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LIST OF ACRONYMS

- AJK Azad Jammu & Kashmir
- CDPC Climate Data Processing Centre
- DCOs District Coordination Officers
- 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 Authorities
- PCIW Pakistan Commissioner for Indus Waters
- PDMA_s Provincial Disaster Management Authority
- PMD Pakistan Meteorological Department
- SDMA State Disaster Management Authority
- WAPDA Water and Power Development Authority
- XEN Executive Engineer

Preface

Issuance of flood report after each flood season is a regular feature of Pakistan Meteorological Department (PMD), Flood Forecasting Division Lahore (FFD), These reports give us a comprehensive overview of all the events happening during the flood season.

Flood report for the year 2016 has been prepared under the kind guidance and instructions of Director General, Pakistan Meteorological Department. It contains all the details pertaining to flood forecasting like monsoon lows tracks, rainfall during wet spells, flood peaks, monthly and seasonal isohyetal maps, normal isopercental maps, flood limits and flood evaluation report. FFD Lahore besides its conventional practice of forecasting is also using flood forecasting models. Recently, beside other models a new flood routing and inundation model IFAS has been run on experimental basis. The foreign trained FFD experts are on the job to customize the model on local condition. The inundation results produced so far by the model are encouraging and helpful in briefing the flood mitigating agencies to minimize the flood losses in the country.

**Chief Meteorologist
Flood Forecasting Division
Lahore**

1 Executive summary

- Monsoon during 2016 was active over North Punjab and upper Khyber Pakhtunkhwa. Seasonal percentage departure map for precipitation during the present monsoon season indicates 25% above normal precipitation for whole of Pakistan. Khyber Pakhtunkhwa, Punjab, Gilgit-Baltistan and Sindh received 37%, 55%, 22%, 2% above normal rainfall respectively while Kashmir and Balochistan received 19% and 17% below normal rainfall respectively.
- Four monsoon lows originated during the present monsoon season, none of them affected Pakistan.
- Nine rain bearing spells occurred during the monsoon season 2016.
- No High Flood situation was observed in River Indus, one instance of Very High Flood flow was recorded in river Chenab. Sharp peaks of High to Very High floods were registered over 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 about the prevailing weather/flood conditions through phone, fax & other electronic sources.
- The website (<http://ffd.pmd.gov.pk/cp/floodpage.htm>) maintained by FFD Lahore was updated regularly. This was a source of real time information to all the concerned authorities, organizations and individuals.
- Five significant flood forecasts /warnings were issued by FFD during monsoon season 2016.
- Overall accuracy of forecast issued by FFD during the Season 2016 has been calculated as 95.8%.

2 Tracks of Monsoon Lows during monsoon season 2016

During the monsoon season 2016 (15th June to 15th October) four monsoon lows/depressions were developed over Bay of Bengal. **1st** Monsoon Low was developed in North Bay of Bengal on 3rd July, 2016. Moving west-northwest wards it was relocated over northeast Madhya Pradesh on 7th July, 2016. Here it dissipated. **2nd** Monsoon Low was developed on 5th August, 2016 over Northwest Bay of Bengal. It moved northwest ward and reached Northwest Madhya Pradesh on 8th August, 2016. From here it moved North-Northwest wards and dissipated on 9th August, 2016. **3rd** Monsoon Low was developed over west Bengal on 11th August, 2016. After moving west wards, it reached northeast Madhya Pradesh on 13th August, 2016. From here it moved quickly North wards and dissipated on 14th August, 2016 over Uttar Pradesh. **4th** and final Monsoon low was developed over northwest Bay of Bengal on 17th August, 2016 .It first moved west Northwest wards and then westwards and dissipated over Rajasthan (India) on 21st August,2016.The paths followed by each low/depression is shown in figure 1.

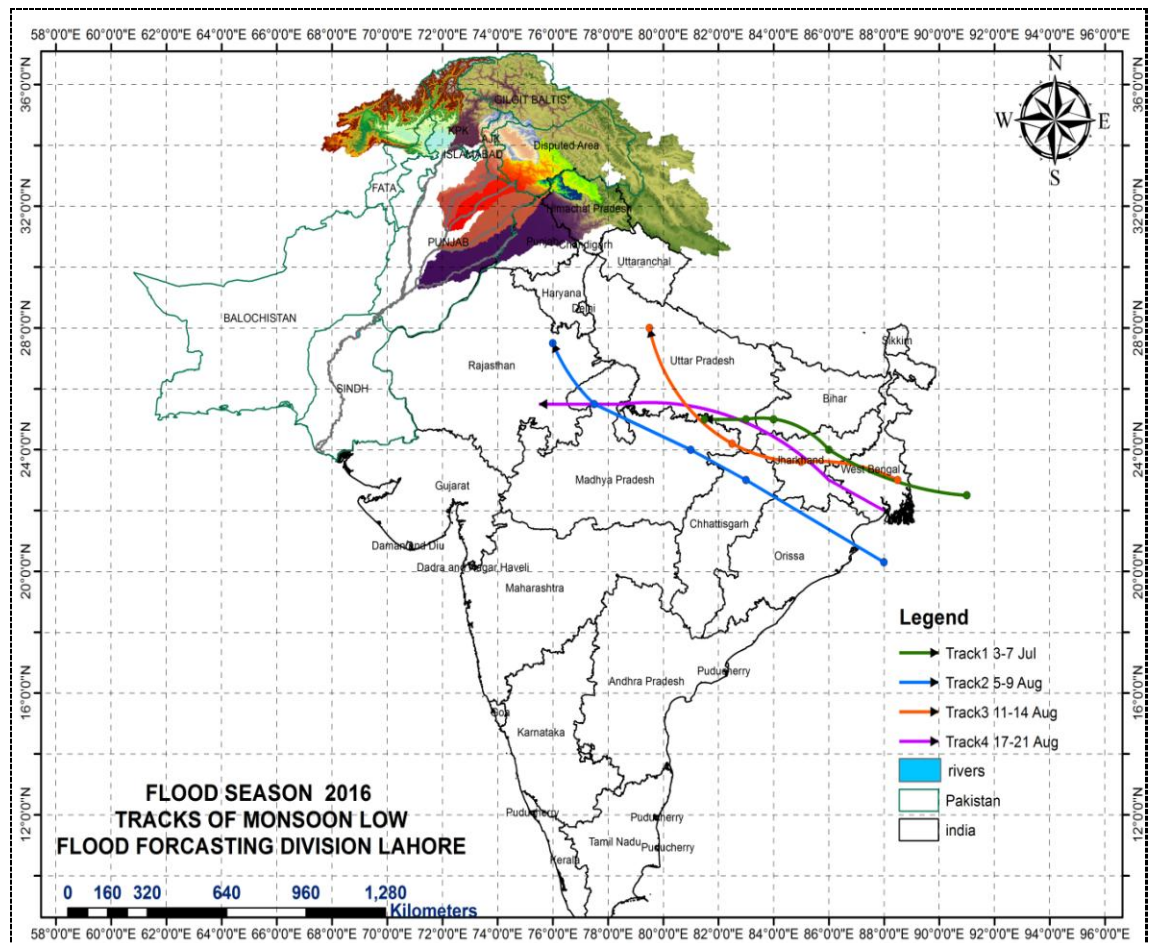


Figure 1: Monsoon tracks 2016.

3 Significant hydro-meteorological events during the month of June 2016

Two significant rainfall spells were reported during the month of June 2016.

3.1 Meteorological events

No monsoonal low was developed over Bay of Bengal during the month of June 2016. The rainfall mostly occurred across the country during the month was due to the accentuation of seasonal low over Balochistan and westerly wave in the North of the country.

Wet spells in each of the months are explained by using the weather charts in the subsequent sections. In each of these charts shaded portion represents 500 hPa patterns, 850 hPa values are shown by blue contour lines while wind vectors represent 925 hPa winds. NCEP-NCAR reanalysis dataset is used to draw these charts.

3.2 Wet spell of June 2016 (21st to 23rd June 2016)

The first wet spell of June 2016 which remained active for three days was mainly due to the presence of the westerly trough accompanied by moist current from Arabian Sea. Figure 2 represents 500 hPa and 850 hPa geopotential height patterns along with 925 hPa wind flow during this spell. It indicates that most parts of Pakistan are under the influence of the westerly wave, southwesterly winds at 925 hPa are also present ensuring enough moisture supply from the Arabian Sea. Figure 3 shows spatial pattern of significant rainfall during this spell which shows that maximum rainfall more than 80 mm occurred over Gujranwala division. Figure 4 represents the temporal distribution of rainfall during the month of June.

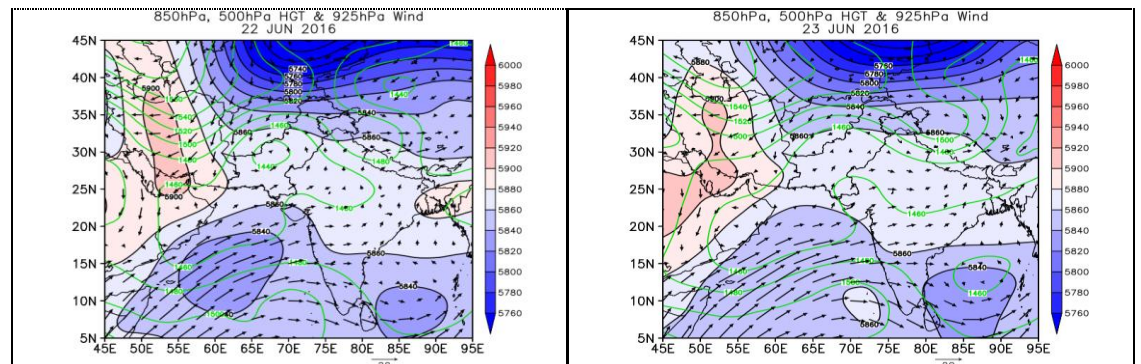


Figure 2: 500 & 850 HPA Geopotential Height patterns and 925 HPA winds from 21st to 23rd June 2016.

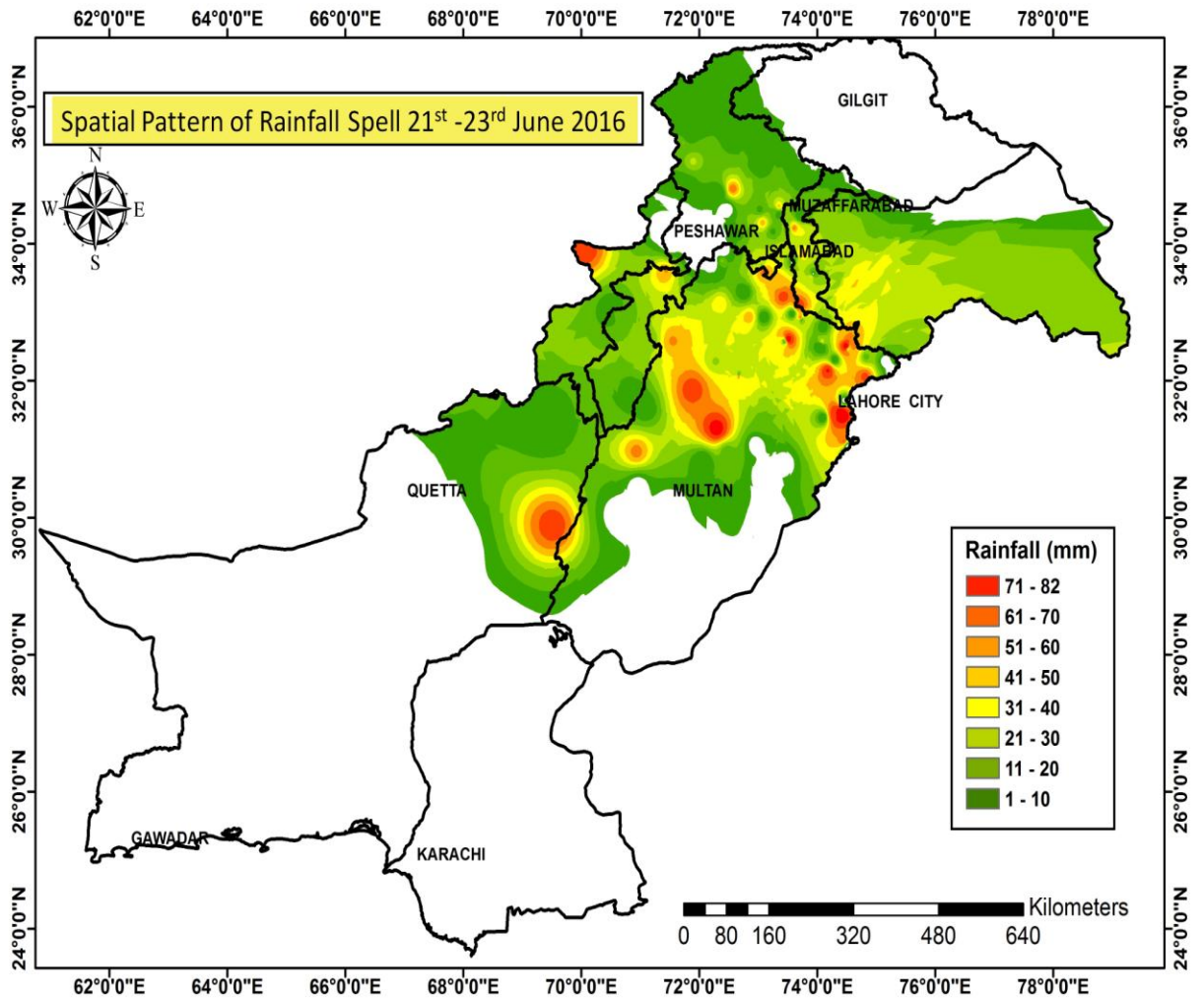


Figure 3: Significant rainfall 21st -23rd June-2016.

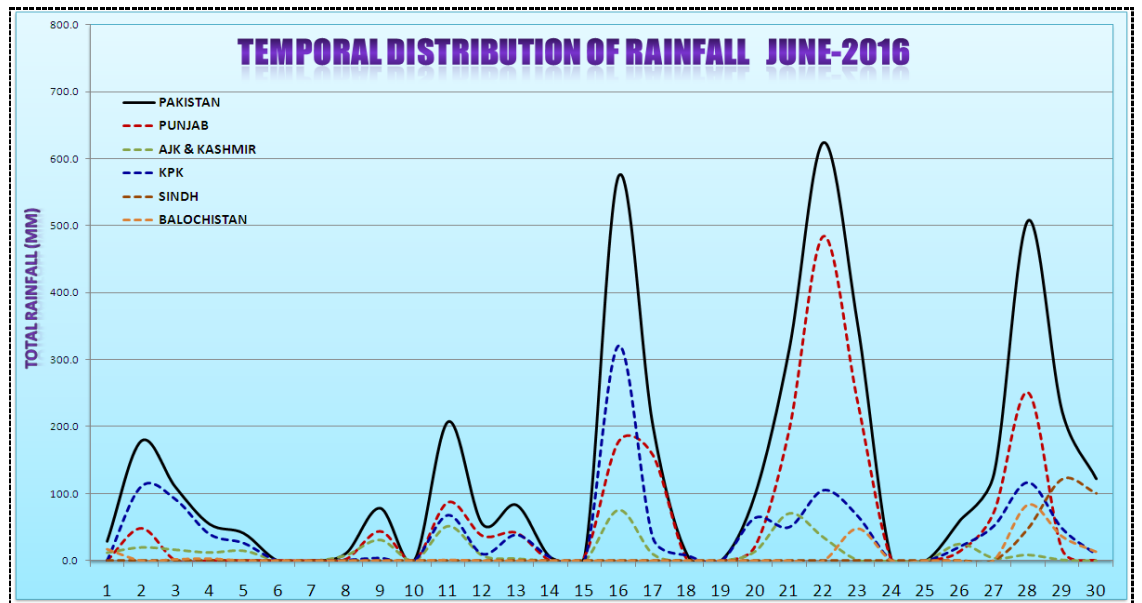


Figure 4: Temporal distribution of rainfall June 2016.

Radar image shows moderate rainfall intensity in the upper catchments of Rivers Chenab & Ravi and satellite images showing dense clouds over central Punjab & lower Khyber Pakhtunkhwa along with Kashmir.

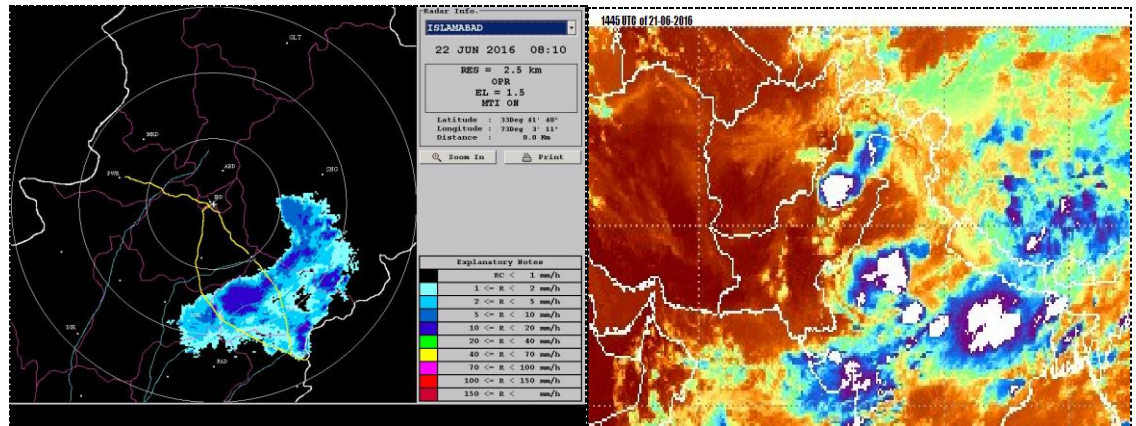


Figure 5: Radar & Satellites Images during the spell 21st -23rd June-2016.

3.3 Wet spell of June 2016 (28th to 30th June 2016)

The second wet spell of June 2016 which remained active for three days was mainly due to the presence of the westerly trough accompanied by moist current from Arabian Sea and Bay of Bengal. Figure 6 represents 500 hPa and 850 hPa Geopotential height patterns along with 925 hPa wind flow during this spell. It indicates that most parts of Pakistan are under the influence of the westerly wave, southwesterly winds at 925 hPa are also present ensuring enough moisture supply from the Arabian Sea.

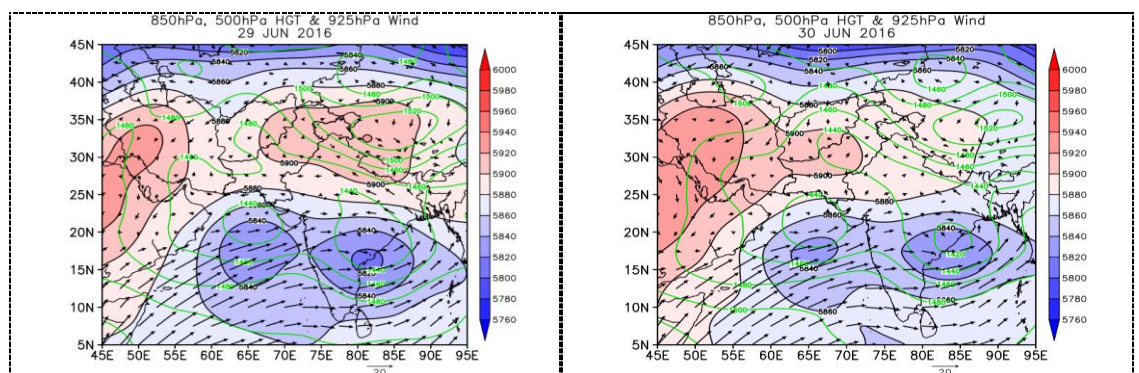


Figure 6: 500 & 850 hPa Geopotential Height patterns and 925 hPa winds from 28th to 30th June 2016.

Figure 7 Spatial pattern of significant rainfall during this spell shows that maximum rainfall of more than 70 mm occurred over Northeast Balochistan.

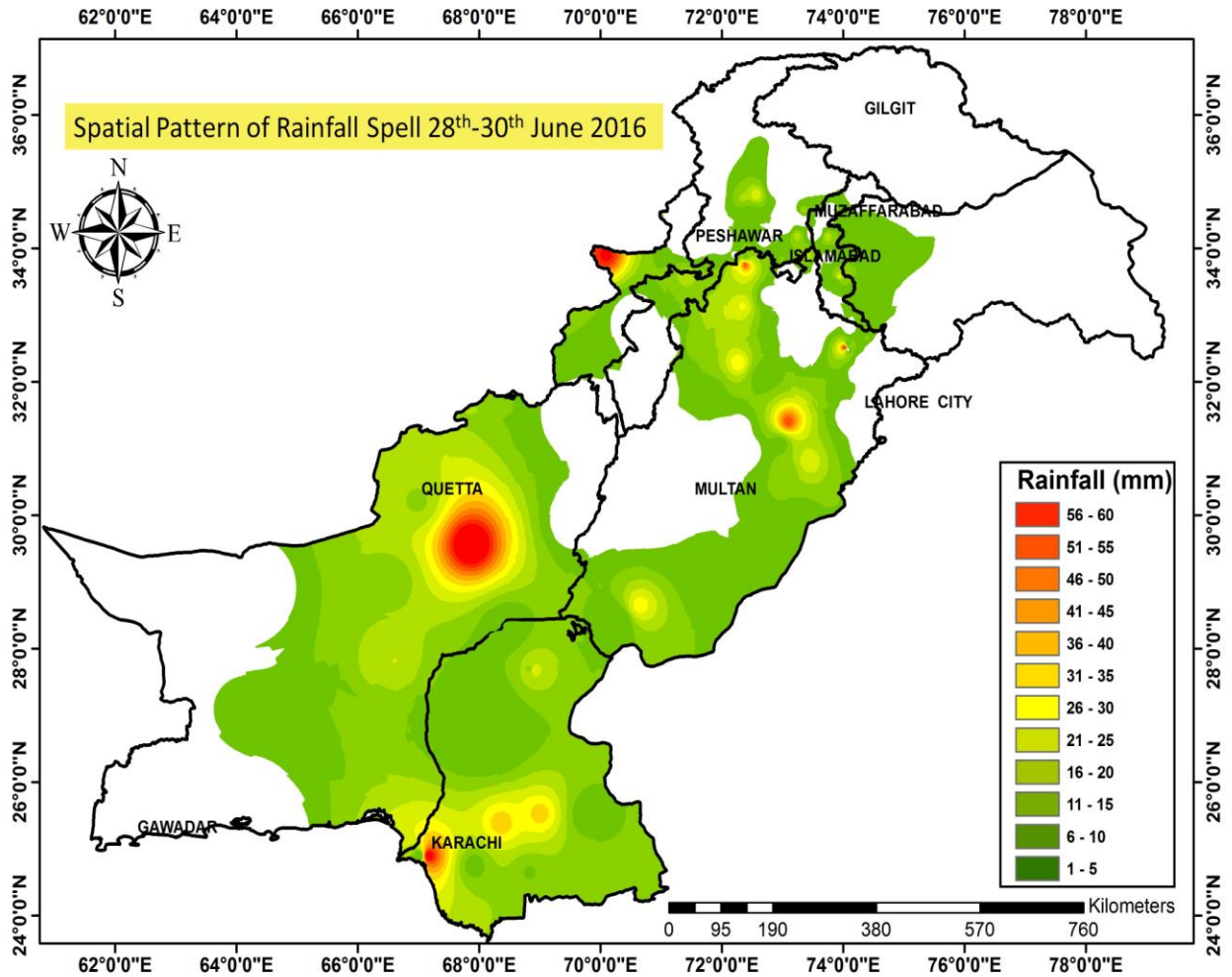


Figure 7: Significant rainfall 28th -30th June-2016.

Satellite images showing moderate clouds over North Sindh & adjoining South Punjab:

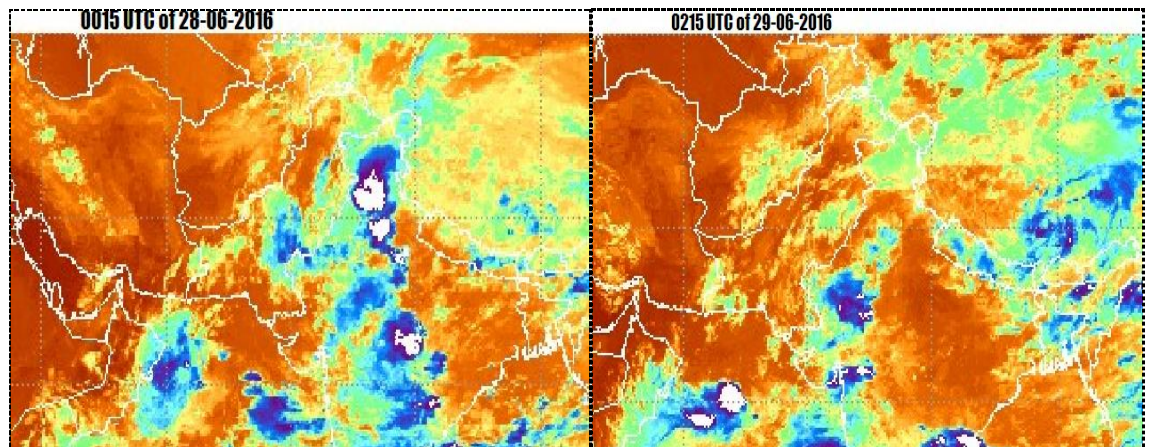


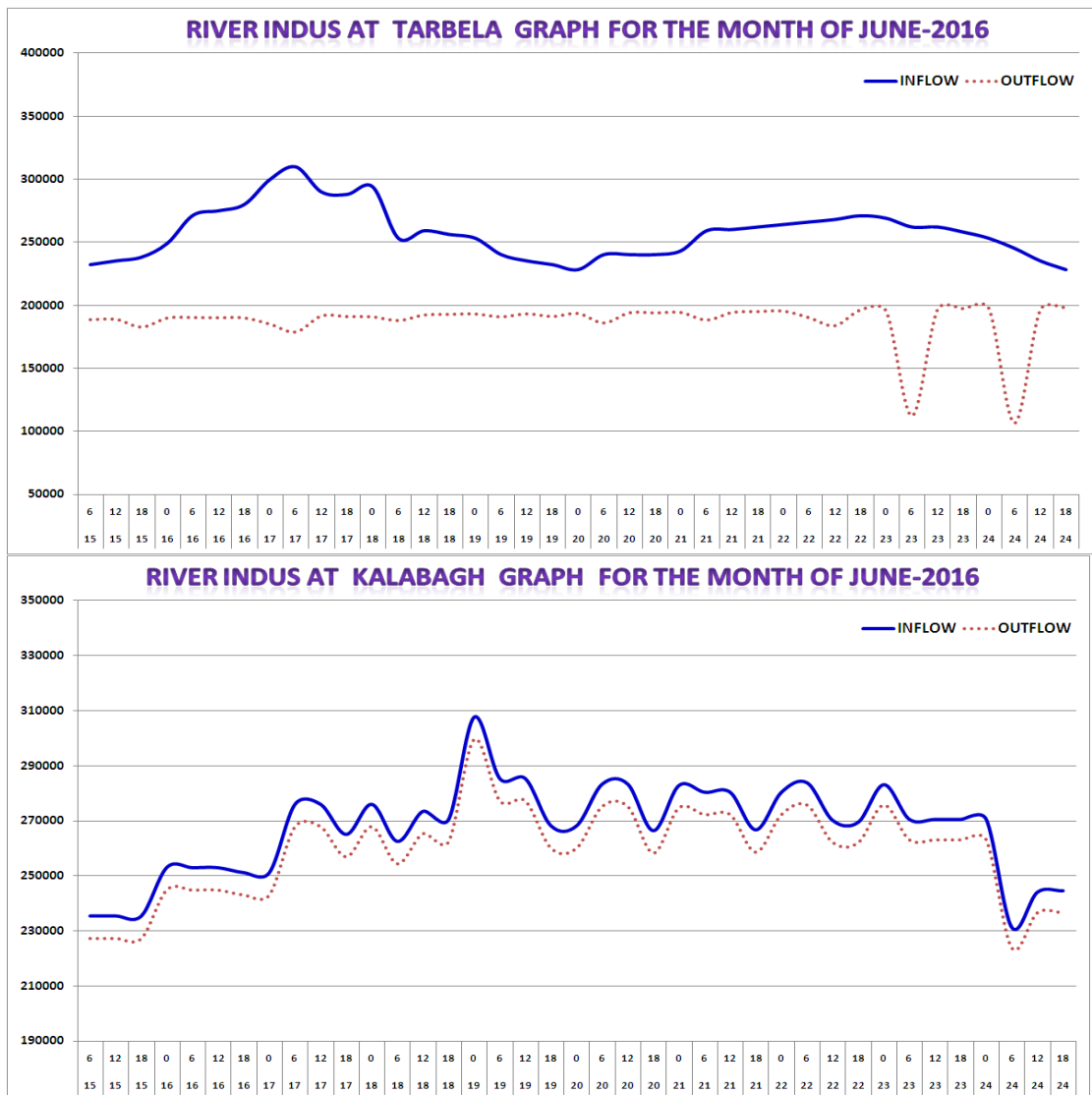
Figure 8: Satellites Images during the spell of 28th -30th June-2016.

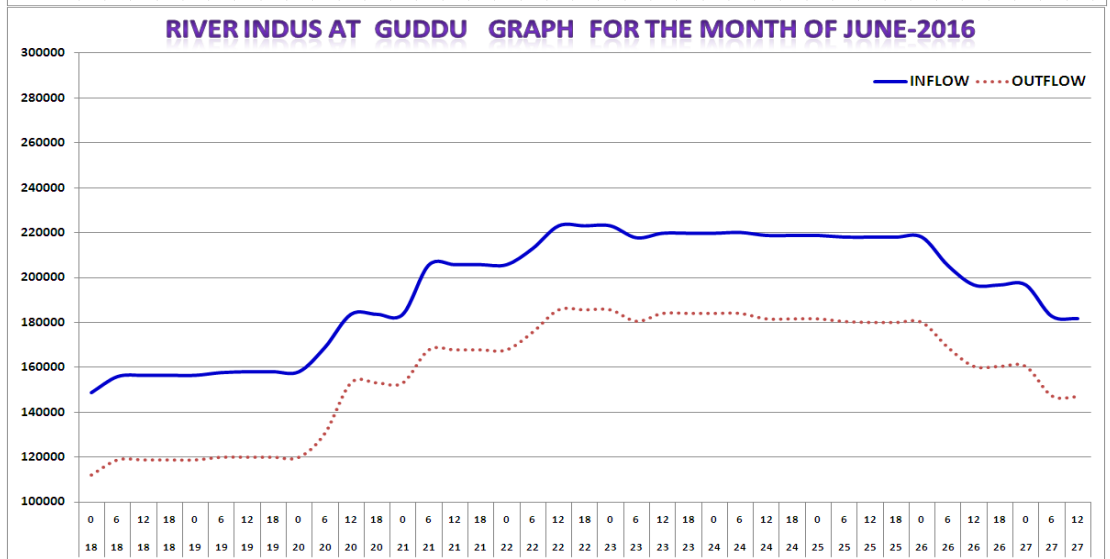
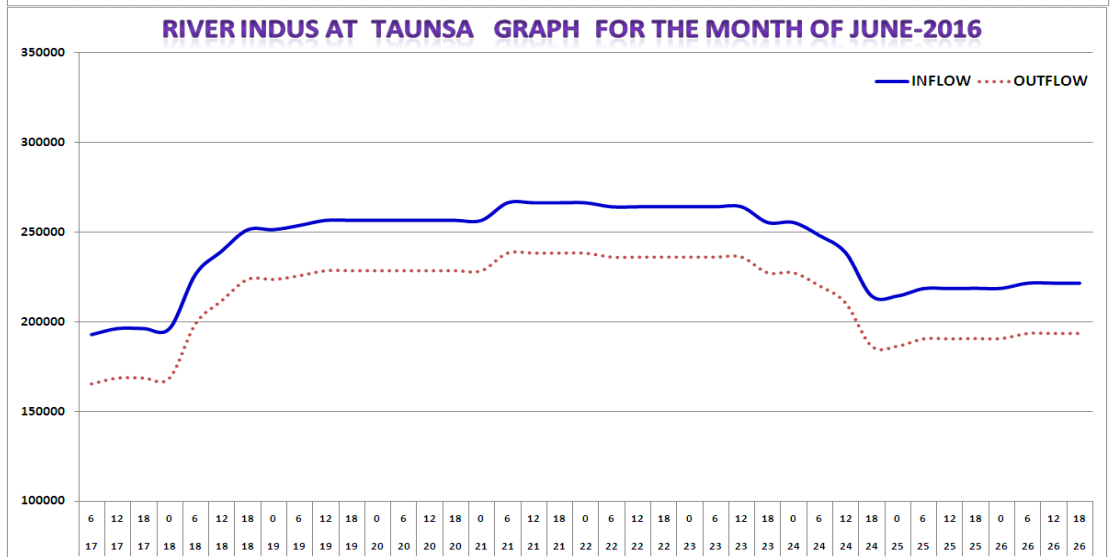
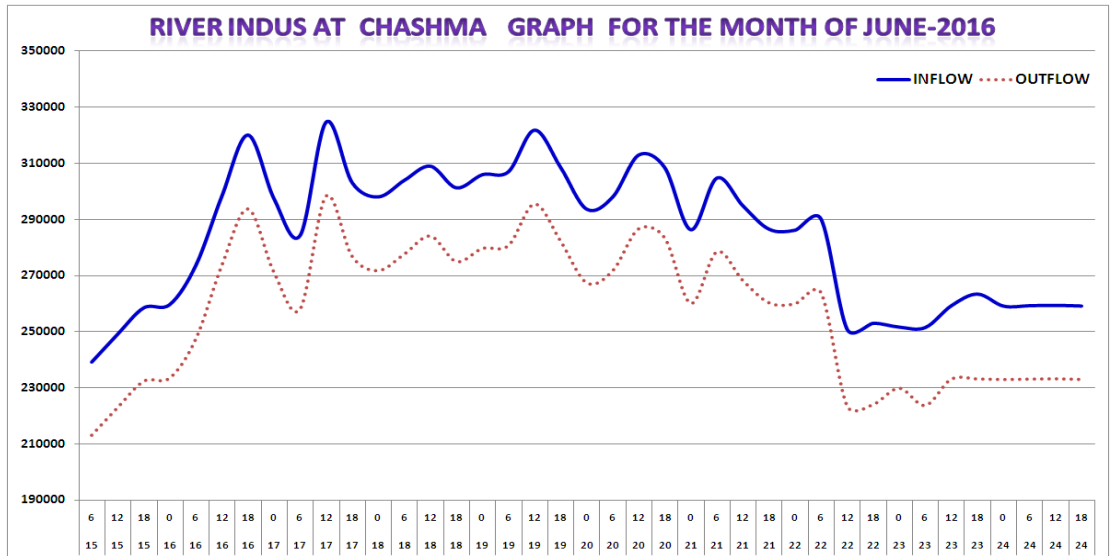
3.4 Position of rivers during June 2016

Flood peaks (Cusecs) recorded during June, 2016 are shown below.

