Measuring change in the extent of water-related ecosystems over time

Sustainable Development Goal
Monitoring Methodology
Indicator 6.6.1

UN environment
United Nations Environment Programme

SUSTAINABLE DEVELOPMENT GOALS

UN WATER

This methodology was updated in March 2020 and replaces the version published in November 2018. The update is made to include supplementary information within the introductory and background sections. Further supplementary information has also been added to several of the sub-indicator sections, allowing a fuller understanding of the process for generating sub-indicator data from satellite-based Earth observations.

Introduction

Freshwater, in sufficient quantity and quality, is essential for all aspects of life and fundamental to sustainable development. Water-related ecosystems - including lakes, rivers, wetlands and groundwater - supply water and food to billions of people, provide unique habitats for many plants and animals and protect us from droughts and floods. While water-related ecosystems hold less than 1% of all water on Earth, these ecosystems harbour exceptional diversity, hosting 40% of all plant and animal species, including more fish species than have been found in the world's oceans (Reid et al, 2019).

Water-related ecosystems possess enormous biological, social, educational and economic values. They sustain the global hydrological cycle, carbon cycle and nutrient cycles. They provide natural purified freshwater, regulate flows and extreme conditions. The goods and services derived from these ecosystems span the breadth of the sustainable development spectrum and underpin sector-wide activities including water for drinking, agriculture, employment, energy generation, navigation, recreation and tourism. Protecting or restoring water-related ecosystems, such as wetlands, coastal mangrove forests and natural flood plains in watercourses is an important nature-based mitigation approach, as these ecosystems act as carbon sinks absorbing greenhouse gas emissions (UN Water, 2019). Wetlands and peatlands represent a major untapped resource for mitigation. Peatlands only cover about 3% of the world's land surface but store at least twice as much carbon as all of Earth's forests, while mangrove soils hold over 6 billion tons of carbon and can sequester up to 3-4 times more carbon than their terrestrial counterparts (IUCN, 2017).

Well-functioning water-related ecosystems and the proper management of water resources has a role in achieving all 17 of the SDGs. However, a significant challenge to effectively protect and restore water-related ecosystems is that the management of these systems often is focused on water provision entirely for human and productive uses, with insufficient consideration taken to ensure the integrity of ecological functions and the biodiversity of species therein. A consequence has been the sacrifice of freshwater life, which can ultimately also lead to the destruction of the ecosystems required to support these same objectives. Nowhere is the biodiversity crisis more acute than in freshwater ecosystems (Albert et al, 2020). Wetlands are disappearing three times faster than forests. An estimated 87 per cent of all wetlands were lost globally in the last 300 years, and more than 50 per cent since 1900 (Gardner et al, 2018).

Threats to water-related ecosystems (flow alteration; loss of connectivity; pollution; habitat degradation and loss; overexploitation of species) are driven by human activities for agriculture, power generation, urbanization, industry, mining, flood management and domestic water supply. Decision makers should utilise all information at their disposal that enable them to better understand the threats to water-related ecosystems and implement appropriate threat mitigation measures. SDG indicator 6.6.1 tracks changes in different types of water-related ecosystem to inform decision makes on how to protect and restore them (SDG target 6.6), so that they can continue to benefit both people and the planet. The indicator data is intended to support all sector-wide decision-making processes that may impact the quantity, quality and ultimately the ecological health of freshwater found in lakes, reservoirs, wetlands, mangroves, rivers and groundwaters.

Contents

1 WATER-RELATED ECOSYSTEMS

1.1 What are water-related ecosystems?

Water-related ecosystems are a sub-set of all ecosystems (MEA, 2005). They contain the world's freshwater resources, natural and artificial, and include lakes and reservoirs; rivers, streams, canals and estuaries, groundwater; and several types of wetlands such as swamps, bogs, fens, peatlands, marshes, paddies and mangroves. Water-related ecosystems can be defined as "a dynamic complex of plant, animal, and micro-organism communities and the non-living environment dominated by the presence of flowing or still water, interacting as a functional unit." (MEA, 2005; Dickens et al, 2019).

1.2 Why are water-related ecosystems important for sustainable development?

Freshwater accounts for 0.01 per cent of the total water on the planet and water-related ecosystems cover just 0.8 per cent of the Earth's surface (MEA, 2005), and yet given these very small percentage figures, it is remarkable to consider the array of goods and services that water-related ecosystems provide to enable and to sustain life on Earth. For example, water-related ecosystems are among the most biologically diverse environments in the world hosting around 10 per cent of the worlds known species. They help sustain the global hydrological cycle, the carbon cycle and nutrient cycle. They provide natural freshwater storage during droughts and regulate water flows in case of floods. They purify water and replenish groundwater and provide a host of services that we use in our everyday lives, including providing water for domestic consumption (water security), agriculture (food security), energy generation, employment, navigation, recreation and tourism.

It is because water-related ecosystems possess such significant value - including social, economic, environmental and biological values - that it is necessary to protect this resource, and in turn, the provision of freshwater services to society and our planet. Freshwater is a fundamental resource that is essential for the wellbeing of all living things. Without effective protection and governance, water-related ecosystems readily become diminished, degraded or can be lost entirely. For countries to develop sustainably we must restore and protect water-related ecosystems.

1.3 Water-related ecosystems within the 2030 Agenda for Sustainable Development

The environmental dimension of the Sustainable Development Goals (SDGs) caters for water-related ecosystems within several targets and indicators. Within the Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development, there are several SDG indicators that measure specific information about water-related ecosystems including: indicator 6.3.2: measuring ambient water quality of inland waters; indicator 6.4.2: measuring water stress and environmental flows; and indicator 15.1.2: measuring freshwater biodiversity and protected areas.

In addition to these SDG indicators, there is one in particular – SDG indicator 6.6.1 - which is entirely dedicated to measuring changes to the quantity, quality and the spatial area of water within different types of water-related ecosystems. The description of SDG indicator 6.6.1 is as follows: **change in the extent of water-related ecosystems over time.** The purpose of this document is to guide practitioners intending to monitor and report official SDG data on SDG indicator 6.6.1. As such the information contained within this document deals entirely with SDG indicator 6.6.1. and has been developed by the indicators official custodian agency, the United Nations Environment Programme[1] (UNEP).

[1] The Ramsar Secretariat is a co-custodian for indicator 6.6.1. Their methodology is based on national reporting to the Ramsar convention and not covered in this document. The national reports to the Ramsar convention are used to inform the narrative reporting on target 6.6.

2 MONITORING & REPORTING INDICATOR 6.6.1

2.1 Data flows and global reporting

The 2030 Agenda calls for a "robust, voluntary, effective, participatory, transparent and integrated follow up and review framework" to monitor progress against the SDGs (United Nations, 2015). The General Assembly tasked the UN Statistical Commission, in which statistical agencies from all UN Member States are represented, with developing a monitoring framework for the SDGs. The Inter-Agency and Expert Group on the SDG Indicators (IAEG-SDG), encompassing 30 countries that represent all regions, was set up to establish a global indicator framework. The IAEG-SDG agreed to a framework of 232 SDG indicators which was subsequently adopted by the UN Statistical Commission, the UN Economic and Social Council (ECOSOC) and finally the UN General Assembly. The goal of SDG monitoring is to generate high-quality, timely, statistically reliable and comparable data at a global scale.

Country ownership of the data is a key principle of the 2030 Agenda, for implementation, progress monitoring and follow-up and review. Each SDG indicator is assigned to a custodian agency to develop a methodology for monitoring and reporting of the indicator. The custodian agency is responsible for leading the development of an internationally established methodology and the design of a data-collection and reporting system for the indicators. The United Nations Environment Programme (UNEP) is the custodian agency of 26 SDG indicators. This includes being the custodian agency responsible for supporting countries with monitoring and reporting official SDG data on indicator 6.6.1.

2.2 Develop, test, adjust – the evolution of the indicator methodology

In developing the methodology for indicator 6.6.1 UNEP set up a technical expert group[2]. This group provided inputs into the development of the monitoring methodology. A first draft (Tier III) methodology was piloted in 2017 and sent to all UN Member States accompanied with relevant capacity support materials. A limited number of Member States (19 per cent) submitted data to UNEP after a period of 8 months. The data that was received was of poor quality and coverage. Countries cited a lack of data to report, and neither time nor resources to initiate new ecosystem monitoring.

