

A 41-year satellite record reveals abrupt redistribution of the Okavango Delta's flood pulse since 2012

Supplementary Information

Huck Rees^{1*}, Octavia Crompton², Mauro Lourenço³, Lukas WinklerPrins⁴, Laurel G. Larsen⁵, Kelly K. Caylor^{1,6}, Vamsi Ganti^{1,7}

¹ Department of Geography, University of California Santa Barbara, Santa Barbara, CA 93106, USA

² USDA Agricultural Research Service Hydrology and Remote Sensing Laboratory, Beltsville, MD 20705, USA

³ National Geographic Okavango Wilderness Project, Wild Bird Trust, Johannesburg, South Africa

⁴ Department of Physical Geography, Stockholm University, Stockholm, Sweden

⁵ Department of Earth Sciences, Uppsala University, Uppsala, Sweden

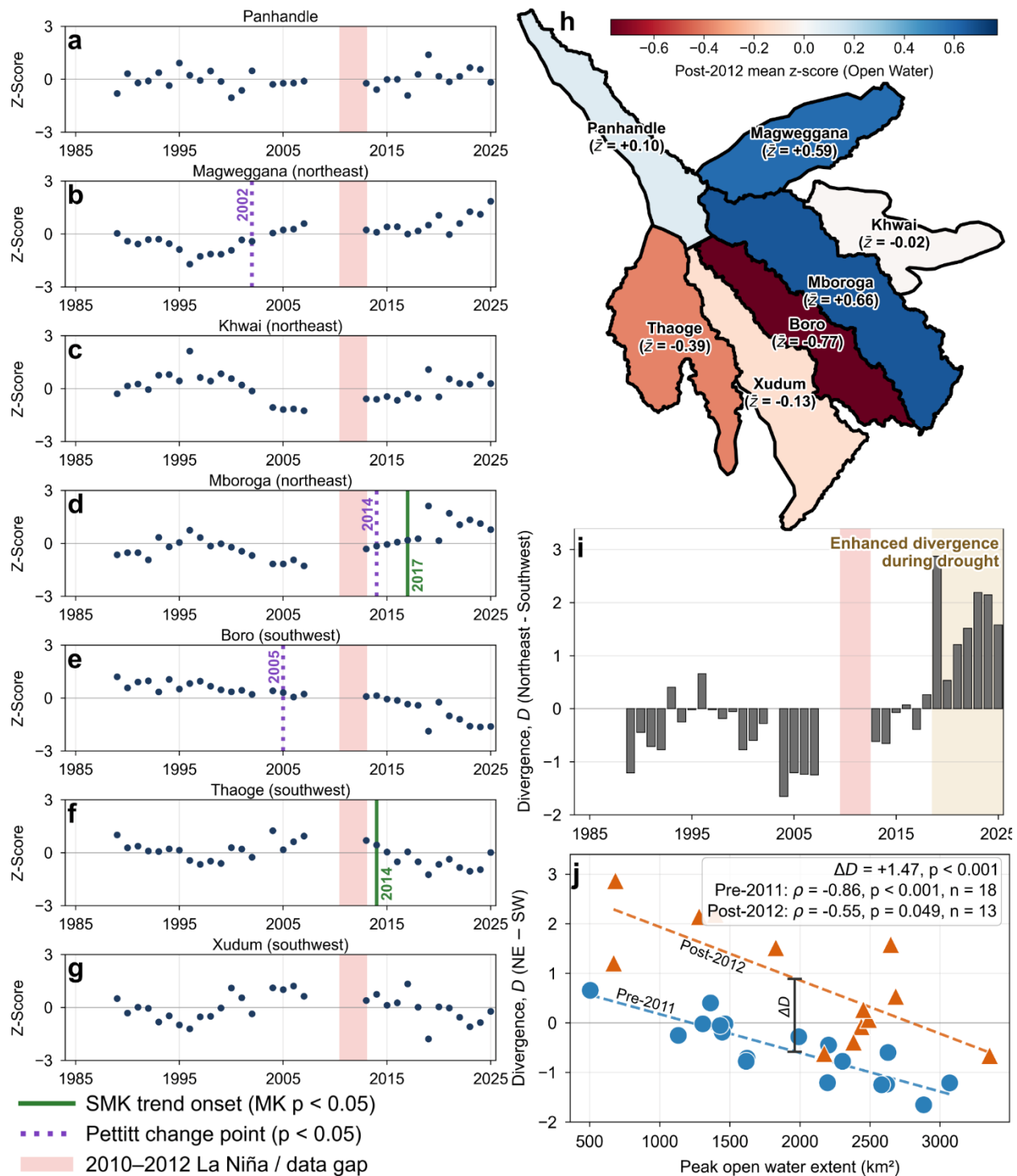
⁶ Bren School of Environmental Science and Management, University of California Santa Barbara, Santa Barbara, CA 93106, USA

