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| **Indicator** | 6.6.1 Change in the extent of water-related ecosystems over time |
| Target | 6.6. By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes. |
| Custodian(s) | UN Environment and the Secretariat of the Ramsar Convention on Wetlands[[1]](#footnote-2) | Tier | I (Nov 2018) |
| Current approach and challenges | The indicator tracks changes over time in the extent of water-related ecosystems, as well as the quantity and quality of water within them. The indicator includes five categories of water-related ecosystems: 1) vegetated wetlands, 2) rivers and estuaries, 3) lakes, 4) aquifers, and 5) artificial waterbodies. Extent includes three components: the spatial extent or surface area, the quality, and the quantity of water-related ecosystems, as per below:Indicator methodology uses a progressive monitoring approach divided across 2 levels with a total of 5 sub-indicators.Level 1: 2 sub-Indicators based on globally available data from earth observations which will be validated by countries against their own methodologies and datasets:*Sub-Indicator 1* – spatial extent of water-related ecosystems *Sub-Indicator 2* – water quality of lakes and artificial water bodiesLevel 2: Data collected by countries through 3 Sub-Indicators:*Sub-Indicator 3* – quantity of water (discharge) in rivers and estuaries *Sub-Indicator 4* – water quality imported from SDG Indicator 6.3.2 *Sub-Indicator 5* – quantity of groundwater within aquifers**Baseline and reporting period:** *Sub-Indicator 1* This sub-indicator has to be computed separately for each of the water-related ecosystem types: spatial extent of natural open water bodies (lakes, rivers, and estuaries), spatial extent of artificial water bodies (reservoirs, canals, harbors, mines and quarries ) and spatial extent of vegetated wetlands (swamps, fens, peatlands, marshes, paddies, and mangroves). Although conceptually clear, in practice differentiating artificial water bodies from lakes in satellite images is a non-trivial task. Sub-Indicators 1 and 2 are based on globally available data from earth observations which will be validated by countries against their own methodologies and datasets. Once validated, the datasets are used to calculate percentage change of spatial extent over time, in five-year intervals, using a 2001-2005 baseline period. The reporting intervals are 2006-2010, 2011-2015 and 2015-2020. The five-year averages are then compared to the baseline as follows.Percentage Change in Spatial Extent= $\frac{(β-γ)}{β }$×100Where β = the average national spatial extent from 2001-2005 Where γ = the average national spatial extent of any other 5 year period *Sub-Indicator 2*Earth observations can only provide information on concentrations of in-water materials that affect the colour of water, i.e. its optical properties. Although there are many other water quality parameters such as dissolved oxygen, electrical conductivity, nitrogen, phosphorus and pH, that determine overall water quality, they do not change the optical properties of the water body and are not included in this sub-indicator (in contrast to sub-indicator 4 / SDG indicator 6.3.2). This sub-indicator, therefore, requires two key parameters to be measured - change in concentration of both chlorophyll a (Chl) and total suspended solids (TSS) on a water body basis, i.e. it is expected that daily observations are averaged over a year for each lake. The annual average per water body of Chl and TSS will be averaged every 5 years, and compared to the Chl and TSS baselines to generate a percentage change (using the same time intervals as sub-indicator 1). The locations where percentage change is excessive can be targeted for increased water quality monitoring and management. *Sub-Indicator 3*Although the methodology for this sub-indicator is flexible to the circumstances of the countries, their river basin status and resources available, they must adhere to the following basic reporting guidelines: • Discharge data from each river/estuary monitored should be collected at least once per month. This data should then be averaged to obtain an annual average discharge per river/estuary monitored. • Each basin should have a minimum of one sampling location, at the point where its water exits into another basin or crosses a national boundary.Countries will then submit 5 years of data on annual average discharges per basin to the custodian agencies. The data from these 5 years will be averaged to smooth short-term variability. To generate national percentage change of discharge over time, a common reference period for all basins must be established. This baseline period will be used to calculate the percentage change of discharge for any subsequent 5-year period. To calculate percentage change in discharge for each five year period following the reference period, the following formula is used: Where:Percentage Change in Discharge= $\frac{(β-γ)}{β }$×100Where β = historical 5-year reference discharge (to be determined by countries based on their data)Where γ = the average discharge of 5 year period of interest*Sub-Indicator 4*The reporting on this indicator (copied from indicator 6.3.2) will follow a 5-year cycle as follows:* Initial baseline data collection completed in 2017
* First reporting cycle in 2020: data collected from 2015 to 2019
* Second reporting cycle in 2025: data collected from 2020 to 2024
* Third reporting cycle in 2030: data collected from 2025 to 2029

*Sub-Indicator 5*Countries will submit 5 years of data on annual average groundwater level per basin to the custodian agencies. The data from these 5 years will be averaged to smooth short-term variability. To generate national percentage change of discharge over time, a common reference period for all basins must be established, i.e. it is up to the countries to determine their national temporal baseline. This baseline period will be used to calculate percentage change of groundwater quantity for any subsequent 5-year period, according to the formula for sub-indicator 1 but for change in groundwater quantity instead of spatial extent, as follows: Percentage Change in Quantity= $\frac{(β-γ)}{β }$×100Where β = historical 5-year reference groundwater level (to be determined by countries based on their data)Where γ = the average groundwater level of 5 year period of interest**Country Validation**All globally available data generated for sub-indicators 1 and 2 are shared with countries for validation, as and when they become available. However, global datasets are not yet available for all aspects of these sub-indicators. For example, global EO-derived datasets of open surface waters (see section 3) currently merge all open water whether it is artificial or natural, a lake or a river. This presents a challenge to countries to further partition these datasets into the natural and artificial categories of water bodies. As for national validation, many countries still lack the necessary tools and training to validate national extracts of these global datasets. Although theoretically the