INITIATIVE ON Asian Mega-Deltas

Leveraging Satellite-based Evapotranspiration Monitoring to Unlock Agricultural Water Use Insights in the Ganges and Mekong Deltas

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Introduction

Effective water resource management is critical to addressing the dual challenges of food security and sustainable development, particularly in water-scarce regions heavily reliant on agriculture (Rosegrant et al., 2009). Evapotranspiration (ET), representing the combined processes of water evaporation and plant transpiration, is a key hydrological variable that significantly influences agricultural productivity and water balance. Approximately 60% of terrestrial precipitation returns to the atmosphere via ET, making it a crucial parameter in understanding water cycle dynamics.

Despite its importance, consistent and spatially extensive ET data have historically been challenging to obtain due to limitations in traditional monitoring methods. Recent advances in remote sensing technologies and modeling approaches, such as the Surface Energy Balance Algorithm for Land (SEBAL), have revolutionized ET estimation across large geographic areas and extended time frames. SEBAL uses satellite imagery and meteorological data to solve energy balance equations, providing robust estimates of ET with high spatial and temporal resolution.

The development of satellite-based ET datasets, mainly through platforms like Google Earth Engine (GEE), has significantly enhanced the scalability and accessibility of ET monitoring. By integrating Landsat imagery with meteorological inputs such as ERA5 data, these models enable comprehensive analyses of long-term trends in ET. From 2014 to 2023, a decade-long dataset of monthly ET was generated for these deltas using Landsat data and the SEBAL model. These deltas are among the world's most productive agricultural areas but are increasingly vulnerable to climate variability and land use changes. Monitoring ET trends provides critical insights into agricultural water use, helping to identify inefficiencies and inform adaptive water management strategies. The derived ET data can also support broader applications such as irrigation planning, drought risk assessment, and validation of hydrological models.

By documenting this work, we aim to underscore the utility of satellite-based ET monitoring as a cornerstone for sustainable agricultural practices and resilient water management systems in deltas and beyond. This initiative aligns with the global push for data-driven decision-making to optimize resource use amidst growing environmental and socio-economic challenges.

Ganges and Mekong Deltas

Our research focuses on two of the world's largest and most agriculturally significant delta systems: the Mekong Delta and the Ganges Delta (Figure 1). Both regions are critical for food security and livelihoods, supporting millions while facing increasing pressures from climate change, population growth, and resource overuse.

Located in Southeast Asia, primarily within Vietnam and parts of Cambodia, the Mekong Delta is often called the 'Rice Bowl' of Vietnam. It produces over 50% of the country's rice, a staple crop for domestic consumption and export. The delta spans approximately 40,000 km^2 and features a complex network of rivers, canals, and floodplains. In addition to rice cultivation, the region is vital for aquaculture, contributing significantly to shrimp and fish farming industries (Sithirith et al., 2024). The Mekong Delta faces significant challenges, including saltwater intrusion, land subsidence, and sea-level rise, which threaten agricultural productivity (Loc et al., 2021; Matheswaran et al., 2023). The region's seasonal climate is characterized by distinct wet and dry periods, heavy rainfall during the monsoon season, and prolonged dry spells. These conditions influence ET patterns, making consistent monitoring crucial for managing water resources effectively.

The Ganges Delta, spanning parts of Bangladesh and India (primarily West Bengal), is the world's largest delta system, covering over 100,000 square kilometers. Formed by the convergence of the Ganges, Brahmaputra, and Meghna rivers, it is renowned for its fertile alluvial soils. The delta supports extensive rice cultivation and serves as a hub for aquaculture. The region is critical for water resources, providing millions of people with irrigation and domestic water supply. However, it is increasingly vulnerable to challenges such as groundwater depletion, frequent flooding, and changing precipitation patterns due to climate change (Murshed and Kaluarachchi, 2018; Jampani et al., 2023). The Sundarbans mangrove forest, a UNESCO

