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COPERNICUS DATA IN SUSTAINABLE DEVELOPMENT GOALS USING IMAGE MAPS

Diploma thesis

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ANOTATION

The main goal of the thesis is to design and compile a set of image maps from the data of the Copernicus project and thereby demonstrate the applicability of satellite data to support solutions to the selected Sustainable Development Goals. The research allows to enhance the accessibility, availability, and utilization of Copernicus as a free and open-source earth observation data, with a view to foster sustainability at a planetary level. 15 most relevant SDG indicators were mapped using the datasets from five Copernicus Services using two different prototypes of thematic image maps. The resulting image maps were transformed into a set of information products in five different cartographic formats following a unique concept of geovisualization whereby each form of visualization was oriented towards a specific purpose and target audience. Multidimensional analysis of Copernicus data facilitated in detecting meaningful trends, patterns and interlinks that occurred in the datasets. Overall, the thesis offers a holistic approach in integrating earth observation and cartography for managing the SDGs. The research outcomes serve to assist the policy makers in informed decision making and effective policy formulation with a rationale that an incremental progress towards the SDG targets will be achieved in due course.

KEYWORDS

Cartography, Earth Observation, Geovisualization, Multidimensional Analysis, GIS

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This thesis has been composed by *Sushmita Subedi* for the Erasmus Mundus Joint Master's Degree Program in Copernicus Master in Digital Earth for the academic years 2021/2022 and 2022/2023 at the Department of Geoinformatics, Faculty of Natural Sciences, Paris Lodron University Salzburg, and Department of Geoinformatics, Faculty of Science, Palacký University Olomouc.

Hereby, I declare that this piece of work is entirely my own, the references cited have been acknowledged and the thesis has not been previously submitted to the fulfilment of the higher degree.

24 May 2023, Olomouc   Sushmita Subedi

I would like offer my sincere gratitude to my supervisor Prof. Dr. Vít Voženílek (Palacký University Olomouc) for his invaluable guidance and motivation throughout my master's thesis. I would also like thank Assoc. Prof. Stefan Lang (Paris Lodron University Salzburg) for guiding me as my co-supervisor. I also appreciate the roles of Jakub Koníček and Dr. Rostislav Nétek from Palacký University Olomouc for providing their insightful comments and feedbacks on poster design and web mapping respectively.

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ASSIGNMENT OF DIPLOMA THESIS

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Theses guidelines

The main goal of the thesis is to design and compile a set of image maps from the data of the COPERNICUS project and thereby demonstrate the applicability of satellite data to support solutions to selected Sustainable Development Goals (SDGs). The student will study in detail the SDGs down to the level of indicators, as well as descriptions of the satellite data of the COPERNICUS project. Student evaluates the relationships between SDGs and COPERNICUS data. Then she will compile image maps for selected SDGs (approx. 15) with methodical text on how to create and use image maps to solve the corresponding SDGs.

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Extent of graphics content:	**as needed**
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Kraak MJ, RE Roth, B Ricker, A Kagawa, and G Le Sourd. 2020. Mapping for a Sustainable World. The United Nations: New York, NY (USA).
Bělka, Luboš & Voženílek, Vít (2013). Prototypes of Orthoimage Maps as Tools for Geophysical Application. Pure and Applied Geophysics. doi: 171. 10.1007/s00024-013-0665-y.
Meeuwissen, N. (2020). Measuring and comparing the progress of four SDG indicators in two countries in Asia using open remote sensing land cover datasets. Wageningen University and Research Centre.
Compendium of Earth Observation Contributions to the SDG Targets and Indicators. (2020, May). EARTH OBSERVATION FOR SDG. European Space Agency.
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LIST OF ABBREVIATIONS

Abbreviation	Meaning
C3S	Copernicus Climate Change Service
CAMS	Copernicus Atmosphere Monitoring Service
CEMS	Copernicus Emergency Management Service
CLMS	Copernicus Land Monitoring Service
CMEMS	Copernicus Marine Environment Monitoring Service
CO2	Carbon Dioxide
CSS	Copernicus Security Service
EO	Earth Observation
ESA	European Space Agency
ETRS	European Terrestrial Reference System
GDA	Geocentric datum of Australia
GIS	Geographic Information System
LAEA	Lambert Azimuthal Equal Area
NAD	North American Datum
NTU	Nephelometric Turbidity Unit
OBIA	Object Based Image Analysis
PM	Particulate Matter
SDGs	Sustainable Development Goals
UN	United Nations
WGS	World Geodetic System

INTRODUCTION

The world today confronts a range of arduous global issues such as climate change, pandemics, food insecurity, water contamination, biodiversity loss, socioeconomic disparities, political discord and other related complications. In order to address such global challenges and achieve better and more sustainable future for all, the UN member states adopted the global agenda of Sustainable Development Goals (SDGs) in 2015. With the joint commitment and collaborative effort of 193 countries, the global agenda of SDGs aims to foster sustainability of actions in ending poverty alongside promoting economic growth and addressing social needs like education, health, and job opportunities while tackling climate change and protecting terrestrial and marine ecosystems.

The development of Global Indicator Framework for monitoring the progress towards SDGs is predominantly based on statistical information. However, it has been well acknowledged that geospatial information, encompassing geographic location and spatial context, is a valuable asset for enhancing the efficacy of the framework. This inclusion can offer important insights into the spatial aspects of development trends and aid in monitoring progress on a localized level to facilitate the targeted interventions. Earth Observation (EO) plays a pivotal role as a prominent data source in elucidating various environmental dimensions of our planet. In addition, it serves as a crucial spatial disaggregation mechanism for a multitude of SDG indicators (ESA, 2020).

Maps have the capability to simplify complex information and unveil spatial patterns that otherwise remain unnoticed. They play an important role in showcasing spatio-temporal trends in worldwide population, socioeconomic inequalities, and alterations in climatic conditions. Well-designed cartographic representations facilitate the monitoring of SDG indicators and enable effective communication of their disproportionate global footprints (Kraak et al., 2020). Such visualizations serve to aid the decision-making processes of both local and national governing bodies, while concurrently augmenting public consciousness of global issues and urging the action to be taken by the concerned authorities.

This research aims to demonstrate the power Copernicus as an earth observation platform in managing and monitoring SDG indicators through the innovative use of image maps. 15 most relevant SDG indicators have been visualized using the datasets from five of the Copernicus Services using two different prototypes of thematic image maps. In addition to cartographic visualizations, the thesis also deals with analysis and interpretation of individual image maps along with methodical description on how to create and use image maps to solve the corresponding SDGs. The results have been transformed into a set of information products in five different cartographic formats following a unique concept of geovisualization. Overall, the thesis offers a holistic approach in integrating earth observation and cartography for managing SDGs and thereby, highlights the crucial role Copernicus data can play in evidence-based decision making in SDG context.

1 OBJECTIVES

The main goal of the thesis is to design and compile a set of image maps from the data of the Copernicus project and thereby demonstrate the applicability of satellite data to support solutions to the selected Sustainable Development Goals (SDGs).

The sub-goals of the thesis can be as divided as follows:

- To monitor the progress of selected SDG indicators over space and time
- To present different prototypes of image maps and their suitability in visualizing the SDG indicators
- To demonstrate a concept of geovisualization utilizing different forms of cartographic information products

The research aims to fulfil the geospatial information requirements pertaining to the measurement and monitoring of the selected SDG targets and indicators. This allows to enhance the accessibility, availability, and utilization of Copernicus as a free and open-source earth observation data, with a view to foster sustainability at a planetary level. The concept encourages inclusive and harmonized collaboration with a deeper understanding of how the integration of earth observation together with cartography can enable the accurate assessment of the advancements made towards the specific SDGs.

Different categories of target audience will be able to derive considerable benefits from the present research, particularly those who lack awareness about the prospects of earth observation in the context of the SDGs. The results of the thesis will be richer in information content and will allow the users to experience dynamics and interactivity within map environment. More importantly, the research outcomes will serve to assist the policy makers in informed decision making and effective policy formulation with a rationale that an incremental progress towards the SDG targets will be achieved in due course.

2 STATE OF ART

SDG through the Lens of Cartography

Sustainable Development Goals (SDGs) are the global agenda adopted by the UN member states in 2015 that aim to address the global challenges and achieve better and more sustainable future for all. The SDGs consist of 17 goals that address the most pressing problems our planet is facing. The goals are further divided into 169 specific targets and 231 unique indicators that measure and monitor progress towards each target (United Nations, 2023).

Figure 1 Sustainable Development Goals (Source: United Nations)

Maps are the most efficient means of communicating geospatial information. Kent et al. (2020) has expounded that the comprehension of spatial dimensions of global inequality and hence, the complex and multifaceted issues underpinning SDGs are highly reliant on the use of maps. The utilization of maps, therefore, can be an effective means of bringing to attention the challenges and accomplishments associated with the SDGs, thus contributing towards a greater understanding on a global scale. In relation to the SDGs, Sourd (2022) highlights on how adequately crafted maps and diagrams serve as impactful visual aids in depicting the areas of achievement and outlining the areas that require further attention and advancement. The use of interactive, online, as well as mobile maps provide substantial advantage in critically analysing, manipulating, administering, scrutinizing and illustrating the SDG indicators. Cartographers can play a pivotal role in the provision of perceptive maps and geospatial information facilitating the measurement and surveillance of progress related to the SDGs that can be useful for policy and decision-makers. In light of the 2030 Agenda for sustainable development, cartographers possess a unique opportunity to exemplify the considerable significance of maps and geospatial data in terms of exploration, analysis, synthesis, and presentation (Kraak et al., 2020).

Earth Observation for SDGs

Satellite based earth observation provide a synoptic view of the Earth’s surface in different scale and resolution. Constructed to attain global coverage, satellite EO possesses a number of pivotal attributes that render it as an indispensable input for some of the SDG indicators, while concurrently serving as a supplementary data provider for a multitude of other indicators. ESA (2020) affirms that up to 34 indicators of SDG can be either directly (17 indicators) or indirectly (17 indicators) informed with EO data across 29 targets and 11 goals. EO networks have made global efforts to systematically arrange various forms of data that are routinely gathered through remote sensors with the pursuit to establish a fundamental collection of essential variables, which are necessary for monitoring the current state and future trajectory of the earth. Maso et al., (2020) illustrate a graphical representation to identify possible linkage between the essential variables and SDG indicators in a way that they connect to EO networks creating a knowledge base. With the Big Data revolution, EO data processing and analytics have advanced significantly. The emergence of cloud computing and high-performance computing has contributed to numerous advancements in the domain of Earth Observation data processing. The utilisation of data cubes facilitates the organisation of satellite imagery into stacks of geographically consistent and accurately calibrated 'tiles', which are supported by a relational database and amenable to swift manipulation through high-performance computing platforms (ESA, 2020). All these advancements in EO technology and infrastructure serve to fulfil the geospatial information requirements of SDGs, encompassing data exploration, retrieval, manipulation, and interpretation of the extensive SDG indicators.

The Potential of Copernicus

Copernicus is the European Union's earth observation program that monitors our planet and its ecosystems. It consists of a constellation of satellites called the Sentinels that collect, store and analyze the earth observation data. Copernicus offers free and openly accessible information products that enable effective planning and decision making. The Copernicus services provide essential information in six thematic areas: ocean, land and atmosphere monitoring, emergency response, security and climate change (Copernicus, 2023).

Figure 2 Copernicus Services (Source: copernicus.eu)

The Copernicus Land Monitoring Service (CLMS) offers geospatial data pertaining to land cover alterations, land utilization, vegetative status, water cycle, and surface energy variables of the Earth to a diverse range of users across the world, particularly those engaged in terrestrial environmental applications. It provides assistance for a diverse range of applications spanning various domains including spatial and urban planning, forest management, water management, agriculture and food security, nature conservation and restoration, rural development, ecosystem accounting, as well as mitigation and adaptation strategies for climate change (CLMS, 2023).

The Copernicus Marine Environment Monitoring Service (CMEMS) comprises the maritime component of the Copernicus program. The resource furnishes dependable, periodic and methodical authoritative data pertaining to the condition of the Blue (physical), White (sea ice) and Green (biogeochemical) aquatic domains, encompassing both global and regional domains. The financial backing for this initiative has been provisioned by the European Commission (EC), while the operational responsibilities are assumed by Mercator Ocean International (CMEMS, 2023).

The Copernicus Climate Change Service (C3S) facilitates the advancement of society by offering authoritative data on the historical, current, and projected climate conditions within Europe and other regions around the globe. The mission of C3S serves to bolster the adaptation and mitigation policies of the European Union via the provision of coherent and reliable climate change-related information. The platform offers free and open access to climate data and utilities aiming support in combatting the effects attributed to climate change (C3S, 2023).

The Copernicus Atmosphere Monitoring Service (CAMS) provides comprehensive datasets and information relating to the composition of the Earth's atmosphere. The service expounds on the current situation of atmosphere as well as provides projections for the future, and also undertakes a thorough examination of historical data spanning several years. CAMS provides support to various domains, encompassing health, environmental monitoring, renewable energies, meteorology, and climatology (CAMS, 2023).

The Copernicus Emergency Management Service (CEMS) supplies relevant stakeholders responsible for the oversight of natural calamities, artificial emergency occurrences, and humanitarian crises with accurate and precise geo-spatial data extrapolated from satellite remote sensing, supplemented by accessible in-situ or open data sources. It facilitates all facets of the emergency management cycle, including measures for readiness, preventative strategies, mitigation of disaster risks, immediate emergency response, and recuperative efforts post-crisis (CEMS, 2023).

The Copernicus Security Service (CSS) is dedicated to security applications endeavours to bolster the policies of the European Union by facilitating the provision of pertinent information to address prevailing security concerns within Europe. The enhancement of crisis prevention, preparedness, and response can be facilitated by focusing on three fundamental domains, namely, border surveillance, maritime surveillance, and provision of assistance to the EU's external activities (Copernicus, 2023).

Use of Image Maps

Image maps are the special maps that portray the geographic space in a particular cartographical projection and map scale, where their content consists of two basic components – image and symbol component (Bělka & Voženílek, 2014). The image component corresponds to the remote sensing image(s) while the symbol component corresponds to the cartographic symbols used in the map.

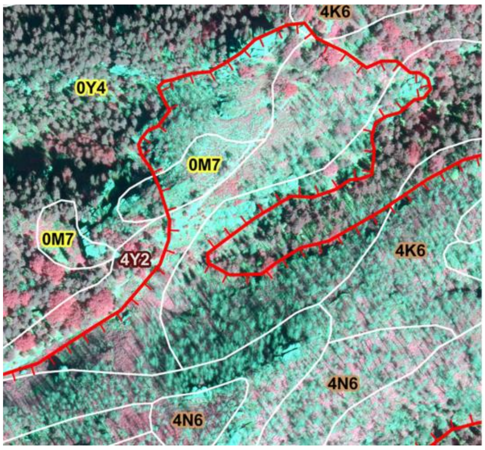


Figure 3 Image Map Example (Bělka & Voženílek, 2014)

Bělka & Voženílek (2014) have introduced two different categories of image maps: topographic image maps and thematic image maps. A thematic image map is a cartographical product that prioritizes one or a group of themes over the others. The utilization of image benefits in such a map can be either to express the thematic content or to use it as a topographic base. The representation of thematic content can be discerned either through image or symbol component. The image component pertains to the theme, whereas the symbol component functions as the topographic base in "front thematic image maps". The categorization of an image map as a "back/rear thematic image map" is assigned when the image component functions as the topographic base, while the symbol component conveys the designated theme. If the image component serves to fulfil both the functions, the thematic image map is referred to as a "double thematic image map". Figure 4 represents the categorization of thematic image maps based on the functionality of image and symbol components in the map.

		Thematic content	
		Image component	Symbol component
Topographic base	Symbol component	Front thematic image map	*it is not an image map*
	Image component	Double thematic image map	Back/rear thematic image map

Figure 4 Categorization of Thematic Image Maps (Bělka & Voženílek, 2014)

Technological Advances in Geovisualization

Graphic design is becoming increasingly popular trend in modern cartography and geovisualization. Incorporating graphic designs into the maps and other cartographic products help to enhance their visual appearances, through the careful application of the principles of design. Opach (2009) discusses on some of the most captivating principles of graphic design accompanied by some remarkable case studies in the context of cartography, their beauty and effectiveness in knowledge transfer. Designing a map poster is one of the most powerful ways to incorporate graphic design in cartography. The purpose of map posters is to provide a concise and fundamental visual overview of a geographic subject matter along with additional visualization elements. The format of a poster presentation demands a conscientious selection of pivotal themes that need to be incorporated within the display. Vujakovic (1995) demonstrates on how map posters help to convey intricate information and ideas through carefully selected combinations of graphics and succinct verbal discourse.

The emergence of web mapping technology constitutes a significant and noteworthy development within the field of cartography. The information on Web is platform-independent, with the ability to disseminate to a larger number of audiences at minimal financial expense while providing an effortless mechanism for frequent updates (Kraak & Brown, 2001). Web mapping offers novel cartographic techniques and possibilities for adding interactivity and multimedia, that are unprecedented in the history of traditional printed maps. Dorman (2020) compares and analyses different alternatives for constructing web maps with their specific applications. The development and proliferation of code-free, graphical interfaces for the creation of sophisticated web maps remains quite popular among the web mapping community. An alternative, more flexible procedure for constructing web maps can be accomplished by means of scripting languages such as R and Python. Numerous programming languages offer software libraries that empower the construction of web maps with minimal coding requirements while accommodating the integration of user-generated data. Nevertheless, competence in the core web technologies of HTML, CSS, and JavaScript ultimately empowers web cartographers to exercise full control over the characteristics of the web maps they are constructing. The JavaScript web mapping libraries provide comprehensive list of plugins and extensions that support the optimization and personalization of the user experience of web maps.

Map animation is considered an expressive medium for the dynamic visualization of spatial data. Also known as movie maps or change maps, animations serve as a powerful visual tool to effectively represent geographical transformations and change phenomena. The information conveyed by static maps is presented in a simultaneous manner, whereas animated maps present data over a period of time. Kraak M.-J. (2007) outlines that animations are not solely limited to narrating a storyline or elucidating a process, but also possess the potential to disclose discernible patterns, interrelationships, or indications of variation that would otherwise remain obscured if only individual maps were examined. Another study by Harrower & Fabrikant (2008) illustrate on how map animations of multidimensional, dynamic geographic phenomena play a significant role in acquiring a deeper comprehension of the human cognitive mechanisms.

Contemporary Research

Sustainable Development Goals (SDGs) are subject to growing concern among modern scientists and researchers. Typically, environmentalists, economists and climate experts are found keenly interested in performing meaningful researches pertaining to the context of SDGs. A larger proportion of these include the regular users of geospatial and earth observation data. Mostly, free and open-source platforms like the Copernicus are preferred by the users to obtain the required data for performing analysis on the related topic or phenomena.

Copernicus (2018) offers a factsheet presenting some examples on how Copernicus concretely contributes to the monitoring of indicators and to selected SDGs, in particular through its six operational Services. The report confirms that Copernicus rigoprously offers datasets required for montitoring the SDG targets 2.4, 3.d, 6.6, 7.3, 11.4, 13.3, 14.4 and 15.1 alongside presenting some use case scenarios. ESA (2020) underlines the important contribution that satellite-based EO can make to the global indicator framework of Agenda 2030, while also presenting the indicator computational method, wherever applicable. Another report by GEO (2017) presents some case studies illustrating where and how EO data has been used for addressing the SDGs and concurrently describing the methods, key issues, results, analysis and outlook.

A study by Meeuwissen (2020) offers comparisions among the progress of four related SDG indicators: 6.6.1, 11.3.1, 15.1.1 and 15.3.1 in two big countries of Asia; China and India using open remote sensing land cover datasets. The study tries to identify the possible patterns, trends, and interlinkages between the indicators & explain the differences between the indicators and the countries. Another area specific comparative approach presented by Giuliani et al. (2021) whereby the authors try to implement a novel approach to compare SDG 11.7.1 in modelling accessibility to urban green areas in four European cities: Geneva, Barcelona, Goteborg and Bistrol using open earth observations. The study resulted in the creation of accessibility maps for each of the cities level capturing both spatial and temporal dynamics of accessibility to the urban green spaces.

The efficacy and limitations of earth observation techniques in mapping of deprived living conditions in support of providing consistent global information for the SDG indicator 11.1.1 “proportion of urban population living in slums, informal settlements or inadequate housing” is well depicted in a research by Kuffer et al. (2018). The study employs the use of machine learning algorithm for mapping urban deprivations and argues that EO-based mapping can be promising as well as equally challenging depending on the morphology of urban area and the type of algorithm used. Verde et al. (2022) introduce a cloud-based mapping approach using deep learning and very high spatial resolution earth observation data to facilitate the SDG 11.7.1 indicator computation in Athens metropolitan area in Greece. In the study, the deep learning classification models were employed for processing PlanetScope and Sentinel-1 imagery, using freely available cloud environments offered by Google.

Giuliani et al. (2021) present an overview of an innovative approach to monitor land degradation of Switzerland at national level using satellite earth observation time-series data in the support of SDG 15.3.1. The study explores the potential of Swiss Data Cube as an analytical cloud computing platform that enables effective and efficient analysis of EO data over full spatial and temporal dimensions. A proof-of-concept workflow is developed whereby the computation of sub-indicators is conducted in Python environment that results to a pixel-based map over the entire country at a spatial resolution of 30 m. The generated indicator provides information on the proportion of degraded, stable, and improved land area at national level for the 2001–2015 period. The conceptual workflow of the reasearch is illustrated in Figure 5.

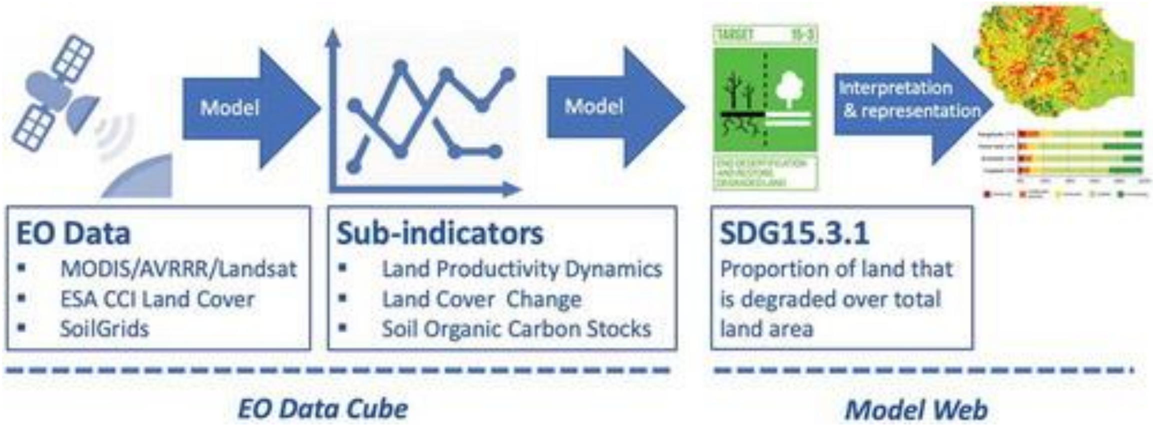


Figure 5 Proof-of-Concept Workflow (Giuliani et al., 2021)

Satellite earth observation proves to be highly promising in monitoring SDG 6 related to clean water and sanitation. In line with SDG 6.6.1, Fitoka et al. (2020) implements an Object-Based Image Analysis (OBIA) approach using Sentinel-2 satellite images for the year 2017, to discriminate 31 classes as wetland and non-wetland in the Greek Ramsar sites and their catchments with the purpose of extracting the possible changes in the spatial extent of water-related ecosystems. Another study conducted by Mulligan et al. (2020) investigates the implementation of remote sensing technology and spatial ecosystem service modelling to realize the objectives set in SDG 6 while accentuating the interconnections among other prominent SDGs. Pahlevan et al. (2022) gives an overview on how EO usage support decision making and promote SDG 6.3.2/6.3.1 reporting in context where many countries face difficulty to report the national water quality data through traditional methods.

The discipline of Earth observation furnishes vital insights into the operational mechanism and functioning of various ecosystems and the factors that contribute to alterations in the environment Therefore, the effective management of ecosystem services within the framework of worldwide sustainability policies necessitates the implementation of dependable monitoring mechanisms. A study by Cord et al. (2017) presents a conceptual framework that elucidates on how the integration of Earth Observation, socioeconomic data, and model-based analysis can assist in the evaluation of the provision and reception of ecosystem services in support of SDG 15. The framework's efficacy is demonstrated through the examination of the three services. The study argues that despite advancements in Earth observation, the utilization of this technology for the comprehensive study of ecosystem services has yet to achieve its maximum capacity. In order to offer direction for priority establishment and stimulate exploration in the domain, the authors propose five priorities aimed at a progressive enhancement of the Earth observation-based monitoring of ecosystem services.

The utilization of satellite remote sensing technology has the potential to support SDG 14 by furnishing indispensable information that help to better understand the oceanic environment and safeguard the marine biodiversity. Bresciani et al. (2017) present a study that aims to examine the efficacy of remote sensing techniques in mapping cyanobacterial blooms occurring in lakes situated in the north of Italy. The authors employ semi-empirical methodologies in the identification of scum and cyanobacteria, along with spectral inversion of bio-optical models that facilitate the detection of adverse impact by cyanobacterial blooms in three closely located meso-eutrophic lakes. Loughland & Saji (2008) delineates the implementation of remote sensing as a tool for detecting and monitoring marine pollution in the Gulf's marine ecosystem emphasizing its utility in detecting oil-related pollution as well as other crucial water quality parameters.

Satellite earth observation platform such as the Copernicus can play a significant role in support of SDG 13 by effectively monitoring climate change and mitigating its adverse effects. The Copernicus satellites are equipped with specialized sensors that have the ability to monitor the atmosphere and detect its compositions. A paper by Peuch et al. (2022) presents the key achievements of Copernicus Atmosphere Monitoring Service (CAMS) and thereby sheds light on its Anthropogenic Carbon Dioxide Emissions Monitoring and Verification Support capacity that helps to monitor the global anthropogenic emissions of key greenhouse gases. The paper further highlights on how CAMS efficiently provides a multitude of worldwide and local data products pertaining to air quality, global emissions and fluxes of greenhouse gases, solar energy, ozone, UV radiation, and climate forcings. Figure 6 depicts the concertration of atmospheric aerosol above the African continent and its surroundings. The data is free and openly accessible through the Atmosphere Data Store (ADS) of Copernicus.

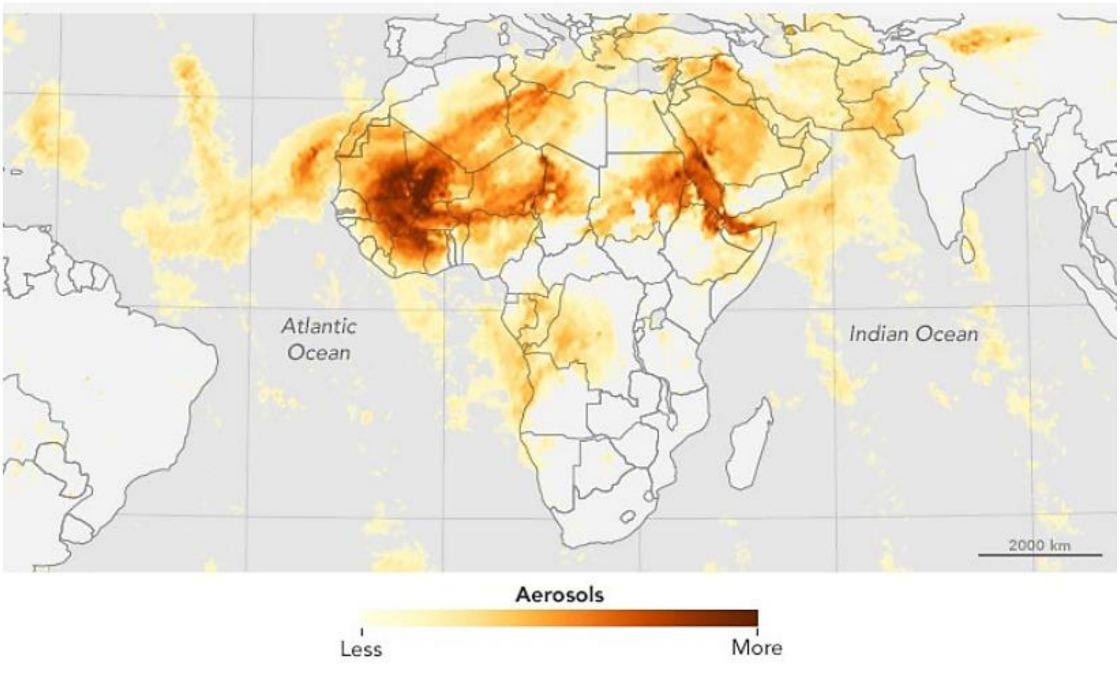


Figure 6 Atmospheric Aerosol Concentration (source: CAMS)

3 METHODOLOGY

Used Methods

The primary method adopted for the research is the multidimensional analysis of Copernicus data depicting the selected SDG topics and their subsequent visualization as image maps. Since a majority of the datasets were in the form of complex multidimensional rasters, multidimensional analysis was used to allow for the simplification and exploration of trends and statistics that occurred in the datasets. Suitable multidimensional functions such as aggregate, subset, trend, temporal profile, anomaly, summary statistics, etc were employed depending on the nature of the individual data depicting each SDG topic. In addition, raster operations and geoprocessing tools were also employed for further adjustment and refinement of the dataset. For the purpose of design and compilation, a number of graphic design techniques supported by Adobe Illustrator were implemented. A unique concept of geovisualization was adopted to visualize the results as five sets of cartographic information products: A4 handy maps, A3 large maps, A2 posters, web maps and animations, each of these oriented towards specific purpose and target audience.

Used Data

The research is based mostly on the free and openly available datasets from the Copernicus project. Copernicus data serves to provide the thematic content for creating the image maps. These datasets have been derived from five different Copernicus services: Copernicus Land Monitoring Service (CLMS) Copernicus Marine Environment Monitoring Service (CMEMS) Copernicus Climate Change Service (C3S) Copernicus Atmosphere Monitoring Service (CAMS) Copernicus Emergency Management Service (CEMS) The sixth component i.e., Copernicus Security Service (CSS) have not been used because of its restricted data policy. The data from the Copernicus Services are mostly multidimensional raster (NetCDF file format), while also in TIFF or shapefile format in a few cases. Table 1 provides a detailed specification of Copernicus data employed for mapping the individual SDGs.

Table 1 Specification of Copernicus data

Title	Copernicus Data	Specification
Soil Loss (SDG 15.3.1)	Dataset: Soil Erosion Indicators for Italy from 1981 to 2080 Provider: Copernicus Climate Change Service	Data type: Gridded Horizontal coverage: Italy Horizontal resolution: 500 m Vertical coverage: Surface Vertical resolution: Single level Temporal coverage: 1981-2080 Temporal resolution: 30-year File format: NetCDF-4
Surface Soil Moisture (SDG 2.4.1)	Dataset: Soil Moisture Gridded Data from 1978 to Present Provider: Copernicus Climate Change Service	Data type: Gridded Projection: WGS 1984 Horizontal coverage: Global Horizontal resolution: 0.25° x 0.25° Vertical coverage: Surface Temporal coverage: 1978 to present

		Temporal resolution: Daily, 10-day, Monthy File format: NetCDF
Turbidity (SDG 6.3.2)	Dataset: Lake Water Quality Provider: Copernicus Global Land Service	Sensor: Sentinel-2 MSI Data type: Gridded Horizontal coverage: Europe and Africa Horizontal resolution: 100 m Temporal coverage: Jan 2019 - present Temporal resolution: 10 days Projection: WGS 1984 File format: NetCDF-4
Built-Up Surface (SDG 11.7.1)	Dataset: Global Human Settlement Built-Up Surface Provider: Copernicus Emergency Management Service	Data type: Gridded Projection: World Mollweide Horizontal coverage: Global Horizontal resolution: 100 m Vertical Coverage: Surface Temporal coverage: 1975 to 2030 Temporal resolution: 5-year File format: TIFF
Particulate Matter 2.5 (SDG 11.6.2)	Dataset: CAMS Global Atmospheric Composition Forecasts Provider: Copernicus Atmosphere Monitoring Service	Data type: Gridded Horizontal coverage: Global Horizontal resolution: 0.4°x0.4° Vertical coverage: Total column Vertical resolution: Single level Temporal coverage: 2015 to present Temporal resolution: Hourly File format: NetCDF-3
Surface Water Chlorophyll (SDG 14.1.1)	Dataset: Mediterranean Sea Biogeochemistry Reanalysis Provider: Copernicus Marine Environment Monitoring Service	Data type: Gridded Horizontal coverage: Mediterranean Sea Horizontal resolution: 4 km Vertical coverage: 125 depth levels Temporal coverage: July 2021 to present Temporal resolution: Daily, Monthly, Yearly Projection: WGS 1984 File format: NetCDF-4
Sea Water pH (SDG 14.3.1)	Dataset: Black Sea Biogeochemistry Reanalysis Provider: Copernicus Marine Environment Monitoring Service	Data type: Gridded Horizontal coverage: Black Sea Horizontal resolution: 3 km Vertical coverage: 31 depth levels Temporal coverage: Jan 2021 to present Temporal resolution: Daily, Monthly Projection: WGS 1984 File format: NetCDF-4
Solar Photovoltaic Power (SDG	Dataset: Climate and Energy Indicators for Europe from 2005 to 2100	Data type: Gridded Horizontal coverage: Europe

7.2.1)	Provider: Copernicus Climate Change Service	Horizontal resolution: 0.25° x 0.25° Vertical coverage: 0 to 100 m Vertical resolution: Single level Temporal coverage: 2005 to 2100 Temporal resolution: 3-hourly, daily File format: NetCDF
Suitability for Aedes Albopictus (SDG 3.3.3)	Dataset: Climatic Suitability for the Presence and Seasonal Activity of Aedes Albopictus Provider: Copernicus Climate Change Service	Data type: Gridded Projection: WGS 1984 Horizontal coverage: Europe Horizontal resolution: 0.1° x 0.1° Vertical coverage: Surface Temporal coverage: 1986-2085 Temporal resolution: Yearly File format: NetCDF
Abundance of Atlantic Salmon (SDG 14.4.1)	Dataset: Fish Abundance and Catch Data for Northwest European Shelf Provider: Copernicus Climate Change Service	Data type: Gridded Horizontal coverage: Northwest European Shelf Horizontal resolution: 0.5° x 0.5° Vertical coverage: Full water column Vertical resolution: Single level Temporal coverage: 2006 uto 2050 Temporal resolution: Yearly File format: NetCDF-4
Atmospheric Carbon Dioxide (SDG 9.4.1)	Dataset: CAMS Global Greenhouse Gas Reanalysis Provider: Copernicus Atmosphere Monitoring Service	Data type: Gridded Horizontal coverage: Global Horizontal resolution: 0.75°x0.75° Vertical coverage: Total column Vertical resolution: Single level Temporal coverage: 2003 to 2020 Temporal resolution: 3-hourly File format: NetCDF
Atmospheric Methane (SDG 13.2.2)	Dataset: CAMS Global Greenhouse Gas Reanalysis Provider: Copernicus Atmosphere Monitoring Service	Data type: Gridded Horizontal coverage: Global Horizontal resolution: 0.75°x0.75° Vertical coverage: Total column Vertical resolution: Single level Temporal coverage: 2003 to 2020 Temporal resolution: 3-hourly File format: NetCDF
Forest Cover (SDG 15.1.1)	Dataset: Global Land Cover Provider: Copernicus Land Monitoring Service	Data type: Gridded Thematic classes: 23 Horizontal coverage: Global Horizontal resolution: 100 m Temporal coverage: 2015-2019

		Temporal resolution: Yearly Projection: WGS 1984 File format: GeoTIFF
Water Ecosystem (SDG 6.6.1)	Dataset: Global Land Cover Provider: Copernicus Land Monitoring Service	Data type: Gridded Thematic classes: 23 Horizontal coverage: Global Horizontal resolution: 100 m Temporal coverage: 2015-2019 Temporal resolution: Yearly Projection: WGS 1984 File format: GeoTIFF
Riparian Grassland (SDG 15.1.2)	Dataset: RZ Land Cover/Land Use Provider: Copernicus Land Monitoring Service	Data type: Vector Thematic classes: 55 Horizontal coverage: Europe Horizontal resolution: 0.5 ha MMU Temporal coverage: 2010-2013, 2017-2020 Reference years: 2012, 2018 Projection: ETRS 1989 LAEA File format: Shapefile

Apart from the Copernicus data, country or area-specific shapefiles from the Esri Living Atlas have been used as the topographic base (symbol component) while creating the image maps. Similarly, Esri World Imagery has been used as the base map (image component) for the compilation of all the image maps. Some statistical datasets from the UN SDG database have also been employed to graphically visualize the SDG indicators in the posters.

Used Software

ArcGIS Pro (v 3.1) was used as the primary software for the processing and analysis of the dataset. The design and compilation of all the image maps were fully performed in ArcGIS Pro environment. For more complex and sophisticated design of large maps and map posters, as well as for the customized logo design, Adobe Illustrator (v 24.2) was employed. The charts and graphs used in the posters were created utilizing the web-based platform of Flourish and Microsoft Excel. The image maps were published as Web Map Service in the ArcGIS server of the University of Salzburg and were shared using the platform of ArcGIS StoryMaps (v 11.1). For the purpose of animations, ArcGIS Pro was primarily used to create and export the map frames while the subsequent adjustments of display properties were facilitated through the use of Microsoft PowerPoint.

Processing Workflow

The workflow for the thesis begins with the definition of cartographic project. During this phase, project specification and objective delineation were performed through the consultation with thesis supervisor. The subsequent stage involved conducting research, whereby a comprehensive examination of the pertinent literature and contemporary research was undertaken. The research facilitated the identification and selection of 15 most relevant SDG topics that can be best addressed with earth observation and geospatial datasets out of 17 goals, 169 targets and 232 indicators. During the research phase, all potential sources of data were reviewed which led to the selection of the most suitable datasets from the repository of Copernicus Services to best visualize the selected SDGs. In addition to this, the analysis of various image map types and subsequently, the selection of most suitable prototype for data visualization was also performed. The next phase was processing and analysis which primarily focused on multidimensional analysis of Copernicus data facilitated by ArcGIS Pro. This resulted in the creation of 15 different image maps which were further transformed and visualized into five sets of different cartographic information products. Figure 7 illustrates the detailed processing workflow of the research.

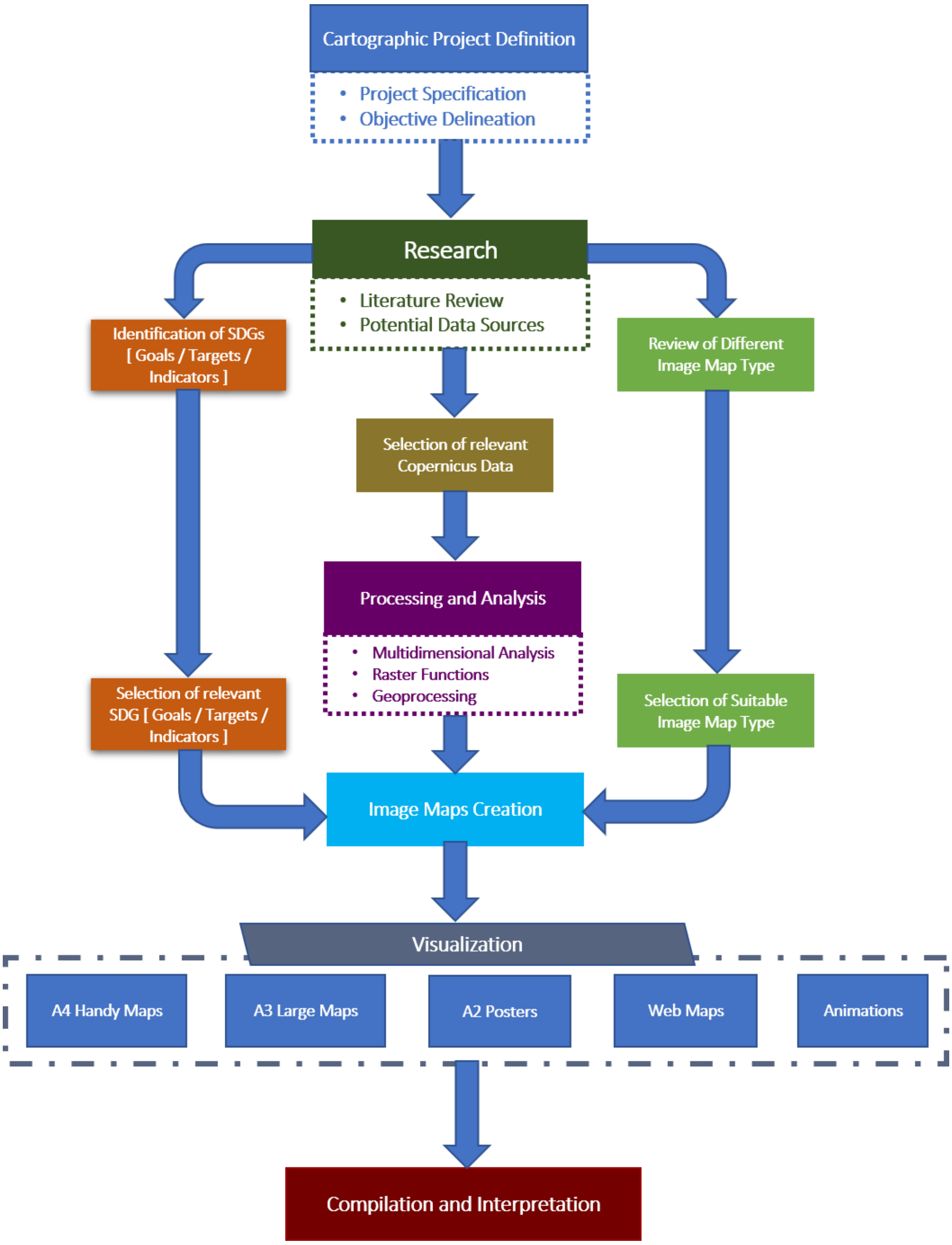


Figure 7 Processing Workflow

4 IMAGE MAP DESIGN

The research is based on the primary objective of designing and compiling a set of image maps that depict the selected SDG topics using the data from Copernicus project. In order to realize this goal as well as other sub-goals, different methods and procedures were adopted which are described thoroughly in the following chapters.

4.1 Cartographic Project Definition

This was the preliminary phase of the thesis that involved regular consultations with supervisor, brainstorming sessions, search for motivation and presentation of ideas. A careful definition of cartographic project is crucial as it leads to an unambiguous and streamlined flow of work procedure, thus helping to attain the set objectives in desired timeframe. This phase incorporated a number of sub activities as listed below:

Schema Definition

An initial plan was proposed to work on approximately 15 SDG topics that can be best visualized using Copernicus data. The innovative concept of image maps was put forward and suggested to utilize for mapping the selected topics.

Objective Delineation

The main goal of the thesis was specified as "to design and compile a set of a set of image maps from the data of the Copernicus project and thereby demonstrate the applicability of satellite data to support solutions to the selected Sustainable Development Goals (SDGs)".

Project Specification

Project specification deals with defining the type of data, source, resolution, format, scale, projection, type of image map, its symbol and image components, their data source, etc. Since varying topics ware mapped for each goal, no single universal specification can be applied to all the mapped topics.

Schedule Design

A work schedule was created by specifying the major milestones for the thesis along with their corresponding time frames. The schedule was planned in such a way that ample time was allocated for literature review, data collection, processing, analysis, design, compilation and documentation.

By the end of the project definition phase, the following 15 SDG goals, targets and indicators were selected as the most relevant topics to be mapped by the utilization of Copernicus data.

SDG 2.4.1	SDG 9.4.1	SDG 14.3.1
SDG 3.3.3	SDG 11.6.2	SDG 14.4.1
SDG 6.3.2	SDG 11.7.1	SDG 15.1.1
SDG 6.6.1	SDG 13.2.2	SDG 15.1.2
SDG 7.2.1	SDG 14.1.1	SDG 15.3.1

4.2 Data Collection

The datasets used for the study can be broadly categorized into three classes:

- Copernicus data
- GIS data
- Statistical data

The most fundamental data were collected from the repository of Copernicus that comprised of five essential Copernicus services. These datasets served as the main thematic content for the creation of image maps. Other supplementary data such as base imagery and GIS shapefiles were acquired from the Living Atlas of Esri while the statistical datasets were obtained from the UN SDG Database. Figure 8 provides a brief overview of the datasets used for mapping the SDGs with their corresponding sources.

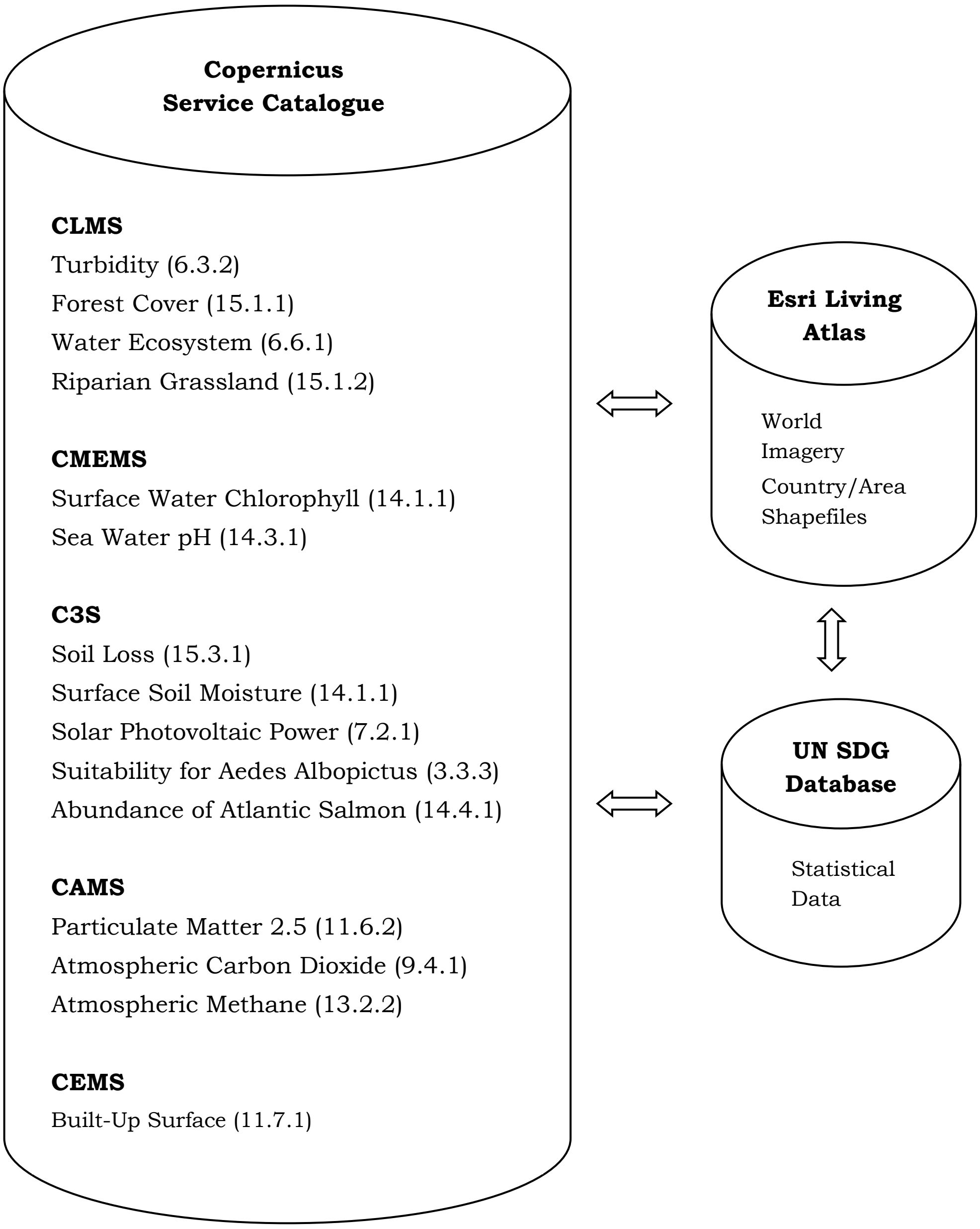


Figure 8 Data Sources

4.3 Study Area Delineation

Different study areas have been considered for the individual topics depending on:

- data availability
- resolution of data
- suitability to map that particular area

The study area therefore ranges from a city to state level, from country to whole continent and in some cases from basins to seas. Since SDGs are global goals, all the regions of the world have been tried to incorporate in the study far as practicable. Table 2 provides a list of study area that were selected for mapping the individual topics.

Table 2 Study area for the selected SDGs

Title	**SDG**	**Study Area**
Soil Loss	15.3.1	Italy
Surface Soil Moisture	2.4.1	Australia
Turbidity	6.3.2	Lake Turkana, Kenya
Built-Up Surface	11.7.1	Vienna, Austria
Particulate Matter 2.5	11.6.2	China
Surface Water Chlorophyll	14.1.1	Mediterranean Sea
Sea Water pH	14.3.1	Black Sea
Solar Photovoltaic Power	7.2.1	Europe
Suitability for Aedes Albopictus	3.3.3	Europe
Abundance of Atlantic Salmon	14.4.1	Northwest European Shelf
Atmospheric Carbon Dioxide	9.4.1	World Continents
Atmospheric Methane	13.2.2	World Continents
Forest Cover	15.1.1	Venezuela
Water Ecosystem	6.6.1	Minnesota, USA
Riparian Grassland	15.1.2	Rhine Basin

4.4 Processing and Analysis

The data acquired from the Copernicus services are mostly multidimensional rasters in NetCDF file format. Multidimensional rasters represent the data captured at multiple times, depths or heights and are usually very large and complex (Esri, 2023). Therefore, some pre-processing and refinement of the data was necessary in order to make it simple, manageable and fit for visualization.

