Climate change science, knowledge and impacts on water resources in South Asia

DIAGNOSTIC PAPER 1

GUILLAUME LACOMBE, PENNAN CHINNASAMY

International Water Management Institute

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Objectives

- Provide a critical review of climate risks that threaten water resources in South Asia
- Review current situation and future trends influenced by climate change
- Identify knowledge gaps and recommendations to improve preparedness and reduce vulnerabilities

Outline

1. Water resources: variability, trends, and drivers
   - Climate, hydrology, aquifers and water demand

2. Water resource risks: shortage, excess, and contamination

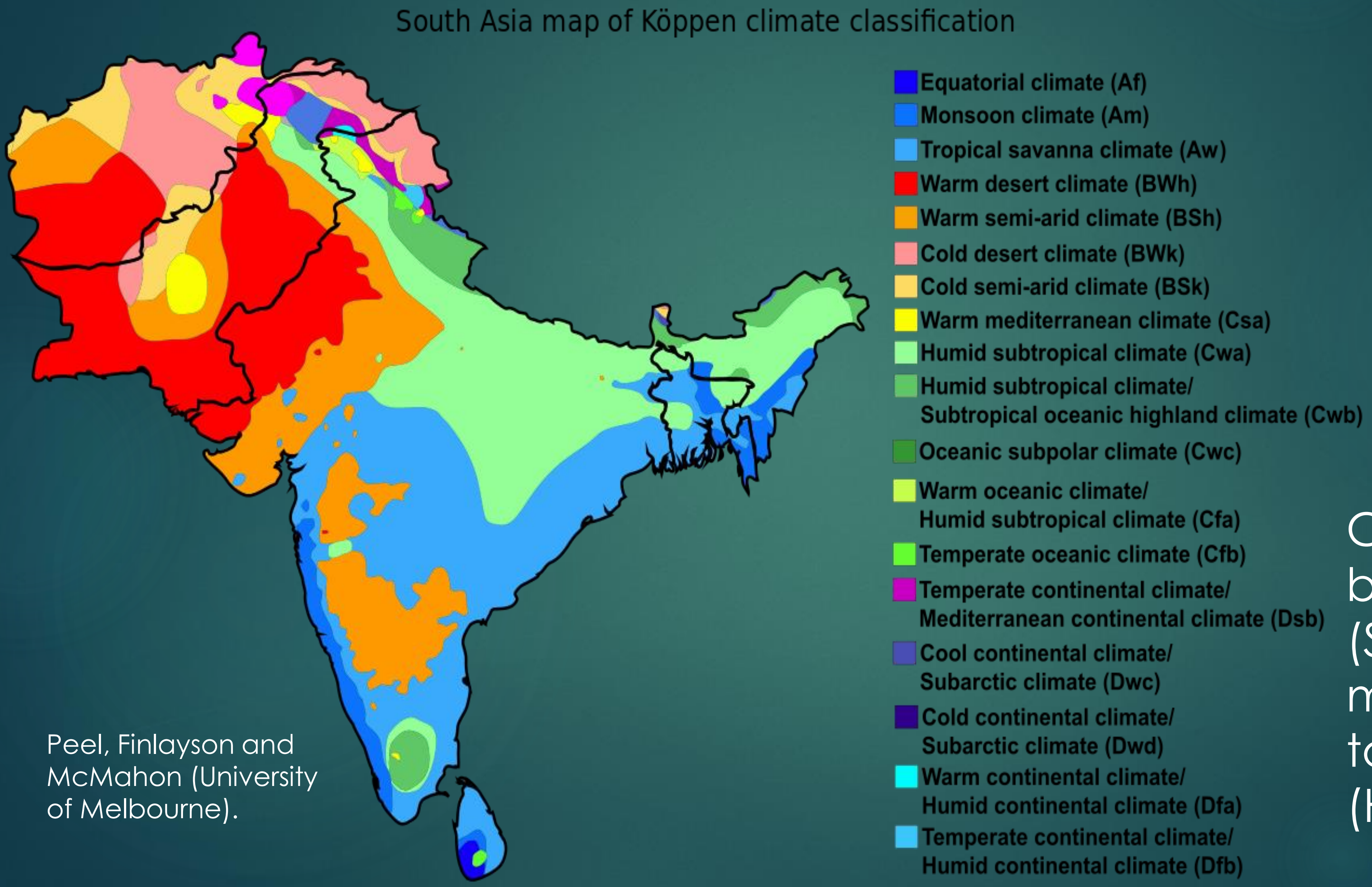
3. Climate change & water resources: CERTAINTIES & UNCERTAINTIES
   - Changes in rainfall, temperature, evaporation, and sea level
   - Consequences on river flow, groundwater recharge, storages and water quality

4. Knowledge gaps and recommendations

Water resources in South Asia: an overview

1. 25% of world's population, 5% of global water resources,
2. Annual per capita water availability (2,500 m^3) below world average (5,900). Continued decline could reach critical 1,000 m^3 in 2025
3. Agriculture: major water consumer (>90% of water abstracted)
4. Growing domestic and industrial demands (e.g. hydropower)
5. Increasing pressure on ecosystems, particularly in downstream areas

Contrasted climate conditions



Peel, Finlayson and McMahon (University of Melbourne).

Climate influenced by Indian Ocean (Southwest monsoon) and topography (Himalayan range)

More than half of South Asia drained by 2 major river basins with very different hydrology

1 Ganges-Brahmaputra-Meghna (GBM)

1300 km^3/year (= 760 mm) mainly from monsoon rain (June-September). **High seasonality**
Ganges: 20-40% of water resources used (75% aquifers, 25% surface). Low water quality

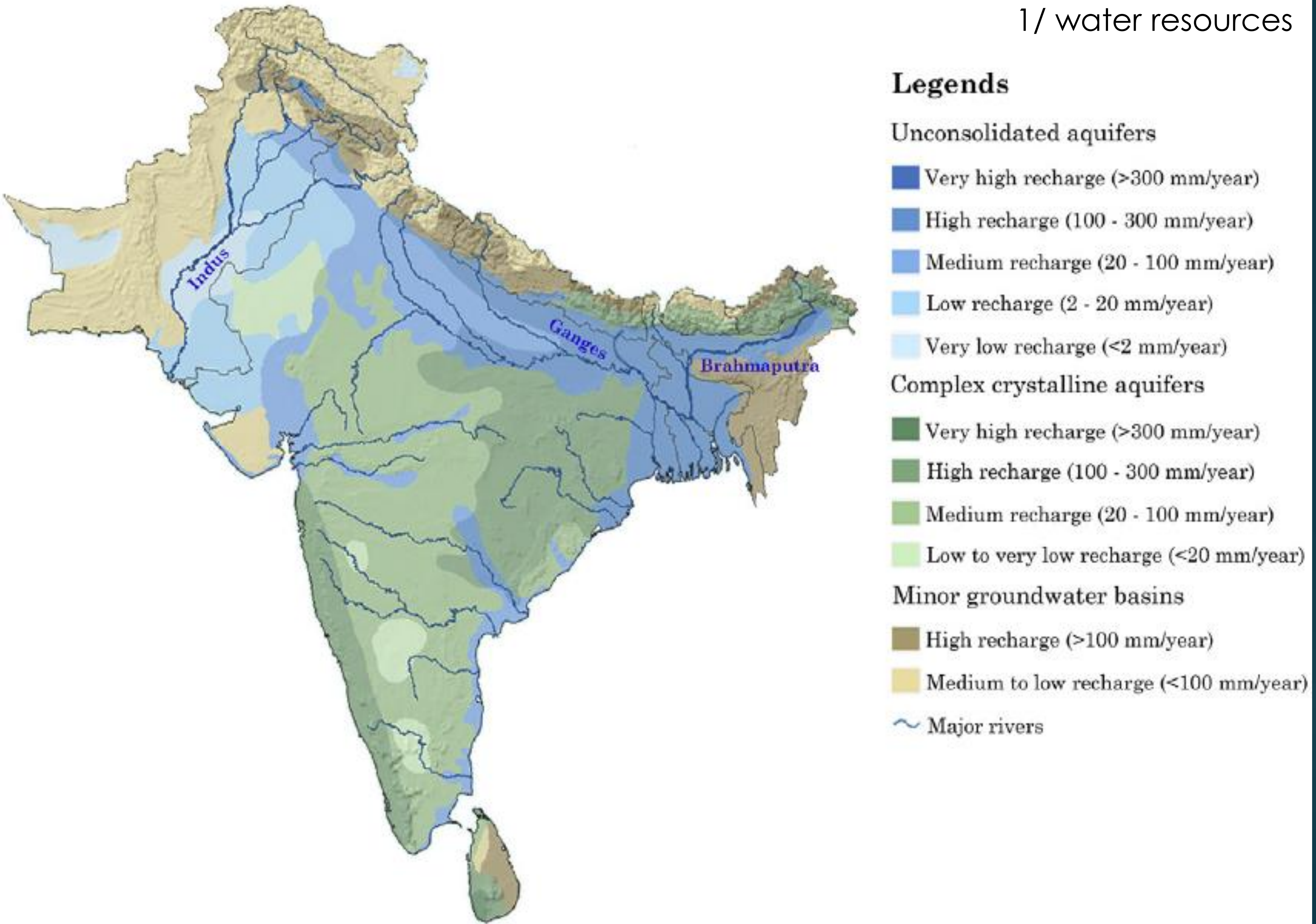
Brahmaputra largely unexploited (low population and steep terrain). Relatively good water quality upstream. 800 million tons of sediments transported annually in GBM

