

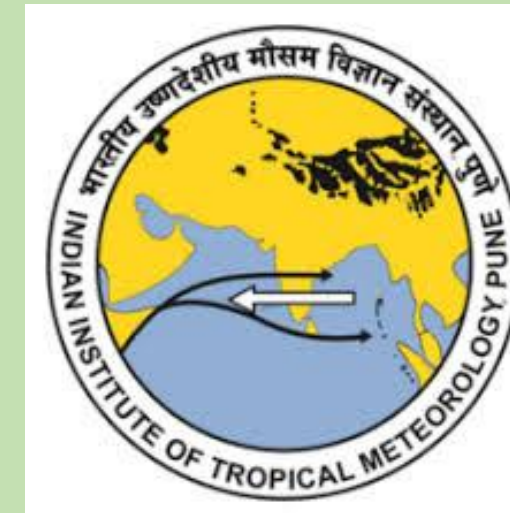


Mapping the Methane Global Models Miss: India's Wetlands at 1 km Resolution

Towards Tracking Wetland Methane Emissions over India Using Multi-Satellite Measurements and Modeling: Part A (Natural Wetlands)

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1 Tracking Wetland CH₄: Why It Matters

- Wetlands are the largest natural CH₄ source, contributing 20–40% of global methane emissions.
- India's wetlands are small, fragmented, and strongly monsoon-driven — poorly captured by coarse global products.
- Global datasets diverge wildly: GLWD reports 35.2 million ha nationally, vs. 6.5 million ha (SAC-ISRO Atlas) and 1.3 million ha (Ramsar) — a >25× spread.
- Indian wetlands remain underrepresented in the global CH₄ budget and are often omitted from national GHG inventories (UNFCCC submissions) for lack of robust methods.

20–40%

of global CH₄ emissions come from wetlands

1 km

resolution — a first for Indian wetlands

2018–23

multi-year observation record

2 Objectives

- Generate high-resolution (1 km) wetland extent maps for India by fusing Sentinel-1, Sentinel-2, and MODIS.
- Estimate wetland CH₄ emissions with a semi-empirical model incorporating heterotrophic respiration, temperature, and precipitation controls.
- Assess spatial, seasonal, and zonal (6-region) variability in wetland extent and emissions.
- Benchmark against Ramsar sites, the SAC-ISRO National Wetland Atlas, GLWD, and independent CH₄ inventories.

3 Methods: Satellite Wetland Mapping

- Fuse Sentinel-1 SAR, Sentinel-2 optical imagery (5 indices — NDWI, MNDWI, NDVI, NDTI, NDMI), and MODIS across six ecological zones.
- Seven index combinations tested; Combination 5 (NDWI+MNDWI+NDVI+NDTI, 2-of-4 rule) gives the most realistic, balanced detection nationwide.

