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LIST OF ACRONYMS

- AJK Azad Jammu & Kashmir
- CDPC Climate Data Processing Centre
- DCO District Coordination Officer
- FFC Federal Flood Commission
- FFD Flood Forecasting Division
- IFAS Integrated Flood Analysis System
- IRSA Indus River System Authority
- KPK Khyber Pakhtunkhwa
- MAF Million Acre Feet
- NCAR National Centre for Atmospheric Research
- NCEP National Centre for Environmental Prediction
- NDMA National Disaster Management Authority
- PCIW Pakistan Commissioner for Indus Water
- PDMA Provincial Disaster Management Authority
- PMD Pakistan Meteorological Department
- SDMA State Disaster Management Authority
- WAPDA Water And Power Development Authority
- XEN Executive Engineer
- BoB Bay of Bengal

Preface

Pakistan has unique flood forecasting problems, which can be understood only if the meteorological causes of the floods are first understood. During summer, at though monsoons are the dominating weather system, yet the systems of westerly waves also continue to affect the country. Intensification of the monsoon weather system and northwards recurving of the monsoon depressions is predominantly due to the westerly waves. Floods in Pakistan are mainly caused by the heavy monsoon rains during movement of the summer monsoon period from July to September. Officially, the flood season is elongated at both ends further to cater for any possible exceptions and covers the period from 15th June to 15th October. Floods in Pakistan are categorized as I, II and III. Category I floods occur when seasonal low over Balochistan intensifies, Category II and III floods which are more catastrophic in nature, are associated with monsoon weather systems originating from Bay of Bengal. They produce heavy rainfall in the catchment areas of rivers flowing in Pakistan. Category III floods are most catastrophic in nature. Under this situation monsoon low/depression under the influence of the westerly wave continues to move in the northerly direction finally ending up in Rawalpindi/Hazara divisions and adjoining areas. The upper catchments of Rivers Jhelum, Chenab and Ravi come under its influence. These are most threatening floods for Mangla reservoir. A rare but devastating flood situation also arises when the westerly wave is strong enough to drag the moisture into the Indus river catchment causing heavy rainfall over Kohistan and Hazara Divisions. The most recent example is the 2010 flood in river Indus and its Tributaries. FFD Lahore besides conventional practice of forecasting is also using flood forecasting models. New flood model IFAS is going through rigorous evaluation and verification routines to customize it under local conditions.

FFD since its establishment is serving the nation by timely disseminating flood forecasts, warnings/alerts and creating awareness during each flood season. Issuance of flood report after the conclusion of flood season is a regular feature of Pakistan Meteorological Department (PMD), Flood Forecasting Division (FFD) Lahore. This report gives a comprehensive overview of all the events occurred during the flood season. Flood report for the year 2018 has been prepared under the kind directives of Director General, Pakistan Meteorological Department. It contains all the details pertaining to flood forecasting regarding tracks of monsoon lows, rainfall amount during wet spells, flood peaks, monthly and seasonal isohyetal maps, normal isopercental maps, flood limits. The flood forecast evaluation report is also added at the end.

**Chief Meteorologist
Flood Forecasting Division
Lahore**

1 Executive summary

- Seasonal percentage departure map for precipitation during the present monsoon season indicates 31% below normal precipitation for whole of country. Calculating on province wise the detail is given as below:
Balochistan 46%, Kashmir 16%, Punjab 15%, Khyber Pakhtunkhwa 13%, Sindh 89% and Gilgit Baltistan 15% received below normal rainfall.
- Nine monsoon lows/Depressions originated during the present monsoon season, none of these entered Pakistan, while only one reached in the vicinity of the country that also recurved from central India to north-northeast ward.
- Two cyclonic storms were also developed during the season. One in Bay of Bengal and other in Arabian Sea. None of them however affected the country.
- Nine rain bearing spells occurred during the monsoon season 2018.
- No High Flood situation was observed in any major river except one instance of High Flood flow in river Chenab. Only one sharp peak of Low flood was registered in River Jhelum at Mangla upstream.
- The supply of hydro-meteorological data from WAPDA, Punjab and Sindh irrigation departments & Pakistan Commissioner for Indus Water (PCIW) remained satisfactory.
- All the concerned federal and provincial authorities, general public, along with print and electronic media were kept in touch with the prevailing weather/flood conditions through phone, fax & other electronic sources.
- Overall accuracy of forecast issued by FFD during the Monsoon Season 2018 was **96%**.

2 Tracks of Monsoon Lows during monsoon season 2018

During the monsoon season 2018 (15th June to 15th October) Nine Monsoon Lows/Depressions were developed.

1st Monsoon low was developed over northwest Bay of Bengal on 8th July, 2018. Moving west wards it was relocated over northwest Madhya Pradesh on 10th July, 2018, where it dissipated.

2nd Monsoon low was developed on 14th July, 2018 over North Bay of Bengal. It moved northwest ward and reached northeast Madhya Pradesh on 18th July, 2018. From here it moved further northwest wards for two day, then again northwest wards and dissipated on 21st July, 2018 near east Rajasthan.

3rd Monsoon low was developed over northwest bay of Bengal on 21st July, 2018. After moving west-northwest wards, it reached south Uttar Pradesh on 25th July, 2018. From here it moved further north wards and dissipated over central Uttar Pradesh on 26th July, 2018.

4th Monsoon low was also developed over north Bay of Bengal on 7th August, 2018. It first moved west northwest wards then northwest wards finally dissipating over Uttar Pradesh on 10th August, 2018.

5th Monsoon low was developed over northwest Bay of Bengal on 14th August, 2018. It moved west northwest wards and after reaching southeast Madhya Pradesh on 17th August, it moved northwest wards and dissipated over Southeast Rajasthan on 18th August, 2018.

6th Monsoon low was developed over east of Odisha (Orissa) 20th August, 2018. It rapidly moved northwest wards and reached northwest Madhya Pradesh on 22nd August, 2018 where it dissipated.

7th Monsoon low was developed over northwest Bay of Bengal on 26th August, 2018 .It first moved west-northwest wards then north west wards and reached over northeast Madhya Pradesh where it dissipated on 29th August, 2018.

8th Monsoon low was developed over northwest Bay of Bengal on 5th September, 2018. It first moved west wards then moving northwest wards it dissipated over southeast Rajasthan on 9th September 2018.

9th and final Monsoon low was developed over central Bay of Bengal on 19th September, 2018. It first moved northwest wards then moving west wards and finally

recurved northeast wards and dissipated over Uttaranchal on 25th September, 2018. The paths followed by each low/depression are shown in figure 1.

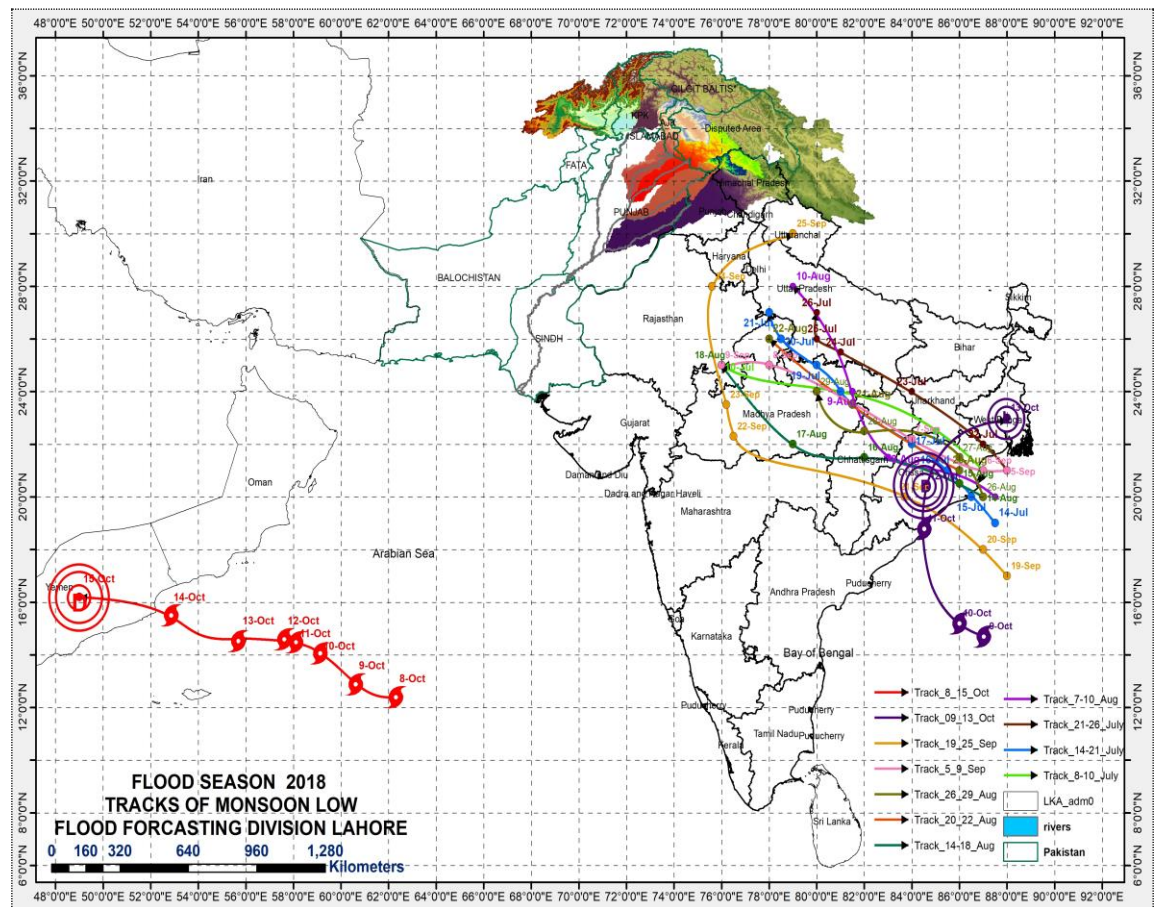


Figure 1: Tracks of rain producing monsoon system in 2018.

3 Significant hydro-meteorological events during the month of June 2018

Only one significant rainfall spell was reported during the month of June 2018 over Pakistan.

3.1 Meteorological events

No monsoon low was developed over Bay of Bengal during the month of June 2018. The rainfall mostly occurred across the country during the month of June 2018 which was due to the accentuation of seasonal low over Balochistan and passing of a westerly wave in the north of the country.

3.2 1st wet spell of June 2018 (26th to 29th June 2018)

The first wet spell of June 2018 which remained active for four days was mainly due to the presence of a westerly trough accompanied by moist current from Arabian Sea. Figure 2 (a-d) represents 500 hPa and 850 hPa geopotential height patterns along with 925 hPa wind flow during the spell. It indicates that most part of Pakistan is under the influence of the westerly wave. Southwesterly winds at 925 hPa are also present ensuring enough moisture supply from the Arabian Sea.

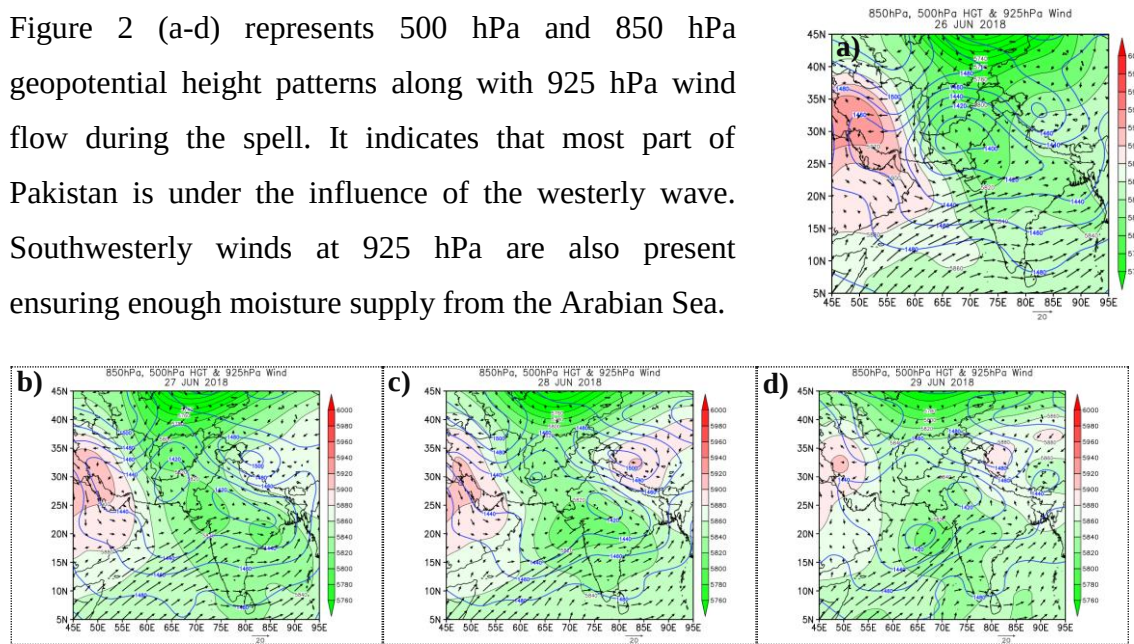


Figure 2: 500 & 850 hPa geopotential Height patterns and 925 hPa winds from 26th to 29th June 2018.

Figure 3 shows spatial distribution of significant rainfall during this spell. Maximum rainfall of more than 140 mm occurred over Faisalabad division. Other maxima of more than 80 mm rainfall is located over southeast Sindh.

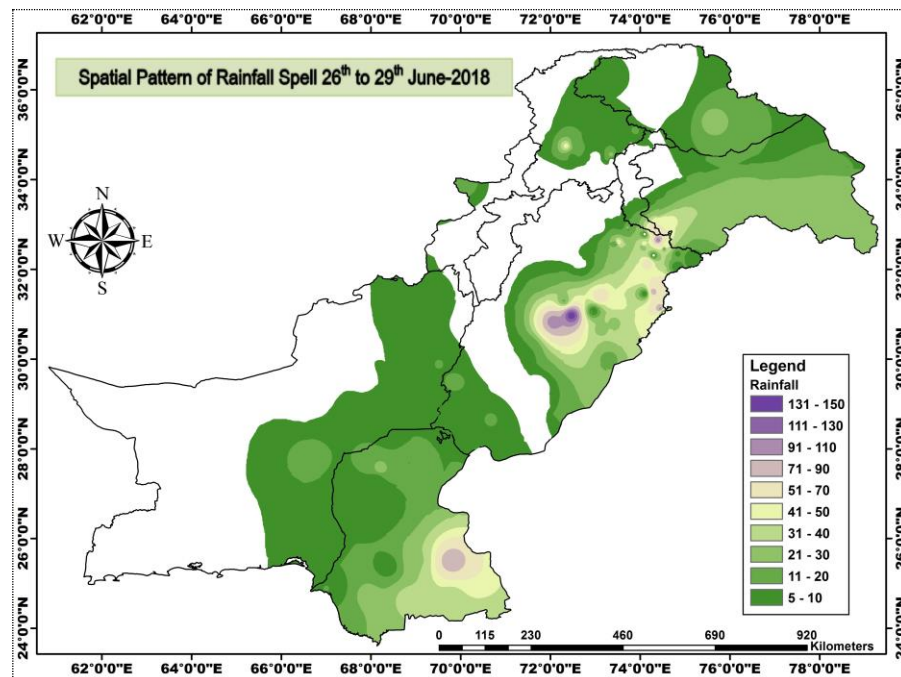


Figure 3: Spatial distribution of significant rainfall map of 26th to 29th June 2018.

Satellite images in figure 4 (a-c) showing dense clouds over south Punjab and North Sindh & thin clouds over north Punjab, Khyber Pakhtunkhwa, Kashmir during the spell of 26th to 29th June-2018.

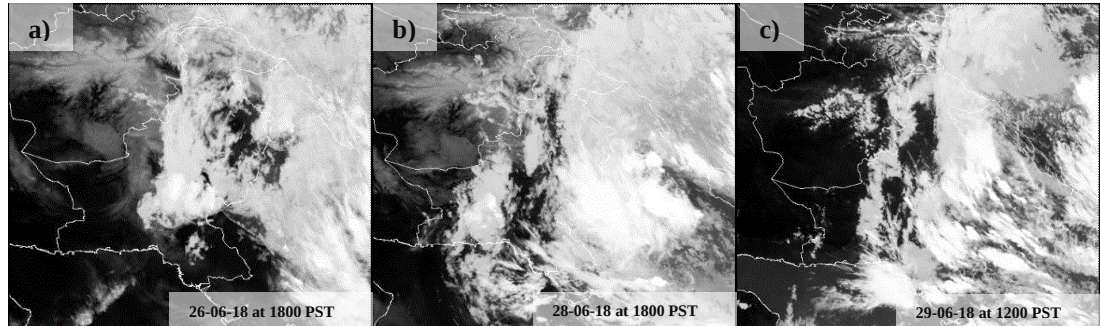


Figure 4: Satellites Images during the spell 26th-29th June 2018.

Figure-5 represents the temporal distribution of rainfall during the month of June 18.

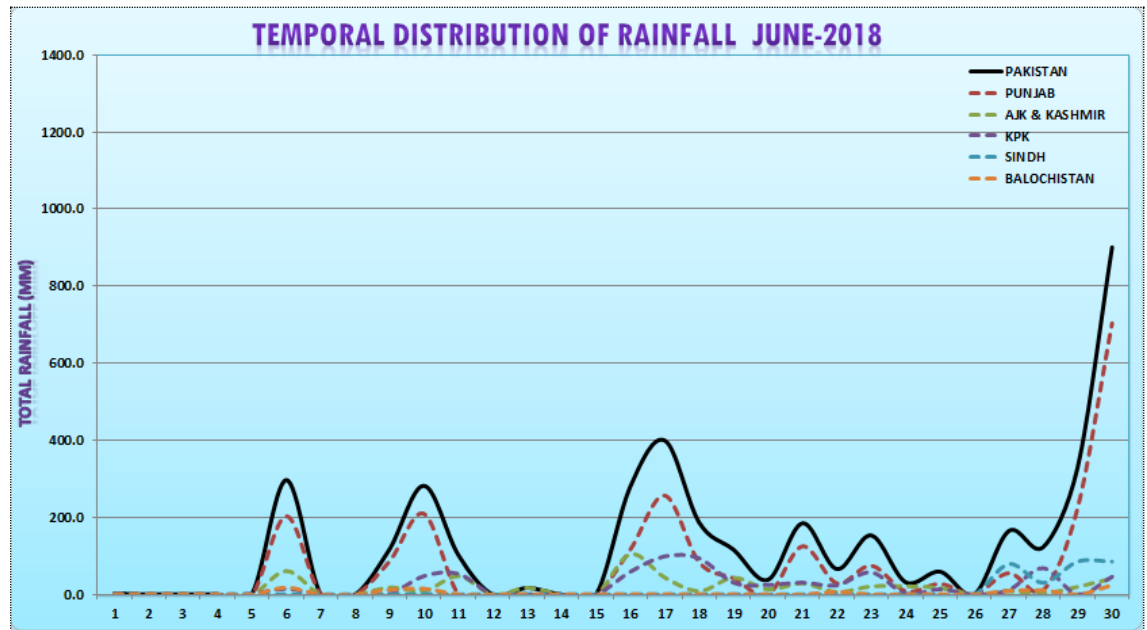


Figure 5: Temporal distribution of rainfall June 2018.

3.3 River position during June 2018

Flood peaks (Cusecs) recorded during June, 2018 in different rivers at various points are in table 1.

Table 1: Maximum peaks recorded during June 2018.