Following on from the global piloting and testing phase, and to address a known global data gap for the indicator, the methodology was revised to incorporate data on water-related ecosystem derived from satellite-based Earth observations. UNEP engaged with a series of partners working with global data products considered relevant and suitable for the indicator. The assessment of global data sources considered data quality, resolution, frequency of measurements, global coverage, time series, and scalability (i.e. disaggregated data at national and sub-national levels). The result was a methodology that is statistically robust producing internationally comparable data without being too onerous for

[2] This group included representatives from the following organisations: IWMI, CBD, Ramsar, ESA, and GEO

countries to report on. The technical expert group was consulted on the updated methodology before submission to the IAEG-SDG for approval.

At the 7th IAEG-SDG meeting in April 2018 the indicator methodology was approved and classified as Tier II. Shortly afterwards, in November 2018, it was reclassified to a Tier I indicator methodology. The Tier I classification means that the indicator is conceptually clear, has an internationally established methodology and standards are available, and data are regularly produced by at least 50 per cent of countries and of the population in every region where the indicator is relevant.

Throughout 2019 UNEP continued to work with its partners to improve the globally available datasets relevant to SDG indicator 6.6.1 and the measurement of changes occurring to different types of water-related ecosystem. As such, this methodology was updated in March 2020 to include more detailed information about the approach used to obtain satellite-based Earth observation data with regard to the sub-indicators.

2.3 Use of geo-spatial data to support global reporting

Geospatial data describes the location and relationship of features, such as water or different land cover types, on the Earth's surface. Such data has significant value in helping realize and implement the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs), 169 Targets and 232 Indicators. It has been estimated that approximately 20% of the SDG indicators can be interpreted and measured either through direct use of geospatial data itself or through integration with statistical data. Thus, obtaining reliable geospatial data has become a crucial task for Member States to prepare their national reports or for UN organisations to undertake global reporting and increasingly make use of the diversity and reliability of open source, high resolution satellite data.

The Working Group on Geo-Spatial Information of the IAEG-SDG reported that global datasets can serve as a sound basis for supporting the preparation of global reports. International agencies may use high quality global datasets to calculate SDG indicators and send disaggregated national level data to national authorities for review and agreement (IAEG-SDG, 2019).

To support countries in fulfilling monitoring and reporting requirements for SDG indicator 6.6.1, UNEP has worked with partner organisations[3] to develop technically robust and internationally comparable global data series, thereby significantly contributing towards filling the global data gap on measuring changes in the extent of water-related ecosystems. UNEP will periodically invite national contact persons to participate in consultations with the aim to validate the estimated national values. The national contact person is expected to review the information provided and communicate any comments or concerns to UNEP – typically within a period of one month (United Nations, 2018). If no response

[3] Partners involved on the production of data products and supporting their consolidation to the SDG661.app include the Joint Research Centre of the European Commission, Google, NASA, JAXA, Global Mangrove Watch, Aberystwyth University, Brookman Consult, and Plymouth Marine Laboratory

is received during this time period (with a courtesy reminder), values will be published in the global SDG database and all thematically connected international publications in order to avoid discrepancies.

2.4 Unpacking SDG indicator 6.6.1

Indicator 6.6.1 is described as follows: **Change in the extent of water-related ecosystems over time**. The indicator aims to collect and provide data on the spatial extent of water-related ecosystems and the quantity and quality of water within them.

2.4.1 Which water-related ecosystem types should be monitored for indicator 6.6.1?

This methodology is framed around the monitoring of different types of water-related ecosystems including lakes, rivers, wetlands, groundwater and artificial waterbodies such as reservoirs. These water-related ecosystems contain freshwater, with the exception of mangroves which contain brackish water (i.e. a combination of fresh and saltwater) however mangroves are still included within indicator 6.6.1. Reservoirs are also included as a category of water-related ecosystem within the indicator methodology; while it is recognized that reservoirs are not traditional water ecosystems which should necessarily warrant protection and restoration, in many countries they hold a noteworthy amount of freshwater and have thus been included. By including data on reservoirs, it is intended that countries can better understand changes occurring to artificial water bodies in conjunction with changes occurring to natural water bodies.

Ecosystems that are *not included* under indicator 6.6.1 are: coral reefs and sea grass which are covered within Goal 14 (Oceans); and mountains, forests, and drylands which are covered within Goal 15 (Land).

The ecosystem type 'wetlands' is a composite of several wetlands typologies including swamps, bogs, fens, peatlands, marshes, and paddies. Mangroves are also a type of wetland ecosystem (a coastal wetland) and global data on mangrove extent per country is now available within the sdg661 data portal. Consequently, mangrove data is presented separately, and it is hoped that this distinct data set will enable ecosystem specific decision-making focused on the protection and restoration of mangroves. Consequently, this methodology refers to wetlands and mangroves separately. It is anticipated that further disaggregation of other wetland typologies will be possible in the coming years as a result of advancing satellite and data production technologies.

The extent to which each of the water-related ecosystems included under indicator 6.6.1 can be measured, uses one or more of the following physical parameters of change: spatial area, quantity (or volume) of water, and water quality. For decision makers to better understand the full extent of ecosystem change, it is advantageous to capture data separately on each of these parameters, although this may not be realistic for all Member States and therefore a progressive monitoring approach is proposed (see section 2.9).

2.4.2 Use of geo-spatial data to monitor changes in water-related ecosystems

An array of satellites continually circle and observe planet Earth, capturing measurements from which different types of land cover - such as snow, bare rock, vegetation, and water – can be distinguished. Each type of land cover reflects different wavelengths of light. For any one location on earth, thousands of images can be combined to classify the land cover into types. Every location on Earth is mapped in this way, and with the technology to process and visualize the data, it becomes possible to understand how different land cover types change over time within a particular location.

For the purposes of supporting UN Member States with monitoring changes to different types of water-related ecosystems, spatial and temporal data derived from satellites are used to measure changes to areas of permanent water, seasonal water, reservoirs, wetlands, mangroves; as well as generating data on the trophic state and turbidity of major water bodies. Satellite images can be represented as numerical data, which in turn are aggregated into meaningful administrative areas such as national, sub-national (e.g. regions and provinces) and river basin boundaries. Global data products for rivers and groundwater have not yet been produced at useful spatial and temporal resolutions to be incorporated into this SDG 6.6.1 methodology. Currently, these data should continue to be provided from modelling or from ground-based measurements.

Data on permanent water, seasonal water, reservoirs, wetlands, mangroves; as well as lake water quality is available for countries to view and download at the SDG 6.6.1 data portal (www.sdg661.appp). At this site, data is visualized for users on geo-spatial maps with accompanying numerical statistics displayed through informational graphics. Countries can access their national and sub-national statistics at any time by visiting the SDG 6.6.1 data portal. UNEP will also periodically send UN Member States their national statistics and the national indicator 6.6.1 focal points will be the recipient of these data communications from UNEP. While the maps and statistics have been produced to support UN member states in monitoring and reporting SDG indicator 6.6.1, the overarching objective is that countries use the information to improve their evidence-based decision making and increase actions that protect and restore water-related ecosystems. All relevant practitioners and decision makers, for example those working in water, environment, climate, energy, agriculture, forestry sectors, are encouraged to access and use the data.

2.4.3 Measuring water-related ecosystems *over time*

SDG indicator 6.6.1 intends to track longer term trends in ecosystem extent changes (i.e. over a number of years) rather than short term fluctuations. The SDG 6.6.1 data portal therefore provides statistical information for each water-related ecosystem type showing the extent to which it is changing over time[4]. Water-related ecosystems (lakes, rivers, wetlands) may span large areas, be numerous in number and be hard to access in their entirety. Numerous in-situ data collection points may be required to accurately measure changes to water quantity, quality and spatial area, over time. In this context there is substantial

4 Except for inland wetlands at the present time (2020) which currently produces a baseline data series (2017-19) but not yet any change statistics. The first year of data to show a change from this baseline will be 2020 with this becoming available in 2021.

benefit to utilizing satellite data sources to measure water-related ecosystems. Observations of water from space are frequently captured though satellites images, with satellites able to map the entire world every 7 days and record images with a resolution of down to 10-30 meters. To statistically represent a change in the extent of an ecosystem type between two periods of time, it is necessary to first define the reference period (or baseline) against which 'change' is then measured.

