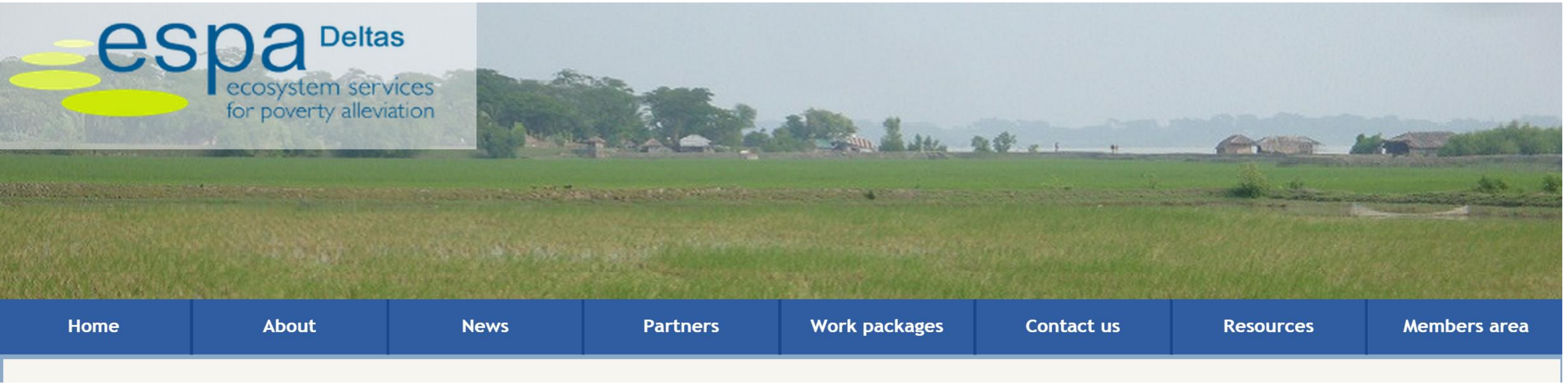
Modelling the Ganges, Brahmaputra and Meghna Rivers: Impacts of Climate Change and Socio-economic Change on Flow and Water Quality in India and Bangladesh

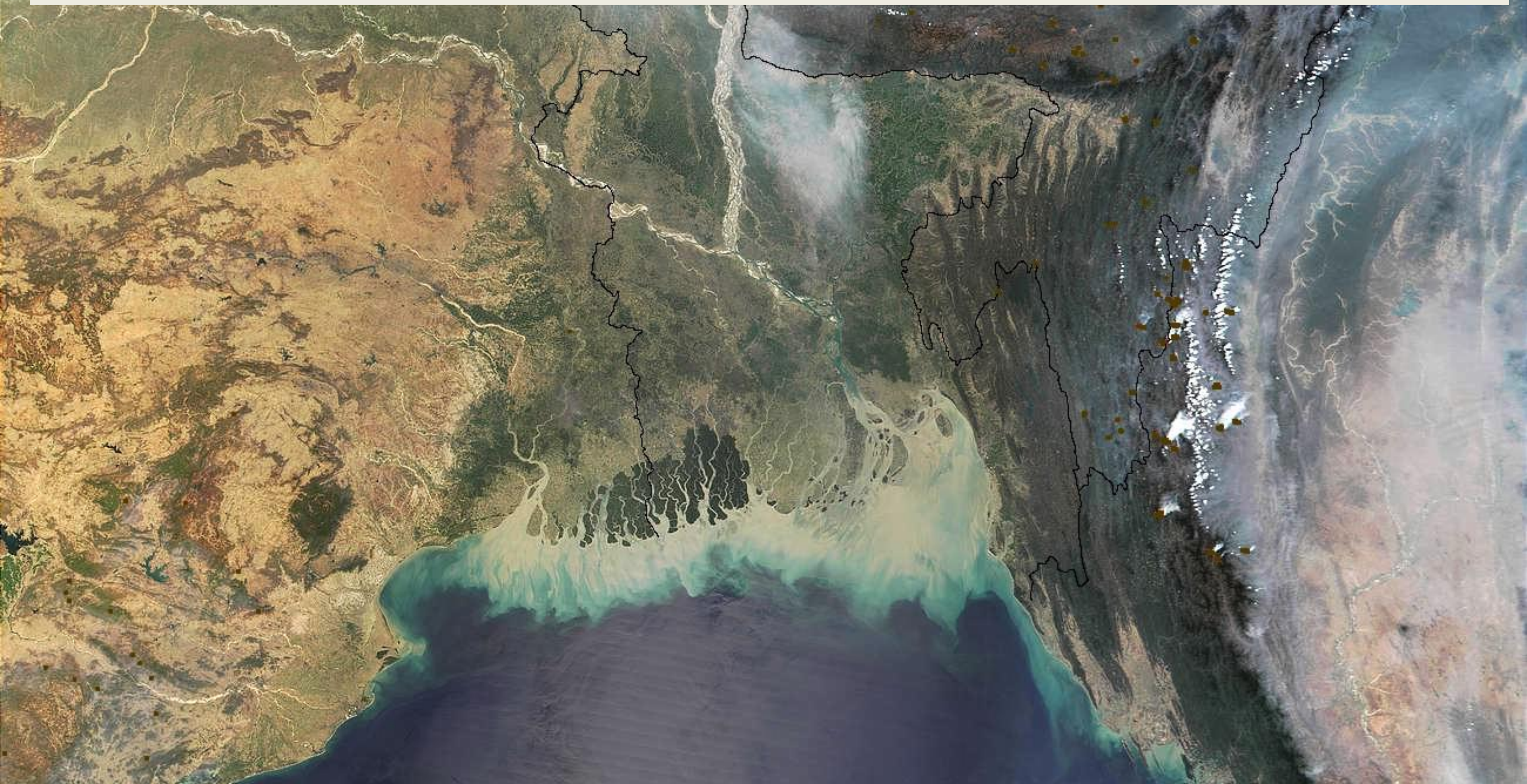
Paul Whitehead and Emily Barbour

www.espadelta.net



ESPA Deltas Project

Coastal ecosystems, governance and poverty: A case study of managing the Ganga-Brahmaputra- Meghna Delta in a changing world



ESPA – Ecosystem Services for Poverty Alleviation

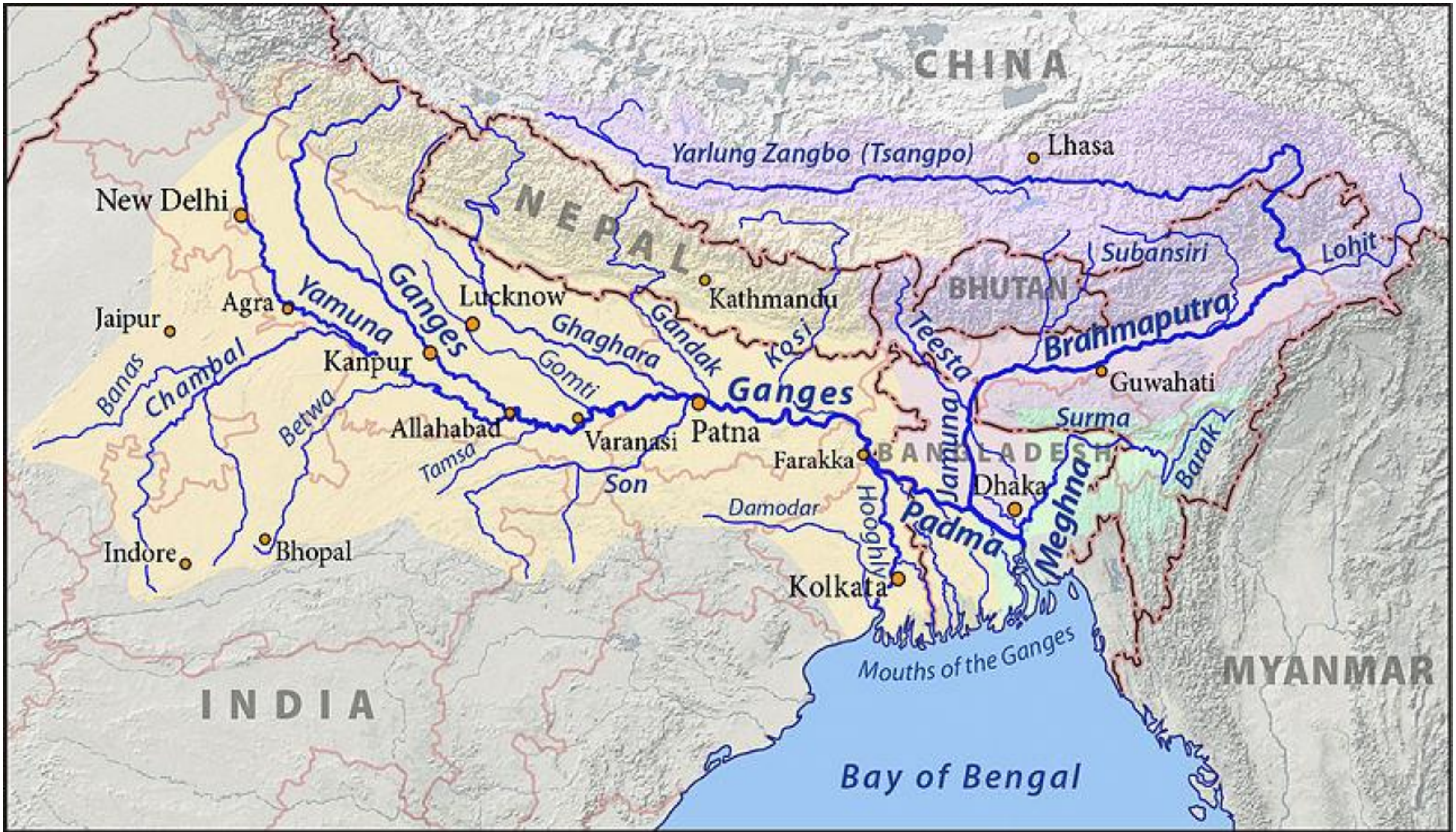
NERC/DFID Partnership within
Living with Environmental Change (LWEC)

Lead by University of Southampton,
With Oxford, Dundee, Exeter, UEA, BUET and 10 other groups in Bangladesh and IIT Kanpur in India

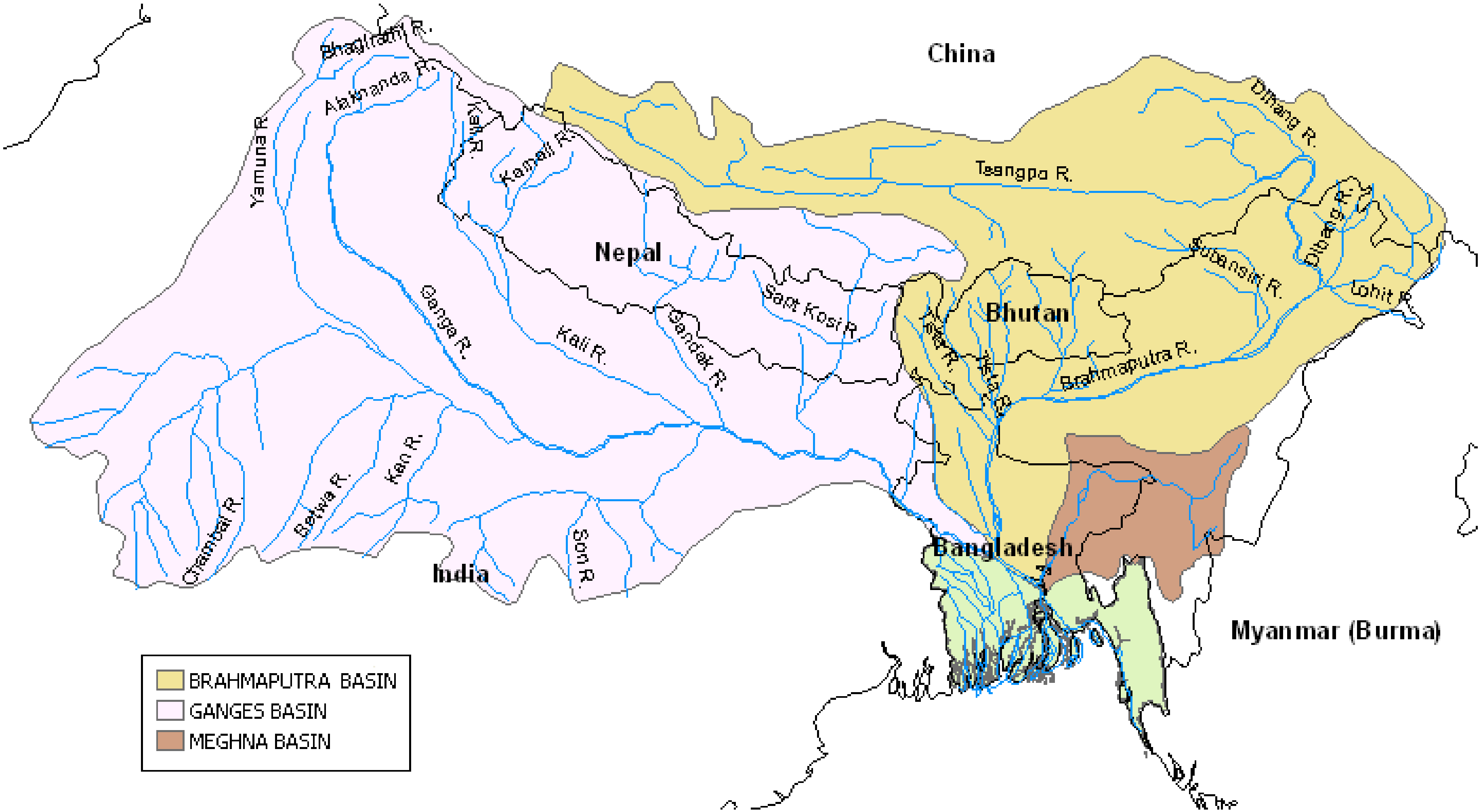
Set in the Delta Regions of Bangladesh addressing issues of Poverty Alleviation

