Kathrin Weise, Bettina Hedden-Dunkhorst
and Simone Wulf (eds.)

Using Satellite Images for Wetland Management and Planning in Africa

A Handbook for Wetland Managers and Practitioners

Federal Agency for Nature Conservation

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Editors
Kathrin Weise
Bettina Hedden-Dunkhorst
Simone Wulf

Lead author
Kathrin Weise

Federal Agency for Nature Conservation

Cover picture:
Photo on Top: Sentinel-2 satellite image of the Northwest coast of Madagascar and the Mahavavy-Kinkony Reserve
Photo Bottom Left: Enlarged image section with fields and settlements along the Mahavavy River, Madagascar
Photo Bottom Right: Enlarged image section with mangrove forests in the Mahavavy River Delta, Madagascar
(All Photos: © Copernicus Sentinel 2020, provided by ESA)

Editors: Kathrin Weise, Bettina Hedden-Dunkhorst and Simone Wulf

Lead author:
Kathrin Weise
Jena Optronik GmbH
Otto-Eppenstein-Strasse 3, 07745 Jena, Germany
E-Mail: kathrin.weise@jena-optronik.de

Scientific supervision:
Dr. Bettina Hedden-Dunkhorst
Simone Wulf
German Federal Agency for Nature Conservation (BfN)
Division I 2.3: International Nature Conservation
Konstantinstr. 110, 53123 Bonn, Germany
E-Mail: bettina.hedden-dunkhorst@bfn.de, simone.wulf@bfn.de

Contributing authors or contributions from:

Benin	Francois-Corneille Tofodji Kedo-wide, Maurille Elegbede, Marius Hugues Degla, Eliane Zekpete, Anne-Marie Jesugnon Ahandessi, Berny´s Zoumenou, Innocent Akpaca, Iyabo Léa Hermione Amoukpo, Euloge Lima
Botswana	Leungo Leepile
Burkina Faso	Djeneba Ouattara/Bamba, Mahamadou Tiendrebeogo
Côte d'Ivoire	Kouassi Firmin Kouame, Aboubakar Toure
Germany	Bettina Hedden-Dunkhorst, Katrin Graefe, Simone Wulf
Guinée-Bissau	Joaozinho Sa
Kenya	Alice Bett
Liberia	Joseph F. Charles, Emmanuel T. Olatunji, Berexford Jallah, Levi Z. Piha
Madagascar	Volatiana Rahanitriniaina
Malawi	William Mgoola
Mali	Ali Abdoulaye Poudiougo, Youssouf Traore
Mauritius	Aradhna Goury
France	Anis Guelmami
Mozambique	Sidonia Muhorro Gueze
Namibia	Billy Kazonganga
Niger	Ibrahim Madougou, Maliki Alhouza
Nigeria	Ahmed Labaran
Senegal	Abdoul Aziz Diouf, Adja Aïssatou Sy, Mamadou Sidibe
Sierra Leone	Alfred Isa Gassama, Yatta H. Kamara-Kattah
South Africa	Umesh Bahadur
Togo	Kossi Agbesime Agbeti, Mensa Aboudou, Eric K. G. Agbessi, Mamalnassoh Abiguime
Uganda	Paul Mafabi, Asadhu Ssebyoto
Zambia	Frank Chisoni Nyoni, Rodwell Chandipo, Siyamibila Mukuwa, Vivas
Zimbabwe	Lioli Fisiwe Mary-Ann Maguma

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Our special thanks go to the Secretariat of the Ramsar Convention and in particular to the Africa team of the Secretariat for your assistance, support and encouragement during the lifetime of the Wetland-Afrika project.

1 Introduction

1.1 What this handbook provides

This handbook aims to demonstrate how satellite images can support information-based management and planning of wetlands, with a focus on Africa. It serves as a manual and roadmap on how to use available remote sensing data and tools for wetland planning and management challenges. However, the handbook is also applicable to other ecosystems and regions outside of Africa.

The handbook was developed specifically for wetland managers and practitioners. It aims to facilitate the uptake of satellite-based approaches by showcasing their applicability and providing concrete examples to guide and inspire their implementation. The manual specifically refers to the GEOclassifier toolbox which was developed for wetland managers in the context of several internationally funded projects. This toolbox is available free of charge. It can be used, for example, to display and analyse satellite images and to map or classify wetland extents and conditions and changes thereof. The resulting satellite products can help to visualize improvements or degradation of wetlands, plan and discuss management measures and foster communication among experts and stakeholders or with the general public. This handbook has been prepared as part of the research and development project “Wetland-Afrika”. The project is introduced in the following section of this chapter. Chapter 2 shortly outlines the state of wetlands in Africa, typical drivers of change and restoration options. Chapters 3 and 4 offer hands-on insights on how to obtain relevant information, based on remote sensing data and tools that are available free of charge. In chapter 5, the handbook introduces the products that can be generated with the GEOclassifier toolbox regarding satellite-based maps and indicators. In order to put maps and indicators into a broader context of application, chapter 6 outlines the applicability of the products in relation to the challenges that wetland management, planning and reporting face. Finally, chapter 7 includes a series of unique case studies prepared by wetland managers and practitioners from different countries and regions across Africa. The examples reflect on wetland challenges and suggest how Earth observation information can help to address these challenges by integrating it into planning and management as well as communication and cooperation among wetland stakeholders.

1.2 The Wetland-Afrika project behind the handbook

Information on wetland extent, their ecological character and ecosystem services is often scattered, underestimated and difficult to find and to access. Satellite-based information can help to close information gaps and support planning, management and reporting. Several projects have therefore developed monitoring tools to provide information on wetland ecosystems, derived from Earth observation data. These include, in chronological order, European Space agency’s projects GlobWetland I & II (GW-I & GW-II) and GlobWetland Africa, the European Union-funded Satellite based Wetland Observation Service (SWOS), and the project Wetland-Afrika.

The Wetland-Afrika project (2018-2020) focused on the application of information from Earth observations and aimed to encourage wetland managers and specialists to make better use of satellite images and existing software as a basis for sustainable wetland planning and management. In order to introduce the toolbox GEOclassifier and to demonstrate its usability in the context of wetland management, planning and policy challenges in Africa, a consultation and hands-on process was part of the project. It included training sessions by the technical project team for wetland managers and specialists from over twenty African countries. With this approach local knowledge and management experiences could be disclosed and integrated and is also incorporated into this handbook.

Wetland-Afrika was initiated, supervised and supported by the German Federal Agency for Nature Conservation (BfN), which holds the national focal point for the Ramsar Convention's Scientific and Technical Review Panel (STRP). The project was funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), which is also the German Designated Ramsar Administrative Authority.

The technical project team at Jena-Optronik GmbH worked in very close cooperation with the Ramsar Convention on Wetlands, in particular with the Africa team at the Ramsar Secretariat and with the Scientific and Technical Review Panel of the Convention.

Wetland experts from twenty African countries, including representatives from several regional initiatives, participated in the project and contributed to two regional consultation and capacity building workshops. The first workshop was hosted and supported by the Ramsar national focal point and additional wetland organizations in Zambia and the second workshop, carried out in as a virtual video workshop was supported by the Ramsar national focal point of Benin.

The African wetland experts and practitioners supported the preparation of this handbook and elaborated and demonstrated in eleven case studies the added value of satellite-derived information for the protection and restoration of wetlands from a users' perspective.

Figure 1: Dja river in Cameroon (Copyright: Kathrin Weise, Jena-Optronik GmbH)

2 Wetlands in brief - status quo and challenges

Wetlands provide essential ecosystem services for people and nature, such as water supply and purification, disaster risk reduction, climate change mitigation and many others. Yet, wetlands are also fragile and threatened; they are one of the fastest declining ecosystem types worldwide. About 64% of wetlands disappeared since 1900 and populations of inland wetland species have declined by 81% since 1970 (Ramsar Convention 2018a).

The pressure on wetlands is likely to intensify in the coming decades due to increased global demand for land and water as well as due to climate change. African wetlands are particularly vulnerable (Ramsar Convention 2018a). Increasing rates of land conversion to agricultural and urban uses, infrastructure development, water diversion and water pollution are some of the main factors causing wetland degradation and loss (Millennium Ecosystem Assessment 2005).

At the same time, water scarcity and more frequent and severe droughts and floods cause major risks for societies. The degradation of wetlands exacerbates these problems. For example, hydrological disconnection of floodplains from rivers not only leads to a decrease in habitat types and biodiversity, but also enhances the risk of devastating flood events. Moreover, drained peatlands lose their ecosystem services in terms of water storage and regulation, while their land surface subsides and the oxidation of drained peat causes the release of enormous quantities of CO_2 into the atmosphere, thereby further contributing to climate change (Ramsar Convention 2018b). In this context, appropriate wetland planning and management is essential. Through the development and implementation of suitable policies and strategies, drivers of wetland loss can be addressed and adequate measures to prevent, mitigate and reverse wetland degradation can be implemented. In many cases, restoration measures are necessary to reach a good ecological status of water bodies.

Some restoration techniques that are applied globally include:

- Reduction of pressures and of drivers of wetland degradation, change of land use to more sustainable practices (wise use)
- Water flow regime re-naturalization, provision of environmental minimum flows in rivers, raising water table in peatlands, closing drainage ditches, reducing water abstraction, cultivation of crops with less water requirements to reduce water demand from the wetland, paludiculture
- Re-meandering river streams and reconnecting riverbeds, removing barriers and restoring connectivity, artificial flash floods, sediment flushing from reservoirs
- Restoration of wetland vegetation, e.g. replanting riparian forests or coastal mangroves
- Reduced inflow of nutrients and pollutants, improving water quality through bio-removal, construction of artificial wetlands, green filters and buffer strips.

The implementation of these and other measures requires intensive planning and management. Satellite images can provide a good information basis in this regard.

Various wetland types characterize the African environment in its river basins, mountains, desert regions and coastal zones and support a great diversity of plant and animal species. Besides, African wetlands include some of the most productive ecosystems in the world, providing essential natural resources for people that can be transformed into food, energy, transportation, etc. (Millennium Ecosystem Assessment 2005).

Africa is still home to a significant number of healthy wetlands. However, many wetlands will experience or are already experiencing high pressure from human activities. The most impactful pressures are drainage for agriculture and settlements, but also changes in wetland water quality due to industrial waste water and agricultural pesticides, or invasive alien species leading to the loss of endemic species and, thus, a resilient ecosystem (Ramsar 2018a). The human pressure on wetlands is expected to increase due to the growing population and expanding demand for food and clean water (Niasse et.al 2004).

Wetland managers in Africa primarily face challenges with regard to environmental and ecological degradation, management and planning, as well as conflicts of interest and stakeholder communication and cooperation. The causes or drivers for these challenges are very diverse.

In this context, wetland planning and management are crucial for sustainable development. Satellite-derived products, specifically Land Use/Land Cover (LULC) maps and Surface Water Dynamics (SWD) maps as well as the derived indicators deliver important information to address these challenges.

Figure 2: Lake Basaka, Ethiopia (Copyright: Kathrin Weise, Jena-Optronik GmbH)

3 Satellite data for wetland mapping

3.1 The potential of satellite-based wetland observation

Information on the extent of wetlands, their ecological character and their services is often scattered, underestimated and difficult to find and access. Satellite-based information can close information gaps and support wetland planning, management and reporting. Moreover, stakeholders at all levels of governance can be involved more easily and get better access to relevant information.

Mapping is a first step to establish baseline information about wetland degradation, including threats, pressures, decline in ecosystem quality, wetland loss etc. An assessment of the mapping results allows for identifying and defining suitable conservation or restoration measures to maintain wetland functions and ecosystem services. Satellite-based methods enable policy- and decision-makers to gather the necessary historical and up-to-date monitoring information for small and large, near and remote areas for decision-making processes.

More specifically, satellite-based mapping products and calculated indicators can be used to map and assess the condition, the pressures and the extent of wetlands as well as other terrestrial and coastal ecosystems. LULC mapping and LULC change mapping are important to monitor and report on wetland ecosystem trends, to assess threats and pressures to wetlands and to map the degree of success of restoration and conservation measures.

Moreover, mapping of water extents, historical flood events and droughts using SWD maps, vegetation indices, water quality as well as LULC and its changes around wetland ecosystems allows for assessing and reporting on the degree of degradation of ecosystems. This is the basis for identifying potential restoration areas on different scales or assessing the capacity of wetlands to regulate floods, for avoiding disasters in floodplains and coastal areas and for identifying or developing green infrastructure elements.

Satellite-based tools can support reporting and monitoring obligations for environmental policies at different levels (from local to global) and enhance the integration of wetland issues in policies.

Furthermore, communication with stakeholders at different levels of governance can be introduced and maintained more easily using satellite-based products, which are objective and non-negotiable in terms of their factual statements.

3.2 Types of satellite data

Wetlands are very dynamic ecosystems characterized by both spatial and temporal variabilities. Hence, satellite data, in particular from the Sentinel satellites of the Copernicus program that are available free of charge, provide an excellent basis to map wetland areas, in order to derive information on their ecological status and trends and to map long and short-term changes.

Satellite data are available from every part of the world, including large, remote and inaccessible areas. Satellite data allow assessing information from the past, back to the 1970ies, to monitor changes and the impact of conversion, drainage and other human activities for wetlands over long periods. However, additional information sources, in particular ground data, if available, should be integrated to calibrate and validate satellite-based mapping results.

Satellite data used for wetland mapping consist of two different types, radar data and optical data.

Radar Data

Synthetic Aperture Radar (SAR) is an active radar sensor which actively sends out a microwave beam and measures the reflected signal. The SAR signal has the ability to penetrate cloud cover and is completely independent from local light conditions, i.e. images can be recorded despite local darkness. SAR signal backscatter measurements are sensitive to the texture of the surface. Radar images can be used to map information on land cover, in particular water, vegetation types and soil moisture (ESA 2020).

Optical Data

Optical sensors detect the solar radiation reflected from targets on the ground. Optical remote sensing makes use of different wavelengths, from visible to near and short-wave up to thermal infrared sensors, to form images of the Earth's surface. How different materials reflect or absorb solar radiation varies and depends on the wavelength of the radiation. Objects on the ground can therefore be differentiated by their reflectance signatures in multispectral satellite images. Since optical sensors measure reflectance of the light and cannot penetrate clouds, the quality of optical satellite imagery depends highly on weather conditions / cloud-free skies and light conditions / daylight.

Freely available radar data is provided for example by the Sentinel-1 mission. Optical data is freely available from the Landsat missions as well as from Sentinel-2 and -3. The ground resolution (=pixel size) of such data ranges from 300m up to 5m (see next sections).

Very high-resolution data with a ground resolution up to 0,5m can provide more detailed information. However, such data is generally not available free of charge. Most products cover only small areas and are rather costly. In addition, their spectral range and the revisit time are not as high and continuous as for freely available Sentinel and Landsat data. Therefore, the added value and availability of such very high-resolution products for wetland mapping is comparably low.

3.3 Sentinel satellites

The European Union/European Space Agency (EU/ESA) Copernicus Sentinel program is guaranteed to be funded for a life time beyond 2030. Hence, the continuous and sustainable availability of Sentinel satellite data with identical properties and a high repetition rate is ensured. Therefore, developed methods and tools relying on Sentinel data will be applicable also in the future.

For wetland mapping, the most suitable satellites of the Copernicus missions are Sentinel-1, -2 and -3. Sentinel satellite data can be downloaded free of charge, e.g. via the Copernicus Open Access Hub (see link below) but also via different other platforms.

Copernicus Open Acces Hub: *https://scihub.copernicus.eu/dhus/#/home*

Please note that the GEOclassifier toolbox primarily uses input files in the GeoTIFF-format (.tif). If you download satellite data with different formats (e.g. Sentinel-2 data as jp2-files from the Copernicus Open Access Hub), it is recommended to convert them first, for example by exporting them as tif-files with the Sentinel SNAP toolbox (see Chapter 4.2).

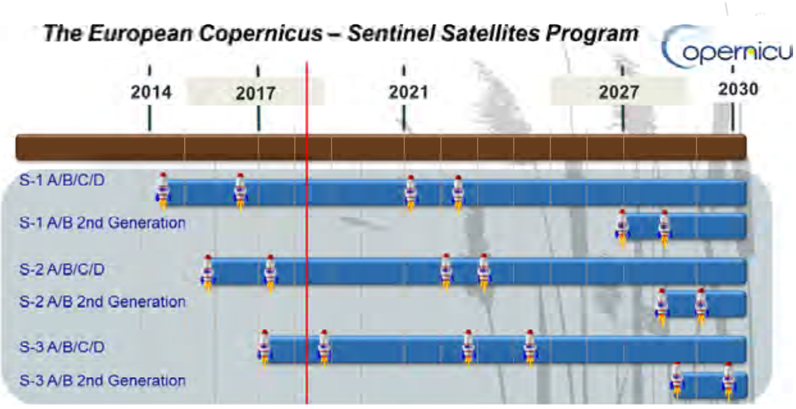


Figure 3: Sentinel-1, -2 and -3 satellite missions of EU/ESA programs until 2030 ensure the permanent availability of the data (Source: ESA 2020)

The following chapters provide information on several Sentinel product examples. More information is available in the ESA Sentinel User Guides (ESA 2021).

The following two images show an example of optical Sentinel-2 and radar Sentinel-1 images. The images display the oil spill disaster in August 2020 along the coastline of Mauritius where a vessel hull cracked. The ship carried 200 tons of diesel and 3,900 tons of fuel oil. Estimated 1,000 tons of it leaked into the sea when the ship's hull cracked on 6 August (Lewis 2020). The cracked ship and oil contamination on the water surface is visible in both data sets.

