Hydrometeorological study on the impact of the weather condition "Rahw" on the Water Resources in Southwestern Regions; Kingdom of Saudi Arabia

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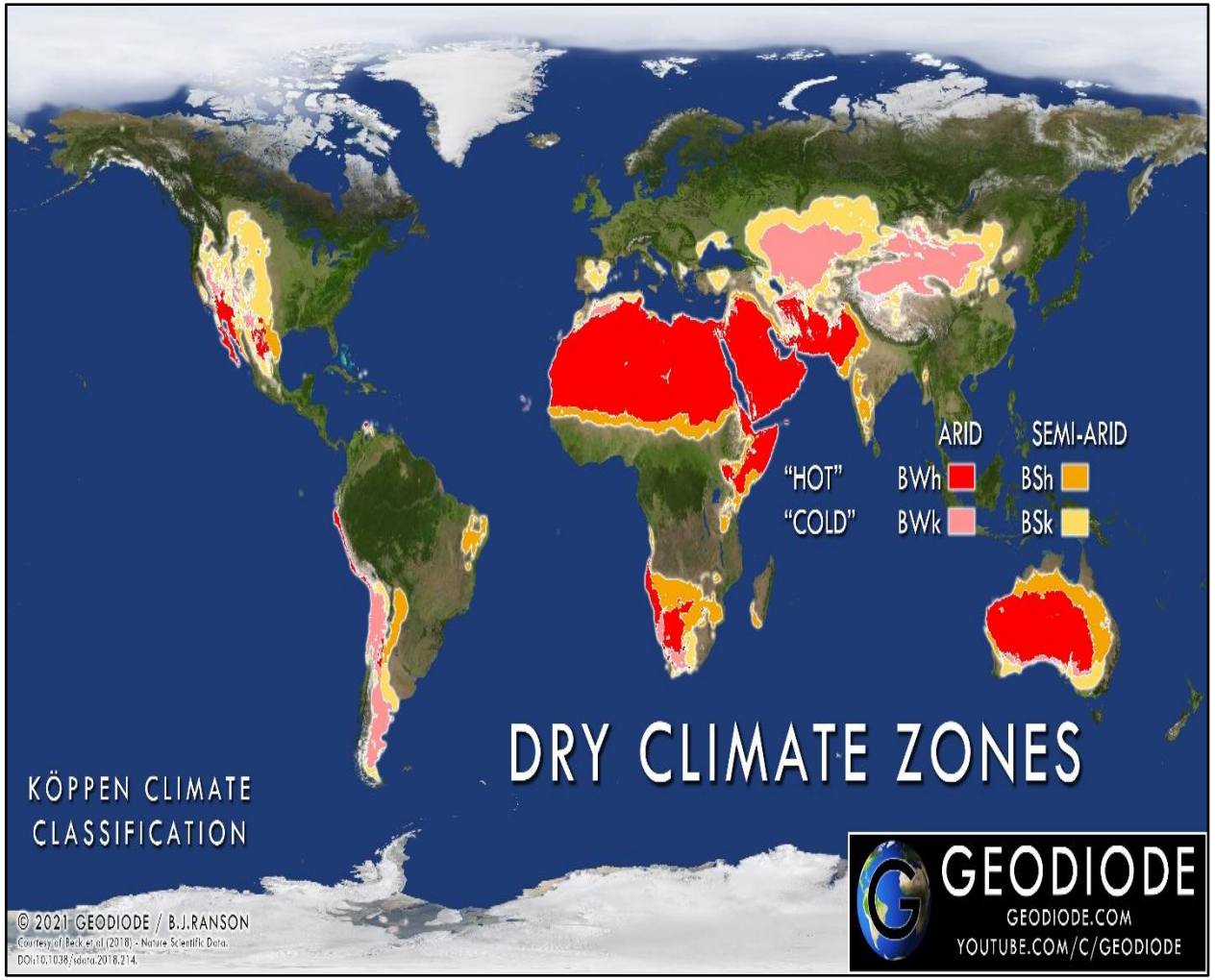
Overview

- Introduction.
- Aim and Objectives of Study.
- Study Area.
- Methodology & Data Collection.
- Rainfall statistical analyses.
- Rainfall Harvesting.
- Conclusion & Recommendations.

Introduction

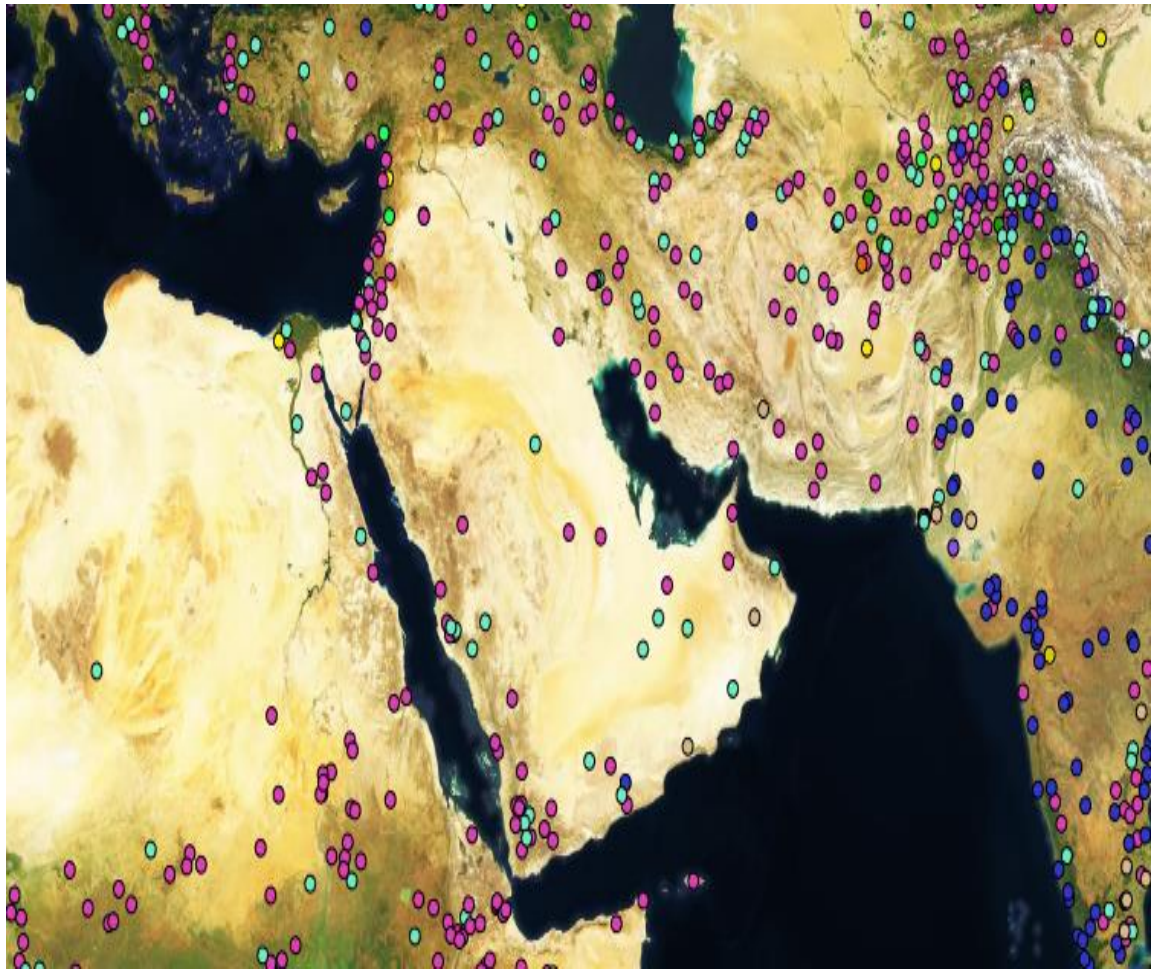
- The climate in GCC is considered as “arid climate Zone (BW).
- In Arid Zone, the rainfall storms exhibit strong spatial variability.
- The rainfall precipitation is very important factor in preparing of the water budgets and assessing the available surface water allocates to meet various water demands.



Dry Climate Zones in the World (Köppen (1936) and Geiger (1961)

Flood Events in Arid and Semi Arid Zone

In the Arid Regions, some heavy rainstorms and whether conditions may be happened annually and continued for few to many days resulting in large, or extreme flood events.



Types of large flood events (1985-2016), as identified by the Dartmouth Flood Observatory, Colorado University, USA.

Introduction

- Many heavy rainstorms, and whether conditions have happened in Saudi Arabia regions and lasted for few or many days.

Jeddah, November 2009

Tabuk , 2013

Rumah, Riyadh,November 2016

Introduction

- In 1953, the United States began using female names for storms and, by 1978, both male and female names were used to identify Northern Pacific storms. This was then adopted in 1979 for storms in the Atlantic basin
- On 28 January 2011, the Saudi Committee for Nomenclature of Distinctive Climatic States over Saudi Arabia (Non-governmental committee) has been established to achieve many goals:

Some Distinctive Weather conditions prevailed in KSA (2010-2020)

- **About (30) Distinctive Weather Conditions have prevailed in Kingdome of Saudi Arabia during different climatic seasons, in the interval from (2011 - 2020),**

1. **Moghdeqah**
   - from 22 March to 21 April 2012 (31 days)
2. **Al Baydaa**
   - from 25 April to 8 May 2013 (14 days)
3. **Sabeghah**
   - from 22-26 November 2015 (5 days)
4. **Al Rabab**
   - from 28 July to 3 August 2016 (7 days)
5. **Joud**
   - from 11-18 February 2017 (8 days)
6. **Ghadaq**
   - from 25 October to 20 November 2018 (27 days)
8. **Rahw**
   - from 24 July to 10 August 2020 (18 days)

Aim of Study (Why the present is needed??)

Very little studies have been dealt with the study of the hydrometeorological impact of the sever rainstorm that have affected the Kingdome of Saudi Arabia.

❖ **The main goals of the present study are :**

- Understanding how was the **rainfall pattern** during the weather condition "Rahw".
- Investigate the **hydrometeorological impact** of the weather condition "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.

Methodology

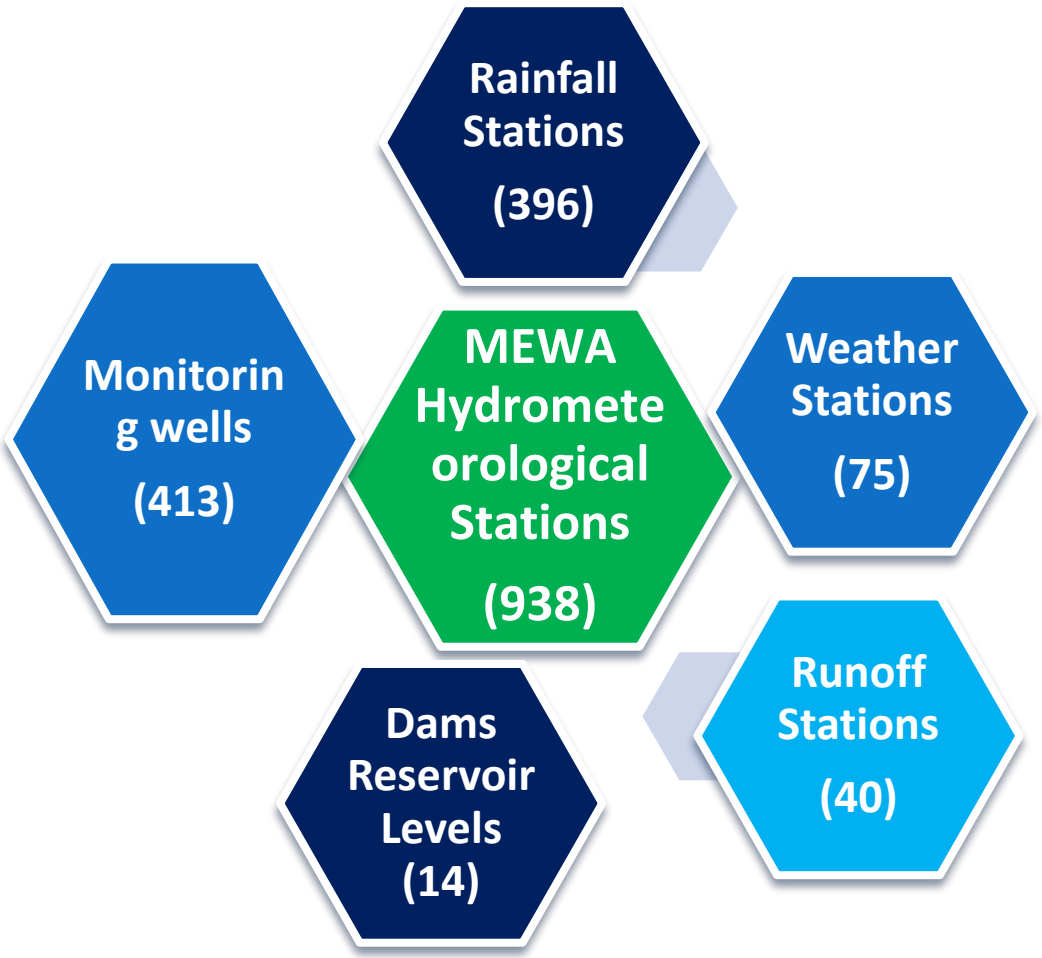
- Studying the spatial distribution of rainfall records and producing the spatial distribution Isohyetal contour maps of all affected area during "Rahw" weather state using ARC GIS techniques.
- Calculating the total affected areas that have received rains during the weather state"Rahw".
- Correlating the daily and monthly rainfall records with the corresponding records during interval (2010-2019), and during the full record (1953-2020).
- Statistically analyzing the daily records of the water levels in dams' reservoirs through Rahw.

Data Collection

- Ministry of Environment, Water and Agriculture (MEWA) has installed a good hydrologic network covering all the Kingdom of Saudi Arabia regions as early as 1953 and up to date.

MEWA Hydrometeorological Networks characterizes by:

- Good geographical coverage.
- Real time, Speed, accuracy and reliability of monitoring information's
- Relatively long historical record years of monitoring (65 years) .