Key Questions and Motivation

- **How will future climate change and socio-economic change in the Ganga, Brahmaputra and Meghna basin impact flows and nutrient fluxes into the Delta?**
- **How can management and policy interventions reduce these impacts?**



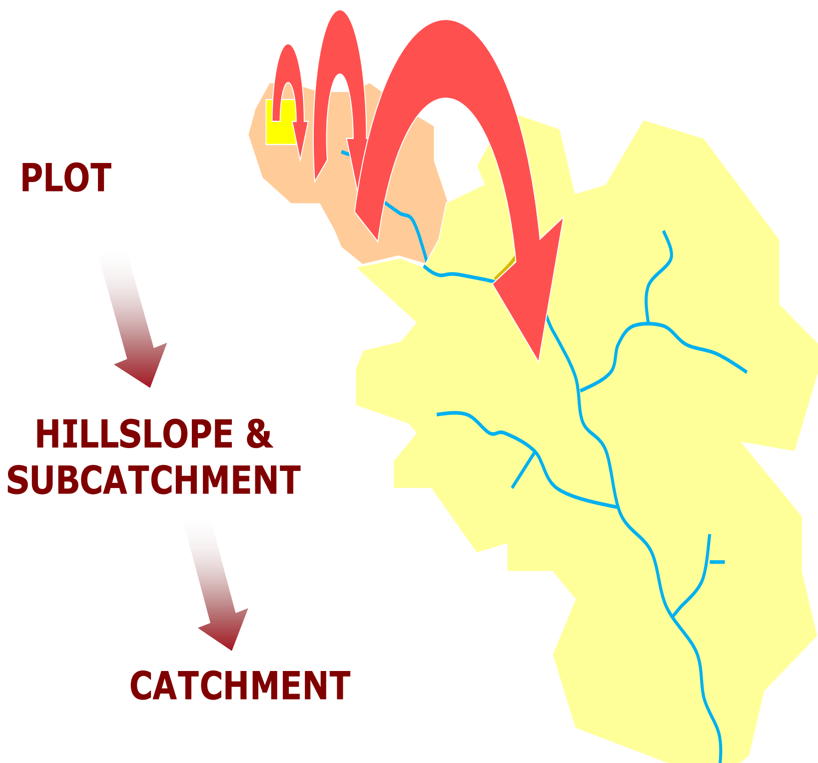
Modelling Ganges, Brahmaputra and Meghna River Systems

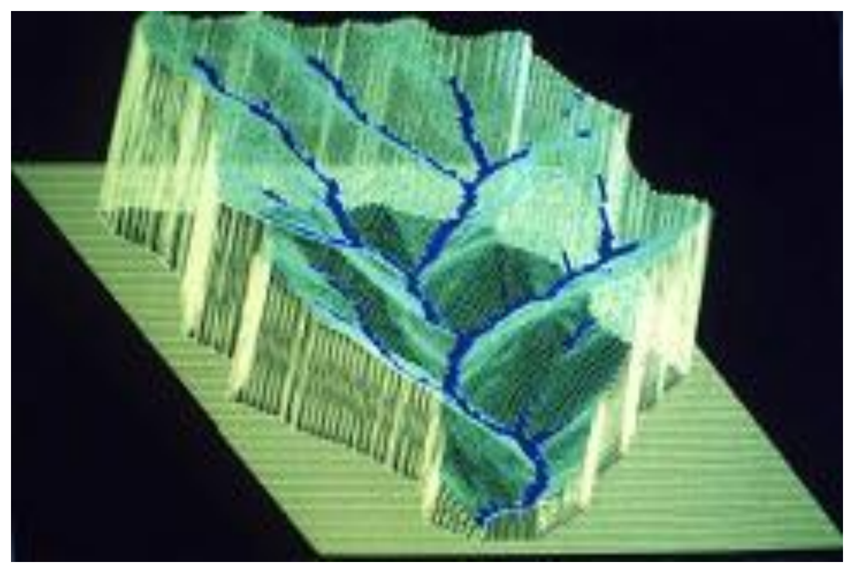


Integrated Catchment Model (INCA)

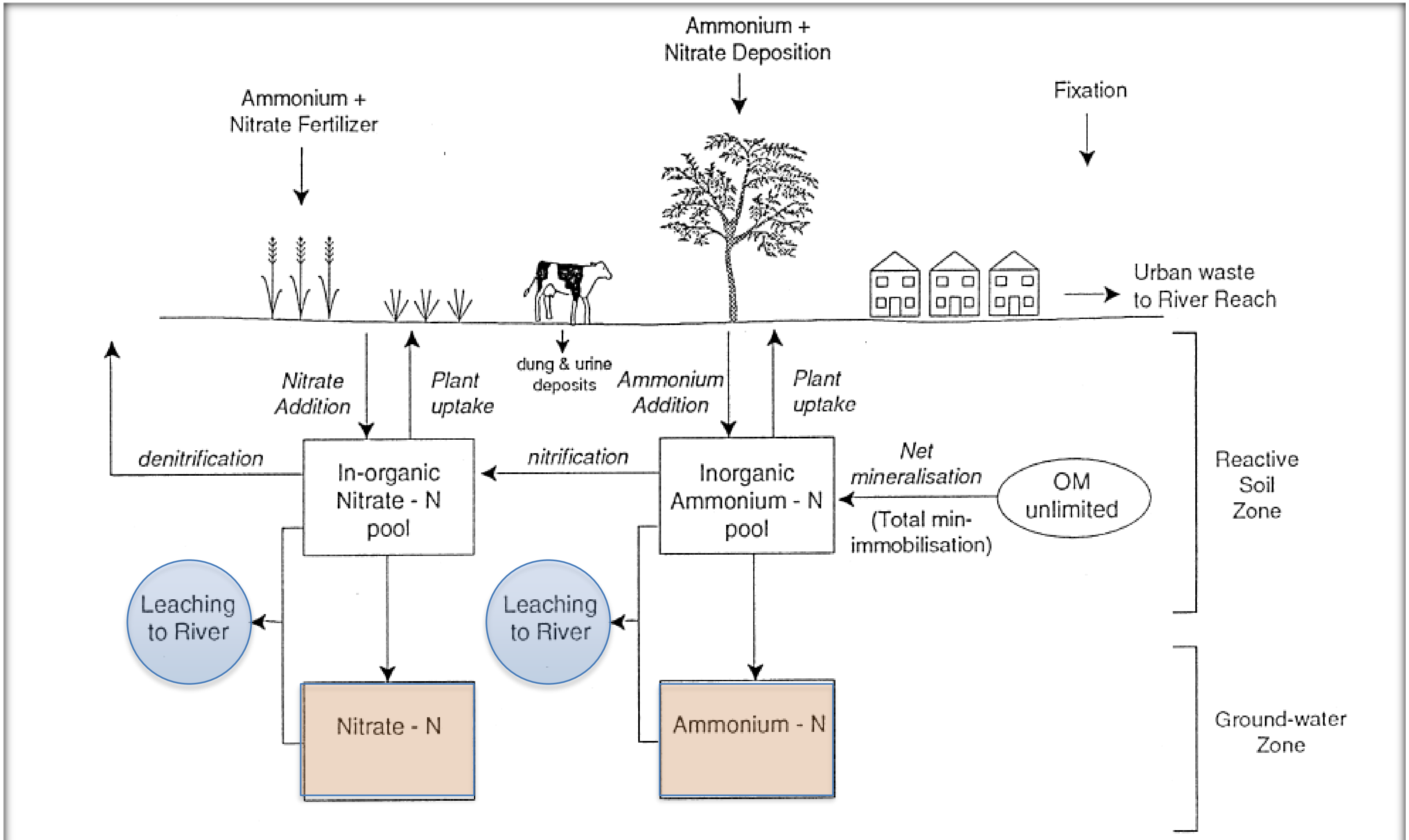
(Hydrology, Nitrogen, Phosphorus, Sediments, Carbon, Metals and Ecology)

- Can account for diffuse and point sources of pollution, land use change and climate change
- Semi distributed and ssuccessfully applied to over 50 catchments (including catchments in Nepal)



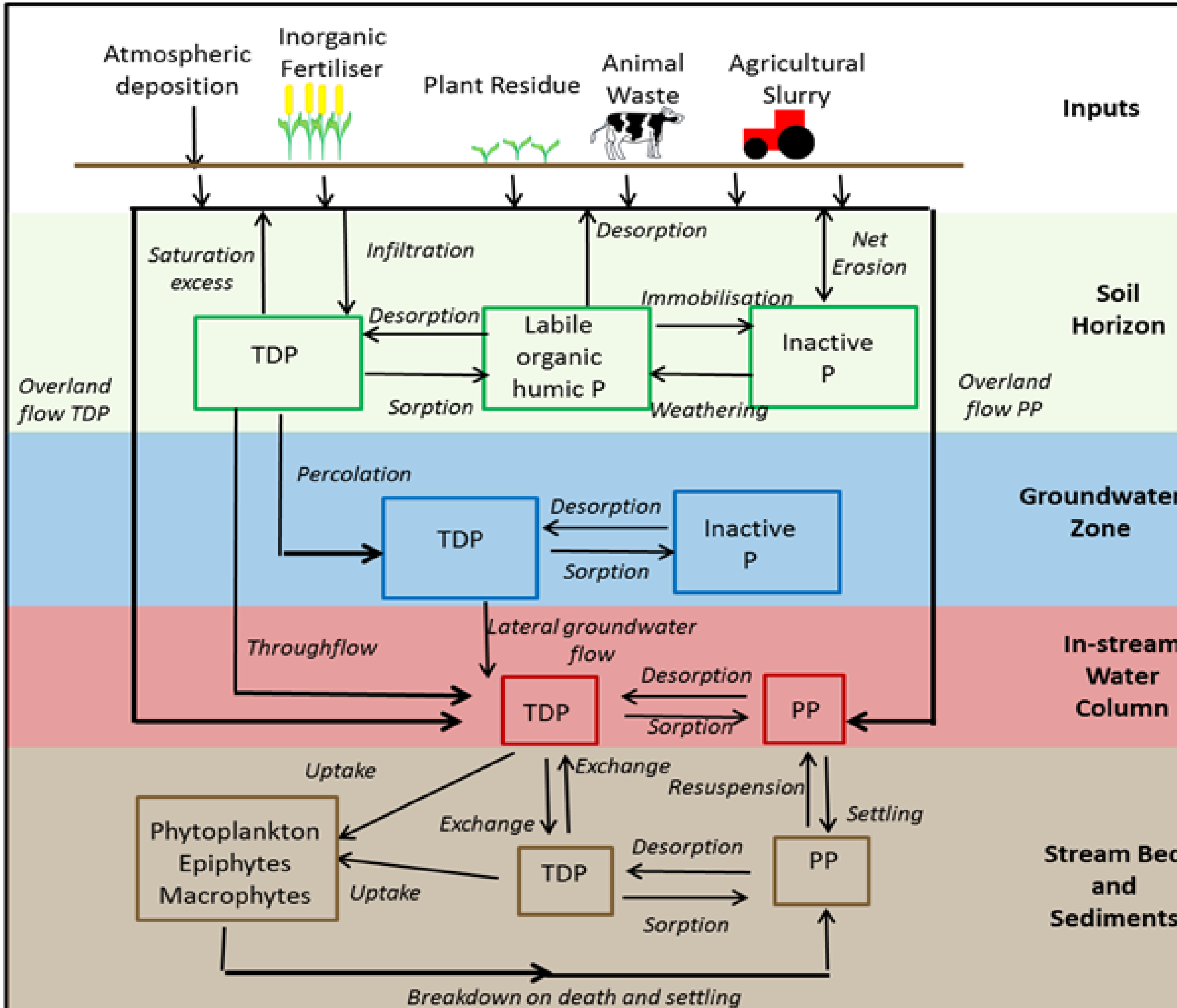


The INCA-N NITROGEN Model Process Pathways

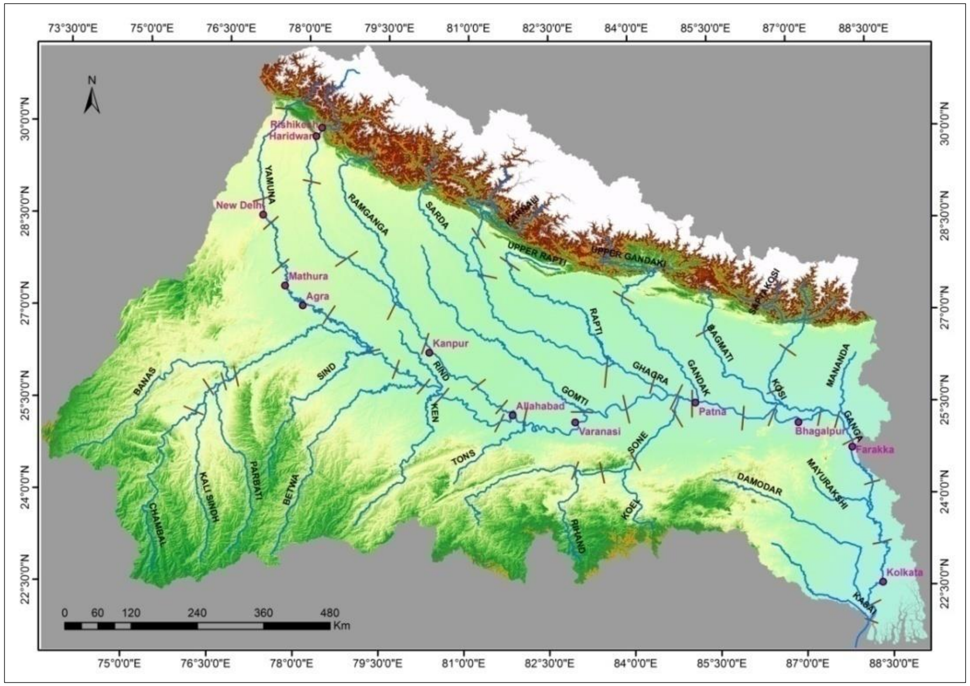


Source: P.G. Whitehead et al./The Science of the Total Environment 210/211 (1998) 547-558

