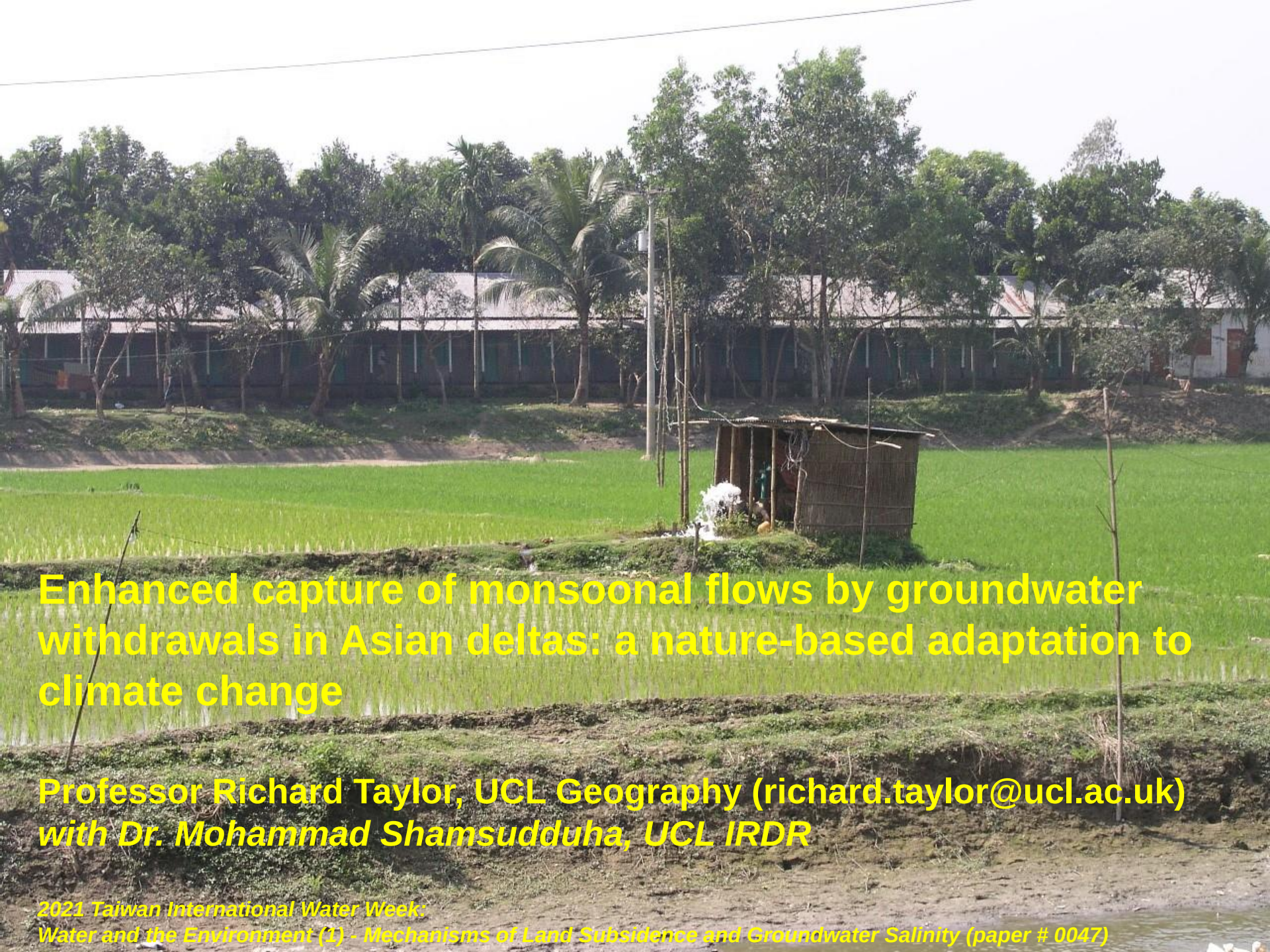

Enhanced capture of monsoonal flows by groundwater withdrawals in Asian deltas: a nature-based adaptation to climate change

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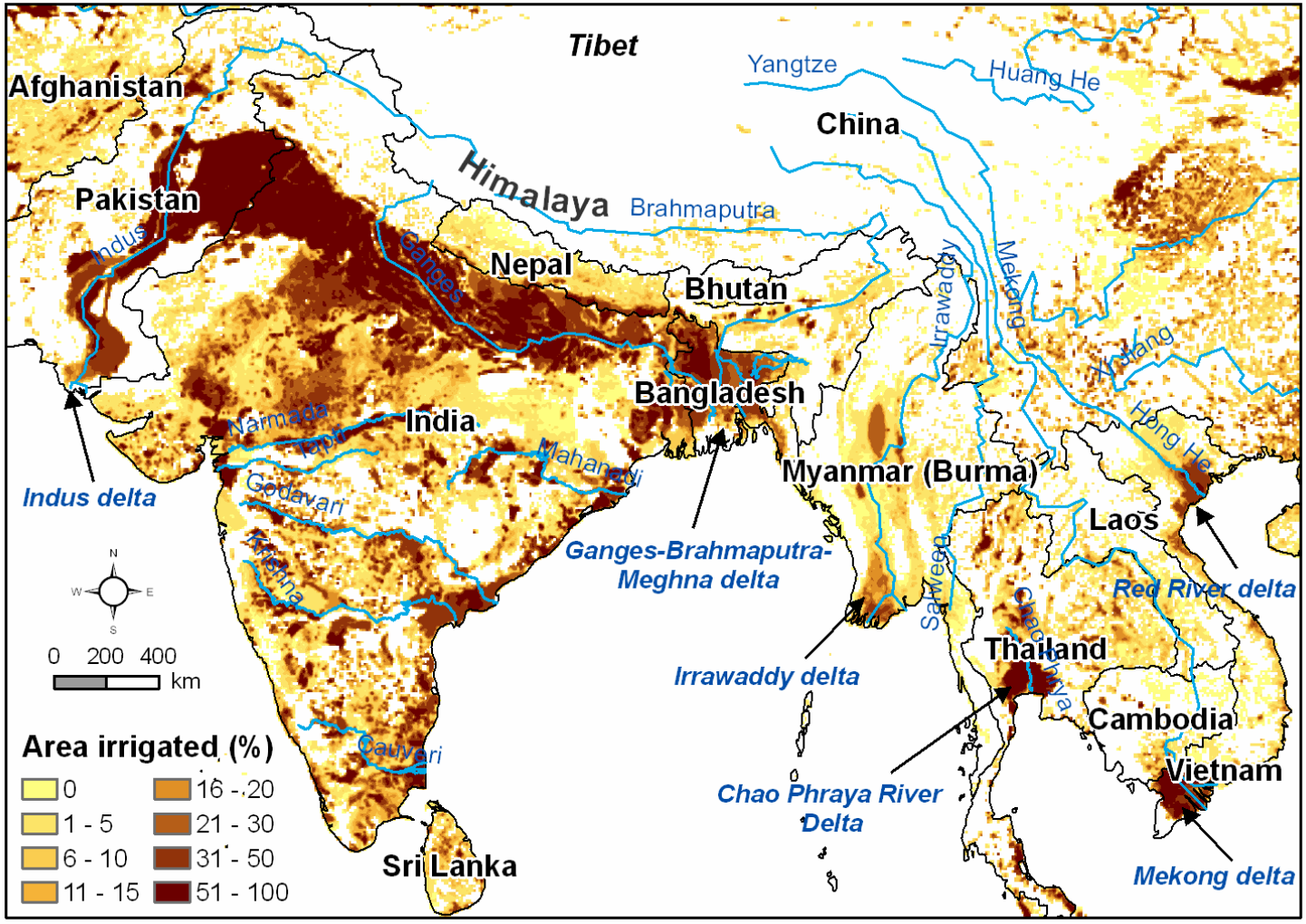
with Dr. Mohammad Shamsudduha, UCL IRDR

