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Hydrometeorological study on the impact of the weather state "Rahw" on the water resources in southwestern regions, Kingdom of Saudi Arabia

Yousry Mattar[a,b,*], Ahmed Al Ghamdi[c]

[a]*Water Deputy Ministry, Ministry of Environment, Water and Agriculture, Riyadh, Kingdom of Saudi Arabia, email: yousrymattar@hotmail.com (Y. Mattar)*
[b]*United Nation Development Program (UNDP), Riyadh, Kingdom of Saudi Arabia*
[c]*Water Resources Directorate, Ministry of Environment, Water and Agriculture, Riyadh, Kingdom of Saudi Arabia*

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ABSTRACT

In the arid regions, some heavy rainstorms and weather states may be happened annually and continued for few to many days resulting in large, or extreme flood events. The western and southwestern regions in the Kingdom of Saudi Arabia (KSA); Al Madinah, Makkah, Al Bahah, Asir, Jazan, and Najran, as well as some parts of the neighboring countries such as Oman, United Arab Emirates, and Yemen have been exposed to a summer weather state which is locally named by Saudi Committee of Nomenclature of Distinguished Weather States as "Rahw". This weather state lasted for 18 d started from 24 July 2020 to 10 August 2020 and resulted in moderate to heavy daily rains. The present study deals with the hydrometeorological impacts of the weather state "Rahw" depending upon the statistical analyses and ARC GIS spatial distribution of 193 rainfall and weather stations, as well as daily records of water levels in 165 constructed and under construction dams' reservoirs. The total geographic areas of Al Madinah, Makkah, Al Bahah, Asir, Jazan, and Najran Regions attain 522,000 km^2, representing 26.6% of the total area of KSA. According to the present study, the total geographic areas that have received rainfall precipitation in these regions during "Rahw" are estimated as 212,672 km^2 and the average total rainfall depth over these regions only is estimated as 69.59 mm, representing 45.8% of the total annual average rainfall depth over these regions. Also, the average total rainfall depth over all KSA during "Rahw" is estimated as 32.56 mm, representing 30.1% of the total annual average rainfall depth over all KSA regions. On the other hand, the calculated average precipitation depth in July 2020 only, attains 32.9 mm and 9.4 rainy days, compared to 20 mm and 5 rainy days of the same month during the interval from 2010 to 2019. Also, the present study concluded that the average precipitation depth in August 2020 is estimated as 27.5 mm and 9.2 rainy days, compared to 27 mm rainfall depth and 7 d rainy during August in interval from 2010–2019. The total rainfall volume received during "Rahw" weather state estimated as 10,894 million m^3 representing 20.2% of the total annual average rainfall volume in these regions, and 7.2% of the total annual average rainfall volume over all KSA regions. Also, the total rainfall volume received during "Rahw" weather state resulted to 1,308 million m^3 direct surface runoff, among of these 352 million m^3 were retained behind 147 constructed dams, and 18 million m^3 behind 8 under construction dams, and the remaining 938 million m^3 is recharged in wadi deposits aquifers in those areas. Also, 201.6 million m^3 of water was released from dams' gates to meet the demands of farmers on the downstream of dams during the rainy state, in addition 8.3 million m^3 was supplied for drinking waters

* Corresponding author.

and treatment plants. The net increase in the water volume behind the dams as a result of "Rahw" weather stations estimated as 142 million m^3. The present study recommends developing and update the operational plans of dams in western and southwestern regions to maximize the benefits from the surface runoff and enhance the water resources during the occurrence of such weather states.

Keywords: Weather state, Hydrometeorology, Water resources, Rainfall, Dams, Saudi Arabia

1. Introduction

Water is vital for human welfare, socio-economic development as well as for supporting the ecosystem [1]. Arab region receives only 2.1% of the world's average annual precipitation and contains as little as 0.3% of the world's annual renewable water resources [2]. The climate of Saudi Arabia is considered as "arid climate zone BW according to the global Climate Classification map based on [3,4] Therefore, the amount of rainfall precipitation that have been received over the country is very important factor in preparing the water budgets and assessing the available surface water allocates to meet various demands. In Saudi Arabia, some heavy rainstorms and weather states may be happened on few days in a year and in some regions of the country [5]. Also, rainfall storms exhibit strong spatial variability, especially during heavy thunderstorms and localized torrential rainstorms [6,7]. Ministry of Agriculture and Water in Saudi Arabia [8] has prepared and published good and more comprehensive water atlas including monthly and annual average rainfall distribution maps over all regions in the country. The average annual rainfall depth over Saudi Arabia was estimated as 79 mm by Qureshi and Khan [9], whereas it was estimated as 82.29 mm by Almazroui [10] based on the observed data of 29 ground stations of the General Authority of Meteorology and Environment GAME former PME. Recently Al Qahtani and Mattar [11] estimated the average annual rainfall depth over Saudi Arabia as 105 mm based on the 50 y records of 190 ground stations of the hydro networks of the Ministry of Environment, Water and Agriculture (MEWA). Hydrometeorology provides ever-advancing knowledge about the hydrological cycle, which is an integral part of the wellbeing of humankind on Earth [12].

The spatial distributions of rainfall over Saudi Arabia have been studied by many authors, among of these is Almazroui [13] who analyzed the rainfall amounts records and concluded that the wet seasons are extending from November–April, whereas the dry season are from June–September. Also, the author [13] considered that the spring is the highest and winter is the second highest rainfall-occurring season, resulting in large amounts of rainfall during the wet season over most of the country. Almazroui [13] employed the regional Climatic Model RCM to simulate and understand the life cycle of the two systems that produced heavy rainfall spells over western Saudi Arabia in November 1996 and compared their spatial patterns with rain-gauge data and with the Climate Prediction Center (CPC). Abdullah and Al-Mazroui [14] studied the rainfall in the south-western region of Saudi Arabia and discussed the rainy seasons and the aridness of the area. Subyani [15] studied the annual and seasonal mean rainfall patterns in southwestern Saudi Arabia. On the other hand, very little studies have been dealt with the study of the hydrological impact of the sever rainstorm that have affected the Kingdome of Saudi Arabia. Rakhecha [16] conducted hydrometeorological studies for the development of water resources in India and concluded that the total water resources of the India are 2,301 km^3.

The Saudi Committee for Nomenclature of Distinguished Weather States Over Saudi Arabia was established on 28 January 2011 to give significant names for the distinctive weather states to facilitate its follow-up during its formation and movement, hydrometeorological analysis and to prevent any confusion when comparison with another weather states. About 30 Distinctive Weather States have prevailed in Kingdom of Saudi Arabia during different climatic seasons. Among of these are "Moghdeqah" which has extended from 22 March to 21 April 2012, "Al Baydaa" has extended from 25 April to 8 May 2013, "Sabeghah" has extended from 22–26 November 2015, "Al Rabab" has extended from 28 July to 3 August 2016, "Joud" from 11–18 April 2017 and "Ghadaq" from 25 October to 20 November 2018. Jeddah city in Makkah Region was affected by three severe thunderstorm events; the first was on the 25 November 2009, where 90 mm of rain fell in just 4 h on that day, where it was described by civil defense officials as the worst in 27 y. The second severe thunderstorm events were on 30 December 2010, whereas the third was on 26 January 2011. Recently, in 2020, the western and southwestern regions of Saudi Arabia; Al Madinah, Makkah, Al Bahah, Asir, Jazan, and Najran, as well as some parts of neighboring countries such as Oman, United Arab Emirates, and Yemen have been exposed to a summer distinctive weather state has lasted for 18 d starting from 24 July to 10 August 2020. During this rainstorm, daily medium to heavy rains have been prevailed. This weather states is locally named by the Saudi Committee for naming distinctive weather states as "Rahw".