INCA P Model


Atmospheric deposition
Inorganic Fertiliser
Plant Residue
Animal Waste
Agricultural Slurry
Inputs
Saturation excess
Infiltration
Desorption
Net Erosion
Immobilisation
Desorption
TDP
Labile organic humic P
Inactive P
Sorption
Weathering
Overland flow TDP
Overland flow PP
Soil Horizon
Percolation
Desorption
TDP
Inactive P
Sorption
Groundwater Zone
Lateral groundwater flow
Throughflow
Desorption
TDP
PP
Sorption
In-stream Water Column
Uptake
Exchange
Resuspension
Settling
Exchange
Phytoplankton Epiphytes Macrophytes
Desorption
TDP
PP
Uptake
Sorption
Stream Bed and Sediments
Breakdown on death and settling

INCA reach divisions for Ganga basin

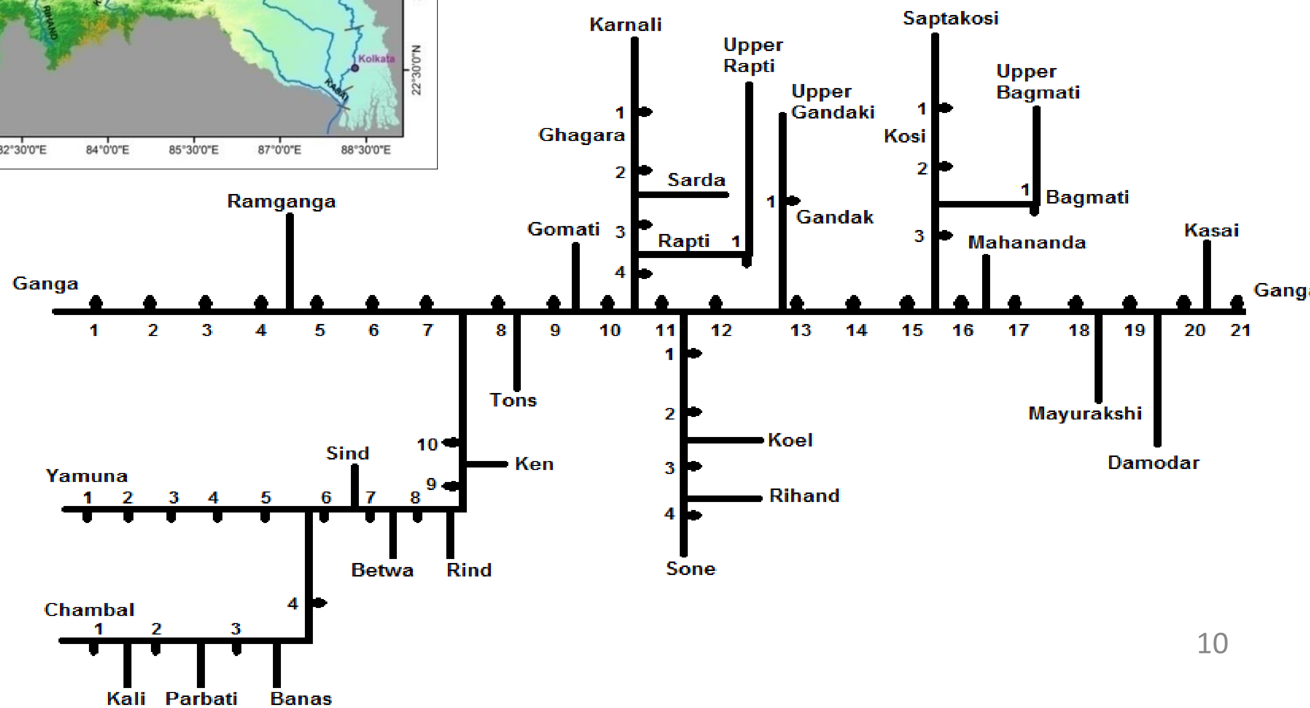


Major Cities and Point Source Pollution

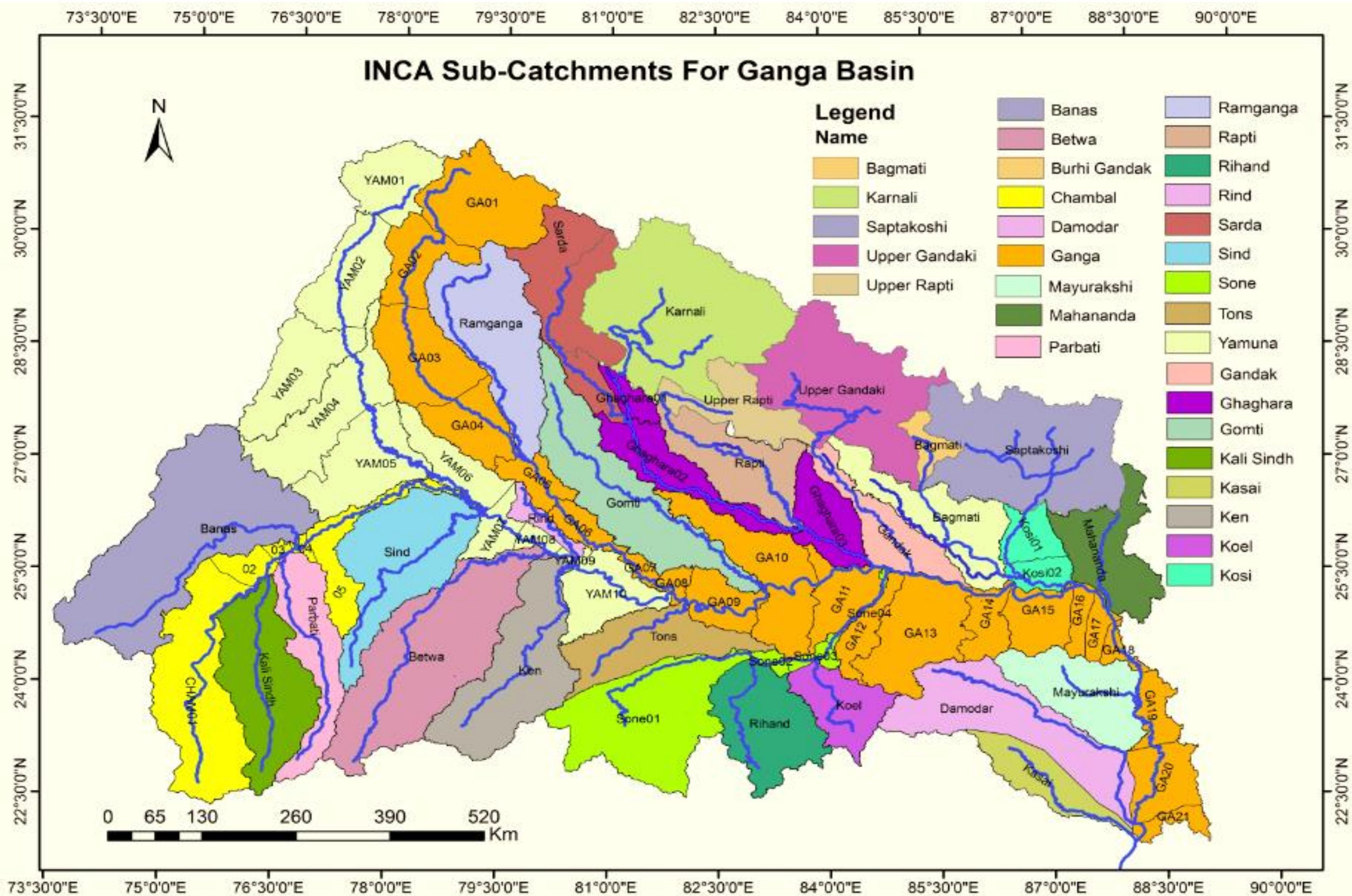
Tributary confluence
Sampling/monitoring point
Effluent input/abstraction

Reach Structure: Ganga Model

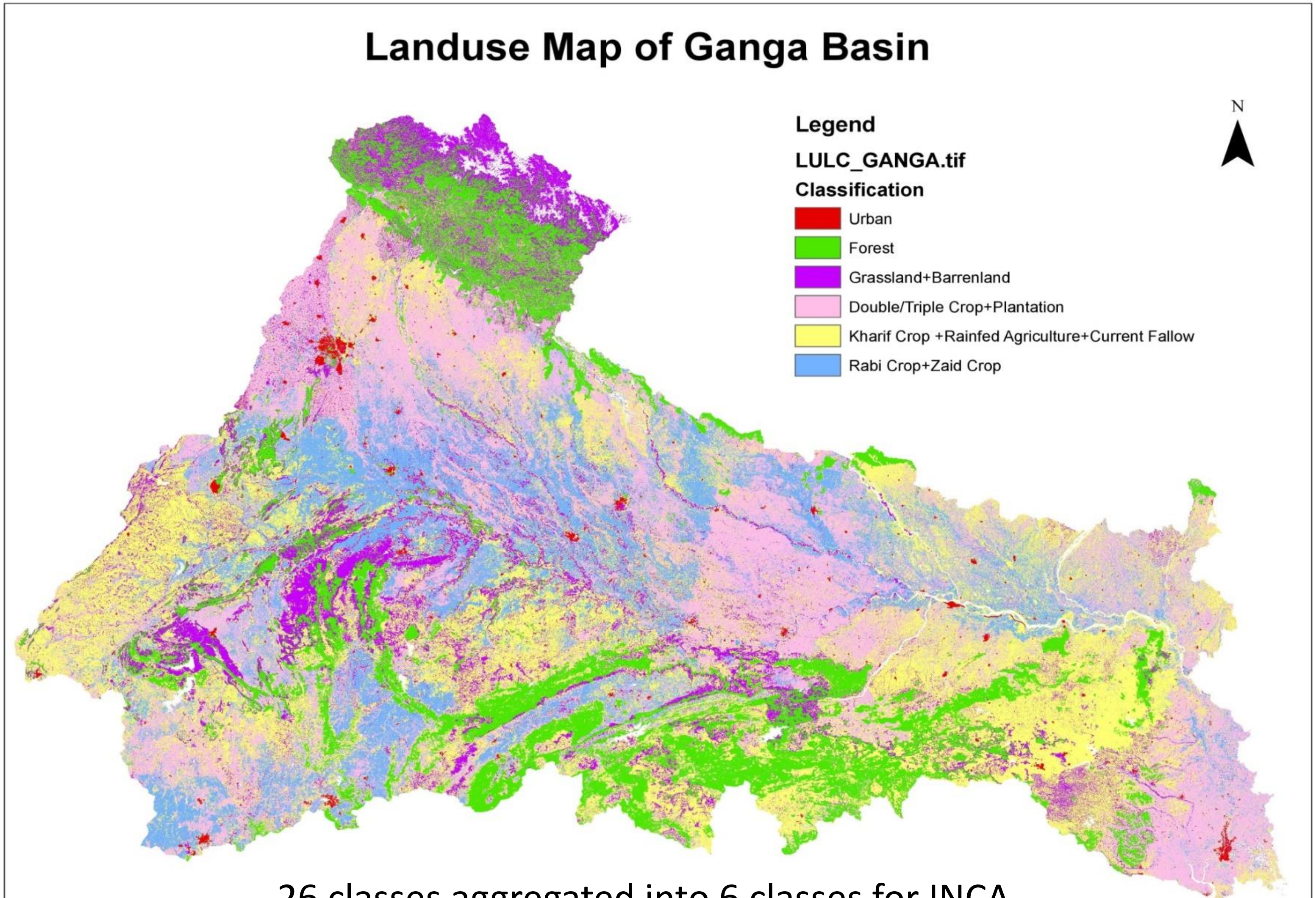
Total 70 reaches
Ganga – 21 reaches
Yamuna – 10 reaches
Other tributaries – 39 reaches



Modelled Sub-Catchments in Ganga



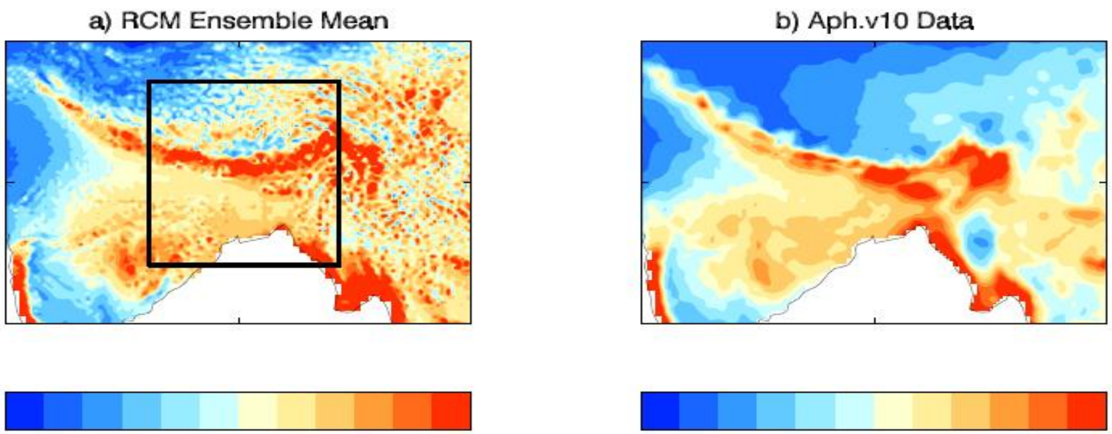
Detailed Land Use Mapping

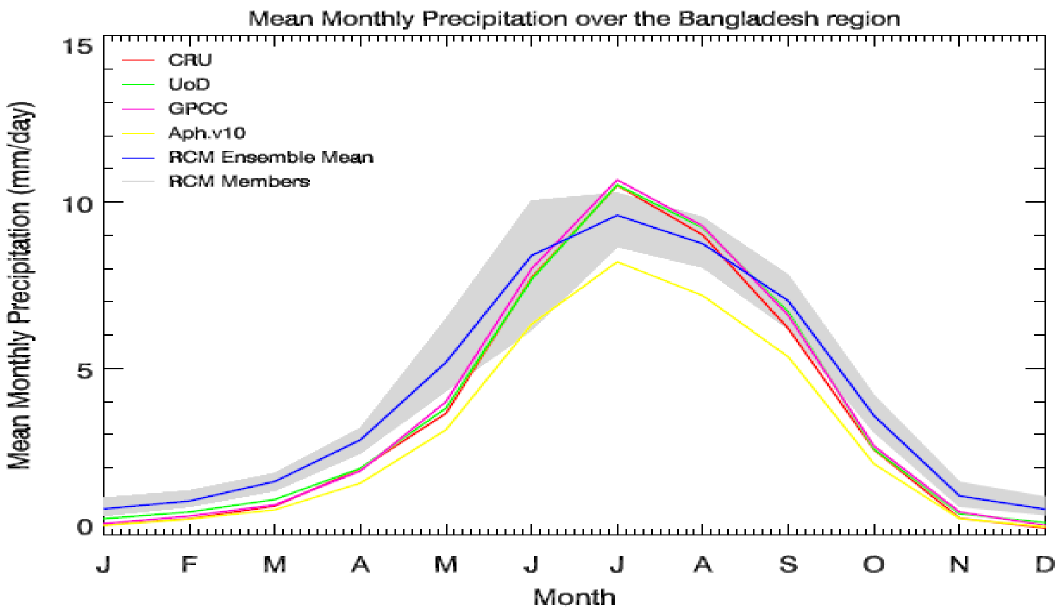


26 classes aggregated into 6 classes for INCA

(Based on NRSC, Hyderabad)