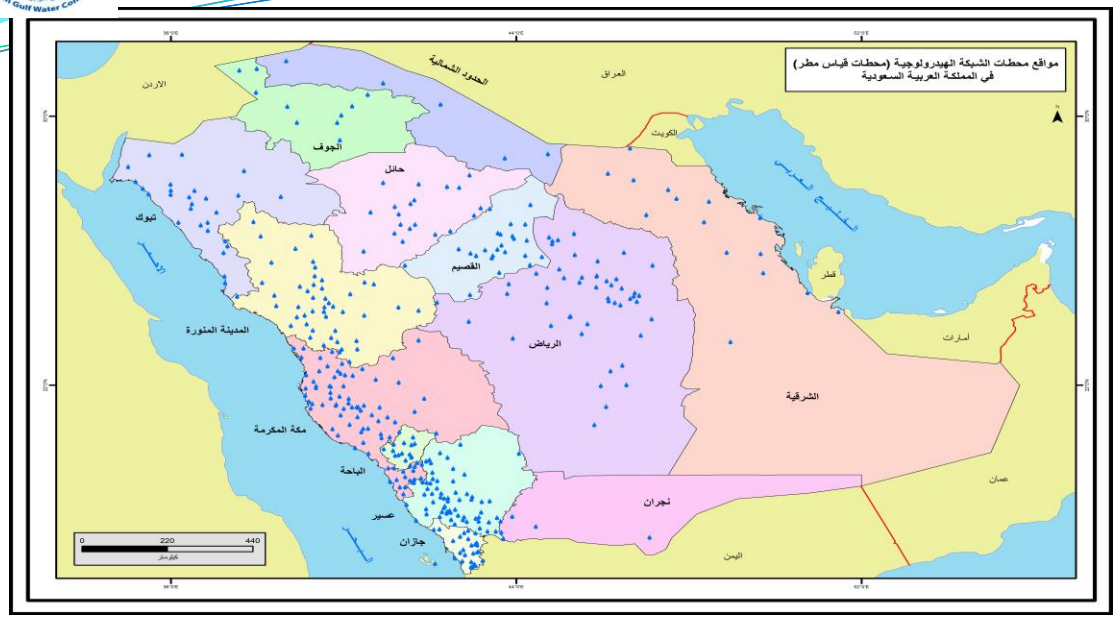


Summary of Distribution of MEWA Hydrometeorological Stations

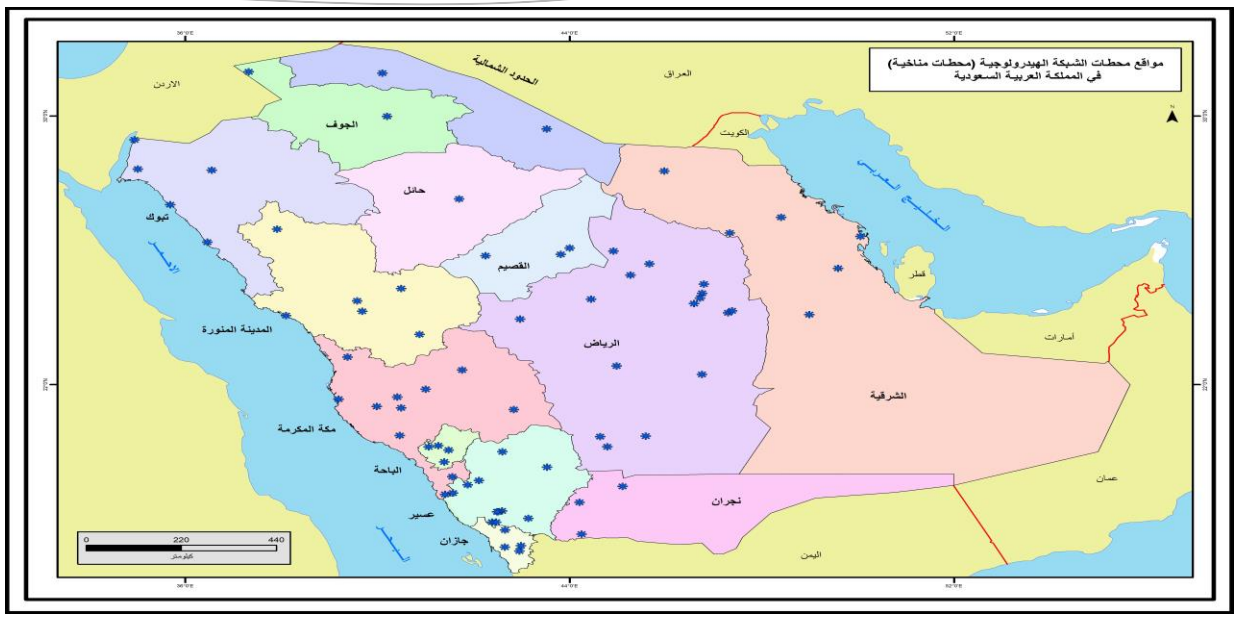
Data Collection

Geographical Distribution of MEWA Hydrometeorological Networks

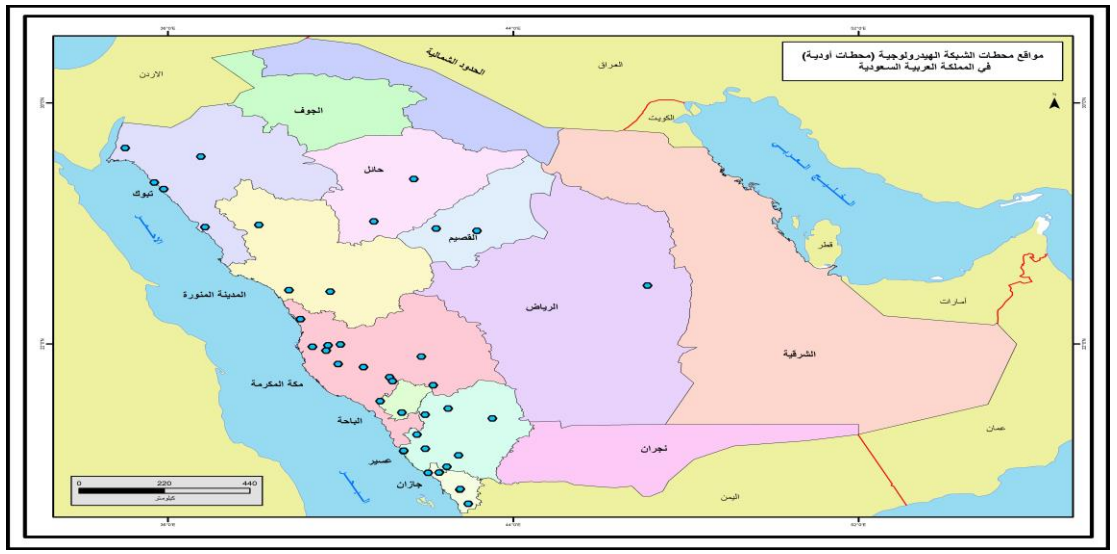
Region	Rainfall Stations	Weather Stations	Runoff Stations	Dams Reservoir Levels Gauges	Monitoring wells	Total
Riyadh	51	17	1	13	80	162
Makkah	83	12	11	0	40	146
Eastern Region	15	6	0	0	85	106
Al Madeinah	48	6	3	0	47	104
Asir	65	10	9	0	19	103
Tabuk	27	5	5	0	28	65
Jazan	27	4	5	0	20	56
Qaseim	24	3	2	1	17	47
Hail	20	1	2	0	16	39
Al Bahah	17	4	2	0	12	35
Al Jouf	10	2	0	0	20	32
Najran	4	3	0	0	21	28
Northern Borders	5	2	0	0	8	15
Total	396	75	40	14	413	938



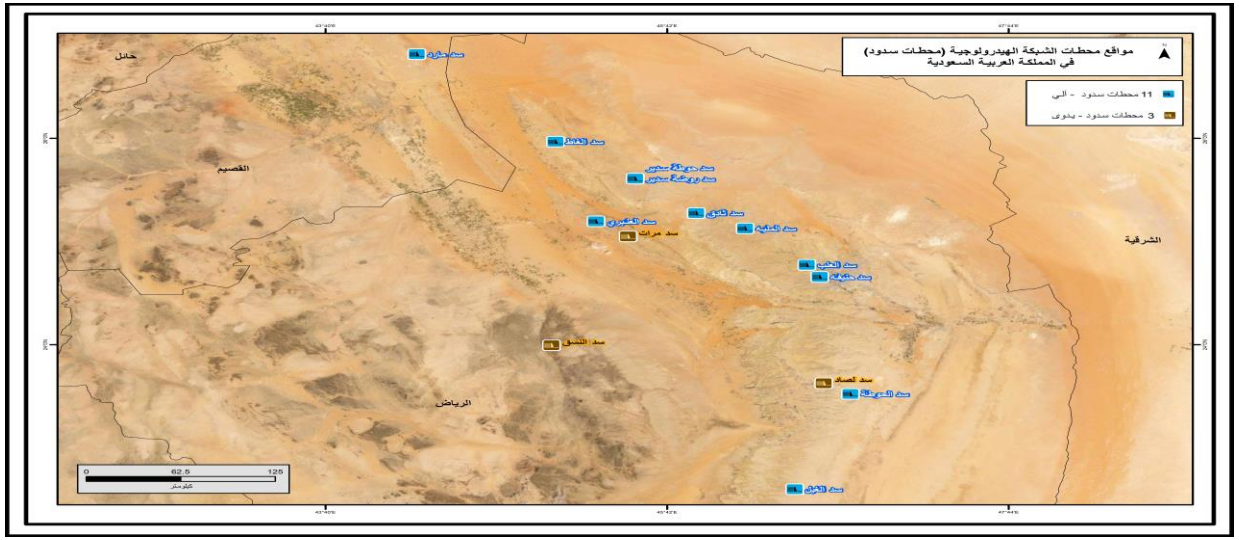
Locations of MEWA hydrologic network Rainfall stations.



Locations of MEWA hydrologic network Weather stations.



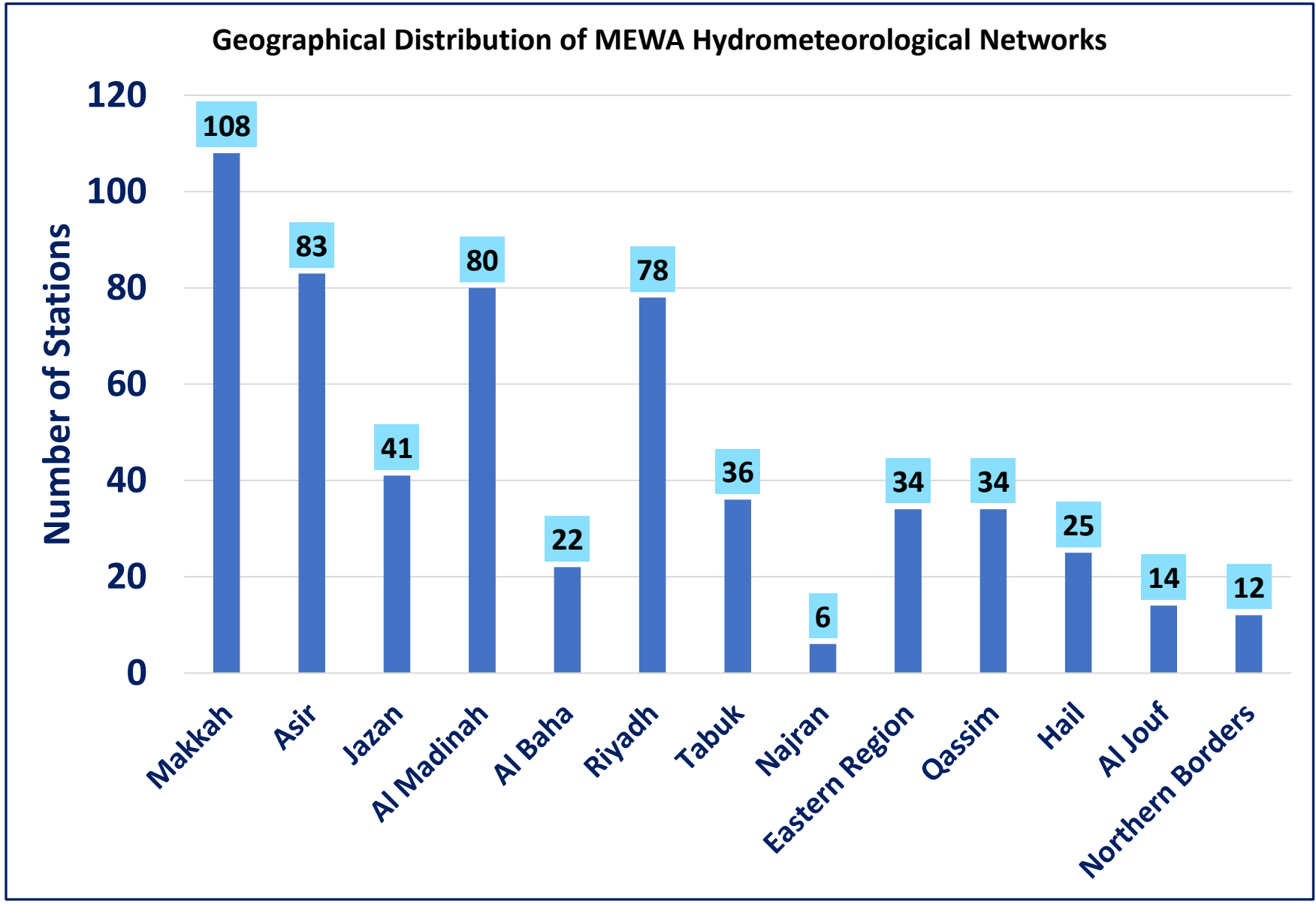
Locations of MEWA hydrologic network Runoff stations.



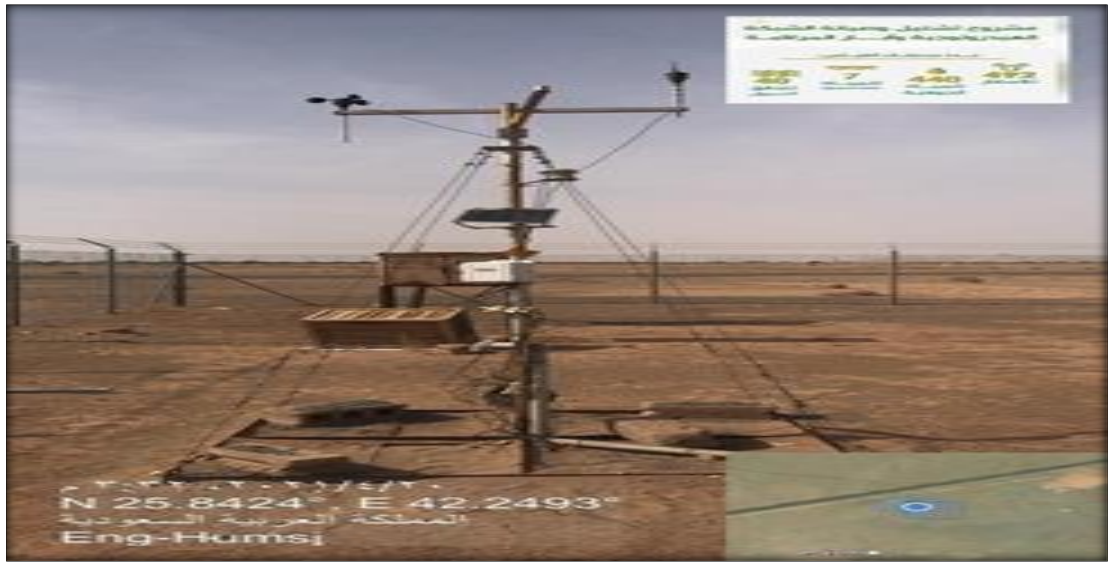
Locations of MEWA hydrologic network Dam reservoirs stations.

Geographical Distribution of MEWA Hydrologic network stations used in the present Study

Region	Average Rainfall depth (mm) in the region within 50 years record
Riyadh	78
Makkah	108
Al Madinah	80
Eastern Region	34
Asir	83
Najran	6
Jazan	41
Al Jouf	14
Northern	12
Qassim	34
Tabuk	36
Al Baha	22
Hail	25
Total	573

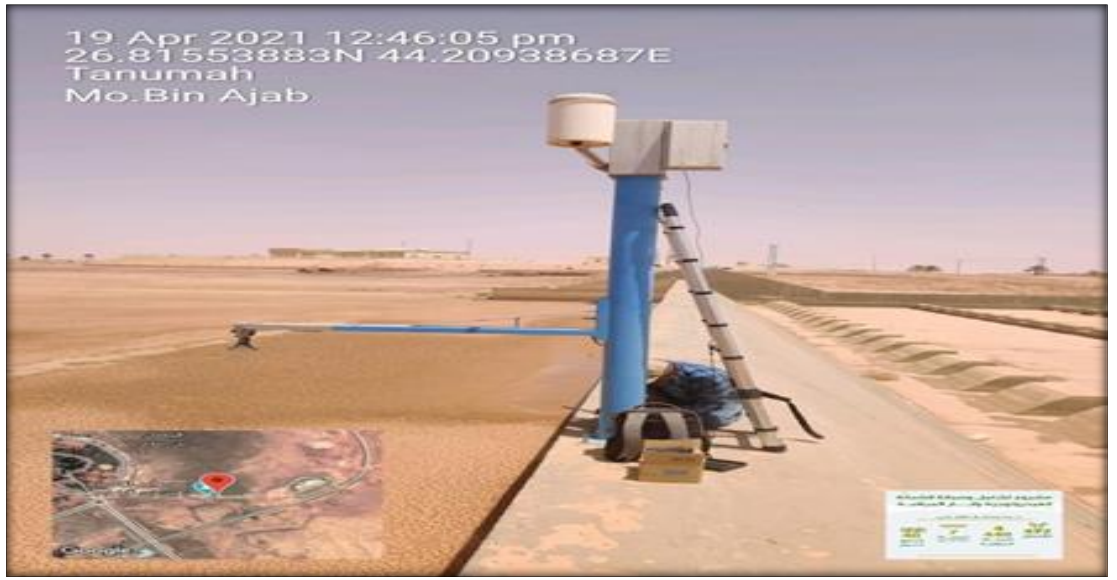


MEWA hydrologic network Rainfall station.