Not all data series represented on the SDG 6.6.1 site use the same reference period. This is due to the availability of recorded observations captured by different satellites. Some satellites, such as the American (NASA) Landsat satellites, have been orbiting Earth since the early 1970's. These satellites have enabled the measurement of changes in the spatial area of open water bodies (i.e. lakes) since this time although early images were of lower quality thus reducing confidence in the outputs. More recently, additional satellites have been placed in Earth's orbit, for example the European Sentinel and several Japanese satellites, allowing image and data capture for other types of water-related ecosystems and parameters (e.g. mangroves, wetlands and water quality). Depending on when the satellites first started capturing data, this results in different reference periods for the various water-related ecosystem types within indicator 6.6.1.

2.4.4 Indicator data at national and sub-national scales

As well as representing data across time, data series on different water-related ecosystem types is available at different spatial scales, including national, sub-national and river basin scales. To depict national statistics the Global Administrative Unit Layers (GAUL) is used. Developed by the United Nations Food and Agricultural Organization (FAO), GAUL aims at compiling and disseminating the most reliable spatial information on administrative units for all countries in the world.

In addition to GAUL, data within the SDG 6.6.1 data portal is presented at basin scales using Hydro-BASINS. Developed on behalf of World Wildlife Fund US (WWF), the HydroBASINS map depicts watershed boundaries at basin and sub-basin scales for the whole world.

The purpose of presenting sub-national statistics within the SDG 6.6.1 data portal is to facilitate the process of sub-national decision making on water-related ecosystems. Decisions relating to a particular water body (e.g. a lake) may often be taken by sub-national authorities. To encourage both national and sub-national decision making towards protecting and restoring water-related ecosystems, data are therefore made available at national and sub-national levels. It is important to note that for global reporting purposed, it is the national statistics per ecosystem type that are reported.

An additional advantage of compiling 6.6.1 data using HydroBASINS it that makes it possible to address the regional and trans-boundary levels. Aquifers, lake and river basins shared by two or more countries account for an estimated 60 percent of global freshwater flow and are home to more than 40 percent of the world's population underscoring the importance to collaborate between riparian states to address the objectives of Target 6.6.

2.5 How does the indictor link to the target?

Indicator 6.6.1 is the only indicator to measure progress towards Target 6.6. In its current articulation Target 6.6. reads: By 2020, protect and restore water-related ecosystems including mountains, forests, wetlands, rivers, aquifers and lakes. The 2020 date was inserted to align the SDG Agenda with earlier commitments to the Convention on Biological Diversity, specifically the Aichi targets that form part of the Strategic Plan for Biodiversity 2011-2020 (CBD 2010). The target language is being reviewed in 2020 with the date updated to 2030 to align to the SDG framework.

The target language uses the term *protect*. In the context of Goal 6 this refers to the protection of ecosystems to ensure that they continue to provide valuable ecosystem services for society, in particular, in relation to sustainable water and sanitation services (Dickens et al, 2017). The value of ecosystems within the SDG framework is largely determined in terms of the services they provide to human society. As such policy and decision makers intending to sustain services provided to people from lakes, rivers, wetlands and groundwaters, require data on the functional state of these ecosystems and whether the functional state is changing over time. To obtain this information it is necessary to monitor changes in the quantity of water (measured by changes to spatial area and volume) and/or changes to the quality of water. The indicator does not measure how much of an ecosystem is protected, for example, through national or international protection designation systems. Instead SDG 6.6.1 enables decision makers to manage the protection status by documenting changes to the physical and chemical parameters describing water-related ecosystems. Hence, the indicator is designed to capture physical and biological information per spatial area; the quantity and quality of water within water-related ecosystems.

The indicator monitoring methodology does not, in its current articulation, capture data on the biological health of fresh-water ecosystems even though the importance of such data is recognised. This is because monitoring ecosystem health is context-specific, and the most appropriate methods are based on local ecological conditions and include the local freshwater biodiversity. Countries are however strongly encouraged to monitor ecosystem health if they have the capacity to do so. Countries may seek to take advantage of the data generated for each sub-indicator, which can be used in combination with in-situ country data, such as bio-indicators, to inform the state of water-related ecosystem health. This additional measure would help better inform decisions that are taken towards the protection and restoration of water-related ecosystems.

2.6 Assessing trends across sub-indicator data

Measuring data per ecosystem type enables valuable ecosystem-level decisions to be taken. In addition, assessing and comparing the combination of changes across several ecosystem types enables decisions towards the protection and restoration of multiple ecosystems within an area. As an example, the data for a particular river basin may reveal that the spatial area of natural water bodies (i.e. lakes) is decreasing while the spatial area of artificial water bodies (i.e. reservoirs) is increasing. When presented with several interlinked datasets within a watershed boundary, decision makers can better discern cause and impact of changes in ecosystem extent. Assessing trends across all sub-indicator data can enable a more comprehensive story to unfold and generate policy and planning decisions that promote ecosystem health, or the ability of ecosystems to maintain their structure and function over time in the face of external pressures.

2.7 The role of national indicator focal points

National indicator focal points play a critical role in data flow processes acting as the single point of entry for custodian agencies to engage Member States regarding indicator monitoring and reporting. A single focal point per country facilitates smooth exchanges in communication, data collection, validation and reporting, as well as dissemination of capacity building and training materials. Such a national indicator focal point (also referred to as a technical focal point) for indicator 6.6.1 may typically be a nominated government official from a relevant state institution such a Ministry or Department with responsibility for water management and/or national environmental statistics. In the longer term, national indicator focal points can promote the ownership and uptake of indicator data within national / sub-national policy and planning processes related to the protection and management of water-related ecosystems.

2.8 A progressive monitoring approach

The 2030 Agenda is a country-led and country-owned process, and this methodology embraces this approach which places responsibility on countries to monitor and report data on all SDG indicators. All global data should be owned and approved nationally to comply with the intention of the 2030 Agenda. Recognizing the global data gaps that exist with regard to nationally available data on water-related ecosystems, this methodology uses globally available data to enhance ground-based measurements. This has the immediate benefit of filling global data gaps and encourages more rapid progression towards achieving Target 6.6. Such an approach has also been adopted for other methodologies such as indicator 15.3.1.

This methodology applies a progressive monitoring approach meaning countries can benefit from the availability of global data products on water-related ecosystems while also (where data and capacity exists) use nationally derived data to compliment and augment a foundational level of reporting on indicator 6.6.1. This approach therefore encourages different levels of ambition. A progressive monitoring approach is beneficial because it prioritizes components of the indicator where high-quality data is widely available, reducing the reporting burden on countries and focusing monitoring efforts on approving existing data and generating limited new data. These focused monitoring efforts will be supported by increased capacity-building, technological advancements, and improved data sharing among the international community.

The progressive monitoring approach is framed using two levels of ambition. As a minimum all countries benefit from a foundational level of data (level 1) that is produced using globally available, accurate and regularly updated data derived from satellite sources. These data are freely accessible and downloadable at the SDG 6.6.1 data portal that allows countries to assess changes to the surface area of naturally occurring permanent and seasonal surface water bodies (lakes and rivers); changes in the area of artificial water bodies (reservoirs); changes in the area of wetlands and mangroves; as well as changes in the trophic state and turbidity of larger water bodies. Where capacity and data exist, countries should strive to augment this foundation of existing data with nationally derived data (level 2) on river flows and groundwater volumes. The following table summarizes the disaggregation of Level 1 foundational data provided from Earth observations and Level 2 nationally derived data.