global data should be generated annually, countries are still required to aggregate the data on a 5-year basis, using averages of the annual data on spatial extent. If the data are not made available to countries on an annual basis then these 5-year averages will not be computed satisfactorily. Once the 5-year averages are computed, they should be validated by countries before being used to report on percentage change. **Classification strategy**As described above, indicator 6.6.1 focuses on 5 categories of water-related ecosystems: 1) vegetated wetlands, 2) rivers and estuaries, 3) lakes, 4) aquifers, and 5) artificial waterbodies. However, for the purposes of reporting on sub-indicator 1, open water bodies (categories 2, 3 and 5) are grouped in order to separate them from vegetated wetlands which require a totally different methodology to map their spatial extent. Once the spatial extent of open water bodies has been determined, they are then further categorised into natural (lakes, riversand estuaries) and artificial open water (quarries, reservoirs etc.). Artificial water bodies are included as a standalone category as they can contain a significant amount of a country’s freshwater even if they are not a natural ecosystem. Sub-indicator 2 concerns lakes and artificial water bodies only, while sub-indicators 3,4 and 5 concern rivers and estuaries, all open water bodies and groundwater in aquifers only, respectively. As for extent of vegetated wetlands, under sub-indicator 1, salt waters are not included in this category (as they are in SDG 14) which otherwise is identical to the Ramsar definition of wetlands which is: “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres”. This means that submerged wetlands like seagrasses or coral reefs are not included under sub-indicator 2 but coastal, vegetated wetlands such as mangroves are.**Methodological change**The 6.6.1 methodology has evolved over time, most recently revised in 2018, and upgraded to Tier I[[2]](#footnote-3). One of the major differences in earlier methodology was that countries reported on the extent of all open water bodies, i.e. grouping artificial and natural water bodies together. This can be potentially misleading and has therefore been revised in 2018, stipulating that they must be reported on as separate categories.  |
| **Opportunities for Earth Observation** |
| Opportunities for EO | Earth Observation is recognized as an important data source for measuring two of the 5 sub-indicators (level 1) while in-situ data are recognised as the main source for the other three (level 2) sub-indicators. However, as this section will show there are opportunities to exploit EO data even further in level 1 sub-indicators and to explore its use with in-situ data for the level 2 sub-indicators, where it is currently not mentioned as a data source.For example, in sub-indicator 1 (spatial extent of water-related ecosystems), currently entirely EO-based, a national extract of global data will be shared with countries for their national level validation, where they have the following options:* **Accept:** country verifies data, validates its use, and data is reported to the United Nations Statistical Division (UNSD).
* **Reject:** country denies the use of data provided, and does not provide replacement data. No data is reported to UNSD.
* **Modification:** country modifies the data provided, or use their own EO-based national data, and re-submits it for reporting to UNSD.
* **Provide own data**: country denies the use of data provided, instead of providing their own data for reporting to UNSD.

The last two options provide opportunities for countries to also use their data (EO and non EO data) and perform their own estimation of the extent of water-related ecosystems, e.g. using freely available platforms and tools (see section 3). EO can be used not only to produce the global datasets but also as a source of information for countries when validating the national extracts from the global datasets. The method for calculating this sub-indicator is detailed in the ‘monitoring methodology for SDG indicator 6.6.1’ (UN Water, 2018), which utilises global datasets generated by EO throughout. Level 2 sub-indicators are based on additional data which are collected by countries. In the long term, it is hoped that countries will develop the capacity to report on Level 2 data. In terms of exploring opportunities for EO in more detail, the following sub-sections give an overview of current possibilities for mapping the different components of each sub-indicator. For sub-indicator 1, these are the spatial extent of open water bodies, with a separate treatment of natural and artificial water bodies and vegetated wetlands. For sub-indicators 2,4 and 5, overviews of EO opportunities are described separately while for sub-indicator 3, indicator 6.3.2. on ambient water body quality is referred to for further reading. As each sub-indicator requires different EO-based approaches and methodologies, they are discussed in separate sub-sections.**Open water bodies:** The spatial extent of open water bodies (lakes, rivers and estuaries), vegetated wetlands and artificial water bodies (reservoirs) can all be monitored using satellite data, but with varying degrees of accuracy and coverage depending on the type of remote sensing approach taken, e.g. whether using optical or radar imagery, or preferably both combined. Open water bodies can, in general, be easily monitored with both optical and radar imagery. The Global Surface Water Explorer (GSWE) from the European Commission’s JRC, based solely on optical imagery, has used the entire archive of Landsat imagery spanning forty years to show the global spatio-temporal variation in surface water at 30m spatial resolution including its intra and inter-annual variation. However, challenges occur due to data gaps within cloudy regions such as the humid tropics where cloud-free observations can hardly be obtained. A weakness of the GSWE datasets is that artificial and natural water bodies are not separated. This is a non-trivial task and requires ancillary data such as boundaries of reservoirs, dam locations and other elements of water infrastructure from water basin authorities, the location and extent of disused quarries and mines to delineate flooded cavities as well as other built-up features such as piers and jetties which can be used to identify an artificial water body. In some cases, artificial water bodies can be identified by their temporal dynamics, as in managed water levels in reservoirs are relatively stable compared to those in natural water bodies such as lakes which fluctuate with the hydrological cycle.