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WATER & CLIMATE LABORATORY
IIT GANDHINAGAR

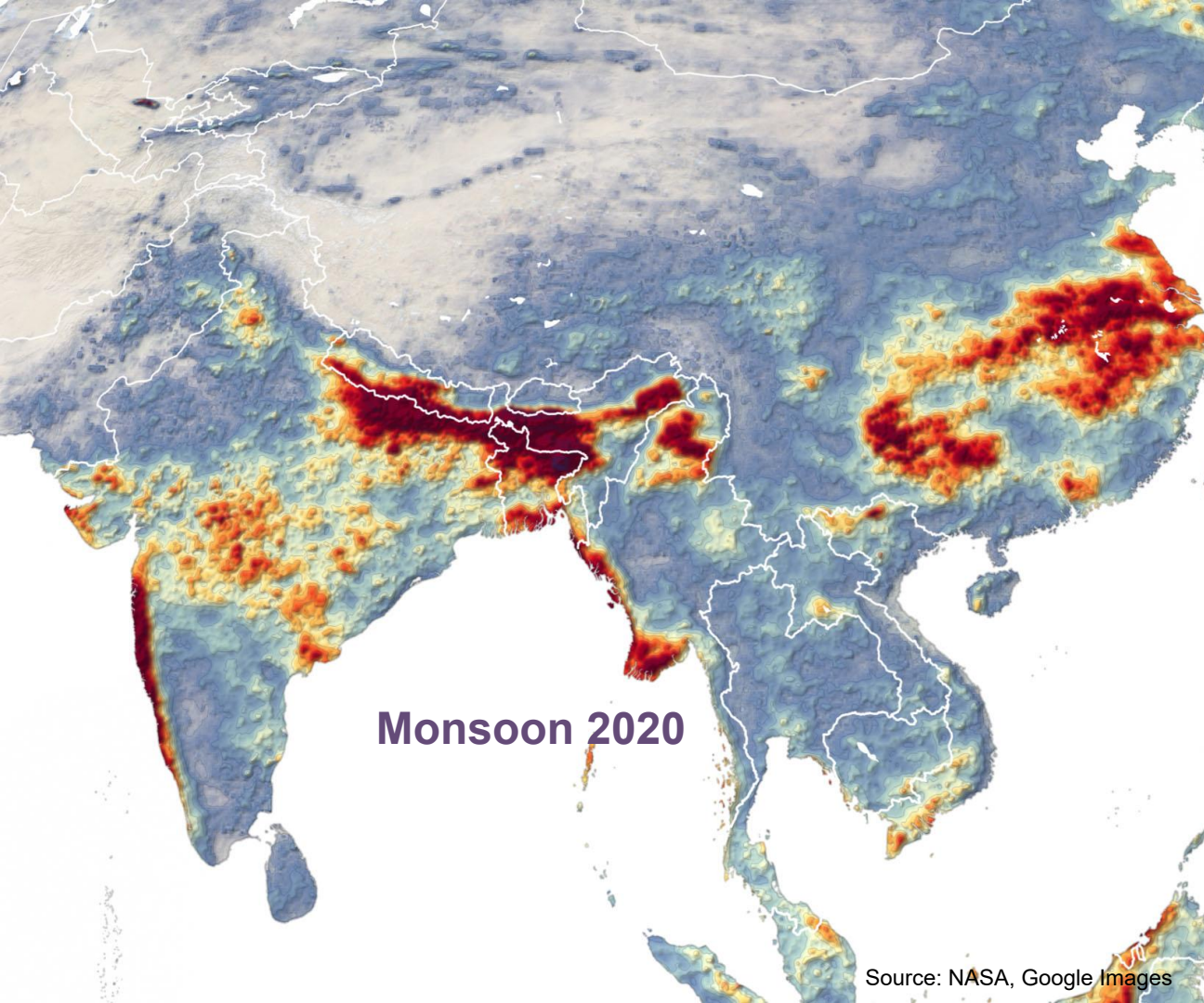# The Pakistan Flood in August 2022: Causes and Implications

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Source: google images

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Monsoon 2020

Source: NASA, Google Images

A displaced family wades through a flooded area in Jafarabad, a district of Pakistan's southwestern Baluchistan province, on Aug. 24. (Zahid Hussain/AP)
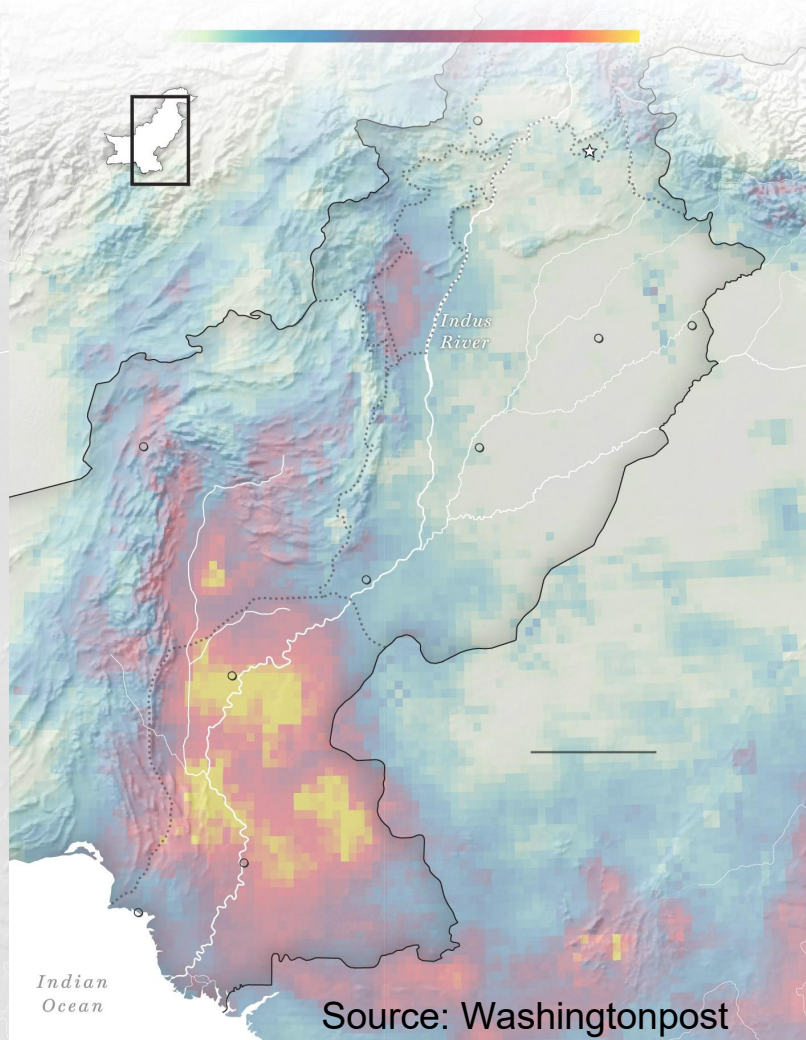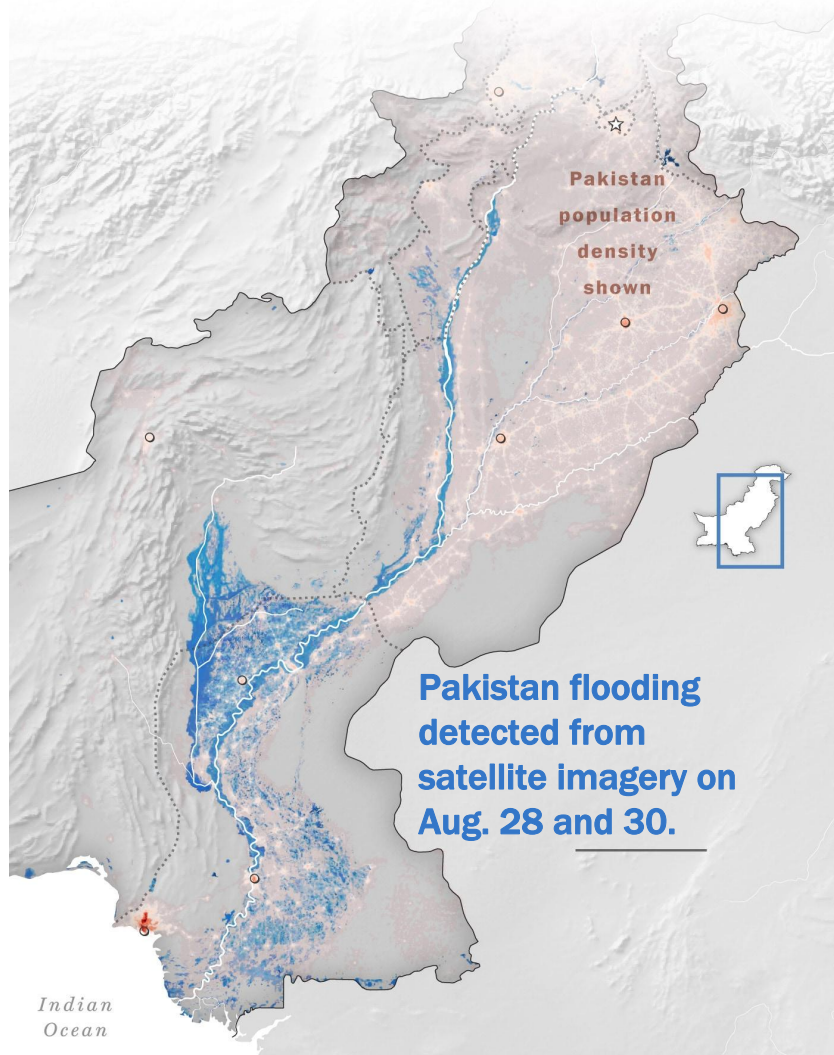
man tries to salvage what he can from his flood-hit home in Shikarpur district, Sindh province, on Aug. 30. (Fareed Khan/AP)

