WETLAND INVENTORY MAPPING

[PRE-INVENTORY PROCESSING]

TRAINING KIT, VERSION 2

Description of the Wetland Pre-Inventory Processing Service

Introduction

The Wetland Pre-Inventory service provides information on the occurrence of surface water and wetness of soils for a selected region and period of interest. Based on the entire archive of freely available Sentinel-1 and Sentinel-2 high-resolution radar and optical satellite imagery, the service allows to report and monitor water and wet soil dynamics over time. Sentinel-1 radar penetrates clouds and takes images day and night, while the optical sensor onboard the Sentinel-2 satellites capture multispectral information covering the visible to the shortwave infrared part of the spectrum.

The service produces two primary outputs and several individual supplementary layers at 10 m resolution:

1. A water and wetness (i.e., wet soil) classification layer based on water and wetness frequencies derived from monthly water and wetness binary masks
2. A water and wetness presence index (WWPI) layer, which is a combination of the water and wetness frequencies and indicates the likelihood that a particular location is a wet soil or water surface

The selected period for the processing should cover at least one year to provide valid results; otherwise, the data might be insufficient for accurate water and wetness detection. The recommended period to get meaningful results is at least two years, however, the classification of permanent and temporary water and wetness often only makes sense considering several years.

Important note: The GlobWetland-Africa water and wetness (wet soil) mapping service is designed to work with Sentinel-1 GRDH and Sentinel-2 L1C images, which means the earliest start date is 01.01.2017. Users do not need to select the input files; this is an automated part of the service.

Submitting a request

Users can access the Wetland Pre-Inventory processing service via the following link:

https://wetland-processing.geoville.com/

After accessing the website, users are requested to register or provide their login credentials (cf. Figure 1). A user needs to provide user details like corresponding e-mail address and affiliation during the registration process. The registration process is completed by confirming the validity of the e-mail address (i.e., the system will send an e-mail to the specified e-mail address with a link to confirm the registration; this link is valid for 5 minutes). Afterwards, users can log in to the main page (cf. Figure 2). The main page shows a map and geographic search functionality, allowing you to zoom to your region of interest. In the top-right part, user details can be accessed and changed. The left part of the page allows defining a new AOI.

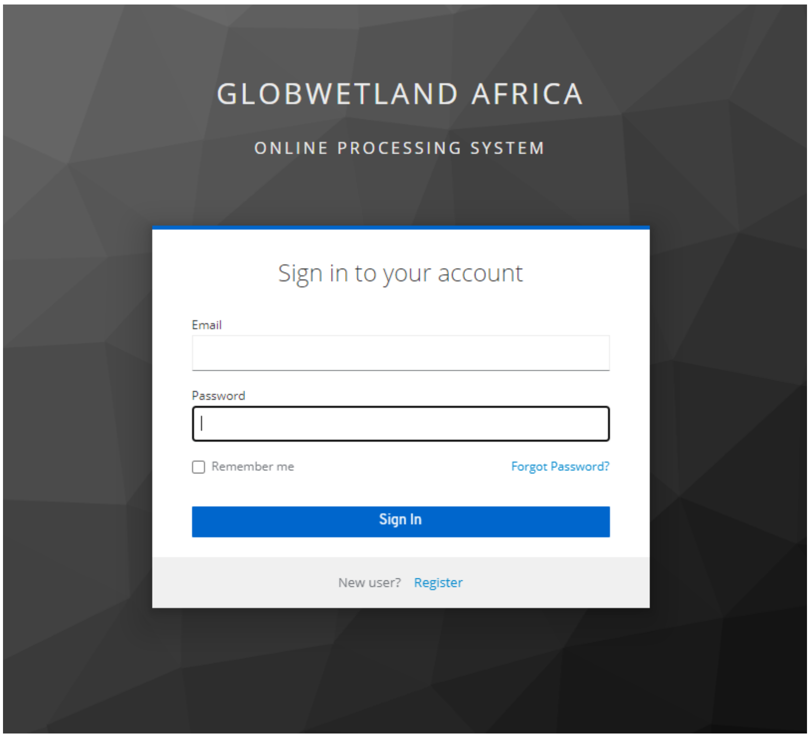

Figure 1: User registration and login.