Date	Rivers	Stations	Peaks Inflows	Flood level
17/6/2016	Indus	Tarbela	310000	Low
18/6/2016	Indus	Kalabagh	307557	Low
17/6/2016	Indus	Chashma	324580	Low
21/6/2016	Indus	Taunsa	266333	Low
22/6/2016	Indus	Guddu	222997	Low
17/6/2016	Kabul	Nowshera	91700	Medium

3.5 Hydrographs during June, 2016





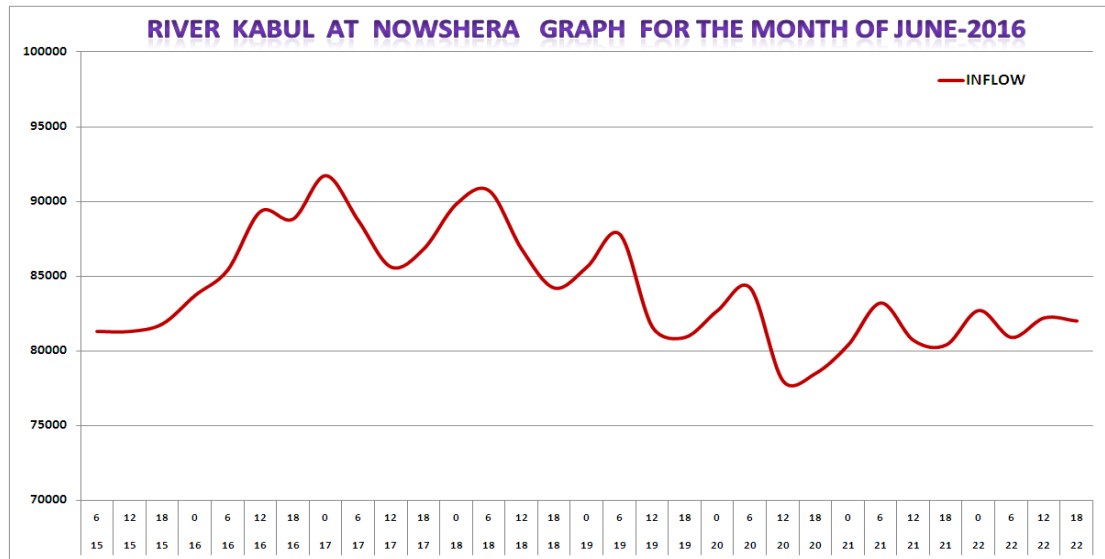


Figure 9: Hydrographs for the month of June-2016.

Figure 10 represents the temporal distribution of rainfall during the month of June

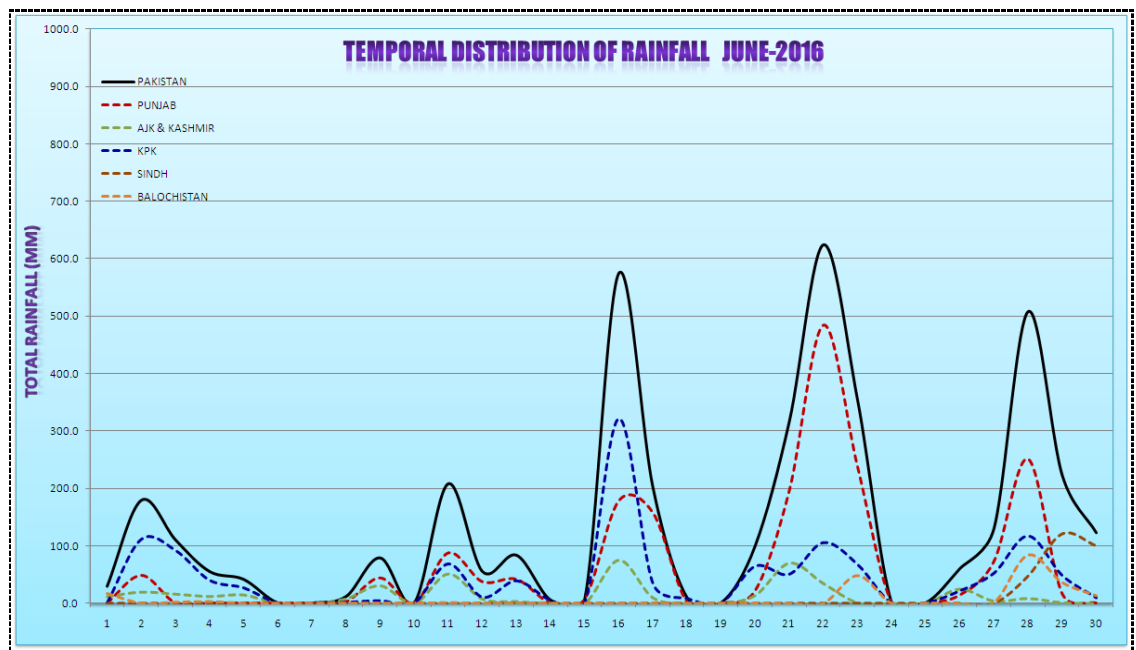


Figure 10: Temporal distribution of rainfall June 2016.

4 Significant hydro-meteorological events during the month of July 2016

Three significant rainfall spells occurred during the month of July 2016.

4.1 Meteorological events

First spell occurred from 2nd to 4th July 2016 was the result of the penetration of moist current from Arabian Sea and Bay of Bengal into sub mountainous areas of Punjab & Kashmir under the effect of westerly wave passing over the Northern parts of the country and accentuation of seasonal low into a well marked low. The second spell of

July observed during 13th to 18th July, 2016 was caused due to the interaction of westerly wave passing over the Northern parts of the country and the moist influx from Arabian Sea. Third & final spell of the Month of July was observed from 26th to 28th July, 2016. It was also caused due to interaction of westerly wave and strong moist current from Arabian Sea and Bay of Bengal.

4.2 First wet Spell of July 2016 (2nd to 4th July 2016)

The first spell of July 2016 which was 3rd of the flood season 2016 lasted for 3 days. It was mainly due to the passage of westerly wave, accentuation of seasonal low and incursion of moist current from Arabian Sea. Figure 11.1 represents an accentuated seasonal low on 2nd July present over northern parts of Balochistan and adjoining areas. Figures 11.2 and 11.3 show the influence of a westerly trough over Pakistan on 2nd and 4th of July. An overall southwesterly trend of 925 hPa winds during the three days can also be witnessed in these charts. This all resulted to produce significant rainfall in lower Khyber Pakhtunkhwa and Northeast Balochistan.

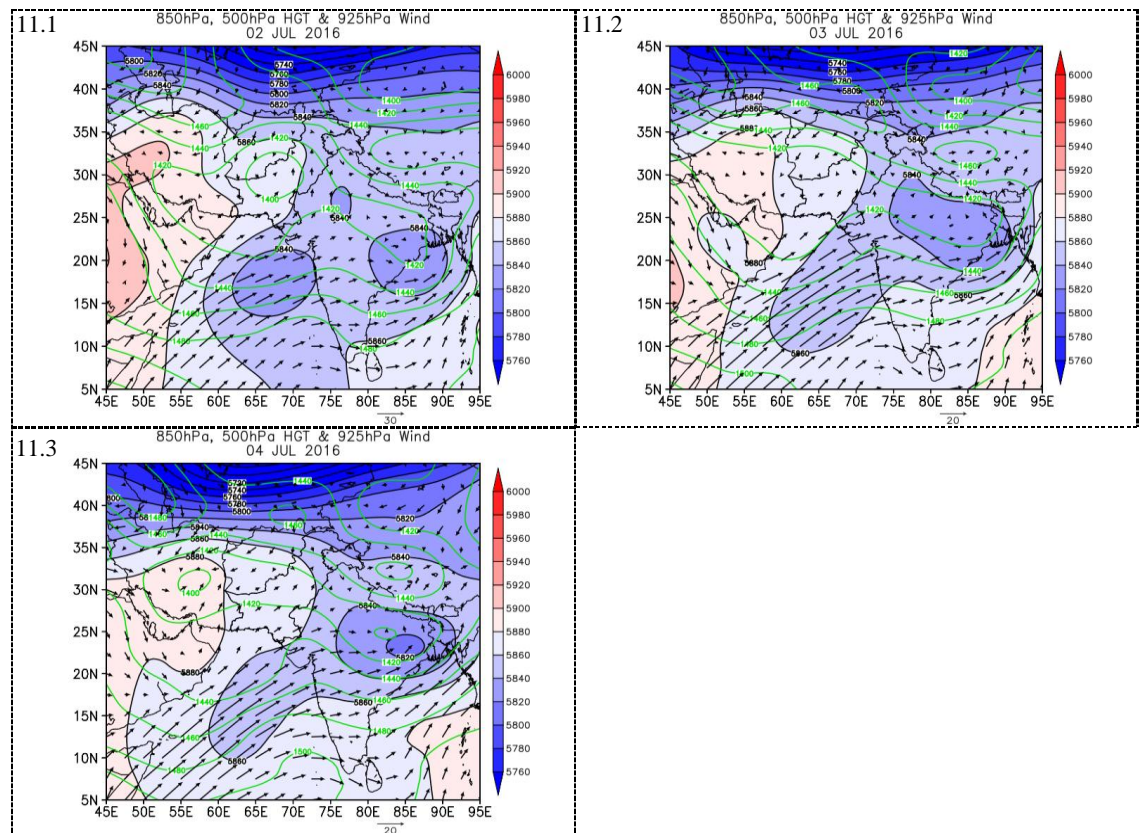


Figure 11: 500 & 850 hPa geopotential height patterns and 925 hPa winds from 06th to 8th July 2016.

Spatial distribution of significant rainfall during the spell is shown in figure 12 which shows that maximum rainfall of more than 100 mm was observed in Northeast Punjab at Sialkot.

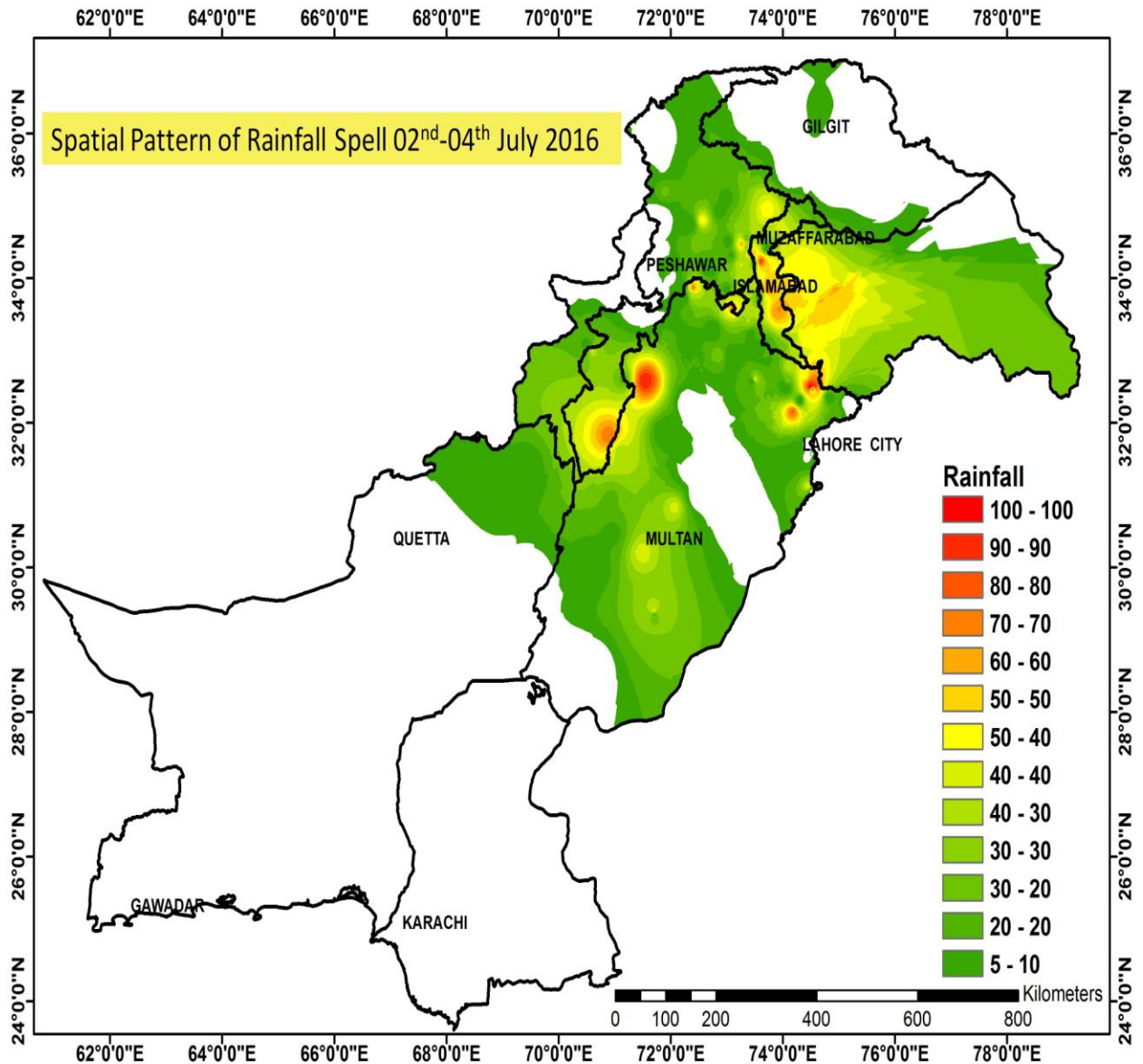


Figure 12: Significant rainfall 02nd -04th July 2016.

Radar image shows moderate rainfall intensity in the upper catchments of Rivers Jhelum , Chenab & Ravi and satellite images showing dense clouds over Punjab, Khyber Pathunkha & Kashmir.

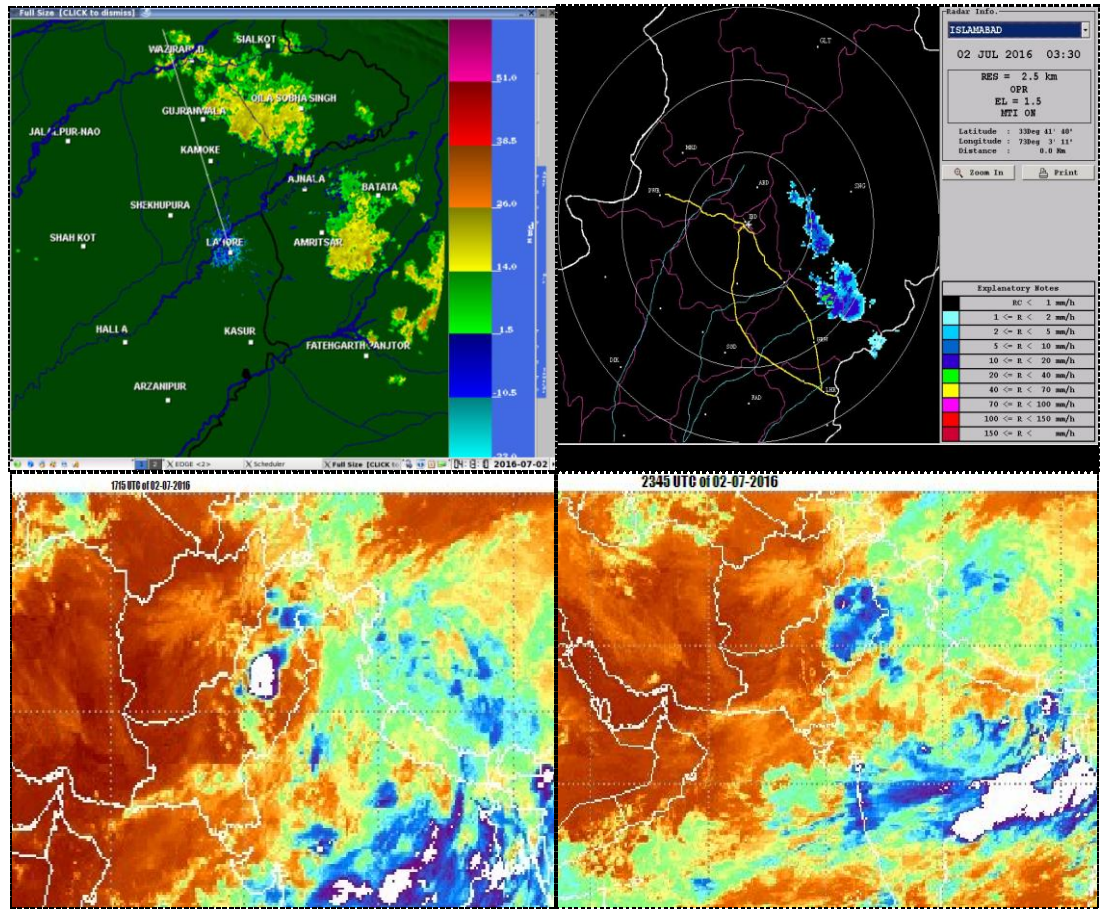


Figure 13: Radar & Satellites Images during the spell of 02nd -04th July 2016.

4.3 Position of rivers due to first wet spell of July

River Kabul at Nowshera remained in state of medium flood during the period while river Indus at Tarbela, Kalabagh, Chashma, Taunsa & Guddu attained Low flood level due to this rainfall spell.

4.4 Second wet spell of July 2016 (13th to 18th July 2016)

This long spell lasted for six days. Moderate to heavy rainfall was recorded at scattered places over Kashmir, Khyber Pakhtunkhwa & Punjab. Figures 14 represent the geopotential heights at 500 hPa, 850 hPa and winds at 925 hPa during this wet spell. It shows strong southwesterly currents at 925 hPa entering most parts of Pakistan. Westerly trough is also seen influencing most parts of the country. This produced rainfall in most parts of Punjab and Kashmir

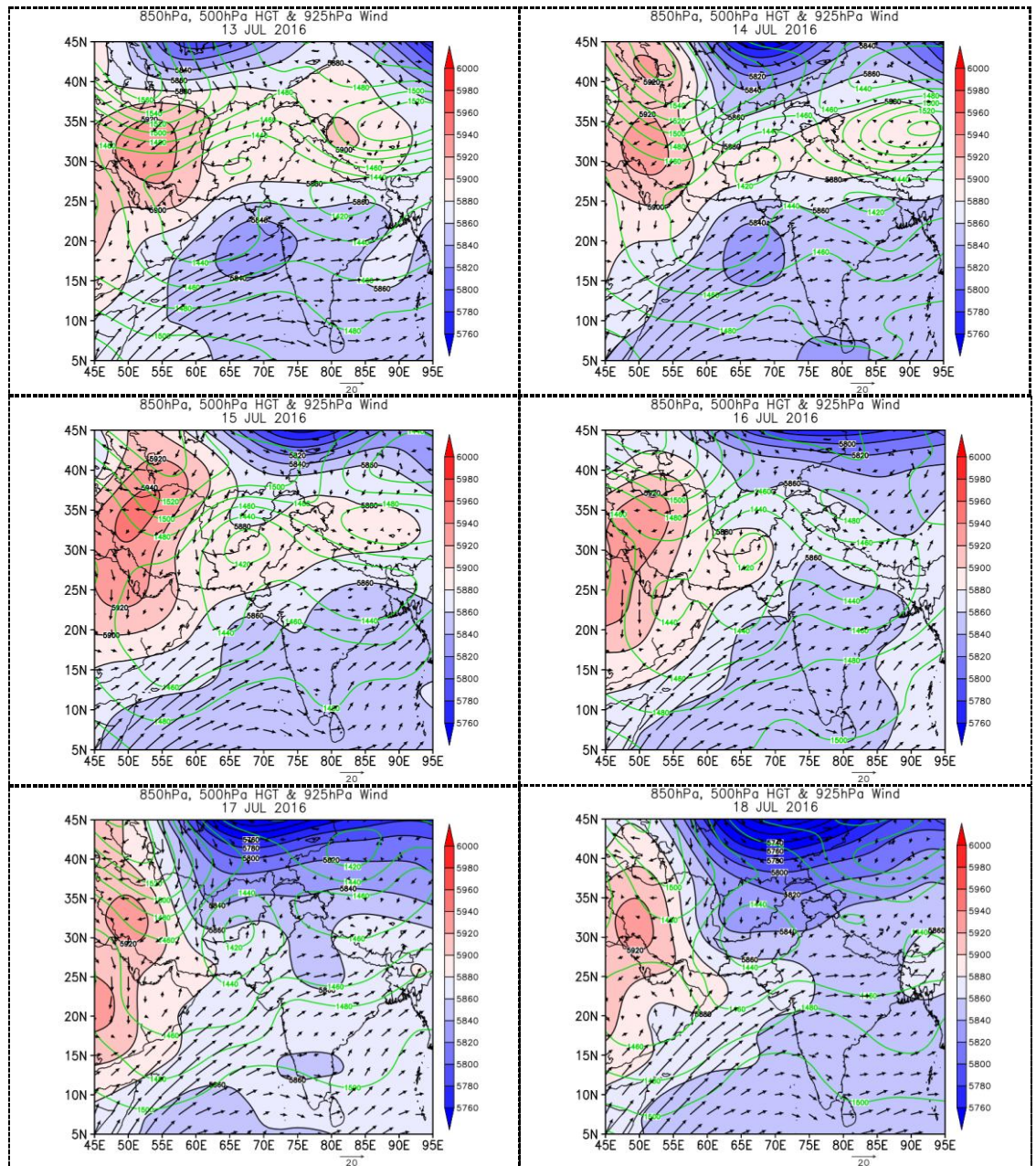


Figure 14: 500 & 850 hPa Geopotential height patterns and 925 hPa winds from 13^h to 18^h July 2016

Spatial rainfall pattern during the spell is shown in figure 15 which shows maximum rainfall of more than 130 mm recorded around Gujranwala, Sargodha, Kakul and Tarbela.

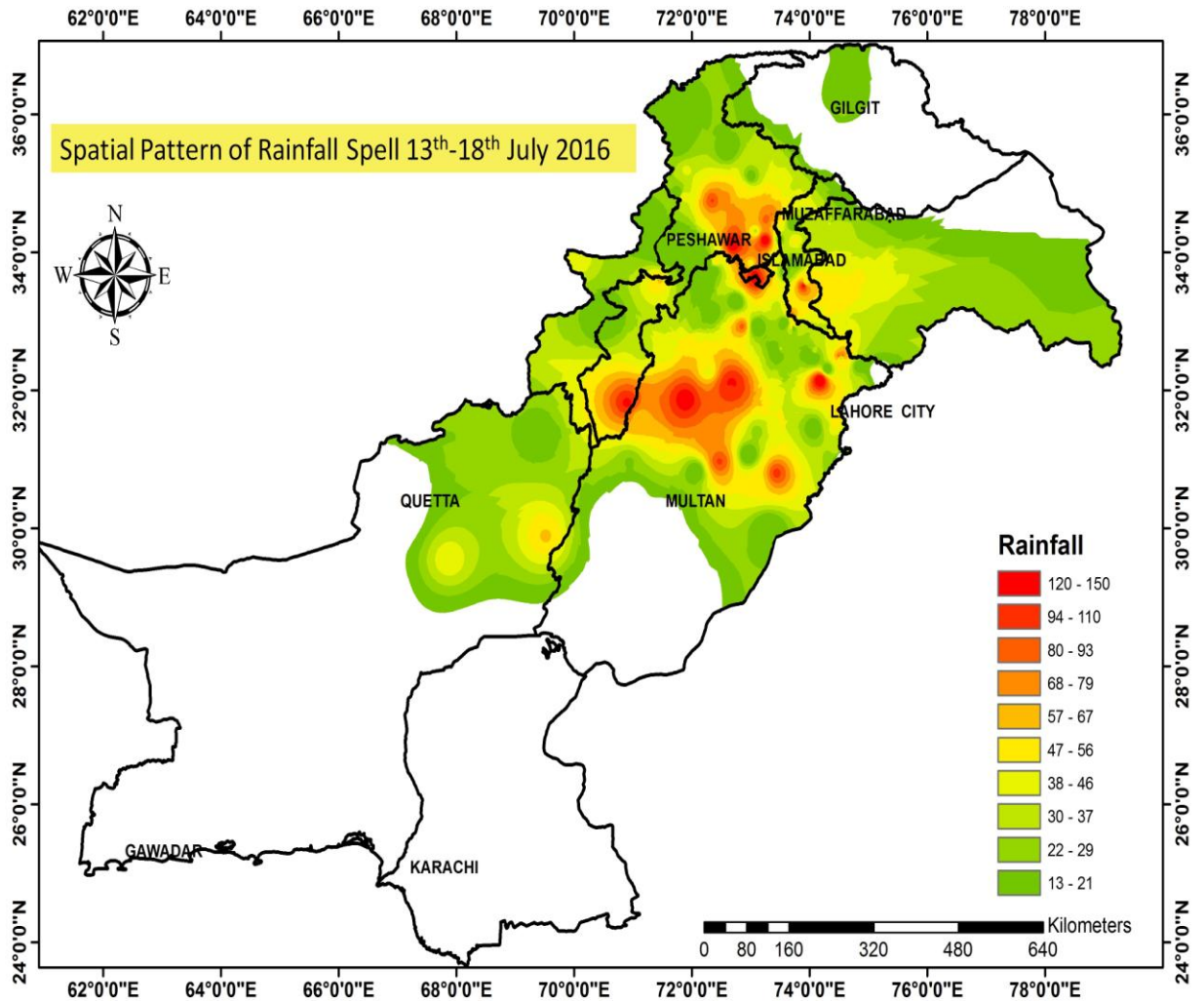


Figure 15: Significant rainfall of July 2016 (13-18 July).

Radar image shows moderate rainfall intensity in the upper catchments of Rivers Chenab & Jhelum and satellite images showing dense clouds over Kashmir.

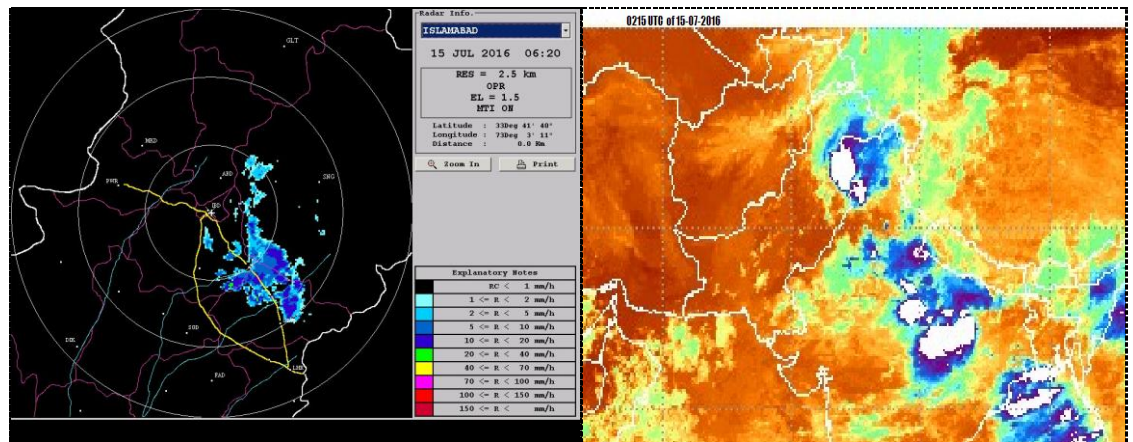


Figure 16: Radar & Satellites Images during the spell of July 2016 (13-18 July).

4.5 Position of rivers due to second wet spell of July

River Kabul at Nowshera & river Indus at Tarbela, Kalabagh, Chashma and Taunsa attained Low flood level due to this rainy spell. All the other major rivers remained below Low flood level.

4.6 Third wet Spell of July 2016 (26th to 28th July 2016)

This spell lasted for three days. The rainfall of heavy to very heavy intensity was recorded over northeast Punjab while moderate to heavy rainfall was observed over Kashmir, North Punjab and northeast Balochistan. Atmospheric conditions for 26th of July are shown in figure 17. Moderate southwesterly incursion at 925 hPa and the presence of a westerly wave produced rainfall during this period.

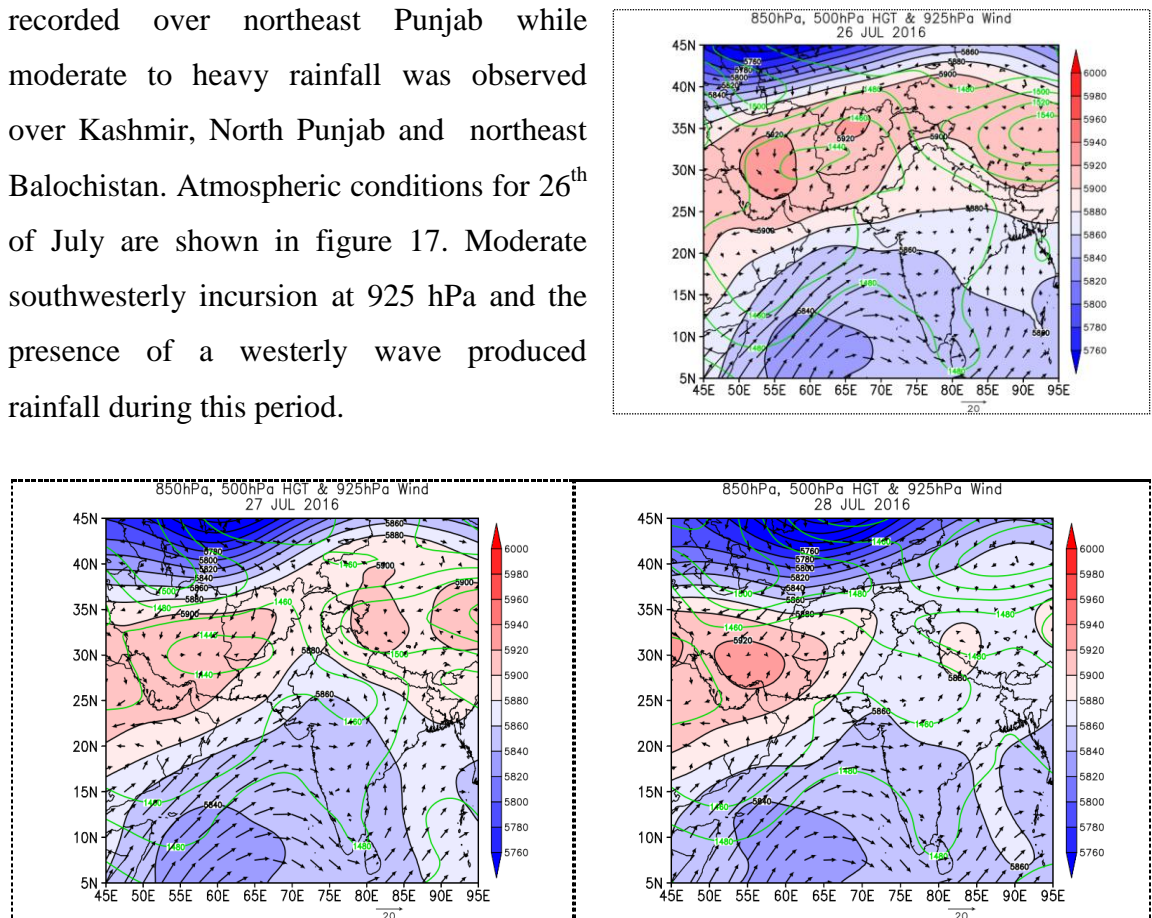


Figure 17: 500 & 850 hPa geopotential height patterns and 925 hPa winds from 26th to 28th July 2016.

Spatial distribution of significant rainfall during this spell is shown in figure 18 which indicates maximum rainfall more than 200 mm around Gujranwala. More than 100mm rainfall was also observed over Murree, Sialkot, Kakul, Sibbi and Kashmir.

