Water Budget Estimation of the Ganges-Brahmaputra Basin Using Remote Sensing and Land Data Assimilation System Results Conclusions

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Abstract

Monitoring the various water cycle components are instrumental in ecological preservation, disaster preparedness, and achieving sustainable water resource management. Remote sensing observations, along with Land Data Assimilation System-derived information, can aid in investigating individual components and processes within the water cycle to characterize spatiotemporal patterns in the change in water availability in large river basins. The Ganges- Brahmaputra, one of the world's largest and most densely populated river basins, covering parts of India, Bangladesh, Nepal, Bhutan, and China, yet poorly gauged for water monitoring, is the area of interest for this case study focusing on estimates of precipitation, evapotranspiration, change in terrestrial water storage, and storm surface runoff from satellite-based NASA GPM (IMERG), NASA MODIS, and NASA GRACE/GRACE FO observations, and GLDAS Catchment Land Surface Model simulations. Data on each water cycle component was analyzed to approximate the total water budget on a sub-basin level. Intra-annual (wet and dry seasons) and inter-annual variability were also quantified for the years 2004-2005, 2009-2010, 2014-2015, and 2019-2020 for the entire Ganges-Brahmaputra basin. Variation in the water budgets, as estimated in billions of cubic meters (BCM) over the analyzed time period, indicates the extent of water stress, drought severity, and flood occurrence in this study area where annual rainfall patterns are predominantly governed by the wet season (i.e., monsoon). The uncertainty of the estimates leading to the inability to close the water balance equation is possibly due to the limitations in satellite observations/model simulations and human activities (e.g., stream flow, irrigation, groundwater pumping, diversion).

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Introduction

Monitoring the various water cycle components is instrumental in ecological preservation, disaster preparedness, and achieving sustainable water resource management. Remote sensing observations, along with Global Land Data Assimilation System- (GLDAS-) derived information, can aid in investigating individual components and processes within the water cycle to characterize spatiotemporal patterns in the change in water availability in large river basins.

The Ganges-Brahmaputra, one of the world's largest and most densely populated river basins, covering parts of India, Bangladesh, Nepal, Bhutan, and China, yet poorly gauged for water monitoring, is the area of interest for this case study. The focus here is on estimates of precipitation, evapotranspiration, change in terrestrial water storage, and storm surface runoff from satellite-based data and model simulations.

Data on each water cycle component have been analyzed to approximate the total water budget on a sub-basin level.

Data and Methods

The water-budget equation for a watershed is:

Precipitation = Evapotranspiration + Change in water storage + Runoff

The following data are used for the estimation of water budget:

- Vectorized polygons at 15 arc-second resolution depicting sub-basin boundaries: HydroBASINS layer for the Asian continent, at level 04 – Source: HydroSHEDS
- Remote sensing (RS) data:

Parameter	Satellite	Product	Spatial & Temporal Resolution	Acquisition
Precipitation	Combined TRMM and GPM Precipitation	Integrated Multi-satellitE Retrievals for GPM (IMERG)	0.1° x 0.1° Monthly	Giovanni
Evapotranspiration	Terra and Aqua MODIS	MOD16A2	500 m 8-Daily	Google Earth Engine
Terrestrial Water Storage Change	GRACE	JPL TELLUS GRACE Level-3 Monthly Land Water-Equivalent-Thickness Surface Mass Anomaly	1° x 1° Monthly	NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC)
	GRACE-FO	JPL TELLUS GRACE-FO Level-3 Monthly Land Water-Equivalent-Thickness Surface Mass Anomaly		

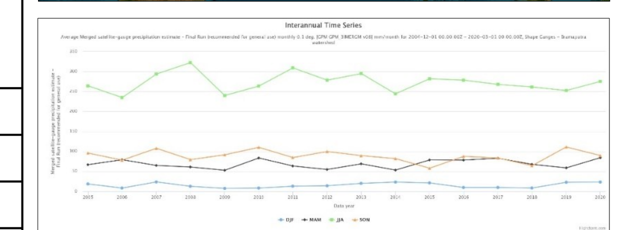
- Global Land Data Assimilation System (GLDAS) data:

Model	Parameter	Spatial Resolution	Acquisition
GLDAS Noah Land Surface Model L4	Precipitation	0.25° x 0.25° Monthly	Goddard Earth Sciences Data and Information Services Center (GES DISC)
	Evapotranspiration		
	Surface Runoff		
	Terrestrial Water Storage		

- Data of each water cycle component were accumulated according to the wet and dry seasons, December-January-February (DJF) and June-July-August (JJA) respectively, for the years 2005, 2010, 2015, and 2020.
- For calculating the basin level water budget components, data were:
  - ❑ spatially averaged by sub-basins
  - ❑ with spatially averaged values multiplied by the sub-basin area
  - ❑ and all the results at the sub-basin level accumulated to obtain basin level results in billion cubic meters (BCM)

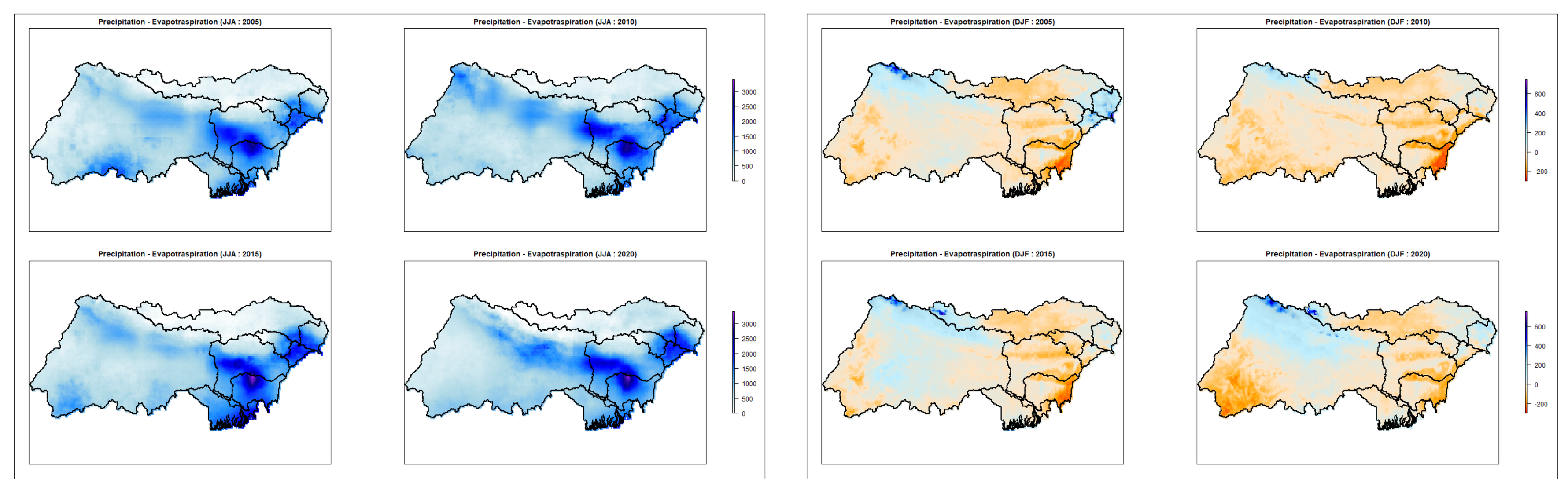
Study Area

Sub-basin	Area covered	Area (sq. km)
1	Dhaka division (Bangladesh)	4,353