Date	Rivers	Stations	Peaks Inflows	Flood level
16/06/2018	Kabul	Nowshera	78500	Low
30/06/2018	Chenab	Marala	114254	Low
30/06/2018	Chenab	Khanki	142329	Low
30/06/2018	Chenab	Qadirabad	141756	Low

3.4 Hydrographs during June 2018

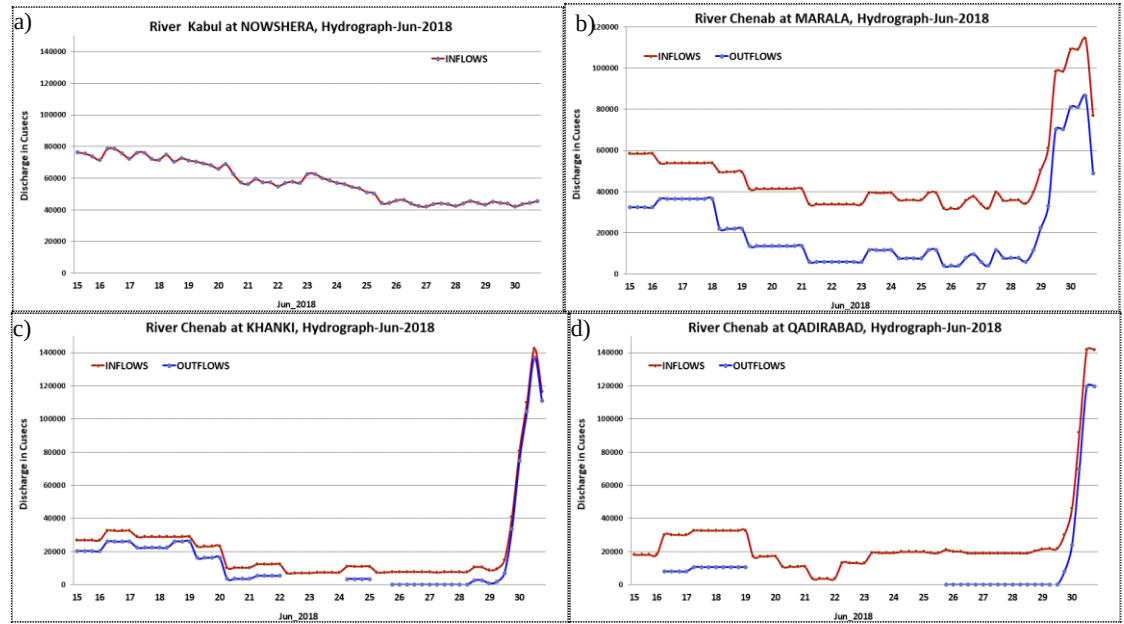


Figure 6: Hydrographs for the month of June 2018.

3.5 Spatial pattern of rainfall during the month of June 2018

Isohyetal map of June 2018 indicates that one maxima rainfall (more than 200 mm) lies over central Punjab around Toba Tek Singh and other centers of rainfall of more than 100 mm lie over Rawlakot, Malam Jabba and Lahore. Two rainfall centers of more than 80 mm are also observed over Chhor in southeast Sindh and over south Punjab near DG Khan. Spatial distribution of significant rainfall map of June 2018 is shown in Figure 7.

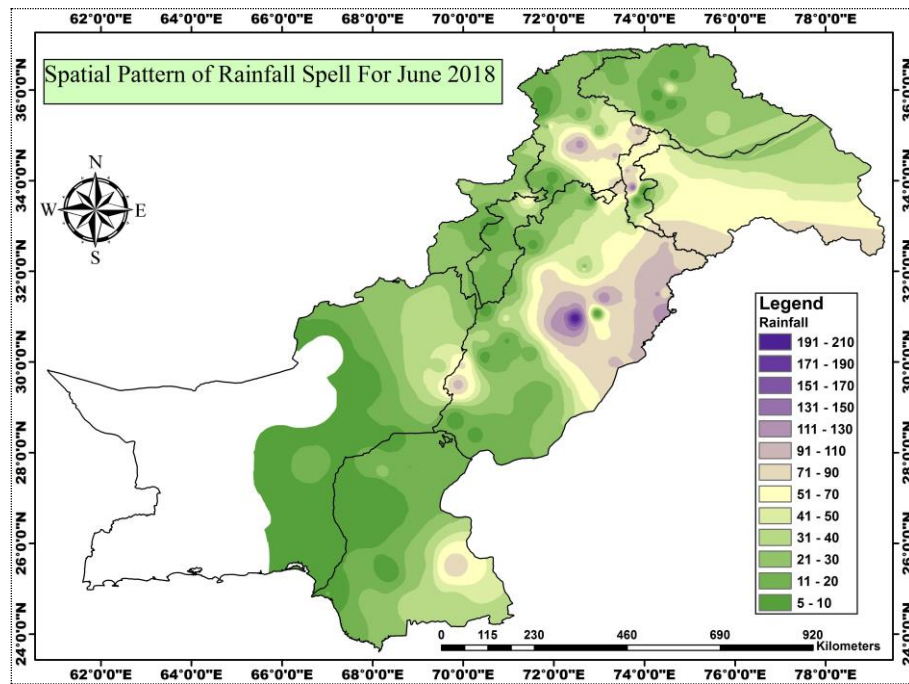


Figure 7: Spatial distribution of significant rainfall map of June 2018.

4 Significant hydro-meteorological events during the month of July 2018

Four significant rainfall spells occurred during the month of July 2018.

4.1 Meteorological events

First spell which occurred from 2nd to 4th July 2018 was the result of penetration of heavily moist current from Arabian Sea into sub mountainous areas of Punjab & Kashmir under the effect of westerly wave passing over northern parts of the country and presence of a seasonal low over Balochistan. The second spell of July was observed during 10th to 12th July, 2018. It was caused by the interaction of westerly wave passing over northern parts of the country and the moist influx from Bay of Bengal. Third spell of the month of July was observed from 16th to 18th July, 2018. It was also caused by moderate moist current from Bay of Bengal and Arabian sea and presence of a westerly wave over the northern parts of the country. Fourth & final spell of the month of July was observed from 22nd to 27th July, 2018. It was caused by the interaction of a westerly wave passing over northern parts of the country and the moist influx from Bay of Bengal.

4.2 1st wet spell of July 2018 (02nd to 04th July 2018)

The first wet spell of July 2018 which remained active for three days was mainly due to the presence of a westerly trough accompanied by moist current from Arabian Sea. Figure 8 (a-c) represents 500 hPa and 850 hPa Geopotential height patterns along with 925 hPa wind flow during this spell. It indicates that many parts of Pakistan are under the influence of westerly wave, Southwesterly winds at 925 hPa are also present ensuring enough moisture supply from the Arabian Sea.

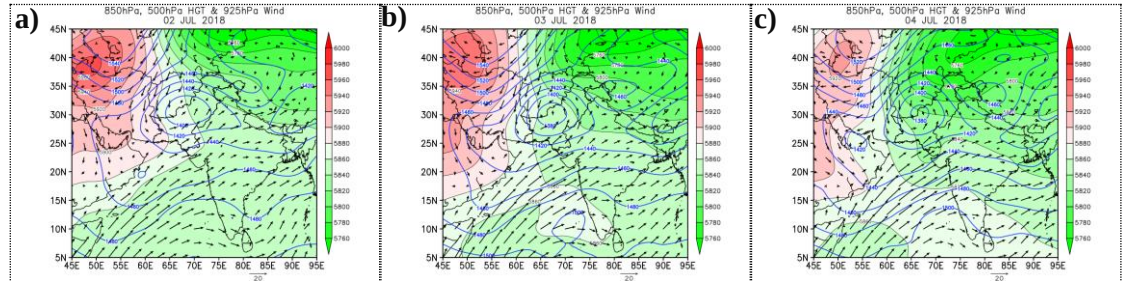


Figure 8: 500 & 850 hPa Geopotential Height patterns and 925 hPa winds from 02nd to 04th July 2018.

Figure 9 indicates the spatial distribution of significant rainfall during the event which shows that maximum rainfall of more than 240 mm occurred over Lahore. Moderate rainfall more than 100 mm was also recorded in Sargodha Division.

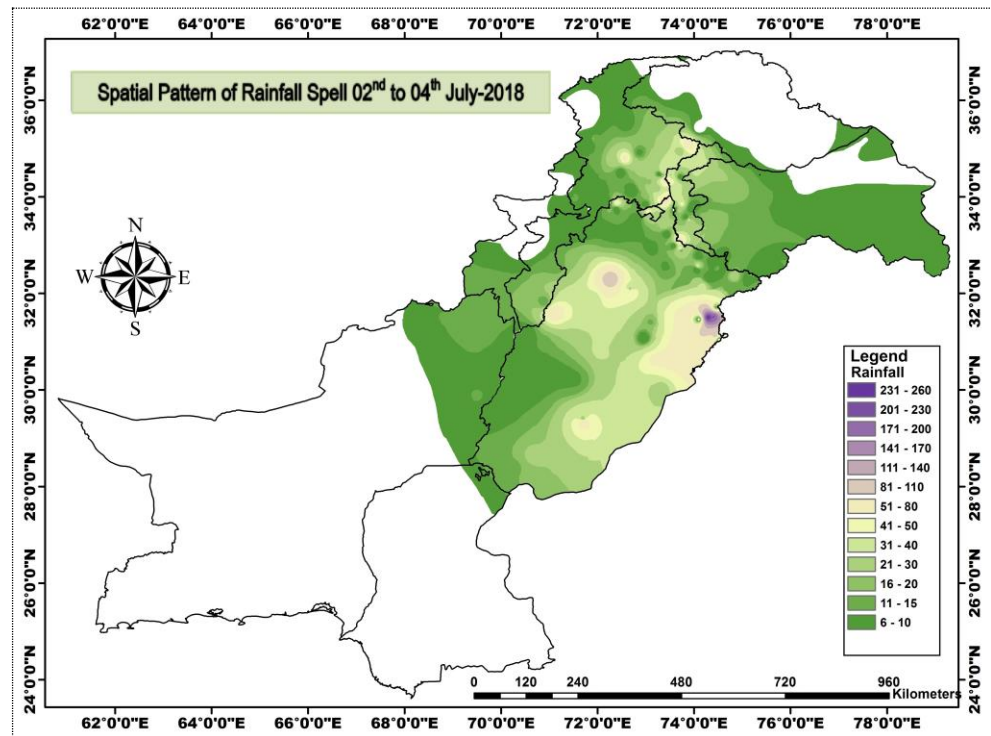


Figure 9: Spatial distribution of significant rainfall map of 02nd -04th July 2018.

Satellite images in figure 10 (a-c) are showing dense clouds over Punjab during the spell.

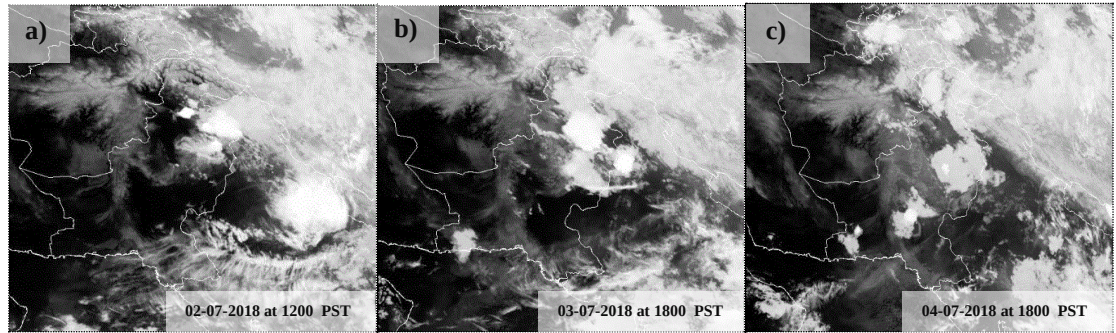


Figure 10: Satellites Images during the spell of 02nd to 04th July 2018.

4.3 Rivers position due to first wet spell of July

No significant flood peak was observed during the period.

4.4 2nd wet spell of July 2018 (10th to 12th July 2018)

The second wet spell of July 2018 which remained active for three days was mainly due to the presence of a westerly trough accompanied by moist current from Arabian Sea and Bay of Bengal. Figure 11 (a-c) represents 500 hPa and 850 hPa Geopotential height patterns along with 925 hPa wind flow during this spell. It indicates that many parts of Pakistan are under the influence of westerly wave, Southwesterly winds at 925 hPa are also present ensuring enough moisture supply from the Arabian Sea.

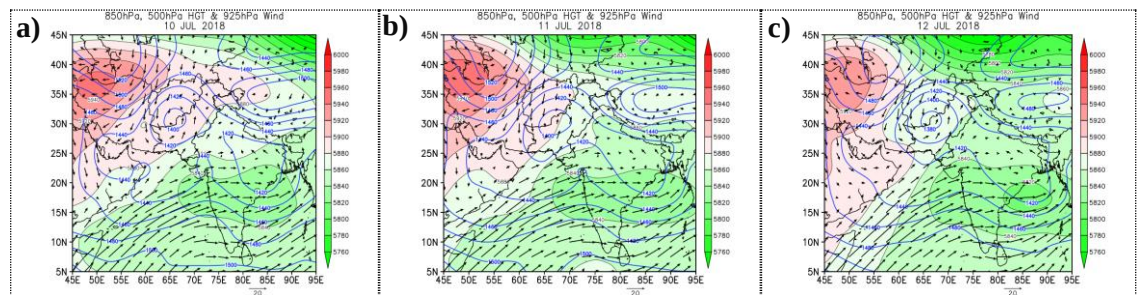


Figure 11: 500 & 850 hPa Geopotential height patterns and 925 hPa winds from 10th to 12th July 2018.

Figure 12 indicates the spatial distribution of significant rainfall during the event which shows that maximum rainfall of more than 140 mm occurred over north and northeast Punjab and Kashmir.

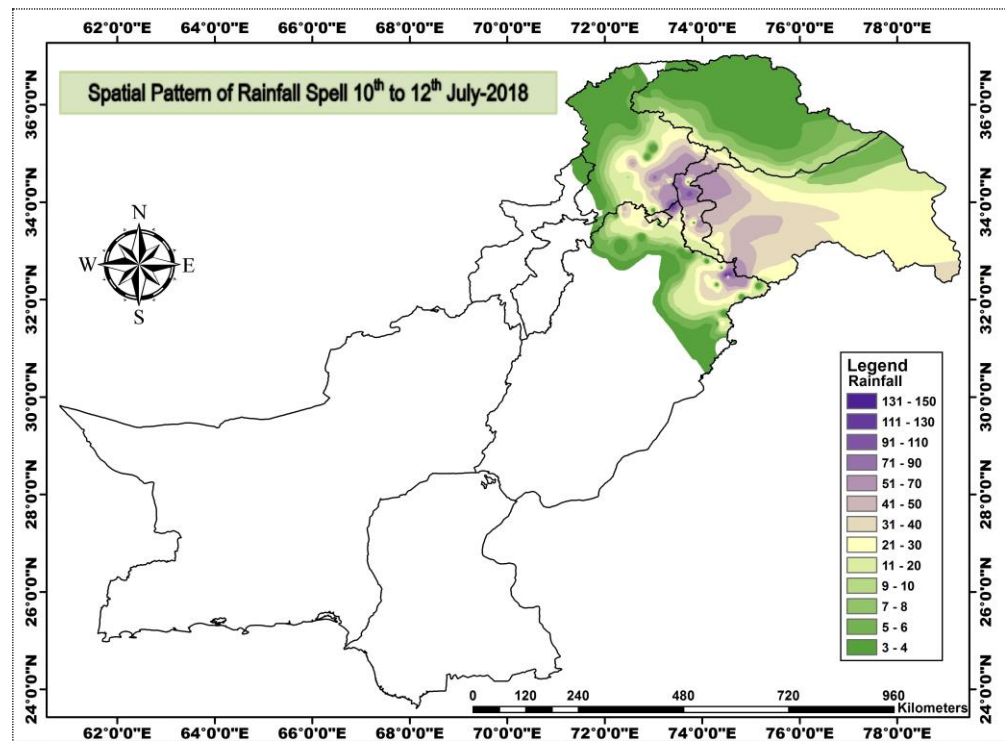


Figure 12: Spatial distribution of significant rainfall map of 10th -12th July 2018.

Satellite images in figure 13 (a-c) are showing dense clouds over north & northeast Punjab during the period.

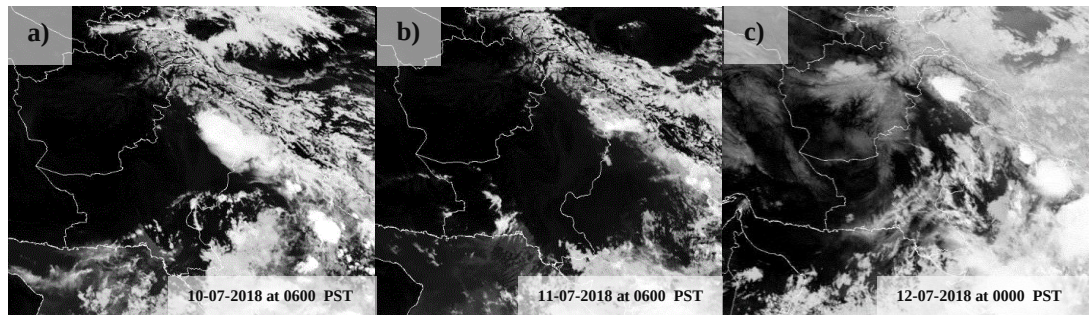


Figure 13: Satellites Images during the spell of 10th -12th July-2018.

4.5 Rivers position due to second wet spell of July

No significant flood peak was observed during the period.

4.6 3rd wet spell of July 2018 (16th to 18th July 2018)

Third spell of July 2018 which was 4th of the flood season 2018, lasted for 3 days. It was mainly due to the passing of a westerly wave, accentuation of seasonal low and incursion of moist current from Arabian Sea and Bay of Bengal as shown in Figure 14 (a-c). An overall southwesterly trend of 925 hPa winds caused rainfall in north & northeast Punjab and Kashmir.

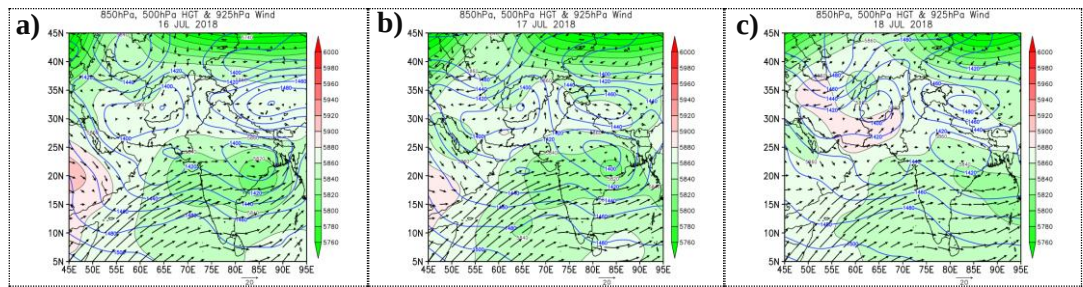


Figure 14: 500 & 850 hPa Geopotential Height patterns and 925 hPa winds from 16th to 18th July 2018.

Figure 15 indicates the spatial distribution of significant rainfall during the event which shows that maximum rainfall of more than 100 mm occurred over north Punjab around Islamabad. Moderate rainfall was observed over Faisalabad Division. Light rainfall was recorded over south Sindh.