Figure 4: Oil Spill visible in Sentinel-2 data, South-East of Mauritius, 2020-08-16 (Copernicus data, provided by ESA)

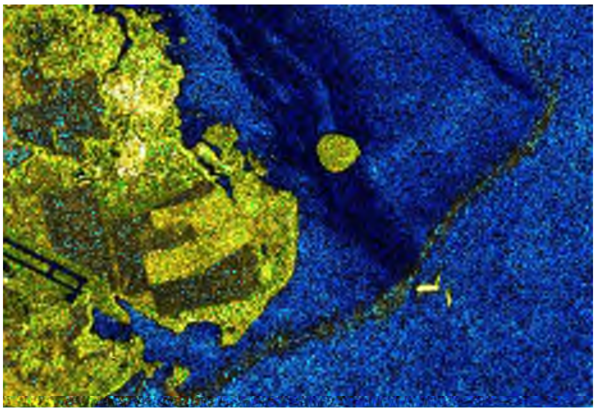


Figure 5: Oil Spill visible in Sentinel-1 data, South-East of Mauritius, 2020-08-10 (Copernicus data, provided by ESA)

3.3.1 Sentinel-1

The Sentinel-1 Mission consists of two identical satellites in the same orbit that cover the entire land surface, large islands, inland and coastal waters every six days. The Earth observation instrument is a C-Band Synthetic Aperture Radar (SAR) sensor. Depending on the acquisition mode, the spatial resolution ranges from 5 m to 100 m. Main fields of application are monitoring of forests, water and agriculture on land and ice, oil spills and ships at sea. Due to its all-weather acquisition capabilities, Sentinel-1 data is also used for emergency mapping of natural disasters. (ESA 2021)

Table 1: Sentinel-1 facts and figures

Sensor	*Spatial coverage*	*Swath width*	*Tile size*	*Temporal resolution*	*Temporal coverage*	*Ground resolution*
Sentinel-1	All land & coastal surfaces, overseas and polar areas, ocean-relevant areas	250 km	250 x 165 km	6 days at the equator	April 03, 2014 - today	5-100m

3.3.2 Sentinel-2

The Sentinel-2 Mission consists of two identical satellites in the same orbit that cover the whole land surface, large islands, inland and coastal waters every five days. They carry innovative wide swath high-resolution multispectral imagers with 13 spectral bands.

The spatial resolution ranges from 10 m for the visible channels 2, 3, 4 and the near infrared channel 8, 20 m for the red edge channels 6, 7, 8A and SWIR channels 5, 6, 7, 11, 12, to 60 m for channels 1, 9, 10.

Main fields of application for Sentinel-2 data are the monitoring of LULC and their changes, mapping of biophysical parameters (e.g. leaf chlorophyll or water content), monitoring of inland and coastal waters as well as disaster and risk mapping (ESA 2021).

Table 2: Sentinel-2 facts and figures

Sensor	*Spatial coverage*	*Swath width*	*Tile size*	*Temporal resolution*	*Temporal coverage*	*Ground resolution*
Sentinel-2	Systematic, all land & coastal (20km) surfaces between -56° & +84° Latitude, islands > 100km²	290km	Single granule 100*100km	5 days at the equator	June 23, 2015 - today	10, 20, 60m

3.3.3 Sentinel-3

Sentinel-3 is primarily an ocean mission, however, the mission is also able to provide atmospheric and land applications.

Sentinel-3 makes use of multiple sensing instruments to accomplish its objectives; Sea and Land Surface Temperature Radiometer (SLSTR), Ocean and Land Colour Instrument (OLCI), SAR Altimeter (SRAL), the satellite tracking system Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), and Microwave Radiometer (MWR) (ESA 2021).

SLSTR and OLCI data can be used for the creation of wetland products; SLSTR data for the creation of surface temperature products and OLCI for water quality products.

Table 3: Sentinel-3 facts and figures

Sensor	***Spatial coverage***	***Swath width***	***Tile size***	***Temporal resolution***	***Temporal coverage***	***Ground resolution***
SLSTR	global	1420 km	half orbit	1,1 days at the equator	Sentinel-3A: 16 Feb. 2016 Sentinel-3B: 25 April 2018 - today	500m – 1 km
OLCI	global	1270 km	half orbit	1,1 days at the equator	Sentinel-3A - 16 Feb. 2016 Sentinel-3B - 25 April 2018	300m - 1,2 km

3.4 Landsat satellites

The Landsat program is the longest lasting satellite program for continuous Earth observation. The first satellite with four spectral bands was launched on 23 July 1972. The Landsat project is an integral part of the Remote Sensing Missions component of the United States Geological Survey (USGS) Land Remote Sensing Program.

In May 30, 2013, data from the Landsat-8 satellite (the successor of the Landsat-MSS, Landsat TM, Landsat ETM+ satellites) became available.

Landsat 8 carries two push-broom instruments: The Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), altogether with 11 spectral bands. The ground resolution ranges from 15 m for the panchromatic channel to 30 m for all other channels (visible, near infrared (NIR), short wavelength infrared (SWIR)) of the OLI instrument and 100 m for data of the TIRS instrument (USGS 2021)

Landsat data can be downloaded free of charge e.g. via the USGS EarthExplorer and also via other platforms.

USGS EarthExplorer: https://earthexplorer.usgs.gov/

Table 4: Landsat 8 facts and figures

Sensor	***Spatial coverage***	***Swath width***	***Tile size***	***Temporal resolution***	***Temporal coverage***	***Ground resolution***
Landsat 8, OLI&TIRS	Global landmass	185km	185X180km	16 days	May 2013 - onwards	OLI: 15, 30m TIRS: 100m

4 Tools for satellite-based wetland management

4.1 The software toolbox GEOclassifier

GEOclassifier is a stand-alone desktop software toolbox, which is available free of charge. It provides a suite of powerful tools for viewing, processing and analysing remote sensing images. GEOclassifier allows performing segmentations (automated object delineation), classifications and indicator calculations with just a few clicks.

The software is applicable to process satellite data of the Sentinel and Landsat missions, which can be obtained free of charge, but also images from other satellite or airborne sources.

GEOclassifier was adapted to be specifically suitable for wetland monitoring and management, but the toolbox is useful also for the monitoring and management of other ecosystems and for applications for other thematic areas (e.g. water, agriculture, forestry or epidemiology). A variety of information about the status and trends in wetlands and their ecological characteristics can be derived with GEOclassifier and used for reporting and monitoring tasks and to build a basis for management decisions.

Highlights of the Software are:

- Tools specifically tailored for wetland mapping/monitoring and reporting
- All wetland mapping tools collected in one stand-alone, freely available toolbox
- Graphical user interface with comfortable functions for displaying and analysing radar- and optical satellite image data
- Segment-/ object-based processing to prepare homogeneous maps with a defined minimum mapping unit to avoid speckled mapping results (the so called “pepper-and-salt effects”)
- Supervised automated classification with comfortable selection of classification-training areas
- Easy integration of local knowledge to train the classifier or improve the automated classification result
- Availability of pre-defined, standardized nomenclatures like Corine Land Cover (CLC), Mapping and Assessment of Ecosystems and their Services (MAES) and Food and Agriculture Organisation Land Cover Classification System (FAO LCCS), all with incorporated typology of the Ramsar convention on wetlands, easy integration of nomenclature updates or new hierarchical nomenclatures
- Predefined indicators to calculate status and trend statistics and produce corresponding masks for visualization with just one click
- Large area processing - transfer of land cover signatures (to areas without information to train the supervised classifier)
- Wide usability for many land cover applications and ecosystem monitoring.

The image viewer is the key GEOclassifier tool for visualization and analysis of images. Different input layers or image channels can be combined and assigned to the three colours Red/Green/Blue (RGB) for visualization. Moreover, the image viewer can overlay satellite images with segmentation and classification results. The image viewer also provides comfortable and easy to use functionalities for the collection of training areas and integration of ground knowledge for a supervised classification, while any of the three available nomenclatures for LULC mapping or the nomenclature for SWD mapping can be applied (nomenclatures details are provided in chapter 5.1).

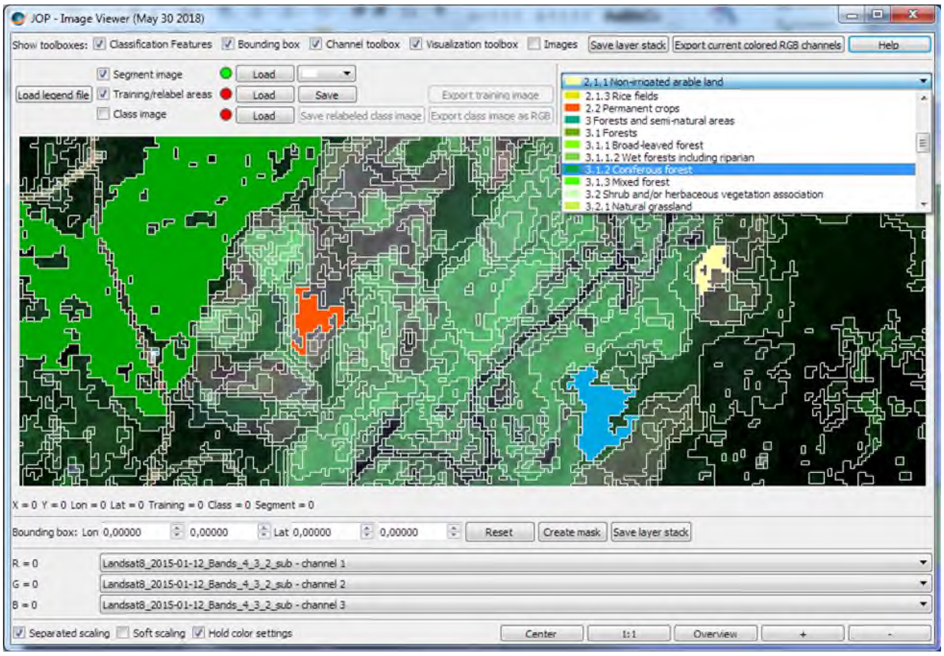


Figure 6: The GEOclassifier Image Viewer, Landsat RGB image overlaid with a segmentation result (white borders) and training areas (coloured segments) for the classification (nomenclature: CLC-Ramsar)

All functions for data processing are available via pull down / sub-menus of the main menu.

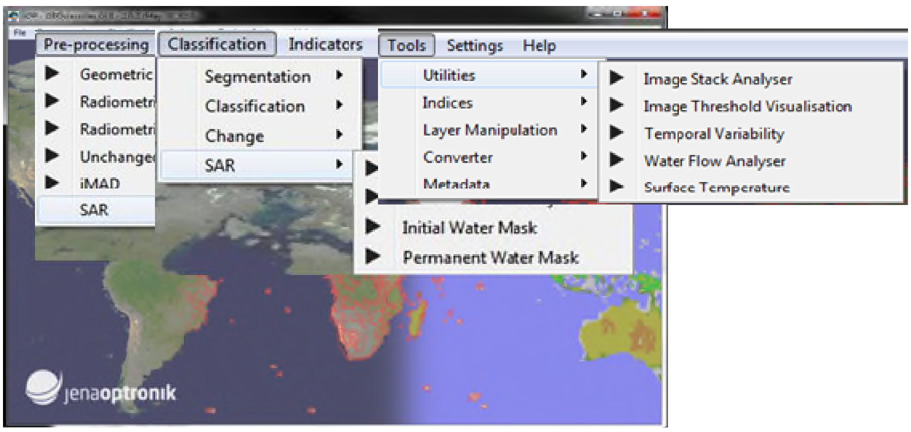


Figure 7: GEOclassifier pull down menu examples for selected functions

All functions are accessible via windows in a similar layout, with two riders, one for all in- and output parameters and one for function-specific parameter settings.

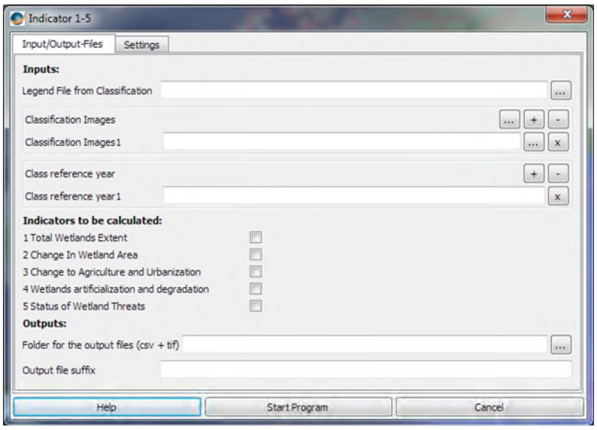


Figure 8: GEOclassifier function layout, example indicator 1 to 5

Access information to download the GEOclassifier toolbox and legend files and to get a free license can be requested via email to geoclassifier@jena-optronik.de.

The software contains help menus and tooltips. For new users, a training of about 3-5 days is recommended. Training sessions with tutorial can be provided on request from the SWOS team.

The GEOclassifier toolbox can be complemented by other freely available or commercial tools. Vice versa, mapping results of GEOclassifier can be integrated into other toolboxes.

GEOclassifier toolbox: Email to: geoclassifier@jena-optronik.de

4.2 SNAP - Sentinel toolboxes

SNAP can be downloaded free of charge from the ESA webpage. It is a common architecture that contains all Sentinel toolboxes. The SNAP platform with its Sentinel toolboxes is recommended to complement the functionalities of GEOclassifier. For example, SNAP can be used to open all typical Sentinel data formats (e.g. jp2-files) and to convert them into GeoTIFF-files (.tif) for further processing with GEOclassifier.

SNAP download: https://step.esa.int/main/download/snap-download/

Since GEOclassifier has just basic and no comprehensive tools for water quality mapping and no tools for radar data pre-processing, the Sentinel-1 toolbox for radar data pre-processing and the Sentinel-3 toolbox for Water Quality mapping are recommended for these purposes.

The *Sentinel-1 Toolbox* consists of a collection of processing tools, data product readers and writers and a display and analysis application from ESA SAR missions including Sentinel-1, ERS-1 & -2 and ENVISAT, as well as third party SAR data from ALOS PALSAR, TerraSAR-X, COSMO-SkyMed and RADARSAT-2. The Toolbox includes tools for radar data calibration, speckle filtering, co-registration, orthorectification, mosaicking, data conversion, polarimetry and interferometry.

For wetland mapping, the pre-processing tools for Sentinel-1 radar data are recommended.

Sentinel-1 Toolbox: http://step.esa.int/main/toolboxes/sentinel-1-toolbox

The *Sentinel-3 Toolbox* consists of a set of visualization, analysis and processing tools for the exploitation of OLCI and SLSTR data from the Sentinel-3 mission, e.g. to produce water quality maps. It also supports the ESA missions ENVISAT (MERIS & AATSR), ERS (ATSR), SMOS as well as third party data from MODIS (Aqua and Terra), Landsat (TM), ALOS (AVNIR & PRISM) and others.

For wetland mapping the water quality tools for Sentinel-3 data are recommended.

Sentinel-3 Toolbox: http://step.esa.int/main/toolboxes/sentinel-3-toolbox

4.3 ArcGIS / QGIS and other tools

The commercial toolbox ArcGIS or the freely available toolboxes QGIS or SAGA can be used to pre- or post-process vector data. Moreover, FRAGSTAT is useful to calculate fragmentation parameters.

ArcGIS is a commercial platform to create, manage, share, and analyse spatial data. It consists of server components, mobile and desktop applications, and developer tools (Esri 2021). Among Geographic Information Systems (GIS), ArcGIS is very commonly used specifically for vector data handling and management. However, it is available only on a commercial basis, licenses have to be purchased.

ArcGIS sign up and download: https://pro.arcgis.com/de/pro-app/latest/get-started/install-and-sign-in-to-arcgis-pro.htm

QGIS is a user-friendly GIS Toolbox available free of charge. It is an Open Source GIS, licensed under the GNU General Public License. It runs on Linux, Unix, Mac OSX, Windows and Android and supports numerous vector, raster, and database formats and functionalities. QGIS is a volunteer driven project (QGIS 2020).

QGIS download: https://www.qgis.org/en/site/forusers/download.html

SAGA is a GIS software that has been designed for an easy and effective implementation of spatial algorithms and runs under Windows and Linux. It is a Free Open Source Software. (SAGA User Group Association 2020)

SAGA download: https://sourceforge.net/projects/saga-gis/

FRAGSTATS is a free software tool that allows the analysis of landscape patterns. One important pattern for wetlands that can be analysed is their fragmentation. (McGarigal et al. 2012)

FRAGSTATS download: https://www.umass.edu/landeco/research/fragstats/downloads/fragstats_downloads.html#FRAGSTATS

5 Map products and indicators for a satellite-based wetland management and planning

5.1 GEOclassifier map products and nomenclatures

The GEOclassifier toolbox provides tools to produce satellite-based wetland maps and indicators, which can be important means to support its users in wetland planning, management and reporting obligations.

The following maps can be derived using GEOclassifier tools:

– Land Use / Land Cover and Change (LULC and LULCC)
– Surface Water Dynamics (SWD)
– Flow velocity
– Potential wetland layer / Inventory and delineation
– Surface temperature trends
– Surface moisture
– Water quality statistics

A challenge for wetland mapping is the transitional nature of wetlands. Many inconsistencies in mapping and wetland delineation appear, as wetlands are usually not defined equally by different users. In addition, different nomenclatures are often used and mapping results are therefore potentially not comparable.

Using standardized nomenclatures enables comparability between different wetland locations and mapping dates. They allow drawing a bigger picture for regions and globally, based on local results. To create consistent and comparable maps of wetlands, clear definitions and standardized nomenclatures are therefore crucial. They are a prerequisite to harmonize mapping results within countries or regions and crucial for any large-scale monitoring and assessment program.

The GEOclassifier toolbox offers different standardized nomenclatures. The nomenclatures and typologies, which have been integrated in the toolbox, are those that are recommended in the context of national, regional and global policies for nature conservation and biodiversity. Updates or additional hierarchical nomenclatures can be integrated easily.

5.2 LULC and SWD – the most important mapping products

The most important mapping products for wetland management are Land Use/Land Cover (LULC) and Surface Water Dynamics (SWD) maps. These two types of maps are also the basis to calculate state and change indicators for long and short term changes and the corresponding masks.

Change mapping is based on LULC or SWD maps from two or more acquisition dates and displays changes detected over time. Detailed change statistics and change masks can be produced automatically from previously prepared maps using the change indicator tools of GEOclassifier.

5.2.1 Nomenclatures for LULC and SWD maps

LULC maps can be produced with GEOclassifier using three standardized hierarchical nomenclatures, the CLC nomenclature, the MAES nomenclature and the LCCS/FAO nomenclature. To improve the applicability of these nomenclatures for wetland mapping, the typology of the Ramsar Convention on Wetlands has been integrated into all three standard-nomenclatures, on different hierarchical levels or on a new level. The resulting nomenclatures cover both the non-wetland and the wetland areas of the total mapping area. The typology of the Ramsar Convention on Wetlands is the basis for crosswalks between the three nomenclatures. The new nomenclatures which include the Ramsar typology have been re-named accordingly (e.g. CLC including Ramsar typology is named CLC-Ramsar).

The most appropriate nomenclatures to map Land Use/Land Cover outside of Europe are the CLC-Ramsar and the LCCS/FAO-Ramsar nomenclatures.