Level 1: Data from Earth observations		
Ecosystem	***Unit***	***Features***
Lakes & Rivers	surface area	annual and multi-annual changes in **permanent water area** (1984-present) statistics for new and lost permanent water (2000-2019) statistics aggregated at national, sub-national & basin scales
Lakes & Rivers	surface area	annual and multi-annual changes in **seasonal water area** (1984-present) statistics for new and lost seasonal water (2000-2019) annual seasonality statistics for periods: 0-1, 3-6, 7-11 months statistics aggregated at national, sub-national & basin scales
Reservoirs	surface area	annual and multi-annual changes in reservoir surface area (1984-prsent) statistics for new and lost reservoir area (2000-2019) statistics aggregated at national, sub-national & basin scales
Mangroves	surface area	annual and multi-annual changes in mangrove area (2000-2016) statistics aggregated at national, sub-national & basin scales
Wetlands	surface area	wetlands area (baseline area comprised of data btw 2016-2018) statistics aggregated at national, sub-national & basin scales wetlands area changes will be included starting in 2021/22
Lakes	water quality	Monthly, annual and multi-annual measurements of trophic state and turbidity for 4,200 lakes globally (at 300m resolution)
Level 2: Data from ground measurements and modelling		
Ecosystem	***Unit***	***Features***
Rivers	flow	modelled natural runoff/streamflow in-situ stream/river flow measurements, aggregated over time, of all major rivers
Groundwater	level	Changes to volume measurements, over time, of all major groundwater aquifers

Table 1: Data delineated by satellite and ground based measurements

Established intergovernmental expert groups such as the Group on Earth Observations (GEO) and the Global Geospatial Information Management Group (GGIM); comprised of United Nations Member States and partnered with National Statistical Offices (NSOs) and international agencies; have informed the design of this methodology with respect to how data is produced, its sources and the spatial and temporal resolution of the data. All data are subject to approval by national authorities. Countries may wish to provide their own satellite-based earth observation data to generate data of a higher resolution. Such data can be used for official SDG Indicator reporting if the data production process follows the same methodological approach to generate national statistics as has been applied by this indicator methodology and explained in the metadata sheets, including categorization of water-related ecosystem types and data reference periods, in order to allow for international comparability of the data and statistical robustness.

3 MONITORING METHODOLOGY

Level 1 Data

Different methodologies are applied to produce each of the global sub-indicator datasets available on the SDG661 data portal. This section summarizes these different methodologies. More technical methodological specifications are available on the SDG661 data portal. Links to any relevant technical publications are also provided within sub-sections below.

Two separate surface water datasets are produced. One for naturally occurring surface water and another for artificial surface water (i.e. reservoirs). The delineation between naturally occurring surface water and artificial surface water has been undertaken to more accurately profile changes in naturally occurring surface water. The methodology for naturally occurring surface water is outlined in section 3.1 and artificial surface water in section 3.2.

3.1 Measuring changes in surface water area of lakes and rivers

3.1.1 Why measure surface water area?

The freshwater found in our lakes, rivers, wetlands and groundwater collectively contain less than 0.01% of Earth's total water [96.5% is held in the oceans and seas, with the remainder held by ice caps, glaciers, ice and snow, groundwater, held in the soil, contained in biological cells (including us!) and in the atmosphere]. It is surface water that is the most accessible and affects many aspects of our world. It affects the exchange of heat, gas and water vapour between the planet's surface and atmosphere. Water is the engine behind the distribution, movement and migration of Earth's plant and animal life and is just as essential for humans. It affects our capacity to grow crops and manage animal grazing lands, to run our industrial processes, to manufacture goods, it influences the movement of disease-vectors, toxins and pollutants, it generates energy directly (hydroelectric) and indirectly (thermoelectric), it is an essential part of our transport network, and forms part of our recreational, cultural and sporting world.

3.1.2 Description of the method used to globally map all surface water

Data on the spatial and temporal dynamics of naturally occurring surface water has been generated for the entire globe. A Global Surface Water dataset (Pekel et al., 2016) has been produced by the European Commission's Joint Research Centre. The dataset documents different facets of the long term (since 1984 onward) water dynamics at 30x30 meter pixel resolution. The dataset documents permanent and seasonal surface water surfaces. All naturally occurring surface water larger in area than 30x30 meters has been mapped and at this 30 meter grid/pixel spatial resolution satellite imagery is predominantly capturing areas of lakes and wide rivers. The data include land areas that are temporarily inundated such as wetlands and paddy fields. Smaller rivers and waterbodies are not captured as they are too narrow to detect or are masked by forest canopy. The data include individual full-resolution images acquired by the Landsat 5, 7 and 8 and Sentinel 1 satellites. These satellites capture images which are distributed publicly by the United States Geological Survey and by the European Union's Copernicus space programme. Together they provide multispectral imagery at 30x30 meter resolution in six visible, near and shortwave infrared channels, plus thermal imagery at 60x60 meters.

The data includes land surfaces that are under water (e.g. a permanent water area) for all twelve months of a year. It also accounts for seasonal and climactic fluctuations of water, meaning lakes and rivers which freeze for part of the year are captured. Areas of permanent ice, such as glaciers and ice caps as well as permanently snow-covered land areas are not included. Areas of consistent cloud cover inhibit the observation of water surfaces in some areas and in these limited locations optical observations may not be available. A global shoreline mask has been applied to the data to prevent ocean water being included in the freshwater statistics and the methodology for this shoreline mask is published in the journal of operational oceanography, available here (Sayer et al. 2019).

The accuracy of the Global Surface Water map was determined using over 40,000 control points from around the world and across the 36 years. The full validation methodology and results have been published in the scientific journal Nature, available here, (Pekel et al., 2016). The validation results show that the water detection expert system produced less than 1% of false water detections, and that less than 5% of water surfaces were missed. The provided maps are derived from the analysis of over four million images collected over 36 years which have been individually processed using an accurate expert system classifier.

The SDG 6.6.1 data portal documents various water transitions relating to permanent and seasonal surface water - these are changes in water state between two points in time (e.g. 2000 - 2019). Data is available for various transitions including new permanent water surfaces (i.e. conversion of a no water place into a permanent water place.); lost permanent water surfaces (i.e. conversion of a permanent water place into a no water place) as well as new and lost seasonal water. These allow monthly water presence or absence data to be captured. It is possible to identify specific months/years in which conditions changed, e.g. the date of filing of a new dam, or the month/year in which a lake disappeared. In addition, data on seasonality are provided, capturing changes resulting from intra and inter-annual variability or resulting from appearance or disappearance of seasonal or permanent water surfaces. The data separates 'permanent' water bodies (those that are present throughout the period of observation) [nominally a year] from 'seasonal' (those that are present for only part of the year).

3.1.3 Calculating the change in surface area of permanent and seasonal surface water

Data on surface water dynamics are available for a 36 year period, from 1984-onward. Every year new annual data is produced and added to this time series. For the purpose of producing national statistics to monitor indicator 6.6.1, annual data starting from year 2000 has been used and includes all annual data up to the present day.

To calculate percentage change in lake and river area using a 2000-2019 dataset, a baseline period is first defined against which to measure change. This methodology uses 2000-2004 as the 5-year baseline period. Averaging all earth observations annually and over a five-year period the baseline is then compared a subsequent 5-year target period. From the baseline and target period, percentage change of spatial extent is calculated using the following formula:

Where β = the average national spatial extent from 2000-2004
Where γ = the average national spatial extent of any other subsequent 5 year period
Percentage Change in Spatial Extent$=((\beta-\gamma))/\beta\times100$

The nature of this formula yields percentage change values as either positive or negative, which helps to indicate how spatial area is changing. On the SDG661 data portal, statistics are displayed using both positive and negative symbols. For interpretation of the statistics, if the value is shown as positive, the statistics represent an area gain while if the value is shown as negative, it represents a loss in surface area.

The use of 'positive' and 'negative' terminology does not imply a positive or negative state of the water-related ecosystem being monitored. Gain or loss in surface water area can be beneficial or detrimental. The resulting impact of a gain or loss in surface area must be locally contextualized. The percentage change statistic produced represents how the total area of lakes, rivers within a given boundary (e.g. nationally) is changing over time. Percentage change statistics aggregated at a national scale should be interpreted with some degree of caution because these statistics reflect the areas of all the lakes and rivers within a country boundary. For this reason, sub-national statistics are also made available including at basin and sub-basin scales. The statistics produced at these smaller scales reflects area changes to a smaller number of lakes and rivers within a basin or sub-section of a basin, allowing for localized, water body specific, decision making to occur.