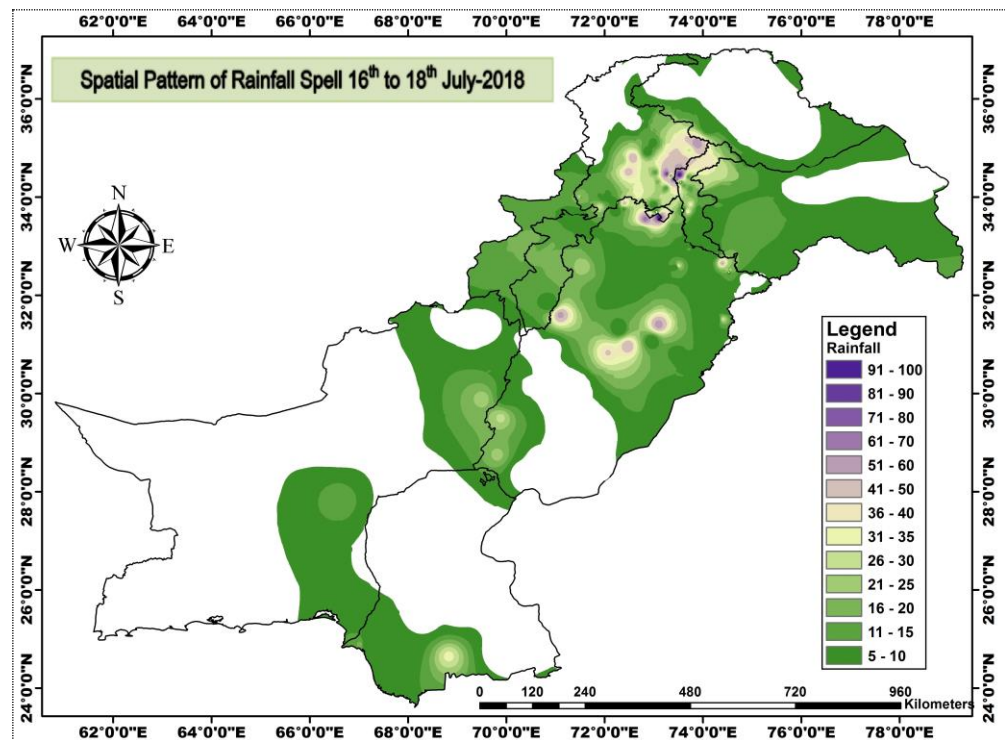


Figure 15: Spatial distribution of significant rainfall map of 16th to 18th July 2018.

Satellite images in figure 16 (a-c) are showing dense clouds over north and northeast Punjab and Kashmir during the spell.

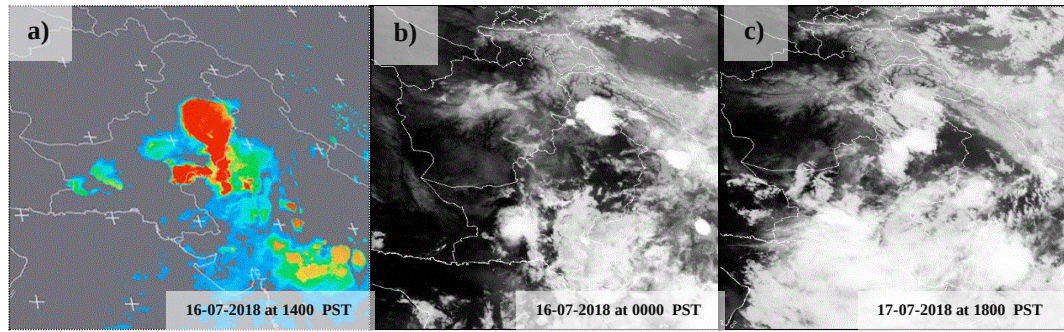


Figure 16: Satellites Images during the spell of 16th -18th July 2018.

4.7 River position due to third wet spell of July

No significant flood peak was observed during the period.

4.8 4th wet spell of July 2018 (22nd to 27th July 2018)

This long spell lasted for six days. Moderate rainfall was recorded at scattered places over Kashmir, Khyber Pakhtunkhwa & Punjab. Figure 17 (a-f) represent the Geopotential heights at 500 hPa, 850 hPa and winds at 925 hPa during this wet spell. It also shows moderate southwesterly currents at 925 hPa entering most parts of Pakistan. Westerly trough is also seen influencing upper parts of the country.

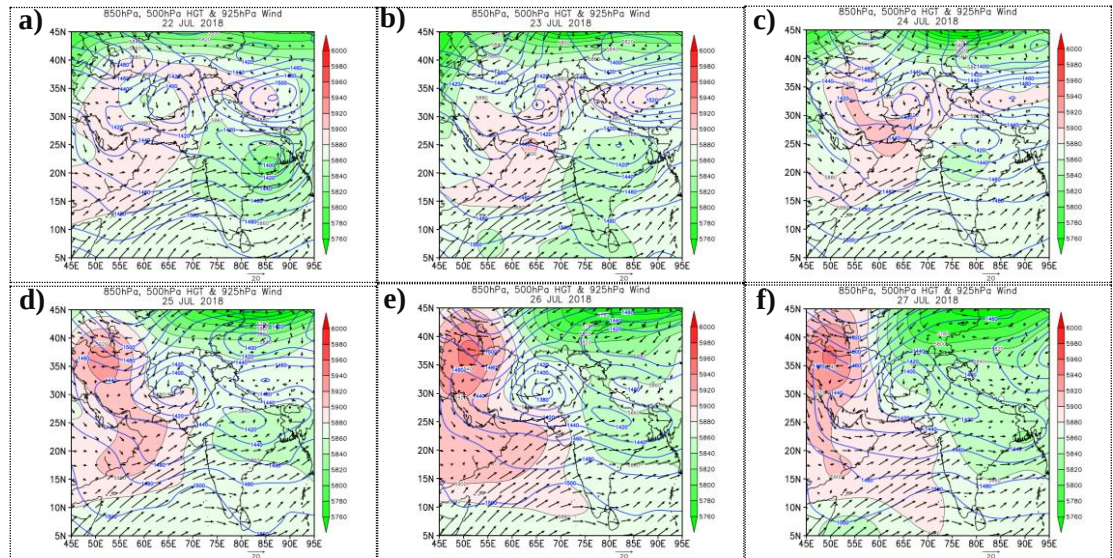


Figure 17: 500 & 850 hPa Geopotential height patterns and 925 hPa winds from 22nd to 27th July 2018.

Figure 18 indicates the spatial distribution of significant rainfall during the event which shows that maximum rainfall of more than 210 mm occurred over north Punjab around Attock. Moderate rainfall of more than 130 mm was recorded over Sargodha Division, and Kashmir.

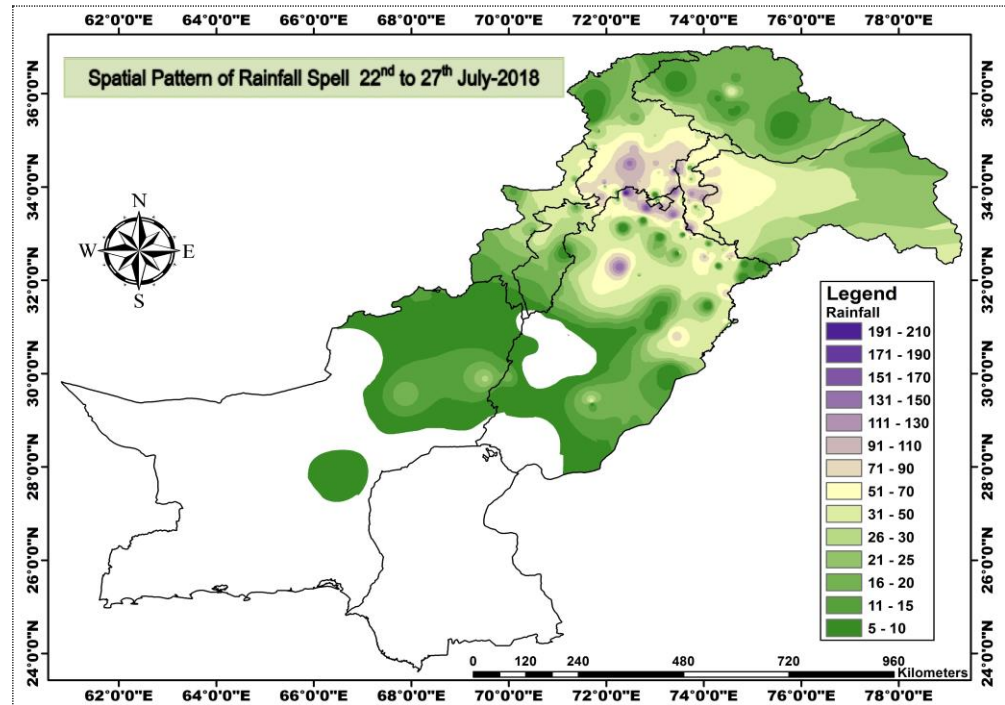


Figure 18: Spatial distribution of significant rainfall map of 22nd to 27th July 2018.

Satellite images in figure 19 (a-f) are showing dense clouds over north Punjab, Khyber Pakhtunkhwa and Kashmir during the period.

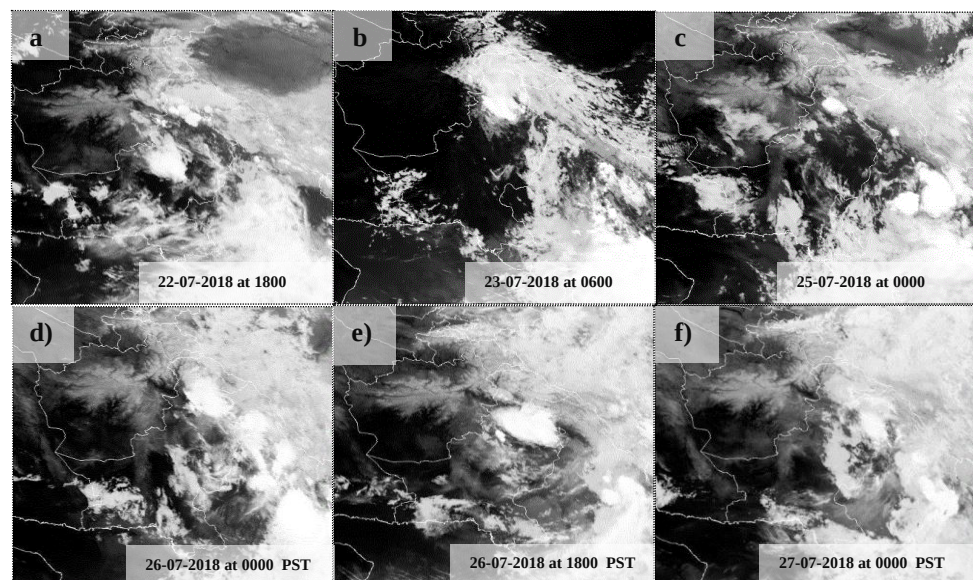


Figure 19: Satellites Images during the spell of 22nd to 27th July-2018.

4.9 Rivers position due to fourth wet spell of July

River Indus at Tarbela & Kalabagh, River Kabul at Nowshera and river Ravi at Balloki attained the state of Low flood during the period. Figure 20 represents the temporal distribution of rainfall during the month of July 2018.

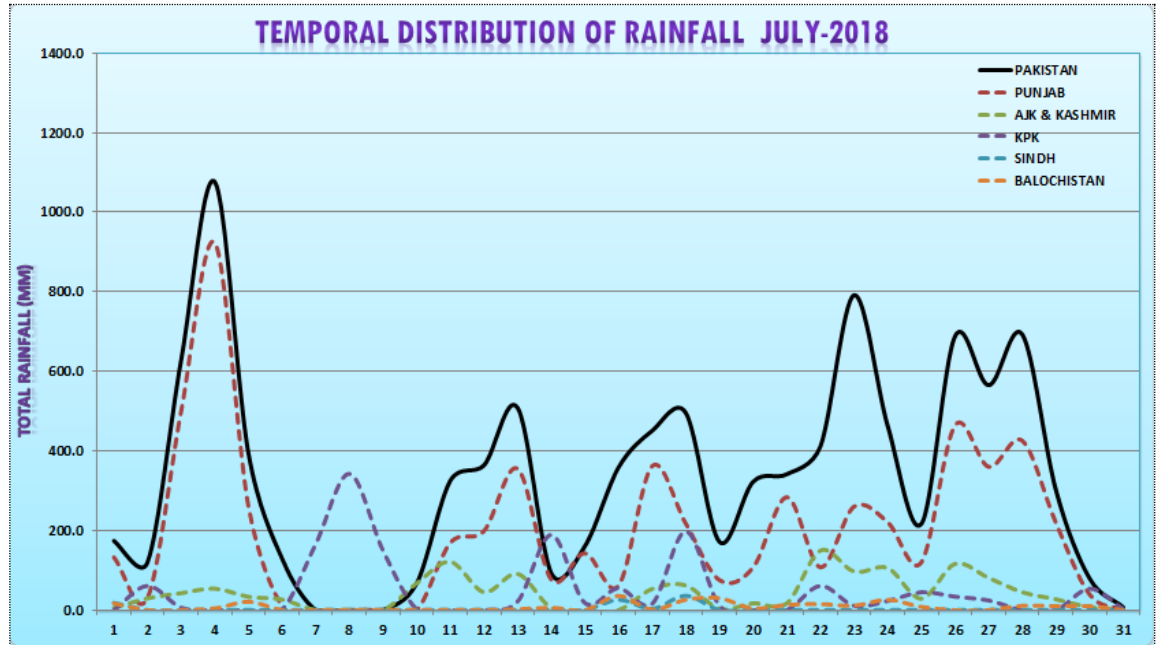


Figure 20: Temporal distribution of rainfall July 2018.

4.10 River position during July 2018

Flood peaks (Cusecs) recorded during June, 2018 in different rivers at various points are in table 2.

Table 2: Maximum peaks recorded during July 2018.

Date	Rivers	Stations	Peaks Inflows	Flood level
24/7/2018	Indus	Tarbela	295000	Low
29/7/2018	Indus	Kalabagh	274687	Low
24/7/2018	Kabul	Nowshera	105300	Medium
30/7/2018	Indus	Chashma	250489	Low
31/7/2018	Kabul	Nowshera	47700	Low
30/7/2018	Ravi	Balloki	53595	Low

4.11 Hydrographs during July, 2018

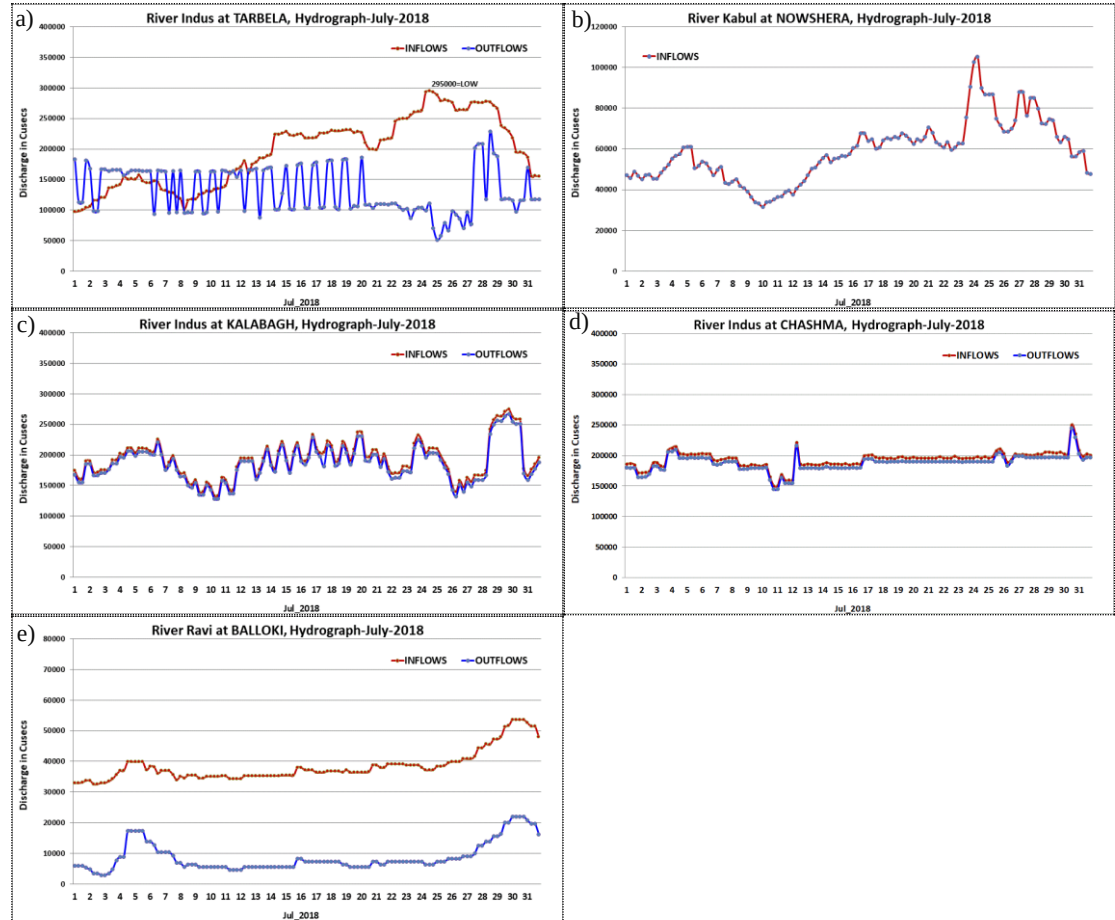


Figure 21: Hydrographs for the month of July 2018.

4.12 Spatial pattern of rainfall during the month of July 2018

Isohyetal map of July 2018 indicates that two maximum rainfall centres (more than 400 mm) are present, one over north Punjab near Attock and other around northeast Punjab over Lahore. Rainfall center of more than 100 mm is also observed over northeast Balochistan over Barkhan as shown in figure 22.

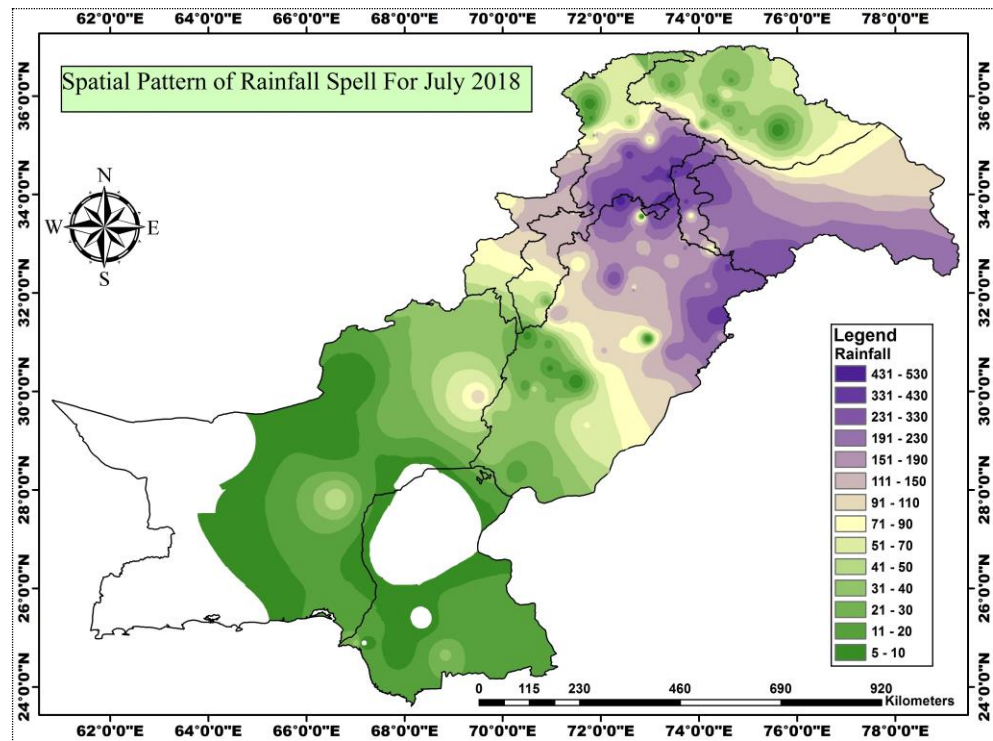


Figure 22: Spatial distribution of significant rainfall map of July 2018.

5 Significant hydro-meteorological events during the month of August 2018

5.1 Meteorological events

Two rainy spells occurred during the month of August 2018. First spell produced rainfall from 6th to 7th August 2018. This spell was caused by the presence of a well marked seasonal low over northeast Balochistan, westerly wave over north of the country and moderate moist current from the Arabian Sea as well as from Bay of Bengal. Second wet spell of August was observed from 20th to 25th. This spell was caused by the interaction of westerly wave over northern parts of the country and seasonal low along with moist current from the Arabian Sea and Bay of Bengal.

