Assessing Compound Floods in a Large Tropical River Basin under Changing Climate

Amina Khatun[1], Poulomi Ganguli[1], Chandranath Chatterjee[1], and Bhabagrahi Sahoo[1]

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Abstract

Compound flooding, characterized by the co-occurrence of multiple drivers is a cause of concern in many world river basins. High river flows accompanied by high rain events are responsible for severe flooding events. Many studies in the recent past have analysed rain and river-flow dominated compound floods. In this study, we assessed the rain and river-flow induced compound flooding scenarios in a large tropical river basin, the Mahanadi River basin, located in eastern India. Since, many high floods have occurred in the past decade in the Mahanadi River basin, we analysed how the historical flood (in the year 2000) will unfold in a projected climate change scenario (in the year 2080) under RCP8.5. We used the bias-corrected hydro-meteorological data of nine Global Climate Models (GCMs) as input forcings to a hydrologic model MIKE11 NAM-HD to simulate the river flows at the head of the Mahanadi delta. The mean areal rainfall for the delta region and the river-flow simulations are forced into a calibrated and validated MIKE FLOOD model to simulate the historical and projected flood inundations. Comparison of the compound floods with the rain-induced and streamflow-induced floods indicate increased compound flooding in the projected scenario. Both historical and projected floods are found to be predominantly influenced by the river flows. Also, both the areal extent and flooding depth are found to be increasing the projected period as compared to the historical counterpart.

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INTRODUCTION

- Six major floods occurred in the Mahanadi River delta between 2000-2014 affecting the lives of millions of people.
- Understanding the compound flood hazards as a whole is essential to know the types of future challenges, both in terms of magnitude and variability, and their impact on the densely populated deltas areas.
- Such assessments will help us to produce realistic scenarios of climate change-induced impacts of these events and thereby, to propose possible adaptation solutions to minimize the risk.

BASIN CHARACTERISTICS

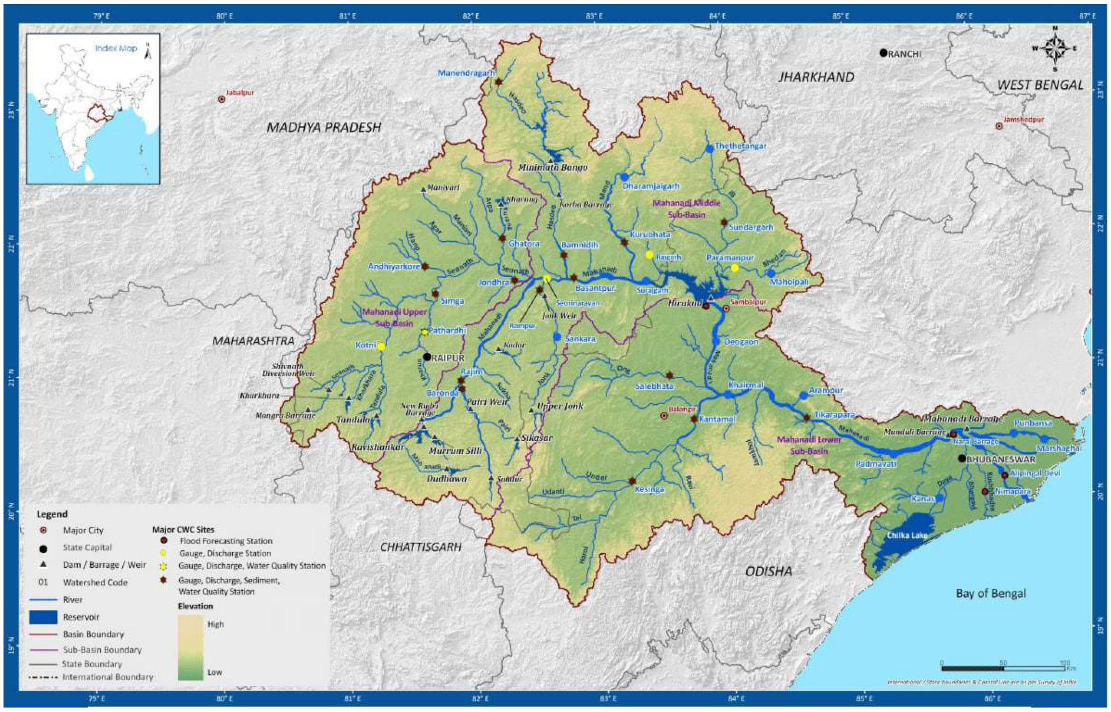


Fig. Mahanadi River basin [Source: Mahanadi Basin Report, CWC(2014)]