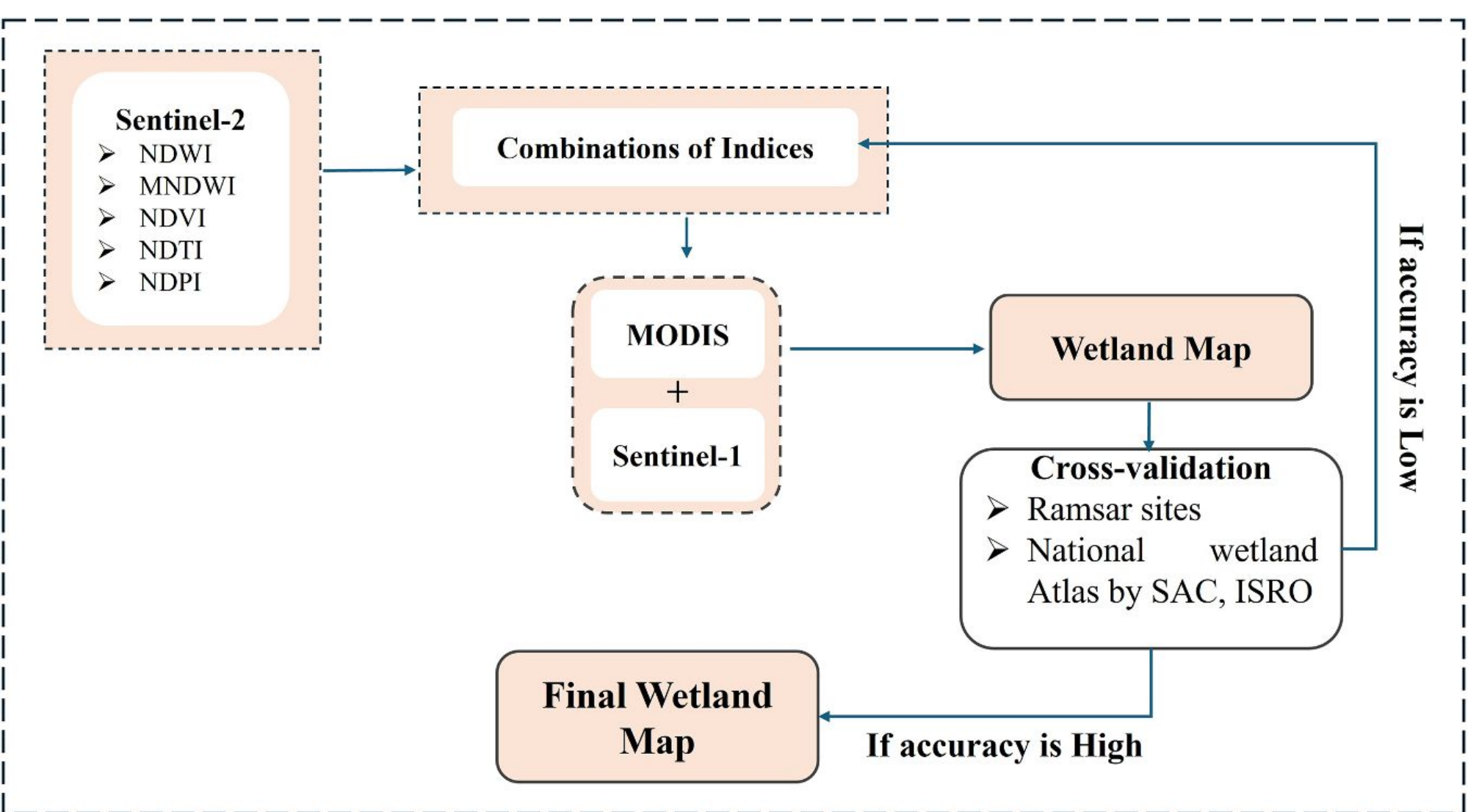


Fig. 1 — Workflow for generating the satellite-derived wetland map.

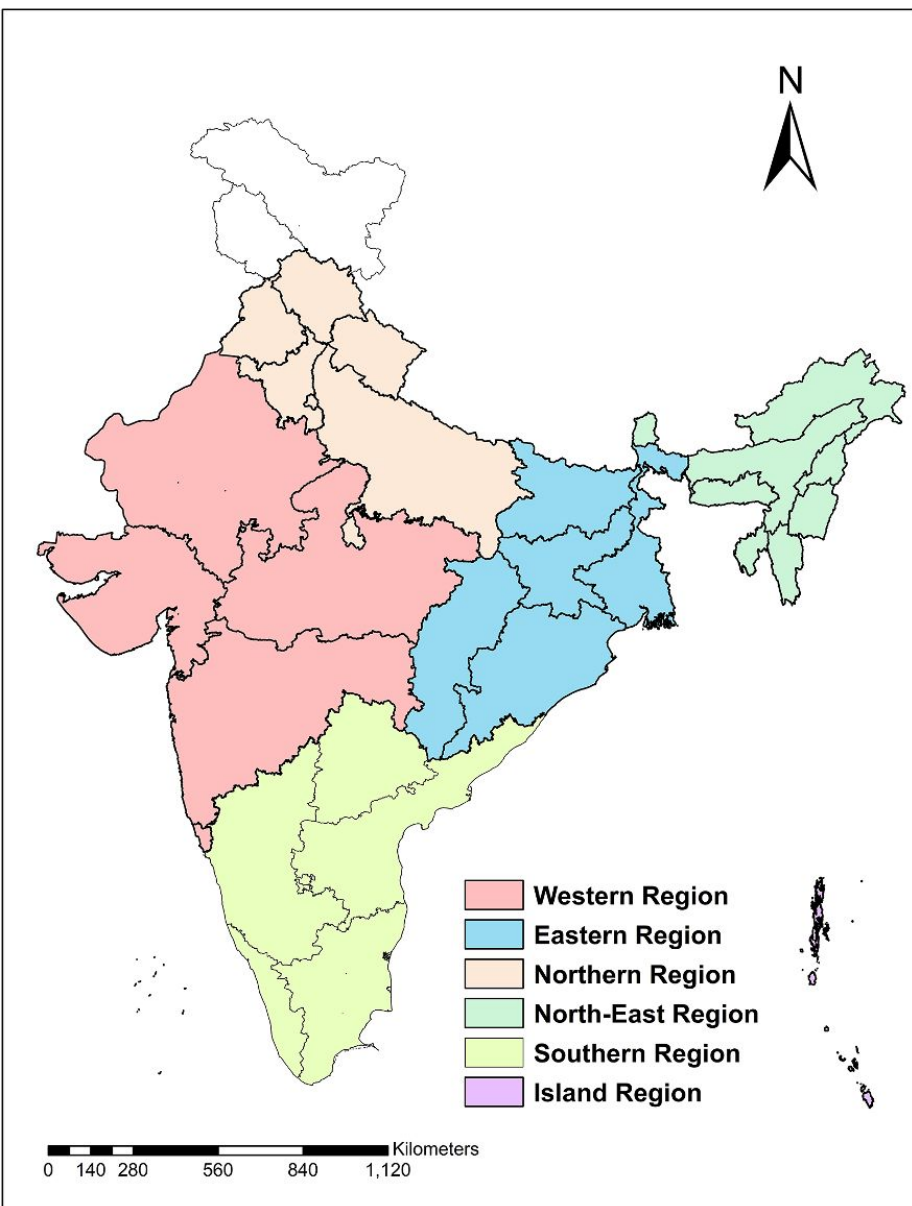


Fig. 2 — Six ecological zones used throughout this study to evaluate classification performance and wetland distribution.