ArcGIS Pro allows the users the select the appropriate variable(s) from a number of variables contained in multidimensional raster. In addition, the user also has options to select the standard time of when the analysis is to be done, and in some cases the standard depth (or height). For instance, while visualizing surface water chlorophyll for Mediterranean Sea using the biogeochemistry reanalysis dataset from CMEMS, the variable “chl” was selected for the standard time 2022-12-01, 00:00:00 and standard depth -5.46 m as illustrated in Figure 9.

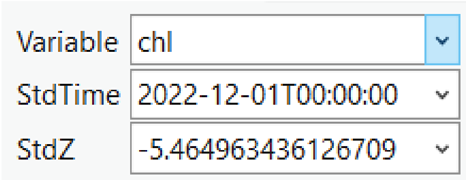


Figure 9 Selection of Variable, Time and Depth

4.4.1 Multidimensional Analysis

Multidimensional analysis of Copernicus data was performed in ArcGIS Pro which allowed for the analysis and interpretation of multiple dimensions of data that are systematically arranged following a hierarchical structure. This facilitated to examine the data from multiple perspectives and helped to identify meaningful trends, patterns and outliers that exist in the dataset. Various multidimensional functions supported by ArcGIS Pro such as aggregate, subset, trend, anomaly, summary statistics, temporal profile, etc were applied for the Copernicus data.

Aggregate

The aggregate tool was used to combine an existing multidimensional raster variable along a particular dimension and generate a new multidimensional raster that contain the desired slices. A number of aggregation functions are supported in ArcGIS Pro including mean, median, maximum, minimum, sum, standard deviation, etc. For example, the data for solar photovoltaic power, which was obtained as daily observations, was aggregated into monthly averages to create 12 time slices per year using the Interval Keyword set to Monthly. The application of aggregate function in multidimensional raster is illustrated in Figure 10.

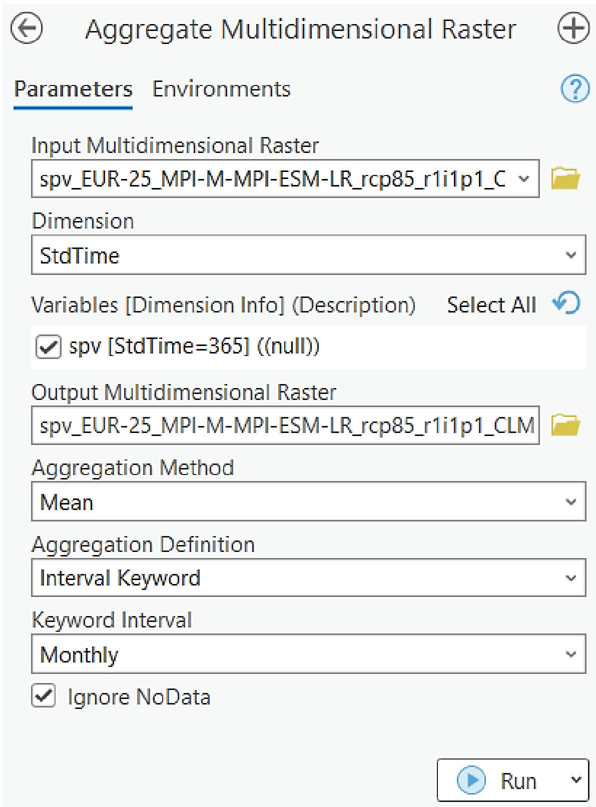


Figure 10 Monthly Aggregation of Solar Photovoltaic Power

Subset

The subset tool facilitated the creation of a new multidimensional raster as a subset of variables from an existing multidimensional raster. This tool was used primarily to extract the data for only a particular time instant or range of time from a set of all available observations. For instance, the data for suitability of Aedes Albopictus obtained from C3S contained yearly observations from 1986 projected up to 2085. This data can be extracted only for the range of year 2011 to 2020 by utilizing the subset function. The application of subset function in multidimensional analysis is illustrated in Figure 11.

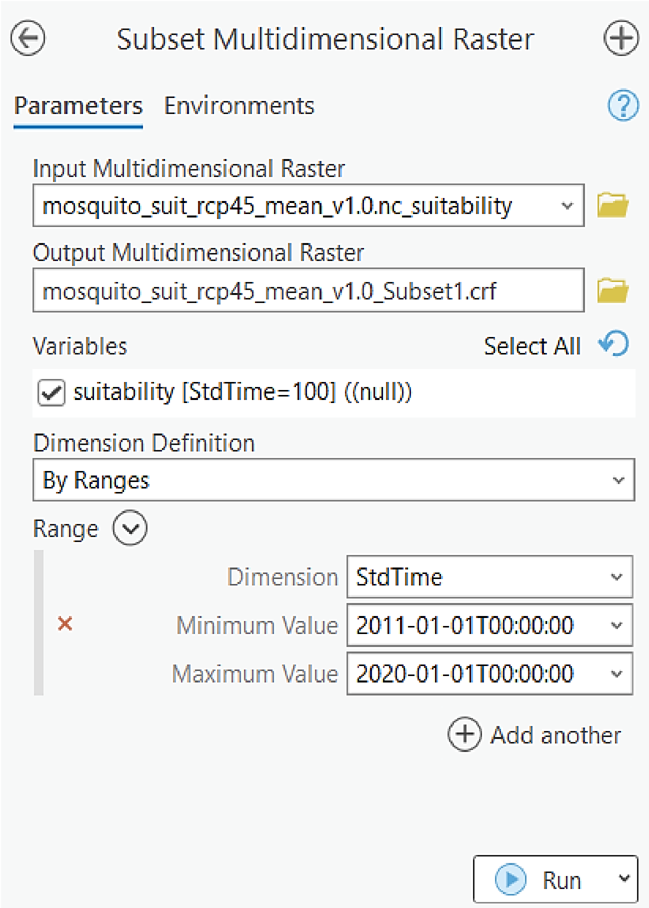


Figure 11 Subset of Suitability Dataset

Trend

The trend tool was used to analyse the trend of the variable(s) over a defined period of time. This tool considers a time range and tries to fit a trend line or curve for each pixel in the dataset. The utilization of this tool facilitated the observation and analysis of where and how the variables have changed with respect to time. ArcGIS Pro supports a variety of trend analyses of multidimensional rasters including linear, harmonic and polynomial trend types. Trend tool applied for instance, to the aforementioned dataset of suitability for Aedes Albopictus considering a period from 2011 to 2020 and linear trend type generated a trend pattern as illustrated in Figure 12.

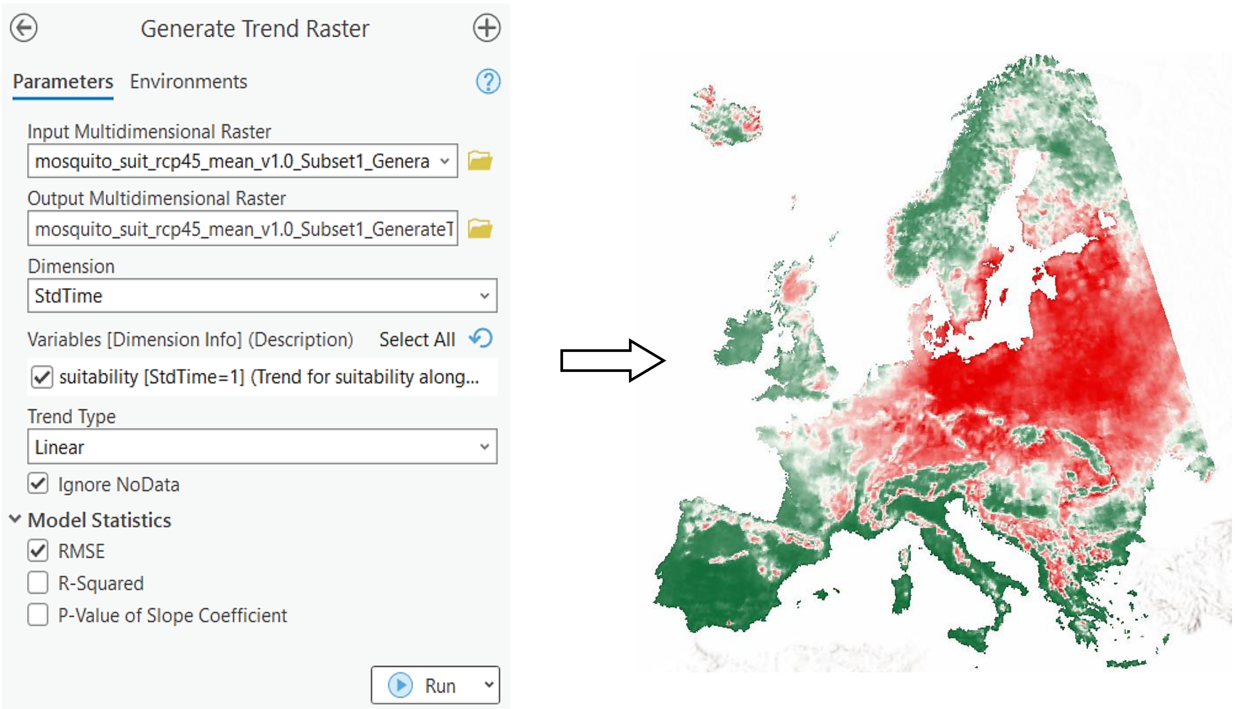


Figure 12 Trend Analysis of Suitability [Red: Increasing, White: Neutral, Green: Decreasing]

Temporal Profile

Temporal profile tool was applied to Copernicus data in order to study the changes in variables occurring with respect to time. This tool offers somewhat similar functionality as the trend tool, but provides graphical visualization of data rather than directly manipulating the pixels. It is particularly suitable for the visualizing the variables of multidimensional raster as a time series, whereby the different values of variables are plotted against time axis. Figure 13 visualizes the temporal profile of Suitability data considering the spatial extent of Iceland for the year 2011 – 2020.

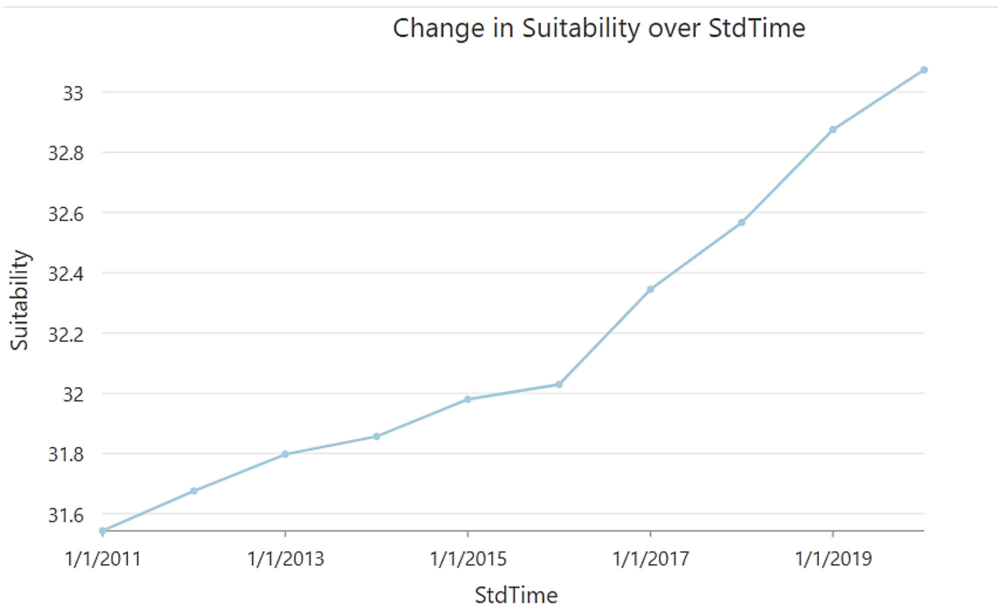


Figure 13 Temporal Profile of Suitability Dataset for Iceland

Summary Statistics

The utilization of summary statistics tool in ArcGIS Pro facilitated the calculation of pixel statistics in Copernicus data. ArcGIS Pro supports a number of statistical functions for the analysis of multidimensional rasters including minimum, maximum, mean, median, standard deviation, minority, majority, range, sum and variety. These tools are quick, intuitive and very convenient for meaningful statistical analysis. Figure 14 depicts a case where the “maximum” function was used to calculate the maximum value of pixels in the Suitability dataset across all time slices.

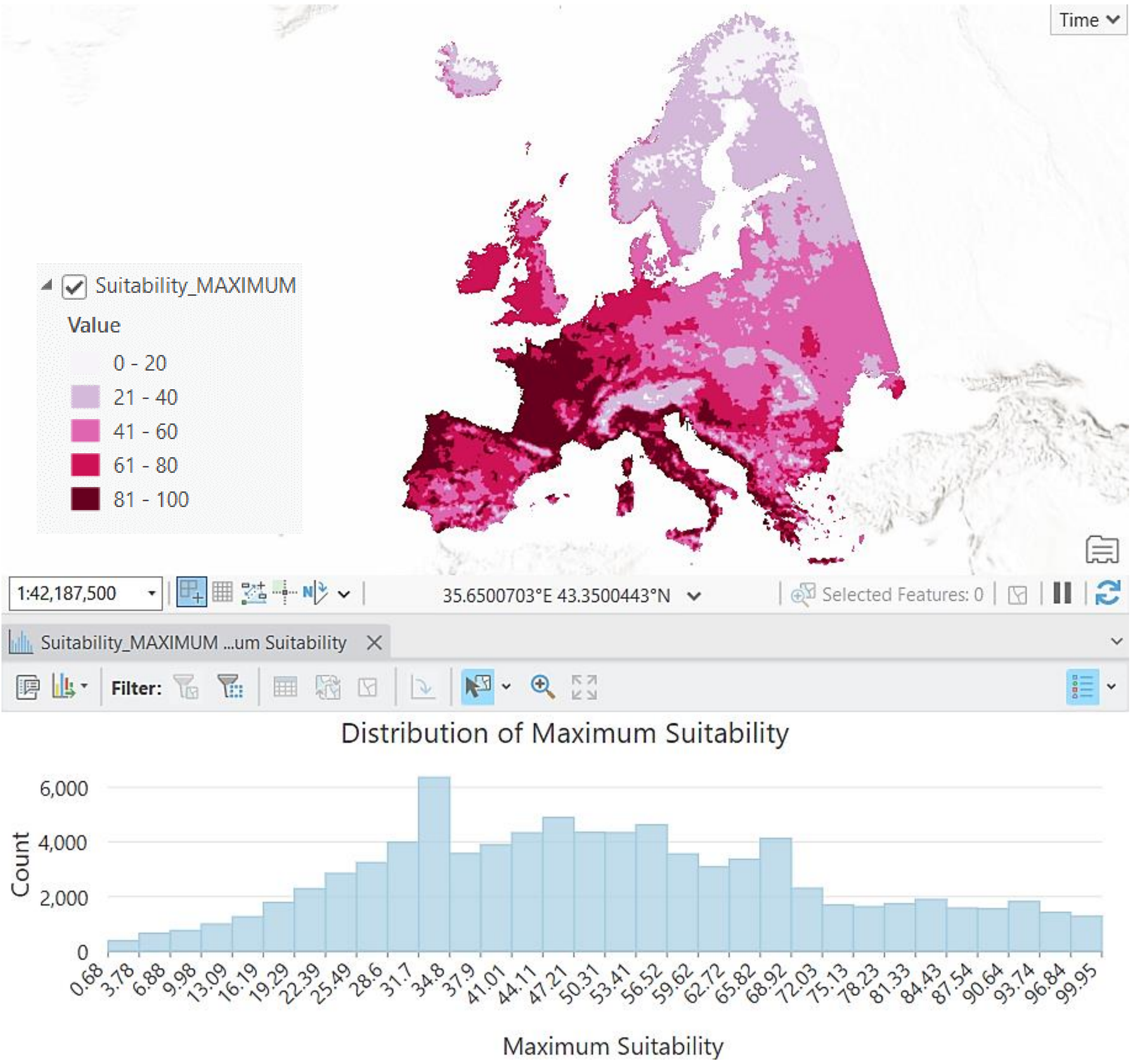


Figure 14 Maximum Suitability Across All Time Slices (2011 – 2020)

Anomaly

Anomaly function was employed to calculate the deviation of the variables in Copernicus data from their mean value. This tool computes the anomaly for each slice in the existing raster and generates a new multidimensional raster. The analysis of anomaly facilitates the detection of outliers or unusual values in the dataset. Figure 15 depicts a case where the anomaly function was used to calculate the deviation of pixels from their mean values in the Suitability dataset across all time slices.

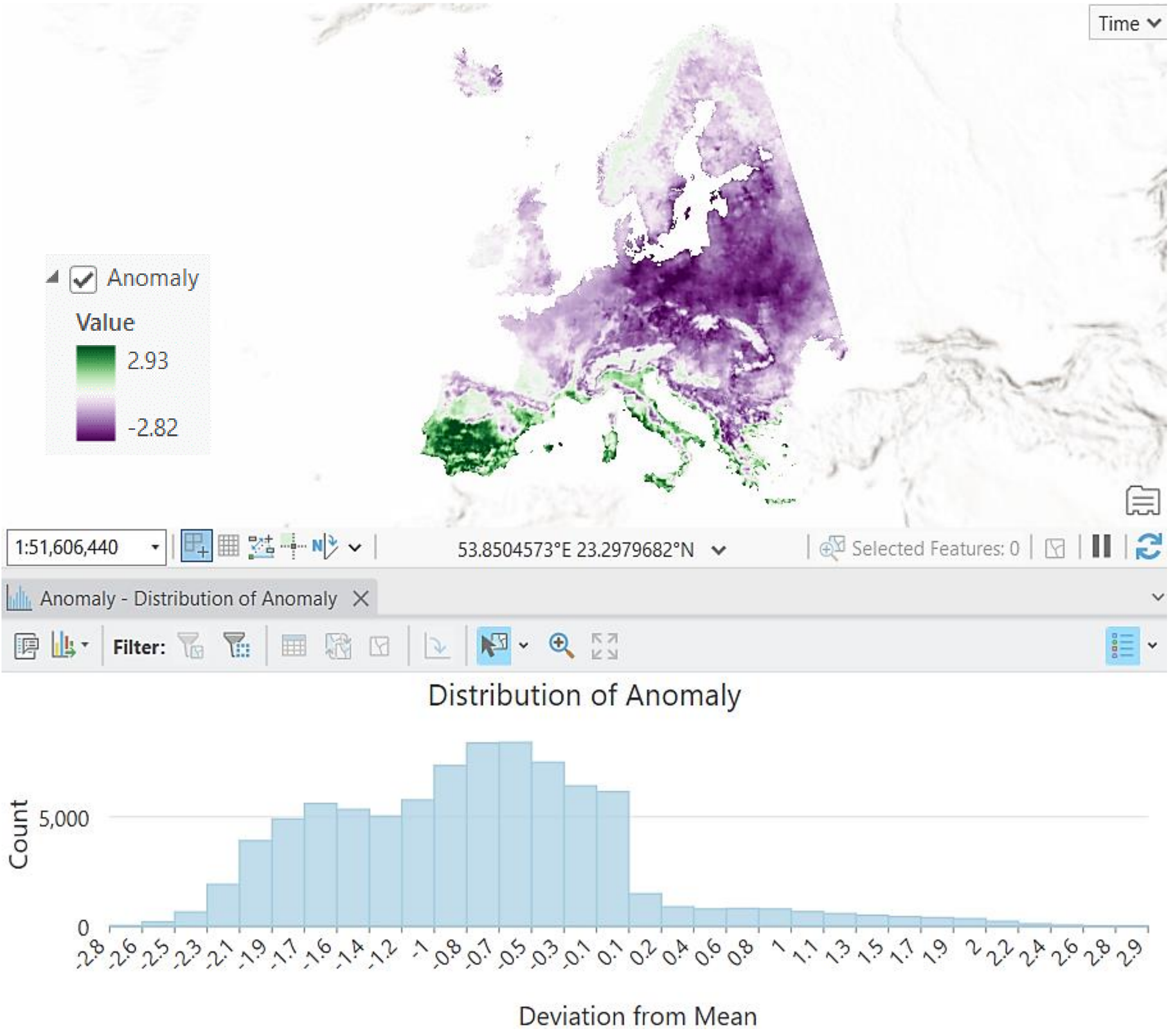


Figure 15 Suitability Anomaly

4.4.2 Data Enhancement

Standardization

Some of the Copernicus data comprised of the values that were not in the standard units of measurement and therefore, the standardization of such data was deemed necessary. For instance, the values for Particulate Matter 2.5 dataset available from CAMS were in of kg/m³, whereas the actual unit of measurement of the data is µg/m³. On one hand, such data are complex with a lot of decimal digits making it difficult for the audience to read and understand them, while on the other hand, the values do not adhere to the widely accepted units of measurement. Therefore, raster calculator tool was used to convert the values of such datasets into their standard units. Figure 16 illustrates the application of raster calculator function for converting the values of Particulate Matter 2.5 from kg/m³ to µg/m³.

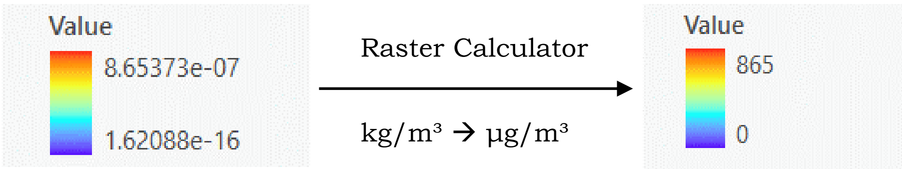


Figure 16 Use of Raster Calculator

Converting Fussy Values to Classified values

Most of the Copernicus data come with the default multipart colour scheme with a fuzzy legend where the data values are stretched along a particular colour ramp. Such display of values are not appropriate for visualization as they create confusion to the audience in identifying exactly where a particular value falls. In order to overcome such issue, the data values were classified into a defined interval of classes. The basis for defining the class intervals was the consultation with subject matter experts as well as the review of pertinent literature and information sources. For instance, lake water with turbidity up to 10 NTU is generally acceptable, up to 50 NTU is considered moderately turbid while greater than 50 NTU is harmful for aquatic plants and animals (DataStream, 2021). The of conversion values from a fuzzy legend to a well categorized legend is illustrated in Figure 17.

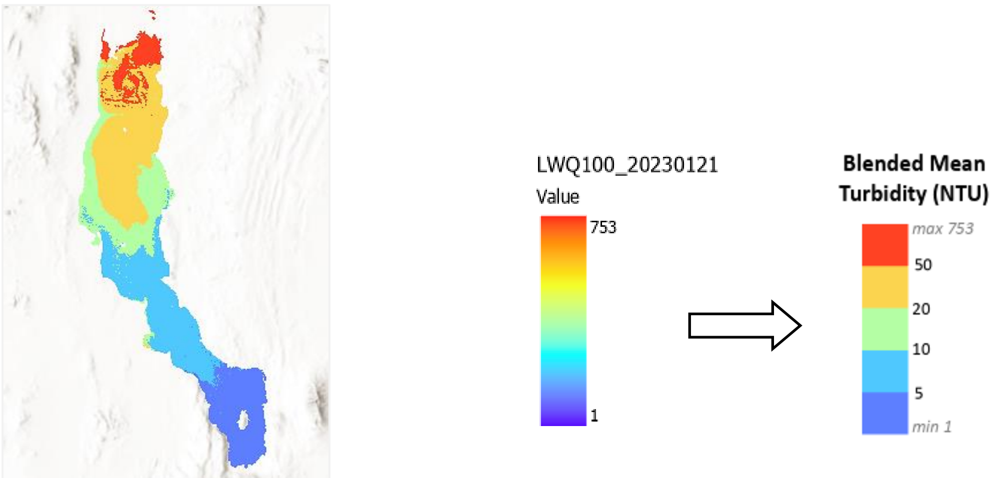


Figure 17 Conversion from Fuzzy Legend to Categorized Legend

4.5 Image Map Specifications

Image Map Type and Components

The most appropriate type of image map for depicting the selected SDG topics were carefully decided and subsequently, their image and symbol components. For the cases pertaining to this research, thematic image maps were best suited for visualizing the selected phenomena. Two different types of thematic image maps were implemented depending on the nature and availability of data. In most of the cases, double thematic image maps were adopted while back/rear thematic image map also deemed applicable in a few cases. Table 3 summarizes the type of image maps used for mapping the selected SDGs along with their corresponding image and symbol components.

Table 3 Image Map type and components

Title	Image Map Type	Components
Soil Loss (SDG 15.3.1)	Double Thematic	Image Component Thematic Content: Soil Loss Raster Topographic Base: Esri World Imagery
		Symbol Component Labeling, Country boundary, Cities
Surface Soil Moisture (SDG 2.4.1)	Double Thematic	Image Component Thematic Content: Soil Moisture Raster Topographic Base: Esri World Imagery
		Symbol Component Labeling, Country boundary, Cities
Turbidity (SDG 6.3.2)	Double Thematic	Image Component Thematic Content: Turbidity Raster Topographic Base: Esri World Imagery
		Symbol Component Labeling, Country boundary
Built-Up Surface (SDG 11.7.1)	Double Thematic	Image Component Thematic Content: Built-Up Surface Raster Topographic Base: Esri World Imagery
		Symbol Component Labeling, State boundary, River
Particulate Matter 2.5 (SDG 11.6.2)	Double Thematic	Image Component Thematic Content: PM 2.5 Raster Topographic Base: Esri World Imagery
		Symbol Component Labeling, Country boundary, Cities
Surface Water Chlorophyll (SDG 14.1.1)	Double Thematic	Image Component Thematic Content: Surface Chlorophyll Raster Topographic Base: Esri World Imagery
		Symbol Component Labeling, Continent boundary
Sea Water pH (SDG 14.3.1)	Double Thematic	Image Component Thematic Content: Sea Water pH (7.5m depth) Topographic Base: Esri World Imagery
		Symbol Component Labeling, Country boundary

Solar Photovoltaic Power (SDG 7.2.1)	Double Thematic	Image Component Thematic Content: Solar Photovoltaic Power Topographic Base: Esri World Imagery
		Symbol Component Labeling, Continent boundary
Suitability for Aedes Albopictus (SDG 3.3.3)	Double Thematic	Image Component Thematic Content: Climatic Suitability for Aedes Albopictus Topographic Base: Esri World Imagery
		Symbol Component Labeling, Continent boundary
Abundance of Atlantic Salmon (SDG 14.4.1)	Double Thematic	Image Component Thematic Content: Abundance of Atlantic Salmon (Gridded) Topographic Base: Esri World Imagery
		Symbol Component Labeling, Country boundary
Atmospheric Carbon Dioxide (SDG 9.4.1)	Double Thematic	Image Component Thematic Content: Atmospheric CO2 Raster Topographic Base: Esri World Imagery
		Symbol Component Labeling
Atmospheric Methane (SDG 13.2.2)	Double Thematic	Image Component Thematic Content: Atmospheric CH4 Raster Topographic Base: Esri World Imagery
		Symbol Component Labeling
Forest Cover (SDG 15.1.1)	Back/Rear Thematic	Symbol Component Thematic Content: Forest Cover, Country boundary, Labeling
		Image Component Topographic Base: Esri World Imagery
Water Ecosystem (SDG 6.6.1)	Back/Rear Thematic	Symbol Component Thematic Content: Water bodies, State boundary, Labeling
		Image Component Topographic Base: Esri World Imagery
Riparian Grassland (SDG 15.1.2)	Back/Rear Thematic	Symbol Component Thematic Content: Riparian Grassland, River network, Labeling
		Image Component Topographic Base: Esri World Imagery

Map Scale and Projection

No uniform map scale or projection could be applied to all the cases in this research due to the heterogeneity in data and study area. Therefore, individual scale and projection systems were considered for each of the image maps depending on the size, location and spatial extent of their study area. Careful selection of scale and projection facilitated the mapping of SDGs topics in the study area more realistically as it helps to minimize the possible distortions that can occur in the shape and area. Table 4 summarizes the scale and projection system adopted for mapping the selected SDGs.

Table 4 Scale and Projection

Title	**Scale**	**Projection**
Soil Loss (SDG 15.3.1)	1:5,700,000	Albers Equal Area Conic
Surface Soil Moisture (SDG 2.4.1)	1:23,000,000	GDA 2020
Turbidity (SDG 6.3.2)	1:900,000	WGS 1984
Built-Up Surface (SDG 11.7.1)	1:160,000	Albers Equal Area Conic
Particulate Matter 2.5 (SDG 11.6.2)	1:25,000,000	South China Sea Lambert
Surface Water Chlorophyll (SDG 14.1.1)	1:16,500,000	WGS 1984
Sea Water pH (SDG 14.3.1)	1:7,500,000	WGS 1984 Web Mercator
Solar Photovoltaic Power (SDG 7.2.1)	1:21,000,000	Lambert Conformal Conic
Suitability for Aedes Albopictus (SDG 3.3.3)	1:20,000,000	Lambert Conformal Conic
Abundance of Atlantic Salmon (SDG 14.4.1)	1:17,000,000	WGS 1984
Atmospheric Carbon Dioxide (SDG 9.4.1)	1:138,500,000	WGS 1984
Atmospheric Methane (SDG 13.2.2)	1:138,500,000	WGS 1984
Forest Cover (SDG 15.1.1)	1:7,000,000	WGS 1984
Water Ecosystem (SDG 6.6.1)	1:3,850,000	NAD 1983
Riparian Grassland (SDG 15.1.2)	1:3,408,000	ETRS 1989 LAEA

Theme Selection

The theme for the image maps were selected in such a way they match exactly with the theme of the corresponding SDGs. This was realized by assigning the same colour to the background and layout elements of the image maps as the colour of the SDG icon. Various transparency options for colour were chosen depending on the relative importance of each background element. Applying the same colour scheme to the related objects or phenomena provides a sense of interconnection and helps the audience to better understand the mapped topic or phenomena. This also facilitates in systematic design and compilation of image maps as well as their derived products. Figure 18 illustrates an example whereby the theme of an image map that visualize the Particulate Pollution in China is matched with the theme of SDG 11: Sustainable Cities and Communities.

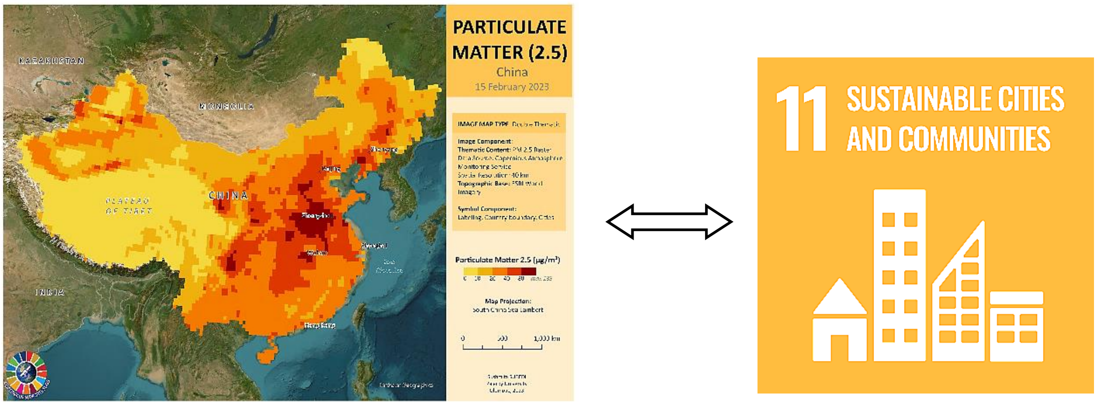


Figure 18 Theme Matching

Logo Design

A customized logo was designed to demonstrate the significant role of Copernicus in the context of Sustainable Development Goals. The logo incorporates simplified graphical themes representing both the Copernicus and SDGs, along with a text "Copernicus Supports SDGs". The logo is placed in a predefined position within the frames of all the image maps. It serves as a watermark and helps to promote the authenticity of all the image maps and their derived products. Figure 18 represents the logo designed for the purpose of this research.

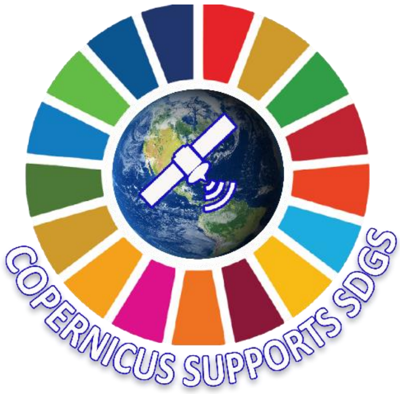
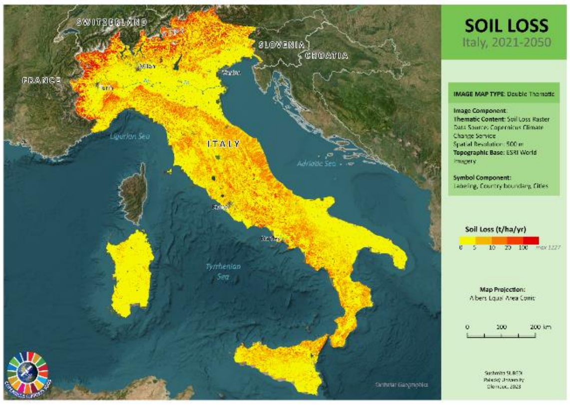


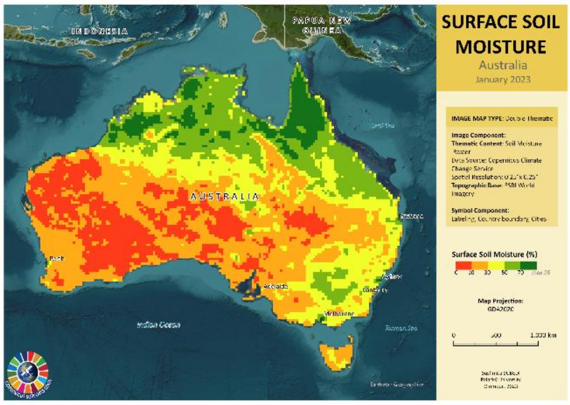
Figure 18 Customized Logo

4.6 Integration

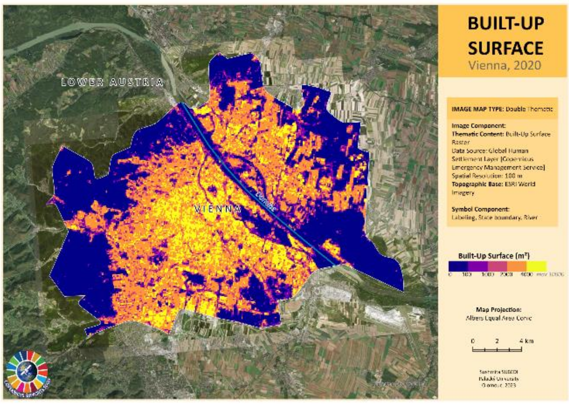
All the bits and pieces of the work were carefully integrated to design the final image maps. The image maps were created in A4 layout in free orientation: landscape or portrait depending on the extent of the mapped area. A balanced map layout was created in which the map body served as the most dominant component. The other layout elements were arranged in proper hierarchical order based on their relative significance. The transparency of the layers were adjusted appropriately such that the thematic content of the maps were not obscured by the base layer. A careful consideration of font type, colour and size was also done to facilitate the audience to read the map information without difficulties. Figure 19 (a – o) present the final looks of the image maps that were designed as preliminary outcomes of the thesis.


SOIL LOSS
Italy, 2021-2050
SWITZERLAND
SLOVENIA
CROATIA
FRANCE
ITALY

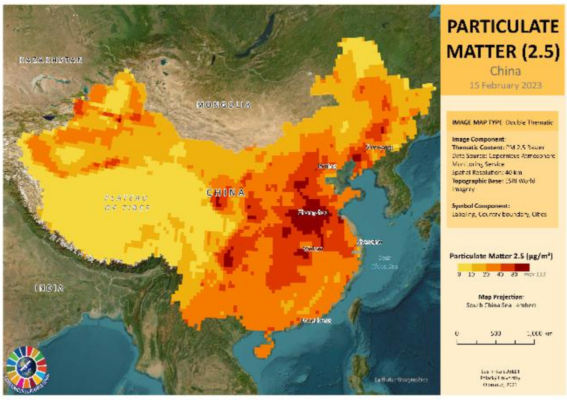
(a)


SURFACE SOIL MOISTURE
Australia
January 2023
INDONESIA
PAPUA NEW GUINEA
AUSTRALIA

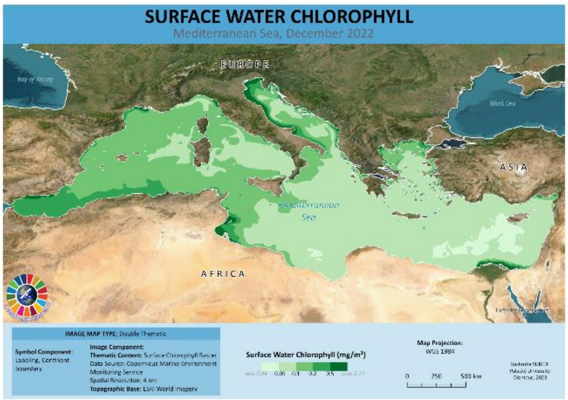
(b)


BUILT-UP SURFACE
Vienna, 2020
LOWER AUSTRIA
VIENNA

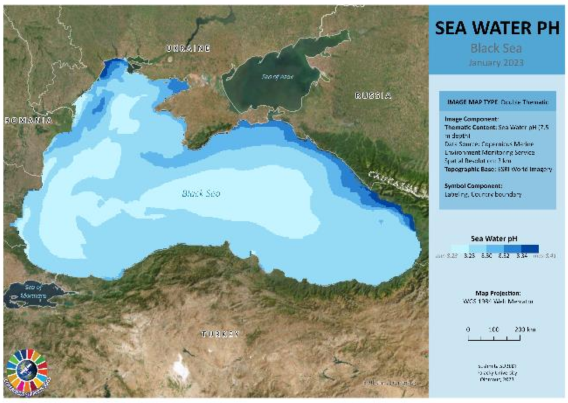
(c)


PARTICULATE MATTER (2.5)
China
15 February 2023
KAZAKHSTAN
MONGOLIA
CHINA
INDIA

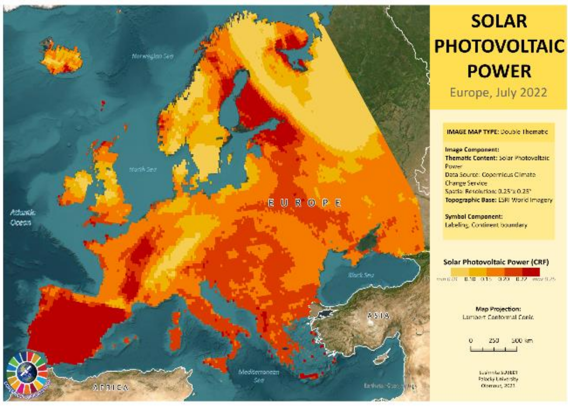
(d)


SURFACE WATER CHLOROPHYLL
Mediterranean Sea, December 2022
EUROPE
ASIA
AFRICA

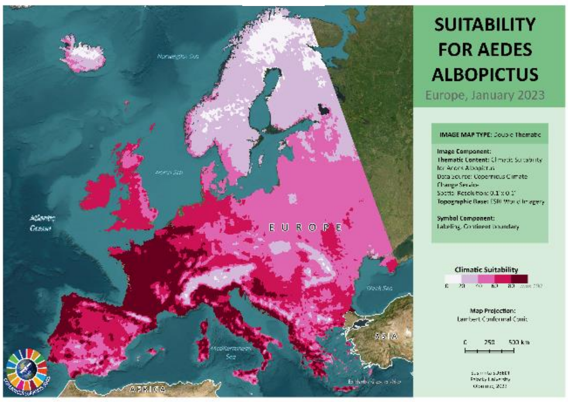
(e)


SEA WATER PH
Black Sea
January 2023
UKRAINE
RUSSIA
ROMANIA
TURKEY

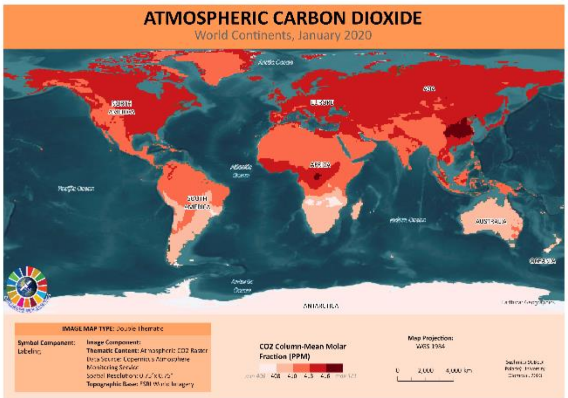
(f)


SOLAR PHOTOVOLTAIC POWER
Europe, July 2022
EUROPE

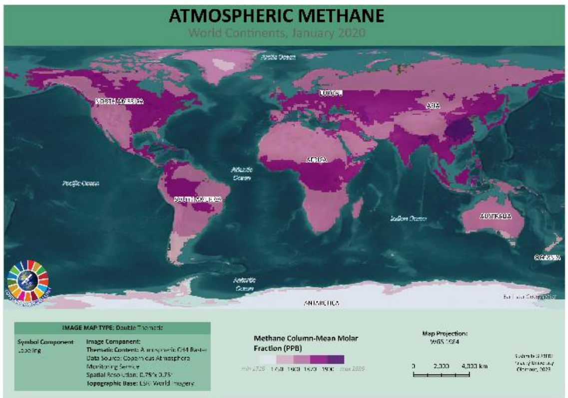
(g)


SUITABILITY FOR AEDES ALBOPICTUS
Europe, January 2023
EUROPE

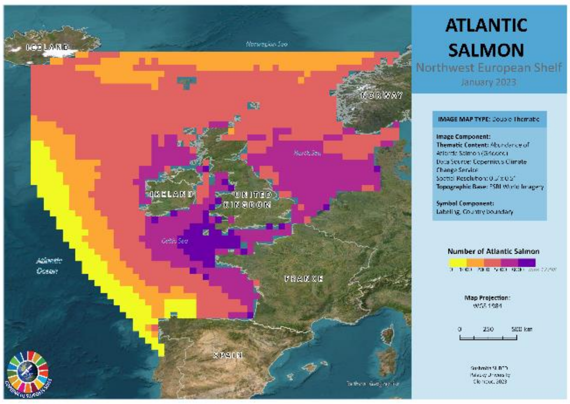
(h)



(i)



(j)



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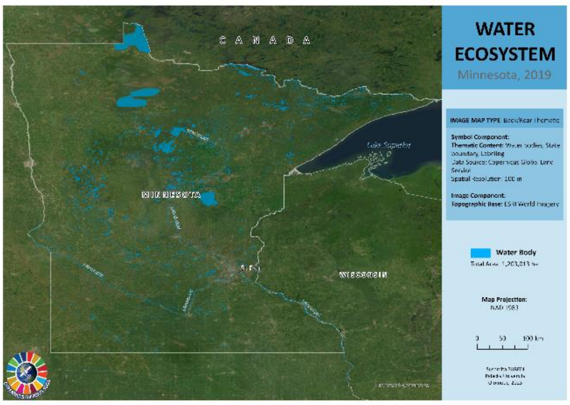
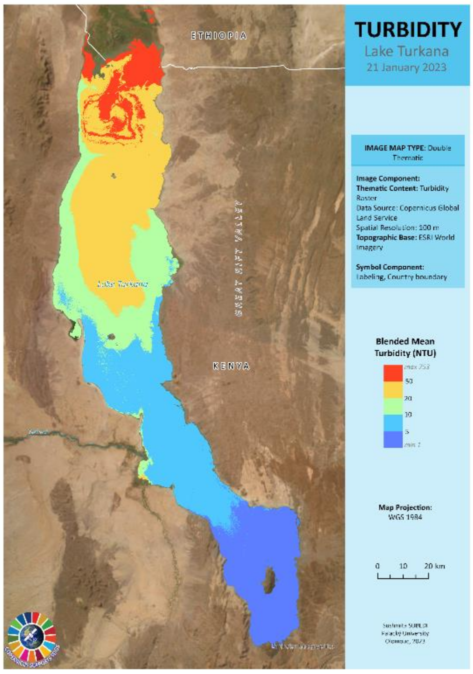
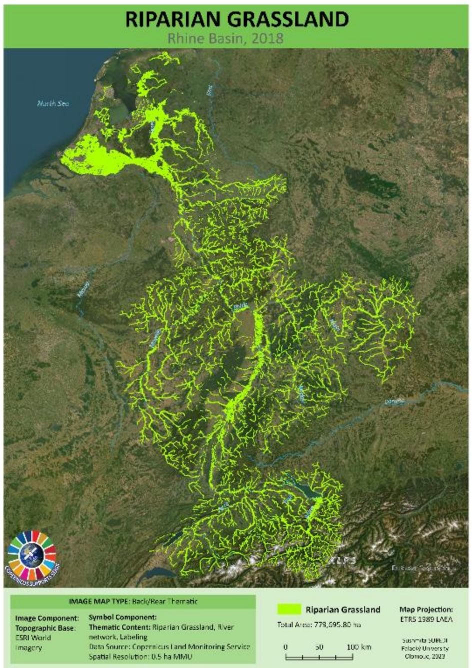
(l)



(m)



(n)



(o)

Figure 19 (a) – (o) Image Maps

4.7 Visualization

Proper visualization of the mapped phenomena serves to effectively communicate the intended message to the target audience. The research resulted in the creation of 15 image maps, each pertaining to the selected SDG topic. The image maps served as the preliminary outputs and facilitated the design of more sophisticated cartographic products for enhanced visualization. In this research, different groups of target audience were considered ranging from non-technical to highly skilled users of map.

4.7.1 Concept of Geovisualization

A unique concept of geovisualization was adopted to disseminate the outcomes of the thesis. The concept was carefully designed through the incorporation of five different formats of cartographic products: A4 handy maps, A3 large maps, A2 posters, web maps and animations. Each of these formats have their own specifics and limitations. The A4 handy map forms the core of the visualization concept and is included either wholly or partially in the visualization of all other formats of output. The main purpose of adhering to this concept of geovisualization is to make the users comprehend that there is no single or universal way to visualize a cartographic information. A multitude of different forms of visualizations can be implemented whereby each format can have a varying degree of information content and can be oriented towards a specific purpose or target audience. Figure 20 depicts the concept of geovisualization adopted for the purpose of visualizing the thesis outcomes.

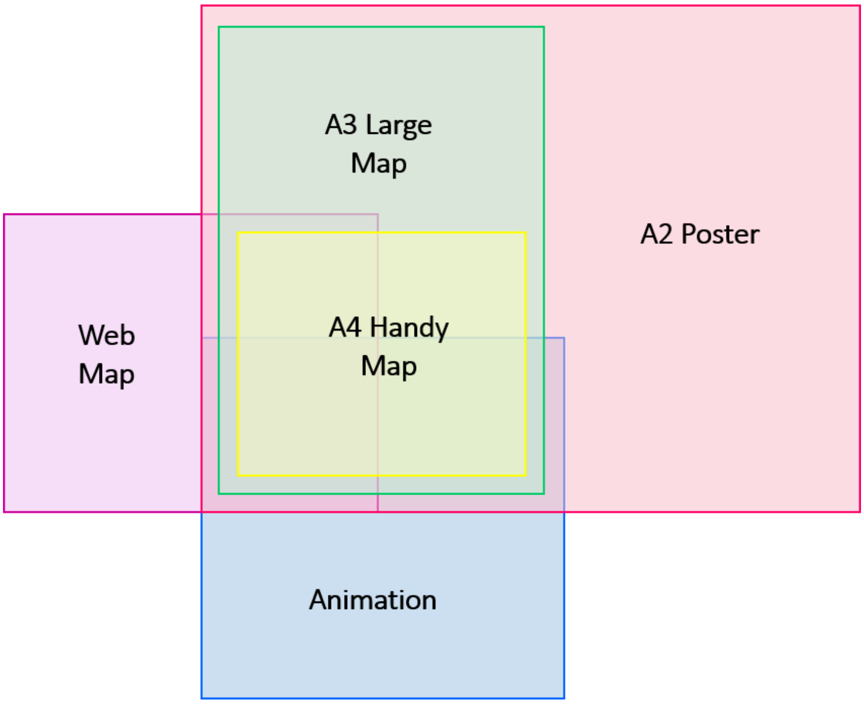


Figure 20 Concept of Geovisualization

A4 Handy Maps

These are the simplest form of output with fewer information content that serve as the foundation for the creation of all other forms of cartographic products. The contents of A4 handy maps include primarily the map frame and the basic layout elements such as the title, subtitle, legend, scale, map projection and imprint along with a customized logo. In addition to this, the information about the image map type, its symbol component and image component along with the corresponding data sources are also included. The purpose of this map is to provide a simple overview on how Copernicus data can be utilized to measure and monitor a particular SDG indicator. The target audience for these maps are the users with some basic knowledge of cartography and map reading. Figure 21 illustrates an example of A4 handy map.