- Area:141,589 km^2 (drains into the Bay of Bengal)
- Average annual rainfall:1200-1400 mm [90% occurs during the monsoon season (June-September)]
- Climate:Tropical monsoon
- Min/MaxTemperature: 12^{o}C/39^o-40^{o}C
- Dominant Landuse: Agriculture (54%), Forest (33%)

BIAS CORRECTION OF GCM

- Nine Global Climate Models (GCMs) used are:

  1. BCC-CSM1.1(m)
  2. GFDL-CM3
  3. GFDL-ESM2G
  4. HadGEM2-AO
  5. IPSL-CM5A-LR
  6. IPSL-CM5A-MR
  7. MIROC5
  8. MIRPOC-ESM-CHEM
  9. NorESM1-m

- Gaussian distribution was used to correct the temperature biases following Thrasher et al. (2012).
- The novel hybrid bias-correction technique (Bisht et al., 2020) was used to correct the biases in the GCM-derived derived precipitation.

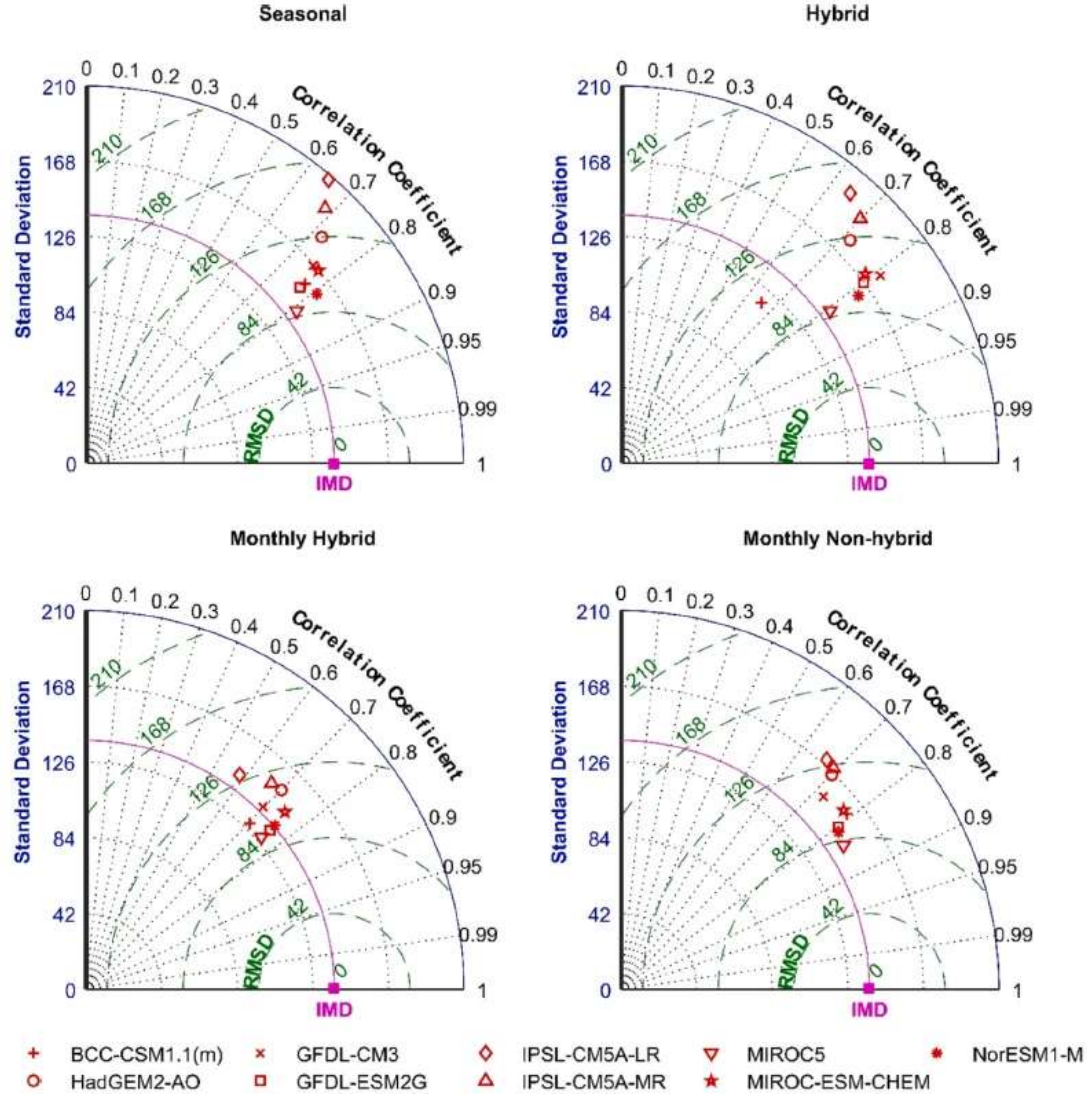


Fig. Taylor diagram for statistical comparison of year wise regional monthly IMD (Observed) rainfall with bias-corrected rainfall of 9 GCMs using different approaches for training period (1976–2005) (Bisht et al., 2020).

FLOOD INUNDATIONS

- MIKE11 NAM-HD model (Bisht et al., 2020) was used to simulate the streamflows at the head of Mahanadi delta.

