Emergency Investigation and Assessment 2022 Pakistan Flood

Investigation Briefing

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Flood Flow Process of the Lower Indus River in Southern Pakistan and Causes of the Flood in Larkana

Since mid-June 2022, Pakistan has been affected by abnormal cyclonic cloud masses, from which rare prolonged heavy rainfall floods inundate nearly 260,000 km^2 across the country, with the most severe inundation of low-lying areas in the western LARKANA alluvial plain of Sindh. Based on the 2022 Indus River flood hydrological report data released by Pakistan, the flood flow of 1976, 2010 and 2015 in history are compared and analyzed. At the same time, with the rainfall area analysis of this flood, the possible causes of severe floods in the LARKANA plain are analyzed.

1. Among the historical Indus River floods, the peak discharge of the August 2022 flood was relatively small, but the inundated area was extremely large

According to the data analysis of the Indus River flood hydrological report released by Pakistan, it is found that the maximum flood peak flow of the Indus River in 2022 is 17,620 m^3/s (**Fig. 1**). Compared with the flood in of 1976, 2010 and 2015, the 2022 flood peak discharge is much smaller than the flood peak flow of 2010 and even smaller than that of 2015 (**Fig. 2**). However, there is an obvious "contrast" between the flooded area in 2022 and its peak discharge. According to the satellite image (**Fig 3**), the inundated area of the 2022 flood in the LARKANA plain (in red, August 25-31, 2022) is much larger than that of the 2010 flood (in yellow, July 28-September 16, 2010), with the inundated area of 160,000 km^2. As the rainfall center of the 2022 flood and the flooded

area are both in the middle and lower Indus River, there is no clear boundary of the inundated area, resulting in a scene of a vast ocean (**Fig. 3B**). However, for the 2010 flood, the rainfall center is not in the LARKANA, the inundated area boundaries are clear, and the inundated area is relatively concentrated in the low-lying areas and river banks in the west of the plain (**Fig. 3C**). Thus it can be seen that the flood peak flow of the Indus River and the location of the rainfall center are the key factors for causes of severe flood disaster in LARKANA plain.