UK Met Office GCM- RCM
(25km grid- calibrated spatially and in time
Met Office Hadley Centre HadRM3P RCM)

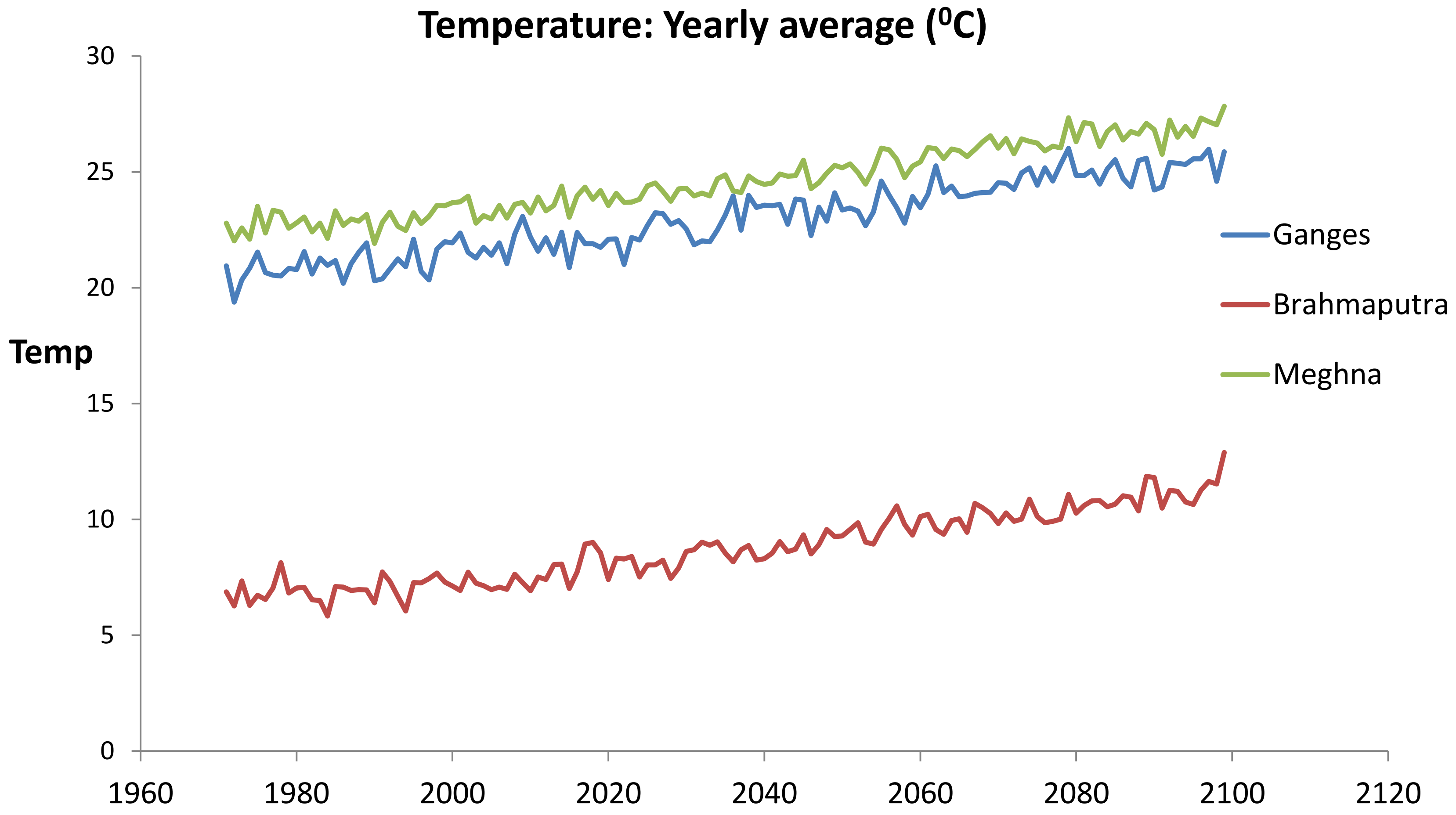




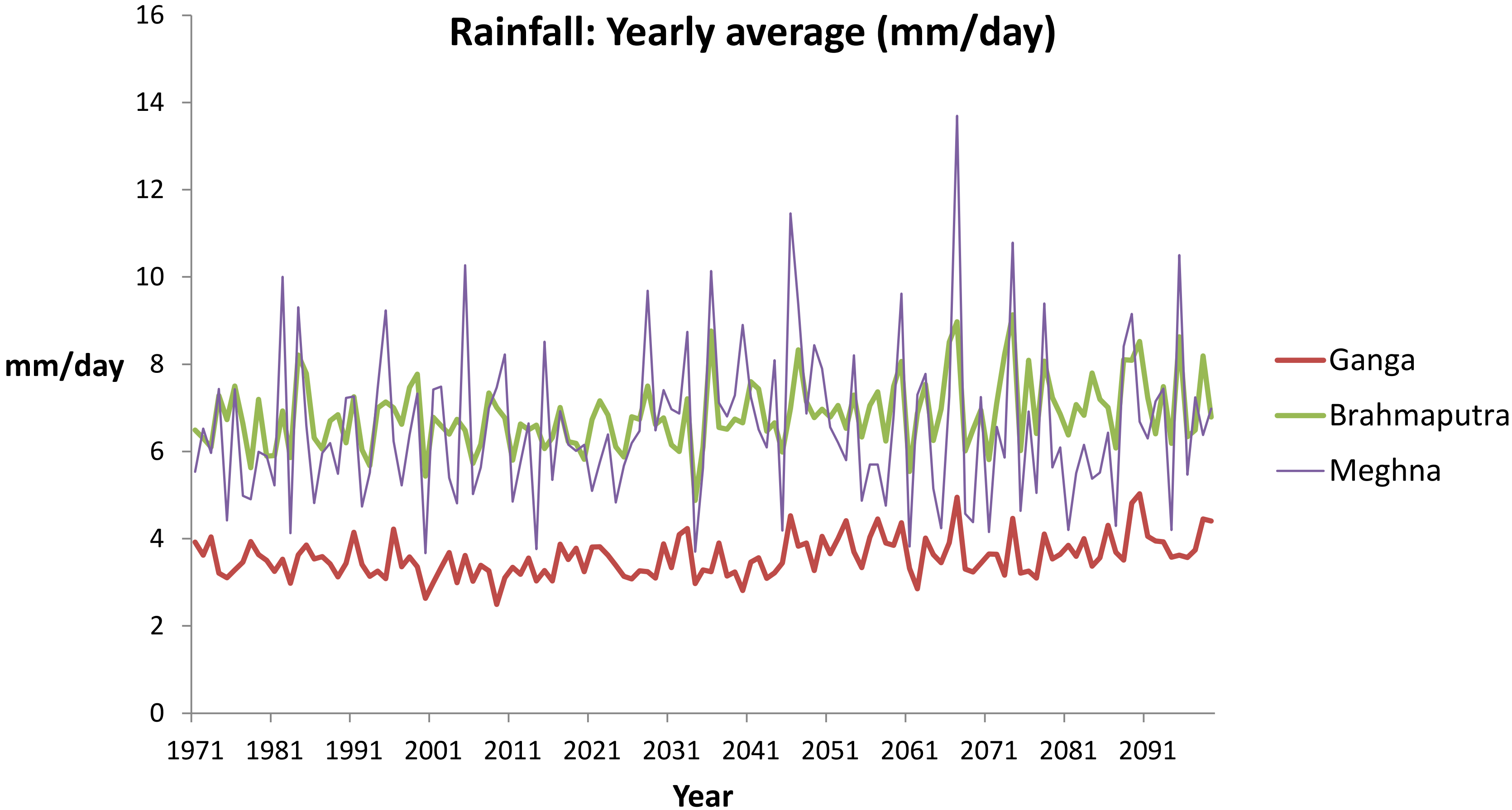
Climate Realizations

- Q_0 – Moderately warmer/wetter
- Q_8 – warmer/drier
- Q_{16} – warmer/wetter

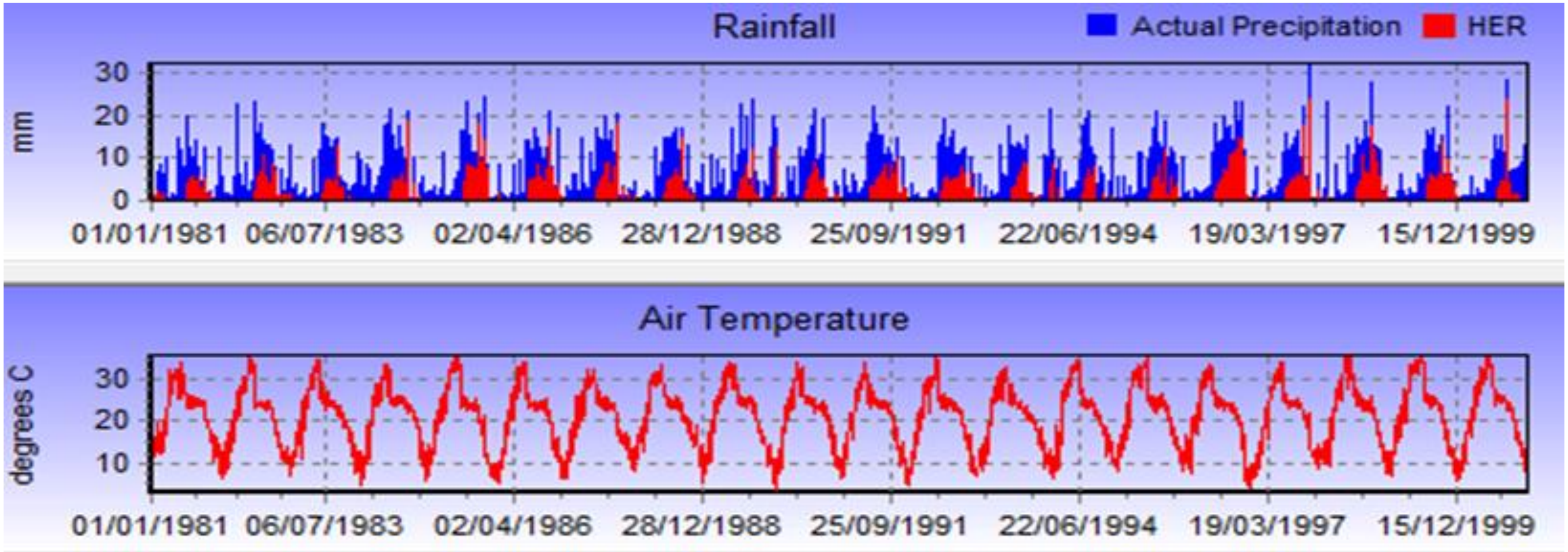
Climate Scenario
Moderately warmer/wetter