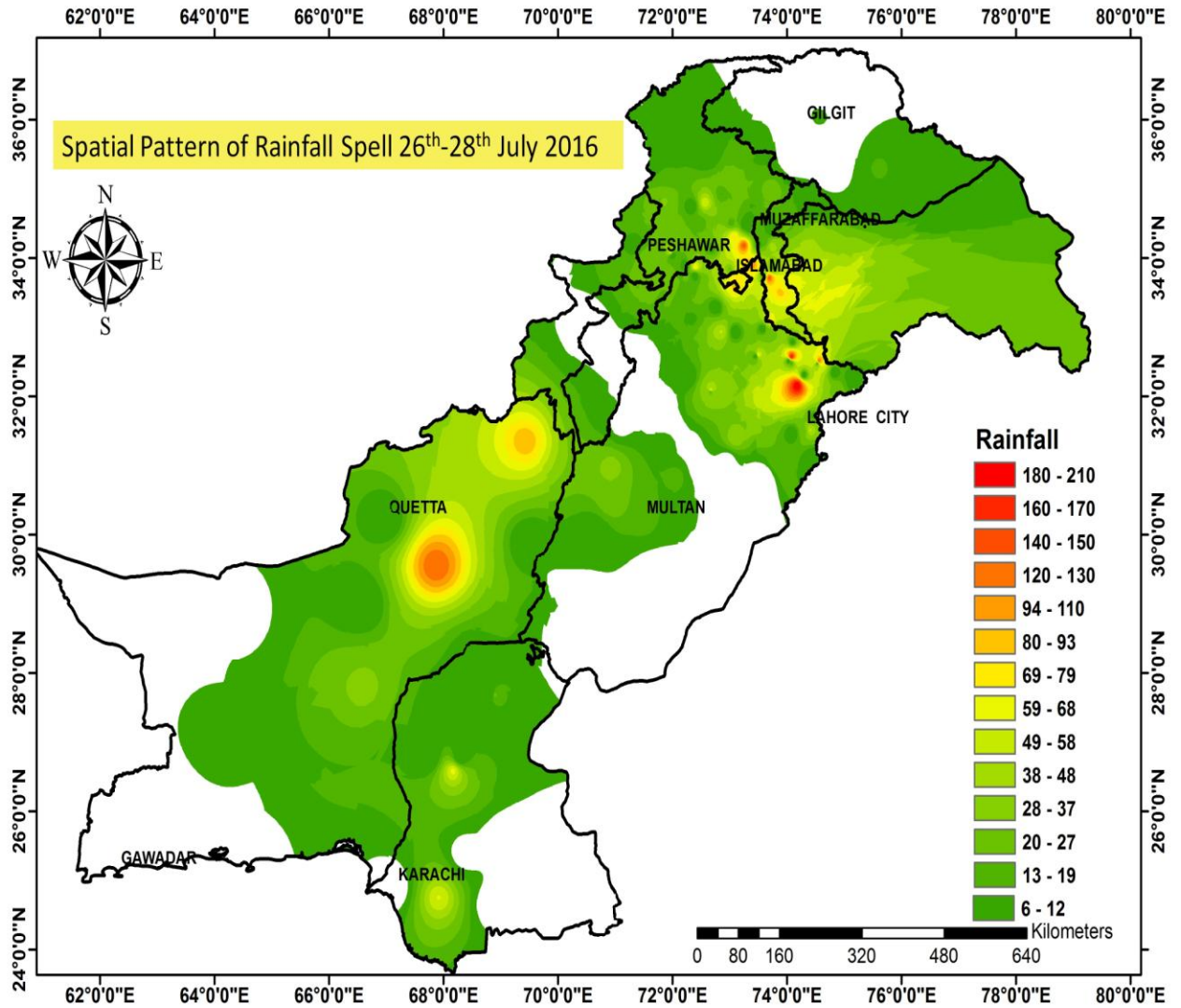
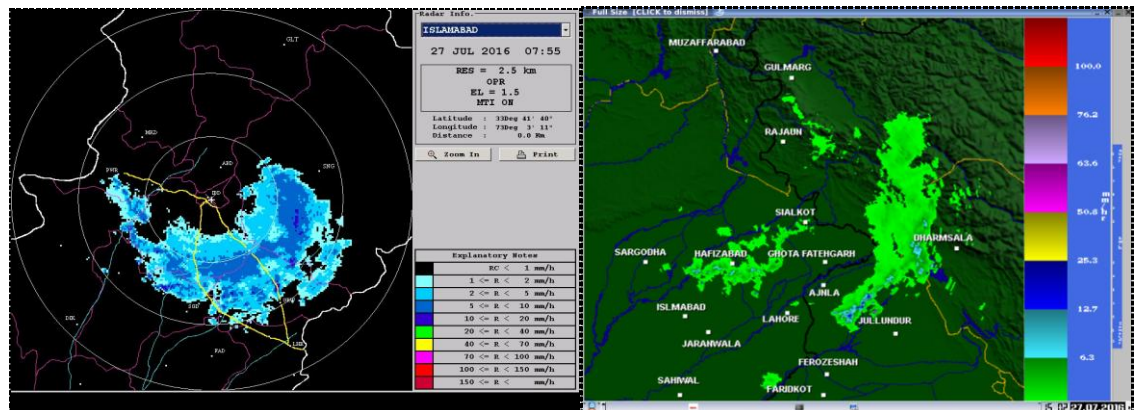


Figure 18: Significant rainfall of July 2016 (26-28 July).

Radar image shows moderate rainfall intensity in the upper catchments of Rivers Chenab & Jhelum along with North Punjab and satellite images showing dense clouds over North Punjab along with Kashmir.



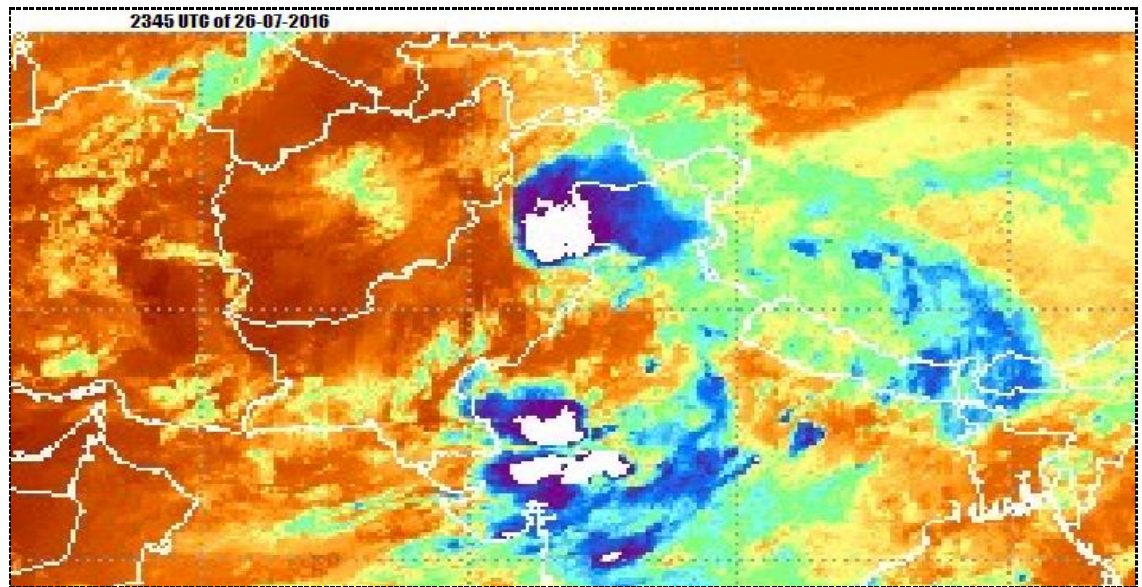


Figure 19: Radar Images during the spell of July 2016 (26-28 July).

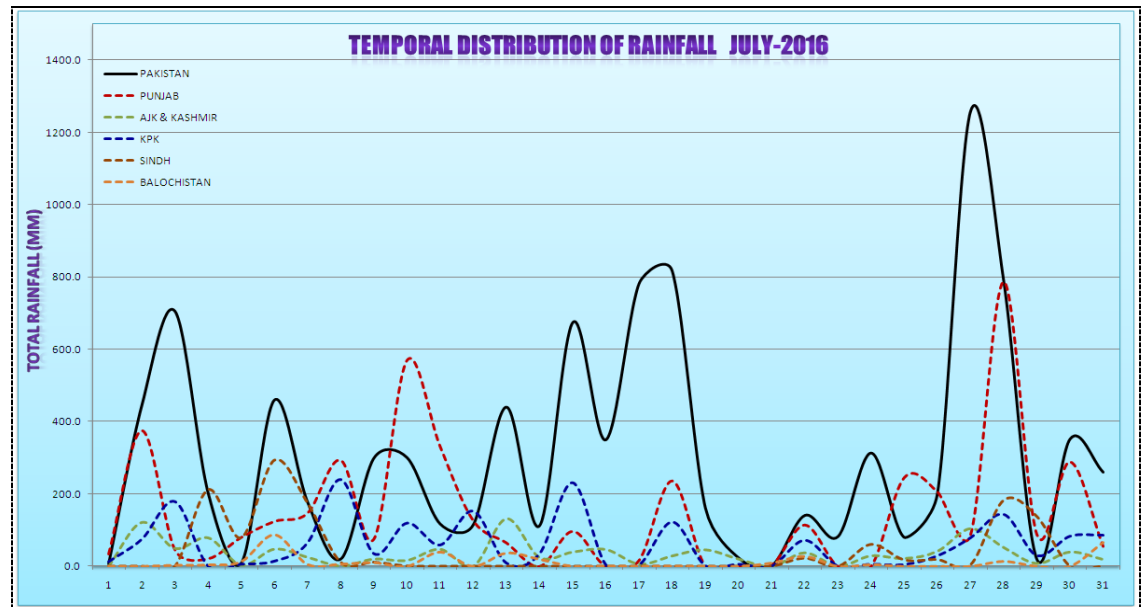


Figure 20: Temporal distribution of rainfall during July 2016.

4.7 Spatial pattern of rainfall during the month of July 2016

Isohyetal map of July 2016 indicates that one maxima of very high rainfall (more than 500 mm) lies over Northeast Punjab around Gujranwala areas and another center of very heavy rainfall of more than 400 mm lies over Kashmir and two heavy rainfall centre of more than 300 mm are over Islamabad and Sargodha as shown in figure 21.

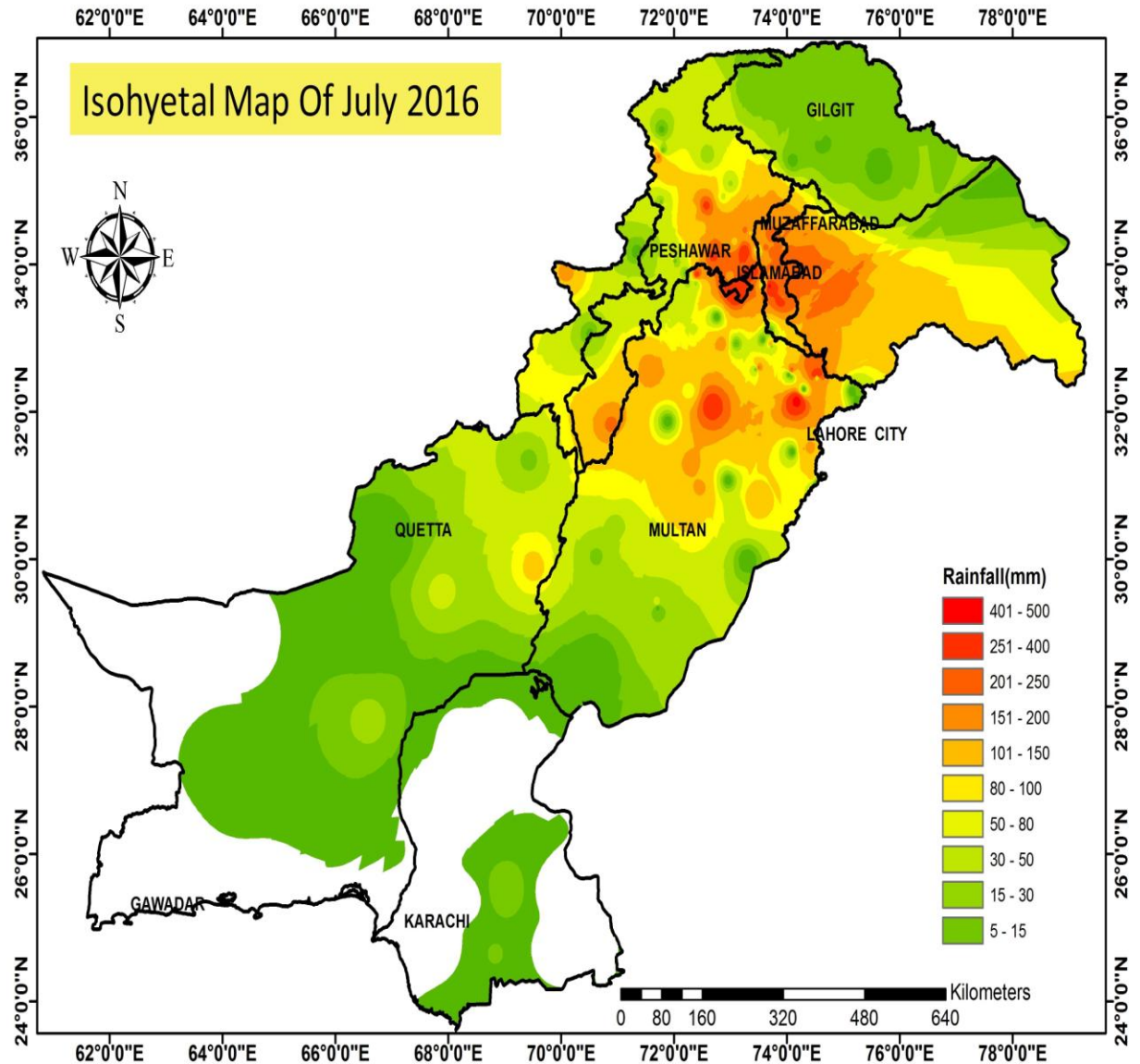


Figure 21: Isohyetal map of July 2016.

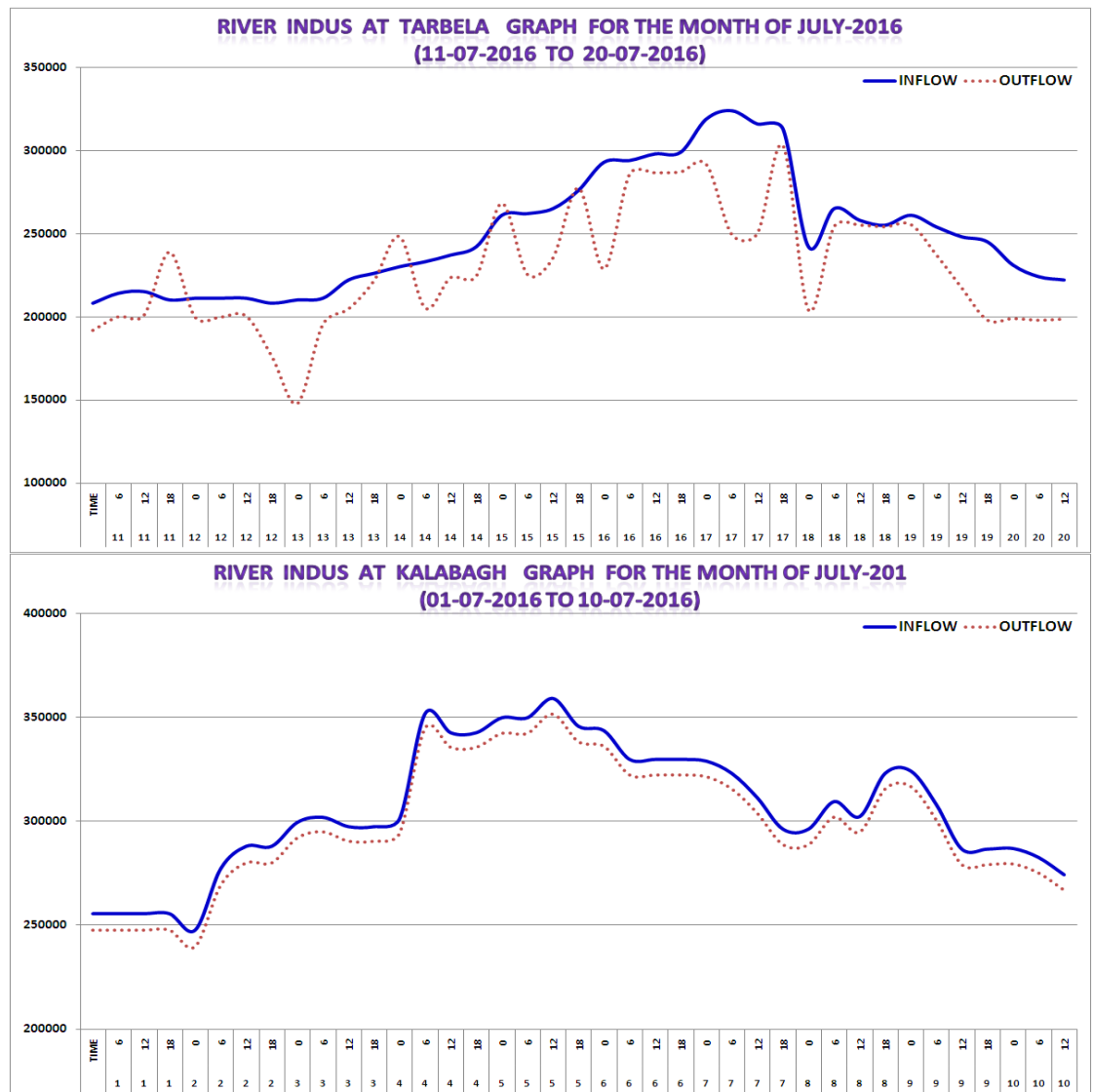
4.8 Position of rivers during the month of July 2016

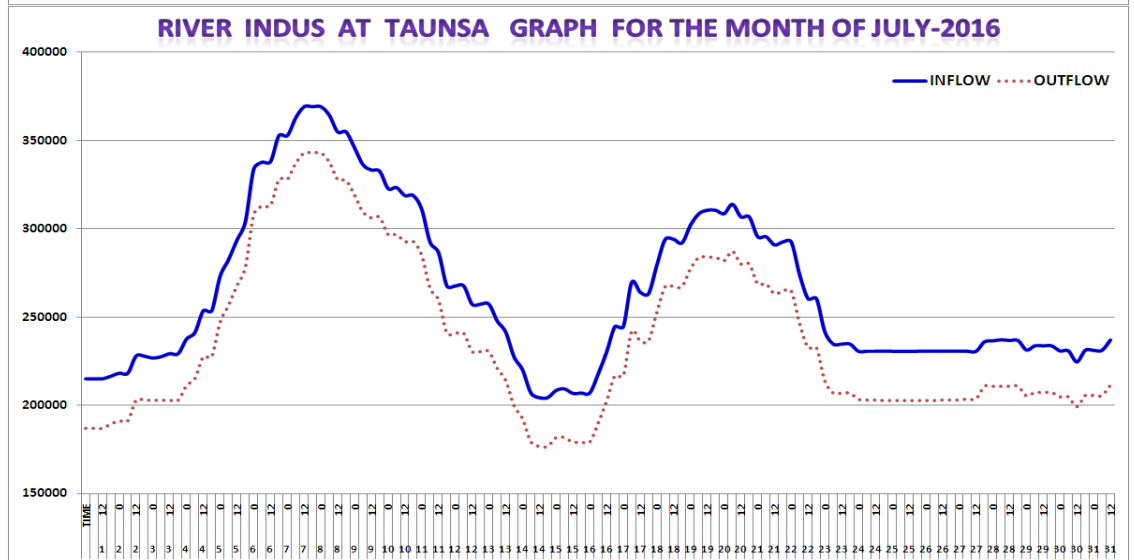
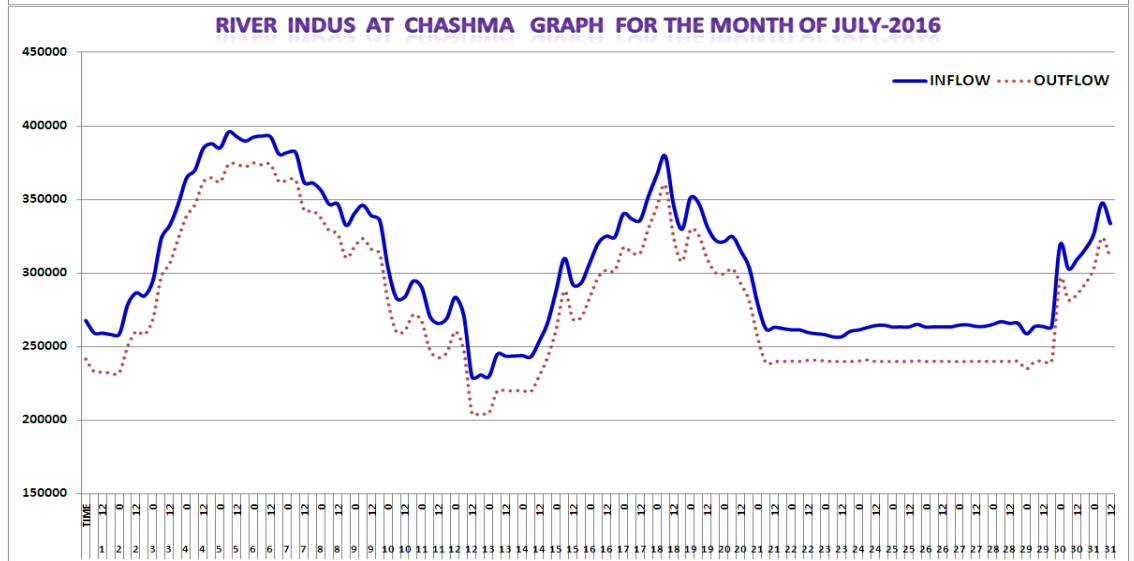
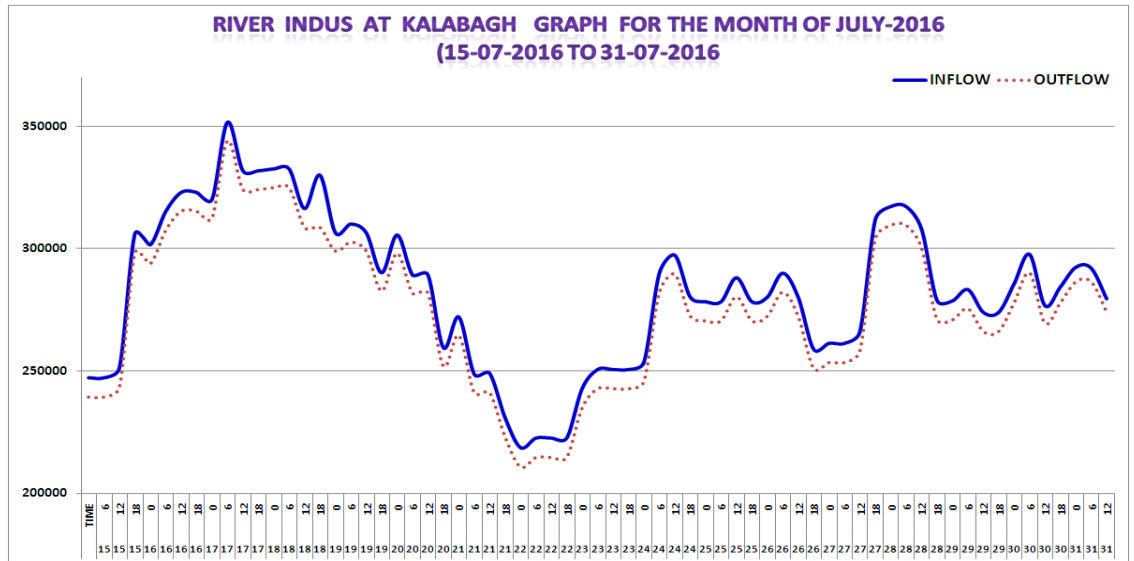
Flood peaks (Cusecs) recorded during July, 2016 are shown below.

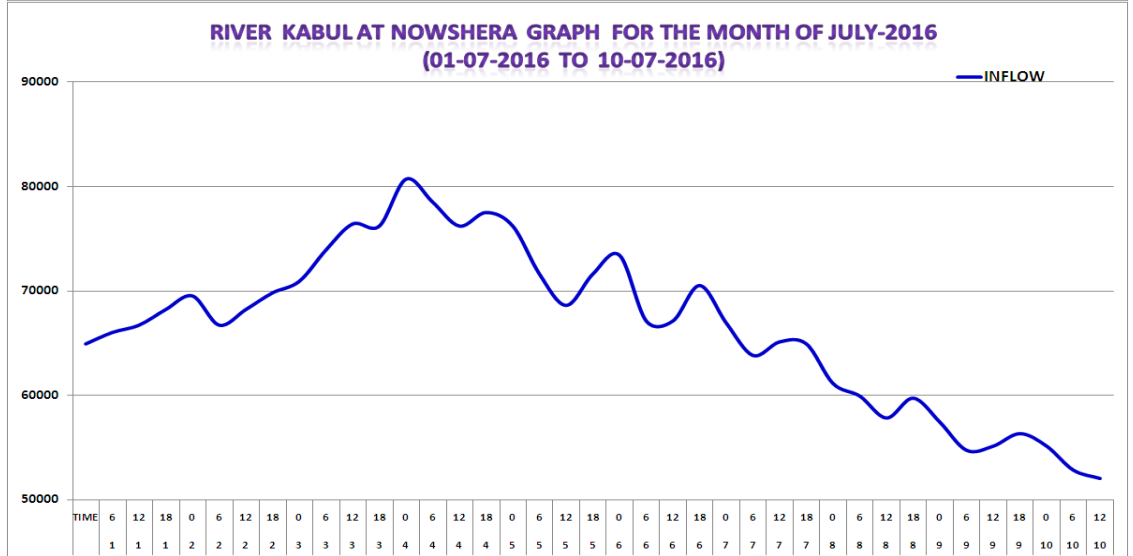
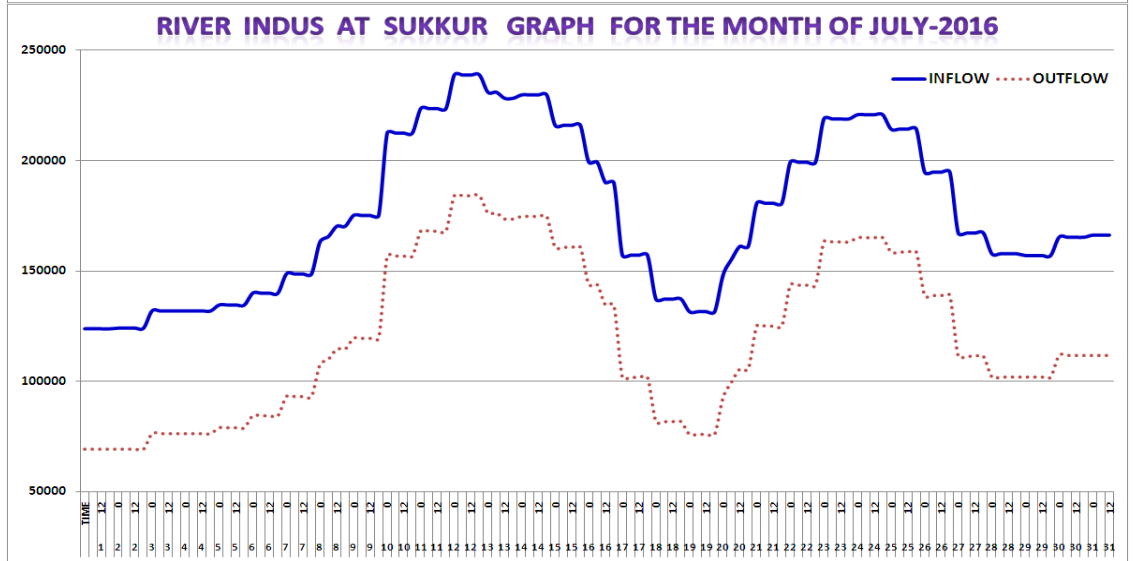
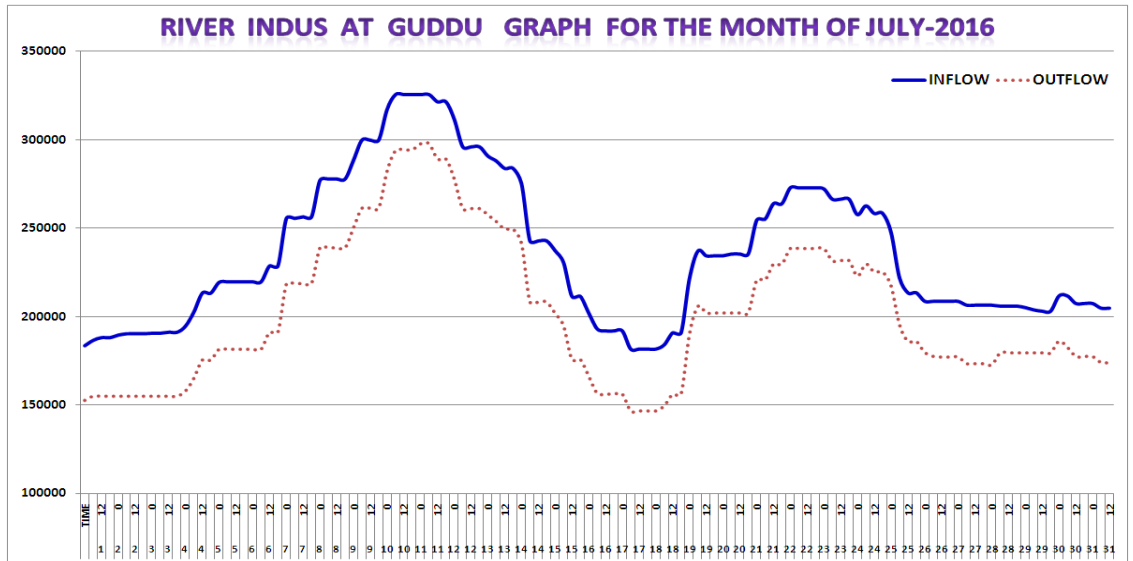
Date	Rivers	Stations	Peaks Inflows	Flood level
04/07/2016	Indus	Tarbela	291000	Low
17/07/2016	Indus	Tarbela	324000	Low
04/07/2016	Kabul	Nowshera	80700	Medium
05/07/2016	Indus	Kalabagh	358990	Low
17/07/2016	Indus	Kalabagh	351726	Low
05/07/2016	Indus	Chashma	396148	Medium
18/07/2016	Indus	Chashma	379609	Medium
31/07/2016	Indus	Chashma	347708	Low
07/07/2016	Indus	Taunsa	369224	Low

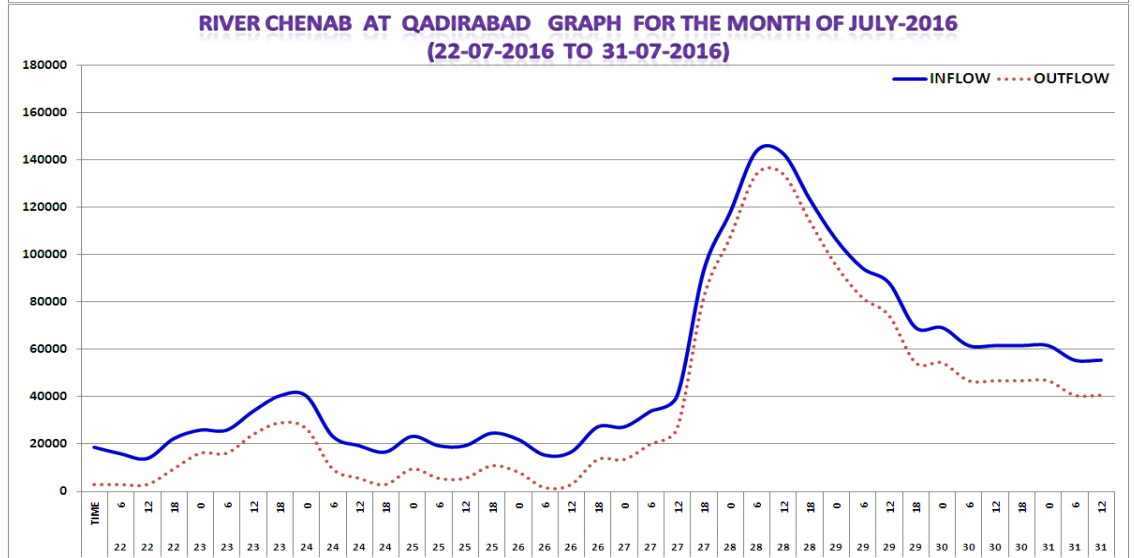
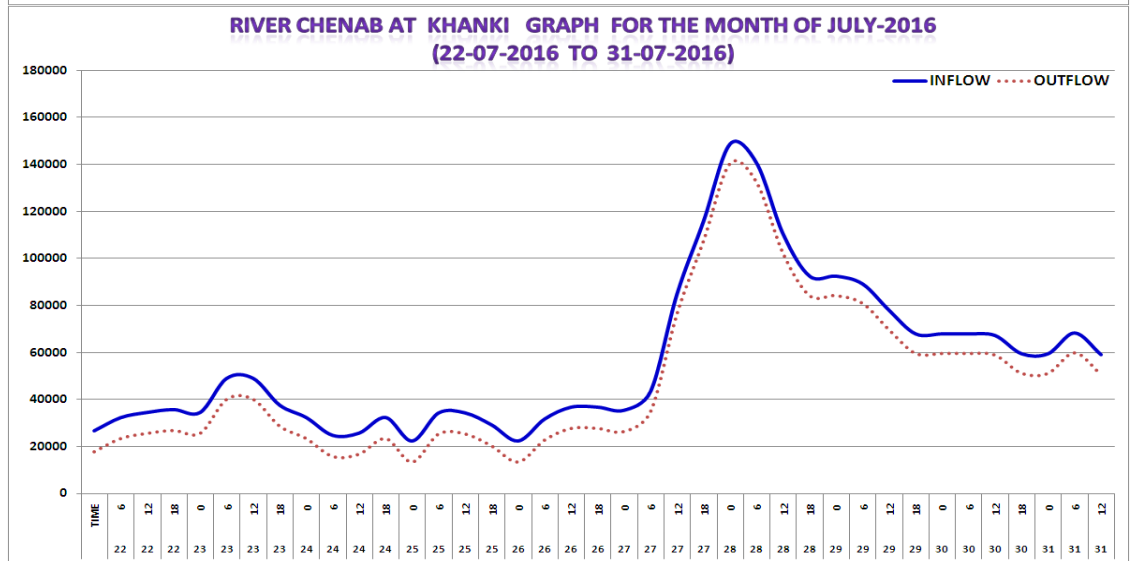
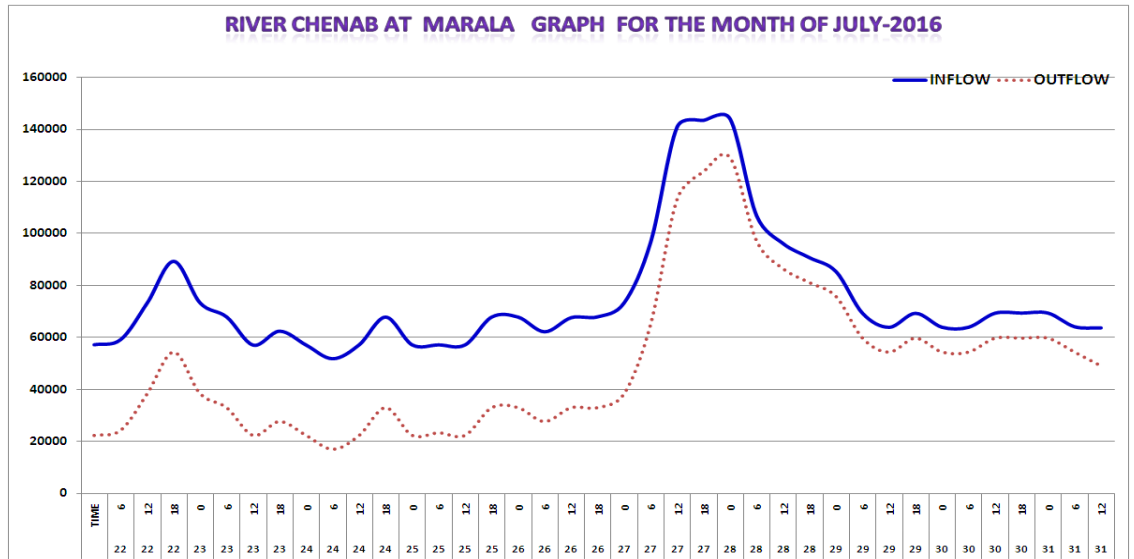
20/07/2016	Indus	Taunsa	313923	Low
10/07/2016	Indus	Guddu	325846	Low
22/07/2016	Indus	Guddu	273047	Low
12/07/2016	Indus	Sukkur	238855	Low
24/07/2016	Indus	Sukkur	220870	Low
28/07/2016	Chenab	Marala	144055	Low
28/07/2016	Chenab	Khanki	148805	Low
28/07/2016	Chenab	Qadirabad	143826	Low
29/07/2016	Ravi	Shahdara	44595	Low
29/07/2016	Ravi	Balloki	53320	Low