India's wetlands were evaluated across six ecological zones (North, East, West, South, North-East, Islands) to capture their highly uneven distribution. Combination 5 consistently improved detection over earlier combinations in every zone — most strikingly in data-sparse regions such as Assam, Kerala, Goa, and the Islands, where coarser products (GLWD) report little to no wetland area at all.

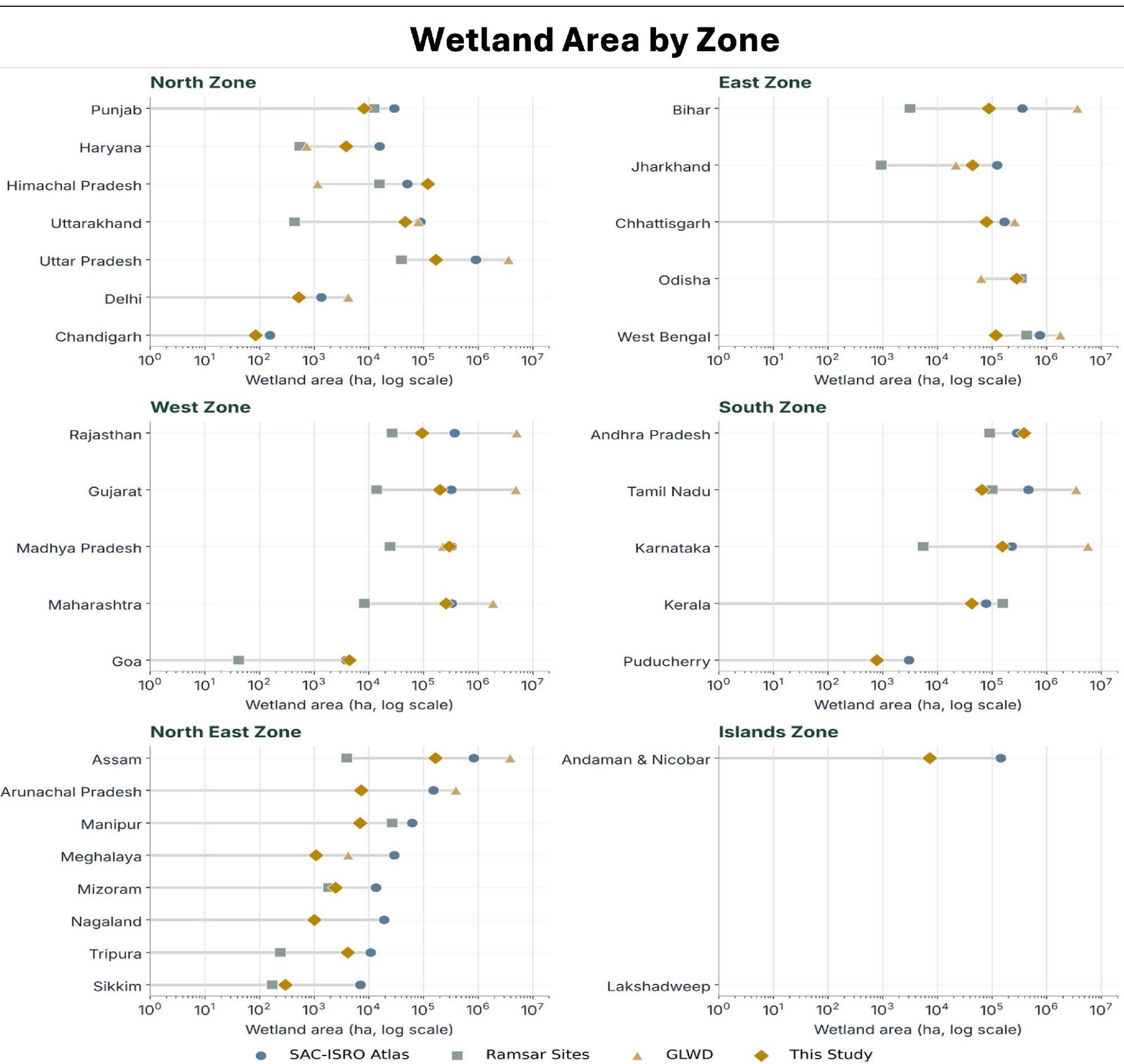


Fig. 3 — Wetland area by zone: SAC-ISRO, Ramsar, GLWD, and all seven tested index combinations, on a log scale.