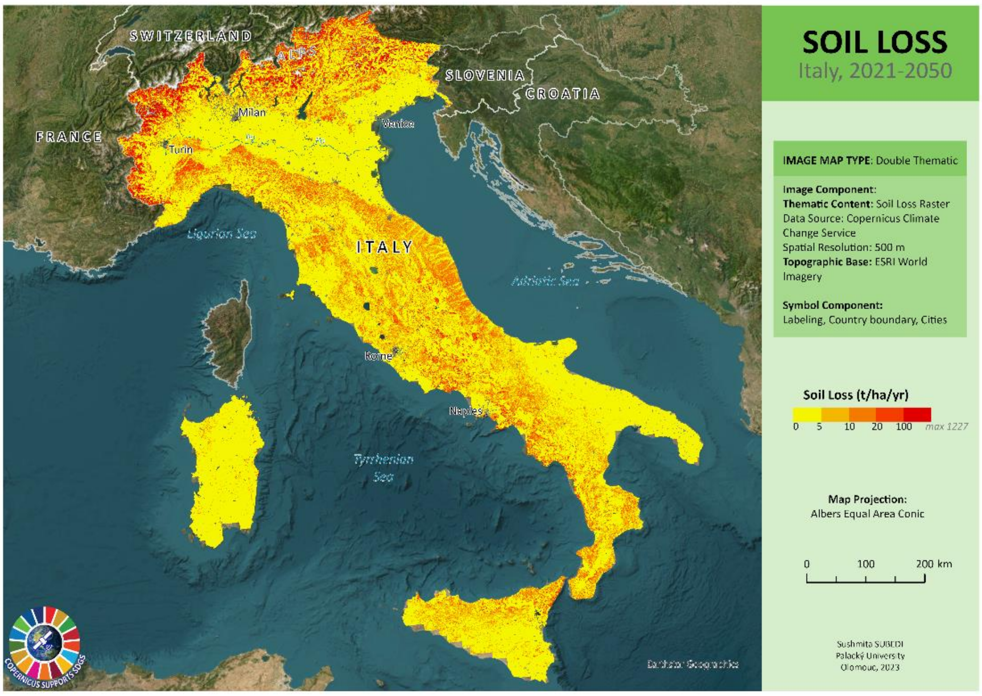


Figure 21 Example of A4 Handy Map

A3 Large Maps

These maps contain all the elements of A4 handy maps along with the addition of a substantial amount of information. A3 large maps provide a detailed information about the Copernicus data and its provider, type, coverage, resolution, format, etc. as well as the information about the relevance of the topic to the selected SDG goal, target and indicator. More importantly, these maps provide textual description about the selected topic and their significance along with a critical analysis and interpretation of the Copernicus data in visualizing the selected SDG. In addition, a location map is also included to provide a general overview of the study area. The target audience for this form of output are the users who are usually hungry for more information and are interested in critical evaluation of the topic addressed. Figure 22 illustrates an example of A3 large map.

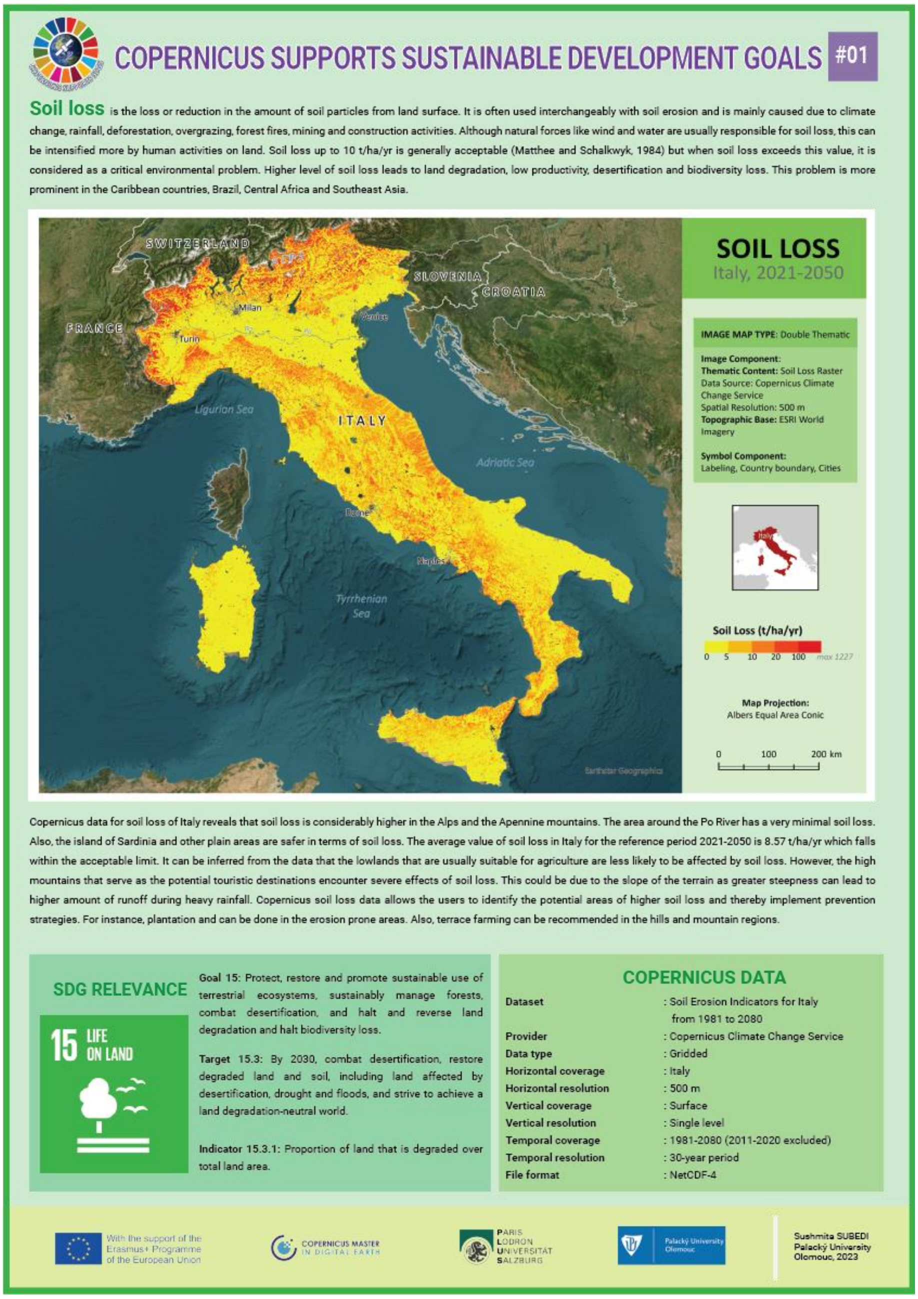


Figure 22 Example of A3 Large Map

A2 Posters

These are complex and more sophisticated formats of outputs that are carefully crafted through the integration of a multitude of design elements and information contents. A2 posters encompass all components featured in A3 large maps, along with other supplementary elements like charts, infographics, pictures, statistics, etc. The A2 posters are designed to be both comprehensive and visually appealing at the same. They help in effectively capturing the attention of the viewers and keep them engaging with the subject matter. The target audience for these maps are the users that seek for a complete and exhaustive information on how Copernicus data can be effectively applied in the SDG context. Figure 23 illustrates an example of A2 poster.

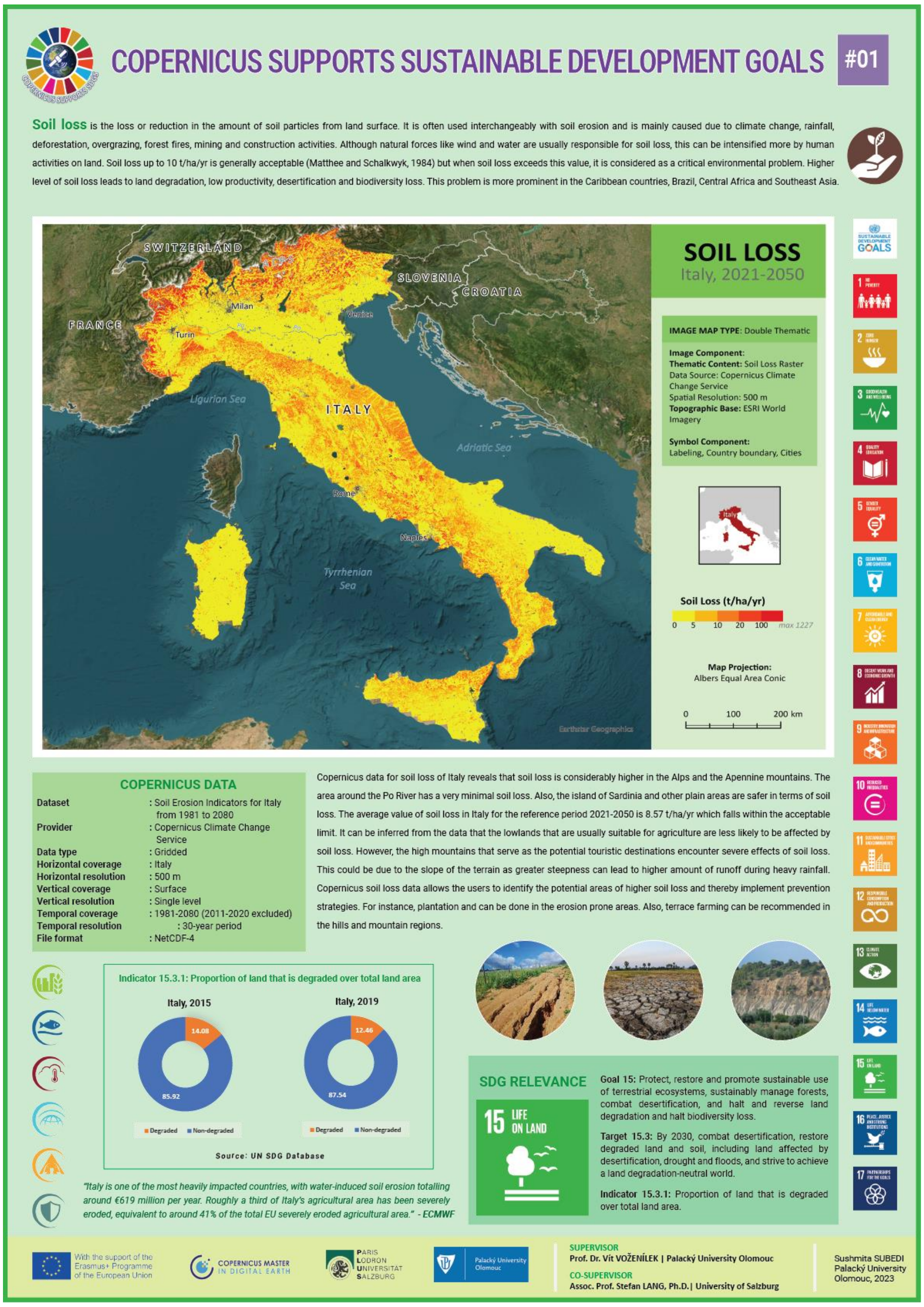


Figure 23 Example of A2 Poster

Web Maps

Web maps are designed with the purpose of adding interactivity to the cartographic products. They constitute of a part of the elements of A4 handy maps along with the addition of various interactive elements. Web mapping allows for the interaction and manipulation of each map element individually. The web maps pertaining the selected SDG topics were published in ArcGIS server and were disseminated through ArcGIS StoryMaps. They support a number of interactive functions including zoom, pan, navigation control, full screen, home button, current location, geocoding, overview map and pop-up windows. The intended audience for web maps are the users who seek to interact with various elements of the maps using desktop, tablet or mobile devices. Figure 24 illustrates an example of web map.

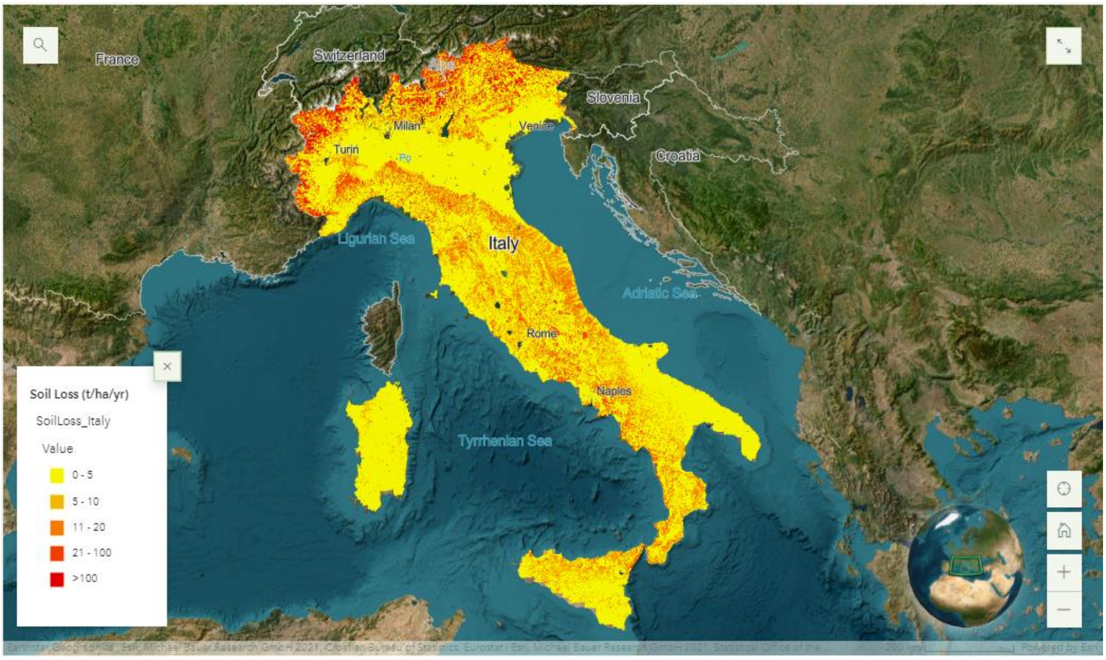


Figure 24 Example of Web Map

Map Animations

Map animations are created with the purpose of visualizing how the selected SDG topic or phenomena changes with time. It consists of a part of the elements of A4 handy maps along with the addition of dynamic map elements. Map animations produce a time series of the geographic phenomena under study and facilitate the users for change detection. A series of static map frames are played in sequence of predefined time spans to give the viewers an appearance of movement or change. Map animations support multimedia functions like pause, play, change speed, step forward/backward, etc. The target audience for map animations are the users who are interested in understanding and analysing the patterns and trends of the geographic phenomena over time. Figure 25 provides a conceptual understanding of map animation.

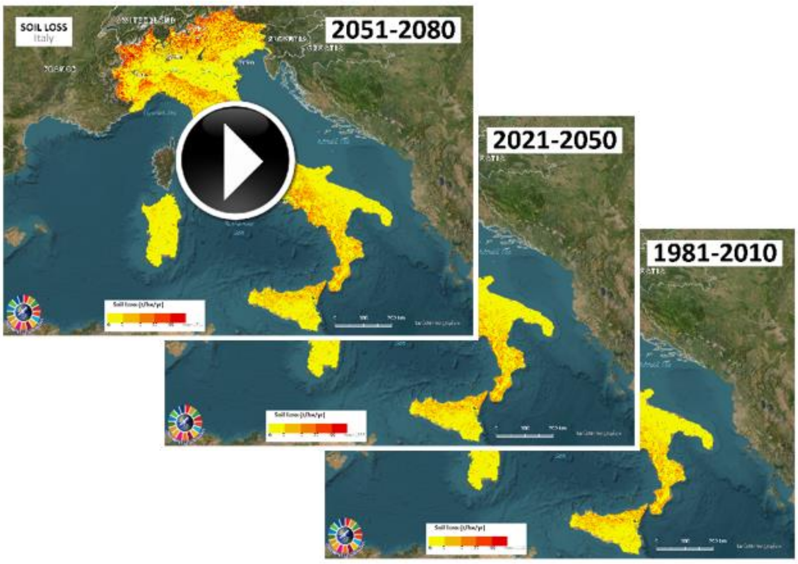


Figure 25 Map Animation

4.8 Compilation

Proper compilation of the created outputs was necessary to facilitate a systematic and organized archive of the thesis results. All the final cartographic products were compiled together into 5 different sets outputs, where each set contain 15 maps of the same category. The compilation for sets of A4 Handy Maps, A3 Large Maps and A2 Posters were facilitated with the addition of two more pages: a cover page and a table of contents page. The cover page provided an enclosure and general overview for the maps while the table of contents provided an exhaustive list of all the mapped topics. For the web maps and animations, compilation was done by utilizing the online platform of ArcGIS StoryMaps. All the web maps were embedded into a single StoryMap and dissimilated publicly through a shareable link of that StoryMap. The same mechanism was also applied in case of map animations for their compilation and dissimilation. All these sets of compiled products are provided separately in the chapter "Attachments" of this text. Overall, a total of 75 products i.e., 5 set of products with 15 maps per set were compiled from the results of this thesis as illustrated in table 5.

Table 5 Compilation of final products

Products	**Number per Set**	**Number of Set**
A4 Handy Maps	15	1
A3 Large Maps	15	1
A2 Posters	15	1
Web Maps	15	1
Map Animations	15	1
Total Products: 15 × 5 = 75		

5 RESULTS

In alignment with the objectives of the thesis, a set of 15 image maps (see subchapter 4.6) and subsequently other sets of higher-order derived products (see subchapter 4.7) were designed and compiled from the data of Copernicus project. These results facilitate in comprehending the significant role of Copernicus in managing and monitoring the selected Sustainable Development Goals. The following section interprets the individual results obtained from the application of Copernicus data in mapping each of the 15 selected SDG topics.

Soil Loss (SDG 15.3.1)

Copernicus data for soil loss of Italy reveals that soil loss is considerably higher in the Alps and the Apennine mountains (see Attachment 1). The area around the Po River has a very minimal soil loss. Also, the island of Sardinia and other plain areas are safer in terms of soil loss. The average value of soil loss in Italy for the reference period 2021-2050 is 8.57 t/ha/yr which falls within the acceptable limit. It can be inferred from the data that the lowlands that are usually suitable for agriculture are less likely to be affected by soil loss. However, the high mountains that serve as the potential touristic destinations encounter severe effects of soil loss. This could be due to the slope of the terrain as greater steepness can lead to higher amount of runoff during heavy rainfall. Copernicus soil loss data allows the users to identify the potential areas of higher soil loss and thereby implement prevention strategies.

Surface Soil Moisture (SDG 2.4.1)

Copernicus data for surface soil moisture of Australia reveals that the continent has an excessive moisture content in its northern extent while its central and western parts face deficit in soil moisture (see Attachment 1). This can be directly related to the topography of the continent as it is composed of deserts its center, plateau towards the west and basins in the north. The surface soil moisture seems to be moderate in the southeastern part of Australia creating a favourable condition for crop growth and productivity. The average value of surface soil moisture of Australia as of January 2023 is 48.5% which falls within the optimum level. The regions having optimum level of soil moisture as indicated by the Copernicus data should be utilized for agricultural purpose as it helps to ensure higher level of crop production.

Turbidity (SDG 6.3.2)

Copernicus data for lake water quality reveals that lake Turkana has clear and less turbid water in its southernmost spatial extent while the level of turbidity significantly increase as we move northwards (see Attachment 1). The lake is characterized with extreme values of turbidity towards the boundary between Kenya and Ethiopia. The average value of turbidity of lake Turkana on 21 January 2023 is 20.32 NTU, which implies that the lake water is moderately turbid. The Omo river wetland situated in the northern boundary of the lake seems to be the major contributor for its higher turbidity towards the north. This could be due to the heavy surface runoff from the catchment area of the river that flow into the lake. Based on Copernicus data, it can be said that the water in the northern part of the lake is totally unsuitable for utility and proper is necessary prior to the lake water consumption.

Built-Up Surface (SDG 11.7.1)

Copernicus data for built-up surface of Vienna reveals that the city is marked with the presence of a very dense urban fabric in its core central region (see Attachment 1). The built-up density decreases gradually as we move away from the center towards the city outskirts. The average value of built-up surface for Vienna city in the year 2020 is 1687.31 m^2, which can be considered quite an ideal value for human settlement. Some small patches visible in dark blue colour in the central part as well as along the periphery of Danube river indicate the presence of parks and other green spaces within the city. The parts of the city bordering to Lower Austria in the eastern and western extents have almost no built-ups due to the presence of forests, meadows, croplands and cemeteries. Copernicus built-up surface data confirms that the affluence of open public space in Vienna city makes it highly suitable for urban livelihood.

Particulate Matter 2.5 (SDG 11.6.2)

Copernicus data for particulate matter 2.5 reveals that the concentration of PM2.5 in China is very high in the urban areas (see Attachment 1). The cities of Zhengzhou and Wuhan have extreme level of particulate pollution whereas the Plateau of Tibet and the region near the Himalaya exhibit a very minimal level of particulate pollution. The average value of PM 2.5 concentration in China as of 15 February 2023 is 23.23 $\mu g/m^3$ which is outside the acceptable level as specified by WHO. Copernicus data helps to discover that human activities are primarily responsible for the particulate pollution in China as the cities with dense human settlements have much higher particle concentration than the natural regions that are untouched by human settlement. This could be due to higher industrial production, fuel combustion, vehicle exhaust and smoking in the cities. The data serves to monitor the air quality of China by identifying the core regions of higher particulate pollution.

Surface Water Chlorophyll (SDG 14.1.1)

Copernicus data for surface water chlorophyll in Mediterranean Sea reveals that the chlorophyll concentration is quite higher in the western extent of the sea than the eastern part (see Attachment 1). Typically, the coastal regions of Italy, France, Spain, Tunisia and Egypt are more concentrated with the presence of chlorophyll. The average value of surface water chlorophyll in Mediterranean Sea as of December 2022 is 0.12 mg/m^3 which falls within the acceptable limit of marine water quality. The distribution of chlorophyll values indicates that the surface water of Mediterranean Sea is fairly ambient and very low in nutrient pollution. It can be visualized from the Copernicus data that the concentration of surface water chlorophyll is much higher in the coastal water than the offshore water. This could be due to the result of high nutrients supply from the mainland region to the coastal area through river runoffs. Copernicus data thus helps to monitor the coastal eutrophication and tropic state of marine resources.

Sea Water pH (SDG 14.3.1)

Copernicus data for sea water pH of Black Sea at 7.5m depth reveals that the sea water is alkaline with slight variations in pH values within its spatial extent (see Attachment 1). It can be observed that the coastal regions of the sea are more alkaline than the offshore areas. Higher pH values are concentrated near the coastal waters of Ukraine and Russia in the north and Georgia in the east while the coastal areas of

Turkey in the south and Bulgaria and Romania in the west have water with low pH values. The average value of sea water pH at 7.5m depth of Black Sea as of January 2023 is 8.29, which falls within the acceptable limit. Copernicus data reveals some signs of ocean acidification in the central part of the sea where lower pH values are evident than the surrounding regions. This implies that the deep waters of Black Sea are more acidic than surface waters.

Solar Photovoltaic Power (SDG 7.2.1)

Copernicus data for solar photovoltaic power generation for Europe reveals that the capacity factor for solar power generation is greater in the southwestern region of the continent (see Attachment 1). Spain and Portugal have the maximum capacity factor ratio while the Alps region, Nordic countries and Russia have the least values. The Balkan region and the Central Europe exhibit moderate values of solar capacity factor. The average value of solar photovoltaic power as capacity factor ratio for Europe in July 2022 is 0.16, which seems to be quite low for the summer observation. This could be possibly due to the geographical extent of Europe as it is situated higher than the equator and has fewer sunshine hours. Copernicus data on solar photovoltaic power helps to identify the regions with higher capacity factor and thereby suggests to establish more solar plants in those regions for maximum power generation. This helps to promote clean energy and minimize the excess of carbon emissions from the burning of fossil fuels.

Suitability for Aedes Albopictus (SDG 3.3.3)

Copernicus data on climatic suitability for Aedes Albopictus in Europe reveals that the Southwestern region of Europe has the most suitable climatic conditions for the mosquito (see Attachment 1). France exhibits the highest climatic suitability than any other country. Italy, Portugal, Croatia and Belgium are also marked with a greater climatic suitability. The Alps region and the Nordic countries are the least climatically suitable regions for the adaptation of the mosquito. The average value for climatic suitability for Aedes Albopictus in Europe as of January 2023 is 50.54 which indicates that Europe is moderately suitable for the breeding of tiger mosquito. Copernicus data helps to identify and confirm that the regions with higher summer temperature, mild winter temperature and sufficient amount of rainfall are at a greater risk for the spread of mosquito. It also supports the evidence that the mosquitoes are lethargic to lower temperatures and suggests the need to uptake necessary measures to prevent the warming of the continent.

Abundance of Atlantic Salmon (SDG 14.4.1)

Copernicus data on abundance of Atlantic Salmon in the Northwest European Shelf reveals that the fish stock is maximum along the English Channel between the boundary of France and the United Kingdom (see Attachment 1). The North Sea and the Celtic Sea are also identified with higher abundance of Atlantic Salmon. The number of Salmon declines considerably as we move away from the coastal region of United Kingdom towards Atlantic Ocean in the West and Norwegian sea in the North. The average number of Atlantic Salmon per 0.5° grid in the Northwest European Shelf as of January 2023 is 3530, which indicates not much abundance of the fish stock. The decline in the number of fishes could be possibly due to overfishing activities, marine pollution, climate change and habitat degradation. Copernicus data on fish abundance helps to monitor the population of fish species and thereby support to regulate overfishing and other illegal practices that threaten the fish stock.

Atmospheric Carbon Dioxide (SDG 9.4.1)

Copernicus data for atmospheric carbon dioxide in the world continents reveals that the concentration of CO2 in the atmosphere has reached to an alarming state (see Attachment 1). The CO2 levels are significantly higher in the northern hemisphere where Asia, Europe, North America and Central Africa are more severely affected than rest of the continents. The highest levels of CO2 concentration can be observed in China and Central Africa while South America, Australia and Antarctica are marked with relatively lower levels of CO2 concentration. The average value of atmospheric carbon dioxide in world continents as of January 2020 is 411 ppm which is already exceeding the critical level. Copernicus data on atmospheric CO2 concentration confirms that our planet is highly vulnerable to the devastating effects of climate change. It points out the urgency to cut down the carbon emissions as soon as possible through the practice of sustainable industrialization.

Atmospheric Methane (SDG 13.2.2)

Copernicus data for atmospheric methane in world continents reveals that Asia has significantly higher concentration of atmospheric methane than any other continents (see Attachment 1). Typically, China and Bangladesh exhibit critically higher levels of methane concentration. Other regions like Central Africa, Europe, Eastern part of North America and Northwestern part of South America are also distinguished with higher levels of methane concentration while Australia, Greenland and Antarctica appear relatively safer. The average value of atmospheric methane in world continents as of January 2020 is 1828 ppb which is not so far away from approaching the critical level. The higher concentration of methane in the atmosphere can be a signal for global warming and climate change. Copernicus data helps to monitor the critical levels of methane and other greenhouse gases in the atmosphere and thereby suggest the immediate need for reducing their emissions.

Forest Cover (SDG 15.1.1)

Copernicus data on forest cover in Venezuela reveals that the country has an abundance of forest particularly in its Southern extent (see Attachment 1). The Amazon rainforest contributes to a major share of the forest area in the country. The total area covered by forests in Venezuela in the year 2019 is 47,426,889 hectares, which indicates 52.01% of total area of the country. This represents a fairly good proportion of forest area in the country, although the forest in Venezuela is found to decline rapidly each year. This is probably resulted from the ongoing deforestation in Venezuela due to mining activities, intensive agriculture, forest fire and overgrazing. The Amazon rainforest in the South undergoes a rapid decline in its area each year due to the mining of gold, coltan, diamond and bauxite in the region of Orinoco. Copernicus data on forest cover helps to monitor the status of forest and thereby suggests the need to take urgent action against deforestation for sustainable forest management.

Water Ecosystem (SDG 6.6.1)

Copernicus data on the spatial extent of water ecosystem in the state of Minnesota, reveals that the state has an abundance of inland water bodies including rivers, lakes, reservoirs ponds, wetlands, etc (see Attachment 1). The total area covered by water bodies in Minnesota in the year 2019 is 1,203,013 hectares, which indicates a fairly good distribution of water bodies in the state. Copernicus data supports the fact that water ecosystems are subject to spatial dynamics i.e., their spatial extent changes over time. The overall area of water bodies in the state of Minnesota is found to increase slightly each year. Such expansion in the surface area could be the result of excessive precipitation or flooding while in some cases, drying out of wetlands and floodplains can also occur due to reduced precipitation or warming. Copernicus data on water bodies help to monitor the status and spatial dynamics of water ecosystem and thereby suggest the necessary measures for their conservation and sustainable management.

Riparian Grassland (SDG 15.1.2)

Copernicus data on riparian grassland in Rhine basin reveals the richness of grassland along the Rhine River and its tributaries (see Attachment 1). It can be observed that the grassland is denser particularly in the northern extent of the basin. The total area covered by riparian grassland in Rhine basin in the year 2018 is 779,695.80 hectares, which indicates the presence of a substantial amount of grassland in the basin. However, the grassland area in the Rhine basin is found to decline considerably than in the reference year 2012. Copernicus data on riparian grassland helps to monitor the status of grasslands in the riparian zones and illustrate how they have changed between the reference years. It recommends the need for the conservation, restoration and sustainable management of grassland in the Rhine basin in order to prevent it from further deterioration.

6 DISCUSSION

For the scope of this thesis, 15 SDG indicators were selected, as not all the indicators could be mapped with the utilization of earth observation data. For instance, it was not appropriate to map the indicators related to poverty, education, gender equality or partnerships as these indicators heavily depend on statistical data and cannot be informed with the application satellite data. Copernicus data was used as the primary data source rather than any other earth observation platform because of its free and open data policy. In addition, Copernicus offers wealth of information not just for Europe but all over the globe that are well archived and updated regularly. The datasets in general, exhibit a greater spatial resolution and temporal coverage, and include some of the historical datasets as well as future forecasts.

The topic for the thesis was rather vague and dealt with a number of multiple disciplines at the same time rather than focusing on one particular topic. Therefore, it was required to conduct a lot of research and study of pertinent literatures comprehensively prior to establishing a proper linkage between SDGs and the Copernicus. Selecting the most suitable SDG topics to be mapped out 17 goals, 169 targets and 232 indicators was a very demanding and time-consuming task. The same challenge was experienced while deciding on the most appropriate dataset for mapping the topics out of hundreds of data products available in the Copernicus repository.

Although Copernicus data was highly suitable for mapping the research topics, it also came with a number of limitations. The multidimensional raster datasets in NetCDF file formats were very large in size and often took a long time to download from the Copernicus catalogue. The same problem was persistent while loading the data in ArcGIS Pro and performing analysis. The processing was very slow, often causing the system to crash and resulting in loss of work. The resolution for some data was not so appropriate to be utilized for mapping the selected phenomena. For instance, the data for particulate matter 2.5 acquired from CAMS had a spatial resolution of 40 km, which was very coarse and was not suitable for mapping even a large country like China.

Copernicus data also had some issues with the spatial and temporal coverage. This spatial coverage problem was experienced particularly in the cases where the datasets were captured along the paths of the satellites, offering an insufficient coverage even for a small region. Similarly, limited temporal coverage in some cases of data were realized while creating animations, whereby no sufficient number of data frames could be generated for visualizing the time series of the data. Another problem encountered with the animations of some dataset was that no visible changes were seen in the subsequent map frames although there was a substantial change in data between the consecutive time periods. This was particularly observed for the map animations depicting Soil Loss (SDG 15.3.1), Forest Cover (SDG 15.1.1), Water Ecosystem (SDG 6.6.1) and Riparian Grassland (SDG 15.1.2).

The shortcomings of Copernicus data associated with this research can be eliminated by opting for other earth observation platforms such as the Landsat. It is also recommended to cross validate the results generated by Copernicus data by using the data from a different satellite platform or in-situ observation.

This research is quite different from other contemporary researches performed on the similar topics. Most of the studies based on the use of satellite data in SDG context are found focusing on the measurement and analysis of only a particular indicator at a time. This study on the contrary, simultaneously assesses a number of SDG indicators that can be well addressed with the application of geospatial data. Unlike many literatures that make use of the statistical data to map the SDG indicators as thematic maps over some predefined enumeration units, this study makes the use of earth observation data directly as the main theme for mapping the SDG indicators over different geographic extents. The research also surpasses other similar studies in terms of the richness of cartographic products generated.

The research is a great combination of both technical and design aspects, aided with research and creativity. It deals with the most crucial global issue of the contemporary period. Since SDGs are a long-term agenda, the research shall hold a potential utility as a foundational resource for subsequent iterations or analogous cartographic offerings that will be anticipated in the future.

CONCLUSION

The thesis was successful in meeting the set objectives of demonstrating the applicability of Copernicus data in devising solutions to the Sustainable Development Goals. 15 thematic image maps depicting the selected SDG topics were designed and compiled by utilizing the data from five of the Copernicus services. The image maps were subsequently transformed into five sets of different cartographic information products: A4 handy maps, A3 large maps, A2 posters, web maps and animations, each of these oriented towards a specific purpose and target audience. A unique concept of geovisualization was implemented by utilizing these formats to effectively communicate the mapped information to each group of target audience.

The application of multidimensional analysis on Copernicus data facilitated in detecting meaningful trends, patterns and interlinks that occurred in the datasets. This was useful for deciding which data of what location and which time period was more appropriate for mapping the selected SDG topics. The analysis of temporal profile of variables enabled the study of change in distribution of values over a time period. Multidimensional tools were also helpful in creating map animations where the data frames of the subsets and aggregations of different variables were used to visualize the temporal change in distribution of data. Such analysis can play a pivotal role in the routine monitoring of SDG indicators, thereby helping to track their progress by determining whether we are moving towards the goal or away from it.

The research has successfully fulfilled the geospatial information requirements pertaining to the measurement and monitoring of the selected SDG targets and indicators. The use of image maps in SDG context proved to be a decent approach in mapping the selected topics. The image and symbol components of the designed thematic image maps perfectly complemented each other, and allowed for overcoming the limitations of one component by the other and vice versa. Proper harmonization of image and symbol components enabled better visualization and effective communication of the mapped phenomena to the intended audience.

The research has revealed the potential of Copernicus data in supporting solutions to selected SDGs. This has allowed for the enhancement of accessibility, availability, and utilization of Copernicus as a free and open-source earth observation data, with a view to foster sustainability at a planetary level. The thesis has offered a holistic approach in integrating earth observation and cartography for managing the SDGs, thereby highlighting the crucial role Copernicus data can play in evidence-based decision making in the SDG context. The research outcomes will serve to assist the policy makers in informed decision making and effective policy formulation with a rationale that an incremental progress towards the SDG targets will be achieved in due course of time.

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LIST OF ATTACHMENTS

ATTACHMENT 1

A4 HANDY MAPS

COPERNICUS DATA IN
SUSTAINABLE DEVELOPMENT GOALS
USING IMAGE MAPS

A4 Handy Maps

Sushmita SUBEDI

Palacký University
Olomouc, 2023

With the support of the Erasmus+ Programme of the European Union

COPERNICUS MASTER IN DIGITAL EARTH

PARIS LODRON UNIVERSITÄT SALZBURG

Palacký University Olomouc

SUPERVISOR
Prof. Dr. Vít VOŽENÍLEK | Palacký University Olomouc

CO-SUPERVISOR
Assoc. Prof. Stefan LANG, Ph.D.| University of Salzburg

Table of Contents

SOIL LOSS

Italy, 2021-2050

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Soil Loss Raster
Data Source: Copernicus Climate Change Service
Spatial Resolution: 500 m
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Country boundary, Cities

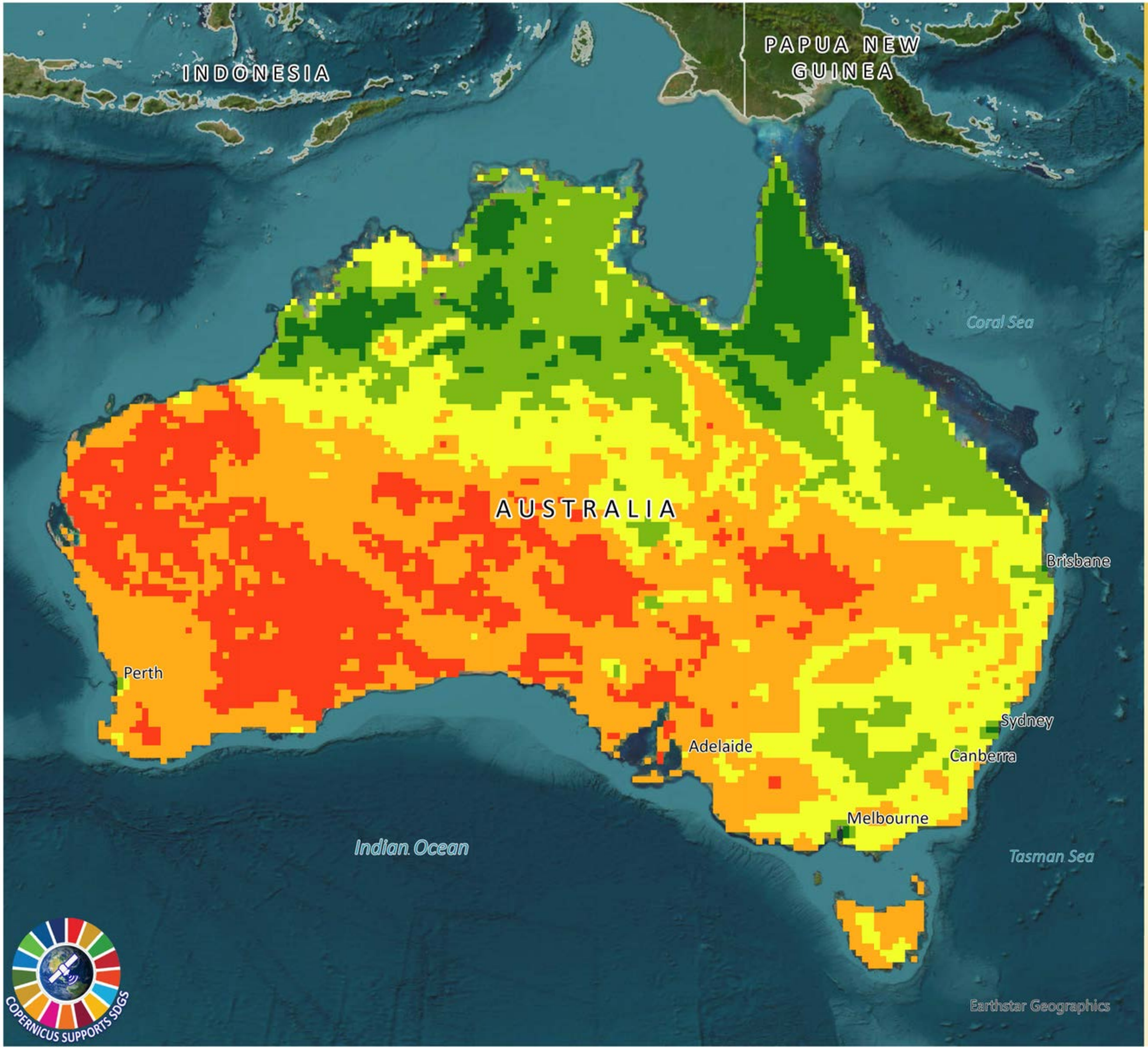
Soil Loss (t/ha/yr)

0 5 10 20 100 *max 1227*

Map Projection:
Albers Equal Area Conic

0 100 200 km

Sushmita SUBEDI
Palacký University
Olomouc, 2023



SURFACE SOIL MOISTURE

Australia

January 2023

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Soil Moisture Raster
Data Source: Copernicus Climate Change Service
Spatial Resolution: 0.25°x 0.25°
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Country boundary, Cities

Surface Soil Moisture (%)

0 10 30 50 70 *max 95*

Map Projection:
GDA2020

0 500 1,000 km

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Palacký University
Olomouc, 2023

TURBIDITY

Lake Turkana

21 January 2023

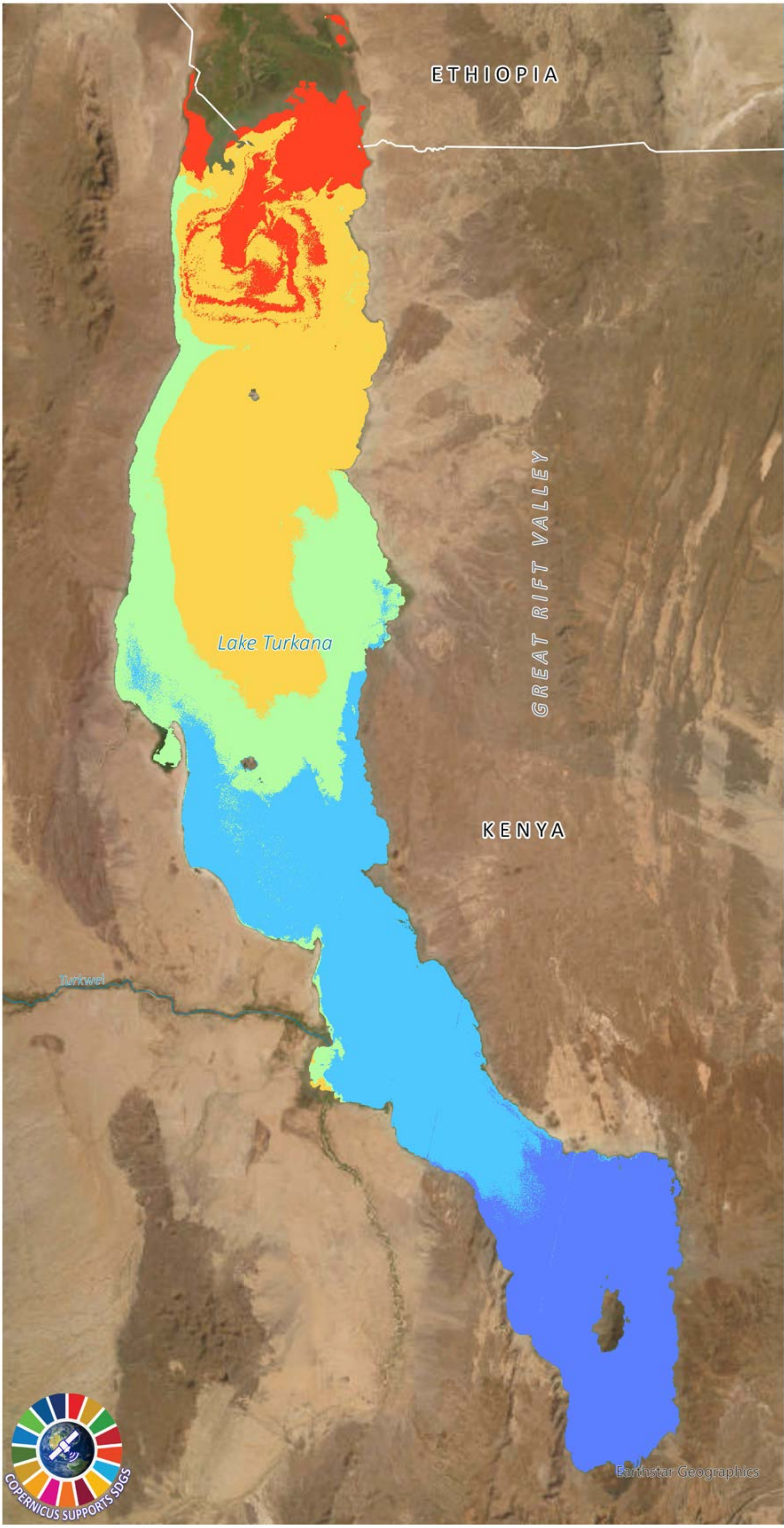

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Turbidity Raster
Data Source: Copernicus Global Land Service
Spatial Resolution: 100 m
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Country boundary

Blended Mean Turbidity (NTU)

max 753
50
20
10
5
min 1

Map Projection:
WGS 1984

0 10 20 km

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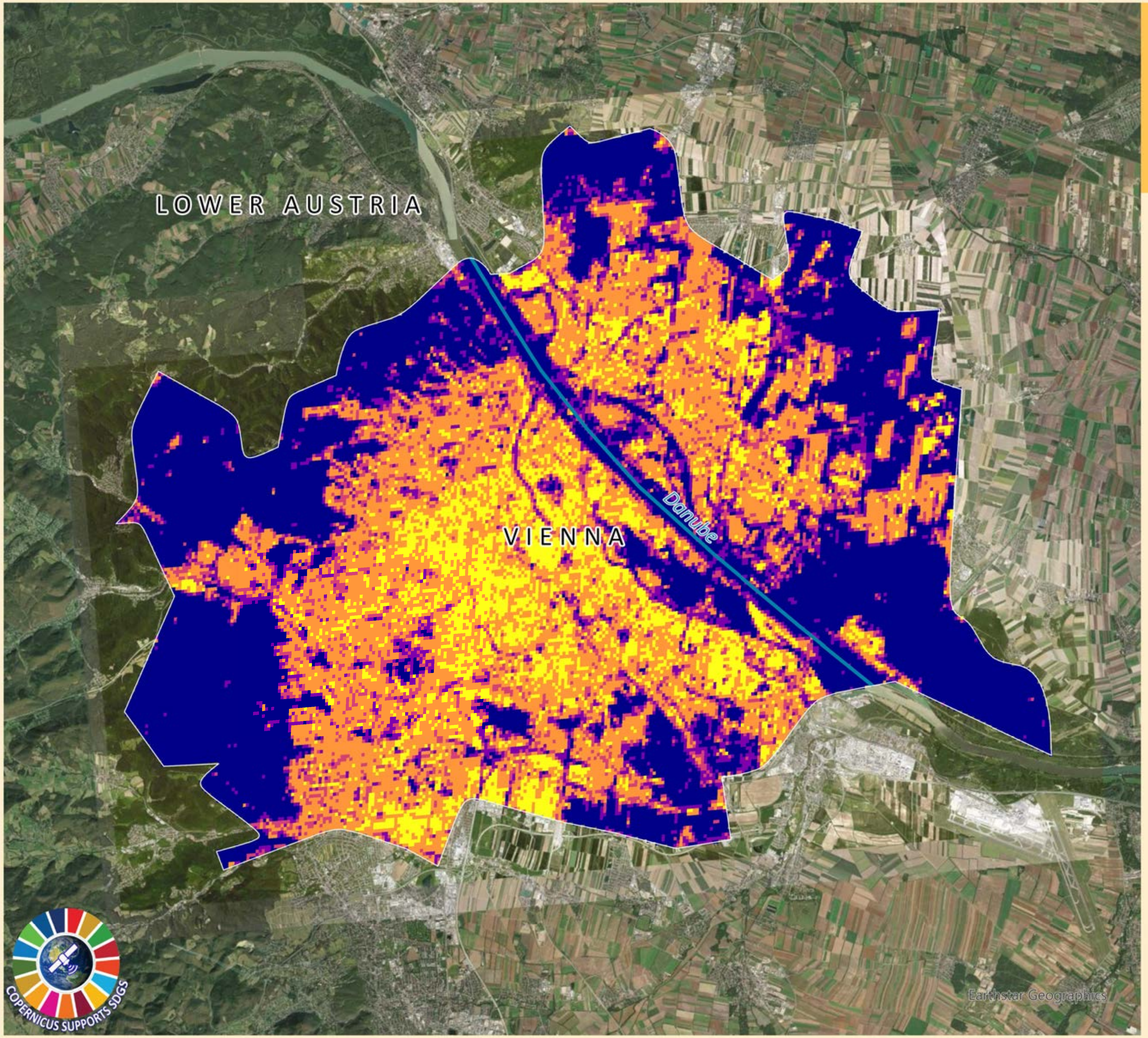

BUILT-UP SURFACE

Vienna, 2020

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Built-Up Surface Raster
Data Source: Global Human Settlement Layer [Copernicus Emergency Management Service]
Spatial Resolution: 100 m
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, State boundary, River

Built-Up Surface (m^2)

0 100 1000 2000 4000 *max 10000*

Map Projection:
Albers Equal Area Conic

0 2 4 km

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Olomouc, 2023

PARTICULATE MATTER (2.5)

China

15 February 2023

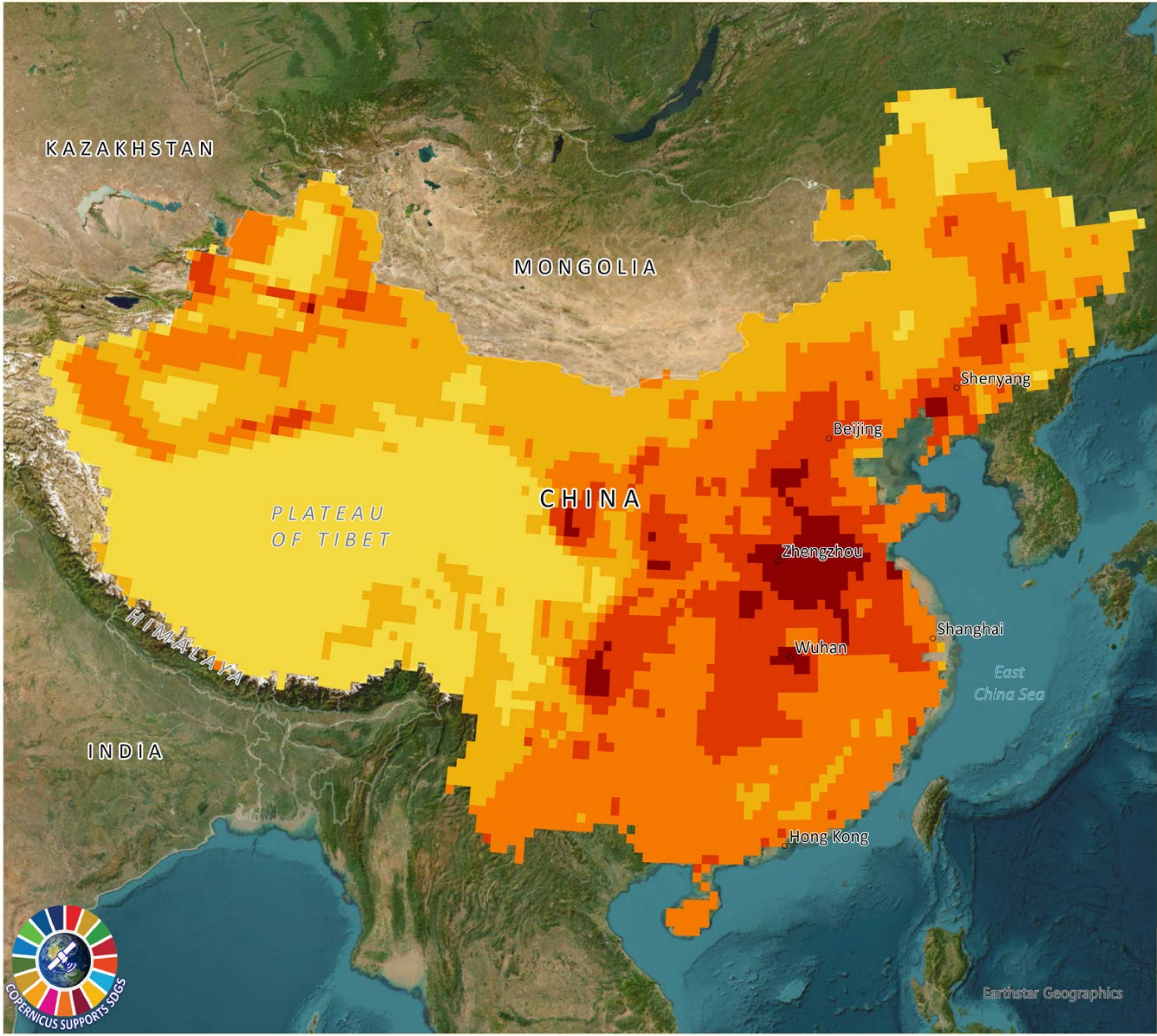

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: PM 2.5 Raster
Data Source: Copernicus Atmosphere Monitoring Service
Spatial Resolution: 40 km
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Country boundary, Cities