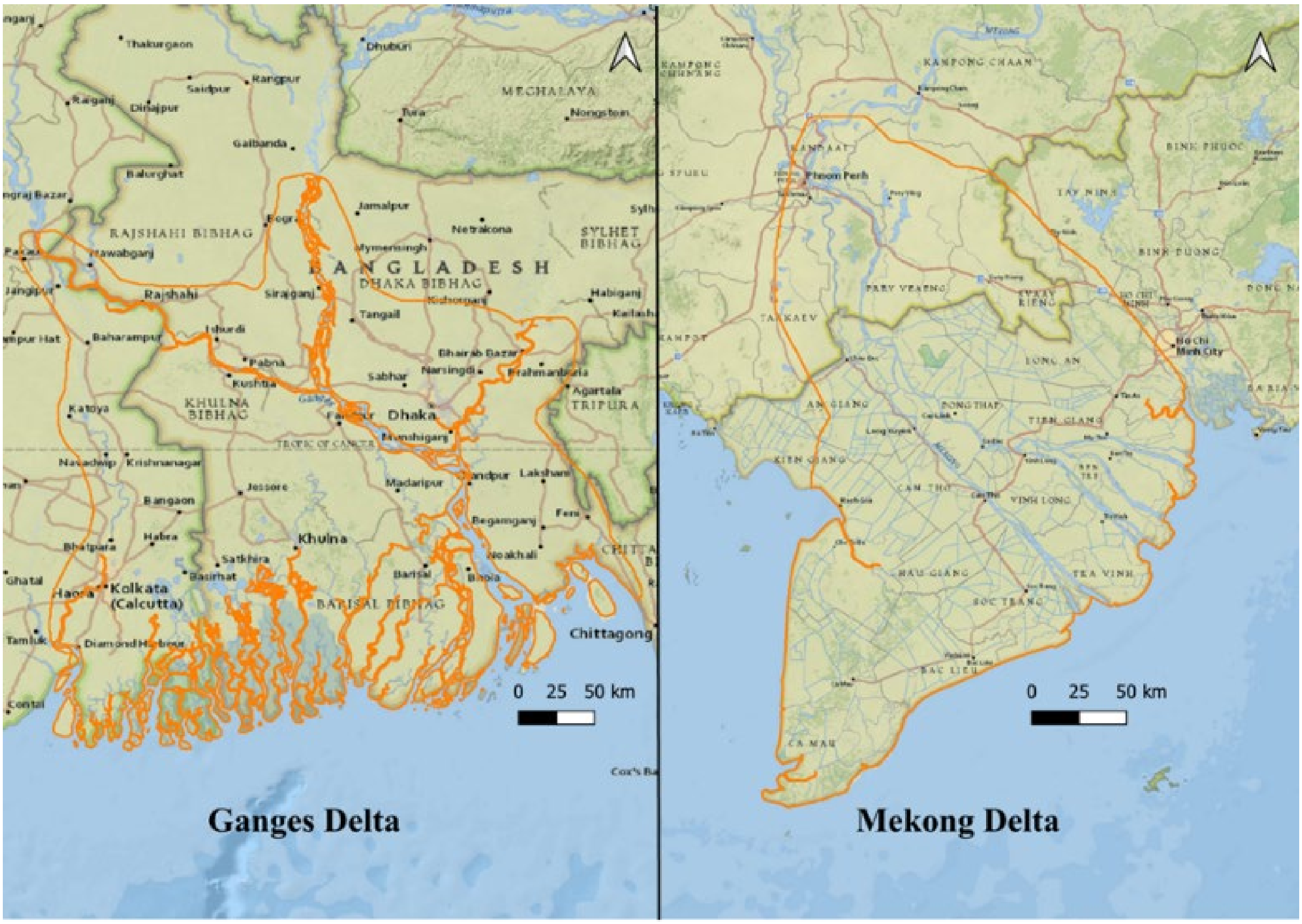

Figure 1. Location and geospatial view of the Ganges and Mekong Deltas.

World Heritage site within the delta, plays a vital role in biodiversity conservation and climate regulation but is also under threat.

Both deltas are highly dynamic systems where water availability, land use, and climate interact in complex ways. Monitoring ET in these regions is essential to understanding and managing their agricultural water use, particularly under the dual pressures of rising food demand and environmental stressors. This study provides a decade-long dataset of satellite-derived monthly ET, offering valuable insights for sustainable water resource management in these critical landscapes.

Methodology

The dataset was primarily developed using the updated version of the SEBAL model implemented in Google Earth Engine (GEE) by Laipelt et al., 2021 to derive actual monthly evapotranspiration (ET_a) estimates. The GEE SEBAL is based on the SEBAL model, a remote sensing-based model that calculates ET using satellite imagery and meteorological inputs, solving the surface energy balance equation (Gonçalves et al., 2022). SEBAL is based on estimating latent heat (LE) as a residual of the instantaneous surface energy balance equation (equation 1) based on thermal and multispectral remote sensing datasets.

$$LE = Rn - H + G \qquad \text{Equation 1}$$

Where LE is the latent heat flux, representing evapotranspiration (W/m^2); Rn is the net radiation flux at the surface (W/m^2); G is the soil heat flux (W/m^2); H is the sensible heat flux (W/m^2).