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4 Emission Model Framework

- Wetland fraction is a weighted blend of Sentinel-2 (0.5), Sentinel-1 (0.25), and MODIS (0.25) detections, further constrained by the GIEMS-MC global inundation dataset.
- CH₄ emission responds to climate through three pathways: temperature-dependent heterotrophic respiration, temperature scaling of CH₄ production, and precipitation-based modulation of wetland activity.
- 18-member ensemble: 3 global scaling factors × 3 temperature dependencies (q10) × 2 wetland-extent representations.

$$E_{CH_4}(x, t) = \alpha \times f_{wet}(x, t) \times R(x, t) \times T_{eff}(x, t) \times P_{eff}(x, t)$$

Governing equation for wetland CH₄ emissions used in this study

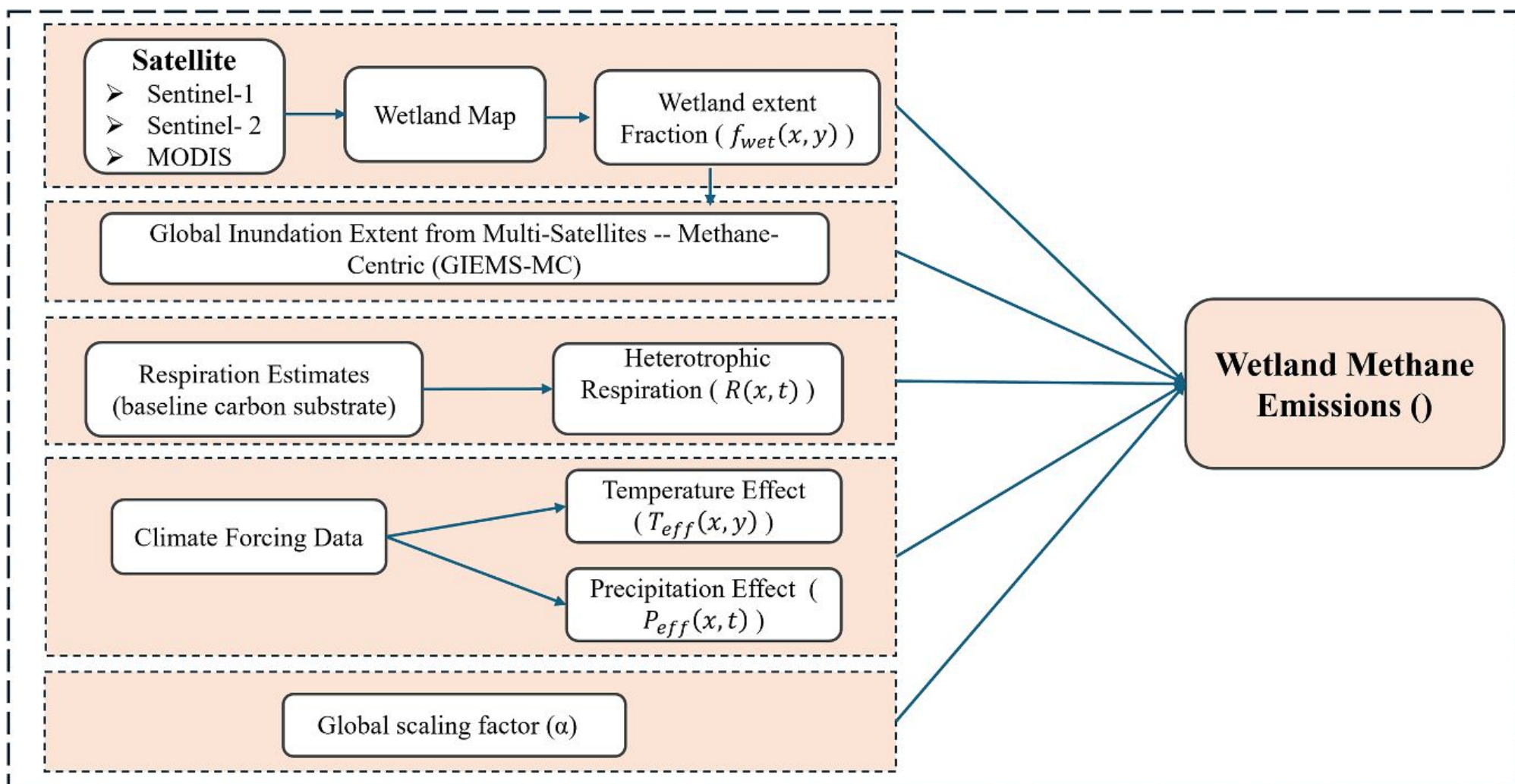


Fig. 4 — Flowchart of the proposed methodology for estimating wetland CH₄ emissions.

5 India's First 1 km Wetland Map (2018–2023)

The map is dominated by the Ganga–Brahmaputra basin, including the Sundarbans mangroves, with substantial additional coverage in the Assam valley, the Mahanadi delta, the Godavari–Krishna estuarine system, and Kerala's backwaters. Numerous smaller clusters — oxbow lakes and fragmented floodplains — appear across central and southern India, features that are typically invisible in global products.