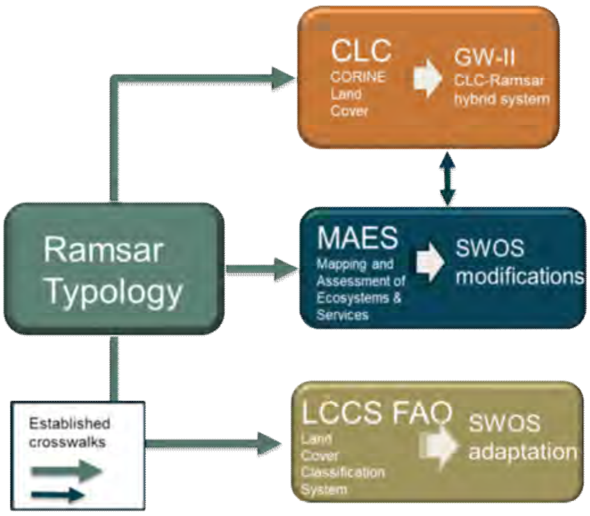


Figure 9: The three hierarchical nomenclatures with integrated Ramsar typology, available in the GEOclassifier toolbox (Source: SWOS 2020)

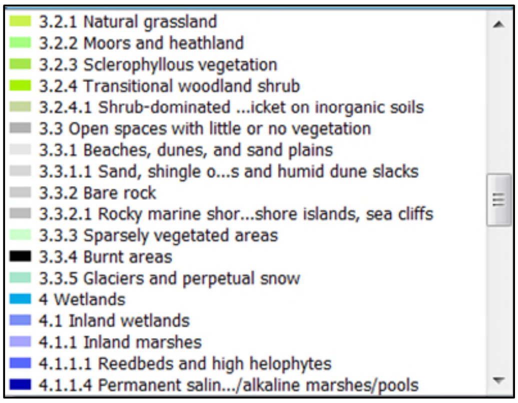


Figure 10: LULC Nomenclature (part of CLC-Ramsar) in GEOclassifier

For the mapping of Surface Water Dynamics, a nomenclature with just three classes is provided in GEOclassifier to distinguish permanent water bodies, seasonally flooded areas and non-flooded areas.

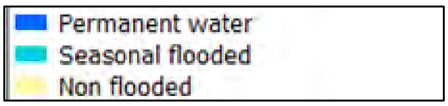


Figure 11: SWD Nomenclature in GEOclassifier with the three classes permanent water, seasonal water and non-flooded areas

5.2.2 Land Use / Land Cover maps (LULC)

For LULC mapping in wetlands, the GEOclassifier toolbox provides a segment-based supervised approach.

Segments are areas with similar properties (logical homogeneous units). GEOclassifier can automatically subdivide the mapping area into such units, based on the properties of the input data. As input for this segmentation process, satellite data from one or more sensors and different acquisition dates can be combined. In particular for radar data, input from more than one acquisition date is crucial for a good delineation of homogeneous segments. A segment-based approach avoids “Pepper and Salt” effects (noise / speckle effects) in classification results, as it allows for the predefinition of a minimum mapping unit (MMU). The recommended minimum segment size or MMU is 1 ha.

The next step of the supervised classification process is the manual definition of training segments, i.e. areas with known habitat types. All LULC classes which should appear in the final maps have to be assigned at least to one training segment. Based on the spectral and temporal characteristics in training segments, the classification function will then compare and automatically assign the trained LULC classes to all remaining segments in the entire mapping area. Ground knowledge (e.g. field data) should be the basis for the definition of training segments to increase the mapping accuracy. Further ground truth data should be used to validate the mapping results after the classification.

The preferred data source of freely available satellite data for high resolution LULC maps is Sentinel-2. In addition, data from the Landsat satellites can be integrated, if not enough cloud-free Sentinel-2 data is available or if maps for dates from before the start of the Sentinel missions should be created.

In permanently or frequently clouded areas, time series of Sentinel-1 data (or data from other radar sensors) could be integrated. However, radar data alone cannot be used to reliably distinguish all detailed LULC classes in wetlands.

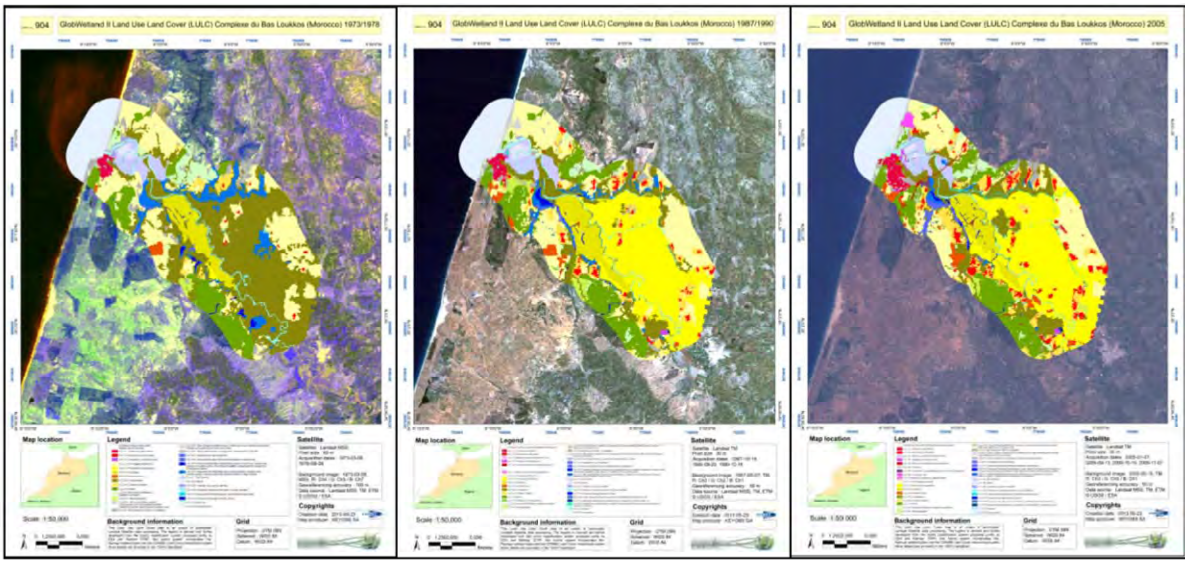


Figure 12: LULC map of Complexe du Bas Loukkos, Morocco 1975, 1990, 2005. The time series demonstrates the conversion of natural wetlands and wet meadows (dark green areas) to artificial wetlands and rice fields (bright yellow) in the middle of the site and the increase of urban areas (red areas) (Source: GW-II 2020)

5.2.3 Surface water dynamics maps (SWD)

SWD maps represent inter-annual changes of the open, vegetation-free surface water extent with three classes

- Permanently flooded
- Seasonally flooded
- Never inundated areas

The area located between the maximum and minimum water extent represents the seasonally flooded area in a wetland. Therefore, the input for SWD mapping should include several acquisition dates from one hydrological cycle and cover at least the real maximum and the real minimum water extent on site.

SWD maps can easily be derived with GEOclassifier using the segment-based supervised classification approach, similar to the LULC mapping, while using the SWD nomenclature. Training areas for all three SWD-classes need to be defined manually. The recommended minimum segment size or MMU is 1 ha.

The input channels for SWD maps could be either radar (Sentinel-1) or optical images (infrared channels of Sentinel-2 or Landsat) from different acquisitions dates in one hydrological cycle (a time frame that covers maximum and minimum water extent). SWD maps can be based on optical data only in cases where enough cloud free data sets are available.

Flow velocity (GEOclassifier products) can be derived from SWD maps in combination with elevation data.

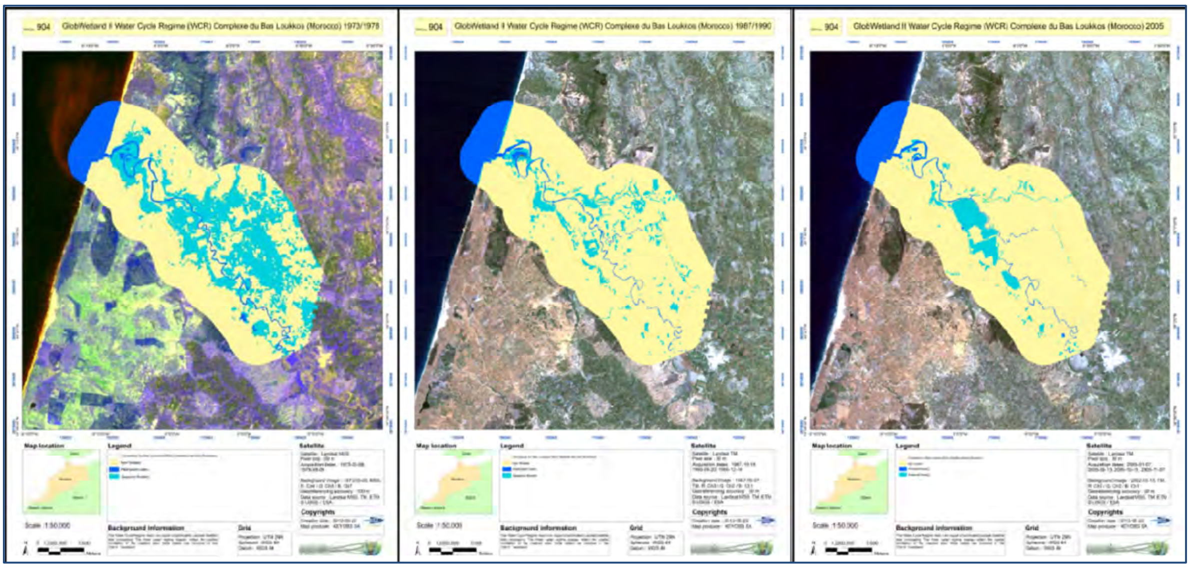


Figure 13: SWD Complexe du Bas Loukkos, Morocco 1975, 1990, 2005. The time series demonstrates the loss of seasonal flooded areas (bright blue) due to the conversion of natural wetlands into artificial wetlands (Source: GW-II 2020)

5.3 Complementary map products

5.3.1 Potential wetland layer for inventory and delineation

A potential wetland layer provides information for the planning of restoration measures in known wetland areas and for the identification and delineation of unknown wetlands. It is a complex product that requires several input layers and processing steps.

Important inputs are SWD maps (GEOclassifier product) and topographic information derived from available elevation data using GEOclassifier functions. Additional useful information could be retrieved from soil maps and soil moisture maps from external sources. Soil moisture (and ocean salinity maps) are available globally for download, although just in a very coarse resolution of about 25km (derived from ESA's SMOS satellite, SMOS = Soil Moisture and Ocean Salinity). Higher resolution soil moisture products are available only for a few places and time frames where local scientific studies have been carried out.

Once the potential wetland area has been identified with different probabilities, LULC maps (GEOclassifier product) of those areas with medium to very high probability will support the identification and delineation of the real wetland areas.

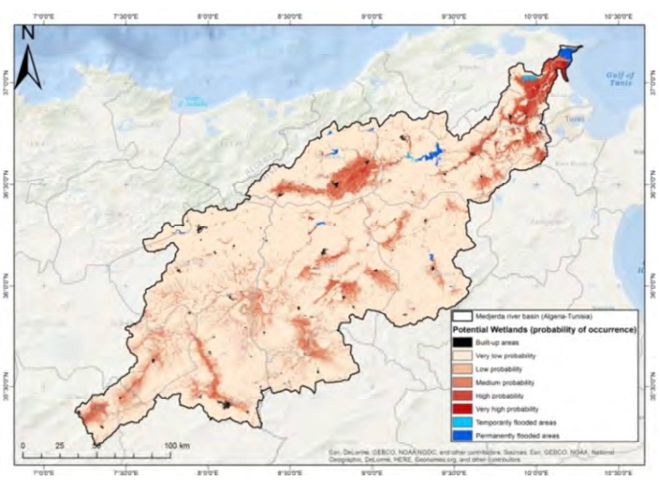


Figure 14: Potential wetlands for the Medjerda river basin (Algeria-Tunisia), 2015. The red areas have a medium, high or very high probability for wetland protection or restoration. Blue areas are temporarily or permanently flooded (Source: SWOS 2020)

Relative and absolute area proportions

Very low probability	71.63 %	1,663,954.67 ha
Low probability	15.88 %	369,025.04 ha
Medium probability	7.49 %	174,053.69 ha
High probability	3.29 %	76,469.41 ha
Built-up areas	0.73 %	17,120.13 ha
Permanently flooded areas	0.44 %	10,358.94 ha
Very high probability	0.27 %	6,400.14 ha
Temporarily flooded areas	0.23 %	5,441.28 ha
Total area:		2,322,823.30 ha

Figure 15: Area proportion of potential wetland area, Medjerda river basin (Algeria-Tunisia), 2015. About 12% of the entire area has a medium, high or very high probability to be a potential wetland area (Source: SWOS 2020)

5.3.2 Surface temperature trends

Land Surface Temperature (LST) maps can be retrieved from Landsat data using the GEOclassifier LST functions, or from Sentinel-3 or Modis thermal bands in a coarser resolution.

Trend calculation allows to identify areas that have heated up and cooled down during certain periods, and to quantify the temperature changes. Large changes in LST are often connected to LULC changes or changes in water regimes and might also indicate changes of evapotranspiration regimes. Moreover, a temperature gradient between agricultural areas and their surroundings is an indicator that can help to identify irrigated fields.

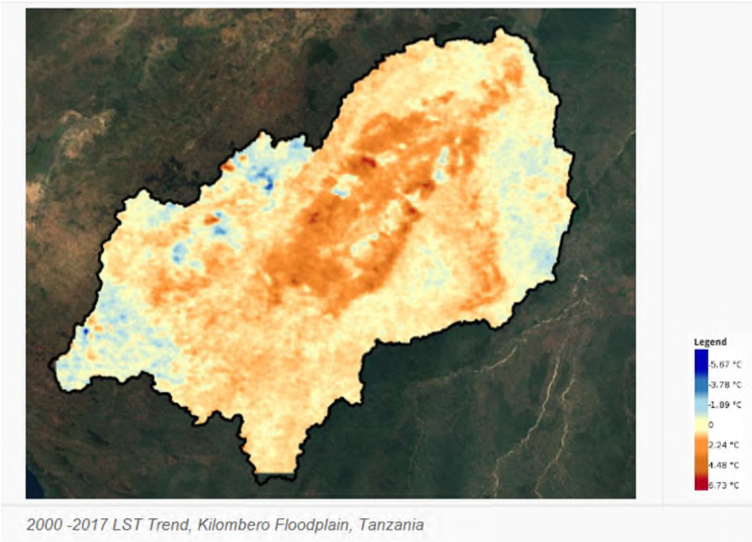


Figure 16: LST Trend analysis for Kilombero floodplain in Tanzania for the time frame 2000 – 2017. High changes of the temperature could be an indicator for changes on the ground, e.g. the dark blue areas with a decrease of about 5°C could be restored wetlands and the dark orange areas in the middle of the Kilombero floodplain could be an indication for a conversion of natural vegetated areas to deforested or sealed areas (Source: SWOS 2020)

5.3.3 Water quality and trends

Water quality maps can be retrieved from MERIS and Sentinel-3 data using the Sentinel-3 toolbox in SNAP. Water quality products include water quality parameters such as chlorophyll (Chl), total suspended sediments (TSM), coloured dissolved organic matter (CDOM) and Secchi depth.

Based on MERIS or Sentinel-3 data, these water quality parameters can be derived for wetlands with open water surfaces (> 3 km^2) where the water depth exceeds the Secchi depth. The parameters can be used as indicators of eutrophication, physical disturbance and contamination, respectively.

Based on these water quality maps, water quality trends can be calculated using the GEO-classifier tool for indicator 7 (for the definition of indicator 7 see section 5.4).

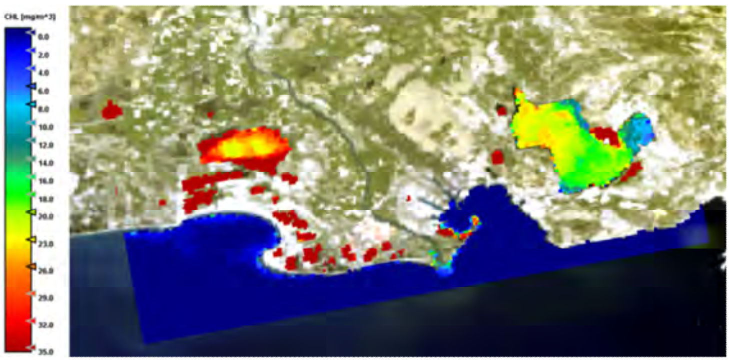


Figure 17: Water Quality – CHL example map, Camargue, France, 08/2011, derived from MERIS data. The Chlorophyll concentration in the two large lakes ranges from medium (lake on the right about 20mg/m³) to high (lake on the left about 35 mg/m³) (Source: SWOS 2020)

5.4 Indicators

Indicators provide statistical information to characterize status and trends in wetland ecosystems. The GEOclassifier indicator functions calculate statistical values and create maps/masks automatically from previously produced LULC and SWD products with standard nomenclatures or from water quality products. For all indicators, different sub-indicators for different planning, management and reporting purposes (e.g. Ramsar Convention on Wetlands and SDG reporting) have been introduced and integrated into GEOclassifier. The various GEOclassifier indicators and sub-indicators are described in the following sections.

1. Total wetlands extent

Indicator 1 includes six sub-indicators and delivers status information about the extent of the different wetland types for one or more points in time.

Sub-indicators:

1.1. area of all wetlands

1.2. area of natural wetlands

1.3. area of artificial wetlands

1.4. area of vegetated wetlands

1.5. area of natural open water bodies

1.6. (optional) area of selected classes

2. Change in wetland area

The change in wetland area is the difference of the extent of the various wetland types between two dates. If more than two input files are used, the function will compare all files with a selected master file and calculate the respective changes of wetland extent for any of the given input dates.

The indicator provides the five sub-indicators.