3.2 Measuring changes in reservoir surface area

3.2.1 Why measure reservoir surface area?

Reservoirs are artificial (human-made) bodies of freshwater, as opposed to lakes which are naturally occurring. Reservoirs are included as a type of water-related ecosystem within the SDG indicator 6.6.1 methodology for two reasons. Firstly because of the contribution they make in providing water services to large numbers of people, including domestic water supply; irrigation; hydroelectric power generation; flood control; and recreation. Secondly, so that changes in one dataset do not mask changes in the another, it is useful to separate naturally occurring surface water from reservoir water. Hence a separate dataset on reservoir dynamics has been produced. In the context of SDG target 6.6 which seeks to protect and restore water-related ecosystems, it is important to stress that while reservoirs provide valuable water services to people, it is also widely recognized that reservoirs adversely impact the connectivity of naturally occurring freshwater systems and are directly attributed to causing significant loss of freshwater biodiversity.

3.2.2 Description of the method used to globally map changes to reservoir surface area

A global reservoir dynamics dataset has been produced by the European Commission's Joint Research Centre. The dataset documents the long term (since 1984 onward) extent dynamics of 8,869 reservoirs at 30x30 meter pixel resolution. The reservoirs dataset represents surface area data on artificial waterbodies including reservoirs formed by dams, flooded areas such as opencast mines and quarries, and water bodies created by hydro-engineering projects such as waterway and harbour construction. The map below shows the reservoirs at their maximum extent. The dataset will be progressively complemented and continuously updated to account for newly build reservoirs.

Figure 1 Global Map of all reservoirs

Each reservoir is documented as separate object with a unique ID assigned. For instance, Figure 2 illustrates a reservoir in Sardinia, Italy, with a true colour, cloud free composite of Sentinel-2 imagery as background.

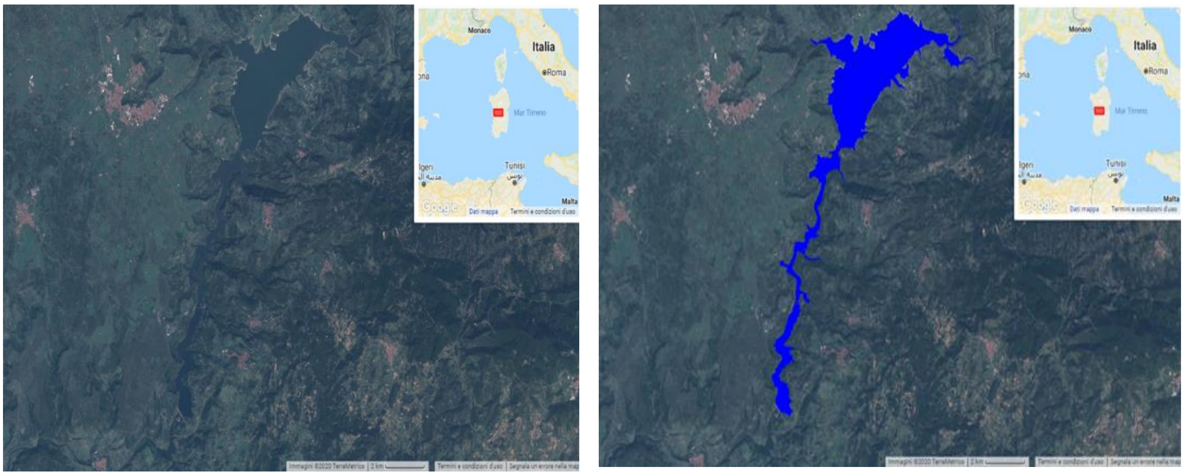

Figure 2 Visualisation of a reservoir in Sardinia, Italy (left image); also shown as maximum water extent for the same reservoir shown with a blue mask (right image)

The reservoirs dataset is derived from the Global Surface Water Explorer (GSWE) dataset, onto which is applied an expert system classifier designed to separate natural and artificial water bodies. The expert systems classifier is non-parametric to account for uncertainty in data, incorporate image interpretation expertise into the classification process, and uses multiple data sources. The expert system has been developed to delineate natural and artificial water using an evidential reasoning approach; the geographic location and the temporal behaviour of each pixel; and fed with the following datasets:

Global Surface Water Explorer (Pekel et al., 2016): This dataset that maps the location and long term (since 1984 onward) temporal distribution of water surfaces at global scale. The maps show different facets of surface water dynamics and document where and when open water was present on the Earth's surface. The maps include natural (rivers, lakes, coastal margins and wetlands) and artificial water bodies (reservoirs formed by dams, flooded areas such as opencast mines and quarries, flood irrigation areas such as paddy fields, and water bodies created by hydro-engineering projects such as waterway and harbour construction). The complete history of any water surface can be accessed at the pixel scale as temporal profile. These profiles allow for identifying specific months or years during which conditions changed, e.g. the date on which a new dam was created, or the month or year in which a lake disappeared. The GSWE dataset is continuously updated providing consistent global monitoring of open water bodies.

Global Reservoir and Dam Database (Lehner et al, 2011): The Global Reservoir and Dam Database v1.3 is the output of an international effort to collate existing dam and reservoir datasets with the aim of providing a single, geographically explicit and reliable database for the scientific community. The initial version (v1.1) of GRanD contains 6,862 records of reservoirs. The latest version (v1.3) augments v1.1 with an additional 458 reservoirs and associated dams to bring the total number of records to 7320.

Global Digital Surface Model: ALOS World 3D - 30m is a global digital surface model (DSM) dataset with a horizontal resolution of approximately 30 meters (1 arcsec mesh). The dataset is based on the DSM dataset (5-meter mesh version) of the World 3D Topographic Data. More details are available in the dataset documentation here.

Digital Elevation Data (Farr et al, 2004): The Shuttle Radar Topography Mission (SRTM, see Farr et al. 2007) is a digital elevation dataset at 30 meters resolution provided by NASA JPL at a resolution of 1 arc-second.

3.2.3 Known limitations and scope for improvements

The current version of the Global Reservoir Dynamics dataset has the following known limitations:

- Some reservoirs built prior 1984 may be missing;
- Reservoirs smaller than 3 hectares (30 000 square meters) may be missing;
- Branches of reservoirs whose width is smaller than 30 meters may be missing.

3.2.4 Calculating the extent to which reservoir area is changing over time

Data on reservoir area dynamics are available for a 36 year period, from 1984-2019. Every year new annual data is produced and added to this time series. For the purpose of producing national statistics to monitor indicator 6.6.1, annual data starting from year 2000 has been used and includes all annual data up to the present day.

To calculate percentage change in reservoir area using a 2000-2019 dataset, a baseline period is first defined against which to measure change. This methodology uses 2000-2004 as the 5-year baseline period. Averaging all earth observations annually and over a five year period the baseline is then compared a subsequent 5 year target period 2015-2019. From the baseline and target period, percentage change of spatial extent is calculated using the following formula:

Where β = the average national spatial extent from 2000-2004
Where γ = the average national spatial extent of any other subsequent 5 year period
Percentage Change in Spatial Extent=$((\beta-\gamma))/\beta\times100$

3.3 Measuring wetland area

3.3.1 Why measure wetland area?

Over 1 billion people rely entirely on the services provided by wetland ecosystems such as swamps, bogs, fens, peatlands, marshes and paddies. Healthy and functional natural wetlands are intrinsically linked with human livelihoods, well-being and sustainable development. However, wetlands are facing major threats, caused by conversion for commercial development and agriculture, overfishing, tourism, pollution and climate change. There is an urgent need to strengthen, and reinforce, national policies and legal frameworks to help countries to protect and restore critical wetland ecosystems. Past efforts, however, have been hampered by the lack of data on the locations, types and sizes of wetland resources. This kind of data and information is crucial to measure the effectiveness of policy, legal and regulatory mechanisms and essential for tracking progress towards the SDGs. Despite the importance of wetlands, and unlike other critical ecosystems (e.g. forests, mangroves and inland water bodies), the extent and dynamics of wetland ecosystems has, until now, been ill defined, characterized and modelled.

3.3.2 Description of the method used to globally map wetlands

Inland vegetated wetlands are mapped according to the following definition: "Inland vegetated wetlands include areas of marshes, peatlands, swamps, bogs and fens, the vegetated parts of flood plains as well as rice paddies and flood recession agriculture". This sub-indicator only measures inland vegetated wetlands and not coastal mangroves (see section 3.5 of this methodology on mangroves). This SDG indicator methodology is used for official reporting of SDG indicator 6.6.1 statistics[5].