Particulate Matter 2.5 (µg/m³)

0 10 20 40 80 *max 133*

Map Projection:
South China Sea Lambert

0 500 1,000 km

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SURFACE WATER CHLOROPHYLL

Mediterranean Sea, December 2022

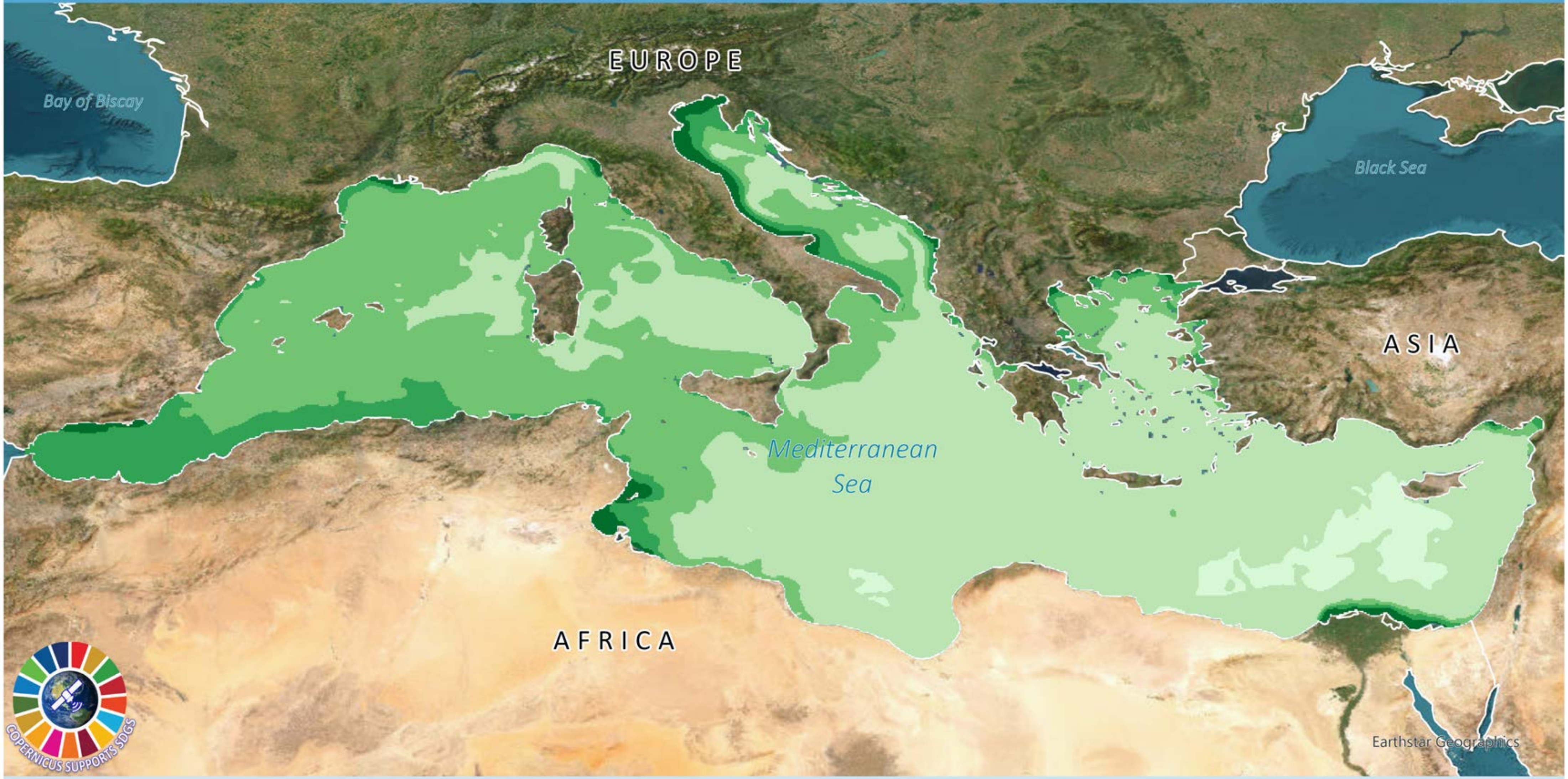

IMAGE MAP TYPE: Double Thematic

Symbol Component: Labeling, Continent boundary

Image Component:
Thematic Content: Surface Chlorophyll Raster
Data Source: Copernicus Marine Environment Monitoring Service
Spatial Resolution: 4 km
Topographic Base: ESRI World Imagery

Surface Water Chlorophyll (mg/m³)

min 0.04 0.05 0.1 0.2 0.5 *max 2.27*

Map Projection:
WGS 1984

0 250 500 km

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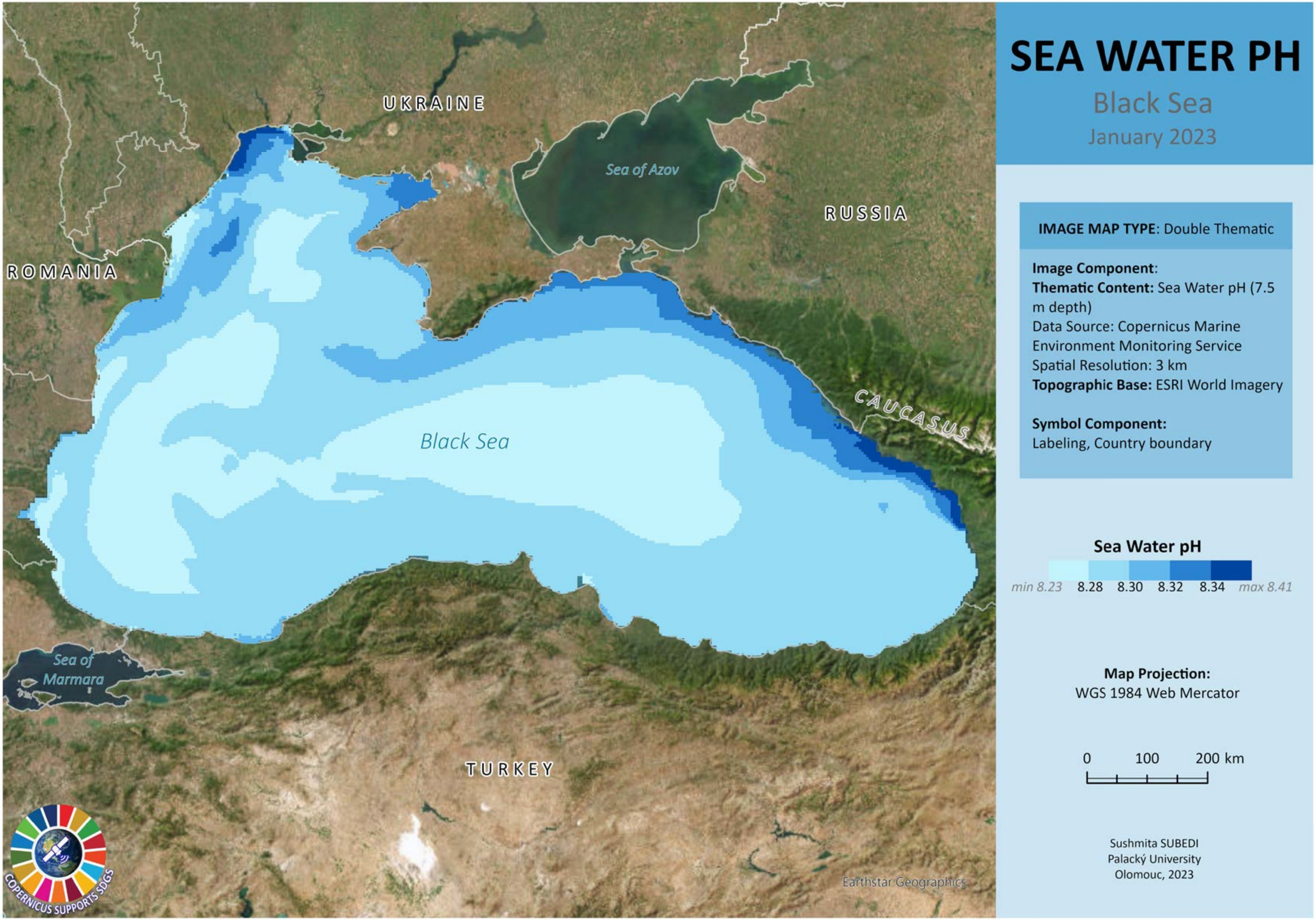
Olomouc, 2023


SEA WATER PH
Black Sea
January 2023
UKRAINE
RUSSIA
ROMANIA
TURKEY
CAUCASUS
Sea of Azov
Black Sea
Sea of Marmara
IMAGE MAP TYPE: Double Thematic
Image Component:
Thematic Content: Sea Water pH (7.5 m depth)
Data Source: Copernicus Marine Environment Monitoring Service
Spatial Resolution: 3 km
Topographic Base: ESRI World Imagery
Symbol Component:
Labeling, Country boundary
Sea Water pH
min 8.23
8.28
8.30
8.32
8.34
max 8.41
Map Projection:
WGS 1984 Web Mercator
0
100
200 km
Sushmita SUBEDI
Palacký University
Olomouc, 2023
Earthstar Geographics
COPERNICUS SUPPORTS SDGS

SOLAR PHOTOVOLTAIC POWER

Europe, July 2022

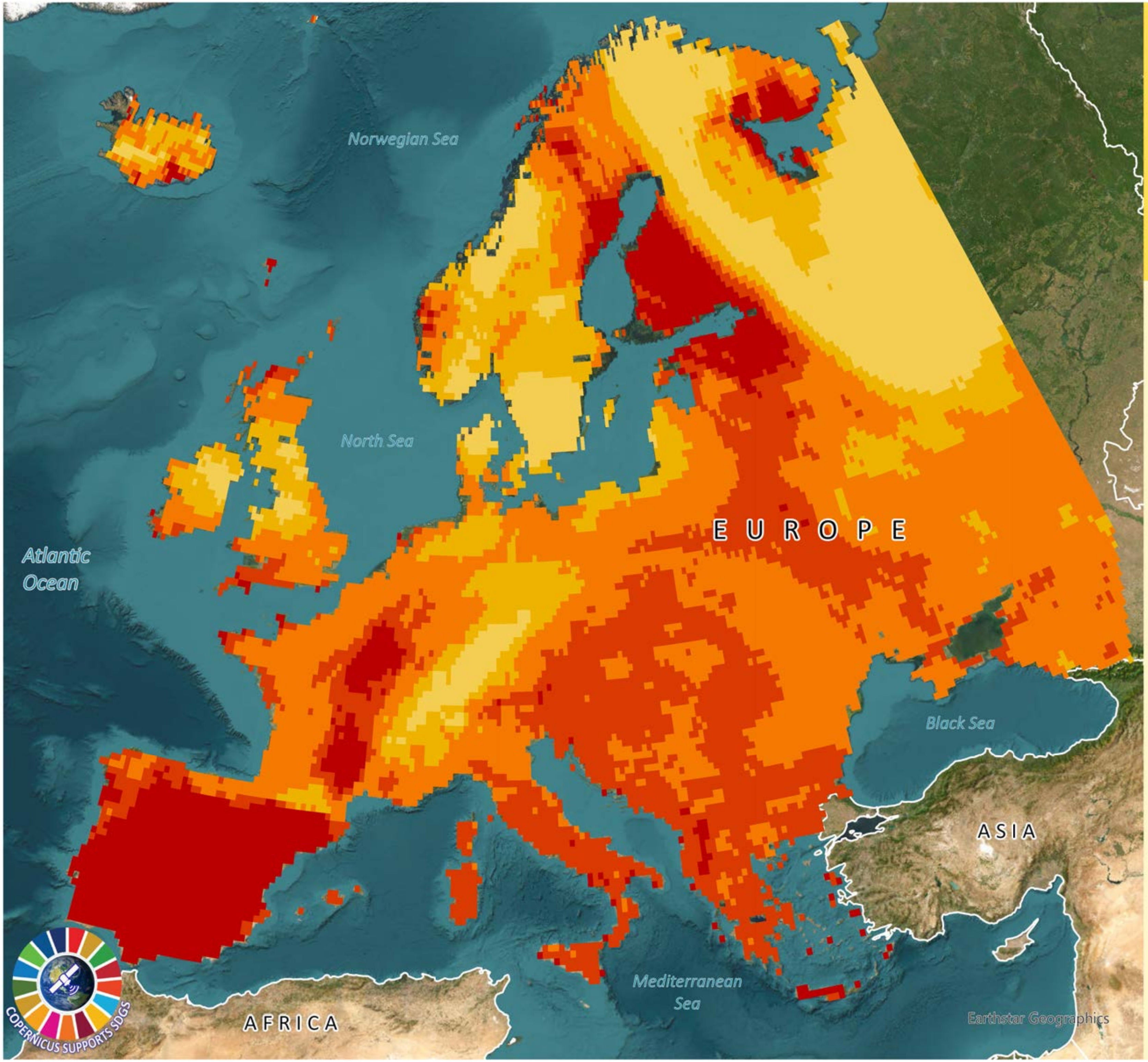


IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Solar Photovoltaic Power
Data Source: Copernicus Climate Change Service
Spatial Resolution: 0.25°x 0.25°
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Continent boundary

Solar Photovoltaic Power (CRF)

min 0.01 | 0.10 | 0.15 | 0.20 | 0.22 | max 0.25

Map Projection:
Lambert Conformal Conic

0 250 500 km

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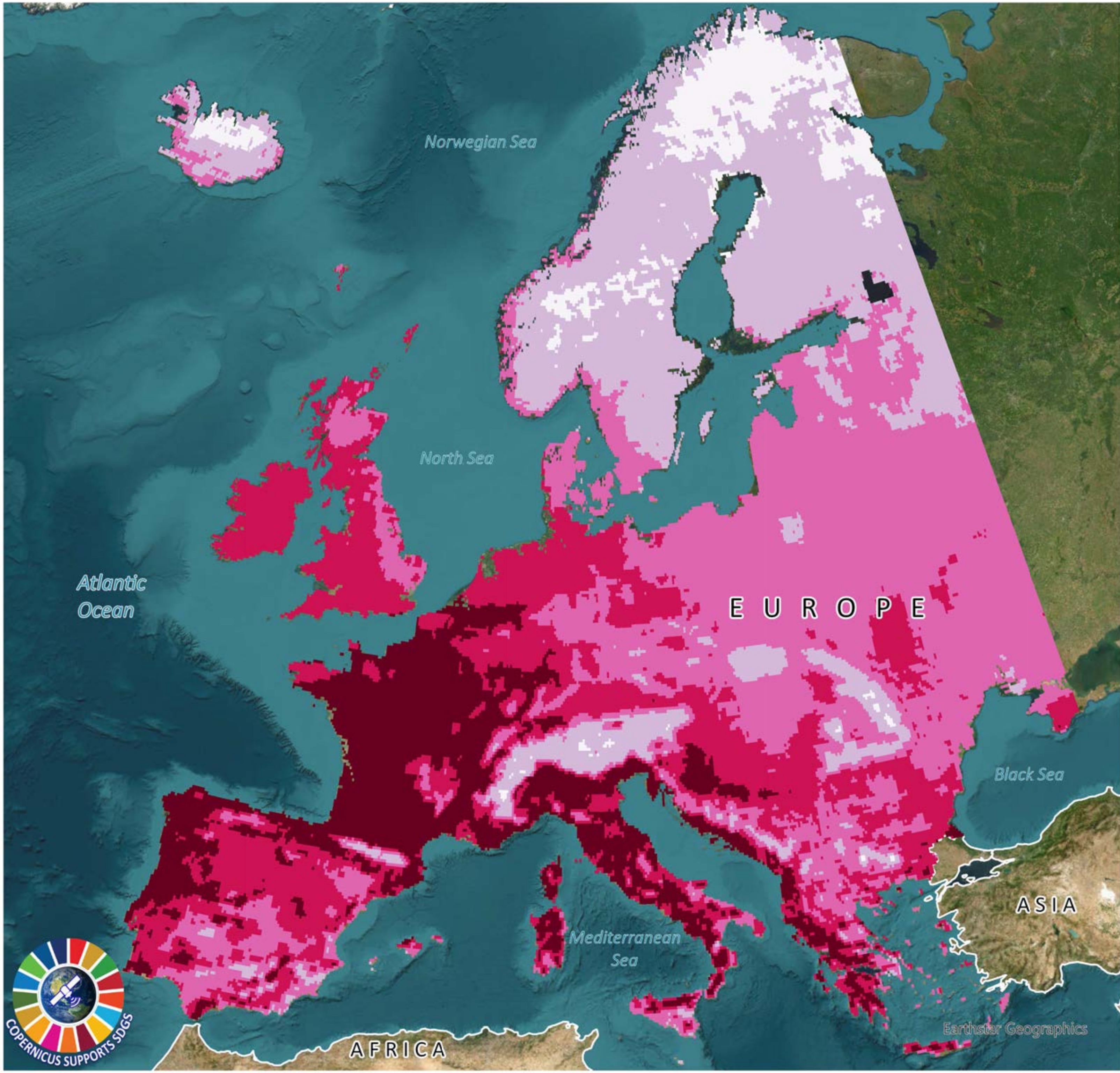
Olomouc, 2023



SUITABILITY FOR AEDES ALBOPICTUS

Europe, January 2023

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Climatic Suitability for Aedes Albopictus
Data Source: Copernicus Climate Change Service
Spatial Resolution: 0.1°x 0.1°
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Continent boundary

Climatic Suitability

0 20 40 60 80 *max 100*

Map Projection:
Lambert Conformal Conic

0 250 500 km

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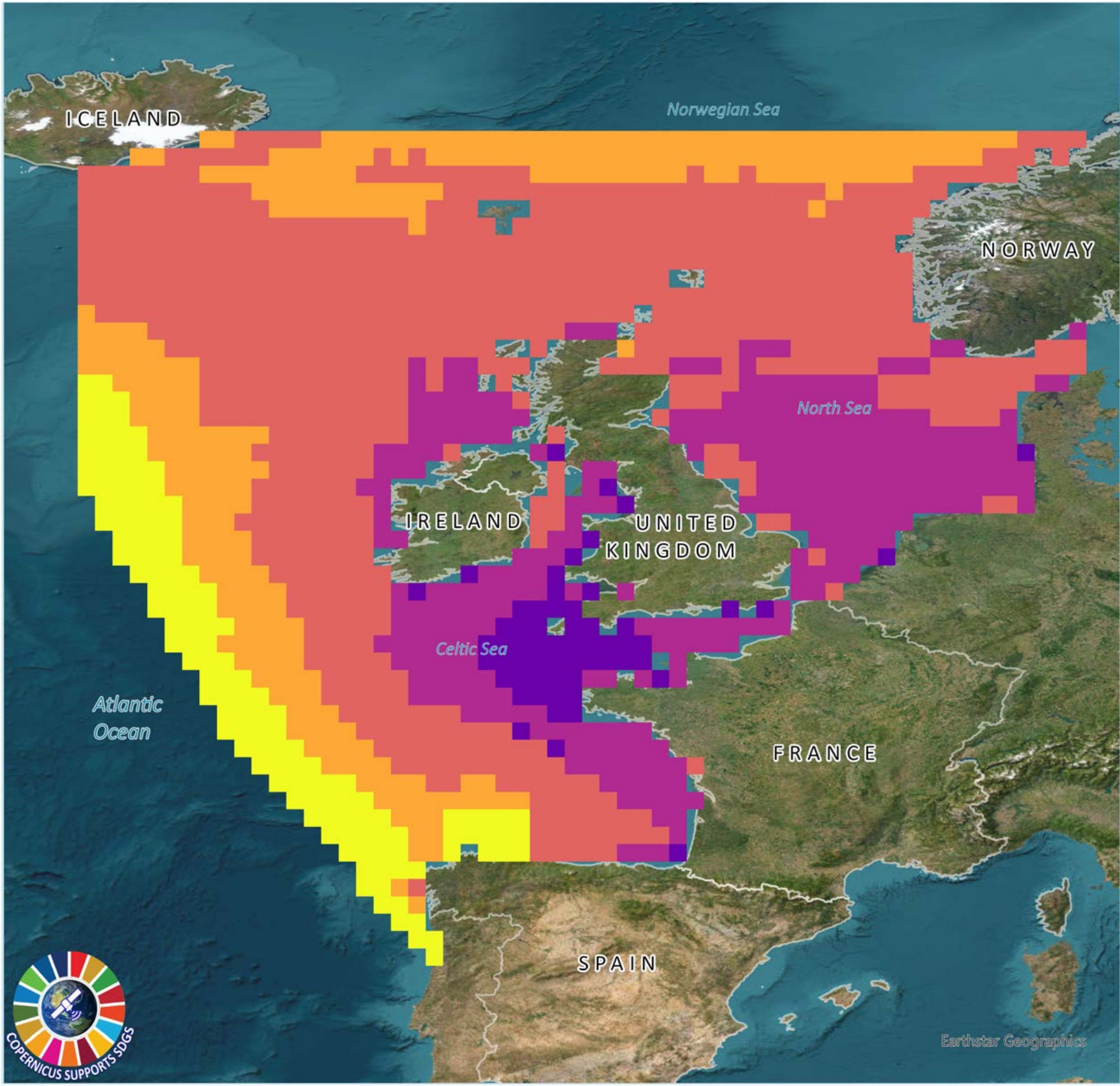
Olomouc, 2023



ATLANTIC SALMON

Northwest European Shelf

January 2023

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Abundance of Atlantic Salmon (Gridded)
Data Source: Copernicus Climate Change Service
Spatial Resolution: 0.5°x 0.5°
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Country boundary

Number of Atlantic Salmon

0 1000 2000 5000 8000 *max 12798*

Map Projection:
WGS 1984

0 250 500 km

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Palacký University
Olomouc, 2023

ATMOSPHERIC CARBON DIOXIDE

World Continents, January 2020

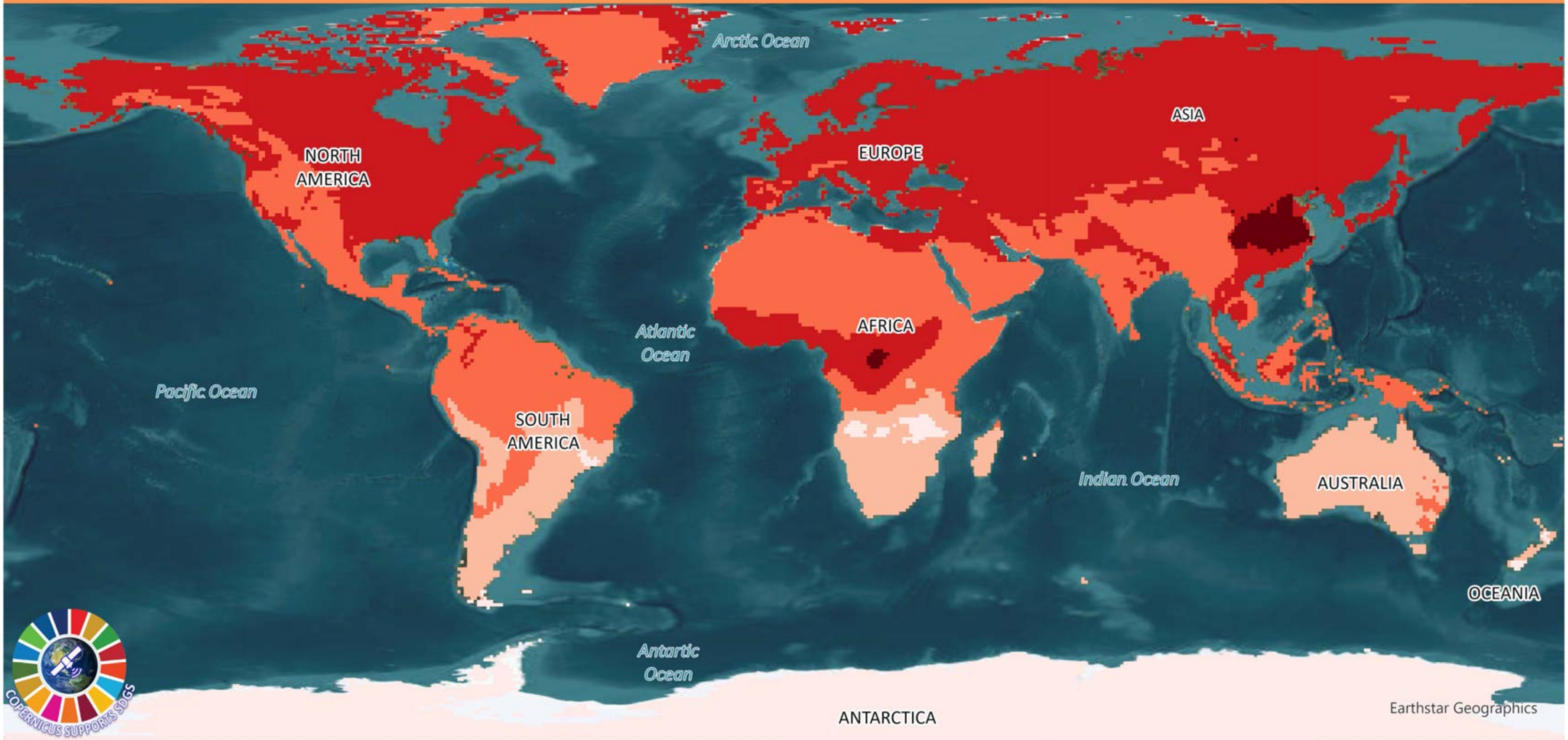

IMAGE MAP TYPE: Double Thematic

Symbol Component: Labeling

Image Component:
Thematic Content: Atmospheric CO2 Raster
Data Source: Copernicus Atmosphere Monitoring Service
Spatial Resolution: 0.75°x 0.75°
Topographic Base: ESRI World Imagery

CO2 Column-Mean Molar Fraction (PPM)

min 406 | 408 | 410 | 413 | 416 | max 421

Map Projection:
WGS 1984

0 2,000 4,000 km

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ATMOSPHERIC METHANE

World Continents, January 2020

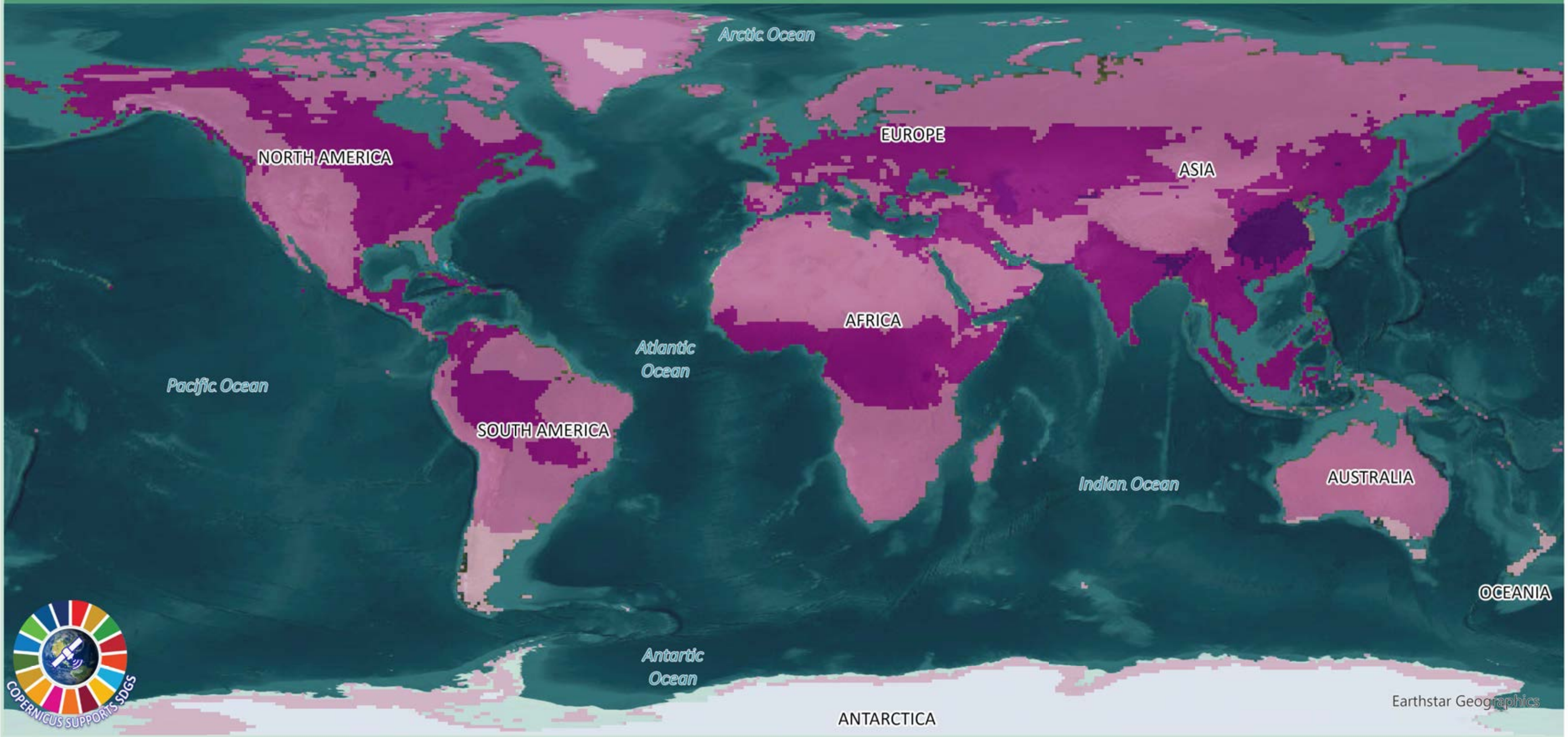

IMAGE MAP TYPE: Double Thematic

Symbol Component: Labeling

Image Component:
Thematic Content: Atmospheric CH4 Raster
Data Source: Copernicus Atmosphere Monitoring Service
Spatial Resolution: 0.75°x 0.75°
Topographic Base: ESRI World Imagery

Methane Column-Mean Molar Fraction (PPB)

min 1716 1750 1800 1870 1900 *max 2039*

Map Projection:
WGS 1984

0 2,000 4,000 km

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FOREST COVER

Venezuela, 2019

IMAGE MAP TYPE: Back/Rear Thematic

Symbol Component:
Thematic Content: Forest Cover, Country boundary, Labeling
Data Source: Copernicus Global Land Service
Spatial Resolution: 100 m

Image Component:
Topographic Base: ESRI World Imagery

Forest

Total Area: 47,426,889 ha

Map Projection:
WGS 1984

0 100 200 km

Sushmita SUBEDI
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WATER ECOSYSTEM

Minnesota, 2019

IMAGE MAP TYPE: Back/Rear Thematic

Symbol Component:
Thematic Content: Water bodies, State boundary, Labeling
Data Source: Copernicus Global Land Service
Spatial Resolution: 100 m

Image Component:
Topographic Base: ESRI World Imagery

Water Body
Total Area: 1,203,013 ha

Map Projection:
NAD 1983

0 50 100 km

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RIPARIAN GRASSLAND

Rhine Basin, 2018

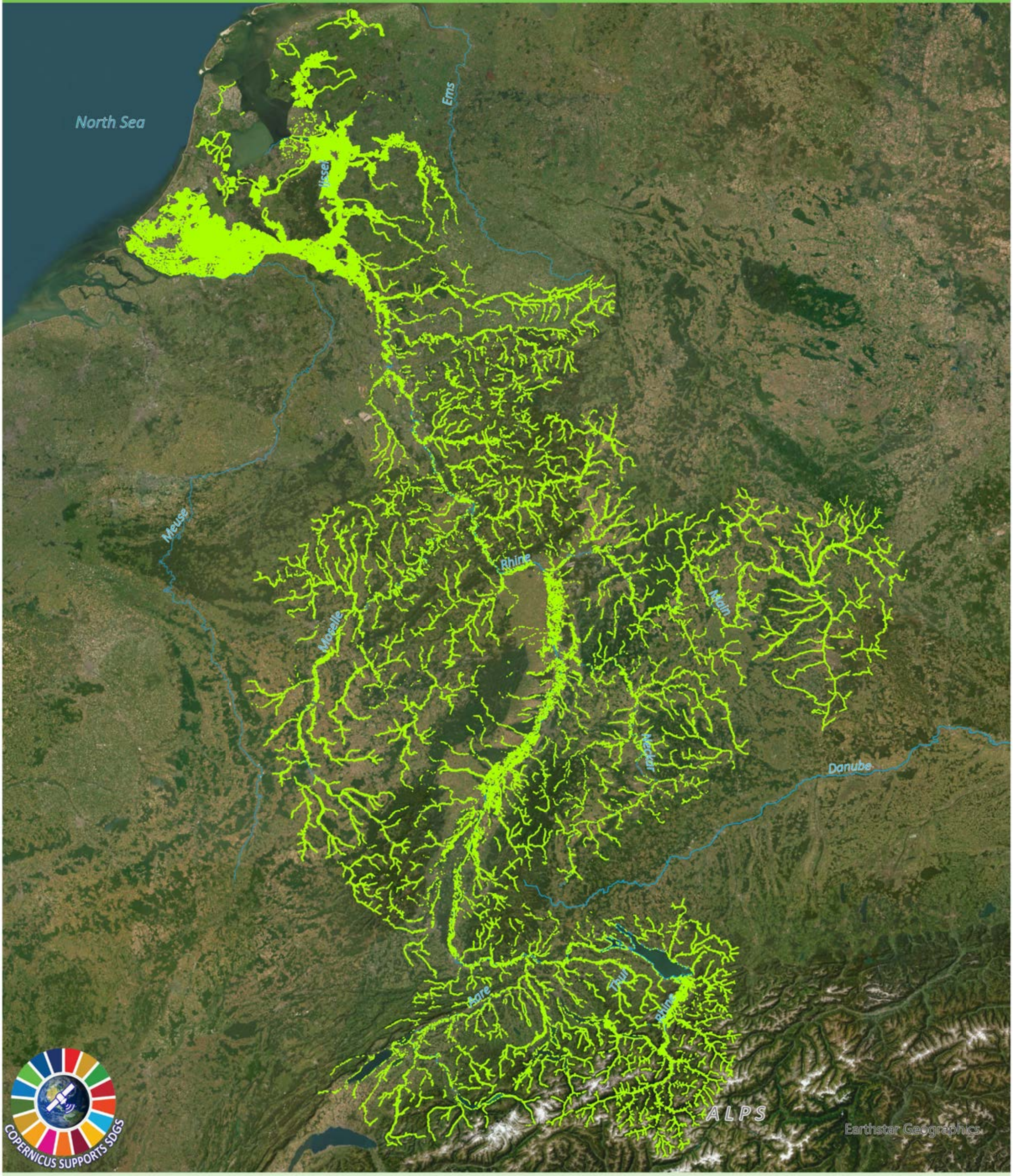

IMAGE MAP TYPE: Back/Rear Thematic

Image Component:
Topographic Base:
ESRI World Imagery

Symbol Component:
Thematic Content: Riparian Grassland, River network, Labeling
Data Source: Copernicus Land Monitoring Service
Spatial Resolution: 0.5 ha MMU

Riparian Grassland
Total Area: 779,695.80 ha

0 50 100 km

Map Projection:
ETRS 1989 LAEA

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ATTACHMENT 2

A3 LARGE MAPS

COPERNICUS DATA IN SUSTAINABLE DEVELOPMENT GOALS USING IMAGE MAPS

A3 Large Maps

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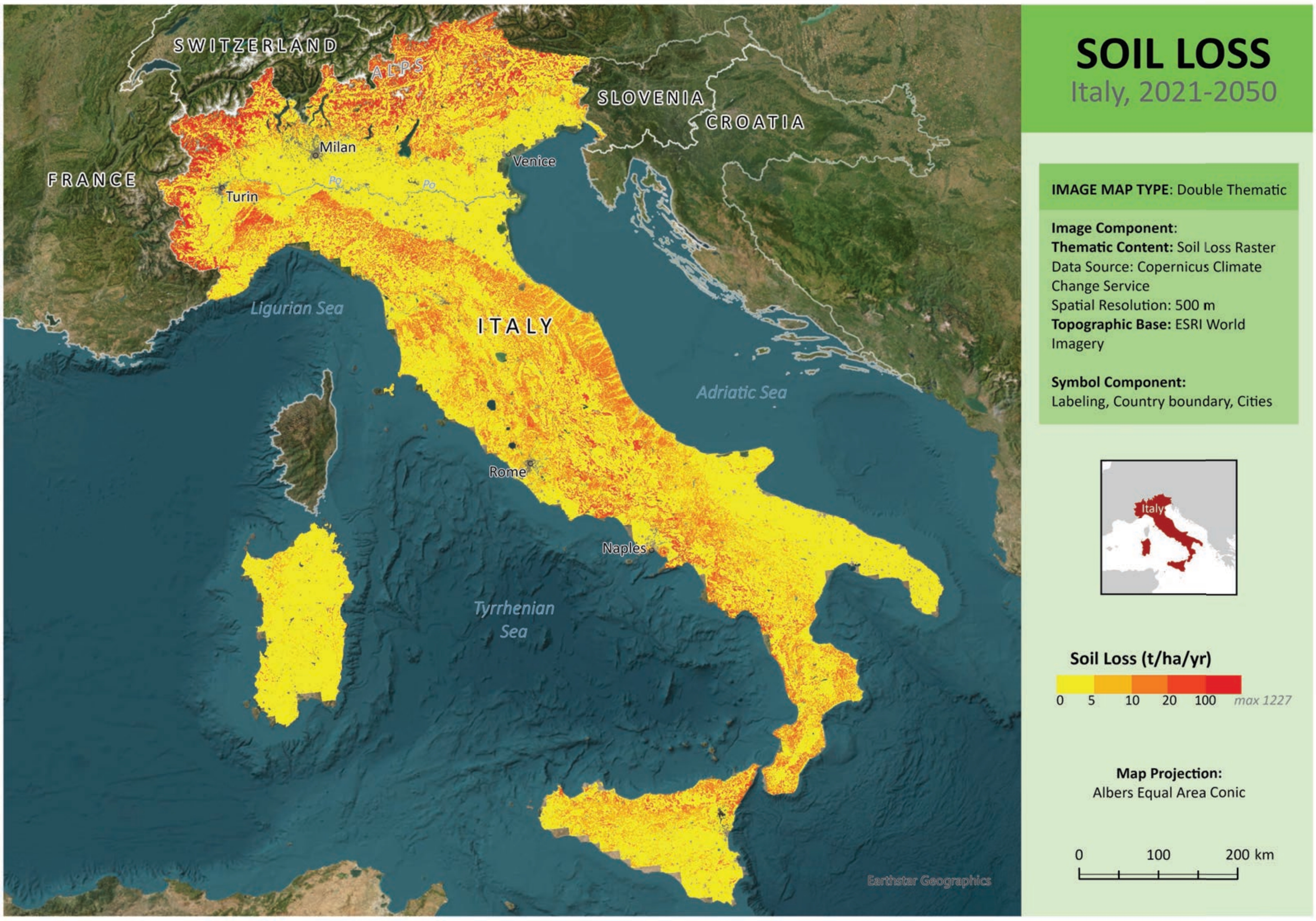
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS #01

Soil loss is the loss or reduction in the amount of soil particles from land surface. It is often used interchangeably with soil erosion and is mainly caused due to climate change, rainfall, deforestation, overgrazing, forest fires, mining and construction activities. Although natural forces like wind and water are usually responsible for soil loss, this can be intensified more by human activities on land. Soil loss up to 10 t/ha/yr is generally acceptable (Matthee and Schalkwyk, 1984) but when soil loss exceeds this value, it is considered as a critical environmental problem. Higher level of soil loss leads to land degradation, low productivity, desertification and biodiversity loss. This problem is more prominent in the Caribbean countries, Brazil, Central Africa and Southeast Asia.



Copernicus data for soil loss of Italy reveals that soil loss is considerably higher in the Alps and the Apennine mountains. The area around the Po River has a very minimal soil loss. Also, the island of Sardinia and other plain areas are safer in terms of soil loss. The average value of soil loss in Italy for the reference period 2021-2050 is 8.57 t/ha/yr which falls within the acceptable limit. It can be inferred from the data that the lowlands that are usually suitable for agriculture are less likely to be affected by soil loss. However, the high mountains that serve as the potential touristic destinations encounter severe effects of soil loss. This could be due to the slope of the terrain as greater steepness can lead to higher amount of runoff during heavy rainfall. Copernicus soil loss data allows the users to identify the potential areas of higher soil loss and thereby implement prevention strategies. For instance, plantation and can be done in the erosion prone areas. Also, terrace farming can be recommended in the hills and mountain regions.

SDG RELEVANCE

15 LIFE ON LAND

Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

Target 15.3: By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.

Indicator 15.3.1: Proportion of land that is degraded over total land area.

COPERNICUS DATA

Dataset	: Soil Erosion Indicators for Italy from 1981 to 2080
Provider	: Copernicus Climate Change Service
Data type	: Gridded
Horizontal coverage	: Italy
Horizontal resolution	: 500 m
Vertical coverage	: Surface
Vertical resolution	: Single level
Temporal coverage	: 1981-2080 (2011-2020 excluded)
Temporal resolution	: 30-year period
File format	: NetCDF-4

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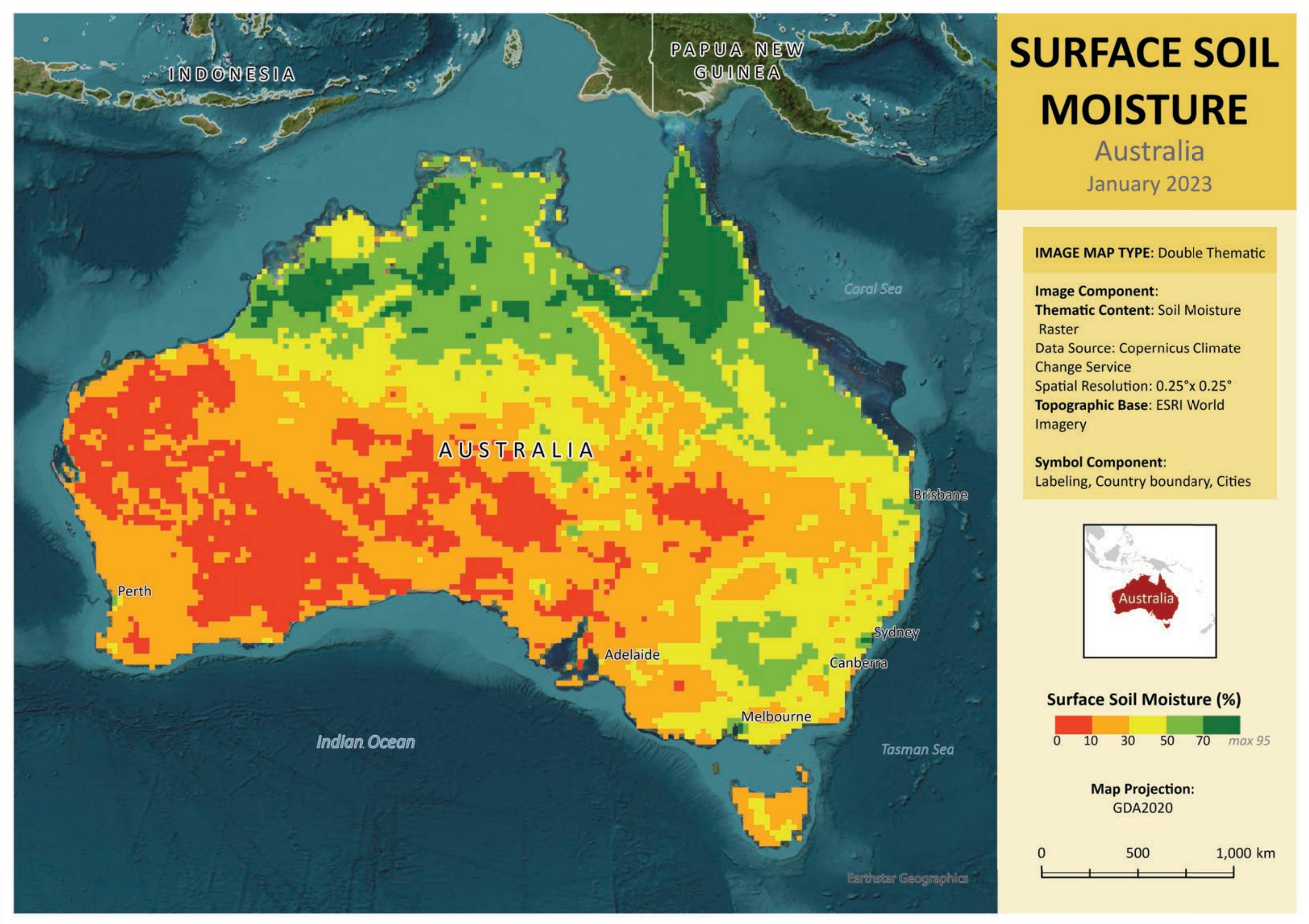
Sushmita SUBEDI
Palacký University
Olomouc, 2023

COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#02

Surface soil moisture is the amount water content present at the topmost level of soil. It is usually measured for a soil layer of 2 to 5 cm depth and is expressed as the percentage of total saturation. Soil moisture is an important factor for crop growth. It helps to regulate the soil temperature and serves as the medium through which plants acquire their nutrients. Surface soil moisture is affected by climate change as well as human activities. The optimum level of surface soil moisture for most of the crops is usually 20% - 60% (EOS, 2023). It is necessary to maintain such level of soil moisture as the deficit or excess can lead to poor crop health, reduced productivity and food scarcity.



Copernicus data for surface soil moisture of Australia reveals that the continent has an excessive moisture content in its northern extent while its central and western parts face deficit in soil moisture. This can be directly related to the topography of the continent as it is composed of deserts its center, plateau towards the west and basins in the north. The surface soil moisture seems to be moderate in the southeastern part of Australia creating a favorable condition for crop growth and productivity. The average value of surface soil moisture of Australia as of January 2023 is 48.5% which falls within the optimum level. The regions having optimum level of soil moisture as indicated by the Copernicus data should be utilized for agricultural purpose as it helps to ensure higher level of crop production. Such regions will require a minimal effort for drainage or irrigation in order to maintain and preserve the moisture content. It can also be recommended that the arid and the damp regions of the continent to be filled with certain crop types that are suited for that particular moisture conditions.