Sub-indicators:

2.1. change of the total wetland area

2.2. change of the natural wetland area

2.3. change of the artificial wetland area

2.4. (optional) changed area of a selected class to another selected class

2.5. (optional) changed area of a selected class to any other class

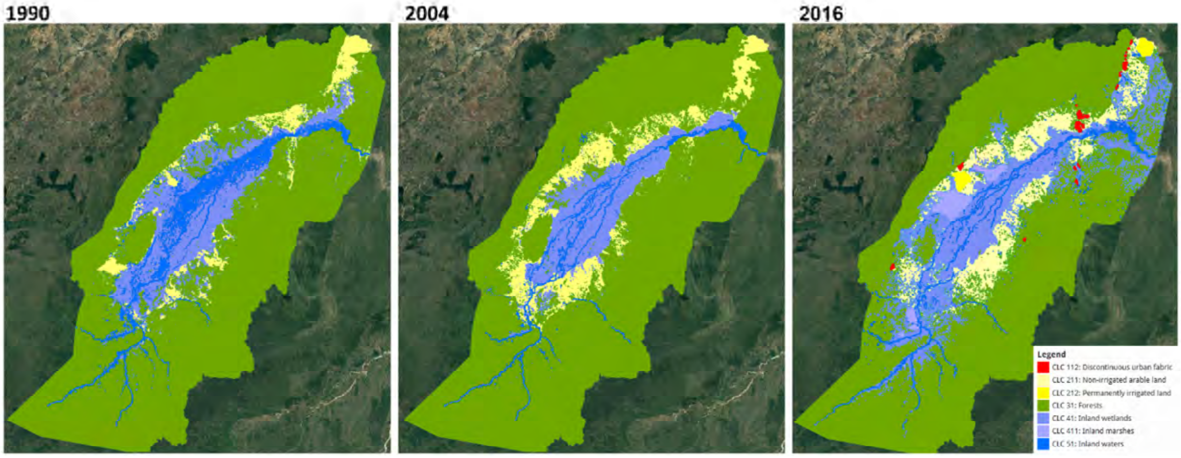


Figure 18: LULC mapping for 1990, 2004, 2016, in Kilombero Floodplain, Tanzania. The proportion of arable land (bright yellow) increased from 1990 to 2004 and again from 2004 to 2016, irrigated agriculture (dark yellow) and urban areas (red areas) are new in 2016 (Source: SWOS 2020)

1990

Relative and absolute area proportions

CLC 31: Forests	66.68 %	1,391,527.64 ha
CLC 41: Inland wetlands	27.97 %	583,758.54 ha
CLC 21: Arable land	4.03 %	84,171.68 ha
CLC 51: Inland waters	1.30 %	27,271.20 ha
Total area:		2,086,729.06 ha

2004

Relative and absolute area proportions

CLC 31: Forests	72.48 %	1,512,212.38 ha
CLC 41: Inland wetlands	16.65 %	347,371.49 ha
CLC 21: Arable land	10.29 %	214,719.83 ha
CLC 51: Inland waters	0.56 %	11,884.02 ha
Total area:		2,086,187.72 ha

2016

Relative and absolute area proportions

CLC 31: Forests	66.97 %	1,397,013.09 ha
CLC 211: Non-irrigated arable land	19.90 %	415,151.04 ha
CLC 41: Inland wetlands	10.72 %	223,801.26 ha
CLC 411: Inland marshes	1.24 %	25,908.23 ha
CLC 212: Permanently irrigated land	0.51 %	10,669.14 ha
CLC 51: Inland waters	0.42 %	8,886.78 ha
CLC 112: Discontinuous urban fabric	0.21 %	4,517.34 ha
Total area:		2,085,946.88 ha

Figure 19: Indicator example: Proportion of land cover types for 1990, 2004, 2016, in Kilombero Floodplain, Tanzania (Source SWOS 2020)

3. Change to Agriculture & Urbanization

Indicator 3 computes the change of wetlands to agriculture and/or urban areas, and the restoration of wetlands (conversion from agriculture or urban to wetland classes) between two dates. For more than two input dates, all input files will be compared with a master file as well as a summary of all changes will be calculated. Indicator 3 has nine sub-indicators:

Sub-indicators:

3.0. change of any wetland to agriculture and urban

3.1. change of natural wetlands to agriculture

3.2. change of natural wetlands to urban

3.3. change of artificial wetlands to agriculture

3.4. change of artificial wetlands to urban

3.5. change of natural dryland to agriculture

3.6. change of natural dryland to urban

3.7. change of agriculture to urban

3.8. any land cover type to natural wetland (= all restoration)

The graphs below show examples for change indicators for the Kilombero floodplain in Tanzania for the two time frames. Indicators show an increased conversion from wetlands and water, semi-natural land and forests to agriculture, as well as an increased loss of forested areas through felling and transitions. The change of wetland and water areas into agricultural land (dark green-blue) was the dominant type of conversion, affecting an area twice as large as that of all other conversions in both time frames.

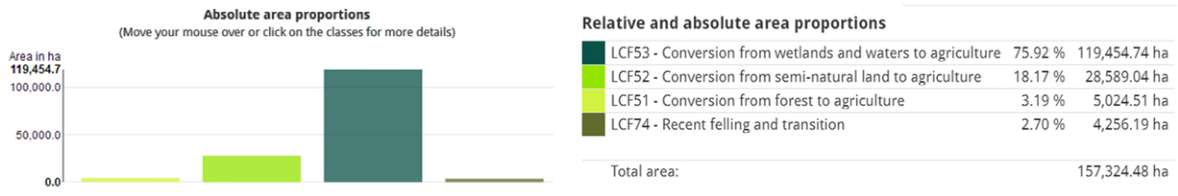


Figure 20: Wetland change statistics for Kilombero, Tanzania, 1990-2004 (Source: SWOS 2020)

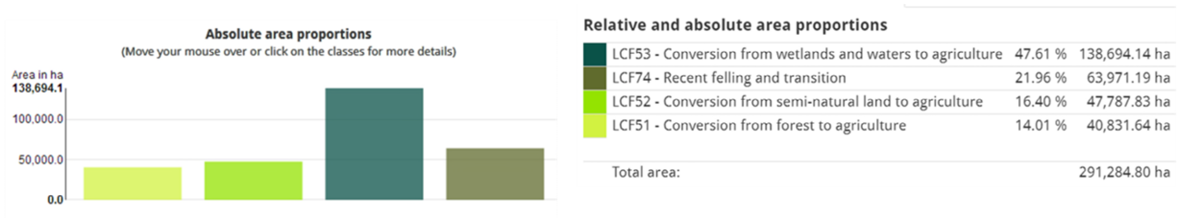


Figure 21: Wetland change statistics for Kilombero, Tanzania, 2004-2016 (Source: SWOS 2020)

4. Wetlands artificialization and degradation

Indicator 4 computes the change of natural wetlands to artificial wetlands and to rice-fields. If more than two input files are used, all input files will be compared with a master file as well as a summary of all changes will be calculated. Indicator 4 provides two sub-indicators.

Sub-indicators:

4.0. wetland artificialization

4.1. wetland artificialization to rice field

5. Status of Wetland Threats

Indicator 5 and its three sub-indicators provide information about the status of the main threats in wetlands, i.e. about agriculture and urban areas. It compares the extent of agricultural and urban areas in a defined region with the wetland areas in that region.

Sub-indicators:

5.0. wetland threats (sum of threats due to urbanization and agriculture)

5.1. urban threats

5.2. agriculture threats

6. Extent of Open Water

Indicator 6 calculates the area of wetlands that is permanently, temporarily or never flooded. Additionally, it calculates the extent of areas that are flooded but not classified as wetlands. There are four sub-indicators:

Sub-indicators:

6.1. wetland areas with permanent open water

6.2. wetland areas with temporal open water

6.3. wetland areas that are never flooded

6.4. flooded areas that are not wetlands (can be flooded permanently or temporally)

Figure 22: The Kafue Flats in Zambia contain extensive areas of temporarily flooded wetlands which are used as grazing land during dry season (Copyright: Bettina Hedden-Dunkhorst, BfN)

7. Status and Trend of Water Quality

This indicator provides a mean value calculation and further temporal aggregations and trend analyses of water quality maps for defined time periods and according to defined value levels.

6 Using satellite information for wetland management, planning and reporting

As presented in the previous chapters, a wide variety of information on wetlands can be derived from satellite images. This chapter outlines how the resulting thematic maps and indicators can be applied to address specific challenges in the context of wetland management in Africa. These challenges are structured into the following four fields:

1. Environmental & ecological degradation (chapter 6.1)
2. Management & planning (chapter 6.2)
3. Stakeholder communication / cooperation (chapter 6.3)
4. Reporting (chapter 6.4)

6.1 Satellite information to address main drivers of environmental & ecological degradation

Major drivers for environmental and ecological degradation of wetlands across Africa are

- Climate change
- Increasing human population, poverty and over-utilization of natural resources
- Industrial development

Challenges in relation to wetland degradation with regard to these drivers are described in the following sections. The corresponding tables (Table 5-7) suggest which thematic maps and satellite-derived products can be used to support the management of these challenges.

6.1.1 Climate change

Climate change causes high pressures for wetlands. This is in particular a risk for many regions in Africa, where rapid and significant environmental changes are already visible. According to the Intergovernmental Panel on Climate Change (IPCC 2020), it is likely that land temperatures in Africa will rise faster than the global land average, particularly in the more arid regions of the continent. Climate change will also amplify existing stress on water availability (IPCC 2020). Changes in the hydrological regime (including extreme events such as droughts or floods) can directly affect wetland extents and water dynamics and cause the loss of ecologically important wetland classes. Moreover, climate change can impact wetlands by causing shifts in species composition, fostering the spread of invasive species and causing the loss of especially vulnerable species. Furthermore, direct impacts in coastal areas are related to sea level rise and salt intrusion (Moomaw 2018).

Major challenges for Africa due to climate change include:

- Floods and droughts with decreased seasonal availability of water for humans, animals and plants
- Sea level rise and coastal flooding with dangers to coastal settlements
- Saltwater intrusion and increased salinity in coastal freshwater wetlands
- Food insecurity as a result of losses of crops and livestock
- Loss of important wetland classes (e.g. loss of mangroves, riparian forests, wet grass-

lands, coral reefs, seagrass, other wetland classes and habitats for threatened species)

- Bush encroachment and spreading of invasive species

Table 5: Thematic mapping and supporting satellite-derived products to address challenges related to climate change

Thematic mapping	***Satellite product***
Floods and droughts with decreased seasonal availability of water	
Frequency and extension of floods	- SWD - Indicator 6 incl. mask files
Droughts and loss of green vegetation	- Vegetation index (e.g. Normalized Difference Vegetation Index - NDVI) - SWD, LULC and changes - Mask files of indicator 1.6
Sea level rise and coastal flooding with dangers to coastal settlements	
Frequency and maximum extent of surface water, extent of urban areas & distance of urban area boundaries to maximize surface water boundaries	- SWD and LULC with focus on urban areas and infrastructure - Mask files of indicator 1.6 and indicator 6 & distance calculations
Saltwater intrusion and increased salinity in coastal freshwater wetlands	
Maximum extent of surface water and the distance between coastal saline / marine water and fresh water bodies	- SWD - Indicator 1.6 and masks - Indicator 6 and masks & distance calculations
Food insecurity	
Loss of areas suitable for food production / cattle grazing	- NDVI, LULC for specific classes - Indicator 1.4, relevant change indicators 2, 3 and 4 including masks
Erosion risk and actual erosion of (agricultural) soils	- LULC with a focus on classes that are prone to erosion - LULC with new classes for visible signs of erosion - Indicators 3.1, 3.3, 3.5, 3.7, 3.8 and masks - Erosion risk maps (based on elevation, soil type and LULC)
Disappearance of relevant food species and their natural habitats (e.g. mangroves as habitat for fish)	- LULC with focus on food-relevant classes - All change indicators 2, 3 and 4, in particular indicator 2.5 and corresponding masks

Loss of important wetland classes	
Loss of mangroves, riparian forests, wet grasslands, seagrass, other wetland classes and habitats for threatened species	- LULC with focus on specific classes and new classes for marine habitats, e.g. seagrass (for classification of new marine classes, a different segmentation process might be necessary for terrestrial LULC maps, e.g. focus on blue channels and selection of very small tolerance values for the segmentation) - All change indicators 2, 3 and 4, in particular indicator 2.5 and corresponding masks
Bush encroachment and spreading of invasive species	
Growing extent of bushes	- LULC and vegetation indices - Indicator 1.6, 2.4 and corresponding masks
Identification of large segments of invasive plant species	- LULC with new classes for invasive vegetation and vegetation indices, both requiring input data for very specific points in time that allow the distinction of invasive and other species (e.g. mapping the flowering period of certain plants) - Indicator 1.6, 2.4 and corresponding masks

6.1.2 Increasing human population, poverty and overuse of natural resources

One important driver for wetland degradation and resulting challenges in Africa is related to human population growth and poverty. The population of Sub-Saharan Africa is expected to double by 2050 (United Nations 2020). This results in the expansion of infrastructure and settlements, as well as an increased demand for land, food, energy and water. Especially people with low income often depend on wetlands, for domestic water, subsistence farming or fishing and other wetland resources such as wood for construction, firewood or charcoal from mangroves. Poverty can foster the uncontrolled construction of settlements in wetlands, often in flood-risk zones, as well as the illegal conversion of land and overexploitation of resources in protected areas.

Increasing human population and poverty therefore results in challenges such as:

- Expansion of human settlements and infrastructure development with encroachment on wetlands (legal and illegal)
- Expansion of agricultural land with encroachment on wetlands (legal and illegal)
- (Over-) exploitation of wetland resources, soil degradation and desertification

Table 6: Thematic mapping and supporting satellite-derived products to address challenges related to increasing human population, poverty and overuse

Thematic mapping	***Satellite product***
Expansion of human settlements, infrastructure development and expansion of agricultural land with encroachment on wetlands (legal and illegal)	
Increase of urban areas, increase of agricultural land, decrease of wetland areas	- LULC, indicators 5.0 – 5.2 - All change indicators 2, 3 and 4 including masks
Decreasing surface water extent	- SWD, indicators 6.1 – 6.4
Pollution through urban waste water inflow or discharge from arable land that decrease water quality	- Water quality, indicator 7
(Over-)exploitation of wetland resources, soil degradation and desertification	
Over-abstraction of ground and surface water for agriculture and domestic use	- SWD, indicators 6.1 – 6.4 - LULC and surface temperature differences for the identification of irrigated fields
Overuse of resources such as mangrove wood and subsequently loss of important ecosystem functions (e.g. coastal protection, erosion control or provision of natural habitats for fish)	- LULC, all change indicators, in particular indicator 2.5 and corresponding masks
Desertification / loss of green vegetation	- Vegetation indices, LULC, indicators 1.6, 2.4, 2.5
Erosion and degradation of soils due to agriculture	- LULC with a focus on wetland classes that are prone to erosion - LULC with wetland classes for visible signs of erosion - Indicators 3.1, 3.3, 3.5, 3.7, 3.8 and masks - Erosion risk maps (based on elevation, soil type and LULC)

6.1.3 Industrial development

Industrial development is another reason for wetland fragmentation and degradation. The construction of industrial sites or related infrastructure in wetland areas as well as industrial resource extraction such as sand and gravel mining in coastal wetlands can cause their direct destruction. Infrastructure development also includes the construction of dams for hydropower generation or the establishment of water reservoirs. These construction works often significantly alter the region's hydrological regimes, decreasing connectivity and potentially impeding the seasonal flooding of downstream areas. Furthermore, pollution from industrial activities can have severe consequences for wetlands. Excessive nutrient input can lead to eutrophication and change water quality, oxygen availability and biodiversity, and can support the growth of certain invasive plant species. Industrial chemicals discharged into the wetlands contaminate water and soils, with often detrimental impacts on wetland biodiversity and ecosystem services. The degradation of wetlands due to industrial development can in turn threaten the livelihoods of local communities depending on wetland resources.

In sum, industrial development will cause challenges for wetlands as a result of:

- Infrastructure development
- Resource mining and extraction
- Construction of dams
- Pollution of wetlands, eutrophication and invasive plant development

Table 7: Thematic mapping and supporting satellite-derived products to address challenges related to industrial development

Thematic mapping	***Satellite product***
Infrastructure development	
Construction of infrastructure elements (e.g. roads, railroads, buildings, bridges, channels, pipelines)	- LULC mapping, indicator 1.6
Forest clearing, conversion of wetlands and other land cover classes to sealed areas	- LULC and vegetation indices, indicators 2.5, 3.2, 3.4, 3.6, 3.7 and corresponding masks
Increasing wetland fragmentation	- LULC mapping, fragmentation mapping
Construction of dams	
Creation of new reservoirs for water abstraction, flood control or hydropower generation	- LULC, SWD, indicator 1.6, relevant change indicators and masks
Decrease or loss of natural wetlands and other relevant land cover classes due to dam construction	- LULC, SWD, all indicators 1 and 2
Changes in water surface area and flow velocity	- SWD, water flow analysis, indicators 6.1 – 6.4
Mining and extraction	
Sand and gravel extraction or other mining activities within or near wetlands, causing degradation and fragmentation of wetlands	- LULC and fragmentation mapping, all indicators 1, 2 and 6
Decreasing water surface area due to (over-)abstraction of ground and surface water for industrial use	- LULC, SWD, indicators 6.1 - 6.4

Pollution of wetlands, eutrophication and invasive plant development	
Mapping of illegal landfills / large accumulations of solid waste in wetlands	- LULC (new classes should be added to the existing nomenclature), indicator 1.6
Decreasing water quality and changes in water color due to pollution from industry or mining	- Water quality, indicator 7
Excessive growth of invasive plant species due to eutrophication	- LULC (with new classes), water quality, indicator 1.6
Loss of open water areas and channels closed by (invasive) vegetation	- LULC (with existing and new classes) and SWD, indicators 6.1 – 6.4
Reduced biodiversity / loss of natural, local species and habitat types	- LULC (with new classes), indicators 1.6, 2.5

6.2 Satellite information to support wetland management and planning

Satellite-derived information can support wetland management and planning in different areas. These include:

- Providing baseline information of wetland status and monitor changes for effective wetland and water use management and planning
- Generating knowledge for system thinking (consider all interconnections) and joint actions
- Planning management measures
- Fostering accountability by monitoring the implementation and results of management activities
- Supporting negotiations among different stakeholders (incl. government sectors) and conflict resolution

Satellite-derived maps and data are especially valuable for assessing and characterizing wetlands in remote areas that are not easily accessible otherwise. Yet, wherever possible, it is recommended to combine satellite-derived data with other available data. These include for example the delineation of protected areas or administrative units, which might help to clarify responsibilities, or field data and knowledge from local experts (including indigenous peoples and local communities) that can be used to complement, refine or validate results. Moreover, data collected by various management authorities (e.g. forest management, agricultural sector, water management) can provide further valuable insights.