⁷ Department of Earth Science, University of California Santa Barbara, Santa Barbara CA 93106, USA

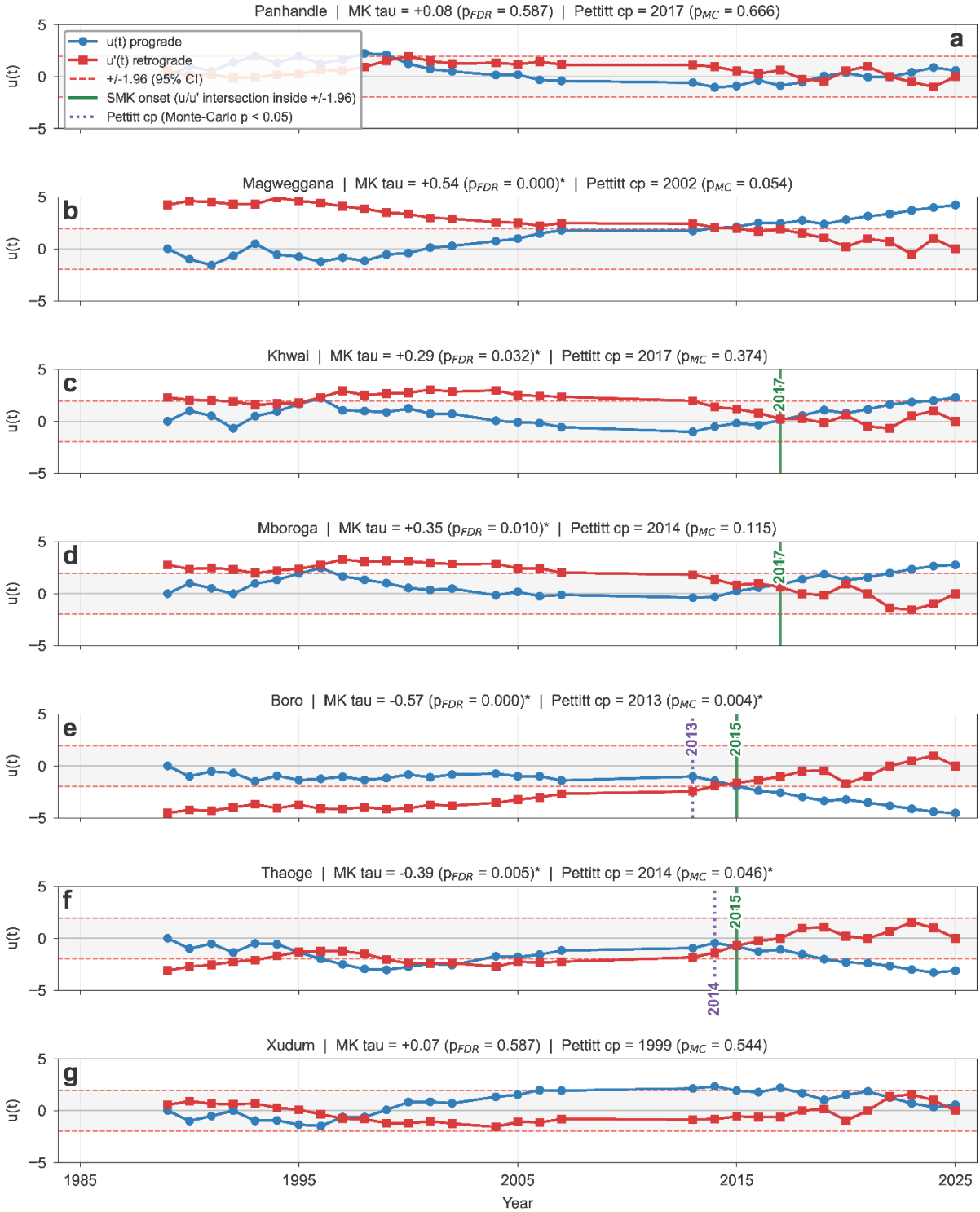
*Corresponding author; E-mail: jamesrees@ucsb.edu

