Lecture 7
Floods in the Humid Tropics (I): Factors contributing to Fluvial Floods

KEY QUESTIONS:

✓ *What factors contribute to fluvial flooding in the humid tropics?*

With the completion of this lecture, attached readings and tutorial, you should be able to understand the:

- Occurrence of fluvial floods when peak discharge exceeds bankfull discharge and inundates adjacent areas that are usually dry
- Natural and human factors contributing to occurrence of fluvial floods in the humid tropics

Lecture Outline

7.1 Introduction: Floods and related terms

7.2 Causes of Fluvial Floods

7.2.1 Natural factors contributing to fluvial floods.

(a) Excessive Rainfall

(b) Snow and Ice-melt

(c) Features of the drainage basin

Box 1: Monsoons, Tropical Cyclones and Flooding in the Humid Tropics

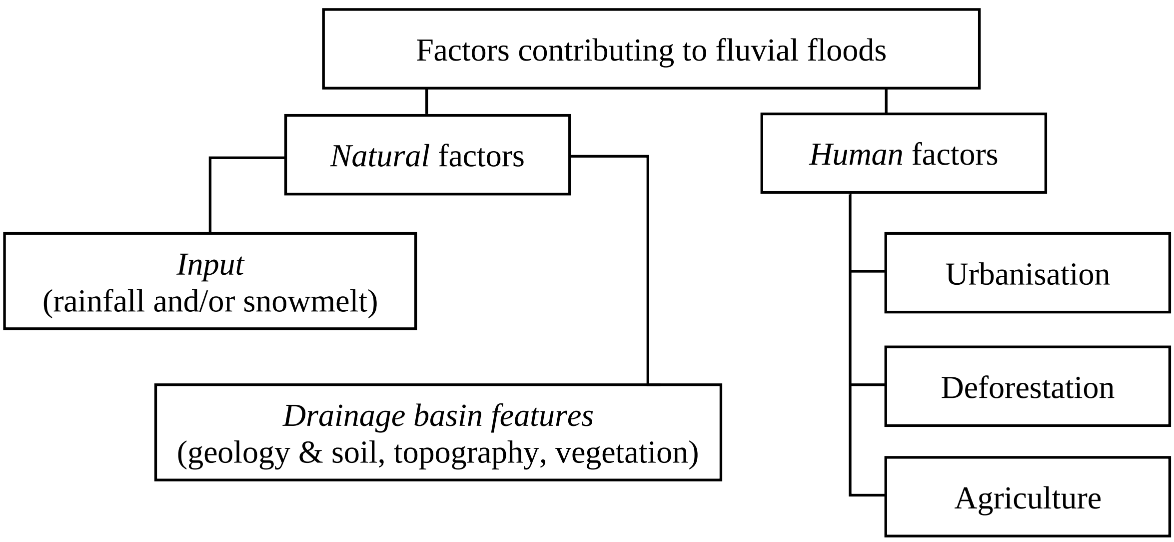
7.2.2 Human factors contributing to fluvial intensify floods.

(a) Urbanisation **(b)** Deforestation **(c)** Agriculture

Box 2: Flooding in KL – caused by human or natural factors?

Reading:

(1) The 2022 Pakistan floods



7.1 Introduction: Floods and related terms

- Floods are the most frequent type of natural disaster. This is because of the widespread distribution of river floodplains (see **Fig. 1**) and low-lying coasts and their long-standing attractions for human settlement.
- Floods can cause widespread devastation, resulting in loss of life and damages to personal property and critical public health infrastructure.
    - According to the WHO, between 1998-2017, floods affected more than 2 billion people worldwide. People who live in floodplains or non-resistant buildings, or lack warning systems and awareness of flooding hazard, are most vulnerable to floods.
- There are three common types of floods, of which, for the purpose of this lecture, we shall focus only on **fluvial** (or river) **floods**.
    - Fluvial floods are caused when consistent rain or snow melt forces a river to exceed capacity. (see more later)
    - Flash floods are caused by rapid and excessive rainfall that raises water heights quickly, and rivers, streams, channels or roads may be overtaken.
    - Coastal floods are caused by storm surges associated with tropical cyclones and tsunami.

- A **fluvial flood** occurs when **river discharge exceeds bankfull discharge**, leading to overbank spillage and inundation of land which is not normally submerged.