Table 8: Thematic mapping and supporting satellite-derived products to assist wetland management and planning

Thematic mapping	***Satellite product***
Provide baseline information on wetland status and monitor changes	
Wetland inventory and delineation	- Potential wetland layer, LULC, SWD, status indicators 1 and 6
Changes in total wetland extent	- LULC, SWD, indicators 2
Wetland threats and degradation, including fragmentation	- LULC, all indicators 3, 4 and 5, fragmentation mapping
Understanding scale, extent and timeframe / frequency of changes (long and short term)	- LULC, SWD and indicators 2, 3, 4, 5, 6 including change masks and modelling for early warning and alerts
Generate knowledge for system thinking	
Assessment of impacts of land use changes or infrastructure development on wetlands	- LULC, SWD and indicators 6 for upstream water extraction and resulting reduced water availability downstream - LULC, SWD and indicators 1 and 2 for the loss of wetlands due to dam construction - LULC and indicators 2, 3 and 4 for the conversion of natural in artificial land cover classes - LULC and fragmentation maps for fragmentation of habitats due to infrastructure construction - Water quality maps and indicator 7 for pollution due to agriculture or industry - Further thematic maps (see previous sections)
Evaluation and quantification of (the loss of) wetland ecosystem services	- LULC and indicators 1.6, 2.5 for loss of mangroves as important areas for the provision of wood, habitat for fish as food and for erosion control - LULC and indicators 6, 3.2, 3.4, 3.6, 3.7 for the expansion of urban areas and loss of flood protection, SWD and indicators 6 for flood mapping - LULC, SWD, WQ and indicators 3.1, 3.3, 3.5, 6, 7. for increased extent of agricultural areas and reduced supply and quality of fresh water - LULC, SWD and indicators 1, 2, 3 for loss of habitats important for biodiversity conservation

	- LULC and indicators 1.6, 2.5 for changes in arable and grassland extent as a basis for the provision of food and fodder - LULC (also with new classes, e.g. for seagrass) and indicators 1.6, 2.5 for reduced extents of areas important for carbon sequestration / climate change mitigation
Support management planning	
Planning of restoration measures	- LULC and SWD, change indicators 3 and 4 and corresponding masks
Validation of maps, identification of details for changes on site	- LULC and SWD, change masks and pure satellite images as a basis for ground work
Planning of new boundaries for protected areas	- LULC and segment boundaries and fragmentation mapping, indicators 5 for wetland threats and corresponding masks
Foster accountability by monitoring the implementation and results of management activities	
Quantify changes due to management actions (long and short term)	- LULC and SWD and all change indicators, in particular 2.4 and 3.8 and corresponding masks
Contribute to reporting	- LULC and SWD and all appropriate indicators and corresponding masks, e.g. 1.3, 1.4 and 1.5 as specific indicators for SDG reporting
Support conflict resolution	
Develop maps for land management and action plans to help manage competing land uses and to support cooperative action from local to regional level	- Large scale LULC and SWD maps incl. change indicators and different scenarios for future development, proposals for different management zones etc.
Clarify responsibilities and monitor (non-) compliance with existing regulations / protection status	- LULC and SWD maps overlaid with administrative boundaries and protected area delineations, including relevant change indicators
Mainstreaming wetland management into other sectors and integrate non-protected areas in management and action plans	- LULC and SWD and trends of changes in wetlands and surrounding buffer zones / watersheds, focus on land cover types that are threatened and / or important for ecosystem service provision
Encourage ownership at local level (see also maps for communication and cooperation, next section) Promotion of ecosystem services provided by the specific wetland area Focus on land cover types, areas and	- LULC and SWD and trends of changes in wetlands and surrounding buffer zones / watersheds

ecosystem services that are threatened and important for the local population (including indigenous communities), like flood protection, habitats for fish, food provision, cultural and touristic places	

6.3 Satellite product packages for stakeholder communication and cooperation

Different cooperation and communication activities, including events, benefit from different sets or packages of satellite-derived maps and data.

Such activities could be e.g.

- Regional, national or local meetings with different stakeholders
- Public awareness raising activities
- Reporting tasks on different levels (global, regional, national)

The level of detail presented on maps should be adapted to the respective purpose. For instance, maps intended for the communication of fundamental trends to the general public should focus on the visualization of main issues or problems to be discussed, whereas a much higher level of detail might be required for the participatory planning of management measures at the local level.

Table 9: Satellite product packages for stakeholder communication and cooperation

Purpose	***Satellite product package***
Regional, national or local meetings with different stakeholders	
Transnational meetings to harmonize the management of transboundary wetlands or activities in a region	Satellite images overlaid with national and regional boundaries and boundaries of protected areas, LULC and SWD maps from different points in time, indicator status and change statistics and masks overlaid on satellite images
Meetings with different national ministries to foster the cooperation for the protection and restoration of wetlands and the integration of wetlands in all related national policies	Satellite images and extract of LULC, SWD and change indicators for different points in time, focusing on changes and threats with different ministerial responsibilities
Meetings in a wetland with all stakeholders and actors of the area/watershed (incl. industry, NGOs, representatives of local government and communities) to show the impact of activities and provide a baseline to identify or implement measures to halt, avoid and reverse degradation in the wetland	Satellite images and extract of LULC, SWD and change indicators for different points in time, focusing on changes and threats with different stakeholder responsibilities
Meeting with the local population to fos-	Pure satellite images, aggregated LULC or SWD

ter ownership, to demonstrate the status of a wetland, show the impact of activities and identify alternatives	maps from different points in time, indicator masks and simple numbers extracted from change indicators
Public awareness raising activities	
Cultural events or school events for young people and future wetland managers to teach how to protect ecosystem services, biodiversity and the beauty of wetlands	Pure satellite maps, aggregated simple LULC maps, SWD maps from different points in time, masks and simple change numbers (small subset of indicators)
Media events, public presentations or information boards in touristic places to show the value of healthy wetlands and explain protection rules	Pure satellite maps from different points in time with overlaid boundaries of protected areas and important habitat types Change masks from the past/potential changes in the future, masks and relevant numbers
Reporting tasks on different levels (global, regional, national) *(More details, specifically for Ramsar and SDG reporting, are provided in chapter 6.4)*	
Ramsar convention and SDG reporting	LULC and SWD maps and indicators from all indicator groups 1-7
Reporting to regional frameworks and national authorities	LULC and SWD for different points in time and selected indicators and masks

6.4 Satellite information to support reporting to international agreements

6.4.1 Convention on Wetlands (Ramsar Convention) reporting

For reporting obligations under the Ramsar Convention, LULC and SWD maps and different GEOclassifier indicators can be used directly to fill in the different chapters of the standardized reports, as listed below:

<u>Area of the Ramsar site, which may be equivalent to:</u>

Indicator 1: Total Wetlands Extent

Sub-Indicator1.0: natural and artificial wetland areas

Sub-Indicator1.1: only natural wetland areas

Sub-Indicator1.2: only artificial wetland areas

<u>General overview of the site is equivalent to:</u>

Indicator 2: Change in wetland area

Sub-Indicator 2.1: surface change for all wetland classes

Sub-Indicator 2.2: surface change for natural wetland classes

Sub-Indicator 2.3: surface change for artificial wetland classes

Physical features of the site are equivalent to:

Indicator 6: Extent of Open Water

Sub-Indicator 6.1: wetland habitats with permanent open water

Sub-Indicator 6.2: wetland habitats with temporary open water

Sub-Indicator 6.3: wetland habitats never flooded

Sub-Indicator 6.4: flooded areas not wetland habitats

Wetland types, general ecological features, current land (including water) use may be equivalent to specific classes in the nomenclature.

Factors adversely affecting the site's ecological character, including changes in land use.

These are equivalent to the following indicators and sub-indicators:

Indicator 3: Change to Agricultural and Urbanization

Sub-Indicator 3.0 – natural and artificial wetland change into agriculture and urban

Sub-Indicator 3.1 – only natural wetland change into agriculture

Sub-Indicator 3.2 – only natural wetland change into urban

Sub-Indicator 3.3 – only artificial wetland change into agriculture

Sub-Indicator 3.4 – only artificial wetland change into urban

Sub-Indicator 3.5 – natural dryland change into agriculture

Sub-Indicator 3.6 – natural dryland change into urban

Sub-Indicator 3.7 – agriculture change in to urban

Sub-Indicator 3.8 – agriculture, urban and artificial wetland change into natural wetland

Indicator 4: Wetlands artificialization and degradation

Sub-Indicator 4.0 change natural wetland into artificial wetland

Sub-Indicator 4.1 change natural wetland into rice fields

Indicator 5: Status of Wetland Threats

Sub-Indicator 5.1 agricultural areas by total area

Sub-Indicator 5.2 urban area by total area

Sub-Indicator 5.3 all natural habitat that are not wetlands

(For more information, see Fitoka et al. 2020)

6.4.2 Sustainable Development Goal (Indicator 6.6.1) reporting

For reporting on the Sustainable Development Goals (SDG) Indicator 6.6.1 “Change in the extent of water-related ecosystems over time”, the GEOclassifier toolbox provides several specifically developed sub-indicators. Furthermore, different GEOclassifier products and indicators can provide inputs for SDG 3 and SDG 15 reporting.

Figure 23: Contributions to SDG 6.6.1, SDG 3 and 15 can be calculated with GEOclassifier tools

The GEOclassifier toolbox includes SDG indicators as sub-indicators of indicator 1.

<u>Sub-indicators for SDG reporting:</u>

Sub-Indicator 1.4 vegetated wetlands extent

Sub-Indicator 1.5 open water bodies

Sub-Indicator 1.6 selected classes for river water bodies

The three sub-indicators allow the direct integration of calculated values into the SDG reporting sheets.

(For more information, see Weise et. al. 2020)

7 Case Studies

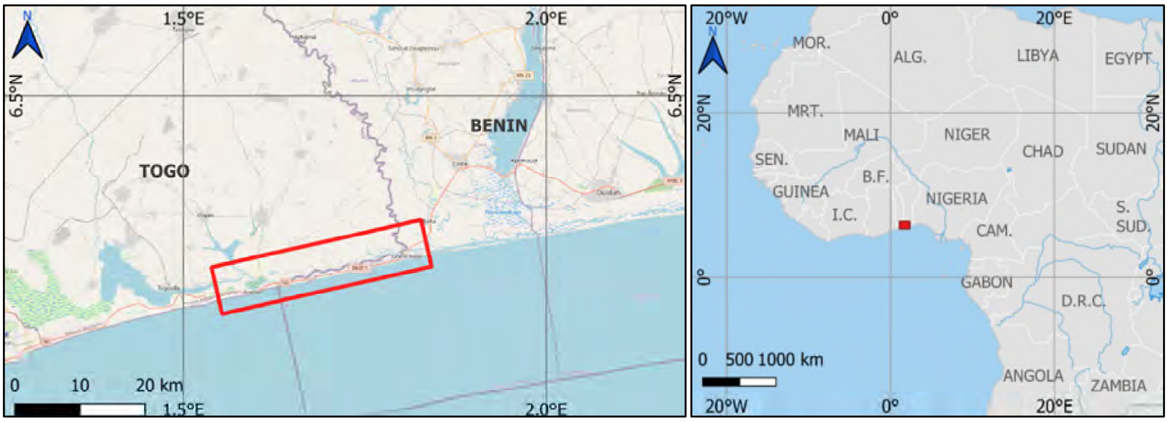
The following case studies were provided by wetland practitioners from eleven African countries. For each wetland site, prevailing threats and management challenges are identified and potential or existing applications of Earth observation data are described. The presented case studies cover not only a wide thematic range of focal topics, but also a wide geographical range of Southern and Western African countries:

- Benin - Chenal Gbaga Transboundary Site)
- Botswana - Okavango Delta
- Burkina Faso – Lake Tengrela
- Côte d'Ivoire - Grand-Bassam
- Madagascar - Lake Kinkony
- Mali – Lake Magui
- Senegal – Tocc Tocc Reserve
- Sierra Leone - Aberdeen Creek
- Togo – Mono Basin
- Zambia – Kafue flats
- Zimbabwe - Driefontein Grasslands

Threats to the presented wetlands include, among others, the over-utilization of wetland resources by growing populations (e.g. Togo), urban encroachment (e.g. Sierra Leone), industrial activities (e.g. Côte d'Ivoire), agricultural practices (e.g. Mali), water abstraction (e.g. Botswana), pollution and coastal erosion (e.g. Benin), siltation and sedimentation (e.g. Madagascar) and the spreading of invasive species (e.g. Senegal).

In many cases, satellite data is needed to characterize the wetland, understand the extent of pressures and monitor land use changes in order to inform and improve wetland management (e.g. Burkina Faso, Madagascar, Mali, Togo, Zambia). Moreover, satellite data can be used to monitor and map suitable habitats for endangered species (e.g. Botswana, Zimbabwe) or inform restoration activities (e.g. Senegal). Potential applications for communication with stakeholders include public awareness-raising measures (e.g. Côte d'Ivoire), the tracking of illegal activities (e.g. Botswana) and the designation of red lines for urban development with local communities (e.g. Sierra Leone). For each of the case studies recent satellite images are used to illustrate the specificities of the respective site.

7.1 Benin - Chenal Gbaga



(The red frame roughly marks the site. Adapted from: Maps © Thunderforest, Data © OpenStreetMap contributors)

Figure 24: Location of the Chenal Gbaga Site

The Benin wetland Chenal Gbaga is a transboundary wetland, located along the coast line in the Mono basin between Benin and Togo (centre coordinates 06°15'30" N 01°43'45" E, area 5338 ha). It has been a designated Ramsar site since March 2016 (IUCN 2018) and the Mono basin has been a UNESCO Biosphere Reserve since 2017. The management plan for the Chenal Gbaga in the Mono basin has been validated in December 2017. The area is also an important tourist destination for Benin.

Wetland threats and management challenges

The urban development within the site has had minor impacts on the wetland, but the expansion of agricultural areas is an issue.

Animal corridors have been destroyed. Trees, mangroves in particular, have been cut (e.g. for firewood or building material) and consequently, due to the reduction of mangroves, but also as a result of the establishment of a new port in Togo, coastal erosion is an issue.

A major threat for the region and the people living along the coastline is the marine phosphorus pollution coming from mines in Togo. The phosphorus factory is located in Kpèmé (Togo) and the pollution goes up to Ouidah (Benin) (about 70km). The local community is impacted by diseases due to phosphorus pollution following the consumption of polluted fish from the sea. In addition, the quantity of fish is decreasing.

Earth observation support

There is a validated management plan for Chenal Gbaga, but there is no restauration plan and no coordinated plan for the management of the transboundary Ramsar site exists.

Earth observation can contribute to:

- providing information on changes in human settlement
- mapping increasing agriculture
- demonstrating the wetland fragmentation and missing animal corridors
- mapping the decreasing extent of mangrove
- indicating areas with coastal erosion
- identifying (phosphorus) pollution of the sea

- improved planning and conflict resolution on the basis of evidence from maps and indicators (including time series maps)

The following images are Sentinel-2 true colour images of the area for different acquisition dates and subsets (with some cloud cover). They show the permanent occurrence of pollution of the sea (in yellow colour) from Kpémé in Togo along the coastline of Benin over a distance of about 70 km.

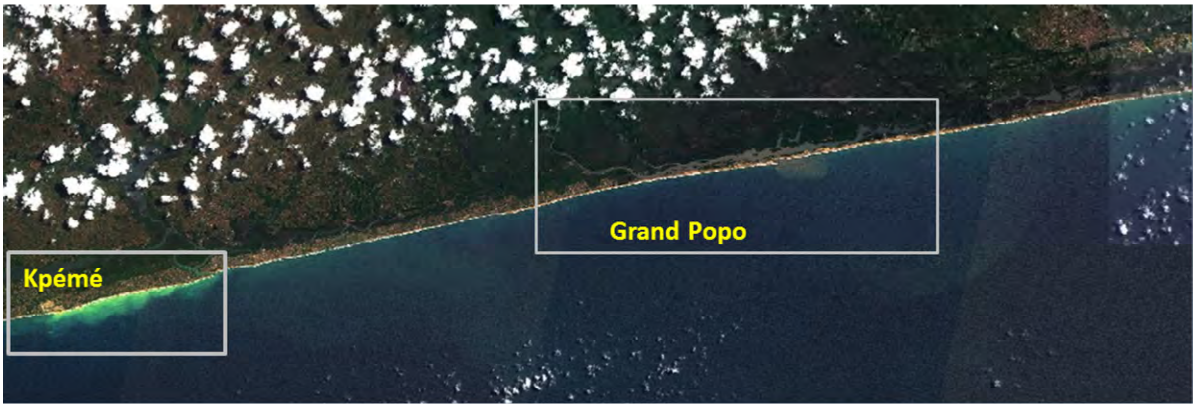
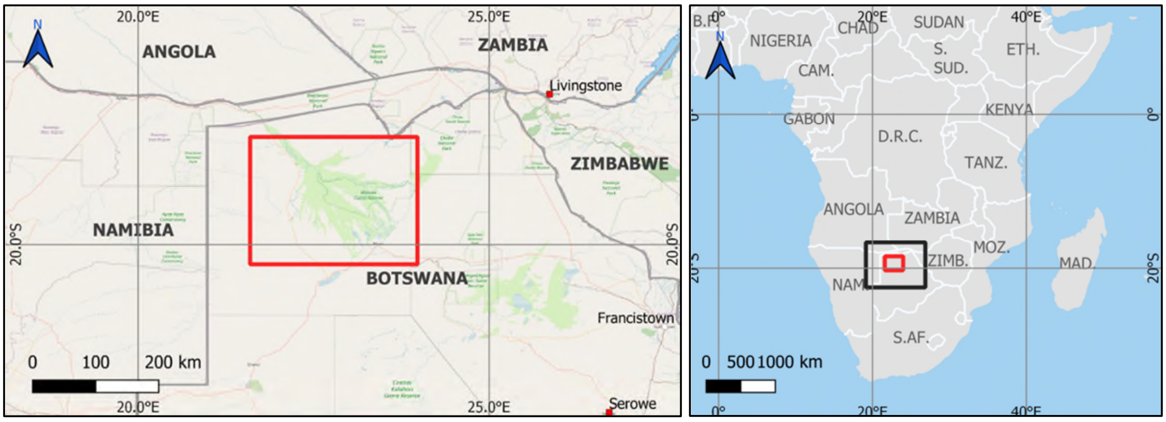


Figure 25: Copernicus Sentinel-2, 2018-05-19, Phosphor pollution from Kpémé (Togo) to Quidah (Benin)

Figure 26: Copernicus Sentinel-2, 2018-05-19, Zoom to Lagune de Grand Popo. In the middle, discharge from a polluted inland water course can be identified due to its brighter colour

Figure 27: Zoom to Kpémé, Copernicus Sentinel-2, 2020-08-16, the displayed sub-image shows areas coloured in yellow along the coastline = areas of phosphorus pollution

7.2 Botswana - Okavango Delta



(The red frame roughly marks the site. Adapted from: Maps © Thunderforest, Data © OpenStreetMap contributors)

Figure 28: Location of the Okavango Delta

The Okavango delta is the only Site of International Importance (Ramsar site) in Botswana. The waters of the Okavango River originate in Angola, traverse Namibia and finally terminate in the Kalahari basin in land-locked Botswana. A key driver of change is wildlife-based tourism which creates major revenue in North West Botswana and the Okavango region at large. The Moremi Game Reserve forms a tourism hub.