2 Indus Basin

200-300 km^3/year (= 170-250 mm) mainly supplied by snow melt providing perennial water supply 75% of water resources used, mainly for irrigation (53% surface; 47% aquifers). High water stress (<1000 m^3/capita.year). 0.44 km^3 of sediments carried annually

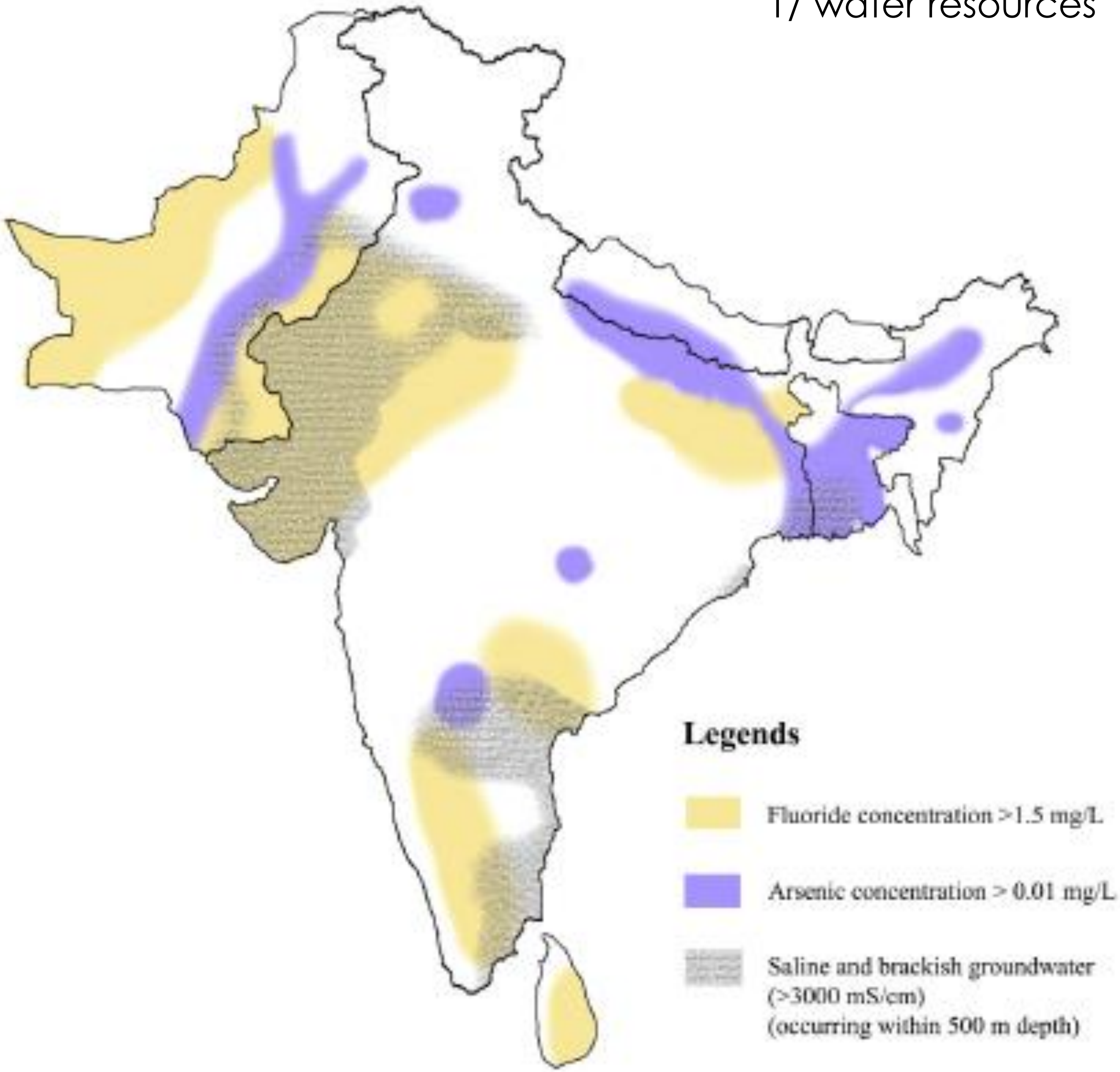
Other basins: Coastal (Southern India, Sri Lanka) and endorheic (Helmand) basins

Aquifers



Recharge rates (Mukherjee et al., 2016)

Aquifers



Groundwater contamination
(Mukherjee et al., 2016)

2/ Climate risks

South Asia concentrates over 40% of natural disasters recorded globally

- **Water excess**: floods destroying infrastructures, crops and causing casualties or diseases
  - GLOF, flash floods, riverine flood and coastal floods
- **Water shortage**: crop yield declines, hydropower loss, lower industrial productions and domestic supplies
  - Rainless periods, low surface and groundwater levels, sediments in storages
- **Water contamination**: diseases, crop yield declines
  - Sea level rise contaminating coastal aquifers, flux of pollutants and contaminants induced by drops in water table levels

Floods (1 million affected people over last century: 80% in India and 14% in Bangladesh)