2	Dhaka and Sylhet division (Bangladesh), Meghalaya, Tripura, and Mizoram (India)	85,201
3	Rajshahi division and all of northern Bangladesh, northern West Bengal (India), all of Sikkim (India) and Bhutan, parts of Assam and Nagaland (India)	185,684
4	Nepal and Uttarakhand, Delhi, Rajasthan, Madhya Pradesh, Uttar Pradesh, Chhattisgarh, Jharkhand, and Bihar (India)	959,458
5	Arunachal Pradesh (India)	22,729
6	Arunachal Pradesh (India)	34,214
7	Arunachal Pradesh (India)	41,857
8	Parts of Tibet (China)	256,166
9	Khulna and Barishal divisions (Bangladesh) and West Bengal (India)	78,436
10	Northern part of Chittagong division (Bangladesh) and Tripura (India)	10,040

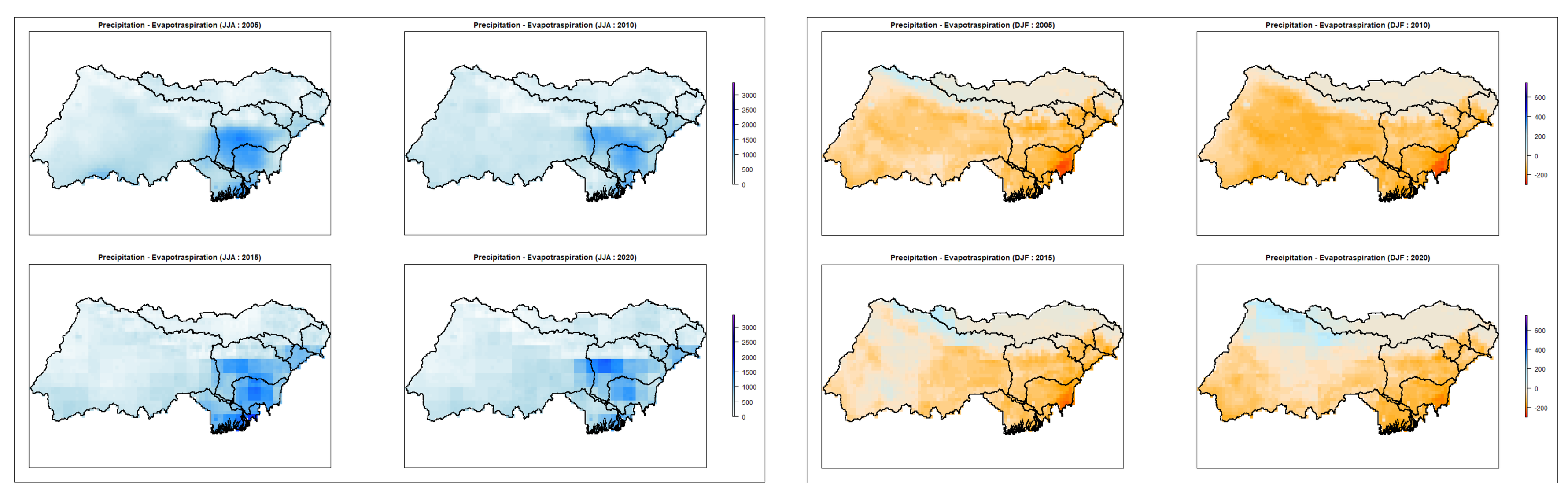


Greatest rainfall: June-July-August; least in December-January-February

Results

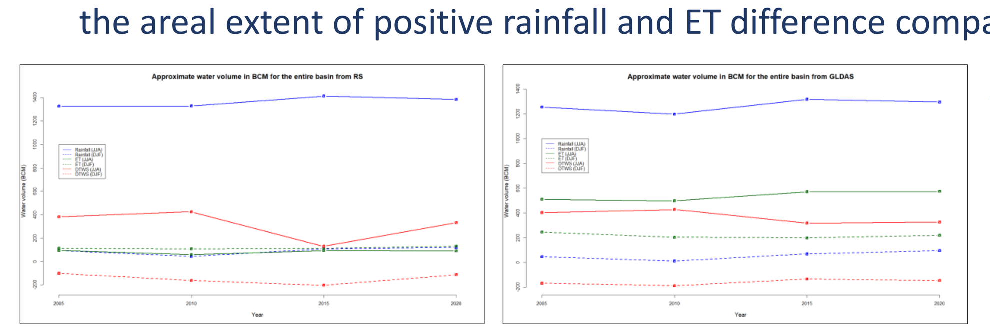


Rainfall – Evapotranspiration (mm) for wet season (left) and dry season (right): Remote sensing observations