SDG RELEVANCE

2 ZERO HUNGER

Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Target 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality

Indicator 2.4.1: Proportion of agricultural area under productive and sustainable agriculture

COPERNICUS DATA

Dataset	: Soil Moisture Gridded Data from 1978 to Present
Provider	: Copernicus Climate Change Service
Data type	: Gridded
Projection	: WGS 1984
Horizontal coverage	: Global
Horizontal resolution	: 0.25° x 0.25°
Vertical coverage	: Surface
Temporal coverage	: 1978 to Present
Temporal resolution	: Daily, 10-day, Monthy
File format	: NetCDF

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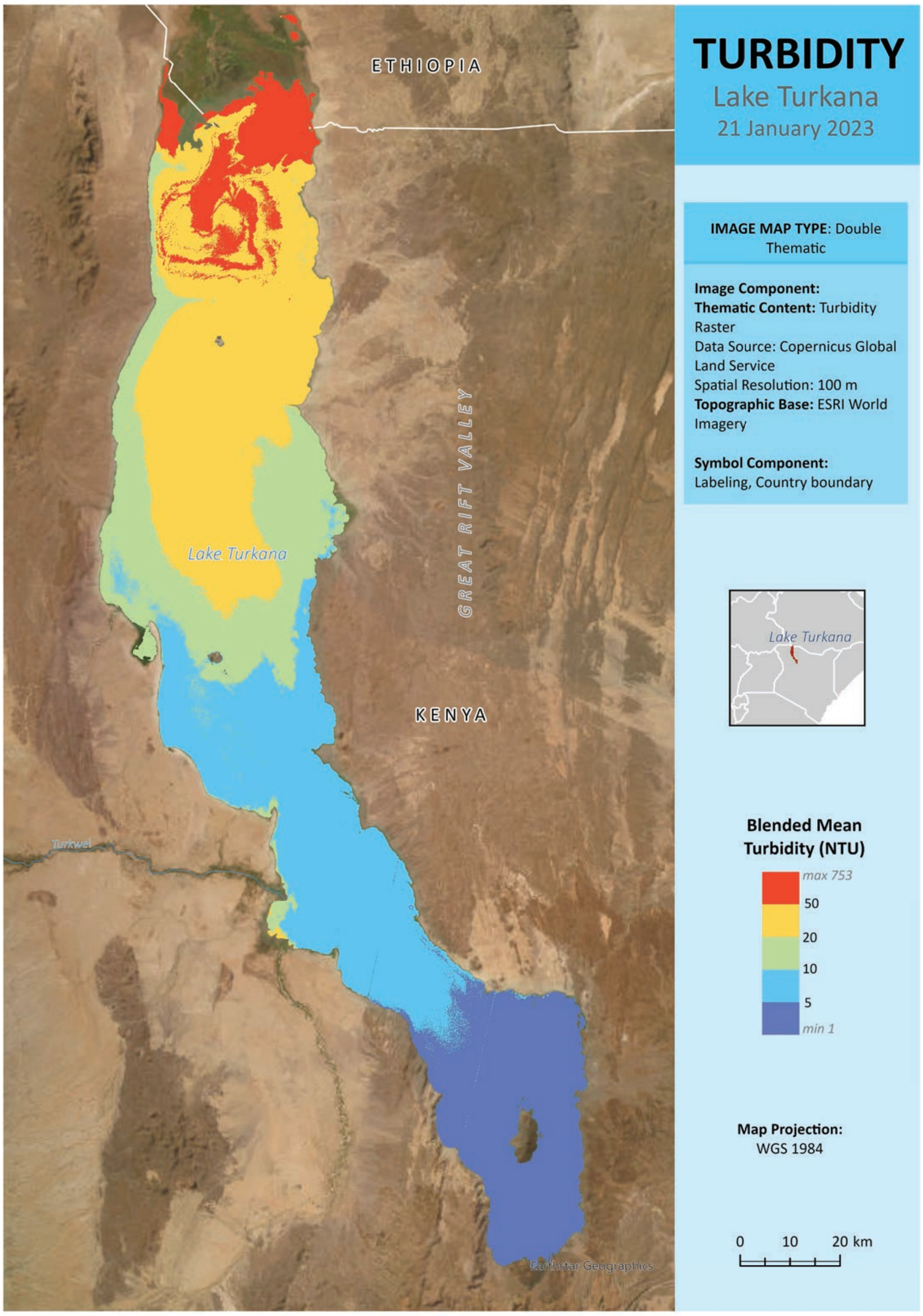
Olomouc, 2023

COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#03

Turbidity refers to the cloudiness or haziness of liquid. It is characterized with the presence of suspended particles that prevent sunlight from penetrating into the deeper parts of water. Turbidity of a water body is usually caused due to the growth of phytoplankton including algae or cyanobacteria, dissolved organic compounds or other elements like slit and clay. Turbidity is an important indicator for measuring water quality. Higher level of turbidity not only makes water unsuitable for drinking but also fosters the growth of pathogens and reduces the aesthetic quality of water. Lake water with turbidity up to 10 NTU is generally acceptable, up to 50 NTU is considered moderately turbid while greater than 50 NTU is harmful for aquatic plants and animals (DataStream, 2021).



SDG RELEVANCE

6 CLEAN WATER AND SANITATION

Goal 6: Ensure availability and sustainable management of water and sanitation for all.

Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

Indicator 6.3.2: Proportion of bodies of water with good ambient water quality.

COPERNICUS DATA

Dataset	: Lake Water Quality
Provider	: Copernicus Global Land Service
Sensor	: Sentinel-2 MSI
Data type	: Gridded
Horizontal coverage	: Europe and Africa
Horizontal resolution	: 100 m
Vertical coverage	: Surface
Temporal coverage	: Jan 2019 - present
Temporal resolution	: 10 days
File format	: NetCDF-4

Copernicus data for lake water quality reveals that lake Turkana has clear and less turbid water in its southernmost spatial extent while the level of turbidity significantly increase as we move northwards. The lake is characterized with extreme values of turbidity towards the boundary between Kenya and Ethiopia. The average value of turbidity of lake Turkana on 21 January 2023 is 20.32 NTU, which implies that the lake water is moderately turbid. The Omo river wetland situated in the northern boundary of the lake seems to be the major contributor for its higher turbidity towards the north. This could be due to the heavy surface runoff from the catchment area of the river that flow into the lake. Based on Copernicus data, it can be said that the water in the northern part of the lake is totally unsuitable for utility. Proper treatment such as disinfection, filtration or use of chemical additives is necessary prior to the lake water consumption. Alternatively, wetland vegetation can be increased in order to naturally reduce the turbidity that result from heavy surface runoffs flowing into the lake.

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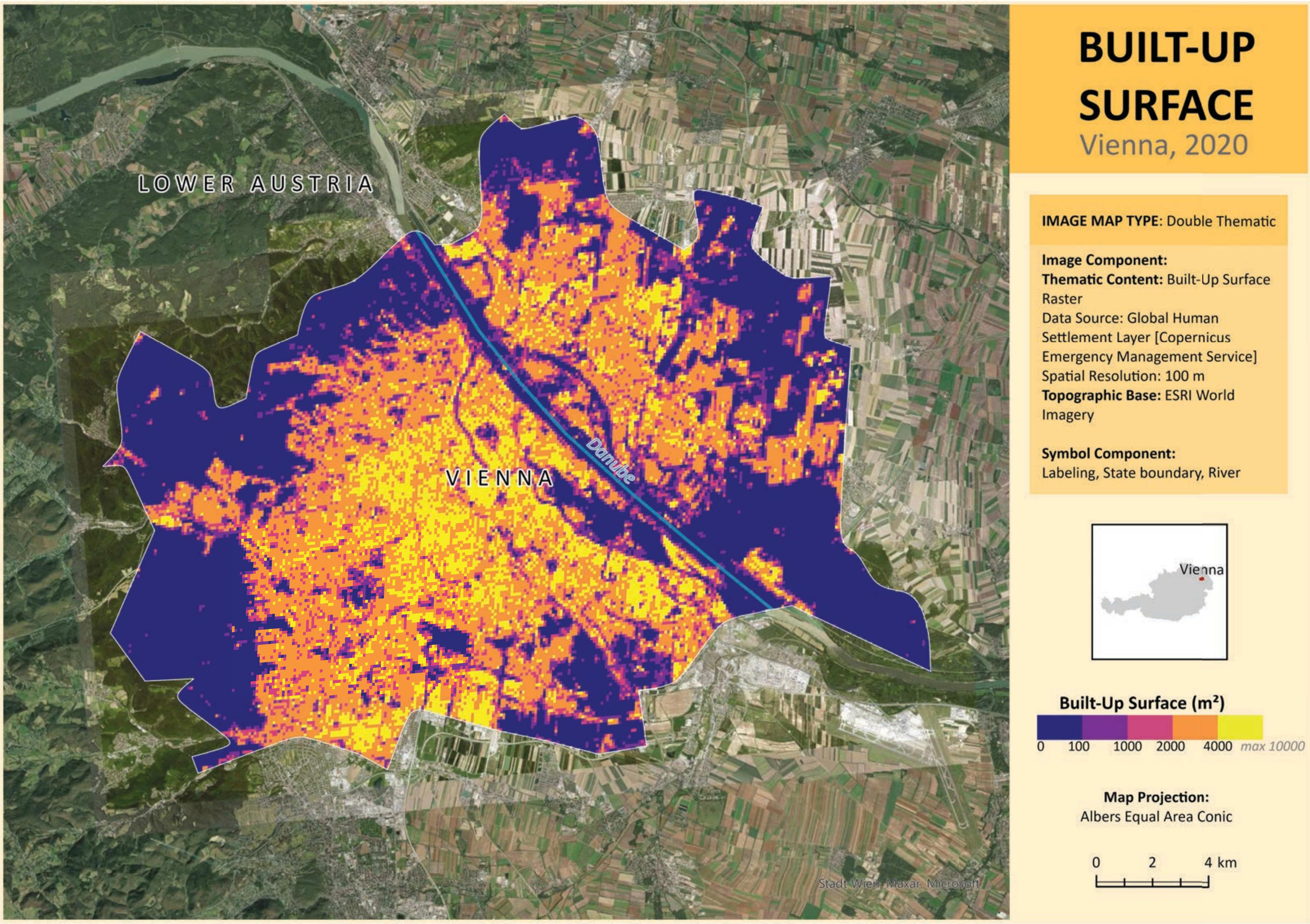
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#04

Built-up surface is the area defined by the presence of buildings or roofed structures. It excludes the area occupied by pavements, streets, parks and open spaces. The level of built of surface determines the quality or habitability of a city. A city with highly dense built-up surface not only looks aesthetically unpleasant but also has problems with urban mobility, social interaction, public health, safety and security. Cities are generally considered as more inclusive and sustainable when they follow a settlement pattern with higher proportion of area dedicated to open public spaces. To ensure an adequate foundation for a well-functioning and prosperous city, the UN-Habitat recommends an average of 45 - 50% of urban land be allocated to streets and open public spaces.



Copernicus data for built-up surface of Vienna reveals that the city is marked with the presence of a very dense urban fabric in its core central region. The built-up density decreases gradually as we move away from the center towards the city outskirts. The average value of built-up surface for Vienna city in the year 2020 is 1687.31 m², which can be considered quite an ideal value for human settlement. Some small patches visible in dark blue color in the central part as well as along the periphery of Danube river indicate the presence of parks and other green spaces within the city. The parts of the city bordering to Lower Austria in the eastern and western extents have almost no built-ups due to the presence of forests, meadows, croplands and cemeteries. Copernicus built-up surface data confirms that the affluence of open public space in Vienna city makes it highly suitable for urban livelihood. The share of public space in the city can be enhanced further by creating boulevards and green corridors particularly in the core central area that are overwhelmed by dense built-up surfaces.

SDG RELEVANCE

11 SUSTAINABLE CITIES AND COMMUNITIES

Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable.

Target 11.7: By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities

Indicator 11.7.1: Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities

COPERNICUS DATA

Dataset	: Global Human Settlement Built-Up Surface
Provider	: Copernicus Emergency Management Service
Data type	: Gridded
Projection	: World Mollweide
Horizontal coverage	: Global
Horizontal resolution	: 100 m
Vertical coverage	: Surface
Temporal coverage	: 1975 to 2030
Temporal resolution	: 5-year interval
File format	: TIFF

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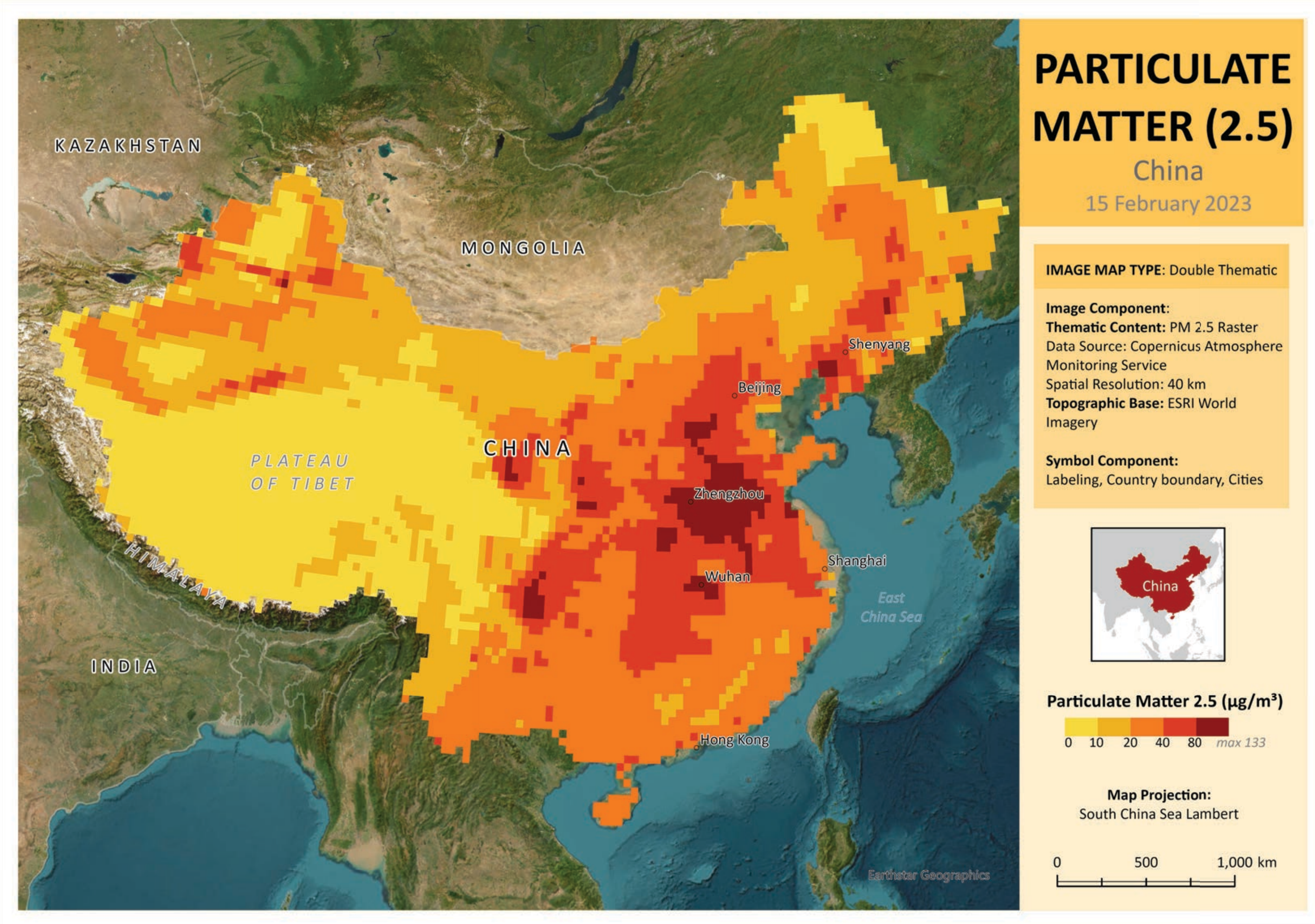
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS #05

Particulate matter are the tiny particles of solid or liquid suspended in the air. Such particles usually include dust, dirt, soot, smoke or drops of liquid. They have different shape, size, composition and may result from both natural as well as anthropogenic sources. The particulate matter found in the atmosphere can be broadly categorized into PM10 and PM2.5, or sometimes even finer. Particulate matter block the incoming solar radiation and lead to poor visibility. They cause adverse health effects related to eyes, skin and lungs. Such pollutants are primarily responsible for lowering the air quality in the cities and deteriorating the urban infrastructure. As per WHO Air Quality Guidelines, the 24-hour average concentration of PM2.5 in the cities should not exceed 15 µg/m³.



Copernicus data for particulate matter 2.5 reveals that the concentration of PM2.5 in China is very high in the urban areas. The cities of Zhengzhou and Wuhan have extreme level of particulate pollution whereas the Plateau of Tibet and the region near the Himalaya exhibit a very minimal level of particulate pollution. The average value of PM 2.5 concentration in China as of 15 February 2023 is 23.23 µg/m³ which is outside the acceptable level as specified by WHO. Copernicus data helps to discover that human activities are primarily responsible for the particulate pollution in China as the cities with dense human settlements have much higher particle concentration than the natural regions that are untouched by human settlement. This could be due to higher industrial production, fuel combustion, vehicle exhaust and smoking in the cities. The data serve to monitor the air quality of China by identifying the core regions of higher particulate pollution. Some immediate actions are suggested to be undertaken in the cities to control particulate pollution such as the minimization of anthropogenic emissions and the use of air filters.

SDG RELEVANCE

11 SUSTAINABLE CITIES AND COMMUNITIES

Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable.

Target 11.6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.

Indicator 11.6.2: Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)

COPERNICUS DATA

Dataset	: CAMS Global Atmospheric Composition Forecasts
Provider	: Copernicus Atmosphere Monitoring Service
Data type	: Gridded
Horizontal coverage	: Global
Horizontal resolution	: 0.4°x0.4°
Vertical coverage	: Total column
Vertical resolution	: Single level
Temporal coverage	: 2015 to present
Temporal resolution	: Hourly
File format	: NetCDF-3

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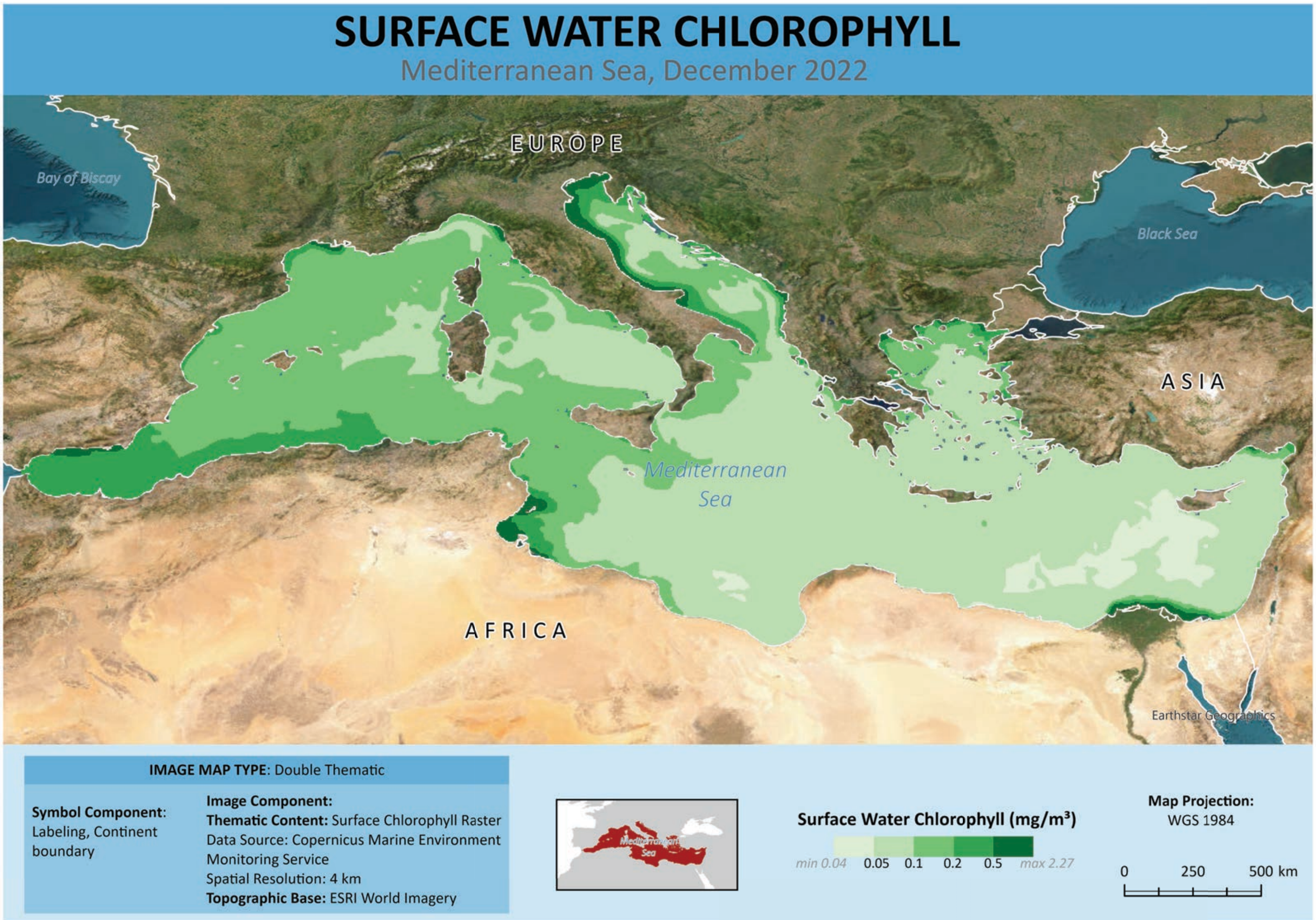
#06

Surface water chlorophyll is an important indicator of coastal eutrophication and marine pollution. Chlorophyll is a common pigment found in the living cells of plant species, algae and cyanobacteria that supports the natural process of photosynthesis. Excessive concentration of chlorophyll in phytoplankton can lead to the accumulation of nutrients such as nitrogen, phosphorous and silica in water. Such over enrichment of nutrients in water bodies fosters algal growth, kills fishes, depletes oxygen levels and increases the toxicity of water. The amount of chlorophyll concentration varies depending on the season, depth, temperature and nature of water bodies. As per the guiding standard for marine water quality, for a healthy and ambient marine water, the concentration of chlorophyll-a should not exceed 4 mg/m³ (MOCCAEUAE, 2020).



Copernicus data for surface water chlorophyll in Mediterranean Sea reveals that the chlorophyll concentration is quite higher in the western extent of the sea than the eastern part. Typically, the coastal regions of Italy, France, Spain, Tunisia and Egypt are more concentrated with the presence of chlorophyll. The average value of surface water chlorophyll in Mediterranean Sea as of December 2022 is 0.12 mg/m³ which falls within the acceptable limit of marine water quality. The distribution of chlorophyll values indicates that the surface water of Mediterranean Sea is fairly ambient and very low in nutrient pollution. It can be visualized from the Copernicus data that the concentration of surface water chlorophyll is much higher in the coastal water than the offshore water. This could be due to the result of high nutrients supply from the mainland region to the coastal area through river runoffs. Copernicus data helps to monitor the coastal eutrophication and tropic state of marine resources by determining the level of chlorophyll concentration and thereby recommends to lower the nutrient pollution through the reduced use of fertilizers and proper sewage disposal.

SDG RELEVANCE

14 LIFE BELOW WATER

Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Target 14.1: By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

Indicator 14.1.1: Index of coastal eutrophication

COPERNICUS DATA

Dataset	: Mediterranean Sea Biogeochemistry Reanalysis
Provider	: Copernicus Marine Environment Monitoring Service
Data type	: Gridded
Horizontal coverage	: Mediterranean Sea
Horizontal resolution	: 4 km
Vertical coverage	: 125 depth levels
Temporal coverage	: July 2021 to present
Temporal resolution	: Daily, Monthly, Yearly
Projection	: WGS 1984
File format	: NetCDF-4

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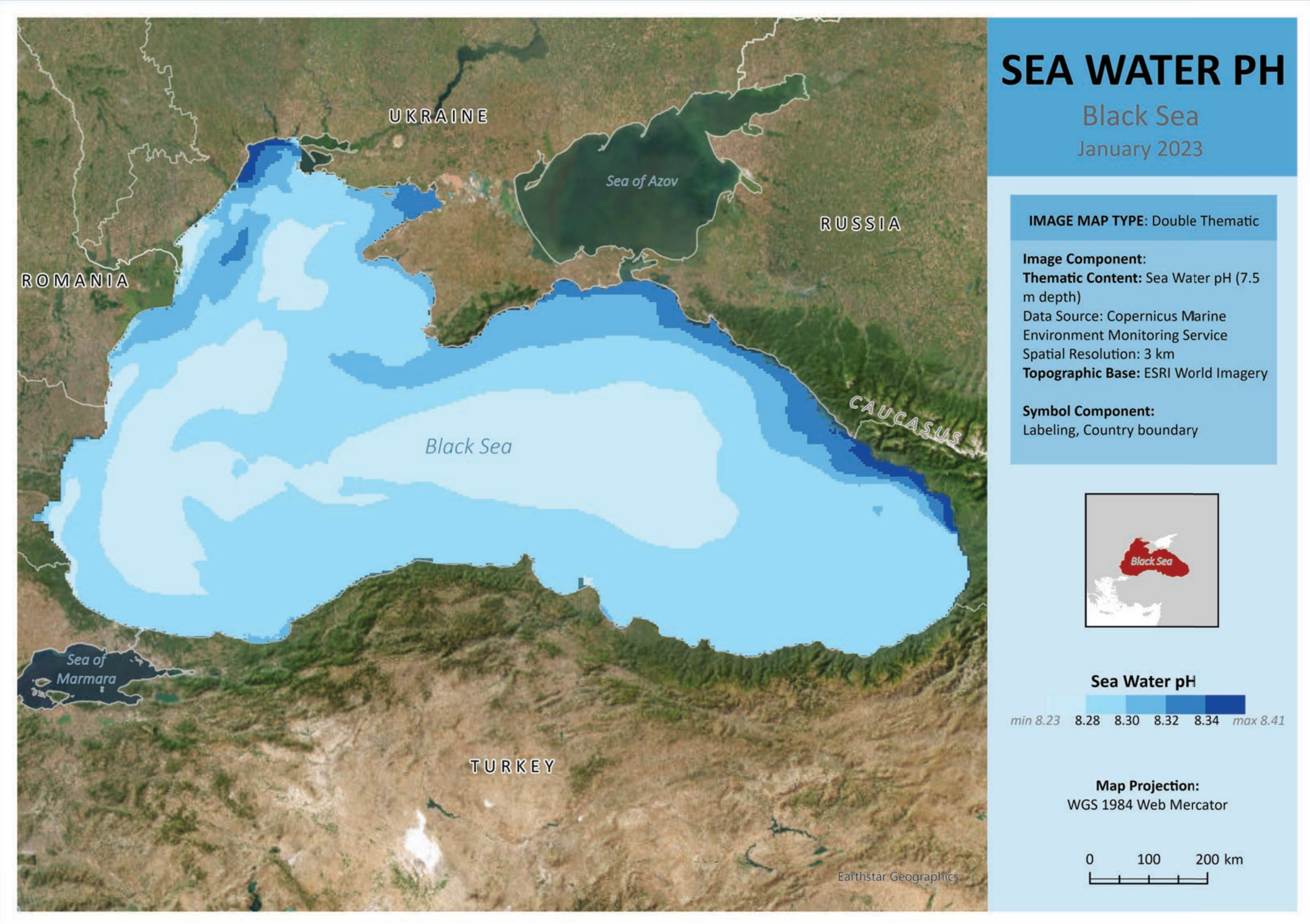
#07

Sea Water PH gives the measure of acidic or alkaline nature of marine water. It plays an important role in the carbon cycle of oceans and helps to monitor the process of ocean acidification. Ocean acidification occurs when the excess of carbon dioxide is absorbed by the oceans. Increase in acidity of sea water has negative impacts on growth and reproduction of shell fish and skeletal creatures. It also affects food web and causes disruption in marine ecosystem. Sea waters are usually slightly alkaline due to the higher concentration of dissolved salts and minerals but their pH can vary with temperature, salinity and depth. Depending on the local conditions, the pH of sea water is expected to range between 7.5 and 8.5 (BBWW, 2021).



Copernicus data for sea water pH of Black Sea at 7.5m depth reveals that the sea water is alkaline with slight variations in pH values within its spatial extent. It can be observed that the coastal regions of the sea are more alkaline than the offshore areas. Higher pH values are concentrated near the coastal waters of Ukraine and Russia in the north and Georgia in the east while the coastal areas of Turkey in the south and Bulgaria and Romania in the west have water with low pH values. The average value of sea water pH at 7.5m depth of Black Sea as of January 2023 is 8.29, which falls within the acceptable limit. Copernicus data reveals some signs of ocean acidification in the central part of the sea where lower pH values are evident than the surrounding regions. This implies that the deep waters of Black Sea are more acidic than surface waters. In order to regulate the acidity of marine resources, it can be recommended to reduce the anthropogenic emissions of carbon dioxide that acts as the main driver for ocean acidification.

SDG RELEVANCE

14 LIFE BELOW WATER

Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Target 14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels

Indicator 14.3.1: Average marine acidity (pH) measured at agreed suite of representative sampling stations

COPERNICUS DATA

Dataset	: Black Sea Biogeochemistry Reanalysis
Provider	: Copernicus Marine Environment Monitoring Service
Data type	: Gridded
Horizontal coverage	: Black Sea
Horizontal resolution	: 3 km
Vertical coverage	: 31 depth levels
Temporal coverage	: January 2021 to present
Temporal resolution	: Daily, Monthly
Projection	: WGS 1984
File format	: NetCDF-4

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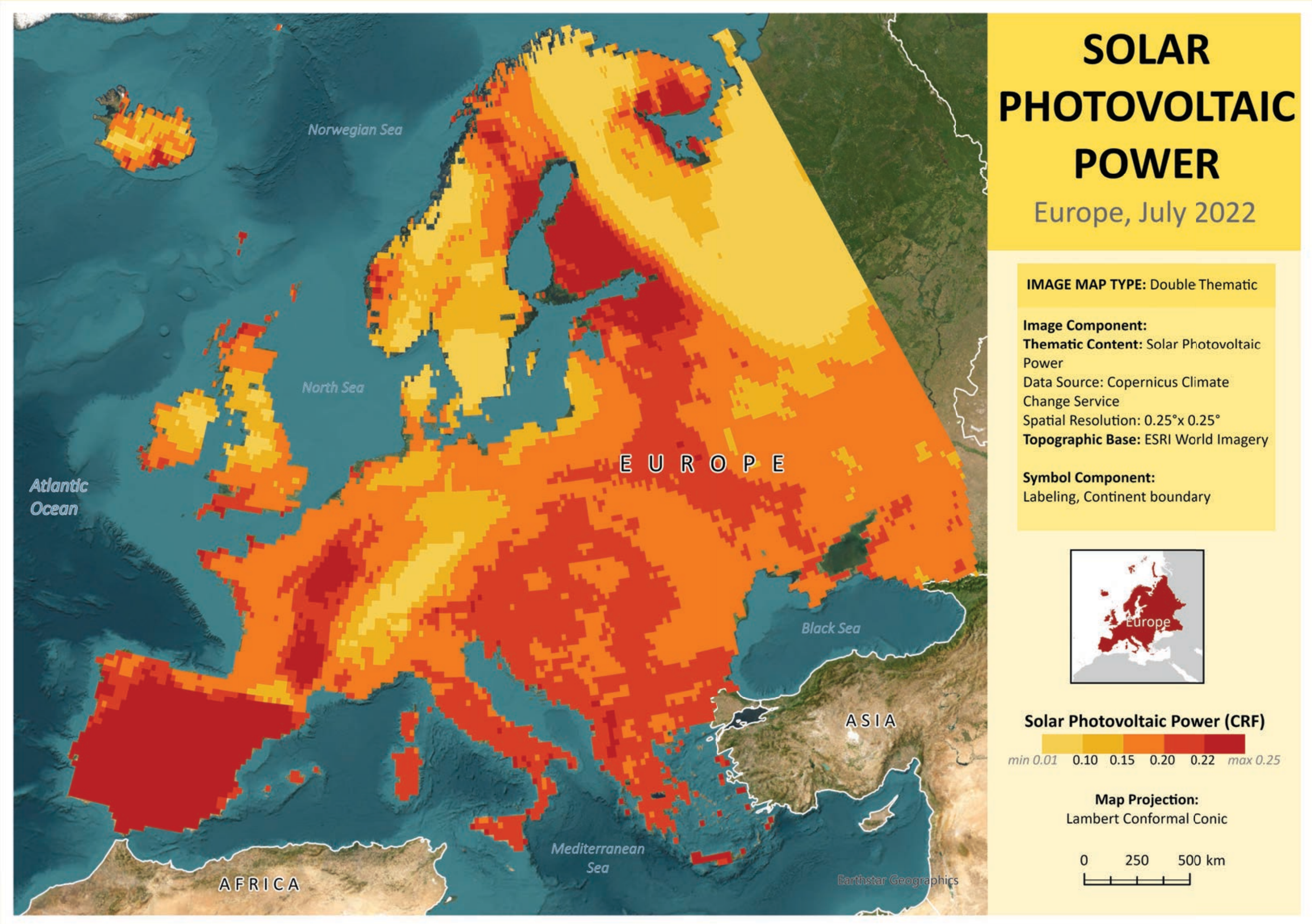
#08

Solar photovoltaic power expressed as capacity factor is the ratio of actual generation of solar power to the installed capacity. Solar energy is the form of renewable energy that is clean, sustainable and totally inexhaustible. The increased use of solar energy helps to reduce carbon emissions and lowers the impact of global warming and climate change. Solar photovoltaics use solar cells to convert sunlight directly into electricity through photovoltaic effect. The capacity factor of solar photovoltaic cells depend on how long the cells are operational or how much of solar energy the cells produce. Higher value of capacity factor indicates better performance of the system. The optimal value of capacity factor for solar energy usually ranges between 0.1 and 0.25 (SolarSena, 2022).



Copernicus data for solar photovoltaic power generation for Europe reveals that the capacity factor for solar power generation is greater in the southwestern region of the continent. Spain and Portugal have the maximum capacity factor ratio while the Alps region, Nordic countries and Russia have the least values. The Balkan region and the Central Europe exhibit moderate values of solar capacity factor. The average value of solar photovoltaic power as capacity factor ratio for Europe in July 2022 is 0.16, which seems to be quite low for the summer observation. This could be possibly due to the geographical extent of Europe as it is situated higher than the equator and has fewer sunshine hours. Copernicus data on solar photovoltaic power helps to identify the regions with higher capacity factor and thereby suggests to establish more solar plants in those regions for maximum power generation. This helps to promote clean energy and minimize the excess of carbon emissions from the burning of fossil fuels. The generation of solar power can also be maximized through proper adjustment of size and inclination of the photovoltaic cells.

SDG RELEVANCE

7 AFFORDABLE AND CLEAN ENERGY

Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all

Target 7.2: By 2030, increase substantially the share of renewable energy in the global energy mix

Indicator 7.2.1: Renewable energy share in the total final energy consumption

COPERNICUS DATA

Dataset	: Climate and Energy Indicators for Europe from 2005 to 2100
Provider	: Copernicus Climate Change Service
Data type	: Gridded
Horizontal coverage	: Europe
Horizontal resolution	: 0.25° x 0.25°
Vertical coverage	: 0 to 100 m
Vertical resolution	: Single level
Temporal coverage	: 2005 to 2100
Temporal resolution	: 3-hourly, daily
File format	: NetCDF

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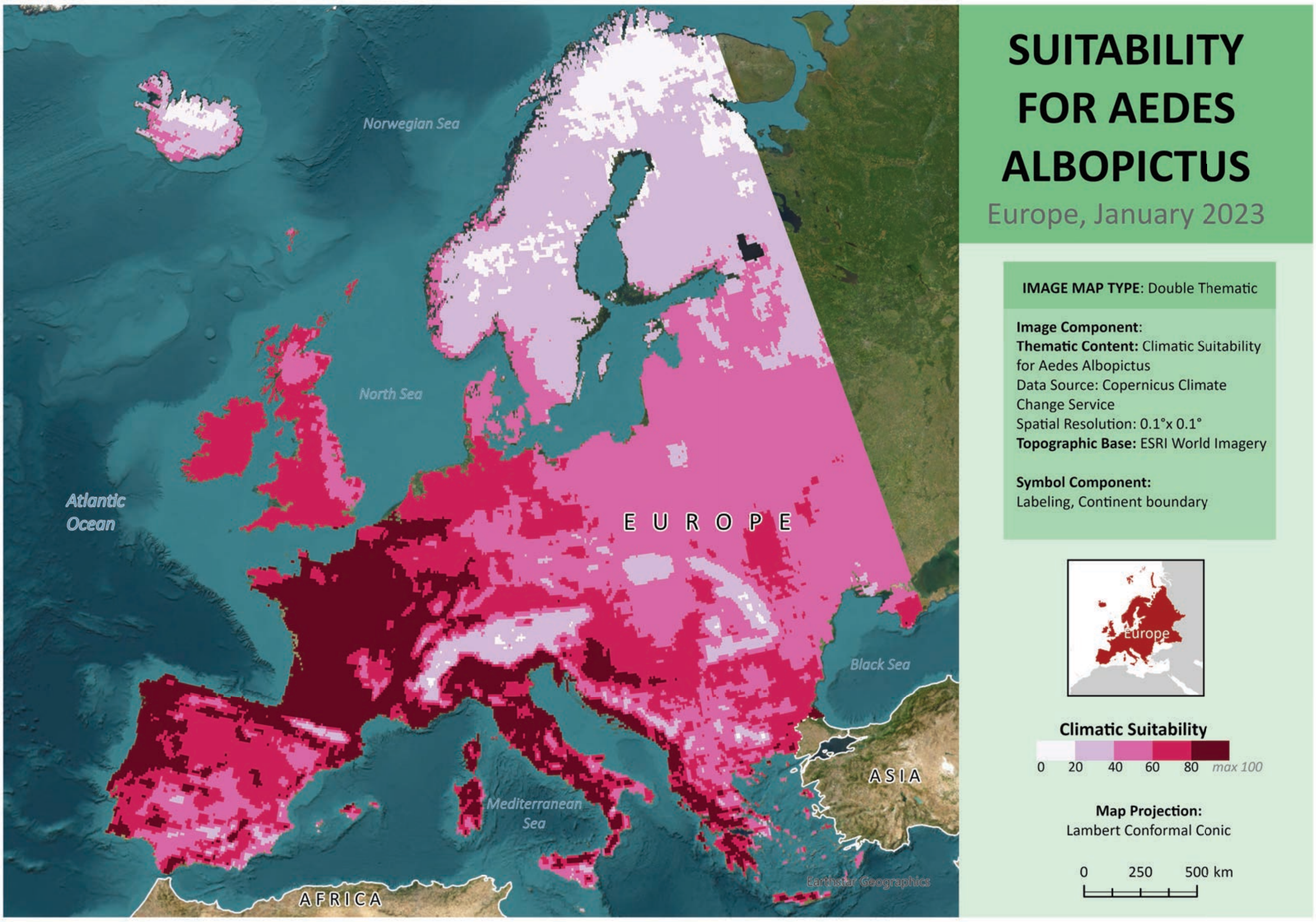
#09

Aedes Albopictus, also known as tiger mosquito is an important transmitter of vector-borne diseases like yellow fever, dengue, Zika and Chikungunya. These species of mosquito were originated from Southeast Asia and are commonly found in tropical and subtropical regions with warm and humid climate. They usually breed in wetlands including swamps and marshes and are capable of multiplying significantly in suitable climatic conditions. The tiger mosquito causes a number of casualties and deaths every year posing a serious threat to health and well-being. Climatic suitability for tiger mosquito depends on various factors such as rainfall, temperature, humidity, etc. It is measured on a scale of 0 to 100 where 0 means the least suitable and 100 means the most suitable climatic condition (C3S, 2019).



Copernicus data on climatic suitability for Aedes Albopictus in Europe reveals that the Southwestern region of Europe has the most suitable climatic conditions for the mosquito. France exhibits the highest climatic suitability than any other country. Italy, Portugal, Croatia and Belgium are also marked with a greater climatic suitability. The Alps region and the Nordic countries are the least climatically suitable regions for the adaptation of the mosquito. The average value for climatic suitability for Aedes Albopictus in Europe as of January 2023 is 50.54 which indicates that Europe is moderately suitable for the breeding of tiger mosquito. Copernicus data helps to identify and confirm that the regions with higher summer temperature, mild winter temperature and sufficient amount of rainfall are at a greater risk for the spread of mosquito. It also supports the evidence that the mosquitoes are lethargic to lower temperatures and suggests the need to uptake necessary measures to prevent the warming of the continent. The suitability for Aedes Albopictus can also be controlled naturally through the elimination of swamps, proper garbage disposal and the growth of mosquito repellant plants.

SDG RELEVANCE

3 GOOD HEALTH AND WELL-BEING

Goal 3: Ensure healthy lives and promote well-being for all at all ages

Target 3.3: By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases

Indicator 3.3.3: Malaria incidence per 1,000 population

COPERNICUS DATA

Dataset	: Climatic Suitability for the Presence and Seasonal Activity of Aedes Albopictus
Provider	: Copernicus Climate Change Service
Data type	: Gridded
Projection	: WGS 1984
Horizontal coverage	: Europe
Horizontal resolution	: 0.1° x 0.1°
Vertical coverage	: Surface
Temporal coverage	: 1986-2085
Temporal resolution	: Seasonal, yearly
File format	: NetCDF

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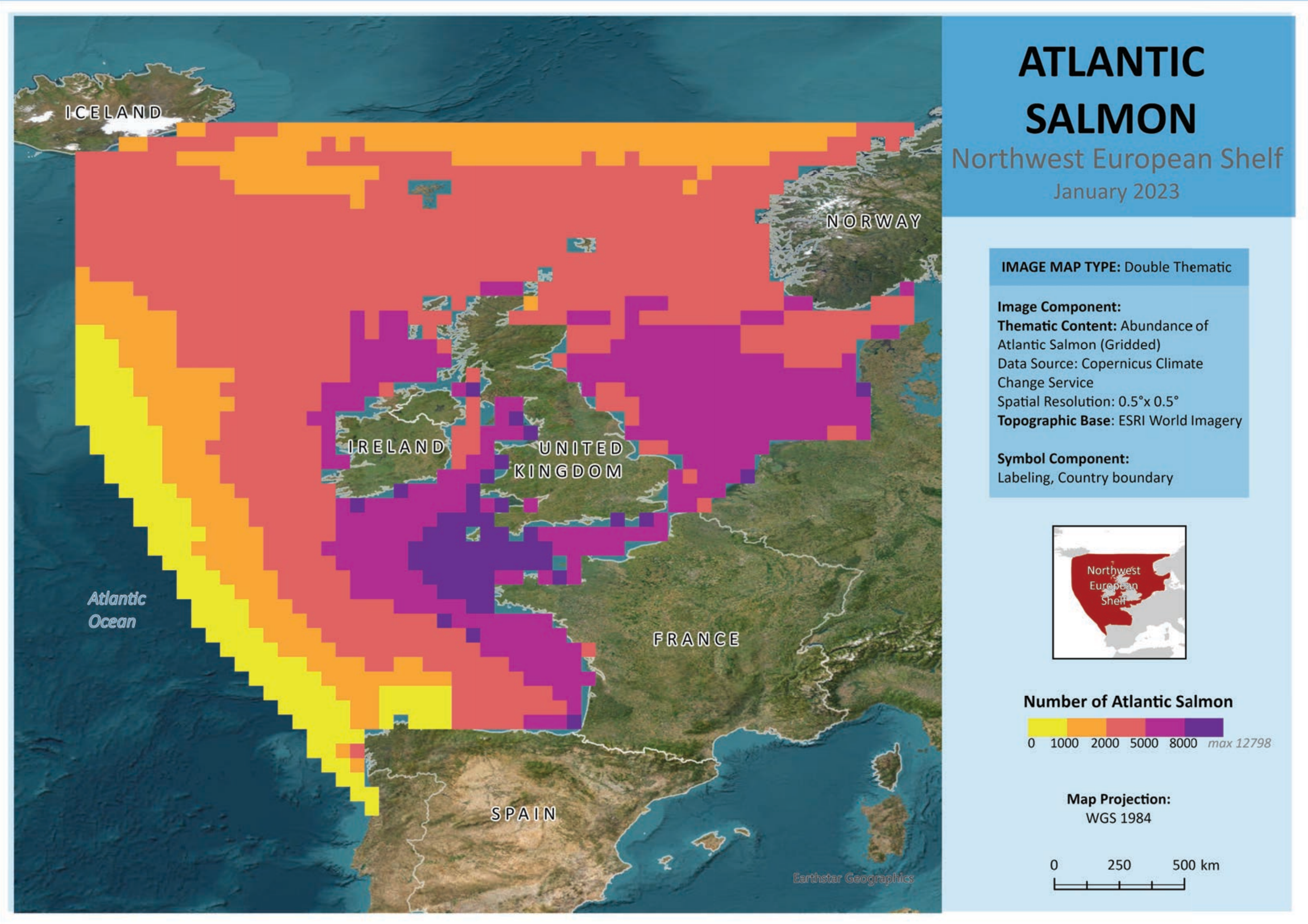
#10

Sustainable fishing is a practice that helps to maintain healthy and productive fish population. Such practice ensures that the abundance of fish does not decline over time due to fishing activities. Changes in the aquatic environment such as warming, acidification, deoxygenation and human activities such as overfishing can pose a serious threat to the fish stocks. Fish species like Atlantic Salmon are highly demanded for human consumption due to their richness in protein and omega-3 fatty acids. Unregulated and illegal harvesting of such fishes can lead to the declination in their number or may even cause permanent extinction in some species. For the North Atlantic Ocean, the abundance of Atlantic Salmon above 5 million can be considered as a sustainable stock (NASCO, 2019).



Copernicus data on abundance of Atlantic Salmon in the Northwest European Shelf reveals that the fish stock is maximum along the English Channel between the boundary of France and the United Kingdom. The North Sea and the Celtic Sea are also identified with higher abundance of Atlantic Salmon. The number of Salmon declines considerably as we move away from the coastal region of United Kingdom towards Atlantic Ocean in the West and Norwegian sea in the North. The average number of Atlantic Salmon per 0.5° grid in the Northwest European Shelf as of January 2023 is 3530, which indicates not much abundance of the fish stock. The decline in the number of fishes could be possibly due to overfishing activities, marine pollution, climate change and habitat degradation. Copernicus data on fish abundance helps to monitor the population of fish species and thereby support to regulate overfishing and other illegal practices that threaten the fish stock. It recommends the need for the maximum sustainable yield which can be achieved through habitat restoration, water quality management and reduction in overexploitation of marine resources.

SDG RELEVANCE

14 LIFE BELOW WATER

Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Target 14.4: By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics

Indicator 14.4.1: Proportion of fish stocks within biologically sustainable levels

COPERNICUS DATA

Dataset	: Fish Abundance and Catch Data for Northwest European Shelf
Provider	: Copernicus Climate Change Service
Data type	: Gridded
Horizontal coverage	: Northwest European Shelf
Horizontal resolution	: 0.5° x 0.5°
Vertical coverage	: Full water column
Vertical resolution	: Single level
Temporal coverage	: 2006 up to 2050
Temporal resolution	: Yearly
File format	: NetCDF-4

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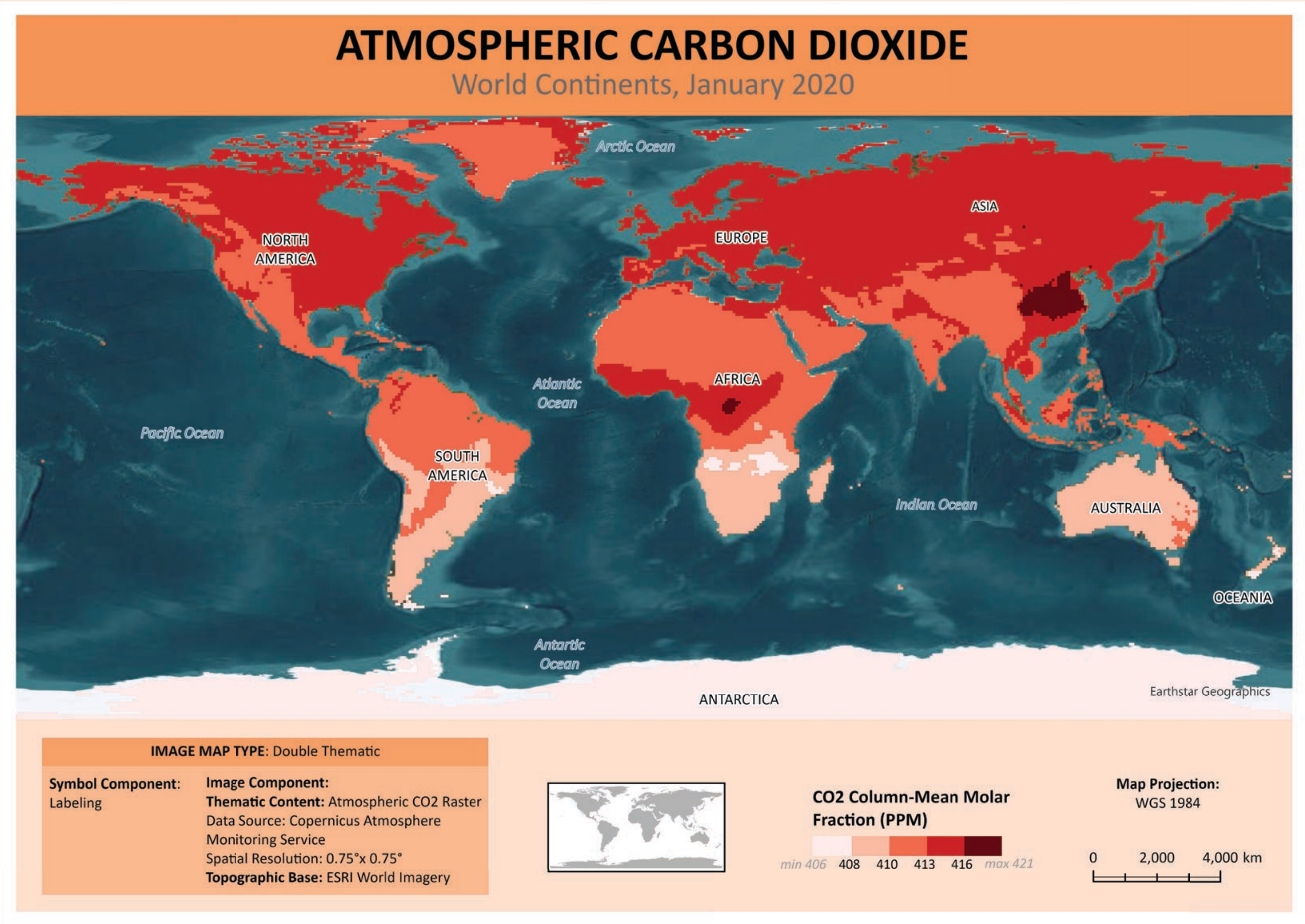
#11

Carbon Dioxide is a greenhouse gas primarily responsible for global warming and climate change. It occurs naturally through the process of cellular respiration as well as through anthropogenic emissions such as fossil fuel combustion, deforestation, vehicle exhaust, etc. Rapid industrialization is the primary reason for the recent increase in levels of carbon dioxide in the atmosphere. With the rise in the concentration of atmospheric carbon dioxide, heat gets trapped inside the earth surface and it starts to warm up. This can lead to severe weather conditions, extreme temperatures and irregular precipitations. As per IPCC, the level of CO2 concentration in the atmosphere should be ideally maintained within 350 ppm. Any concentration exceeding 400 ppm is considered as a potentially dangerous driver for inducing climate change.