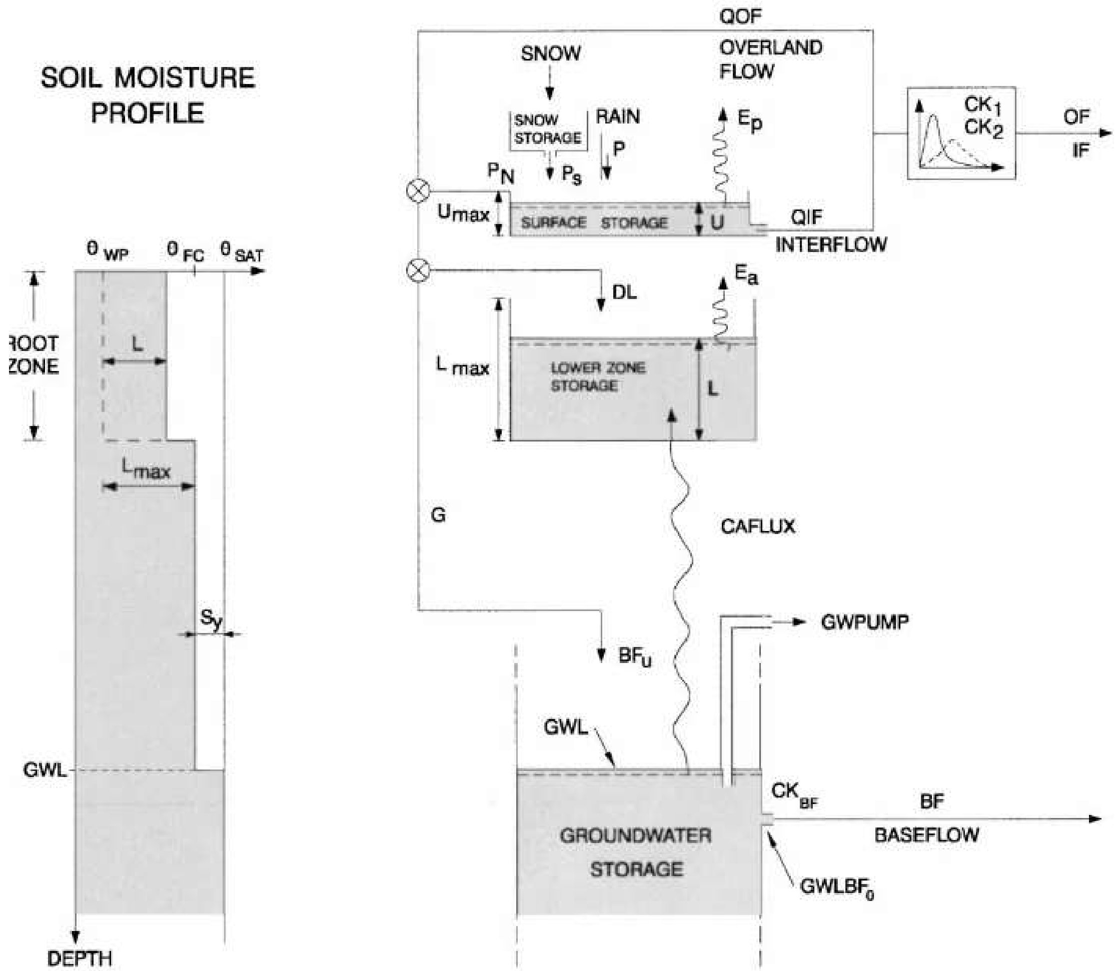