Climate Scenario
Moderately warmer/wetter

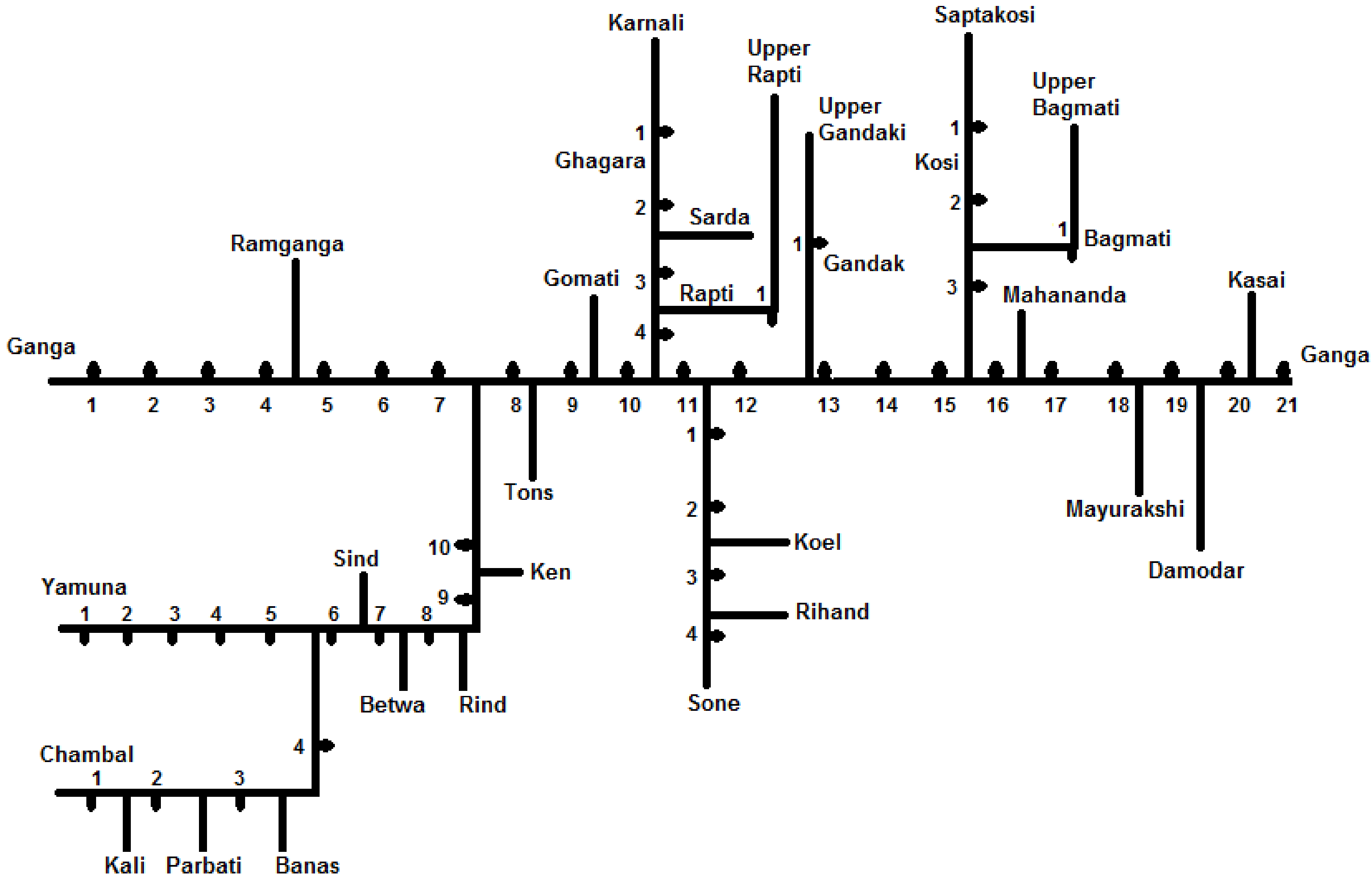


Time Series Inputs for INCA Model

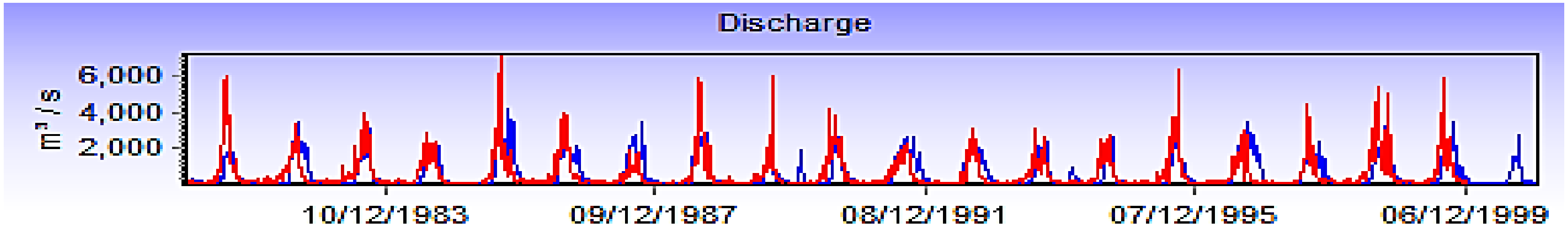


1981-2000
(Daily time series data)

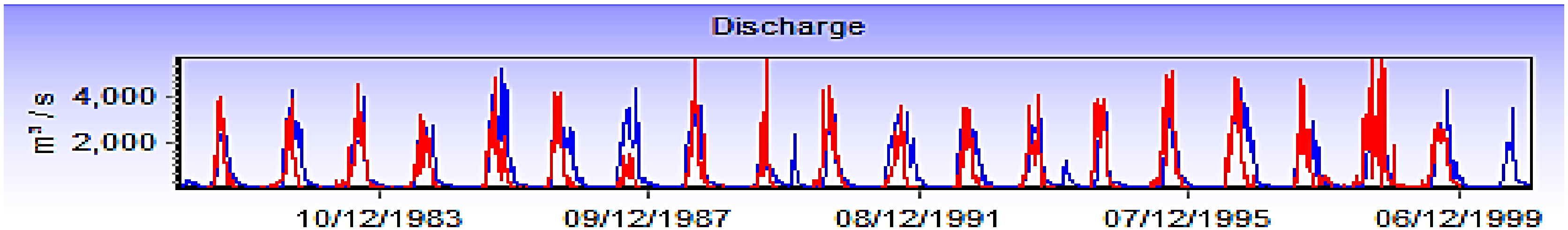
INCA Reach Structure for the Ganges



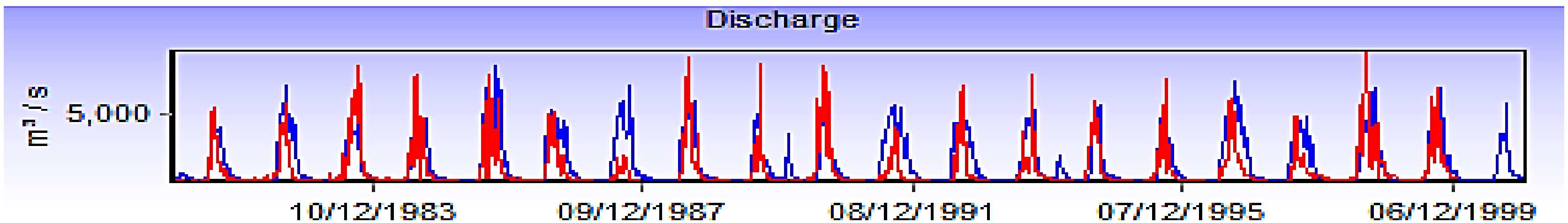
Model Calibration - flow gauges on the Ganga River system



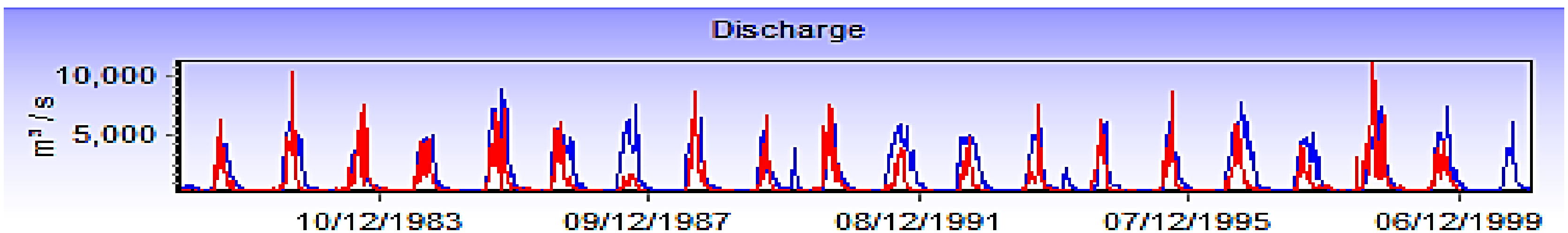
GA07
Garh



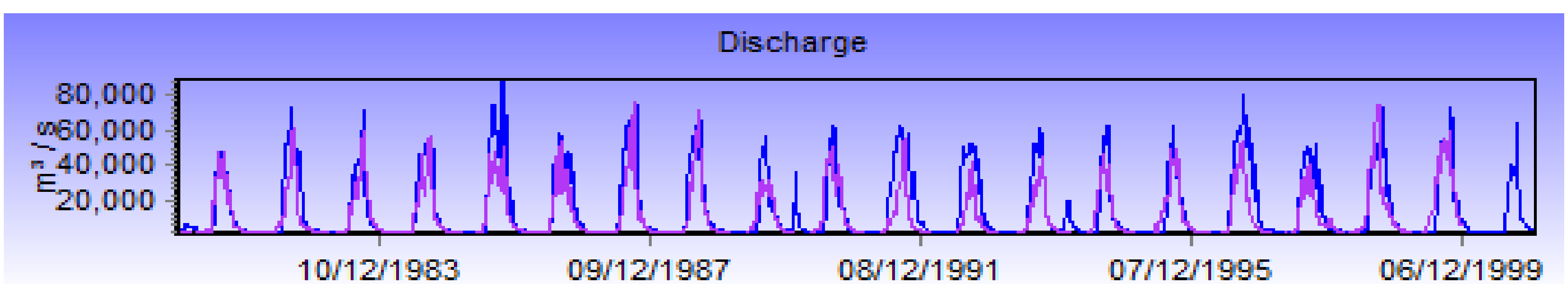
GA04
Kachla



GA05
Ankinghat

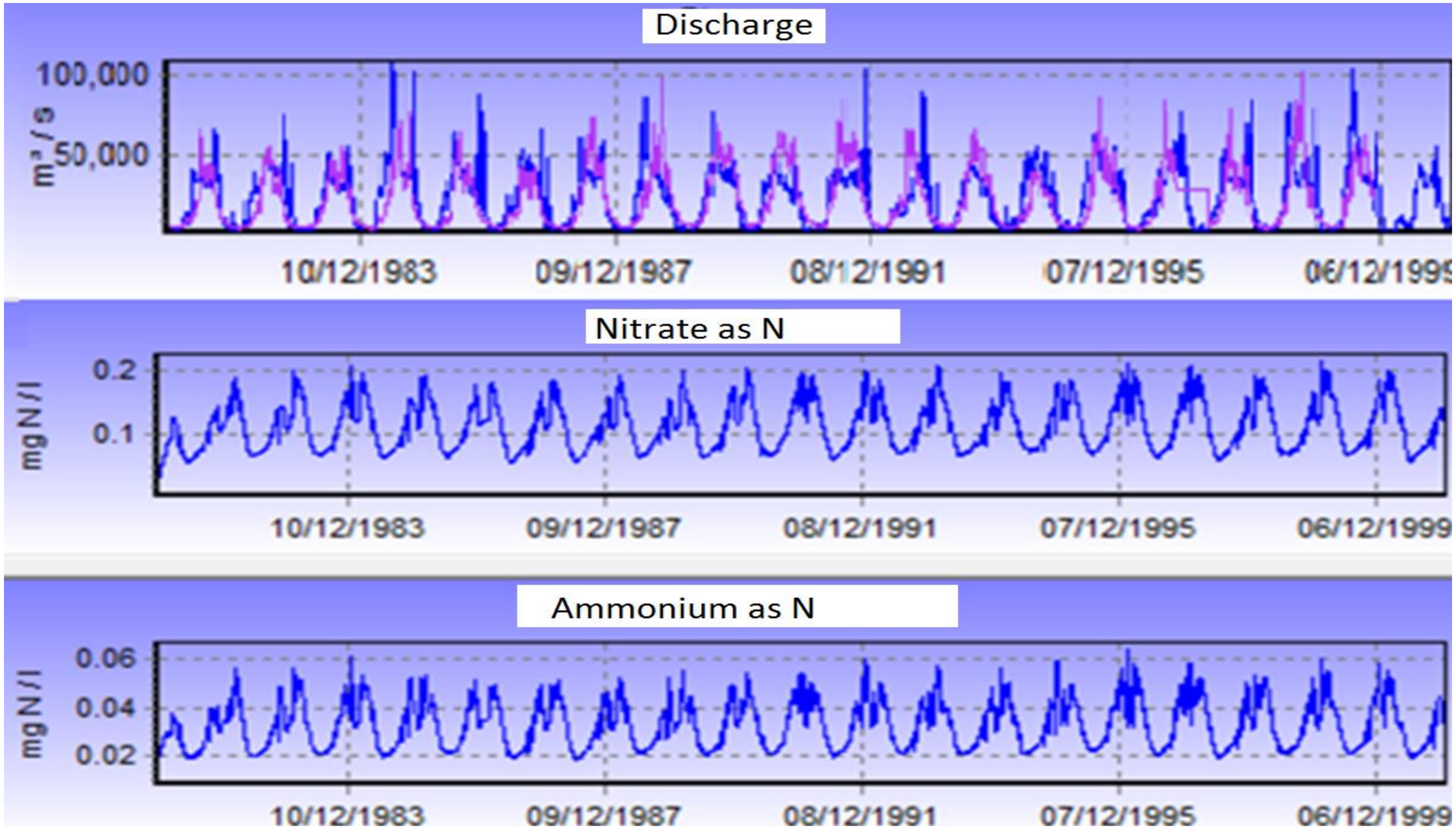


GA06
Kanpur



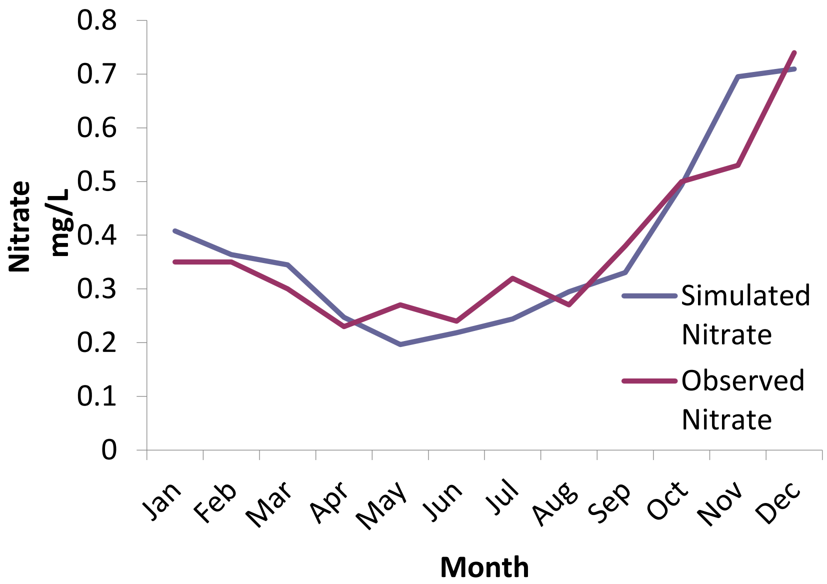
Hardinge
Bridge
Bangladesh

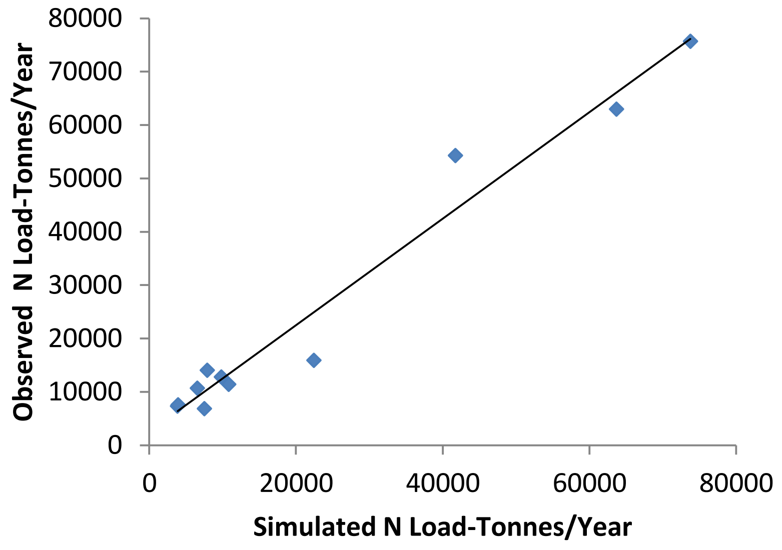
Brahmaputra Simulation 1981-2000



Calibration of N concentrations and Flux

At Kanpur (Reach GA06)