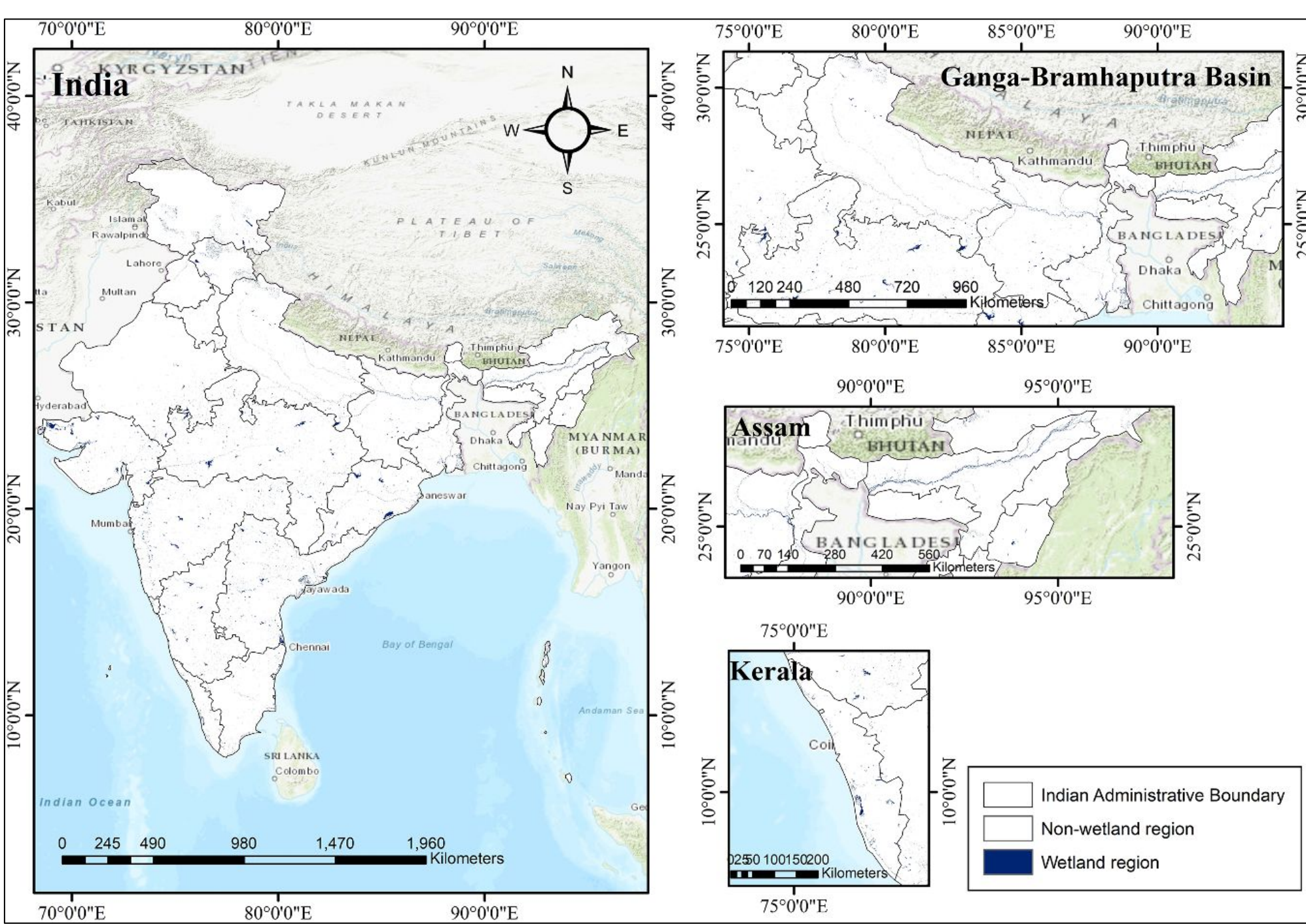


Fig. 5 — Satellite-derived wetland map of India at 1 km resolution, with regional insets for the Ganga–Brahmaputra basin, Assam, and Kerala.

2.65 M ha

THIS STUDY

6.49 M ha

SAC-ISRO ATLAS

1.31 M ha

RAMSAR SITES

35.2 M ha

GLWD

National wetland extent across datasets — GLWD's coarse static mask overestimates by >25×; this study resolves realistic, fragmented extent.

