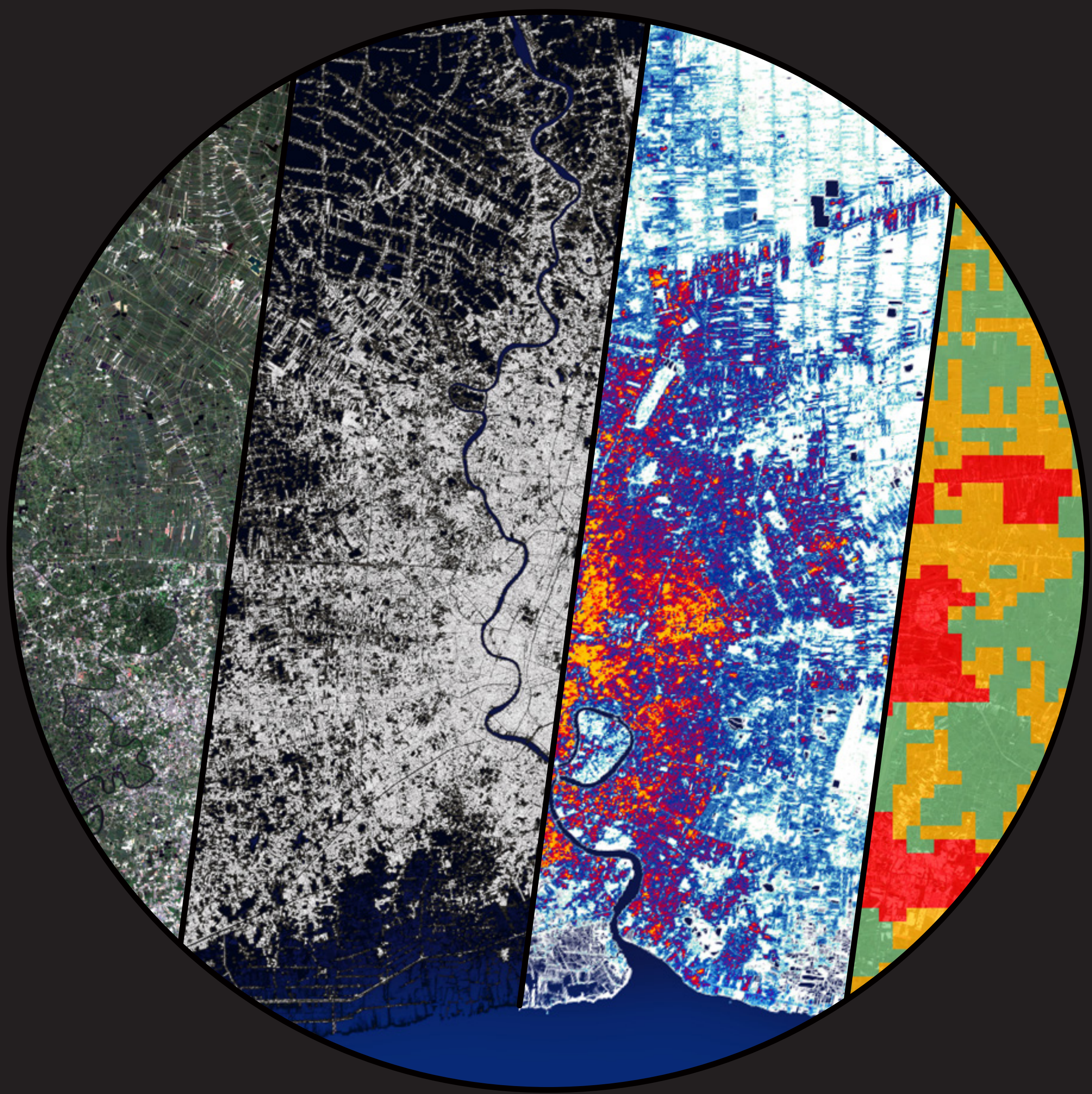
ISSN 1813-9424

European Commission

Atlas of the Human Planet 2024



EUR 31897 EN

Joint Research Centre

ATLAS OF THE HUMAN PLANET 2024

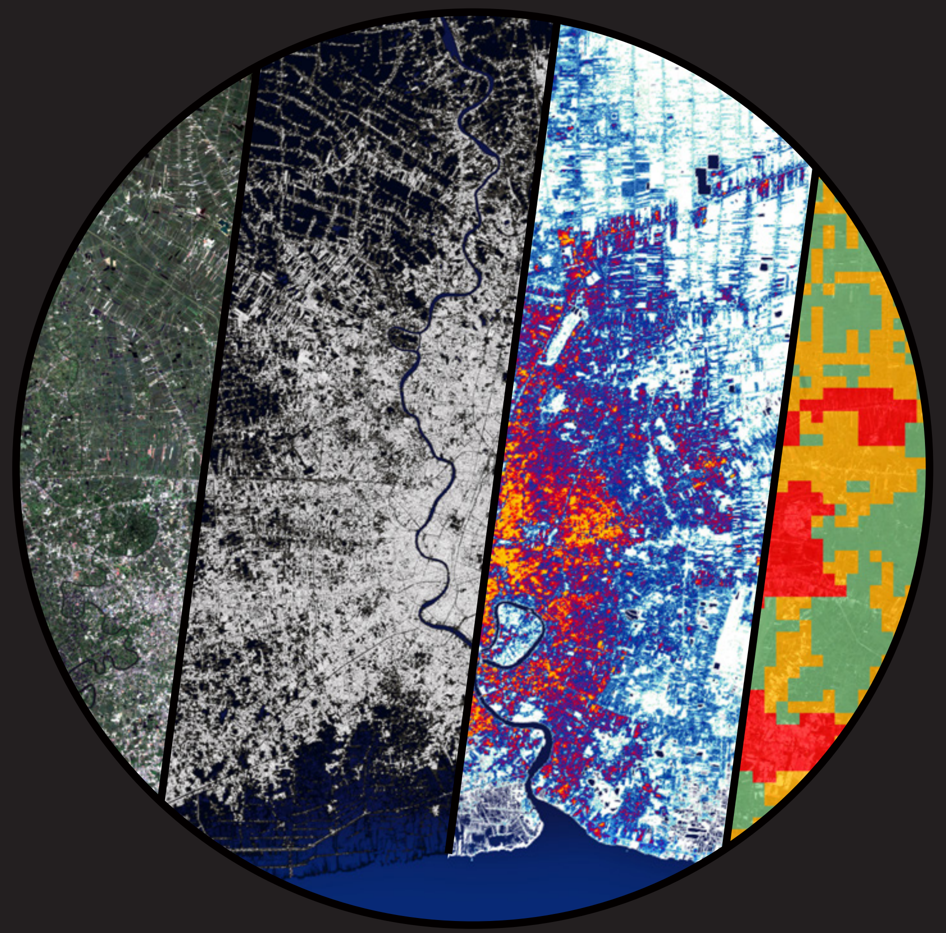
EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC136039
EUR 31897 EN

Print ISBN 978-92-68-14302-5 ISSN 1018-5593 doi:10.2760/855738 KJ-NA-31-897-EN-C
PDF ISBN 978-92-68-14301-8 ISSN 1831-9424 doi:10.2760/808886 KJ-NA-31-897-EN-N

Luxembourg: Publications Office of the European Union, 2024.

How to cite this report: European Commission, Joint Research Centre, Ehrlich, D., Kemper, T., Uhl, J. H., Marí Rivero, I., Florio, P., Pesaresi, M., Melchiorri, M., Politis, P., Maffenini, L., Schiavina, M., Tommasi, P., Carioli, A., Krasnodębska, K., *Atlas of the Human Planet 2024*, Ehrlich, D. and Kemper, T., editor(s), Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/808886, JRC136039.



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It is my honour and privilege to introduce the Atlas of the Human Planet 2024. This remarkable work, shedding light on the complex relationship between humanity and our planet, is at the forefront of global research on human settlements.

At its core, the Atlas showcases how the scientists behind the Global Human Settlement Layer transform free and open data and geo-information offered by the European Union through the Copernicus Space Programme into understanding the dynamic interplay between human populations and the natural environment. This work examines ways in which human settlements interact with landscapes and ecosystems upon which we rely. Through maps, charts and storylines, the publication provides a compelling, evidence-based exploration of the multi-sectoral implications of human development and urbanisation for our planet.