Figure 3. Wetland extent map for the territory of Uganda

[5] It does not apply the very broad definition of wetlands used by the Ramsar Convention on Wetlands, which may be interpreted to mean all water within a country including the marine environment. The SDG indicator 6.6.1 definition refers to only a specific group of inland vegetated wetlands typologies. Countries may benefit from using the SDG wetlands extent data within reports to the Ramsar Convention on Wetlands.

A high-resolution global geo-spatial mapping of inland vegetated wetlands has been produced detailing the spatial extent of wetlands per country. The data on wetlands has been produced to support countries with monitoring their wetland ecosystems and bridge an existing global data gap. The data production method uses a consistent wetland monitoring mechanism based on satellite Earth Observation data and the global map includes the entire land surface of Earth except for Antarctica and a few small islands.

As wetlands tend to be susceptible to high annual variations, multi-annual data was collected to even out potential annual biases and create a robust estimate of wetland extent. Data was gathered from 2016, 2017 and 2018 and combined to produce a wetlands area baseline measurement (in km^2). Future annual updates will enable wetlands change statistics to be produced and these once available these will be displayed on the SDG 6.6.1 data portal. Predicting wetland extent using Earth Observation data relies on four components: stratification, training data, machine learning, and post-processing. The approach uses all available data from the satellites Sentinel-1, Sentinel-2, and Landsat 8 to predict wetland probability. A Digital Elevation Model is used to qualify wetland predictions and a post-processing routine converts the wetland probability map into a map of wetland extent.

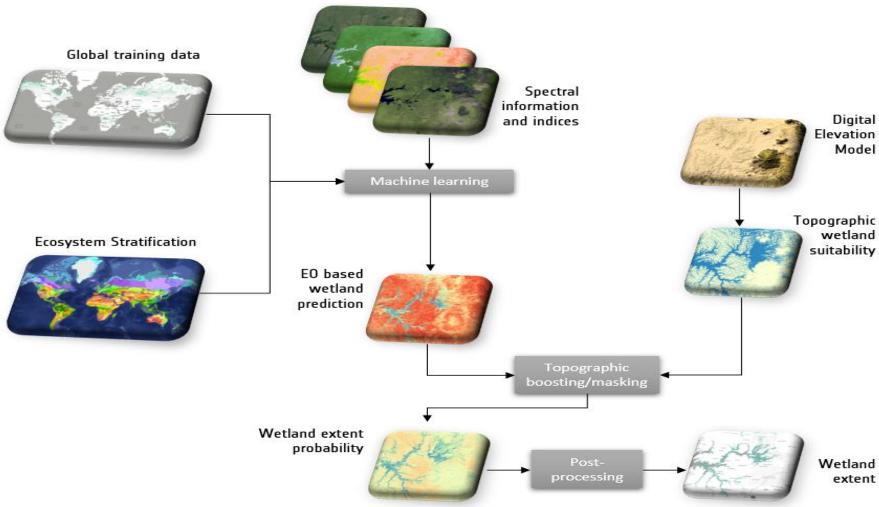

Figure 4. Workflow for mapping global wetland extent

In addition, topographic information from satellite-derived Digital Elevation Models (DEMs) are used. Close to 4 million satellite images amounting to 2.8 petabyte of data were analysed and classified as wetland or non-wetland using an automated machine learning model.

Users of the global wetland map should be aware that the map represents a first line rapid assessment of the global distribution of vegetated wetlands. The methodology applied identifies vegetated inland wetlands. This may generate underestimations compared to national statistics which may integrate metrics on surface water and coastal/marine wetlands. Data accuracy for the available wetlands data is approximately 70% and wetland data with 100% accuracy is not feasible at this current time. While it is based on a scientifically sound and robust mapping approach, there will inevitably be inaccuracies in the wetland predictions both in terms of commission and omission errors. Notable commission errors are for instance high-intensive irrigated agriculture parcels being classified as wetlands because they resemble many of the inherent spectral characteristics of wetlands (i.e. high moisture and vegetation presence even in dry season). Omission errors will mainly be attributed to the large diversity of wetlands. Despite best effort to train the model across the widest range of wetlands possible, there will be types of wetlands and instances of wetland behaviour that will not be adequately captured in a global model. For instance, some ephemeral wetlands are rarely flooded or wet and therefore often missed by satellite datasets. In other cases, the wet part of a wetland may occur under a dense vegetation canopy, which is difficult to assess using Earth Observation data, where the presence of water/moist conditions is not easily detected. Other limitations of the data are:

- Only regional stratification is applied including strata spanning several countries. Using a finer level of stratification will help improve local/national wetland predictions;
- The accuracy of the wetlands map will improve further once cross referenced with more national wetland inventories and ground truthing;
- Terrain information from satellite derived DEMs is key input for mapping wetlands globally. The current reference datasets are the 30-meter SRTM DEM which covers the globe from 60ºNorth to 56ºSouth, while the region north of 60 degrees north relied on a lower resolution 90-meter DEM model was used. Options for 30-meter DEMs north of 60ºN exists and should be considered in future updates;
- Small islands and potentially even entire small island states fall outside the acquisition plan of the Sentinel satellites. As a result, no wetland prediction has been performed for these areas. It will be possible to develop separate models for these missing islands using alternative input satellite data (e.g. using Landsat alone).

Future updates and iterations of the wetlands map will address the above limitations, including a potential shift into a deep learning model to more explicitly reflect temporal and spatial aspects of wetland predictions. Despite limitations with the methodology the production of high-resolution wetland mapping for the entire globe is at the forefront of currently available technology and computing power. It represents a huge step forward towards reporting accurate, statistically robust wetland data.

3.3.3 Calculating the change in surface area of wetlands per country

No change in surface area has yet been calculated. However, a baseline surface area has been calculated per country. This methodology uses a 2017 baseline (based on input imagery data from 2016 to 2018 to even out potential annual biases). Going forward, updates to this wetland area datasets will be produced annually. Once the update is produced it will be possible to calculate change of wetland area from the baseline reference period. Using this baseline period, percentage change of spatial extent is calculated using the following formula:

Percentage change in wetland extent $((\beta-\gamma))/\beta\times100$
Where β is the spatial wetland extent for the baseline reference period
Where γ is the spatial extent for the reporting period.

3.4 Measuring changes in mangrove area

3.4.1 Why measure mangroves?

Mangrove swamps are forested intertidal ecosystems that are distributed globally between approximately N32° (Bermuda) to S39° (Victoria, Australia). Mangroves perform critical landscape-level functions related to the regulation of freshwater, nutrients and sediment inputs into marine areas. They also help to control the quality of marine coastal waters and are of critical importance as breeding and nursery sites for birds, fish, and crustaceans. It has been estimated that nearly two thirds of all fish harvested globally in the marine environment ultimately depend on the health of tropical coastal ecosystems. Mangroves furthermore receive large inputs of matter and energy from both land and sea and constitute important pools for carbon storage (Lucas et al., 2014).

Once abundant along the world's tropical and subtropical coastlines, mangroves are in decline at a rate similar to that of terrestrial (natural) forest, with about four to five percent of the global coverage lost during the past two decades (Ramsar Convention, 2018; FAO, 2015). Significant drivers of change include removal for aquaculture, agriculture, energy exploitation and other industrial development, with an unknown proportion of the remaining mangroves fragmented and degraded (Thomas et al., 2017). Mangroves are also sensitive to climate change effects such as sea level rise, temperature extremes and geographic range, and changes in hydrology.

Information on the state and change trends of mangroves at both national and global levels is limited. This is due in part because mangroves often fall between the national jurisdictions of wetlands and for forestry, and in part because of their often remote and inaccessible locations, which make periodic mapping and monitoring by conventional means costly and time consuming. Mangrove soils hold over 6 billion tons of carbon and can sequester up to 3-4 times more carbon than their terrestrial counterparts but are categorized as forests within the UN Framework Convention on Climate Change's REDD+ scheme[6] (IUCN, 2017), and should therefore be included in national emissions reports.