4.9 Hydrographs recorded during the month of July 2016 are as below









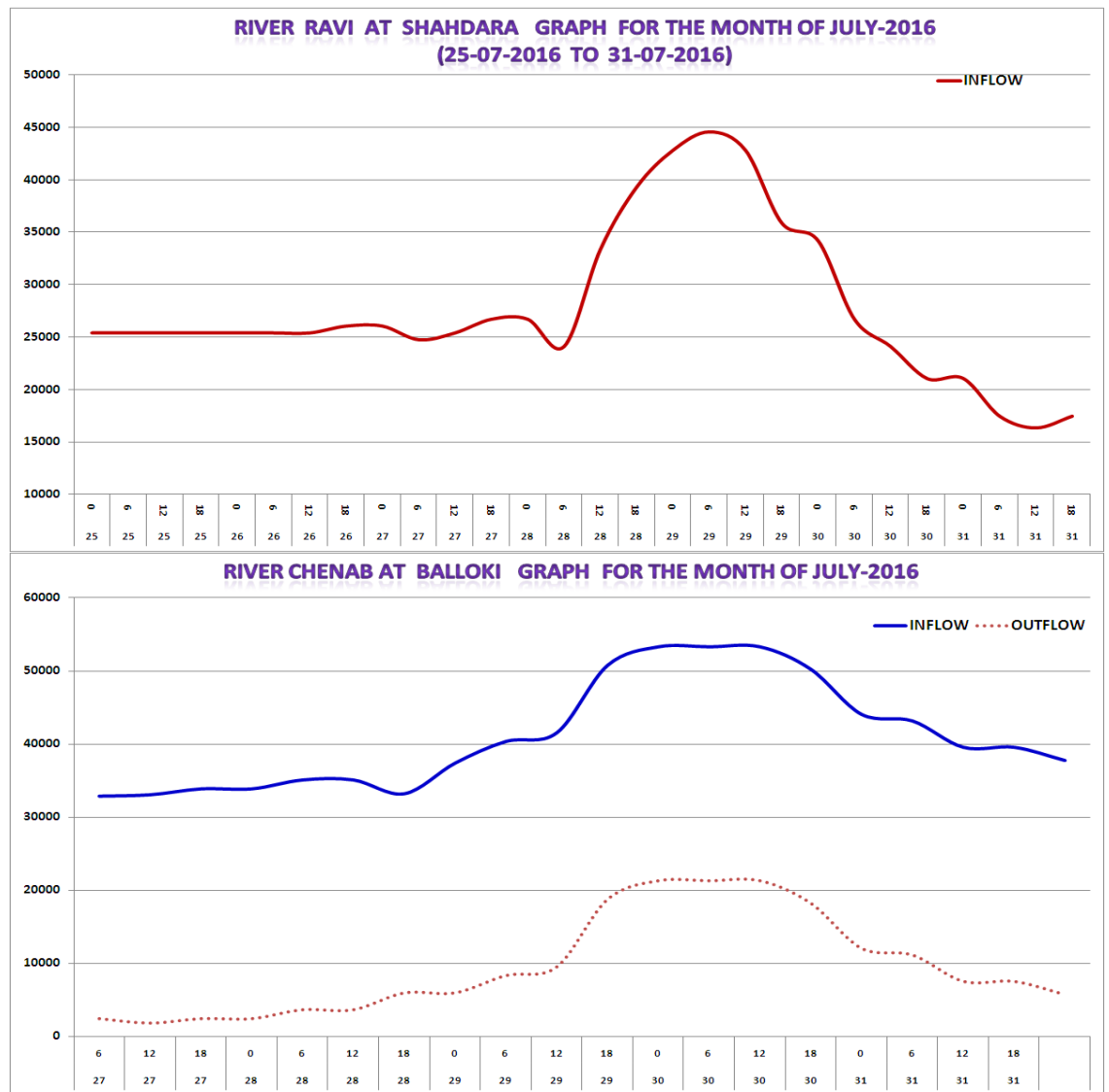


Figure 22: Hydrographs for the month of July-2016.

5 Significant hydro-meteorological events during the month of August 2016

5.1 Meteorological events

Three rainy spells occurred during the month of August. First spell produced rainfall from 4th to 8th August 2016. This spell was caused by the interaction of a trough of westerly wave with the presence of seasonal low over northeast Balochistan and moderate moist current from the Arabian Sea and Bay of Bengal. Second wet spell of the August was observed from 10th to 12th August 2016. This spell was caused by the interaction of a seasonal low and moist current from the Arabian Sea. Third and final spell occurred from 25th to 30th August 2016. This spell was caused by passing of a westerly wave along with accentuation of seasonal low and penetration of moist current from both the sources.

5.2 First wet spell of August (04th to 8th August 2016)

The rainfall during the first spell of August, the 6th of the season, occurred during 4th to 8th August 2016. Heavy to very heavy rainfall was observed in this spell over the upper catchment of River Indus. Moderate to heavy rain was observed in Sindh and Kashmir. Atmospheric conditions during this wet spell are shown in figure 23. It shows a westerly trough at 500 hPa and southwesterly flow at lower level in Sindh.

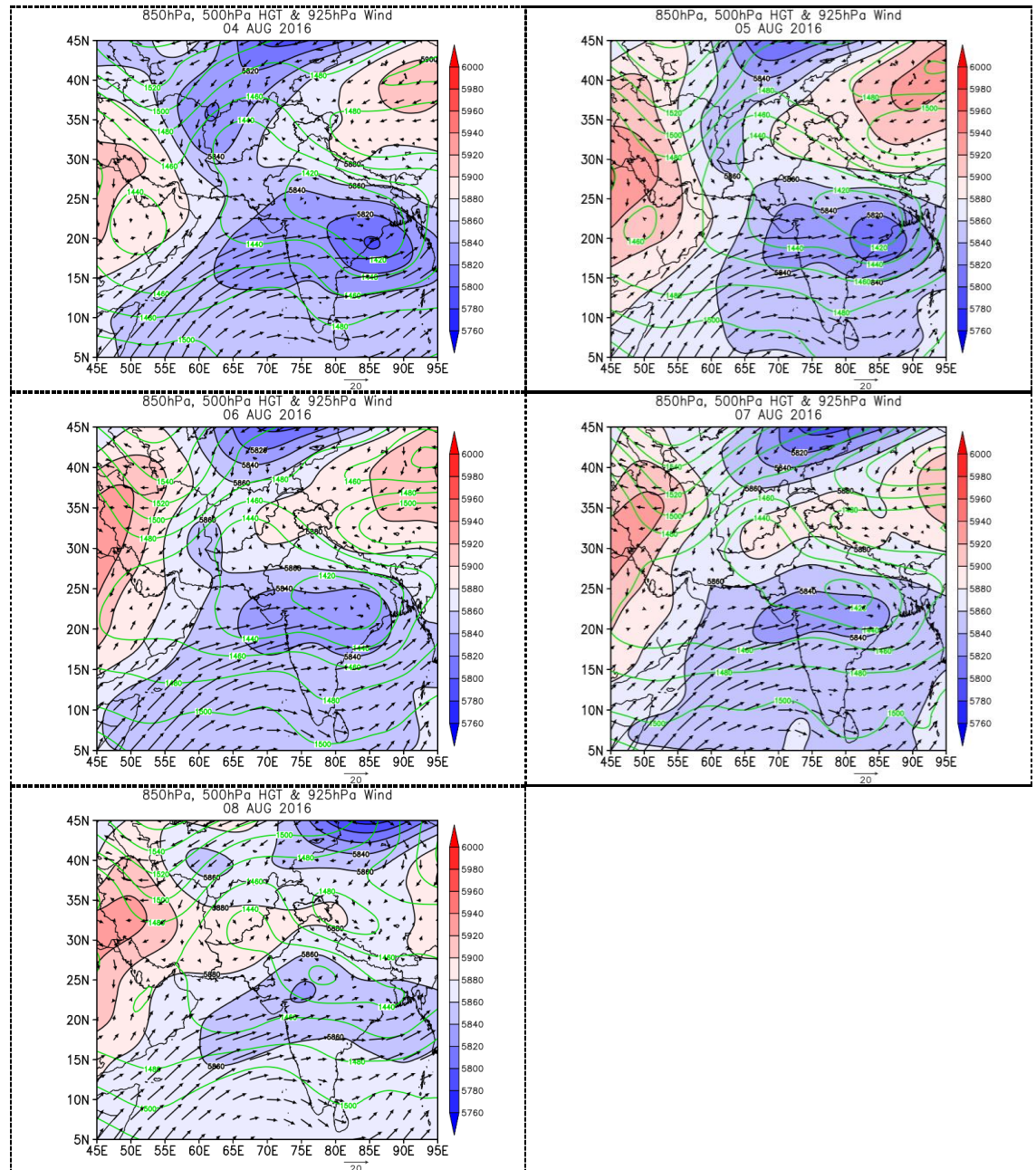


Figure 23: 500 & 850 hPa geopotential height patterns and 925 hPa winds on 4th to 8th August 2016.

Isohyetal map of 4th to 8th August 2016 indicates that one maxima of rainfall (more than 200 mm) lies over upper Khyber Pakhtunkhwa and another maximum rainfall of more than 100 mm lies over south Sindh. Figure 24 gives the spatial distribution of significant rainfall during the present spell.

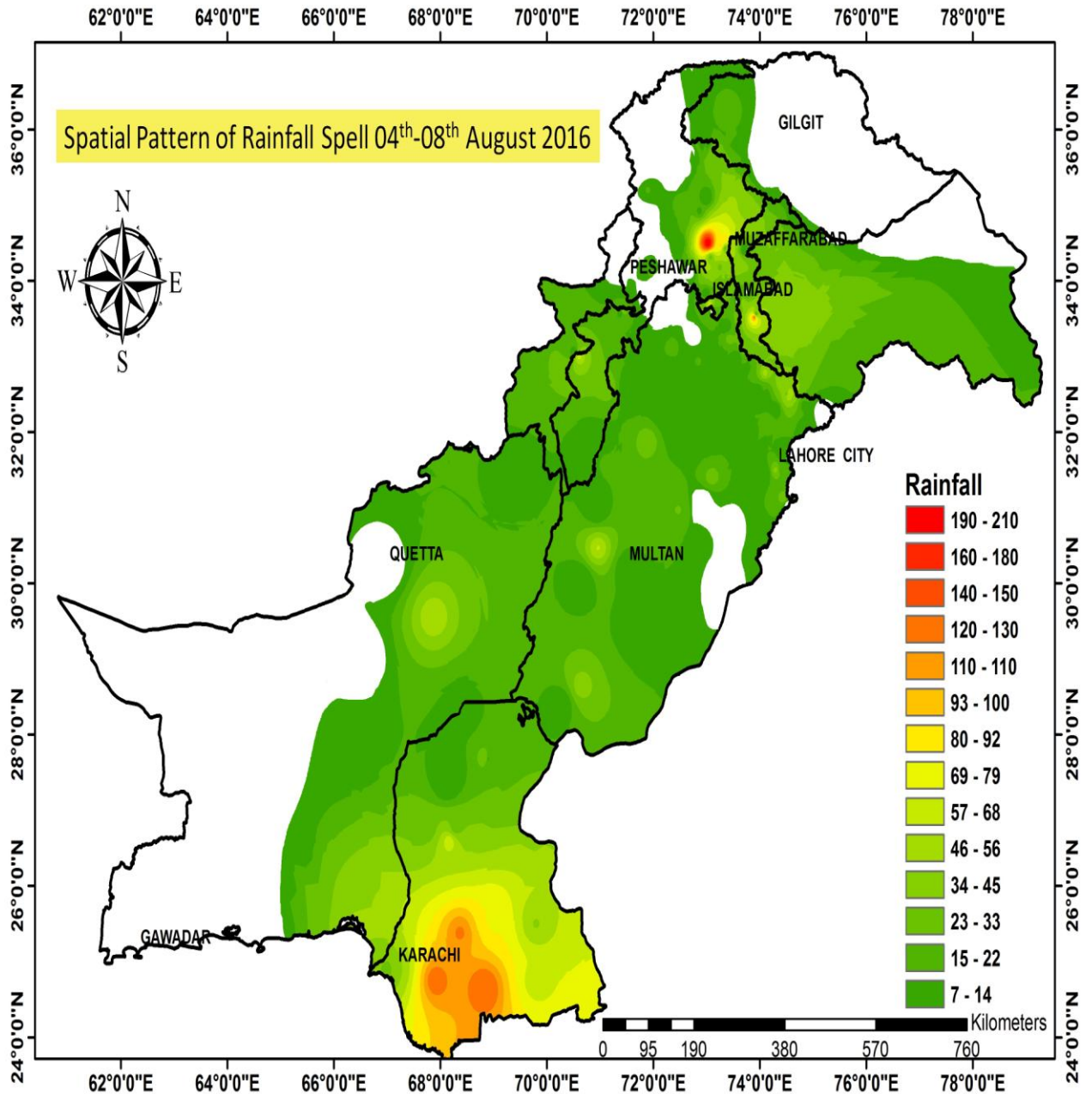


Figure 24: Significant rainfall of August 2016 (04-08 August).

Radar image shows moderate rainfall intensity in the upper catchments of Rivers Chenab, Jhelum & Ravi and satellite images showing dense clouds over Northeast Punjab, Kashmir & Sindh.

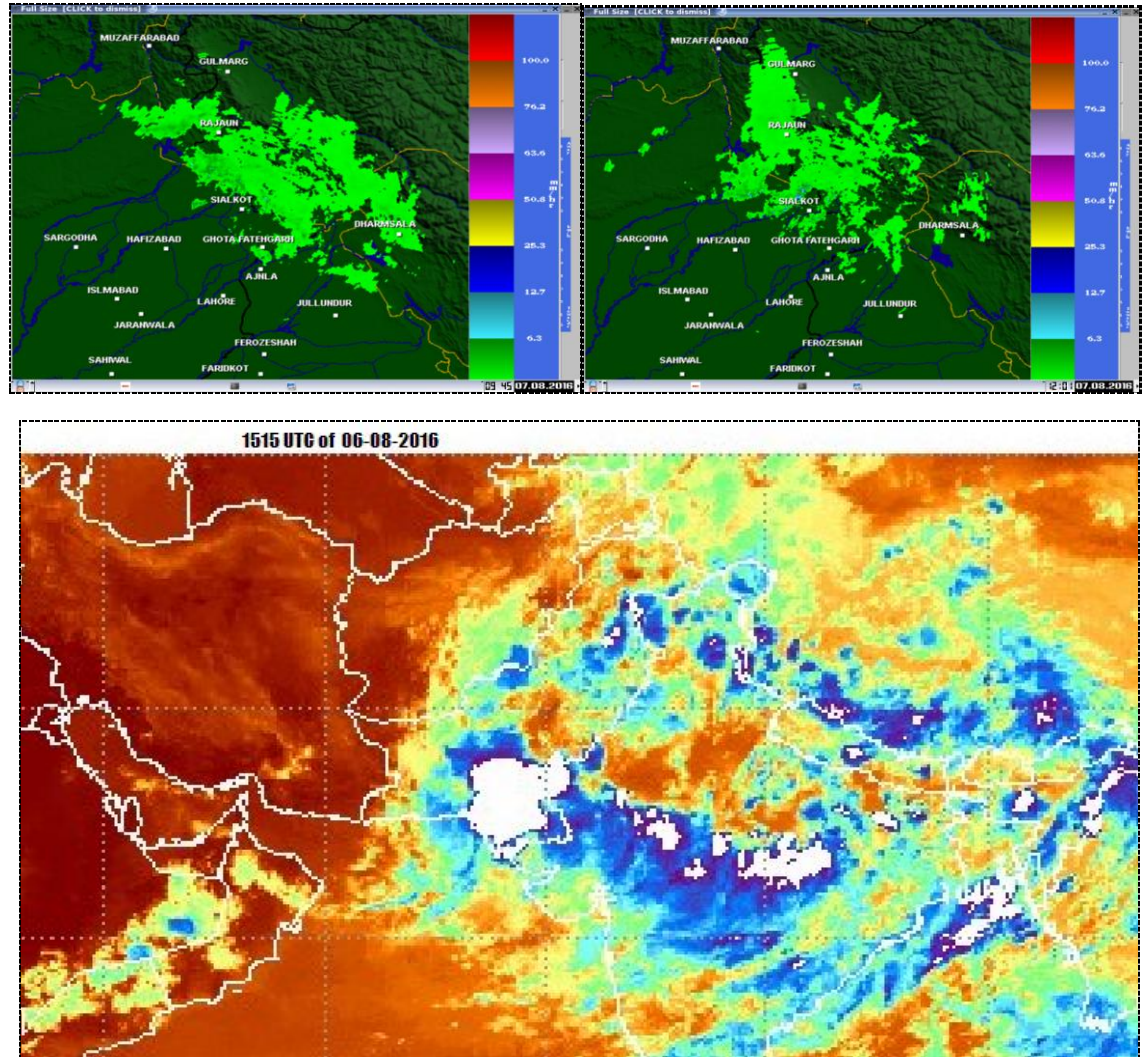


Figure 25: Radar & Satellites Images during the spell of August 2016 (04-08 August).

5.3 Position of rivers during first spell of August

Due to very heavy rainfall in the upper catchments of river Chenab in India, very High flood was observed in river Chenab at Marala, Khanki, and Qadirabad. Due to moderately heavy rainfall over the upper catchments of river Jhelum, a sharp peak of very high flood was recorded in river Jhelum at Mangla upstream. Low Flood situation was also recorded in river Indus at Tarbela and river Chenab at Trimu.

5.4 Second wet spell of August (10th to 12th August 2016)

Rainfall of moderate intensity was recorded over North and Northeast Punjab and Kashmir. Figure 26 represents 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.

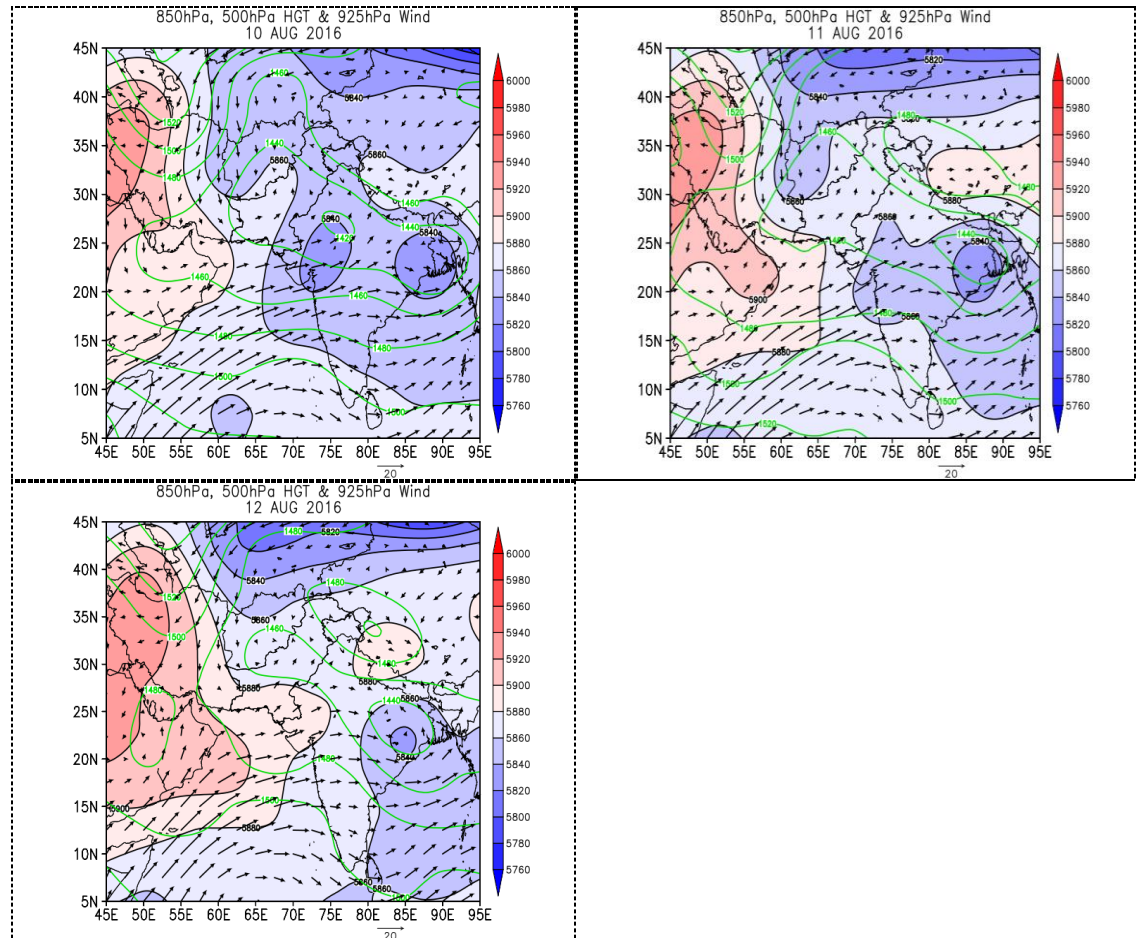


Figure 26: 500 & 850 hPa geopotential height patterns and 925 hPa winds on 10th to 12th August 2016.

Figure 27 shows the spatial distribution of significant rainfall of more than 100 mm recorded over Northeast Punjab

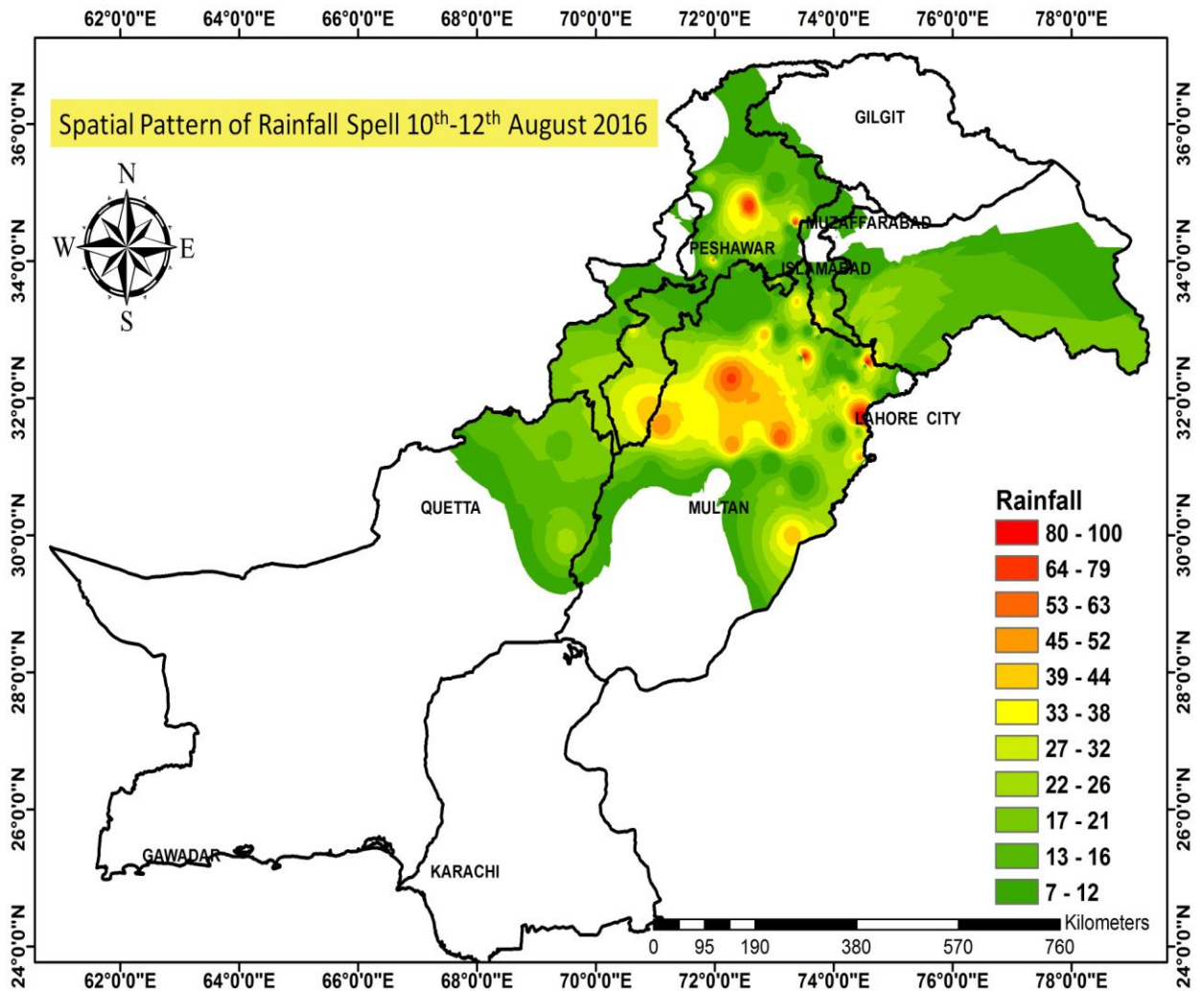


Figure 27: Significant rainfall of August 2016 (10-12 August).

Radar image shows light rainfall intensity in the upper catchments of Rivers Chenab & Jhelum and satellite images showing dense clouds over Suleman range & South Punjab.

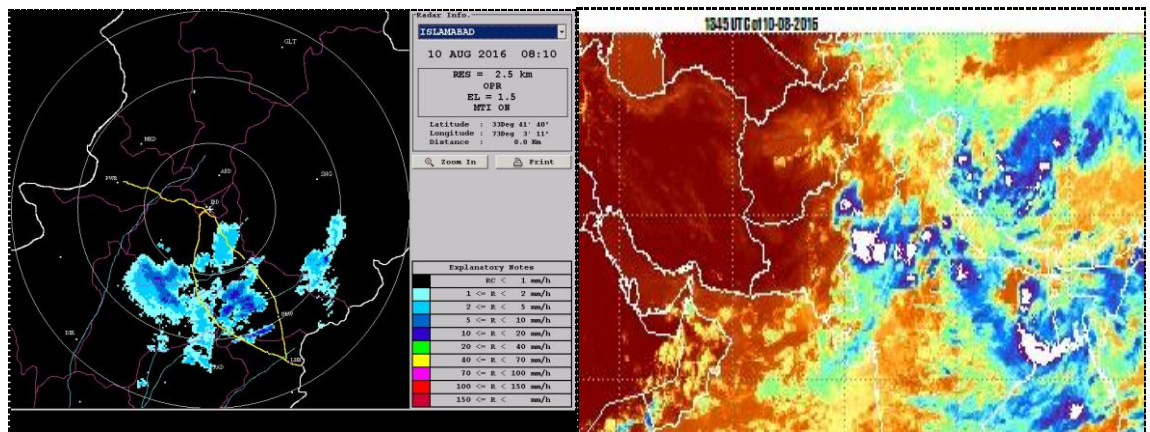


Figure 28: Radar & Satellites Images during the spell of August 2016 (10-12 August).

5.5 Position of rivers during the second spell of August

During this spell Low flood level was recorded in River Indus at Tarbela, Kalabagh, Chashma, Taunsa and in River Chenab at Trimu.

5.6 Third wet spell of August (25th to 30th August 2016)

Third spell in August was caused due to the passing of a westerly wave and accentuation of seasonal low. Figure 29 shows this situation with a strong southwesterly flow at lower level. Warm moist air from the Arabian Sea interacted with cold dry air producing significant rainfall in Lahore, and Islamabad.

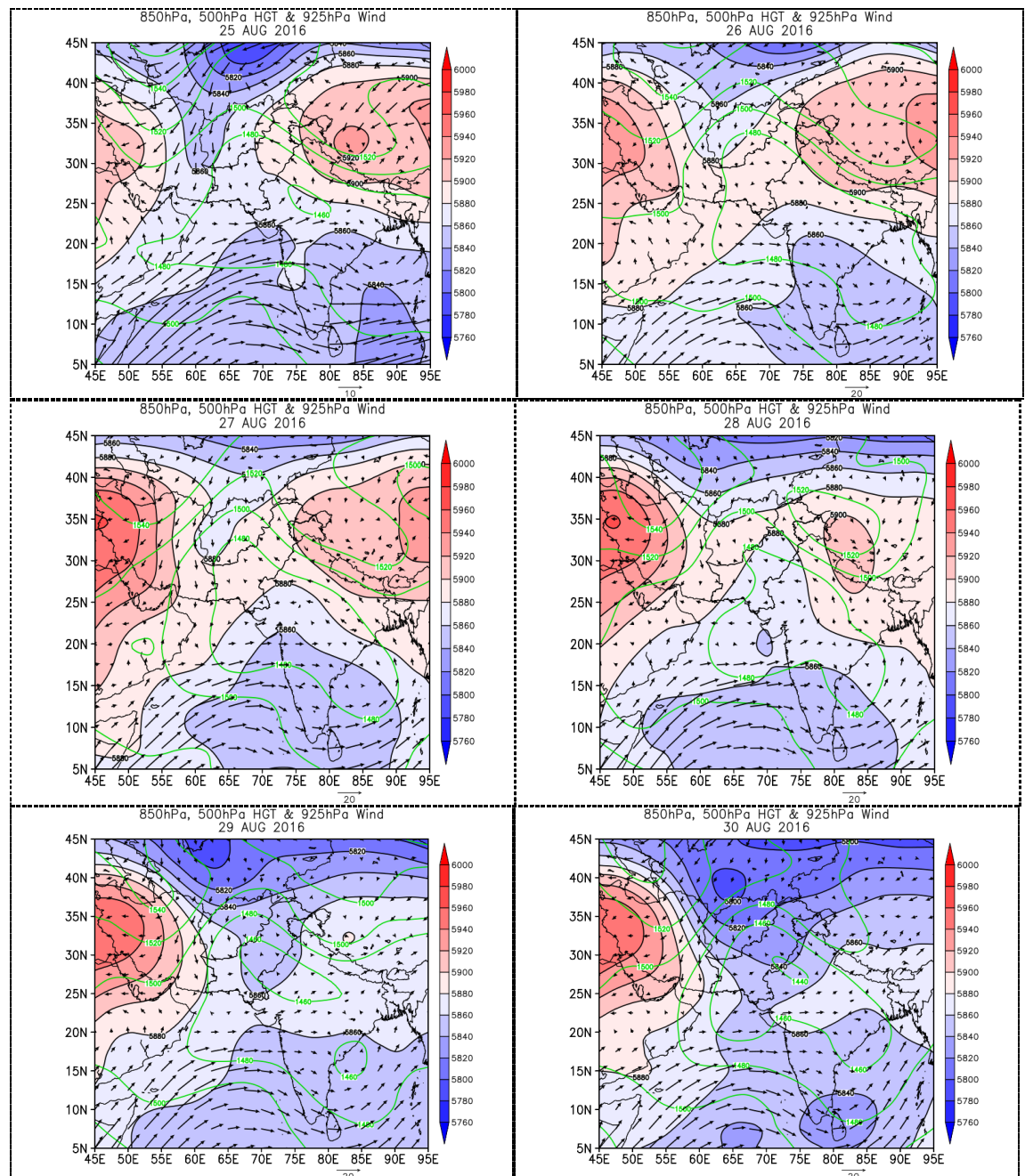


Figure 29: 500 & 850 hPa geopotential height patterns and 925 hPa winds from 25th to 30th August 2016.