Using INCA to Assess Environmental Change

- Climate Realisations
- 3 selected from 17 RCM simulations
- Mid century 2041-2060
- End of Century
- 2080-2099

Q_0 – Moderately warmer/wetter
Q_8 – warmer/not so wet
Q_{16} – warmer/wetter

- Socio-Economic
- Business as Usual
- More Sustainable
- Less Sustainable

- Population changes
- Sewage treatment works capacity and design for water quality control
- Water demands for irrigation and public supply
- Atmospheric nitrogen deposition
- Land use change
- Water transfer plans

Scenario Framework

- IPCC Shared Socio-economic pathways (SSPs)

SSP1 Sustainability	**SSP2** Middle of the Road	**SSP3** Regional Rivalry	**SSP4** Inequality	**SSP5** Fossil-fuelled Development

SRES A1B
(RCP4.5/6 -8.5)

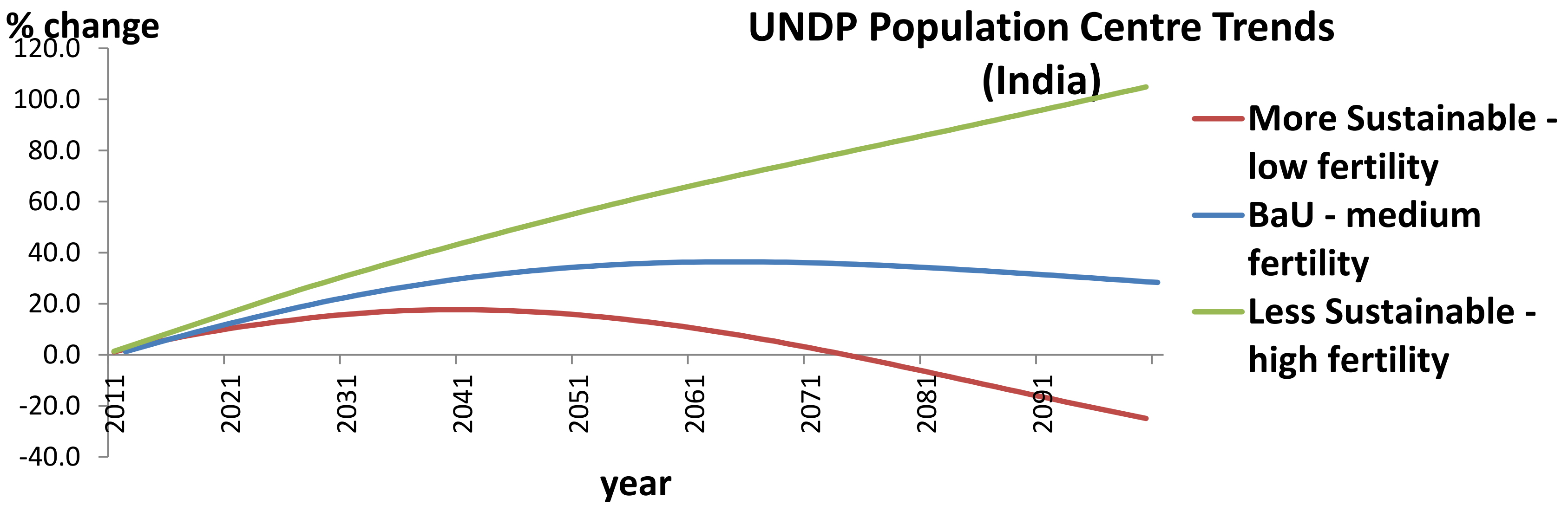
Development

Climate Change
incl. sea level rise

	More Sustainable	**Business as Usual**	**Less Sustainable**
Moderately warmer/ wetter	1	2	3
Warmer/ drier	4	5	6
Warmer/ wetter	7	8	9

Scenario Analysis
building on the IPCC 2014 SSP Strategy

- Population changes
- Sewage treatment works capacity and design for water quality control
- Water demands for irrigation and public supply
- Atmospheric nitrogen deposition
- Land use change
- Water transfer plans



Water Infrastructure

Major Transfer Plans (River Interlinking project)

Peninsular Component

1. Mahanadi - Godavari
2. Inchampalli - Nagarjunasagar
3. Inchampalli - Pulichintala
4. Polavaram - Vijayvada
5. Almatti - Pennar
6. Srisailam - Pennar
7. Nagarjunsagar - Somasila
8. Somasila -Grand Anicut
9. Kattalai - Vaigai - Gundar
10. Ken - Betwa
11. Parbati - Kalisindh - Chambal
12. Par - Tapi - Narmada
13. Damanganga - Pinjal
14. Bedti - Varda
15. Netravati - Hemavati
16. Pamba - Achankovil - Vaippar

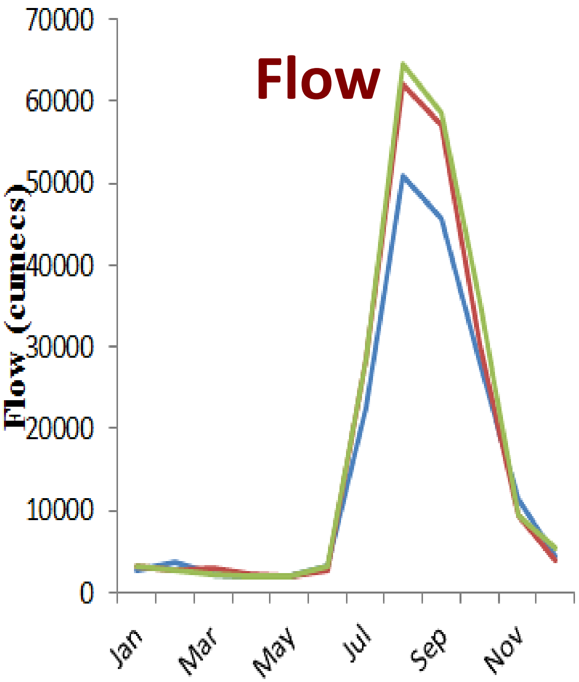
Himalyan Component

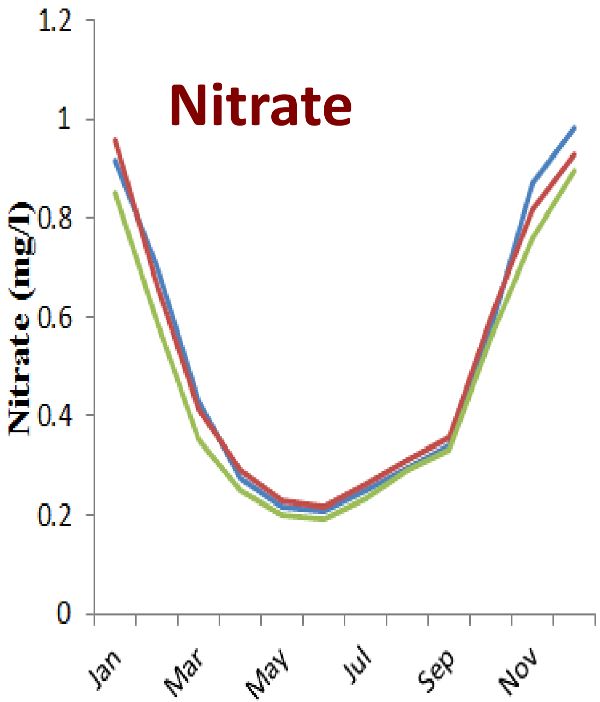
1. Kosi - Mechi
2. Kosi - Ghagra
3. Gandak - Ganga
4. Ghagra - Yamuna
5. Sarda - Yamuna
6. Yamuna - Rajasthan
7. Rajasthan - Sabarmati
8. Chunar - Sone Barrage
9. Sone Dam - Souther Tributaries of Ganga
10. Manas - Sankosh - Tista - Ganga
11. Jogighopa - Tista - Farakka (Alternate)
12. Farakka - Sunderbans
13. Ganga (Farakka) - Damodar - Subernarekha
14. Subernarekha - Mahanadi

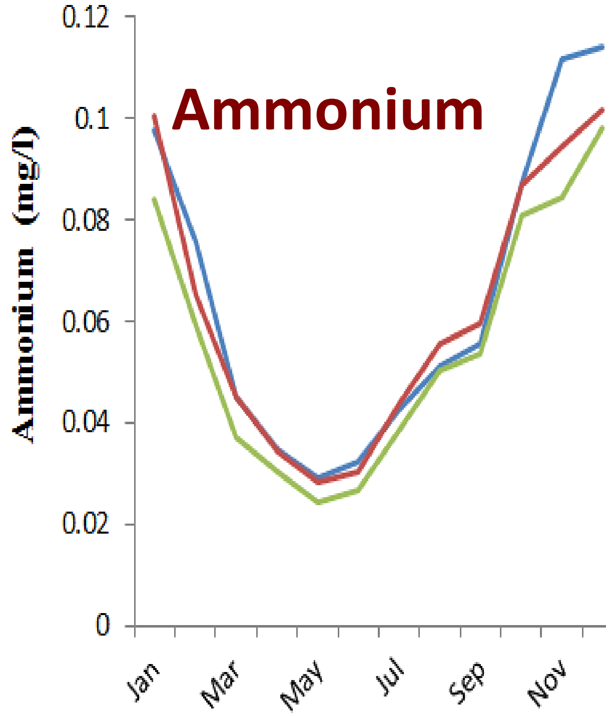
Estimated Flows, Nitrate and Ammonia at Farakka

