

# WetlandMapper: A Python package for automatic wetland mapping, dynamics classification, and cover-type characterisation from multispectral time-series data

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## Software

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## Summary

WetlandMapper is an open-source Python package that operationalises two peer-reviewed remote-sensing frameworks for automated wetland analysis from multispectral satellite data, now expanded with comprehensive spectral index computation, terrain analysis, and enhanced visualisation capabilities. The package is available on PyPI (`pip install wetlandmapper`) and archived at Zenodo ([Singh, 2026](#)).

The first framework is a **wetland dynamics classification** method ([Singh & Sinha, 2022a](#)) that maps floodplain wetlands at basin scale from a multi-temporal MNDWI time series and classifies each wetland pixel into one of six temporal dynamics classes: *Persistent*, *New*, *Intensifying*, *Diminishing*, *Lost*, and *Intermittent*.

The second framework is a **Wetland Cover Type (WCT) classification** method ([Singh et al., 2022](#)) that combines multiple spectral indices to characterise the biophysical surface composition of wetland pixels into stable, ecologically interpretable cover types including open clear water, turbid water, aquatic vegetation, and moist soil.

The package now includes comprehensive **spectral index computation** supporting six indices (MNDWI, NDWI, NDVI, NDTI, AWEIsh, AWEInsh) for flexible water detection and vegetation analysis, a **terrain analysis module** for topographic corrections and artifact masking, and **visualisation utilities** for interactive plotting of results.

These modules address complementary monitoring questions: the dynamics module characterises *when and how* wetland inundation is changing over time, the WCT module characterises *what* is present at the wetland surface at any given time, the spectral indices provide flexible water and vegetation detection, and the terrain module enables topographic corrections for improved accuracy in hilly terrain. All operate on xarray DataArray objects ([Hoyer & Hamman, 2017](#)), enabling dask-backed parallel processing of large raster archives. Users may supply their own pre-processed imagery or retrieve analysis-ready surface-reflectance data directly from Google Earth Engine (GEE; Gorelick et al. ([2017](#)))) via an integrated optional acquisition submodule that supports all Landsat missions (4, 5, 7, 8, and 9), Sentinel-2, MODIS, and shapefile-path or GeoJSON area-of-interest inputs.

## Statement of Need

Wetlands cover roughly 5–8% of Earth's land surface and deliver ecosystem services valued at tens of trillions of dollars annually, yet global wetland area has declined by approximately

39 35% since 1970 (Davidson, 2014; Ramsar Convention Secretariat, 2018). Operational  
40 monitoring at basin to continental scales — tracking both inundation dynamics and biophysical  
41 surface conditions — is essential for conservation management, restoration prioritisation, and  
42 international reporting obligations under the Ramsar Convention.

43 Existing tools for remote sensing-based wetland analysis suffer from one or more of the following  
44 limitations: (1) they characterise only binary inundation extent and do not resolve temporal  
45 dynamics or surface cover composition (Pekel et al., 2016); (2) they are embedded in proprietary  
46 platforms (ArcGIS Model Builder, GEE JavaScript API) that resist integration into scripted,  
47 reproducible workflows; (3) they address either dynamics or cover characterisation but not  
48 both within a single interoperable framework; (4) their methods are distributed as single-use  
49 scripts rather than tested, documented software libraries with version histories; (5) they lack  
50 comprehensive spectral index libraries for flexible water and vegetation detection; and (6) they  
51 do not account for topographic effects that can confound wetland classification in hilly terrain.

52 WetlandMapper addresses all six gaps. It provides a fully Pythonic, open-source library that  
53 unifies the dynamics-classification method of Singh & Sinha (2021) and Singh & Sinha (2022a)  
54 — previously dependent on ArcGIS — and the WCT method of Singh et al. (2022) — previously  
55 distributed only as GEE JavaScript code and an ArcGIS toolbox — while adding comprehensive  
56 spectral index computation, terrain analysis for topographic corrections, visualisation utilities,  
57 and a flexible data-ingestion pathway that supports both user-supplied imagery and automated  
58 GEE retrieval. Both core methods require no labelled training data and operate on any  
59 multispectral archive from which the required indices can be computed.