5.2 1st wet spell of August (06th to 7th August 2018)

The rainfall during the first spell of August occurred during 6th to 7th August 2018. Moderate to heavy rainfall was observed during this spell over the upper catchments of river Indus and Jhelum along with north and northeast Punjab. Atmospheric conditions during this wet spell are shown in figure 23 (a-b). It shows a southwesterly flow at lower level in Punjab.

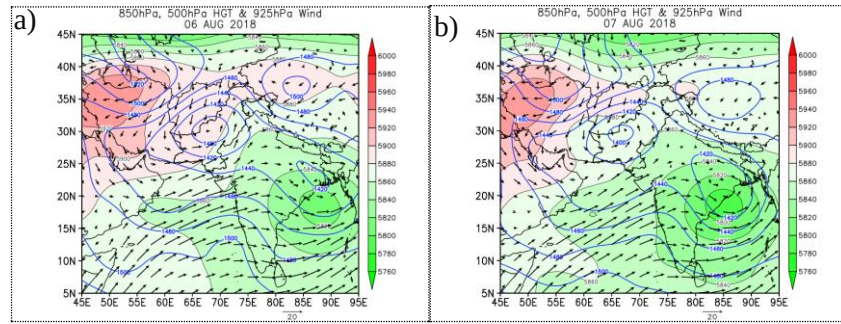


Figure 23: 500 & 850 hPa geopotential height patterns and 925 hPa winds on 06th to 7th August 2018.

Figure 24, Isohyetal map of 6th to 7th August 2018 indicates that one maxima of rainfall (more than 190 mm) lies over Khyber Pakhtunkhwa around Shinkiri. Another maximum of rainfall of more than 160 mm lies over north Punjab near Rawalpindi.

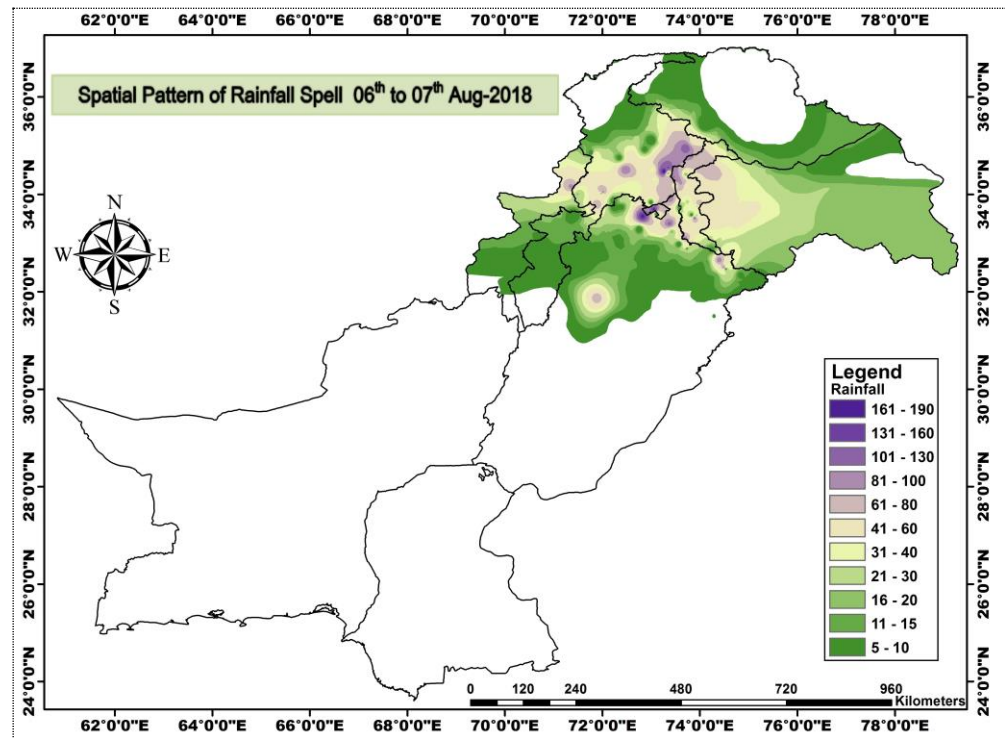


Figure 24: Spatial distribution of significant rainfall map of August 2018 (06-07 August).

Satellite images in figure 25 (a & b) are showing dense clouds over north-northeast Punjab & Kashmir.

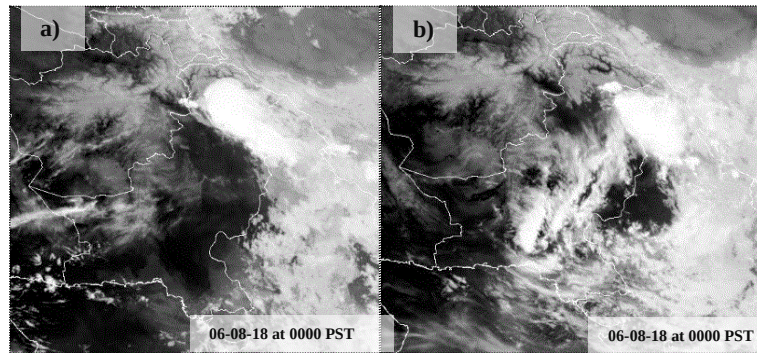


Figure 25: Satellites Images during the spell of August 2018 (02-05 August).

5.3 Rivers position during first spell of August-2018

Due to moderate to heavy rainfall in the upper catchments of river Indus, Jhelum and Chenab, Medium level flood was recorded in Chenab at Marala. Low level flood was also observed in river Indus at Kalabagh, river Jhelum at Mangla and river Chenab at Khanki & Qadirabad.

5.4 2nd wet spell of August (20th to 25th August 2018)

Rainfall of moderate to heavy intensity was recorded over north-northeast Punjab and Kashmir. Figure 26 (a-f) represent the atmospheric conditions during this wet spell. This wet spell was caused by a westerly trough affecting upper parts of the country and the influx of southwesterly currents at 925 hPa.

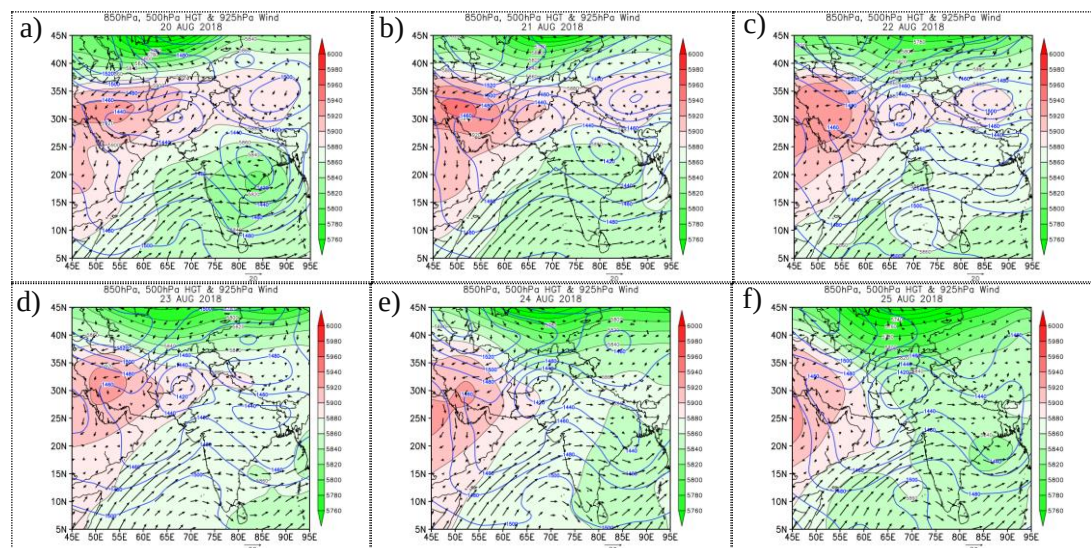


Figure 26: 500 & 850 hPa Geopotential height patterns and 925 hPa winds on 20th to 25th August 2018.

Figure 27 shows the spatial distribution of significant rainfall of more than 150 mm recorded over Northeast Punjab around Marala and Islamabad.

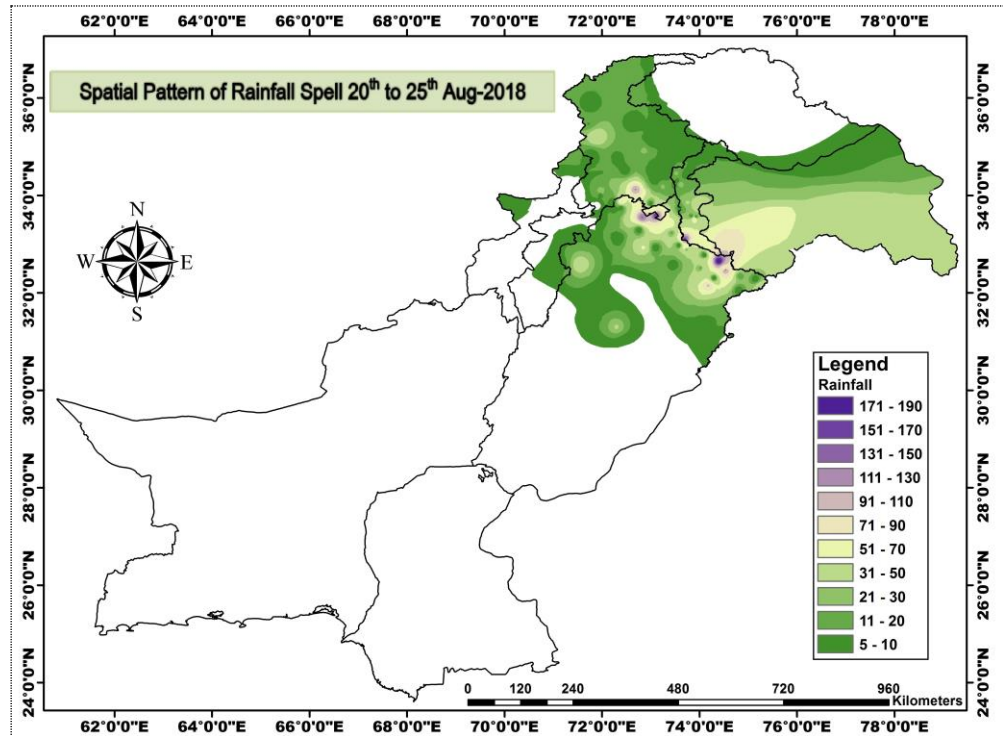


Figure 27: Spatial distribution of significant rainfall map of August 2018 (20-25 August).

Satellite image in figure 28 (a-c) is showing dense clouds over north and northeast Punjab.

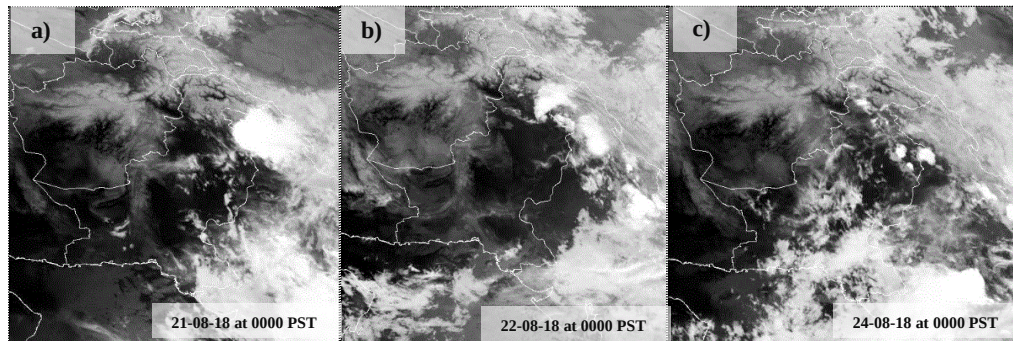


Figure 28: Radar & Satellites Images during the spell of August 2018 (20-25 August).

5.5 Rivers position during the second spell of August-2018

Due to moderate to heavy rainfall, low level flood was recorded in Indus at Kalabagh & Chashma and in river Ravi at Balloki.

5.6 Spatial distribution of rainfall during the month of August 2018

The precipitation during the month of August is shown in figure 29 which indicates monsoon activity remained over north Punjab and Kashmir. One center of maximum rainfall exceeding 500 mm is located at Islamabad. While another maxima of slightly above 200 mm is located around Kashmir & northeast Punjab. West Balochistan remained dry during the month.

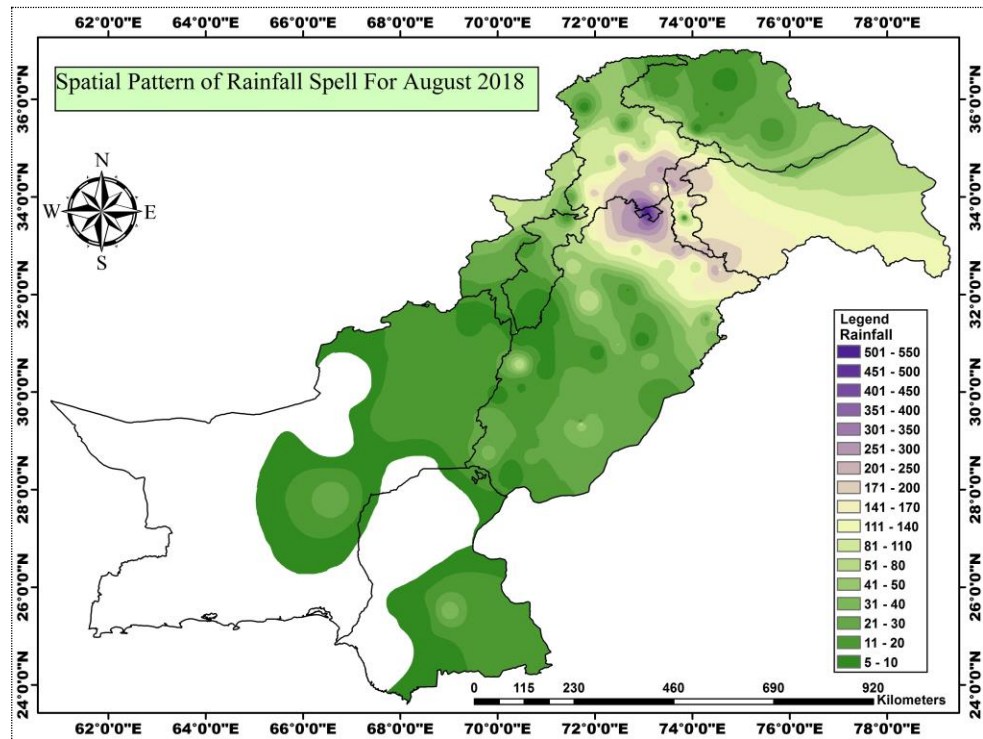


Figure 29: Spatial distribution of significant rainfall map of August 2018.

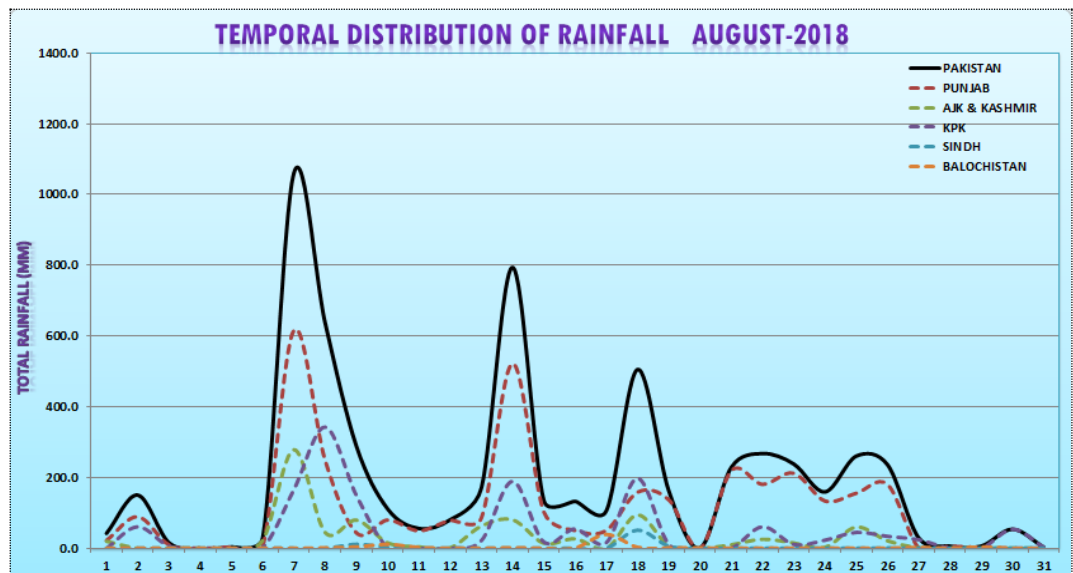


Figure 30: Temporal distribution of rainfall during August 2018.

5.7 Rivers position during the month of August-2018

Flood peaks recorded during August, 2018 are shown in table 3.

Table 3: Maximum peaks recorded during August 2018.

Date	Rivers	Stations	Peaks Inflows (Cusecs)	Flood level
09/08/18	Indus	Tarbela	275000	Low
14/8/18	Indus	Chashma	253956	Low
10/08/18	Indus	Chashma	335912	Low
15/08/18	Indus	Chashma	271415	Low
20/08/18	Indus	Chashma	307333	Low
26/08/18	Jhelum	Mangla	86000	Low
07/08/18	Indus	Kalabagh	280529	Low
08/08/18	Indus	Kalabagh	319154	Low
15/08/18	Indus	Kalabagh	286898	Low
26/08/18	Indus	Taunsa	297265	Low
17/08/18	Chenab	Marala	179894	Medium
07/08/18	Chenab	Marala	201878	High
13/08/18	Chenab	Khanki	189820	Medium
13/8/18	Chenab	Khanki	113431	Low
08/08/18	Chenab	Qadirabad	123564	Low
08/08/18	Chenab	Qadirabad	194031	Medium
14/08/18	Ravi	Balloki	51805	Low
10/08/18	Ravi	Balloki	53140	Low
16/08/18	Ravi	Balloki	50815	Low
24/08/18	Indus	Guddu	256035	Low
20/08/18	Indus	Guddu	243229	Low
30/08/18	Indus	Sukkur	211595	Low

5.8 Hydrographs observed during the month of August 2018 are shown in figure 31

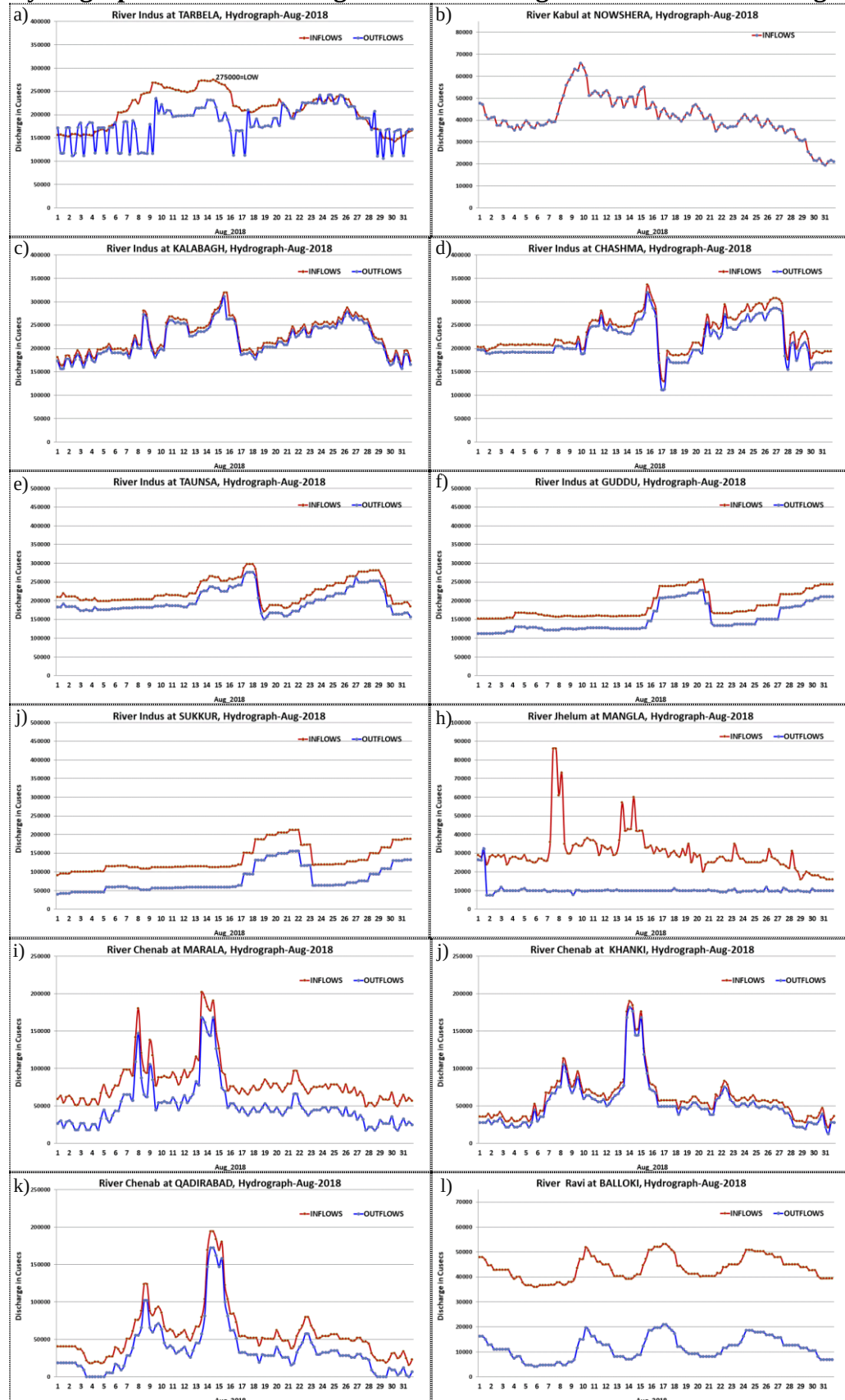


Figure 31: Hydrographs for the month of August-2018.