Copernicus data for atmospheric carbon dioxide in the world continents reveals that the concentration of CO2 in the atmosphere has reached to an alarming state. The CO2 levels are significantly higher in the northern hemisphere where Asia, Europe, North America and Central Africa are more severely affected than rest of the continents. The highest levels of CO2 concentration can be observed in China and Central Africa while South America, Australia and Antarctica are marked with relatively lower levels of CO2 concentration. The average value of atmospheric carbon dioxide in world continents as of January 2020 is 411 ppm which is already exceeding the critical level. Copernicus data on atmospheric CO2 concentration confirms that our planet is highly vulnerable to the devastating effects of climate change. It points out the urgency to cut down the carbon emissions as soon as possible through the practice of sustainable industrialization. The excessive concentration of carbon dioxide resulting from the combustion of fossil fuels can be minimized by using low carbon alternatives or switching to renewable energy sources such as solar energy, hydropower, wind energy, geothermal energy, etc.

SDG RELEVANCE

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Target 9.4: By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities

Indicator 9.4.1: CO2 emission per unit of value added

COPERNICUS DATA

Dataset	: CAMS Global Greenhouse Gas Reanalysis
Provider	: Copernicus Atmosphere Monitoring Service
Data type	: Gridded
Horizontal coverage	: Global
Horizontal resolution	: 0.75°x0.75°
Vertical coverage	: Total column
Vertical resolution	: Single level
Temporal coverage	: 2003 to 2020
Temporal resolution	: 3-hourly
File format	: NetCDF

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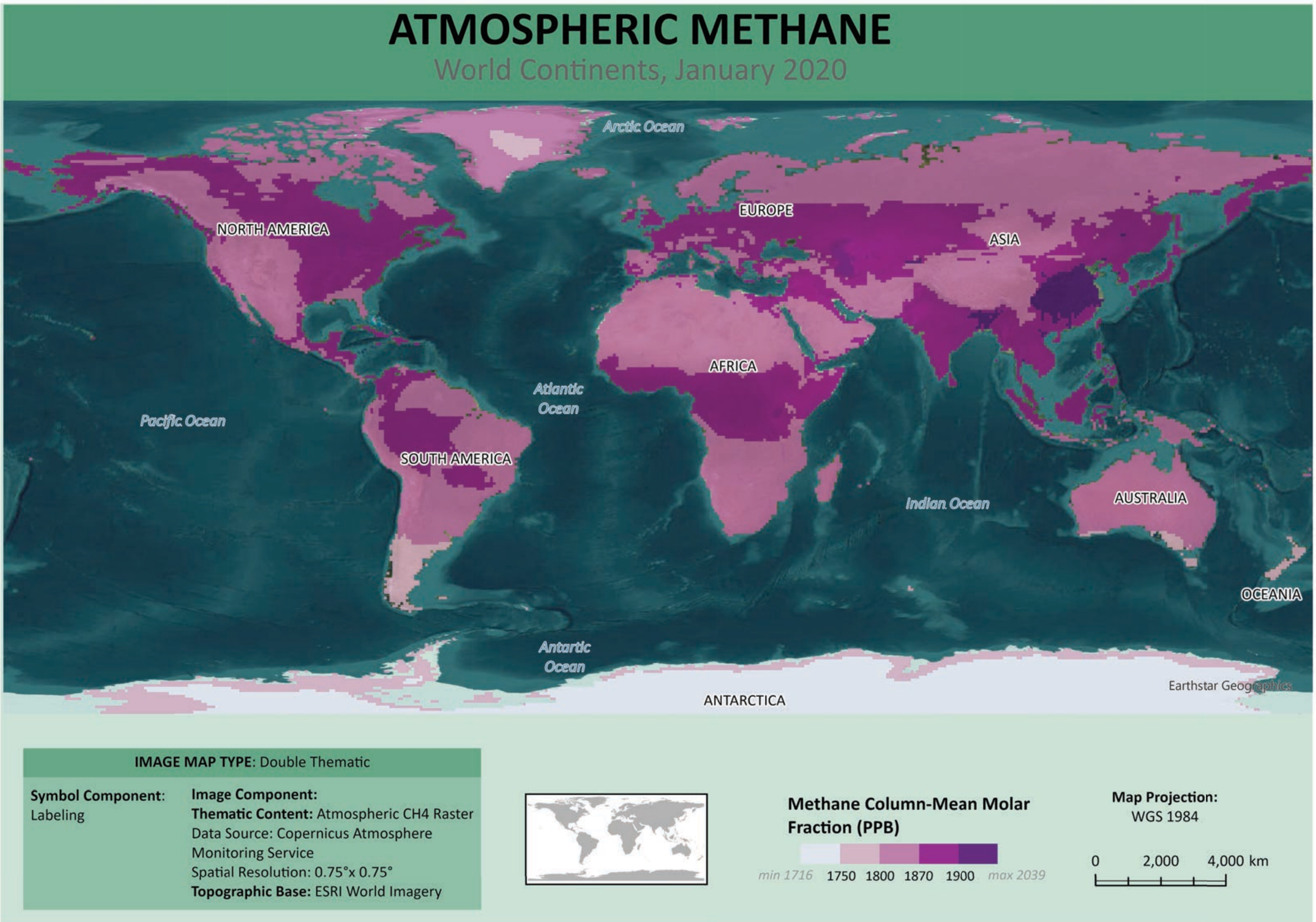
#12

Greenhouse gases are the gases that cause greenhouse effect by trapping the incoming solar radiation and slowing the rate at which the energy escape to the space. The most common greenhouse gases occurring in the atmosphere are carbon dioxide, methane, water vapour, nitrous oxide and ozone. These gases help to keep our planet warm and habitable but their excessive concentration in the atmosphere can lead to global warming. Atmospheric methane is stronger and has higher potential of trapping heat than the same volume of any other greenhouse gases. Methane is mostly released from oil and gas extractions, biomass burning, livestock fermentation, landfills, agriculture and industries. As per IPCC, methane concentration in atmosphere above 1900 ppb can be considered as highly critical for our planet.



Copernicus data for atmospheric methane in world continents reveals that Asia has significantly higher concentration of atmospheric methane than any other continents. Typically, China and Bangladesh exhibit critically higher levels of methane concentration. Other regions like Central Africa, Europe, Eastern part of North America and Northwestern part of South America are also distinguished with higher levels of methane concentration while Australia, Greenland and Antarctica appear relatively safer. The average value of atmospheric methane in world continents as of January 2020 is 1828 ppb which is not so far away from approaching the critical level. The higher concentration of methane in the atmosphere can be a signal for global warming and climate change. Copernicus data helps to monitor the critical levels of methane and other greenhouse gases in the atmosphere and thereby suggest the immediate need for reducing their emissions. The excessive concentration of greenhouse gases can be reduced by switching to clean and green energy sources as early as possible. The emissions can also be reduced through the recycle of waste products as well as through the adoption of climate friendly agriculture and industrial practices.

SDG RELEVANCE

13 CLIMATE ACTION

Goal 13: Take urgent action to combat climate change and its impacts

Target 13.2: Integrate climate change measures into national policies, strategies and planning

Indicator 13.2.2: Total greenhouse gas emissions per year

COPERNICUS DATA

Dataset	: CAMS Global Greenhouse Gas Reanalysis
Provider	: Copernicus Atmosphere Monitoring Service
Data type	: Gridded
Horizontal coverage	: Global
Horizontal resolution	: 0.75°x0.75°
Vertical coverage	: Total column
Vertical resolution	: Single level
Temporal coverage	: 2003 to 2020
Temporal resolution	: 3-hourly
File format	: NetCDF

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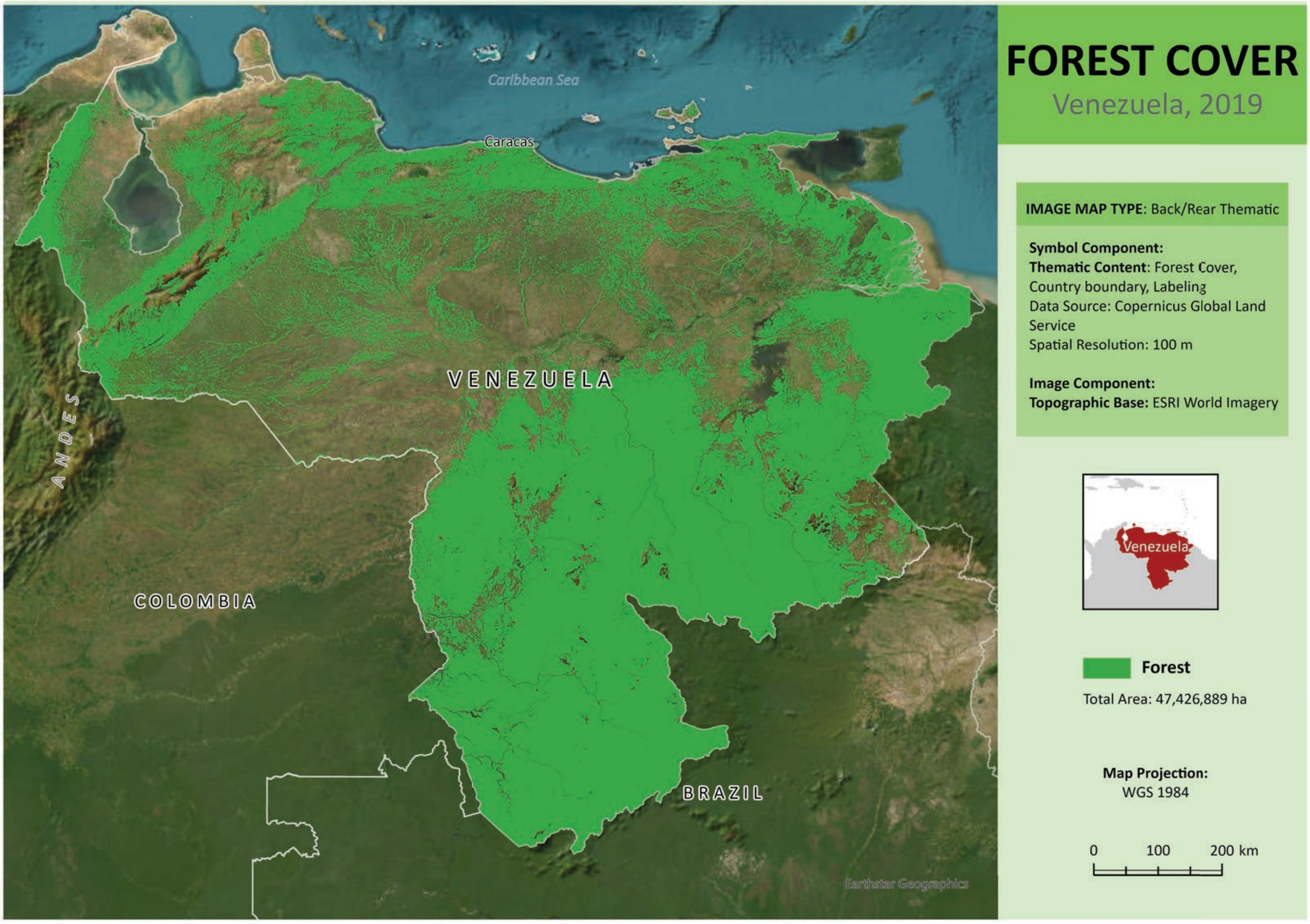
#13

Forests are important natural resource that constitute the terrestrial ecosystem. They support life and provide food, shelter and protection to a variety of wild creatures. Forests regulate the water cycle, release oxygen into the atmosphere as well as play a crucial role in absorbing the excess of carbon emissions. Forests are increasingly being destroyed due to residential, agricultural, industrial and commercial purposes. Rapid deforestation can lead to the occurrence of natural disasters like landslide, flood, drought, erosion, etc causing a serious threat to the biodiversity. Forests once destroyed take a long time to regenerate and might never recover to the same state as before. The problem of deforestation is highly prominent in the tropical rainforests of Southeast Asia, Latin America and Africa.



Copernicus data on global land cover provides spatial information on various land cover categories across the globe. The map visualizes Copernicus data on forest cover in Venezuela which reveals that the country has an abundance of forest particularly in its Southern extent. The Amazon rainforest contributes to a major share of the forest area in the country. The total area covered by forests in Venezuela in the year 2019 is 47,426,889 hectares, which indicates 52.01% of total area of the country. This represents a fairly good proportion of forest area in the country, although the forest in Venezuela is found to decline rapidly each year. This is probably resulted from the ongoing deforestation in Venezuela due to mining activities, intensive agriculture, forest fire and overgrazing. The Amazon rainforest in the South undergoes a rapid decline in its area each year due to the mining of gold, coltan, diamond and bauxite in the region of Orinoco. Copernicus data on forest cover helps to monitor the status of forest and thereby suggests the need to take urgent action against deforestation for sustainable forest management.

SDG RELEVANCE

15 LIFE ON LAND

Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Target 15.1: By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements

Indicator 15.1.1: Forest area as a proportion of total land area

COPERNICUS DATA

Dataset	: Global Land Cover
Provider	: Copernicus Land Monitoring Service
Data type	: Gridded
Thematic classes	: 23
Horizontal coverage	: Global
Horizontal resolution	: 100 m
Temporal coverage	: 2015-2019
Temporal resolution	: Yearly
Projection	: WGS 1984
File format	: GeoTIFF

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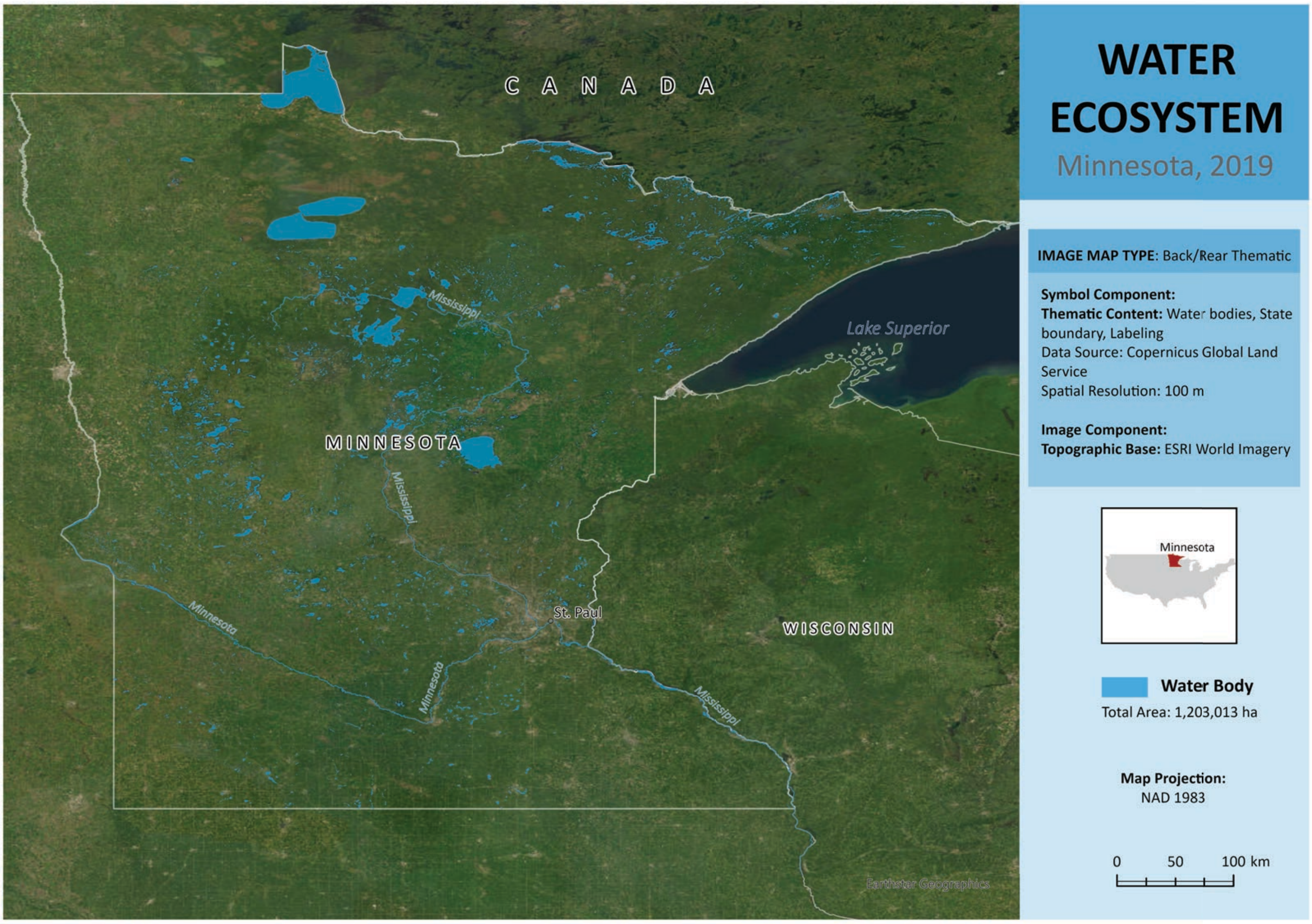
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#14

Water ecosystem constitute of water bodies such as rivers, lakes, seas, oceans, ponds, reservoirs, wetlands, etc. They occur in various shapes and sizes and can be permanent as well as seasonal. Water ecosystems not only provide water for drinking and utility purpose but also support the entire aquatic and marine life. The abundance of healthy water ecosystem helps to enhance the freshness and aesthetics of natural environment. Water ecosystems are increasingly being degraded due to their over exploitation from human intervention. Human activities affect both the quality and quantity of water ecosystem resulting to pollution, turbidity, acidification and oxygen depletion. Unsustainable management of water ecosystem can lead to abnormal surface water dynamics causing the unnatural rate of expansion or shrinkage of water bodies.



Copernicus data on global land cover provides spatial information on various land cover categories across the globe. The map visualizes Copernicus data on the spatial extent of water ecosystem in the state of Minnesota, which reveals that the state has an abundance of inland water bodies including rivers, lakes, reservoirs ponds, wetlands, etc. The total area covered by water bodies in Minnesota in the year 2019 is 1,203,013 hectares, which indicates a fairly good distribution of water bodies in the state. Copernicus data supports the fact that water ecosystems are subject to spatial dynamics i.e., their spatial extent changes over time. The overall area of water bodies in the state of Minnesota is found to increase slightly each year. Such expansion in the surface area could be the result of excessive precipitation or flooding while in some cases, drying out of wetlands and floodplains can also occur due to reduced precipitation or warming. Copernicus data on water bodies help to monitor the status and spatial dynamics of water ecosystem and thereby suggest the necessary measures for their conservation and sustainable management.

SDG RELEVANCE

6 CLEAN WATER AND SANITATION

Goal 6: Ensure availability and sustainable management of water and sanitation for all

Target 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

Indicator 6.6.1: Change in the extent of water-related ecosystems over time

COPERNICUS DATA

Dataset	: Global Land Cover
Provider	: Copernicus Land Monitoring Service
Data type	: Gridded
Thematic classes	: 23
Horizontal coverage	: Global
Horizontal resolution	: 100 m
Temporal coverage	: 2015-2019
Temporal resolution	: Yearly
Projection	: WGS 1984
File format	: GeoTIFF

With the support of the Erasmus+ Programme of the European Union

COPERNICUS MASTER IN DIGITAL EARTH

PARIS LODRON UNIVERSITÄT SALZBURG

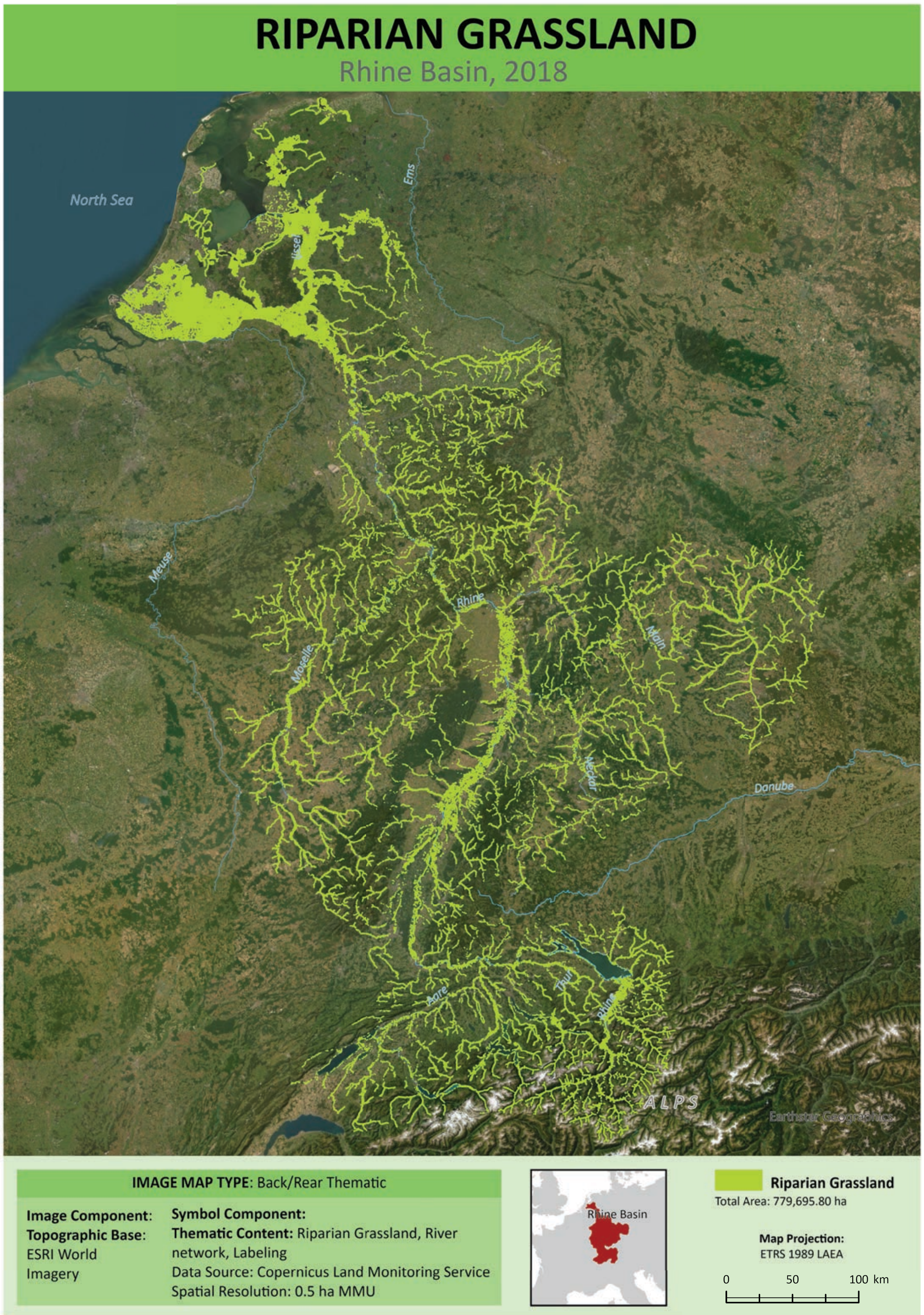
Palacký University Olomouc

Sushmita SUBEDI
Palacký University
Olomouc, 2023

COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#15

Riparian grassland are the green, ecologically important zones along the rivers, streams and freshwater bodies. They play a crucial role in soil conservation, chemical filtration, flood control and protection of aquatic ecosystem. Riparian grasslands provide food to herbivorous creatures and shelter to insects, invertebrates and microorganisms. They also help to maintain natural greenery and regulate the water and nutrient cycles. Riparian grasslands are being increasingly destroyed due to human interventions such as agricultural and residential expansion, use of pesticides and chemical fertilizers, overgrazing, irrigation, fishing, etc. Destruction of riparian grasslands can cause serious threats to both the terrestrial and aquatic ecosystem. Some negative impacts of grassland deterioration include disruption in food web, loss of soil moisture, excessive runoffs, dust storms and desertification.



SDG RELEVANCE

15 LIFE ON LAND

Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Target 15.1: By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements

Indicator 15.1.2: Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type

COPERNICUS DATA

Dataset	**: RZ Land Cover/Land Use**
Provider	**: Copernicus Land Monitoring Service**
Data type	**: Vector**
Thematic classes	**: 55**
Horizontal coverage	**: Europe**
Horizontal resolution	**: 0.5 ha MMU**
Temporal coverage	**: 2010-2013, 2017-2020**
Reference years	**: 2012, 2018**
Projection	**: ETRS 1989 LAEA**
File format	**: Shapefile**

Copernicus data on riparian zone land cover/ land use provides detailed information on the state and characteristics of riparian zones across the European continent. The map visualizes Copernicus data on riparian grassland in Rhine basin which reveals the richness of grassland along the Rhine River and its tributaries. It can be observed that the grassland is denser particularly in the northern extent of the basin. The total area covered by riparian grassland in Rhine basin in the year 2018 is 779,695.80 hectares, which indicates the presence of a substantial amount of grassland in the basin. However, the grassland area in the Rhine basin is found to decline considerably than in the reference year 2012. Copernicus data on riparian grassland helps to monitor the status of grasslands in the riparian zones and illustrate how they have changed between the reference years. It recommends the need for the conservation, restoration and sustainable management of grassland in the Rhine basin in order to prevent it from further deterioration. This can be achieved by minimizing the overexploitation of grasslands and by controlling human intervention on natural resources.

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ATTACHMENT 3

A2 POSTERS

COPERNICUS DATA IN SUSTAINABLE DEVELOPMENT GOALS USING IMAGE MAPS

A2 Posters

Sushmita SUBEDI
Palacký University
Olomouc, 2023

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#01

Soil loss is the loss or reduction in the amount of soil particles from land surface. It is often used interchangeably with soil erosion and is mainly caused due to climate change, rainfall, deforestation, overgrazing, forest fires, mining and construction activities. Although natural forces like wind and water are usually responsible for soil loss, this can be intensified more by human activities on land. Soil loss up to 10 t/ha/yr is generally acceptable (Matthee and Schalkwyk, 1984) but when soil loss exceeds this value, it is considered as a critical environmental problem. Higher level of soil loss leads to land degradation, low productivity, desertification and biodiversity loss. This problem is more prominent in the Caribbean countries, Brazil, Central Africa and Southeast Asia.

SOIL LOSS
Italy, 2021-2050

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Soil Loss Raster
Data Source: Copernicus Climate Change Service
Spatial Resolution: 500 m
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Country boundary, Cities

Soil Loss (t/ha/yr)
0 5 10 20 100 *max 1227*

Map Projection:
Albers Equal Area Conic

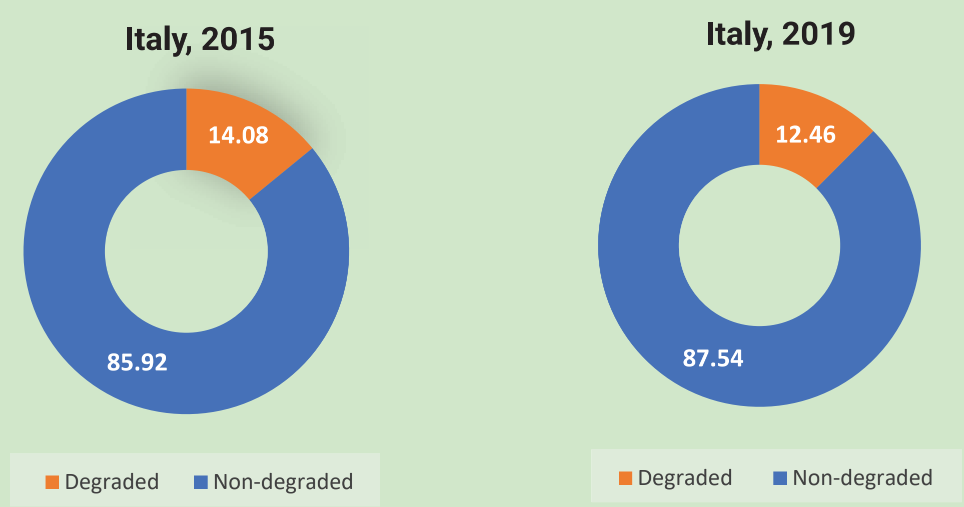
0 100 200 km

COPERNICUS DATA

Dataset	: Soil Erosion Indicators for Italy from 1981 to 2080
Provider	: Copernicus Climate Change Service
Data type	: Gridded
Horizontal coverage	: Italy
Horizontal resolution	: 500 m
Vertical coverage	: Surface
Vertical resolution	: Single level
Temporal coverage	: 1981-2080 (2011-2020 excluded)
Temporal resolution	: 30-year period
File format	: NetCDF-4

Copernicus data for soil loss of Italy reveals that soil loss is considerably higher in the Alps and the Apennine mountains. The area around the Po River has a very minimal soil loss. Also, the island of Sardinia and other plain areas are safer in terms of soil loss. The average value of soil loss in Italy for the reference period 2021-2050 is 8.57 t/ha/yr which falls within the acceptable limit. It can be inferred from the data that the lowlands that are usually suitable for agriculture are less likely to be affected by soil loss. However, the high mountains that serve as the potential touristic destinations encounter severe effects of soil loss. This could be due to the slope of the terrain as greater steepness can lead to higher amount of runoff during heavy rainfall. Copernicus soil loss data allows the users to identify the potential areas of higher soil loss and thereby implement prevention strategies. For instance, plantation and can be done in the erosion prone areas. Also, terrace farming can be recommended in the hills and mountain regions.

Indicator 15.3.1: Proportion of land that is degraded over total land area



Source: UN SDG Database

*"Italy is one of the most heavily impacted countries, with water-induced soil erosion totalling around €619 million per year. Roughly a third of Italy's agricultural area has been severely eroded, equivalent to around 41% of the total EU severely eroded agricultural area." - **ECMWF***

SDG RELEVANCE

15 LIFE ON LAND

Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

Target 15.3: By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.

Indicator 15.3.1: Proportion of land that is degraded over total land area.

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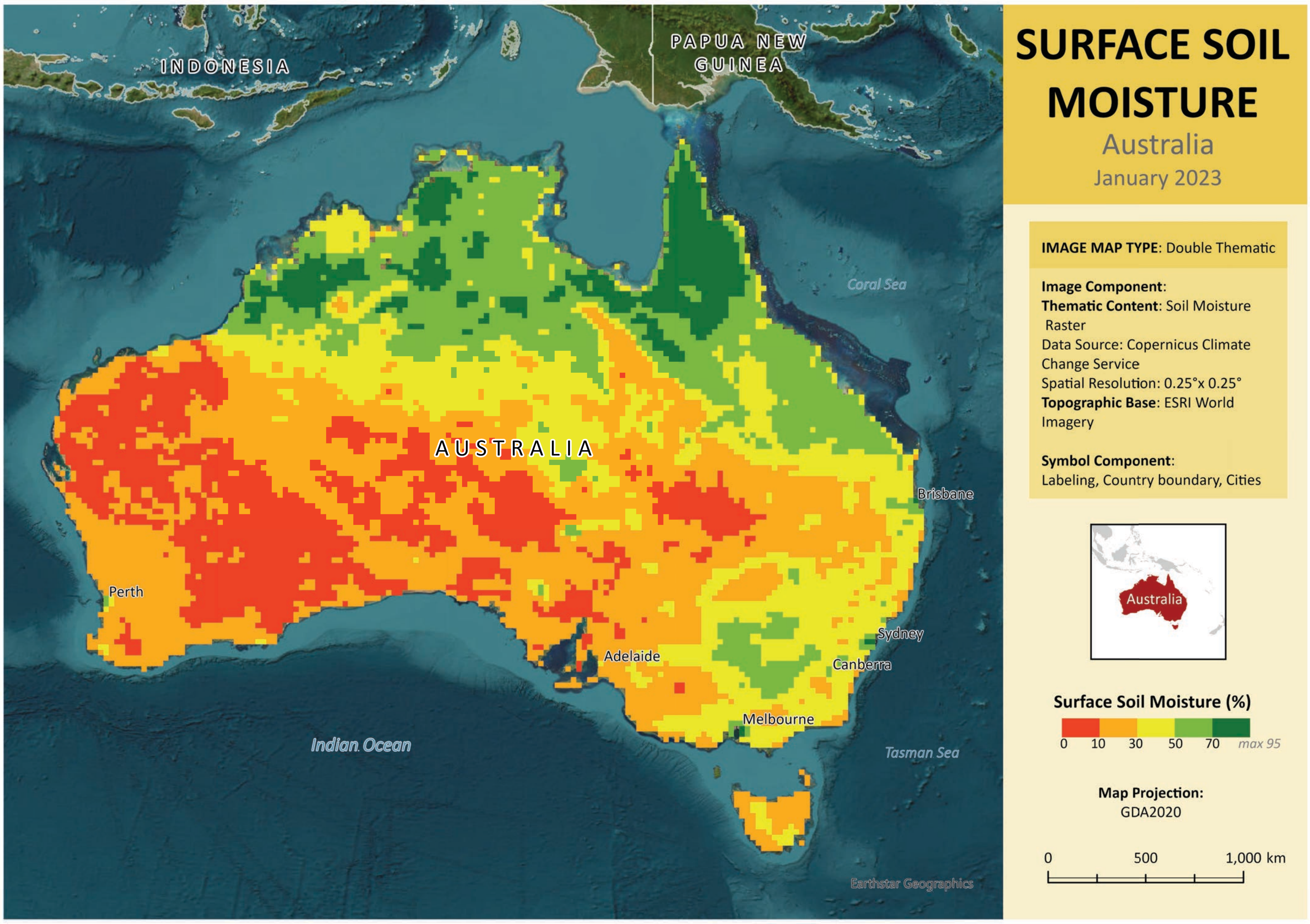
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#02

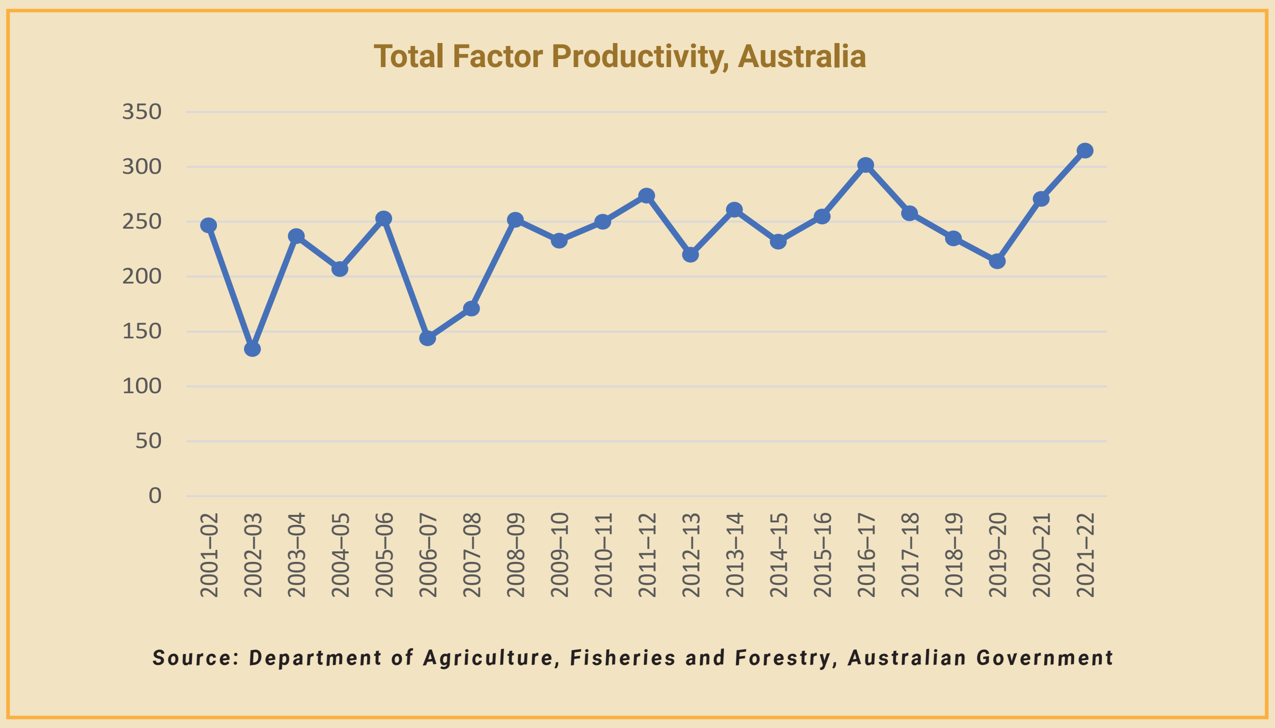
Surface soil moisture is the amount water content present at the topmost level of soil. It is usually measured for a soil layer of 2 to 5 cm depth and is expressed as the percentage of total saturation. Soil moisture is an important factor for crop growth. It helps to regulate the soil temperature and serves as the medium through which plants acquire their nutrients. Surface soil moisture is affected by climate change as well as human activities. The optimum level of surface soil moisture for most of the crops is usually 20% - 60% (EOS, 2023). It is necessary to maintain such level of soil moisture as the deficit or excess can lead to poor crop health, reduced productivity and food scarcity.



Copernicus data for surface soil moisture of Australia reveals that the continent has an excessive moisture content in its northern extent while its central and western parts face deficit in soil moisture. This can be directly related to the topography of the continent as it is composed of deserts its center, plateau towards the west and basins in the north. The surface soil moisture seems to be moderate in the southeastern part of Australia creating a favorable condition for crop growth and productivity. The average value of surface soil moisture of Australia as of January 2023 is 48.5% which falls within the optimum level. The regions having optimum level of soil moisture as indicated by the Copernicus data should be utilized for agricultural purpose as it helps to ensure higher level of crop production. Such regions will require a minimal effort for drainage or irrigation in order to maintain and preserve the moisture content. It can also be recommended that the arid and the damp regions of the continent to be filled with certain crop types that are suited for that particular moisture conditions.

COPERNICUS DATA

Dataset	: Soil Moisture Gridded Data from 1978 to Present
Provider	: Copernicus Climate Change Service
Data type	: Gridded
Projection	: WGS 1984
Horizontal coverage	: Global
Horizontal resolution	: 0.25° x 0.25°
Vertical coverage	: Surface
Temporal coverage	: 1978 to present
Temporal resolution	: Daily, 10-day, Monthy
File format	: NetCDF



"Australia is one of the driest continents on earth. Its soils are ancient and depleted, and just 6 percent of its total area, 45 million hectares, is arable land. But the country produces enough food for 60 million and, overall, is a net exporter by a factor of almost three to one."

SDG RELE-

2 ZERO HUNGER

Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Target 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality

Indicator 2.4.1: Proportion of agricultural area under productive and sustainable agriculture

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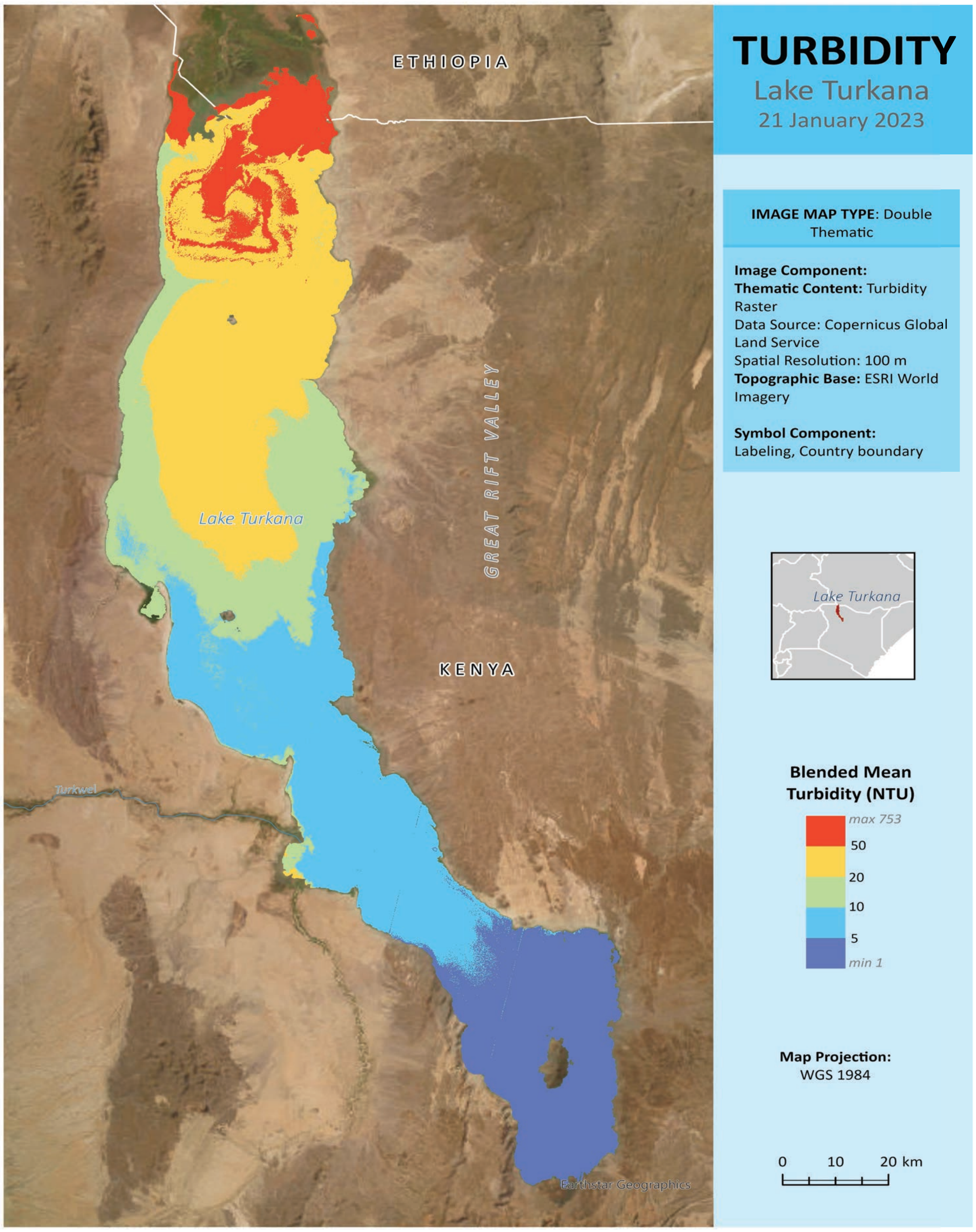
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#03

Turbidity refers to the cloudiness or haziness of liquid. It is characterized with the presence of suspended particles that prevent sunlight from penetrating into the deeper parts of water. Turbidity of a water body is usually caused due to the growth of phytoplankton including algae or cyanobacteria, dissolved organic compounds or other elements like slit and clay. Turbidity is an important indicator for measuring water quality. Higher level of turbidity not only makes water unsuitable for drinking but also fosters the growth of pathogens and reduces the aesthetic quality of water. Lake water with turbidity up to 10 NTU is generally acceptable, up to 50 NTU is considered moderately turbid while greater than 50 NTU is harmful for aquatic plants and animals (DataStream, 2021).

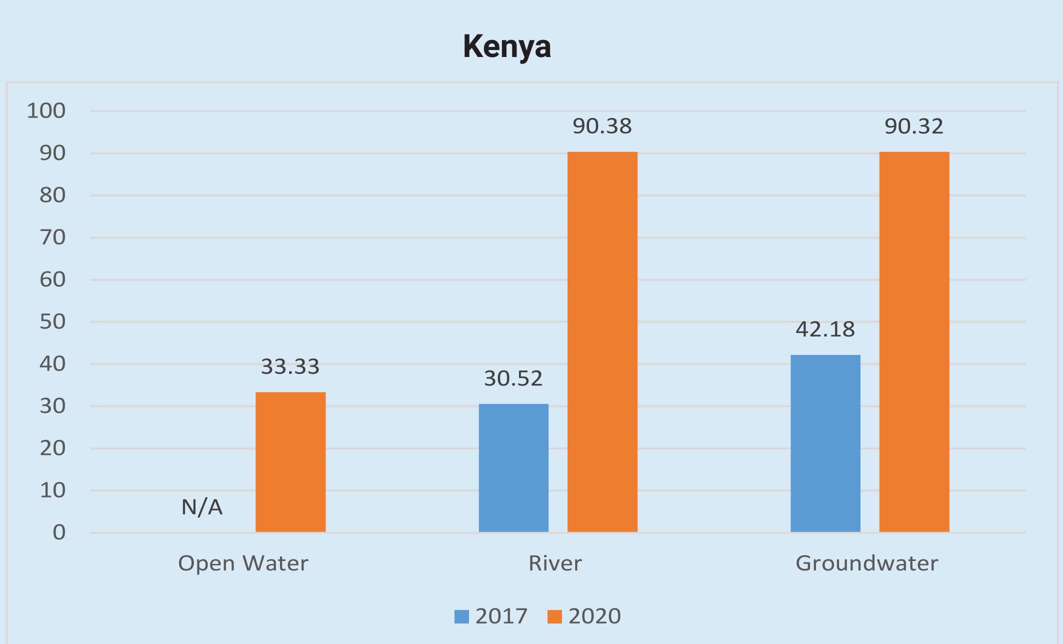


COPERNICUS DATA

Dataset	: Lake Water Quality
Provider	: Copernicus Global Land Service
Sensor	: Sentinel-2 , MSI
Data type	: Gridded
Horizontal coverage	: Europe and Africa
Horizontal resolution	: 100 m
Vertical coverage	: Surface
Temporal coverage	: Jan 2019 - present
Temporal resolution	: 10 days
File format	: NetCDF-4

Copernicus data for lake water quality reveals that lake Turkana has clear and less turbid water in its southernmost spatial extent while the level of turbidity significantly increase as we move northwards. The lake is characterized with extreme values of turbidity towards the boundary between Kenya and Ethiopia. The average value of turbidity of lake Turkana on 21 January 2023 is 20.32 NTU, which implies that the lake water is moderately turbid. The Omo river wetland situated in the northern boundary of the lake seems to be the major contributor for its higher turbidity towards the north. This could be due to the heavy surface runoff from the catchment area of the river that flow into the lake. Based on Copernicus data, it can be said that the water in the northern part of the lake is totally unsuitable for utility. Proper treatment such as disinfection, filtration or use of chemical additives is necessary prior to the lake water consumption. Alternatively, wetland vegetation can be increased in order to naturally reduce the turbidity that result from heavy surface runoffs flowing into the lake.

Indicator 6.3.2: Proportion of bodies of water with good ambient water quality



Source: UN SDG Database

*"Lake Turkana is a saltwater lake with high levels of fluoride. The water is unsafe for consumption. However, with no other alternatives, residents have been forced to drink this water in order to survive. Disease and deformity credited to the consumption of lakewater are common." **-UNICEF***

SDG RELEVANCE

6 CLEAN WATER AND SANITATION

Goal 6: Ensure availability and sustainable management of water and sanitation for all

Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

Indicator 6.3.2: Proportion of bodies of water with good ambient water quality

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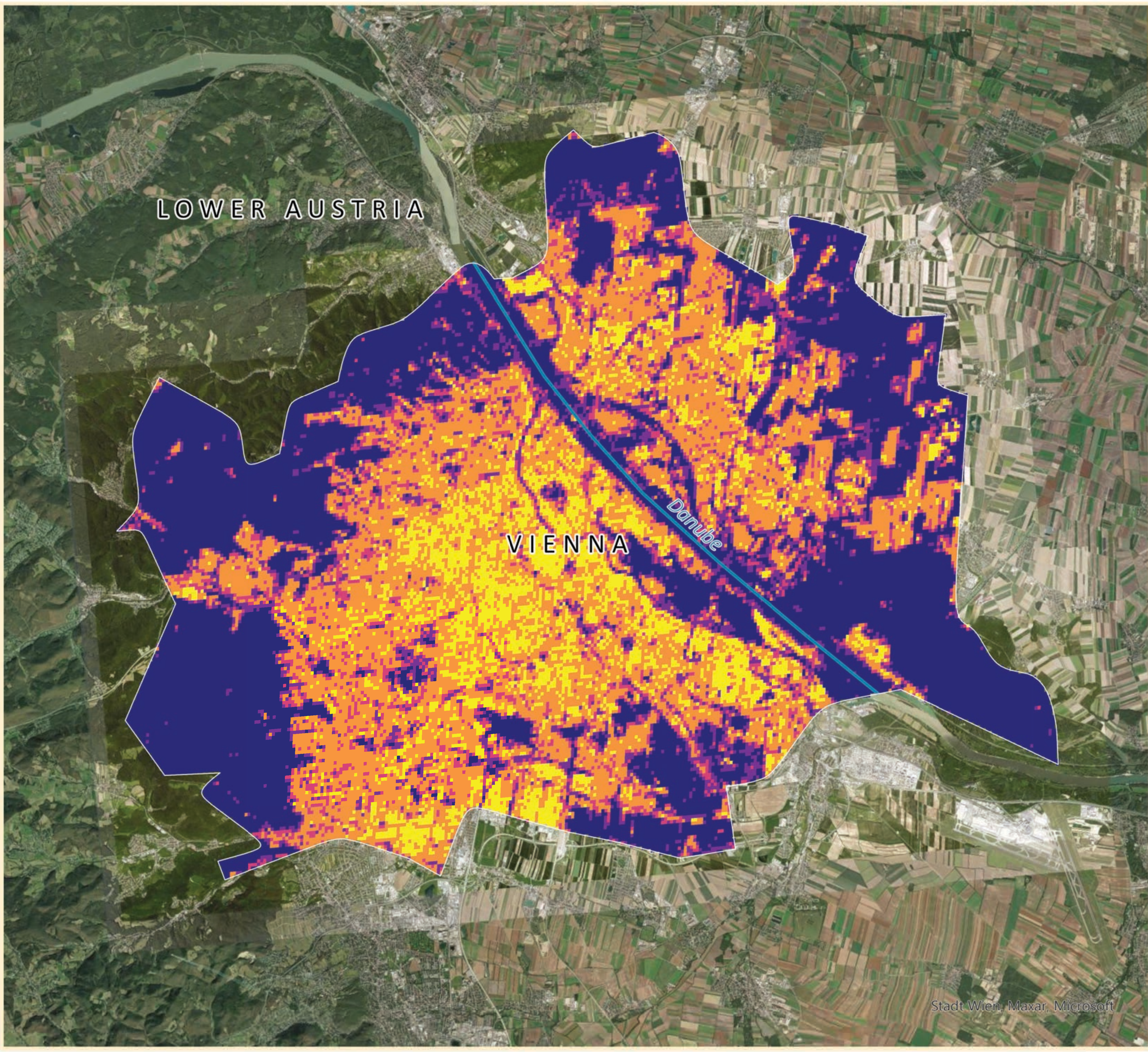
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#04

Built-up surface is the area defined by the presence of buildings or roofed structures. It excludes the area occupied by pavements, streets, parks and open spaces. The level of built of surface determines the quality or habitability of a city. A city with highly dense built-up surface not only looks aesthetically unpleasant but also has problems with urban mobility, social interaction, public health, safety and security. Cities are generally considered as more inclusive and sustainable when they follow a settlement pattern with higher proportion of area dedicated to open public spaces. To ensure an adequate foundation for a well-functioning and prosperous city, the UN-Habitat recommends an average of 45 - 50% of urban land be allocated to streets and open public spaces.