Source: Washingtonpost

Pakistan population density shown

Pakistan flooding detected from satellite imagery on Aug. 28 and 30.

Indus River

Indian Ocean

Indian Ocean

Source: Washingtonpost

People set up temporary tents on the side of the street in Sindh province after floods forced them from their homes. (Asif Hassan/AFP)

Residents survey their damaged houses on the outskirts of Quetta, Baluchistan province, on Aug. 27. (Jamal Taraqai/EPA-EFE/Shutterstock)

Source: Washingtonpost

Pakistan floods' death toll nears 1,700, puts pressure on fragile economy

Inflation in Pakistan reaches 27%

October 01, 2022 07:29 pm | Updated November 09, 2022 04:37 pm IST – Islamabad:

5.7 million Pakistan flood victims to face food crisis: United Nations

World News
Published on Oct 03, 2022 03:36 PM IST

Flood Losses Now Estimated at $40 Billion: Pakistan Officials

- Pakistan to present case at United Nation's COP next month
- Costs of flood damage were earlier pegged around $30 billion

Record Flooding: $40 Billion Of Damage In Pakistan As Monsoons Devastate South Asia

Pakistan floods, and the pulls and pressures of India-Pak disaster diplomacy

Pakistan floods: PM Narendra Modi has expressed sympathy. For New Delhi, the decision to offer further help will involve balancing between projecting power as a global responder and managing the ruling party's domestic political base.

Climate change likely helped cause deadly Pakistan floods, scientists find

September 19, 2022 · 12:18 PM ET

2022 Pakistan floods that killed almost 2,000 termed one of world's biggest climate tragedies ever

Pakistan floods: Child deaths, livestock loss, upcoming winter threat stares nation. All you need to know
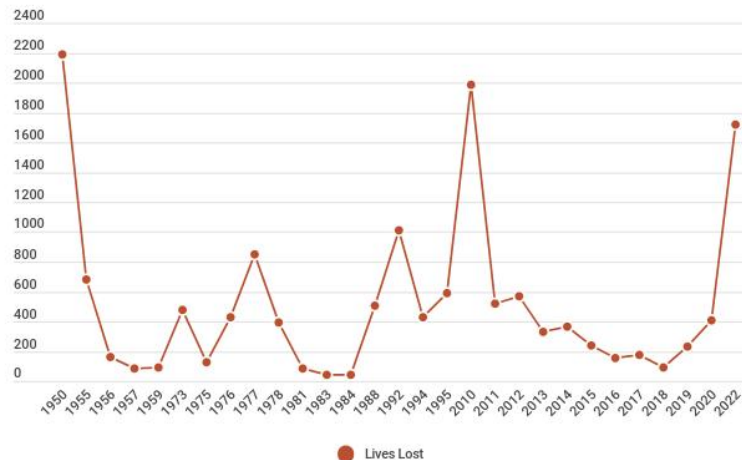
Pakistan Flood Fatalities between 1950-2022

Data Source: Government of Pakistan Ministry of Water Resources

Photo credit: UNDP

Damages caused by 2022 Pakistan flood

1700+ deaths

12,800+ injured

1.4 million+ Houses damaged

850,000+ Houses destroyed

13,000+ Kilometres of road affected

5.5 million+ Acres of cropland affected

430+ Bridges affected

1.1 million+ Livestock lost
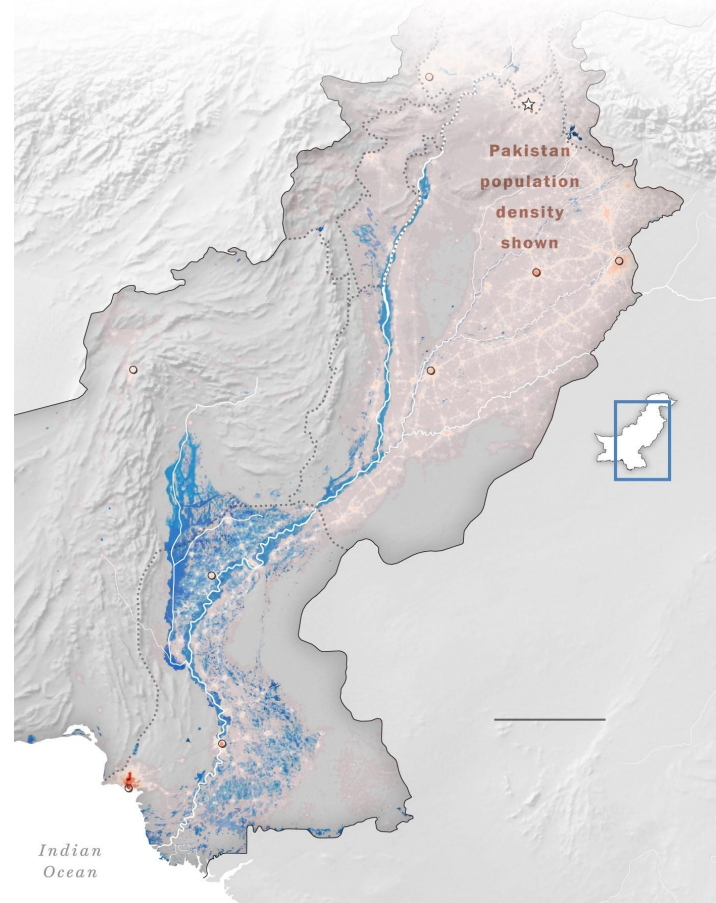
Source: National Disaster Management Authority (NDMA), Government of Pakistan 19 October 2022 & Pakistan food security and Agriculture 5 October 2022