2. Aim of study

Very little studies have been dealt with the study of the hydrometeorological impact of the sever rainstorm that have affected the Kingdom of Saudi Arabia. The aim of the present study is to:

- Understand how was the rainfall pattern during the weather state "Rahw".
- Investigate the hydrometeorological impact of the weather state "Rahw" on the water resources in southwestern regions in Saudi Arabia.
- Estimate the rainfall harvesting volume of rainfall, runoff have been stored in the dams' reservoirs for different demands.

- Mange and optimize the benefits from the renewable surface water behind dams in water supply, irrigation, aquifer recharge.

3. Methodology and data collection

The statistical and spatial distribution analyses of daily time series records of the hydro networks of the Ministry of Environment, Water, and agriculture (MEWA) were carried out using ARC GIS techniques. This includes 193 rainfall and weather stations (Table 1), as well as daily records of water levels in 165 constructed and under construction dams' reservoirs. The data of rainfall precipitation and water levels in dam reservoirs were collected from MEWA daily Bulletins within 18 d starting from 24 July 2020 to 10 August 2020. The locations of MEWA hydrologic network stations recorded during "Rahw" state is shown in Fig. 1. The daily and monthly rainfall precipitations of the stations have been correlated with the corresponding records of these stations during interval from 2010 to 2019. The spatial distribution maps of the affected area by the weather state "Rahw" have been also utilized. The total affected areas that have received rains during the weather state "Rahw" attained 212,672 km^2, representing 40.7% of the total area of the southwestern regions only.

4. Spatial distribution and statistical analysis of rainfall

MEWA has installed a good hydrologic network covering all the Kingdom of Saudi Arabia regions as early as 1958 and up to date. This hydrologic network is considered as one of the largest hydrologic networks in the Arabian and Gulf countries. The hydrologic network includes 1,073 gauges with different types and purposes including 573 rainfall ground stations, 73 weather ground stations, 315 monitoring wells, 40 runoff gauges and 7 water level gauges in the dam reservoirs. The weather state "Rahw" has begun on the Friday, 24/7/2020, where 57 rainfall and weather stations of MEWA, have recorded rainfall precipitation in 4 regions; these are Al Bahah, Makkah, Jazan, and Asir, in ascending order. On the second day 25/7/2020, the number of rainfall stations that recorded precipitation in the southwestern regions decreased and attained 23 stations only in four regions, including 10 stations in Al Madinah region, 6 stations in Makkah Region, 4 stations in Asir Region, and 3 stations in Riyadh region. It is noted that on the second day, none of the hydrological network stations throughout Jazan Region have recorded any precipitation. Over time, the geographical distribution of the rainstorm "Rahw" was gradually expanded, and on the third day 26/7/2020, precipitation was recorded at 86 ground stations. Fig. 1 shows NASA daily accumulated precipitation in 26/7/2020 during "Rahw" state in KSA.

The maximum extension of the weather state "Rahw" has reached on 27/7/2020, where the number of rains was recorded in 133 stations in 6 regions, which is the largest number of stations recorded during the weather state "Rahw" with 31 stations In the Jazan Region, 23 stations in the Asir Region, and 15 stations in the Makkah Region, then 8 stations in the Al Madinah region, and 2 stations for the first time in the Najran Region in the Rahw state. On 30/7/2020 the number of stations that recorded rain reached 102, and on 31/7/2020 recorded 111 stations, then on 4/8/2020 it recorded 93 stations. Then, the gradual decline in the spread of the rain situation began, reaching its lowest level on 9/8/2020, with 4 stations in only 3 regions, namely, Jazan Region, with 2 stations, and one station in each of the Asir and Al Madinah regions. Spatial distribution of the total rainfall precipitation within Jazan, Asir, Makkah, Al Madeinah, Al Bahah and Najran regions during "Rahw" state are shown in Figs. 3–8, respectively.

4.1. Maximum daily rainfall

The hydrological network ground stations of MEWA have recorded relatively high amounts of precipitation for

Table 1
Distribution of the rainfall and weather stations recorded rainfall during the weather state "Rahw" 2020

Region	Number of hydrologic network recorded rainfall during Rahw 2020	Number of weather and rainfall stations in MEWA hydrologic network	Average rainfall depth (mm) in the region within 50 y record
Riyadh	3	78	90
Makkah	53	108	100
Al Madinah	28	80	53
Eastern Region	0	34	60
Asir	49	83	210
Najran	2	6	75
Jazan	34	41	275
Al-Jouf	0	14	40
Northern Borders	0	12	70
Al-Qassim	0	34	90
Tabuk	2	36	35
Al Bahah	22	22	200
Hail	0	25	70
Total	193	573	103

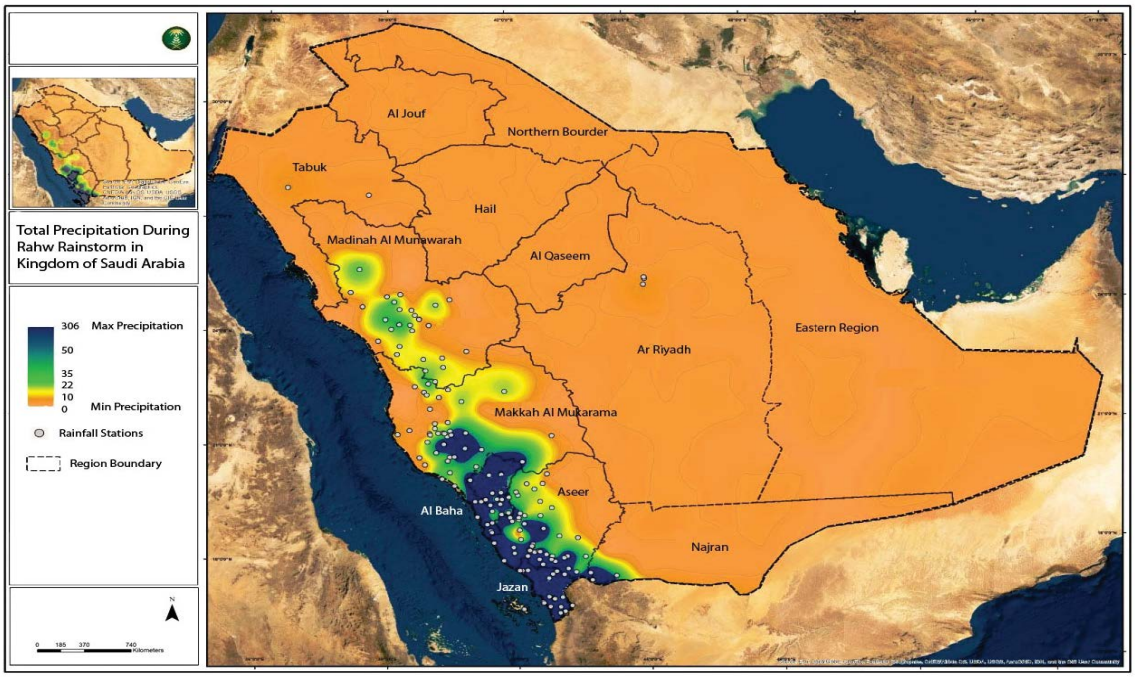

Fig. 1. Location of MEWA hydrologic network stations recorded during "Rahw" rainstorm in KSA.