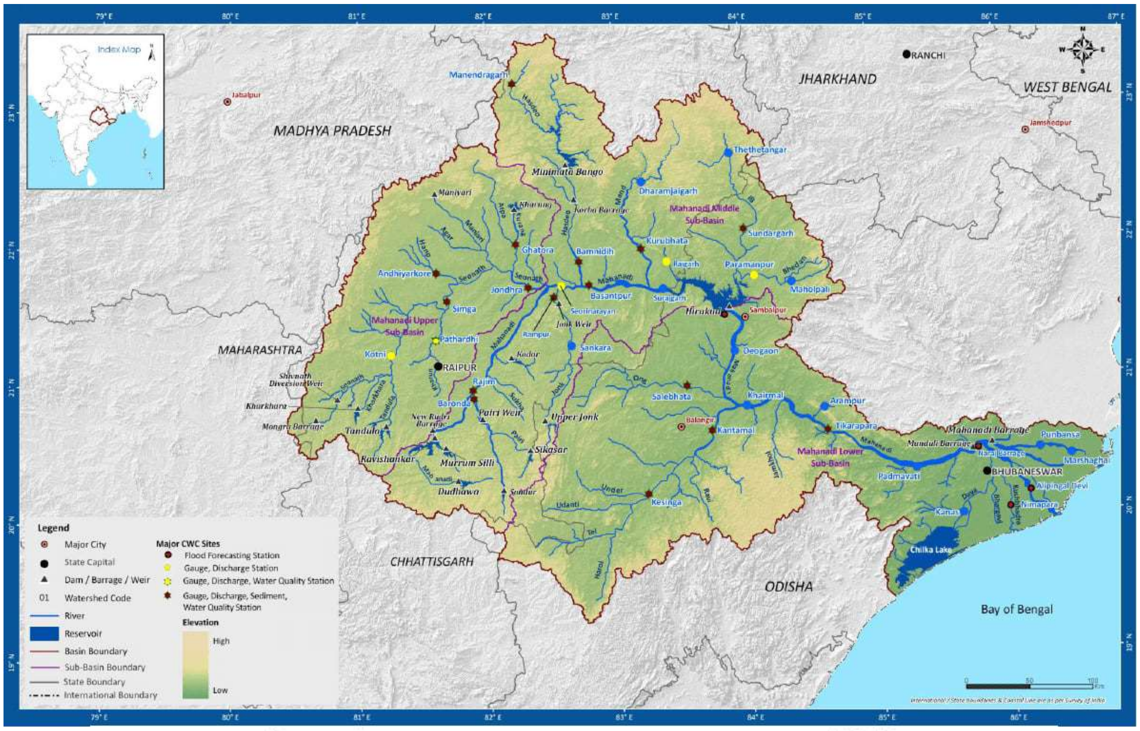
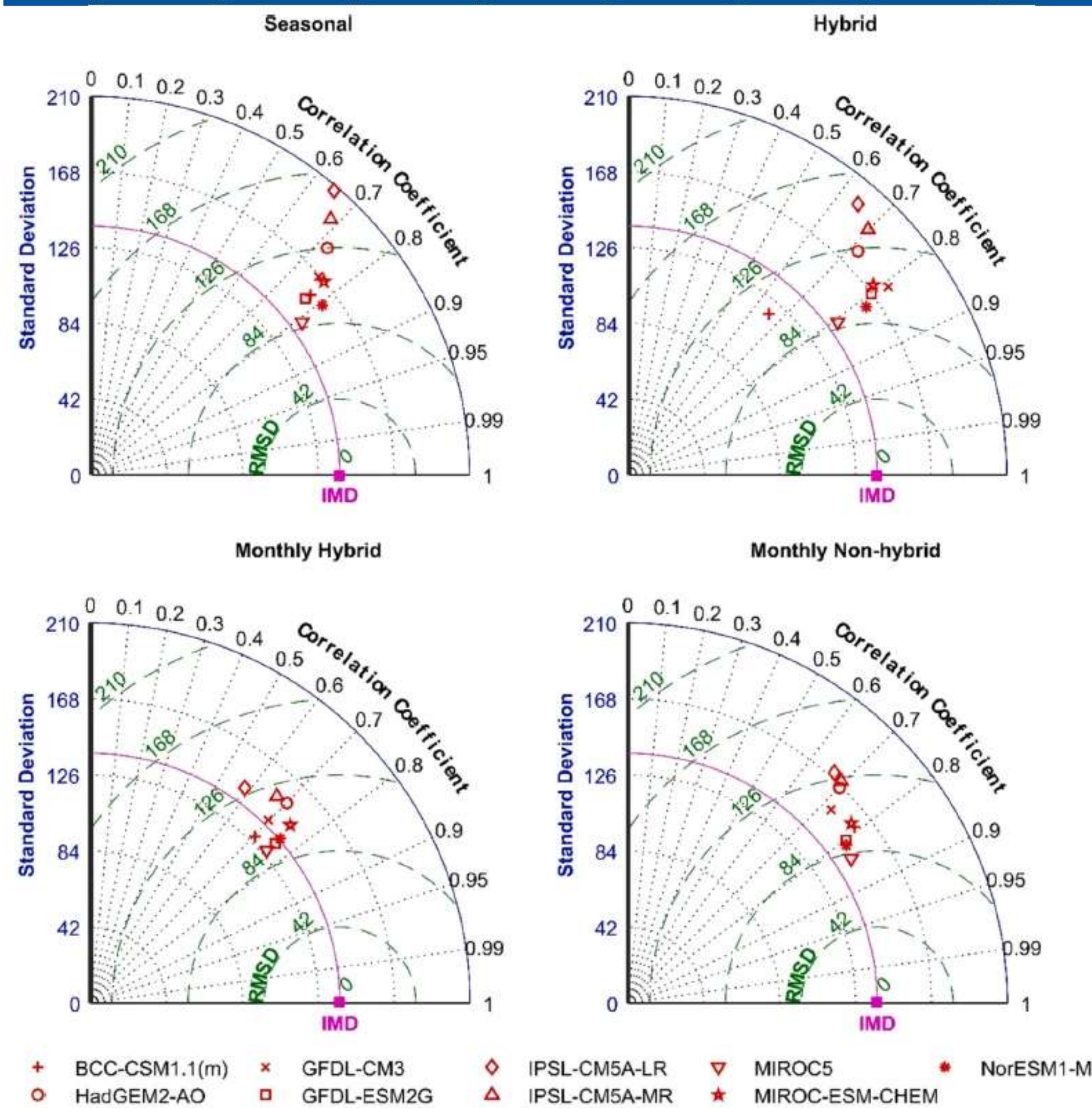