BUILT-UP SURFACE

Vienna, 2020

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Built-Up Surface Raster
Data Source: Global Human Settlement Layer [Copernicus Emergency Management Service]
Spatial Resolution: 100 m
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, State boundary, River

Built-Up Surface (m²)

0 | 100 | 1000 | 2000 | 4000 | *max 10000*

Map Projection:
Albers Equal Area Conic

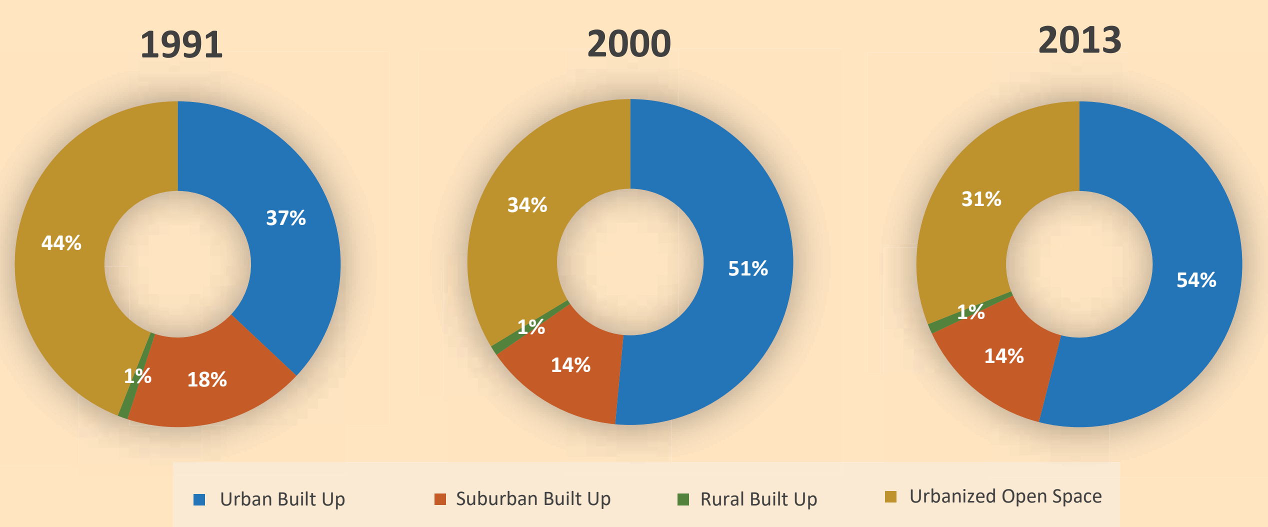
0 2 4 km

COPERNICUS DATA

Dataset	: Global Human Settlement Built-Up Surface
Provider	: Copernicus Emergency Management Service
Data type	: Gridded
Projection	: World Mollweide
Horizontal coverage	: Global
Horizontal resolution	: 100 m
Vertical coverage	: Surface
Temporal coverage	: 1975 to 2030
Temporal resolution	: 5-year interval
File format	: TIFF

Copernicus data for built-up surface of Vienna reveals that the city is marked with the presence of a very dense urban fabric in its core central region. The built-up density decreases gradually as we move away from the center towards the city outskirts. The average value of built-up surface for Vienna city in the year 2020 is 1687.31 m², which can be considered quite an ideal value for human settlement. Some small patches visible in dark blue color in the central part as well as along the periphery of Danube river indicate the presence of parks and other green spaces within the city. The parts of the city bordering to Lower Austria in the eastern and western extents have almost no built-ups due to the presence of forests, meadows, croplands and cemeteries. Copernicus built-up surface data confirms that the affluence of open public space in Vienna city makes it highly suitable for urban livelihood. The share of public space in the city can be enhanced further by creating boulevards and green corridors particularly in the core central area that are overwhelmed by dense built-up surfaces.

Urban Composition of Vienna



Source: Atlas of Urban Expansion

*"Vienna is a city where nature and the built environment comfortably coexist. With 90 parks and gardens, green spaces constitute about half of the city's land area. This comes out to about 120 square meters of green space for each of Vienna's inhabitants - among the highest ratios of any city in the world." **– Eco Business***

SDG RELEVANCE

11 SUSTAINABLE CITIES AND COMMUNITIES

Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable.

Target 11.7: By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities

Indicator 11.7.1: Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities

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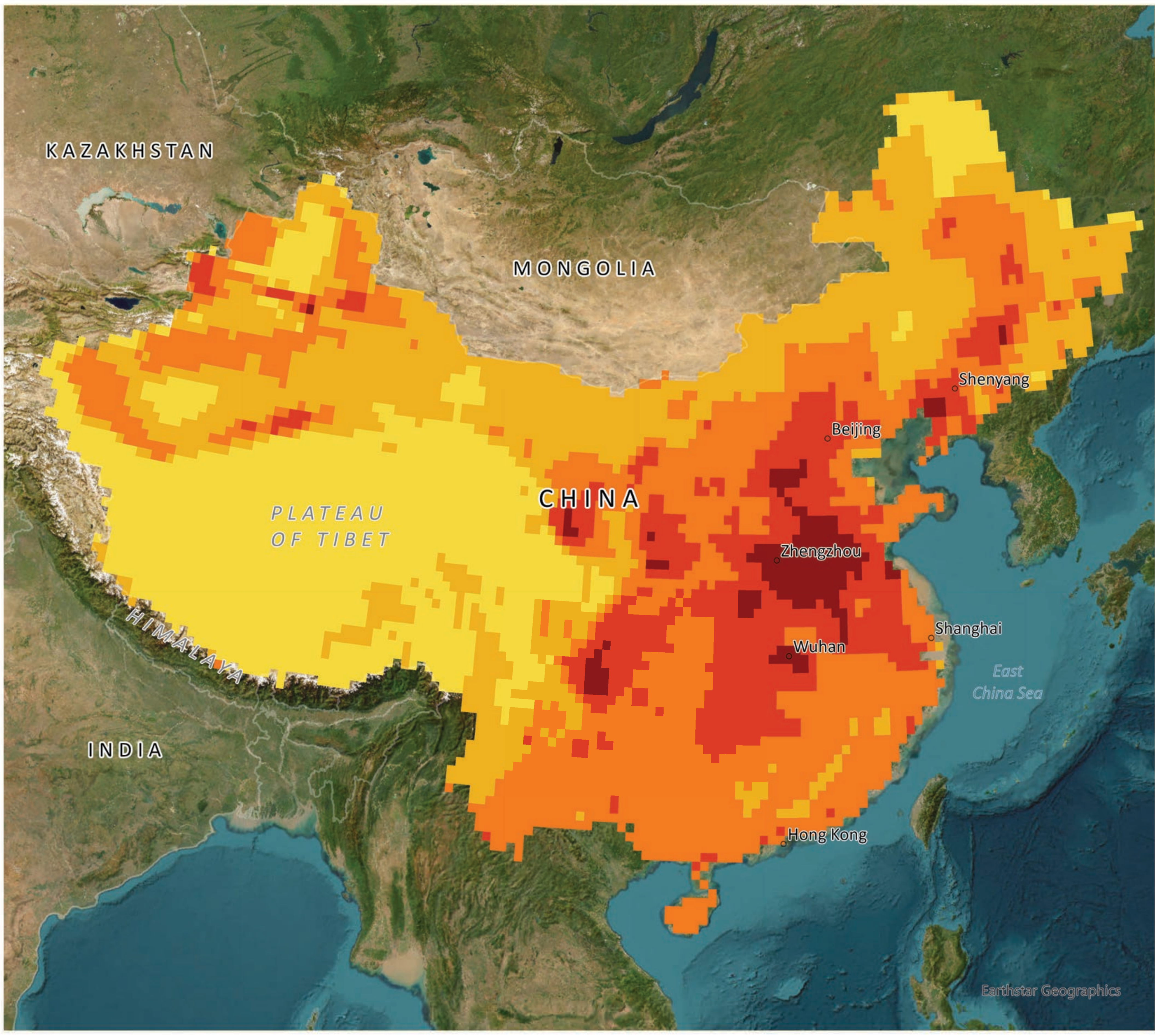
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#05

Particulate matter are the tiny particles of solid or liquid suspended in the air. Such particles usually include dust, dirt, soot, smoke or drops of liquid. They have different shape, size, composition and may result from both natural as well as anthropogenic sources. The particulate matter found in the atmosphere can be broadly categorized into PM10 and PM2.5, or sometimes even finer. Particulate matter block the incoming solar radiation and lead to poor visibility. They cause adverse health effects related to eyes, skin and lungs. Such pollutants are primarily responsible for lowering the air quality in the cities and deteriorating the urban infrastructure. As per WHO Air Quality Guidelines, the 24-hour average concentration of PM2.5 in the cities should not exceed 15 µg/m³.



PARTICULATE MATTER (2.5)

China

15 February 2023

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: PM 2.5 Raster
Data Source: Copernicus Atmosphere Monitoring Service
Spatial Resolution: 40 km
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Country boundary, Cities

Particulate Matter 2.5 (µg/m³)

0 10 20 40 80 *max 133*

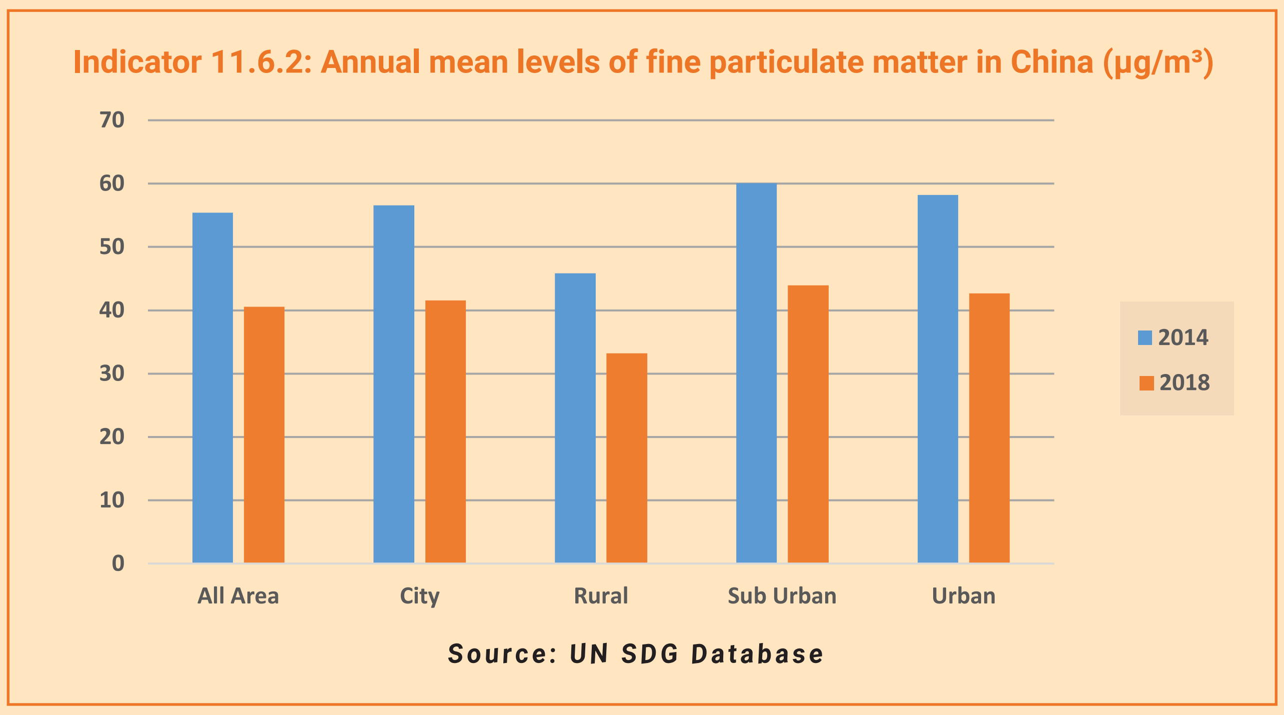
Map Projection:
South China Sea Lambert

0 500 1,000 km

COPERNICUS DATA

Dataset	: CAMS Global Atmospheric Composition Forecasts
Provider	: Copernicus Atmosphere Monitoring Service
Data type	: Gridded
Horizontal coverage	: Global
Horizontal resolution	: 0.4°x0.4°
Vertical coverage	: Total column
Vertical resolution	: Single level
Temporal coverage	: 2015 to present
Temporal resolution	: Hourly
File format	: NetCDF-3

Copernicus data for particulate matter 2.5 reveals that the concentration of PM2.5 in China is very high in the urban areas. The cities of Zhengzhou and Wuhan have extreme level of particulate pollution whereas the Plateau of Tibet and the region near the Himalaya exhibit a very minimal level of particulate pollution. The average value of PM 2.5 concentration in China as of 15 February 2023 is 23.23 µg/m³ which is outside the acceptable level as specified by WHO. Copernicus data helps to discover that human activities are primarily responsible for the particulate pollution in China as the cities with dense human settlements have much higher particle concentration than the natural regions that are untouched by human settlement. This could be due to higher industrial production, fuel combustion, vehicle exhaust and smoking in the cities. The data serve to monitor the air quality of China by identifying the core regions of higher particulate pollution. Some immediate actions are suggested to be undertaken in the cities to control particulate pollution such as the minimization of anthropogenic emissions and the use of air filters.



*"Ninety-nine percent of China's 1.4 billion people live in areas where the annual average particulate pollution level exceeds the WHO guideline. Fifty-five percent live in areas where particulate pollution exceeds the national standard." **-AQLI***

SDG RELEVANCE

11 SUSTAINABLE CITIES AND COMMUNITIES

Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable.

Target 11.6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.

Indicator 11.6.2: Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)

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COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#06

Surface water chlorophyll is an important indicator of coastal eutrophication and marine pollution. Chlorophyll is a common pigment found in the living cells of plant species, algae and cyanobacteria that supports the natural process of photosynthesis. Excessive concentration of chlorophyll in phytoplankton can lead to the accumulation of nutrients such as nitrogen, phosphorous and silica in water. Such over enrichment of nutrients in water bodies fosters algal growth, kills fishes, depletes oxygen levels and increases the toxicity of water. The amount of chlorophyll concentration varies depending on the season, depth, temperature and nature of water bodies. As per the guiding standard for marine water quality, for a healthy and ambient marine water, the concentration of chlorophyll-a should not exceed 4 mg/m³ (MOCCAEUAE, 2020).

SURFACE WATER CHLOROPHYLL

Mediterranean Sea, December 2022

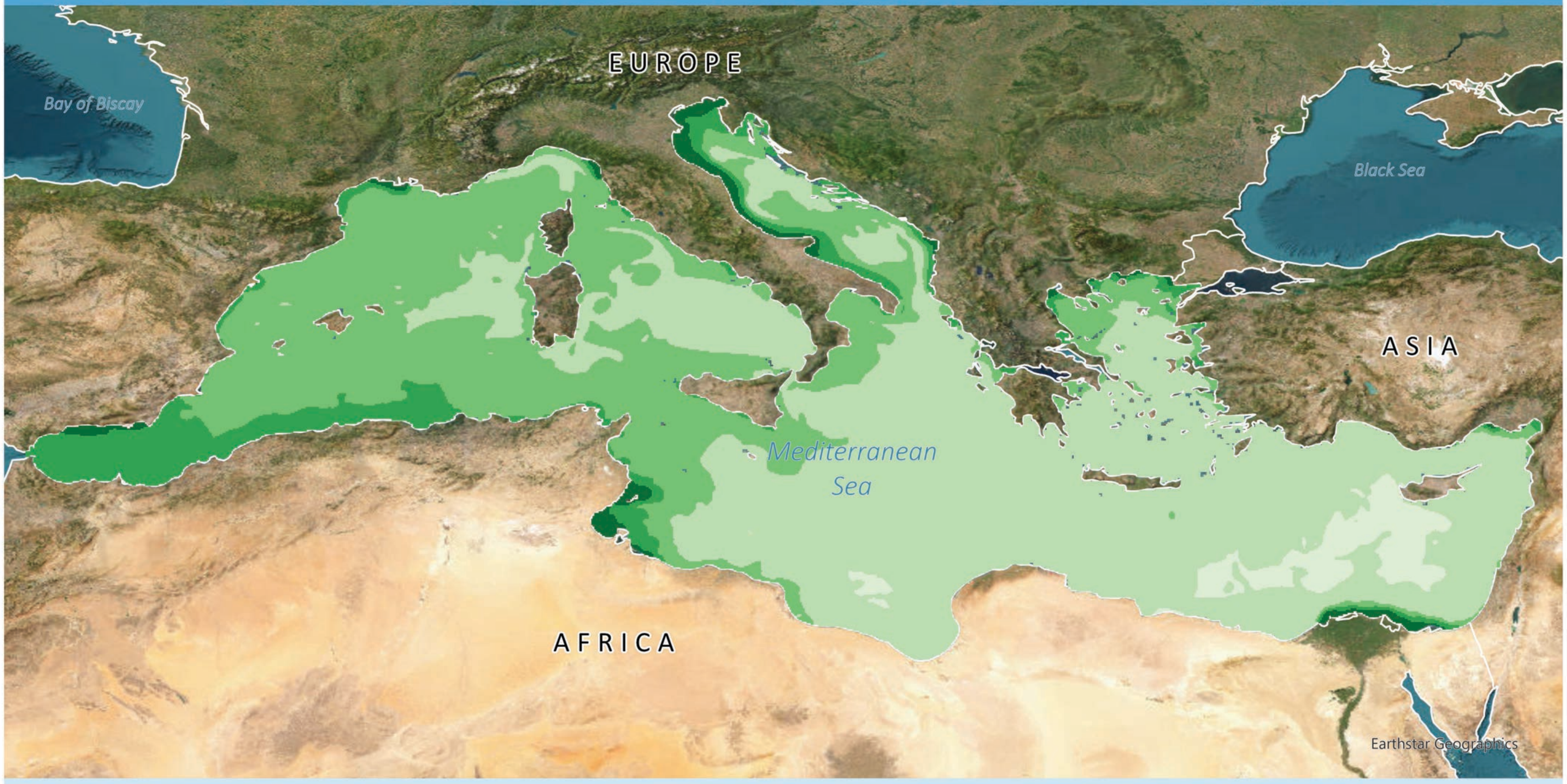


IMAGE MAP TYPE: Double Thematic

Symbol Component: Labeling, Continent boundary

Image Component:
Thematic Content: Surface Chlorophyll Raster
Data Source: Copernicus Marine Environment Monitoring Service
Spatial Resolution: 4 km
Topographic Base: ESRI World Imagery

Surface Water Chlorophyll (mg/m³)

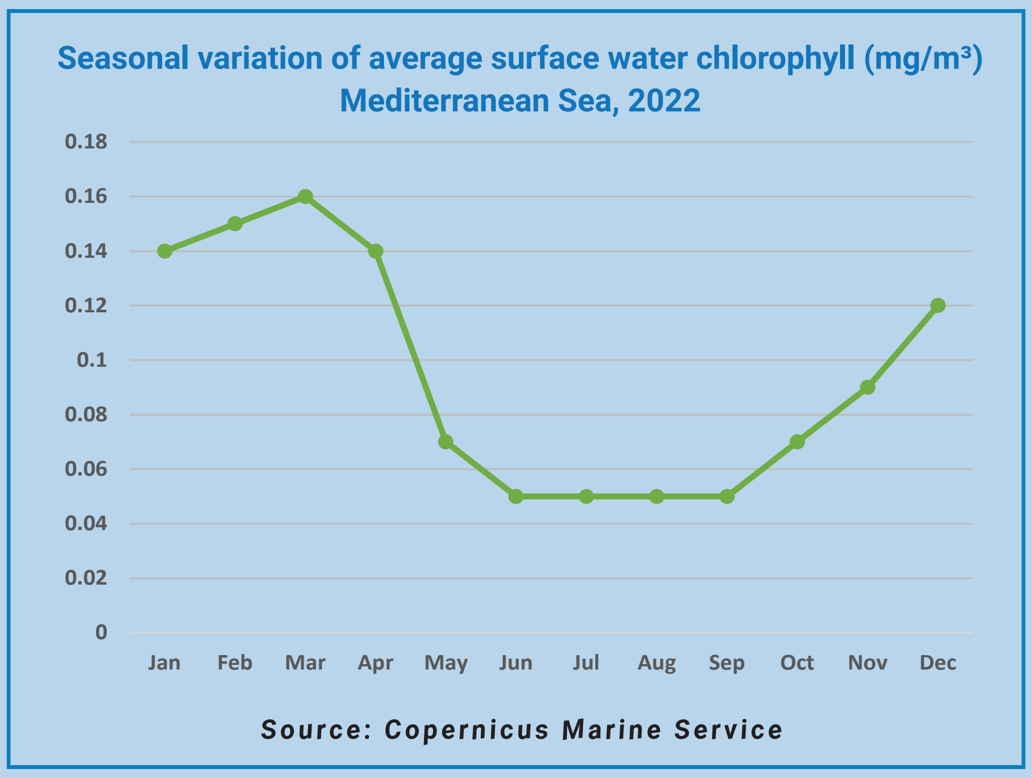
min 0.04 0.05 0.1 0.2 0.5 *max 2.27*

Map Projection: WGS 1984

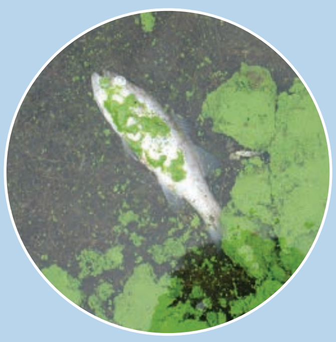
0 250 500 km

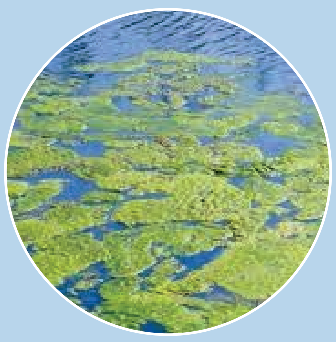
COPERNICUS DATA

Dataset	: Mediterranean Sea Biogeochemistry Reanalysis
Provider	: Copernicus Marine Environment Monitoring Service
Data type	: Gridded
Horizontal coverage	: Mediterranean Sea
Horizontal resolution	: 4 km
Vertical coverage	: 125 depth levels
Temporal coverage	: July 2021 to present
Temporal resolution	: Daily, Monthly, Yearly
Projection	: WGS 1984
File format	: NetCDF-4



*"Chlorophyll-a has increased in many coastal areas, parts of the Southern Ocean and circumglobally along the southern Subtropical Front. It is alarming that the oceans are losing oxygen at a rapid rate estimated at 2% since 1960." **-UNESCO***





Copernicus data for surface water chlorophyll in Mediterranean Sea reveals that the chlorophyll concentration is quite higher in the western extent of the sea than the eastern part. Typically, the coastal regions of Italy, France, Spain, Tunisia and Egypt are more concentrated with the presence of chlorophyll. The average value of surface water chlorophyll in Mediterranean Sea as of December 2022 is 0.12 mg/m³ which falls within the acceptable limit of marine water quality. The distribution of chlorophyll values indicates that the surface water of Mediterranean Sea is fairly ambient and very low in nutrient pollution. It can be visualized from the Copernicus data that the concentration of surface water chlorophyll is much higher in the coastal water than the offshore water. This could be due to the result of high nutrients supply from the mainland region to the coastal area through river runoffs. Copernicus data helps to monitor the coastal eutrophication and tropic state of marine resources by determining the level of chlorophyll concentration and thereby recommends to lower the nutrient pollution through the reduced use of fertilizers and proper sewage disposal.

SDG RELEVANCE

14 LIFE BELOW WATER

Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Target 14.1: By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

Indicator 14.1.1: Index of coastal eutrophication

With the support of the Erasmus+ Programme of the European Union

COPERNICUS MASTER IN DIGITAL EARTH

PARIS LODRON UNIVERSITÄT SALZBURG

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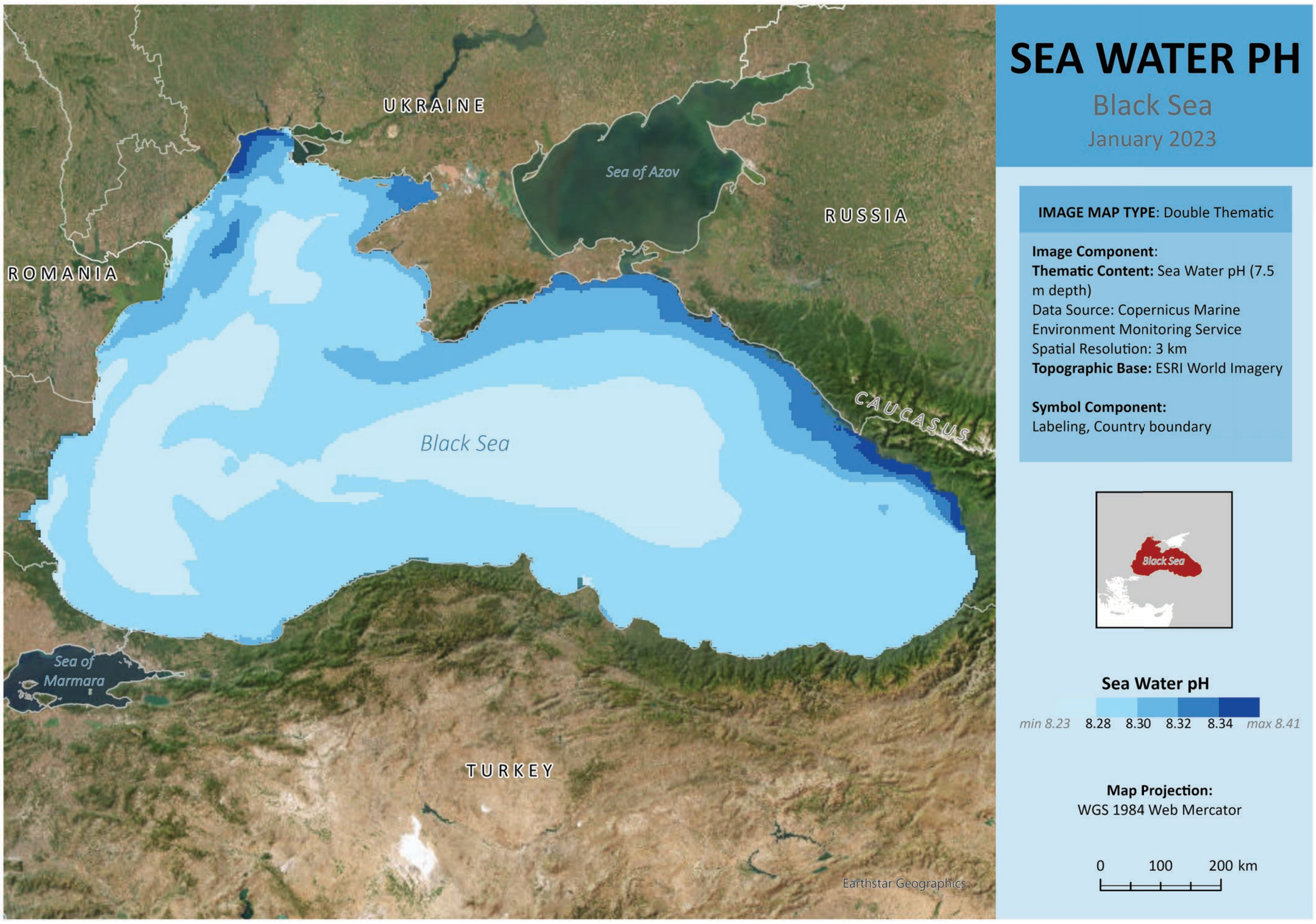
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#07

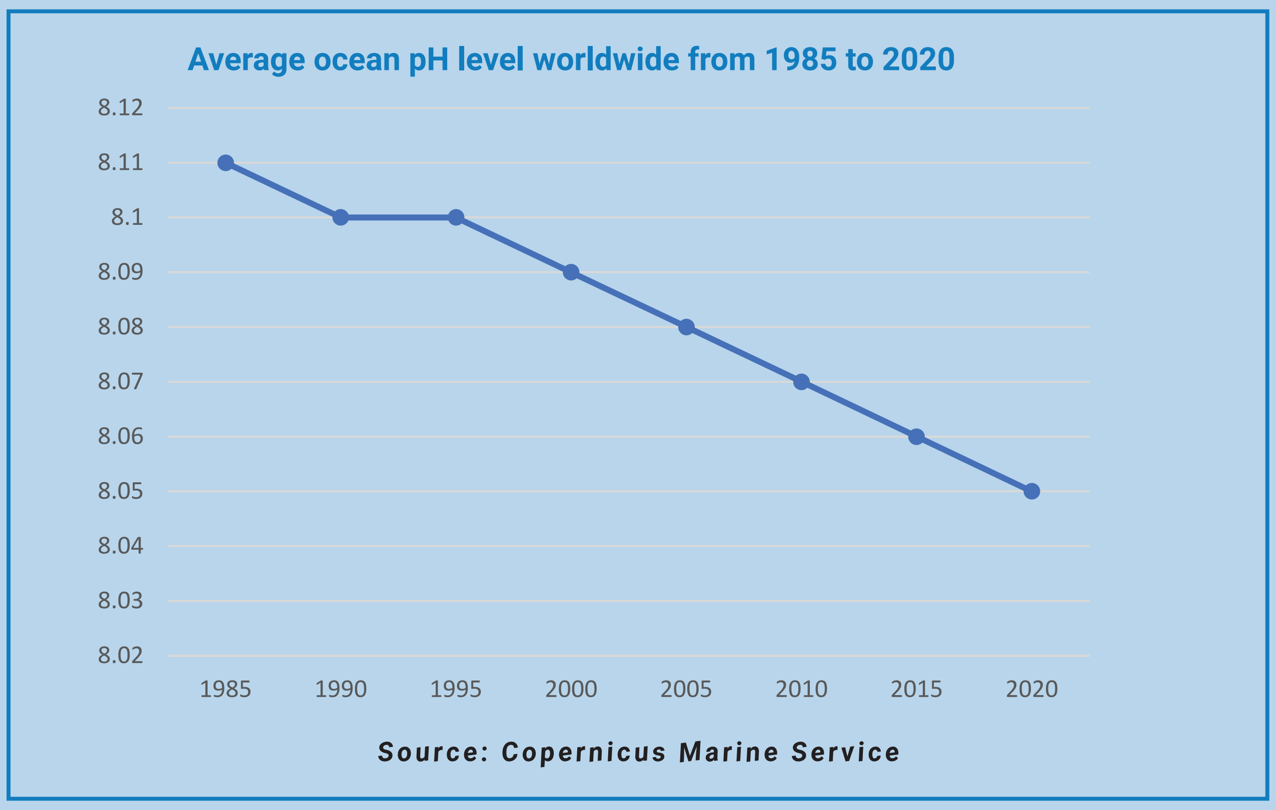
Sea Water PH gives the measure of acidic or alkaline nature of marine water. It plays an important role in the carbon cycle of oceans and helps to monitor the process of ocean acidification. Ocean acidification occurs when the excess of carbon dioxide is absorbed by the oceans. Increase in acidity of sea water has negative impacts on growth and reproduction of shell fish and skeletal creatures. It also affects food web and causes disruption in marine ecosystem. Sea waters are usually slightly alkaline due to the higher concentration of dissolved salts and minerals but their pH can vary with temperature, salinity and depth. Depending on the local conditions, the pH of sea water is expected to range between 7.5 and 8.5 (BBWW, 2021).



Copernicus data for sea water pH of Black Sea at 7.5m depth reveals that the sea water is alkaline with slight variations in pH values within its spatial extent. It can be observed that the coastal regions of the sea are more alkaline than the offshore areas. Higher pH values are concentrated near the coastal waters of Ukraine and Russia in the north and Georgia in the east while the coastal areas of Turkey in the south and Bulgaria and Romania in the west have water with low pH values. The average value of sea water pH at 7.5m depth of Black Sea as of January 2023 is 8.29, which falls within the acceptable limit. Copernicus data reveals some signs of ocean acidification in the central part of the sea where lower pH values are evident than the surrounding regions. This implies that the deep waters of Black Sea are more acidic than surface waters. In order to regulate the acidity of marine resources, it can be recommended to reduce the anthropogenic emissions of carbon dioxide that acts as the main driver for ocean acidification.

COPERNICUS DATA

Dataset	: Black Sea Biogeochemistry Reanalysis
Provider	: Copernicus Marine Environment Monitoring Service
Data type	: Gridded
Horizontal coverage	: Black Sea
Horizontal resolution	: 3 km
Vertical coverage	: 31 depth levels
Temporal coverage	: January 2021 to present
Temporal resolution	: Daily, Monthly
Projection	: WGS 1984
File format	: NetCDF-4



"95 percent of open ocean surface water has become more acidic since the late 1980s. By 2100, the pH of the ocean could decrease to about 7.8, making the oceans 150 percent more acidic and affecting half of all marine life." -IPCC

SDG RELEVANCE

14 LIFE BELOW WATER

Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Target 14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels

Indicator 14.3.1: Average marine acidity (pH) measured at agreed suite of representative sampling stations

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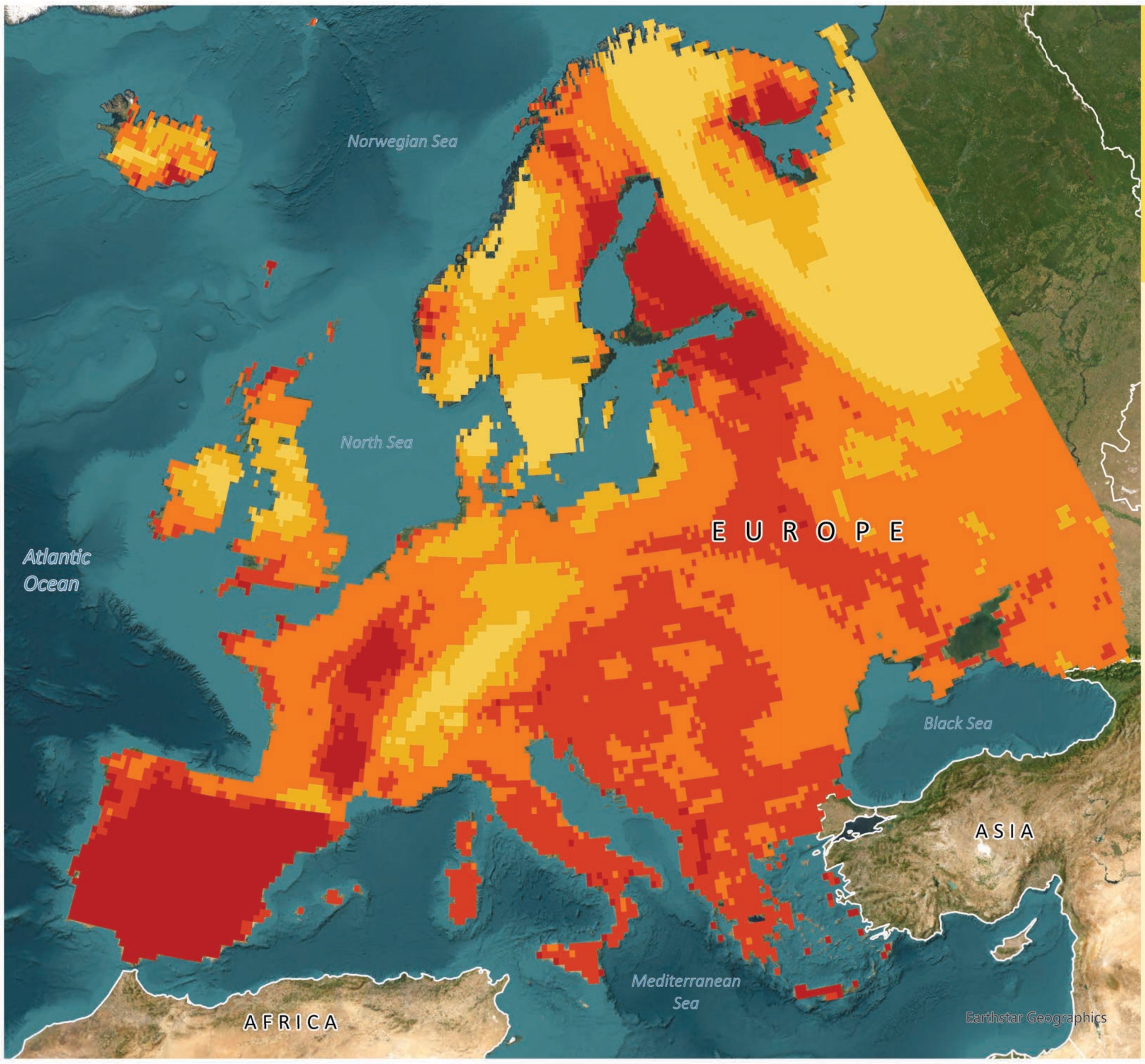
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#08

Solar photovoltaic power expressed as capacity factor is the ratio of actual generation of solar power to the installed capacity. Solar energy is the form of renewable energy that is clean, sustainable and totally inexhaustible. The increased use of solar energy helps to reduce carbon emissions and lowers the impact of global warming and climate change. Solar photovoltaics use solar cells to convert sunlight directly into electricity through photovoltaic effect. The capacity factor of solar photovoltaic cells depend on how long the cells are operational or how much of solar energy the cells produce. Higher value of capacity factor indicates better performance of the system. The optimal value of capacity factor for solar energy usually ranges between 0.1 and 0.25 (SolarSena, 2022).



SOLAR PHOTOVOLTAIC POWER

Europe, July 2022

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Solar Photovoltaic Power
Data Source: Copernicus Climate Change Service
Spatial Resolution: 0.25°x 0.25°
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Continent boundary

Solar Photovoltaic Power (CRF)

min 0.01 | 0.10 | 0.15 | 0.20 | 0.22 | max 0.25

Map Projection:
Lambert Conformal Conic

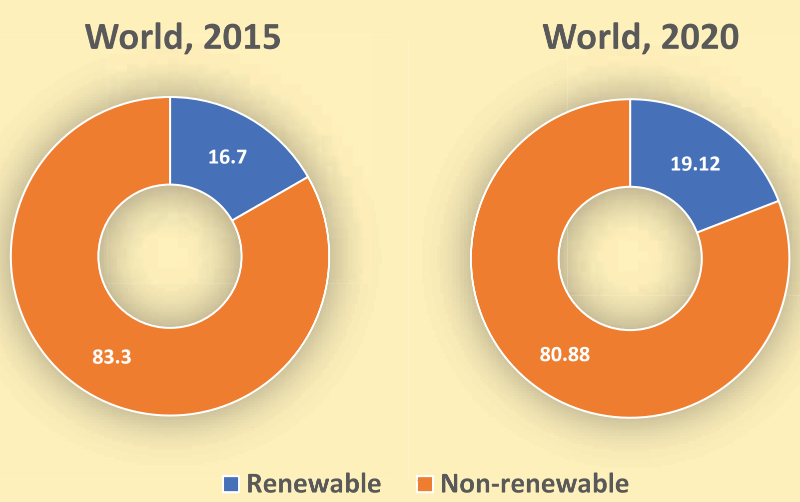
0 250 500 km

Copernicus data for solar photovoltaic power generation for Europe reveals that the capacity factor for solar power generation is greater in the southwestern region of the continent. Spain and Portugal have the maximum capacity factor ratio while the Alps region, Nordic countries and Russia have the least values. The Balkan region and the Central Europe exhibit moderate values of solar capacity factor. The average value of solar photovoltaic power as capacity factor ratio for Europe in July 2022 is 0.16, which seems to be quite low for the summer observation. This could be possibly due to the geographical extent of Europe as it is situated higher than the equator and has fewer sunshine hours. Copernicus data on solar photovoltaic power helps to identify the regions with higher capacity factor and thereby suggests to establish more solar plants in those regions for maximum power generation. This helps to promote clean energy and minimize the excess of carbon emissions from the burning of fossil fuels. The generation of solar power can also be maximized through proper adjustment of size and inclination of the photovoltaic cells.

COPERNICUS DATA

Dataset	: Climate and Energy Indicators for Europe from 2005 to 2100
Provider	: Copernicus Climate Change Service
Data type	: Gridded
Horizontal coverage	: Europe
Horizontal resolution	: 0.25° x 0.25°
Vertical coverage	: 0 to 100 m
Vertical resolution	: Single level
Temporal coverage	: 2005 to 2100
Temporal resolution	: 3-hourly, daily
File format	: NetCDF

Indicator 7.2.1: Renewable energy share in the total final energy consumption (%)



Source: UN SDG Database

"Solar PV generation increased by a record 179 TWh in 2021, marking 22% growth on 2020. Solar PV accounted for 3.6% of global electricity generation, and it remains the third largest renewable electricity technology behind hydropower and wind." -IEA

SDG RELE-

7 AFFORDABLE AND CLEAN ENERGY

Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all

Target 7.2: By 2030, increase substantially the share of renewable energy in the global energy mix

Indicator 7.2.1: Renewable energy share in the total final energy consumption

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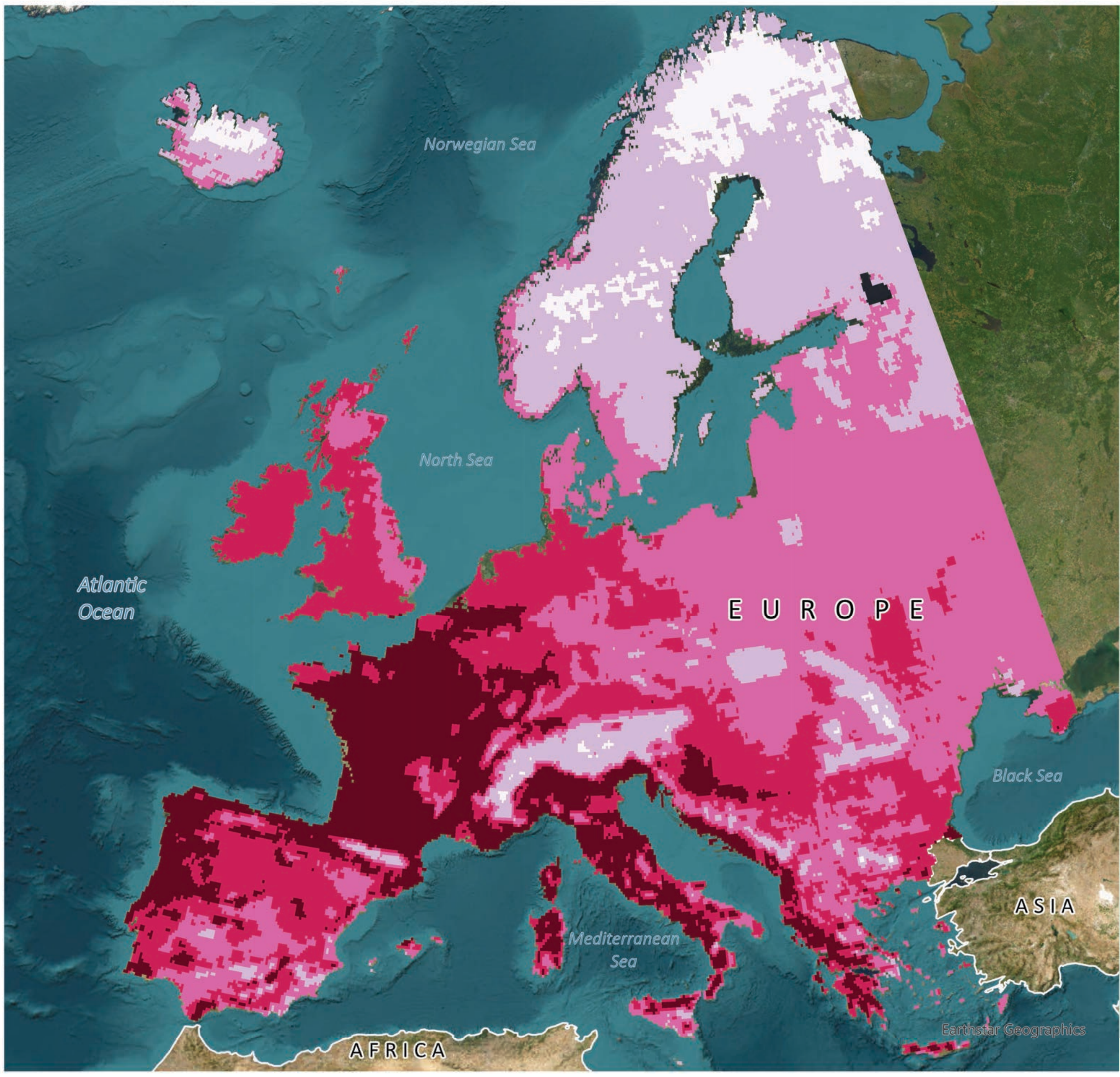
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#09

Aedes Albopictus, also known as tiger mosquito is an important transmitter of vector-borne diseases like yellow fever, dengue, Zika and Chikungunya. These species of mosquito were originated from Southeast Asia and are commonly found in tropical and subtropical regions with warm and humid climate. They usually breed in wetlands including swamps and marshes and are capable of multiplying significantly in suitable climatic conditions. The tiger mosquito causes a number of casualties and deaths every year posing a serious threat to health and well-being. Climatic suitability for tiger mosquito depends on various factors such as rainfall, temperature, humidity, etc. It is measured on a scale of 0 to 100 where 0 means the least suitable and 100 means the most suitable climatic condition (C3S, 2019).



SUITABILITY FOR AEDES ALBOPICTUS

Europe, January 2023

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Climatic Suitability for Aedes Albopictus
Data Source: Copernicus Climate Change Service
Spatial Resolution: 0.1°x 0.1°
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Continent boundary

Climatic Suitability

0 20 40 60 80 *max 100*

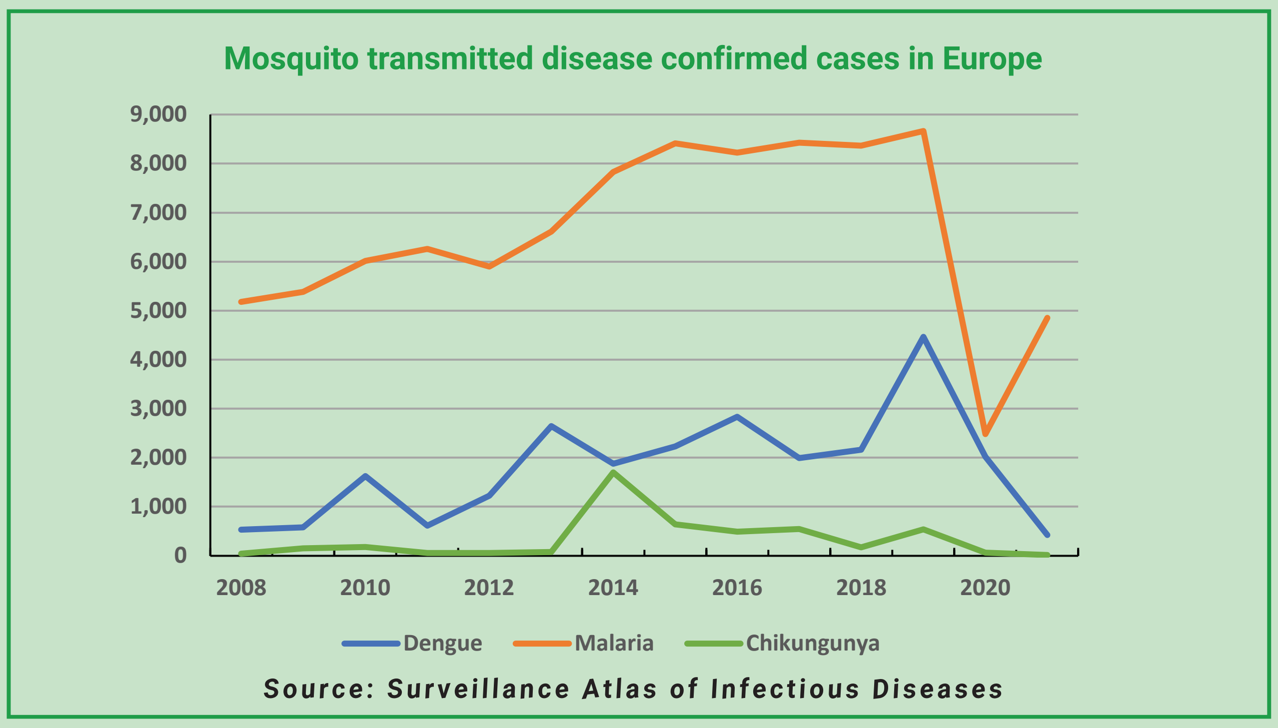
Map Projection:
Lambert Conformal Conic

0 250 500 km

Copernicus data on climatic suitability for Aedes Albopictus in Europe reveals that the Southwestern region of Europe has the most suitable climatic conditions for the mosquito. France exhibits the highest climatic suitability than any other country. Italy, Portugal, Croatia and Belgium are also marked with a greater climatic suitability. The Alps region and the Nordic countries are the least climatically suitable regions for the adaptation of the mosquito. The average value for climatic suitability for Aedes Albopictus in Europe as of January 2023 is 50.54 which indicates that Europe is moderately suitable for the breeding of tiger mosquito. Copernicus data helps to identify and confirm that the regions with higher summer temperature, mild winter temperature and sufficient amount of rainfall are at a greater risk for the spread of mosquito. It also supports the evidence that the mosquitoes are lethargic to lower temperatures and suggests the need to uptake necessary measures to prevent the warming of the continent. The suitability for Aedes Albopictus can also be controlled naturally through the elimination of swamps, proper garbage disposal and the growth of mosquito repellant plants.