**Vegetated wetlands:** EO can also be used to monitor vegetated wetlands, such as mangroves with high accuracy, again by combining information from optical and radar instruments. While optical imagery allows the surface water dynamics to be observed and separated from the vegetation canopy, radar can then enhance the separation by penetrating the vegetation canopy to underlying, standing water, e.g. using longer wavelength SAR such as P- and L-band. Therefore, areas of inundated vegetation can be better disguised from both open water and vegetation, confusion between them is reduced and vegetated wetlands can be reported on separately. Other radar-based parameters to aid vegetated wetland identification are the moisture content of soils which can indicate the presence of wetland even if there is no surface water, whereas optical imagery is more sensitive to vegetation coverage but also to the absorption of water in the NIR and SWIR spectral regions. Information from both sensor systems is often combined with elevation data to extract the extent of vegetated wetlands more accurately as vegetated wetland are most prevalent in low-lying, flat areas. Overall, the most suitable approaches combine information from optical and radar systems to tackle the many challenges for EO-based water and wetland monitoring considering the diversity of available ecosystems. Today, mangroves as well as their changes since 1996, have been mapped consistently for the pan-tropical region by the Kyoto & Carbon Global Mangrove Watch initiative, led by the Japanese Space Agency (JAXA). Annual maps are now planned. Other vegetated wetlands such as saltmarshes or peatlands have not been mapped as systematically although there are ongoing efforts by the Global Peatlands Initiative to produce a rapid global assessment of peatland extent and carbon content using remote sensing, starting in their four partner countries: Indonesia, Peru, Democratic Republic of Congo and the Republic of Congo. Peatlands, saltmarshes and mangroves are valued not only as water-related ecosystems but also as carbon sinks and stores of global significance and therefore are urgently in need of rapid identification and extent and condition mapping.**Water quality of lakes and artificial water bodies:** This sub-indicator requires data on Chlorophyll a (Chl) and total suspended solids (TSS) in lakes and artificial water bodies. Both of these parameters can be derived from optical EO sensors using empirical algorithms that describe the relationship between spectral reflectance and water quality. As these parameters fundamentally alter the “colour” of the water body in terms of the photosynthetic content, coverage can be provided by both multi-spectral land sensors at high resolution and ocean colour scanners at medium resolutions.Multi-spectral land sensors such as the Landsat 8 Operational Land Imager (OLI) and Sentinel-2 Multispectral Instrument (MSI) have the capacity to map water quality of small water bodies (~1ha) given that a spatial resolution of up to 10m can be achieved with the MSI. However, in situ water samples are necessary at a commensurate spatial resolution to drive the empirical model. Ocean colour sensors such as Sentinel-3 OLCI, Envisat MERIS (decommissioned), NOAA/NASA VIIRS and NASA Terra/Aqua MODIS are coarser (≥250m) meaning that small lakes or other water bodies are either undetectable or averaged out over large areas but that in situ sampling of the water body can afford to be less dense. As these medium resolution sensors have a wider swath width they tend to have a high revisit time and therefore offer the possibility of more frequent observations than higher resolution sensors. Satellite sensors do offer other water parameters which can help in an assessment of water quality such as water temperature.**Quantity of water (discharge) in rivers and estuaries:** This sub-indicator is primarily measured in-situ, with techniques including gauging stations and discharge meters. However, EO data can also be used in discharge models. These models typically use a relatively simple rainfall-runoff model calibrated against point flow or water level data. The main inputs are rainfall and topography, both of which are available from EO sources. Additionally, satellite altimetry can be used to estimate 2 different aspects of water (discharge):change in water volumes and water discharge. By measuring altitude above terrain height, satellite altimetry can be used to estimate water levels of open water bodes, along with changes of these over time. Traditional radar altimeters have had footprints which have been too large to reliably estimate elevation parameters over smaller water bodies, due to interference from land. However, new lasers-based systems, like ICESat-2, provides altimetry data with much smaller footprints which makes it possible to map changes in water volume over time in smaller lakes, and through this determine water availability and long term drought indicators.**Water quality imported from 6.3.2**– see SDG support sheet 6.3.2**Quantity of groundwater within aquifers:** The data source for this sub-indicator is primarily in-situ data using boreholes. However experimental EO methods are in development that can support countries in future reporting. The Gravity Recovery and Climate Experiment (GRACE) and GRACE-FO (follow-on) missions[[3]](#footnote-4) monitor tiny gravity changes, caused by motion in underground water and mass in storage. This could provide a means to measure relative changes to groundwater within aquifers but it is not yet ready for operational reporting.  |
| EO datasets and platforms  | As this a complex and broad indicator there are a range of satellite data sources and global data products which could be used for indicator reporting. In addition, there are several online platform and tools who provide options and support for accessing or deriving various inputs for computation of indicator 6.1.1. **Satellite Data**Raw satellite imagery for the mapping of water bodies, vegetated wetlands and water quality can be obtained from public and freely-accessible data collections as well as from commercial distributors. A summary of the available options is provided in the table below:

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| --- | --- | --- | --- | --- | --- |
| Sensor | Type | Spatial resolution | Temporal coverage /Revisit time | Data policy | Comment |
| Sentinel-1 | SAR (c-band) | 10 m | From 2014 / At least every 12 days globally | Free and open | Limited historical data but the long-term continuity is secured under the Copernicus program  |
| Sentinel-2 | Multi-spectral | 10 m | From 2015 / Every 5 days globally | Free and open | As above |
| Sentinel-3  | Colour instrument | 300 m | From 2016/At least every 2 days globally | Free and open | As above but this provides continuity to the Envisat MERIS mission which provided water quality data |
| Landsat | Multi-spectral | 30 m | Since 1984 / Every 16 days globally | Free and open | The 30-meter resolution is a drawback compared to Sentinels but the long temporal coverage is invaluable for historic mapping |
| MODIS | Multi-spectral | 250m,500m and 1km | Since 2002/At least every 2 days globally | Free and open | Frequent revisit time and spectral bands for water quality monitoring |
| MERIS | Colour instrument | 300m and 1.2km | 2002-2011/At least every 3 days globally | Free and open | As for Sentinel-3 but discontinued |