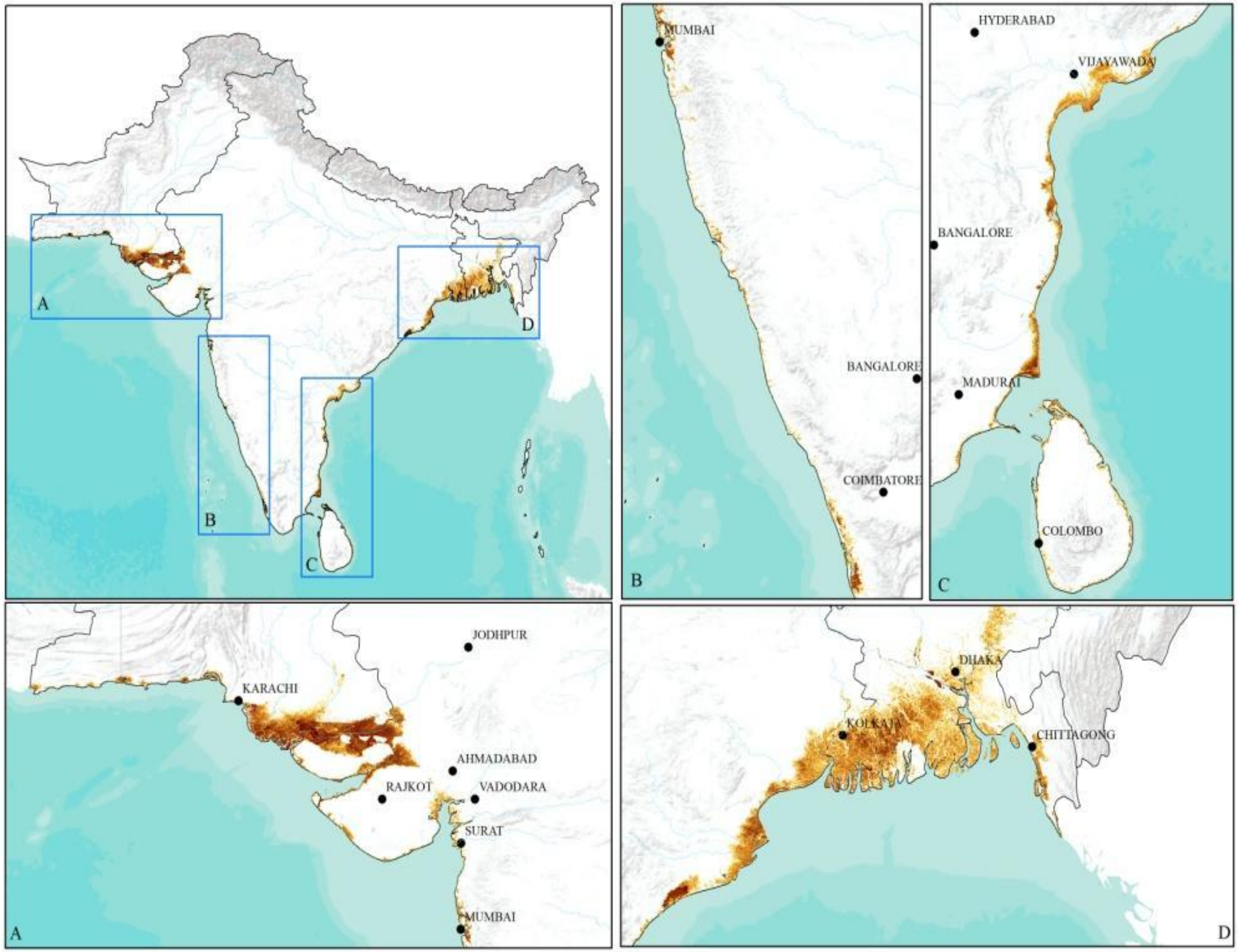
(http://www.emdat.be/)

- **Flash-floods and landslides** in mountains
  - aggravated by slopes, land-use changes, settlements in flood-prone areas
  - Afghanistan, Northern Bangladesh, Indu Kush Himalayas region, e.g. glacial lake outburst floods (GLOF)

GLOF in Nepal

- **Riverine floods** in alluvial plain. Higher vulnerability in flat densely populated river delta. Aggravated by flat/low terrain, land-use change
  - Bangladesh (coincidence of flood pulses in GBM system), India, Pakistan, Sri Lanka

- **Coastal floods** mainly due to cyclones creating local sea-level surges
  - Will worsen in the future as the sea level rises



Hazard map accounting for sea-level rise rate, costal slope and elevation, tidal range, tsunami arrival height
(Giriraj et al., 2016)

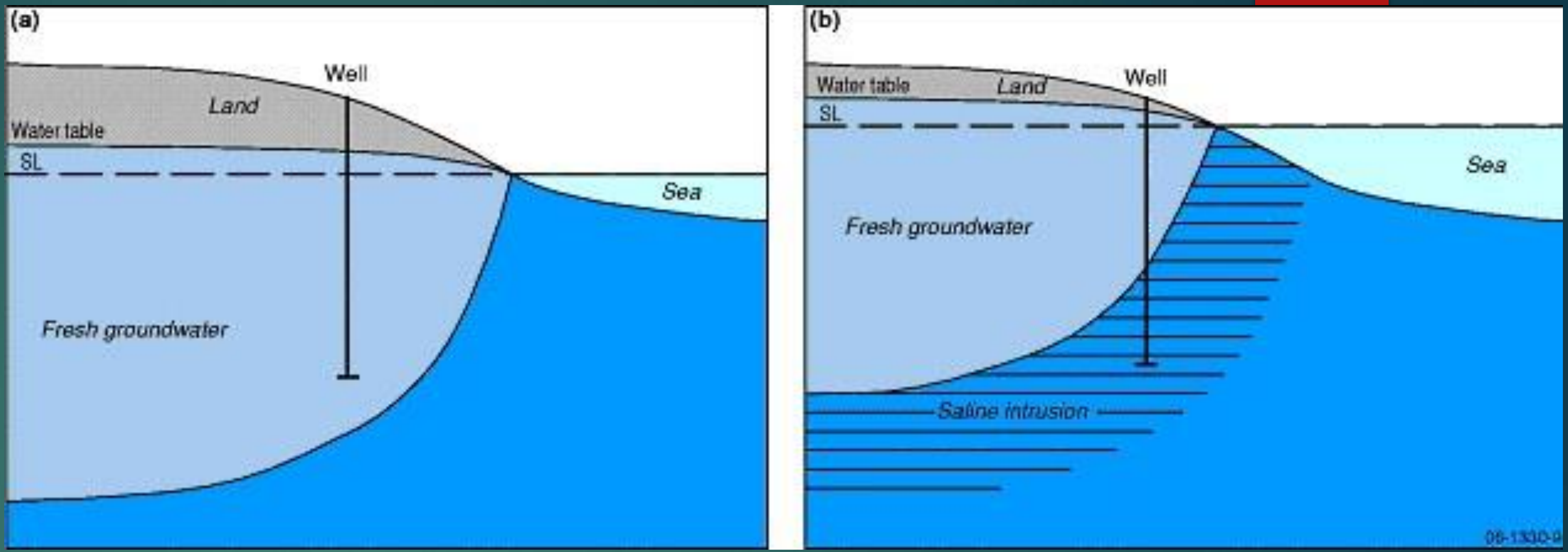
Water shortages (6.1 million casualties caused by droughts over last century) (http://www.emdat.be/)

- **Low rainfall** → lower crop yields, less food
  - Semi-arid and arid countries
- **Low river flow** ← less rainfall, glacier and snow, land-use change, upstream diversion)
  - Indus Basin (Pakistan), GBM in dry season (Bangladesh) and many other countries
- **Water-table drawdown** ← pumping and reduced groundwater recharge

- **Reservoir siltation** in erosion-prone environments
  - Sediment transport and deposition (e.g. Tarbela dam)