Rainfall Departures during the summer monsoon, 2022

- National rainfall for the month of June 2022 was largely **(+68%)** above normal. Balochistan **(+47.6%)** an Sindh **(-14%)**

- National rainfall for the month of July 2022 was largely **(+180%)** above average and stands as record wettest July since 1961.

- July 2022 rainfall was excessively above average over Balochistan (+450%) & Sindh (+307%), both rank as the wettest ever during past 62 years.

- National rainfall for the month of **August 2022 was excessively (+243%)** above average and stands as record wettest August since 1961.

- August 2022 rainfall was excessively above average over Balochistan (+590%) & Sindh (+726%)

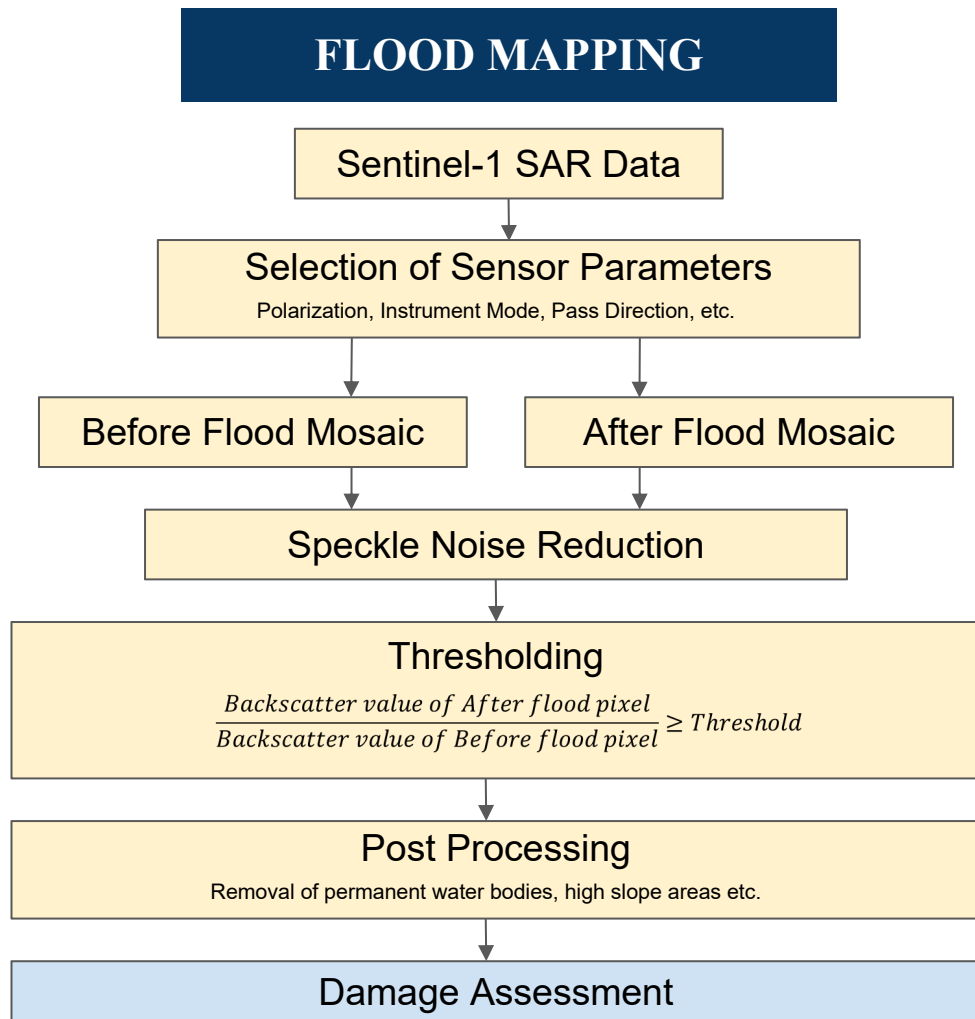- National rainfall for the month of September 2022 was below average (-21%).

Pakistan population density shown

Indian Ocean

The 2022 flood event in the context of the top 20 flood events in Pakistan that led to the death of more than 100 people.

Sl. No.	Year	Area (km²)	Dead	Displaced	Major cause	Severity	Other affected countrie
1	1992	873375.01	2750	3000000	Monsoonal rain	2	India
2	2010	129691.63	1750	10000000	Monsoonal Rain	2	0
3	**2022**	**265365.00***	**1496**	**32000000**	**Monsoonal Rain**		**0**
4	1995	672265.35	600	600000	Monsoonal rain	1	0
5	2011	32667.16	434	660000	Monsoonal Rain	1.5	0
6	2012	23036.11	400	742000	Monsoonal Rain	1.5	0
7	1994	343251.55	333	30000	Monsoonal rain	1	0
8	2014	253686.93	300	30000	Monsoonal Rain	2	India
9	1998	165619.86	300	240000	Heavy rain	1	Iran
10	2005	123212.59	300	40000	Heavy rain	1	0