| ALOS 2 PALSAR 2 | SAR (L-band) | 100 meters (SCANSAR mode) | Since ~2000/ 42 days for the tropics only | Commercial | Capable of sub-canopy detail but at the expense of cost |
| VIIRS | Multi-spectral | 375m, 750m | Since ~2002/ Sub-daily, e.g. 3-4 times per day at mid-latitudes | Free and open | Similar to MODIS in terms of specifications and to provide continuity |
| GRACE | Gravitometer | Curent estimates suggest a catchment of the size ≈63,000 km2 can be resolved at an error level of 2 cm in terms of equivalent water height | Since ~2002, decommissioned 2017/ Every 30 days | Free and open | Acquires estimates of water storage in shallow aquifers |
| Topex/Poseidon, ERS-1, ERS-2, GFO, Jason-1, Envisat RA2, Sentinel 3 SRAL | Altimetry satellites (decommissioned) | Variable | 1992-2013/ Variable | Free and open | historic data on water levels (for baseline) |
| CFOSat, Sentinel-3A/B, Jason-2 and 3, Saral, HY-2, Cryosat | Altimetry satellites (in operation) | Variable | 2013-present/ Variable | Free and open | contemporary estimates of change |

Sentinel data can be accessed through the Data and Information Access Services (DIAS) or the Conventional Data Hubs (<https://www.copernicus.eu/en/access-data>) while Landsat, MODIS and VIIRS data are available via the EarthExplorer (<https://earthexplorer.usgs.gov/> ). The MERIS data archive is available from MERCI MERIS (<https://merisrr-merci-ds.eo.esa.int/merci>) and PALSAR 2 data can be accessed through the [Japan Aerospace Exploration Agency](http://global.jaxa.jp/) (JAXA)  [Earth Observation Research Center](http://www.eorc.jaxa.jp/en/index.html) (EORC) (<https://www.eorc.jaxa.jp/ALOS/en/dataset/dataset_index.htm>). Altimetry observations from Jason is available via USDA Global Reservoir and Lake Monitor (G-REALM) <https://ipad.fas.usda.gov/cropexplorer/global_reservoir/> . Commercial satellite data can be purchased through data providers and their reseller network.**EO based global datasets***Natural open water bodies (lakes, rivers and estuaries)** **The Global Surface Water Explorer (GSWE)** is developed and maintained by the European Commission’s Joint Research Centre (JRC). It uses only Landsat imagery to provide the spatial extent of the world’s surface water resources including their temporal dynamics over the last 32 years: <https://global-surface-water.appspot.com/>

*Artificial open water bodies (reservoirs)** **The Global Dam Watch** is a partnership of leading academic institutions and NGOs that curate and make freely available global data on dams and reservoirs. Therefore, it can be used by countries to link the presence of dams to water bodies obtained from the GSWE and the river network from other resources. Only one of the three datasets on GDW is EO-derived - GOOD2, a map of 38,660 dams visible in Google Earth imagery. The others - the Global Reservoir and Dam Database ([GRanD](http://globaldamwatch.org/grand/)) maps the location and attribute data of 7,320 dams greater than 15m in height or with a reservoir of more than 0.1km3. Future Hydropower Reservoirs and Dams ([FHReD](http://globaldamwatch.org/fhred/)) maps 3,700 dams that are under construction or in advanced planning stages. <http://globaldamwatch.org/>

*Vegetated wetlands* * **The Global Mangrove Watch (GMW)** developed under JAXA’s Kyoto & Carbon initiative, provides geospatial information about mangrove extent and changes to the Ramsar Convention, national wetland practitioners, decision-makers and NGOs. The global mangrove extent baseline map for the year 2010 is displayed on WRI’s Global Forest Watch portal: https://www.globalforestwatch.org. Data are available for baseline changes from 1996 and 1997 (JERS-1), 2007 to 2010 (ALOS) and from 2015 (ALOS-2) on the GMW website: <https://www.globalmangrovewatch.org/>
* **The Global Wetlands Map** is developed under the framework of the Sustainable Wetlands Adaptation and Mitigation Program ([SWAMP](https://www.cifor.org/swamp/)) and provides access to information and data on the distribution of tropical wetlands, peatlands and carbon stocks. The data is based on satellite images using MODIS data and covers the tropical and subtropical regions up to 30 degrees North and 70 degrees South. The data products are available for the baseline year 2011 and can be accessed from the global wetland map website; <https://www.cifor.org/global-wetlands/>

*Water quality of lakes** **The Copernicus Global Land Services** is now providing operational WQ products at 300m and 1km for lakes globally. However, global 100m WQ products from Sentinel-2 data are expected by the end of 2019. Historic data are available from May 2002 to March 2012, based on MERIS imagery, and present data from Sentinel-3 OLCI from May 2016 onwards. The data product is composed of three core datasets:
	+ Turbidity or water clarity
	+ Trophic state index or eutrophication status
	+ Lake surface reflectances or water colour

*Water levels** Altimetry derived time series water levels from large rivers and lakes are available from a number of different sources e.g. LEGOS Hydroweb (http://www.legos.obs-mip.fr/en/soa/hydrologie/hydroweb/),THEIA Hydroweb (<http://hydroweb.theia-land.fr/>) and Database for Hydrological Time Series of Inland Waters (DAHITI) (https://dahiti.dgfi.tum.de/). Time series are typically constructed from the combined use of various altimetry missions including: ERS-1 & 2, Topes/Poseidon, Envisat, S3 SRAL and Jason*.*

**Platforms and Tools*** **The Surface Water Viewer** has beenco-developed by UN Environment, Google and the JRC to enable countries to view and download time series data as well as statistical data between 1984 and 2018 on the spatial extent of water-related ecosystems and their temporal dynamics. Data can be disaggregated by sub-national, national and hydro basin boundaries. <https://www.sdg661.app/home>
* **GlobWetland Africa** is an open and free software toolbox, developed by ESA in partnership with the Ramsar Convention, which enables end-to-end processing workflows for wetland delineation, wetland habitat mapping, monitoring of inundation regimes, extraction of water quality and modelling of river basin hydrology. For water quality, the toolbox draws upon functions already built into the SNAP/BEAM toolset. However, it builds on water quality functionality through added workflows (monitoring of aquatic eutrophication and physical disturbance). Output indicators: Time series of chlorophyll concentration (mg/m³), turbidity, suspended sediment concentration (g/m³), indicators for floating vegetation.
* **ESA SNAP/BEAM and Sentinel-3 toolboxes**can be used for pre-processing optical data for use in water quality algorithms. SNAP is the SeNtinel’s Application Platform. It is a generic, open-source platform for ESA Toolboxes ideal for the exploitation of Earth Observation data. SNAP tools allow the user to pre-process the EO data before WQ parameter retrieval. SNAP can be used to process MERIS L2 product data for use in water quality algorithms, e.g. in atmospheric correction over water. The sentinel-3 toolbox has similar functionality but specifically for the OLCI data of Sentinel-3.