Groundwater contamination

Due to combination of anthropogenic and natural dynamics



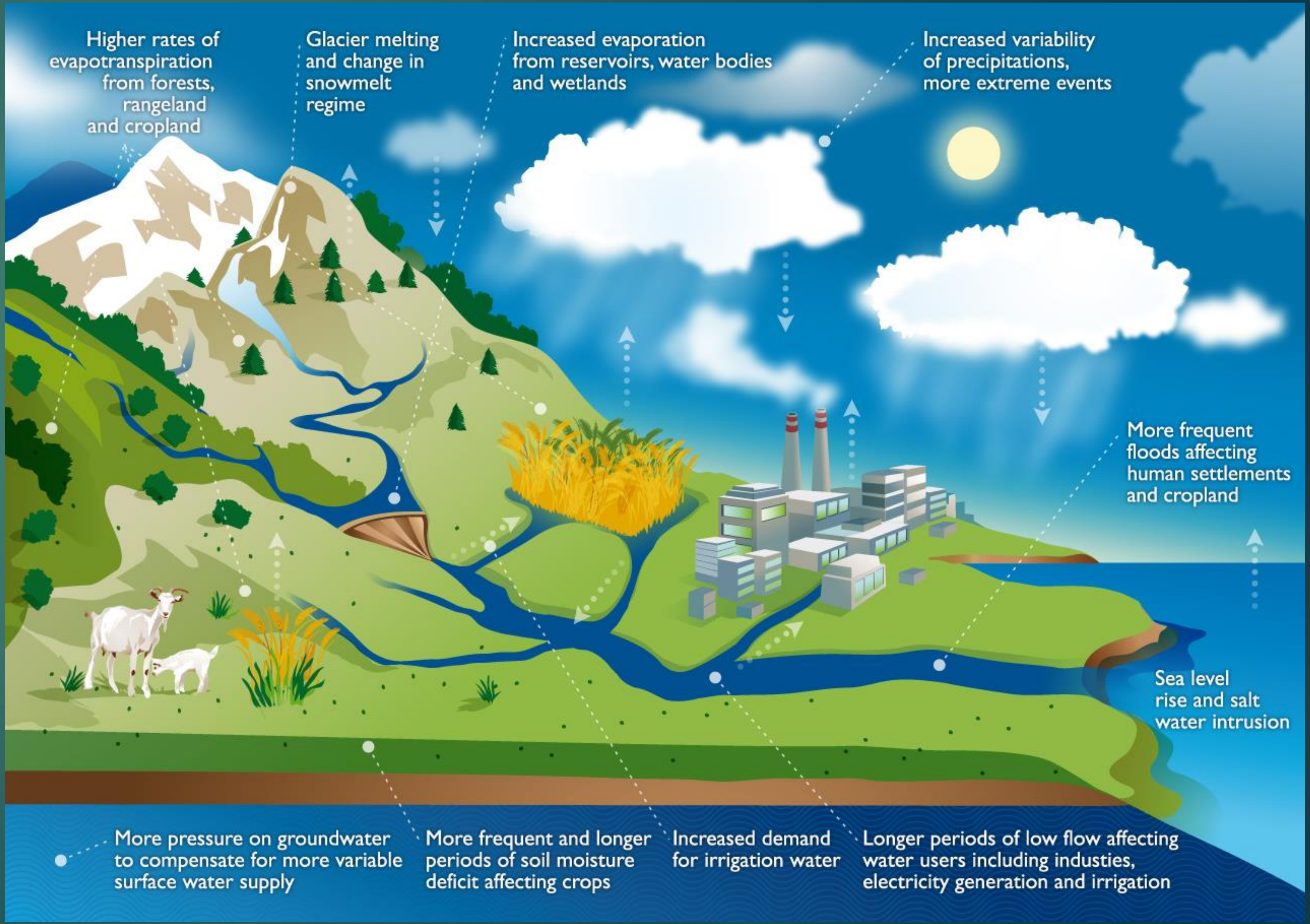
Geoscience Australia

Climate-related causes:

- **Saline intrusion** in coastal aquifers ← sea level storm surge, flow reduction in river deltas
  - e.g. Bangladesh, Pakistan
- **Groundwater level drawdown** ← droughts/reduced recharge
  - mobilization of endogenic contaminants, infiltration of toxic residual from agriculture/industries
  - Coastal aquifers in Sri Lanka, alluvial aquifer of the Indus and GBM

3/ Climate change and water resources

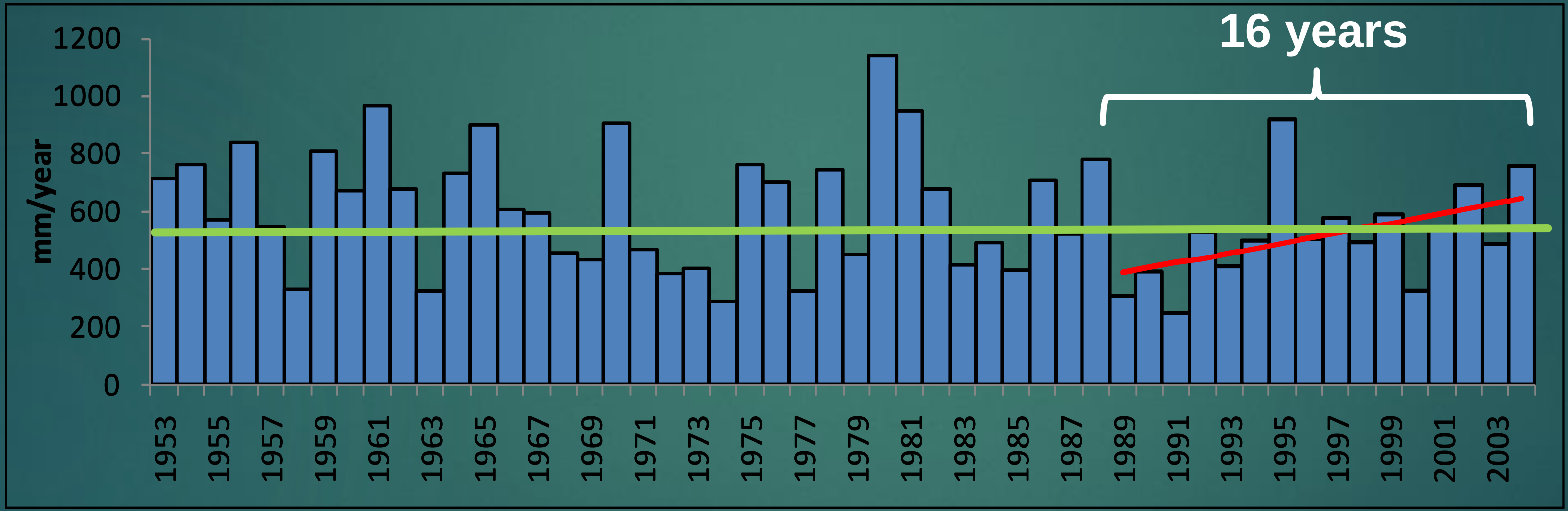
- Global warming alters water cycle and storages through:
  - ↑ temperature and evaporation
  - ↑ sea level
  - Modified rainfall patterns (intensity, frequency, seasonality)
- … in turn altering streamflow, sediments, groundwater recharge and water storages