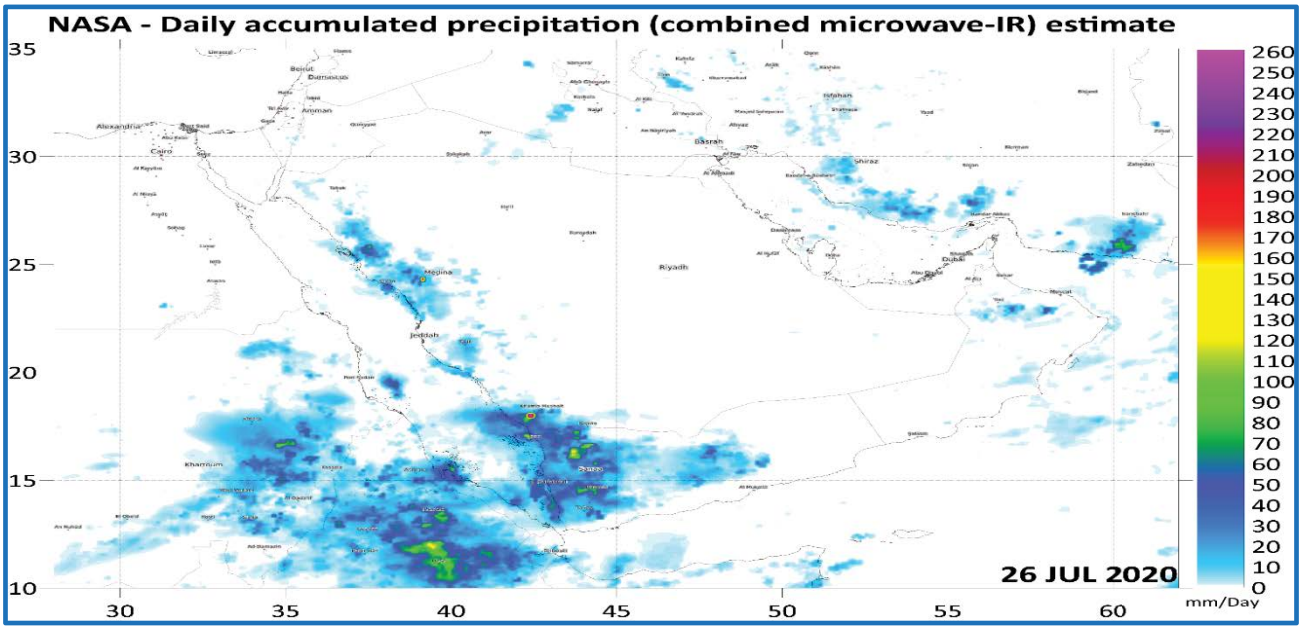

Fig. 2. NASA daily accumulated precipitation in 26/7/2020 during the weather state "Rahw".

1 d (24 h), and nearly 90% of the total amount of daily precipitation has received during a period of 2–6 h only. The rain station Damad in Jazan Region has recorded the maximum amount of daily precipitation during "Rahw" state attaining 83.1 mm, followed by Al-Shifa rain station located in Al Taif, Makkah Region 71.6 mm, Mensab in Bahr Abu Sakina in Muhayil, Asir Region 61 mm, then Al Bahah Station 45.4 mm, followed by Najran 36.8 mm, North Al-Fereash station in Al Madinah region 28.4 mm, as shown in Table 2. Whereas the maximum accumulative rainfall precipitation during the weather state "Rahw" is illustrated in Table 3.

4.2. Average depth and volume of rainfall precipitation

The daily rainfall precipitation records for all rainfall and weather stations during the weather state "Rahw" were obtained and the accumulated precipitation depths

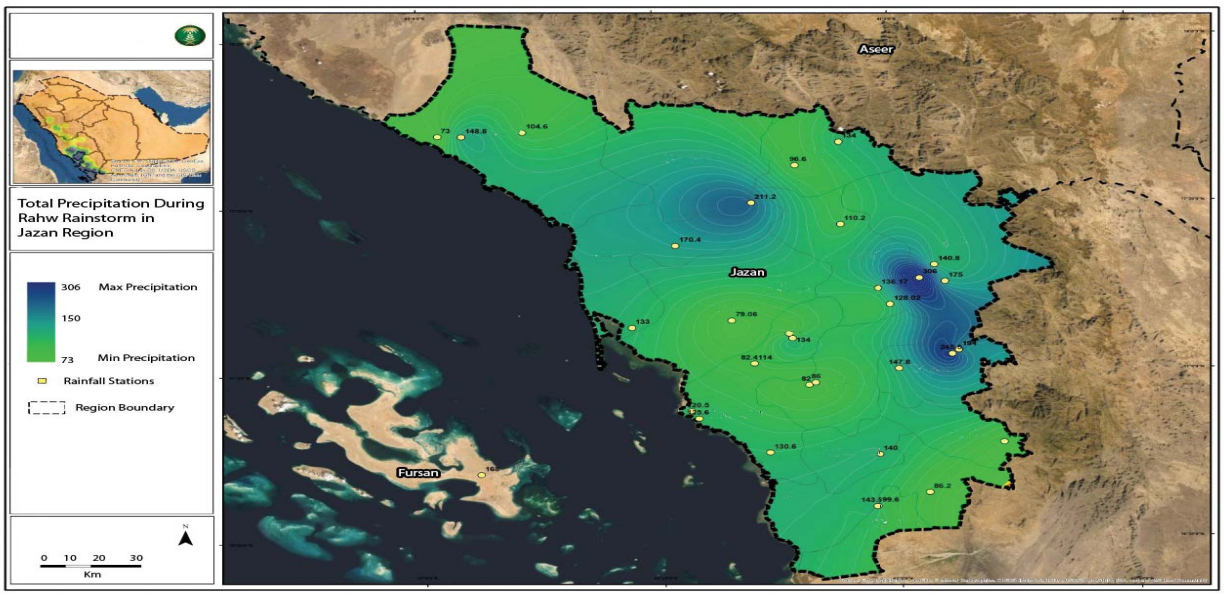

Fig. 3. Rainfall distribution in Jazan Region during the weather state "Rahw".

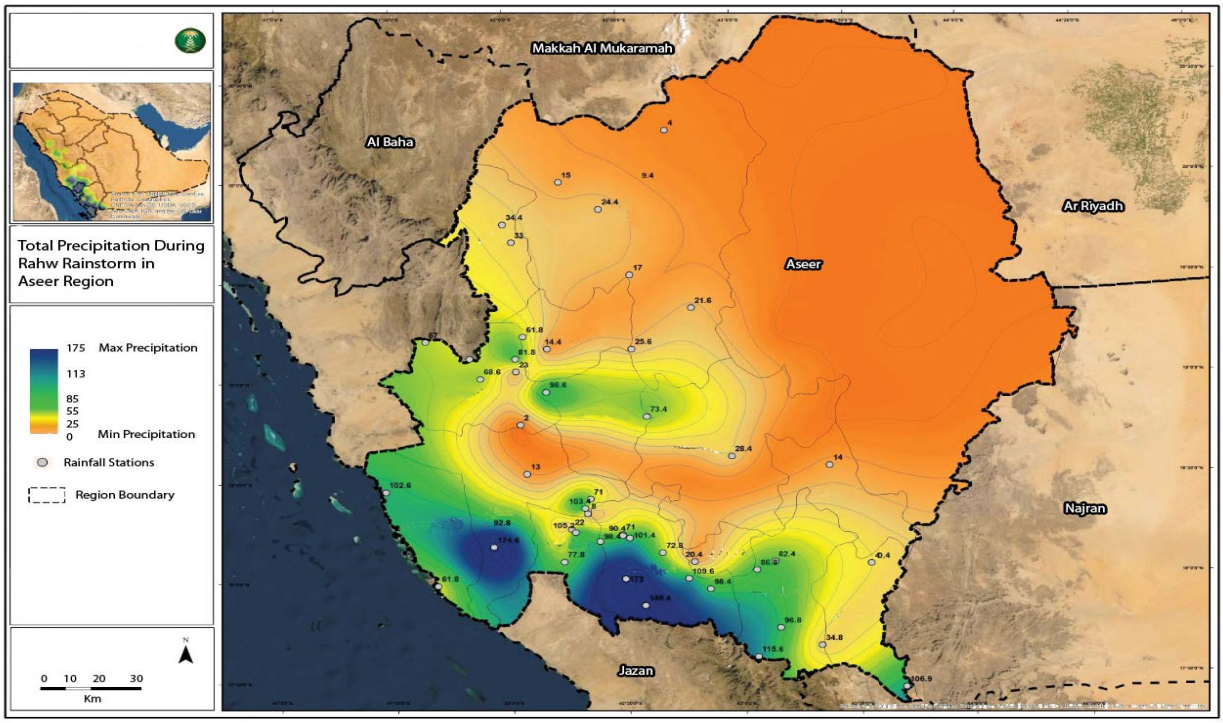

Fig. 4. Rainfall distribution in Asir Region during the weather state "Rahw".