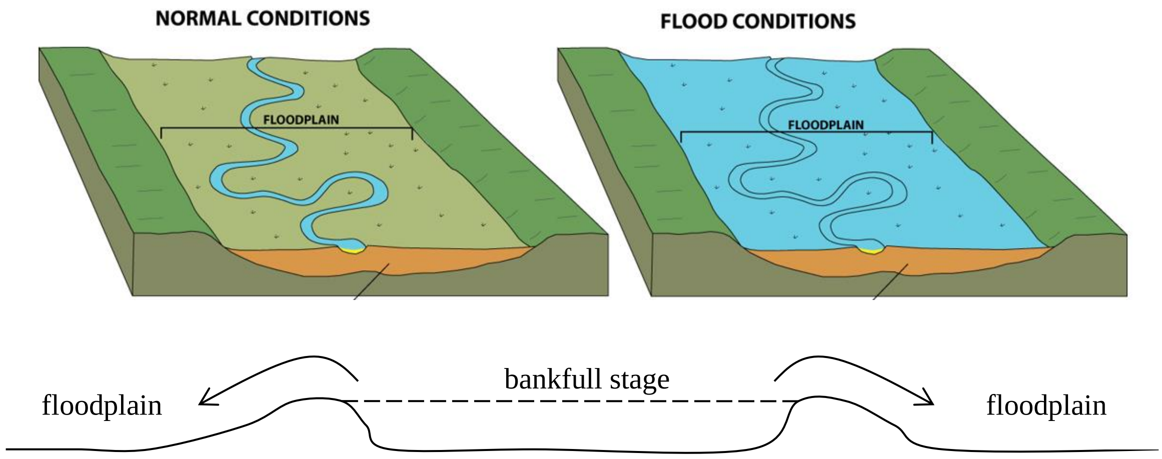


Fig. 1 Flood and Floodplain

- Most of the time, a river's water and sediment load are transported in the river channel itself. The flat, low-lying area adjacent to many river channels that is subjected to recurrent flooding is a **floodplain** (see **Fig. 1**). The function of the floodplain is to act as a temporary store of discharge and alluvium at times when the river overflows its channel. (Alluvium: material deposited by rivers – it consists of silt, sand, clay, and gravel and often contains a good deal of organic matter, thus yielding fertile soils)
    - Despite the continued risks of living in a flood-prone area, many of the world's floodplains have high population densities. Floodplains provide areas of flat, fertile land with a ready water supply and are thus ideal locations for intensive agriculture, industrial activities, and urban development.

- Examples of densely populated floodplains include the Ganges in India and Bangladesh, and Nile in Egypt. These human activities on vulnerable floodplains which are naturally prone to flooding place lives and property at risk during floods.

- **Flood frequency** refers to how often an area will experience flood, while **flood magnitude** refers to the impact and intensity of a flood event.

7.2 Causes of Fluvial Floods

- Most floods are a result of overland flow and rapid throughflow (see **Fig. 2**). These produce a rise in discharge which can be reflected in a hydrograph (see **Fig. 3**).
- The relative importance of quickflow processes (i.e. overland flow and rapid throughflow) and slowflow (i.e. slow throughflow and baseflow) processes are dependent on a range of factors, both physical and human (recall **Lect 6**).