The only Ramsar site in Botswana hosts a notable part of the region's birdlife. Although no avian species are endemic in the area, it hosts important breeding sites for various birds, notably for the charismatic wattled crane, which has been monitored here intermittently for nearly three decades.

A river delta which traverses the Kalahari Desert, the Okavango is an oasis of life, which has conserved its pristineness into present times due to past occurrences of the Tsetse fly. With the acknowledged continued integrity of the Okavango Delta comes an ever-increasing desire to erect infrastructure here. However, without relevant evidence, site-level sensitivity assessment has been challenging.

Wetland threats and management challenges

By most standards, the Okavango Delta is a pristine wilderness area. To give effect to the Ramsar Convention here, the Okavango Delta management plan has been developed to guide all development in the area. This has arguably contributed to the delta's continued relative integrity. This integrity, however, attracts a proliferation of anthropogenic activities within and around the delta; mainly being nature-based tourism and ancillary projects. This may further cause a loss of land coverage and the modification of surface water distribution.

Threats and management challenges in the wetland are upstream abstraction and diversion of water. However, although no major single abstractions have occurred which the change can be attributed to, a cumulative effect of small-scale activities is having a visible impact on the historical flow and surface water distribution, especially close to the town of Maun.

The fringes of the Okavango Delta comprise seasonal rivers which are inundated infrequently, at times going dry for years as the area is believed to follow a 20-year flood cycle. This creates uncertainty in the flooding regime of certain localized areas, which developers exploit, arguably causing irreversible modifications in areas which should have attracted more proactive mitigation. A lack of knowledge is a threat in the management of the wetland, which poses a continuing challenge to decision makers.

Currently, no on-demand objective evidence is available on flood risk for water adjacent areas. This needs not be detailed, but rudimentary evidence which can inform the most basic of screening processes. The management of environmental impacts is coordinated through the Environmental Assessment Act, which screens for, among other things, the sensitivity of proposed sites.

Earth observation support

Satellite data will be used to map wetlands in remote areas. Given the lack of ground monitoring, illicit abstraction / diversion of water and exploitations of rivers and resources results in the overall change in the hydrological pattern of streams.

Satellite-based monitoring would enable change detection in areas where wetland and land cover clearance have occurred. This can be matched to authorised activities and,where these have not been authorised, the situation can be stopped prior to points of no return. Furthermore, satellite-based monitoring can be used to account for visible changes in wetlands, specifically, changes in surface water distribution and/or quality. Although this is a reactive activity, it has the advantage of preventing further degradation where such activities are continuing, hence informing intervention measures and priorities.

This approach can be used as a surveillance tool in conjunction with ground truth, to halt emerging threats, and inform law enforcement, hence enabling regulatory action in resource/infrastructure deficient environments. A satellite-based monitoring interface would enable detection of illicit activities, similarly to a fire information management system which would enable remote monitoring with email alerts. When other countries are interested to implement the idea, the next move would be to scale to regional level for ecosystem-based monitoring.

Figure 29: Overview Okavango Delta, Botswana, Copernicus Sentinel-2, 2020-09-10

Figure 30: Okavango Delta at the border between Namibia and Botswana, Copernicus Sentinel-2, 2020-09-10, the border is visible in Sentinel data

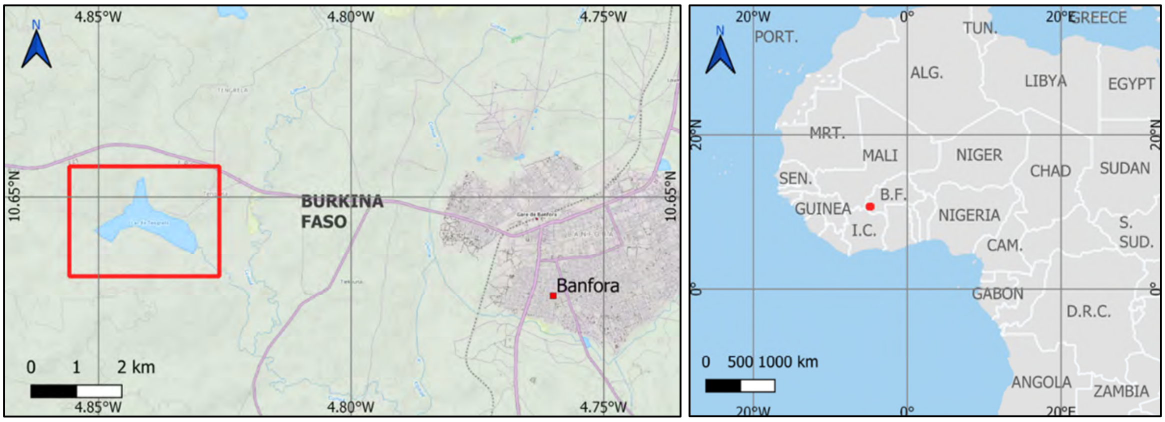
To inform water bird conservation through habitat management, it is key to make evidence-based decisions in the prioritizing of conservation action. The present spatial occurrence pattern of the wattled crane was previously modelled using historical distribution data in conjunction with known environmental conditions. Primarily, this used land cover classification which was a product of other unrelated exercises. However, because the land cover classification was more suited for terrestrial environments, the output of the modelling exercise proved less than ideal. The presence of an application better suited for classifying wetland environments would improve the differentiation of water classes and, hence, provide a more powerful tool for assessing habitat suitability.

Satellite imagery coinciding with past aerial surveys on the wattled crane can be used to identify water classes in the historical habitat. From this, present day satellite imagery can then be derived for classification, the product of which can then be fed into Maximum Entropy modelling to predict the distribution of the wattled crane in the Okavango Delta. This information can thus guide conservation action by emphasizing priority areas, as well as focusing research effort in resource constrained environments.

A demonstration of the suitability of such products can drive similar evidence-based analyses for similar species in wetland areas across the region. A continued refinement of the method and a collation of further field data would streamline the output into a more usable form.

Satellite-derived flood risk and water extent categorization of various areas within the wetland can inform decision-making. This has the advantage of being a purely desktop-based exercise which is not subjective. The information can be derived from historical flood-season imagery (January-May). In situations where classification explicitly infers high flood risk in sites proposed for infrastructural development, appropriate mitigation can be motivated for. The tool could hence be used continuously including further refinements as additional information gets available, making environmental screening ultimately systematic and transparent. It could primarily be applied by environmental authorities, which are usually the first points of reference when proponents seek environmental authorisations. Once the product has been developed to categorise specific sites, a product thereof can also be used by project proponents to find out where their proposed sites fall within the sensitivity categorisation. In South Africa e.g., the Environmental Screening Tool demonstrates a use that could ultimately be adapted to Okavango and by using the GEOclassifier toolbox for initial classification tasks. Within Botswana, this could also be useful for other wetlands such as Linyanti, Chobe, and Makgadikgadi.

7.3 Burkina Faso – Lake Tengrela



(The red frame roughly marks the site. Adapted from: Maps © Thunderforest, Data © OpenStreetMap contributors)

Figure 31: Location of Lake Tengrela

Tengrela Lake (Ramsar Site No. 1881) is located between 10.63 ° N and 10.67 ° N latitude and between 4.82 ° W and 4.87 ° W longitude. The lake is home to a large population of hippos, fish and birds. It is one of the major tourist attractions of Burkina Faso.

Wetland threats and management challenges

This body of water is under the influence of several major threats that risk irreversible degradation if measures are not taken in time to protect this ecological niche:

- The proliferation of invasive species has negative impacts on the water body, the biological diversity of the site and major economic activities (agriculture, livestock, fishing) of the local population.
- Cultivation practices on the banks such as market gardening favour the progressive silting up of the lake, with the risk of pollution of this body of water by chemical fertilizers and the drying up of the lake.
- Due to a lack of rigorous surveillance, wildlife (hippos) are often the object of poaching.
- In addition, the presence of cattle on the edges of the lake all year round, due to the expanse of water, has an impact on the flora.

These factors and threats have unfortunate consequences for the life of the lake, which has already lost some of its surface area, as well as some of the aquatic species previously found there.

Earth observation support

The use of satellite imagery can be of great benefit to the management of the site.

- Control of invasive plant species:

Many possibilities are offered by remote sensing, in terms of mapping, risk analysis and management of invasive aquatic plants. These include: vegetation mapping, detection of changes in the vegetation from one year to another, etc. Hence, satellite imagery could be used for monitoring and assisting the management of invasive plants. The detection of invasive species may be based on the presence of a specific feature, such as a particularly distinct bloom, that would be noticeable in satellite images at a certain point in time.

- Assessment of the lake area

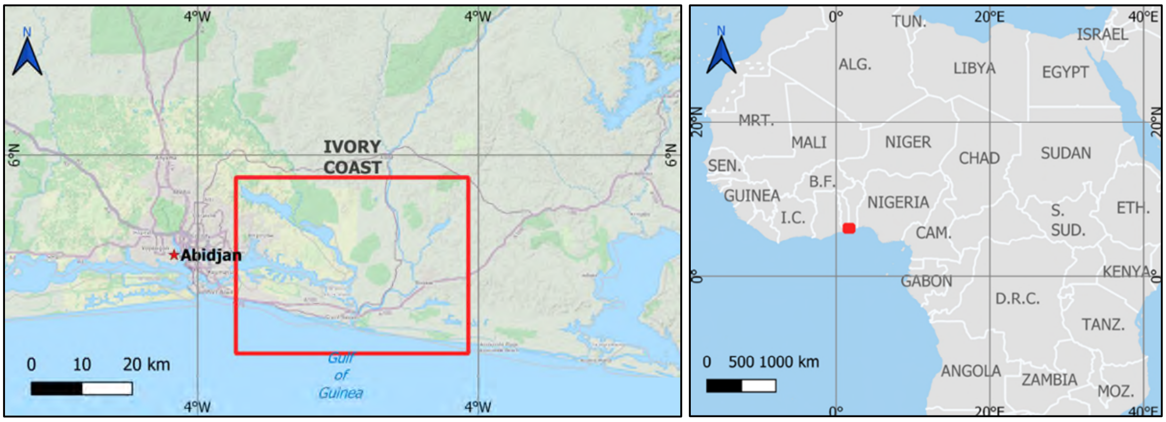
The remote sensing images, by the homogeneous, synoptic and repetitive nature of the observations (as with the Sentinel-2 images which are produced regularly), constitute a source of information particularly well suited for lake monitoring.

- Habitat monitoring

Satellite images will allow the mapping of natural habitats from both remote sensing data and comprehensive field surveys. This will highlight the degradation of natural habitats and the encroachment of human activities on the surface of the lake.

Figure 32: Tengrela, Burkina Faso, Copernicus Sentinel-2, 2020-04-12

7.4 Côte d'Ivoire - Grand-Bassam



(The red frame roughly marks the site. Adapted from: Maps © Thunderforest, Data © OpenStreetMap contributors)

Figure 33: Location of Grand-Bassam Wetlands

The Grand-Bassam Ramsar Site is located along the Ivorian coast on the edge of the Atlantic Ocean, around 05° 21' North latitude and 03° 46' West longitude, in the South-East of Côte d'Ivoire, in the sub-prefecture and in the administrative region of Sud Comoé. The site serves as a stopover for many species of migratory water-birds.

Threats and challenges

The threats are multiple, including sand extraction by dredging, excessive cutting of mangroves for firewood and smoke-wood, as well as urbanization and chemical pollution of water and land resulting e.g. from treatments of agro-industrial crops.

The Grand-Bassam wetland is subject to strong agro-industrial activity upstream. The clearing of vegetation for agriculture and increased cutting of mangroves have caused the loss of biodiversity and water pollution (flow of chemicals to the river and the lagoon) due to regular flooding during the floods of the Comoé. Added to this is urbanisation and sand extraction in the wetland, which directly results in degradation of aquatic habitats, reduction of wetland area and increased loss of wild avian fauna.

The challenges are to raise awareness and inform all stakeholders, including all direct and indirect actors, to create a coordination and dialogue mechanism at the local level and to use satellite images to monitor the development of the site.

Figure 34: Part of Grand-Bassam in Abidjan, Côte d'Ivoire, Copernicus Sentinel-2, 2020-01-05

Earth observation Support

To improve this situation, satellite images can be used to monitor the dynamics of the vegetation in the wetland, to monitor the development of the site and to raise awareness of all stakeholders (managers of agricultural companies, administrative authorities, the local population, etc.). Satellite images will help to identify areas important for the conservation of water birds and other animal species.

Moreover, the production of an awareness raising manual on wetland conservation and environmental education booklet is planned.

Maps and statistics below (prepared by the wetland team of Côte d'Ivoire) show that in 1985, littoral/coastal forest was the most dominant land cover type in the wetland, covering 32% of the total area (12,844 ha). Land clearance or fallow covered an area of 9,292 ha. Mangrove vegetation represented only 1% of the wetland in 1985, which corresponds to an area of 552 ha. Degraded soils or habitats covered an area of 6,472 ha, respectively 16%.

Due to an intensification of agricultural activities in this area, cleared or fallow land has increased to 13,446 ha or 33% in 2017. Oil palm and rubber tree plantations are widely cultivated and occupy vast areas of 1,048 ha, or 3% of the total area. Coastal forest covers an area of just 10,454 ha, or 26%.

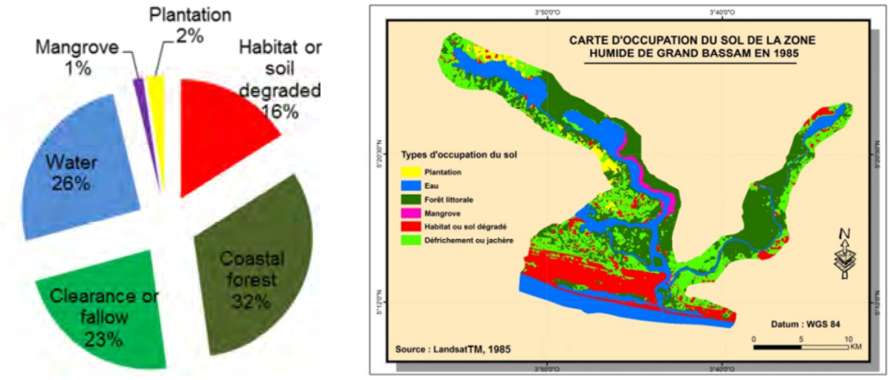


Figure 35: Distribution of land cover in the Grand-Bassam wetland in 1985, (provided by the wetland team of Côte d'Ivoire 2020)

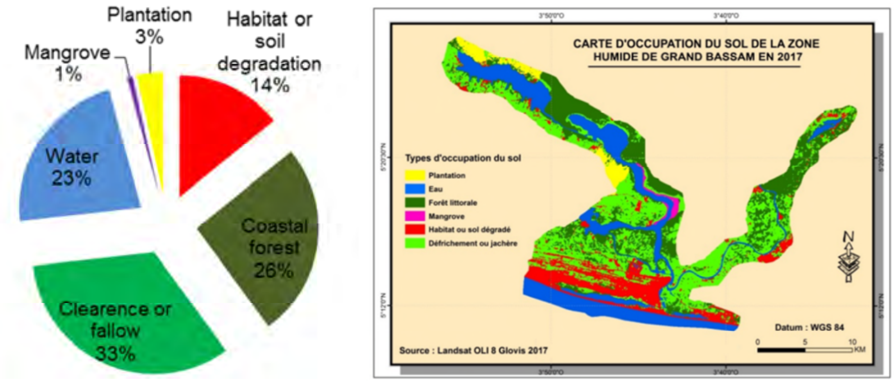
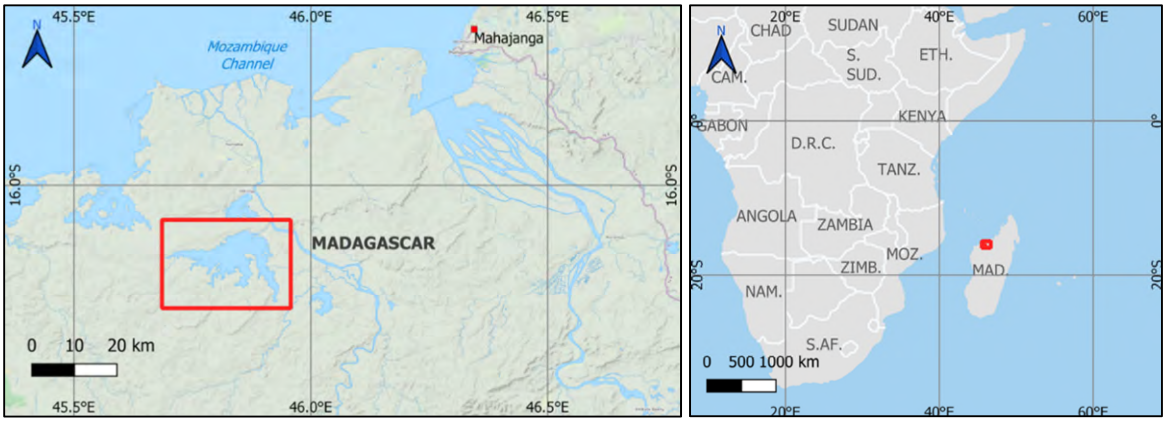


Figure 36: Distribution of land cover in the Grand-Bassam wetland in 2017 (provided by the wetland team of Côte d'Ivoire 2020)

7.5 Madagascar - Lake Kinkony



(The red frame roughly marks the site. Adapted from: Maps © Thunderforest, Data © OpenStreetMap contributors)

Figure 37: Location of Lake Kinkony

The "Mahavavy Kinkony Complex", a protected area with a total area of 302,400 ha, is home to Madagascar's second-largest lake: Lake Kinkony.