* **Hydrology Thematic Exploitation Platform (TEP)** - the TEP for Hydrology is a tool where the members of the community can rapidly and easily access to a large number of Earth Observation data, integrate their own data and tools (in-situ data, socioeconomic data, analysis tools...) and process their processors (service prototypes, hydrological models, meteorological models) within a user-friendly environment. Thematic applications include Water Observation and Information System (WOIS – open-source tool for water-related satellite data processing), flood monitoring service, hydrological modelling service, water level service and small water body mapping service.
 |
| International Initiatives | **The GEO Wetlands** initiative aims to realise the possibility of a Global Wetlands Observation System (GWOS) on behalf of the Ramsar Convention. Being a GEO Initiative it adopts the basic principles of openness and data sharing. This will be achieved through a wetland community geo-portal. GEO-Wetlands is already building a community of wetland observation practitioners, spanning a range of actors and has pilot projects, e.g. Global Mangrove Watch, with a view to building the GWOS. <https://www.earthobservations.org/activity.php?id=122>**The GEO AquaWatch**, the GEO Water Quality Initiative, aims to develop and build the global capacity and utility of Earth Observation-derived water quality data, products and information to support water resources management and decision making. AquaWatch is aiming to produce a global monitoring system for water quality by 2025 called the Water Quality Information Service which will be a direct contribution to indicator 6.3.2 (water quality), 6.1.1 and 6.1.12 (sanitation). <https://www.geoaquawatch.org/>**The Global Peatlands Initiative** aims to improve the conservation, restoration and sustainable management of peatlands. It is a partnership led by UN Environment. Although primarily focused on the reduction of carbon emissions from peatland degradation, it also addresses peatlands as an important ecosystem and is of direct relevance for indicator 6.6.1. Mapping the extent of peatlands using EO in priority countries is a key aim of the initiative. |
| **Proposed Methodology** |
| Step-to-Step guide for EO integration into SDG framework | The preceding sections have documented the background to the indicator methodology and suggested global EO datasets, tools and platforms which can be used to access data and resource related to the 6.6.1 sub-indicators. While global EO approaches are important, particularly for the Level 1 sub-indicators, there are also opportunities for countries, briefly alluded to in the “Opportunities” section, to compute the indicators themselves from EO data. This section contains an end-to-end description of the EO Processing Chain for those countries who would like to do produce the indicators (or sub-indicators) themselves. Each sub-section replicates the same structure, consisting of the steps required to obtain, process and validate the EO data and derived indicators. The mapping of water-related ecosystems is a domain of ongoing research which will eventually provide operational methodologies. Therefore, not all methods of computing the sub-indicators from EO data have been comprehensively described here, only those which are mature enough for countries to implement by themselves. **Spatial extent of water-related ecosystems****STEP 1: Get data**As a first step users need to verify whether the public domain datasets are representative of the reporting period as well as consider the need and availability of more precise datasets. If the public domain datasets are considered inadequate users have the option to acquire new EO imagery and water-related data to generate updated information on the spatial extent, quantity and quality. Typically, the extent and location of artificial water bodies will be obtained through a government department or ministry while users who wish to use EO imagery alone to identify artificial from natural water bodies will need to bring their own EO data and machine learning methods, e.g. for mapping dams. This might require access to commercial optical imagery at very high resolution to identify dams and other water management related infrastructure. Openly available medium resolution imagery (e.g. Sentinel and Landsat) might be perfectly adequate for mapping water body extent and quality, depending on their size and distribution. Sentinels 1 and 2 and Landsat, can also be used to map vegetated wetlands and which have a free and open data policy.**STEP 2: Process data** To derive the extent of water-related ecosystems (and vegetated wetlands in particular), a multitemporal approach is recommended making use of both optical and radar observations over a period of 2 to 5 years. The length of the period depends on the regional conditions (i.e. availability of soil moisture). Whereas in some regions a short period might be sufficient to track the dynamics of water-related ecosystems, arid regions might require a longer time period to fully track these dynamics. The more observations are included in the analysis, the higher will be the precision of the resulting product on the wetland extent.The basic idea of the proposed approach is to derive information about the presence of water and wet soils (wetness) within the particular time period to report the Water and Wetness Presence/Probability Index (WWPI). This information together with local expert knowledge can be used to extract the extent of water-related ecosystems.Information about surface water and the wetness of soils are ideally derived from the optical and radar datasets and fused in the end to give a map of the WWPI. The optical approach is based on Sentinel-2 Multi-Spectral Imager (MSI) data for which a selection of spectral indices is calculated. A combination of these indices and the Topographic Wetness Index yields the water and wetness probabilities. Subsequently, split-based dynamic image thresholding is applied to derive water and wetness extents for each Sentinel-2 scene (or multi-temporal composites). Finally, these extents are aggregated to get water and wetness frequencies (Ludwig et al., 2019).The radar-based algorithm builds on geophysical parameters, surface soil moisture dynamics and water bodies, mainly derived from Sentinel-1 backscatter time series to identify permanent/temporary wet and flooded areas. In addition, it is possible to identify flooded vegetation according to the double-bounce scattering principle in densely vegetated wetlands. The non-flood prone areas are masked using the Height Above Nearest Drainage (HAND) index which is generated using the digital elevation model and flow direction within the drainage network.After the separate processing of the optical and radar imagery, the data are fused into a combined water and wetness product. A rule-based classification can be applied to finally derive the wetland extent based on local expert knowledge and in situ information to help fine-tune the algorithm for the regional context (environmental conditions).The above-described approach allows to distinguish between vegetated wetlands and open surface waters since both types of ecosystems are separately derived. Moreover, information on open surface waters could also be taken from the Global Surface Water Explorer. Additional datasets may be of use for supplementing this data, including Global Mangrove Watch. As a next step, open surface waters need to be further disaggregated into (1) lakes, (2) rivers and estuaries, and (3) artificial water bodies. For artificial water bodies, a combination of approaches can be used. This includes overlaying the wetland extent dataset with national datasets for artificial water bodies (if they exist). Examining significant changes from one year to the next can also give an indication of the presence of