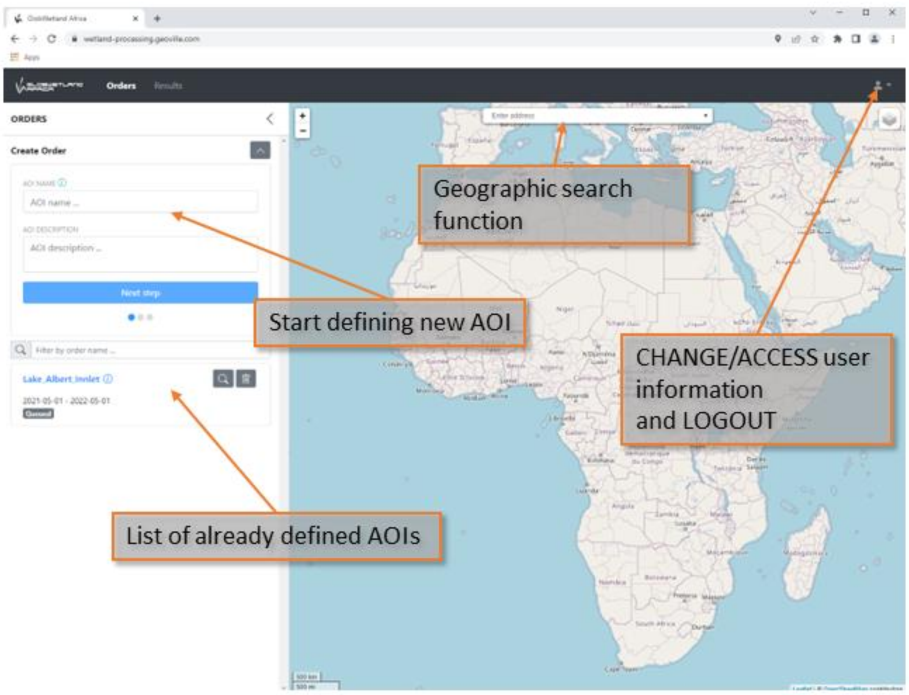

Figure 2: Welcome (Orders) page.

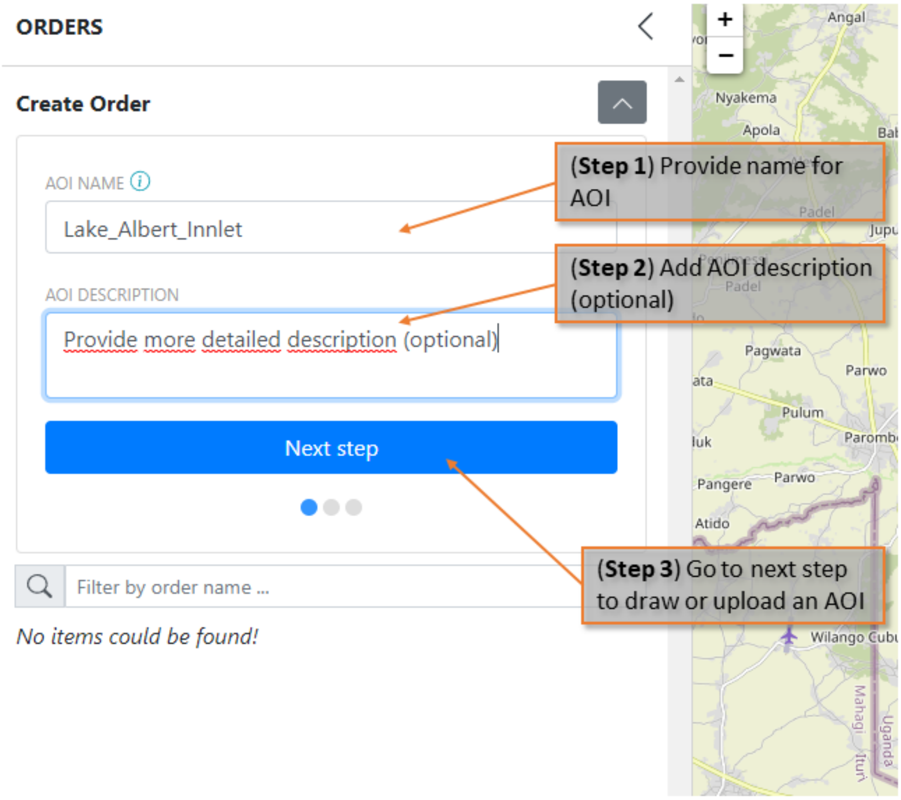

Figure 3: Start creating an order by specifying AOI.

To define a new AOI allowing the initiation of the EO data processing and creation of the EO-based Wetland pre-Inventory product (cf. dialogue explained Figure 3), a user needs to specify an AOI and period of interest:

- **Area of interest [MANDATORY]:** First, a name for the AOI needs to be provided (cf. Figure 3); the description of the AOI is optional. The AOI should be large enough to include enough reference data for all target classes. The AOI can be simply drawn into the map canvas using the editing tools in the left part of the map (cf. Figure 4) or being uploaded as a GeoJSON file. **Be aware that multi-polygons provided via a GeoJSON file are not supported and will cause a failure of the job submission**. If the GeoJSON file has been correctly uploaded, the respective AOI will appear on the web map.
- **Start Date [MANDATORY]**: Please select the period's start date for which the Wetland pre-Inventory shall be processed (cf. Figure 5). This service currently uses Sentinel-2 data at L2A processing level, which has been available since 2017. Hence the start date must not precede this date. This service automatically sets the end date to the last day of the selected month, irrespective of the chosen day (DD). Only data from within the defined period are considered.
- **End Date [MANDATORY]**: Please select the period's end date for which the Wetland pre-Inventory shall be processed (cf. Figure 5). The end date must be at least one year later than the start date.

This service automatically sets the end date to the last day of the selected month, irrespective of the chosen day (DD). Only data from within the defined period are considered.

After successfully submitting the processing job, the user will see a similar overview as shown in Figure 6, with the new AOI listed on the left-hand side indicating the current processing status. The processing of the data will usually take a couple of days.

Users can check the status and progress of the submitted AOI on the "Results" page (cf. Figure 7). This page shows a list of the submitted AOIs, including their status. The status can be

- *Queued*, i.e., submitted, but the processing has not yet started
- *In Progress*, i.e., the processing started but is not yet finished
- *Finished*, i.e., the data is ready for download
- *Failed*, i.e., the processing of the data failed

When the processing is finished, users can use the download button to download the resulting data. Further analysis and editing of the downloaded data (in GeoTIFF format) can be done by using QGIS and the provided GlobWetland Africa Toolbox (or in any other GIS applications, such as ArcGIS, SNAP, or Monteverdi). A more detailed description of the results is provided in *Service Outputs* section.