Supplementary Note 1. Characterization of the monthly AdDSWE inundation record

Across the full archive, monthly inundation extent (classes 1–4 combined) ranged from 10,136 km² (July 1989) to 2,032 km² (November 2019), with a mean annual maximum of 7,180 km² and a mean annual minimum of 4,762 km². Open water extent (classes 3 and 4) ranged from 4,331 km² (May 2010) to 139 km² (December 1992), with a mean annual maximum of 2,109 km² and a mean annual minimum of 397 km². Open water composes on average 17.7% of total inundation extent across the full record, achieving its highest proportion in July at 29.1% and its lowest proportion in January at 5.7%. Open water and total inundation extent typically peak in July (Fig. 2d).

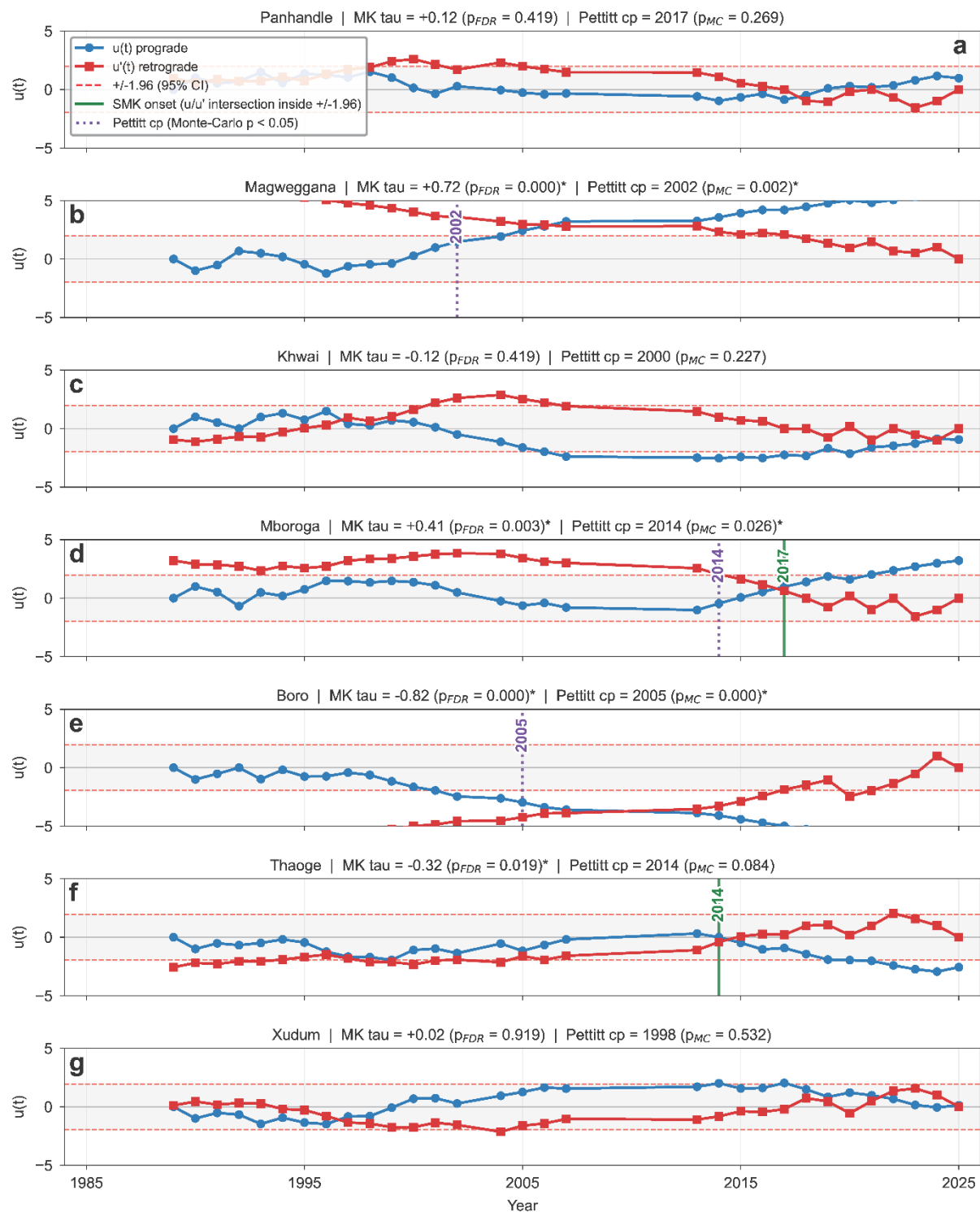