2021 Taiwan International Water Week:
Water and the Environment (1) - Mechanisms of Land Subsidence and Groundwater Salinity (paper # 0047)

alluvial plains and irrigation of rice in Asia

- under Asia's Green Revolution, irrigation of rice using shallow groundwater by smallholder farmers increased rapidly - Asian farmers now account for 90% of the world's rice production *Bandumula (2017) P. Nat. A. Sci., India B 88, 1323-1328.*

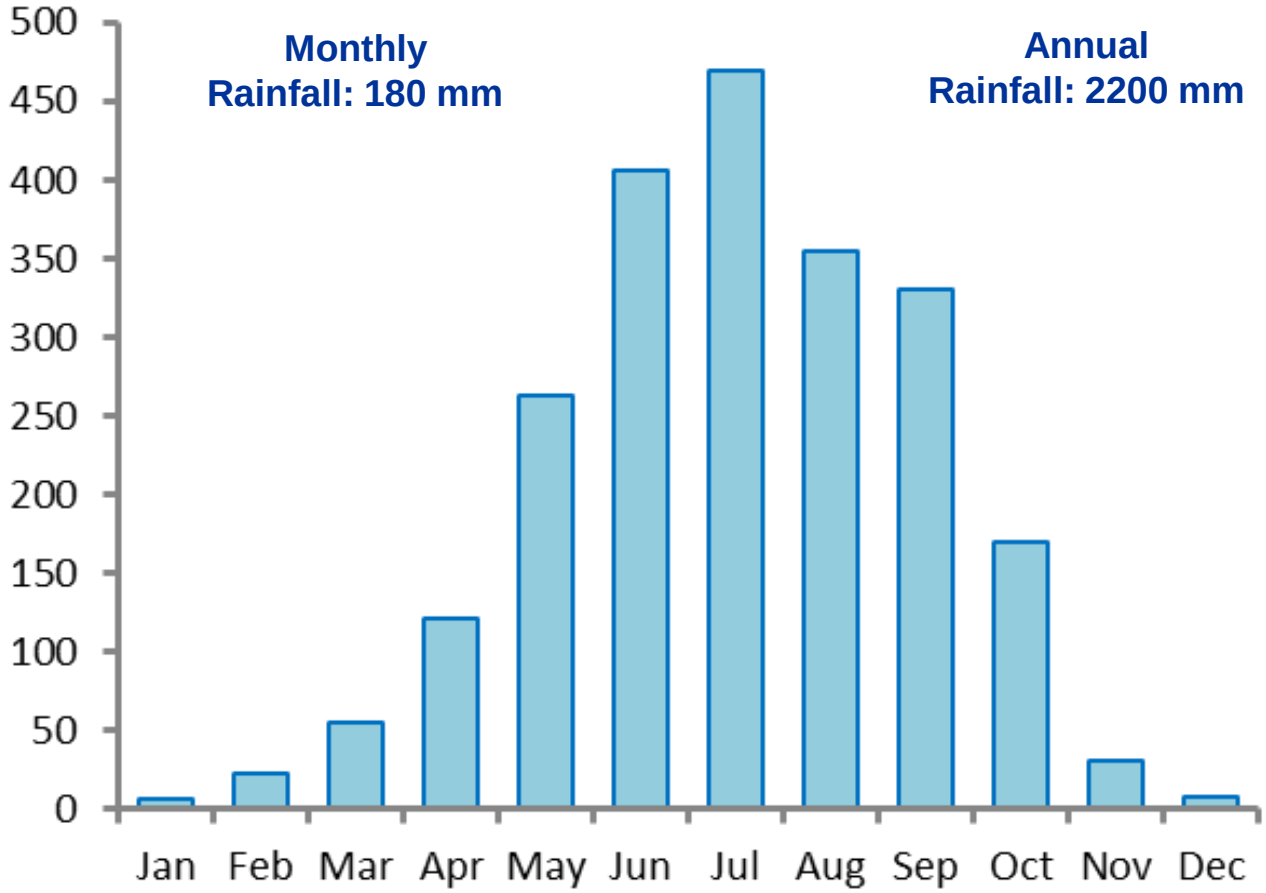


% irrigation data source: Siebert et al. (2006)

seasonality in rainfall and river discharge

- regional river basin hydrology is characterised by strong seasonal imbalances in rainfall associated with the Asian monsoon
- in the Bengal Basin, 80% of the annual discharge of major rivers (Ganges, Brahmaputra) occurs between July and October

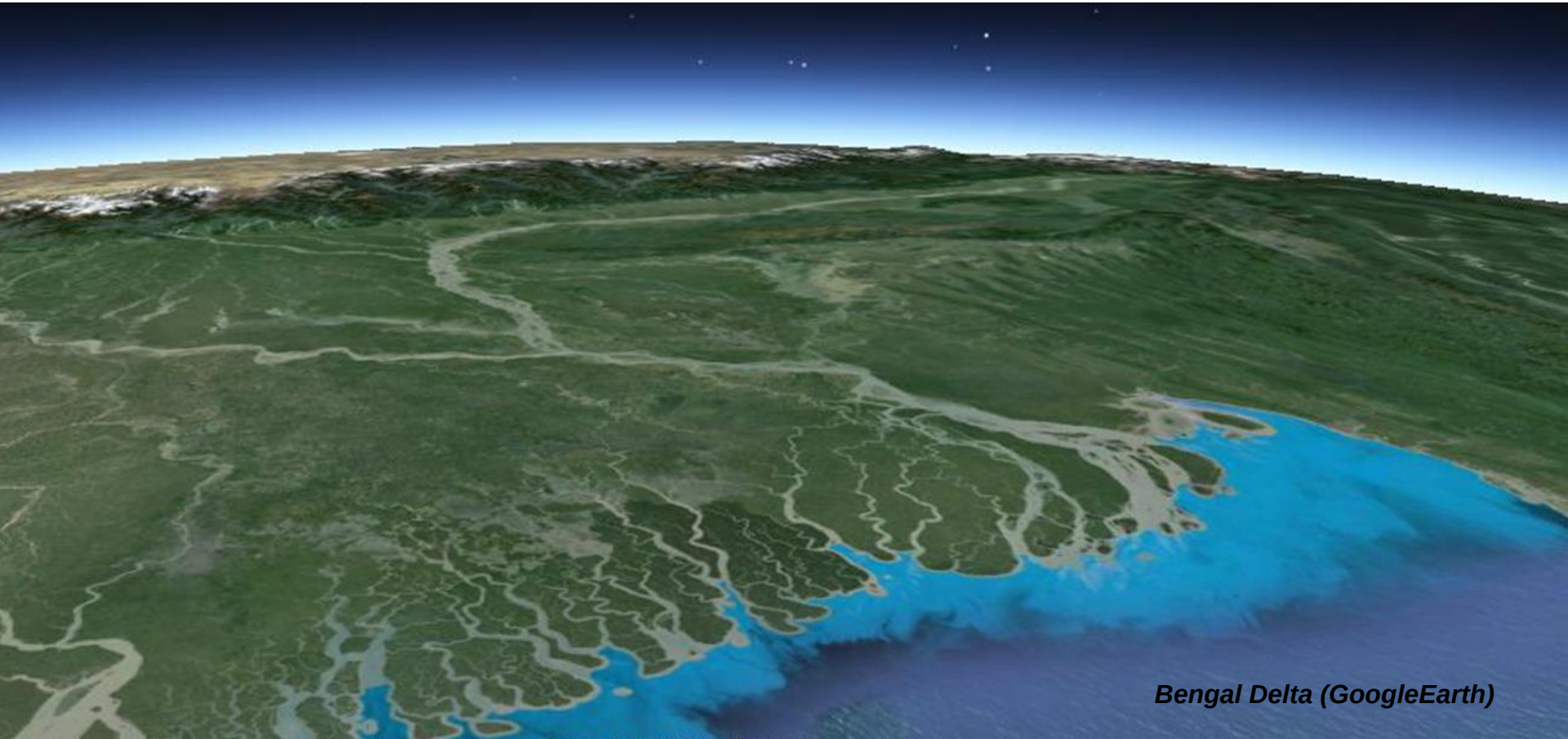
Rasul (2015) Int. J. River Basin Manag. 13, 387-400.