UNFCC

3/ Climate change and water resources

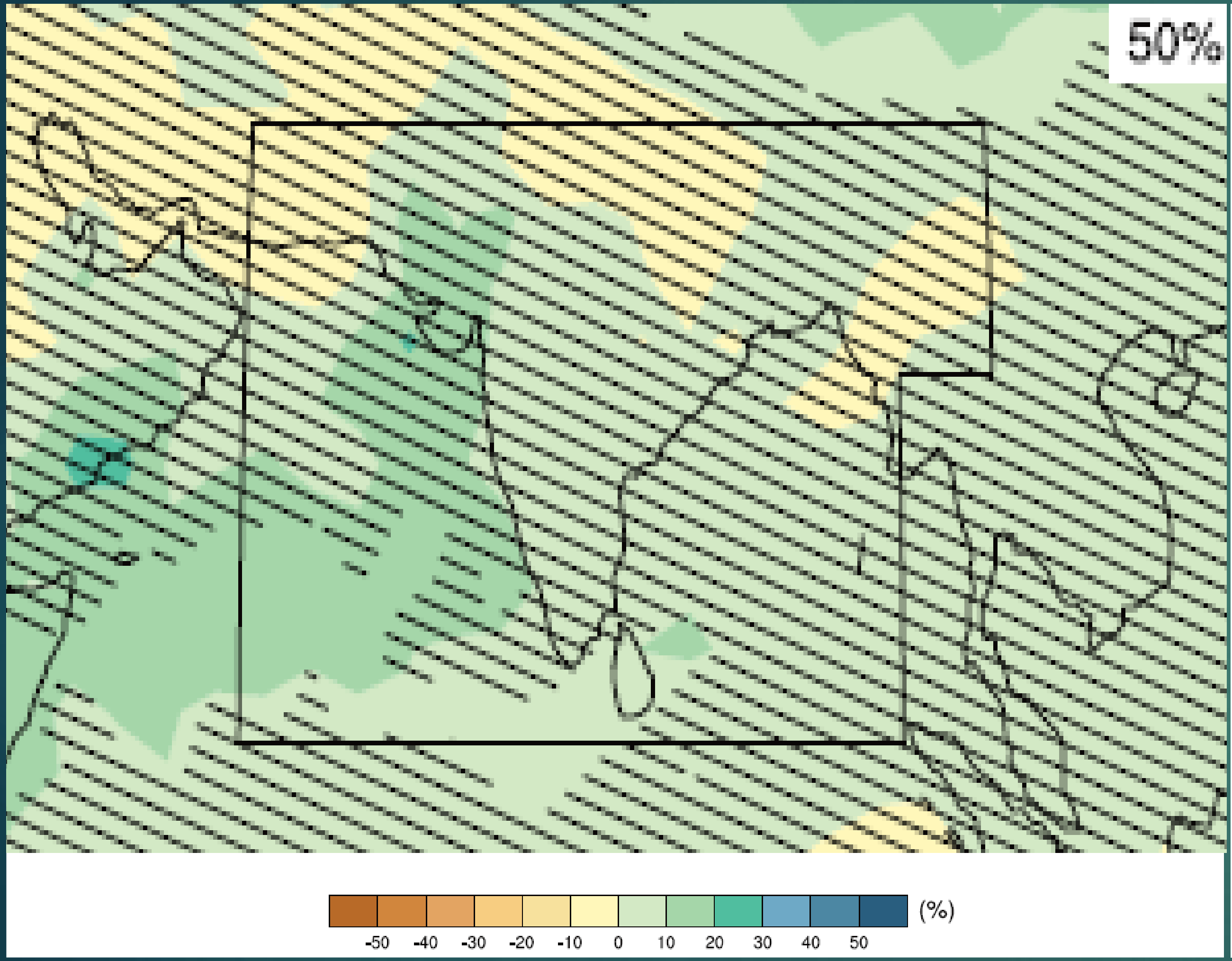
- Observed trends and model projections
  - **Rainfall trends** hardly detectable. High variability: seasonal, inter-annual, inter-decadal
  - **Past**: depend on periods, variables, domains, trend tests, statistical significance levels.



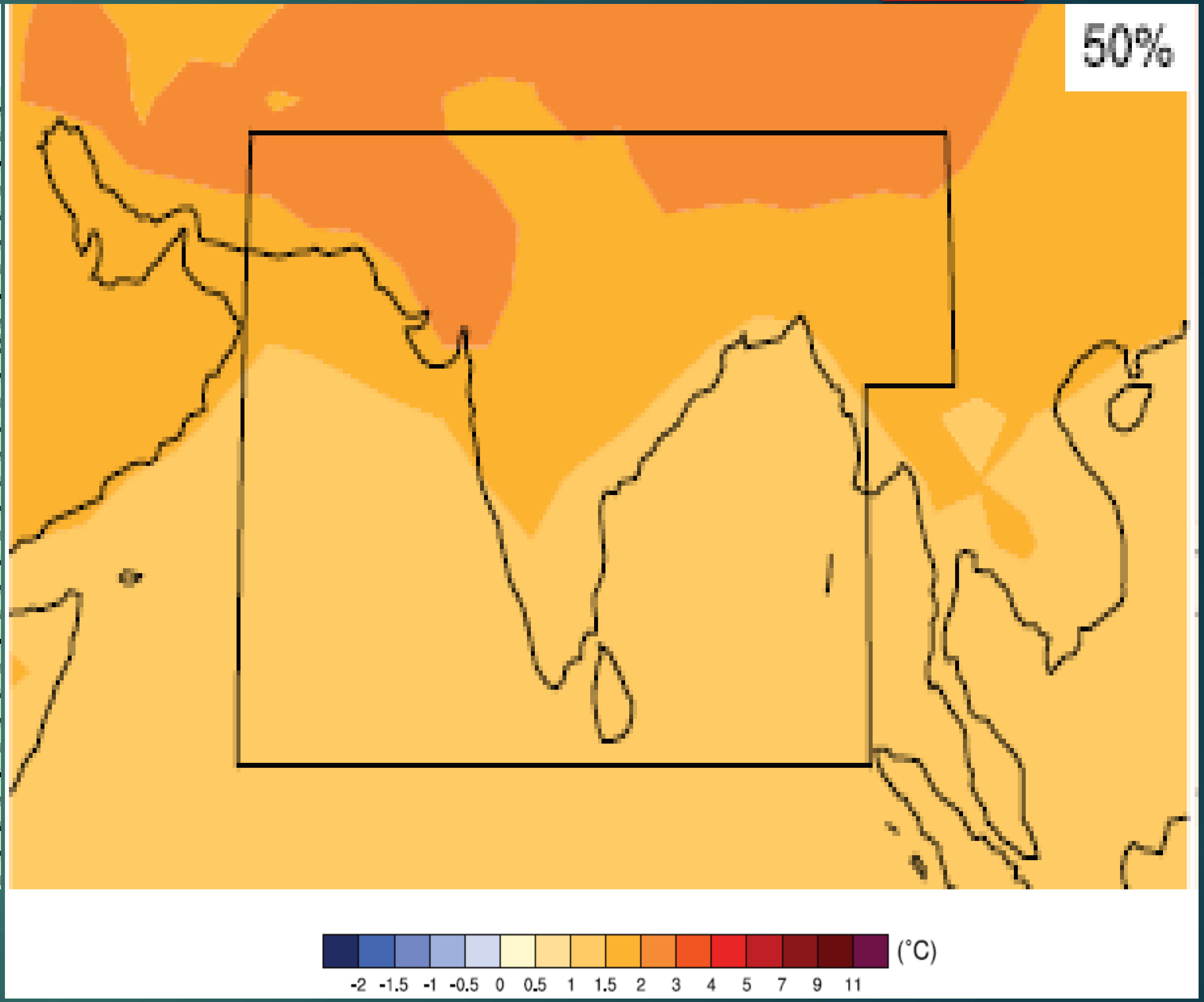
Example of 52-year time series

- **Predictions** depend on models & scenarios → need to refer to most updated model intercomparison CMIP5 (IPCC, 2014)
- **Effects on water resources** compounded by many other drivers (e.g. water abstraction)