Supplementary Fig. 1. Distributary-scale reorganization and divergence of open water area share since 2012. **a–g** Annual mean z-score time series of each distributary's share of open water inundation, showing significant sequential Mann-Kendall (SMK) onsets and Pettitt change points. **h** Map of the Panhandle and six distributaries colored by mean monthly z-score over the post-2012 epoch. **i** Annual northeast-southwest divergence index D . **j** D versus peak open water extent, by epoch, with per-epoch fits; ΔD is the ANCOVA offset at the mean peak annual open water extent.



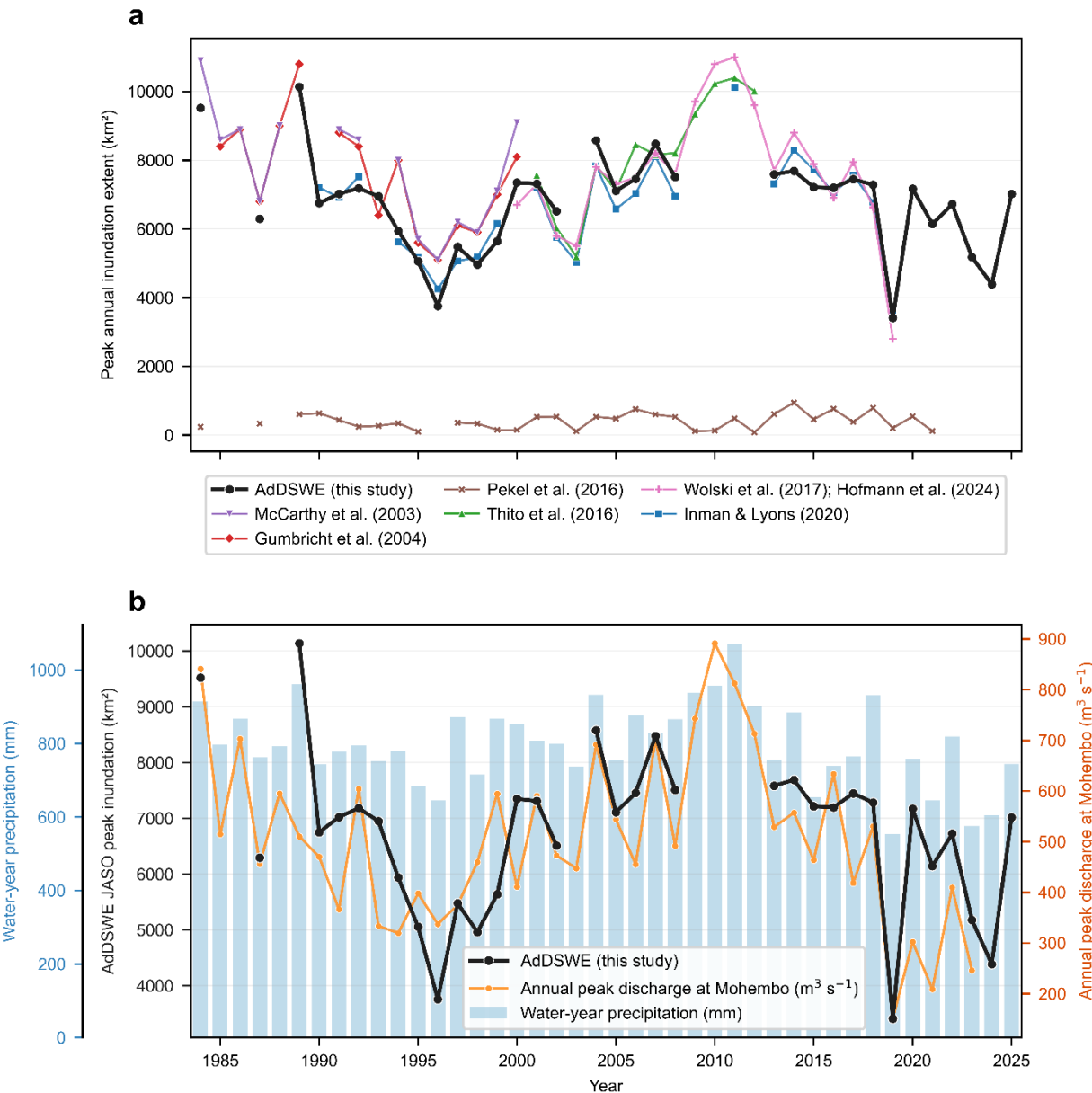
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36 **Supplementary Fig. 2. Sequential Mann-Kendall and Pettitt change-point diagnostics for each**
 37 **distributary's share of total inundation area (AdDSWE classes ≥ 1).** Each panel shows the
 38 prograde rank statistic $u(t)$ (blue circles) and retrograde rank statistic $u'(t)$ (red squares).