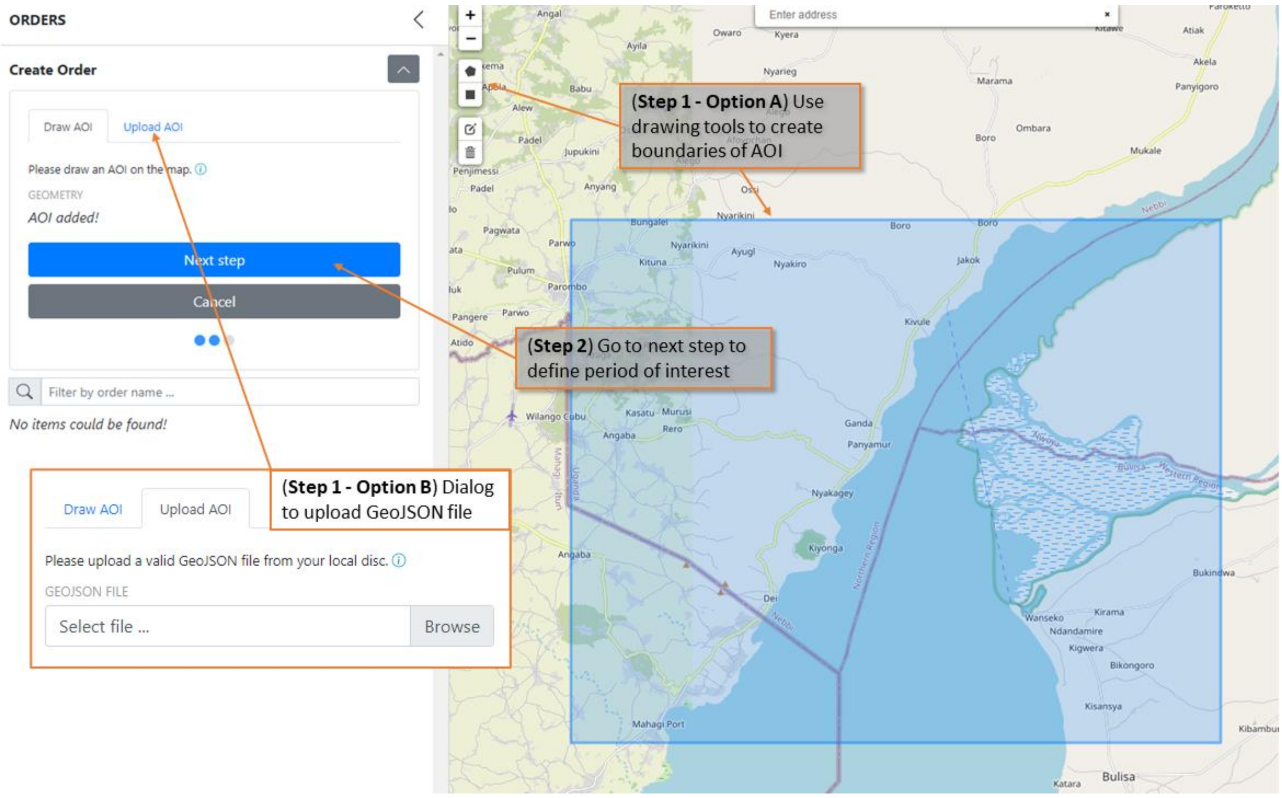

Figure 4: Dialog and tools to draw or upload an AOI.