The key datasets needed for ET_a estimation by GEE SEBAL consisting of Landsat 8 ad 9, ERA 5 Land reanalysis data for meteorological inputs, and the Digital Elevation Model (DEM) for the model domain were all available within the GEE platform. However, the publicly available model from Laipelt et al., 2021 used a deprecated version of Landsat surface reflectance data, which was updated to use the updated version of Landsat 8 and 9 surface reflectance data in the GEE. The detailed workflow to derive ET_a from GEE SEBAL is provided in Laipelt et al. (2021). The GEE SEBAL produced scene-based ET_a for the dates on which Landsat data was available from 2014 to 2023. Since both the Ganges and Mekong Deltas are in the monsoonal climate, a significant number of Landsat images are affected by cloud cover. The cloud removal module within GEE SEBAL removed the area covered by the clouds. The resultant ET_a outputs with gaps were then subjected to a spatio-temporal interpolation process in Geographic Resources Analysis Support System (GRASS) geographic information system software based on the methodology followed by Pareeth and Karimi (2024). The interpolated daily ET_a images were then aggregated to monthly ET_a directly within GRASS.

This methodology leverages remote sensing's scalability and GEE's computational efficiency, providing robust and replicable ET estimates (Matheswaran et al., 2023). The approach also underscores the value of integrating satellite data with meteorological reanalysis for large-scale water resource assessments in data-scarce regions.

Dataset description

The GEE SEBAL model was run for 2168 images from Landsat 8 and Landsat 9 over the Ganges and Mekong Delta, covering six individual tiles each from 2014 to 2023. The monthly ET_a dataset covers the entire Mekong and Ganges deltas at 30 m resolution on a public data server (Puvanenthirarajah and Matheswaran, 2025). The dataset will be updated annually in December as new input data from Landsat 8 and 9 and ERA5-Land meteorological data become available. The monthly ET_a dataset is provided as a compressed GEOTIFF with the filenames following the structure YYYY-MM, in which the YYYY represents the year and MM represents the month corresponding to ET_a. The monthly ET_a data from 2014 to 2023 for ten years were archived separately in two zip files, namely Ganges_ET_a_2014 to 2023 and Mekong_ET_a_2014 to 2023.

The aggregated ET_a datasets for the Ganges delta (Figure 2) represent the long-term monthly average from 2014 to 2023. The temporal ET_a patterns are consistent with the overall evaporative demand, evident from the high ET_a observed in March to May across the entire deltaic region (>150 mm/month), which coincides with the summer season. This is mainly due to high evaporative demand and water availability throughout the year in the deltaic region. By contrast, the peak agricultural season from June to September showed significant spatial variation within each month, with high ET_a values concentrated in agricultural pockets. The monthly ET_a ranges are within the reasonable range as seen in other datasets like WaPOR or GLEAM. Like the long-term average monthly ET_a patterns, yearly ET_a estimates for the Ganges delta were derived by aggregating monthly values, which showed consistent values across the ten-year period for which the datasets were derived. Similar to the Ganges delta's long-term monthly average ET_a values, the Mekong delta showed high ETa values during the summer season from December to May, mainly due to a combination of high evaporative demand and intensive agricultural activity (Figure 3). The monsoon season, which brings most of the rainfall across the Mekong basin from June to November, showed relatively lower monthly ET_a values than the dry season. The datasets revealed that, unlike in interior agricultural landscapes, the Ganges and Mekong deltaic regions showed high crop water consumption in the dry season rather than the primary farming season (Figure 4).