Data source: BWDB

low relief of alluvial plains across Asia

- conventional approaches to the storage of seasonal river discharge employ dams but the low-lying relief of densely populated alluvial plains in Asia challenges the implementation of such infrastructure



Bengal Delta (GoogleEarth)

“The Ganges Water Machine”

- *nature-based* solution to freshwater storage proposed in 1975 wherein incremental increases in dry-season groundwater pumpage for irrigation beside river channels lowers groundwater levels and enhances leakage under gravity of river flow during the subsequent monsoon

- where favourable, groundwater pumpage increases capture and storage of seasonal freshwater surpluses while mitigating the monsoonal flood risk

The Ganges Water Machine

Roger Revelle and V. Lakshminarayana

The river Ganges and its tributaries, and the flat and fertile plain through which they flow, are one of earth's great natural resources. For thousands of years abundant water and generous land have provided the foundation for a highly developed civilization based on agriculture and for one of the world's largest concentrations of human populations. But farming is mainly traditional and at a subsistence level, with little surplus, and as a result the population has remained overwhelmingly rural and most people are desperately long been moribund and now serves only as a spill channel for Ganges floods. Within India, the Ganges Basin, as we have defined it, covers 800,000 square kilometers (*1*). Its population is about 225 million, somewhat more than that of the United States, which covers nearly ten times the area. At present rates of growth, the population will double in 30 years.

The fundamental problems of land and water development in the Ganges Plain arise from the highly seasonal flow of the river and its tributaries.

Present Needs for the Ganges Low Flow

Irrigation in Bangladesh. The average rainfall in Bangladesh is higher, and the potential for increasing groundwater recharge from rain is greater, than in the Indian part of the Ganges Plain. Unfortunately, there is a wide variation among different districts, just as in India. Revelle and Herman (*3*) estimated that water from the Ganges is needed in Bangladesh during the low flow season to supplement groundwater irrigation in three districts in the northwestern part of the country. In the southwest, where the groundwater is saline, Ganges water is the sole irrigation source. In other districts some Ganges water is needed to minimize saltwater intrusion. The sum of these needs totals about 1.8×10^6 ha-m.

Diversion of low flow waters for Calcutta port maintenance. Part of the Ganges waters during the low flow season must be diverted at the Farakka

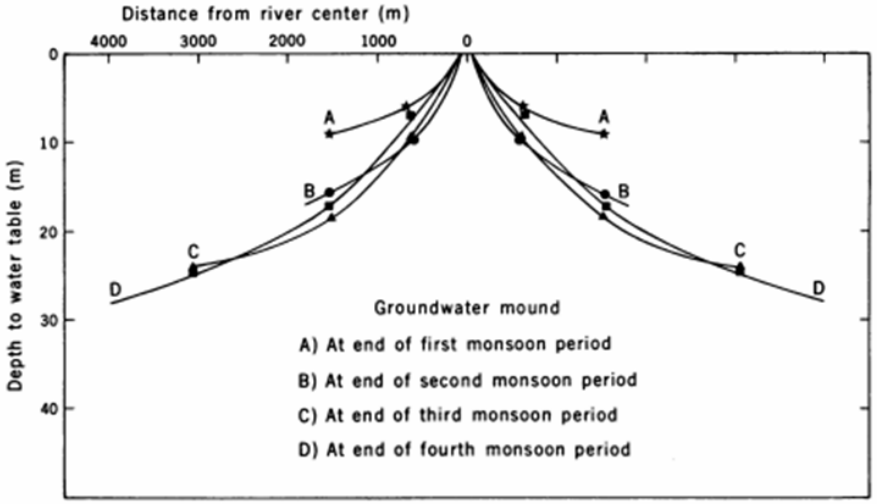


Fig. 2. Growth of groundwater mound under uniform recharge from river.

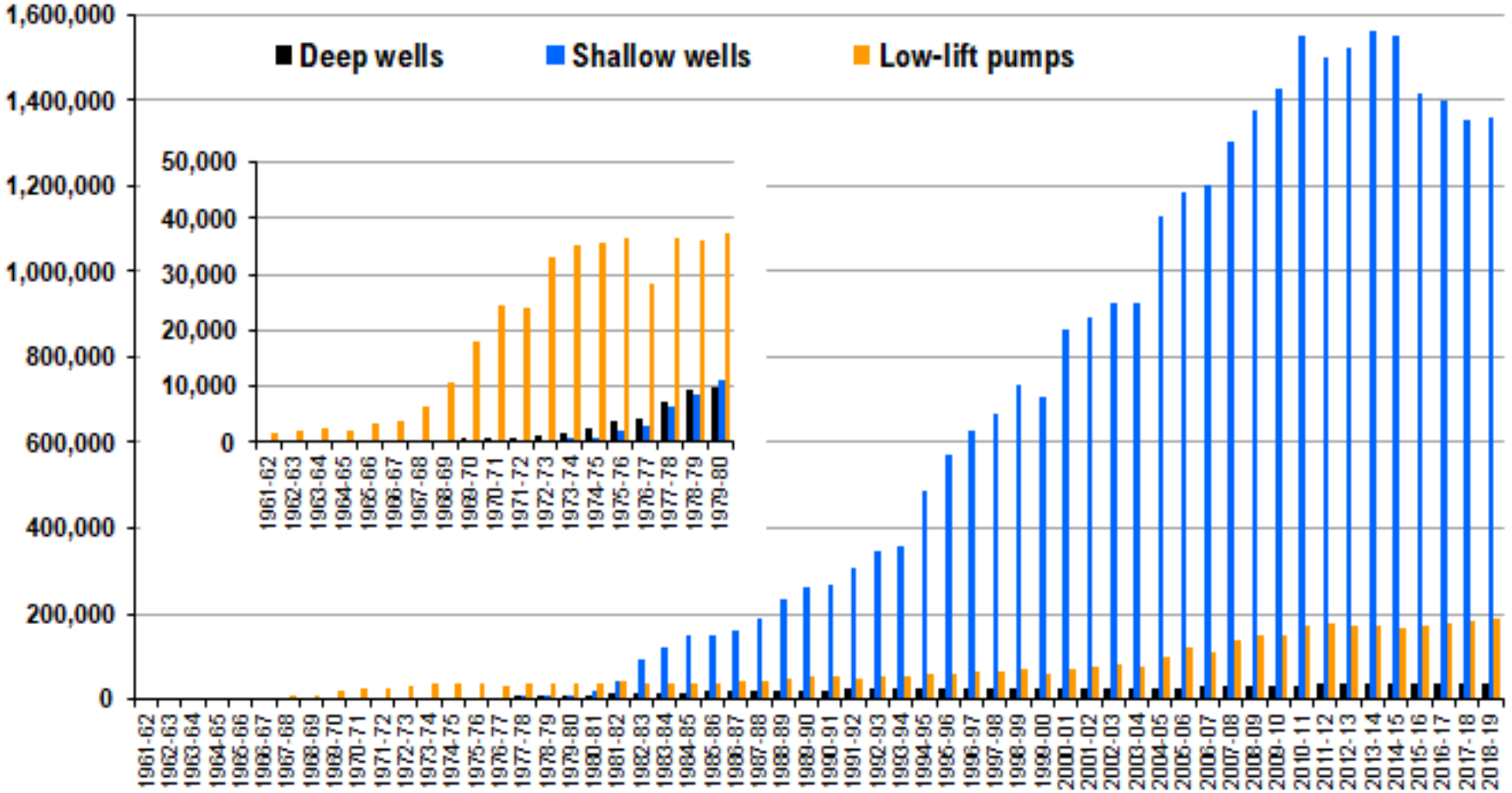
Revelle and Lakshminarayana (1975) Science 188: 611-616.