3.4.2 Description of the method used to measure mangrove area

Global mangrove area maps were derived in two phases, initially producing a global map showing mangrove extent (for 2010) and thereafter producing six additional annual data layers (for 1996, 2007, 2008, 2009, 2015 and 2016). The method uses a combination of radar (ALOS PALSAR) and optical (Landsat-5, -7) satellite data. Approximately 15,000 Landsat scenes and 1,500 ALOS PALSAR (1 x 1 degree) mosaic tiles were used to create optical and radar image composites covering the coastlines along the tropical and sub-tropical coastlines in the Americas, Africa, Asia and Oceania. The classification was confined using a mangrove habitat mask, which defined regions where mangrove ecosystems can be expected to exist. The mangrove habitat definition was generated based on

[6] Reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries

geographical parameters such as latitude, elevation and distance from ocean water. Training for the habitat mask and classification of the 2010 mangrove mask was based on randomly sampling some 38 million points using historical mangrove maps for the year 2000 (Giri et al., 2010; Spalding et al., 2010), water occurrence maps (Pekel et al, 2017), and Digital Elevation Model data (SRTM-30).

The maps for the other six epochs were derived by detection and classification of mangrove losses (defined as a decrease in radar backscatter intensity) and mangrove gains (defined and a backscatter increase) between the 2010 ALOS PALSAR data on one hand, and JERS-1 SAR (1996), ALOS PALSAR (2007, 2008 & 2009) and ALOS-2 PALSAR-2 (2015 & 2016) data on the other. The change pixels for each annual dataset were then added or removed from the 2010 baseline raster mask (buffered to allow detection of mangrove gains also immediately outside of the mask) to produce the yearly extent maps.

Classification accuracy of the 2010 baseline dataset was assessed with approximately 53,800 randomly sampled points across 20 randomly selected regions. The overall accuracy was estimated to 95.25 %, while User's (commission error) and Producer's (omission error) accuracies for the mangrove class were estimated at 97.5% and 94.0%, respectively. Classification accuracies of the changes were assessed with over 45,000 points, with an overall accuracy of 75.0 %. The User's accuracies for the loss, gain and no-change classes respectively were estimated at 66.5%, 73.1% and 83.5%. The corresponding Producer's accuracies for the three classes were estimated as 87.5%, 73.0% and 69.0%, respectively.

Limitations of the data:

- The mangroves map is a global dataset, and as such, it should not be expected to achieve the same high level of accuracy everywhere as a local scale map derived through ground surveys or the use of very high spatial resolution geospatial data. A global area mapping exercise using consistent data and methods – although supplemented with ground-based data for calibration and validation – for logistical reasons generally requires a trade-off in terms of local scale accuracy. Nonetheless, global maps can be improved locally (or nationally) by adding improved information (in-situ data and aerial or drone data) for training and re-classification.
- Several different factors can affect the classification accuracy, including satellite data availability, mangrove species composition and level of degradation.
- While the original pixel spacing of the satellite data used for the mapping is 25-30 metres, a minimum mapping unit of approximately 1 hectare is recommended due to the classification uncertainty of a single pixel. The classification errors (in particular omission errors) typically increase in regions of disturbance and fragmentation such as aquaculture ponds, as well as along riverine or coastal reef mangroves that form narrow shoreline fringes of a few pixels.
- In general, the mangrove seaward border is more accurately defined than the landward side where distinction between mangrove and certain wetland or terrestrial vegetation species can be unclear.
- Striping artefacts due to Landsat-7 scanline error are present in some areas, particularly West African regions due to lack of Landsat-5 data and persistent cloud cover.

- Known data gaps in this version (v2.0) of the dataset: Aldabra island group (Seychelles); Andaman and Nicobar Islands (India); Bermuda (U.K.); Chagos Islands; Europa Island (France); Fiji (part east of Antemeridian); Guam and Saipan (U.S.); Kiribati; Maldives; Marshall Islands; Peru (south of latitude S4°), and Wallis and Futuna Islands (France).

As with wetland mapping the production of high-resolution mangrove data for the entire globe is at the forefront of currently available technology and computing power. It represents a huge step forward towards reporting accurate, statistically robust mangrove data which can be updated continuously.

3.4.3 Calculating the area of mangrove per country

Data on mangroves area are available for 1996, 2007, 2008, 2009, 2010, 2015 and 2016). New annual data is for 2017 and 2018 will be produced during 2020. For the purpose of producing national statistics to monitor indicator 6.6.1, the year 2000 has been used as a proxy based on the 1996 annual dataset to align with this baseline with that of the surface water dataset. National mangrove extent for the year 2000 will be used as the baseline reference period. Annual mangrove extent is compared to this baseline year. Percentage change of spatial extent is calculated using the following formula:

Where β = the national spatial extent from year 2000
Where γ = the national spatial extent of any other subsequent annual period
Percentage Change in Spatial Extent=$((\beta-\gamma))/\beta\times100$

3.5 Measuring lake turbidity and trophic state

3.5.1 Why measure lake turbidity and trophic state?

Turbidity is a key indicator of water clarity, quantifying the haziness of the water and acting as an indicator of underwater light availability. Trophic State Index refers to the degree at which organic matter accumulates in the water body and is most commonly used in relation to monitoring eutrophication. In this context both water parameters may be used to infer a particular state, or quality, of a freshwater body.

3.5.2 Description of the method used to globally map reservoir area

The global dataset measures two lake water parameters: Turbidity (TUR) and an estimate of Trophic State Index (TSI). The products were produced by the Copernicus, the Earth Observation program of the European Union. For the two parameters the dataset documents monthly averages as well as multi-annual per-monthly averages for the periods 2006-2010 and 2017-2019. The products are mapped at a 300x300 meter pixel resolution capturing data for a total of 4265 lakes. Each lake has individual identification information allowing it to be related to other hydrological datasets. A list of all lake IDs and additional information (location, name – where known, area) is available. Turbidity is derived from suspended solids concentration estimates and the Trophic State Index is derived from phytoplankton biomass by proxy of chlorophyll-a.

Trophic classification	Trophic State Index, CGLOPS TSI values	Chlorophyll-a (µg/l) (upper limit)
Oligotrophic	0	0.04
	10	0.12
	20	0.34
	30	0.94
Mesotrophic	40	2.6
	50	6.4
Eutrophic	60	20
	70	56
Hypereutrophic	80	154
	90	427
	100	1183

Table 2: Trophic state index and related chlorophyll-a concentration classes (according to Carlson (1977))

Products in the period 2006 - 2010 are based on observations from the MERIS sensor, whereas the product 2017-2019 is derived from OLCI sensors. Land/water buffer maps as well as ice maps were applied to improve the accuracy of the data.

The following figure is an example visualisation of the two lake water parameters for Lake Huron showing Trophic State Index 10-day average (left) and turbidity 10 day-average (right).

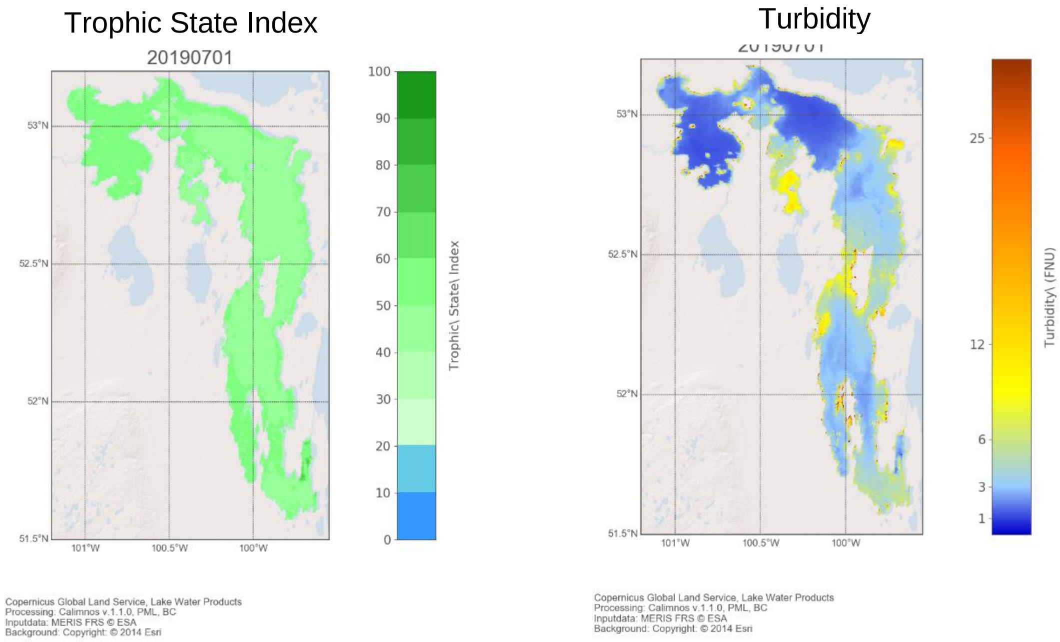

Figure 5: Lake Winnipegosis - Trophic State Index (left) and turbidity (right) monthly product July 2019

The products were tested against consistency (time series) and against in situ data, both for a selected set of lakes. A detailed technical methodology is available to download at the SDG661 data portal (SDG661.app).