6 Where the Methane Comes From

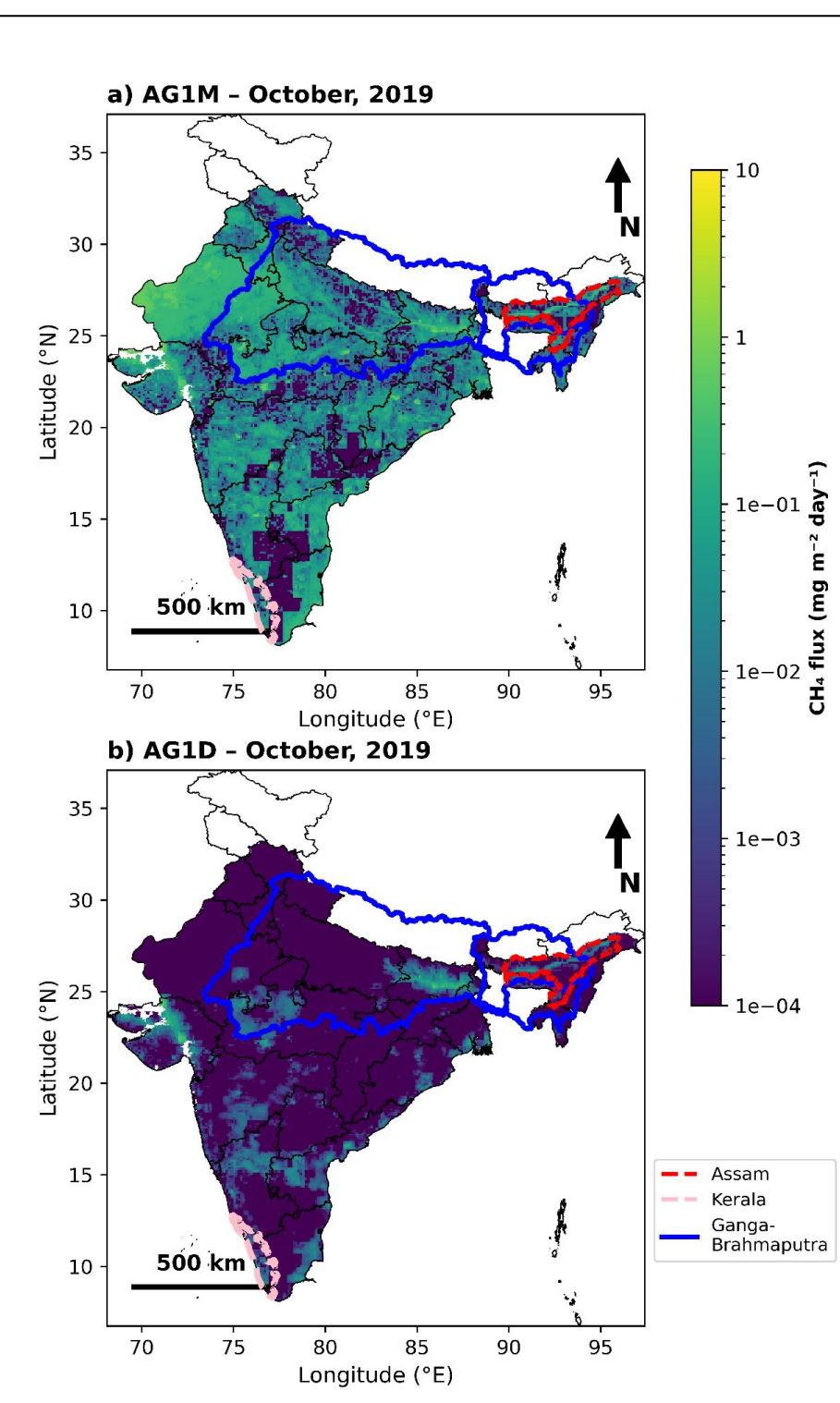


Fig. 6 — CH₄ emissions from wetlands: (a) satellite-only extent (AGIM) and (b) GIEMS-MC-constrained extent (AGID), October 2019.

Sentinel-1 SAR

~20 m · 6–12 day revisit

Sentinel-2 Optical

10–20 m · 5 day revisit

MODIS

250–500 m · daily

Satellite inputs fused to build the wetland map, complemented by ERA5 temperature and CHIRPS precipitation for emission forcing.

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7 A Larger, More Realistic Picture

- National estimate: ~0.5–2.5 Tg CH₄ yr^{−1} (2018–2023) across the 18-member ensemble.
- Exceeds WetCHARTs (~0.06–0.5 Tg yr^{−1}), which relies on coarse (0.25°–0.5°), largely static wetland masks.
- Aligns closely with an independent atmospheric-inversion estimate (Janardanan et al. 2020, ~2.4 Tg CH₄ yr^{−1}).
- Lower than the Global Methane Budget's regional estimate (Saunio et al., ~5–6 Tg CH₄ yr^{−1}) — reflecting a narrower, natural-wetland-only definition.
- Wetlands contribute an estimated ~5–7% of India's national CH₄ budget.