rise in groundwater-fed irrigation

- in Bangladesh, rise in dry-season groundwater-fed irrigation of Boro rice transformed single-crop rain-fed floodplains into productive double and triple cropping lands, making it the world's fourth highest producer of rice

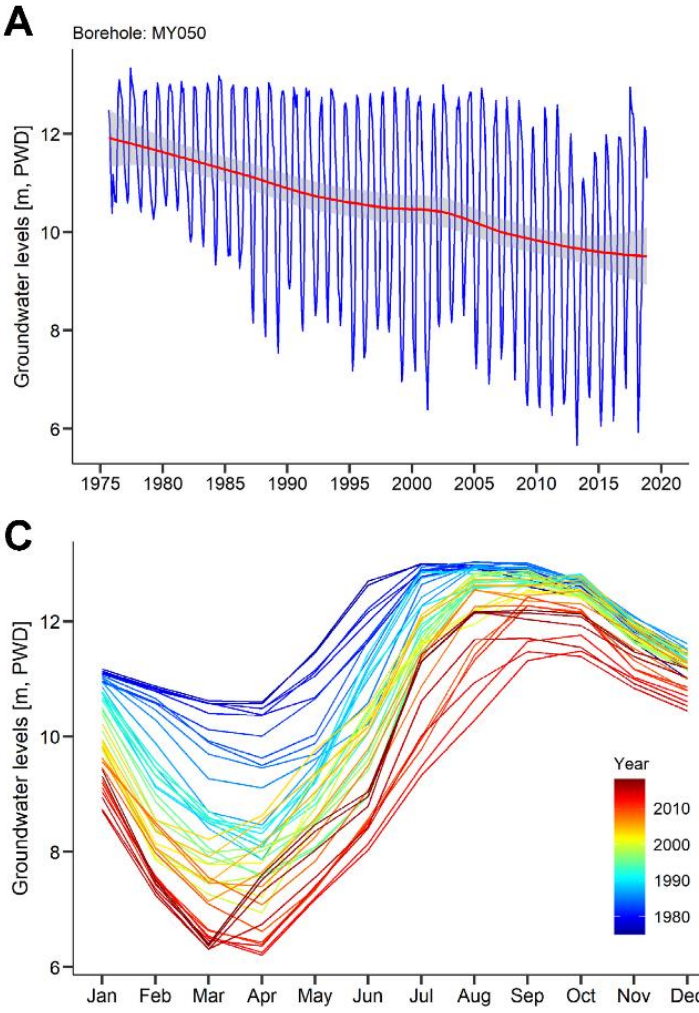
Bandumula (2017) P. Nat. A. Sci., India B 88, 1323-1328.

annual pumpage (2015) = ~32 km^3



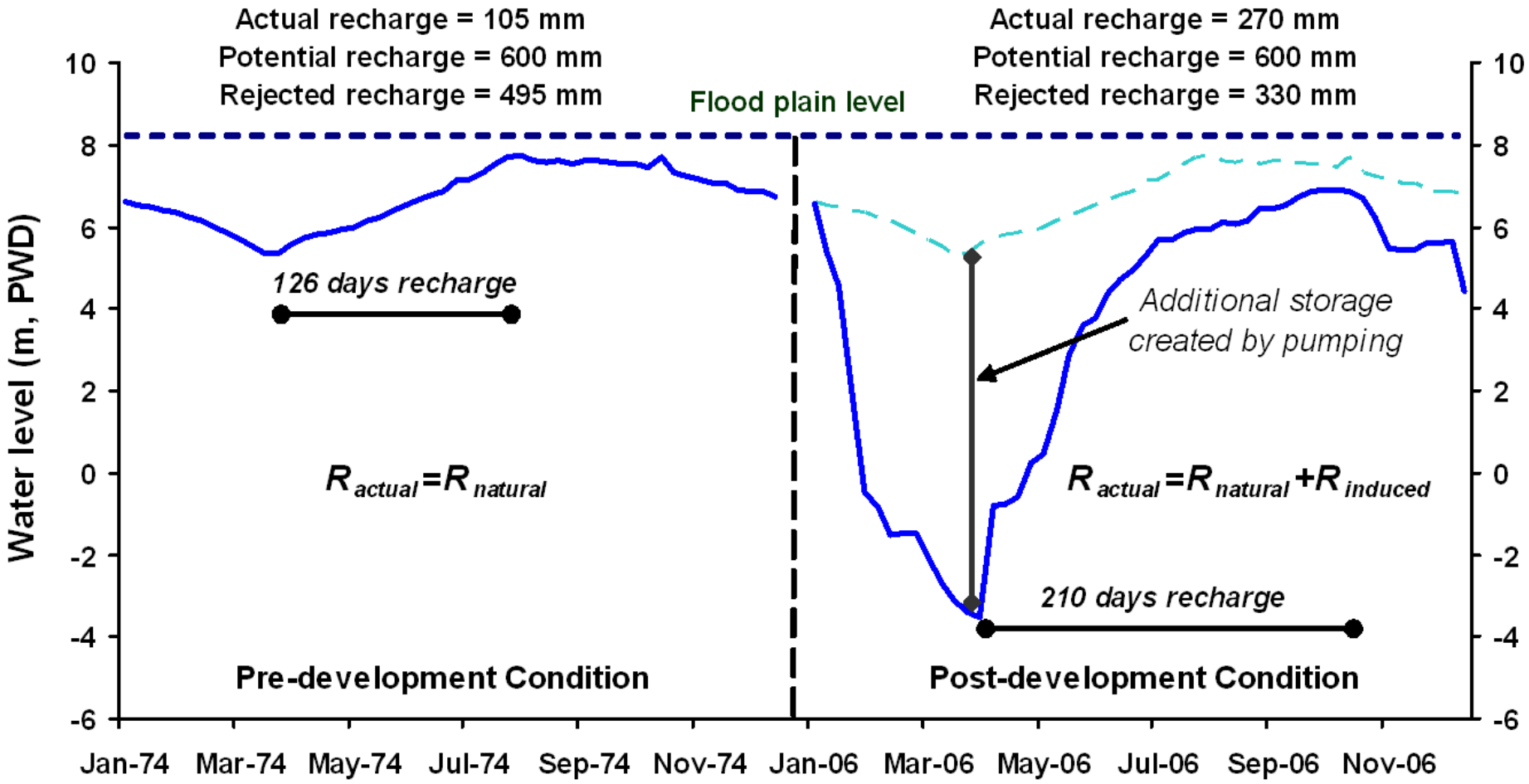
Ganges Water Machine (GWM) in Bangladesh

