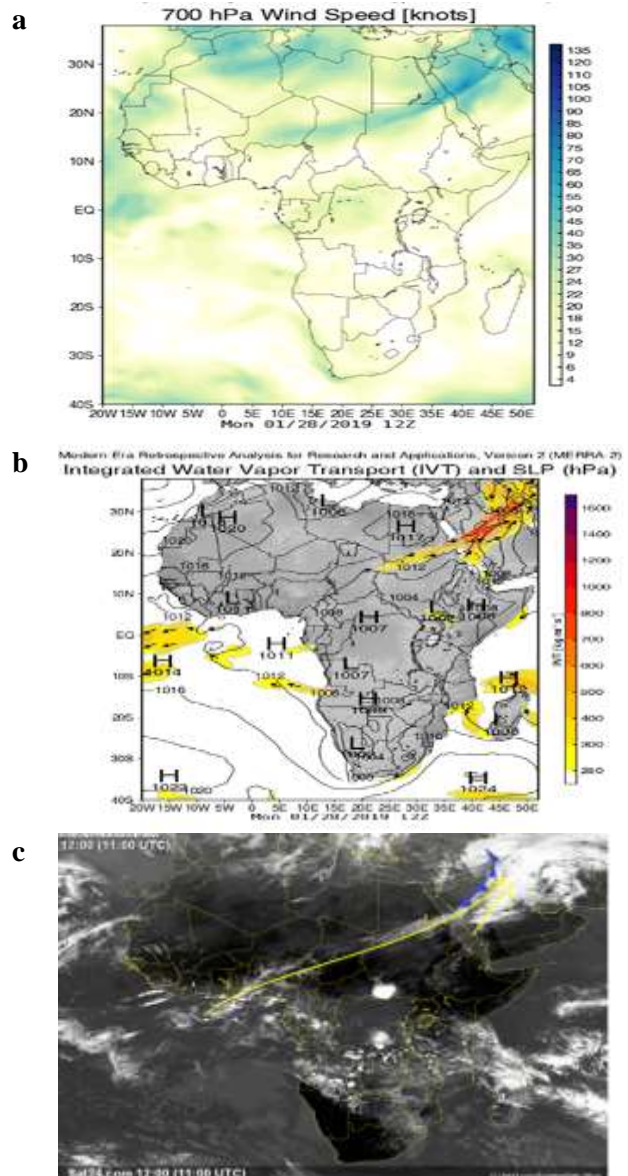


Figure 8. Moisture flux and its sources: (a) wind speed at 700 mb, (b) Integrated water vapor transport show the humidity advection from west and east Africa, (c) satellite image in IR band appears cloud along moisture transport line.

**CONCLUSION**

- The meandering of the polar jet stream to southward lead to troughs formed with a low geopotential surface and large horizontal temperature gradient which will be developed into the mid-latitude depression.
- The intensification of the relative positive vorticity that appears over Iraq came as a result of the presence of a high shear of the horizontal winds at the level of 500 mb, which led to a rapid rise of the air that led to rain formation.

- Horizontal thermal differences led to deepen the depression; this led to the formation of a cold front that propagated from the northwest towards the southeast. When it was strengthened by the process of rising air and forming rainy clouds.
- The convective activity in the tropical region allowed moisture to transfer from the tropics to the subtropics and mid-latitudes. By flows in the upper atmosphere that are associated with the formation of the subtropical jet stream. Subtropical jet stream contributes to the transport of moisture from tropical regions in West Africa and East Africa.
- There is no doubt that the increase in sea surface temperatures in the tropics will lead to an increase in the preparation of moisture to the mid latitude depression, thus an increase in the frequency of torrential rains.

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