artificial water bodies. This uses the premise that open water locations where spatial extent has increased or decreased significantly from one year to another indicate an artificial waterbody has been formed. This should then be further refined by examining if the shift in spatial extent remains constant over a year, to distinguish from waterbodies changing in spatial extent due to seasonal fluctuations. **STEP 3: Validate data**The mapping of wetlands from remote sensing is challenging in that there is a frequent confusion between flooded areas (or surface waters) and wetlands, despite their major ecological difference: some wetlands are only rarely and partly flooded, whereas many non-wetland habitats (e.g. agricultural or forest) can occasionally be flooded (Perennou et al., 2018). This means that validation requires local knowledge of wetland dynamics to interpret the classification of wetland correctly. In addition, validation procedures are slightly different between open water bodies and vegetated wetlands. After the production of the vegetated wetlands map, it is necessary to validate them independently to assess their quality and correctness. A sampling approach should be employed whereby sample points for the validation should be selected strategically, with a good spread of points geographically and equally between vegetated and non-vegetated wetland. The amount of points is dependent on the resources available and the time needed for interpretation but should reach a statistical minimum, i.e. there should be enough points to produce a statistically robust sample. Once a set of sample points has been selected, the validation procedure should use a consistent approach, standard procedures and the same interpreters across vegetated wetlands layer. There are open-source tools which can be used to support the validation procedure, e.g. LACO-Wiki[[4]](#footnote-5), an established, open, free, online validation package, which gives access to Google and Bing imagery, Copernicus web services and other datasets available through a Web Map Service (WMS). This allows the user to distribute the processing across different WMS. It is user-friendly and straightforward to set up and save validation sessions which can be resumed when required. The validation approach taken will depend on whether the open water bodes and vegetated wetlands are in the same dataset or in two separate datasets to validate. If the water bodies and vegetated wetland classes are in a single dataset then a blind, plausibility or enhanced plausibility approach against the full dataset nomenclature can be used. The detailed results can then be summarised and reported as required by the indicator. The different validation possibilities open to the interpreter are explained below:**Blind:** the interpreter is not aware of the class recorded in the product being validated and will do a blind interpretation **Plausibility**: the interpreter is aware of the class recorded in the product being validated, but has to determine whether it is correct or not without giving a plausible alternative**Enhanced plausibility**: the interpreter is aware of the class recorded in the product being validated, if a code is partially valid, e.g. grassland vs. flooded grassland, the object can be flagged as correctIf the water bodies and vegetated wetland classes are not in a single dataset then the water could be validated with blind or plausibility yes/no and the wetland can be validated with an enhanced plausibility approach.The list of tasks needed to run a validation session in LACO-Wiki is listed below:*Task 1: Technical review:* Review the technical specifications of the vegetated wetland product against the user requirements for the indicator – are they compliant? Visually check the wetland product against Bing and Google imagery and Open Street Map (OSM). Note any deviations and evaluate for discussion and/or correction. Design a sampling scheme to distribute a total number of sample points across the national extract of the global product based on the area mapped and the number of thematic classes present (in the case of vegetated wetlands).*Task 2: Data preparation/validation session set up.* Prepare the product datasets and plan the validation activity in detail. Reformat, clean and re-project the products to be suitable for importing into LACO-Wiki. Load the product into LACO-Wiki and check that the meta data present in the system is correct for the data set, i.e. spatial resolution, time of image acquisition etc. Set up an appropriate legend based on the nomenclature used for vegetated wetland (if any). For the wetland product prepare a sample set and a validation session.*Task 3: Validation point collection.* For the wetland product, the interpreter steps through the individual sample points and performs an interpretation of the area represented by the sample vector object surrounding the sample point to determine if it is vegetated wetland or not. At each sample point/vector object, the interpreter assesses the correctness of the classification, if necessary, selects the most detailed alternative thematic class that can be identified from the available reference data before moving on to the next sample point. This process is then repeated for each sample point in each validation session.*Task 4: Reporting.* The detailed analysis of the validation data should be undertaken by the indicator custodian, e.g. to produce a contingency matrix of errors of omission versus commission. However, depending on the approach taken, i.e. blind, plausibility or enhanced plausibility, there will be different results as these approaches make certain assumptions and record different levels of information. For example, in the binary maps (water/no water, vegetated wetlands/no vegetated wetlands), LACO-Wiki will produce a contingency matrix of errors of omission versus commission. In the case of classified types of vegetated wetlands, there will be per class accuracies and overall users’ and producers’ accuracy which allow the user of the global datasets to understand how well they perform in mapping different wetland classes in the national context. Regardless of the approach taken and to inform future validation efforts, progress and summary report should be prepared, including a description of the validation process, details of the application of the process, summary accuracy analysis (confusion matrix outputs from LACO-Wiki), issues arising and lessons learnt. **Water quality of lakes and artificial water bodies****STEP 1: Obtain data**Sentinel-3, Sentinel-2 and Landsat 8 and Envisat MERIS (ideally full resolution –FR)MODIS Calibrated Radiances: Surface reflectance must be determined for the solar reflective bands (bands 1-19, 26) through knowledge of the solar irradiance (e.g., determined from MODIS solar-diffuser data, and from the target-illumination geometry).VIIRS Spectral Reflectance and WG parameters are ravailable from NOAA from October 2011to presentat 375 m.User-supplied *in-situ* data**STEP 2: Process data** When cloud-free MODIS, VIIRS, Landsat, Sentinel-2 or Sentinel-3 images become available, the images must be processed and reduced to water quality indicators. The methodology for this Sub-Indicator requires that Earth observations are generated and processed into two datasets of chlorophyll a (Chl) and total suspended solids (TSS) within lakes globally. This is a complex process but there are toolboxes available to national users to enable the extraction of these water quality parameters from EO data. Approximate workflow (based on SNAP/BEAM)* create a batch file (workflow manager) in SNAP (export as an xml file) for all steps
* In the case of water quality, the data (pre-) processing is also done in SNAP, e.g. atmospheric correction
* Within SNAP, different water quality algorithms can be used:
	+ The FUB algorithm (Schroeder et al., 2007), named after the Free University of Berlin, is a bundle of dedicated NN algorithms for chl-a, total suspended matter (TSM) and coloured dissolved organic matter (CDOM) retrieval from MERIS L1B data
	+ The Maximum Peak Height algorithm (MPH; Matthews et al., 2012), uses Rayleigh corrected MERIS bands 6–10 and 14 for the retrieval of the red-NIR reflectance peak height and position, which allow for the identification of cyanobacteria- and eukaryote-dominated pixels, water surface covering by cyanobacteria scum or floating vegetation, and chl-a quantification
* WQ parameters (chl-a and TSS) can be further refined, in absolute terms depending on availability and quality of field measurements:
	+ CHL – Chlorophyll *a*, µg l-1(CHL-α concentration is provided as a proxy for phytoplankton abundance and algal biomass)
	+ TSM – Total Suspended Sediments, mg l-1, (particulate matter)

**STEP 3: Validate data**Water quality validation requires reference data from an *in situ* water sampling sites. Reference data should be obtained by countries through local water quality monitoring authorities or university research stations before attempting to validate the EO-derived product.Validation of water quality products is usually based on two types of analysis, matchups and time series. Match-up analysis process the pixels for a certain measurement date. It is specified by the position of the reference measurement and a certain time constraint, e.g. same day or +/- 3 hours, between measurement and overflight. The input for a match-up extraction is a table of in-situ data with location, date, time, measurement values. The output of the match-up extraction is a table with all in-situ information plus all EO data products. Match-up extraction is used for the generation of regression plots and statistics to compare reference measurements and satellite-derived parameters. Time series extraction processes for each station (location) of an input (reference) data set the respective pixels of all overflights covering this position, or all monthly means for the generated products. Thus, one station will generate many extractions. Time series extraction is used for the generation of time series plots, which can either show only the satellite-derived parameters (consistency check) or together with the in-situ data to show the agreement between both measurement methods. Once matchups or time series extractions have been performed, a filtering on the resulting pixels is applied. This filtering allows for the removing of non-valid pixels, e.g. cloud or land (or land influenced) pixels, or outliers (outside of the algorithm training range for example). **Quantity of water (discharge) in rivers and estuaries****STEP 1: Obtain data**There are two main EO based approaches to streamflow (discharge) measurement by EO – hydrological modelling and indirect estimation based on physical flow laws. Depending on the method used, different datasets will have to be obtained. The hydrological models vary greatly in terms of model complexity, from simple rainfall-runoff models to advanced models taking into account multiple aspects of the hydrological cycle (e.g. abstraction losses, deep aquifer storage). Calibration and parameterisation of the advanced models is difficult in many river basins due to the lack of sufficient observations. It also requires the expertise of a highly-skilled modeller. Therefore, for global applicability, the simpler models are preferred. The basic data requirement of any hydrological model is a digital elevation model (DEM) which is used to derive the stream network and water routing. The Shuttle Radar Topography Mission (STRM) DEM is free to access and has been frequently used for this purpose. Another required data set is the rainfall estimate. Famine Early Warning System Rainfall Estimate (FEWS-RFE) and Tropical Rainfall Measuring Mission (TRMM) are two satellite-based rainfall estimate products suitable for use in hydrological models. The final requirement of the simple models is an estimate of temperature or potential evapotranspiration which is derived based on meteorological datasets, such as ERA-5 available from the Copernicus Data Store. More advanced hydrological models might require more inputs, some of which can be satisfied by satellite observations. For example, actual evapotranspiration could be derived using thermal and optical data from Sentinel-3 satellite, soil moisture could be derived from Sentinel-1 observations, large changes in aquifer storage could be estimated using the GRACE or GOCE satellites and water levels can be estimated from altimeters flying on CryoSat2 or Sentinel-3 satellites. The indirect approaches require three main inputs observed over a longer period of time: river width, water surface height and slope. River width can be calculated from water extent derived from opticalobservations (e.g. from Sentinel-2 or Landsat satellites) or SAR observations (e.g. from Sentinel-1 satellites). Water surface height and slope can be estimated based on altimeter measurements, e.g. from CryoSat2 or Sentinel-3 satellites.Both approaches require some discharge measurements in order to calibrate the models. Those measurements could be historical or (especially in case of indirect approach) obtained from a river section with similar hydrological and geomorphological properties. **STEP 2: Process data** **Hydrological modelling**The focus here is on simple hydrological models since complex models have very demanding data requirements and need to be set-up by an experienced hydrologist or modeller. An example of a simple but effective model is the Budyko Hydrological Model available in the GlobWetand Africa toolbox. It couples a simple rainfall-runoff model and a routing scheme and can be set-up and executed within the toolbox by following step-by-step instructions. The first step in setting up the model is to delineate water streams and their flow directions and contributing areas based on a DEM. Based on this the watersheds (sub-basins) and stream reaches and their geometries (length, slope, etc.) can be defined. In the next step, the precipitation and meteorological data is retrieved and processed to derive mean precipitation and mean minimum and maximum air temperatures at daily timesteps within each sub-basin area. Once the input data is pre-processed the model needs to be calibrated based on historical discharge measurements. The calibration routine tests different model parameterisations and compares the model output with the observed discharge in order to select the best fitting parameters. Once the calibration is completed the model is ready for use and can be driven by recent precipitation and meteorological datasets.**Indirect estimation**Indirect discharge estimation typically apply basic flow laws and the principle of mass conservation to work out the river’s discharge. The approach assume that water mass within a river channel is conserved, and this assumption only holds over short river reaches and a stable cross-section. The indirect discharge estimation is obtained by the following steps: 1. Download the altimetry datat from a given area of interest.
2. Extract valid altimetry levels. Water masks with sufficiently high resolution are required to extract altimetry levels which is not contaminated from other surfaces. Both Sentinel and/or Landsat imagery has proved useful to derive accurate river masks for extracting valid altimetry observations.
3. Obvious outliers are removed by comparing the water level (h) with SRTM elevation (e) i.e. data points are discarded if |h–e| > 20 m.
4. Convert altimetry levels to discharge. Various methods can be used which is adapted to different data-availability scenarios: [a] with an in situ rating curve available\*, [b] secondly with one simultaneous field measurement of cross-section and discharge, and [c] finally with only historical discharge data available.