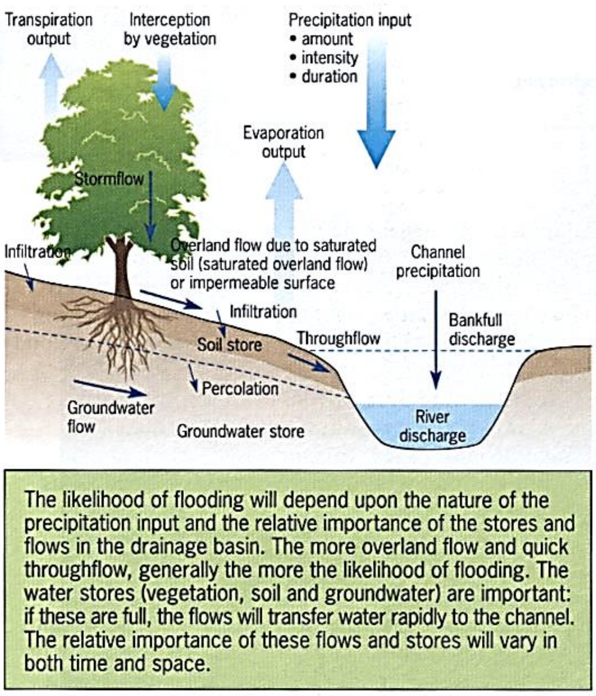


Fig. 2 **Water stores and flows in a drainage basin**

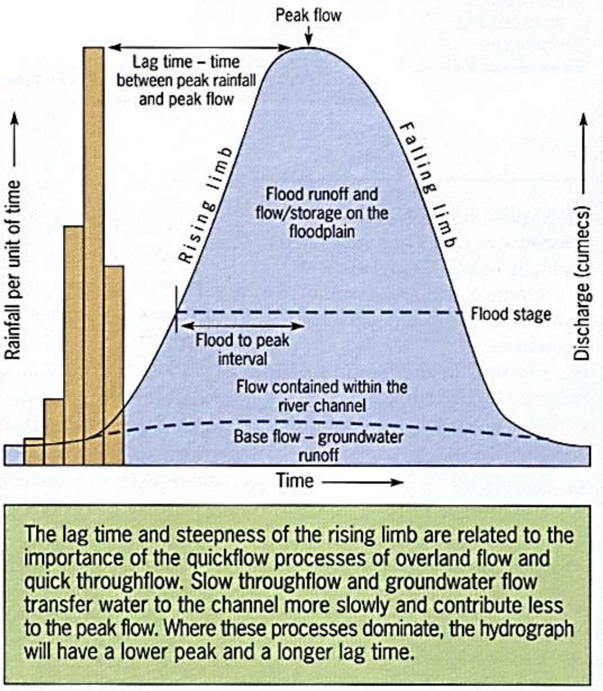


Fig. 3 **The flood hydrograph**

- Physical factors which result in excess input of water **cause** river floods, while physical and human factors that alter the characteristics of the drainage basin can **intensify** the occurrence of floods. ***In sum, flooding is caused by the excessive input of precipitation and exacerbated by human activities.***

7.2.1 Natural factors that contribute to fluvial flooding

- Flood occurrence is mainly determined by the <u>interaction</u> between the **input of precipitation** and the **features of the drainage basin**, such as surface conditions, topography and vegetation.

Natural factors contributing to fluvial floods

- *Input* (rainfall and/or snowmelt)
- *Drainage basin features* (geology & soil, topography, vegetation)

(a) Excessive Rainfall

- Atmospheric extremes, especially excessive rainfalls, are the *most common cause* of floods. Unsurprisingly so as this is the main input pathway of most drainage basin especially in the humid tropics.
- As we have learnt in **Lect 6 Section 6.2.1(b)(c)(d)**, seasonality, amount, intensity and duration of rainfall are all capable of generating high volumes of stormflow (i.e. overland flow and rapid throughflow).
- They vary from semi-predictable seasonal rains over wide geographic areas, which gives rise to the annual wet season floods in tropical areas, to almost random convectional storms over small basins. See **Box 1** for a more detailed write-up.

<u>Box 1</u>: **Monsoons, Tropical Cyclones and Flooding in the Humid Tropics**

The frequency of high magnitude rain events is high in the **<u>humid tropics</u>** <u>(especially Af and Am)</u>. **Monsoon** (see Lect 4) and **tropical cyclones** (also Lect 4) in particular bring periods of high magnitude, prolonged and/or intense rainfall and increase the likelihood of floods.

- In the case of prolonged rainfall (for instance during **wet monsoon** months), high antecedent moisture may mean that soil moisture and groundwater storages are already full. Subsequent rainfall on saturated soil generates SOF on the surface, which flows quickly to the channel. Water stored in soil moisture and groundwater storages will also be continually released to the channel as throughflow and baseflow, keeping discharge level high and making it easier for river discharge to exceed bankfull discharge, thus causing flood.
  - For example, high magnitude and prolonged monsoon rains in August 2022 (also described by the UN Chief as "a monsoon on steroids") led to severe flooding of the Indus River and its many tributaries in Pakistan, affecting more than 33 million Pakistanis. (See **Reading 1**)
- During high magnitude and high intensity rainstorms in the humid tropics (for example, brought by **tropical cyclones**), rainfall intensity is likely to exceed the infiltration capacity of the surface, especially in urbanised or deforested drainage basins. This generates large volumes of HOF, which flow quickly to the channel and cause floods when river discharge exceeds bankfull discharge.
  - For example, as we saw in **Lect 4 Box 1**, within a span of <u>only 10 days</u>, Typhoon Haiyan and two other earlier smaller storms, brought copious amounts of rainfall to the central Philippines. Typhoon Haiyan alone generated an average of 400 mm of rainfall. (For comparison, Singapore's <u>annual</u> rainfall is about 2400mm)

(b) Snow and Ice-melt

- In **Lect 6**, we learnt that snow acts as a water store. Snow and ice melt are common at high altitudes in the tropics, for example the Himalayas and the Andes, where on these high mountains snow accumulate.
  - The melting of winter snow in late spring or early summer releases large volumes of water, which itself is capable of raising river discharge.
  - In instances where the surface is mostly impermeable, such as when the ground is still frozen, there will be no infiltration and the snowmelt waters will generate large volumes of HOF and eventual raise river discharge even more, which may exceed bankfull discharge, thus causing flood.