3.5.3 Calculating Turbidity and Trophic State Index statistics

A baseline reference period has been produced comprising monthly averages across 5 years of observations for the period 2006-2010. From these five years of data, 12 monthly averages (one for each month of the year) for both trophic state and turbidity, were derived. A further set of observations are then used to calculate change against the baseline data. These monthly data comprise years 2017,18,19. The 12 monthly averages for these three years have been derived.

Monthly deviation of the multiannual baseline is computed using the following equation: month_average-Month_baseline)/Month_baseline x 100

For each pixel, and for each month, the number of valid observations has been counted and the number of months where there were monthly deviations, falling in one of the following range of values: 0-25%, 25-50% (medium), 50-75%, 75-100% (high). An annual deviation synthesis is also produced.

Level 2 Data

The Sub-Indicators included in Level 2 are aspects of Indicator 6.6.1 which are either modelled or need to be monitored ‘in situ’ within countries themselves. The custodian agency will periodically request in situ Level 2 data collected by countries and after quality control, submit appropriate data to UNSD.

3.6 Measuring or modelling river flow (discharge)

River and estuary discharge, or the volume of water moving downstream per unit of time, is an essential metric for understanding water quantity within an ecosystem and availability for human use. This section describes key considerations for monitoring discharge and provides criteria for discharge data generated to support Indicator 6.6.1.

Common in-situ monitoring methods: There are a variety of methods for monitoring discharge *in situ* and selection should be based on the size and type of the waterbody, terrain and velocity of water flow, the desired accuracy of measurement, as well as finances available. Two the most common and accessible approaches are gauging stations and using current meters. In many countries, gauging stations are the most prevalent means for measuring river discharge as they allow even for continuous and often real-time monitoring. These are fixed locations along a river or estuary where the change in water surface level (stage) is monitored at locations where a unique relationship exists between stage and flow and a so-called rating curve can be produced. Water surface height (stage) is captured frequently, and the discharge estimated, most often at monthly intervals but in many places, this is available at daily intervals or even continuously. Current meters and other instruments can be used to monitor flow and calculate discharge. For example, propeller, pygmy or electromagnetic current meters are often used to measure velocity and can be used in conjunction with cross-sectional area methods to obtain flow rates. Acoustic Doppler Current Profiler’s (ADCPs) are widely used for larger rivers/estuaries to accurately measure bed depth, velocity, and discharge. They are often attached to boats and dragged along a waterbody, but permanent installations can also be found, sending out acoustic waves and measuring acoustic reflectance. Meters and instruments like ADCPs are significantly more costly than other methods of measurement and require skilled operators and good maintenance programmes. However, in larger rivers they may be the most appropriate option, especially during high flow conditions.

Location of Monitoring: The chosen monitoring method may dictate where along a river or estuary the discharge is captured. For example, if fixed weirs are in place, monitoring will always take place here. Since *in situ* discharge monitoring can be time and cost-intensive, choosing strategic locations which represent a whole river or estuary is recommended. The minimum monitoring effort is to locate one flow measuring site within proximity to each basin’s exit (into another basin). In addition, monitoring at the exit point from all major tributaries adds a substantial level of information. Where there is a local impact on discharge due to human influence, then it is recommended to monitor flow upstream and downstream of these areas so that the overall situation can be managed.

Frequency of Monitoring: The quantity of water in a river or estuary can change rapidly in response to rainfall and weather patterns. The more data on discharge there is, the higher the accuracy is of that discharge data. However, again it is important to focus efforts and choose a strategic frequency for monitoring. Data on discharge should ideally be collected at a given location once a month at minimum (ideally at a daily frequency) and this data can then be used to determine annual and long-term trends. The quantity of water in estuaries may be significantly influenced by tidal inflows, thus this indicator is limited to the freshwater inflows to the estuary from the upstream river.

Modelling Discharge: In addition to *in situ* monitoring which always is impacted by all forms of flow moderation, storage or abstractions upstream, discharge may also be modelled from one of the many available models which use climatic and land-use data, amongst other data, to estimate both natural and present-day flows. Globally hydrological model applications are available and in some countries these or similar models have been developed for the local context and are calibrated using real measured data. It is recommended that modelled discharge data is complimented by measured *in situ* data wherever possible to ensure accuracy. Conceptual hydrological models for flow and discharge estimation are normally less amenable to detecting the flow impacts of minor land-cover changes over time as the models are calibrated on historical flow data and associated land-use conditions.

3.7 Measuring quantity of groundwater within aquifers

The changes to the quantity of groundwater within aquifers is important information for many countries that rely heavily on groundwater availability. For the purposes of Indicator 6.6.1 monitoring the changes to groundwater levels gives a good indication of changes to the water stored in an aquifer. Furthermore, only significant ground water aquifers, that can be seen as individual freshwater ecosystems will be included in the reporting.

Location of Monitoring: Measuring the level of groundwater within an aquifer is done through the use of boreholes. One of the challenges in setting up monitoring is choosing the location of boreholes which will adequately represent the total groundwater situation for an aquifer. The number of boreholes that need to be monitored cannot be prescribed because the distribution of groundwater can be variable depending on the location and characteristics of aquifers. It is recommended that sufficient boreholes to characterise the area should be monitored, with the capacity of the country being a factor in deciding how many would best represent the area. It is highly recommended that data should be taken from observation boreholes / monitoring boreholes (these are boreholes which are not equipped with pumps). Data from used (pumped) boreholes should be avoided. In case a pumped borehole needs to be used for measurements, then it is crucial to allow for a sufficiently long recovery period in which the borehole is not used so that the groundwater level in the borehole can stabilise prior to any measurement.

Frequency of Monitoring: Groundwater levels change as a result of changes in groundwater recharge (affected by climate conditions, and land use) and by anthropogenic removals from the system (groundwater abstraction). Seasonal and wet/dry cycle influences need to be understood and hence monthly monitoring is optimal, but collection at least twice per year, in the wet and dry seasons, is necessary.

Criteria for Indicator 6.6.1 Data

Groundwater quantity data provided to the custodian agency(s) will be quality checked to ensure data integrity. Collection of groundwater level data generates statistics that are a proxy to the quantity of groundwater in an aquifer over time. In order to examine this change over time, percentage change in groundwater level will be generated and validated between the custodian agency(s) and the country. Calculating percentage change at a national level requires the establishment of a common reference period for all basins, which can either be based on historical groundwater level data (preferred) or modelled data if available. In cases where these are unavailable, a more recent period can be adopted to represent the 'baseline' or reference period.

4 GLOBAL DATA PORTAL FOR INDICATOR 6.6.1

The development of the SDG 6.6.1 data portal has been driven by the need to support national monitoring and reporting processes and facilitate data-based decision making towards protecting and restoring water-related ecosystems. As described in the sections above, rigorous methodological approaches have been applied to produce data of high accuracy. The data available (as of March 2020) covers many aspects of SDG indicator 6.6.1. These existing datasets will be regularly updated. UNEP will continue to work with partners in an effort to bring new datasets into the portal for uptake and use by Member States including; reservoir volume dynamics and lake volume dynamics; and modelled river flow data. These additional datasets will complement the existing data on changes in the extent of water-related ecosystems and provide yet further useful information to underpin good decision making towards protecting and restoring water-related ecosystems.

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