6 Significant hydro-meteorological events during the month of September 2018

During the month of September two monsoon lows were developed over Bay of Bengal and two wet spells were recorded during the month.

6.1 1st wet spell of September (14th to 15th September 2018)

The first rainy spell of September occurred from 14th to 15th September 2018. During this event light to moderate rainfall was reported from Sargodha, Faisalabad and Rawalpindi Divisions and Khyber Pakhtunkhwa. This situation was created by the presence of a westerly wave over north of Pakistan interacting with the presence of sufficient moisture available as shown in Figure 32 (a-b). Figure 33 shows the spatial distribution of rainfall during this spell.

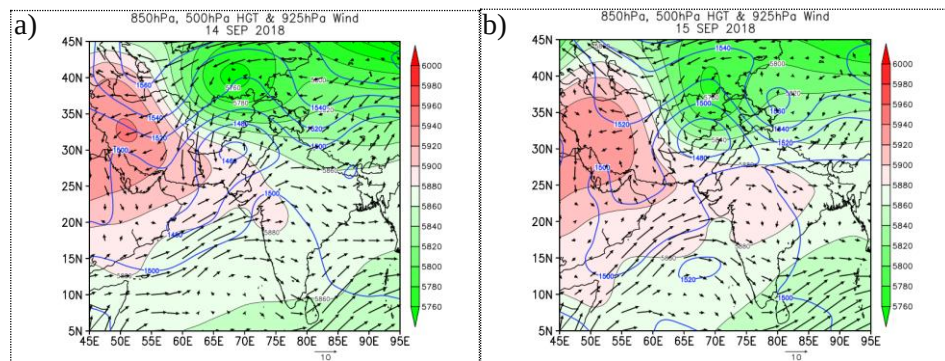


Figure 32: 500 & 850 hPa geopotential height patterns and 925 hPa winds on 14th to 15th September 2018.

Figure 33 shows the spatial distribution of significant rainfall of more than 50 mm recorded over Sargodha and Faisalabad Divisions.

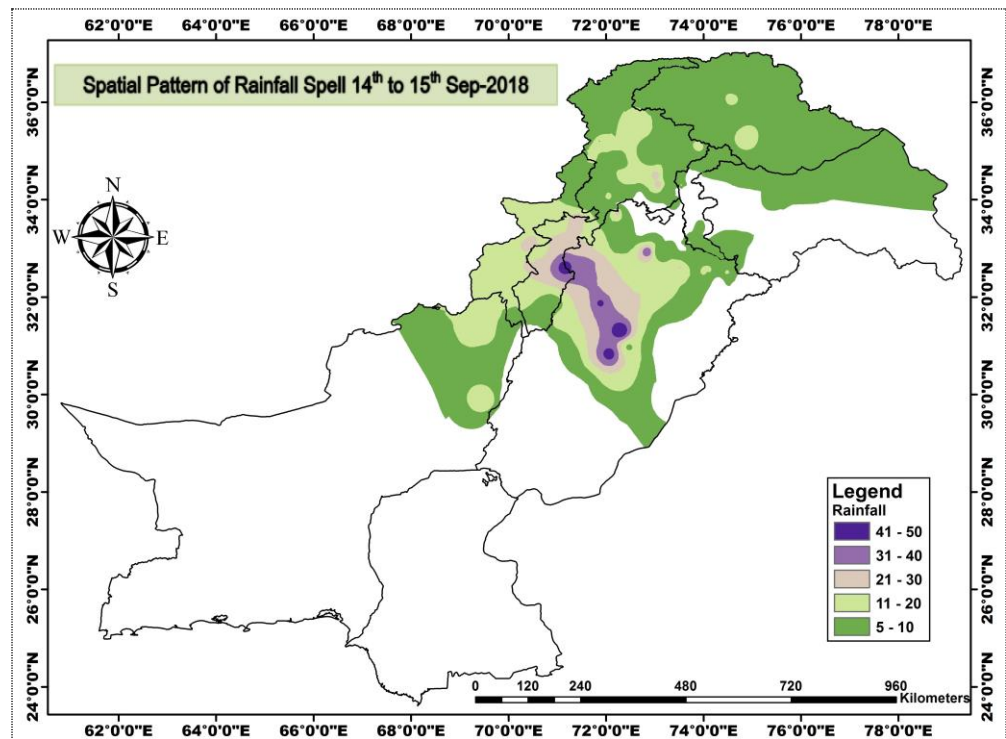


Figure 33: Spatial distribution of significant rainfall map of September 2018 (14-15 September).

Satellite image in figure 34 (a & b) shows moderate clouds over North Punjab, upper Khyber Pakhtunkhwa and Kashmir.

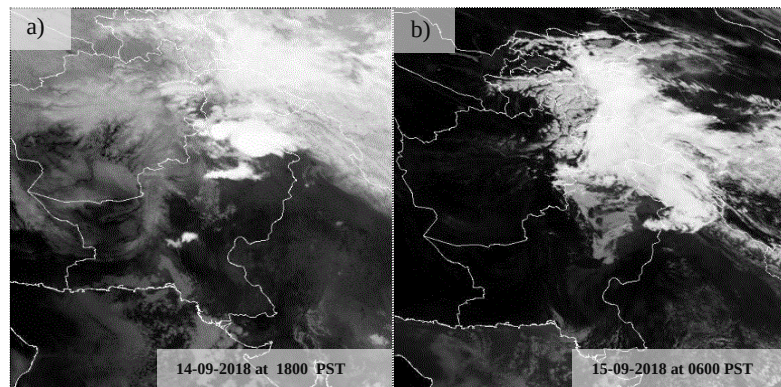


Figure 34: Satellites Images during the spell of September 2018 (14-15 September).

6.2 Cyclonic Storm/Depression over Bay of Bengal (19th to 25th Sep, Second Spell of September 2018).

6.3 Introduction

On 19th September 2018 a cyclonic depression was formed in Bay of Bengal (BoB). It crossed the Indian states of Orissa, Madhya Pradesh, and Rajasthan, later re-curving to enter Haryana and finally dissipating over Himachal Pradesh. This was a very unusual monsoon weather system as most of the monsoon systems formed in mid-September don't travel long distance across India. Path followed by this weather system is commonly associated with depressions formed in peak monsoon season. It triggered flooding in parts of India and caused the water flows to increase in River Ravi and Sutlej and their associated nullahs in Pakistan.

6.4 Background

During the northern hemisphere summer Inter Tropical Convergence Zone (ITCZ) shifts 20°-25°N and is present over Indo-Gangetic plain and the southwest monsoons blow from Arabian Sea and BoB. The ITCZ in this position is often called as the monsoon trough. Most of the BoB cyclonic depressions are formed within the monsoon trough. And their seasonal variation depends on the location of monsoon trough.

According to a study most number of monsoon weather systems formed over BoB originate in the months of May and November (Alam, Hossain, and Shafee 2003). During the period of 1961-2010 cyclonic depressions have showed a significantly decreasing trend over BoB during the monsoon and post monsoon seasons (Mohapatra et al. 2017).

Floods in Pakistan are ranked, from less severe to most severe, as category I, II and III. Category I floods occur when heat or seasonal low over Balochistan is intensified, and that mainly due to presence of a strong westerly weather system, transporting the moisture from Arabian Sea to the catchments of Rivers Chenab and Jhelum. It may result in heavy downpour caused due to the orographic lifting of moisture laden winds. Rainfall produced is in short intervals, mainly in late evening/night or early morning causing a sharp flood peak of 3 to 5 lakh cusecs under extreme conditions in River Jhelum. Category II and III floods which are more catastrophic in nature, are associated with monsoon lows/depressions originating from BoB. Major floods in Pakistan have

occurred due to depressions/ lows moving from BoB crossing India and then producing heavy rainfall in the catchment areas of rivers flowing in Pakistan. In case of category II floods a monsoon low on reaching Indian state of Rajasthan or its adjoining areas re-curves in the northeast direction towards the upper catchments of Sutlej, Ravi and Chenab Rivers causing extremely heavy rainfalls and consequently floods, first across the border in India, and then within a few hours at the rim stations in Pakistan. Category III floods are most catastrophic in nature under this situation monsoon low/depression under the influence of the westerly wave continues to move in the northerly direction finally ending up in Rawalpindi/Hazara divisions and adjoining areas. The upper catchments of Rivers Jhelum, Chenab and Ravi come under its influence. These are most threatening floods for Mangla reservoir. Flood of 1992 is an example of it. Meteorological conditions relating to category II and III floods are shown in figure 35 and 36 respectively.

Flood forecasting is a three tier process. First one is the precipitation stage in which the amount of rainfall in the catchments is predicted and later monitored in real time. Prediction for precipitation amount is done by means of various different resolution Numerical Weather Prediction (NWP) model outputs. Real time monitoring of actual rainfall in the catchments is done by using the observations from surface weather observatories, network of Automatic Weather Stations (AWS), RADAR outputs and satellite imageries. Next is the flood formation stage which starts with the generation of runoff and the formation of flood wave. Two different models are used for this purpose one is Flood Early Warning System (FEWS) and the other one is Integrated Flood Analysis System (IFAS). Apart from these, indigenously developed analytical techniques are also employed to forecast the amount of runoff and the degree of flood peak. Last stage is the routing of flood wave below the rim station. This is done by using a routing model developed at Flood Forecasting Division (FFD), Lahore. Routing technique is also enhanced by using Rainfall Runoff Inundation (RRI) model.

In case of likely category II or III floods a warning system is established to forewarn the concerned authorities, related to local government and disaster management. First alert known as Blue Alert is issued when monsoon low/depression reaches Indian Rajasthan and is expected to re-curve in northerly direction. This alert is an indication that there is a possibility of flood within next 24-72 hours subject to the movement of the weather

system towards the catchments areas. Second alert is known as Yellow Alert, which must be treated as a warning, indicating that the weather system has re-curved in the northerly direction and poses an imminent threat of heavy downpour in the catchment areas. Finally a Red Alert is issued when the low/depression starts to directly affect the catchment areas and heavy rainfall has started. These are qualitative forecasts which are issued in advance. Actual quantification of flood peak is done when real time storm rain becomes available.

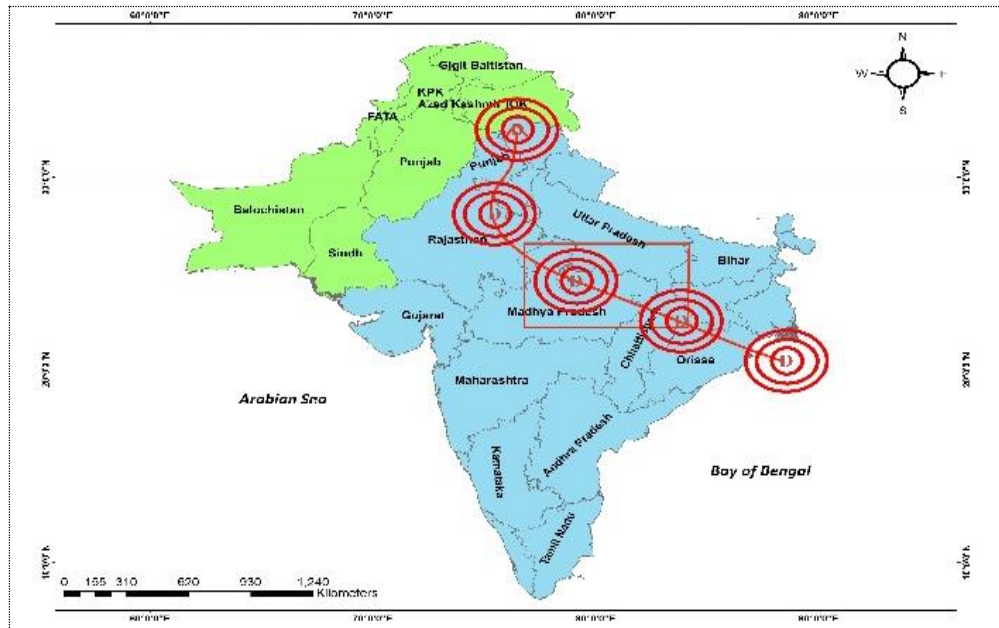


Figure 35: Meteorological situation relating to category II floods.

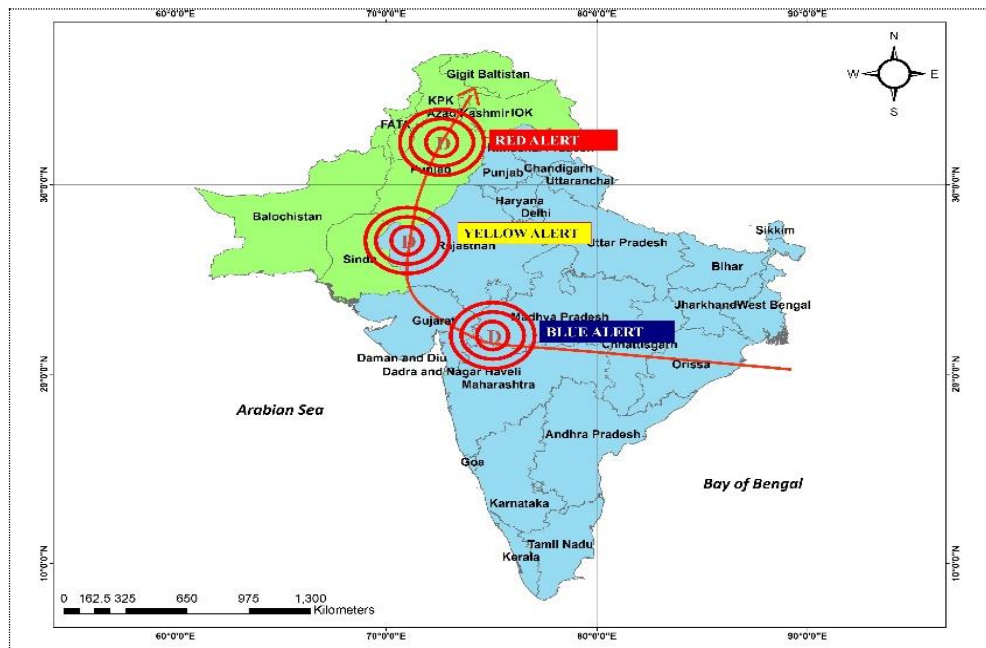


Figure 36: Meteorological situation relating to category III floods.

6.5 Track of September 2018 monsoon weather system

On 19th September a depression was formed in east central BoB which was termed as BoB 07. On the same day Joint Typhoon Warning Center (JTWC) also issued a Tropical Cyclone Formation Alert (TCFA). On 20th September this system intensified into a deep depression and later that day further intensified into a Cyclonic Storm Daye. This cyclonic storm made the land fall between 1900-2000 UTC of 20th September over south Odisha, also impacting the adjoining north Andhra Pradesh coast near Gopalpur, producing heavy rains and strong winds of 60 to 70 km/h gusting to 80 km/h in various districts of the region (IMD 2018). This cyclonic storm weakened into a deep depression on 0000 UTC of 21st September after moving in west-northwest ward direction. It took the status of cyclonic storm for only six hours. Following the same track it converted into a depression over west Madhya Pradesh on 1200 UTC of 21st. According to IMD (2018) lowest central pressure attained by the weather system was estimated to be 992 hPa between 1500 UTC to 18000 UTC of 21st September. At 1200 UTC of 22nd September it moved over west Madhya Pradesh and adjoining east Rajasthan as a well-marked low pressure area, it remained as a well-marked low pressure area over south Rajasthan till 0300 UTC of 23rd. The weather system converted into a low pressure area at 0000 UTC of 24th September as it moved over southwest Uttar Pradesh and south Haryana. Before dissipating this low

pressure area had come under the influence of a westerly wave which pushed it further eastwards, producing rainfall in Himalayas and the plains in south. It became insignificant in the morning of 25th September. No part of Pakistan or Kashmir came under its direct influence. Track followed by the monsoon depression from 19th to 25th September 2018 is shown in figure 37.

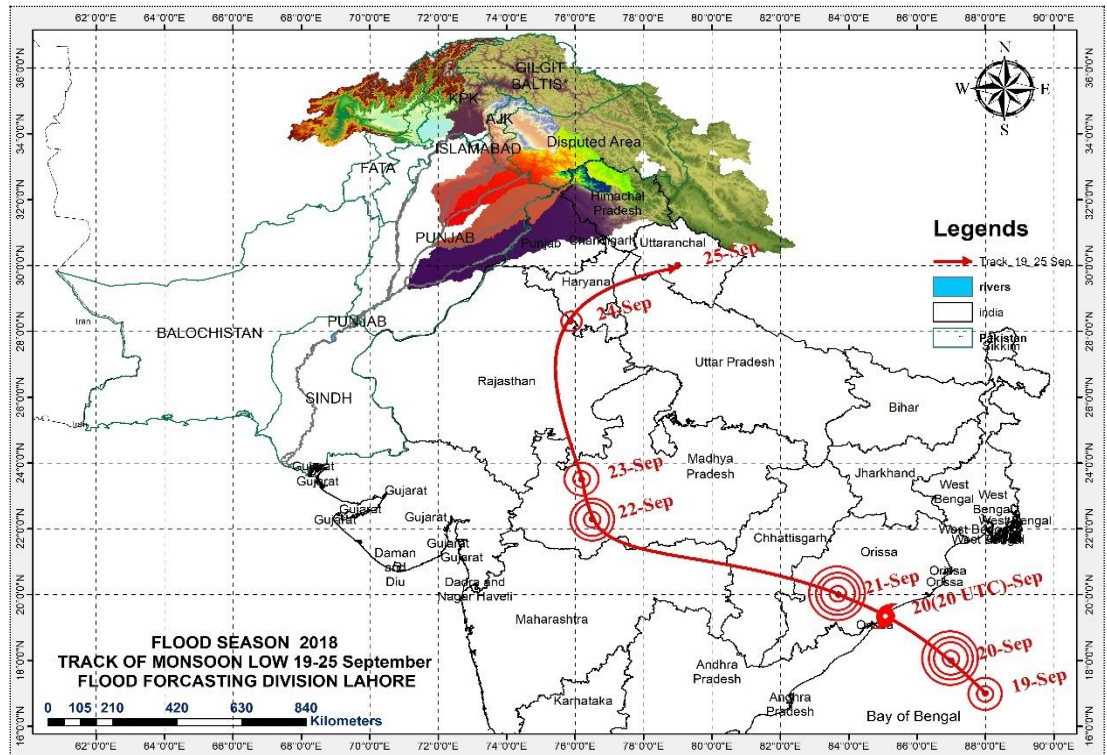


Figure 37: Track of monsoon system 19th - 25th September 2018. Red line indicates the track of the system while the number of circles indicates the increasing and decreasing intensity.