- Factors which affect the amount of snow and ice melt include the thickness of snow/ice, the nature of the ground and the rate of melting. Gradual melting leads to sustained high discharge, while sudden melting may cause large floods. The most dangerous melt conditions often arise from rain falling on snow to give a combined flow.
  - For example, between 30% and 50% of the entire country of Bangladesh is flooded during the summer monsoon season every year, where **monsoon rains** *and* **snow melt** from the Himalayas produce large amounts of water in the country.
  - 80% of Bangladesh comprises low-lying, flat, fertile floodplain and delta land of alluvium deposited regularly by the Rivers Ganges, Brahmaputra and Meghna (see **Fig. 4**).
  - Total rainfall within the Brahmaputra-Ganges-Meghna catchment is very high and very seasonal – 75% of annual rainfall occurs in the summer monsoon between June and September. Furthermore, the Ganges and Brahmaputra carry snow melt waters from the Himalayas. This normally reaches the delta in June and July. As a result, peak discharges of the rivers are immense (up to 100 000 m^3/s in the Brahmaputra) and often exceed bankfull discharge, resulting in fluvial floods.

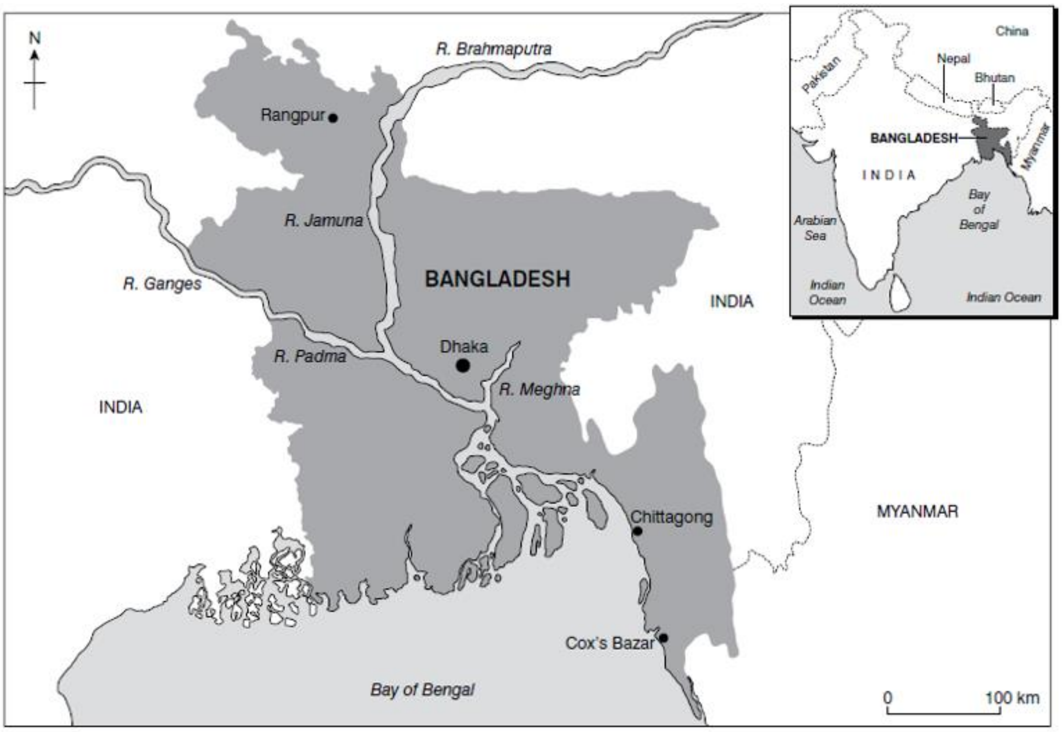


Fig. 4 Location of Bangladesh and its river systems

(c) Features of the drainage basin

- In **Lect 6**, we have learnt how **geology and soil condition**, **basin topography** and **vegetation cover** affects the stores, pathways and output (especially discharge, which directly affects the occurrence of fluvial floods). These are all natural factors that work together with the input (rainfall and/or snowmelt) to cause fluvial floods.
- Even though the material is not reproduced here, <u>you must</u> refer to **Lect 6** for the elaboration on these factors, paying attention to how they contribute to peak discharge exceeding bankfull discharge of a channel.

7.2.2 Human factors that contribute to fluvial flooding

- These are factors that increase the flood response to a given precipitation input. For example, between two different drainage basins subjected to the same rainfall event, it is not uncommon that one generates floods but the other doesn't (or flood is of smaller magnitude).