Outline

- ❏ Flood extent

- ❏ Extreme rainfall analysis

- ❏ Hydrological conditions during flood

- ❏ Role of Atmospheric rivers in Pakistan flood 2022

- ❏ Frequency of extreme rainfall events in future

- ❏ Forecast predictability of this extreme rainfall event

Datasets

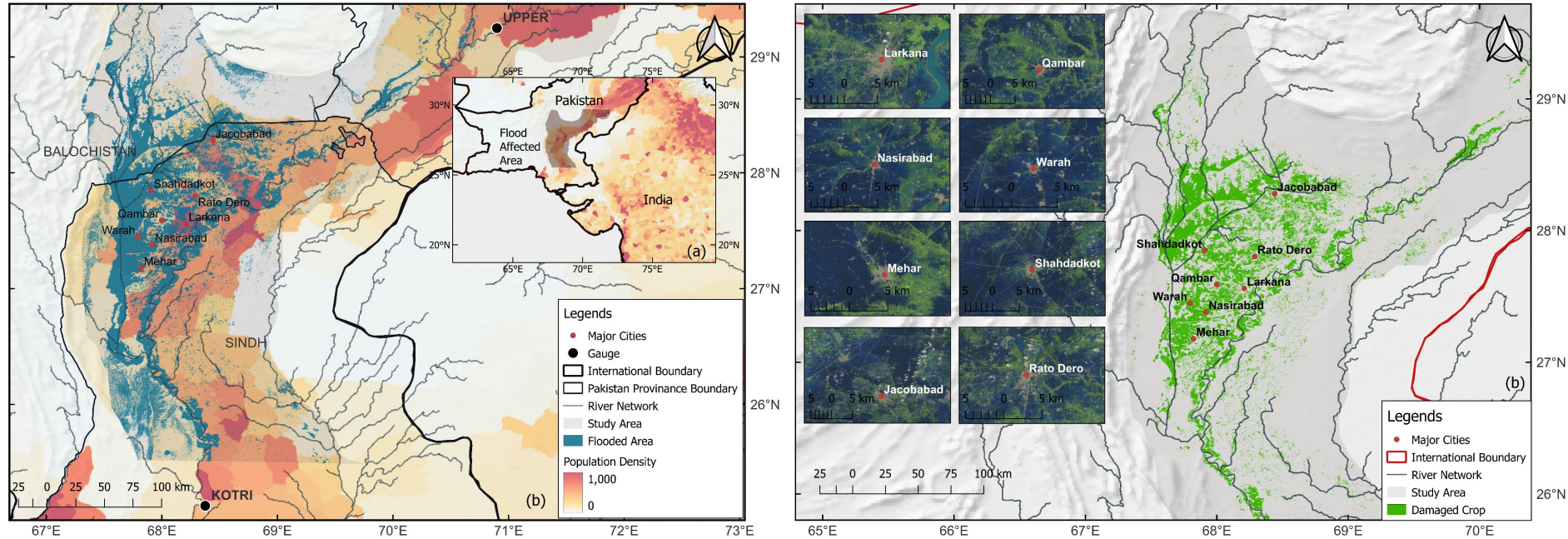| Data	Time of Acquisition	Spatial Resolution	Provider /Source of data
Sentinel-1 SAR GRD After flood Before flood	28/08/2022 to 30/8/2022 02/05/2022 to 09/05/2022	10 m	Copernicus Sentinel data [2022](https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S1_GRD)
Sentinel-2	31/08/2022	10 m	Copernicus Sentinel data [2022] (https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S2_SR)
MODIS Terra MOD09GQ.061	29/08/2022 to 30/08/2022	250 m	NASA MOD09GQ Version 6.1 (https://developers.google.com/earth-engine/datasets/catalog/MODIS_061_MOD09GQ)
Population GPW v4	2020	1 km	SEDAC (https://sedac.ciesin.columbia.edu/data/collection/gpw-v4)
LULC	2021	10 m	ESRI (https://livingatlas.arcgis.com/landcover/)

Figure 1. (a) Map of flood extend and the population exposed to flooding. 1(a) shows the flood-affected region in the southern provinces of Pakistan. The densely populated right bank of the Indus river is majorly affected by flooding. Major affected cities are marked on the figure. The location of the upstream and downstream stations (Panjanad and Kotri, respectively) at which streamflow values are simulated are also indicated in the figure. The flood extend is prepared using Sentinel-2 and MODIS satellite data. Detailed information is provided in the supplementary section. Figure 1b shows the crop areas affected during the 2022 flood vent. The crop data is obtained from Sentinel-2 based ESRI LULC classification at 10m spatial resolution. The inset figures, generated using sentinel-2, depict the true color images of flood extent in the major cities.

- **We analyzed the deviation of rainfall in 2022 august to its climatology to identify the main period of extreme rainfall**

- **Using accumulated rainfall, we identify the most affected regions exceeding 400 mm rainfall for 15 accumulated days over Pakistan.**
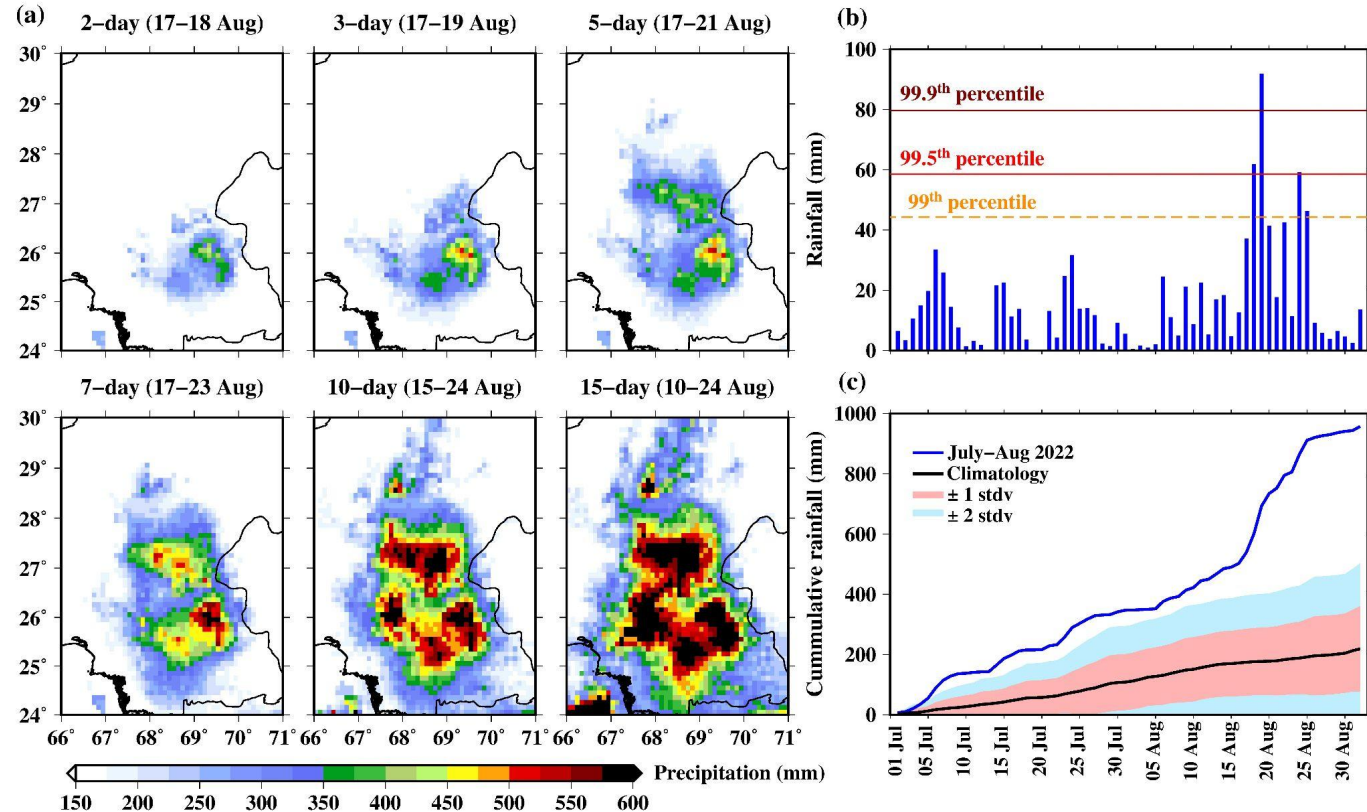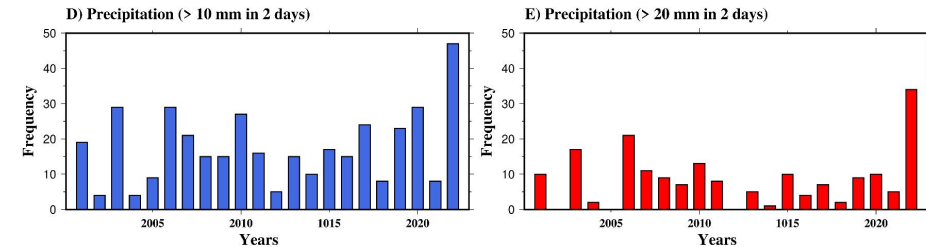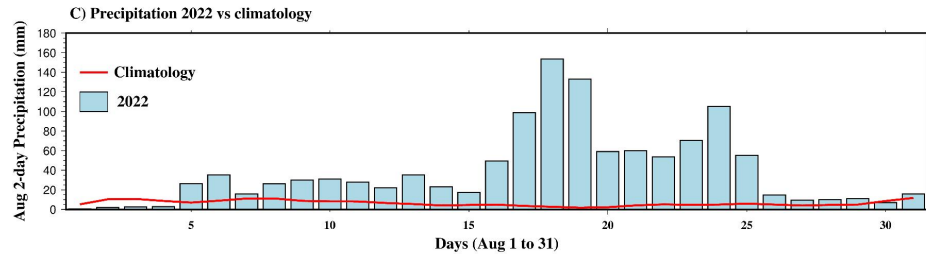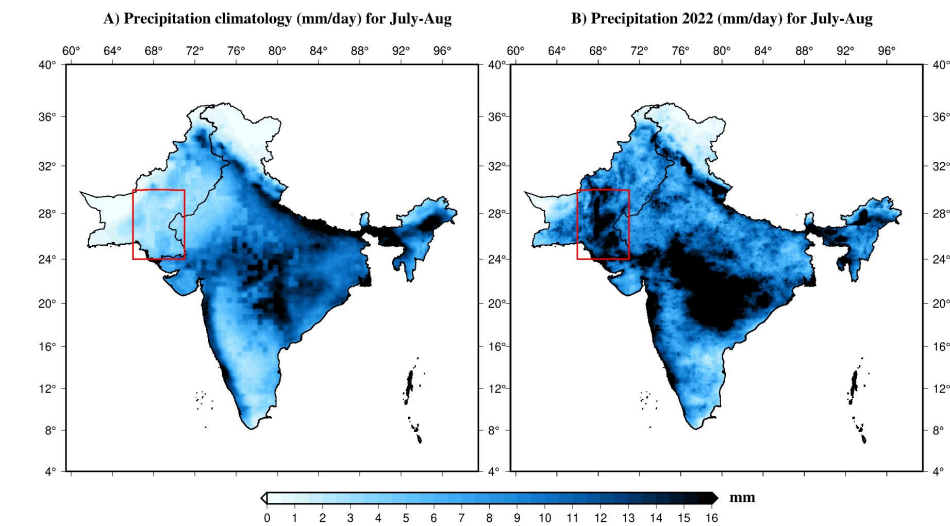