were calculated. Then the total weighted areal precipitation depths and volumes were calculated for each region using Thiessen Polygons method. The total geographic area affected with "Rahw" state in Al Bahah, Jazan, Asir, Makkah, Al Madinah and Najran Regions have been calculated as 212,672 km^2, representing only 40.7% of the total area of those regions which attained as 522,355 km^2 Saudi Geological Survey, 2016. The lowest precipitation value was in Riyadh region as 2.6 mm, followed by Tabuk Region 3.1 mm, Al Madinah region 17.8 mm, Makkah Region 42.3 mm, then Asir Region 64.5 mm, Najran 69.6 mm, Al Bahah Region 89.6 mm and Jazan Region 133.8 mm. Generally, the average total precipitation depth over all Kingdom of Saudi Arabia (KSA) regions during the weather state "Rahw" was estimated as 32.56 mm, representing 30.90% of the total average depth of the annual precipitation

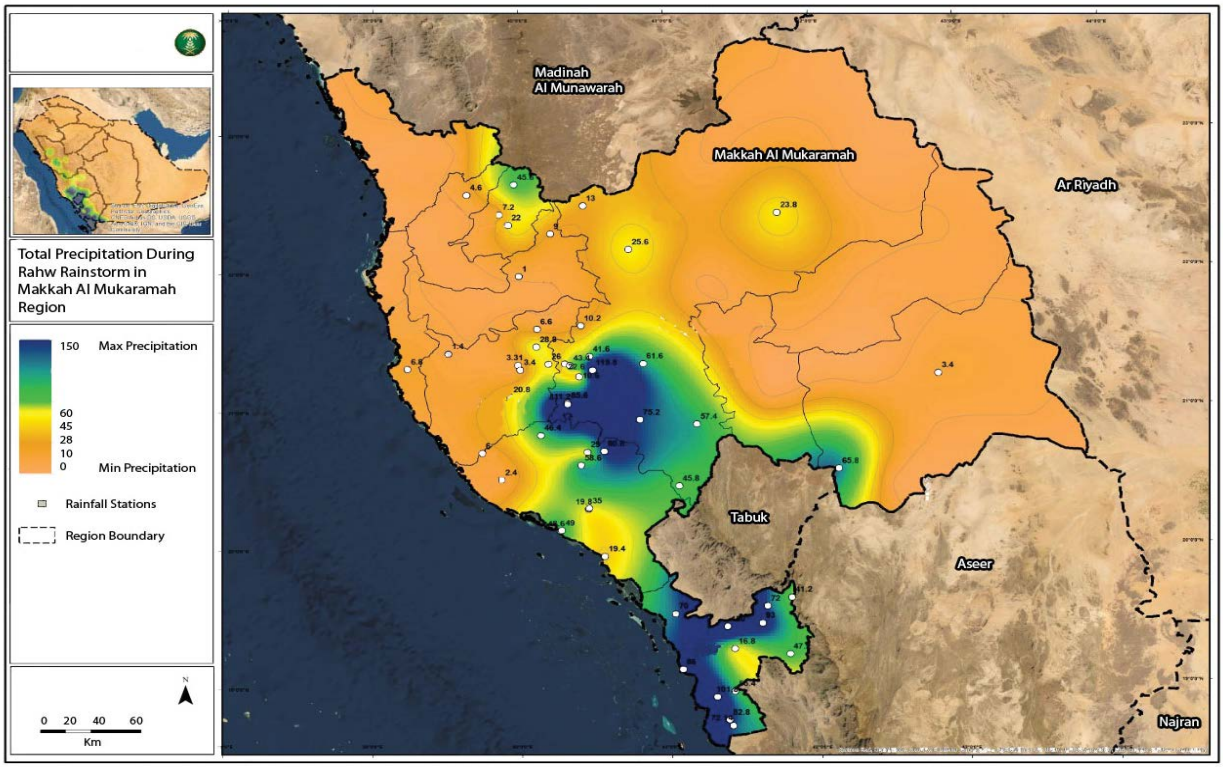

Fig. 5. Rainfall distribution in Makkah Region during the weather state "Rahw".

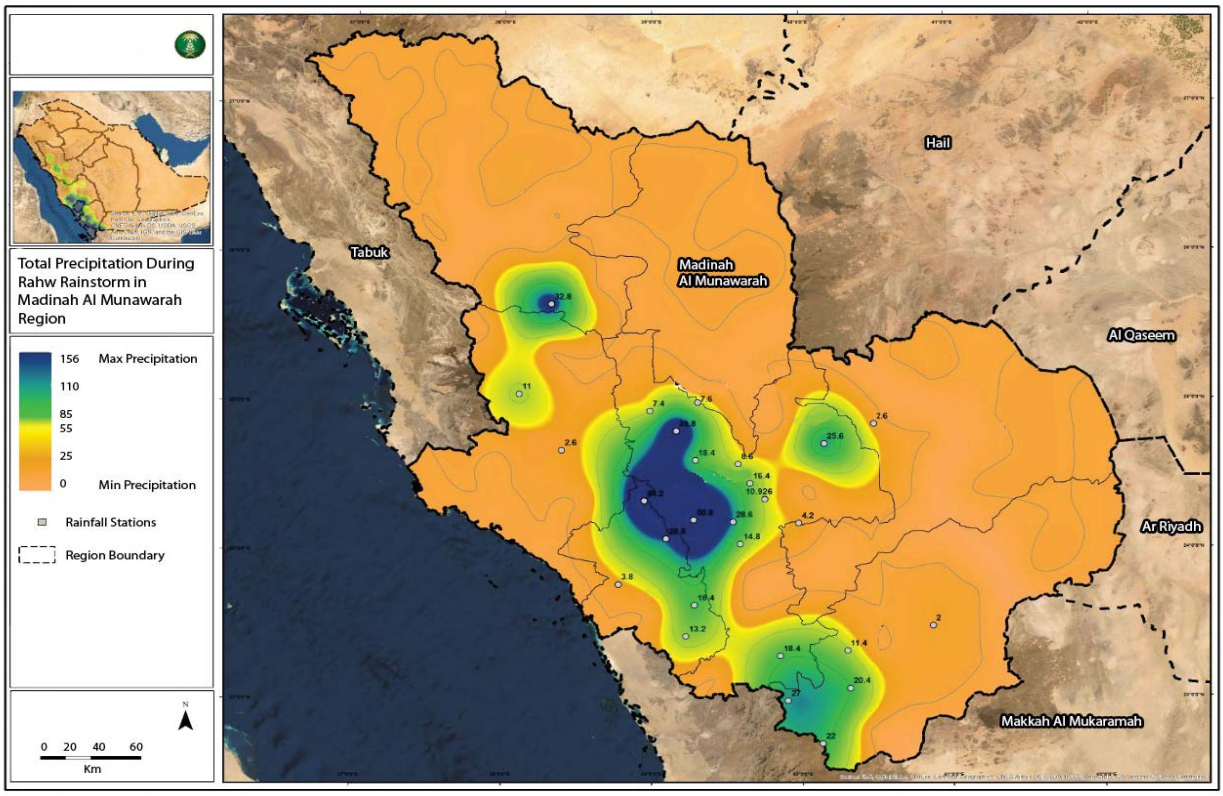

Fig. 6. Rainfall distribution in Al Madinah Region during the weather state "Rahw".