MEWA hydrologic network Weather station.

MEWA hydrologic network Runoff station.

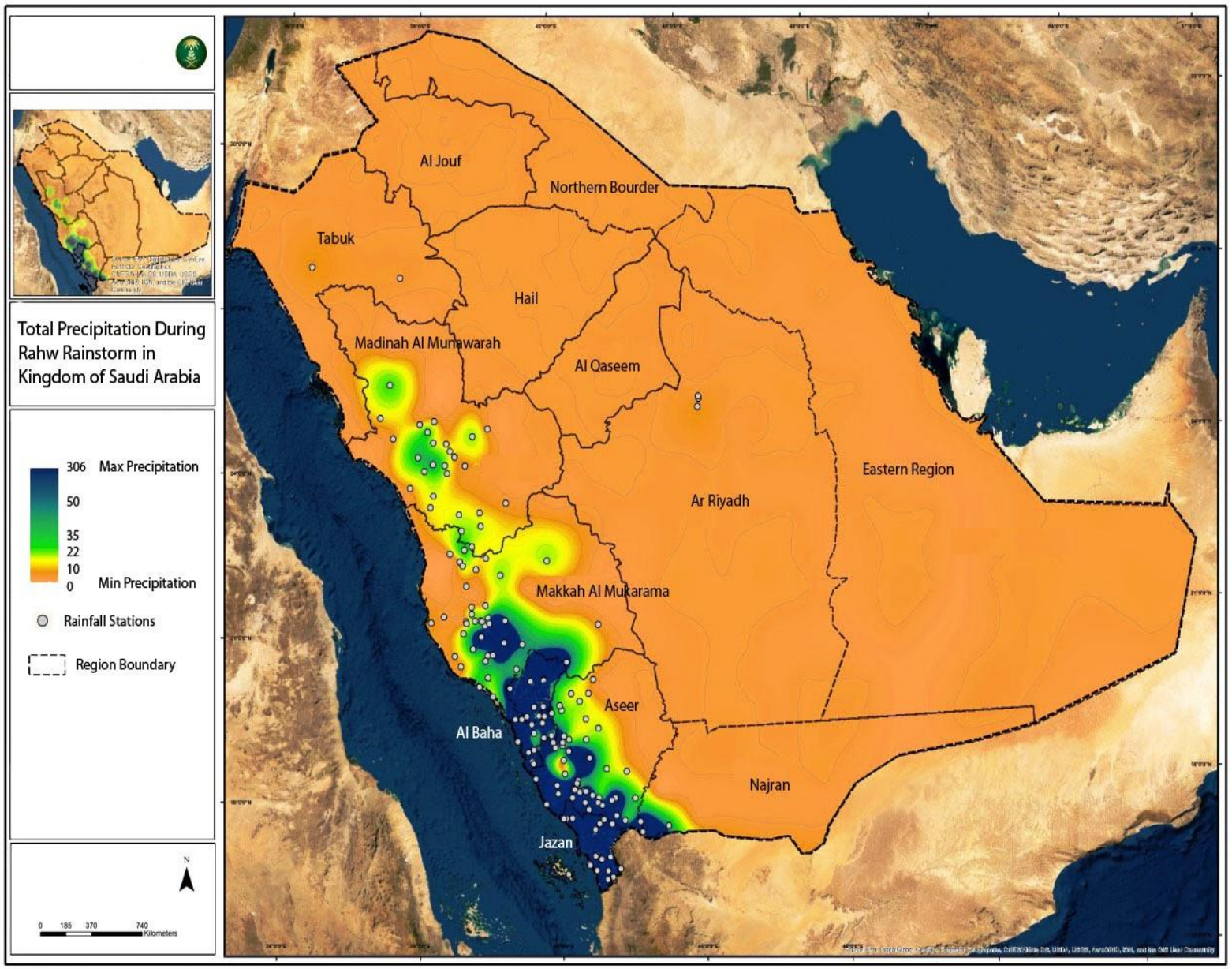


MEWA hydrologic network Dam reservoirs station.

Rainfall Statistical analyses

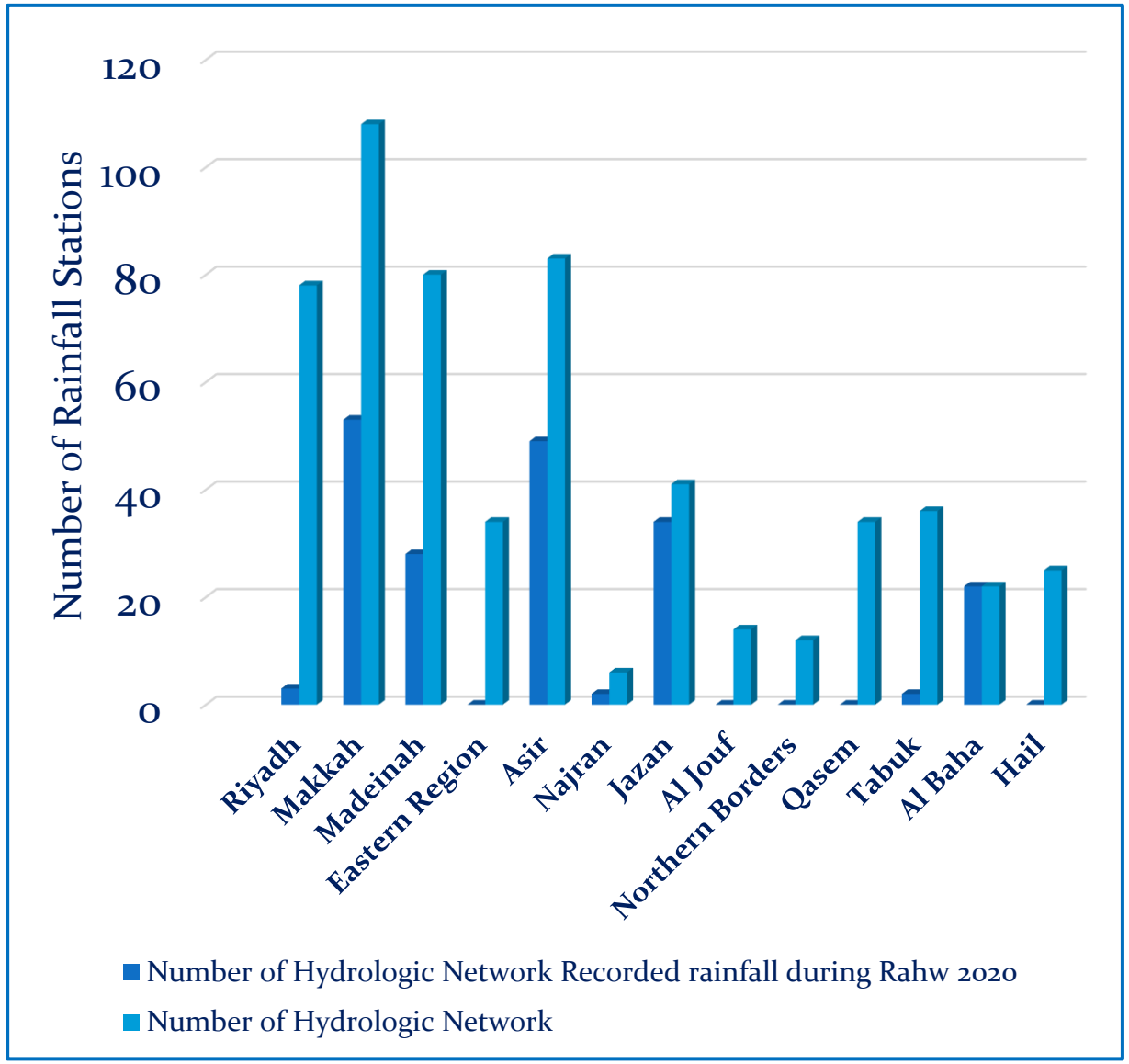
All obtained Rainfall data records of (193) MEWA Stations have been statistically analyzed using Spatial analyses tool in ARC GIS Application,

Isohyetal contour maps of the Spatial Distribution of the rainfall recorded during weather state“Rahw” have been produced in all affected regions.

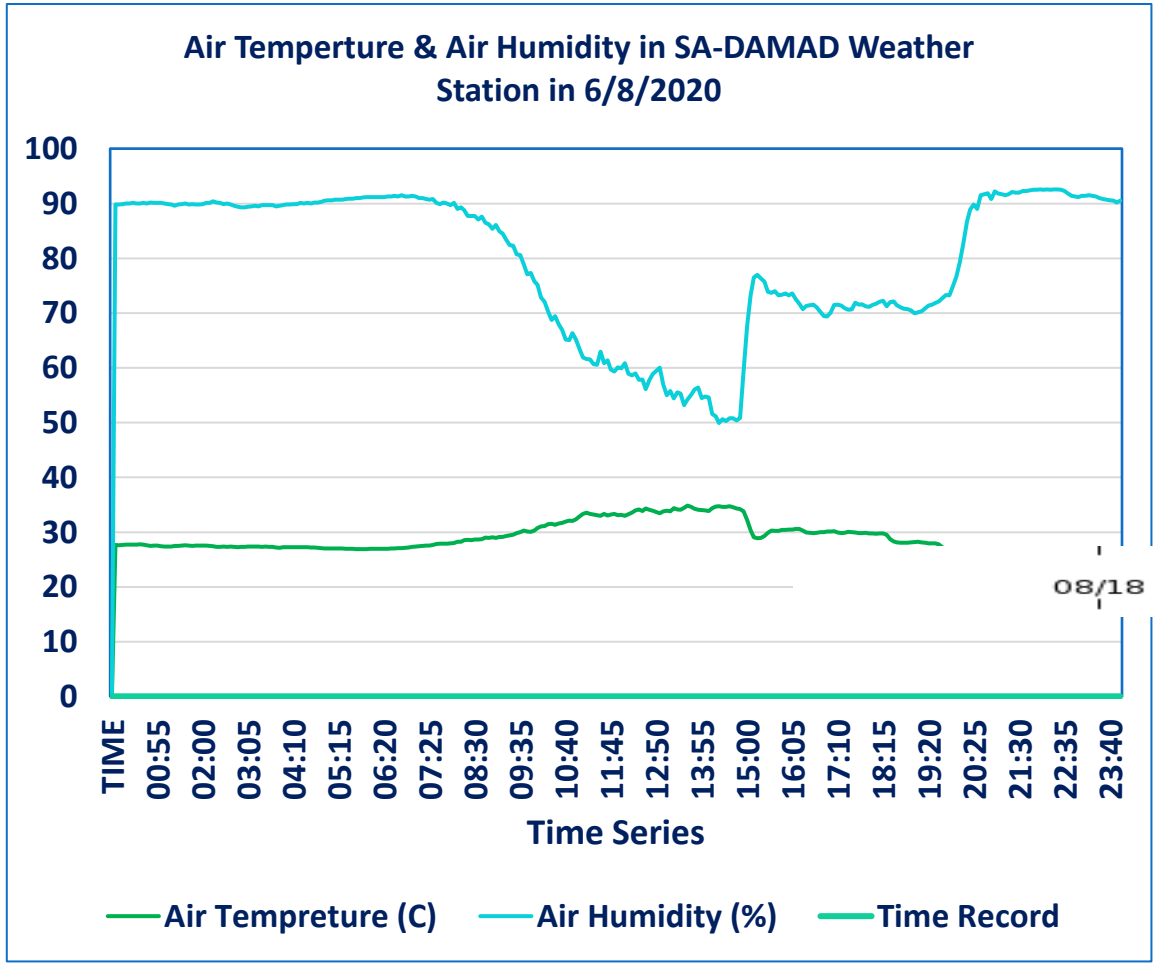


MEWA Hydrologic network stations that recorded during Rahw

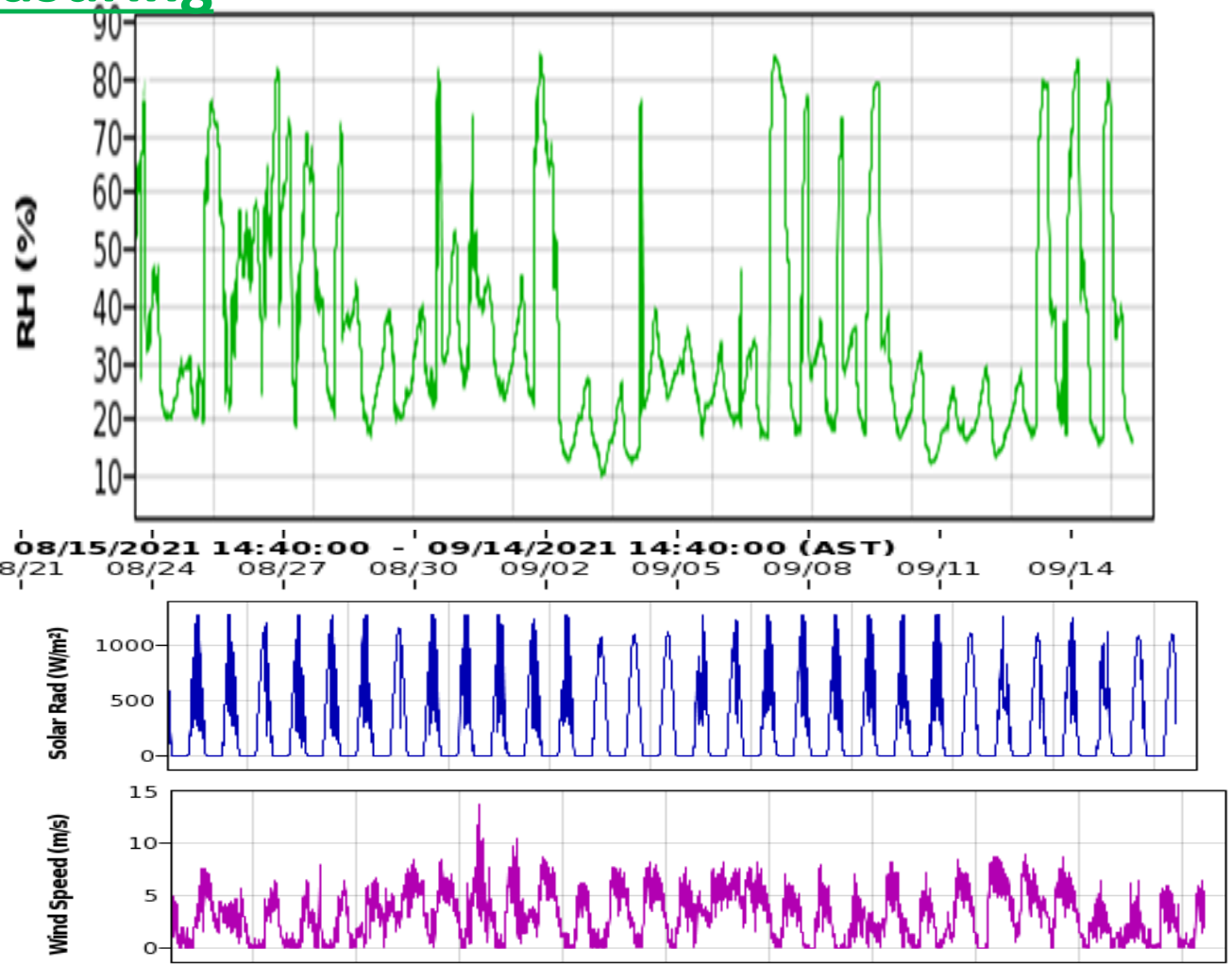
Region	Number of Hydrologic Network Recorded rainfall during Rahw 2020	Number of Hydrologic Network	Average Rainfall depth (mm) in the region within 50 years record
Makkah	53	108	100
Asir	49	83	210
Jazan	34	41	275
Al Madinah	28	80	53
Al Baha	22	22	200
Riyadh	3	78	90
Tabuk	2	36	35
Najran	2	6	75
Eastern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