Figure 2. Precipitation extent during the 2022 flood in Pakistan. (a) Multi-day maximum accumulated precipitation during July-August 2022. (b) Observed daily precipitation (mm) over the affected area (continuous grids having 15-day maximum precipitation >400mm). (c) Cumulative rainfall from 1 June to 31 August 2022 (blue) and its climatology (black) for the affected area. The shaded region show the standard deviations from the climatological mean. The satellite based precipitation from GPM-IMERG (2001-2022) is used to analyse the extreme precipitation during the 2022 flood event.

A) Precipitation climatology (mm/day) for July-Aug

B) Precipitation 2022 (mm/day) for July-Aug

C) Precipitation 2022 vs climatology

— Climatology

□ 2022

D) Precipitation (> 10 mm in 2 days)

E) Precipitation (> 20 mm in 2 days)

- **Extremely anomalous rainfall in August 2022 over Pakistan**

- **Highest number of days exceeding >=10 mm and 20 mm rainfall in 2022 July-August.**

Figure 3. (a) July-August GPM precipitation [mm/day] climatology for 2003–2021. (b) The observed GPM rainfall averaged for Pakistan (60°N–76°N; 24°E–30°E, red rectangle). (c) 2-day accumulated rainfall of climatology over the selected red region in August 2022. (d) Frequency of two days accumulated rainfall of 10 mm and (e) 20 mm over Pakistan (66°N–76°N; 24°E–30°E).

Role of Atmospheric Rivers

- **We identify the grids with an IVT greater than 85th percentile of the climatological IVT and make clusters out of contiguous grids in the region (40-85E, 0-35N), termed as preliminary atmospheric rivers.**

- **IVT intensity greater than 600 kg/m/s was present during both the ARs, which is abnormally high, considering the arid conditions in Pakistan.**

- **A relatively low MSLP (less than 999 hPa) developed over the study area [66-71E, 24-30 N] compared to the surrounding region (more than 1005 hPa) during the ARs (Figure. 5b, d).**
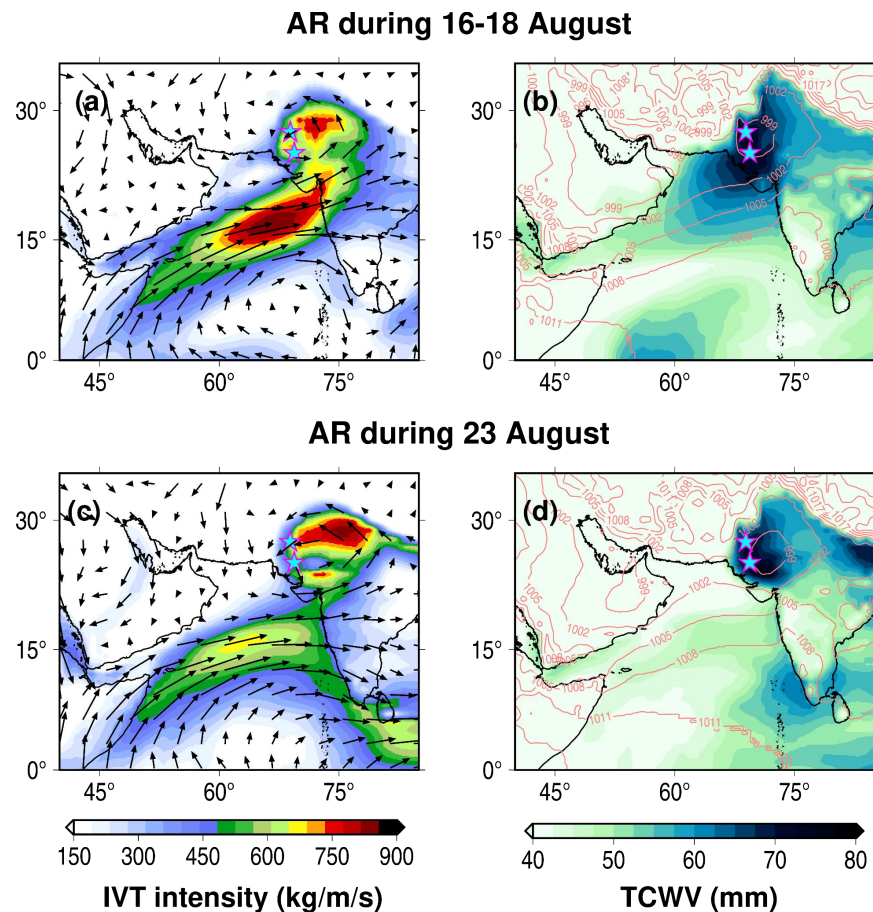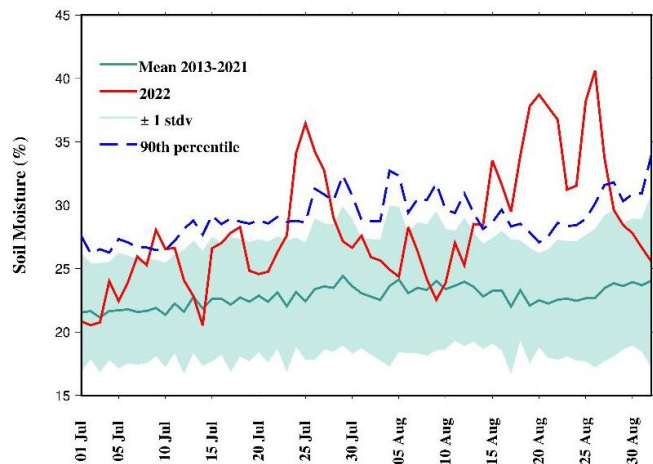