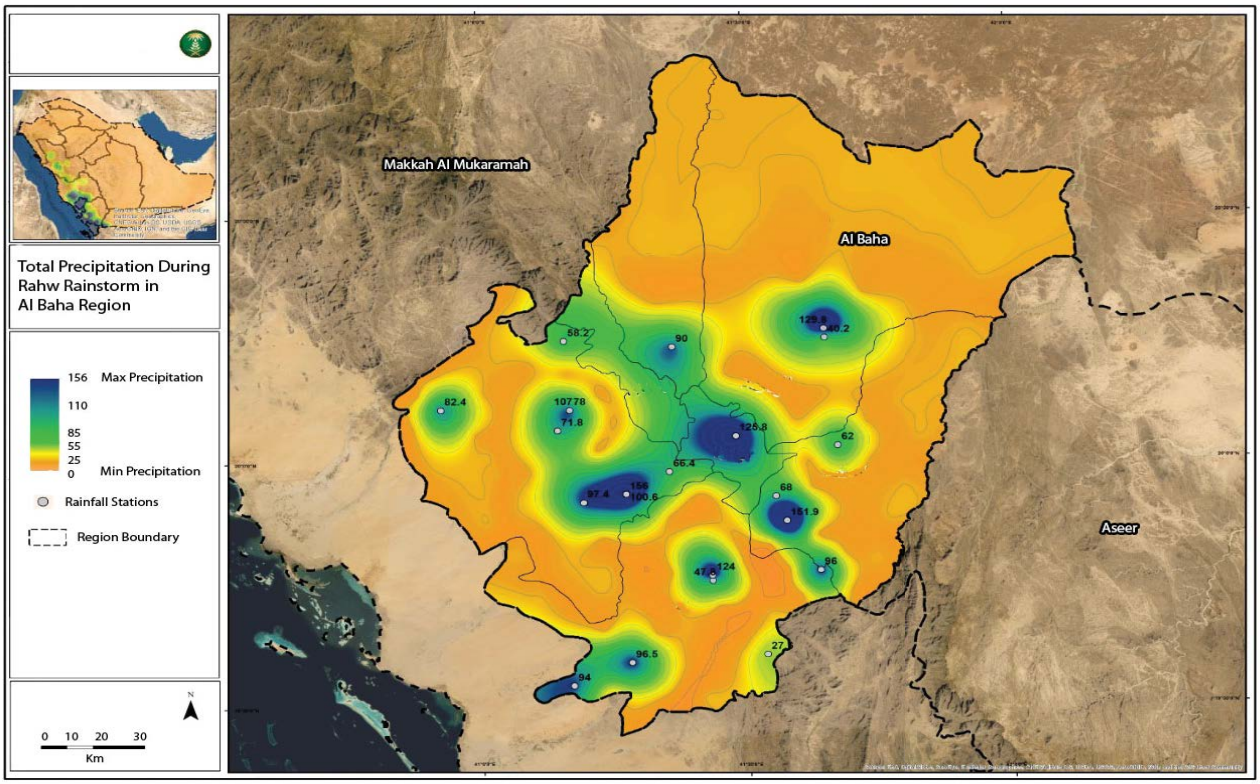

Fig. 7. Rainfall distribution in Al Bahah Region during the weather state "Rahw".

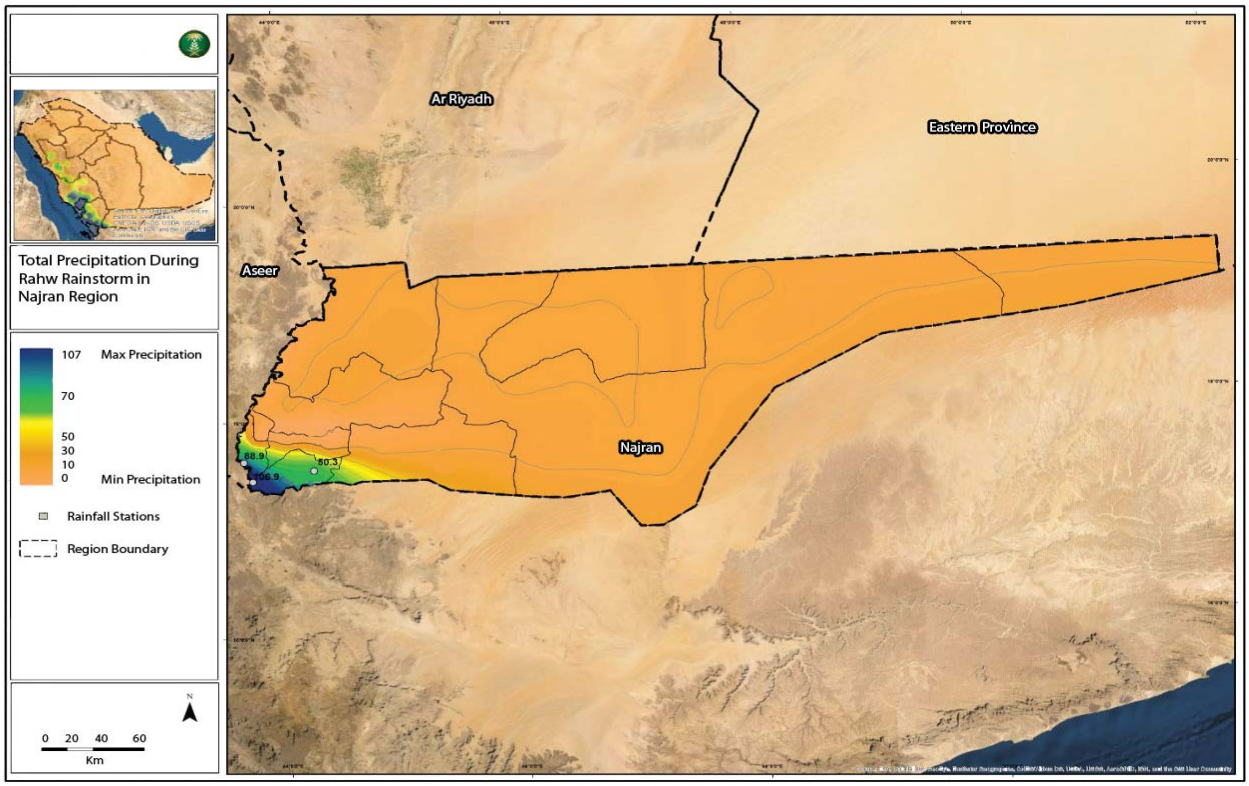

Fig. 8. Rainfall distribution in Najran Region during the weather state "Rahw".

Table 2
Maximum daily rainfall precipitation during the weather state "Rahw"

Region	Rainfall station	Maximum daily precipitation depth during Rahw (mm)
Jazan	Damad	83.1
Makkah	Al Shifa/Al-Taief	71.6
Asir	Mensab/Muhayl	61
Al Bahah	Al Bahah City	45.4
Najran	Najran City	36.8
Al Madinah	North Al Fereash	28.4

Table 3
Maximum accumulative rainfall precipitation during the weather state "Rahw"

Region	Rainfall station	Maximum accumulative precipitation (mm)
Al Bahah	Qilwah	156
Jazan	Abian	306
Asir	Mensab/Muhayl	174.6
Makkah	Tholatha Al Khurma	130
Al Madinah	Northern Al Fereash	50.6
Najran	Al Namasah	88.9

over all the Kingdom regions within 50 y record, is estimated as 103 mm by Mattar and Al Qahtani [17]. Whereas the average accumulated precipitation depth during the weather state "Rahw" over the western and southwestern six regions was estimated as 69.59 mm, representing 45.8% of the total average annual precipitation over these regions within 50 y record. Table 4 shows the average depths and volumes of precipitation for each region during Rahw state and correlated them with the crossponding average annual precipitation in all KSA regions within 50 y record. The time series of rainfall intensity and cumulative rainfall depth of Damad weather station in 6/8/2020, Jazan Region is shown in Figs. 9 and 10, respectively. Whereas Fig. 11 shows the corresponding air temperature and air relative humidity in the same station.