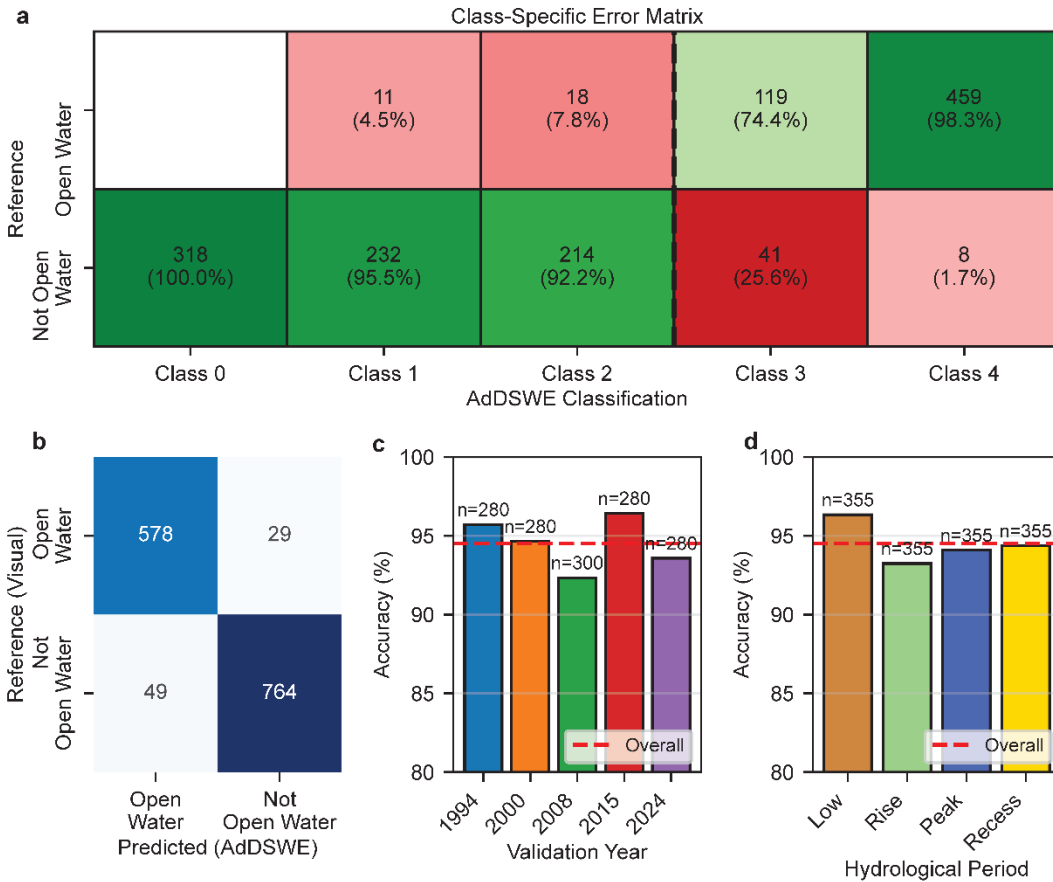


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40 **Supplementary Fig. 3. Sequential Mann-Kendall and Pettitt change-point diagnostics for each**
 41 **distributary's share of open water area (AdDSWE classes ≥ 3).** Each panel shows the prograde
 42 rank statistic $u(t)$ (blue circles) and retrograde rank statistic $u'(t)$ (red squares).



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45 **Supplementary Fig. 4. Inter-product comparison of Okavango Delta peak inundation and**
46 **hydrologic forcing, 1984–2025. a** Peak annual inundation extent (km²) from AdDSWE (total
47 inundation; JASO window; black) and six prior remote-sensing products^{1–7}. **b** AdDSWE JASO peak
48 total inundation plotted against water-year total precipitation⁸ (CHIRPS) and annual peak discharge
49 at Mohembo from the Global Runoff Data Centre (GRDC).



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51 **Supplementary Fig. 5. Validation of the Adapted Dynamic Surface Water Extent (AdDSWE)**
 52 **open water classification.** **a** Class-specific error matrix showing how each AdDSWE confidence
 53 class (0–4) distributes between visually classified open water and not-open-water reference points;
 54 green shading indicates cells where the AdDSWE class matches its expected reference category
 55 and red shading indicates disagreement. The vertical dashed line between class 2 and class 3
 56 marks the threshold separating not open water (dry land and water under canopy (WUC); 0–2) from