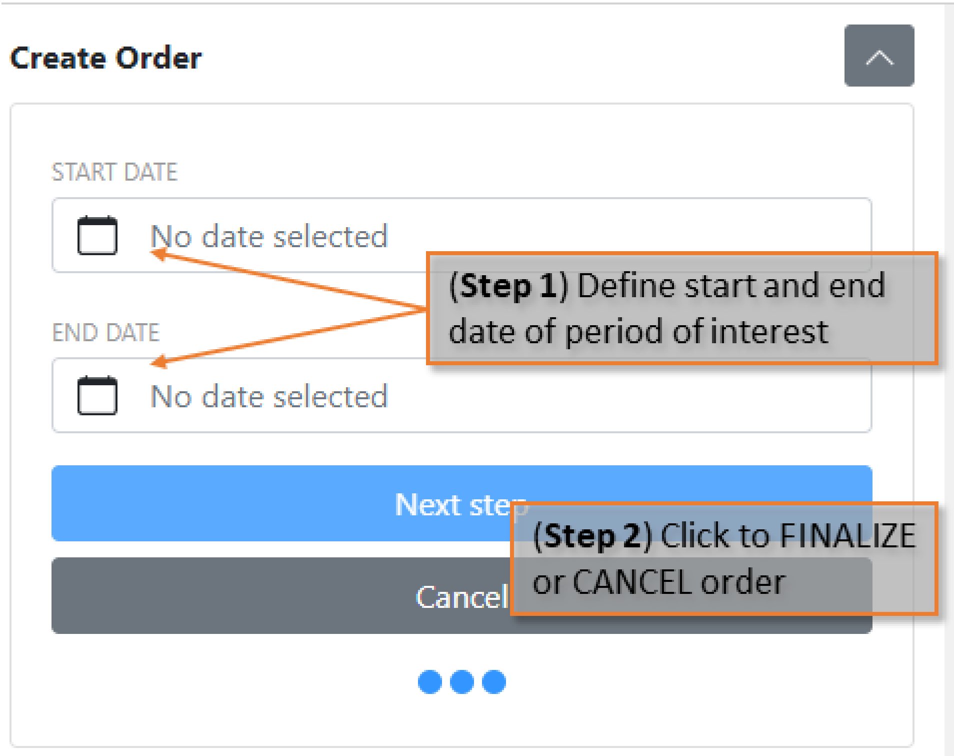

Figure 5: Dialog to specify a period of interest and finalise the order.

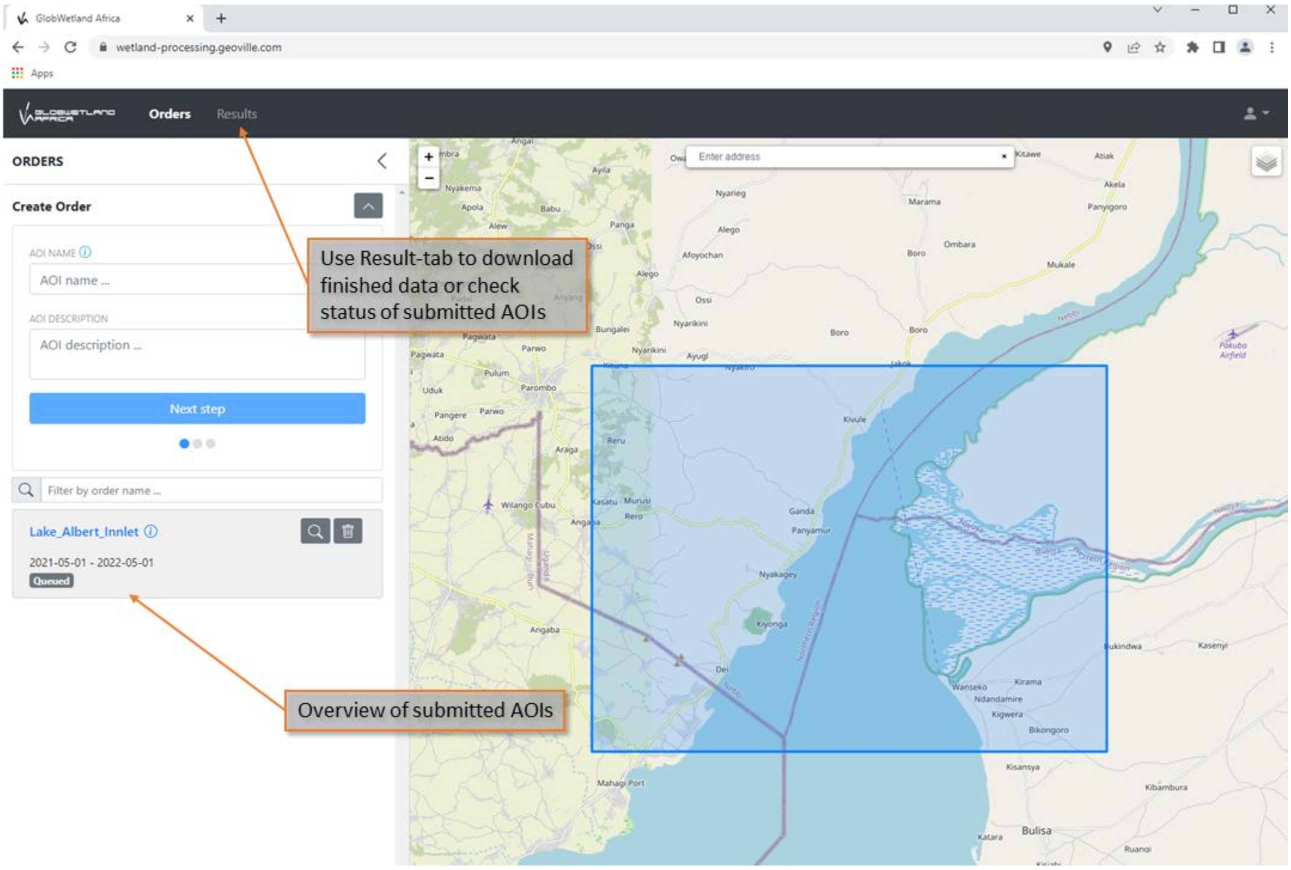

Figure 6: Page overview after submission of AOI for processing.