AR during 16-18 August

AR during 23 August

IVT intensity (kg/m/s)

TCWV (mm)

Figure 5. Atmospheric river (AR) during August 2022 flood in pakistan. (a-b) Vertically integrated moisture transport (IVT, kg/m/s) and total column water vapour (TCWV, mm) in the presence of AR during 16-18 August 2022. (c-d) Same as (a-b) but for AR during 23 August 2022. The contours in (b) and (d) show the isobars in hPa.

Soil Moisture Conditions during flood

We estimated 2-15 day mean soil moisture anomaly on 15 August using the volumetric soil moisture percentile observations from 2013-2022.

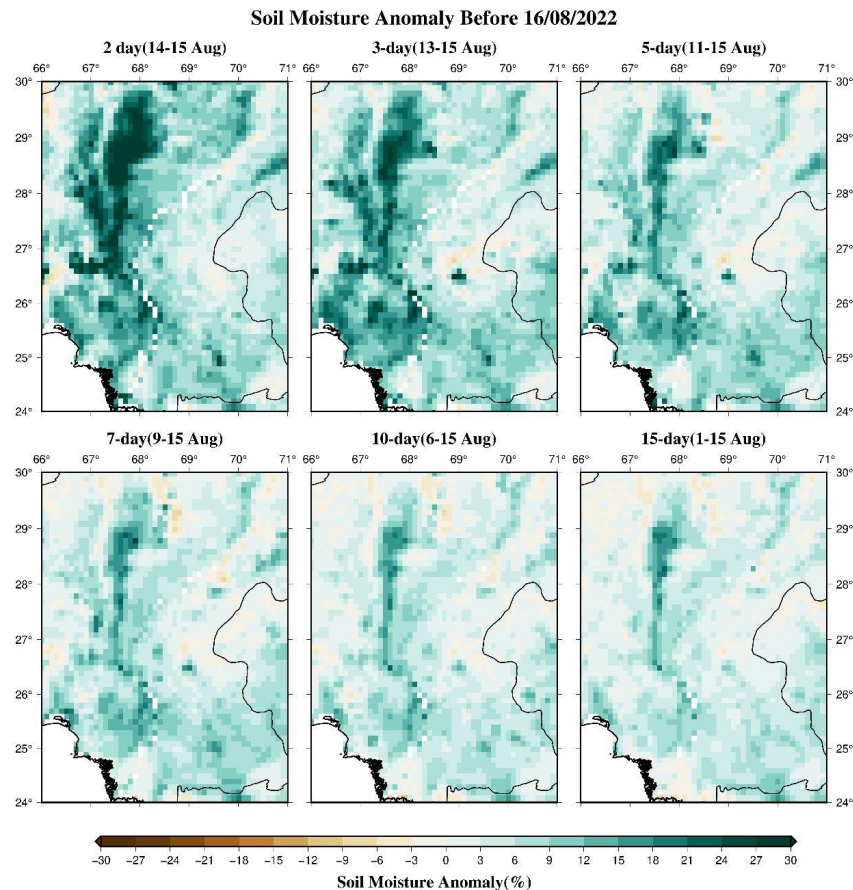*Advanced Microwave Scanning Radiometer 2 (AMSR2) and Land Parameter Retrieval Model (LPRM)*
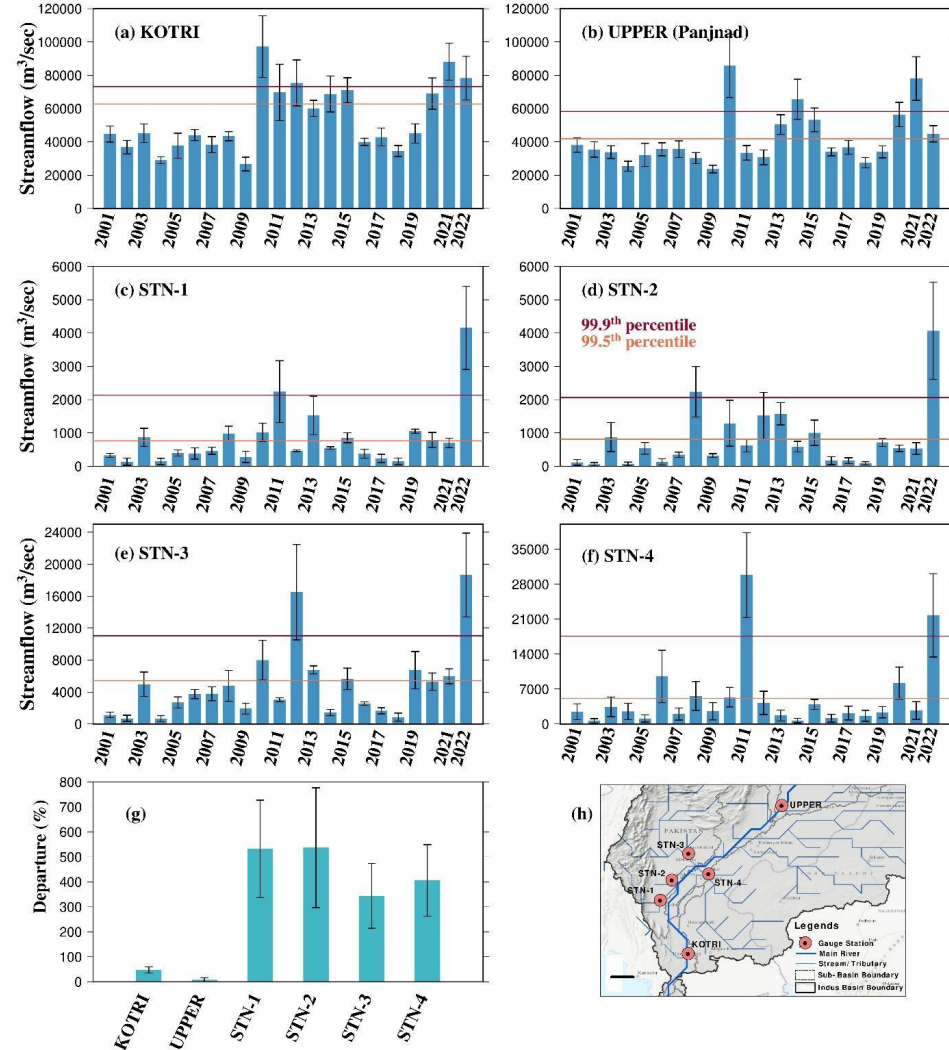

Figure 4. Spatial distribution of multi-day mean soil moisture on 15 August 2022. The spatial plots show the soil moisture anomaly on 15th August 2022 estimated at different durations from 2 to 15 days with reference to mean calendar day soil moisture from 2013 to 2021. The temporal plot shows daily soil moisture evolution for the study area from 1 July to 31 August.