- GWM characterised by an *increasing amplitude in seasonal groundwater-level oscillations* over time
- operation of GWM in the Bengal Basin identified by statistical clustering and visual inspection of 465 multi-decadal piezometric records



computation of recharge capture: WTF

- Water-Table Fluctuation (WTF) method used to estimate recharge amplified by dry-season abstraction for irrigation, which *increases available groundwater storage*

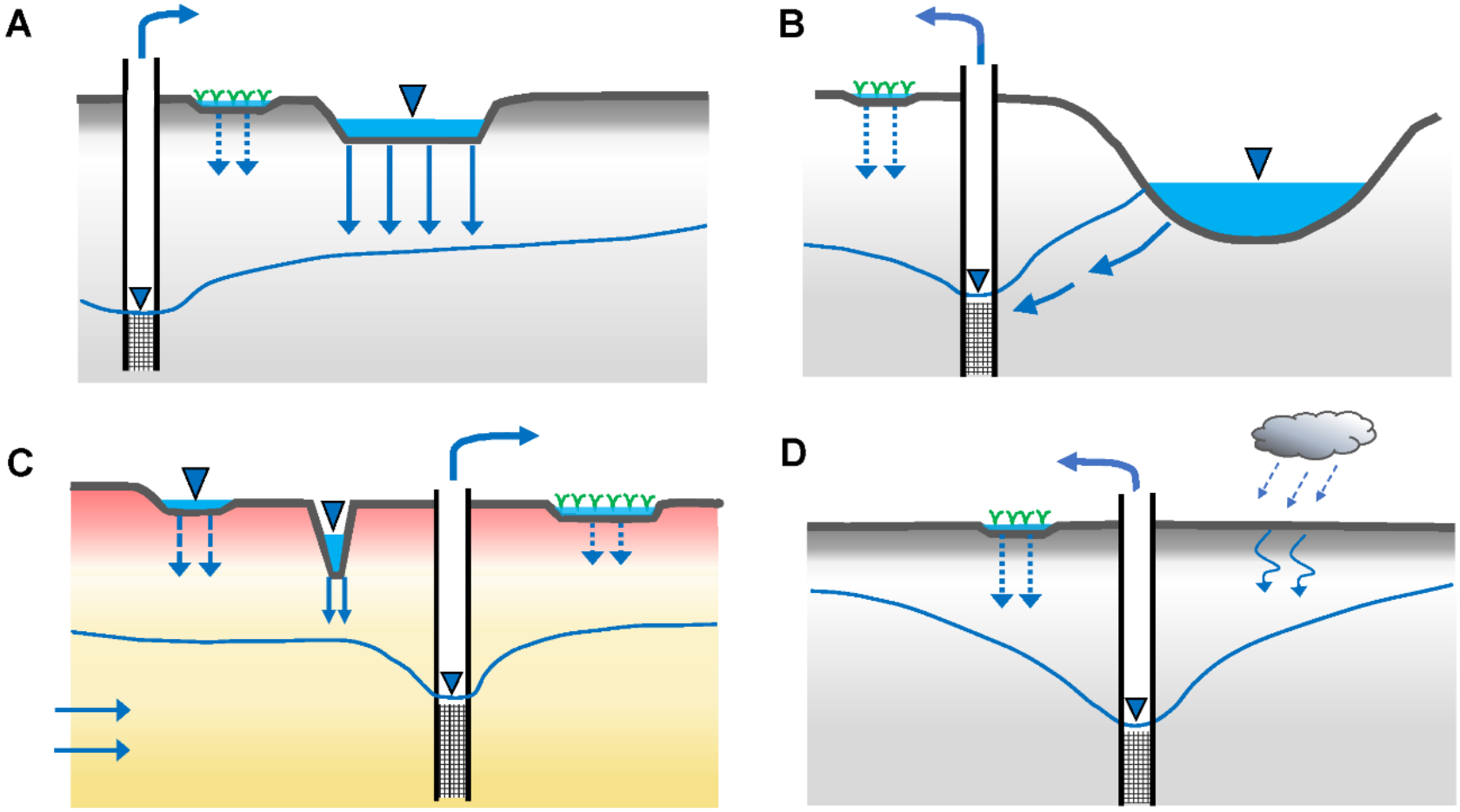


Shamsudduha, Taylor *et al.* (2011) *Hydrogeol. J.* 19: 901-916.

freshwater capture by the Ganges Water Machine

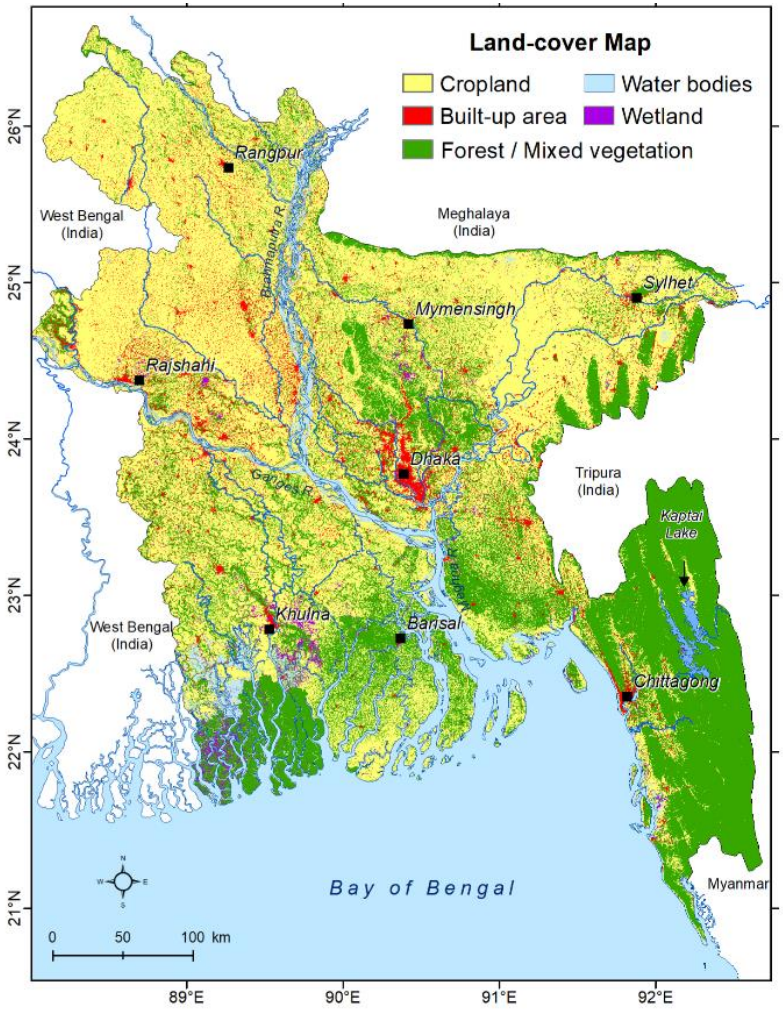
- groundwater recharge pathways induced by groundwater abstraction include: leakage from localized surface water bodies (rivers, ponds, lakes), enhanced lateral groundwater flow, and diffuse recharge