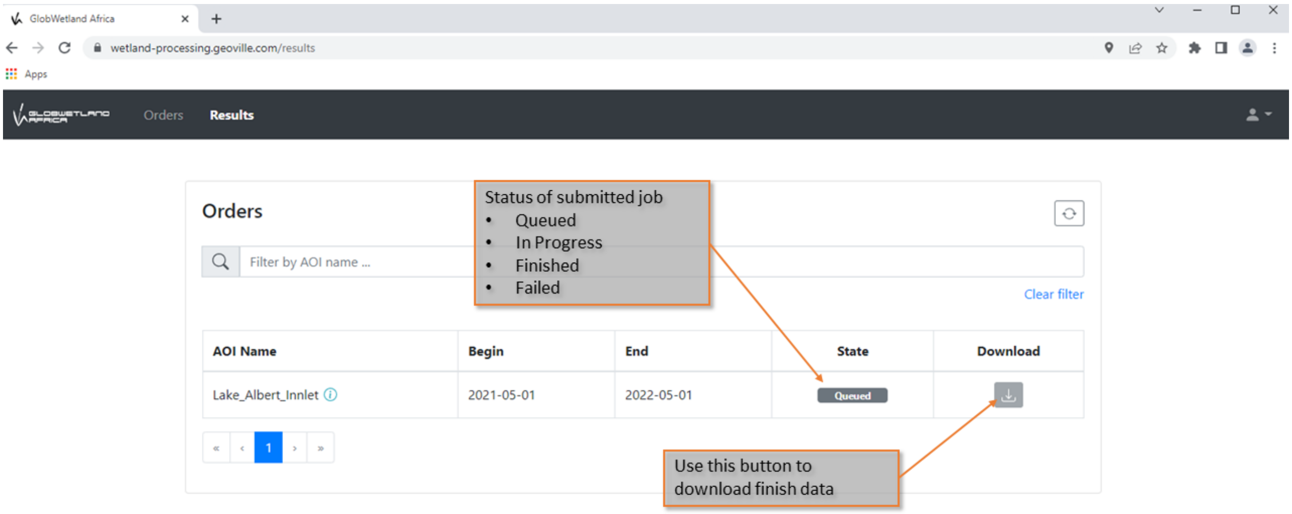

Figure 7: Overview of "Results" subpage.

Service Outputs

The Wetland Pre-Inventory Service will generate the following raster layers (cf. Table 1) as GeoTIFF in 10-meter spatial resolution. The service outputs focus on the physical properties of water and wet soils but do not detect wetlands in the ecological sense. However, when mapping wetlands areas, one general issue is that no single scientific definition exists. The methodology applied on a large scale provides a consistent and objective map of water and wet surfaces, building the foundation for a final wetland classification according to specific user definitions and needs. Incorporating additional information (e.g., information about land use) will allow users to compile the final wetland map.

Table 1: Output layers of Wetland Pre-Inventory service.

Output	Unit/range	Count output files
Water/Wetness classification (total, sparse veg., dense veg., soil)	0 - Dry, 1 - Permanent water, 2 - Temporary water, 3 - Permanent wet, 4 - Temporary wet, 255: no data	4
Wetland probability	1 - Permanent Water, 2 - Wetland (high prob), 3 - Wetland (medium prob), 4 - Wetland (low prob.)	1
WWPI	Water & Wetness presence index [1:100], 255: no data	1
Water frequency	[1:100], 255: no data	1
Wetness frequency	[1:100], 255: no data	1
Sparse vegetation wetness frequency	[1:100], 255: no data	1
Dense vegetation wetness frequency	[1:100], 255: no data	1
Bare soil wetness frequency	[1:100], 255: no data	1
Dry frequency	[1:100], 255: no data	1
Nummer of observations	[1:n] where n is the length of the time series in months	1

In the following paragraphs, we provide a short description of the various output products.

- **Water/Wetness classification**: The four output layers provide a rule-based classification considering all pixels (total), bare soil (soil), sparsely vegetated (sparse veg), and densely vegetated (dense veg.) areas. The provided classes (dry, permanent water, temporary water, permanent wet soil, temporary wet soil) are derived from the various frequency products according to the rules as summarised in Table 2.

- **Wetland probability**: This layer provides a probability-based classification of wetland areas based on the Water/Wetness classification and the Water and Wetness Presence Index (WWPI) according to the rules as summarised in Table 3.
- **Water and Wetness Presence Index (WWPI):** The Water Wetness Presence (=Probability) Index is derived based on the water and wetness frequencies. It is calculated using

$$WWPI = \frac{\sum water + (0{,}75 * \sum wet)}{n} * 100$$

  where ∑water is the number of water occurrences per pixel, ∑wet is the number of wetness occurrences per pixel and n is the number of valid observations per pixel. The WWPI is given in percent.

- **Frequency layers**: all monthly masks for the various surface types (dry, water, bare, sparsely and densely vegetated) are merged into separate image stacks to calculate the individual frequencies according to the following formula

$$f(ST) = \frac{1}{n}\sum_{i=1}^{n} x \sim [0{,}1]$$

  where f is the frequency per surface type (ST) and pixel, n is the number of valid observations per pixel, and x the pixel value of the classified image.

- **Number of observations**: Number of monthly observations considered to calculate the output products.

Post-Processing

For the post-processing (making use of the GlobWetland Africa Toolbox) of the Water Wetness product, different layers can be helpful. A good example is the Global Human Settlement Layer (GHSL). This has a resolution of 10 meters and corresponds to the product resolution and was created with data from 2017 to 2018. This layer is suitable for masking out sealed areas and reducing wrong classified water or wetness pixels. This is especially the case in large factory buildings with reflective roofs, greenhouses, and airports.

In addition to this layer, the CCI land cover layer can also be used. It was created using Sentinel-2 data from Dec 2015 to Dec 2016. The layer covers the entire continent of Africa but only has a resolution of 20 meters. In addition to the "Build up areas" class, other classes can also help mask out errors, for example, the “cropland” or “tree cover” class. Similar to the CCI land cover layer, a useful and only recently released product is the ESA World Cover layer based on Sentinel-2 and Sentinel-1.