COPERNICUS DATA

Dataset	: Climatic Suitability for the Presence and Seasonal Activity of Aedes Albopictus
Provider	: Copernicus Climate Change Service
Data type	: Gridded
Projection	: WGS 1984
Horizontal coverage	: Europe
Horizontal resolution	: 0.1° x 0.1°
Vertical coverage	: Surface
Temporal coverage	: 1986-2085
Temporal resolution	: Seasonal, yearly
File format	: NetCDF



"Each year, nearly three-quarters of a million people die from mosquito-borne diseases. Since 2008, malaria cases across Europe have risen by 62%, dengue, Zika and Chikungunya are up by a remarkable 700%, and cases of West Nile virus spiked dramatically in 2018."

SDG RELE-

3 GOOD HEALTH AND WELL-BEING

Goal 3: Ensure healthy lives and promote well-being for all at all ages

Target 3.3: By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases

Indicator 3.3.3: Malaria incidence per 1,000 population

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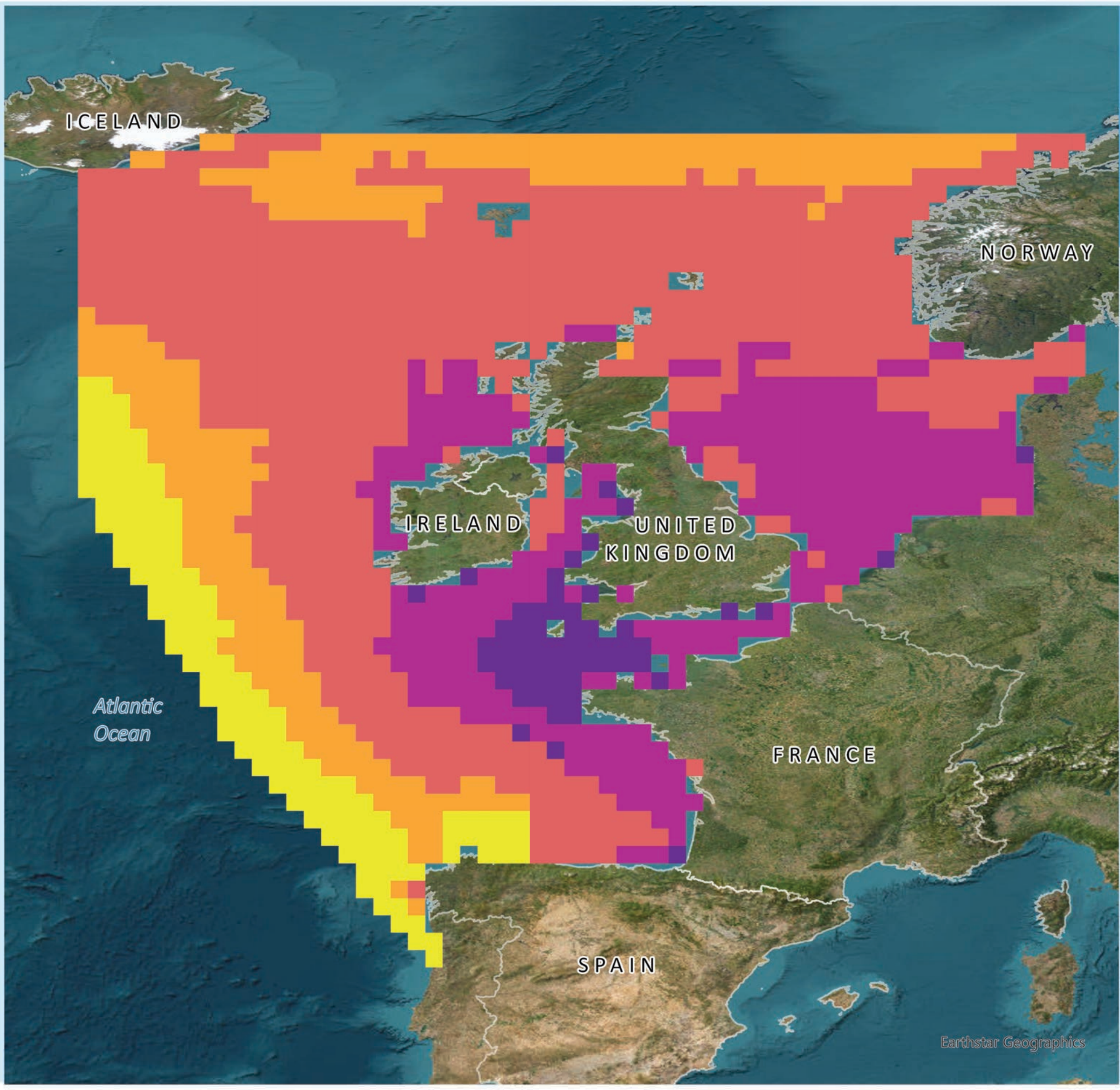
COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS #10

Sustainable fishing is a practice that helps to maintain healthy and productive fish population. Such practice ensures that the abundance of fish does not decline over time due to fishing activities. Changes in the aquatic environment such as warming, acidification, deoxygenation and human activities such as overfishing can pose a serious threat to the fish stocks. Fish species like Atlantic Salmon are highly demanded for human consumption due to their richness in protein and omega-3 fatty acids. Unregulated and illegal harvesting of such fishes can lead to the declination in their number or may even cause permanent extinction in some species. For the North Atlantic Ocean, the abundance of Atlantic Salmon above 5 million can be considered as a sustainable stock (NASCO, 2019).



ATLANTIC SALMON

Northwest European Shelf

January 2023

IMAGE MAP TYPE: Double Thematic

Image Component:
Thematic Content: Abundance of Atlantic Salmon (Gridded)
Data Source: Copernicus Climate Change Service
Spatial Resolution: 0.5°x 0.5°
Topographic Base: ESRI World Imagery

Symbol Component:
Labeling, Country boundary

Number of Atlantic Salmon

0 1000 2000 5000 8000 *max 12798*

Map Projection:
WGS 1984

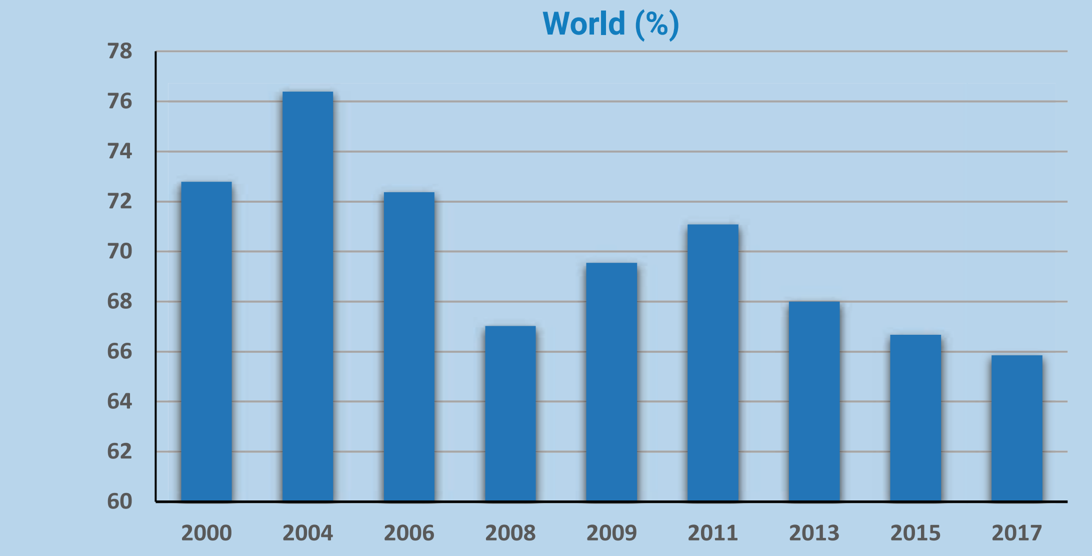
0 250 500 km

Copernicus data on abundance of Atlantic Salmon in the Northwest European Shelf reveals that the fish stock is maximum along the English Channel between the boundary of France and the United Kingdom. The North Sea and the Celtic Sea are also identified with higher abundance of Atlantic Salmon. The number of Salmon declines considerably as we move away from the coastal region of United Kingdom towards Atlantic Ocean in the West and Norwegian sea in the North. The average number of Atlantic Salmon per 0.5° grid in the Northwest European Shelf as of January 2023 is 3530, which indicates not much abundance of the fish stock. The decline in the number of fishes could be possibly due to overfishing activities, marine pollution, climate change and habitat degradation. Copernicus data on fish abundance helps to monitor the population of fish species and thereby support to regulate overfishing and other illegal practices that threaten the fish stock. It recommends the need for the maximum sustainable yield which can be achieved through habitat restoration, water quality management and reduction in overexploitation of marine resources.

COPERNICUS DATA

Dataset	: Fish Abundance and Catch Data for Northwest European Shelf
Provider	: Copernicus Climate Change Service
Data type	: Gridded
Horizontal coverage	: Northwest European Shelf
Horizontal resolution	: 0.5° x 0.5°
Vertical coverage	: Full water column
Vertical resolution	: Single level
Temporal coverage	: 2006 up to 2050
Temporal resolution	: Yearly
File format	: NetCDF-4

Indicator 14.4.1: Proportion of fish stocks within biologically sustainable levels, World (%)



Source: UN SDG Database

"Demand for seafood and advances in technology have led to fishing practices that are depleting fish and shellfish populations around the world. Fishers remove more than 77 billion kilograms of wildlife from the sea each year. Scientists fear that continuing to fish at this rate may soon result in a collapse of the world's fisheries." -National Geographic

SDG RELE-

Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Target 14.4: By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics

Indicator 14.4.1: Proportion of fish stocks within biologically sustainable levels

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COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS #11

Carbon Dioxide is a greenhouse gas primarily responsible for global warming and climate change. It occurs naturally through the process of cellular respiration as well as through anthropogenic emissions such as fossil fuel combustion, deforestation, vehicle exhaust, etc. Rapid industrialization is the primary reason for the recent increase in levels of carbon dioxide in the atmosphere. With the rise in the concentration of atmospheric carbon dioxide, heat gets trapped inside the earth surface and it starts to warm up. This can lead to severe weather conditions, extreme temperatures and irregular precipitations. As per IPCC, the level of CO_2 concentration in the atmosphere should be ideally maintained within 350 ppm. Any concentration exceeding 400 ppm is considered as a potentially dangerous driver for inducing climate change.

ATMOSPHERIC CARBON DIOXIDE

World Continents, January 2020

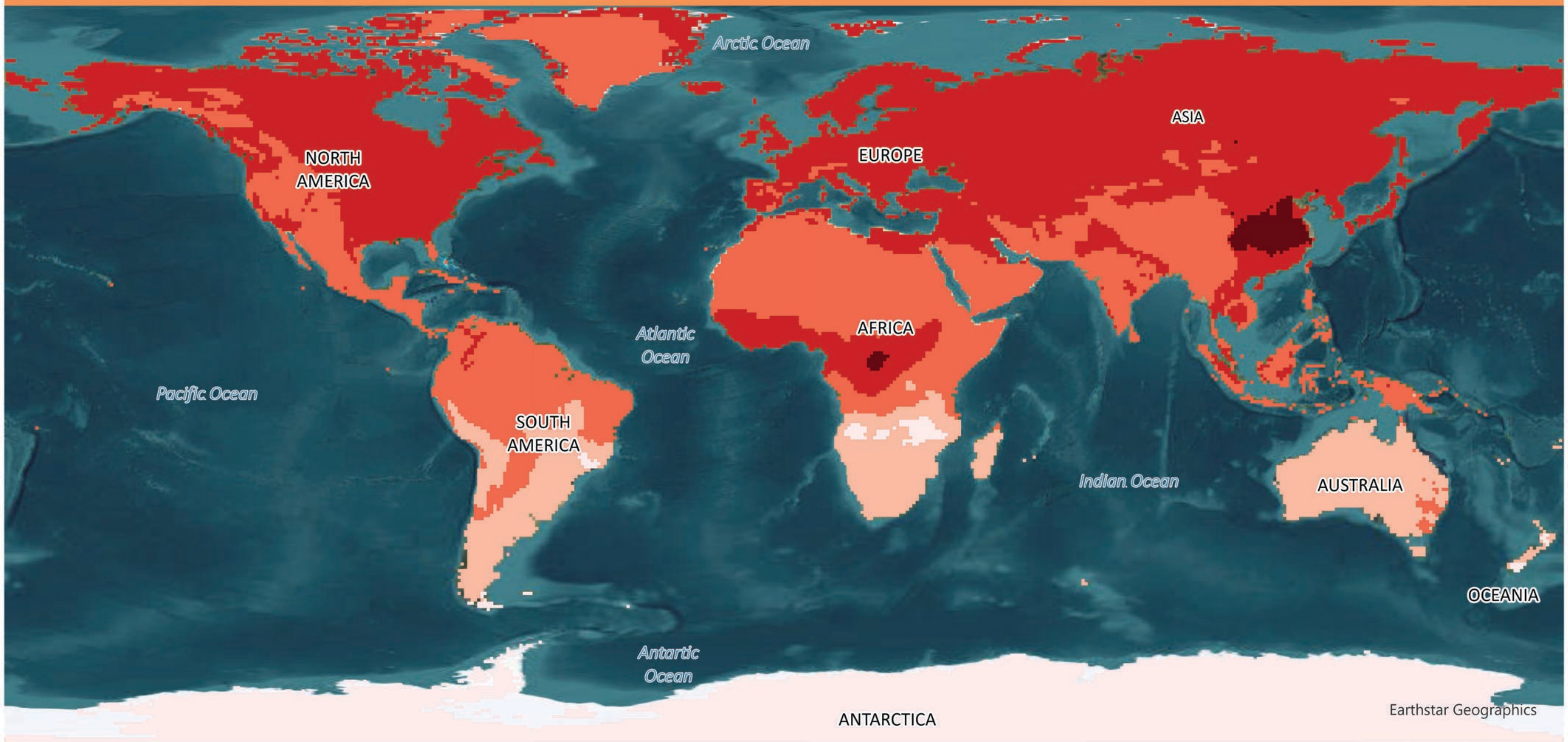


IMAGE MAP TYPE: Double Thematic

Symbol Component: Labeling

Image Component:
Thematic Content: Atmospheric CO2 Raster
Data Source: Copernicus Atmosphere Monitoring Service
Spatial Resolution: 0.75°x 0.75°
Topographic Base: ESRI World Imagery

CO2 Column-Mean Molar Fraction (PPM)

min 406 | 408 | 410 | 413 | 416 | max 421

Map Projection: WGS 1984

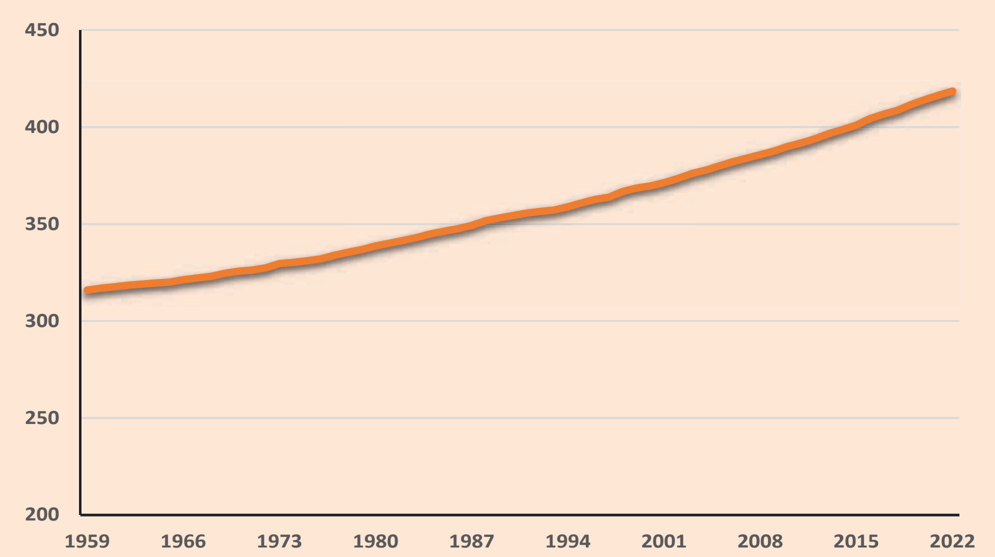
0 2,000 4,000 km

COPERNICUS DATA

Dataset	: CAMS Global Greenhouse Gas Reanalysis
Provider	: Copernicus Atmosphere Monitoring Service
Data type	: Gridded
Horizontal coverage	: Global
Horizontal resolution	: 0.75°x0.75°
Vertical coverage	: Total column
Vertical resolution	: Single level
Temporal coverage	: 2003 to 2020
Temporal resolution	: 3-hourly
File format	: NetCDF

Copernicus data for atmospheric carbon dioxide in the world continents reveals that the concentration of CO2 in the atmosphere has reached to an alarming state. The CO2 levels are significantly higher in the northern hemisphere where Asia, Europe, North America and Central Africa are more severely affected than rest of the continents. The highest levels of CO2 concentration can be observed in China and Central Africa while South America, Australia and Antarctica are marked with relatively lower levels of CO2 concentration. The average value of atmospheric carbon dioxide in world continents as of January 2020 is 411 ppm which is already exceeding the critical level. Copernicus data on atmospheric CO2 concentration confirms that our planet is highly vulnerable to the devastating effects of climate change. It points out the urgency to cut down the carbon emissions as soon as possible through the practice of sustainable industrialization. The excessive concentration of carbon dioxide resulting from the combustion of fossil fuels can be minimized by using low carbon alternatives or switching to renewable energy sources such as solar energy, hydropower, wind energy, geothermal energy, etc.

Global Trend in Atmospheric Carbon Dioxide Concentration (PPM)



Source: NOAA

"CO2 produced by human activities is the largest contributor to global warming. By 2020, its concentration in the atmosphere had risen to 48% above its pre-industrial level." ***-Climate Action***

SDG RELEVANCE

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Target 9.4: By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities

Indicator 9.4.1: CO2 emission per unit of value added

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COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#12

Greenhouse gases are the gases that cause greenhouse effect by trapping the incoming solar radiation and slowing the rate at which the energy escape to the space. The most common greenhouse gases occurring in the atmosphere are carbon dioxide, methane, water vapour, nitrous oxide and ozone. These gases help to keep our planet warm and habitable but their excessive concentration in the atmosphere can lead to global warming. Atmospheric methane is stronger and has higher potential of trapping heat than the same volume of any other greenhouse gases. Methane is mostly released from oil and gas extractions, biomass burning, livestock fermentation, landfills, agriculture and industries. As per IPCC, methane concentration in atmosphere above 1900 ppb can be considered as highly critical for our planet.

ATMOSPHERIC METHANE

World Continents, January 2020

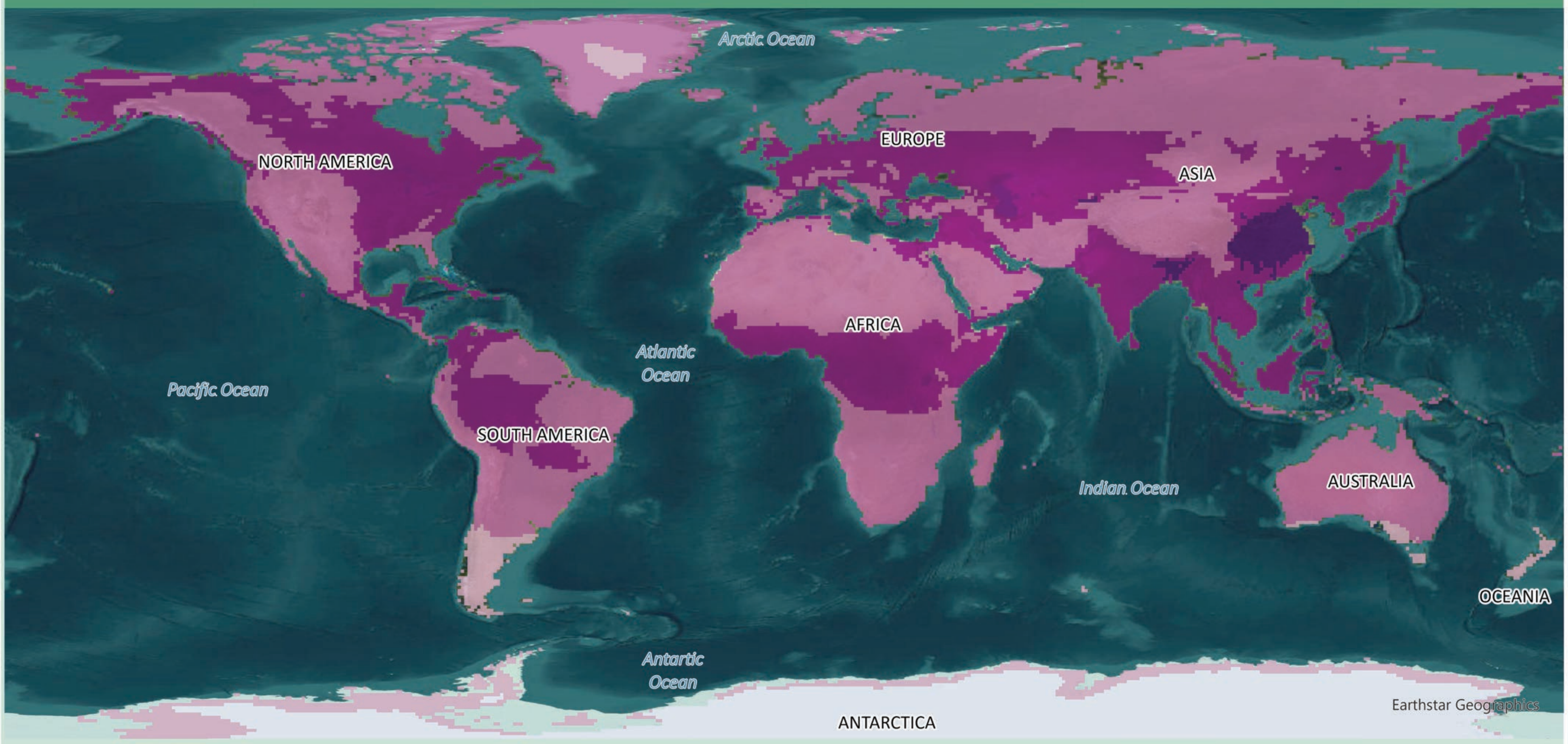


IMAGE MAP TYPE: Double Thematic

Symbol Component: Labeling

Image Component:
Thematic Content: Atmospheric CH4 Raster
Data Source: Copernicus Atmosphere Monitoring Service
Spatial Resolution: 0.75°x 0.75°
Topographic Base: ESRI World Imagery

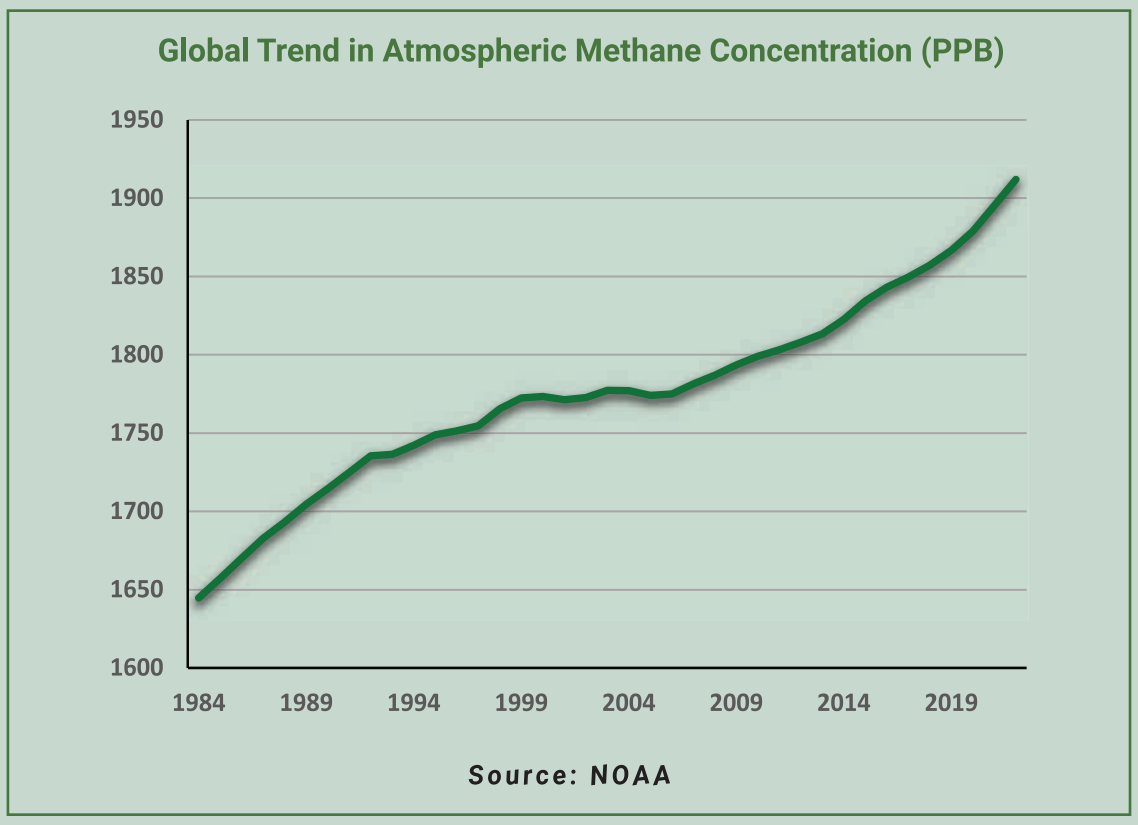
Methane Column-Mean Molar Fraction (PPB)

min 1716 | 1750 | 1800 | 1870 | 1900 | max 2039

Map Projection: WGS 1984

0 | 2,000 | 4,000 km

Copernicus data for atmospheric methane in world continents reveals that Asia has significantly higher concentration of atmospheric methane than any other continents. Typically, China and Bangladesh exhibit critically higher levels of methane concentration. Other regions like Central Africa, Europe, Eastern part of North America and Northwestern part of South America are also distinguished with higher levels of methane concentration while Australia, Greenland and Antarctica appear relatively safer. The average value of atmospheric methane in world continents as of January 2020 is 1828 ppb which is not so far away from approaching the critical level. The higher concentration of methane in the atmosphere can be a signal for global warming and climate change. Copernicus data helps to monitor the critical levels of methane and other greenhouse gases in the atmosphere and thereby suggest the immediate need for reducing their emissions. The excessive concentration of greenhouse gases can be reduced by switching to clean and green energy sources as early as possible. The emissions can also be reduced through the recycle of waste products as well as through the adoption of climate friendly agriculture and industrial practices.



"For many years, methane was overlooked in the climate change conversation. Methane has more than 80 times the warming power of carbon dioxide over the first 20 years after it reaches the atmosphere. Acting now to reduce methane emissions will have immediate benefits to the climate." -EDF

COPERNICUS DATA

Dataset	: CAMS Global Greenhouse Gas Reanalysis
Provider	: Copernicus Atmosphere Monitoring Service
Data type	: Gridded
Horizontal coverage	: Global
Horizontal resolution	: 0.75°x0.75°
Vertical coverage	: Total column
Vertical resolution	: Single level
Temporal coverage	: 2003 to 2020
Temporal resolution	: 3-hourly
File format	: NetCDF

SDG RELEVANCE

13 CLIMATE ACTION

Goal 13: Take urgent action to combat climate change and its impacts

Target 13.2: Integrate climate change measures into national policies, strategies and planning

Indicator 13.2.2: Total greenhouse gas emissions per year

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COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#13

Forests are important natural resource that constitute the terrestrial ecosystem. They support life and provide food, shelter and protection to a variety of wild creatures. Forests regulate the water cycle, release oxygen into the atmosphere as well as play a crucial role in absorbing the excess of carbon emissions. Forests are increasingly being destroyed due to residential, agricultural, industrial and commercial purposes. Rapid deforestation can lead to the occurrence of natural disasters like landslide, flood, drought, erosion, etc causing a serious threat to the biodiversity. Forests once destroyed take a long time to regenerate and might never recover to the same state as before. The problem of deforestation is highly prominent in the tropical rainforests of Southeast Asia, Latin America and Africa.

FOREST COVER

Venezuela, 2019

IMAGE MAP TYPE: Back/Rear Thematic

Symbol Component:
Thematic Content: Forest Cover, Country boundary, Labeling
Data Source: Copernicus Global Land Service
Spatial Resolution: 100 m

Image Component:
Topographic Base: ESRI World Imagery

Forest

Total Area: 47,426,889 ha

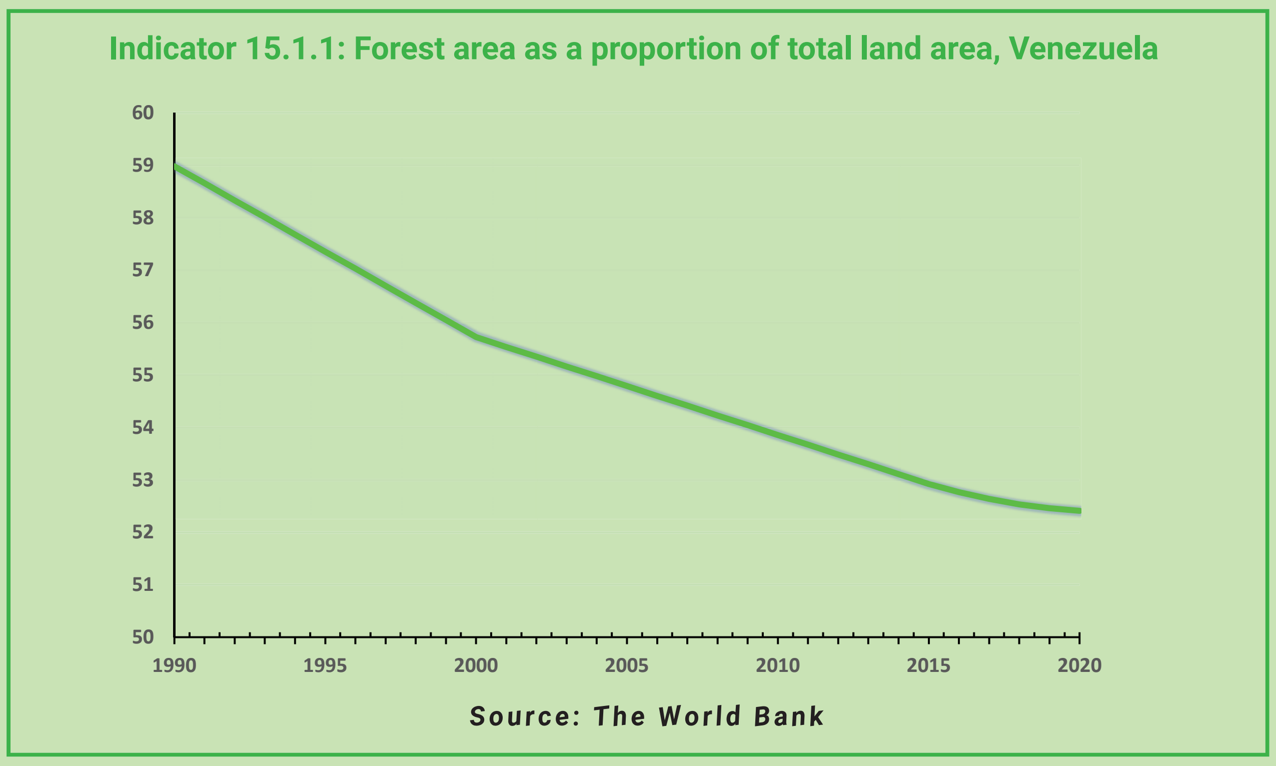
Map Projection:
WGS 1984

0 100 200 km

Copernicus data on global land cover provides spatial information on various land cover categories across the globe. The map visualizes Copernicus data on forest cover in Venezuela which reveals that the country has an abundance of forest particularly in its Southern extent. The Amazon rainforest contributes to a major share of the forest area in the country. The total area covered by forests in Venezuela in the year 2019 is 47,426,889 hectares, which indicates 52.01% of total area of the country. This represents a fairly good proportion of forest area in the country, although the forest in Venezuela is found to decline rapidly each year. This is probably resulted from the ongoing deforestation in Venezuela due to mining activities, intensive agriculture, forest fire and overgrazing. The Amazon rainforest in the South undergoes a rapid decline in its area each year due to the mining of gold, coltan, diamond and bauxite in the region of Orinoco. Copernicus data on forest cover helps to monitor the status of forest and thereby suggests the need to take urgent action against deforestation for sustainable forest management.

COPERNICUS DATA

Dataset	: Global Land Cover
Provider	: Copernicus Land Monitoring Service
Data type	: Gridded
Thematic classes	: 23
Horizontal coverage	: Global
Horizontal resolution	: 100 m
Temporal coverage	: 2015-2019
Temporal resolution	: Yearly
Projection	: WGS 1984
File format	: GeoTIFF



*"Deforestation is a particular concern in the tropical rain forests because these forests are home to much of the world's biodiversity. In 2019, the tropics lost close to 30 soccer fields worth of trees every single minute." -**WWF***

SDG RELE-

15 LIFE ON LAND

Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Target 15.1: By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements

Indicator 15.1.1: Forest area as a proportion of total land area

With the support of the Erasmus+ Programme of the European Union

COPERNICUS MASTER IN DIGITAL EARTH

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Palacký University Olomouc

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Olomouc, 2023

COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#14

Water ecosystem constitute of water bodies such as rivers, lakes, seas, oceans, ponds, reservoirs, wetlands, etc. They occur in various shapes and sizes and can be permanent as well as seasonal. Water ecosystems not only provide water for drinking and utility purpose but also support the entire aquatic and marine life. The abundance of healthy water ecosystem helps to enhance the freshness and aesthetics of natural environment. Water ecosystems are increasingly being degraded due to their over exploitation from human intervention. Human activities affect both the quality and quantity of water ecosystem resulting to pollution, turbidity, acidification and oxygen depletion. Unsustainable management of water ecosystem can lead to abnormal surface water dynamics causing the unnatural rate of expansion or shrinkage of water bodies.

WATER ECOSYSTEM

Minnesota, 2019

IMAGE MAP TYPE: Back/Rear Thematic

Symbol Component:
Thematic Content: Water bodies, State boundary, Labeling
Data Source: Copernicus Global Land Service
Spatial Resolution: 100 m

Image Component:
Topographic Base: ESRI World Imagery

Water Body
Total Area: 1,203,013 ha

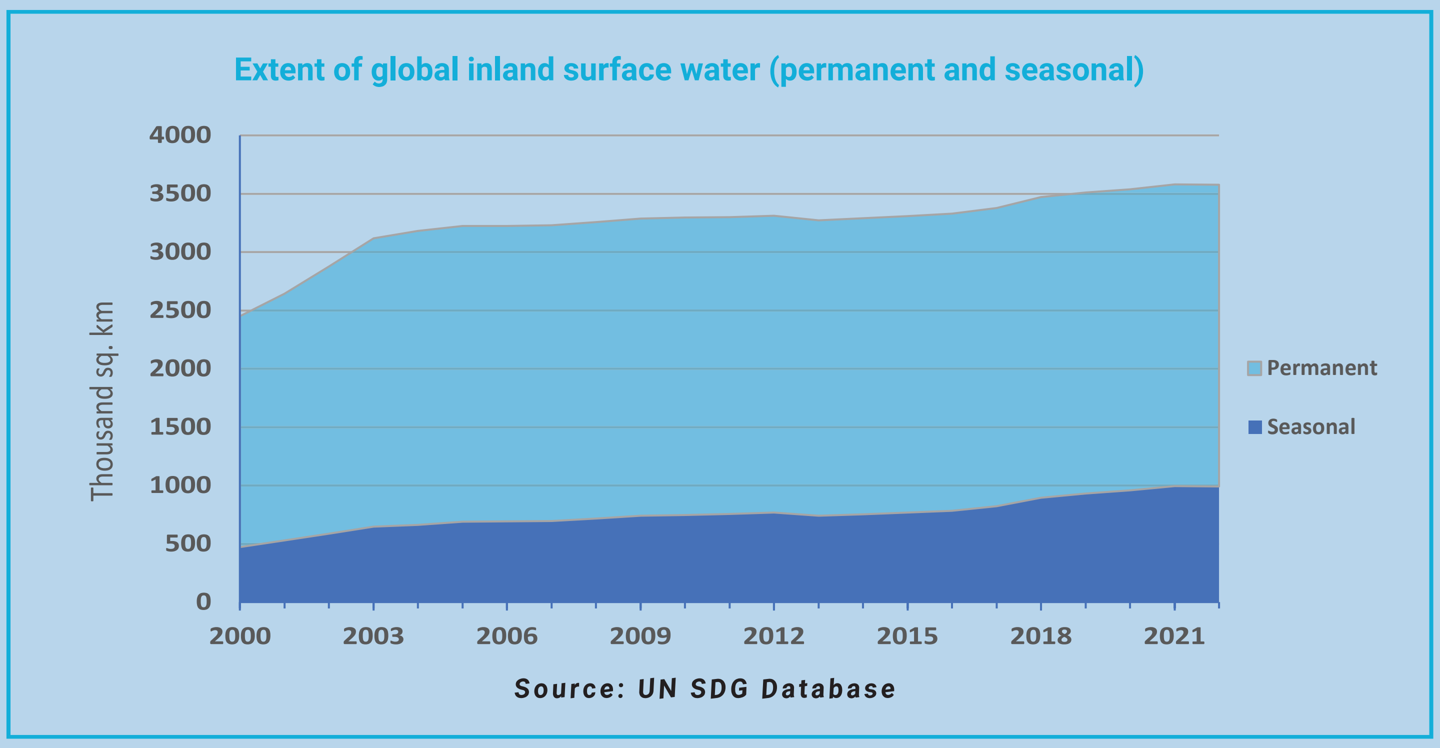
Map Projection:
NAD 1983

0 50 100 km

Copernicus data on global land cover provides spatial information on various land cover categories across the globe. The map visualizes Copernicus data on the spatial extent of water ecosystem in the state of Minnesota, which reveals that the state has an abundance of inland water bodies including rivers, lakes, reservoirs ponds, wetlands, etc. The total area covered by water bodies in Minnesota in the year 2019 is 1,203,013 hectares, which indicates a fairly good distribution of water bodies in the state. Copernicus data supports the fact that water ecosystems are subject to spatial dynamics i.e., their spatial extent changes over time. The overall area of water bodies in the state of Minnesota is found to increase slightly each year. Such expansion in the surface area could be the result of excessive precipitation or flooding while in some cases, drying out of wetlands and floodplains can also occur due to reduced precipitation or warming. Copernicus data on water bodies help to monitor the status and spatial dynamics of water ecosystem and thereby suggest the necessary measures for their conservation and sustainable management.

COPERNICUS DATA

Dataset	: Global Land Cover
Provider	: Copernicus Land Monitoring Service
Data type	: Gridded
Thematic classes	: 23
Horizontal coverage	: Global
Horizontal resolution	: 100 m
Temporal coverage	: 2015-2019
Temporal resolution	: Yearly
Projection	: WGS 1984
File format	: GeoTIFF



"Only 0.5 percent of water on Earth is useable and available as freshwater and climate change is dangerously affecting that supply. Over the past 20 years, terrestrial water storage including soil moisture, snow and ice has dropped at a rate of 1 cm per year, with major ramifications for water security." -WMO

SDG RELEVANCE

6 CLEAN WATER AND SANITATION

Goal 6: Ensure availability and sustainable management of water and sanitation for all

Target 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

Indicator 6.6.1: Change in the extent of water-related ecosystems over time

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COPERNICUS SUPPORTS SUSTAINABLE DEVELOPMENT GOALS

#15

Riparian grassland are the green, ecologically important zones along the rivers, streams and freshwater bodies. They play a crucial role in soil conservation, chemical filtration, flood control and protection of aquatic ecosystem. Riparian grasslands provide food to herbivorous creatures and shelter to insects, invertebrates and microorganisms. They also help to maintain natural greenery and regulate the water and nutrient cycles. Riparian grasslands are being increasingly destroyed due to human interventions such as agricultural and residential expansion, use of pesticides and chemical fertilizers, overgrazing, irrigation, fishing, etc. Destruction of riparian grasslands can cause serious threats to both the terrestrial and aquatic ecosystem. Some negative impacts of grassland deterioration include disruption in food web, loss of soil moisture, excessive runoffs, dust storms and desertification.

RIPARIAN GRASSLAND

Rhine Basin, 2018

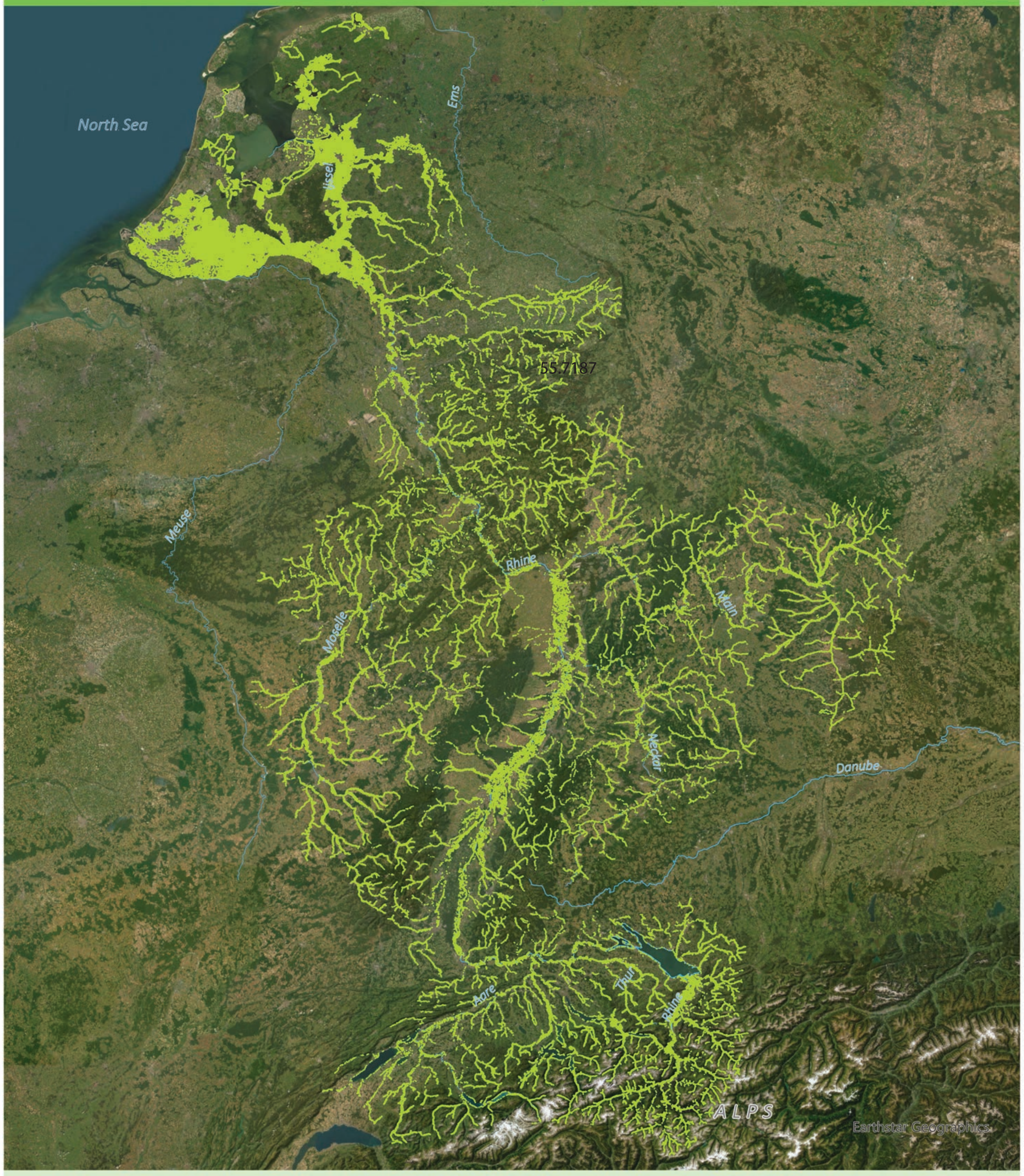


IMAGE MAP TYPE: Back/Rear Thematic

Image Component: **Topographic Base:** ESRI World Imagery

Symbol Component: **Thematic Content:** Riparian Grassland, River network, Labeling
Data Source: Copernicus Land Monitoring Service
Spatial Resolution: 0.5 ha MMU

Riparian Grassland
Total Area: 779,695.80 ha

Map Projection: ETRS 1989 LAEA

0 50 100 km

SDG RELEVANCE

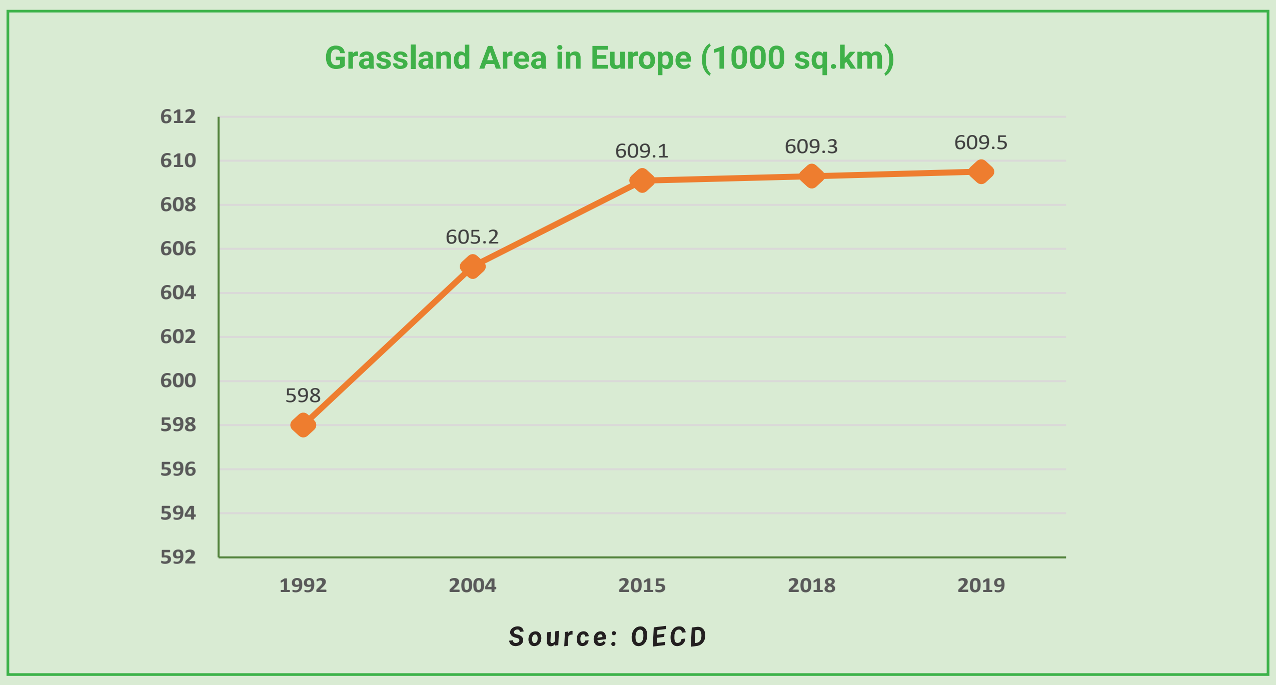
15 LIFE ON LAND

Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

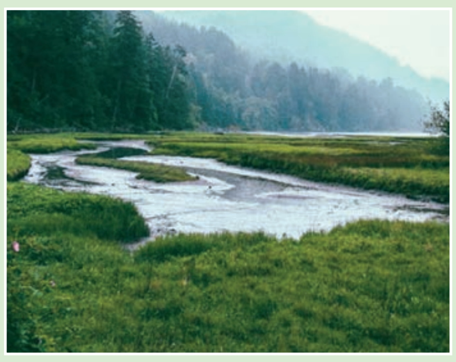
Target 15.1: By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements

Indicator 15.1.2: Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type

Copernicus data on riparian zone land cover/ land use provides detailed information on the state and characteristics of riparian zones across the European continent. The map visualizes Copernicus data on riparian grassland in Rhine basin which reveals the richness of grassland along the Rhine River and its tributaries. It can be observed that the grassland is denser particularly in the northern extent of the basin. The total area covered by riparian grassland in Rhine basin in the year 2018 is 779,695.80 hectares, which indicates the presence of a substantial amount of grassland in the basin. However, the grassland area in the Rhine basin is found to decline considerably than in the reference year 2012. Copernicus data on riparian grassland helps to monitor the status of grasslands in the riparian zones and illustrate how they have changed between the reference years. It recommends the need for the conservation, restoration and sustainable management of grassland in the Rhine basin in order to prevent it from further deterioration. This can be achieved by minimizing the overexploitation of grasslands and by controlling human intervention on natural resources.



*"Grasslands account for between 20 and 40 percent of the world's land area. Still, only a small percentage - less than 10 percent of the world's grassland is protected." **-National Geographic***



COPERNICUS DATA

Dataset	: RZ Land Cover/Land Use
Provider	: Copernicus Land Monitoring Service
Data type	: Vector
Thematic classes	: 55
Horizontal coverage	: Europe
Horizontal resolution	: 0.5 ha MMU
Temporal coverage	: 2010-2013, 2017-2020
Reference years	: 2012, 2018
Projection	: ETRS 1989 LAEA
File format	: Shapefile

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ATTACHMENT 4

WEB MAPS

ATTACHMENT 5

ANIMATIONS