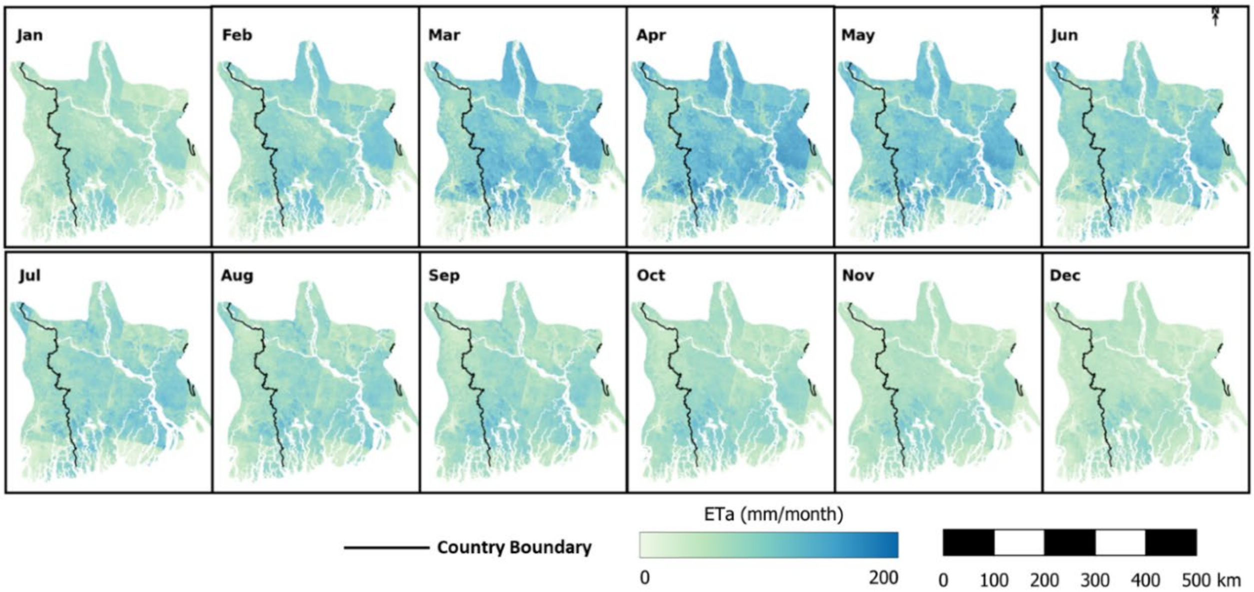

Figure 2: Average monthly ET_a for the Ganges Delta (based on the data from 2014 to 2023).