Furthermore, Open Street Map provides helpful information in some areas. This is a freely available dataset that can be downloaded country by country. It contains, for instance, roads and railroads lines that can complement the previously mentioned layers.

How to best use the provided information

The proposed methodology for the Wetland pre-Inventory underwent extensive testing over large areas and across different bio-geographic regions. Although training and evaluation data were used to develop and validate the methodology, it is now a fully automated approach without the need for training data. It relies on a dynamic, tile-based image thresholding methodology to identify open surface water and wet soil (also referred to as wetness) areas using multitemporal optical (Sentinel-2) and radar (Sentinel-1) satellite imagery.

The validation of selected monthly water and wet soil masks yielded highly satisfying results reaching at least 92% overall accuracy for various large-scale test regions (with water exceeding 96% user accuracy). Moreover, plausibility checks using climate data and site descriptions by Ramsar indicate that the derived classifications convey a plausible representation of water and wetness occurrence throughout the year. Typical omission errors occur along the edges of wetlands and narrow streams or valleys. Legitimate misclassifications occasionally occur within low lying forests, densely vegetated wetlands, and peatlands. Wetness among peatlands is often only present at greater soil depth and only detectable right after the thawing period in spring or summer in the case of northern latitudes. As a result, the contrast between the wetness of the peatland and the surrounding dry area is less pronounced, reducing the capability of the algorithm to delineate the wetland accurately.

When mapping wetland areas, one general issue is that no unique, scientific definition of wetlands exists (cf. Tiner, 2016). Thus, while some definitions include agricultural areas as wetlands, others do not. With the underlying approach, we present a methodology to consistently detect the occurrence of open water and wet soils (wetness) serving as a pre-inventory of wetlands and building the foundation for a final wetland classification according to the user definition and needs. The classification product provided through the service (i.e., Water/Wetness classification total) is used in the context of the Copernicus Pan-European High-Resolution Layer on Water and Wetness (2015 and 2018; Langanke et al., 2016). Using this classification together with the provided subclasses (i.e., the distinction of vegetation cover fraction) and the additional supporting products (i.e., WWPI, frequency layers) as provided with the service, and combining them with additional layers (e.g., other land cover products, Open Street Map, etc.) as described below in the "Post processing" section, will enable users to establish a regional or national Wetland Inventory product. The WWPI can also serve as a starting point to identify and delineate areas prone to wetlands (pre-inventory) and apply a more detailed land cover nomenclature (e.g., Ramsar definition; Tiner, 2016) to these areas.

Irrespective of the various existing wetland definitions and nomenclatures, tracking long-term changes of the WWPI will allow detecting changes in the occurrence of water and wet soils in a subjective manner and independent of any definitions.

Processing methodology (background)

The following simplified flowchart shows the main processing blocks within the Wetland pre-Inventory service. In the following paragraphs a short description of the individual blocks will be provided.

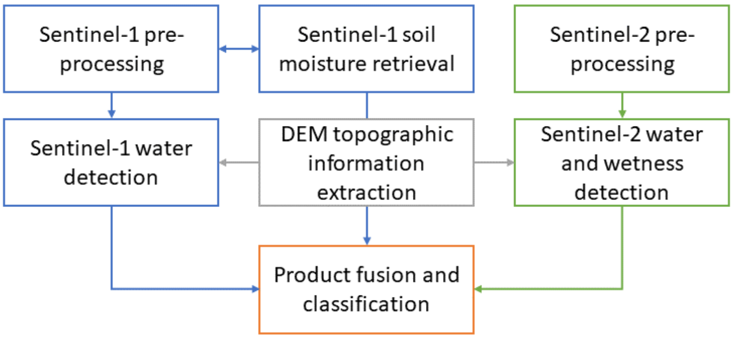

Figure 8: Processing blocks and flow within the Wetland pre-Inventory processing service.

Sentinel-1 pre-processing

The Sentinel-1 data is pre-processed as follows using the newest ESA SNAP software release:

- Orbit geometry corrections: application of the precise orbit files to the individual images, which can be downloaded days to weeks after generation from the Copernicus Precise Orbit Determination (POD) Service
- Border noise removal: removal of artefacts originating from the initial preparation of the raw Sentinel-1 data when the signal was transformed into spatial imagery
- Radiometric calibration: conversion of the radar reflectivity stored as Digital Numbers (DN) to physical units called radar backscatter coefficients or radar cross-sections
- Multilooking (only for soil moisture): this step degrades the spatial resolution while the radiometric resolution is improved, and speckle noise is reduced
- Speckle filtering: reduction of speckle noise originating from random interference of wave contributions from the many individual scatterers within one resolution cell based on the Refined Lee (Lee, et al., 1994) filter
- Terrain correction: correction of image distortions like layover and foreshortening, which are a result of the side looking acquisition geometry of a SAR system.

Sentinel-2 pre-processing

The Sentinel-2 imagery is pre-processed by applying Sen2Cor (v. 2.10) atmospheric correction and cloud screening. An additional cloud shadow removal step is applied to detect missed shadows. Monthly image composites are then generated by using the geometric median algorithm (Roberts, et al., 2017). For each composite, water and wetness sensitive spectral indices such as the Normalized Difference Water Index (NDWI) are computed.