6.6 Monitoring and forecast

Pakistan Meteorological Department, Flood Forecasting Division, Lahore started the monitoring of this weather system and its likely track before it has developed into a depression. Model outputs from different NWP centers were constantly analyzed, assistance was also taken from satellite imageries. Forecasts issued by regional centers was also taken into account. FFD started mentioning its development stages and path in its daily flood bulletin from 17th September 2018. Eventually an alert was issued on 21st September and a warning on 22nd September regarding the impact of the weather system on river flows in Pakistan. Synoptic Situation related to this monsoon weather system is shown in figure 38. It is situated over central India on 21st September, swiftly moves to Indian Rajasthan and then is seen re-curving to North where it comes

into the grip of a westerly wave present over Pakistan, which moves it further eastwards and finally dissipating on 25th September. Precipitation distribution according to CPC .50x.50 Global Daily Unified Gauge-Based Analysis of Precipitation is shown in figure 39. Indicating two peak rainfalls one in the initial stage when the monsoon system makes the land fall and then in the final stage, before dissipating where peak rainfall has more spatial distribution than in the initial stage. The rainfall in the final stage is more owing to the interaction of the westerly wave. CPC datasets show a significant rainfall in catchment areas of Rivers Ravi and Chenab on 22nd and 23rd September as shown in figure 40.

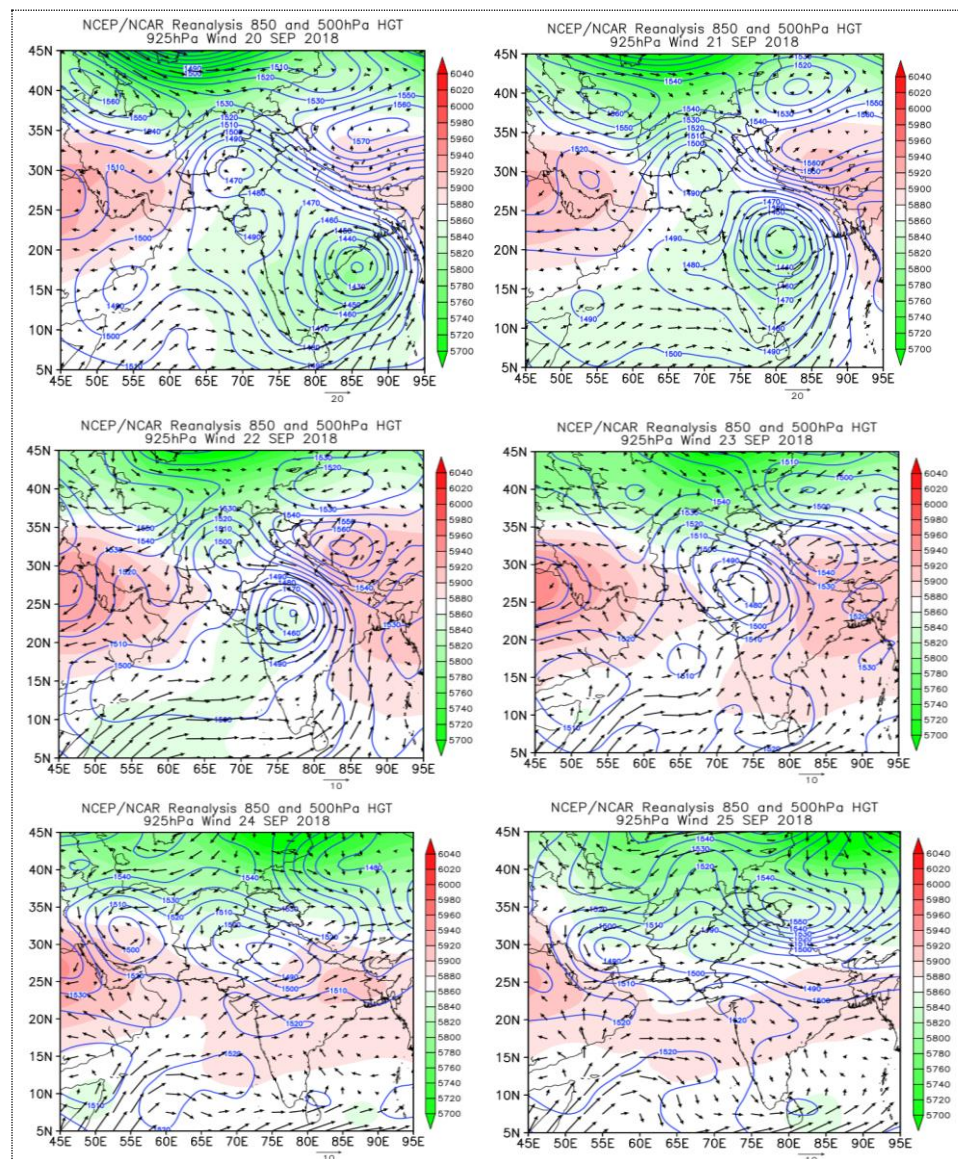


Figure 38: Model outputs from NCEP/NCAR reanalysis datasets with 2.5° resolution. Blue contours indicate 850 hPa, while red and green shades show 500 hPa geo potential heights. Black arrows indicate 925 hPa winds.

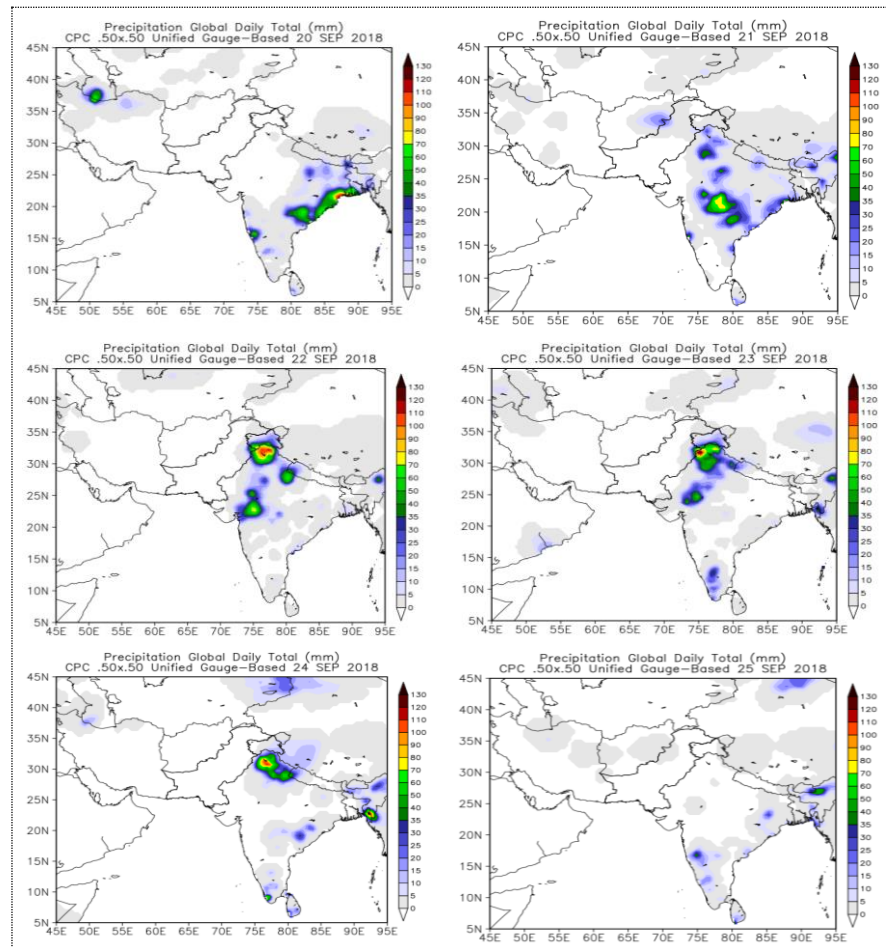


Figure 39: Rainfall (mm) distribution over India and Pakistan.

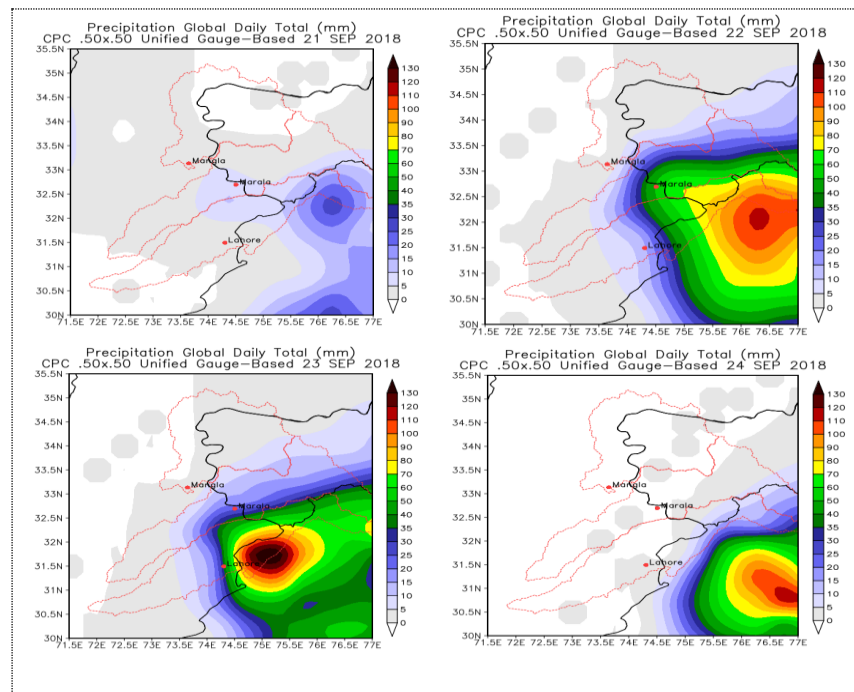


Figure 40: Rainfall (mm) distribution over catchments of Rivers Jhelum, Chenab and Ravi.

6.7 Impact on river flows in Pakistan

Historically monsoon weather systems re-curving from Indian Rajasthan have the tendency to move and dissipate over Kashmir and adjoining areas, producing heavy rainfall and devastating floods in the downstream of rivers having catchment areas there (PMD 2008). Keeping in view these historical tracks and the prevailing meteorological situation FFD, Lahore issued a warning on 22nd September 2018 regarding a very high flood, on 23rd September, in River Chenab at Marala and downstream, River Jhelum at Mangla, Rivers Ravi and Sutlej along with associated Nullahs of Rivers Chenab and Ravi. Flows in Rivers Ravi and Sutlej in Pakistan depend on releases from across the border. As the system later tracked northeastwards the catchment areas of Rivers Jhelum and Chenab remained practically unaffected by this weather system thus having no significant influence in the flows in the said two rivers. However the flows in the feeding Nullahs of Rivers Chenab and Ravi increased significantly. Water level at the rim stations of Ravi and Sutlej in Pakistan also increased to a larger extent as the amount of water released from irrigation head works across the border was amplified due to the prevailing weather system over there.

Inflow at Mangla attained its highest value of 25000 cusecs at 0000 PST of 24th September not even reaching the low level flood limits. Chenab at Marala peaked 91000 cusecs at 1200 PST of 24th September almost touching the low level flood limits. River Ravi at Jassar reached to more than 66000 cusecs crossing the low level flood limit of 50000 cusecs at 0600 PST of 25th September. GS Wala at River Sutlej recorded a gauge height of 17.7 feet almost reaching the low level flood limits. Flows at Jassar and GS Wala are dependent on the releases from the Indian water reservoirs. Bein Nullah at Shakargarh recorded a maximum peak of almost 4500 cusecs crossing the medium flood limits at 1800 PST of 23rd September. It remained in medium flood for almost 18 hours. Nullah Deigh at Kingra also reached 16500 cusecs crossing the medium flood level at 0000 PST of 24th September. Nullah Aik at Ura crossed the lower flood limits of 20000 cusecs at 1200 PST of 24th September. Nullah Basantar at Jassar peaked almost 5500 cusecs crossing the medium flood limits at 0000 PST of 25th September. It remained in medium flood for nearly 18 hours. Nullah Palku at Wazirabad remained below low flood level during the event. Hydrographs of these selected water channels are shown in figure 41. Each figure showing the maximum peak attained during the period.

Qualitative forecast issued on 22nd September proved to be over estimating the situation related to the monsoon low. From the hydrographs it can be assessed that inflow at Mangla remained unthreatening. Even Chenab at Marala could not reach low flood level limits. Nullahs Bein, Deg and Basantar crossed the medium flood limits and proved catastrophic in the areas where no well-marked channels were present. According to one news report Nullah Deg in particular destroyed many houses and farms in district Sialkot (Ahmad Shahzad 2018). However quantitative forecasts issued every day for the flows during next 24 hours proved to be much accurate. Apart for River Jhelum at Mangla for which 50 to 110 thousand cusecs was forecasted on 23rd September however only 25000 cusecs was recorded. For River Chenab at Marala 50 to 150 thousand cusecs was forecasted and almost 100 thousand cusecs was recorded on 24th. River Ravi at Jassar was expected to peak between 40 to 90 thousand cusecs on 25th where peak of 67 thousand cusecs was recorded. At GS Wala a gauge height of 16 to 18 feet was forecasted whereas 17.7 feet was recorded on 27th September.

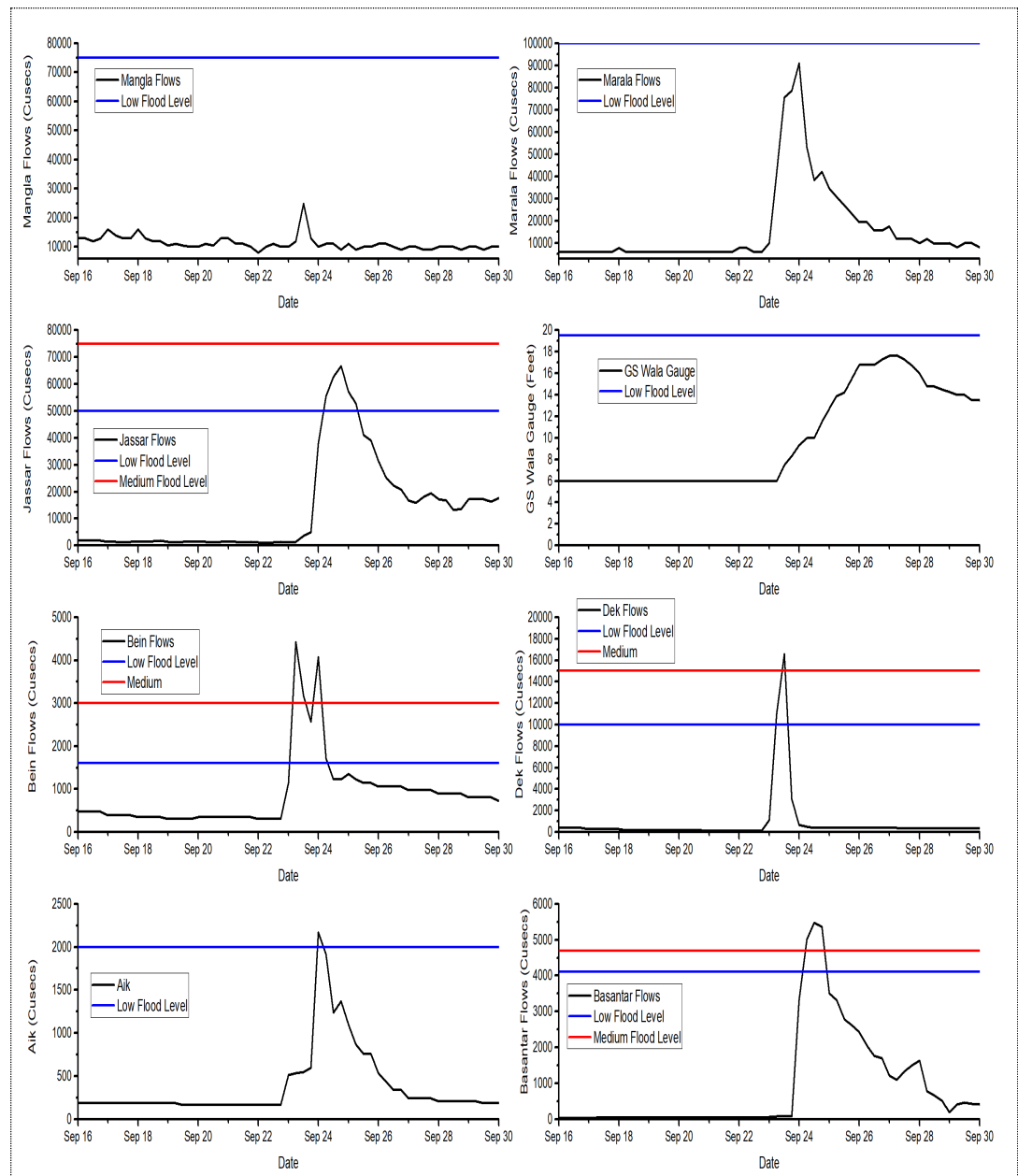


Figure 41: Hydrographs of selected rivers and nullahs during 16th to 30th September. Blue and red lines indicate low and medium flood limits of each water channel respectively while the black line indicates flow at that point during the period.

Figure 42 shows the spatial distribution of rainfall during this spell. Figure shows the maximum rainfall more than 70mm recorded over Northeast Punjab.

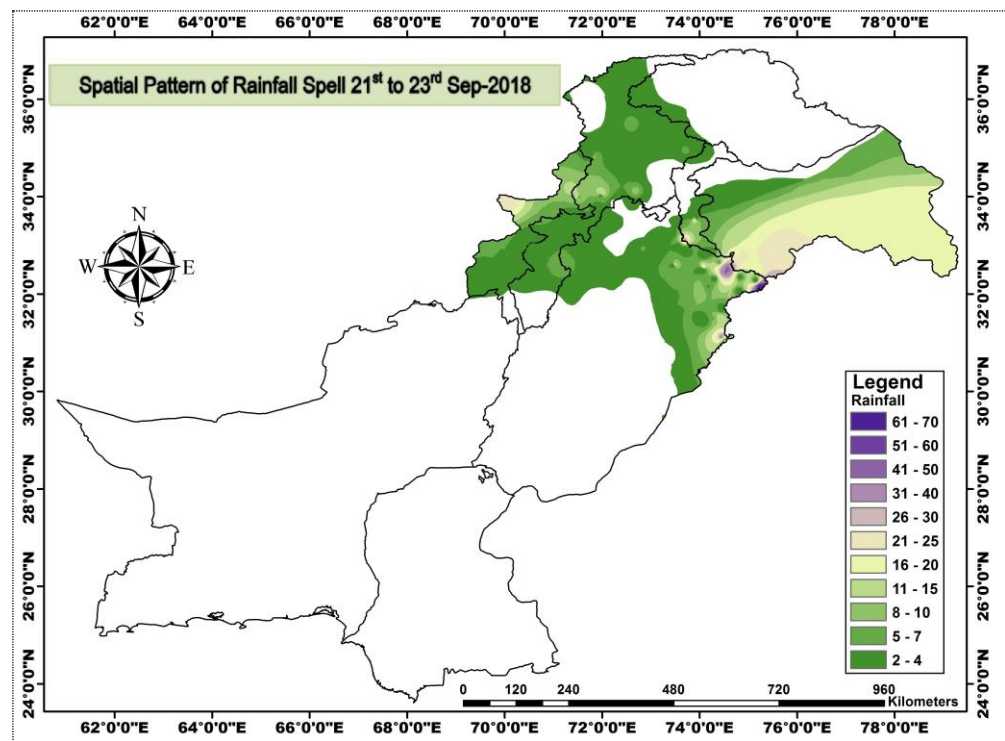


Figure 42: Spatial distribution of significant rainfall map of September 2018 (21-23 September).