\*An interesting emerging technology is to use drones to measure water surface elevation, land surface elevation and water surface velocity. By combining the three parameters reliable uniform flow rating curve can be established for specific RA virtual stations. Rating curves which can then be used to translate water surface elevation data from satellite radar altimetry into river discharge.**STEP 3: Validate data**Validation requires discharge observations from in-situ measurements. This requires installation of river gauging stations or other sensors from which the water flow can be estimated. Commonly used metrics to summarize errors in water levels are mean error and Root Mean Square Error (RMSE). The mean error tends to zero for a single dimension when bias is absent. Bias refers to a systematic pattern of error – when bias is absent, error is said to be random. RMSE is computed as the square root of the mean of the squared errors: $RMSE=\sqrt{\frac{1}{n}}\sum\_{i=1}^{n}∆x\_{i}^{2}$ ,where n is the number of samples and x is the map estimate for sample i. RMSE is a measure of the magnitude of error which does incorporate bias. The RMSE provides a measure of accuracy in the units of the variable in question and it is therefore useful for evaluating accuracies in continuous fields including discharge. A previous study in the Zambezi region using retracked ENVISAT altimetry data has demonstrated the potential for obtaining stage measurements for rivers down to 80 m wide with an RMSE relative to in situ levels of 0.32 to 0.72 m at different locations (Michailovskyet al. 2012). It is reasonable to expect similar or better accuracies using the new generation of sensors (i.e. Sentinel-3, Jason-CS/Sentinel-6 and SWOT) due to improved sensor design compared to ENVISAT.**Water quality imported from 6.3.2**– see SDG support sheet 6.3.2**Quantity of groundwater within aquifers**EO data are not yet ready for operational reporting.  |
| **Recommendations for implementation**  |
| Activities | * Engage with UN Environment to update the step by step methodology
* The need for a credible dataset for sub-indicator 1 on vegetated wetlands covering more than just mangroves need to be addressed as a priority
 |
| Timeframe | **Current indicator timeframe considerations:**The methodology envisages that level 1 indicator data, i.e. global datasets of the spatial extent of water-related ecosystems and water quality, would be generated annually, then summarised as five-yearly averages. Countries would then be required to validate these 5-year averages and report accordingly. The change in national spatial extent is calculated using 5-year averages to account for seasonal and climatic fluctuations.For sub-indicator 1, a historical baseline of 2001-2005 is recommended to compare subsequent 5-year averages of change, therefore there almost three 5-year periods elapsed since the baseline:* 2006-2010
* 2011-2015
* 2016-2020

A historical baseline has not been defined for the other sub-indicators, therefore it would be good to clarify for countries what the historical 5 year reference period should be and is it is up to countries to determine their own baseline, how reporting can be consistent at a global level. |
| **References** | **Indicator background** UN Statistics Division, 2018. Metadata 6.6.1a. (latest update October 2018): <https://unstats.un.org/sdgs/metadata/files/Metadata-06-06-01a.pdf>UN-Water, 2018. Step-by-step methodology for monitoring ecosystems (6.6.1)Latest revision of the methodology: 2 March 2018<https://www.unwater.org/publications/step-step-methodology-monitoring-ecosystems-6-6-1/>UN Environment, 2018. Progress on Water-Related Ecosystems, Piloting the monitoring methodology and initial findings for SDG indicator 6.6.1: <http://www.unwater.org/app/uploads/2018/10/SDG6_Indicator_Report_661-progress-on-water-related-ecosystems-2018.pdf>Ramsar (1994). Article 3.2, Convention on Wetlands of International Importance Especially as Waterfowl Habitat.**Publications** Lehner, B., R-Liermann, C., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., Döll, P. et al. (2008). High resolution mapping of the world’s reservoirs and dams for sustainable river flow management. Frontiers in Ecology and the Environment. Source: GWSP Digital Water Atlas. Map 81: GRanD Database (V1.0). Retrieved from <http://atlas.gwsp.org>Ludwig, C., Walli, A., Schleicher, C., Weichselbaum, J., & Riffler, M. (2019). A highly automated algorithm for wetland detection using multi-temporal optical satellite data. Remote Sensing of Environment, 224, 333-351Matthews, M. W., Bernard, S., and Robertson, L.: An algorithm for detecting trophic status (chlorophyll-a), cyanobacterialdominance, surface scums and floating vegetation in inland and coastal waters, Remote Sens. Environ., 124, 637–652, https://doi.org/10.1016/j.rse.2012.05.032, 2012.Michailovsky, C. I. B., McEnnis, S., Berry, P. A. M., Smith, R., & Bauer-Gottwein, P. (2012). River monitoring from satellite radar altimetry in the Zambezi River basin. Hydrology and Earth System Sciences, 16(7), 2181-2192.Pekel, J. F., Cottam, A., Gorelick, N., & Belward, A. S. (2016). High-resolution mapping of global surface water and its long-term changes. *Nature, 540* (7633), 418.Perennou, C., Guelmami, A., Paganini, M., Philipson, P., Poulin, B., Strauch, A., … Geijzendorffer, I. R. (2018). Chapter Six - Mapping Mediterranean Wetlands With Remote Sensing: A Good-Looking Map Is Not Always a Good Map. In D. A. Bohan, A. J. Dumbrell, G. Woodward, & M. B. T.-A. in E. R. Jackson (Eds.), *Next Generation Biomonitoring: Part 1* (Vol. 58, pp. 243–277). Academic Press. https://doi.org/https://doi.org/10.1016/bs.aecr.2017.12.002Schroeder, T., Schaale, M., and Fischer, J.: Retrieval of atmospheric and oceanic properties from MERIS measurements: A new Case2 water processor for BEAM, Int. J. Remote Sens., 28, 5627– 5632, 2007**EO** t**echnical sites** Joint Research Centre, 2019. The Global Surface Water Explorer:<https://global-surface-water.appspot.com>Global Mangrove Watch, 2019. GMW (v2.0), is now available for download from the UN Ocean data viewer:<http://data.unep-wcmc.org/datasets/45>Un Environment 2019. Water-Related Ecosystems: Surface Water Viewer:<https://www.sdg661.app/data-products/surface-water-viewer>Copernicus Global Land Service, 2019: Lake Water Quality products: <https://land.copernicus.eu/global/products/lwq> |

1. This indicator has two custodian agencies: UN Environment and RAMSAR, respectively. They apply two different methods. At the time of writing (primo Nov 2018), the UN Environment methodology is the official version. [↑](#footnote-ref-2)
2. As of the 8th meeting of the IAEG-SDG in November 2018 [↑](#footnote-ref-3)
3. <https://gracefo.jpl.nasa.gov/science/water-storage/> [↑](#footnote-ref-4)
4. <https://laco-wiki.net> [↑](#footnote-ref-5)