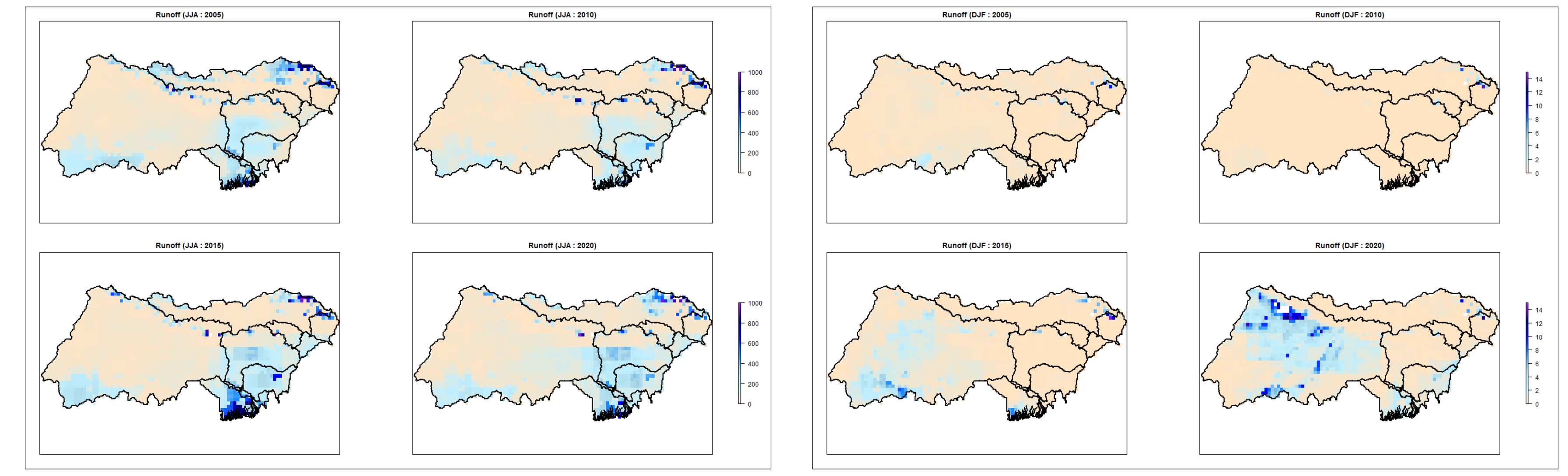
Rainfall – Evapotranspiration (mm) for wet season (left) and dry season (right): GLDAS estimation

- For all the years (both RS and GLDAS), during the wet season, the maximum differences between rainfall and Evapotranspiration (ET) are pronounced in Meghalaya, India, the wettest place on earth.
- Difference between rainfall and ET reached the maximum in significant areas of the Indian northeast and southern Bangladesh in 2015, with a slight decrease in 2020.
- 2010 was marked for receiving the least dry season rainfall, and it was evident from a significant decrease in the areal extent of positive rainfall and ET difference compared to other years.