Streamflow simulations of the 2022 flood event

- **All stations exceeds the 99.9th percentile threshold of the 2001-2021 annual maximum discharge time series, except in the upstream station, Panjanad. Similarly, the percentage streamflow departure.**

- **Extreme precipitation (16-24 August) along with wet antecedent soil moisture conditions translated to higher streamflow values at the four locations.**

- **Contribution from the upstream reaches of the Indus basin to the observed August flooding is less significant.**

Figure 6. Ensemble streamflow simulations from four hydrological models (VIC, CLM, NOAH-MP and H08) at six different locations along the Indus basin, which includes one station each at the (a) downstream (Kotri) and (b) upstream (Panjanad) point of the flood affected region and (c-g) four stations on either side of the Indus river. Figures (5 a-f) show the annual maximum flow from 2001 to 2022. The 99.9th and 99.5th thresholds of annual maximum streamflow from 2001-2021 is denoted in the figure. Figure 5-g depicts the percentage departure of the ensemble mean of annual maximum streamflow in 2022 at six stations.

Future projections of extreme precipitation events

- **The frequency of extreme precipitation is projected to rise in all the warming scenarios.**

- **The frequency of seven-day and ten-day precipitation is projected to quadruple by the end of the 21st century in the SSP5-8.5 scenario.**

- **Multiday precipitation encompasses extreme precipitation and antecedent soil moisture conditions and is more likely to translate to floods.**
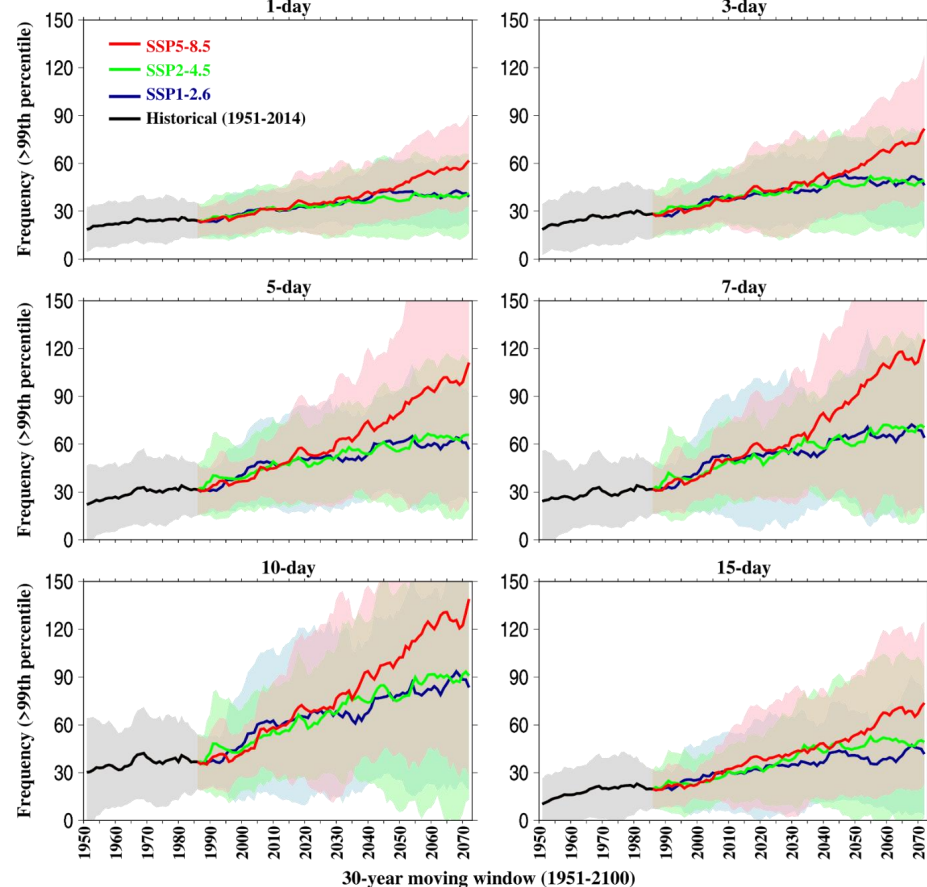

Figure 7. The multi-model ensemble mean frequency of precipitation exceeding 99th percentile of rainy days (>0.2mm per day) for the historical (1950-2014; with pre-industrial forcing) and future period (2015-2100; includes anthropogenic greenhouse gases) for 1-day, 3-day, 5day, 7day, 10-day and 15-day accumulated precipitation, and for three warming scenarios (SSP1-2.6, SSP2-4.5 and SSP5-8.5). The period 2001-2014 was selected as the reference period to estimate the 99th percentile value for the nine CMIP6-GCMs. The frequency is estimated using a 30-day moving window. Shading represents the standard deviation for each emission scenario.

Was the 2022 Pakistan flood predictable?

Forecast Models details

Model	Lead time	Resolution	Ensemble size	Reforecast Frequency	Historic length	Prediction frequency
UKMO	D 0–60	N96L85	4	4/month	1991-2016	Daily
KMA	D 0–60	N216 L85	4	4/month	1993-2016	Daily
GFS	D 0-10	T1534L64	10	-	-	Daily

Observed data

We obtained NASA's Level 3 Integrated Multi-satellite Retrievals for Global Precipitation Mission (GPM) 3IMERGHHL v06- Late Run at 0.1° spatial resolution from 2001 to August 2022

● **Both S2S forecast models (KMA and UKMO) displayed excellent predictability in regard to the total amount of rainfall between August 17 and August 18 at all leads (1-day to 7-day in advance).**