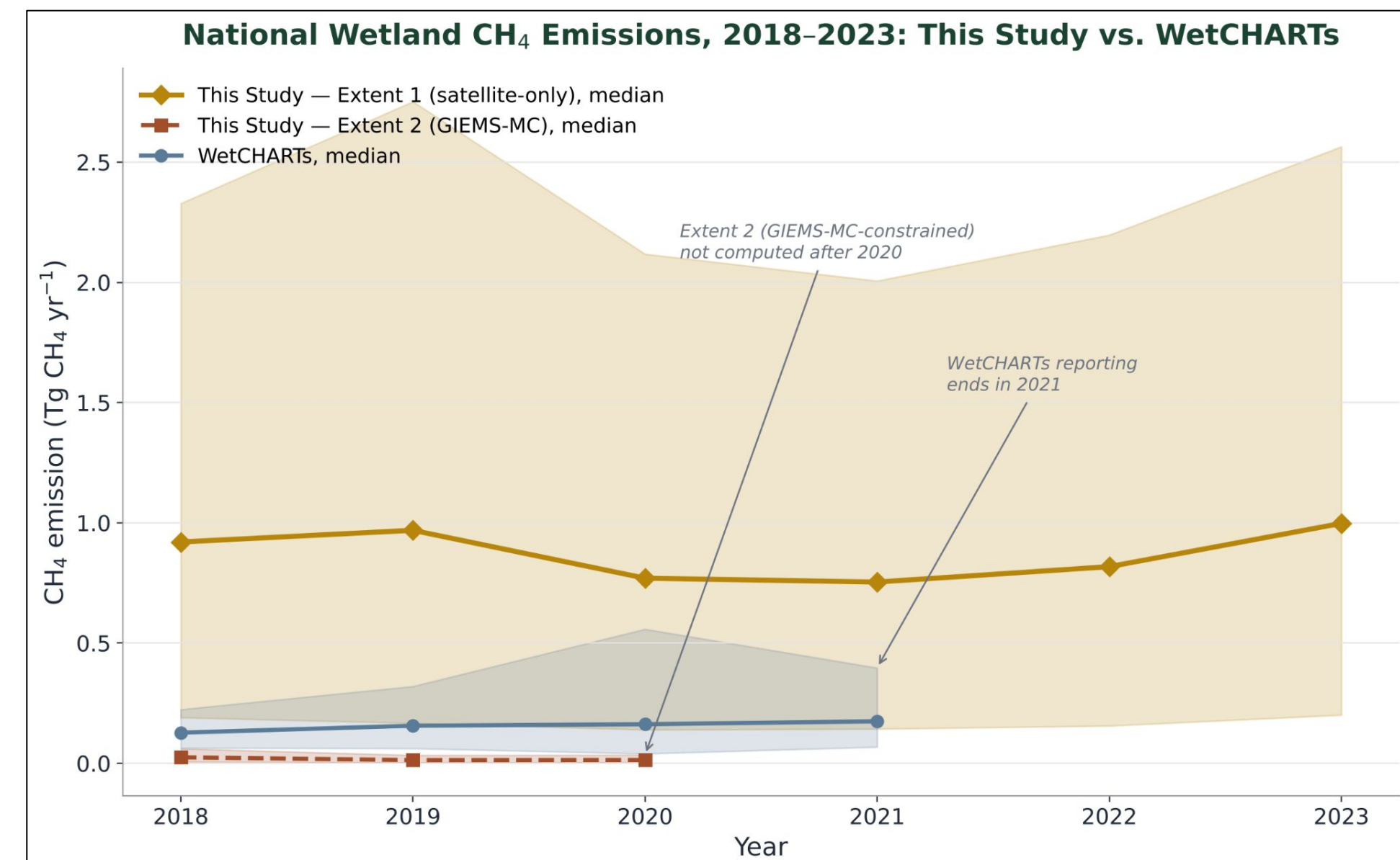


Fig. 7 — CH₄ emission estimates by model and year (2018–2023), spanning the full 18-member ensemble.

0.5–2.5

THIS STUDY

0.06–0.5

WETCHARTS

~2.4

JANARDANAN '20

5–6

SAUNIO GMB

Estimated annual natural-wetland CH₄ emissions over India (Tg CH₄ yr^{−1}), this study vs. independent inventories.

8 Validation — Ramsar Sites & Field Evidence

- Combination 5 achieved complete (100%) overlap with 62 of 108 Ramsar sites nationwide.
- Goa: GLWD shows zero wetlands; this method correctly captures Carambolim, Sarzora, and Durga lakes, matching Ramsar and state records.
- Bhoj Wetland (Bhopal): GLWD misrepresents its extent; this method's delineation is confirmed by ground photographs.
- Vembanad–Kol (Kerala), India's largest lake ecosystem, and Manipur's Loktak Lake — both under-represented or omitted in GLWD — are traced far more accurately here.