(a) Urbanisation

- Urbanisation increases the magnitude and frequency of floods in at least four ways.
  i. The creation of **highly impermeable surfaces**, such as roofs and roads, inhibits infiltration so that a higher proportion of storm rainfall appears as runoff. Small flood peaks may be increased up to 10 times by urbanisation and 1:100 year event may be doubled in size by a 30% paving cover of the basin.
  ii. **Hydraulically smooth urban surfaces**, serviced with a **dense network of surface drains and underground sewers**, deliver water more rapidly to the channel. This increases the speed of the flood onset, reducing the lag time between peak rainfall and peak flow by about half.
  iii. The natural river channel is often constricted by the **intrusion of bridge supports or riverside facilities**, thus reducing its carrying capacity. This increases the frequency with which high flows overtop the banks.
  iv. **Insufficient and/or poorly maintained storm-water drainage** following building development is a major cause of urban flooding. The design capacity of many urban storm-water drainage systems, even in developed countries, is not adequate. The Orchard Road floods in 2010 and 2011, though strongly related to intensive rain, can also be attributed to blocked drainage.

Box 2: **Flooding in KL – caused by human or natural factors?**

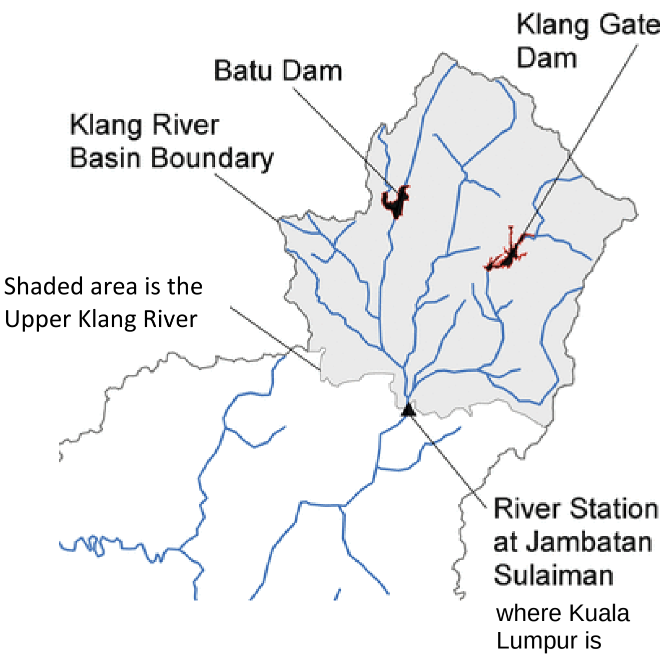


Fig. 5 Kuala Lumpur in the Upper Klang River Basin

Kuala Lumpur, the capital city of Malaysia, experiences frequent flooding.

KL is in the Af climate, so it experiences high rainfall which becomes even more during the monsoon months. KL is at the foot of a relatively steep and fan-shaped basin, providing almost perfect hydrological conditions for generating floods. This meant that even if KL is not a city, the chance of flooding is already high.

Yet KL is also highly urbanised, which helps increase the likelihood of flooding in significant ways.

(b) Deforestation

- Change in surface cover via deforestation – *the permanent removal of vegetation* – encourages the generation of HOF (see **Lect 6**).
- With the removal of the forest canopy and plant roots, the loose and unconsolidated topsoil becomes more susceptible to erosion through surface runoff. **The increased surface runoff carries eroded soil downstream, where the increase in deposition within the channel raises the river beds and reduces channel capacity**. (See **Fig. 6**)
- In small basins, more than four-fold increases in flood peak flows have been recorded together with suspended sediment concentrations as much as 100 times greater than in rivers draining undisturbed forested land.