Radar & satellite observations during the spell are shown below:

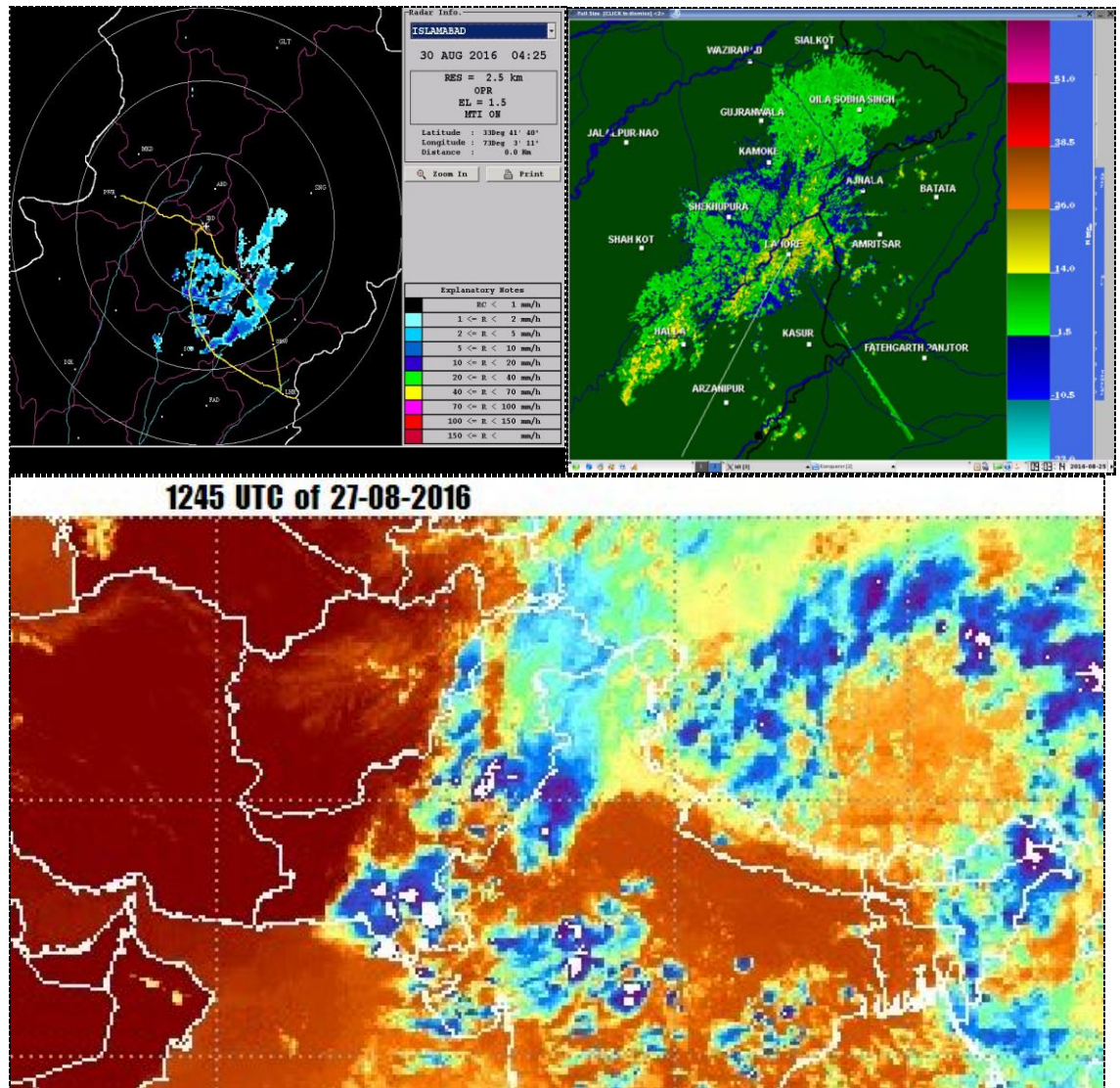


Figure 30: Radar & Satellites Images during the spell of August 2016 (25-30 August).

Isohyetal map of 25th to 30th August 2016 indicates that one maxima of rainfall (more than 200 mm) lies over Lahore another center of high rainfall of more than 100 mm is observed over Rawalpindi division and Okara. Spatial distribution of rainfall during the spell is shown in figure 31.

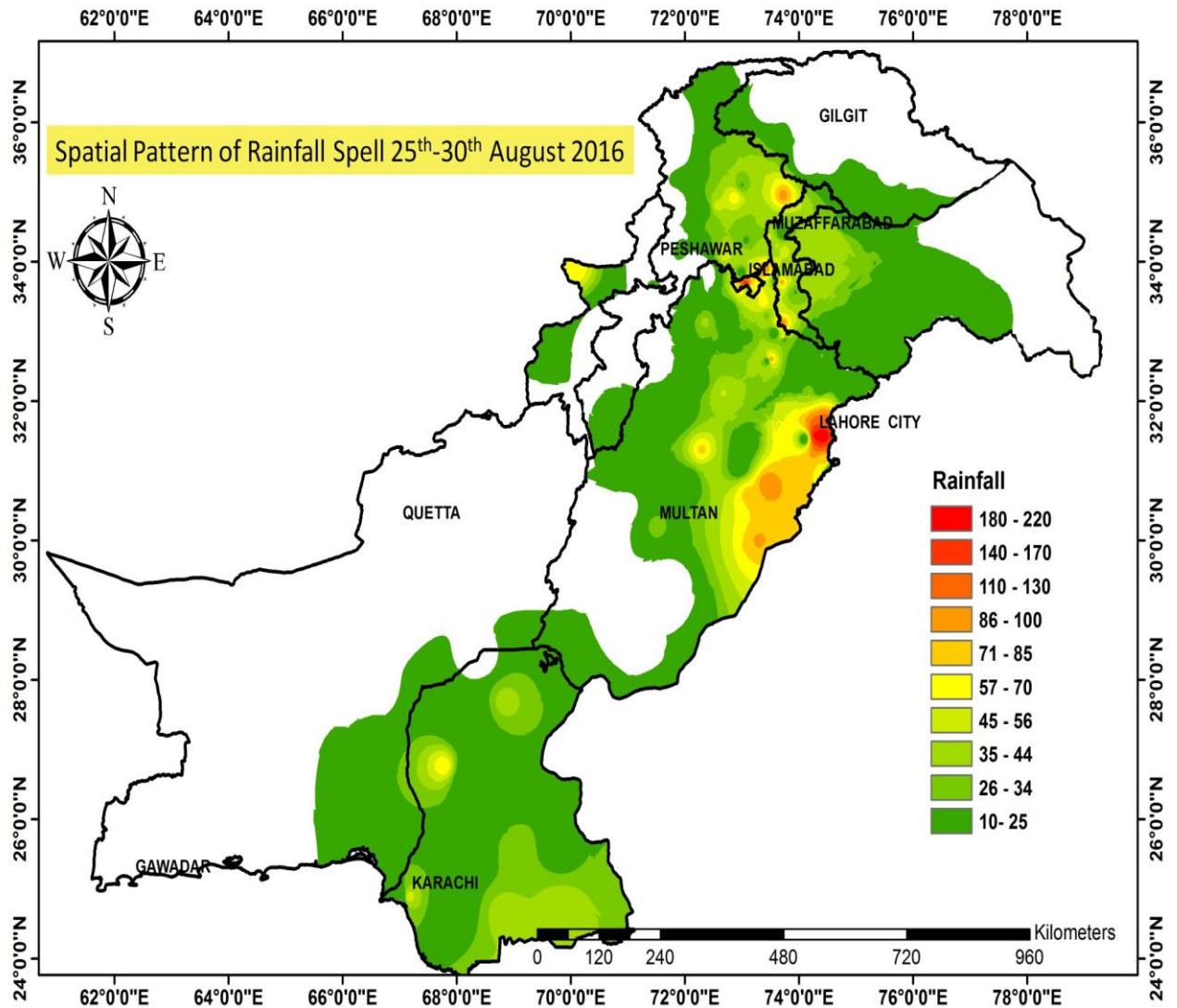


Figure 31: Significant rainfall of August 2016 (25-30 August).

5.7 Position of rivers during the Spell

No significant flood situation was observed in all the major rivers.

5.8 Spatial pattern of rainfall during the month of August 2016

The monthly precipitation during the month of August is shown in figure 32 indicates normal monsoon activity over most parts of the country. Two centers of maximum rainfall exceeding 300 mm are located over upper Khyber Pakhtunkhwa around Malam Jabba and over northeast Punjab around Lahore. While another maxima of slightly above 200 mm was found around Islamabad & Kashmir. More than 100 mm was recorded over South Sindh & northeast Balochistan.

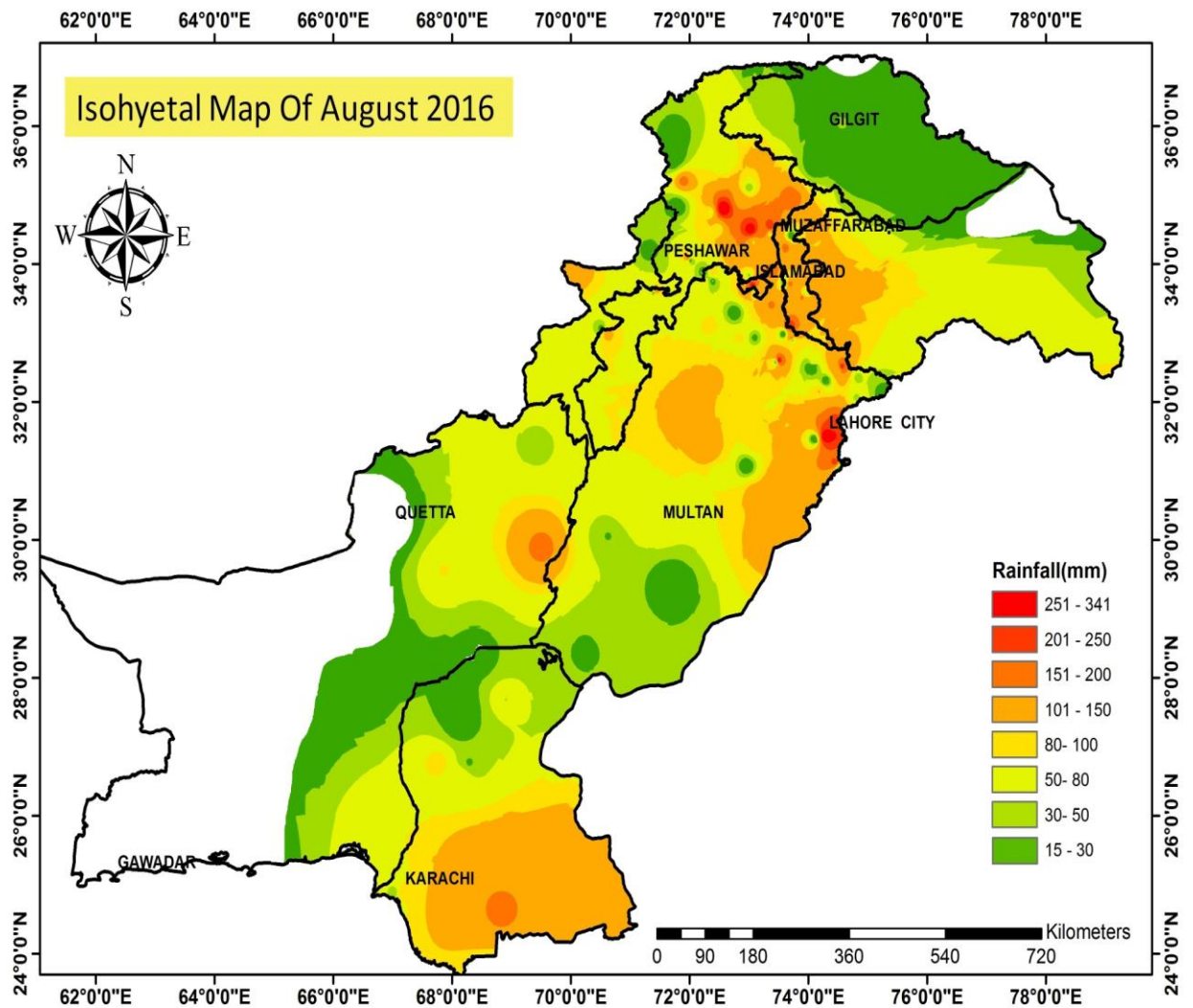


Figure 32: Isohyetal map of August 2016.

Figure 33 shows the temporal distribution of rainfall during the month of August.

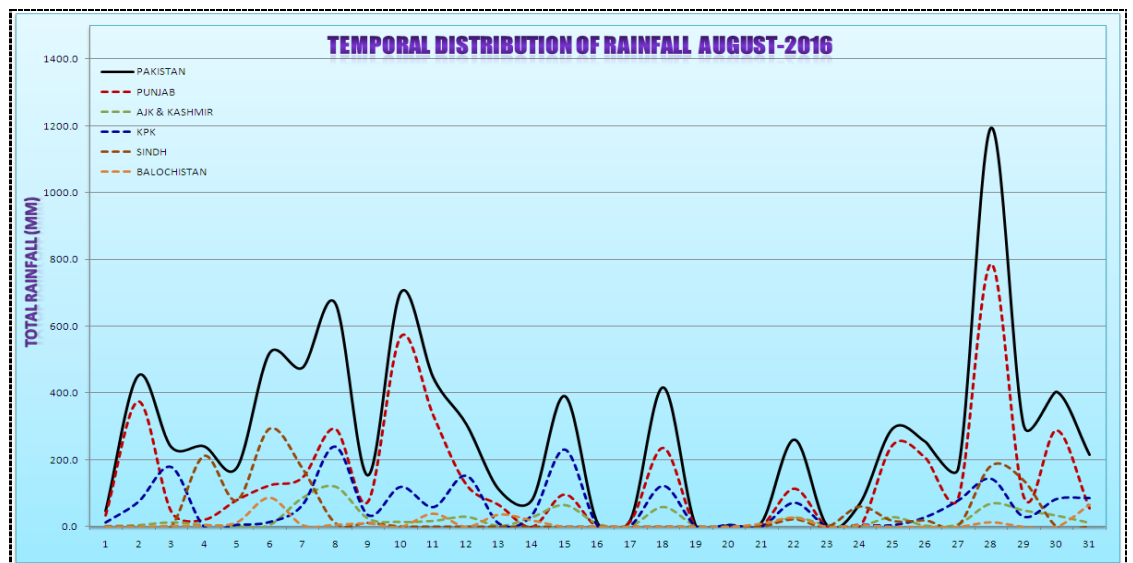


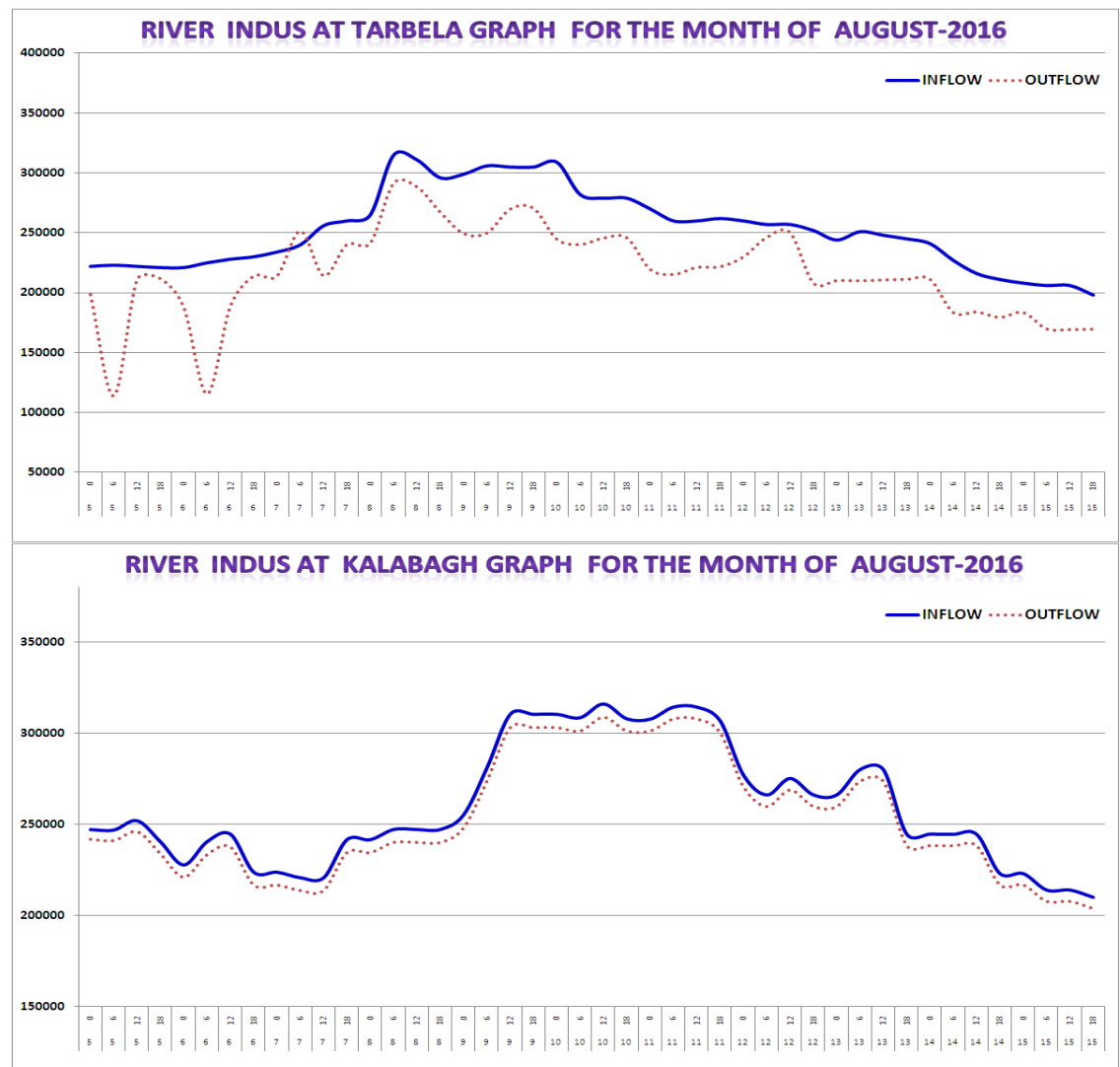
Figure 33: Temporal distribution of rainfall during August 2016.

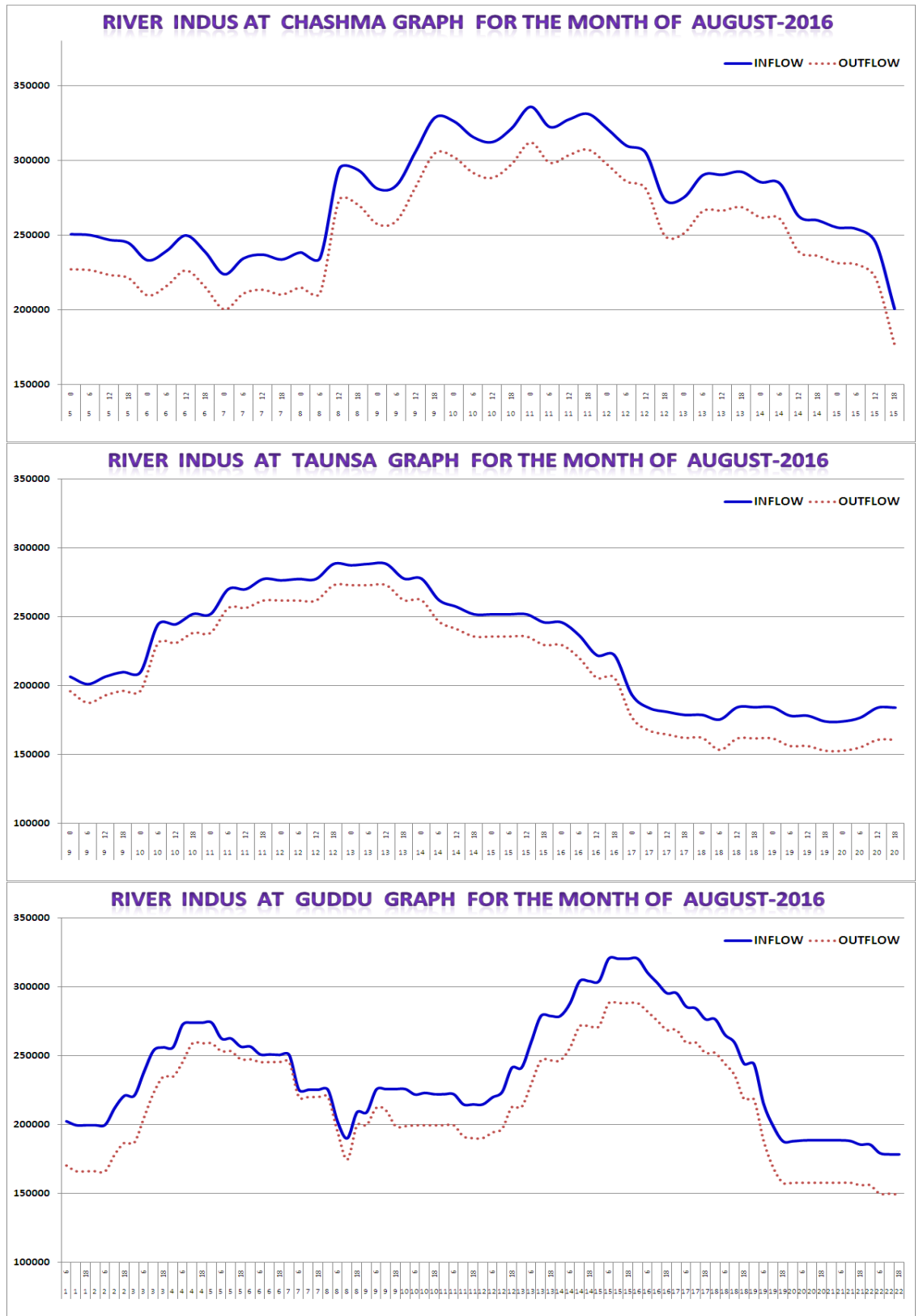
5.9 Position of rivers during the month

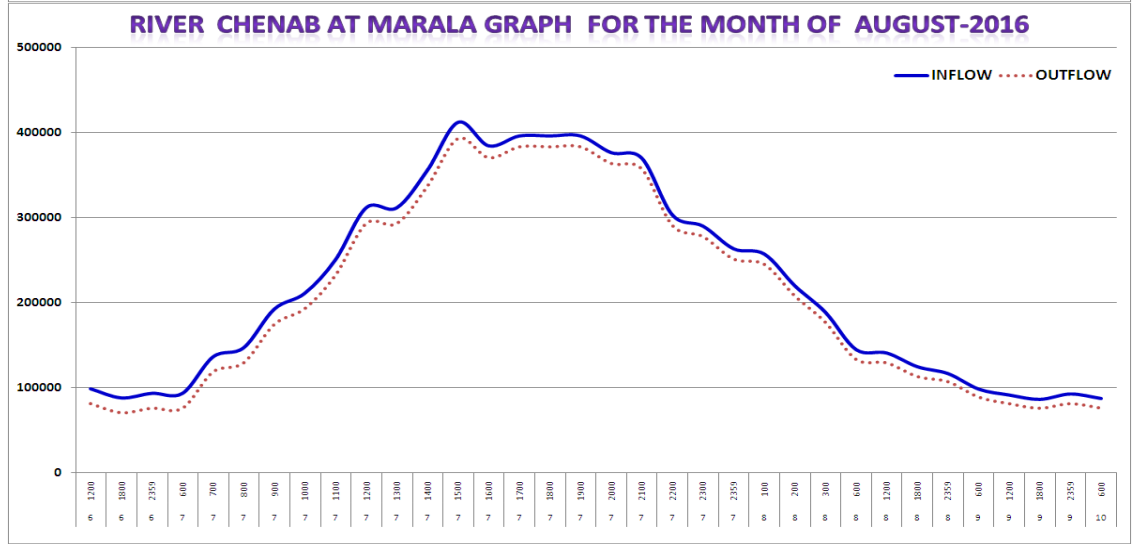
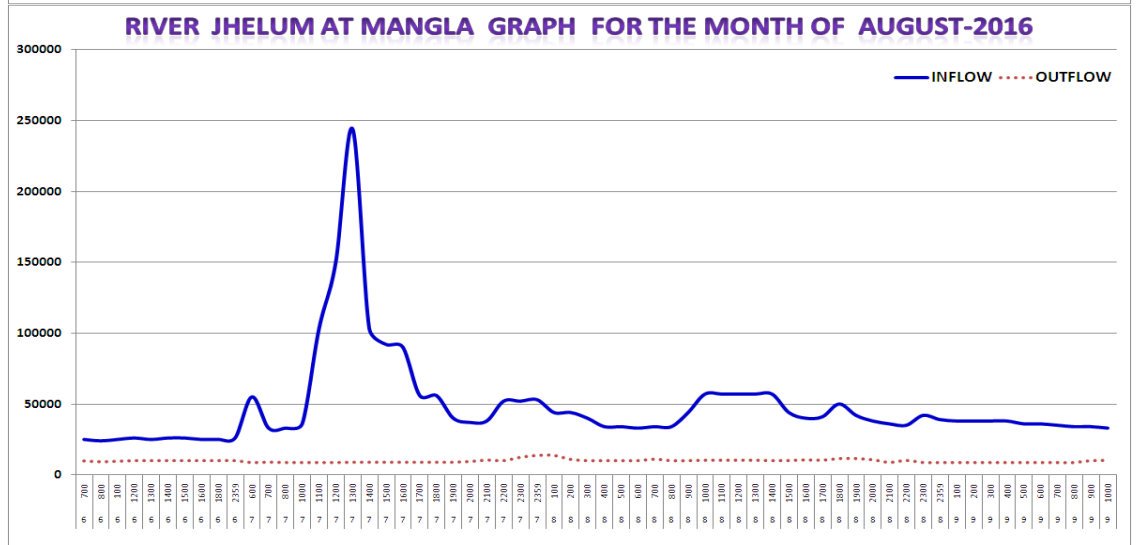
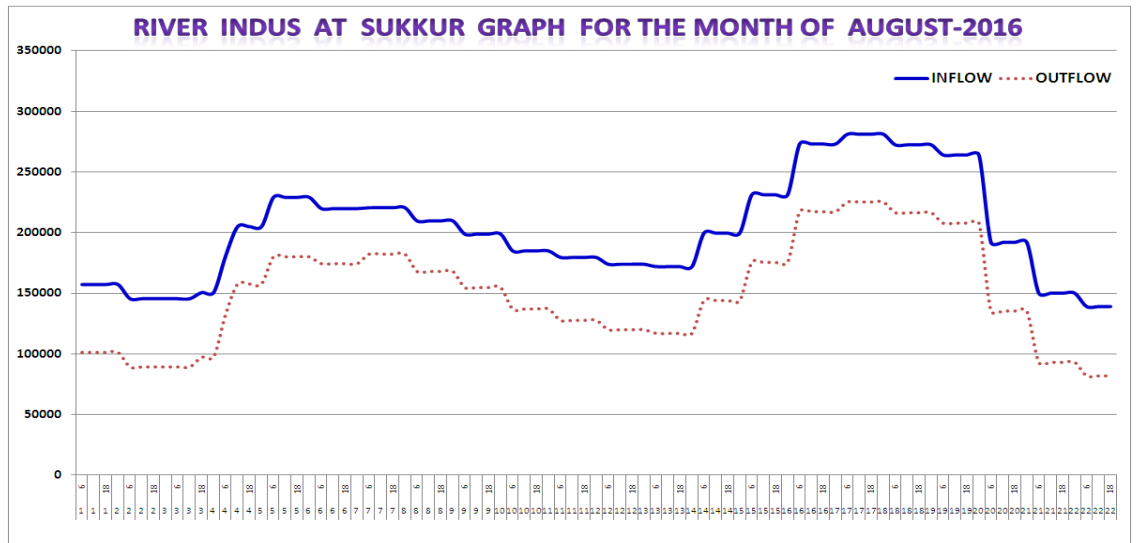
Flood peaks (Cusecs) recorded during August, 2016 are shown below.

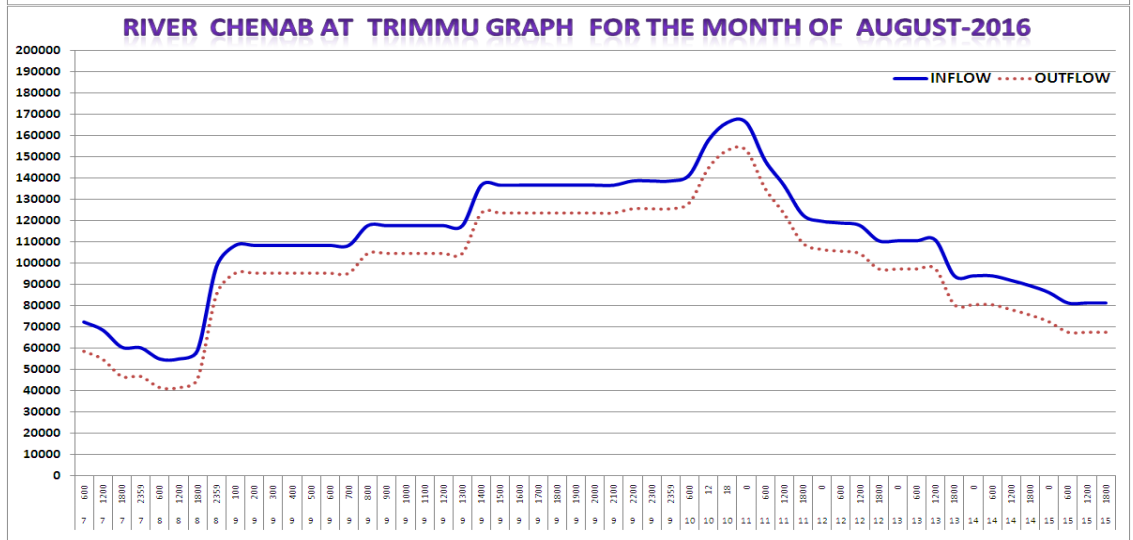
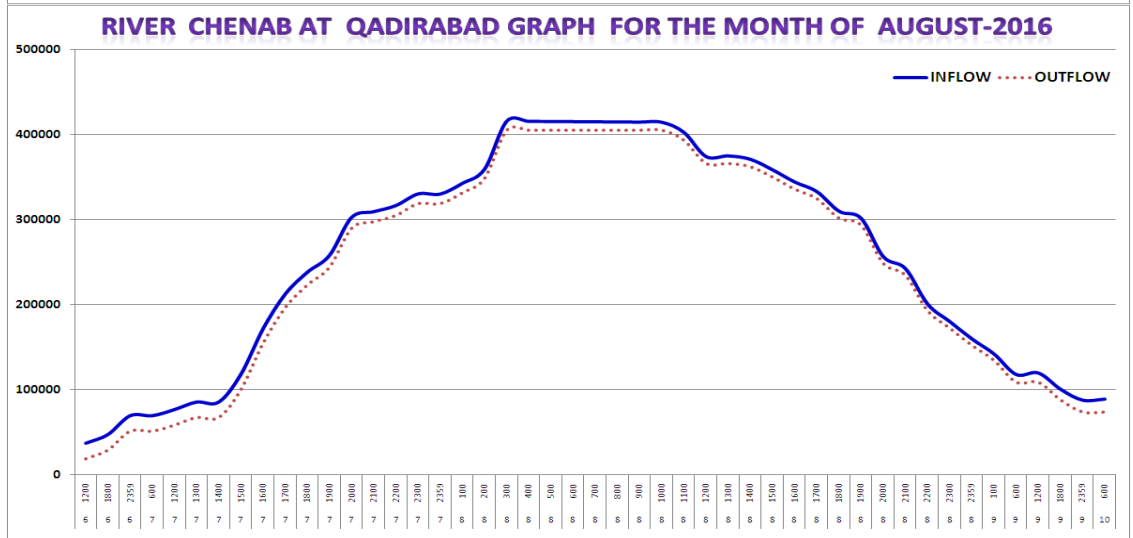
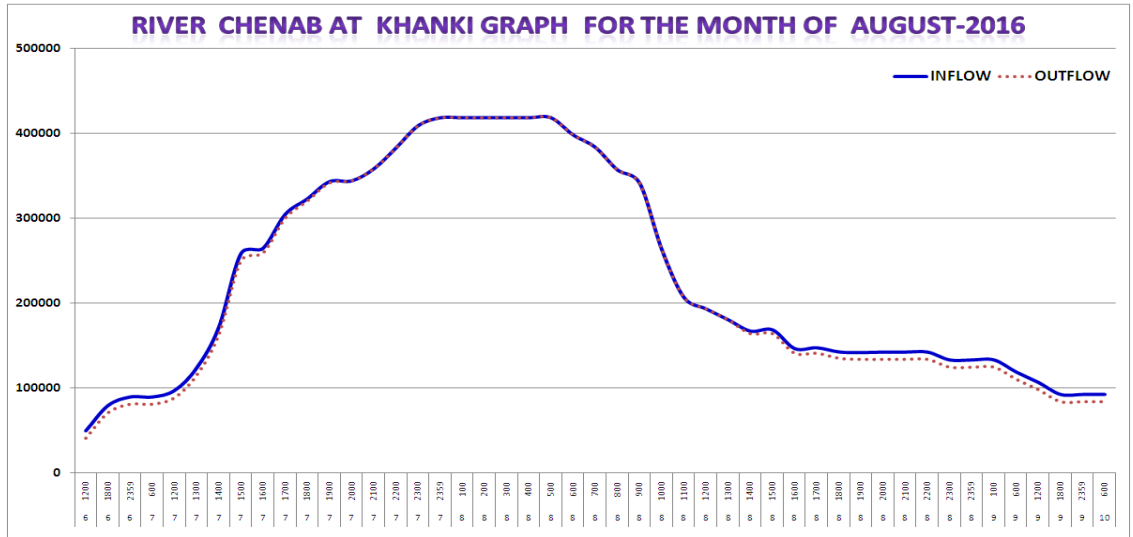
Date	Rivers	Stations	Peaks Inflows	Flood level
07/08/2016	Jhelum	Mangla	244000	V.High
07/08/2016	Chenab	Marala	412065	V.High
07/08/2016	Chenab	Khanki	418736	V.High
07/08/2016	Chenab	Qadirabad	416492	V.High
10/08/2016	Chenab	Trimu	166139	Low
08/08/2016	Indus	Tarbela	315000	Low
10/08/2016	Indus	Kalabagh	316131	Low
11/08/2016	Indus	Chashma	336097	Low
12/08/2016	Indus	Taunsa	288616	Low
15/08/2016	Indus	Guddu	320618	Low
17/08/2016	Indus	Sukkur	281515	Low
08/08/2016	Ravi	Shahdara	44595	Low
09/08/2016	Ravi	Balloki	60425	Low

5.10 Hydrographs observed during the month of August 2016 are as under









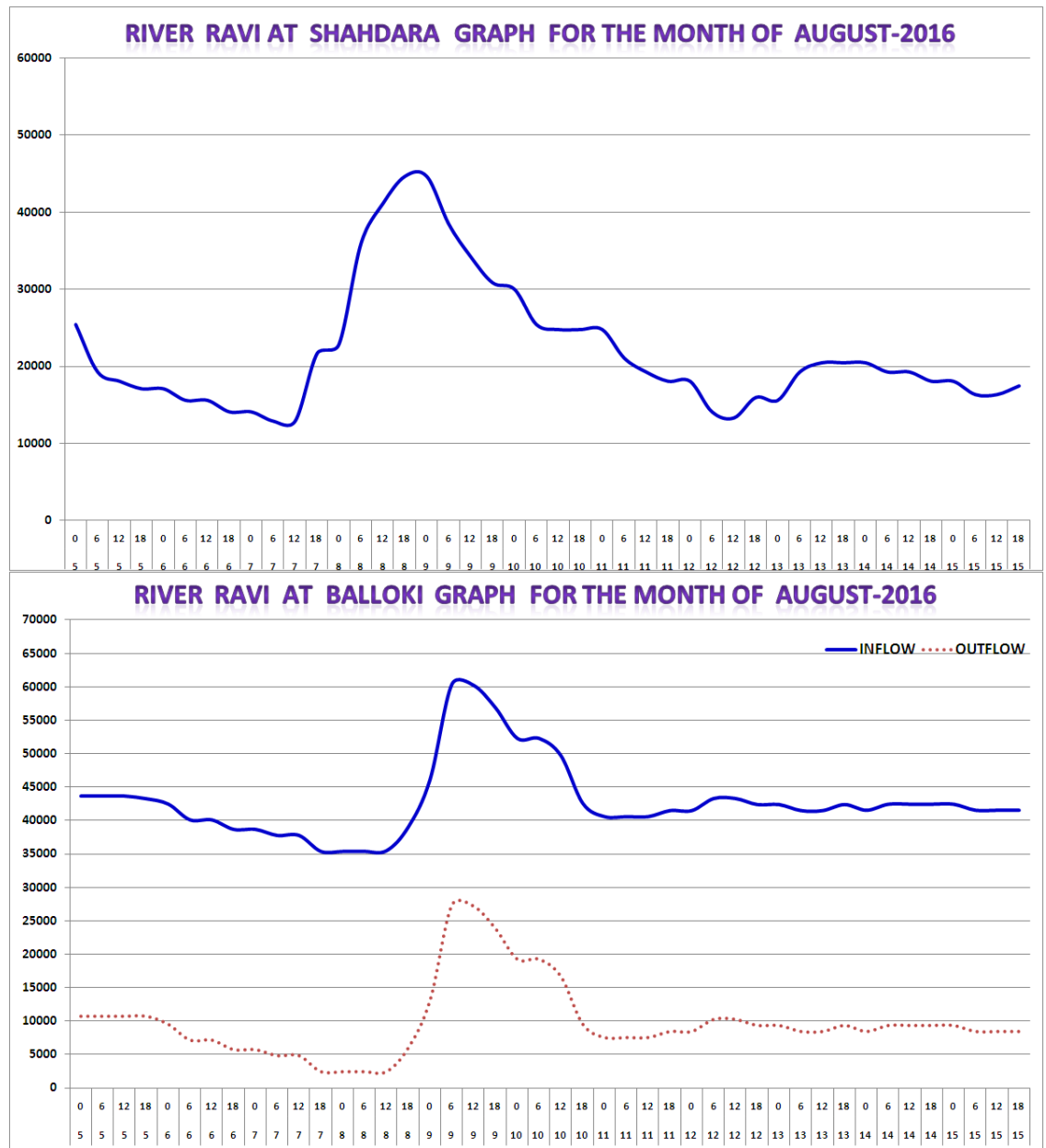


Figure 34: Hydrographs for the month of August-2016.