## 60 State of the Field

61 The JRC Global Surface Water dataset (Pekel et al., 2016) characterises long-term open-  
62 water occurrence globally at 30 m resolution but does not distinguish wetland surface types.  
63 Machine-learning approaches achieve high classification accuracy but require labelled training  
64 data that are rarely available at regional scales (Mahdavi et al., 2018; Slagter et al., 2020).  
65 SAR-based methods handle cloud cover but require specialist pre-processing workflows and  
66 site-specific thresholding. Most tools lack comprehensive spectral index libraries or terrain  
67 correction capabilities needed for robust wetland analysis across diverse landscapes.

68 The methods unified in WetlandMapper occupy a practical middle ground — no training labels,  
69 applicable to any cloud-free multispectral archive, and producing ecologically interpretable  
70 outputs — while providing comprehensive spectral index computation, terrain analysis for  
71 topographic corrections, and visualisation utilities. WetlandMapper makes these capabilities  
72 accessible in a reusable, tested Python library for the first time.

## 73 Software Design and Methods

### 74 Wetland Dynamics Classification

75 This module implements the basin-scale inventory and hydrodynamics framework of Singh &  
76 Sinha (2022a). Given a multi-temporal MNDWI raster stack, each time step is first thresholded  
77 to a binary water-presence layer:

$$W_t = \begin{cases} 1 & \text{if } \text{MNDWI}_t > \tau \\ 0 & \text{otherwise} \end{cases}$$

78 where  $\tau = 0$  by default (positive MNDWI indicates a water-dominated pixel; Xu (2006)).  
79 Three summary statistics are then derived across the full time series of length  $T$ , split by a  
80 configurable temporal window  $n$ :

$$W_{\text{percent}} = \frac{\sum_{t=1}^T W_t}{T} \times 100, \quad W_{\text{historic}} = \sum_{t=1}^n W_t, \quad W_{\text{recent}} = \sum_{t=T-n+1}^T W_t$$

81 The temporal change signal  $\Delta W = W_{\text{recent}} - W_{\text{historic}}$  is used together with  $W_{\text{percent}}$  and  
 82 two user-adjustable wet-frequency thresholds ( $\theta_{\text{wet}}, \theta_{\text{persis}}$ ) to assign each pixel to one of six  
 83 dynamics classes:

| Class        | Primary condition  |
|--------------|--|
| Persistent   | $W_{\text{percent}} \geq \theta_{\text{persis}}$                           |
| New          | $\Delta W = +n$  |
| Intensifying | $W_{\text{percent}} \geq \theta_{\text{wet}}; 0 < \Delta W < n$            |
| Diminishing  | $W_{\text{percent}} \geq \theta_{\text{wet}}; -n < \Delta W < 0$           |
| Lost         | $\Delta W = -n$  |
| Intermittent | $W_{\text{percent}} \geq \theta_{\text{wet}}; \text{no directional trend}$ |
| Non-wetland  | $W_{\text{percent}} < \theta_{\text{wet}}$                                 |

84 The entire classification is implemented using vectorised `xr.where` operations, enabling chunked  
 85 parallel execution via Dask with no Python-level pixel iteration.

## 86 Wetland Cover Type Classification

87 This module implements the multi-index WCT framework of Singh et al. (2022). Three  
 88 spectral indices are computed from the same multispectral image:

$$\text{MNDWI} = \frac{G - \text{SWIR}}{G + \text{SWIR}}, \quad \text{NDVI} = \frac{\text{NIR} - R}{\text{NIR} + R}, \quad \text{NDTI} = \frac{R - G}{R + G}$$

89 MNDWI delineates the extent of surface water; NDVI quantifies vegetation presence and  
 90 density; NDTI quantifies water turbidity. Their combined spectral signatures partition wetland  
 91 pixels into five biophysically distinct cover types. Two classification implementations are  
 92 provided: the original quartile-based combination code method (`classify_wct_ema`), and an  
 93 improved continuous-threshold variant (`classify_wct`) that allows sub-quartile calibration for  
 94 different sensors or seasons.