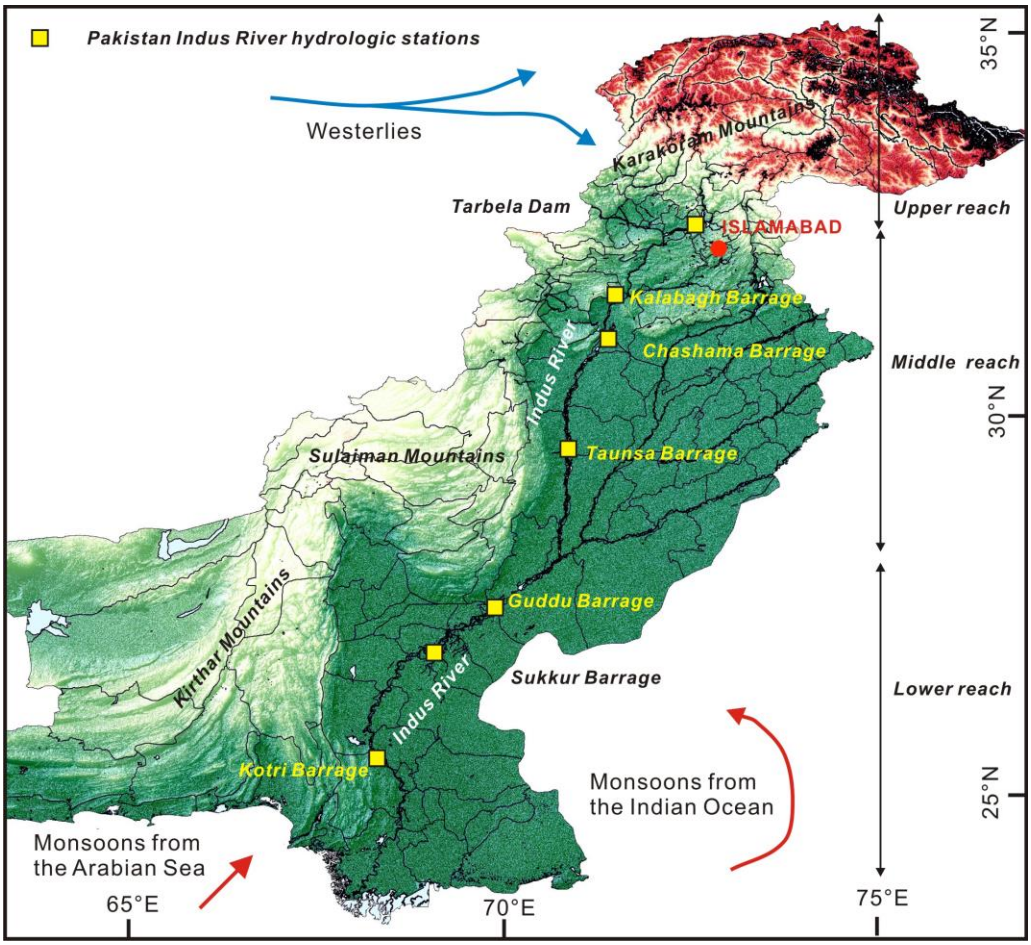

Figure 1. River section of the Indus River and boundary of upper, middle and lower Indus River and section location.

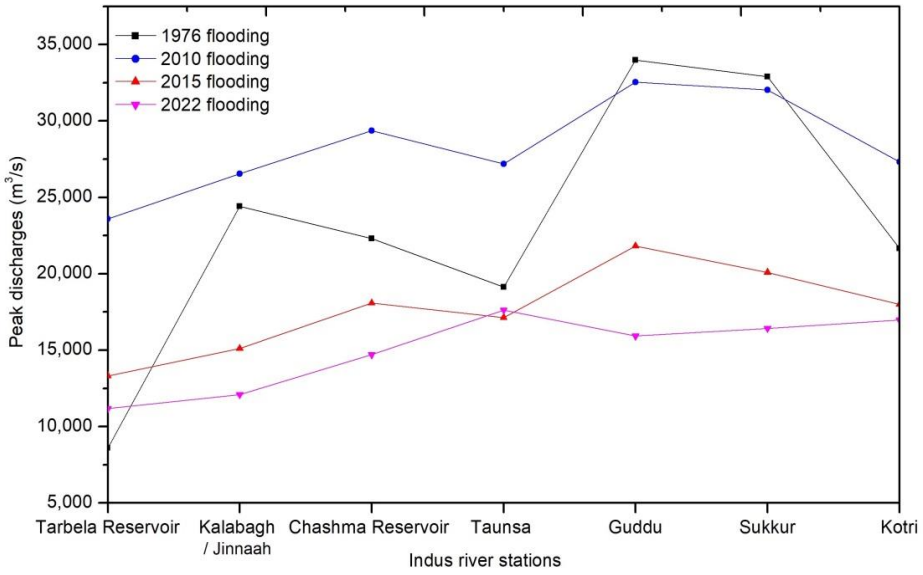

Figure 2. The peak flow of 2022 flood in the Indus River is much smaller than those of several floods in history (data from the Pakistan Flood Report)