6 Significant hydro-meteorological events during the month of September 2016

No monsoon low developed during the month of September over Bay of Bengal. Only one wet spell was recorded during the month.

6.1 First wet spell of September (12th to 14th September 2016)

The only rainy spell of September occurred during 12th to 14th September 2016. During this period light to moderate rainfall was reported from North & Northeast Punjab, Khyber Pakhtunkhwa & Kashmir and this situation was created by the presence of a westerly wave over most parts of Pakistan in presence of sufficient moisture available as shown in Figure 35. This westerly wave pushed the subtropical high eastwards Figure 36 shows the spatial distribution of this rainfall spell.

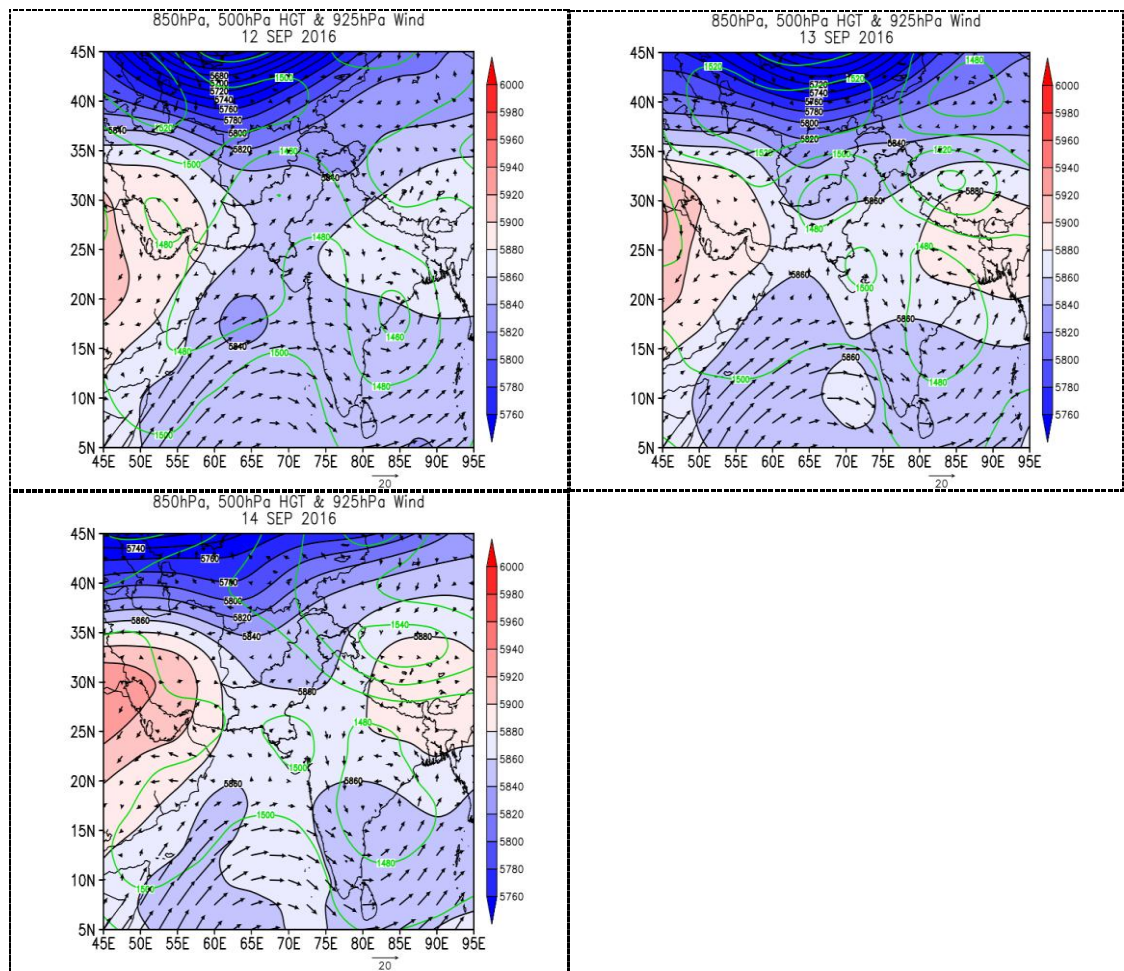


Figure 35: 500 & 850 hPa geopotential height patterns and 925 hPa winds on 12th to 14th September 2016.

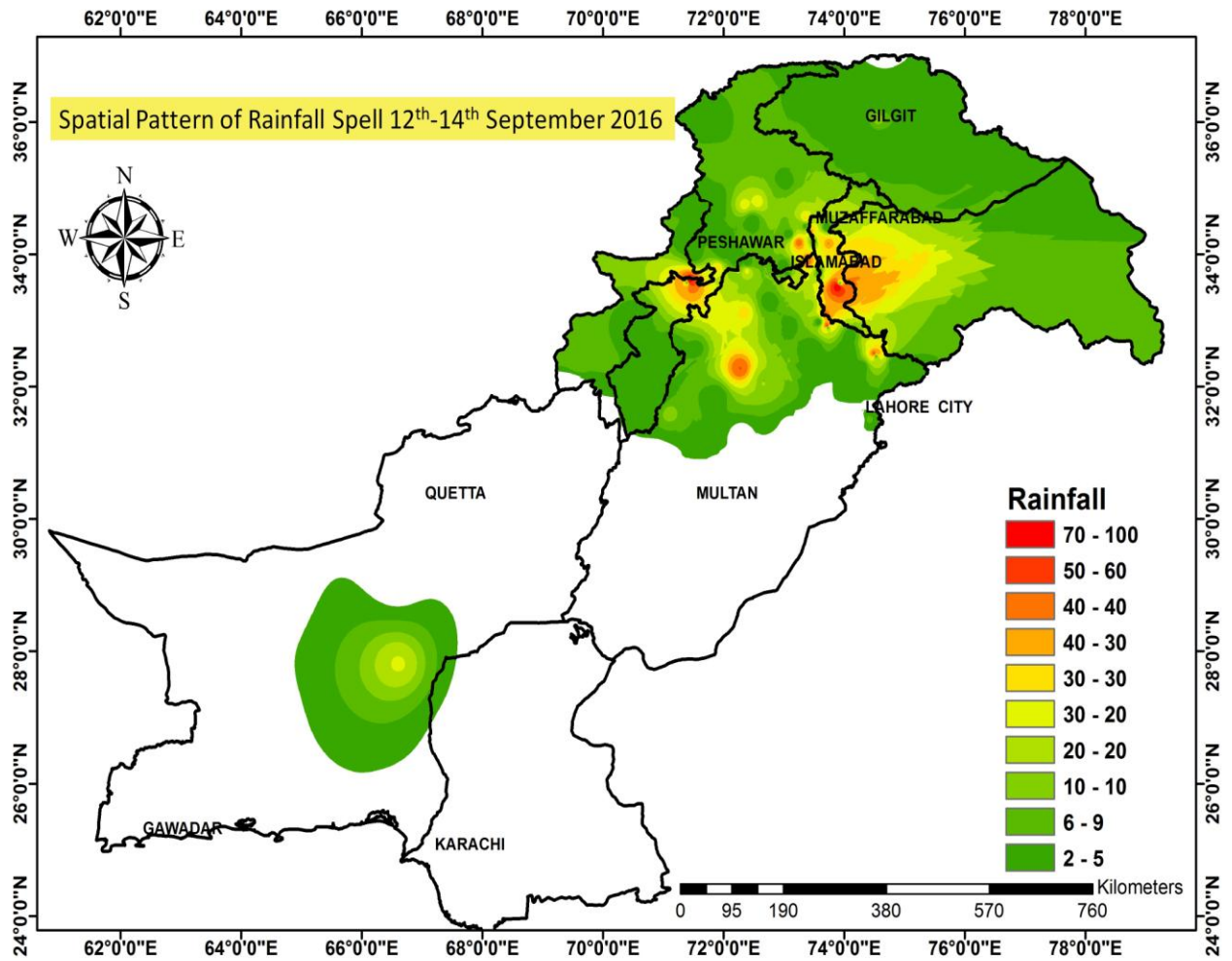


Figure 36: Significant rainfall of September 2016 (12-14 September).

Radar image shows light to moderate rainfall intensity in the upper catchments of Rivers Chenab & Jhelum and satellite images showing moderate clouds over North Punjab & upper Khyber Pakhtunkha along with Kashmir

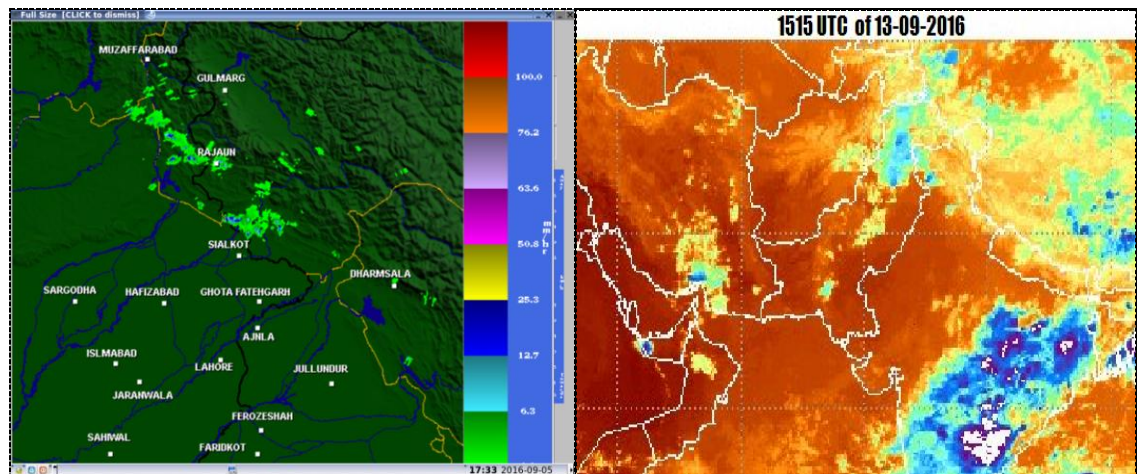


Figure 37: Radar & Satellites Images during the spell of September 2016 (20-27 September).

6.2 Position of rivers during the month of September 2016

Due to this spell no significant change in river flows was observed.

6.3 Spatial pattern of rainfall during the month of September 2016

A rainfall maxima of more than 120 mm is located around Northeast Punjab over Lahore while another center of moderately heavy rainfall above 100 mm is found over Kashmir as shown in figure 38.

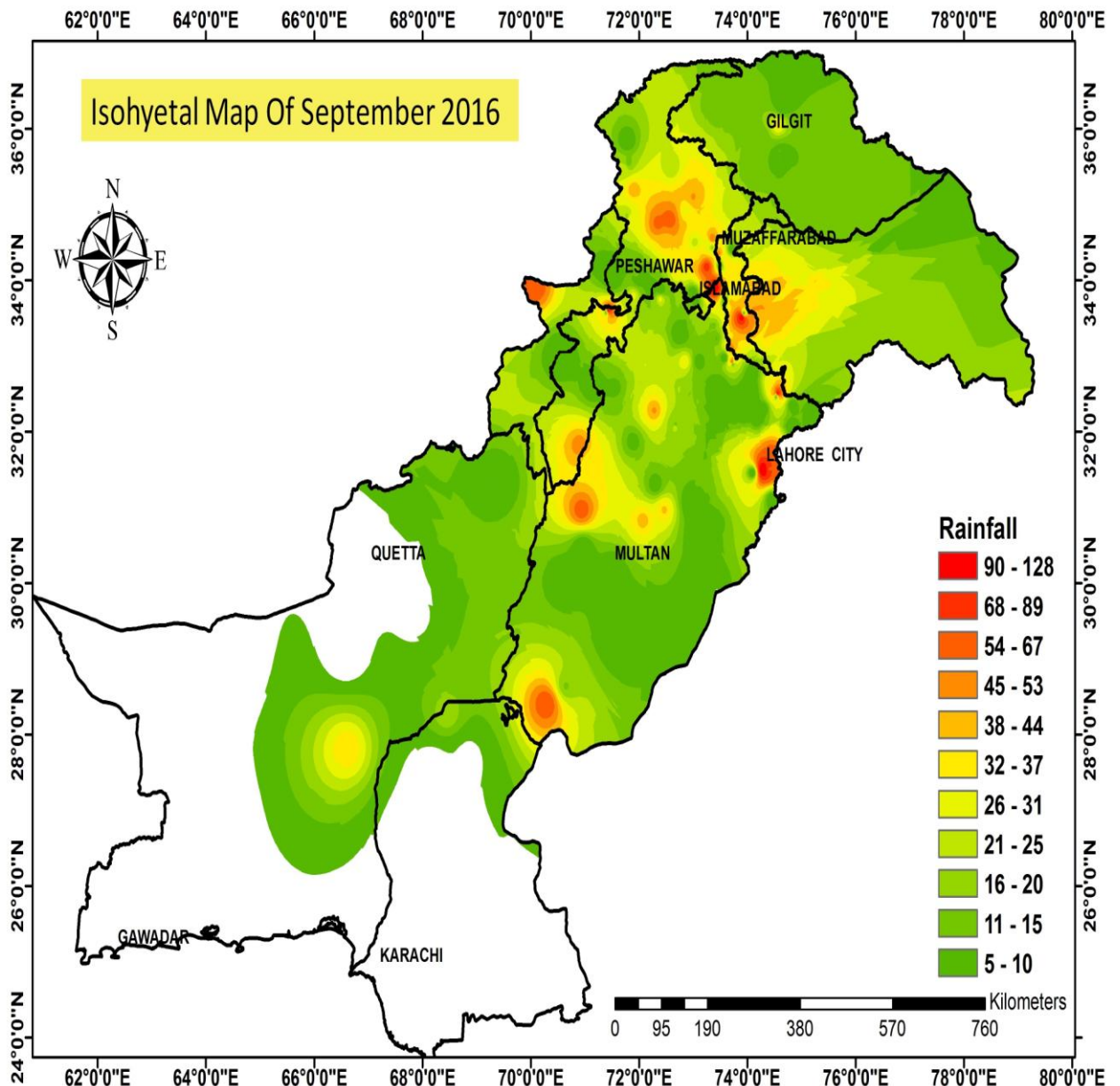


Figure 38: Isohyetal map of September 2016.

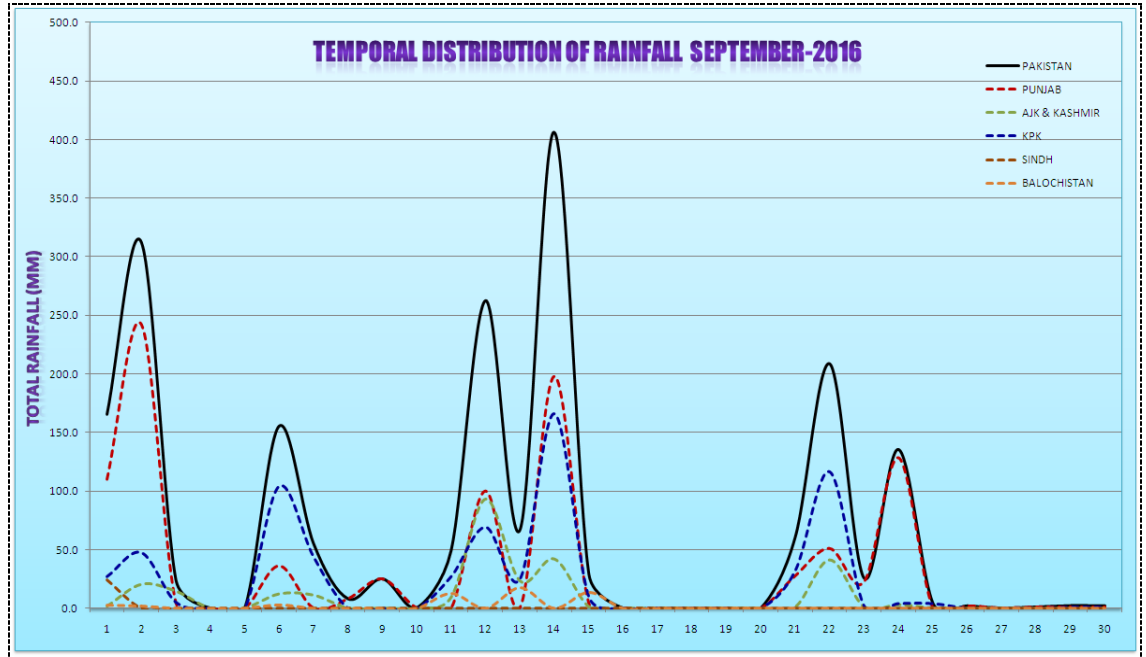
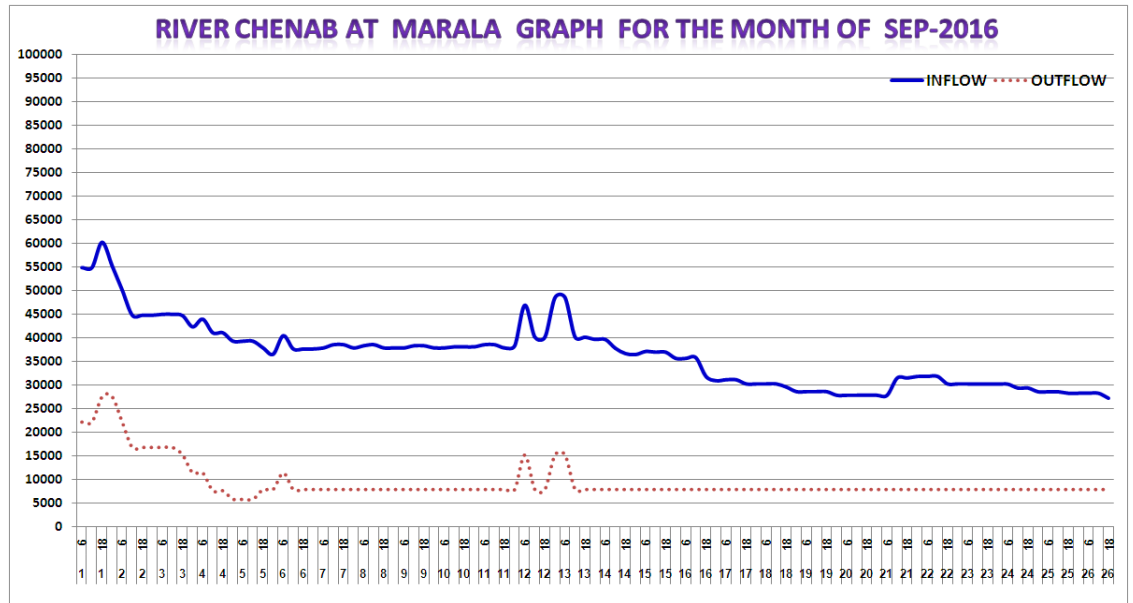
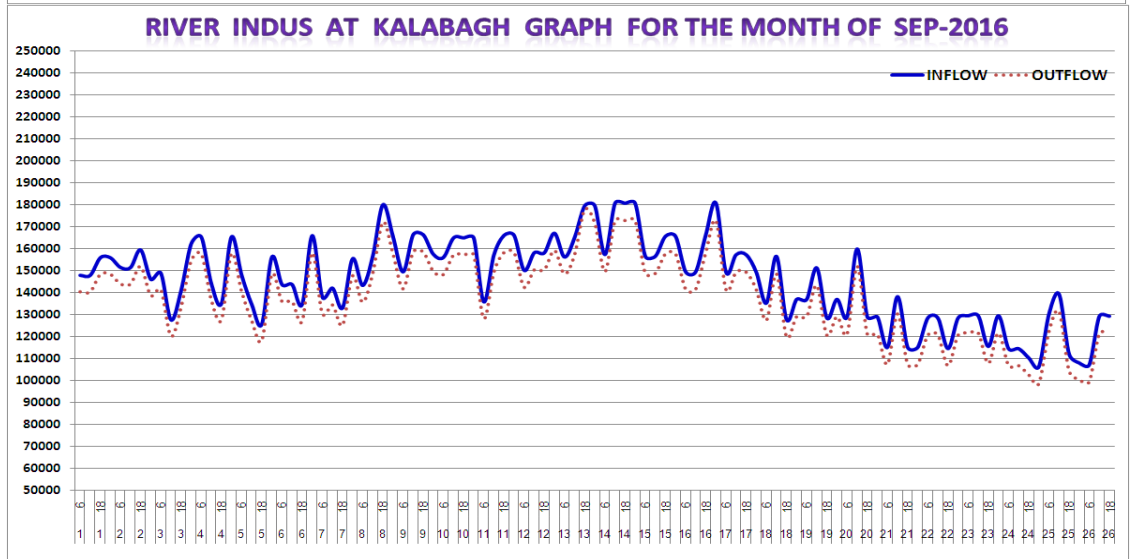
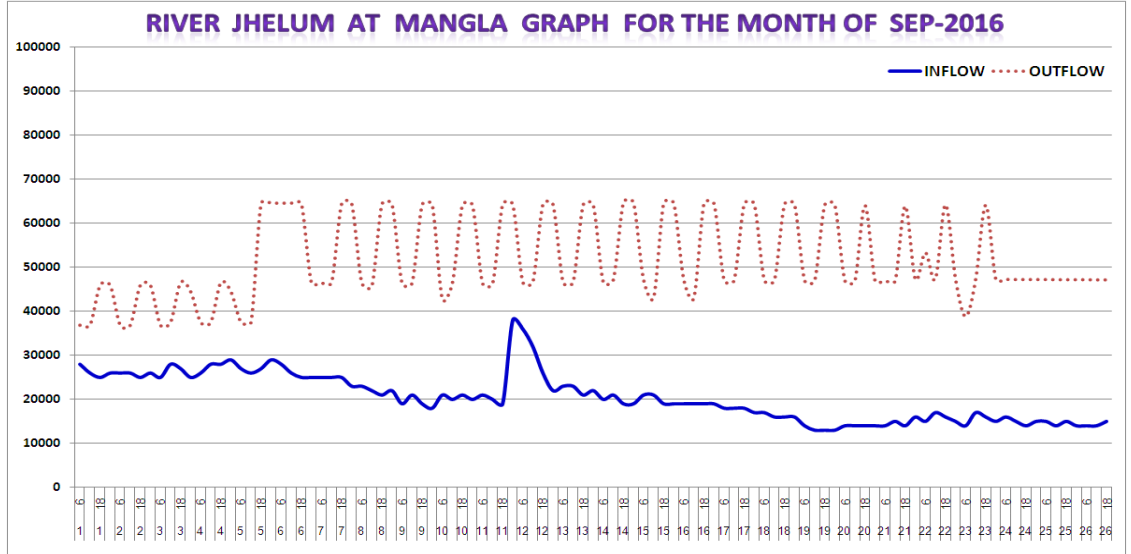
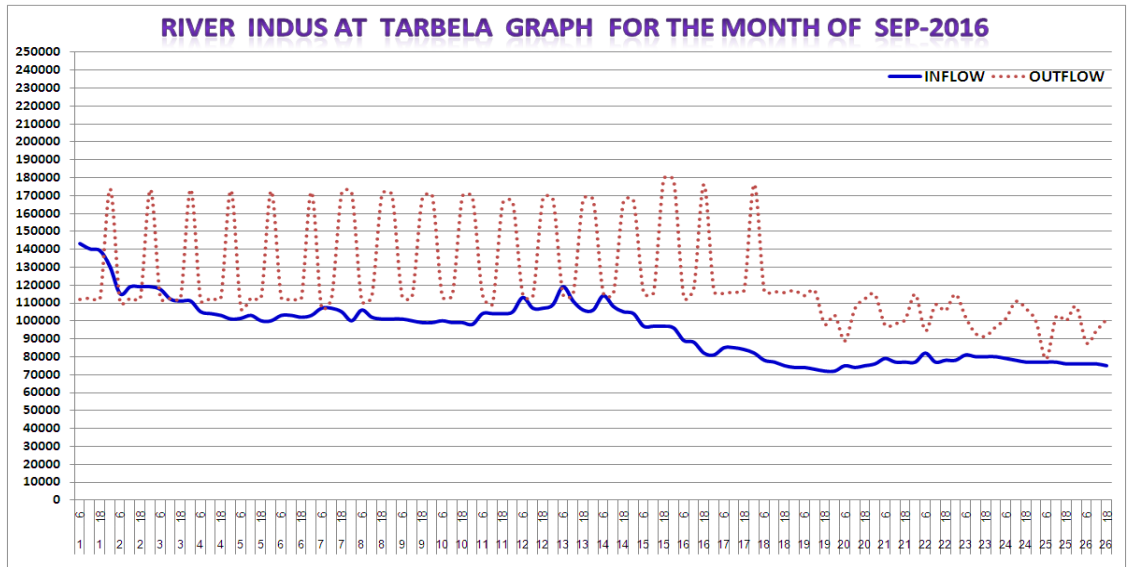


Figure 39: Temporal distribution of rainfall during September 2016 (20-27 September).

6.4 Position of rivers during the month of September

No significant flood peak was observed during the month of September-2016.





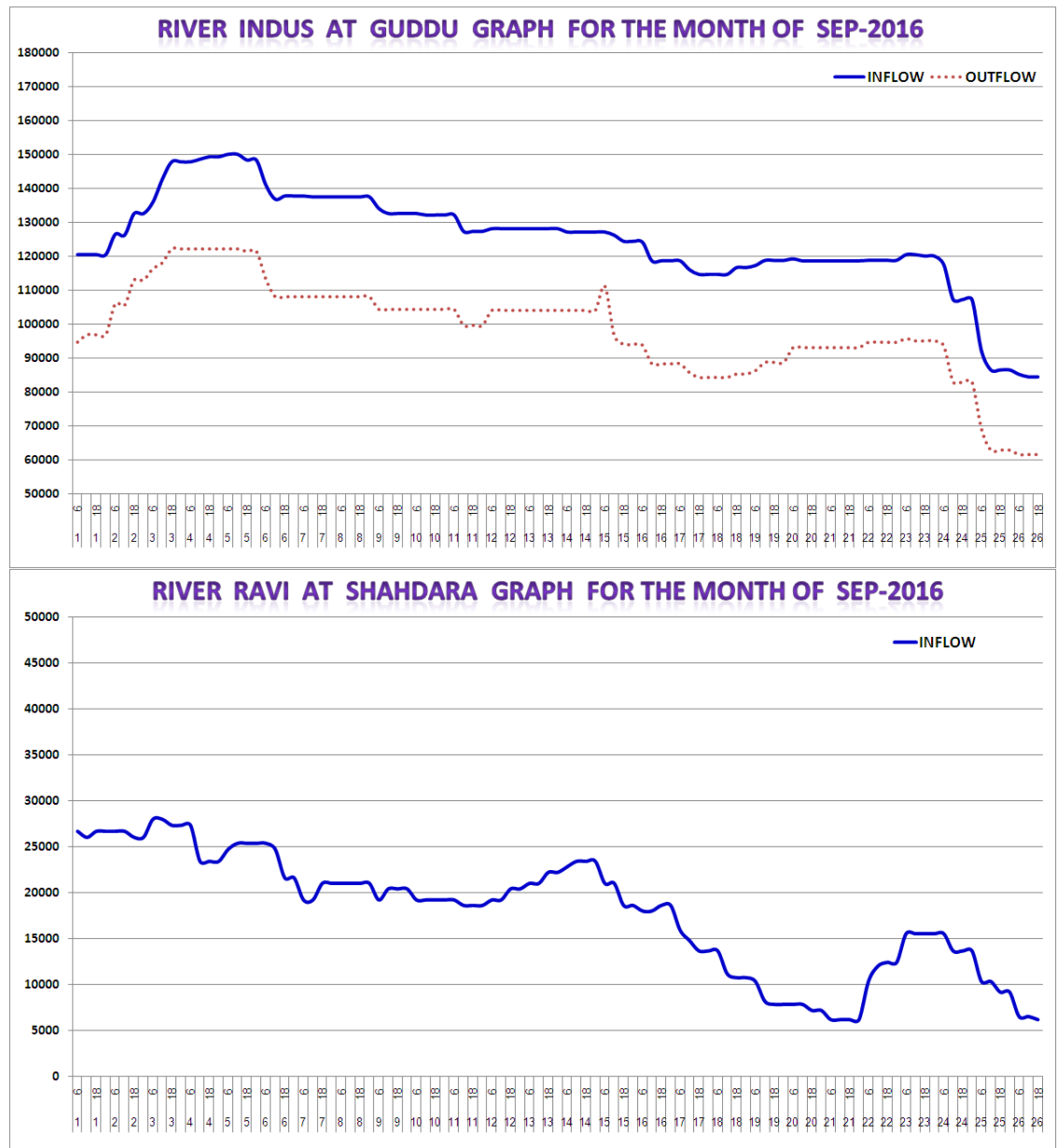


Figure 40: Hydrographs for the month of September-2016.

7 Seasonal rainfall pattern July to September 2016

Seasonal rainfall pattern during the season is shown in figure 41. Region of maximum precipitation (more than 500 mm) is located over Mandibahuddin in North Punjab. Other two center of extreme rainfall of more than 450 mm are located over Northeast Punjab & Kashmir. West Balochistan remained almost dry during the season.