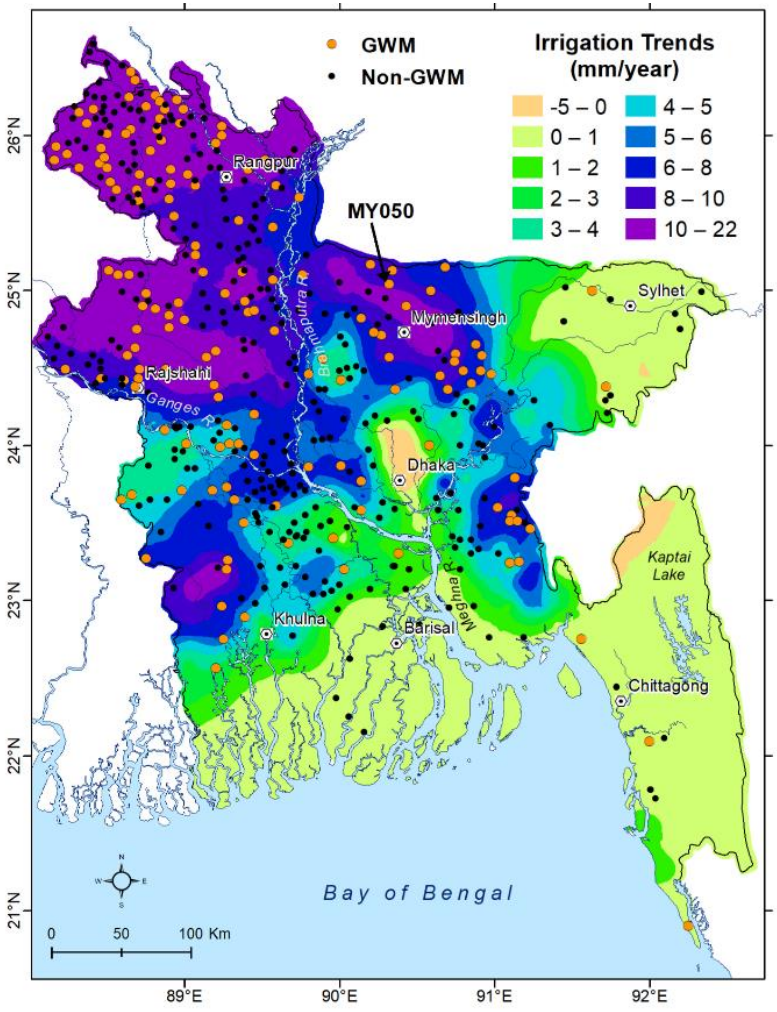
Shamsudduha, Taylor et al. (2011) Hydrogeol. J. 19: 901-916.
Nowreen, Taylor et al. (2020) Hydrogeol. J. 28: 2917-2932.



freshwater capture by the Ganges Water Machine

- operation of GWM detected in 35% (163) of 465 records, primarily in northern, western, and north-central Bangladesh where groundwater-fed irrigation is highest and…

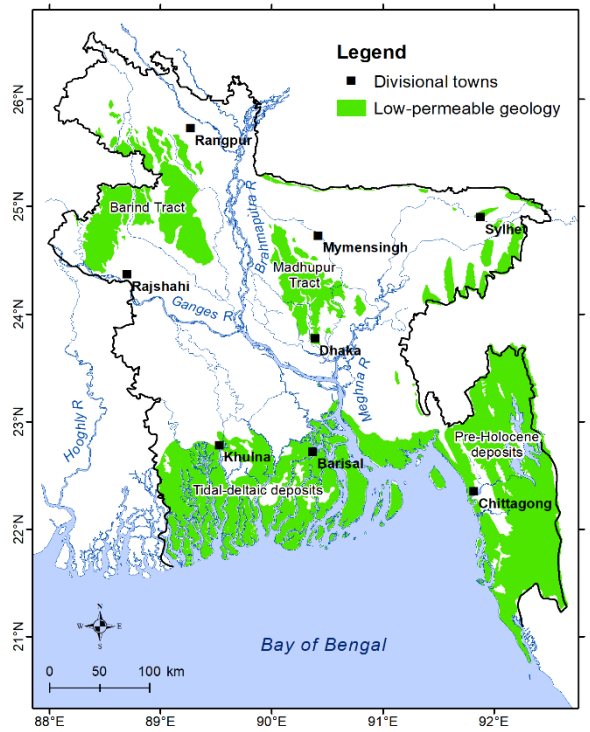


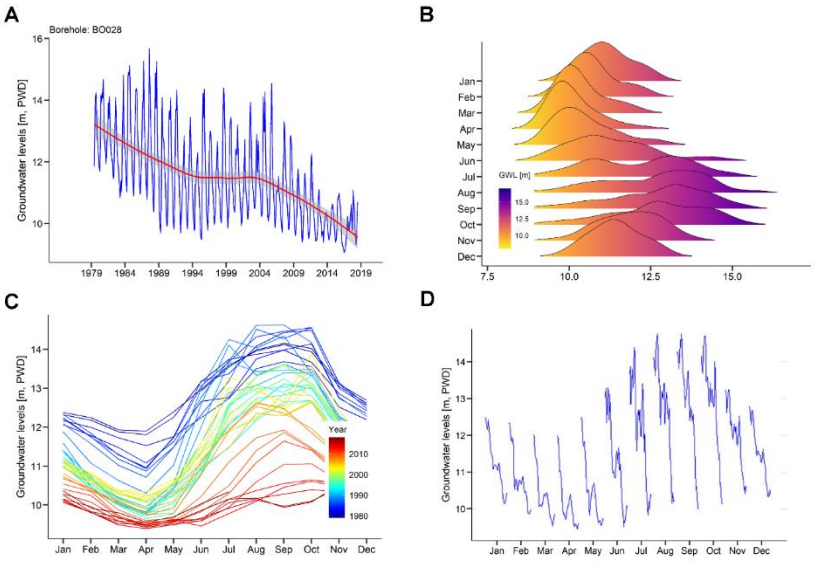


where permeable soils enable amplified recharge.

- sandy soils promote capture of monsoonal floodwaters and rainfall, sustaining increased groundwater withdrawals (operation of GWM) through amplified recharge

- clay cover restricts capture of monsoonal floodwaters and rainfall, leading to decreased seasonality and groundwater depletion