 57 open water (3–4). **b** Binary confusion matrix after collapsing classes 3–4 into a single open water
 58 class and classes 0–2 into a single not-open-water class. **c** Overall accuracy stratified by validation
 59 year, spanning the five Landsat sensor eras sampled: 1994, 2000, 2008 (representing 2007–2009),
 60 2015, and 2024. **d** Overall accuracy stratified by hydrological phase; the red dashed line in both
 61 panels denotes the overall accuracy reported in **b**.

Supplementary Table 1. Stratified open water area classification accuracy metrics. Metrics reported by Landsat sensor era, hydrological phase, and interpreter confidence (total n = 1,420).

Stratum	n	OA (%)	kappa	OW PA (%)	OW UA (%)	NOW PA (%)	NOW UA (%)	Omission (%)	Commission (%)	TP	TN	FP	FN
Overall	1420	94.5	0.888	95.2	92.2	94	96.3	4.8	7.8	578	764	49	29
Sensor Era													
1994	280	95.7	0.91	96.2	92.7	95.4	97.6	3.8	7.3	102	166	8	4
2000	280	94.6	0.891	95.8	91.9	93.8	96.8	4.2	8.1	114	151	10	5
2008	300	92.3	0.844	97.5	85.3	89	98.2	2.5	14.7	116	161	20	3
2015	280	96.4	0.928	99.2	93.3	94.1	99.3	0.8	6.7	126	144	9	1
2024	280	93.6	0.871	88.2	98.4	98.6	89.9	11.8	1.6	120	142	2	16
Hydrological Phase													
Low	355	96.3	0.918	95	94.2	97	97.4	5	5.8	114	228	7	6
Rise	355	93.2	0.865	91.8	94.9	94.8	91.6	8.2	5.1	167	164	9	15
Peak	355	94.1	0.882	99.4	89.7	88.9	99.4	0.6	10.3	174	160	20	1
Recess	355	94.4	0.88	94.6	90.4	94.2	96.8	5.4	9.6	123	212	13	7
Interpreter Confidence													
Certain	1162	98.7	0.974	98.8	98.2	98.6	99.1	1.2	1.8	495	652	9	6
Uncertain	258	75.6	0.508	78.3	67.5	73.7	83	21.7	32.5	83	112	40	23