Real Time Weather Elements Measuring



Air Temperature & Air Relative Humidity in DAMAD Weather Station in 6/8/2020, Jazan Region

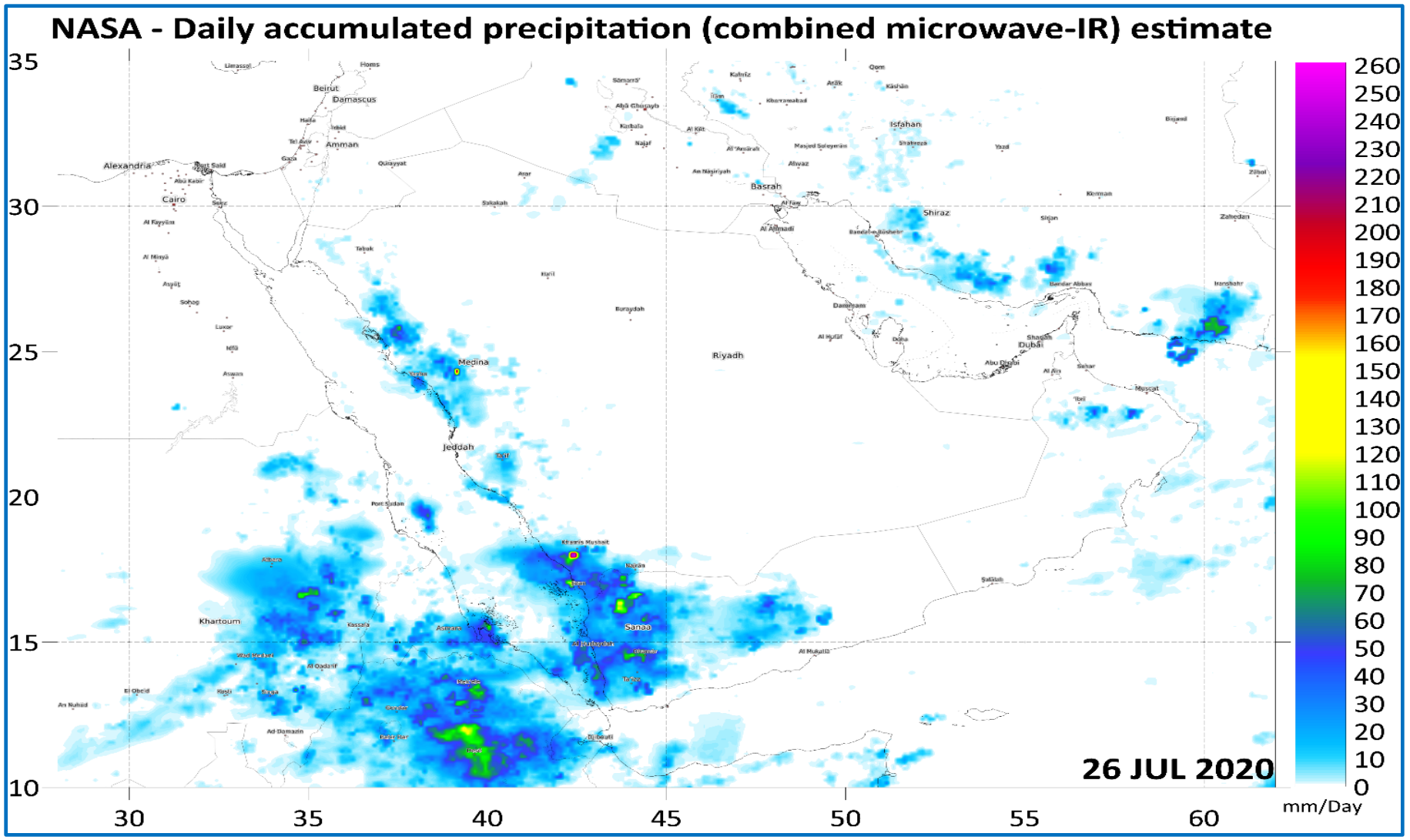


Time Series Record of Wind Speed, Solar Radiation, Air Relative Humidity in DAMAD Weather Station in 15/8/2020, Jazan Region

Radar Records

During Weather state“Rahw” the Rainfall precipitation records have been obtained from NASA records and correlated with the corresponding records in MEWA Hydrometeorological ground stations.

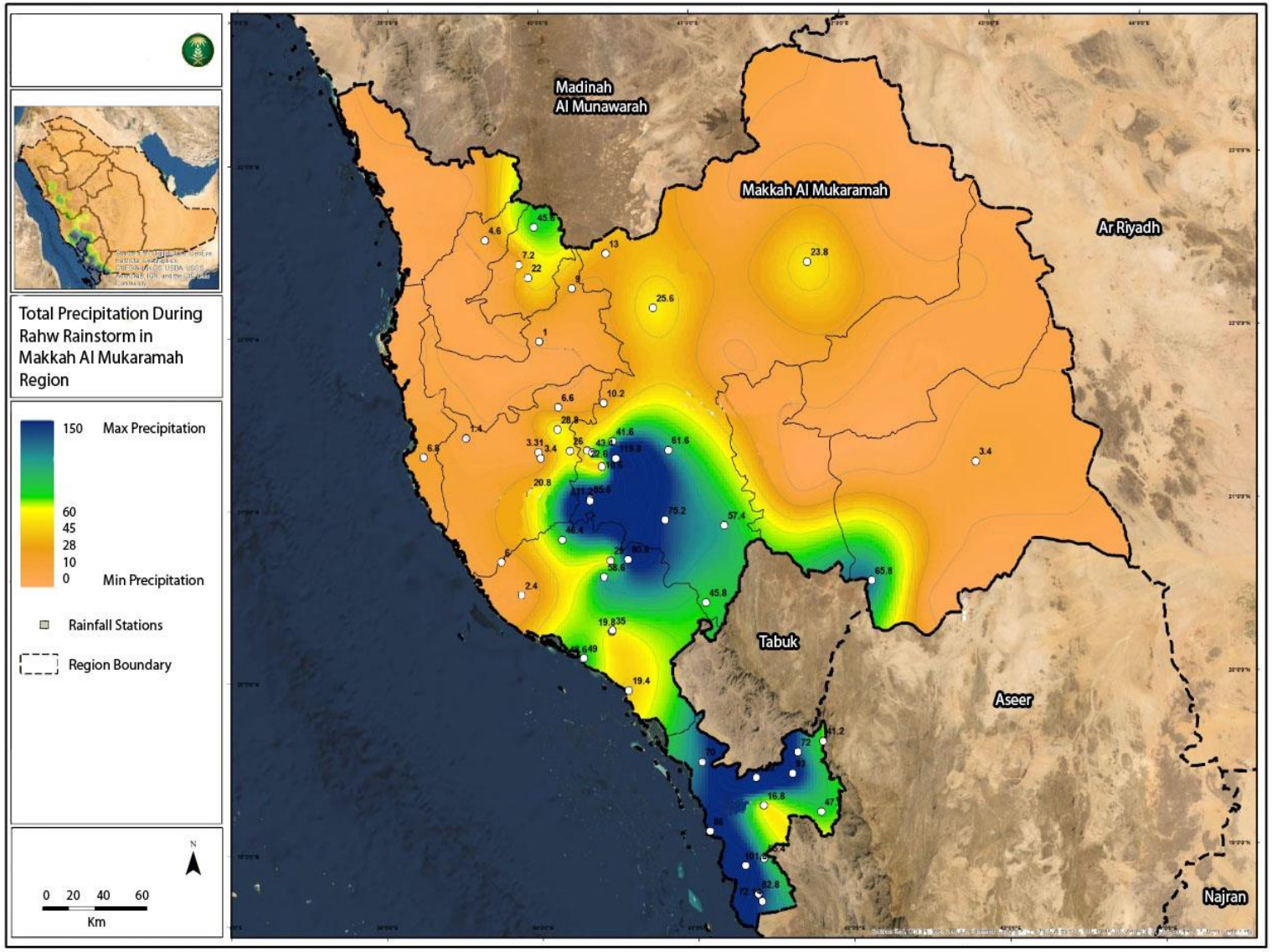
NASA daily accumulated precipitation in 26/7/2020 during the weather state“Rahw”



Makkah Region

Number of Rainfall Station Recorded during Rahw: (53) of (108) stations

The affected Area: 89,736 km² (66 %) of the total area of the region)

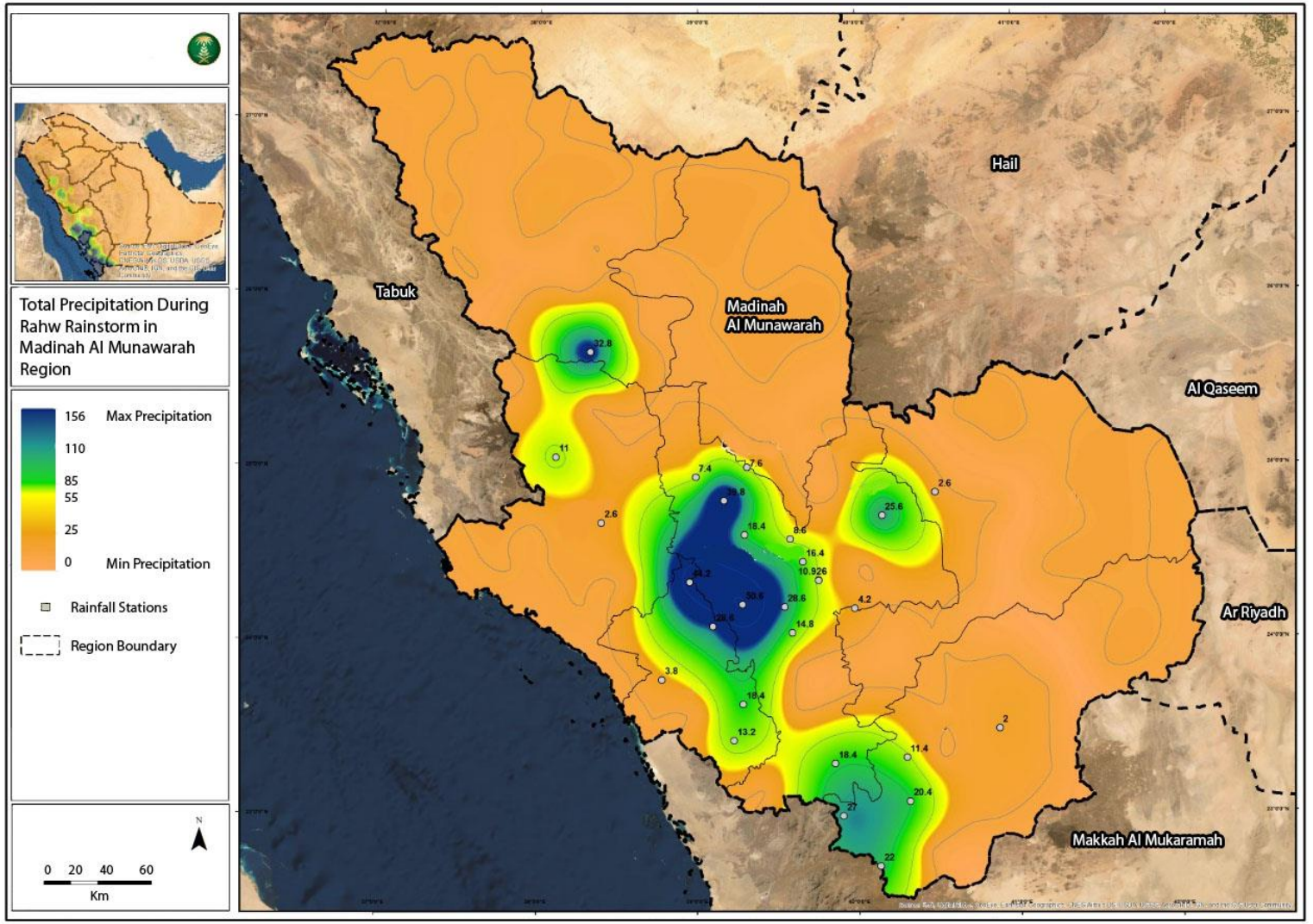


Rainfall Spatial Distribution in Makkah Region during the weather state“Rahw”

Al Madeinah Region

Number of Rainfall Station Recorded during Rahw: (28).

The affected Area: 39,916 km² (27 %) of the total area of the region).

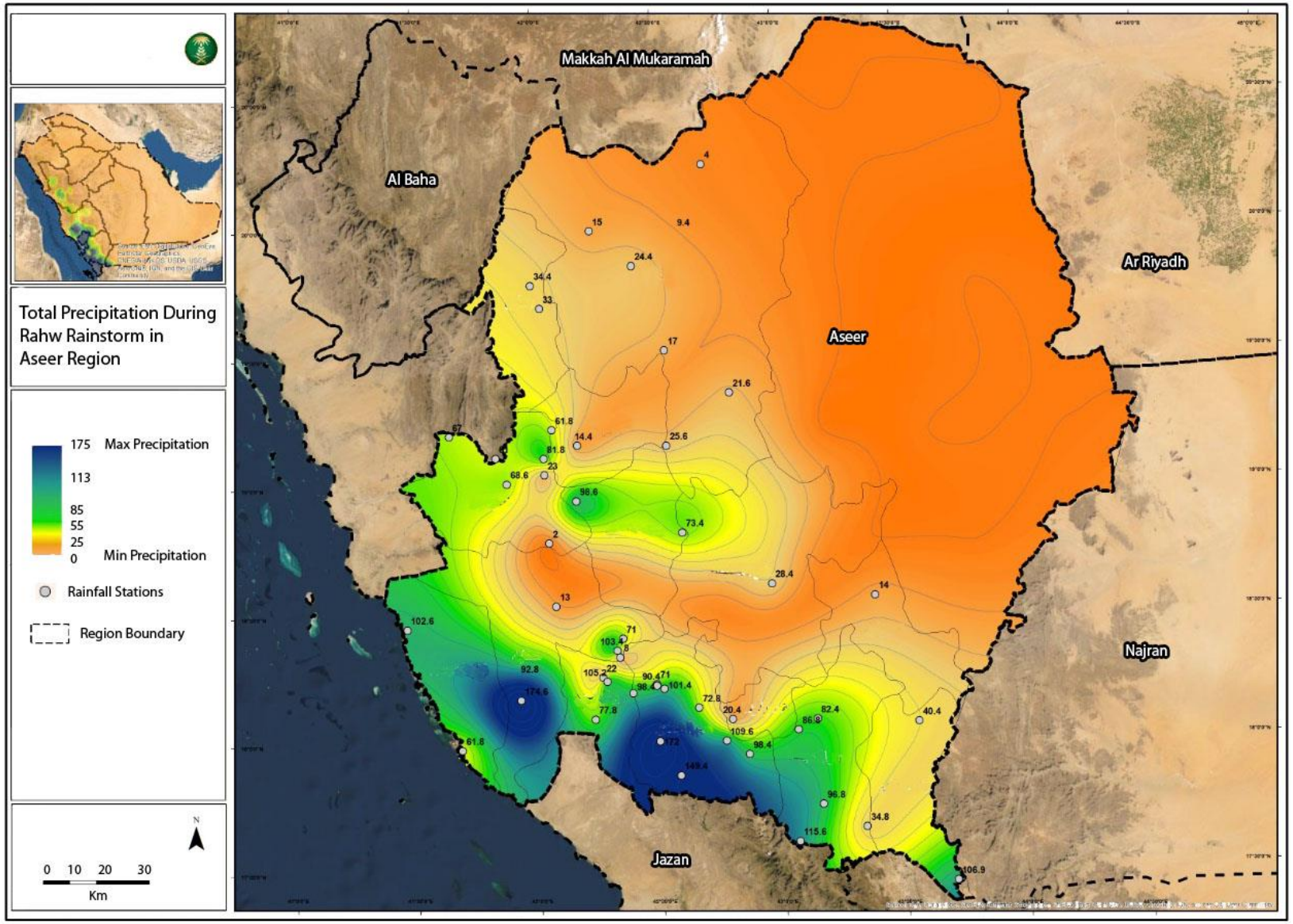


Rainfall Spatial Distribution in Al Madeinah Region during “Rahw”

Asir Region

Number of Rainfall Station Recorded during Rahw: (49).