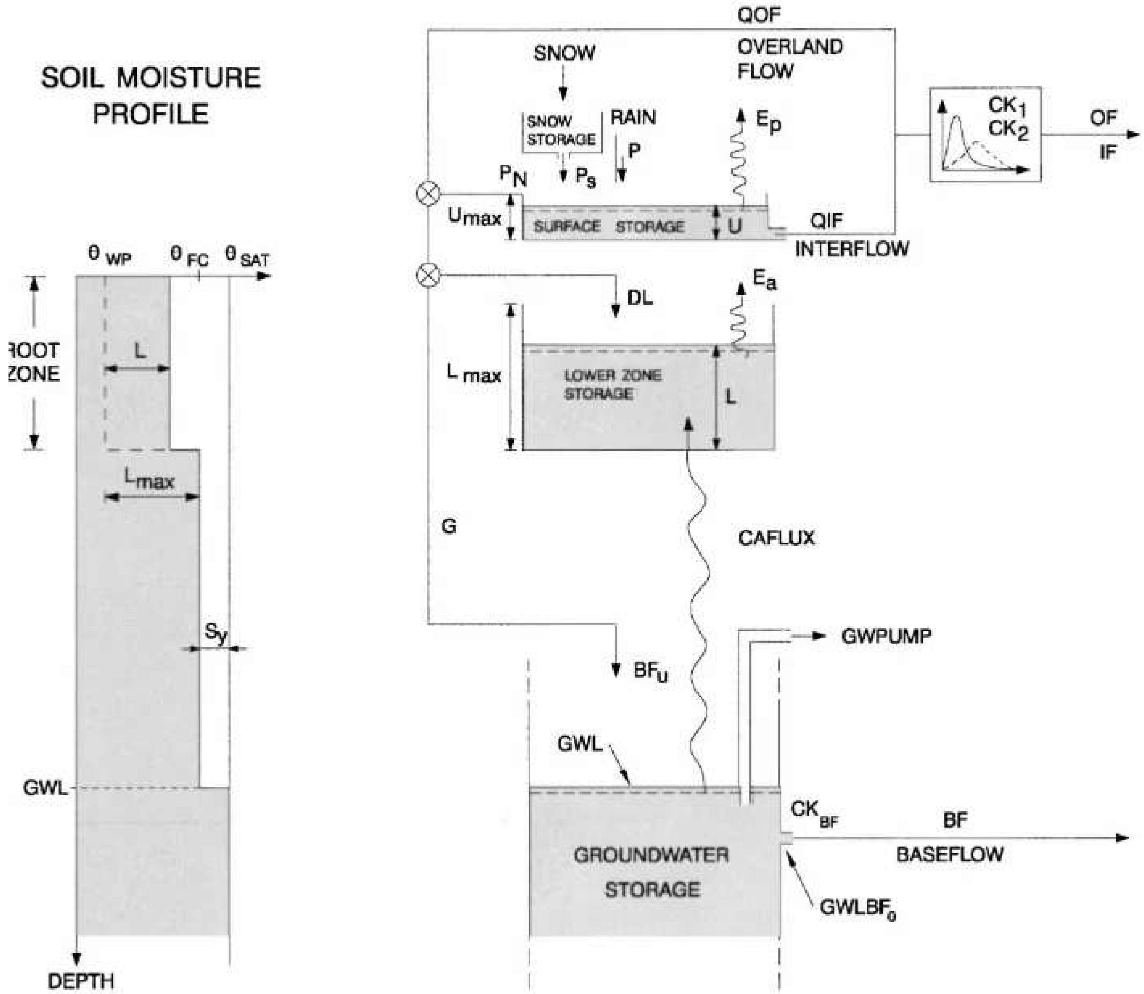