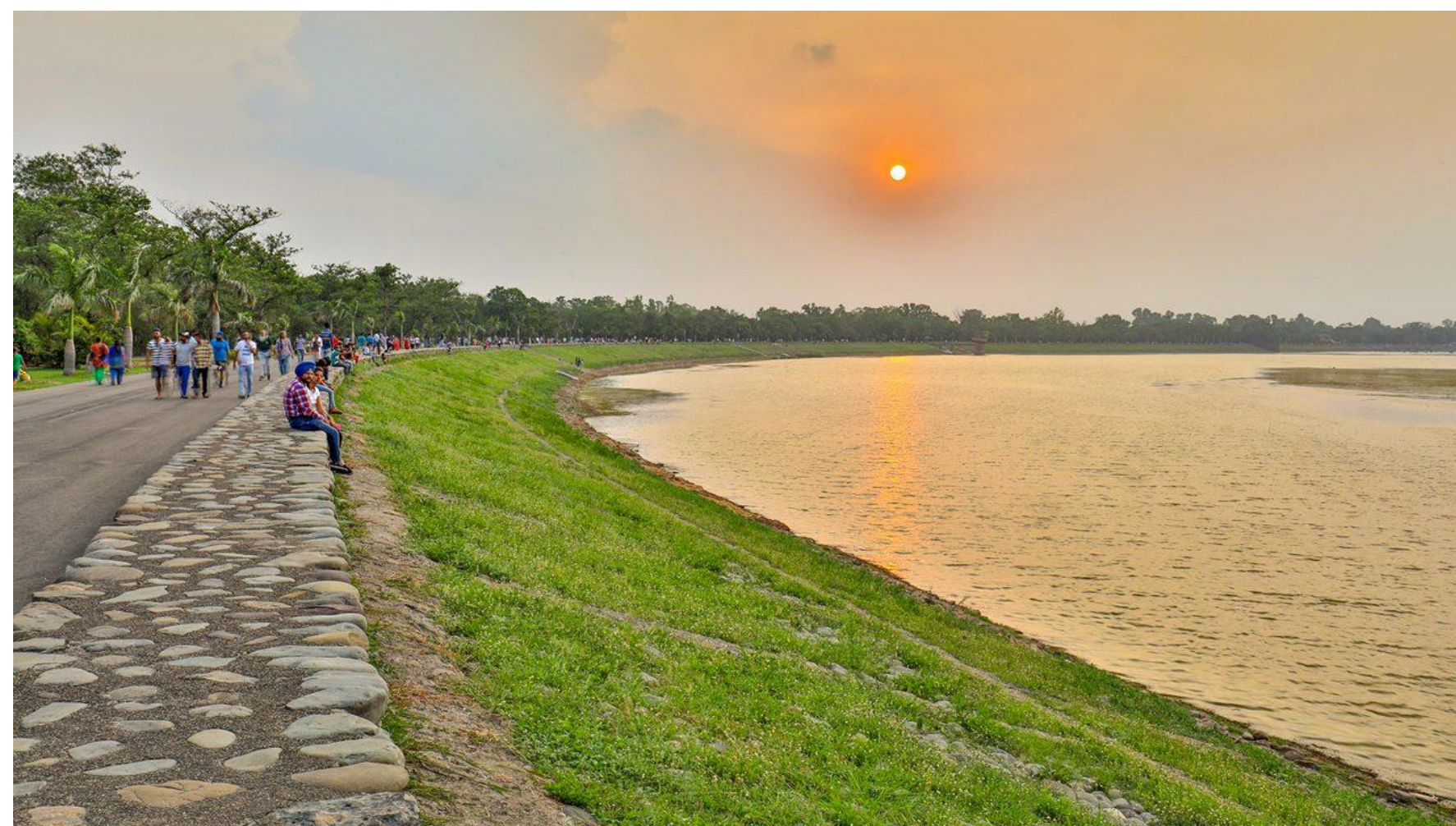


Fig. 8 — Sukhna Wetland (Chandigarh): captured by this method, missed entirely by GLWD.

Model Sensitivity

Wetland-extent choice and temperature dependence are the strongest controls on emissions — temperature parameterization alone drives >20-fold differences between Extent 1 and Extent 2 outputs. Global scaling factor and model family (AG/BG/CG) further modulate flux magnitude, with the largest emissions when AG models, high temperature sensitivity, and Extent 2 align.

9 Why This Is New for India

- First satellite-constrained, high-resolution (1 km), multi-year (2018–2023) natural-wetland CH₄ dataset for India.
- Two complementary wetland-extent products — Extent 1 (satellite-only) and Extent 2 (satellite + GIEMS-MC) — bracket structural uncertainty.
- Explicitly excludes rice paddies and other managed wetlands, isolating the natural-wetland CH₄ signal (rice systems are addressed separately in Part B).
- Designed as a prior for atmospheric inversions and to support India's NDC and UNFCCC greenhouse-gas reporting, where wetlands are often omitted.

10 Key Takeaways

- First high-resolution (1 km), satellite-constrained wetland CH₄ dataset for India (2018–2023).
- Captures small, fragmented, and seasonal wetlands systematically missed by GLWD and WetCHARTs.
- Ganga–Brahmaputra basin, Assam, and Kerala's backwaters are the dominant national hotspots.
- Forms the foundation extended to managed rice systems in Part B of this study.

Limitations & Future Scope

Fixed sensor weights and the coarse (0.25°) GIEMS-MC constraint limit fine-scale accuracy; direct CH₄ flux validation remains sparse. Future work: flux-tower networks, finer-resolution climate inputs, and extension to other monsoon regions (Southeast Asia, Africa, South America).



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