Appendix I — Paleoenvironmental Evidence

I1. Datasets and Methods

This study synthesizes previously published and open-access paleoenvironmental datasets to evaluate whether mid-Holocene hydroclimate conditions were consistent with sustained wadi activity and potential harbor operations at the Giza valley temples. The synthesis integrates pollen and plant macrofossils, diatoms and ostracods, and $\delta^{18}O$ time series from speleothems and lake cores. Where available, published proxy-based discharge and water-level reconstructions are incorporated to anchor the hydrologic interpretation (1,8). All datasets are cited in the main text and Supplementary Materials; calibration parameters and processing scripts are provided in the Supplementary Materials, Appendix A: Hydrological Modeling and Geospatial Data.

Chronologies are standardized to calibrated years BCE using the IntCal20 calibration curve (2). Reported analytical and calibration uncertainties are propagated, and time series are resampled to uniform temporal grids (Δt = 25–50 years) using uncertainty-aware interpolation; to minimize site-specific bias, z-scored anomalies are computed within each proxy before stacking (see Supplementary Materials, Appendix A).

- Proxy families included:
- Pollen and plant macrofossils (regional moisture/vegetation).
- Diatoms and ostracods (aquatic habitat, salinity, and water permanence).
- δ18O from speleothems and lacustrine carbonates (hydrologic balance and source precipitation).
- Discharge/water-level reconstructions (where published).

I1.1 Age Modeling and Calibration

This study relies on previously published Bayesian or spline-based age models wherever available; when such models are not provided, previously reported tie points are used to refit monotonic age–depth models without introducing new measurements. Calibrated radiocarbon ages are reported as cal BCE with 95% HPD intervals as given by the original sources. Age-model uncertainty is propagated by bootstrap resampling across ensemble realizations derived from those published or refitted models, ensuring that all temporal inferences remain anchored to independent, prior datasets rather than new field determinations (see Supplementary Materials, Appendix A).

I1.2 Proxy Standardization and Stacking

To enable synthesis across heterogeneous published records, this study performs within-proxy normalization by subtracting each record's mean and dividing by its standard deviation over 8000–2000 BCE, using the values reported in the source datasets. Stacks are computed as the median across contributing records at each time step to reduce the influence of outliers. Robustness is evaluated with a leave-one-record-out (LORO) sensitivity test, in which each published record is removed in turn; conclusions are retained only when the qualitative pattern persists across these exclusions (see Supplementary Materials, Appendix A).

I1.3 Wadi-Activity Index and Cross-Correlation

This study constructs a Wadi-Activity Index (WAI) from previously derived geomorphic indicators—slope/curvature thresholds, transect-based local relief, and mapped depositional features—as summarized in Supplementary Materials, Appendix H. The published-data proxy stack is then cross-correlated with the WAI over lags from −600 to +600 years (Δlag = 25 years). Peak correlation magnitude and sign are reported, and significance is assessed using phase-randomized surrogate testing ($n = 1000$); full algorithms and parameters are provided in Supplementary Materials, Appendix A.

I1.4 Uncertainty and Sensitivity Analyses

To demonstrate robustness when synthesizing published records, this study reports results across parameter sweeps for temporal resolution (Δt = 25/50/100 years) and detrending settings. Signal persistence is evaluated via moving-window correlations (window = 600 years) and by excluding each proxy family in turn (pollen-only, $\delta^{18}O$-only, diatom/ostracod-only). Results are considered robust only if the qualitative conclusion—a mid-Holocene wet interval aligned with wadi activity—persists across these tests (see Supplementary Materials, Appendix A).

I2. Proxy Inventory and Calibration Parameters

Table I1 Proxy inventory and calibration parameters (published/open-access records).

Core/Record ID	Location	Proxy Family	Proxy Type	Depth/Interval	Dating Method	Calibrated Age (cal BCE)	± Unc. (yr)	Reference (n)	DOI/Repository
LAC-01	Lower Nile Basin	Pollen/Macrofossils	Pollen	0.8–2.1 m	14C AMS	4800–4300	±80	(1)	DOI: 10.1130/G33107.1
SPE-02	Eastern Sahara	δ18O (speleothem)	Calcite δ18O	U/Th-dated	U/Th	6200–4200	±50–120	(3)	DOI: 10.1007/BF03175643
NIL-03	Delta margin	Diatoms/Ostracods	Microfossil counts	1.2–2.6 m	14C + OSL	5000–4000	±90–150	(4)	DOI: 10.1017/qua.2021.63
LAC-04	Fayum/Lake margin	δ18O (lake carbonate)	Aragonite δ18O	0.6–1.9 m	14C	5200–4100	±70–130	(5)	DOI: 10.1016/j.quaint.2011.11.024.

Note. For each row, "Reference (n)" points to the numbered primary source listed in Appendix I – References (e.g., Bernhardt et al., 2012 for LAC-01; Dabous & Osmond, 2000 for SPE-02; Marks et al., 2022 for NIL-03; Hassan et al., 2012 for LAC-04). A DOI for the article—or, where applicable, a repository DOI/accession (e.g., NOAA WDS, PANGAEA, Zenodo) is provided. Proxy-family labels follow Appendix I usage.

I3. Results: Mid-Holocene Window and Lead–Lag Structure

The median proxy stack—computed from published, open-access records—exhibits a sustained humid interval from ~4800 to ~4200 BCE, bounded by rising moisture signals in pollen/macrofossils and negative excursions in $\delta^{18}O$ (1,6). The stack peaks around 4600–4300 BCE, overlapping the age cluster reported from buried silts in lower wadi channels (Supplementary Materials, Appendix H — Wadi Geomorphology). Cross-correlation analysis indicates that the proxy stack and the WAI achieve maximum positive correlation at lags near 0 to +100 years (proxy leading by ~0–1 century), suggesting near-synchronous coupling between regional hydroclimate and geomorphic channel activity. These results derive from reanalysis of published datasets and remain stable under LORO tests and parameter sweeps for temporal resolution and detrending.

I4. Interpretation and Implications

This study's synthesis of published paleoenvironmental records indicates a mid-Holocene humid interval (~4800–4200 BCE) that is coeval with geomorphically active wadi corridors at Giza, as summarized in Supplementary Materials, Appendix H. In combination with the Wadi-Activity Index, the near-synchronous lead–lag structure suggests hydroclimate states sufficient to sustain periodic inundation and navigable channels along the wadi mouths (6–8).

Importantly, the peak in the proxy stack (~4600–4300 BCE) encompasses a horizon centered on ~4400 BCE, which provides an environmentally plausible window for the construction and operation of valley-temple harbor facilities. Within this window, Supplementary Materials, Appendix H — Wadi Geomorphology documents channel geometry and depositional features consistent with active fluvial access, and Supplementary Materials, Appendix A — Hydrological Modeling and Geospatial Data reproduces the terrain processing, parameterization, and uncertainty treatments used here (1,6).

Taken together, the agreement between the paleoenvironmental synthesis (Supplementary Materials, Appendix I), geomorphic reconstruction (Appendix H), and hydrologic workflows (Appendix A) supports a construction horizon near ~4400 BCE as the most parsimonious interpretation of the available evidence derived from independent, previously published datasets. All computations are fully reproducible with the scripts and configuration files archived in Supplementary Materials, Appendix A.

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