## 95 Spectral Index Computation

96 The package provides comprehensive spectral index computation supporting six indices for  
 97 flexible water detection and vegetation analysis:

- 98 ■ **MNDWI**: Modified Normalised Difference Water Index (Xu, 2006)
- 99 ■ **NDWI**: Normalised Difference Water Index (McFeeters, 1996)
- 100 ■ **NDVI**: Normalised Difference Vegetation Index
- 101 ■ **NDTI**: Normalised Difference Turbidity Index
- 102 ■ **AWEIsh**: Automated Water Extraction Index with shadow suppression (Feyisa et al.,  
 103 2014)
- 104 ■ **AWEInsh**: Automated Water Extraction Index without shadow suppression (Feyisa et  
 105 al., 2014)

106 Users can compute individual indices or use `compute_indices()` for the core WCT indices  
 107 (MNDWI, NDVI, NDTI) or `compute_water_indices()` for comprehensive water detection  
 108 across all available water indices.

## 109 Terrain Analysis

110 The terrain analysis module provides topographic corrections essential for accurate wetland  
111 classification in hilly or mountainous terrain where slope and topographic position can confound  
112 spectral signatures. Functions include:

- 113 ■ **Slope computation:** Local slope calculation from digital elevation models
- 114 ■ **Topographic Position Index (TPI):** Relative topographic position within a local  
115 neighborhood
- 116 ■ **Local range:** Local elevation variability for terrain complexity assessment
- 117 ■ **DEM depression mapping:** Identification of closed depressions from raw versus pit-filled  
118 DEMs using integer division and binary reclassification, following the riverine wetland  
119 mapping protocol of Sinha et al. (2017)
- 120 ■ **Terrain artifact masking:** Automated masking of steep slopes that may cause classification  
121 errors in wetland detection

122 This terrain functionality therefore supports both topographic false-positive reduction in rugged  
123 settings and depression-focused wetland candidate mapping in low-relief floodplains.

## 124 Data Acquisition and Temporal Aggregation

125 The optional `wetlandmapper.gee` submodule supports all five Landsat missions (4, 5, 7, 8,  
126 9), Sentinel-2, and MODIS. A "LandsatAll" option automatically merges available missions  
127 for any requested date range with harmonised band names, enabling long-record analyses  
128 from 1982 to the present day. "MODISAll" provides similar functionality for MODIS Terra  
129 and Aqua missions. An optional `use_slc_off` parameter controls whether Landsat 7 images  
130 acquired after the 2003 Scan Line Corrector failure (which cause ~22% data gaps per scene)  
131 are included. Areas of interest may be provided as a GeoJSON dict, a shapefile path, or a  
132 GeoJSON file path; multi-feature shapefiles are dissolved to a single boundary automatically.

133 Server-side temporal compositing reduces data transfer volume for long time series: users may  
134 request one median composite per year, month, or meteorological season (DJF / MAM / JJA  
135 / SON) rather than every individual scene. The same temporal aggregation functionality is  
136 also available client-side via `aggregate_time()`, which operates on any `xarray DataArray` or  
137 `Dataset` regardless of data source.

## 138 Dependencies and Installation

139 WetlandMapper requires Python 3.9. Core dependencies are `numpy` (Harris et al., 2020), `xarray`  
140 (Hoyer & Hamman, 2017), and `rioxarray` (Snow & others, 2022). The GEE submodule  
141 additionally requires `earthengine-api`, `rasterio`, `xee`, `dask`, and `geopandas`. The plotting  
142 submodule requires `matplotlib` (Hunter, 2007).

143 Installation via **conda** (recommended for ease of dependency management):

```
# Core functionality
```

```
conda install -c conda-forge wetlandmapper
```

```
# With Google Earth Engine support
```

```
conda install -c conda-forge wetlandmapper geopandas earthengine-api xee dask rasterio
```

```
# Complete installation with all extras
```

```
conda install -c conda-forge wetlandmapper geopandas earthengine-api xee dask rasterio m
```

144 Alternatively, installation via **pip**:

```
pip install wetlandmapper
```

```
# core
```

```
pip install "wetlandmapper[gee]"
```

```
# with GEE + shapefile support
```

```

pip install "wetlandmapper[plot]"           # with visualisation utilities
pip install "wetlandmapper[all]"           # complete installation

```

145 Detailed platform-specific installation instructions, including GEE authentication setup, are  
 146 provided in `INSTALL.md` in the repository.