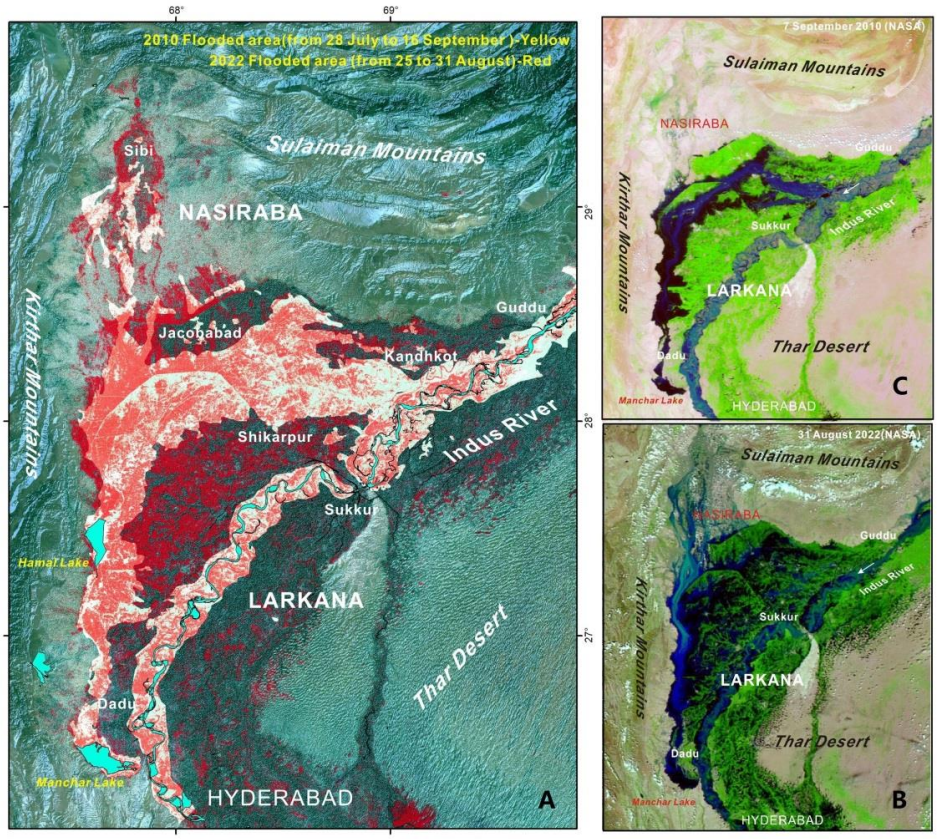

Figure 3. A. The inundated area (red part) of the 2022 flood in the Larkana plain is much larger than that of the 2010 megaflood (yellow part, data from UNOSAT); B 2022 heavy rainfall flood inundated areas like a vast ocean; C 2010 megaflood inundated low-lying areas in the west

2. The flood peak of the curved section in the LARKANA plain remains high due to multiple heavy rainfalls in the alluvial plain of the middle Indus River

From the overall inversion analysis of the 2022 flood flow process of the Indus River (**Fig. 4**), the flood disaster causes of the LARKANA plain can be further clarified. From August 26 to 27, a sudden flood peak (11,190 m^3/s) occurred at the TARBELA Reservoir in the upper Indus River. Also, from August 27 to 31, there was a significant increase in flood flow at the Kalabagh Hydrological Station, with the flood peak appearing on August 28 (12,096 m^3/s). In addition, the Chashma Reservoir in the middle Indus River had three flood flow increases, respectively, from August 18 to 20, from August 22 to 24, and from August 26 to 31, while the flood peak occurred on August 30 (14,700 m^3/s); the Taunsa Hydrological Station had four flood flow increases, respectively on August 15, from August 18 to 19, from August 21 to 22, and from August 26 to September 1, while the flood peak appeared on August 30 (17,620 m^3/s); the Guddu Hydrological Station flood flow increased from August 21 to September 3, with the flood peak occurring on August 23 (15,920 m^3/s); the Sukkur Hydrological Station flood flow increased from August 22 to September 4, with flood peak appearing on August 25 (16,430 m^3/s); and as of September 5, the Korti Hydrological Station flood flow in the lower Indus River continued to increase (**Fig. 4D**).

It can be seen that the Tarbela-Kalabagh section of the upper Indus River mainly experienced a single process of increasing flood flow since August 13 (**Fig. 4A**), while the discharges of the Chashma-Taunsa section of the middle Indus River have increased 4 times (**Fig. 4B**). As a result, the Guddu-Sukkur meander belt of LARKANA Plain continuously with high water level and stagnant (**Fig. 4C)**, resulting in poor drainage and flooding.