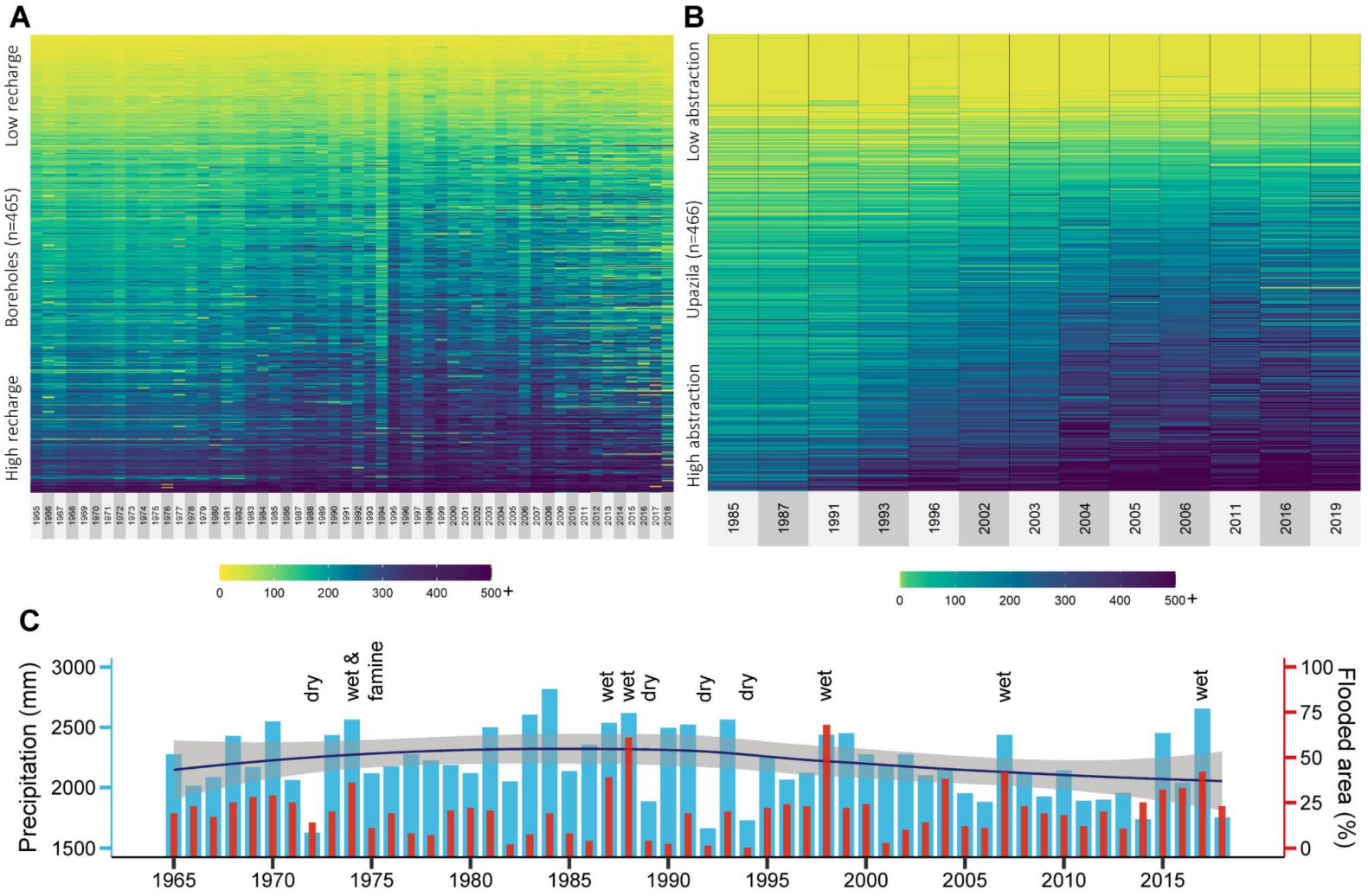




Shamsudduha, Taylor *et al.* (2015) Water Resour. Res. 51: 685-703.
Shamsudduha, Taylor *et al.* (2012) Water Resour. Res. 48: W02508.

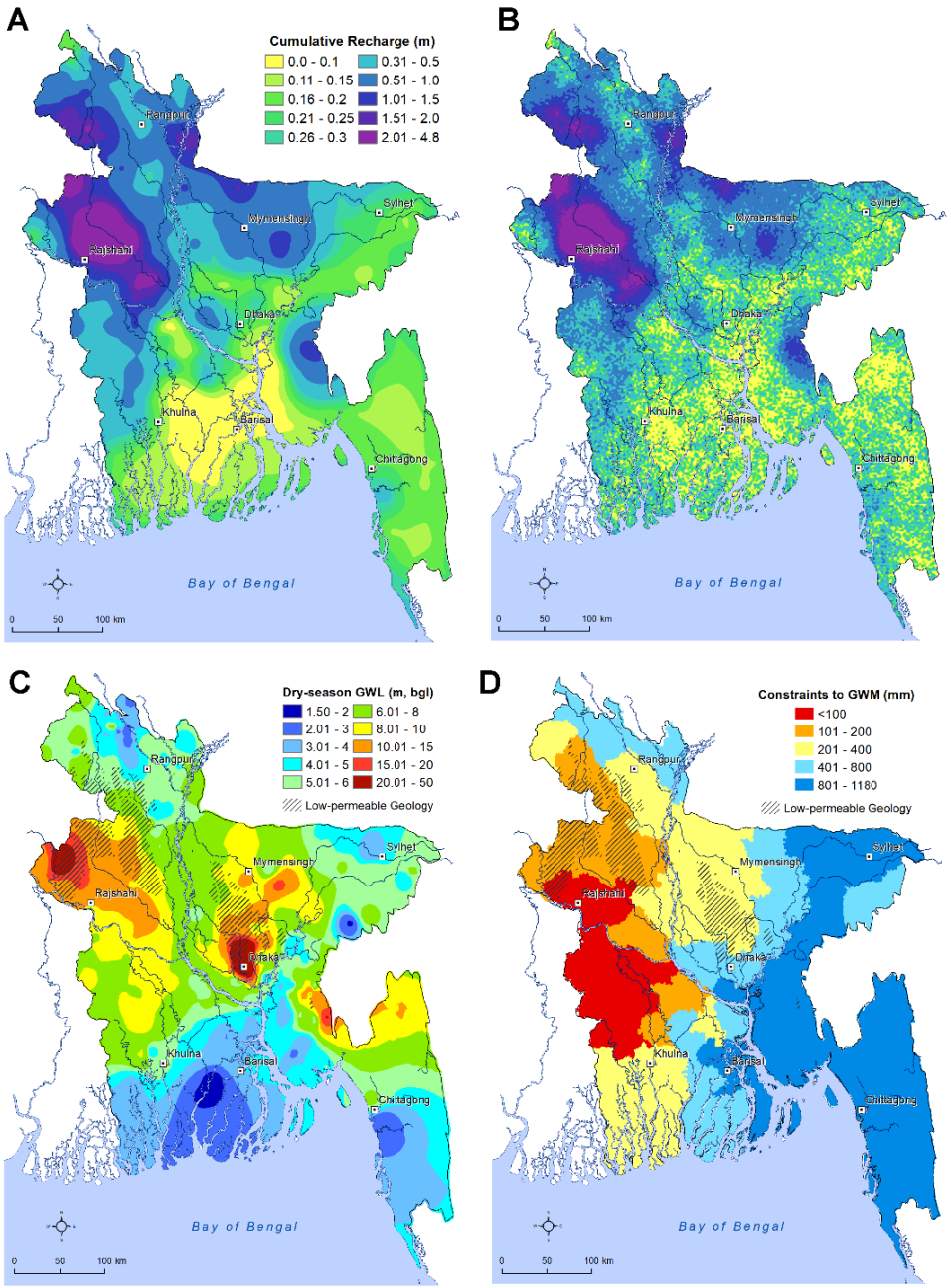
climate resilience of freshwater capture by GWM

- rise in groundwater recharge (freshwater capture) corresponds to increased groundwater pumpage for irrigation over a period (1985 to 2018) when annual rainfall is marginally in decline