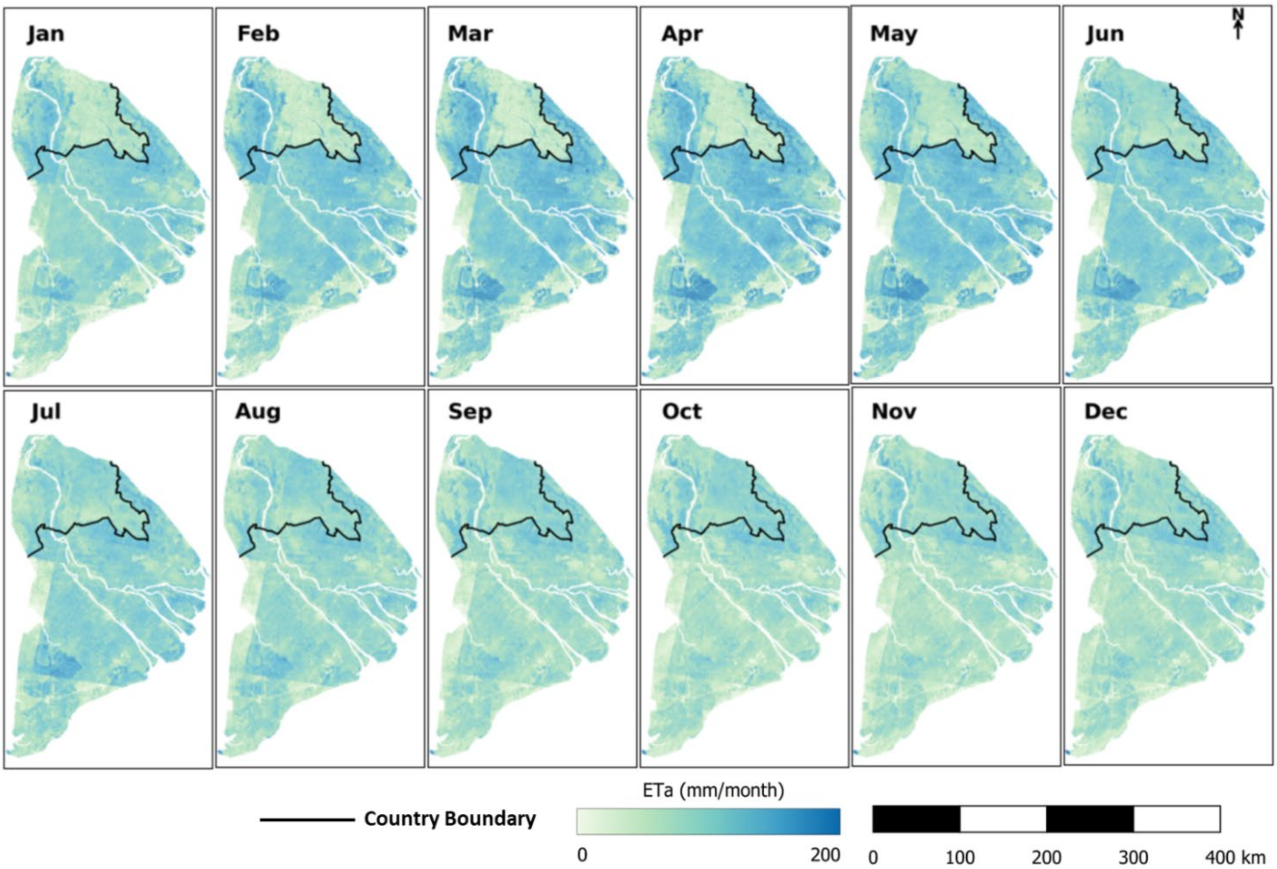

Figure 3. Average monthly ET_a for the Mekong Delta (based on the data from 2014 to 2023).

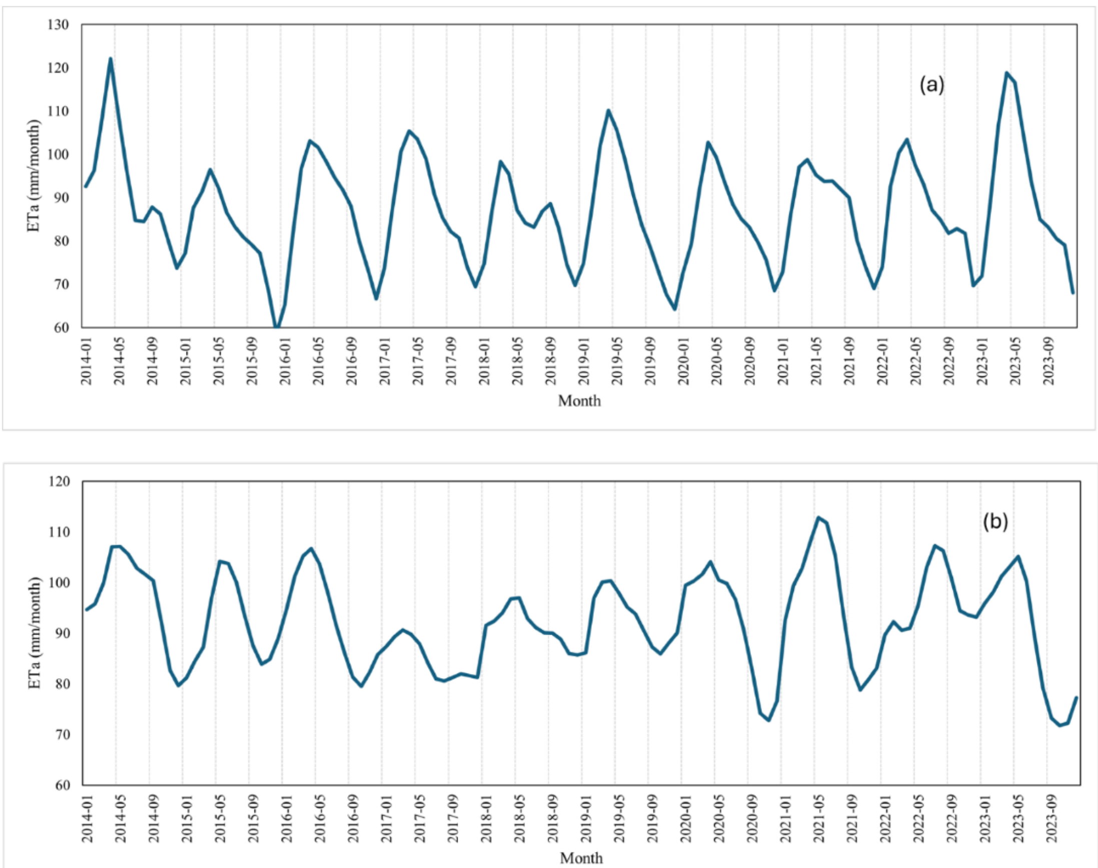

Figure 4. Average monthly ET_a for the (a) Ganges and (b) Mekong Deltas from 2014 to 2023.