Satellite image in figure 43 (a & b) is showing moderate clouds over north Punjab & upper Khyber Pakhtunkhwa along with Kashmir.

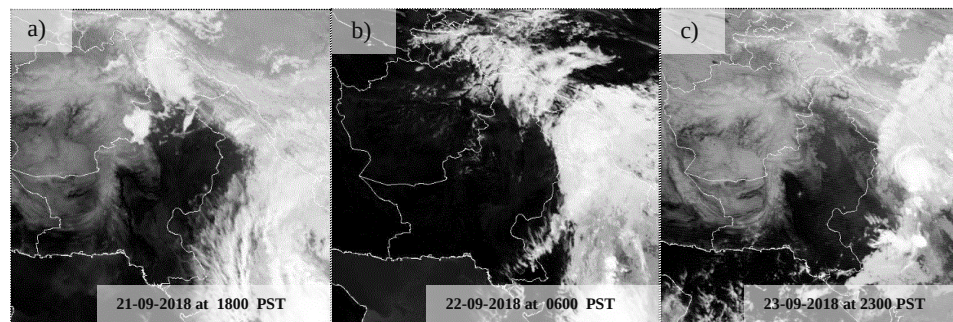


Figure 43: Satellite Images during the spell of September 2018 (21-23 September).

6.8 Spatial pattern of rainfall during the month of September 2018

Rainfall maxima of more than 100 mm is located at Sialkot in northeast Punjab and over Islamabad while another center of rainfall above 90 mm found at Kotli in Kashmir. light to moderate rainfall was also recorded over Sargodha division over Noorpur Thal and northeast Balochistan over Barkhan as shown in figure 44.

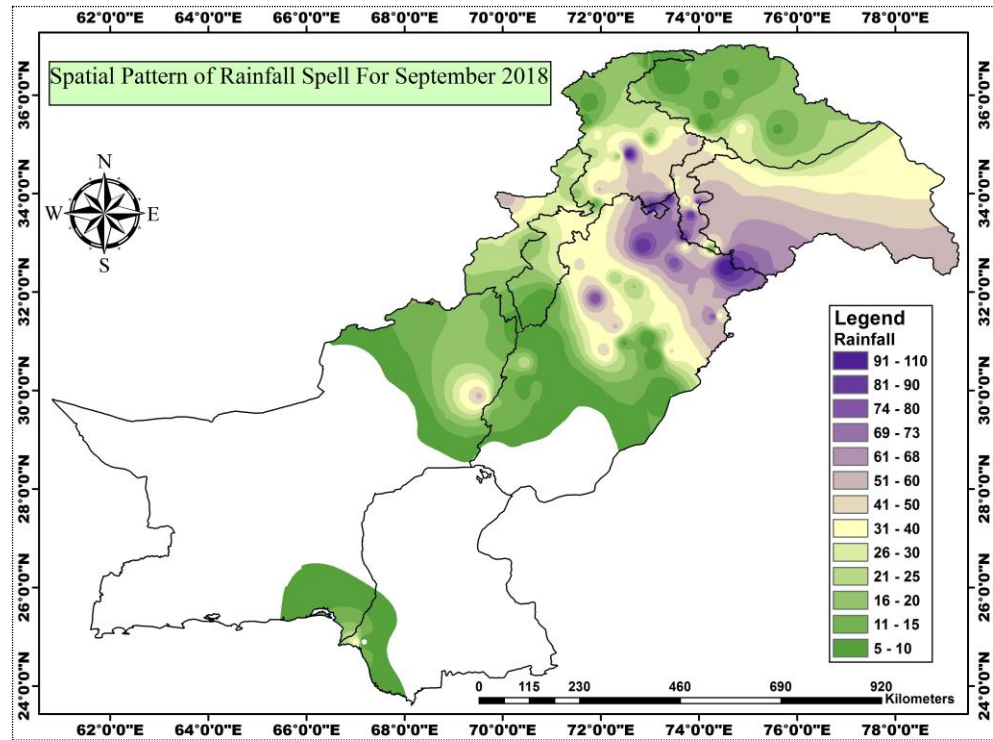


Figure 44: Spatial distribution of significant rainfall map of September 2018.

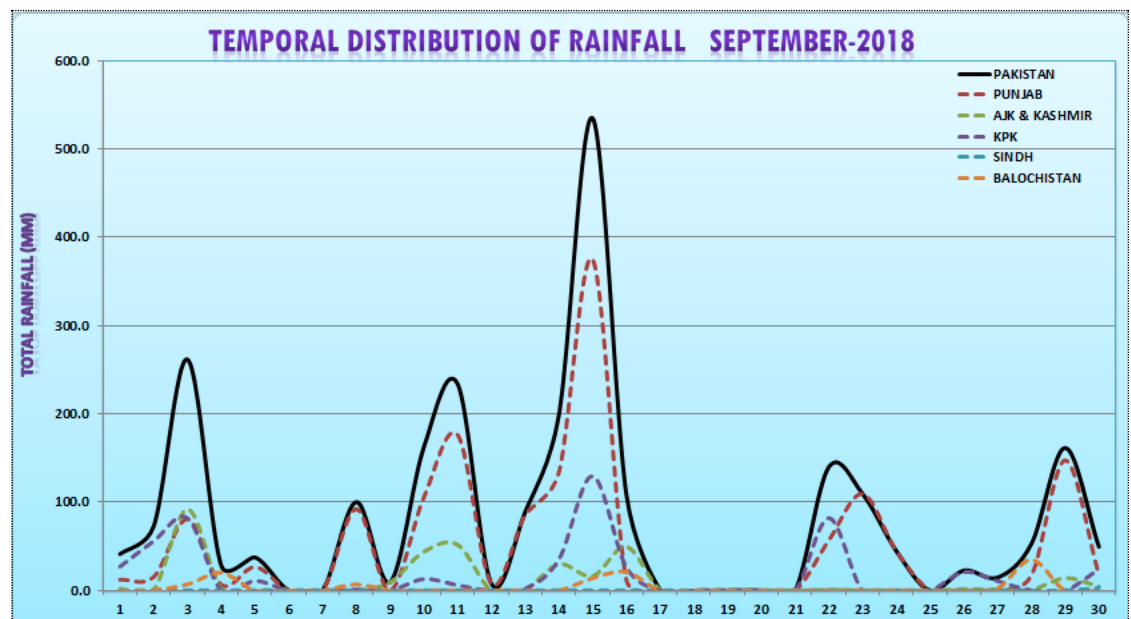


Figure 45: Temporal distribution of rainfall during September 2018 .

6.9 Rivers position during the month of September-2018

Flood peaks recorded during September, 2018 are shown in table 4

Table 4: Maximum peaks recorded during September 2018

Date	Rivers	Stations	Peaks Inflows (Cusecs)	Flood level
27/9/2018	Ravi	Balloki	68030	Medium
24/9/2018	Chenab	Marala	103752	Low
24/9/2018	Chenab	Khanki	105208	Low
24/9/2018	Chenab	Qadirabad	103400	Low

6.10 Hydrographs recorded during the month of September 2018 are as below

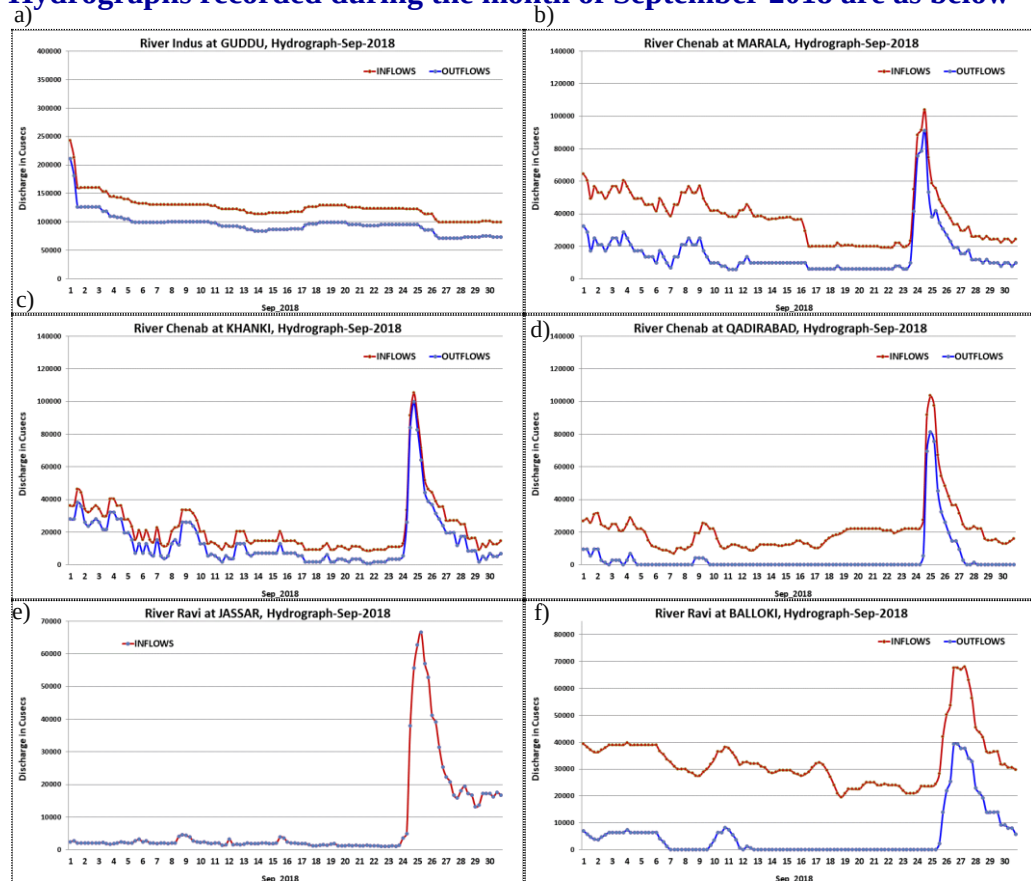


Figure 46: Hydrographs for the month of September-2018.

7 Seasonal rainfall pattern June to September 2018

Seasonal rainfall distribution during the season is shown in figure 47. Region of maximum precipitation (more than 1000 mm) is located over Islamabad in north Punjab. Another center of extreme rainfall of more than 700 mm is located over northeast Punjab. West Balochistan remained almost dry during the season.

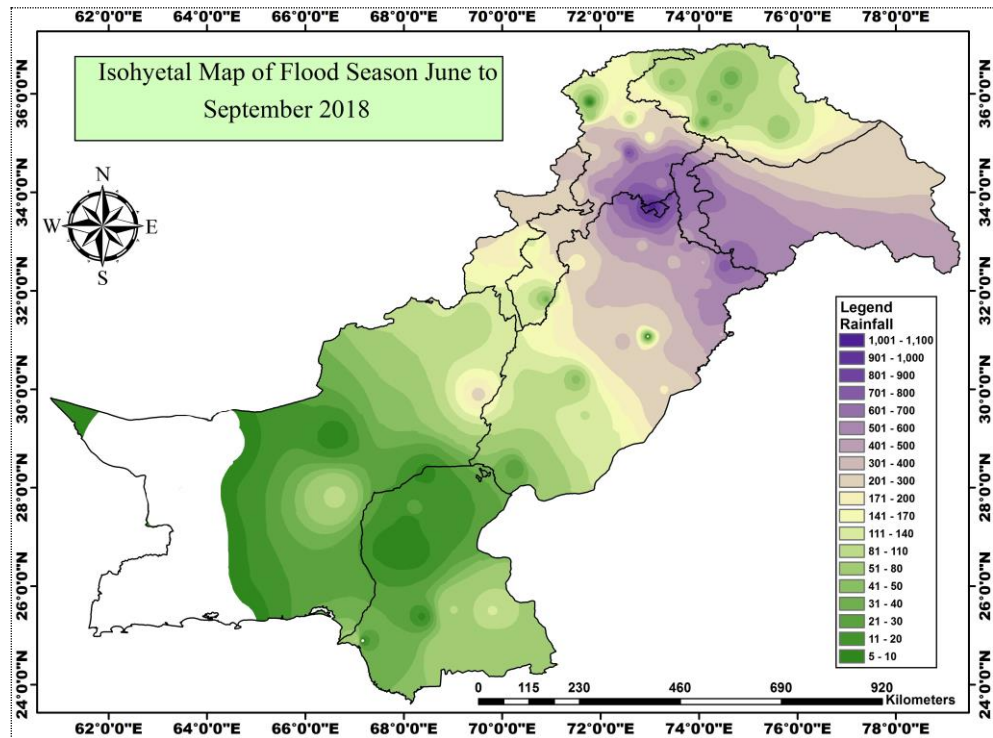


Figure 47: Spatial distribution of significant rainfall map of June-September 2018.

8 Seasonal area weighted precipitation from July-September 2018

The seasonal percentage departure precipitation map obtained from Climate Data Processing Centre (CDPC) of Pakistan Meteorological Department for monsoon season 2018 indicates that below normal (-31 %) rainfall was recorded during monsoon (JAS) 2018 season. On regional scale, the seasonal rainfall was largely deficient over southern Pakistan region (Sindh & Balochistan) and slightly below normal elsewhere during September, country rainfall was below normal (-35%) and below normal rainfall were all over provinces except Balochistan where it was above normal. In August, country rainfall was below normal (-51%) and below normal rainfall was recorded over all provinces.

In July, country rainfall was below normal (-12%) and was above normal over Punjab, KPK & GB, below normal over Sindh & Balochistan and close to normal over AJK as shown in figure 47. Isopercental map of rainfall is also prepared which is shown in figure 48.

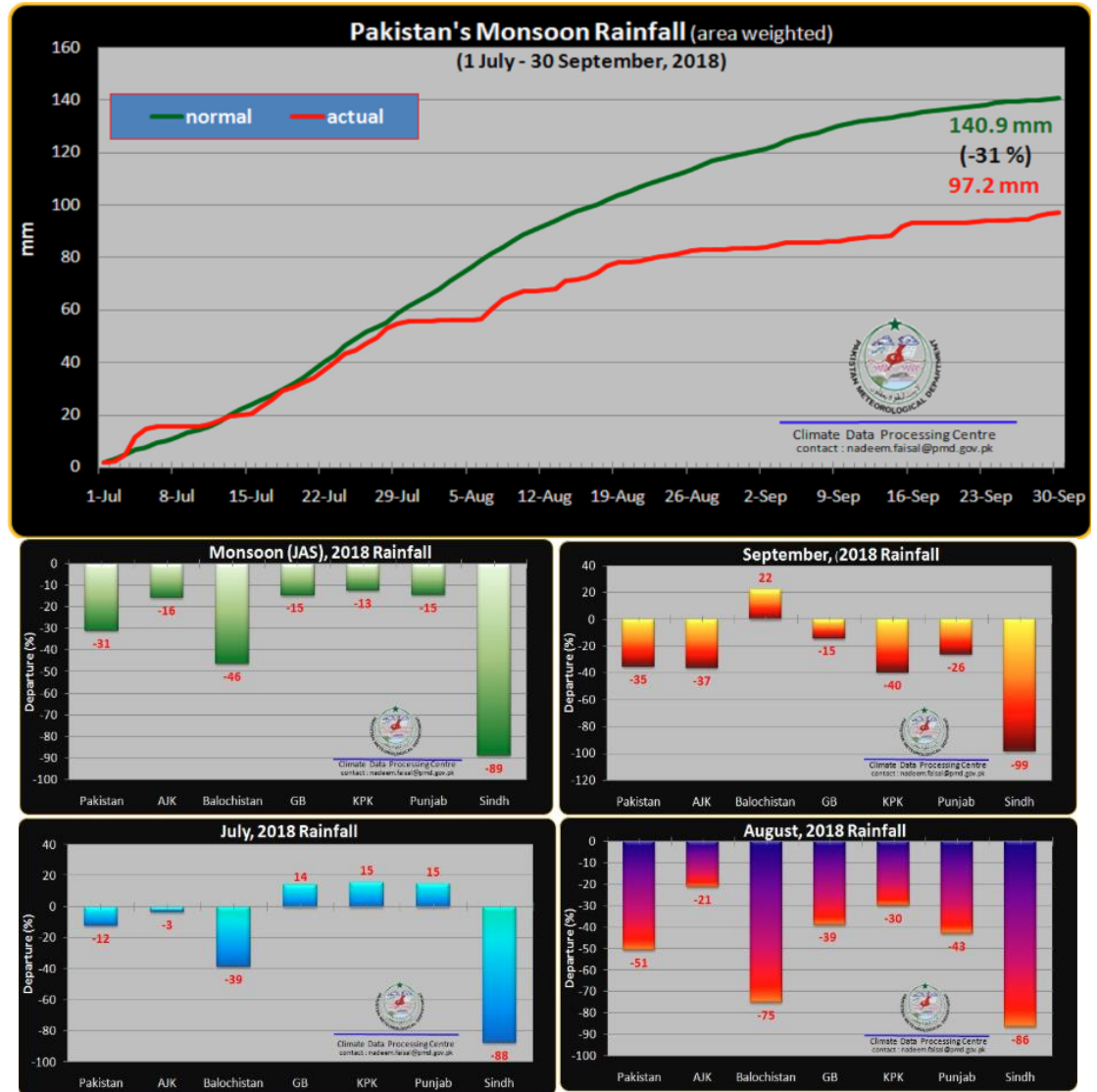


Figure 48: Monsoon July-Aug-Sept (JAS) 2018 rainfall.

Source: CDPC Karachi

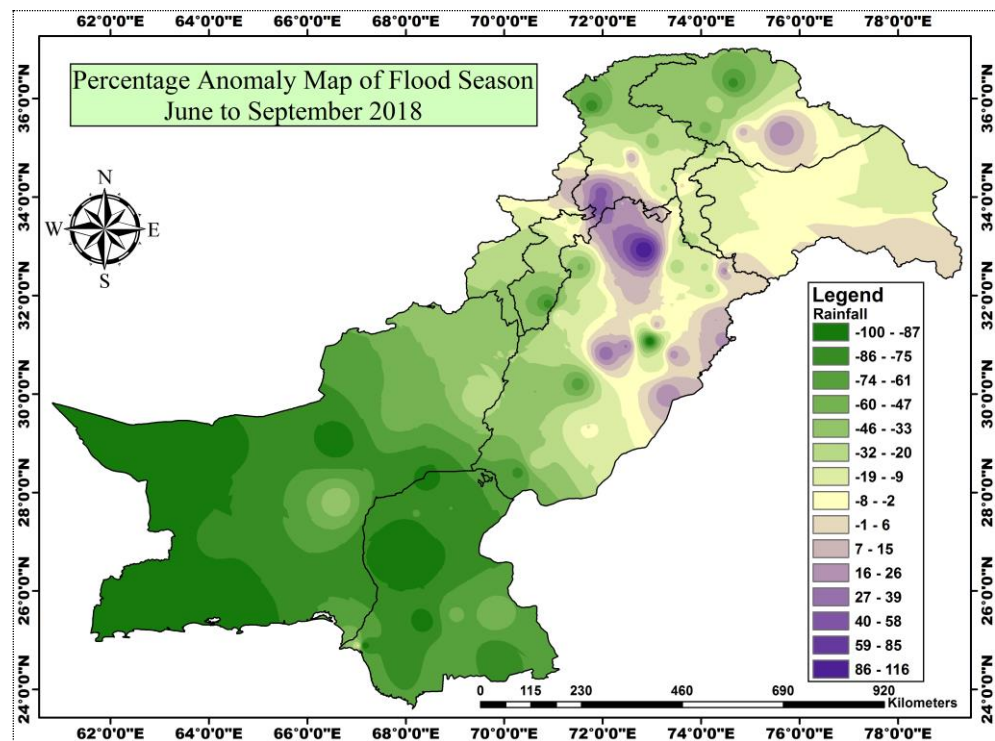


Figure 49: Seasonal percentage departure map (July-September 2018).