Fig. NAM model structure (Madsen et al., 2000).

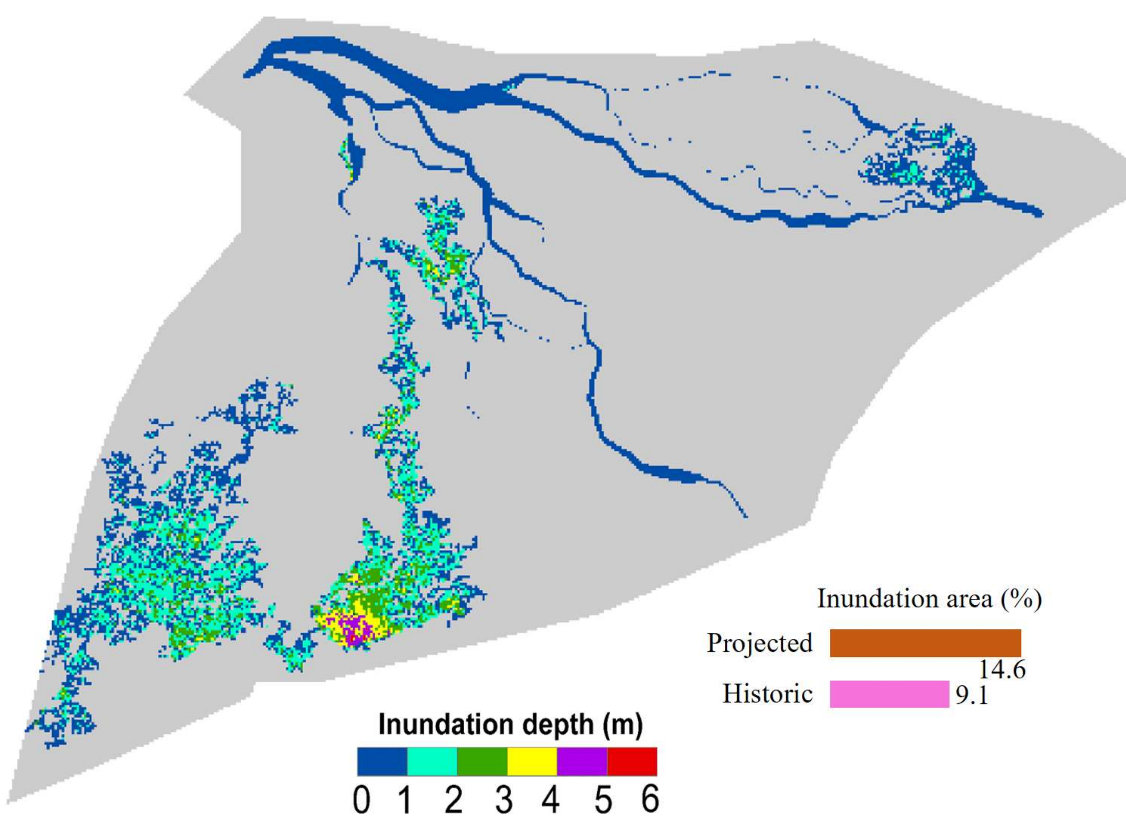
- Simulated streamflows at the head of delta and gridded rainfall in the delta region was used to simulate the inundation depth and extent in the year 2000 and 2080 using MIKE FLOOD model.