OW = Open Water; OA = Overall Accuracy; kappa = Cohen's Kappa; PA = Producer's Accuracy; UA = User's Accuracy; TP/TN/FP/FN = True/False Positives/Negatives

Supplementary Note 2. Temporal gap filling results and compositing quality

We assessed temporal compositing quality via the mean per-pixel expansion value of monthly quality control rasters ($\overline{QC}$). For each product, a pixel's assigned expansion value indicates the number of months the compositing window needed to be expanded to capture enough Landsat scene(s) to generate a classifiable optical image at the pixel. Across the full archive, the mean $\overline{QC}$ was 0.15 (median = 0.04), indicating that the vast majority of pixels in a typical monthly composite were drawn from same-month or near-same-month imagery. While 54.1% of months required some degree of temporal gap-filling, average expansion never exceeded one month in any individual composite (max $\overline{QC}$ = 0.96), and 92.9% of all months had a mean expansion of less than 0.5 months. Compositing quality improved substantially over the archive as multi-sensor coverage increased: mean $\overline{QC}$ declined from 0.25 during the single-sensor Landsat 5 era (1984–1998) to 0.03 during the Landsat 8/9 era (2014–2025), reflecting the higher revisit frequency. Rainy season months (November–April; mean $\overline{QC}$ = 0.19) required modestly greater temporal expansion than dry season months (May–October; mean $\overline{QC}$ = 0.11). The poorest-quality composites were concentrated in November and in years with anomalously high rainfall, with the ten highest $\overline{QC}$ months all occurring prior to 2010. These quality patterns are spatially and temporally consistent with known Landsat archive characteristics and do not affect the validity of the classification record; users are directed to the accompanying QC rasters to identify and, if necessary, exclude months requiring greater temporal interpolation for time-sensitive applications.

Supplementary Note 3. Inundation misclassification from burn scars

Burn scars are common in the Okavango Delta⁹, and recently burned surfaces are spectrally dark across the visible and near-infrared regions due to charcoal deposition and vegetation loss¹⁰. This signature can partially overlap with that of open water and could in principle be misclassified by some of the partial-surface-water tests in the original DSWE algorithm¹¹. We therefore cross-checked AdDSWE classifications against the MODIS Collection 6.1 burned area product^{12,13} (MCD64A1). For each month from November 2000 onward (the start of the MCD64A1 record) we overlaid the monthly burned-area mask on the corresponding AdDSWE classification and visually inspected the spatial coincidence of the two layers across the delta. Burn scars and AdDSWE water classes occasionally co-occurred, and we identified isolated cases in which recent burns appear to have elevated the AdDSWE confidence class, but no month exhibited burn-driven misclassification at a magnitude that would alter delta-wide inundation extent or its spatial distribution. The strong agreement of AdDSWE with the independently derived record of Inman and Lyons³ (Fig. 7e, f) and its scaling with antecedent water-year precipitation (Figure 7e) further indicate that the inundation patterns reported here are not materially affected by burn-scar contamination.

Supplementary Note 4. Definition of the peak annual inundation window

We apply two windows for extracting peak annual inundation extent. The narrower July through October (JASO) window appears only in cross-study comparisons, where we align AdDSWE to other hydrologic time series and the compositing window of Inman and Lyons³ (Fig. 7; Supplementary Fig. 4a, b). All analyses internal to this study, including peak annual flood extent as the ANCOVA covariate and the flood-magnitude term in the divergence relationships, use the wider May through October window. The wider window accommodates genuine early-season peaks. In several years the flood pulse crests in May or June, and a JASO window truncates these years to a recessional value that understates the annual maximum. May through October spans the full range of observed pulse arrival and crest timing across the record while remaining within the flood season. We exclude November through April despite occasional annual maxima in March and April. These early maxima are typically followed by a second maximum later in the summer (the actual flood peak), and they occur at or before the typical timing for peak discharge at Molembo, indicating they do not reflect the true maximum extent of the annual flood pulse. They instead likely reflect heavy localized rainfall over the delta, which generates extensive but short-lived surface water and elevated soil moisture during the wet season. We treat these maxima as real inundation rather than classification artifacts, but exclude them because they do not represent the annual flood pulse which is the target of our analyses.

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