● **The GFS, on the other hand, was only able to forecast extremely heavy precipitation at one day lead, underestimating the affected region.**
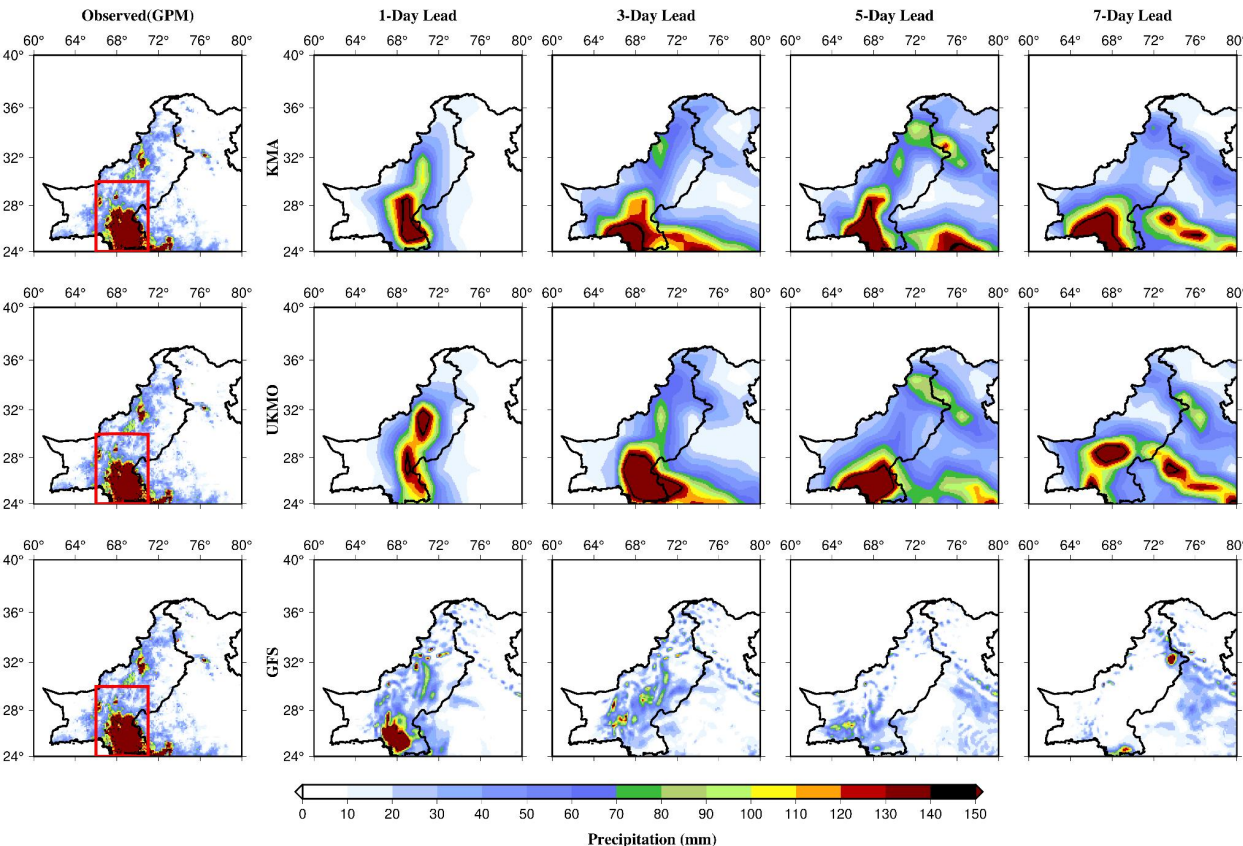
Figure 8. Spatial distribution of accumulated rainfall (unit: mm) during 17-18 August in Selected Pakistan region predicted by the three models 1 day, 3 days, 5 days, and 7 days in advance, respectively: (a2–a4) KMA model; (b2–b4) UKMO model; (c2–c4) GFS model. The first column (a1, b1, and c1) represents observed (GPM) accumulated rainfall during the same period.

A) UKMO

B) KMA

Predictability of models

- **To explore the probabilistic predictions, we first consider the probability of rainfall exceeding the threshold of one SD above the observed climatology.**

- **August 18 event was predicted using UKMO almost 4 days in advance with a probability >80% over the climatological average plus 1 standard deviation (Figure 3a).**

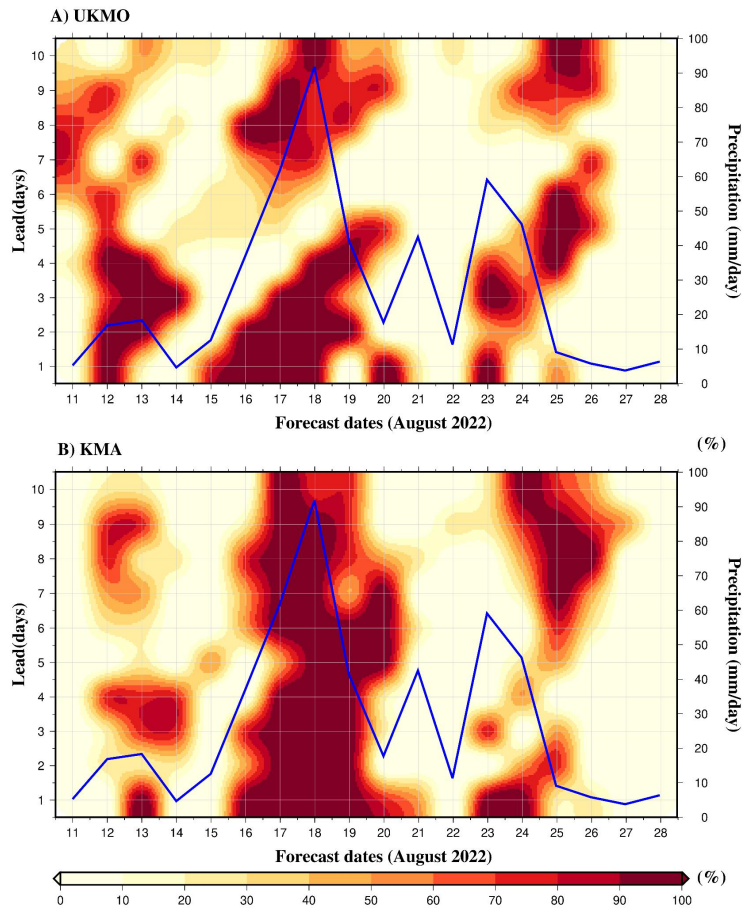- **On the other hand, KMA was to predict a 10-day lead with a probability greater than 80%**

Figure 9. Forecast lead time diagram of the probability that the S2S models (a) UKMO, and (b) KMA forecast for the red region (Figure 1a) exceeds the observed GPM August climatology (2003–2021) plus 1 standard deviation. The blue line represents the observed GPM rainfall [mm/day] averaged for the same region from August, 11-28, 2022 (units on the right axis). The colorbar shows the probability of exceeding August climatology (2003–2021) plus 1 standard deviation from 0 to 100 % at a different lead time (1 to 10 days) shown on the left axis.

Conclusions

- The southern provinces of Pakistan received more than 350% of average precipitation in July and August based on 2001-2021 mean.

- Extreme precipitation event in August is associated with atmospheric rivers. The frequency of similar precipitation events is projected to quadruple under the warming climate

- Both of the S2S models (KMA and UKMO) displayed excellent predictability in regard to the total amount of rainfall on 17-18th August 2022 over Pakistan. Whereas the GFS forecast product was found to lose its predictability after a 1-day forecast.

- The major finding of this study is that the flood was highly predictable 8-10 days in advance with a probability greater than 80% in August 2022 using S2S models.

- A high probability of flooding could have been anticipated 7 days in advance using these two S2S models.

- Pakistan would benefit from these forecasting models, which can be used in operational flood forecasting systems and early warning systems in future.

Thank you