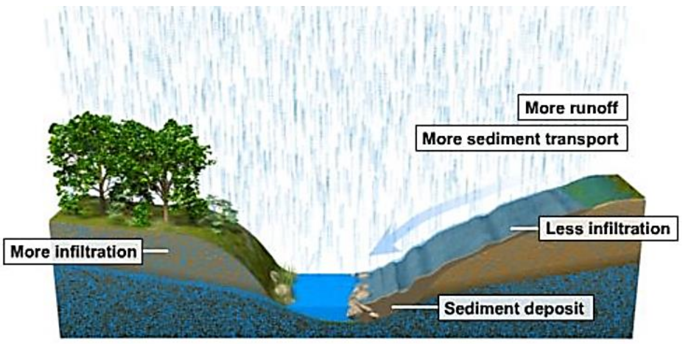


Fig. 6 Deforestation effects

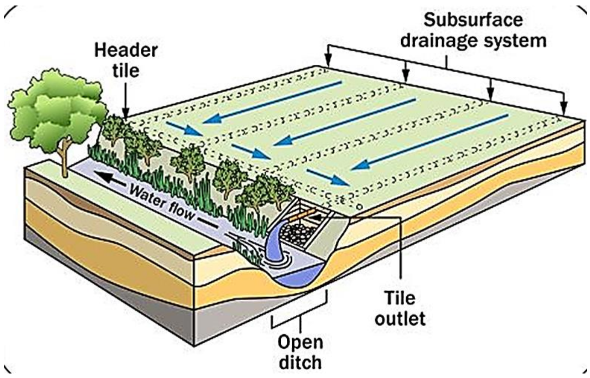


Fig. 7 Agriculture land draining

(c) Agriculture

- The conversion of forested land to agricultural use usually has the effect of lowering infiltration rates and increasing surface runoff. The roots of **crops tend to be thinner and shallower** than the roots of trees and are thus less effective in providing pathways for water to infiltrate. In addition, **compaction of soil by tractors and cattle** further reduces its infiltration capacity and HOF occurs when rainfall intensity exceeds the low infiltration capacity of the soil.
- **Agriculture land draining** refers to the process of *draining excess water on agricultural land away rapidly with the use of underground drains* (see **Fig. 7**). The excess water will eventually be channeled into the rivers. The aim of agricultural land draining is to reduce water ponding on the surface and enable the use of land which otherwise will be too waterlogged for high productivity farming (e.g. clayey soils).
  - These drains can efficiently release water from the field to the stream channels and the presence of these drains is similar to an increase in stream density (albeit underground) and this leads to quick rise in stream discharge during rainstorms and hence again the likelihood of flooding.
  - Additionally, with soil tilling (ploughing) involved in agriculture, the water drained from agricultural land is also likely to contain topsoil that has been washed away by surface runoff. When sediments are washed into rivers and deposited, the carrying capacity of the river is reduced. This is similar to the effects following deforestation (see **part (b)** above).

Reading 1

The 2022 Pakistan floods

Introduction

More than one-third of Pakistan is under water due to unprecedented levels of flooding. Estimates suggest that 1,265 people have been killed, with 6,000+ injured.

The scale of the tragedy is already being compared to the devastating floods of 2010 when more than 2,000 people were killed, marking the event as the deadliest in Pakistan's history.

There are four provinces in Pakistan: Balochistan, Khyber Pakhtunkhwa, Punjab, and Sindh plus the Islamabad Capital Territory. The Sindh province is bisected by the Indus, Pakistan's largest river, which flows from the upstream northern highlands of the Himalayas down to the Arabian Ocean.

Glacial meltwater from the Himalayas and Karakoram mountain range plus snow melt and monsoon rains all supply the Indus with water. The Indus is 3,200 km long and has a large discharge of 5,533 m^3/s (approximately twice as much as the river Nile in Egypt, placing it 52nd in the world). Flooding often occurs in the southeast of the country, in the Sindh province.