MADHYA PRADESH
JHARKHAND
WEST BENGAL
MAHARASHTRA
CHHATTISGARH
ODISHA
Bay of Bengal
RANCHI
RAIPUR
BHUBANESWAR
Mahanadi Upper Sub-Basin
Mahanadi Middle Sub-Basin
Mahanadi Lower Sub-Basin
Chilka Lake
Legend
Major City
State Capital
Dam / Barrage / Weir
Watershed Code
River
Reservoir
Basin Boundary
Sub-Basin Boundary
State Boundary
International Boundary
Major CWC Sites
Flood Forecasting Station
Gauge, Discharge Station
Gauge, Discharge, Water Quality Station
Gauge, Discharge, Sediment, Water Quality Station
Elevation
High
Low


Seasonal
Hybrid
Monthly Hybrid
Monthly Non-hybrid
Standard Deviation
Correlation Coefficient
RMSD
IMD
0
42
84
126
168
210
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.95
0.99
1
BCC-CSM1.1(m)
GFDL-CM3
IPSL-CM5A-LR
MIROC5
NorESM1-M
HadGEM2-AO
GFDL-ESM2G
IPSL-CM5A-MR
MIROC-ESM-CHEM



SOIL MOISTURE PROFILE
θ WP
θ FC
θ SAT
OOT
ZONE
L
Lmax
Sy
GWL
DEPTH
QOF
SNOW
OVERLAND FLOW
SNOW STORAGE
RAIN
Ep
P
PN
Ps
Umax
SURFACE STORAGE
U
QIF
INTERFLOW
CK1
CK2
OF
IF
DL
Ea
L max
LOWER ZONE STORAGE
L
G
CAFLUX
GWPUMP
BFu
GWL
CKBF
BF
BASEFLOW
GROUNDWATER STORAGE
GWLBF0



Inundation area (%)
Projected
14.6
Historic
9.1
Inundation depth (m)
0 1 2 3 4 5 6

DISCUSSION

Results

- Increased compound floods in the year 2080 both in terms of areal extent and flooding depth.
- Streamflows are the major contributor of compound floods as compared to rainfall.