Climate Scenario Q_0

Blue – 1990s
Red – 2050s
Green – 2090s

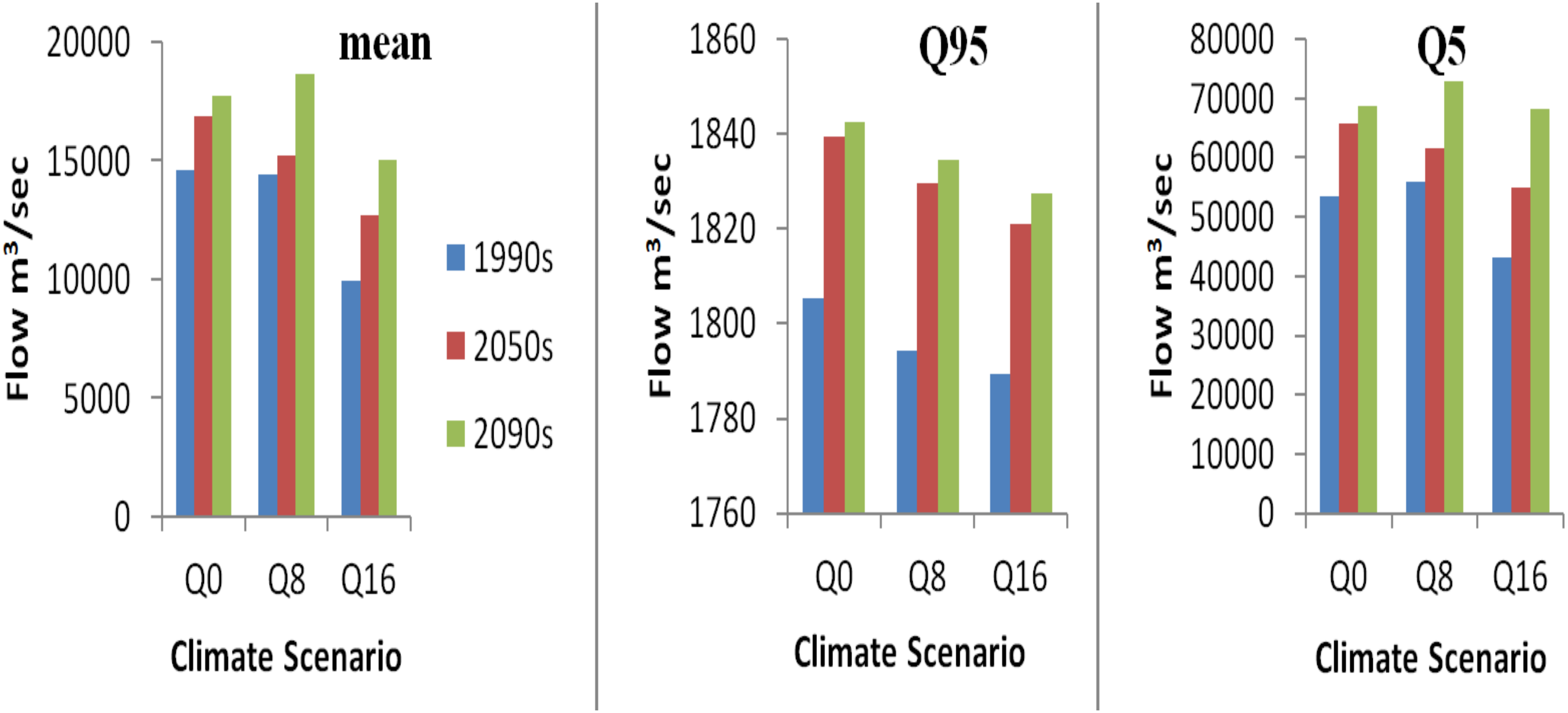






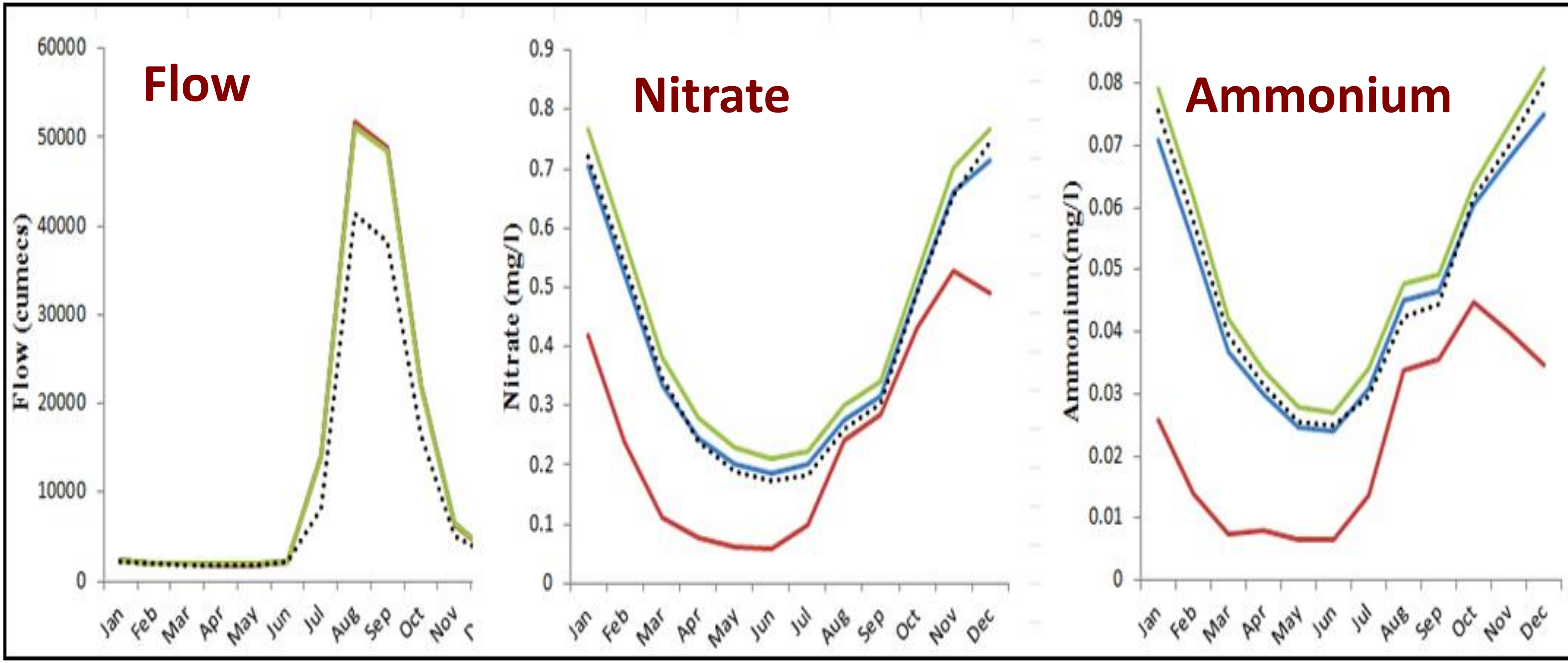
- No major shift in timing of monsoon season
- Large Change in peak flows
- Nitrate and Ammonia follow the dilution trend due to increased flows

Effects of Different Climate Realisations in the Ganges at Farakka



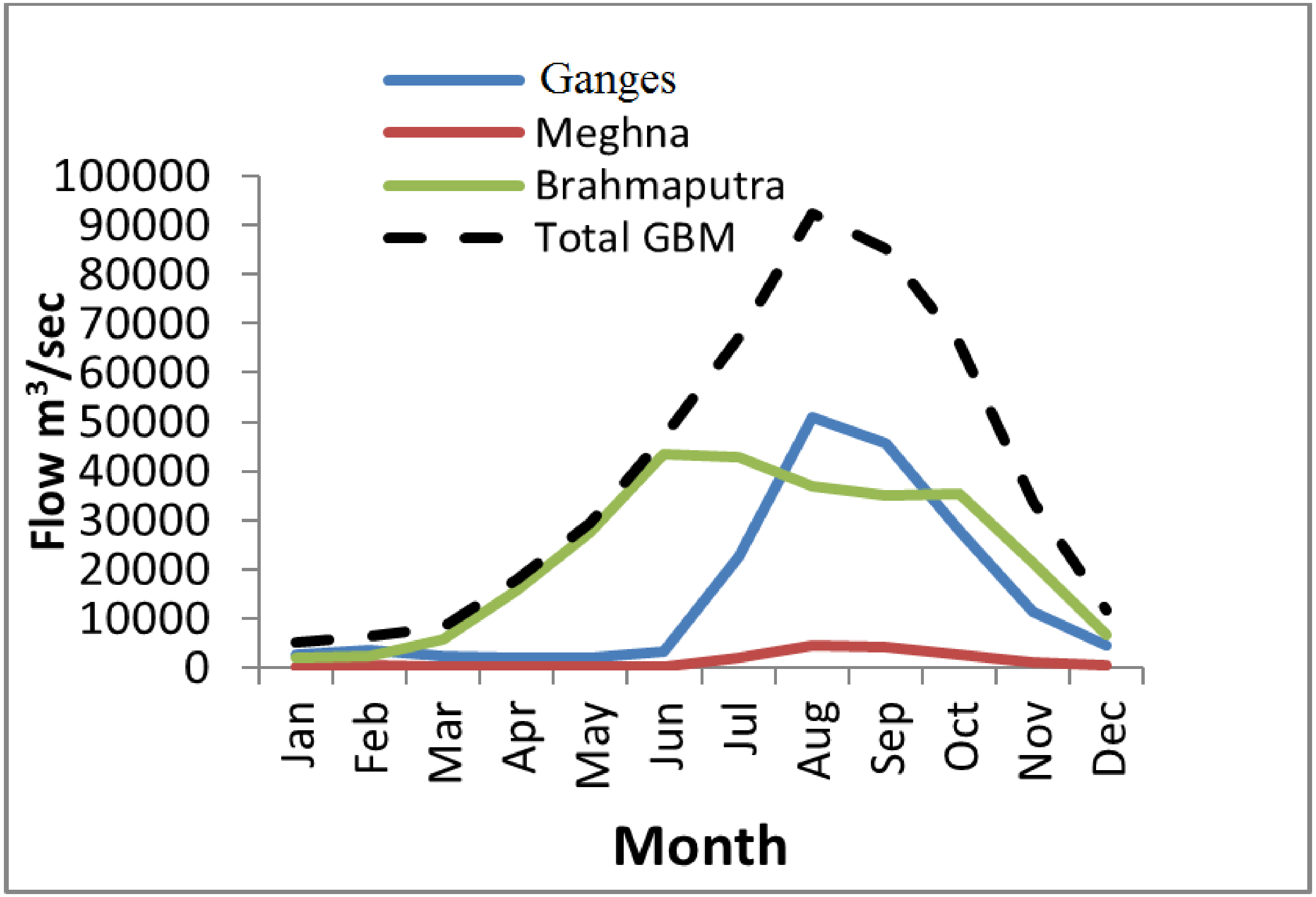
Effects of Socio-economics on Ganga Flow and Water Quality

Blue – BaU; Red – MS; Green – LS; Dotted – baseline 1990s

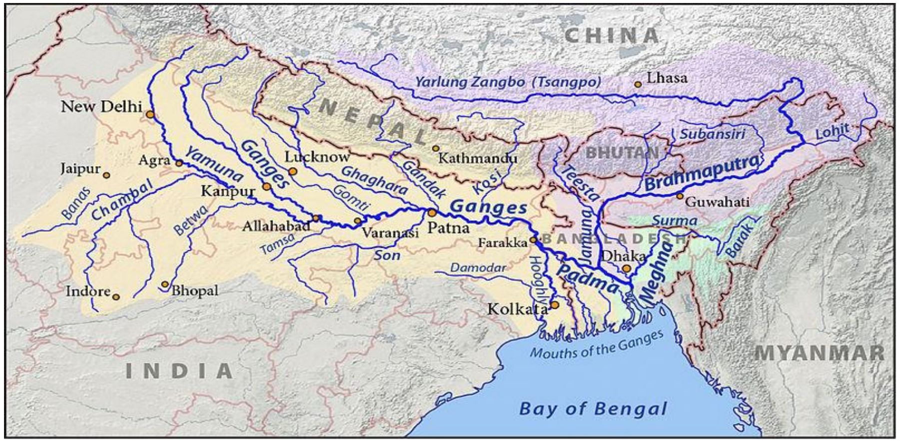


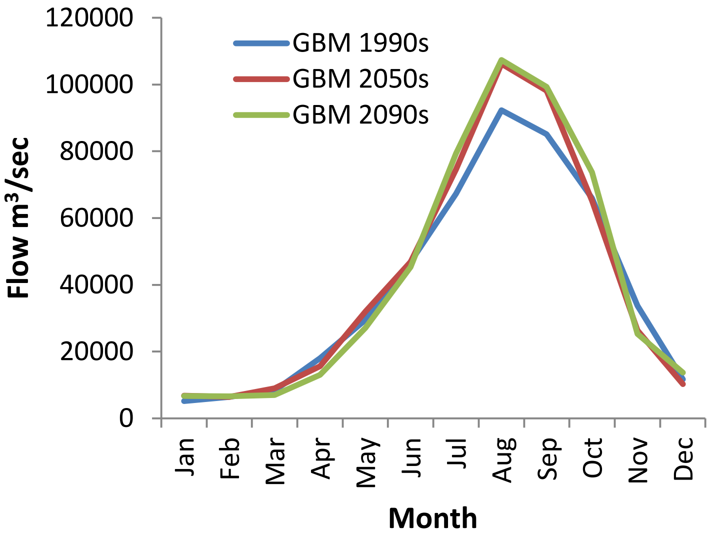
- No major difference in flows (no major change in irrigation flows & water transfers simulated)
- Large reduction in N and NO_3 under MS scenario – reflects improved effluent treatment, implications for river ecology and reduced nitrogen load into Bangladesh (similar results for P)

Full GBM Results- baseline

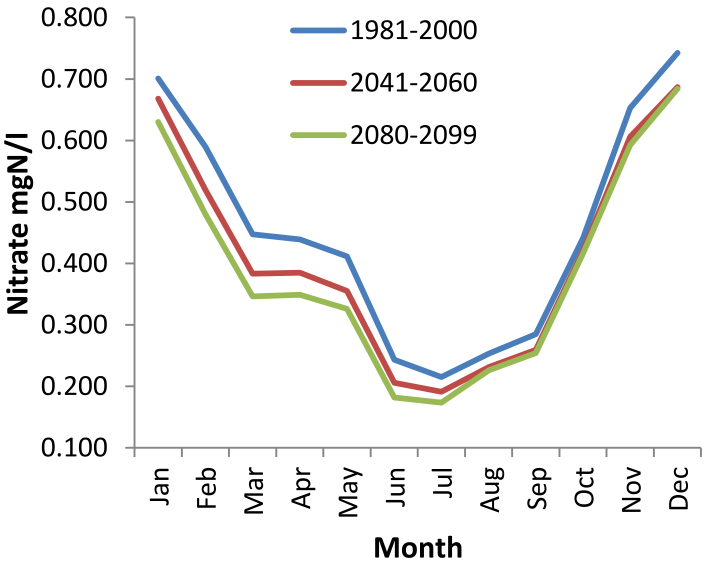


Assessing the impact of climate and socio-economic changes on flow and water quality in the Ganges-Brahmaputra-Meghna Basin