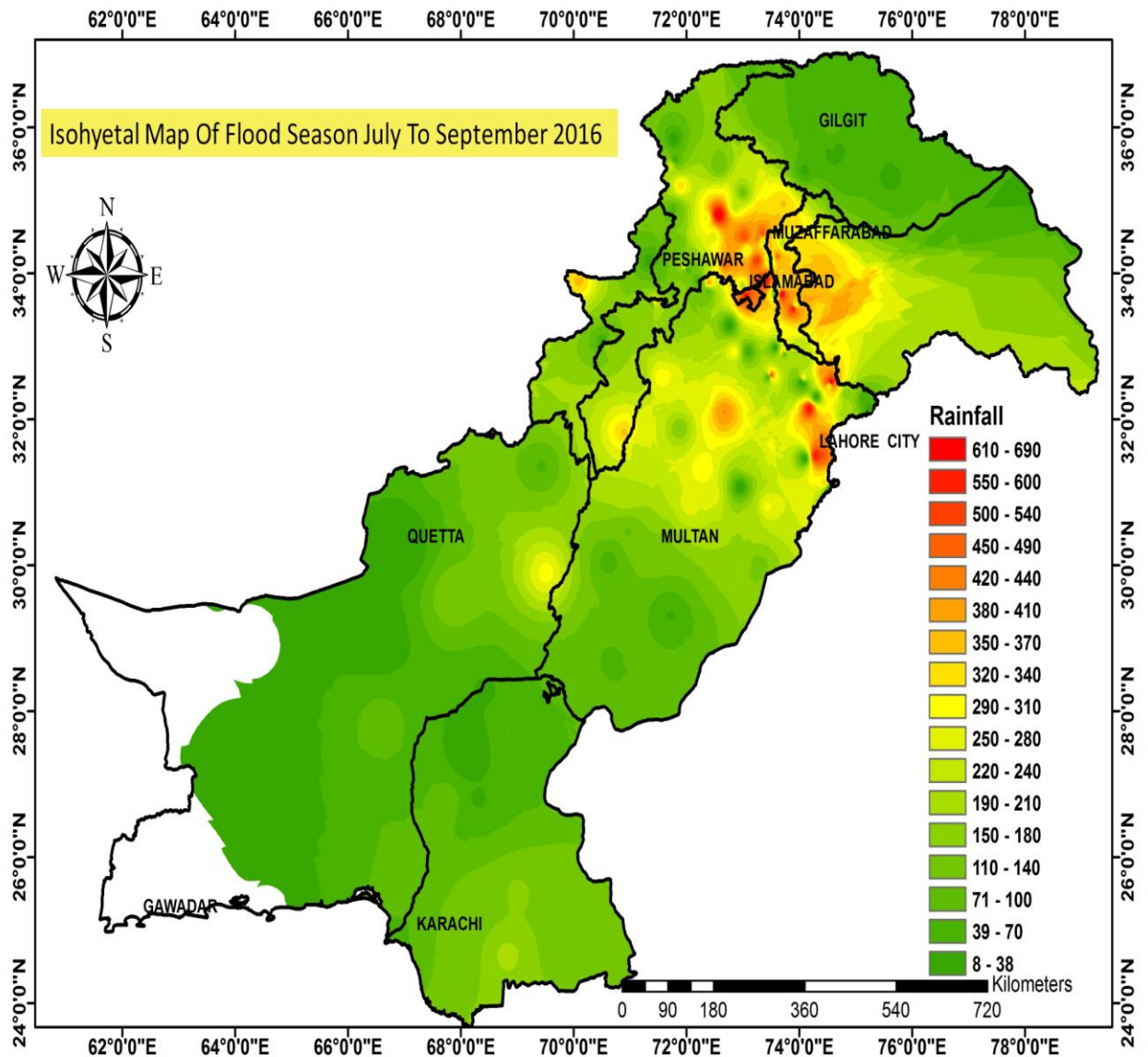


Figure 41: Seasonal isohyetal map (July-September-2016).

8 Seasonal area weighted precipitation from July-September 2016

The seasonal percentage departure precipitation map obtained from Climate Data Processing Centre (CDPC) of Pakistan Meteorological Department for monsoon 2016 indicates 25% more than normal precipitation on all Pakistan basis. Scattering it at provincial level, it is observed that Khyber Pakhtunkhwa, Punjab, Gilgit Baltistan and Sindh received 37%, 55%, 22% and 2% respectively above normal rainfall while Kashmir received relatively less rainfall where precipitation remained 19% below normal and Balochistan received 17% below normal rainfall as shown in figure 42. Isopercental map of rainfall also prepared which is shown in figure 43.

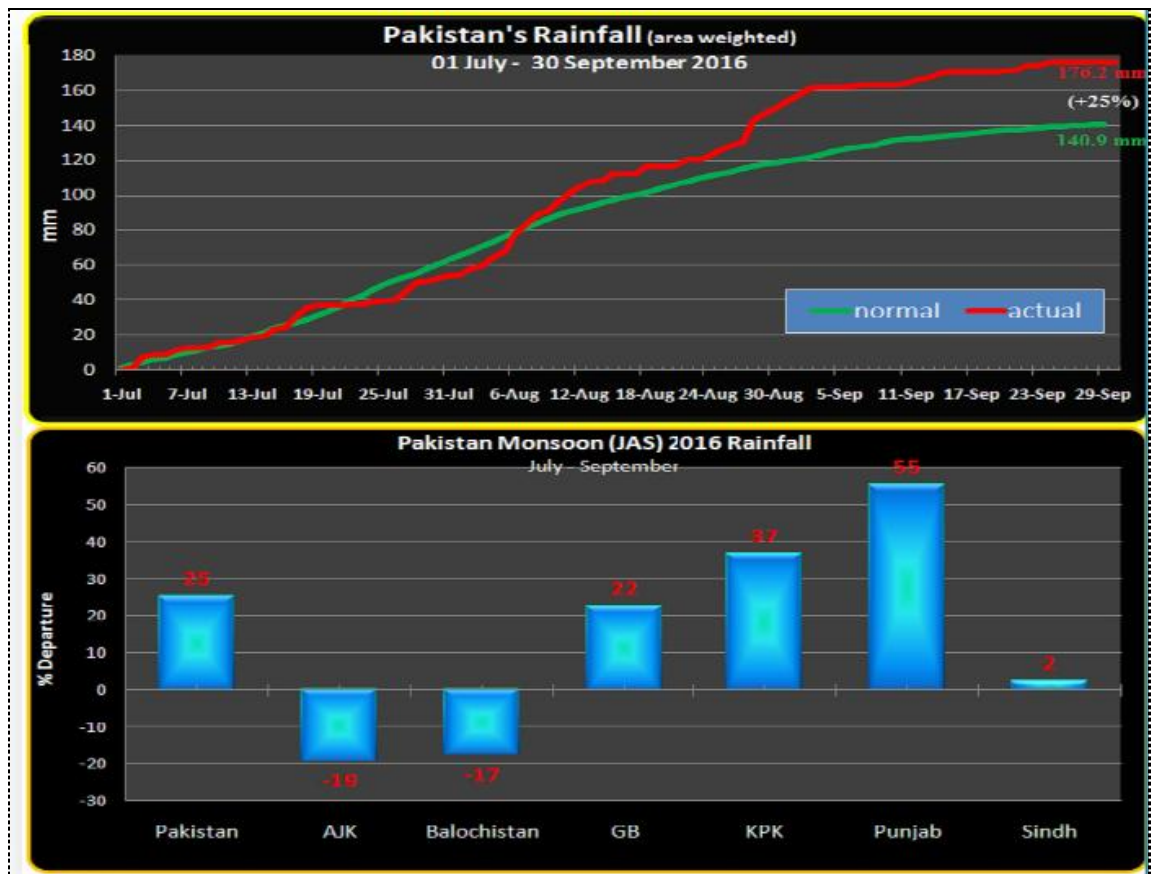


Figure 42: Monsoon July-Aug-Sept (JAS) 2016 rainfall.

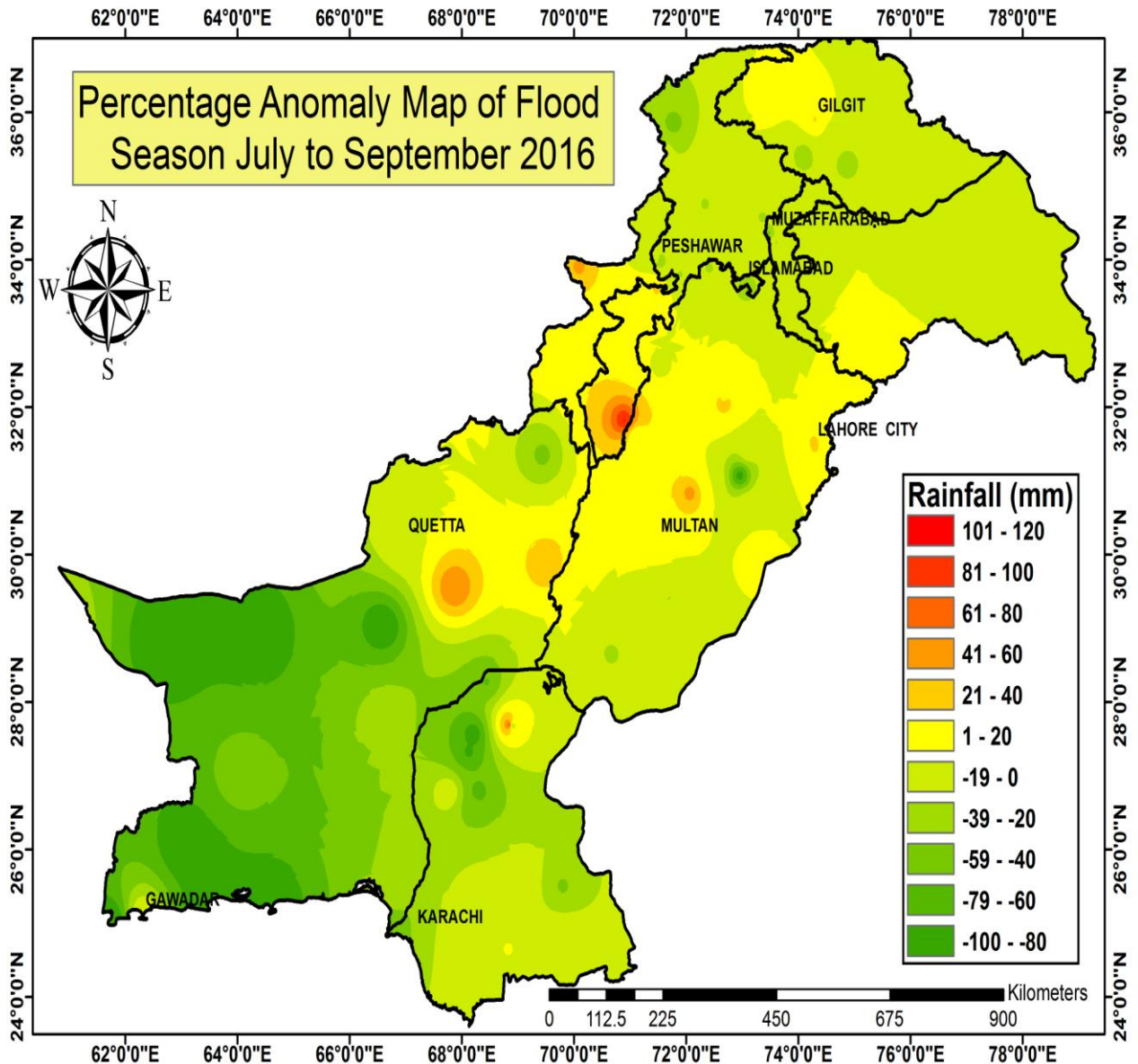


Figure 43: Seasonal percentage departure map (July-September 2016).

9 Kharif season forecast

Water availability (MAF) forecast for Kharif season was issued on 05th April, 2016 for River Indus at Tarbela & River Jhelum at Mangla. Comparison of forecasted and observed volume (MAF) is shown in fig 44.

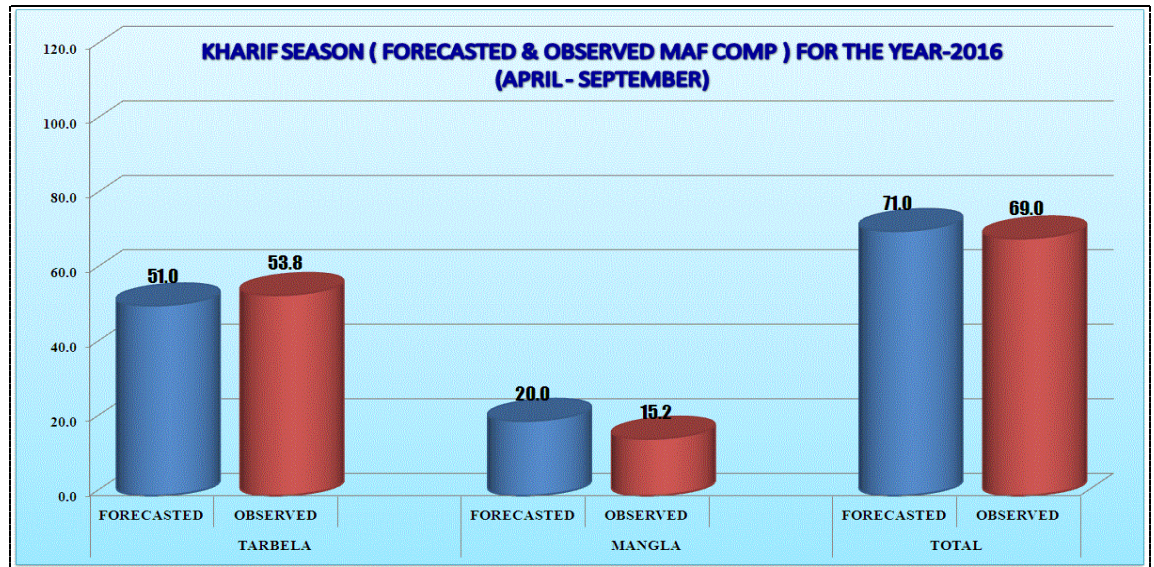
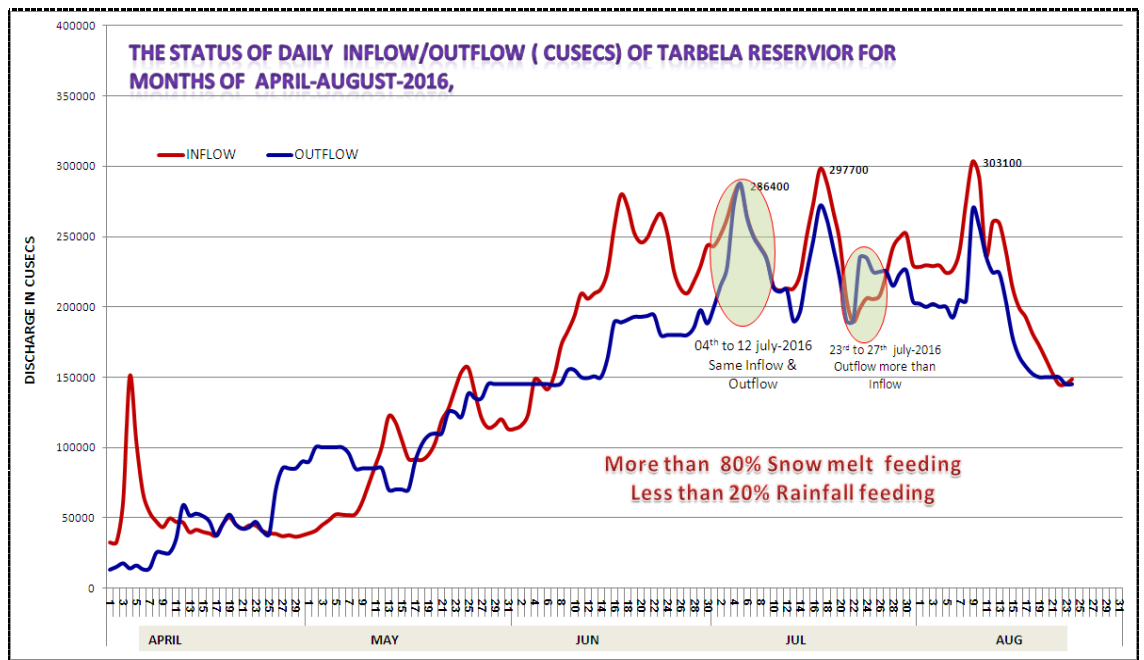


Figure 44:Kharif Season forecast (April-September 2016).

10 Filling of Tarbela reservoir during the Flood Season-2016.

Average inflows and outflows during April to August 2016 and corresponding dam level from June to August are shown in fig 45. Graph-1 shows that from 04th to 12th July-2016 inflow and outflow remained same. While outflows were more than inflows during 23rd to 27th July-2016, which may be the cause that maximum conservation level of Tarbela dam was not attained.



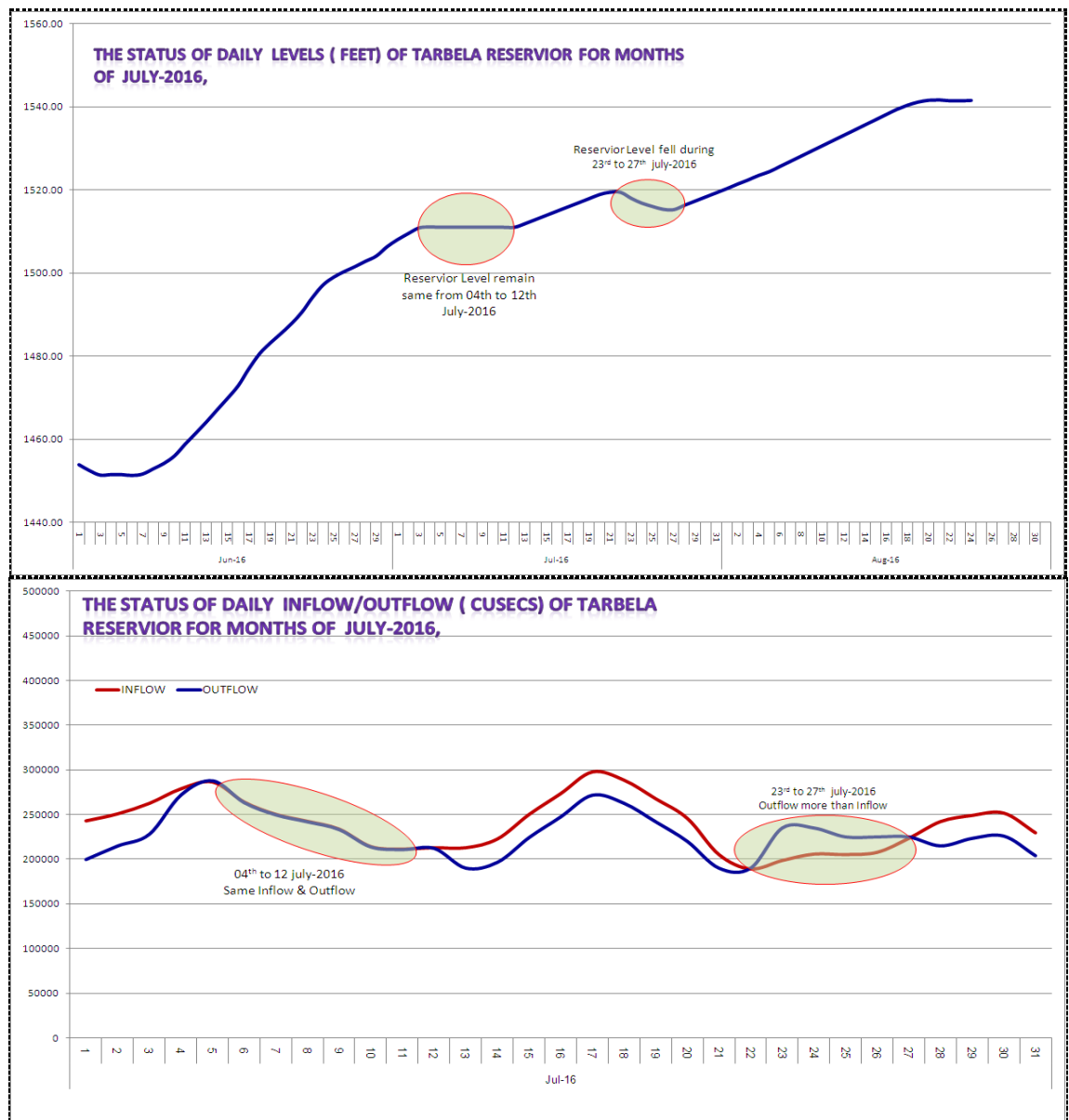


Figure 45: Filling of Tarbela Reservoir

11 Reduced river flows in Mangla catchment during monsoon 2016

The dam is located 115 km south-east of Islamabad, on the river Jhelum at Mangla. The dam is physically located both in the state of Azad Jammu and Kashmir and the province of Punjab (district Jhelum). The Jhelum basin (upstream of Mangla) extends over the southern slopes of the north-west terminus of the Himalayan mountain range and the reservoir is situated in the south-west sub-basin in the Siwalik soft rocks. The original catchment area at the dam site is about 12,870 sq. miles.

The mountain range in which the river Jhelum flows is rugged, contains steep slopes, and presents extreme weather conditions. The catchment area lies in the active monsoon belt, in summer heavy rainfall and in winter light showers and snowfall is the norm. In winter precipitation is mostly deposited in the Mangla catchment as snow, which is a source of runoff during summer months. The major source of rainfall is the monsoon weather system with July & August being the most active months. The higher June inflow is attributed to increased quantity of snow-melt (due to rising temperatures) while the July-September increase is a combination of rainfall and snow-melt.

The Mangla reservoir was built for irrigation as well as power generation. The variability in climatic variables (temperature and precipitation) at spatial and temporal scales affects the stream flows. Present studies reveal that the annual mean temperature has increased in all the five basins of Jhelum catchment. The annual stream flows in rivers Kanshi, Poonch, Kunhar, Neelum, and Jhelum have decreased up to 35%, 37%, 5% and 11 % in spring season with increase of 1°C temperature during the last three decades (1971-2010).

The Glaciers at upper Mangla catchment are not as significant as the rainfall, which affects the lower part of the catchment and could cause the flooding in low lying areas. Despite this, it has also been accepted that the seasonal snowfall has more significant contribution to river flow during summer season as compared to glaciers melting. Furthermore, the glaciers of Kashmir lie in Mangla watershed which is drained by Jhelum River contributing about 16 percent flows to the Indus River system.

Another study revealed that climate change is occurring at a rapid pace more with warming trends in lower part of Mangla catchment whereas cooling trends were observed in higher part. The prevailing trends, caused by climate change, have an effect on the flows which may be the cause of decrease in runoff generated from seasonal snow melt which also needs further investigation on rainfall distribution due to temperature changes.

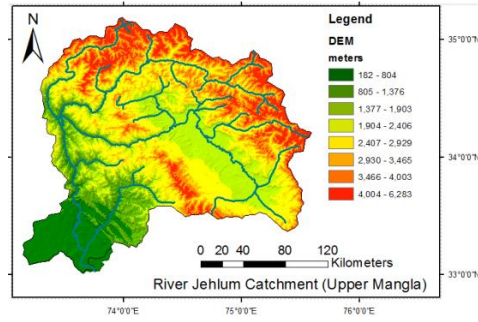


Figure 46 Jhelum Catchment (Upper Mangla)

Figure 46 is the representation of upper Mangla Catchment in terms of elevation using ASTER 30m DEM data.

The Figure 47 shows the location of River Jhelum, catchment and its sub-catchments at upper Mangla Dam. Moreover, it also shows the locations of selected gauging station for meteorological observations.

Ref: <https://hal.inria.fr/file/index/docid/719226/filename/M-1.pdf>

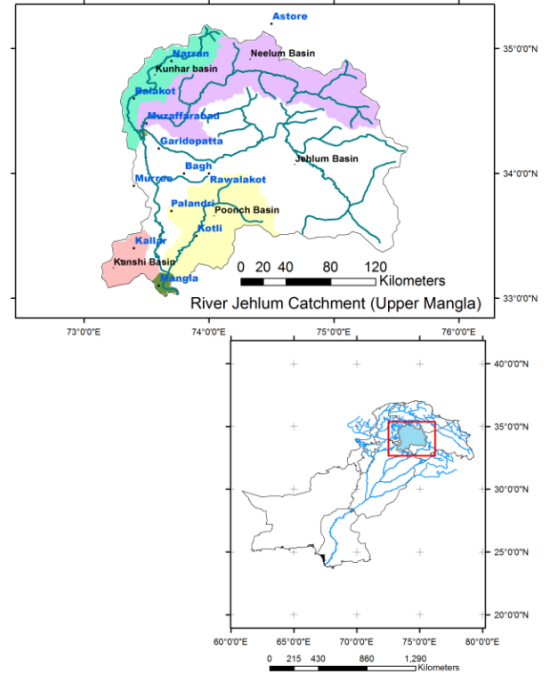


Figure 47 River Jhelum sub-basin (black text) and Meteorological Observatories (Blue text) locations

12 FEWS results comparison with actual discharges 2016

FEWS model was run on daily basis throughout the flood season i-e., from 15th June to 15th October, 2016.

12.1 Analysis of FEWS results based on up to 04th August 2016 Forecast:

FEWS made forecast on 04th August 2016 that all rivers will be flowing in their normal state during the next five days (up to 9th August 2016).

12.2 Analysis of FEWS results based on 05th August 2016 Forecast at Marala:

when the model was run on 5th August 2016, it produced a maximum peak of 137987 Cs on 10th August 2016 at 17:00 hours at Marala in River Chenab while all other rivers were shown flowing in their normal state during the next five days (up to 10th August 2016). Graphically, it is enumerated below:

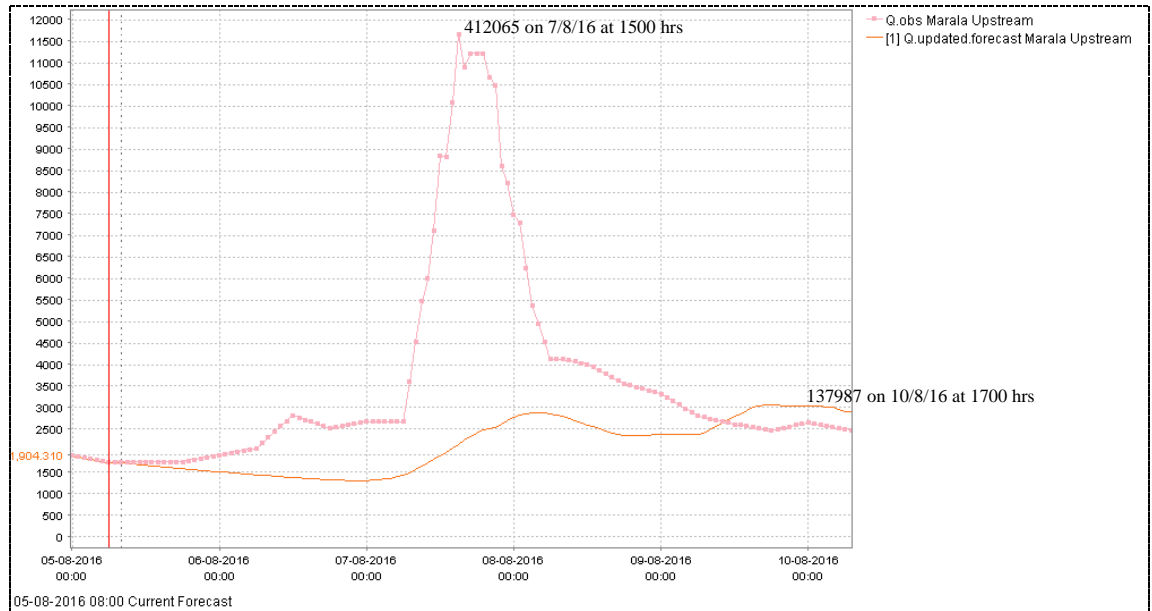


Figure 48: Analysis of FEWS results based on 5th to 10th August-2016

12.3 Analysis of FEWS results based on 06th August 2016 Forecast at Marala:

The model was run on 6th August 2016, it generated a maximum peak of 108982 Cs on 08th August 2016 at 03:00 hours at Marala, in River Chenab while all other rivers were shown flowing in their normal state during the next five days (up to 11th August 2016). Graphically, it is enumerated below:

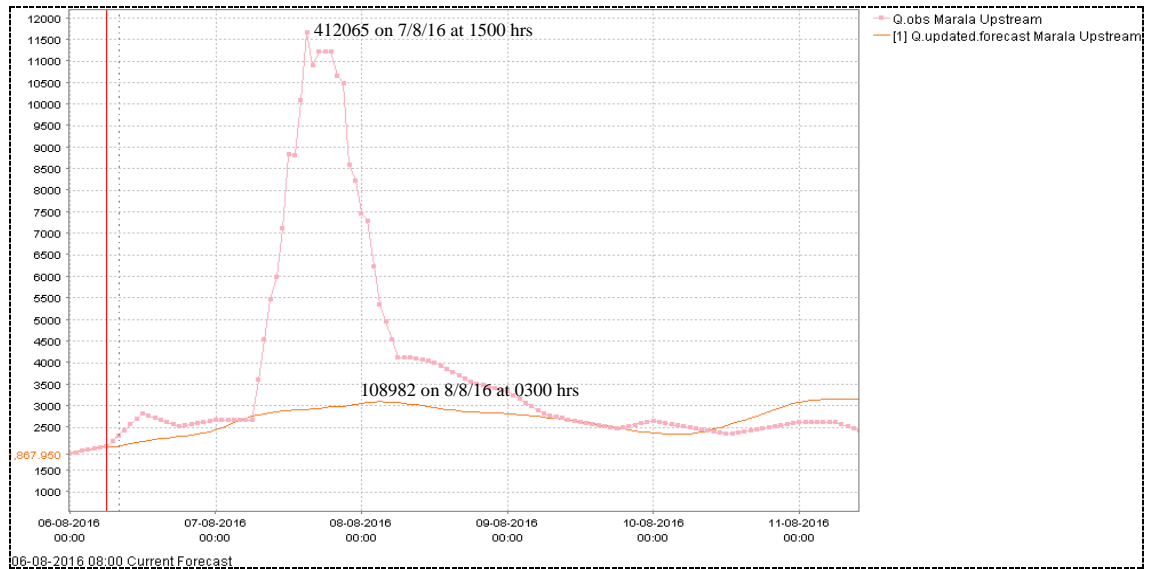


Figure 49: Analysis of FEWS results based on 6th to 11th August-2016

12.4 Analysis of FEWS results based on 07th August 2016 Forecast at Marala:

According to Model Forecast made on 07th August 2016, a maximum peak of 209999 Cs was predicted on 07th August 2016 at 13:00 hours at Marala in River Chenab during the next five days (up to 12th August 2016). Graphically, it is enumerated below:

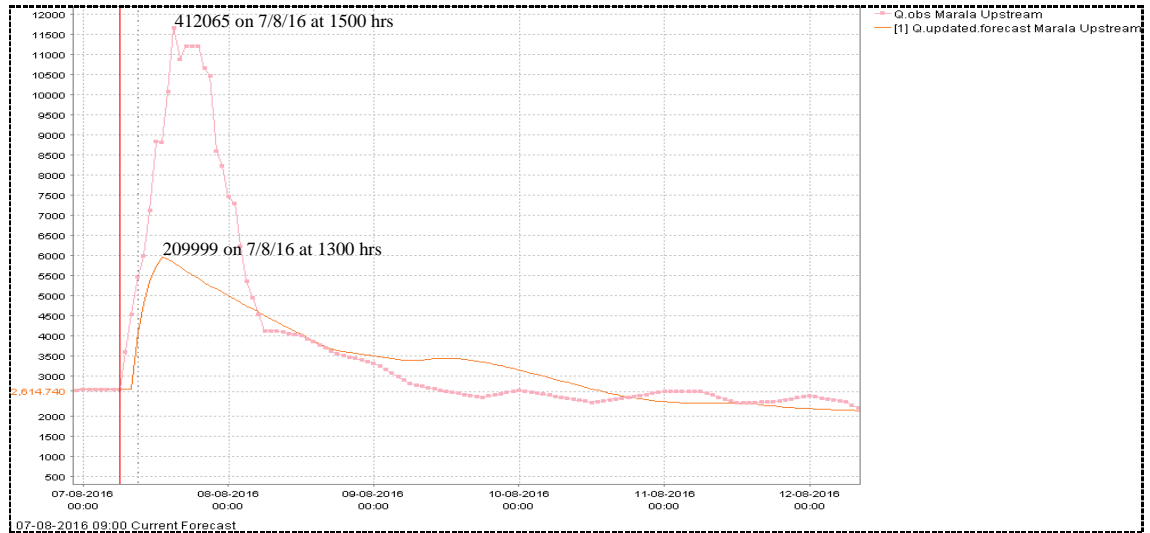


Figure 50: Analysis of FEWS results based on 7th to 12th August-2016

12.5 Analysis of FEWS results based on 07th August 2016 Forecast at Mangla:

Similarly, an inflow of about 80000 Cs was also predicted from 07th August 2016 at 22:00 hours to 12th August 2016 at Mangla, River Jhelum while all other rivers were shown flowing in their normal state during the next five days (up to 12th August 2016). Graphically, it is enumerated below:

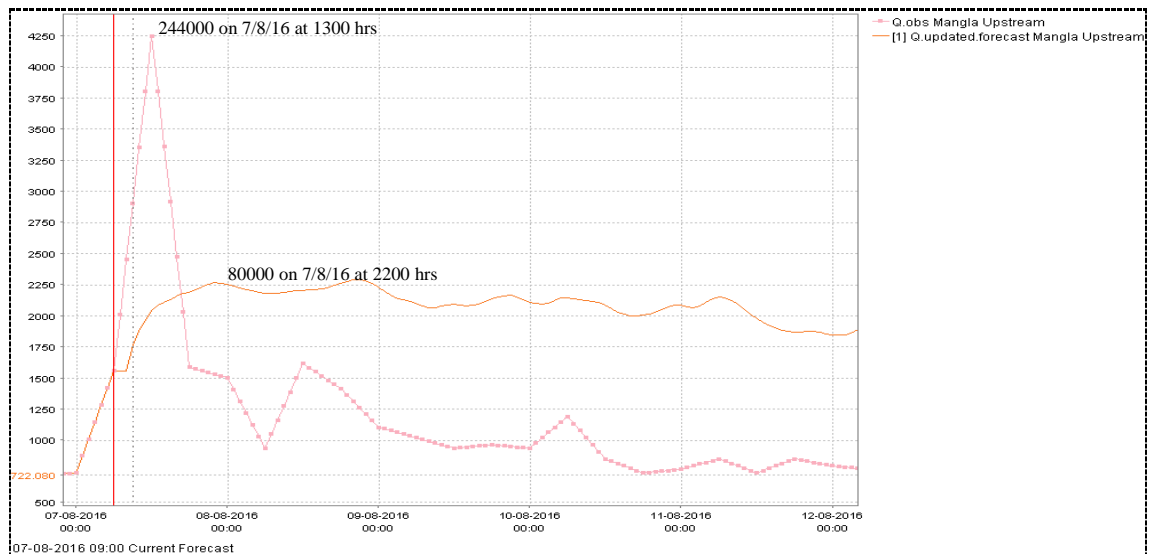


Figure 51: Analysis of FEWS results based on 7th to 12th August-2016

12.6 Analysis of FEWS results based on 07th August 2016 Forecast at Khanki:

Model gave discharge peak 284584 cusecs on 08.08.2016 at 11:00 Hrs. against actual flood peak 418736 cusecs on 08.08.2016 at 0000 hrs. Graphically, it is enumerated below:

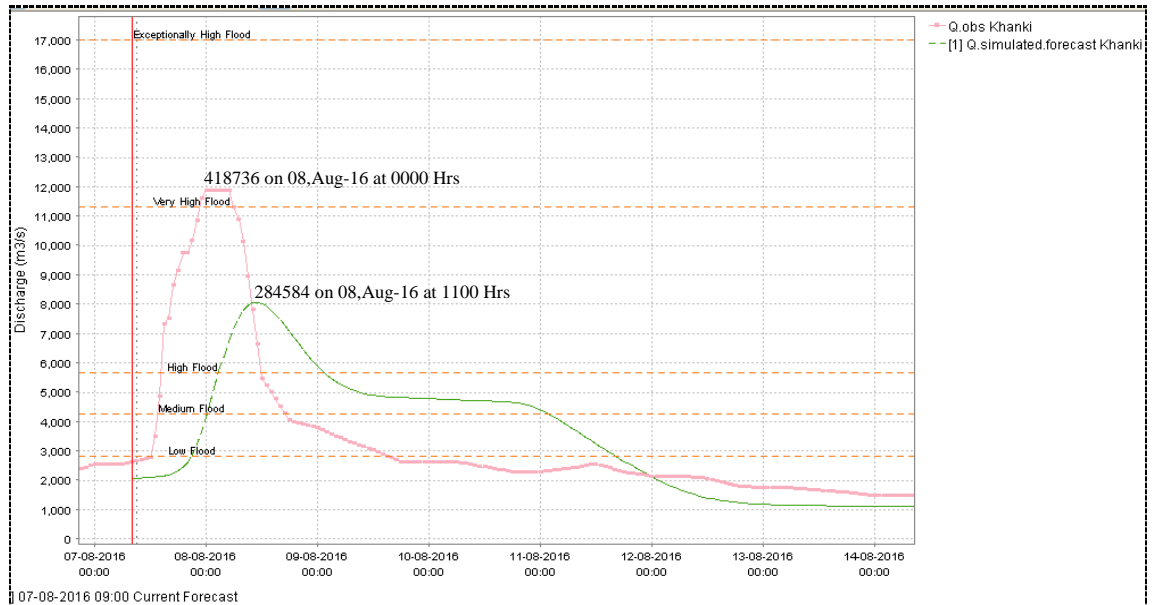


Figure 52: Analysis of FEWS results based on 7th to 14th August-2016

12.7 Analysis of FEWS results based on 07th August 2016 Forecast at Qadirabad:

The model produced flow peak 249254 cusecs on 08.08.2016 at 20:00 Hrs. against actual flood peak 416492 cusecs on 08.08.2016 at 0300 hrs. Graphically, it is enumerated below:

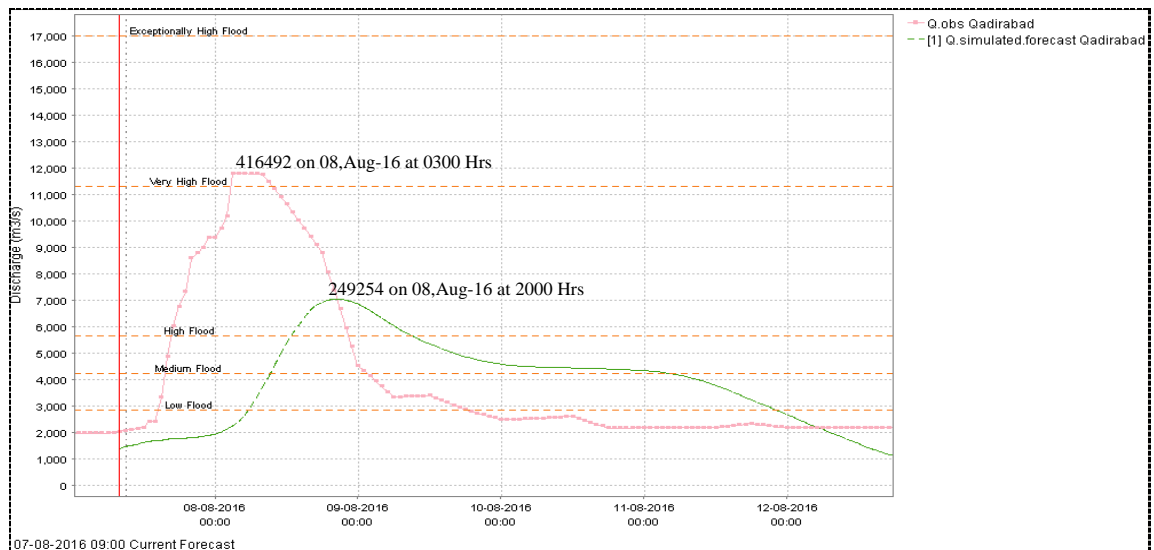


Figure 53: Analysis of FEWS results based on 7th to 12th August-2016

12.8 Analysis of FEWS results based on 07th August 2016 Forecast at Trimmu:

The model produced flow peak 232681 cusecs on 12.08.2016 at 15:00 Hrs. against actual flood peak 166139 cusecs on 10.08.16 at 1800hrs.

12.9 Analysis of FEWS results based on 08th August 2016 Forecast at Trimmu:

The model produced flow peak 215891 cusecs on 12.08.2016 at 14:00 Hrs.

12.10 Analysis of FEWS results based on 09th August 2016 Forecast at Trimmu:

The model produced flow peak 212045 cusecs on 12.08.2016 at 12:00 Hrs.

12.11 Analysis of FEWS results based on 10th August 2016 Forecast at Trimmu:

The model produced flow peak 221891 cusecs on 12.08.2016 at 11:00 Hrs.

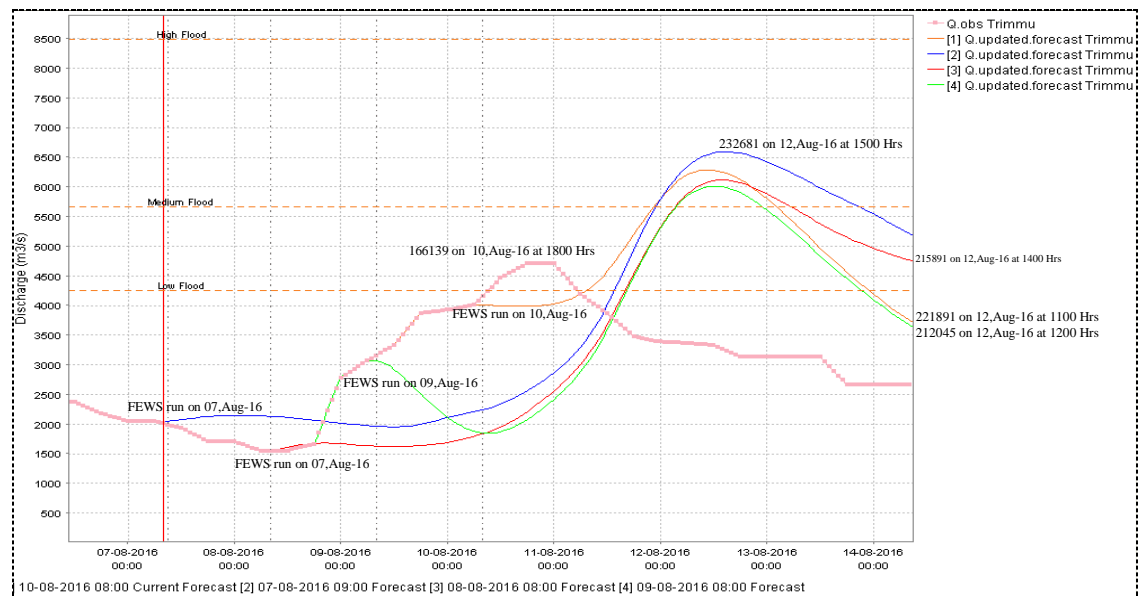


Figure 54: Analysis of FEWS results based on 7th to 14th August-2016

Conclusion:

The performance of FEWS was found not up to the mark with respect to magnitude as well as time.

13 Indus IFAS Results 2016

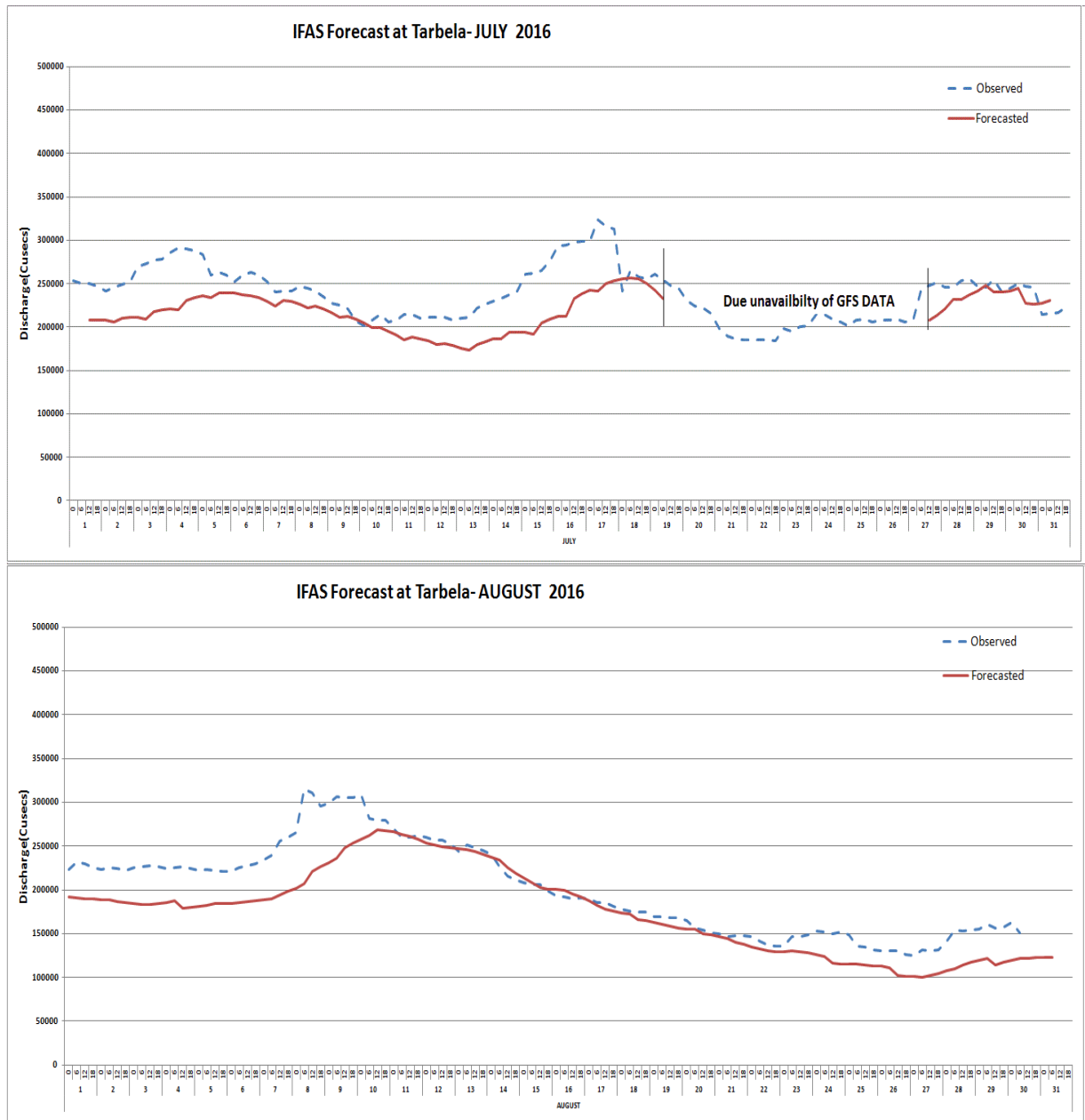
Presently the Indus IFAS has been customized/calibrated on Indus river only and is at validation stage. Two models are encapsulated in INDUS IFAS, one is Integrated flood Analysis system(IFAS) and other is Rainfall runoff inundation models(RRI). Model was run on daily basis throughout the flood season from 15th June to 15th October, 2016. As there was no major peak observed during the flood season so the 6-hourly daily forecast comparisons were made with 6-hourly

observed upstream Discharge of July, August and September while is given below.

13.1 Indus IFAS July & August, 2016 Results

The Indus IFAS takes the GFS Forecasted Rainfall data which was not available from 20th to 27th July.

IFAS Results



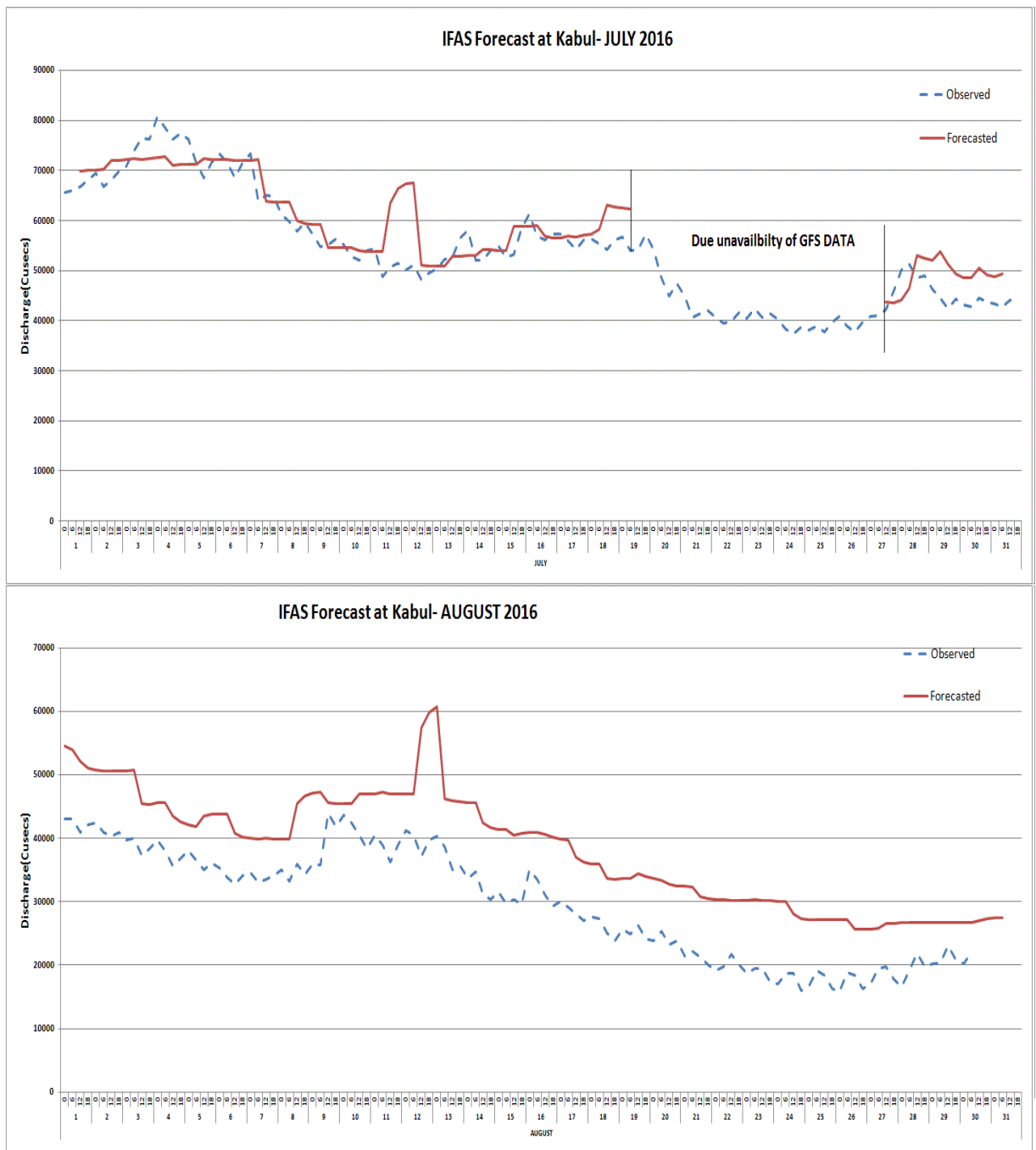
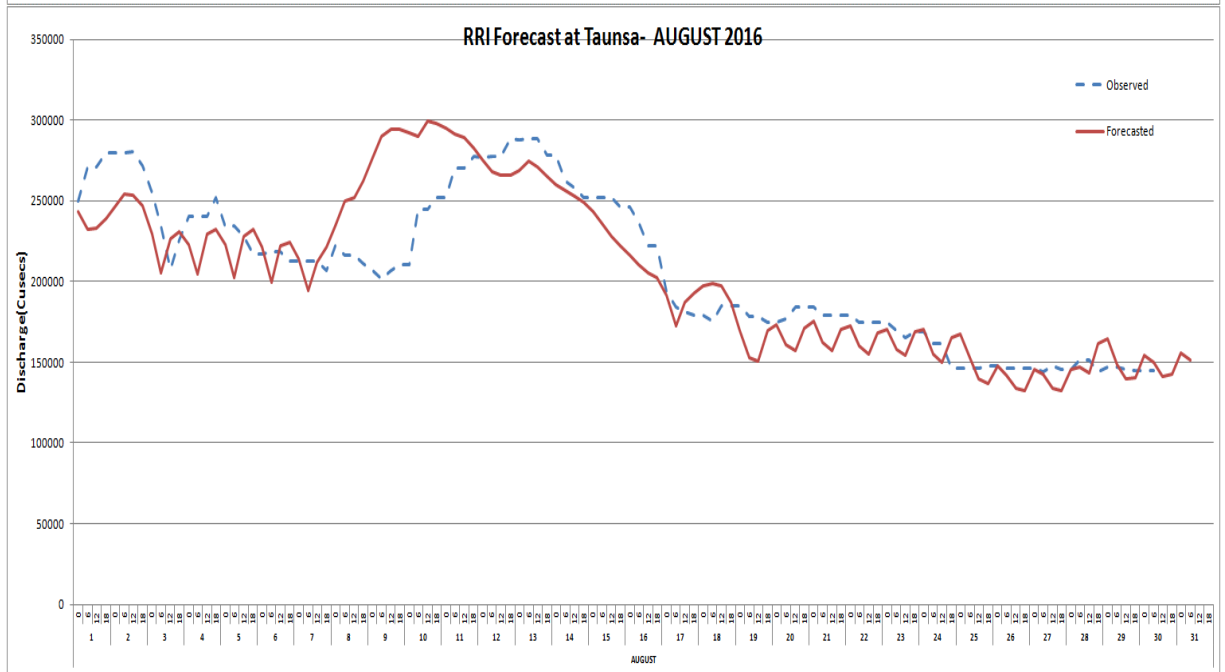
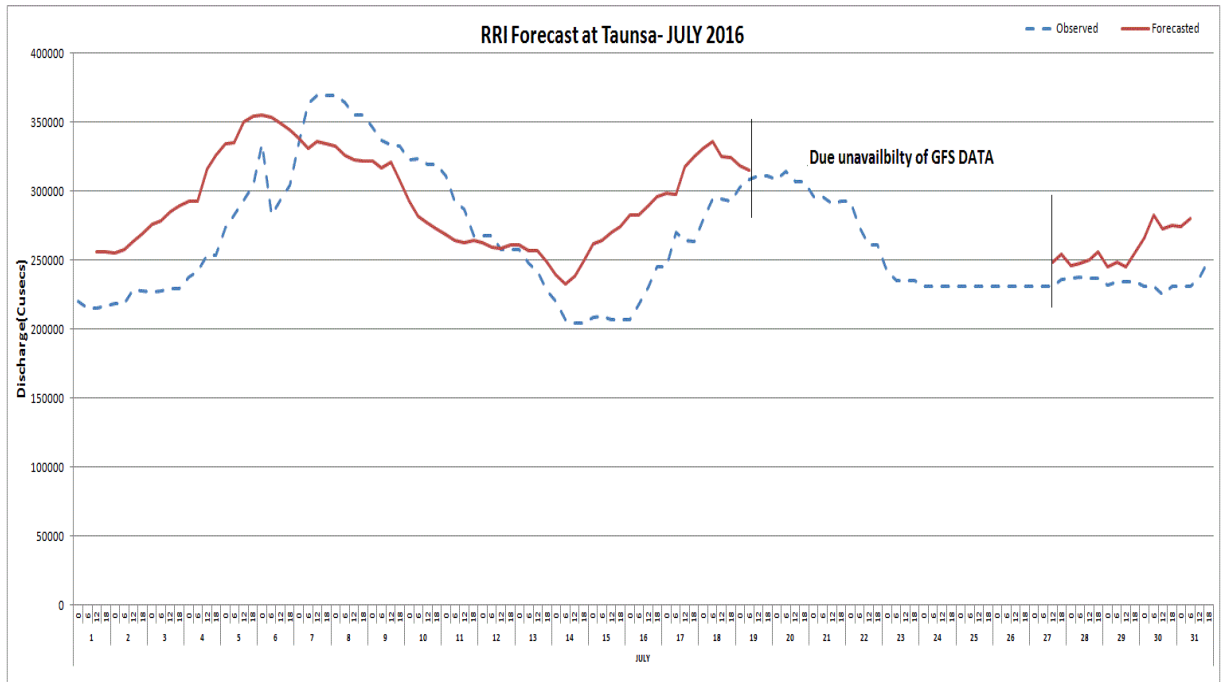


Figure 55: IFAS Result graphs of river Indus (July to August-2016)

RRI Results



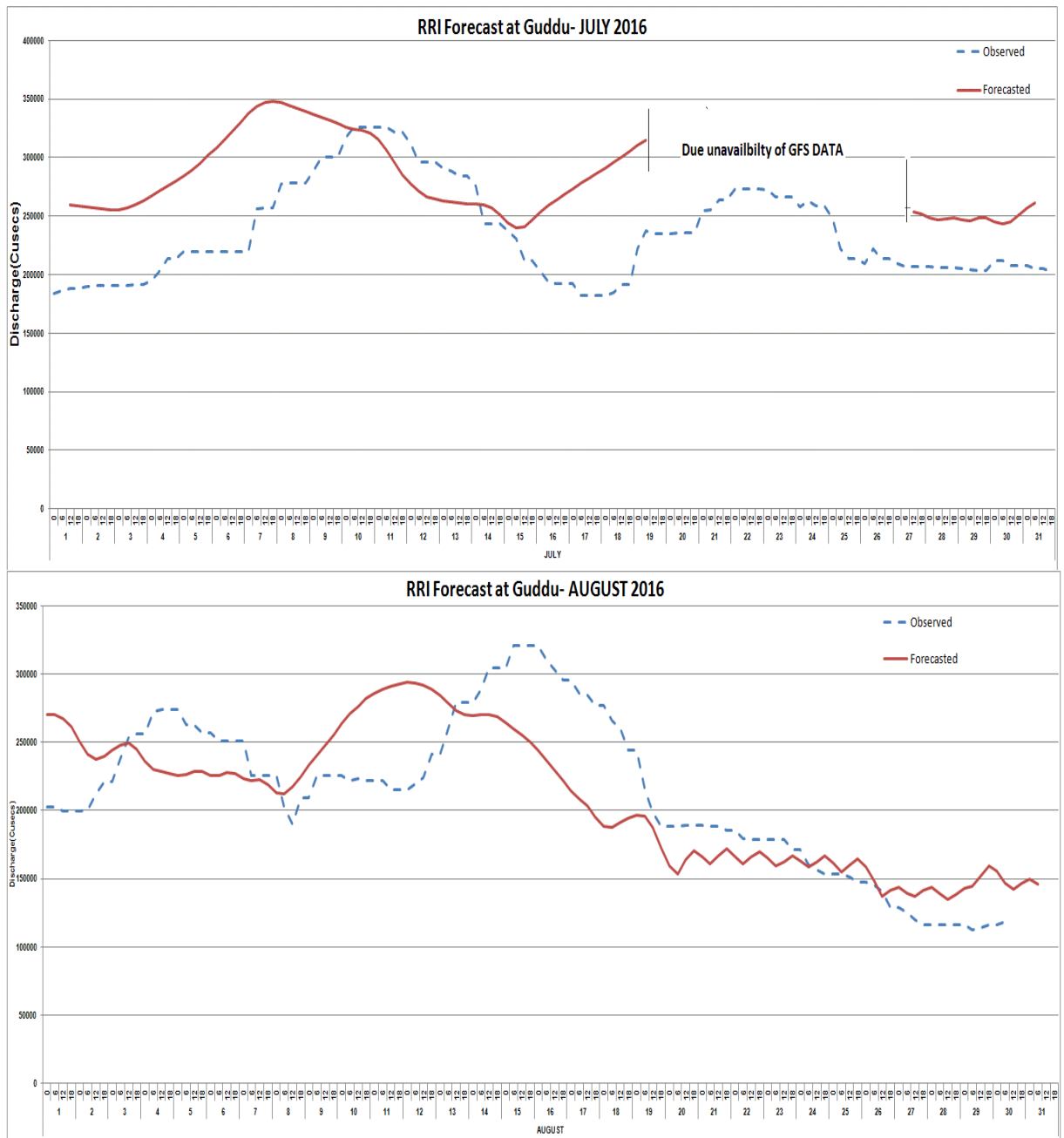


Figure 56: RRI Result graphs of river Indus (July to August-2016)

14 Flood Hazard Mapping.

During flood season 2016, Flood Forecasting Division Lahore started to produce flood hazard mapping in the shape of inundation maps, both for planning purpose and due to actual flood level in each river. These informations are available on the PMD website (<http://www.ffd.pmd.gov.pk/ffdinundation/ffdinundation.htm>) for planning and management purpose, while the forecasting inundation mapping is available on the main flood forecast page under “ Inundation Map-2016 “.

15 Weakness/Problems faced by PMD/FFD during the Flood Season-2016.

Issuance of Seasonal Flood Report after each flood season is a regular feature of Pakistan Meteorological Department, Flood Forecasting Division Lahore. These reports give us a complete overview of all the events happened during the flood season. Flood Forecasting Division has been facing following issues/problems during the Flood season-2016 while issuing timely and accurate Flood Forecast/Warning.

1. Unavailability of timely Telemetric Data.
2. Upstream discharge values at 0600 PST do not match with preceding six hourly data specially at Tarbela
3. Upstream discharge values of Chashma do not match with downstream of Kalabagh.
4. Flood limits of rivers Ravi and Sutlej need to be revised.
5. Flood data at Downstream of Besham & Upstream of Tarbela do not match with each other.
6. Quantitative Precipitation Measurement (QPM) Radars at Lahore, Mangla & Sialkot Provided underestimated rainfall during the season which did not match with the inflows in Chenab & Jhelum rivers. These Radars are required to be replaced.
7. Flood Early Warning System (FEWS) model did not provide satisfactory results. This model also needs to be upgraded along with Inclusion of upstream Tarbela and Kabul river sections for improved results.
8. Financial and Human resources lacked which needs to be enhanced for improved results.

16 Flood forecast evaluation report

The Flood Forecast evaluation report for 2016 for all categories of flood is given below:

Date	Rivers	Stations	Peaks Inflows (In thousands of cusecs)	Forecast (In thousands of cusecs)	Percentage (%) Accuracy
17/6/2016	Indus	Tarbela	310.0	270-300	97
18/6/2016	Indus	Kalabagh	307.6	260-280	90
17/6/2016	Indus	Chashma	324.6	275-300	92
21/6/2016	Indus	Taunsa	266.3	255-270	100
22/6/2016	Indus	Guddu	223.0	210-220	99
17/6/2016	Kabul	Nowshera	91.7	85-100	100
04/07/2016	Indus	Tarbela	291.0	290-320	100
17/07/2016	Indus	Tarbela	324.0	300-330	100
04/07/2016	Kabul	Nowshera	80.7	70-90	100
05/07/2016	Indus	Kalabagh	359.0	340-360	100
17/07/2016	Indus	Kalabagh	351.7	320-350	99.5
05/07/2016	Indus	Chashma	396.1	360-385	97
18/07/2016	Indus	Chashma	379.6	320-360	95
31/07/2016	Indus	Chashma	347.7	280-320	92
07/07/2016	Indus	Taunsa	369.2	350-370	100
20/07/2016	Indus	Taunsa	313.9	305-320	100
10/07/2016	Indus	Guddu	325.8	310-340	100
22/07/2016	Indus	Guddu	2730.	240-260	82
12/07/2016	Indus	Sukkur	238.9	220-250	100
24/07/2016	Indus	Sukkur	220.9	220-240	100
28/07/2016	Chenab	Marala	144.1	100 R 250	100
28/07/2016	Chenab	Khanki	148.8	100 R 250	100
28/07/2016	Chenab	Qadirabad	143.8	130-170	100
29/07/2016	Ravi	Shahdara	44.6	25-35	80
29/07/2016	Ravi	Balloki	53.3	50-90	100
07/08/2016	Jhelum	Mangla	244.0	200	82
07/08/2016	Chenab	Marala	412.1	200 R 300	63
07/08/2016	Chenab	Khanki	418.7	380-410	98
07/08/2016	Chenab	Qadirabad	416.5	380-410	99
10/08/2016	Chenab	Trimu	166.1	160 R 210	100
08/08/2016	Indus	Tarbela	315.0	240-260	79
10/08/2016	Indus	Kalabagh	316.1	300-340	100
11/08/2016	Indus	Chashma	336.1	310-350	100
12/08/2016	Indus	Taunsa	288.6	275-290	100
15/08/2016	Indus	Guddu	320.6	290-310	97
17/08/2016	Indus	Sukkur	281.5	260-281	100
08/08/2016	Ravi	Shahdara	44.6	35-45	100
09/08/2016	Ravi	Balloki	60.4	40-70	100
Over all Accuracy					95.8%

R: Rising F: Falling

The overall accuracy of the forecast issued by FFD, Lahore during the flood season 2016 has been calculated which shows a good **95.8%** against all odds.

17 Flood limits (in lacs of cusecs):

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

18 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 collected and verified in pre flood season.

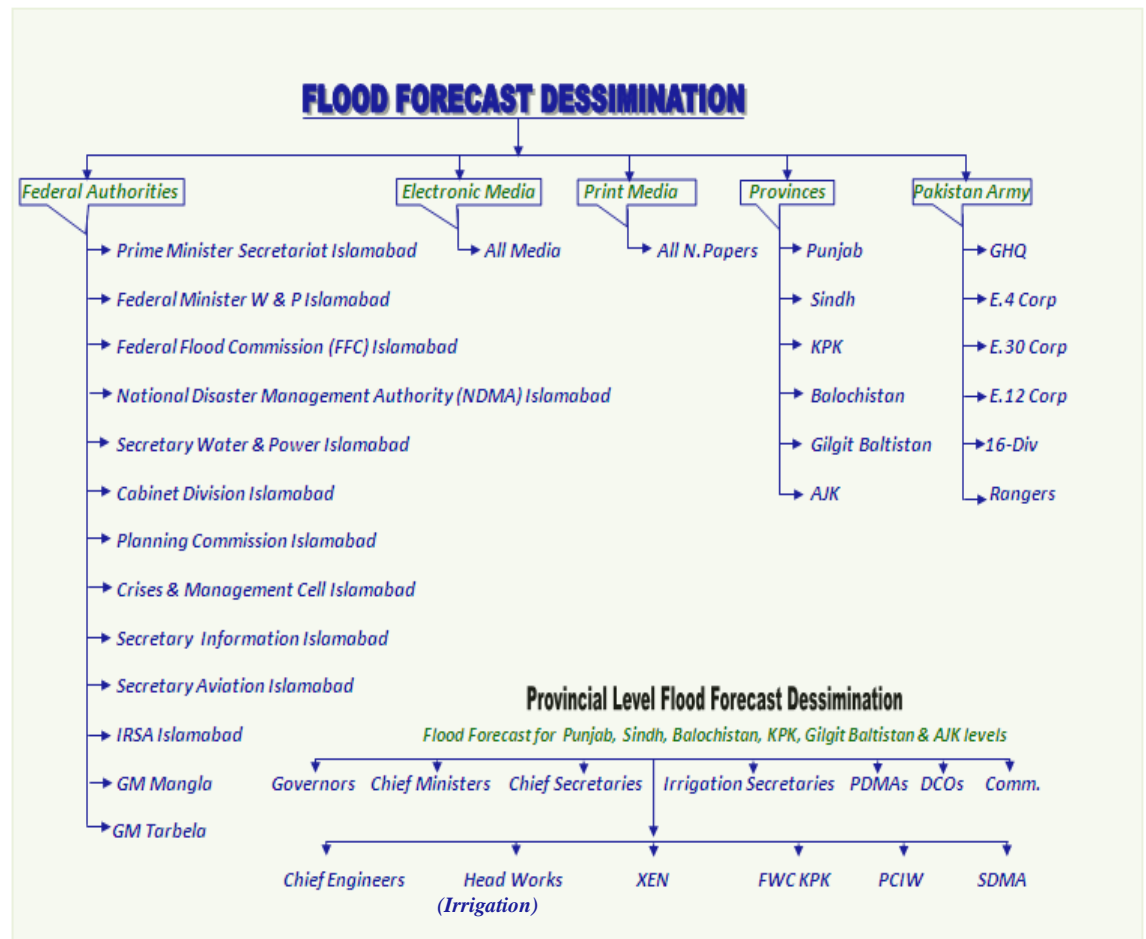


Figure 57: Flood Forecast Dissemination chart.