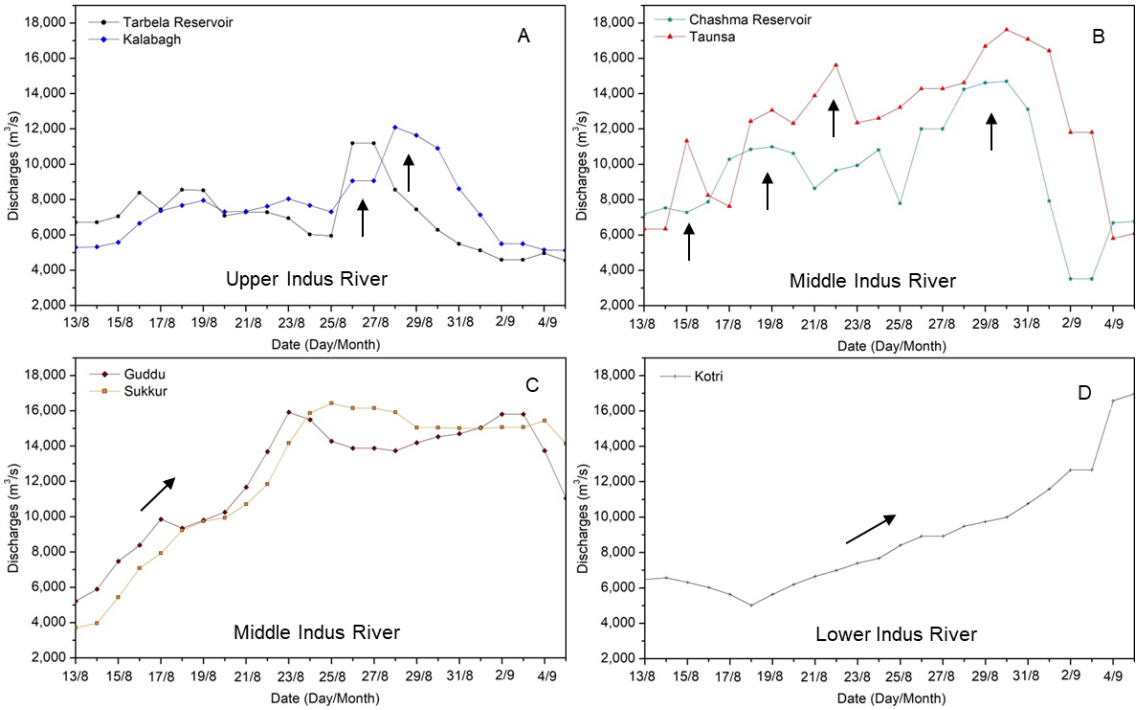

Figure 4. The 2022 flood flow hydrograph from August 13 to September 5 and flood flow increase process in Hydrological Observatory Stations along the Indus River (Data from Pakistan Flood Report)

3. The abnormal presence of South Asian summer monsoon cyclonic warm moist clouds over LARKANA is a key factor for floods in southern Pakistan.

In the middle and late August, precipitation was mainly concentrated in the southern plains of Pakistan (**Fig. 5)**, and precipitation over the LARKANA plain exceeded 300mm and lasted half a month. The continuous rainfall caused poor drainage in a wide range of plains and hilly areas, which was also the main reason for the flooding.

It can be seen from the satellite image that there was an obvious cyclonic cloud over southern Pakistan from August 18 to 26 (**Fig. 6 Left**), and the cloud stayed for several days continuously, bringing heavy rainfall to the large alluvial plain area from Chashma Reservoir to LARKANA (**Fig. 6 Right**). After that, despite the decrease in clouds and rainfall from 26 to 30, the flood flow (~15,000 m^3/s) in the downstream LARKANA floodplain remained high due to the influence of topography, and the flood peak in the section from Guddu to Sukkur lasted for 14 days until early September. After nearly half a month of increased flooding in the lower and middle Indus River,

floodwaters continued to pour into the low-lying Manchar Lake. On September 6, the largest freshwater lake in Pakistan breached its dams, and the breakout further exacerbated the flooding around Manchar Lake.