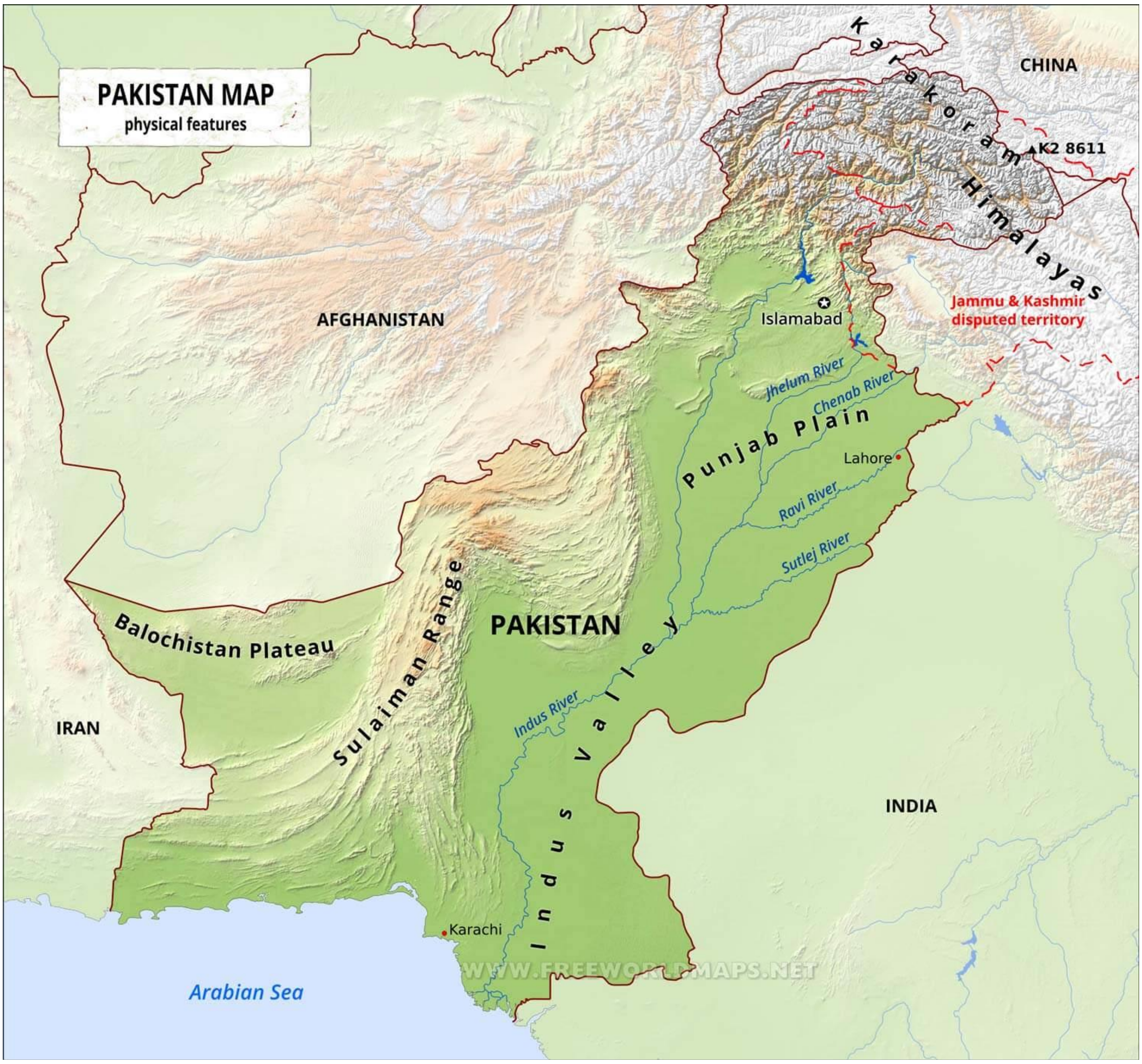


Figure 1 a topographic map of Pakistan, the Sindh provincial capital is Karachi

However, the average discharge for the Indus does not accurately depict the situation in Pakistan because there are extreme spikes in flow, discharge, and flood water at times throughout the year. For example, last week the Indus burst its banks and as much as 17,000 m^3/s of water was discharged. This was caused by Pakistan receiving 190% more rainfall from June to August (compared to average rainfall for this time period over the past 30 years).

The Sindh province to the south of the country has been severely impacted, as it has a wide flat central plain (the Indus river valley), covering 51,800 km^2.

Sindh province

The main economic industry of Sindh is agriculture, which the Indus river has supported for millennia.

The flow of the Indus is typically high between mid-July and mid-August due to environmental factors. However, this year rainfall in Sindh has been exceptionally heavy in recent months.