The site comprises of a mixture of ecological habitats ranging from wetlands such as lakes, rivers, marshes, coasts and sea to the dry forest in the West. It is home to many endemic and threatened species.

Figure 38: Lake Kinkony, Madagascar (Copyright: Harison Andriambelo, 2018)

Wetland threats and management challenges

The destruction of the different types of habitats located upstream of the wetlands as a result of charcoal production and the extension of arable land causes the sedimentation of lowlands areas. This leads to irreversible silting of water bodies and the reduction in surface area and depth of wetlands. The magnitude of this process is difficult to measure, but it promotes the conversion of newly silted areas into rice fields and the development of invasive animal and plant species. This lack of knowledge of the extent of degradation constitutes a major challenge for the management of the site.

The dry forest around the Kinkony wetlands covers an area of 77,900 ha. Mangroves and marine areas located between the land-sea border extend to about 17,500 ha. The wetlands cover around 15,000 ha of rivers and 14,000 ha of lakes. The quality and ecological integrity of lake and marshland habitats strongly depend on the magnitude and extent of the pressures and threats that emerge upstream. Land and forest conversion upstream, following human actions (charcoal, conversion to crop areas, etc.) constitute a serious threat to the habitats of wetlands downstream. These pressures are manifested constantly over time and in space, and lead to massive losses of habitats, ecosystem processes and species.

Satellite-derived information showing changes in forest cover and water classes will help to analyse and understand the silting process and assess the magnitude and extent of this pressure. Spatial data in GIS format will allow the information to be used in an appropriate GIS environment.

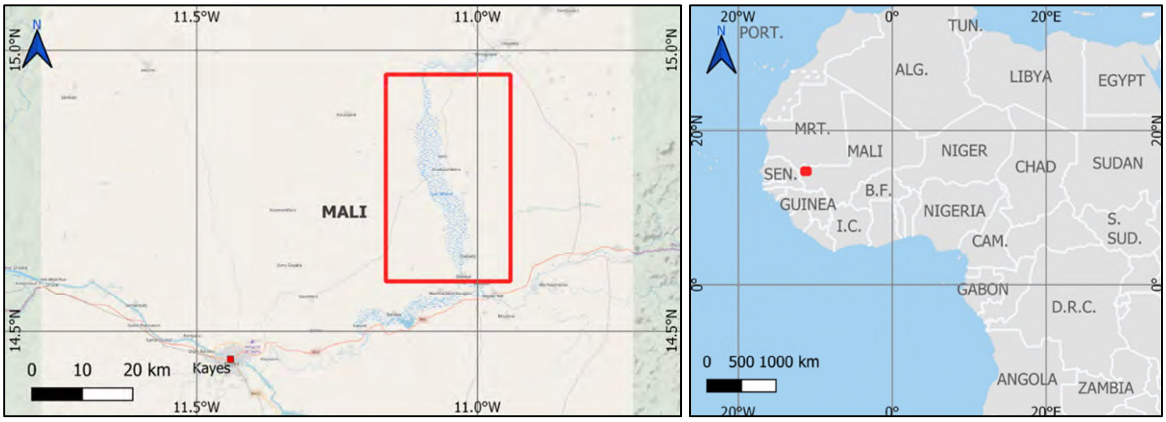
Earth observation support

Satellite-derived information will help describe the silting process in and around the Kinkony wetlands. It will be used to analyse the main and secondary causes as well as the consequences of the sedimentation process on a larger scale.

This step is crucial for planning the appropriate conservation and management measures for the site. Currently, the strategies pursued are mainly based on expert opinion and visual observations at the site level which may not reflect the magnitude and extent of this pressure. In addition, since this process is common in the western part of the country, the findings of this approach could be used in other sites with conditions and contexts similar to the Kinkony site.

Figure 39: Kinkony wetland area, Madagascar, Copernicus Sentinel-2, 2020-09-20

7.6 Mali – Lake Magui



(The red frame roughly marks the site. Adapted from: Maps © Thunderforest, Data © OpenStreetMap contributors)

Figure 40: Location of Lake Magui

Lake Magui is located 65km north of the town of Kayes (circle of Kayes) in the Sahelian zone between longitude 14°30‘ N and 15° N; in a large depression in the Terekole-Kolimbine basin. The annual average precipitation fluctuates around 600 mm. The vegetation cover is highly degraded and consists mainly of thorny and combretaceae species.

Large fauna has disappeared from the area following climatic hazards and very strong human pressure. However, the avifauna is very well supplied, because the area is a wetland serving as a transit point for migrating birds that will later continue their flight from Mali to the Niger Delta.

<u>Wetland threats and management challenges</u>

The sustainable and integrated management of the wetlands in the watershed as well as the sub-regional cooperation for the management and sustainable use of the wetlands of the river basin are major challenges.

Threats are climate change, invasive plants, pollution, salinization of land, silting up, and conversion of wetlands. Ecosystem services are affected, such as groundwater recharge, biodiversity and resources, tourism, portable water supply, water and nutrient cycling.

A specific change in land use is that crops are being seeded in the lake bed, resulting in the degradation of the banks, conflicts between users, silting up of the bed, degradation of wildlife habitats, degradation of plant formations, loss of biodiversity, and change in the hydrological regime.

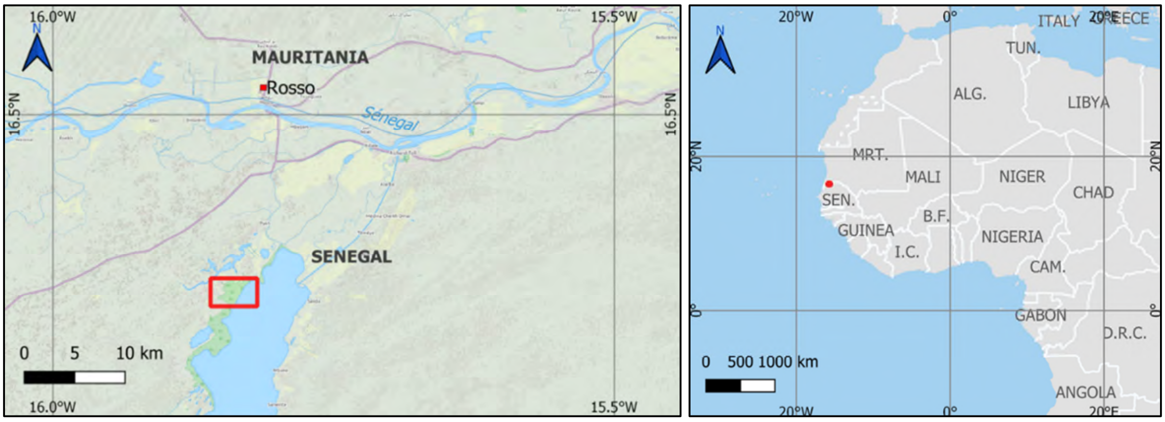
Improving the conservation of the basin's habitats and its biodiversity poses a major challenge.

<u>Earth observation support</u>

Useful satellite-derived products will be basin evolution maps, characterisation of the main wetlands in the basin (land use dynamics, state of ecosystems and resources, uses, threats). Stakeholders in the basin are communities, local, regional, national and sub-regional decision makers; NGOs, partners etc.

Figure 41: Lake Magui, Mali, Copernicus Sentinel-2, 2019-11-13

7.7 Senegal – Tocc Tocc Reserve



(The red frame roughly marks the site. Adapted from: Maps © Thunderforest, Data © OpenStreetMap contributors)

Figure 42: Location of Tocc Tocc Community Reserve

The Tocc Tocc Community Nature Reserve (RNC) is located between 16°20'38" N and 15°50'13" W with a size of over 273 ha. It is contiguous to Lac de Guiers, Dakar's main source of drinking water. Despite its small size, the reserve is of great importance due to its specific diversity which led to its classification as a Ramsar Site in 2013. It includes two main areas, a terrestrial one (20% of the total area), with *Tamarix aphylla* as the dominant species and constituting the domain of predilection for some terrestrial mammals (patas, common jackal, etc.). This zone is limited at its lower part by a strip of typha. The second main part is a waterbody (80% of the total area) consisting mainly of a basin of fresh water. It is home to more than 98 species of fish, waterfowl, as well as the Adanson freshwater mud turtle (*Pelusios adansonii*) and the iconic West African manatee (*Trichechus senegalensis*) (IUCN 2020).

Due to the presence of significant biodiversity and the presence of endangered species, especially the African manatee, the area is nominated as a Ramsar Site. There exists a management plan and a management team is available.

Wetland threats and management challenges

Threats for the area are due to anthropogenic pressures and effects of climate change. The main threats facing the site are overfishing and the uncontrolled abstraction of the water (Ramsar Convention 2013). A major problem is the proliferation of aquatic plants (*Typha australis*). The propagation of *Typha australis* in the reserve generates negative effects on biodiversity with a loss of habitat for birds, fish, etc., and a degradation of ecosystem services, in particular navigability, fishing activities, water for livestock, etc. A management system for natural resources is missing and there is a lack of adequate financial, human and infrastructure resources.

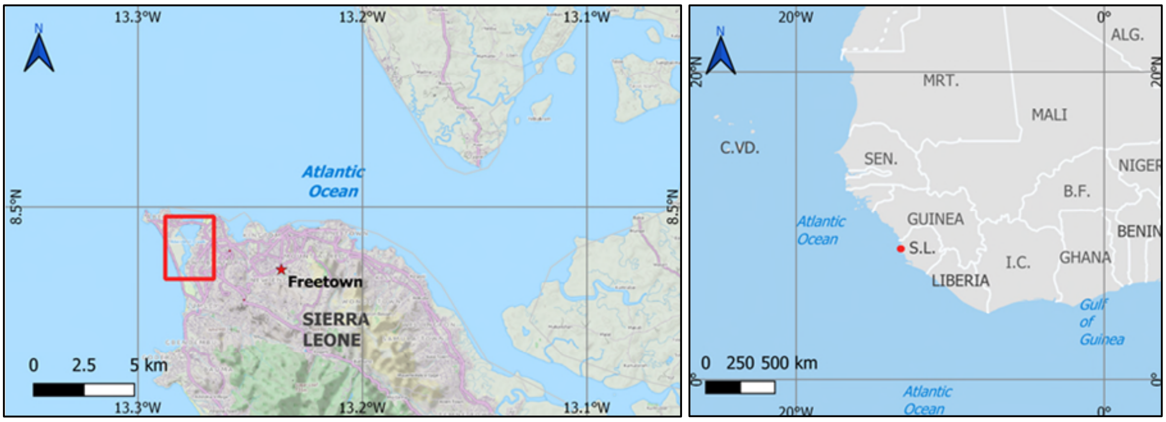
Figure 43: Tocc Tocc reserve Senegal, Copernicus Sentinel-2, 2020-04-07

Earth observation support

It is important to limit the spread of Typha. Thus, as part of the review of the reserve's development plan, satellite images can be used to:

- Determine the level of propagation between 2000 and 2020
- Identify the areas to be developed and which will be cleaned up in order to rehabilitate the habitats
- Define a schedule of planning activities (identify the best times)
- Define a satellite monitoring/surveillance protocol
- Define a maintenance protocol linked to the monitoring protocol

7.8 Sierra Leone - Aberdeen Creek



(The red frame roughly marks the site. Adapted from: Maps © Thunderforest, Data © OpenStreetMap contributors)

Figure 44: Location of the Aberdeen Creek

Aberdeen Creek is located in the North-North West of the Freetown Peninsula between Latitudes 8.4550 N and 8.4950 N & Longitudes 13.2720 W and 13.2850 W. Communities of the Aberdeen Creek are remote and mainly composed of minor slum communities.

Wetland threats and management challenges

The size of the Aberdeen Creek was approximately 700 – 750 acres in 2014 and in 2019 it has reduced to approximately 650 acres.

It has faced significant levels of encroachment due to housing and infrastructural development. Notably, the edges of the creek are gradually degraded (cutting of mangroves and area backfilled with filth/soil) and transformed into settlement. Since 2014, mangroves reduced significantly in the creek.

It is worthy to note that in the 2019 spatial assessment on the Aberdeen Creek and establishment of a redline along its edges, communities requested for more opportunities to expand their settlements into the creek. Sometimes before stakeholders of these communities (authorities and cliques) had been confronting the National Protected Area Authority's (NPAA) game-guards and officials with serious arguments that even resulted in fatal injuries and destruction of properties.

However, due to these anomalies, NPAA and the communities negotiated to establish a final redline which should prevent communities from exhibiting further encroachments into the creek. Before the establishment of this redline, the NPAA GIS Department developed imageries of each community along the edges of the creek. These images were integrated with data indicating trends of encroachment levels and were presented to the community stakeholders. The environmental impacts of these kinds of encroachments were further explained to them.

Earth observation support

With the establishment of NPAA in Sierra Leone, its GIS Department has been dependent on the application of Google Earth (a Landsat/ Copernicus images) where images are required for map production as well as analysing trends of encroachment levels of protected areas (more specifically wetlands). Recently in November 2019, NPAA conducted a spatial assessment on the Aberdeen Creek and established a redline along its edges which inhibits communities from practicing further encroachment into the creek. The results were compared with the extent of the creek in 2014 (see map below).

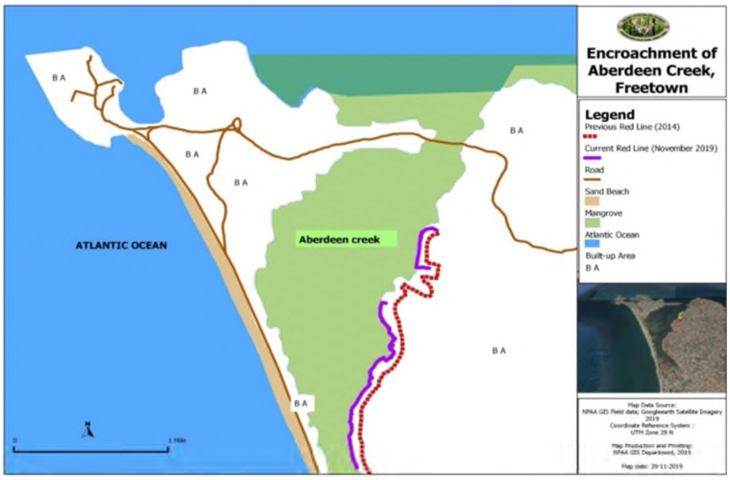


Figure 45: Decreasing extension of the Aberdeen Creek in 2014 (red line) and 2019 (violet line) (provided by the wetland team of Sierra Leone, 2020)

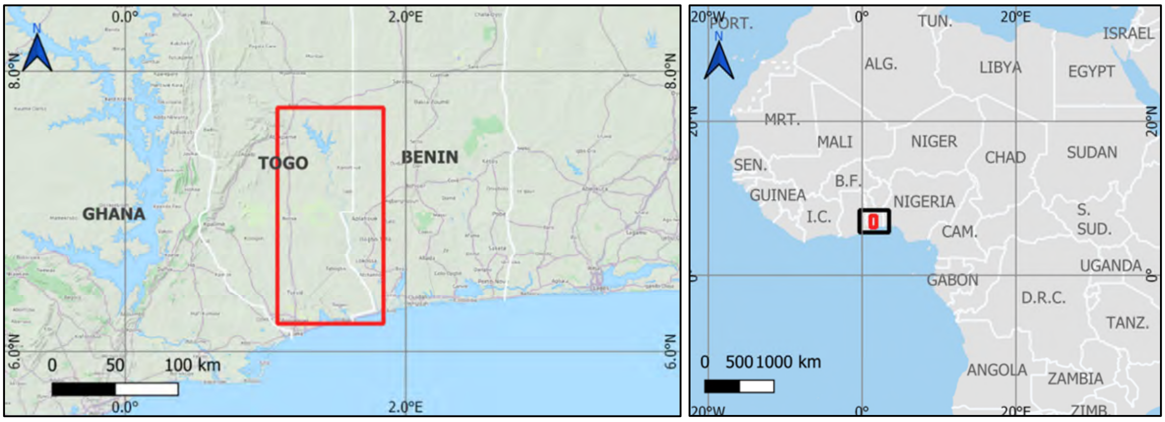
Figure 46: Aberdeen Creek in Freetown, Copernicus Sentinel-2, 2020-09-01

It is worth noting that the use of the images helped communities to understand their areas and actions, so as to decide on preventing further encroachments and avoiding respective environmental impacts.

It is recommended that satellite images must be used in similar projects in order to

- Monitor changes in the land cover over specific periods
- Provide easy observation and mapping of the land cover (mangroves, grasslands, riparian forests swamps and flooded plains) of wetlands resources where there are inadequate resources on the ground
- Depict trends of land use patterns within wetlands
- Create easy interpretations of geographic features changes due to anthropogenic activities and to inform policies and prioritize planning actions
- Determine the level of management action to be taken to restore wetlands over time
- Help authorities to observe and address local and transboundary encroachment and identify opportunities for cooperation among various sectors in a country.

7.9 Togo – Mono Basin



(The red frame roughly marks the site. Adapted from: Maps © Thunderforest, Data © OpenStreetMap contributors)

Figure 47: Location of the Mono Basin

The Mono River is the major river of eastern Togo. The river is approximately 400 km long. The Nangbeto dam was built in 1987 in a partnership between Benin and Togo.

Wetland threats and management challenges

Wetland threats in the wetland zone downstream of the Mono basin are the increase in human population, siltation, coastal erosion, invasive plants and degradation of vegetation, deforestation, wildfires, poaching and overfishing. Management challenges in the wetland are continuous degradation of the area due to the increase in population and the associated needs for water, food and energy. Like everywhere else across the country, the population of the study area is growing very rapidly with an annual growth rate of around 3%. With this increase in population comes an increased demand for water, food and energy. The population is predominantly rural and agriculture, livestock breeding and fishing are the main socio-economic activities. The population depends mainly on firewood and charcoal as the main sources of domestic energy. The increase in population results in an alteration of wetlands and a scarcity of their resources, especially in a context of lack of integrated management. This threat corresponds to the conversion of the wetland into an agricultural and urban area.