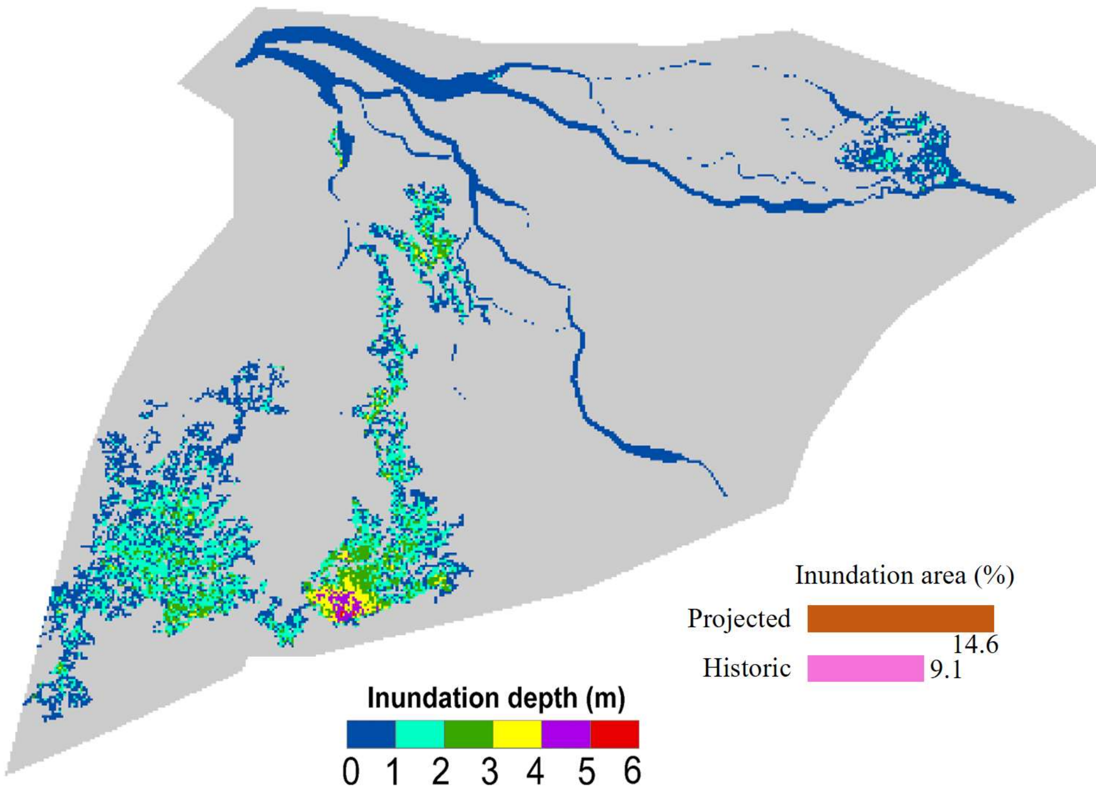


Fig. Maximum projected flood inundation extent and depth.

What's next?

- Compare historical and projected floods based on return periods (the traditional way of analysing climate-change impacts on floods).
- Compare the results with that obtained from only one year (2080) future flood simulations.

What's the take home message?

- Floods occurred due to individual driver might not be extreme, but it will behave differently when modulated by multiple drivers (as a compound case).
- Hence, compound floods needs to be analysed to aid policymakers in developing future flood management and adaptation strategies.

References

- Bisht DS, Mohite AR, Pratyasha P, Khatun A, Chatterjee C, Raghuwanshi NS, Singh R, Sahoo B. 2020. Impact of climate change on streamflow regime of a large Indian river basin using a novel monthly hybrid bias correction technique and a conceptual modeling framework. *Journal of Hydrology* **590** DOI: 10.1016/j.jhydrol.2020.125448
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Broad Area of Research: Impact of climate change on floods

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