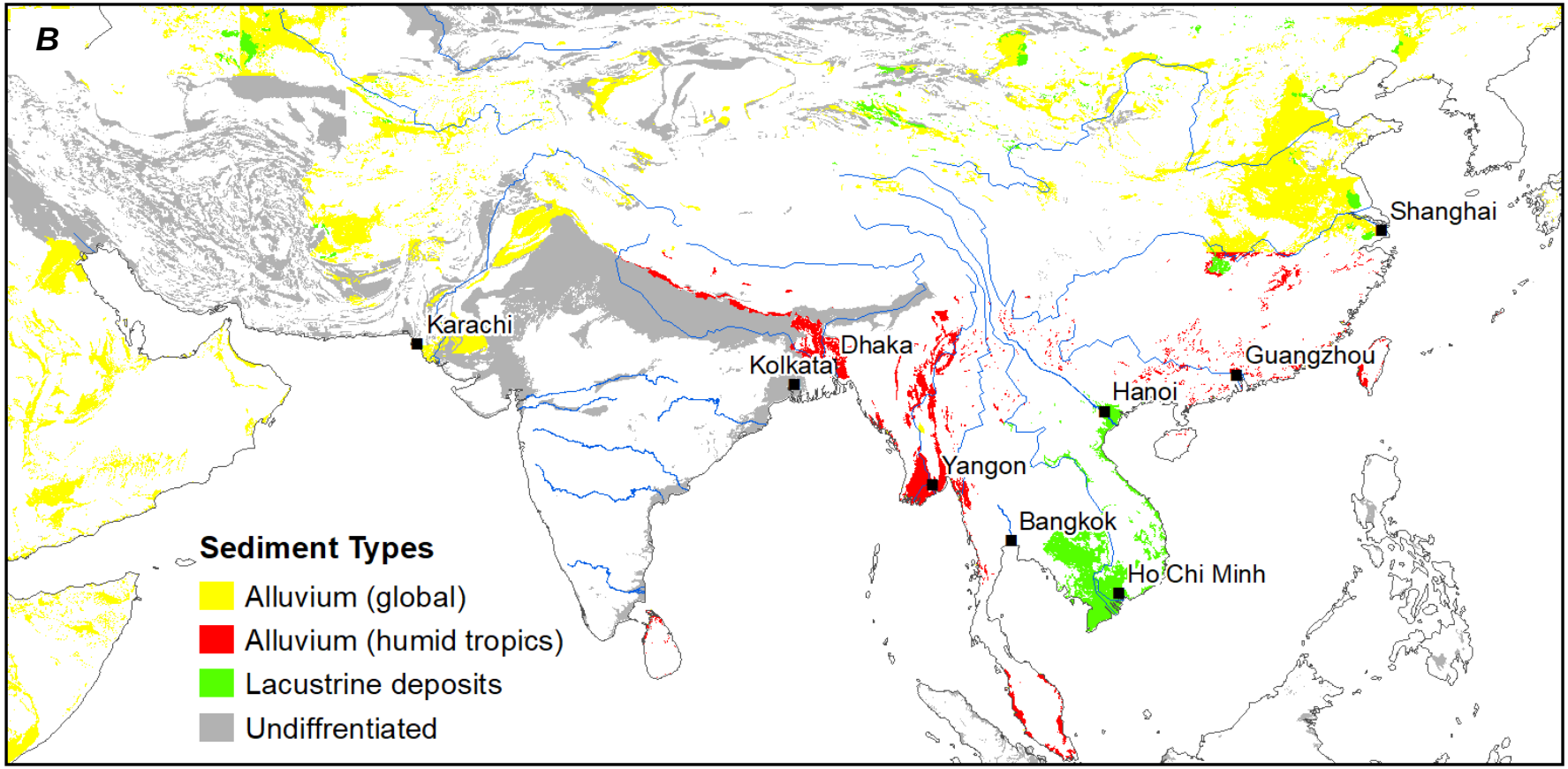
freshwater capture by smallholder farmers

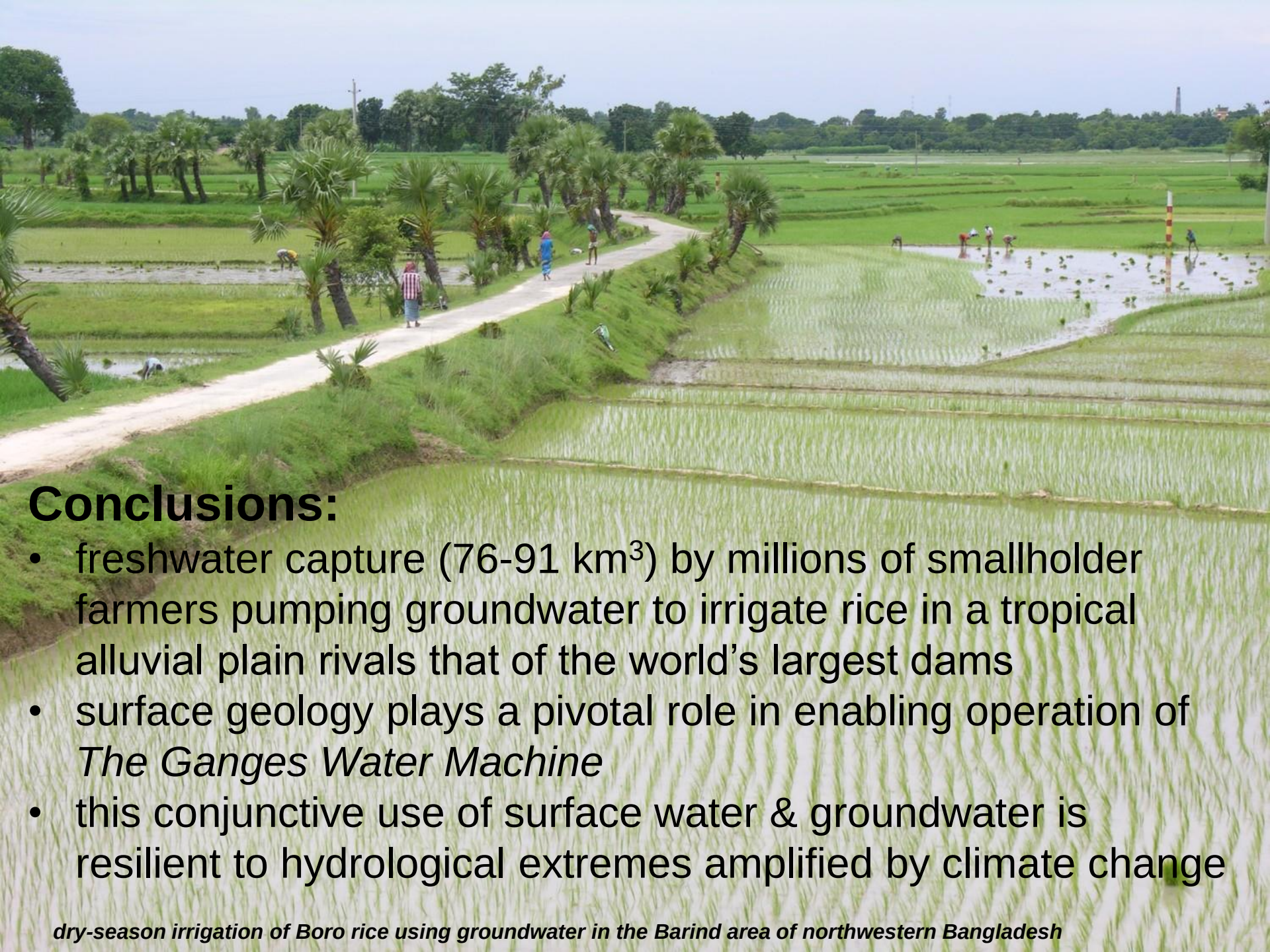
- total freshwater capture by ~16 million smallholder farmers across the Bengal Basin of Bangladesh from 1988 to 2018 ranges from 76 to 91 km^3 – twice the reservoir capacity of the Three Gorges Dam (~39 km^3)
- freshwater capture is highest north of Rajshahi (along River Atrai) where rainfall is lowest and trends in irrigation are highest
- opportunities to expand operation of the GWM in Bengal Basin are largely restricted to River Brahmaputra floodplains of north-central Bangladesh



opportunities for wider use of GWM in Asia?

- alluvial plains cover an area of ~4 million km^2 in the seasonally humid tropics, scope to scale up operation of the GWM to improve sustainability of irrigated food production not only globally but also the alluvial plains of tropical Asia and Taiwan





Conclusions:

- freshwater capture (76-91 km^3) by millions of smallholder farmers pumping groundwater to irrigate rice in a tropical alluvial plain rivals that of the world's largest dams
- surface geology plays a pivotal role in enabling operation of *The Ganges Water Machine*
- this conjunctive use of surface water & groundwater is resilient to hydrological extremes amplified by climate change

dry-season irrigation of Boro rice using groundwater in the Barind area of northwestern Bangladesh


Thanks for your attention!