Figure 48: Nangbeto Dam, Togo, Copernicus Sentinel-2, 2019-11-30

Earth observation support

Information from satellites showing changes in land use and variations in water extent will allow the examination and assessment of the extent of degradation in the area in order to raise awareness among stakeholders. Spatial data in raster and vector format will enable the use of a Geographic Information System (GIS) to develop thematic maps showing the evolution of pressures on the wetland and their adverse consequences in the context of climate change and wellbeing of the local population. This, therefore, requires data that can be used to model the land use. Satellite information could also be used to sensitize stakeholders in other wetlands under human pressure for better management planning of the area.

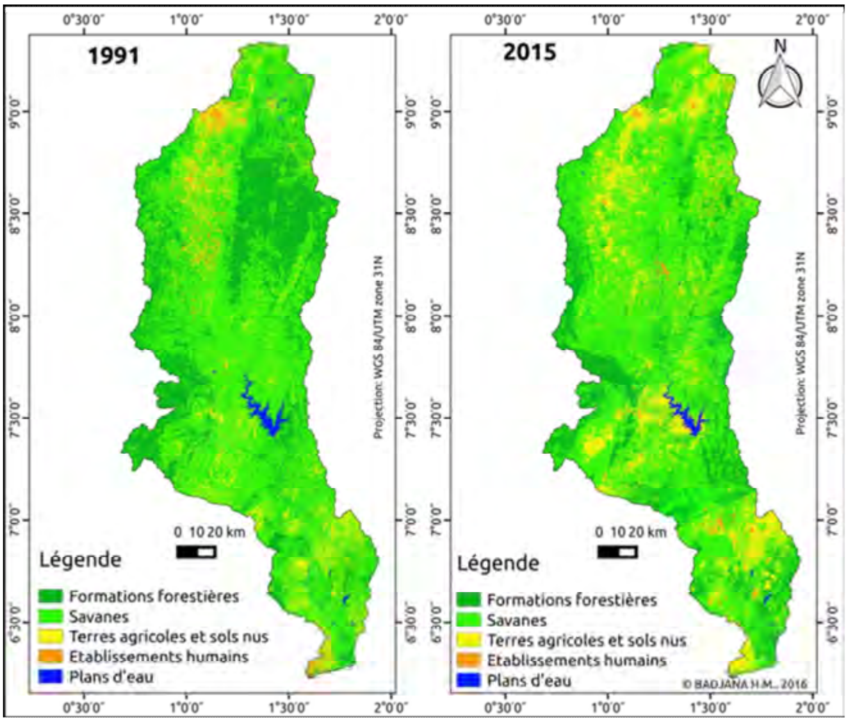
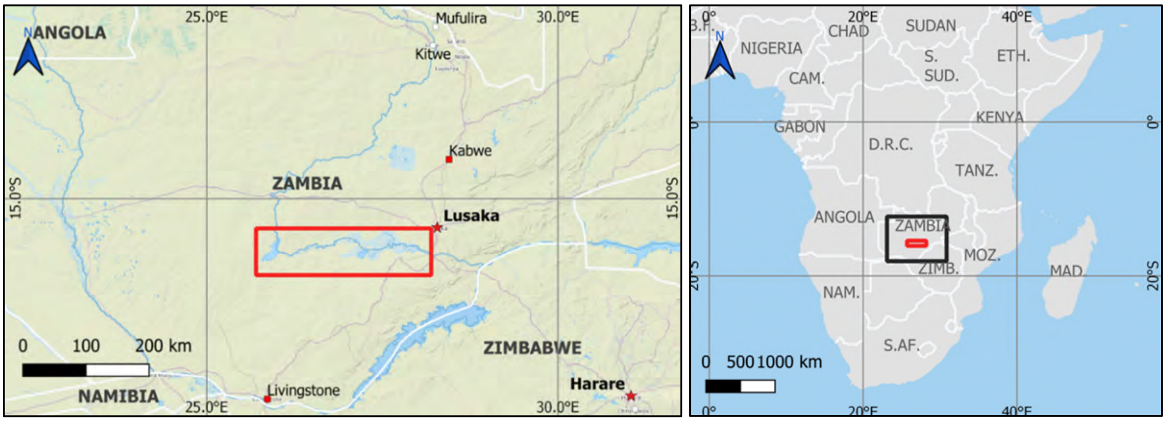


Figure 49: Evolution of land use between 1991 and 2015 in the Mono basin, the increasing yellow and orange areas in the map indicate increasing agricultural and urban areas (maps are provided by the wetland team of Senegal)

7.10 Zambia – Kafue Flats



(The red frame roughly marks the site. Adapted from: Maps © Thunderforest, Data © OpenStreetMap contributors)

Figure 50: Location of the Kafue Flats

The Kafue Flats are located in the Southern & Central Provinces of Zambia with a Size of 600,500 ha. The Ramsar Site was extended from 83,000 to 600,500 ha on 2 February 2007. As one of the first Ramsar Sites in Zambia it has been designated already in August 1991. There is a vast expanse of floodplains, grasslands, woodland zones and geothermal areas of high biodiversity in a complex patter of lagoons, oxbow lakes, abandoned river channels, marshes, and levees. The site supports many endangered and endemic species, and it hosts migratory animals as well as 67 fish species. The site possesses natural filtering and storage abilities, thus providing clean and plentiful water and acting as a natural sink for nutrients and other micro-elements (Ramsar Convention 2007).

Figure 51: Kafue Flats Sep. 2019 (Copyright: Kathrin Weise, Jena-Optronik GmbH)

Wetland threats and management challenges

The inhabitants gain their livelihoods from fishing and pastoral livestock husbandry. Draft management plans for the Blue Lagoon and Lochnivar National Parks have been formulated with the participation of different stakeholders. Supported by the Zambian Wildlife Authority anti-poaching law enforcement unit, these plans should help to combat the threats of over-fishing, poaching, poor management and weed invasion by Mimosa. The Kafue flats have experienced many human interventions, e.g. through the construction of hydro power infrastructure which caused major impacts on the vegetation.

Figure 52: Kafue Flats overview, Zambia, Copernicus Sentinel-2, 2020-08-07/10

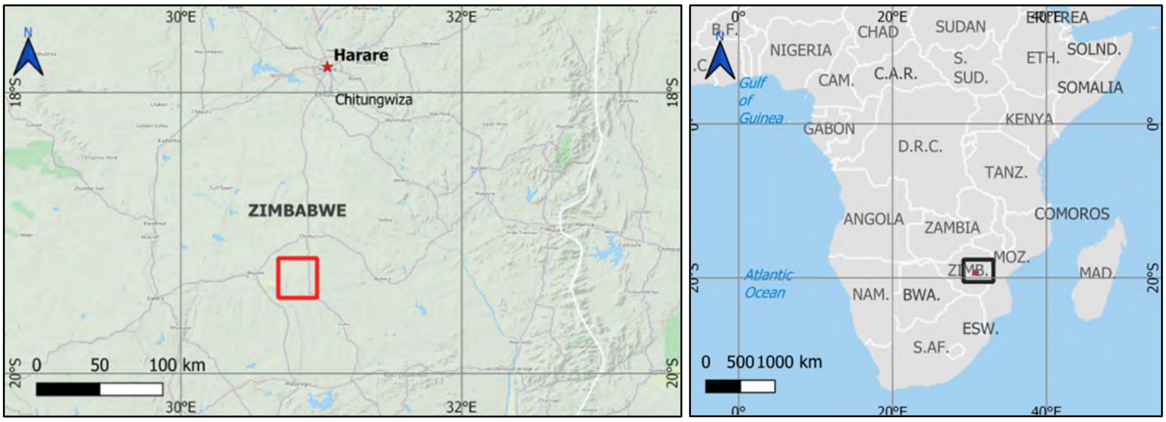
Figure 53: Lake Itezhi-Tezhi in the West of Kafue Flats, Zambia. Left side: Minimum water extent (Copernicus Sentinel-2, 2019-12-19), Right side: Maximum water extent (Copernicus Sentinel-2, 2020-06-01)

Earth observation support

Since there is no final management plan yet, and land use poses a major threat to the area, Earth observation can contribute e.g. to:,

- Mapping weed invasion boundaries
- Mapping minimum and maximum water extent
- Mapping the agriculture areas, roads, urban developments and in particular show the impact of human interventions due to the hydro power constructions
- Mapping the extent of the managed flood-plains.

7.11 Zimbabwe - Driefontein Grasslands



(The red frame roughly marks the site. Adapted from: Maps © Thunderforest, Data © OpenStreetMap contributors)

Figure 54: Location of Driefontein Grasslands

The Driefontein Grasslands are a Ramsar Site located in central Zimbabwe. The site is not part of the national protected area systems and thus it is communally managed. It is is also an Important Bird Area (IBA) and in particular it supports three globally threatened bird species. The Ramsar Site forms the headwaters of the central watershed with more than five rivers originating from this biodiversity-rich area. Its wetlands sustain livelihoods of rural communities both onsite and downstream.

Figure 55: Wattled Crane in the Driefontein Grasslands 2020 (Copyright: Togarasei Fakarayi)

Wetland threats and management challenges

The wetlands are mainly threatened by cultivation, veld fires and overgrazing. The soils in most parts of Driefontein Grasslands are sandy with high drainage, resulting in pressures on wetlands. The soils in low lying areas are fertile. Balancing wetland conservation and human livelihood improvements is key in ensuring improved wetland conservation in the Driefontein Grasslands.

Earth observation support

Medium resolution satellite data has been used to map and establish the current status of wetlands in the Driefontein Grasslands. The wetland maps produced have formed a generalized baseline to characterise the wetlands.

Satellite based information and maps are useful to:

- Establish wetland inventories with detailed profiling and monitoring wetland habitats
- Track breeding and foraging pairs of the globally threatened crane bird species
- Monitor land use and land cover changes to establish the extent of encroachment and effectiveness of current interventions
- Monitor water cycle regime to track wetland moisture levels.

Figure 56: Driefontein, Zimbabwe, Copernicus Sentinel-2, 2019-12-18

Bibliography

ESA (2020): ESA Earth Online, 2000 - 2020 Sentinel-3. https://earth.esa.int/web/guest/missions/esa-eo-missions/sentinel-3

ESA (2021): Sentinel User Guides. https://sentinel.esa.int/web/sentinel/user-guides

Esri (2021): What is ArcGIS. https://developers.arcgis.com/documentation/core-concepts/what-is-arcgis/

Fitoka, E., Tompoulidou, M., Hatziiordanou, L., Apostolakis, A., Höfer, R., Weise, K., Ververis, C. (2020): Water-related ecosystems' mapping and assessment based on remote sensing techniques and geospatial analysis: The SWOS national service case of the Greek Ramsar Sites and their catchments. In: Remote Sensing Of Environment 245, Special Issue on Earth Observation for the Sustainable Development Goals. https://www.sciencedirect.com/science/article/pii/S0034425720301656

GW-II (2020): GlobWetland II WebGIS: http://webgis.jena-optronik.de/

IPCC (2014): Climate Change Regional Aspects 2014, Impacts, Adoption, and Vulnerability, Part B: Regional Aspects, page 1202, Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartB_FINAL.pdf

IUCN (2018): Plan de gestion du site Ramsar transfrontalier du Chenal Gbaga dans le bassin du Mono entre le Bénin et le Togo et son projet de mise en œuvr. https://www.iucn.org/sites/dev/files/content/documents/plan_de_gestion_chenal_gbaga_final.pdfIUCN (2020): IUCN Red List of Threatened Species 2020. https://www.iucnredlist.org

Lewis, D. (2020): How Mauritius is cleaning up after major oil spill in biodiversity hotspot. In: *Nature* 585, 172 . https://www.nature.com/articles/d41586-020-02446-7

McGarigal, K., Cushman, SA., Ene, E: (2012**):** FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html

Millennium Ecosystem Assessment (2005): Ecosystems and Human Well-Being: Wetlands and Water Synthesis. http://millenniumassessment.org/en/index.html.

Moomaw, W.R., Chmura, G.L., Davies, G.L., Finlayson, C.M., Middleton, B.A., Natali, S.M., Perry, J.E., Roulet, N. & Sutton-Grier A. E.(2018): Wetlands In a Changing Climate: Science, Policy and Management. Wetlands 38, 183-205. https://link.springer.com/article/10.1007/s13157-018-1023-8

Niasse, M., Afouda, A., Amani, A., (2004): Reducing West Africa's vulnerability to climate impacts on water resources, wetlands and desertification: elements for regional strategy for preparedness and adaptation. https://www.iucn.org/content/reducing-west-africas-vulnerability-climate-impacts-water-resources-wetlands-and-desertification

Olatunji, E.T., Charles, J.F.(2020): Change detection analysis of mangrove ecosystems in the Mesurado Wetland, Montserrado County, Liberia, IJRES 7, 17-24. http://bluepenjournals.org/ijres/pdf/2020/September/Olatunji_and_Charles.pdf

Ramsar Convention (2007): Ramsar Site Information Service: Kafue Flats. https://rsis.ramsar.org/ris/530?language=en

Ramsar Convention (2013): Ramsar Site Information Service: Tooc Tocc Community Reserve. https://rsis.ramsar.org/fr/ris/2199?language=fr

Ramsar Convention (2018a): Global Wetland Outlook: State of the World’s Wetlands and their Services to People. Ramsar Convention Secretariat. www.global-wetland-outlook.ramsar.org/

Ramsar Convention (2018b): Briefing Note 10, Wetland Restoration for Climate Change Resilience, Ramsar Briefing Note 10. https://www.ramsar.org/document/briefing-note-10-wetland-restoration-for-climate-change-resilience

Ramsar Convention (2019): Wetlands: A natural solution to climate change. Statement by the Secretary General of the Ramsar Convention. https://www.ramsar.org/news/wetlands-and-climate-changeRamsar (2013): Ramsar Site Information Service: Tooc Tocc Reserve https://rsis.ramsar.org/fr/ris/2199?language=fr

SWOS (2018): SWOS Achievements, Innovations and Visions. https://www.swos-service.eu/brochures/

SWOS (2020): SWOS and GEO-Wetlands Community Portal. http://portal.swos-service.eu/mapviewer/detail/1.html

United Nations (2019): World Population Prospects 2019: Highlights. https://population.un.org/wpp/Publications/Files/WPP2019_10KeyFindings.pdf

USGS (2021): Landsat Missions, Landsat 8. https://www.usgs.gov/core-science-systems/nli/landsat/landsat-8?qt-science_support_page_related_con=0#qt-science_support_page_related_con

Weise, K., Höfer, R. Franke, J., Guelmami, A., Simonson, W., Muro, J., O'Connor, B., Strauch, A., Flink, S., Eberle,J., Mino,E., Thulin, S., Philipson, P., Valkengoed, E.van, Truckenbrodt, J., Zander, F., Sánchez, A., Schröderk, C., Thonfeld, F., Fitoka, E., Scott, E., Ling, Schwarz, M., Kunz, I., Thürmer, G., Plasmeijer, A., Hilarides, L.(2020): "Wetland extent tools for SDG 6.6.1 reporting from the Satellite-based Wetland Observation Service (SWOS)", Remote Sensing Of Environment, Special Issue: Earth Observation for the Sustainable Development Goals

Download links for data or tools

GEOclassifier toolbox:

Request software and license via email to: geoclassifier@jena-optronik.de

Free satellite data:

Sentinel satellite data available at ESA Copernicus Open Access Hub: https://scihub.copernicus.eu/dhus/#/home

Landsat satellite data available e.g. at USGS EarthExplorer: https://earthexplorer.usgs.gov/

Toolboxes for (pre-)processing Sentinel data:

SNAP toolboxes available at: https://step.esa.int/main/download/snap-download/

Sentinel1 Toolbox: http://step.esa.int/main/toolboxes/sentinel-1-toolbox

Sentinel3 Toolbox: http://step.esa.int/main/toolboxes/sentinel-3-toolbox

Sentinel User Guides: https://sentinel.esa.int/web/sentinel/user-guides

GIS tools:

QGIS download: https://www.qgis.org/en/site/forusers/download.html

ArcGIS sign up and download: https://pro.arcgis.com/de/pro-app/latest/get-started/install-and-sign-in-to-arcgis-pro.htm

SAGA download: https://sourceforge.net/projects/saga-gis/

FRAGSTATS download: https://www.umass.edu/landeco/research/fragstats/downloads/fragstats_downloads.html#FRAGSTATS

Further resources:

Glob-Wetland II WebGIS: http://webgis.jena-optronik.de/

Ramsar Site Information Service: https://rsis.ramsar.org/

SWOS & GEO-Wetlands Community: http://portal.swos-service.eu/mapviewer/detail/1.html

Abbreviations

AATSR	Advanced Along-Track Scanning Radiometer
ALOS	Advanced Land Observing Satellite
ATSR	Along Track Scanning Radiometer
AVNIR	Advanced Visible and Near Infrared Radiometer
BfN	Federal Agency for Nature Conservation / Bundesamt für Naturschutz
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CDOM	Coloured Dissolved organic matter
CLC	CORINE Land Cover
ENVISAT	Environmental Satellite
EO	Earth Observation
ERS	European Remote Sensing satellite
ESA	European Space Agency
ETM	Enhanced Thematic Mapper
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographical Information System
GW-I	GlobWetland I
GW-II	GlobWetland II
JOP	Jena-Optronik GmbH
LCCS	Land Cover Classification System
LST	Land Surface Temperature
LULC	Land Use Land Cover
LULCC	Land Use Land Cover Change
MAES	Mapping and Assessment of Ecosystems and their Services
MERIS	Medium Resolution Imaging Spectroradiometer
MMU	Minimum Mapping Unit
MODIS	Moderate-resolution Imaging Spectroradiometer
MSS	Multispectral scanner
NGO	Non-Governmental Organization
NIR	Near InfraRed
NDVI	Normalized Difference Vegetation Index
NPAA	National Protected Area Authority's
OLCI	Ocean and Land Colour Instrument

OLI	Operational Land Imager
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PRISM	Panchromatic Remote-sensing Instrument for Stereo Mapping
Ramsar	Ramsar Convention on Wetlands
RGB	Red-Green-Blue colour composite
SAGA	System for Automated Geoscientific Analyses
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goals
SLSTR	Sea and Land Surface Temperature
STRP	Scientific and Technical Review Panel of Ramsar
SMOS	Soil Moisture and Ocean Salinity satellite
SNAP	Sentinel Application Platform
SWD	Surface Water Dynamics
SWIR	Short Wavelength InfraRed
SWOS	Satellite-based Wetland Observation Service
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TSM	Total Suspended sediments
USGS	United States Geological Survey
WQ	Water Quality