4.3. Comparison of the average rainfall depth for July and August months

The number of rainy days and the average depth of precipitation during the July and August months in the period from 2010 to 2019 were calculated and compared with the corresponding precipitation values recorded for the same months in 2020. The average precipitation depth for July 2020 was 32.9 mm and 9.4 rainy days, compared to the average precipitation depth of 20 mm and 5 rainy days during the period from 2010 to 2019.

4.4. July precipitation

It was found that the July is considered as a distinctive rainy month during the period from 2010 to 2019 with an average precipitation depth of 56 mm in Najran Region, 44 mm in Jazan Region, and 23 mm in Asir Region, 17 mm in Al Bahah, and 17 mm in Makkah, while rain was rarely recorded during the July month in the Eastern Region with an average of 8 mm, Tabuk Region 5 mm, and Riyadh region 2 mm. While no rain was recorded in July during the period from 2010 to 2019 in Al Madinah, Al-Jouf, Hail, and the Northern Borders regions.

4.5. Precipitation features of July 2020

- July 2020 was marked by an increase in the rainfall precipitations in Jazan Region 81 mm, Najran Region

Table 4
Average precipitation depth and volume over all KSA regions during the weather state "Rahw"

Region	Average annual precipitation depth for 50 y record	Average precipitation depth (mm) during Rahw	Geographic area (km^2) affected by Rahw state	Percentage of the affected area %	Average precipitation volume (M m^3)	Average runoff volume (M m^3)
Riyadh	90	2.6	0	0	0	0
Makkah	100	42.3	89,736	66	3,799	460
Al Madinah	53	17.8	39,916	27	709	28
Eastern Region	60	0	0	0	0	0
Asir	210	64.5	53,800	67	3,467	451
Najran	75	69.6	12,025	09	837	70
Jazan	275	133.8	12,242	94	1,638	246
Al-Jouf	40	0	0	0	0	0
Northern Borders	70	0	0	0	0	0
Al-Qassim	90	0	0	0	0	0
Tabuk	35	3.1	0	0	0	0
Al Bahah	200	89.6	4,954	41	444	53
Hail	70	0	0	0	0	0
Total	103	32.56	212,672	11	10,894	1,308

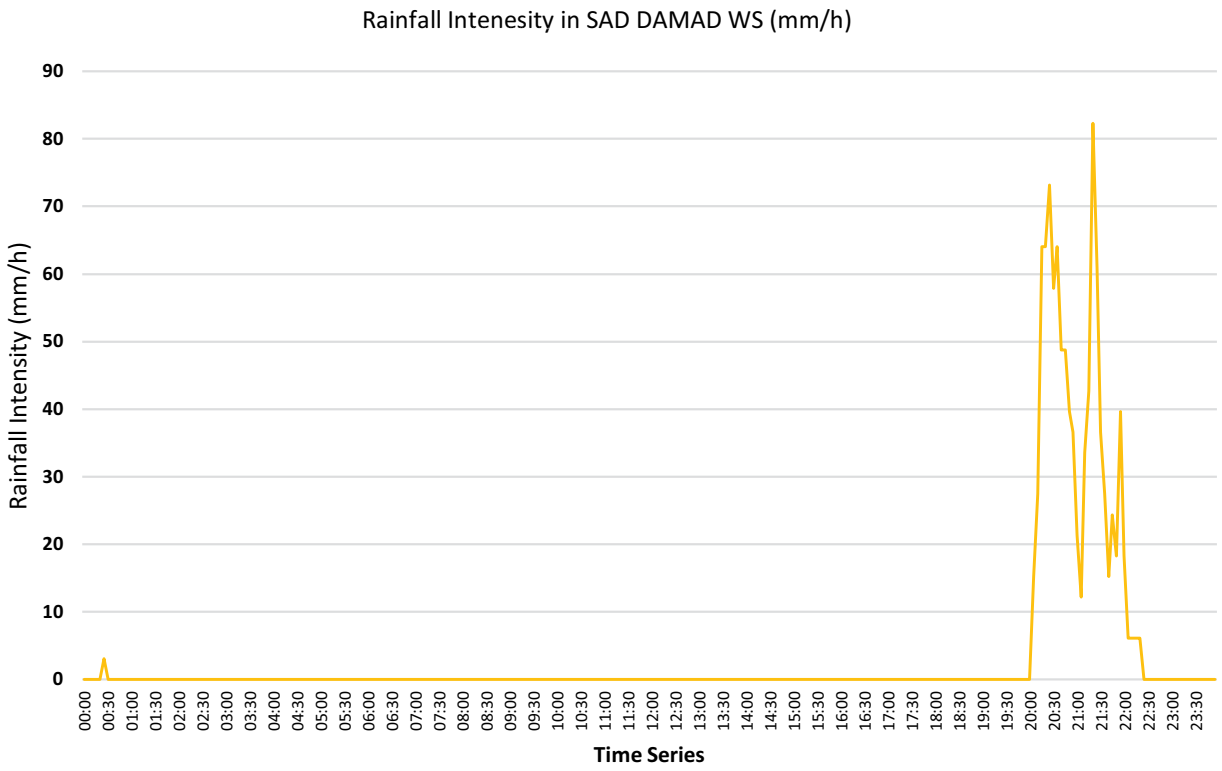

Fig. 9. Time series of rainfall intensity in Damad weather station in 6/8/2020, Jazan Region.

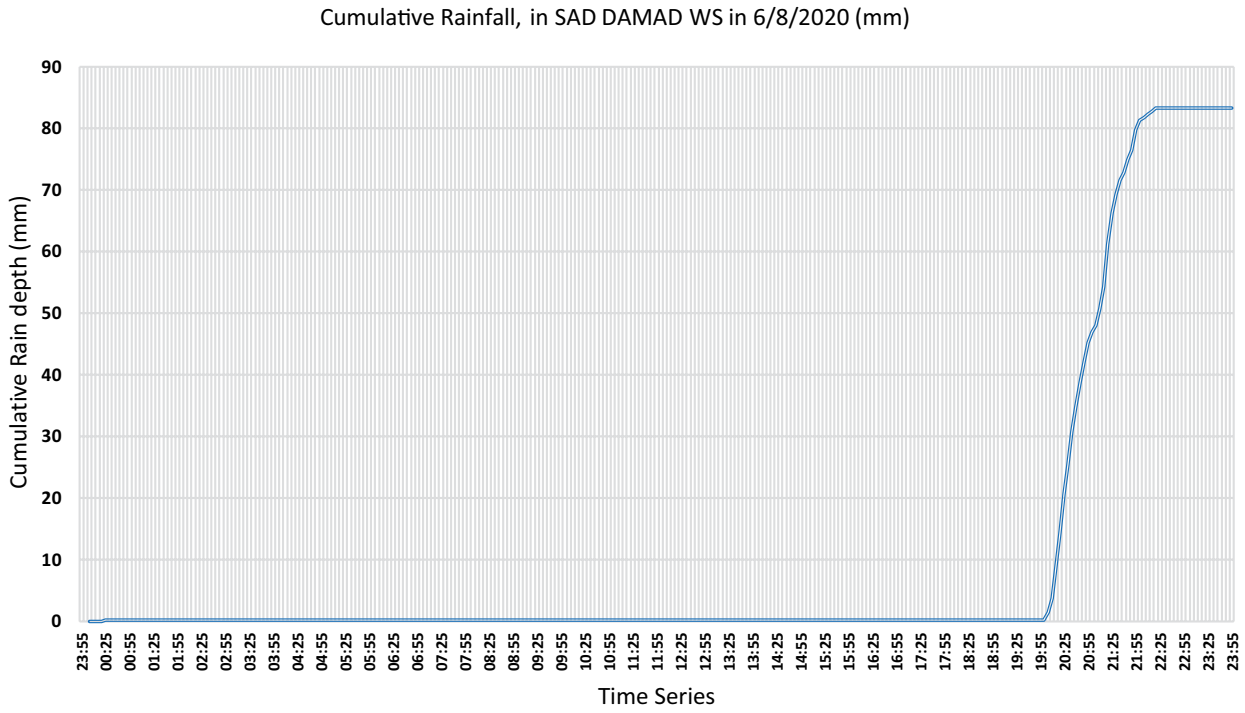

Fig. 10. Cumulative rainfall depth in Damad weather station in 6/8/2020, Jazan Region.