Rainfall



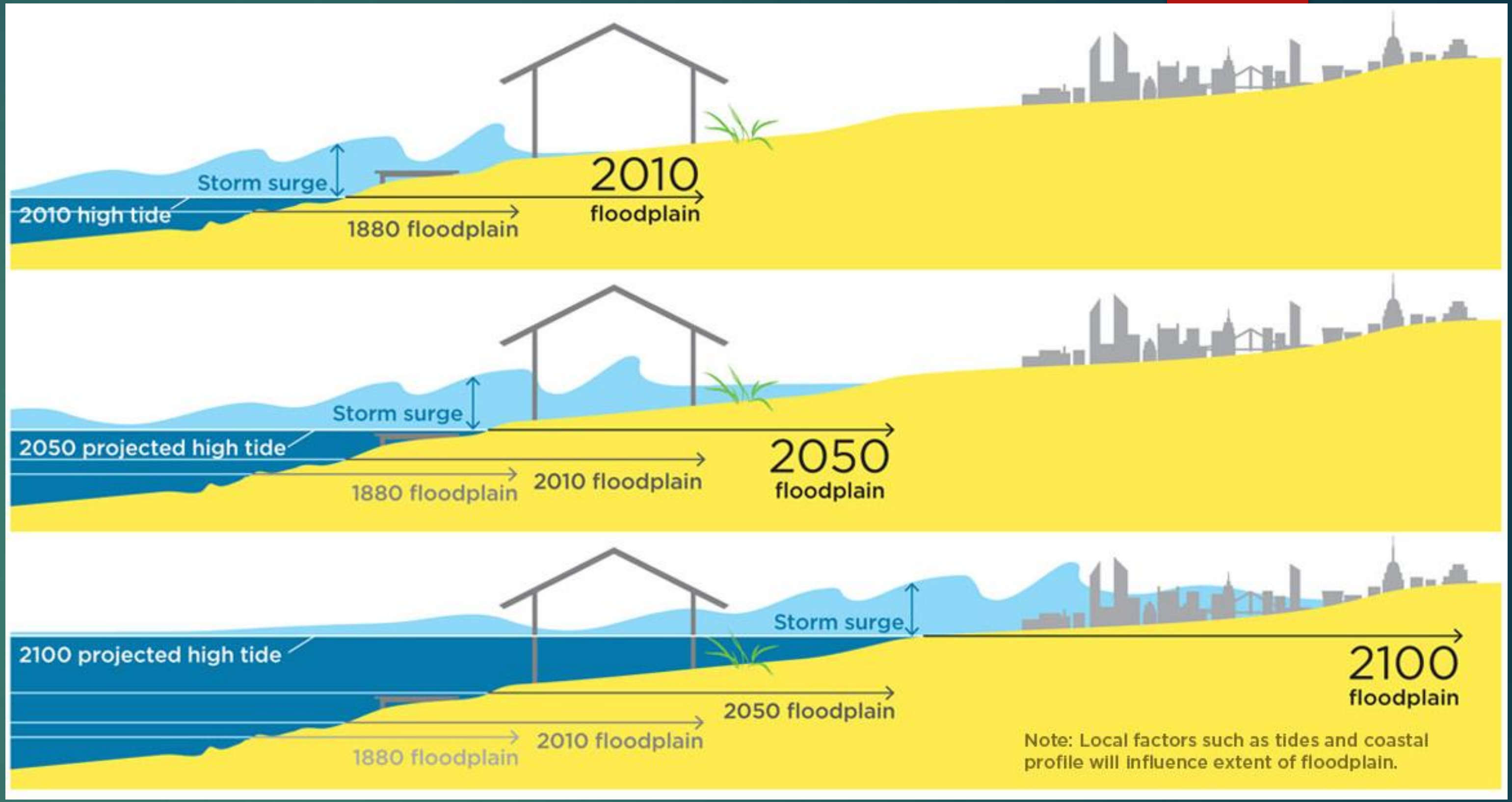
Temperature



5th phase of the Coupled Model Inter-comparison Project (CMIP5) (IPCC, 2014)

Sea level rise

- **Observations:** Global rate since 1850s exceeds that of previous 2,000 years
  - +2 to +5mm/year along South Asian coasts since 2000, (Nicholls and Cazenave, 2010)



Union of concerned scientists 2015

- **Projections:** under all emissions scenarios, future sea level rise likely to exceed past 3 decades rate. By end of 21st century, sea level higher by 50-100 cm

Climate changes & water resource risks: CERTAINTIES and UNCERTAINTIES…

CERTAINTIES: global warming will induce

1. Heavier rainfall, more frequent and larger inland and coastal floods (cyclones). More erosion → downstream siltation of reservoirs
2. Earlier monsoon onset (Annamalai et al., 2007) = earlier flood pulse,
3. High-altitude summer melting of glaciers → increased summer runoff followed by reduction as glaciers shrink (e.g. Indus Basin) (2 + 3 → irrigation water shortages in summer)
4. Sea level rise → salt contamination of coastal aquifers and coastal floods.
5. Rise in drought severity (heat waves) and crop water stress

Climate changes & water resource risks: CERTAINTIES and UNCERTAINTIES…

UNCERTAINTIES

1. Change in annual and seasonal river flow patterns in snow-fed basins (e.g. Indus)
   - Rising winter temperature → snow sublimation (=water loss)
   - Rising winter precipitation → snow accumulation → increased snowmelt in spring

   Two counteracting changes, compounded by albedo variations (Archer et al., 2010)

2. Change in seasonal and annual rainfall (cf. IPCC projections)

3. Groundwater recharge depends on distribution of rainfall events (more concentrated → higher recharge), rising evapotranspiration (→ less recharge), and river flows (snowmelt-controlled recharge in Indus vs. monsoon-driven recharge in Ganges)

4. Further uncertainties caused by non-climatic factors: land-use change, soil degradation, water withdrawals

Knowledge gaps & recommendations

More hydro-meteorological data from ground measurements

To better understand processes

- **Ice and snow mass balance** influenced by changes in precipitation, temperature, and other variables to predict downstream flow

- Sparce monitoring network in >4,500m areas

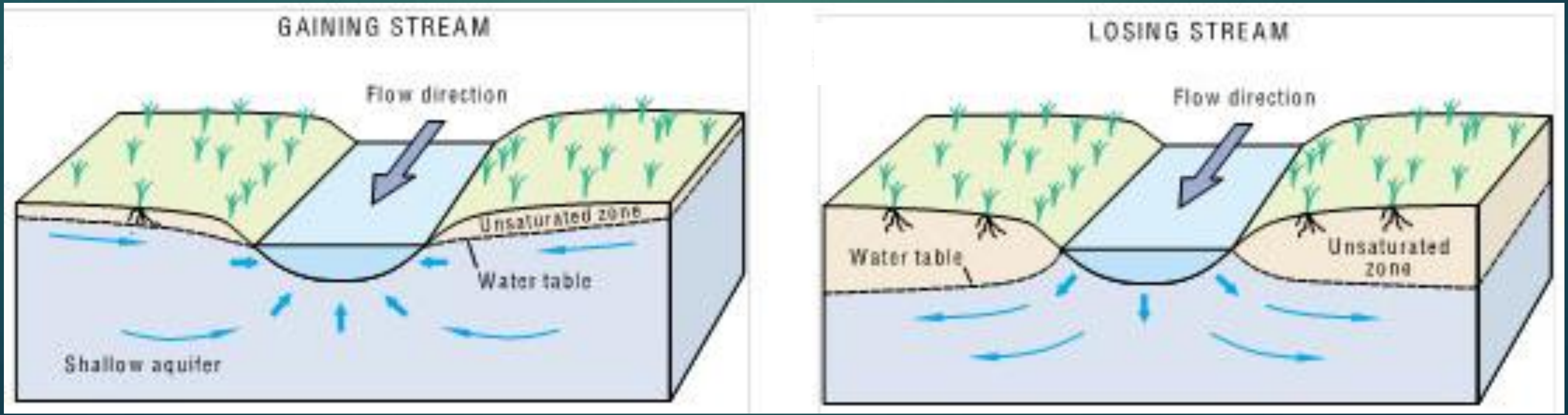
(Credit: Jane Qiu)