## 147 Usage

148 A minimal end-to-end example for each workflow:

```

import xarray as xr
from wetlandmapper import compute_mndwi, classify_dynamics
from wetlandmapper import compute_indices, classify_wct_ema
from wetlandmapper import compute_water_indices, compute_slope
from wetlandmapper.plotting import plot_dynamics, plot_wct
from wetlandmapper.gee import fetch

# --- Dynamics: fetch annual composites from all Landsat missions ---
mndwi = fetch("study_area.shp", "1984-01-01", "2023-12-31",
              sensor="LandsatAll", temporal_aggregation="annual")
dynamics = classify_dynamics(mndwi, nYear=3,
                             thresholdWet=25, thresholdPersis=75)
dynamics.rio.to_raster("wetland_dynamics.tif")

# --- WCT: single composite → 5 biophysical cover types
# --- ds_composite is an xarray multispectral dataset (a Landsat .tiff)
ds_composite = xr.load_dataset('Landsat.tiff')
indices = compute_indices(ds_composite, green_band="B3", red_band="B4",
                           nir_band="B5", swir_band="B6")
wct = classify_wct_ema(indices)
wct.rio.to_raster("wetland_cover_types.tif")

# --- Comprehensive water detection with all available indices ---
water_indices = compute_water_indices(ds_composite,
                                       blue_band="B2", green_band="B3",
                                       red_band="B4", nir_band="B5",
                                       swir_band="B6", swir2_band="B7")
water_indices # Contains MNDWI, NDWI, AWEIsh, AWEInsh

# --- Terrain analysis for topographic corrections ---
dem = xr.open_dataset("elevation.nc")["elevation"]
slope = compute_slope(dem)
# Apply terrain masking to reduce false positives in steep areas

# --- Visualisation ---
plot_dynamics(dynamics, title="Wetland Dynamics Classification")
plot_wct(wct, title="Wetland Cover Types")

```

149 A Jupyter notebook demonstrating both workflows on synthetic data, with full GEE acquisition,  
 150 terrain analysis, and interactive visualisation sections, is included in the repository.

## 151 Validation and Results

152 The dynamics module is derived from Singh & Sinha (2022a), where the frequency-based  
 153 temporal aggregation method can effectively distinguish permanently inundated, seasonally

active, and recently changed wetlands at basin scale, providing a validated inventory framework applicable to wetland restoration prioritisation (Singh & Sinha, 2022b).

The WCT module is derived from Singh et al. (2022), where the MNDWI–NDVI–NDTI combination was validated across three Ramsar-listed wetlands in contrasting geomorphic and climatic settings — Kaabar Tal (Ganga floodplain), Chilika Lagoon (coastal), and Nal Sarovar (semi-arid) — demonstrating that the WCTs are stable in space and time, meaning comparable biophysical conditions correspond to the same WCT irrespective of geographic location.

The depression-mapping terrain workflow follows the riverine wetland protocol of Sinha et al. (2017), in which raw and pit-filled DEMs are compared to delineate closed depressions that can act as wetland candidates in flat floodplain environments.

By unifying both workflows in a single, tested Python package with flexible data ingestion, WetlandMapper enables application of these frameworks globally in fully scripted, reproducible workflows, without dependence on proprietary GEE or ArcGIS environments.

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## AI Assistance

Development of this software package was assisted by Claude (Anthropic), an AI language model, for tasks including code scaffolding, packaging configuration, continuous integration setup, docstring writing, and debugging. The scientific methodology, classification algorithms, spectral index thresholds, and validation are based entirely on the author's prior peer-reviewed work (Singh et al., 2022; Singh & Sinha, 2021, 2022a; Sinha et al., 2017), and all scientific content, design decisions, and results presented here are the author's own.

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