DEM topographic information extraction

The Topographic Wetness Index and Height Above Nearest Drainage (HAND; Rennó, et al., 2008) indices are calculated and used to identify areas which are unlikely to contain wet soil surfaces or surface water.

Sentinel-1 water detection

A pixel-based adaptive thresholding approach is applied to the monthly aggregated (e.g., median) Sentinel-1 radar backscatter signals. The method uses a dynamic variable backscatter threshold for each pixel based on statistical information from the adjacent pixels. The resulting water mask is then masked by the HAND index.

Sentinel-1 soil moisture retrieval

If the area of interest is non or sparsely vegetated, wetness masks derived from soil moisture estimations are included in the classification. Soil moisture is estimated by a multi-sensor, time-series-data-based approach. Starting from the course resolution SMAP (9km) soil moisture data and MODIS NDVI imagery, a statistical downscaling procedure using Artificial Neural Networks (ANN) is applied (Alemohammad, et al., 2018). The desired target resolution is reached by performing the downscaling procedural iterative. To finish, the semi-empirical Water Cloud Model (Attema & Ulaby, 1978) is calibrated and applied to high-resolution Sentinel-1 time series data. The method is limited by the moderate Sentinel-1 wavelength (C-Band), especially in densely vegetated wetlands such as swamps or mangroves. To combine the soil moisture with the Sentinel-2 wetness masks, moisture binary masks are derived by applying a threshold (e.g., at 35.0 Vol.%).

Sentinel-2 water and wetness detection

The Sentinel-2 water detection methodology uses water sensitive spectral indices (NDWI, mNDWI, MBWI) computed from the monthly composites. Similar to the Sentinel-1-based water detection, a dynamic tile-based thresholding method as described in Ludwig et al. (2019) determines water and non-water areas on a monthly basis.

For the detection of wet soil (wetness) surfaces, three different types of vegetation coverage are considered. Therefore, all non-water areas are split into either bare soil, sparsely vegetated, or densely vegetated areas using an NDVI-based criterion to distinguish these types. For each of these classes, a particular combination of spectral indices is used to differentiate between dry and wet surfaces. This is done in a similar manner as the water detection making use of dynamic tile-based thresholding. A detailed description of the used indices and the algorithm is given in Ludwig et al. (2019).

Product fusion and classification

After having the monthly masks separately derived for the optical and SAR monthly data, both results need to be fused into combined monthly masks. This is done using a rule-based approach.

Based on the cumulative water, wet and dry layers, and the total number of valid monthly observations, frequencies (in percent) are calculated for water, wet (soil, dense vegetation, sparse vegetation and all combined) and dry, which gives six water, wet and dry frequency layers. These relative frequencies form the basis to swiftly generate the thematic classification of permanent water and temporary wetness for the main product.

Table 2: Ruleset for the Wetland pre-Inventory classification.

		Frequency layers		
Code	Class	Water relative frequency	Wet relative frequency	Dry relative frequency
1	Permanent water • always water	> 85% Water	<=15% Wet	<=15%
2	Temporary water • alteration of dry and water • alteration of wet and water • with varying degrees of wetness • water instances dominate over wet	>25 - 85% Water	15 - 75% Wet Water > Wet	<=75%
3	Permanently wet areas • always wet	<=25%	> 75% Wet	<=25%
4	Temporary wet areas • alteration of dry and wet • with minor instances of water • wet instances dominate over water	25 - 75%	25 - 75% Wet > Water	<=75%
0	No water/no wet (dry) • always / mostly dry • with minor instances of water or wet	<=25%	<=25%	> 75%

Table 3: Classes of wetland probability map including classification rules

Code	Wetland Probability Class	WWPI	Water / Wetness class (cf. Table 2)
1	Permanent Water		Permanent water
2	High Wetland Probability	50 < WWPI < 100	Permanently wet or temporary water
3	Medium Wetland Probability	25 < WWPI < 50	Temporary water
4	Low Wetland Probability	0 < WWPI < 25	Temporarily wet

Input Data

This chapter provides a short description of the main input data used within the Wetland pre-Inventory product service. Table 4 provides a summary of the data in use and to which part in the processing they contribute.

Table 4: Required input data for the WI algorithms and workflows

Sensor	Product	Resolution	Method
Sentinel-1	GRDH	10m	Water detection, Soil moisture, Wetland type classification
Sentinel-2	L1C/L2A	10m	Water & wetness detection, Soil moisture, Wetland type classification
SRTM	SRTM v4	90m	TWI, HAND for water & wetness detection
SMAP soil moisture	SMAP_L3_SM_P_E	36km / 9km	Soil moisture
MODIS NDVI	MYD13A3, MYD13A1	500m / 250m	Soil moisture
IMERG	3B-HHR-L.MS.MRG.3IMERG daily	10km	Soil moisture post-processing

Sentinel-1

Sentinel-1 currently consists of two satellites carrying C-band Synthetic Aperture Radar (SAR). Sentinel-1A was the first satellite launched as part of the Copernicus constellation of satellites, operated by the European Space Agency. It was launched in April 2014, and the next, Sentinel-1B, was launched two years later (Sentinel-1B stopped providing data after the end of December 2021 due to a failure of the sensor). Another two Sentinel-1 satellites are in development. They operate on a Near-Polar Sun-synchronous orbit at an altitude of 693 km.