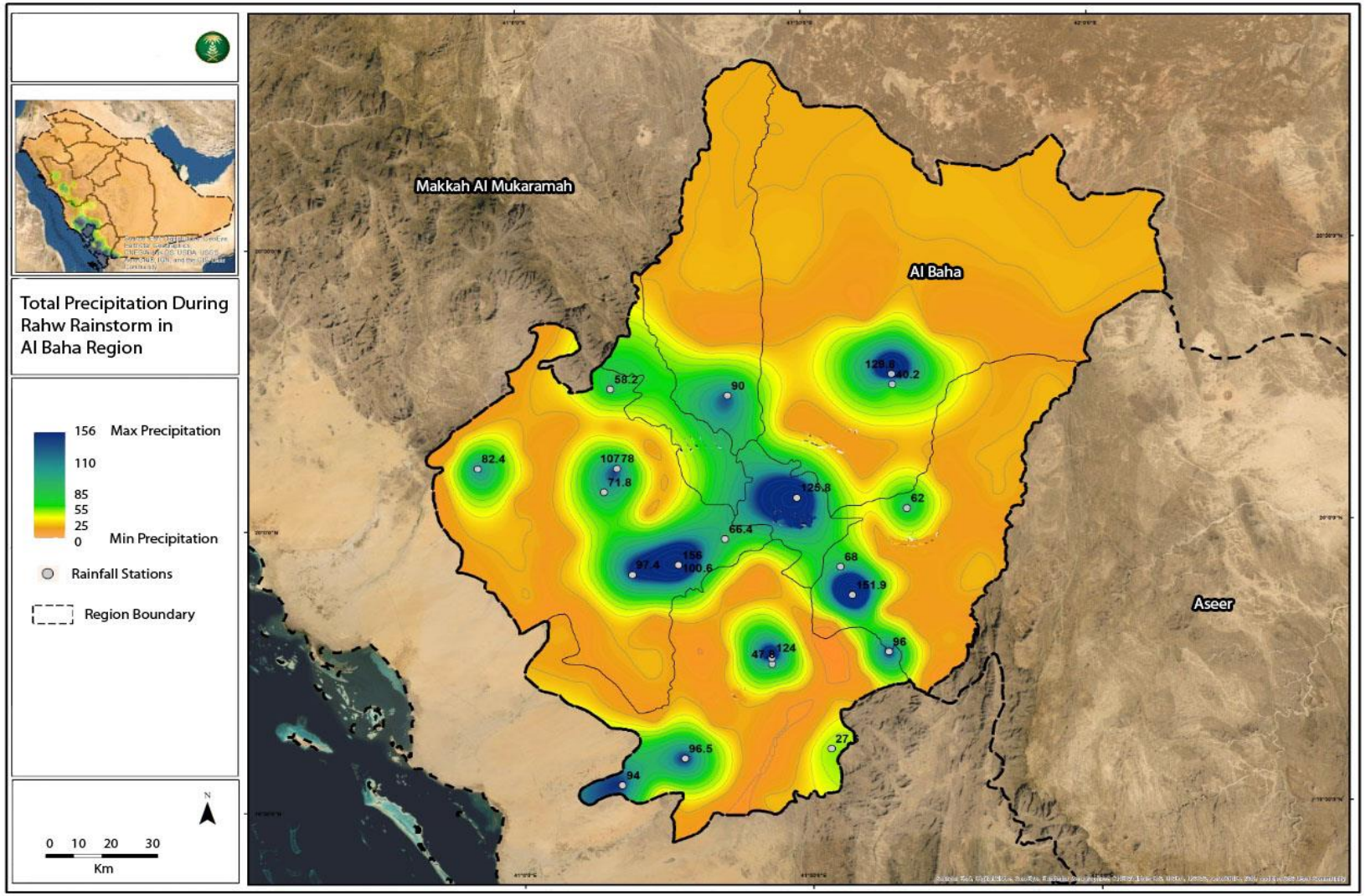
The affected Area: 53,800 km² (67 %) of the total area of the region)



Rainfall Spatial Distribution in Asir Region during "Rahw"

Al Baha Region

Number of Rainfall Station Recorded during Rahw: (22)
The affected Area: 4,954 km² (44 %) of the total area of the region)

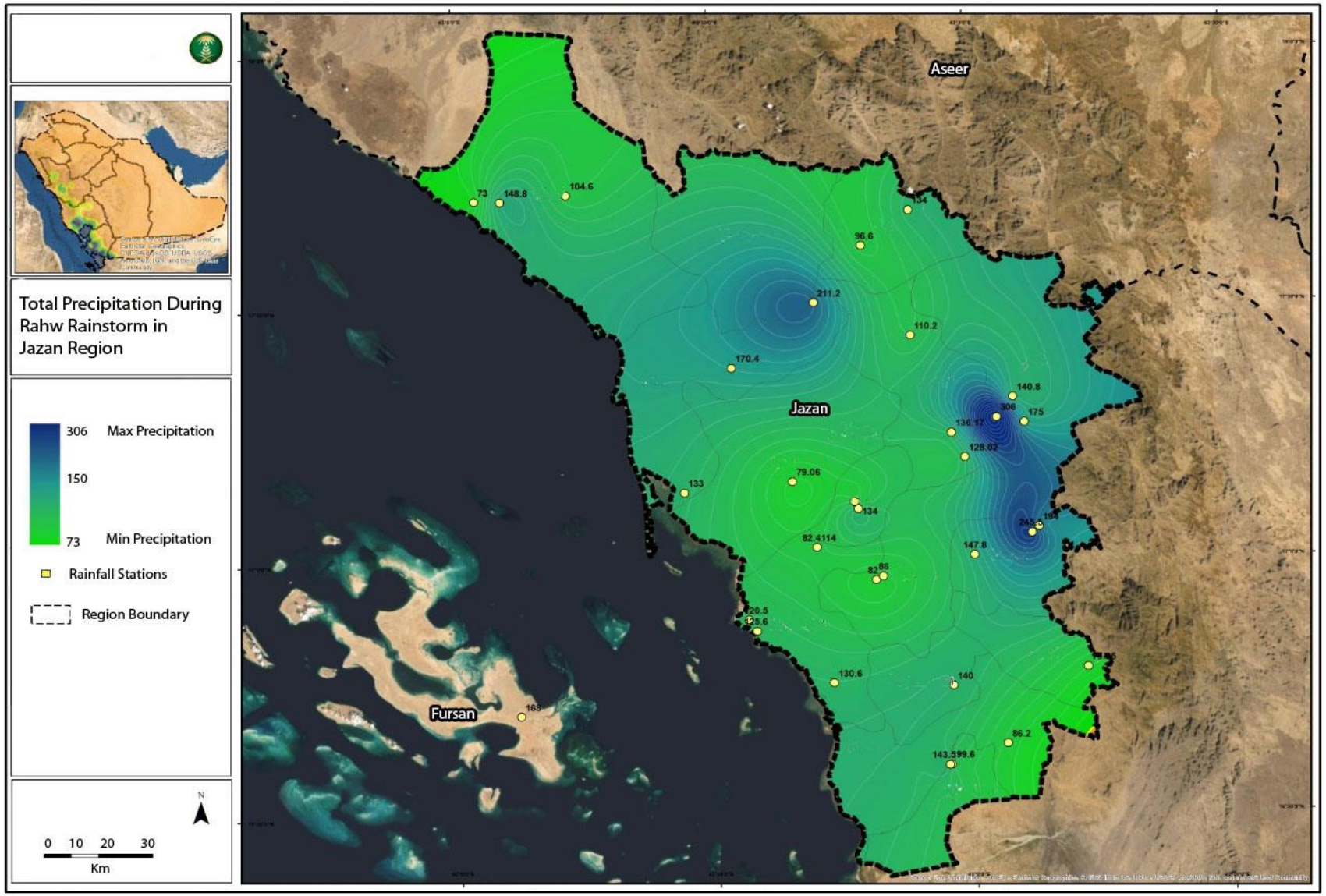


Rainfall Spatial Distribution in Al Bahah Region during “Rahw”

Jazan Region

Number of Rainfall Station Recorded during Rahw: (34)

The affected Area: 12,242 km² (94 %) of the total area of the region)

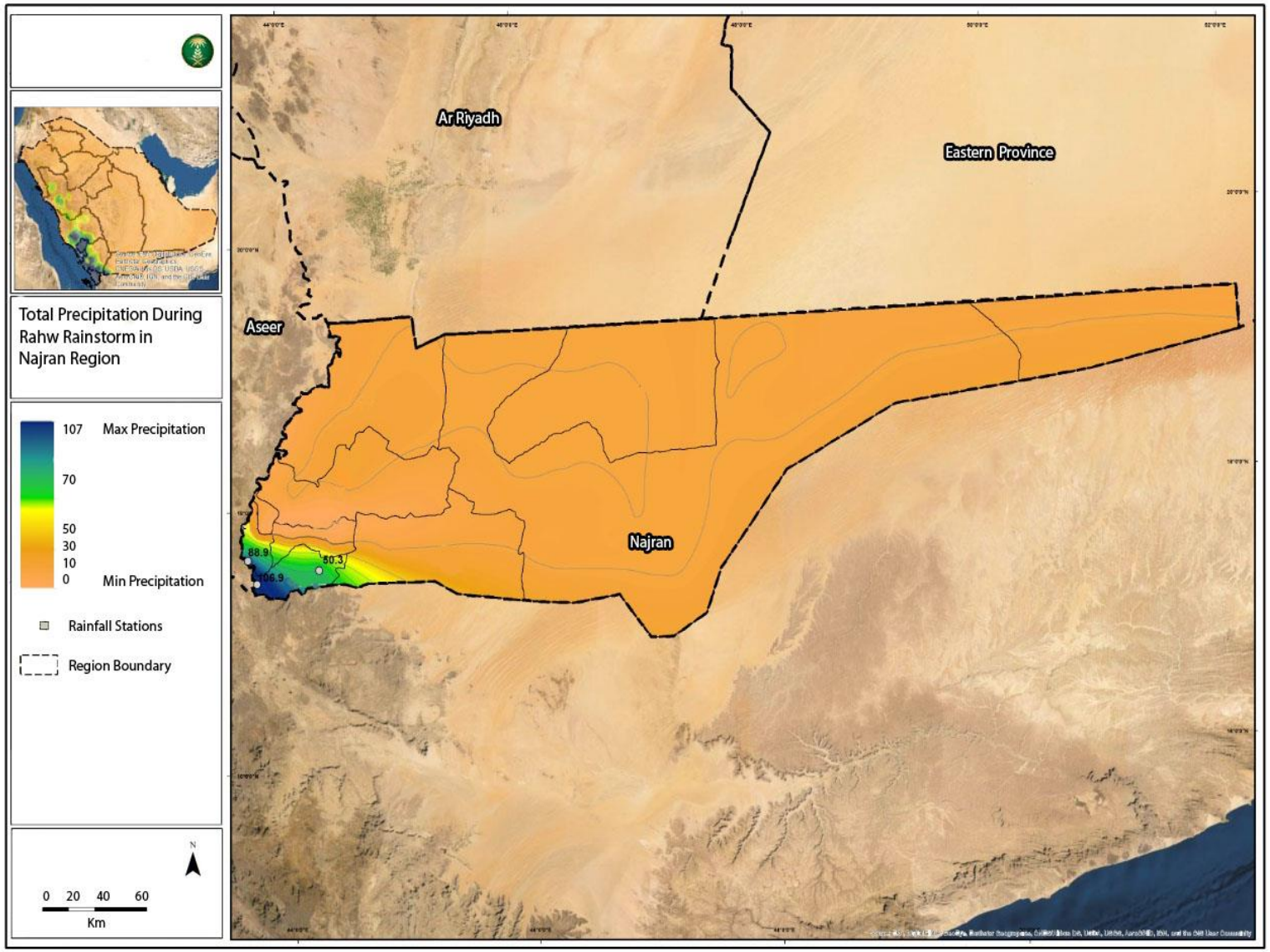


Rainfall Spatial Distribution in Jazan Region during“Rahw”

Najran Region

Number of Rainfall Station Recorded during Rahw: (2).

The affected Area: 12,025 km2 (9 %) of the total area of the region).