Knowledge gaps & recommendations

More hydro-meteorological data from ground measurements

To better understand processes (cont.):

- **Surface-groundwater interactions** (quality and quantity), spatial and temporal variations and drivers to improve management of artificial and natural storages and buffer increased variability
    - Need to increase number of river gauging stations and monitoring wells,



USGS Circular 1139

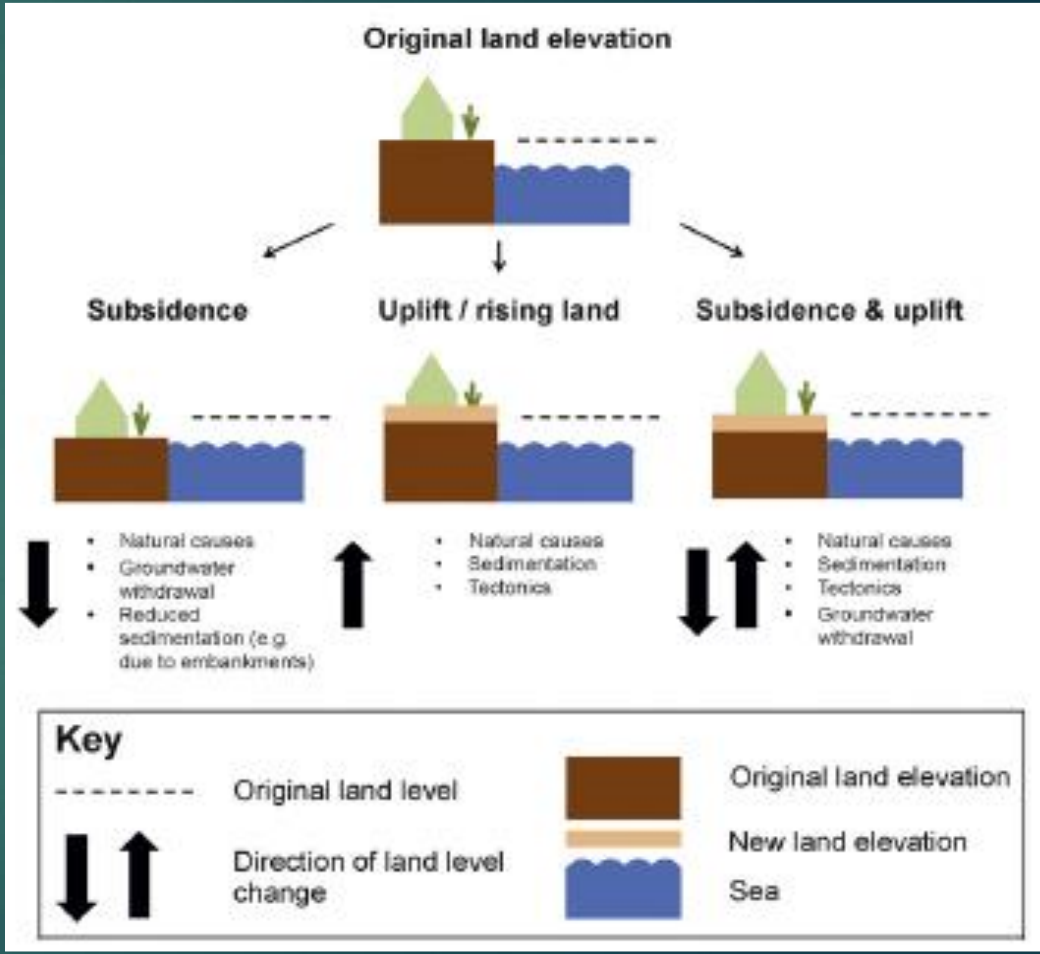
Knowledge gaps & recommendations

More hydro-meteorological data from ground measurements

To better understand processes (cont.):

- **Sea level rise and land subsidence** are difficult to disentangle: tectonics, compaction, sedimentation, river embankments limiting sediment deposition, groundwater abstraction)

- Need to accurately monitor local variation in sea level changes relative to coast lines



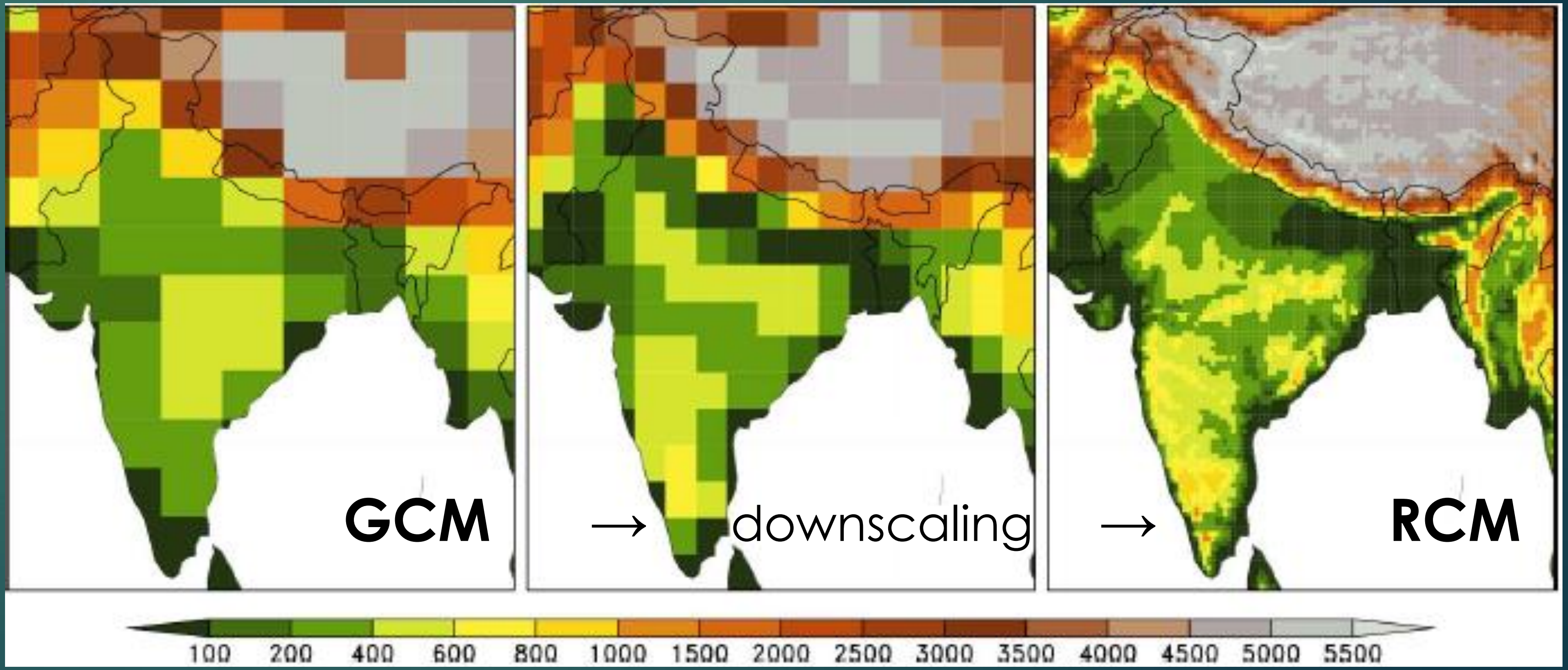
Case of the Ganges-Brahmaputra-Meghna Delta (Brown and Nicholls, 2015)

Knowledge gaps & recommendations

More hydro-meteorological data from ground measurements

To improve regional climate projections and hydro(geo)logical forecasts

- GCM cannot capture local topographic features influencing fine-scale precipitation and temperature
- Hydrological effect of land-use change (role of soil in rainfall-runoff relationship)



Kumar et al.