Comparison of SEBAL ET_a with WaPOR ET_a

Direct measurements of ET_a are not readily available in the Ganges and Mekong Deltas, and an intercomparison was made with publicly available 100 m WaPOR data. The SEBAL ET_a model's accuracy was assessed by comparing its results with WaPOR ET_a datasets for every pixel on an annual timescale. The results revealed an R^2 value of 0.76 for the Mekong Delta and 0.66 for the Ganges Delta, indicating a strong to moderate correlation (Figure 5). These findings demonstrate that the SEBAL ET_a model performs well in capturing the spatial and temporal variability of ET, particularly in the Mekong Delta. The linear regression analysis highlights a notable agreement between ET_a estimates from SEBAL and WaPOR datasets, further validating the reliability of the SEBAL model for ET assessment in these regions.

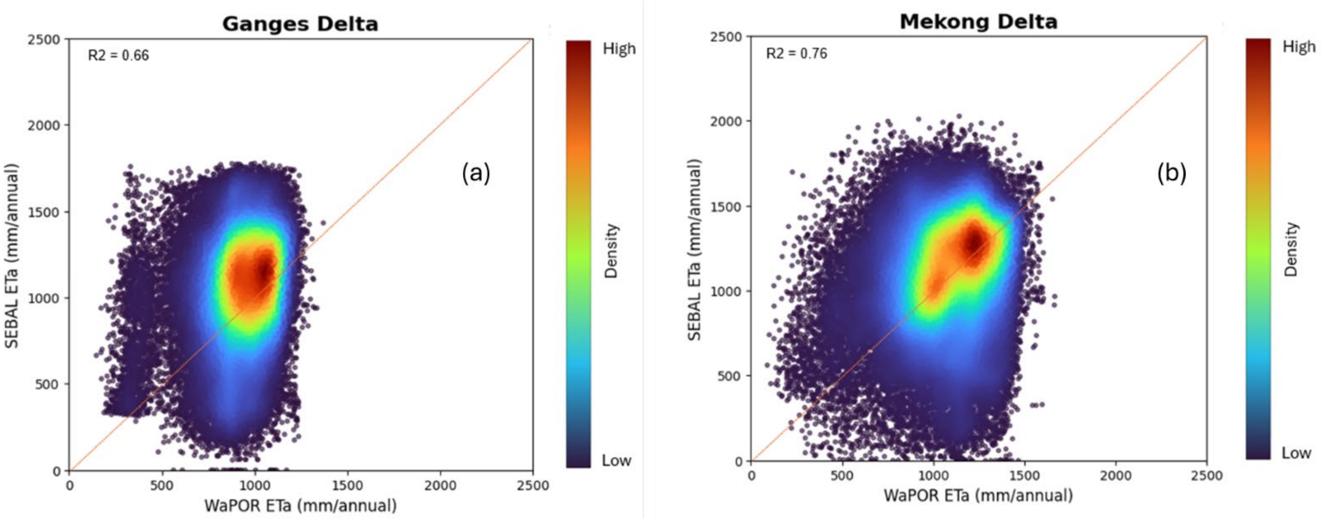

Figure 5. Scatter plot for annual average ET_a in the a) Ganges and b) Mekong Deltas.

Potential applications

The crop water consumption datasets have significant potential for supporting agricultural water management activities in the deltaic region. Forthcoming applications are planned to leverage this dataset.

- Evaluating water use in irrigated systems in the Cambodian part of the Mekong Delta to assess competing water uses for fish refugees.
- Assessing the performance of irrigated systems through productivity indicators to support operational irrigated area management activities in the Mekong Delta.
- Estimating the polder level water use patterns and agricultural production in the Ganges Delta.

Overall, comprehensive calibration and validation of hydrologic models using a combination of discharge and ETa datasets can help water resources planning and management in these deltaic systems.

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CGIAR Initiative on Asian Mega-Deltas

The CGIAR Initiative on Asian Mega-Deltas aims to create resilient, inclusive, and productive deltas that maintain socio-ecological integrity, adapt to climatic and other stressors, and support human prosperity and wellbeing by removing systemic barriers to the scaling of transformative technologies and practices in the community, national and regional levels. https://www.cgiar.org/initiative/asian-mega-deltas/

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Cover photo: Paddy rice fields surrounded by irrigation canals in Mekong Deltas (photo: Dr. Mahesh Jampani)

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