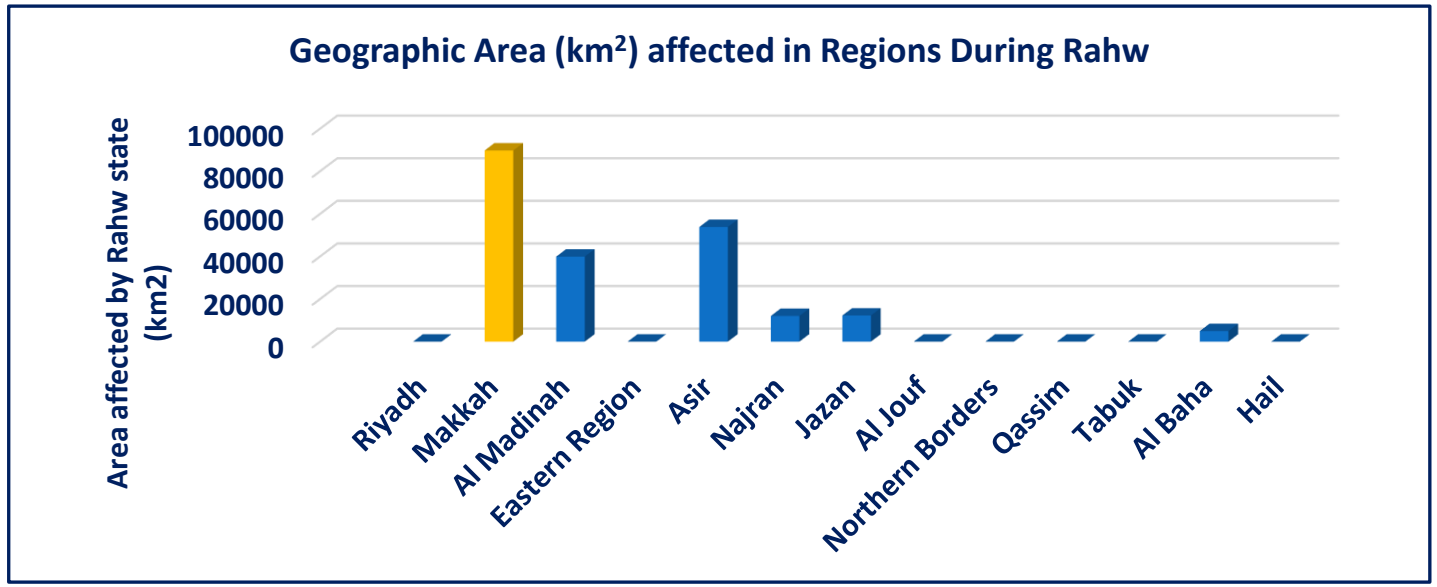


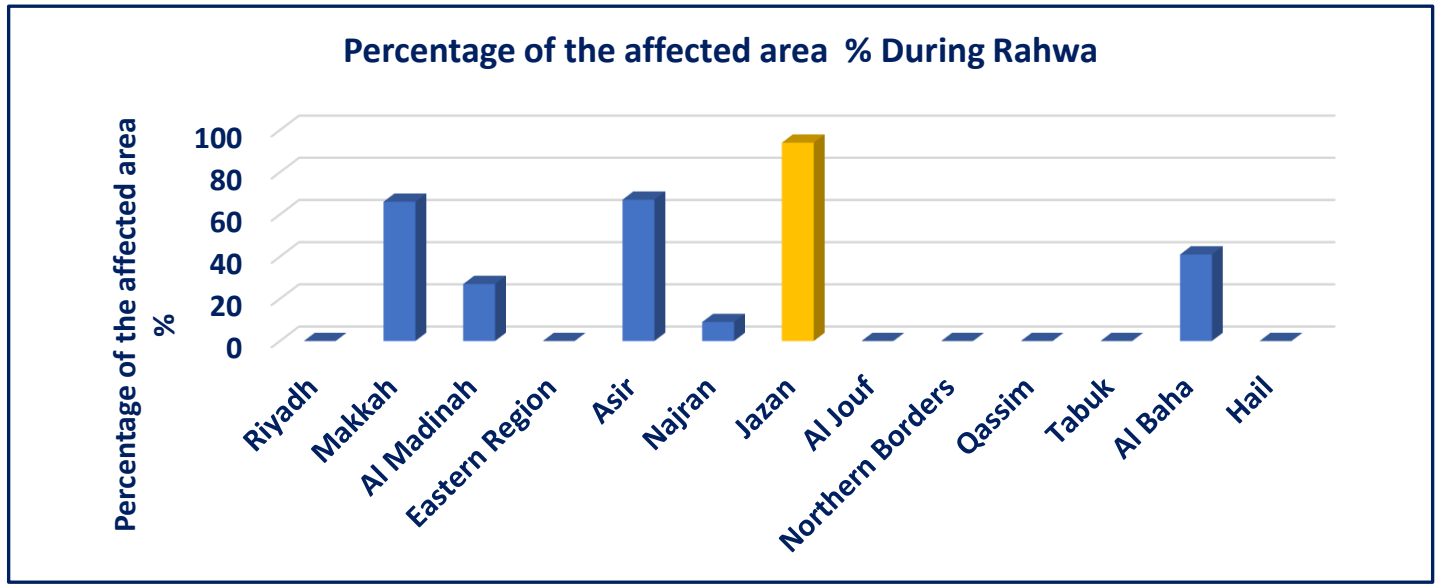
Rainfall Spatial Distribution in Najran Region during "Rahw"

Results : Affected Area

Region	Geographic Area (km^2) affected by Rahw state	Percentage of the affected area relative to total Region area %
Riyadh	0	0
Makkah	89,736	66
Al Madinah	39,916	27
Eastern Region	0	0
Asir	53,800	67
Najran	12,025	9
Jazan	12,242	94
Al Jouf	0	0
Northern Borders	0	0
Qassim	0	0
Tabuk	0	0
Al Baha	4,954	41
Hail	0	0
Total	212,672	11

The total and percentage of the affected geographic area in regions during Rahwa State

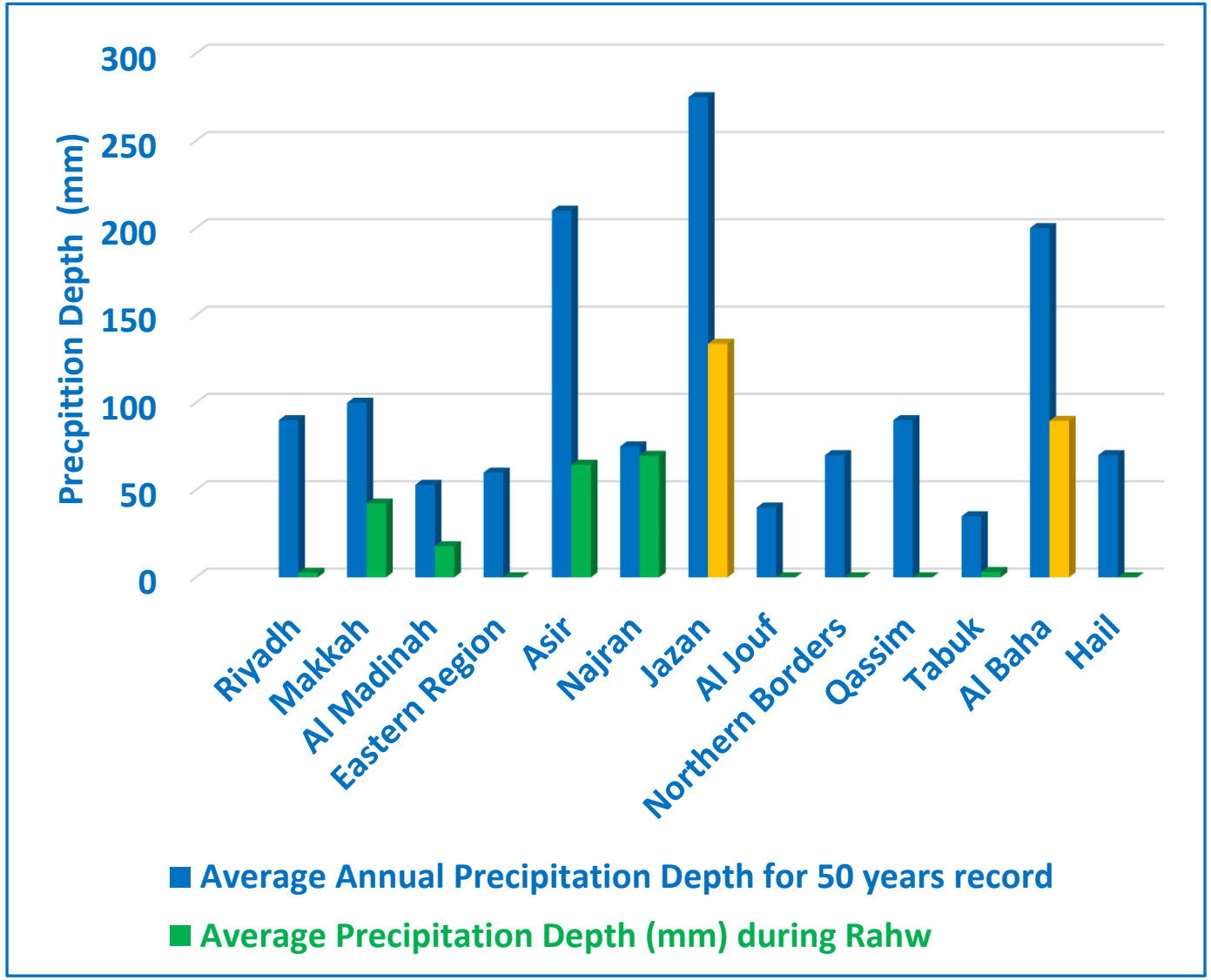




Results: Precipitation Depth

Region	Average Annual Precipitation Depth for 50 years record	Average Precipitation Depth (mm) during Rahw
Riyadh	90	2.6
Makkah	100	42.3
Al Madinah	53	17.8
Eastern Region	60	0
Asir	210	64.5
Najran	75	69.6
Jazan	275	133.8
Al Jouf	40	0
Northern Borders	70	0
Qassim	90	0
Tabuk	35	3.1
Al Baha	200	89.6
Hail	70	0
Total	103	32.56

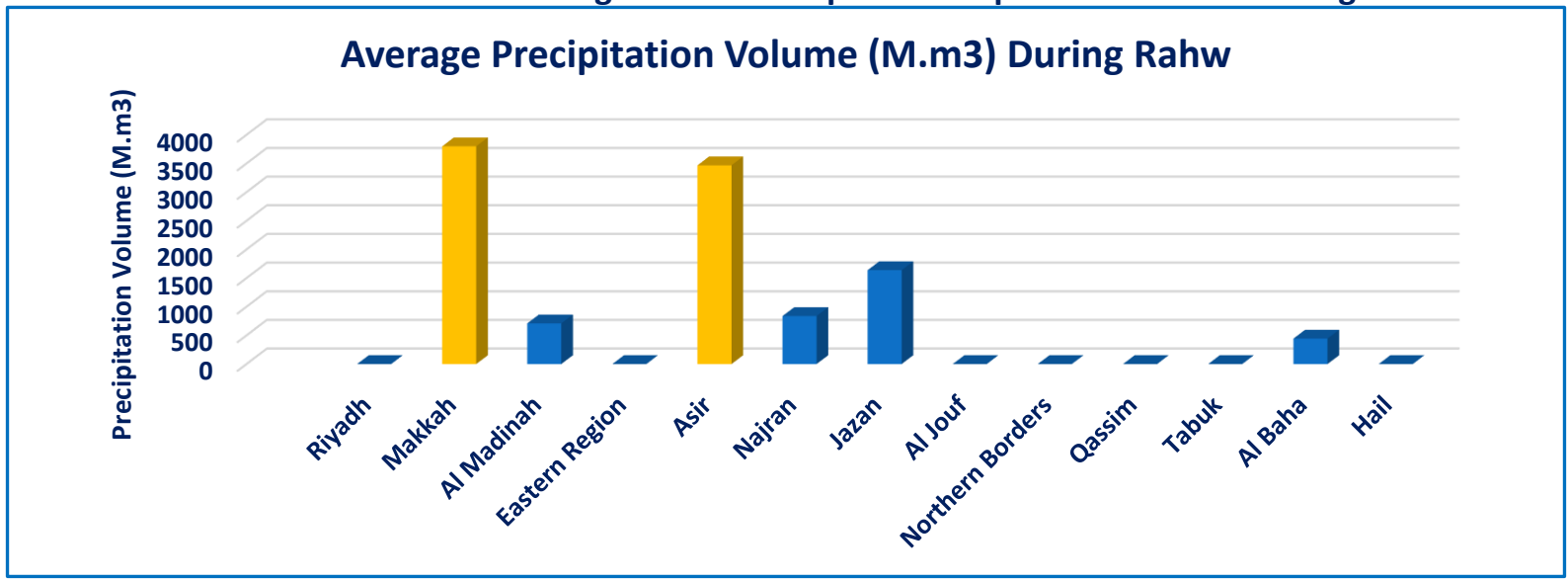
Correlation between the Average annual Precipitation depth (mm) and the corresponding values during Rahwa State

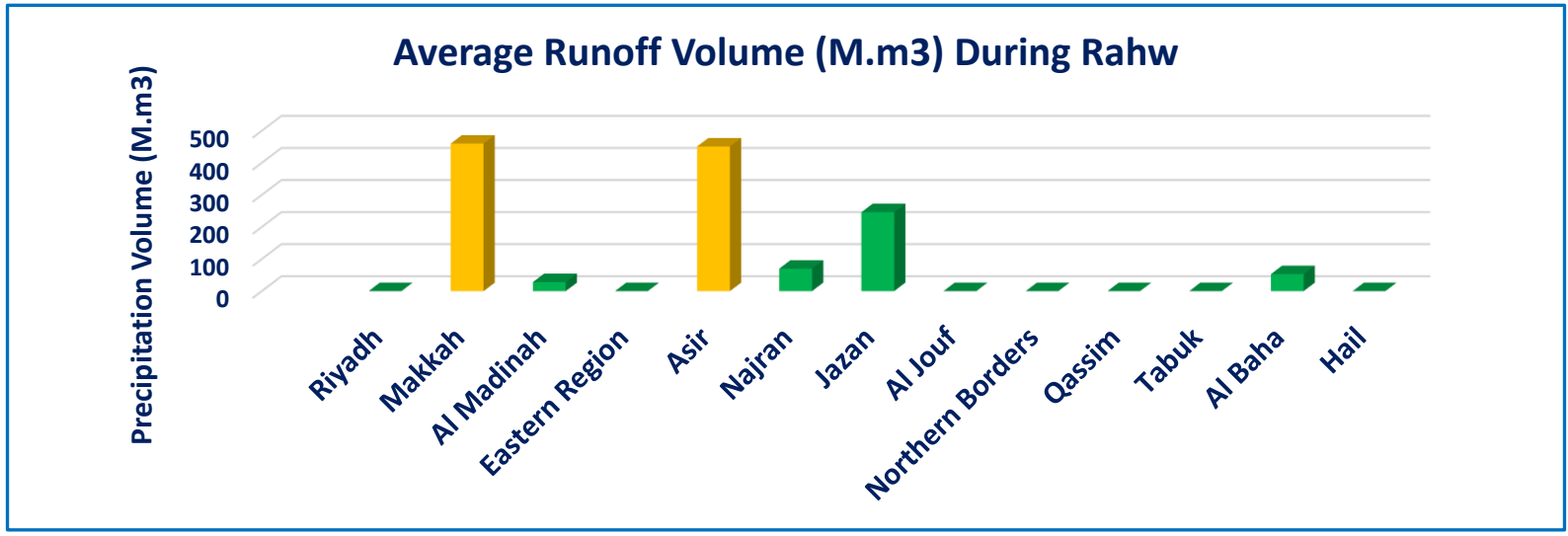


Results: Precipitation & Runoff Volumes

Region	Average Precipitation Volume (M.m^3)	Average Runoff Volume (M.m^3)
Riyadh	0	0
Makkah	3,799	460
Al Madinah	709	28
Eastern Region	0	0
Asir	3,467	451
Najran	837	70
Jazan	1,638	246
Al Jouf	0	0
Northern Borders	0	0
Qassim	0	0
Tabuk	0	0
Al Baha	444	53
Hail	0	0
Total	10,894	1,308

Correlation between the Average annual Precipitation depth and volumes during Rahwa State