Knowledge gaps & recommendations

Building capacities, communicating, and coordinating actions

Improving technics for crop water use efficiency and water productivity

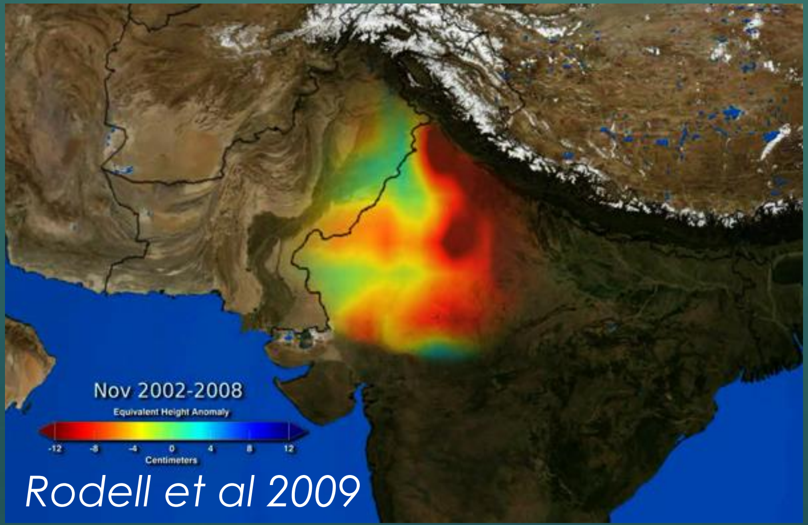
- parsimonious irrigation (drip irrigation) adjusted to crops and soils
- limiting water losses (leakages, deep percolation, evaporation)
- Adjust crop selection to local weather patterns
- Levelling of irrigated fields

Knowledge gaps & recommendations

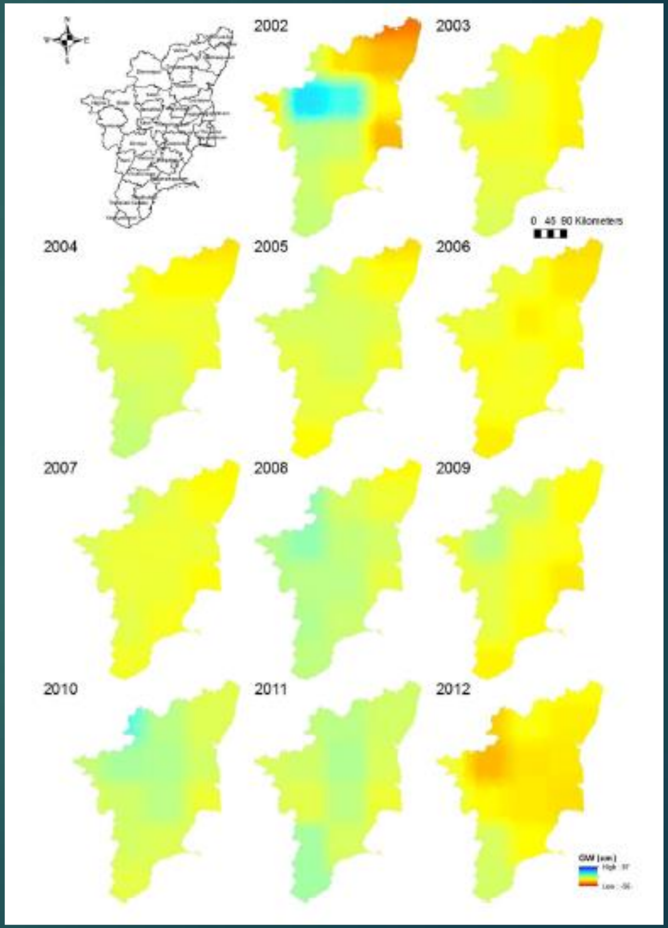
Building capacities, communicating, and coordinating actions

Improve capacity of analysis of remote sensing products (research centers, flood mitigation centers)

- To map flood- and drought prone areas,
- To assess and predict water resources in ungauged areas



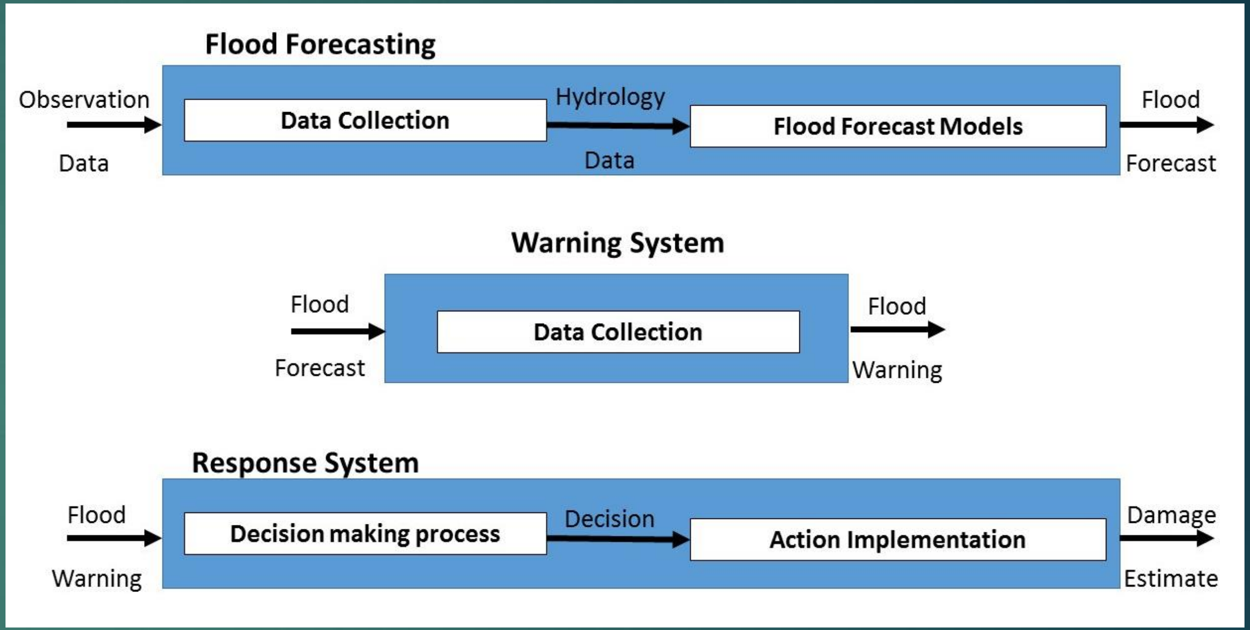
Rodell et al 2009



Chinnasamy and Agoramoorthy 2015

Knowledge gaps & recommendations

Building capacities, communicating, and coordinating actions



Coordination for improved forecast dissemination (early warning systems), from prediction centers to exposed communities

Regional approach required for South Asian countries to adapt to climate change

- to tackle regional issues (e.g. large-scale flooding),
- to promote data sharing and coordinate transboundary early warning systems,
- to build capacity in research and development amongst national institutions

Thank you for your attention…