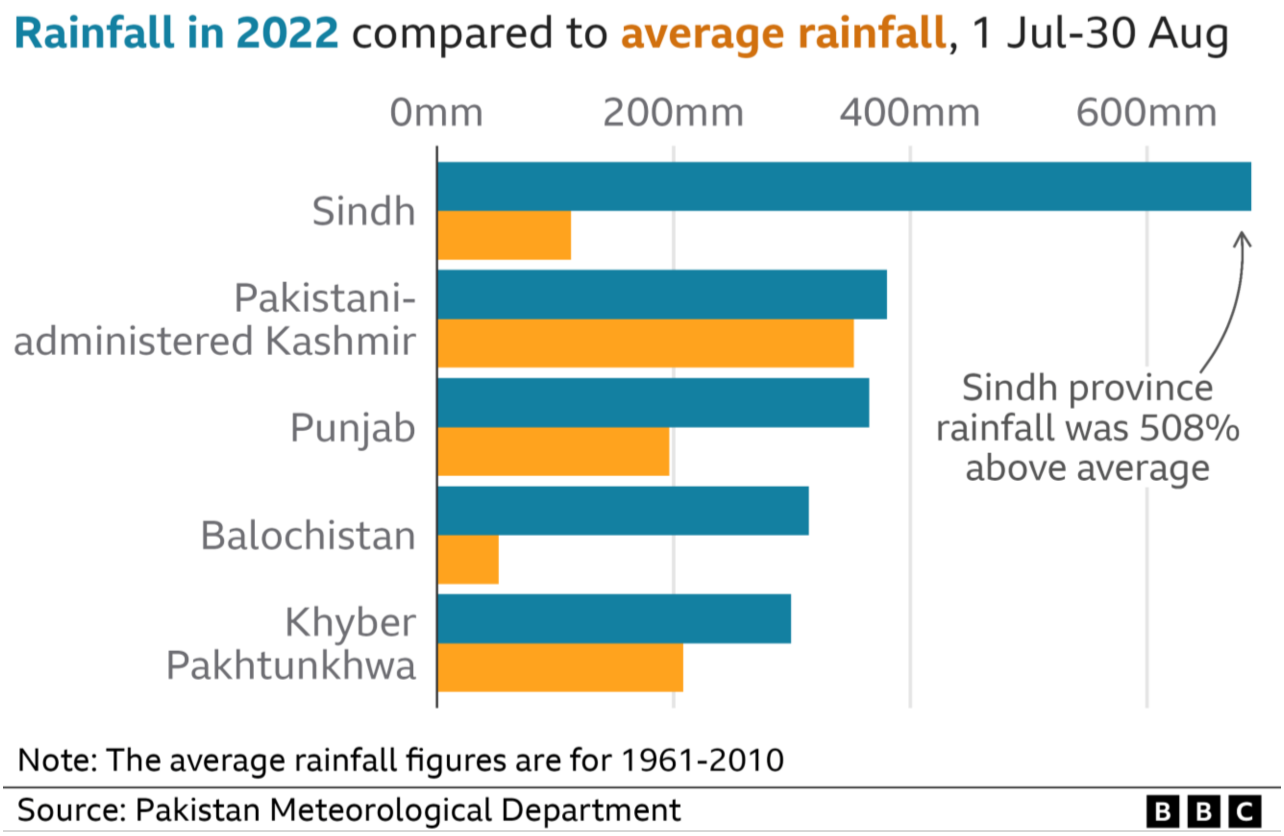


Figure 2 rainfall is well above average in most regions across Pakistan © BBC

Is climate change to blame?

Recent heavy rainfall is only part of the story. This flood event is widely being reported as a climate-related disaster due to extreme changes in monsoon behaviour, precipitation patterns, and melting glaciers.

These contributing factors have been accentuated by increases in global temperature. The UN secretary general, António Guterres, emphasised the link to climate change saying "today, it's Pakistan. Tomorrow, it could be your country" signalling to the world that more needs to be done in the fight against climate change.

The monsoon rainfall was particularly heavy this year due to changes in air temperature across the Arabian Ocean. It is likely that climate change affected the intensity of the monsoon as record amounts of rain fell across the country throughout August (as much as 500-700% more than usual).

The IPCC has reported that South Asia has warmed by around 0.7°C since 1900. This leads to heavy monsoon rain because the warmer atmosphere holds more moisture.

The likelihood of seeing phenomena that may cause severe monsoon conditions is likely to increase. This year, the La Niña event in the Pacific and meanders in the jet stream created perfect conditions for the unusual monsoon rains.

Glacial melt is a growing problem around the world. In Pakistan this is a particular problem as the country has more glaciers than anywhere else in the world, (there are 7,000) excluding the polar regions. This year there has been triple the usual amount of glacial lake outbursts, causing catastrophic flooding.

Initial impact	Short term response
More than 1,265 people have been killed	The WHO has said that more than 6.4 million people are in dire need of humanitarian aid
A million homes have been destroyed or badly damaged	The UN has appealed for $160 million (£139 million) to help with what it has called an "unprecedented climate catastrophe"
33 million people have been directly affected	Aid agencies have asked the government to allow food imports from neighbouring India (the border is normally closed)
Total flood damage estimates exceed £8.7 billion	The UK government has announced humanitarian support of up to £15 million to help Pakistan's flood response
Sindh, with a population of 50 million, has been hardest hit, receiving 466% more rain than the 30-year average	A French aircraft carrying relief goods landed in Islamabad on Saturday and was received by the national health services minister Abdul Qadir Patel

Table 1 a brief summary of the 2022 Pakistan floods

Further work

- BBC Pakistan floods: One third of country is under water - minister
- Publishing Service UK Government Pakistan Toponymic fact file 2019
- Reuters South Pakistan braces for yet more flooding as waters flow down from north
- BBC Pakistan floods: Time running out for families in Sindh
- NASA World of Change: Seasons of the Indus River
- BBC Pakistan floods: Map and satellite photos show extent of devastation
- CNN Pakistan's melting glaciers are 'erupting' and worsening floods
- The Conversation Pakistan floods: what role did climate change play?