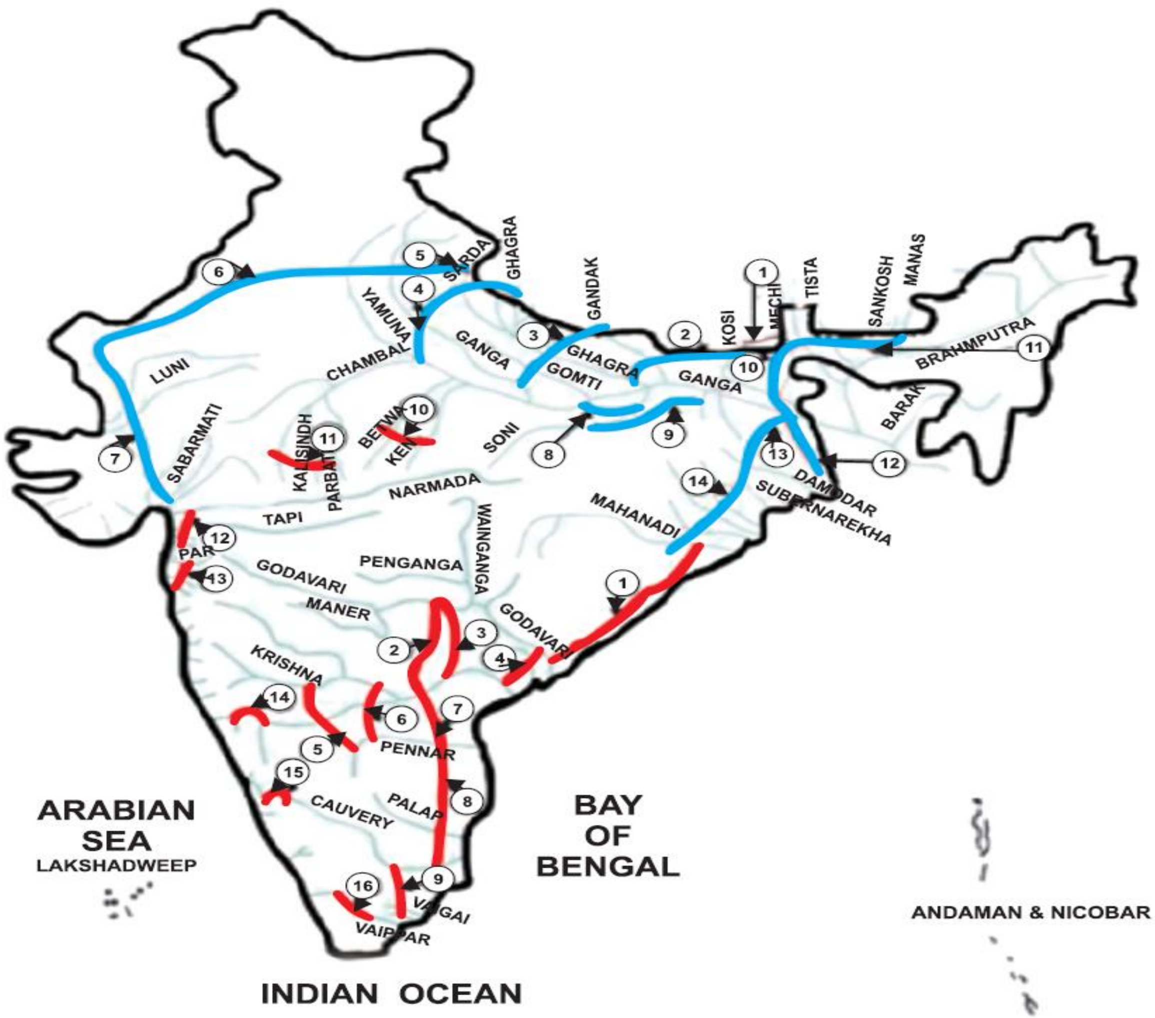
Change in monthly flow for the SRES A1B scenario for the 2050s and 2090s.



Change in Nitrate-N Monthly Concentrations for the SRES A1B scenario for the 2050s and 2090s.

Water Infrastructure

Major Transfer Plans (River Interlinking project)



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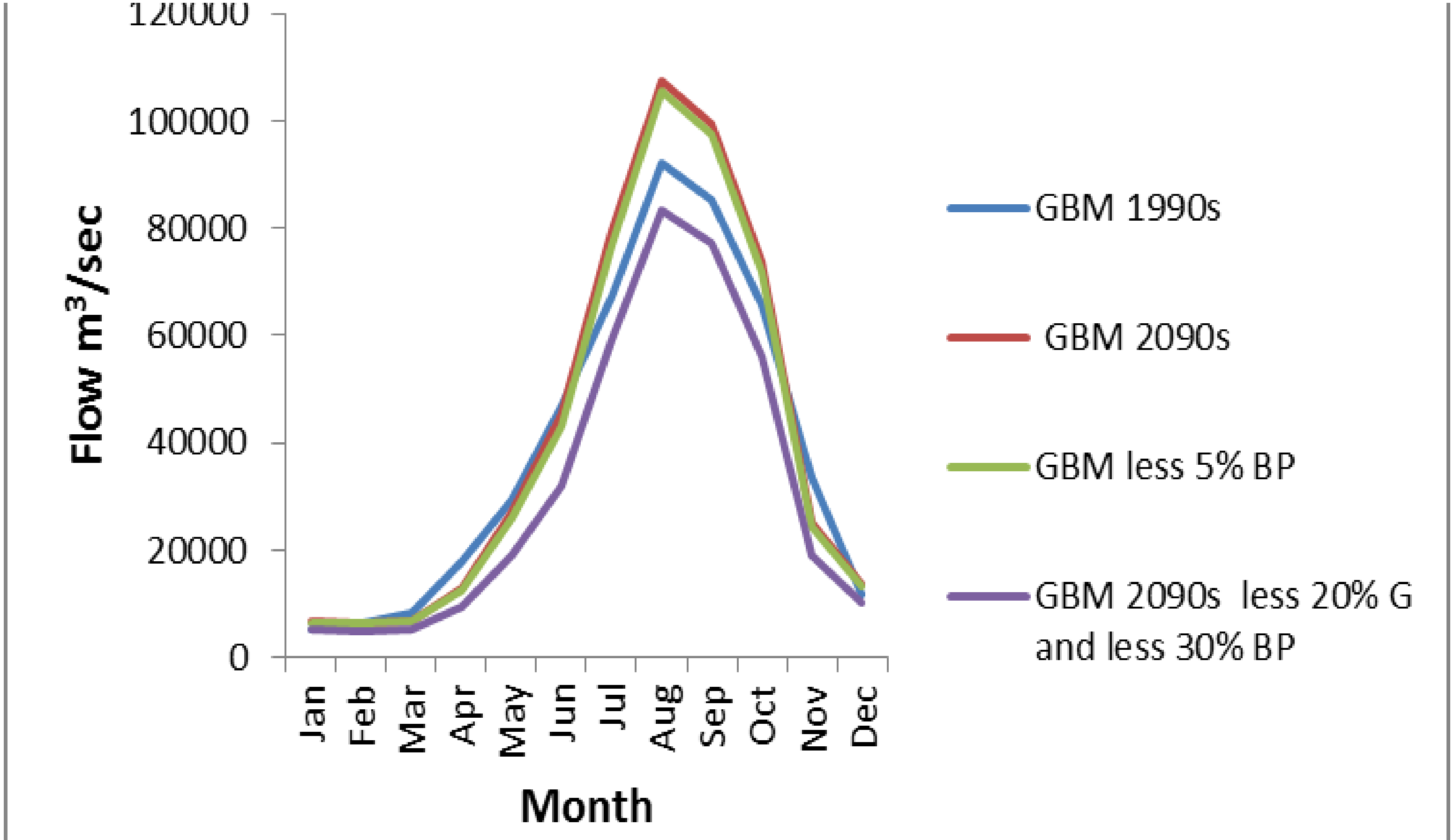
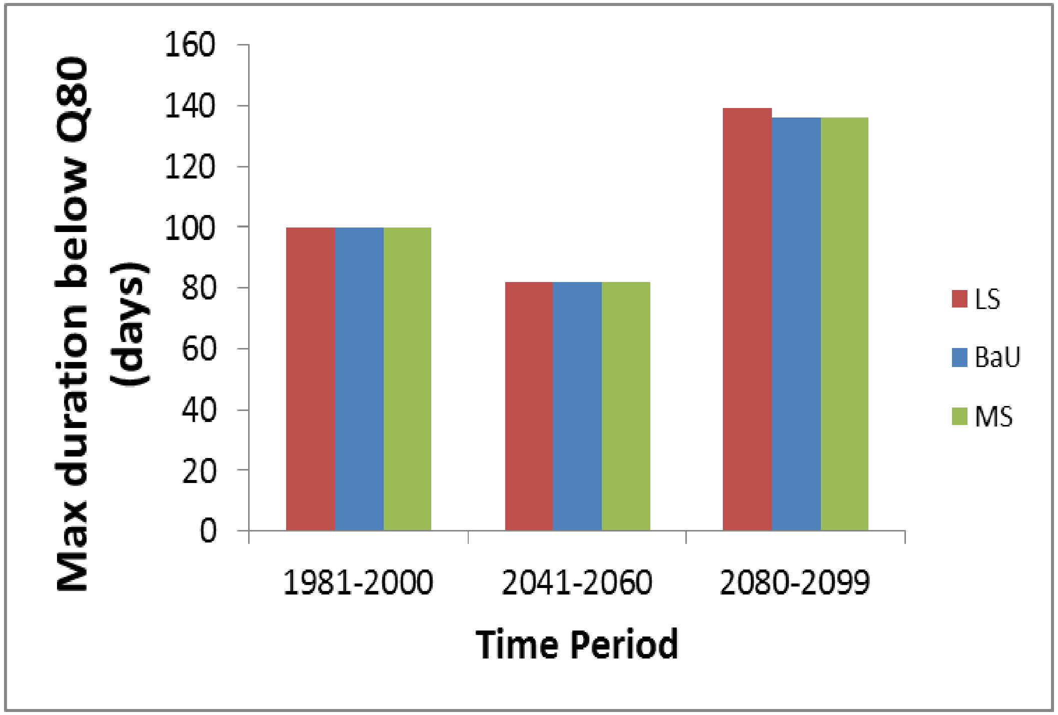
Water transfer Scenarios



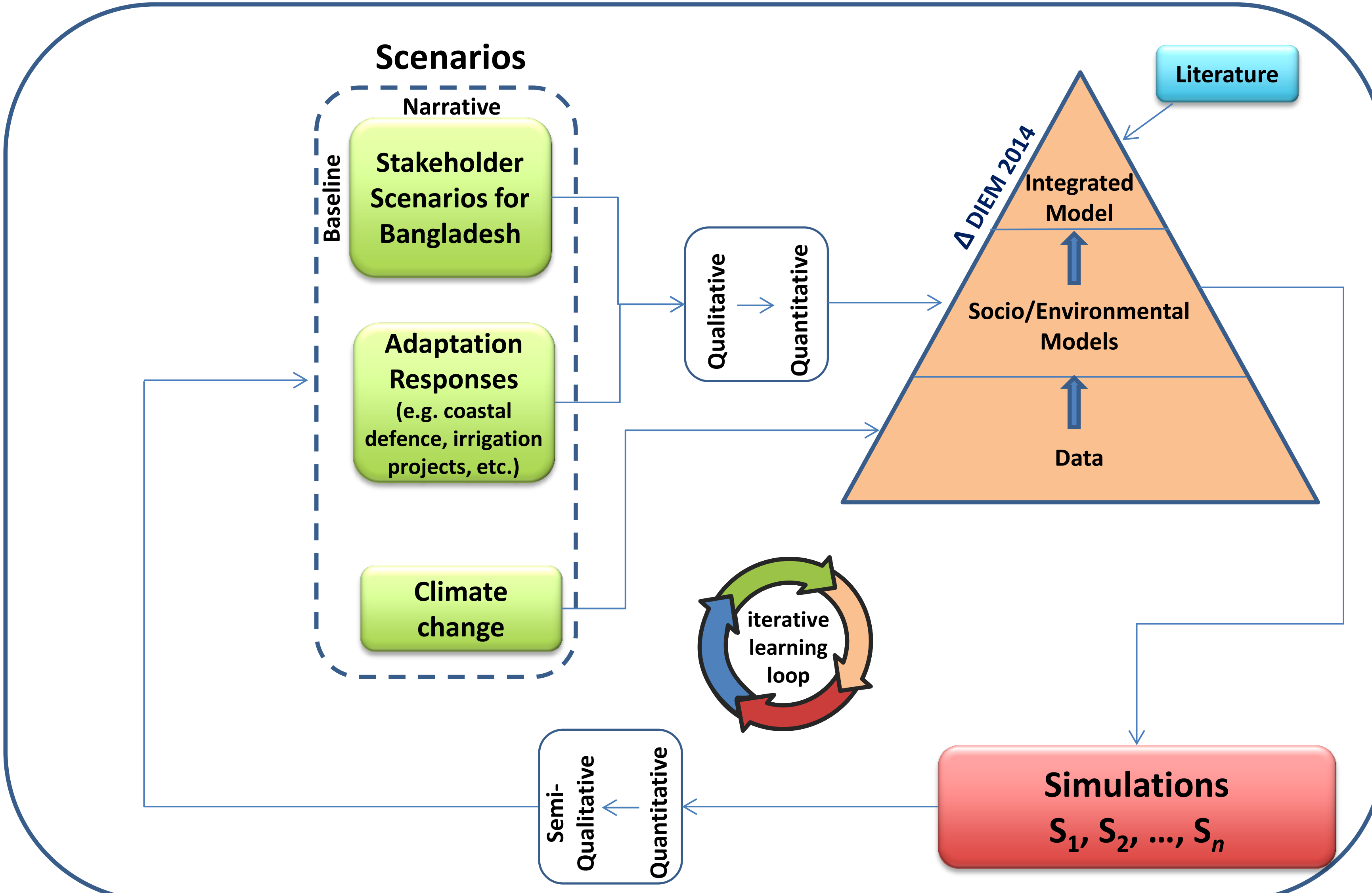
- Impact of water transfers on flows is very significant
- 22% reduction in peak flows for 2090s; 48% reduction in low flows for 2090s
- => Large scale impact on delta ecosystem



Impact of climate and socio-economic change (excluding dams and major water transfers) on low flows - number of days below Q80 (5700 m^3/sec) showing increased drought periods in the 2090s

Whitehead et al. (2015). Impacts of Climate Change and Socio-economic Scenarios on Flow and Water Quality of the Ganges, Brahmaputra and Meghna (GBM) River Systems: Low Flow and Flood Statistics . *Environmental Science: Process & Impacts.* (in press)

What Next---Stakeholder driven process to evaluate management plans



Conclusions

1. INCA model simulates the spatial and temporal complexity of flows and N-flux (P and Sediments) in a large river system.
2. Significant climatic shift with increased temperatures and change precipitation could have significant impact on flows, increasing peak flows and more frequent droughts.
3. Socio Economic Changes could have a large effect on flows during droughts where increased irrigation will reduce low flows, plus impact of Water Transfers could be very significant in the GBM delta.
4. Clean up of the Ganga River will reduce Nitrogen (and Phosphorus) fluxes into Bangladesh.
5. Process based model of the GBM rivers can now be used to evaluate alternative policies in more detail (e.g. dam effects, different agricultural strategies, point source pollution, different Ganga Clean up strategies etc.).