The satellites have four operating modes:

- Strip Map (5x5m over an 80 km swath)
- Interferometric Wide Swath (5x20m over a 250 km swath)
- Extra Wide Swath (25x100m over a 400 km swath)
- Wave Mode (5x20m, producing 20x20 km sample images at intervals of 100km)

All modes but the last operate with a single [HH or VV] or double [HH + HV or VV + VH] polarisation, while Wave Mode only offers single (HH or VV) polarisation data products.

Sentinel-1 one is used for:

- Marine monitoring - sea-ice, oil spills, shipping
- Land monitoring - agriculture, forestry
- Emergency response - flooding, earthquakes, volcanoes, landslides

Sentinel-2

Sentinel-2 consists of two satellites collecting optical imagery at a temporal resolution of approximately five days. The sensors have 13 bands, covering the visible, near-infrared, and short-wave infrared parts of the spectrum. The visible bands (2, 3, 4) and the NIR band (8) have a resolution of 10m, while all the other bands have resolutions of either 20m or 60m. The twin satellites cover all land surfaces between 56° S and 84° N, plus coastal waters and the Mediterranean Sea. They conduct a sun-synchronous orbit at an altitude of 786 km and have a 290 km wide field of view.

Sentinel-2A was launched in June 2015, and Sentinel-2B was launched in March 2017. Their main applications include:

- Landscape monitoring for land-use change
- Agricultural crop monitoring
- Vegetation and forest monitoring
- Inland and coastal water monitoring
- Ice, glacier, and snow cover monitoring
- Flood mapping and management

Shuttle Radar Topography Mission (SRTM)

SRTM is a publicly available digital elevation model produced by NASA. Data were collected over an 11-day Space Shuttle mission in February 2000, using a technique known as Interferometric Synthetic Aperture Radar. Initially, the highest resolution terrain model was withheld, however, this was publicly released in 2014, allowing anyone to utilise the 30m global digital elevation model. Most parts of the world are covered by this dataset which ranges from 54° S to 60° N, although some areas have been restricted.

The original SRTM database included voids or no-data areas - particularly in very mountainous areas. In these areas, other data sources have been utilised to improve the model – most notably using new interpolation algorithms and auxiliary digital elevation models.

Soil Moisture Active Passive (SMAP)

SMAP is an environmental monitoring satellite launched by NASA in January 2015. It orbits at an altitude of 680 km in a near-polar sun-synchronous orbit carrying a passive radiometer and an L-band Synthetic Aperture Radar. The 1000 km wide swath allows an almost global revisit every two to three days, at a resolution of one to three kilometres. The instruments onboard can penetrate through moderate vegetation and sense moisture and the freeze-thaw state in the top five centimetres of soil.

The SMAP programme monitors hydrological and ecosystem processes, including the exchange of water, carbon, and energy between the Earth and the atmosphere. The data assists in:

- Weather and climate forecasting
- Drought monitoring
- Flood and landslide forecasting
- Crop yield forecasting
- Crop water stress monitoring
- Human health initiatives including famine, heat stress, virus transmission rates, and disaster response

Moderate Resolution Imaging Spectroradiometer - Normalised Difference Vegetation Index (MODIS NDVI)

The MODIS sensors orbit the Earth on the Terra and Aqua satellites, launched in 1999 and 2002 respectively. They provide almost daily coverages with spatial resolutions of 250 m to 1 km, however, the used product is aggregated to eight days. The instruments detect surface reflectance and thermal emission across 36 bands, with wavelengths ranging from 0.4 to 14.4 µm. Generally, the MODIS instruments were designed to provide large-scale data about Earth's cloud cover and radiation budget, as well as oceanic processes, land-based processes, and those occurring in the lower atmosphere.

The Normalised Difference Vegetation Index (NDVI) is calculated using the formula:

NDVI = (NIR – RED) / (NIR + RED)
where NIR is the reflection in the near-infrared spectrum and RED is the reflection in the red range of the spectrum.

The NDVI can be calculated using data from MODIS, and is useful for global vegetation monitoring as it compensates for changes in lighting conditions, surface slope, exposure, and other factors. The index is a simple measure of plant health based on how plants (specifically how chlorophyll and cellular structures) reflect various wavelengths. The equation returns a number between -1.0 and +1.0, where moderate values of 0.2 to 0.3 indicate shrubs and meadows, and larger values of 0.6 to 0.8 indicate temperate and tropical forests.

Integrated Multi-satellitE Retrievals for Global Precipitation Measurement (IMERG)

Global Precipitation Measurement (GPM) is a joint mission between several international space agencies, most prominently JAXA and NASA. At the centre of the GPM mission is the Core Observatory, launched in February 2014 and rotating in a low earth orbit of just over 400 km. This satellite has a dual-frequency precipitation radar operating on 245 km and 120 km swaths, as well as a passive microwave imager collecting precipitation data across an 885 km swath. The GPM Core Observatory is also assisted by a constellation of other spacecrafts.

IMERG, part of the overall GPM project, is an algorithm which combines data from a number of microwave precipitation monitoring satellites and develops the data into 0.1° x 0.1° grids at a temporal resolution of 30 minutes. Initially, it provides a quick estimate, which evolves and becomes more precise as more data is added, merging and interpolating the information until finally, monthly gauge data is added to create a research-level data product.

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