62 mm, Al Bahah Region 59 mm, Makkah Region 21 mm, Al Madinah 12 mm. Note that July in the regions of Jazan, Asir, and Makkah recorded the highest rainfall in the same month in 2016 at an average of 134 mm in Jazan, at an average of 59 mm in Asir, at an average of 47 mm in the Makkah Region.

- The highest number of rainy days were recorded in July 2020 with an average of 25 rainy days in the Asir Region,

17 rainy days in the Al Bahah Region, 12 rainy days in Al Madinah region, 10 rainy days in the Makkah Region and 8 rainy days in Najran Region, as illustrated in Table 5.

4.6. August precipitation

The meteorological statistical analyses of the rainfall records of MEWA stations showed that August was a rainy month during the period 2010–2019 in Jazan Region with an average depth 58 mm, and Asir Region 38 mm, Makkah Region 28 mm, Al Bahah Region 20 mm, Al Madinah region 10 mm, and Najran 8 mm. While no rain has been recorded in August in the rest of the Kingdom's regions during the same period. The average depth of precipitation for August 2020 was 27.5 mm, and 9.2 rainy days, compared to 27 mm precipitation and 7 rainy days during August within the period from 2010–2019, as illustrated in Table 6.

4.7. Precipitation features of August 2020

- August 2020 was characterized by an increase in the monthly average rainfall depth in Jazan Region 66 mm, Al Bahah Region 27 mm, and Najran Region 14 mm.
- August 2020 has recorded the highest average monthly rainfall in Jazan, Asir, Makkah and Al Madinah during 2016, at a rate of 167, 99, and 103 mm respectively.
- August 2017 recorded the highest rainfall of 37 mm in Al Bahah Region during the period from 2010–2019.

4.8. Frequencies of "Rahw" climate state

The statistical analyses of the rainfall records of MEWA hydrologic networks concluded that more than thirty distinctive weather states have prevailed over Saudi Arabia during different climatic seasons between 2011 and 2021, but

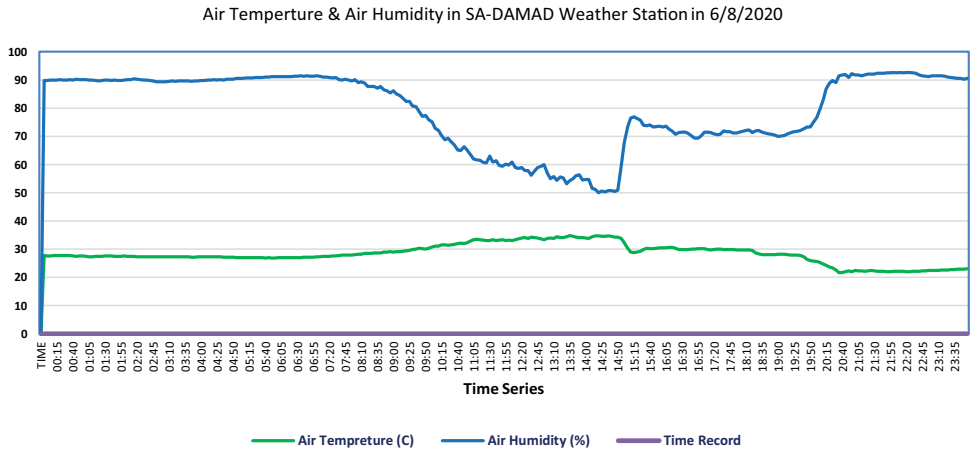

Fig. 11. Air temperature and air relative humidity in Damad weather station in 6/8/2020, Jazan Region.

Table 5
Average precipitation depth and rainy days in July in KSA regions

Region	Average precipitation depth (h mm) in July	Maximum precipitation depth (mm) in July	Record year	Average rainy days in July	Maximum rainy days in July	Record year	Average precipitation depth (h mm) in July 2020 mm	Average rainy days in July 2020
Al Bahah	17	59	2020	5	17	2020	59	17
Jazan	44	134	2016	5	12	2019	81	11
Asir	23	59	2016	12	25	2020	43	25
Makkah	17	47	2016	5	10	2020	21	10
Al Madinah	8	12	2020	4	12	2020	12	9
Najran	56	62	2020	7	8	2020	62	8
Riyadh	3	3	2020	1	1	2020	3	1
Tabuk	5	6	2020	2	2	2020	6	2
Eastern Region	8	9	2020	2	2	2020	9	2
Al-Jouf	0	0		0	0		0	0
Northern Borders	0	0		0	0		0	0
Al-Qassim	0	0		0	0		0	0
Hail	0	0		0	0		0	0

Table 6
Average precipitation depth and rainy days in August in KSA regions

Region	Average precipitation depth (mm) in August	Maximum precipitation depth (mm) in August	Record year	Average rainy days in August	Maximum rainy days in August	Record year	Average precipitation depth (mm) in August 2020	Average rainy days in August 2020
Al Bahah	20	37	2017	6	21	2019	27	9
Jazan	58	167	2016	13	18	2013, 2016	66	13
Asir	38	99	2016	14	23	2019	28	17
Makkah	28	103	2016	5	23	2019	21	10
Al Madinah	10	22	2016	3	7	2015	9	4
Najran	8	14	2020	3	3	2020	14	3
Riyadh	0	0		0	0		0	0
Tabuk	0	0		0	0		0	0
Eastern Region	0	0		0	0		0	0
Al-Jouf	0	0		0	0		0	0
Northern Borders	0	0		0	0		0	0
Al-Qassim	0	0		0	0		0	0
Hail	0	0		0	0		0	0

little weather states have prevailed in the summer season, among of these was called as "Al Rabab" and has extended from 28 July to 3 August 2016. Therefor the authors have the opinion that the weather state "Rahw" is considered as the frequency of "Al Rabab" weather state which have approximately occurred in the same interval in 2016.

5. Average runoff volumes on the regions

The total average cumulative precipitation volume over the affected areas by the weather state "Rahw" was estimated as 10,894 million m^3. The direct surface runoff volume in the areas affected by "Rahw" was estimated based on the averages of the cumulative rainfall and the empirical runoff coefficients of Al Hasan and Mattar [18] as shown in Table 7. Figs. 12 and 13 show the average precipitation and average runoff volumes, respectively during the weather state "Rahw" in KSA. The direct surface runoff is estimated as 1,308 million m^3. Among this runoff, 352 million m^3 were received into the constructed dams' reservoirs and 18 million m^3 into the under-construction dams' reservoirs.