9 Kharif season forecast

Water availability (MAF) forecast for Kharif season was issued on 30th March, 2018 for Tarbela at River Indus & for Mangla at River Jhelum. Comparison of forecasted and observed volume (MAF) is shown in fig 50

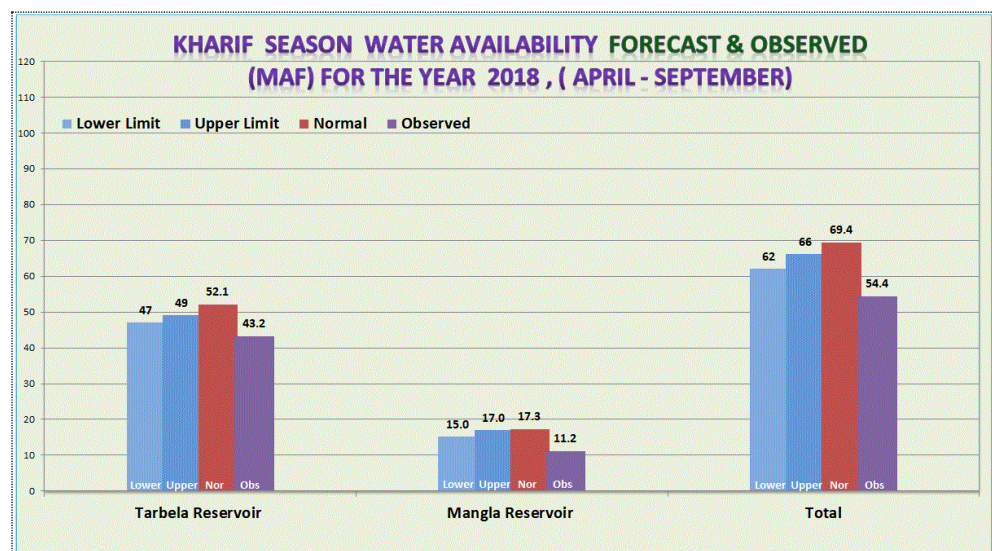


Figure 50: Kharif Season forecast & Observed MAF (April-September 2018).

10 Flood forecast evaluation report

The Flood Forecast evaluation report for 2018 for all categories of flood is given in table 5

Table 5: Flood forecast evaluation table

Station	Forecast	ObsInflows	Date	Time	Accu %
Kabul	70-80	75800	16/06/18	600	100
Marala	90-130	114254	30/06/18	1200	100
Khanki	110-155	142329	30/06/18	1200	100
Qadirabad	90 R 145	141756	30/06/18	1200	100
Tarbela	270-300	295000	24/07/18	1200	100
Kalabagh	260-270	274687	29/07/18	1800	98
Chashma	210-250	250489	30/07/18	600	99
Kabul	60-90	105300	24/07/18	600	84
Kabul	50-60	47700	31/07/18	1800	96
Balloki	40-50	53595	29/07/18	2359	92
Kabul	60-75	66000	09/08/18	1800	100
Tarbela	270-285	275000	14/8/18	1200	100
Chashma	210-270	253956	10/08/18	1800	100
Chashma	250-290	335912	15/08/18	1800	86
Chashma	210-250	271415	20/08/18	2359	92
Chashma	270-300	307333	26/08/18	1800	98
Mangla	50-150	86000	07/08/18	1200	100
Kalabagh	220-260	280529	08/08/18	1200	92
Kalabagh	240-300	319154	15/08/18	1200	94
Kalabagh	250-265	286898	26/08/18	600	92
Taunsa	280-300	297265	17/08/18	1200	100
Marala	100-180	179894	07/08/18	2359	100
Marala	170-300	201878	13/08/18	1200	100
Khanki	140 R 250	189820	13/8/18	2359	100
Khanki	100-180	113431	08/08/18	600	100
Qadirabad	100-170	123564	08/08/18	1200	100
Qadirabad	130-240	194031	14/08/18	600	100
Balloki	40-65	51805	10/08/18	600	100
Balloki	55-65	53140	16/08/18	2359	100
Balloki	45-55	50815	24/08/18	600	100
Guddu	250-270	256035	20/08/18	600	100
Guddu	200-240	243229	30/08/18	1800	98
Sukkur	205-220	211595	21/08/18	600	100
Marala	100-150	103752	24/09/18	1200	100
Balloki	55-75	68030	27/09/18	600	100

The overall accuracy of the forecast issued by FFD, Lahore during the flood season 2018 has been calculated which shows a good **96.0%** against all odds.

11 Flow chart of daily routine work at FFD Lahore

The website (<http://ffd.pmd.gov.pk/cp/floodpage.htm>) is maintained by FFD Lahore and is updated regularly. This is a source of real time information to all the stake holders, concerned authorities, organizations and individuals.

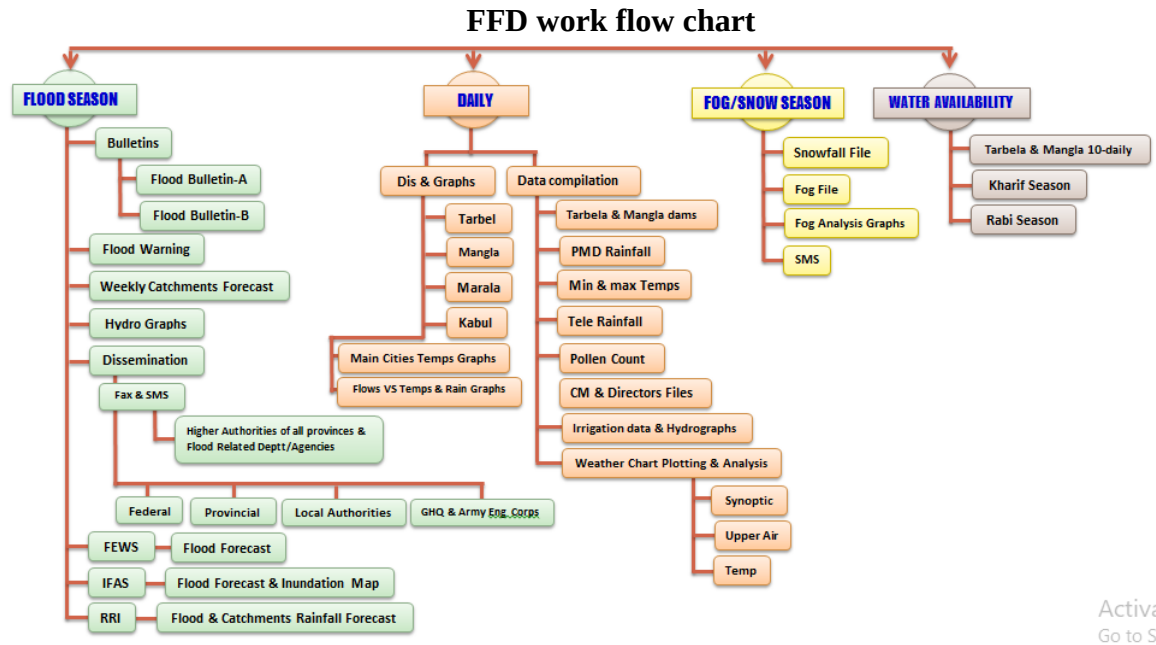


Figure 51: FFD Lahore work flow chart.

Sr#	Work	Time Interval
1	Flood Bulletins A & B	Updated daily
2	Weekly Catchment Forecast	Updated daily
3	Flood Warning	When required
4	Inundation Map	When required
5	FEWS Model Forecast	Twice a day & when required
6	IFAS Model Forecast	Updated daily & when required
7	RRI Model Forecast	Updated daily & when required
8	Hydrographs	Hourly & six hourly basis
9	Discharge file (Tarbela & Mangla Dams)	Updated daily
10	Discharges Graphs (Tarbela, Mangla, Marala & Kabul)	Updated daily
11	Flows VS Temps & Rain Graphs	Updated daily
12	PMD Rainfall data	Updated daily
13	Temperatures data	Updated daily
14	Main Cities Temperature Graphs	Updated daily
15	WAPDA Telemetric Rainfall	Updated daily
16	MAF Forecast (Tarbela & Mangla Dams)	10 day basis
17	Kharif MAF Forecast (Tarbela & Mangla Dams)	Six monthly basis
18	Rabi MAF Forecast (Tarbela & Mangla Dams)	Six monthly basis
19	Pollen Count for Lahore City	Updated daily
20	Fax	Daily & when required
21	SMS	Hourly & six hourly basis & when required

12 Flood Forecast Dissemination

Dissemination of flood forecast and warning is an important part of flood mitigation. Flood information is communicated on daily basis using different modes of communication i.e phone, fax and cellular networks. Electronic versions of daily flood forecast is also available to different agencies and organizations. This is also made a part of FFD web page. To ensure that flood forecast is disseminated to the right person at the right time, contact numbers are also collected and verified during pre flood season.



Figure 52: Flood report dissemination chart.

13 Internship at Flood Forecasting Division Lahore

FFD Lahore offers Internship program for the young students of different Universities & Colleges providing a hands-on opportunity to work in the field of Meteorology, Hydrology, Seismology, GIS and Weather Radar. They can learn how theory applies to the practical field and provide a valuable experience that makes them a strong candidate in practical life. The number of internee students during 2018 is shown in table 6.

Table 6: List of internees

University/College		Students
	Punjab University Lahore	46
	COMSATS Institute of Technology	02
	Lahore College for Women University, Lahore	45
	Kinnaird College for Women, Lahore	08
	Government College University Lahore	19
	Dr. AQ Khan Institute	04
	Govt College of Technology	03
	LIESMARS_Wuhan University_China	01

14 Facilities Provided By FFD Lahore during the Flood Season

- Flood Forecasting Division Lahore provides semi furnished accommodation facilities to the Police Tele Communication officers & officials in the office premises.
- Flood Forecasting Division Lahore has provided space & facilities to Environmental Protection Department (EPD), Punjab to install their instruments to monitor air quality of Lahore.
- Sports facilities were also provided to the flood relating agencies working in FFD during the flood season.
- Flood Forecasting Division Lahore also provided facilities to media for live coverage regarding Flood/Weather events.

15 Monsoon Season 2018 Damages/Losses

No of Deaths, Injured Persons and Houses Damaged during the Flood 2018 are shown in table 7.

Table 7: Flood forecast evaluation table

PRELIMINARY DAMAGES / LOSSES MONSOON – 2018

(FROM 20 JUNE TO 14 September 2018)

Province	Deaths				Injured				Houses Damaged		
	M	F	C	T	M	F	C	T	P	F	T
Punjab	24	2	5	31	47	12	13	72	7	1	8
Khyber Pakhtunkhwa	5	5	12	22	12	14	14	40	133	49	182
Balochistan	1	-	-	1	-	-	-	-	-	-	-
Azad Jammu & Kashmir	15	5	1	21	20	10	-	30	37	23	60
Gilgit Baltistan	2	2	-	4	1	-	-	1	43	57	100
Tribal Districts of KP	1	-	8	9	2	7	6	15	10	2	12
TOTAL	48	14	26	88	82	43	33	158	230	132	362

Source. PDMA's

M, F, C & T denotes Male, Female, Children & Total while P & F denote Partially & Fully

Source: FFC Islamabad

16 Flood limits (in Lacs of cusecs):**Table 8: Flood limits**

River	Site	Design Capacity	Low	Med	High	V.high	Ex.high
Kabul	Nowshera	-	0.45	0.80	1.4	2.0	4.0
	Warsak	15.0	0.30	0.45	1.0	2.0	4.0
Indus	Tarbela	15.0	2.5	3.75	5.0	6.5	8.0
	Attock	-	2.5	3.75	5.0	6.5	8.0
	Kalabagh	9.5	2.5	3.75	5.0	6.5	8.0
	Chashma	9.5	2.5	3.75	5.0	6.5	8.0
	Taunsa	10.0	2.5	3.75	5.0	6.5	8.0
	Guddu	12.0	2.0	3.5	5.0	7.0	9.0
	Sukkur	9.0	2.0	3.5	5.0	7.0	9.0
	Kotri	8.5	2.0	3.0	4.5	6.5	8.0
Jhelum	Kohala	-	1.0	1.5	2.0	3.0	4.0
	Mangla	10.6	0.75	1.1	1.5	2.25	3.0
	Rasul	8.5	0.75	1.1	1.5	2.25	3.0
Chenab	Marala	11.0	1.0	1.5	2.0	4.0	6.0
	Khanki	8.0	1.0	1.5	2.0	4.0	6.0
	Qadirabad	8.07	1.0	1.5	2.0	4.0	6.0
	Trimmu	6.45	1.5	2.0	3.0	4.5	6.0
	Panjnad	7.0	1.5	2.0	3.0	4.5	6.0
Ravi	Jassar	2.75	0.5	0.75	1.0	1.5	2.0
	Ravi syphon	4.5	0.4	0.65	0.9	1.35	1.8
	Shahdra	2.5	0.4	0.65	0.9	1.35	1.8
	Balloki	2.25	0.4	0.65	0.9	1.35	1.8
	Sidhnai	1.5	0.3	0.46	0.6	0.9	1.3
Sutlej	Sulemanki	3.25	0.5	0.8	1.2	1.75	2.25
	Islam	3.0	0.5	0.8	1.2	1.75	2.25

17 Time Lag

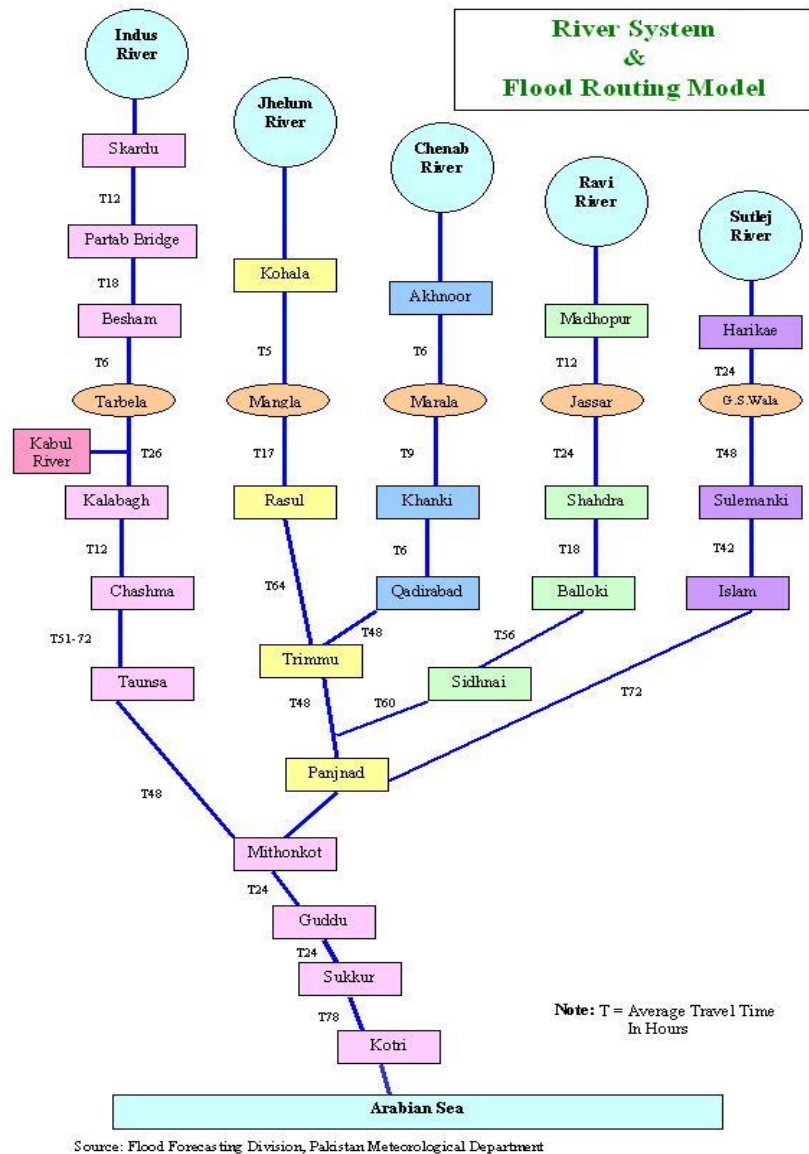


Figure 53: Time Lag

18 Maximum Flood Peaks Discharge during Flood Season-2018.

Maximum Flood Peaks recorded during Flood Season-2018 is shown below

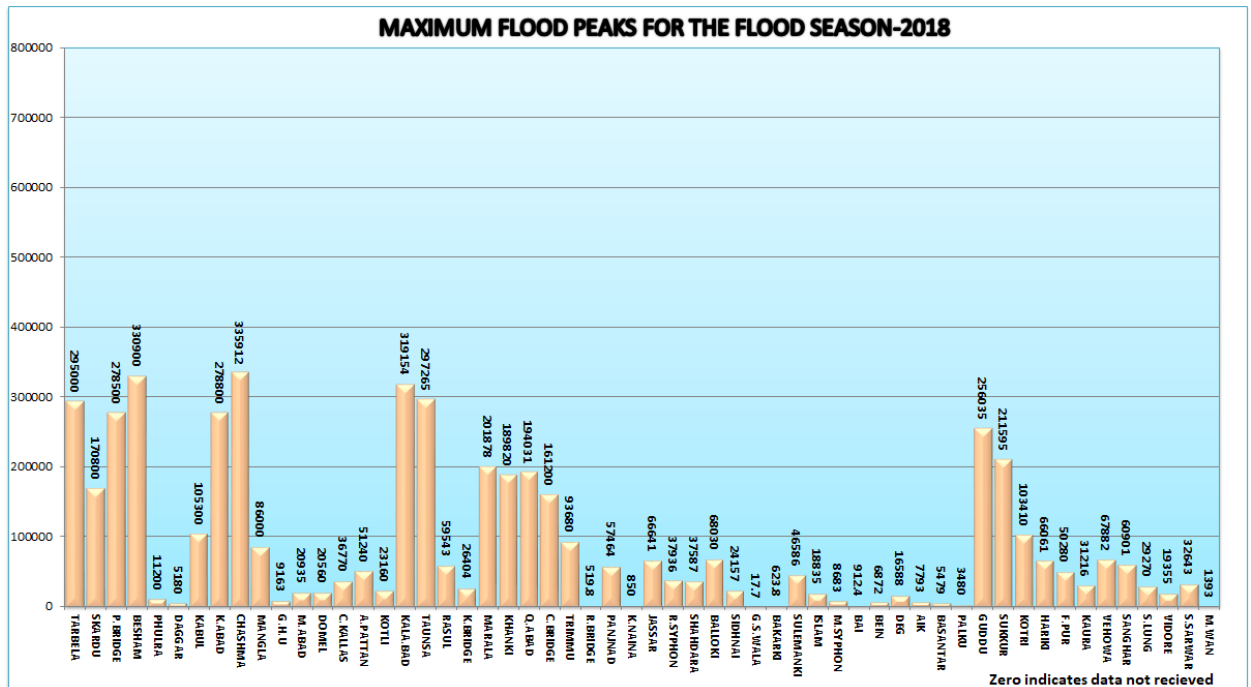


Figure 54: Maximum flood peaks recorded during the season 2018