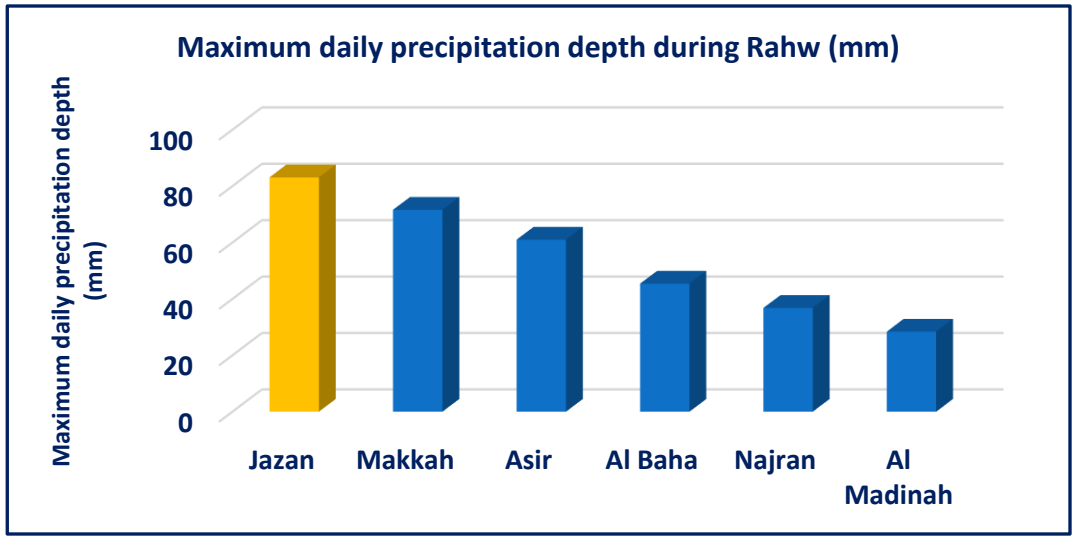




Results: Maximum Daily Precipitation

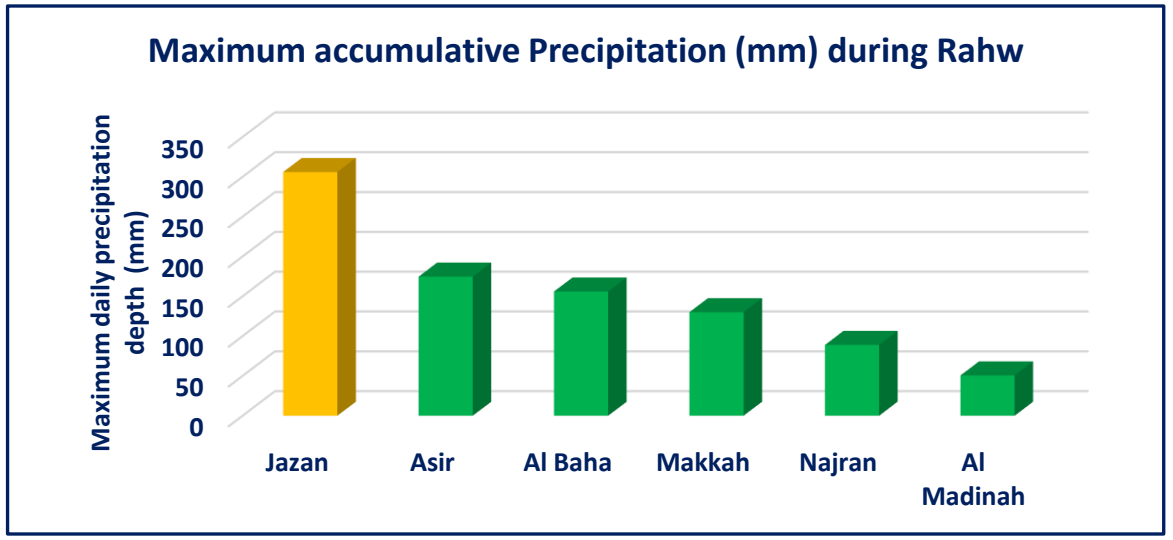
Maximum daily rainfall precipitation during the weather state“Rahw”

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

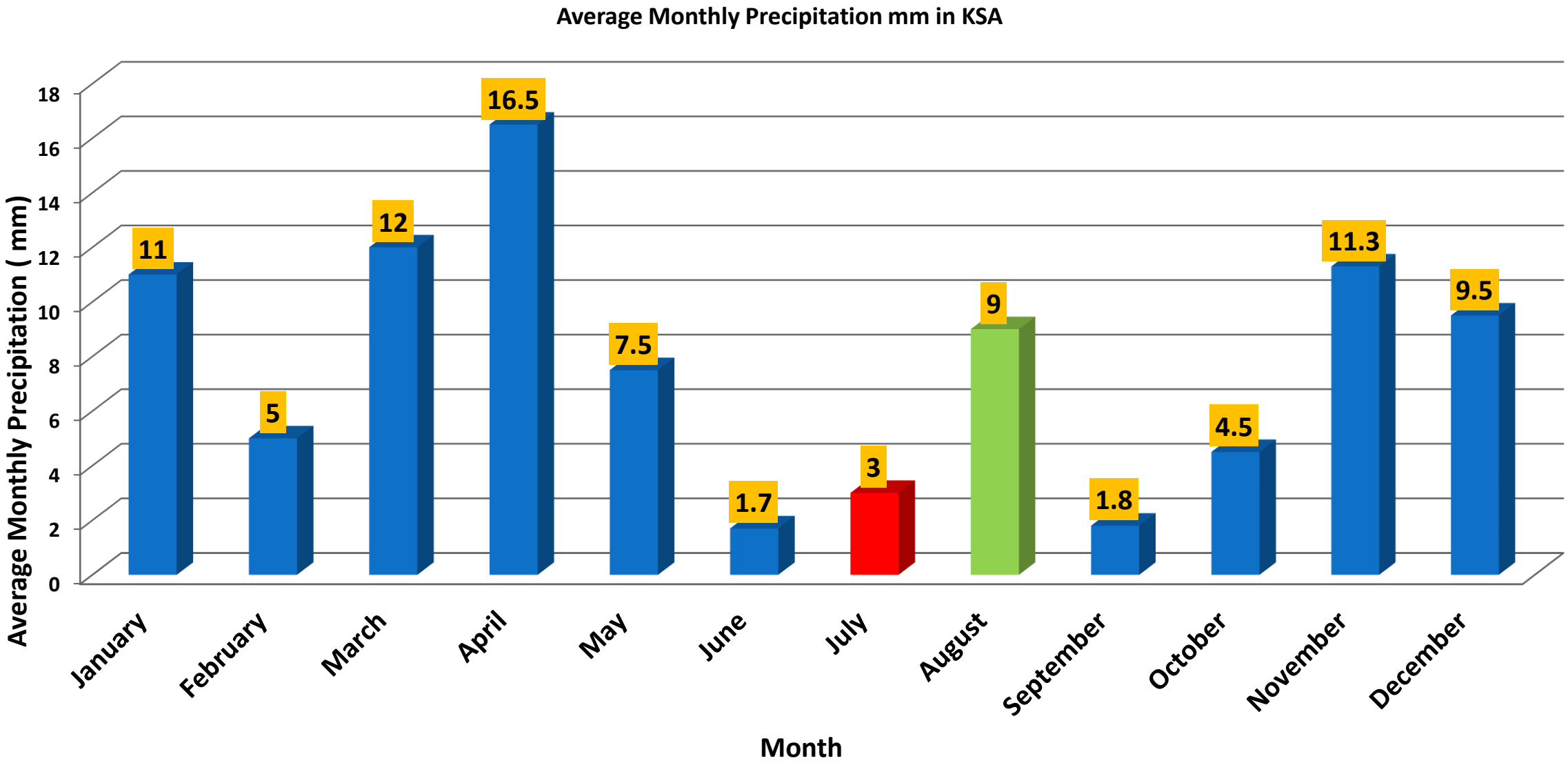


Maximum Accumulative rainfall precipitation during the weather state“Rahw”

Region	Rainfall Station	Maximum accumulative Precipitation (mm) durimg Rahw
Jazan	Abian	306
Asir	Mensab/Muhayl	174.6
Al Baha	Qilwah	156
Makkah	Tholatha Al Khurm	130
Najran	Al Namasah	88.9
Al Madinah	Northern Al Fereash	50.6



Average Monthly Precipitation in KSA for Full Record (50 years)



Results: Correlation of Average and Maximum Precipitation in July & August

1. The average rainfall received in July (2020) attained (22.8) mm which is greater than the average rainfall has been received in the same month during the last ten years (14)mm.
2. The average rainfall received in August (2020) attained (12.7) mm which is greater than the average rainfall has been received in the same month during the last ten years (12)mm).
3. 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.
4. While August recorded the highest average rainfall of (37) mm in 2017 in Al Baha region in the last ten years.

Correlation of Average and Maximum Precipitation in July & August

July

Region	Average Preciptation in July Last 10 years (mm)	Maximum Preciptation in July (mm)	Year	Average Number of Rainy days in July	Maximum Number of Rainy days in July	Year	Average Preciptation in July 2020 (mm)	Average Number of Rainy days in July (2020)
Al Baha	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 Madeinah	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	8	9	2020	2	2	2020	9	2
Al Jouf	0		2020	0			0	0
Northern	0		2020	0			0	0
Qassem	0		2020	0			0	0
Hail	0		2020	0			0	0
Average	14			3			22.8	6.5

August

Region	Average Preciptation in August Last 10 years (mm)	Maximum Preciptation in August (mm)	Year	Average Number of Rainy days in August	Maximum Number of Rainy days in August	Year	Average Preciptation in August 2020 (mm)	Average Number of Rainy days in August (2020)
Al Baha	20	37	2017	6	21	2019	27	9
Jazan	58	167	2016	13	18	2016-2013	66	13
Asir	38	99	2016	14	23	2019	28	17
Makkah	28	103	2016	5	23	2019	21	10
Al Madeinah	10	22	2016	3	7	2015	9	4
Najran	8	14	2020	3	3	2020	14	3
Riyadh	0	0	2020	0	0	2020	0	0
Tabuk	0	0	2020	0	0	2020	0	0
Al Jouf	0	0	2020	0	0	2020	0	0
Northern	0	0	2020	0	0	2020	0	0
Eastern	0	0	2020	0	0	2020	0	0
Qassem	0	0	2020	0	0	2020	0	0
Hail	0	0	2020	0	0	2020	0	0
Average	12			3			12.7	4.3

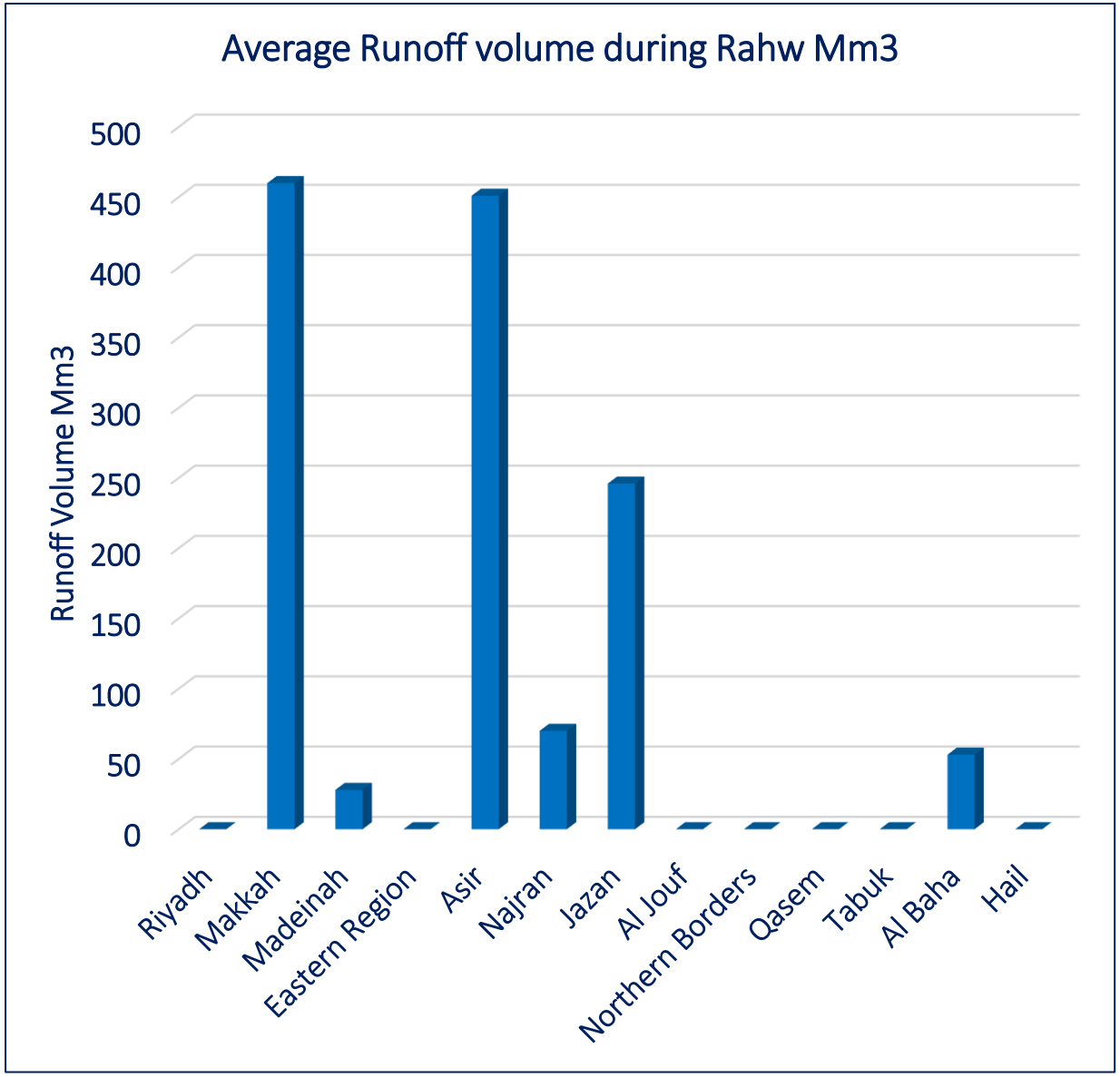
Runoff Harvesting in Dam Reservoirs

Dam Storage Capacities before and after Rahw condition

Region	Storage Capacities before Rahw (m^3)	Storage Capacities of dams after Rahw (.m^3)	Net Storage volumes in dams after Rahw (m^3)	Volume of Released Water from dam gates (m^3)	Volume of supplied Water for drinking (m^3)	Total Flood volumes arrived at dams during Rahw (m^3)
Riyadh	3,202,980	1,181,055	-2,021,925	0	0	0
Makkah	190,761,104	244,661,435	53,900,331	29,006,990	0	85,935,127
Al Madinah	12,625	838,270	825,645	2,966,147	0	3,791,792
Eastern Region	0	0	0	0	0	0
Asir	202,890,338	221,747,542	18,857,204	10,872,228	2,847,709	36,587,384
Najran	0	23,385,130	23,385,130	93,874,570	0	112,374,570
Jazan	169,016,980	198,038,673	29,021,693	61,739,777	5,040,000	90,923,470
Al Jouf	0	0	0	0	0	0
Northern Borders	0	0	0	0	0	0
Qassim	0	0	0	0	0	0
Tabuk	0	0	0	0	0	0
Al Baha	30,244,158	48,371,312	18,127,154	3,177,048	457,680	22,465,038
Hail	0	0	0	0	0	0
Total	596,128,185	738,223,417	142,095,232	201,636,760	8,345,389	352,077,381