Table 7
Total precipitation and runoff volumes in the western and southwestern regions during the weather state "Rahw"

Region	Total precipitation volume during Rahw M m^3	Average total runoff volume during Rahw M m^3
Makkah	3,799	460
Al Madinah	709	28
Asir	3,467	451
Najran	837	70
Jazan	1,638	246
Al Bahah	444	53
Total	10,894	1,308

5.1. Runoff in dam reservoirs

The daily record of the water levels of the retained water behind the dams in Saudi Arabia showed that the flowing of many wadies and the runoff reached to the reservoirs of 165 dams, and this led to increasing in the volume of water in these reservoirs by 370 million m^3. Whereas the volume of retained water behind these dams was estimated as 596.1 million m^3 before Rahw weather state and 738.2 million m^3 at the end of Rahw state. To meet the demands of the farmers downstream the dams during the rainy state, about 201.6 million m^3 of surface runoff was released from dam gates of which the volume of 89 million m^3 was released from Najran surface dam only. As well as 8.3 million m^3 was supplied for the treatment plants constructed on some dams. Therefore, the net increase in the storage volume of dam's reservoirs because of "Rahw" is estimated as 142 million m^3.

5.2. Releasing of dam gates during Rahw

During "Rahw" climate state, many dams in the southwestern regions have received considerable amounts of daily surface runoff resulting to rising of the water levels in the dams' reservoirs to more than 75% of the spillway height. The emergency operational plans of these dams have been applied. The gates of some dams were released to drain water in the downstream to meet the demand of farmers and enhance the groundwater recharge in the wells. The total volume of released water from the dams' gates attained 201.62 million m^3, of them. 93.87 million m^3 were drained from the dams of Najran Region, 61.7 million m^3

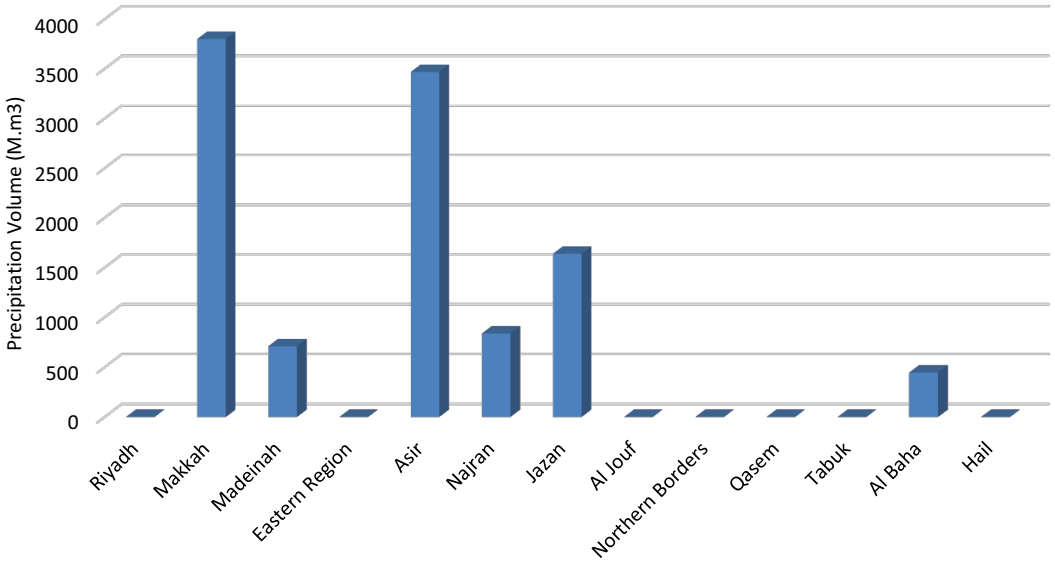

Fig. 12. Average precipitation volume (M m^3) during the weather state "Rahw".

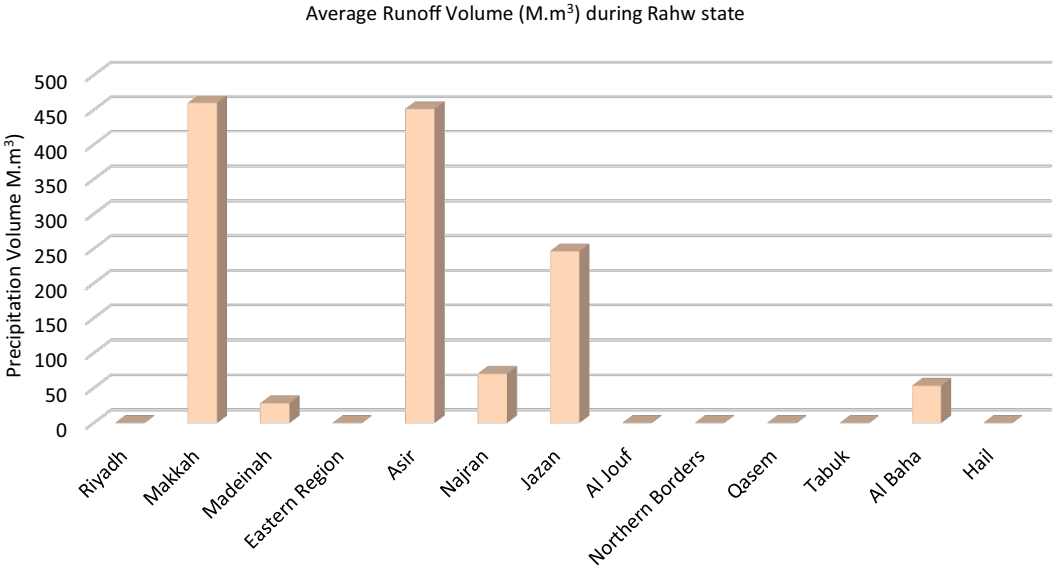

Fig. 13. Average runoff volume (M m^3) during the weather state "Rahw".

from the dams of Jazan Region, 29.0 million m^3 from the dams of Makkah Region, 10.87 million m^3 from dams of Asir Region, 3.18 million m^3 from dams of Al Bahah Region, and 3.0 million m^3 from dams of Al Madinah region.

6. Conclusion

More than thirty distinctive weather states have prevailed over the Kingdom of Saudi Arabia during different climatic seasons between 2011 and 2020, but very little climate states have prevailed during the summer season, among of these is "Al Rabab" weather state which has extended from 28 July 2016 to 3 August 2016.

The western and southwestern regions of the Kingdom of Saudi Arabia; Al Madinah, Makkah, Al Bahah, Asir, Jazan, and Najran have been subjected to a distinctive summer weather state locally named as "Rahw", which has lasted for 18 d, from 24 July 2020 until, 10 August 2020, and resulted on medium to very heavy rains.

The total geographic area affected with Rahw was estimated as 212,672 km^2, representing only 40.7% of the total area of these regions.

The average cumulative rainfall depth on the affected areas of the southwestern regions is estimated as 69.59 mm and the corresponding precipitation volume is estimated as 10,894 million m^3.

The average rainfall received in July 2020 is greater than the average rainfall has been received in the same month during the last 10 y in each Jazan, Najran, Al Bahah and Makkah Regions.

August month recorded in Jazan, Asir, Makkah and Al Madinah regions the highest rates of rain during the year

2016, at a rate of 167 mm in Jazan, 99 mm in Asir, and 103 mm in Makkah Region. While August recorded the highest rainfall of 37 mm in 2017 in Al Bahah Region in the last 10 y.

Releasing of dam's gates during "Rahw", and the flow of wadies in the areas affected by Rahw led to the strengthening of the groundwater recharge of the wadi deposits which led to the significant rise in the groundwater level in the farmers' wells.

It is advised to use the "Rahw" rainstorm as a guideline in the design of rainstorms of flood mitigation projects, and for studying the meteorological zones in Kingdome of Saudi Arabia.

The present study recommends developing and update the operational plans of dams in western and southwestern regions to maximize the benefits of the surface runoff and enhance the water resources during the occurrence of such rainstorms.

Continuous coordination with the Civil Defence and the emirates of the regions is highly recommended to warn citizens not to be near the wadi streams because of the possibility of opening the gates of the dams at any time.

A free storage volume must be maintained in the dam's reservoirs corresponding to 50% of the total storage capacity of the dam to accommodate any runoff volumes may reach the dam during rainstorms.

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