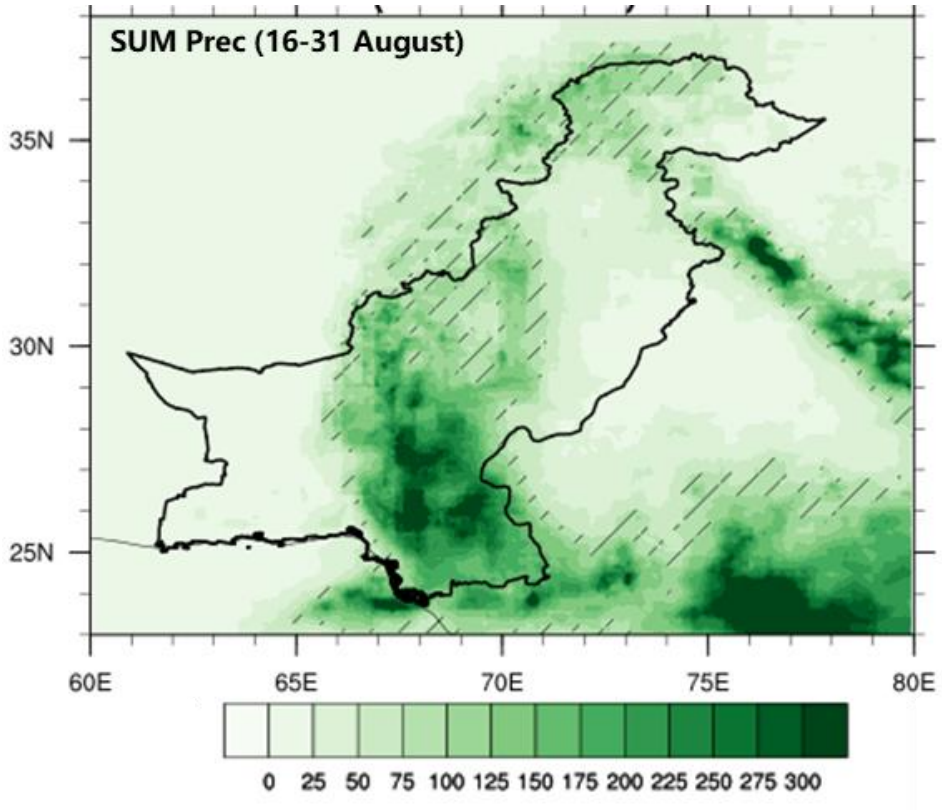

Figure. 5 Precipitation concentrated in the southern part of Pakistan in late August (unit: mm; Data from MSWEP)

In summary, the flood peak along the Indus River in 2022 is not large. Still, heavy rainfall continuously stayed in the floodplain. It increased many times because the middle and lower alluvial plain was covered by the abnormal monsoon rainstorm for a long time, which led to a long-term high level of flooding. Combined with topographic conditions, it has been witnessed that flooding extent in the LARKANA floodplain and the water volume of Nechel Lake continued to increase, resulting in the dam bursting and forming an outburst flood, which exacerbated the extent of the flood disaster. Overall, the Great Flood of 2022 resulted from the superimposed effect of the main river floods formed by heavy rainfall in the northern mountainous areas and the continued heavy precipitation in the flooded areas, leading to a larger inundation of the downstream plain areas.

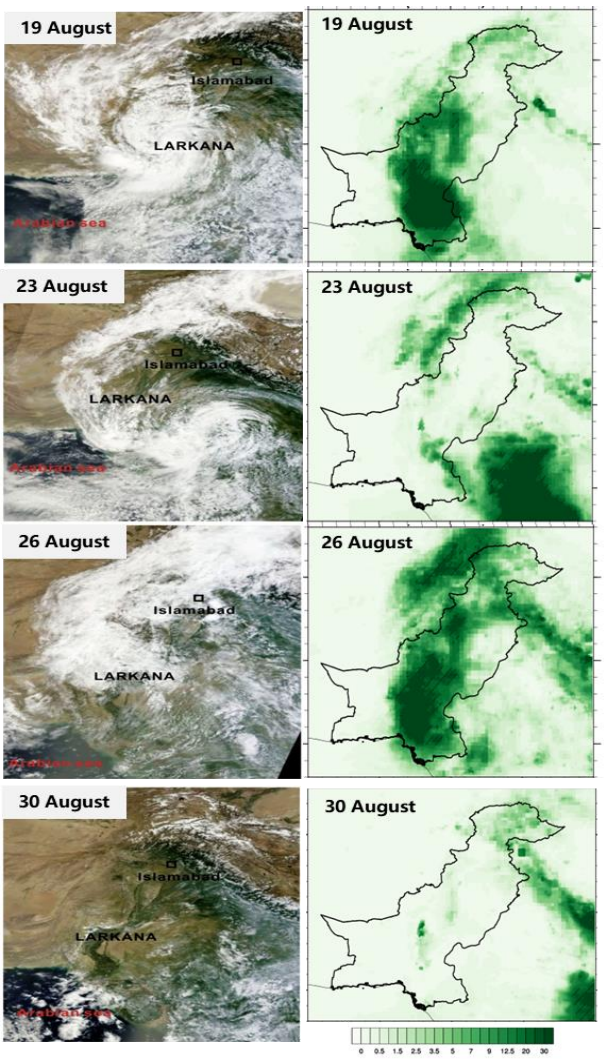

Figure 6. NASA satellite image of Pakistan in mid-late August (Left: data from NASA satellite imagery) with rainfall fall areas (Right: data from MSWEP; in mm/day)

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