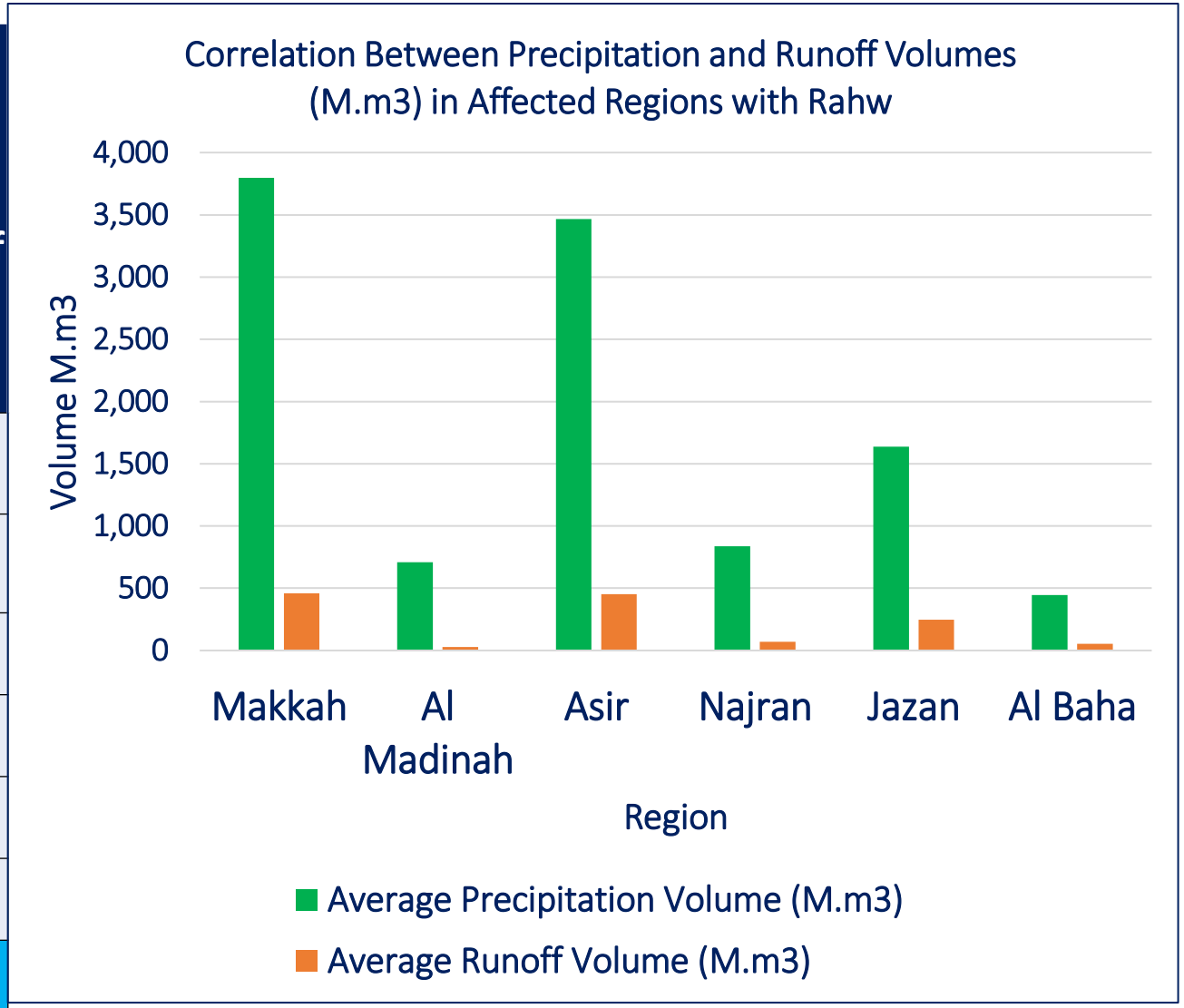
Runoff Harvesting in Dam Reservoirs

Region	Average Precipitation depth during Rahw mm	Average Precipitation volume during Rahw Mm3	Average Runoff volume during Rahw Mm3
Riyadh	2.6	0	0
Makkah	42.3	3,799	460
Al Madeinah	17.8	709	28
Eastern Region	0	0	0
Asir	64.5	3,467	451
Najran	69.6	837	70
Jazan	133.8	1,638	246
Al Jouf		0	0
Northern Borders		0	0
Qaseem		0	0
Tabuk	3.1	0	0
Al Baha	89.6	444	53
Hail	0	0	0
	52.91	10,894	1,308



Estimated Average Runoff Coefficient on the Regions

Region	Average Precipitation Volume ($M.m^3$)	Average Runoff Volume ($M.m^3$)	Average Runoff Coefficient of The Region
Makkah	3,799	460	12
Al Madinah	709	28	4
Asir	3,467	451	13
Najran	837	70	8
Jazan	1,638	246	15
Al Baha	444	53	12
Total	10,894	1,308	

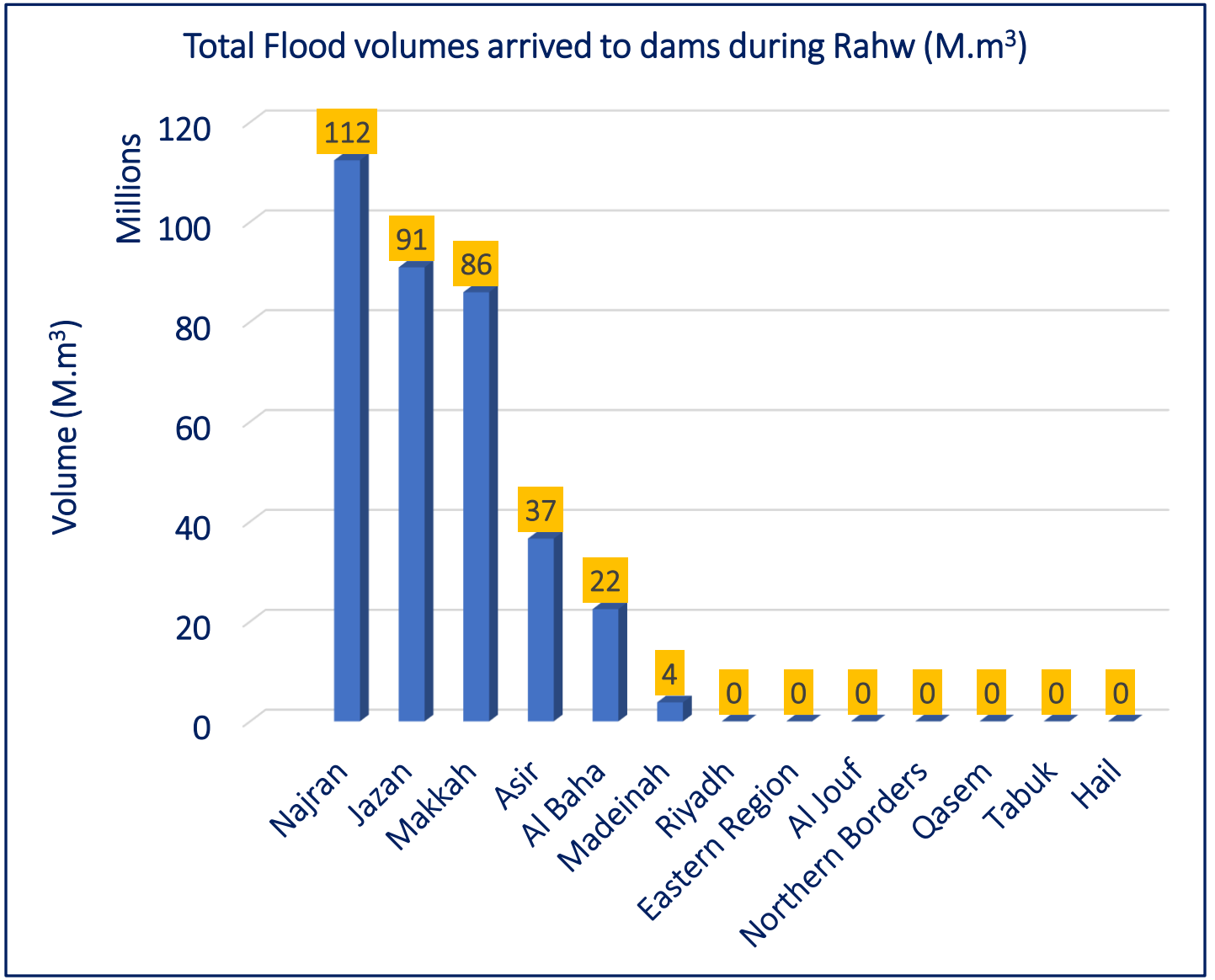


Runoff Harvesting in Dam Reservoirs

- Many dams in the southwestern regions have received considerable amounts of daily surface runoff During "Rahw" climate state attaining (352) million m^3
- Total Numbers of Dams affected With Rahw attained (147) dams, among of theses (43) dams have been spilled.
- The water levels in dams' reservoirs increase to more than (75%) of the spillway height.
- The emergency operational plans of these dams have been applied.
- The gates of many dams were released to drain water in the downstream to meet the demand of farmers and enhance the groundwater recharge in the wells.
- Total volume of released water from the dams' gates attained (201.62) million m^3
- Total volume of supplied Water for drinking from the dams' reservoirs attained (8.34) million m^3

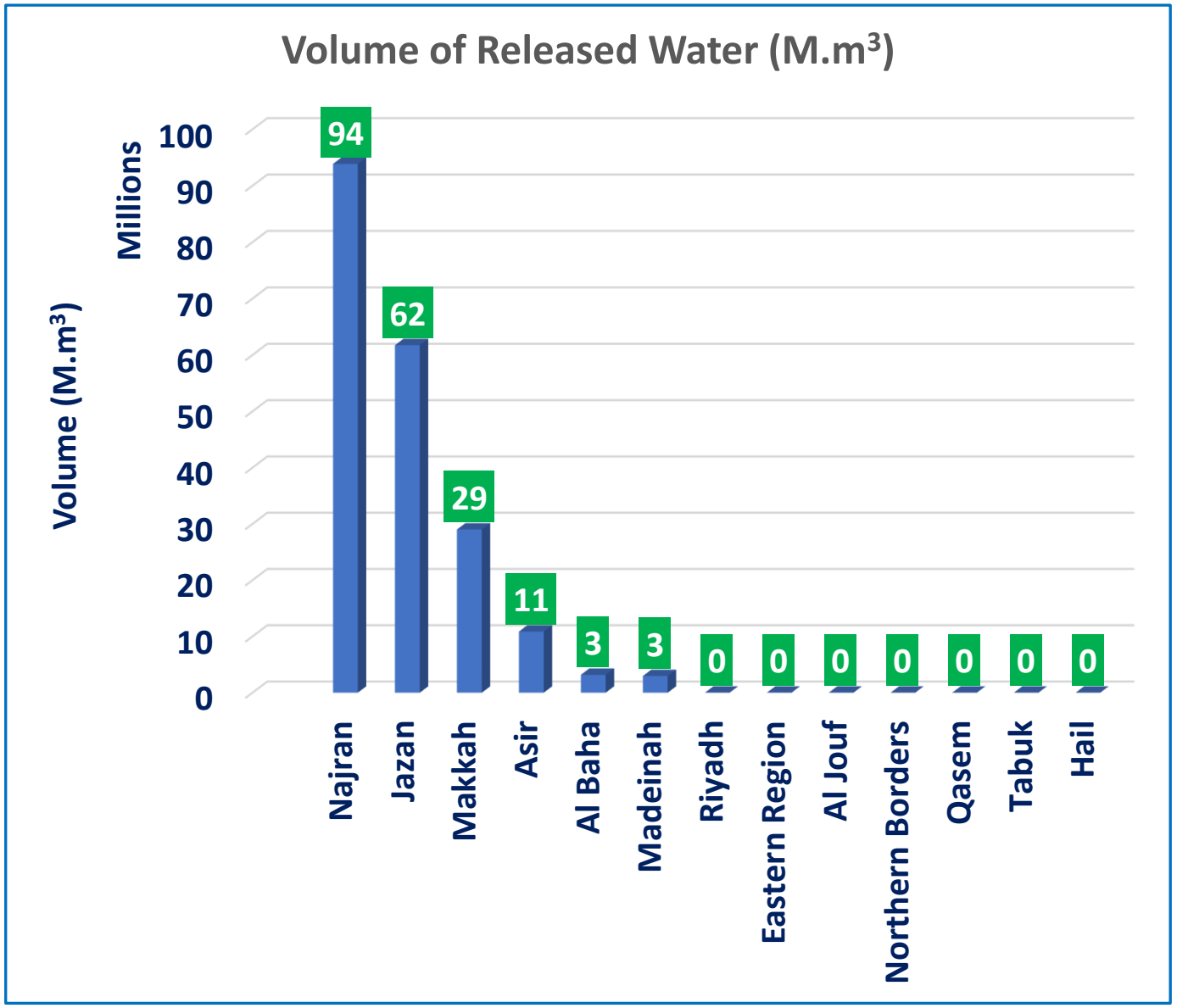
Total Flood volumes received in Dam Reservoirs During Rahw

Region	Storage Capacities before Rahw (M.m^3)	Stoarge Capacities of dams after Rahw (M.m^3)	Total Flood volumes arrived to dams during Rahw (M.m^3)
Najran	0	23,385,130	112,374,570
Jazan	169,016,980	198,038,673	90,923,470
Makkah	190,761,104	244,661,435	85,935,127
Asir	202,890,338	221,747,542	36,587,384
Al Baha	30,244,158	48,371,312	22,465,038
Al Madeinah	12,625	838,270	3,791,792
Riyadh	3,202,980	1,181,055	0
Eastern Region	0	0	0
Al Jouf	0	0	0
Northern Borders	0	0	0
Qasem	0	0	0
Tabuk	0	0	0
Hail	0	0	0



Total Flood Volumes Released from Dam Reservoirs During Rahw

Region	Volume of Released Water (M.m³)	Volume of supplied Water for drinking (M. m³)	Total Flood volumes arrived to dams during Rahw (M. m³)
Najran	93,874,570	0	112,374,570
Jazan	61,739,777	5,040,000	90,923,470
Makkah	29,006,990	0	85,935,127
Asir	10,872,228	2,847,709	36,587,384
Al Baha	3,177,048	457,680	22,465,038
Madeinah	2,966,147	0	3,791,792
Riyadh	0	0	0
Eastern Region	0	0	0
Al Jouf	0	0	0
Northern Borders	0	0	0
Qasem	0	0	0
Tabuk	0	0	0
Hail	0	0	0
Total	201,636,760	8,345,389	352,077,381



Frequencies of "Rahw climate state

"Al Rabab" and has extended for (7) days 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, but with longer period but with lower intensity

1. • Moghdeqah
   • from 22 March to 21 April 2012 (31 days)
2. • Al Baydaa
   • from 25 April to 8 May 2013 (14 days)
3. • Sabeghah
   • from 22-26 November 2015 (5 days)
4. • Al Rabab
   • from 28 July to 3 August 2016 (7 days)
5. • Joud
   • from 11-18 February 2017 (8 days)
6. • Ghadaq
   • from 25 October to 20 November 2018 (27 days)
8. • Rahw
   • from 24 July to 10 August 2020 (18 days)

Conclusion

1. The western and southwestern regions of the Kingdom of Saudi Arabia; have been subjected to a distinctive summer weather state locally named as “Rahw”, which has lasted for (18) days, from 24 July 2020 until, 10 August 2020, and resulted on medium to very heavy rains.
2. Rahw state is considered as frequency of Al Rabab weather state in 2016.
3. 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 and (11%) of the total area of Saudi Arabia.
4. The average rainfall depth on the affected areas of the southwestern regions is estimated as (52.9) mm and the corresponding precipitation volume is estimated as (10,894) million and (1,308) million m^3 as Runoff Volume.
5. The average rainfall depth over all Saudi Arabia regions is estimated as (32.6) mm correlated with average rainfall annual depth (103)mm.
6. The Correlation Between Precipitation and Runoff Volumes in the affected Regions with Rahw resulted in Estimation of the Runoff Coefficient of the regions, which can be used as a guide for further similar studies.
7. Many dams in the southwestern regions have received considerable amounts of daily surface runoff During “Rahw” climate state attaining (352) million m^3 representing (3%) of the total received runoff
8. The Total volume of released water from the dams' gates attained (201.62) million m^3 led to the strengthening of the groundwater recharge of the wadi deposits and significant rise in the groundwater level in the farmers’ wells.

Recommendations

1. It is advised to use the “Rahw” rainstorm as a guideline in the design of flood mitigation projects, and for studying the meteorological zones in Kingdome of Saudi Arabia.
2. The present study recommends to develop 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.
3. 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.
4. A free storage volume must be maintained in the dam’s reservoirs corresponding to (50% of the total storage capacity of the dam in order to accommodate any runoff volumes may reach the dam during rainstorms.