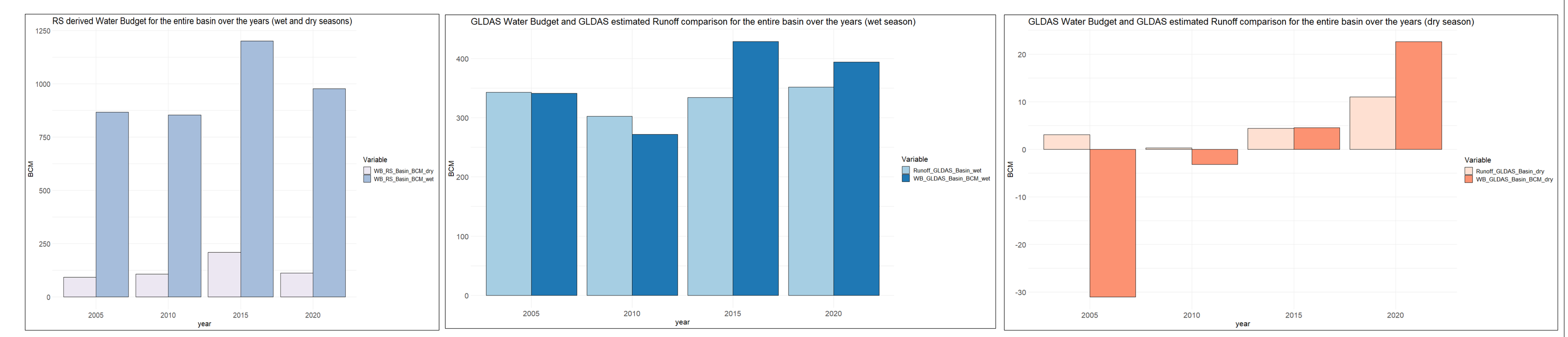


The basin-level totals in BCM of water volume of each component of the hydrologic cycle matched well for RS and GLDAS estimations except for ET, for which the dry season ET was significantly underestimated by RS.

Results



Runoff (mm) for wet season (left) and dry season (right): GLDAS estimation



Wet and dry season water budgets (basin totals in BCM) and comparison with GLDAS estimated runoff volume

- RS and GLDAS show similar patterns of water budget estimation (rainfall – ET – change in total surface water storage). There are differences in magnitude due to the varying estimates of ET by the MODIS satellite and the GLDAS model.
- The dry seasons of 2015 and 2020 were relatively wetter than 2005 and 2010 and this fact was more established by the significant increase in dry season runoff and the transition of negative to positive water budgets (GLDAS), along with the increase in magnitude of the positive water budget (RS). The dry season decreased in ET and change in total water storage (DTWS) for both 2005 to 2010 and 2015 to 2020.
- The maximum value of wet season water budget in 2015 (both RS and GLDAS) was the result of temporally maximum rainfall received by the entire basin and at the same time, the considerable decrease in change in total water storage. This low value of DTWS is attributed to the great amount of rainfall received during the previous three months (March-April-May), which is evident from the interannual basin averaged rainfall time series for different seasons in the year.
- From GLDAS estimation, the dry season runoff varied more when compared to wet season runoff. This change was reflected throughout the regions of sub-basin 04.

Conclusions

- ET is the most uncertain parameter. Water budget can be underestimated substantially due to the overestimation of ET.
- Variation in the water budgets, as estimated in billions of cubic meters (BCM) over the analyzed time period may provide an indication of the extent of water stress, drought severity, and flood occurrence in this study area.
- The uncertainty of the estimates leading to the inability to close the water balance equation is possibly due to the limitations in satellite observations/model simulations and human activities (e.g., stream flow, irrigation, groundwater pumping, diversion).

References

1. Singha, C., & Swain, K. C. (2021). Using earth observations and GLDAS model to monitor water budgets for river basin management. *In Advanced Modelling and Innovations in Water Resources Engineering: Select Proceedings of AMIWRE 2021* (pp. 493-515). Springer Singapore.

2. ARSET - Using earth observations to monitor water budgets for river basin management II (https://appliedsciences.nasa.gov/get-involved/training/english/arset-using-earth-observations-monitor-water-budgets-river-basin)

Acknowledgments

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