But the Atlas is not just a compelling visual narrative. It also serves as a call to action. It is a reminder that the fate of our planet is inextricably linked to our choices and actions. By highlighting the interconnectedness of human society and the natural world, the Atlas emphasises the critical need for sustainable and equitable development, the protection and restoration of the Earth's vital ecosystems, and the profound challenges of climate change and environmental degradation.

The Atlas of the Human Planet 2024 is a testament to the power of evidence-based policy and informed decision-making. The underlying data, produced by the European Commission's Joint Research Centre, provide a wealth of information and insights. With long-term datasets, monitoring of the present conditions and projections for the future, it equips policymakers, planners and stakeholders with the necessary knowledge and tools to make strategic decisions, to anticipate and mitigate potential risks and to foster a more resilient and sustainable future for all.

Ultimately, this work embodies the commitment of the European Union to addressing global challenges beyond borders and based on the evidence of science, aiming for a brighter future for humanity.

I am confident that this Atlas will serve as a valuable resource for governments, institutions and organisations worldwide, inspiring bold and transformative action to address the pressing environmental and social challenges of our time.

Acknowledgments

The Atlas of the Human Planet 2024 has been compiled using datasets generated by the Global Human Settlement Layer (GHSL) team of the European Commission's Joint Research Centre (JRC), and a network of research and policy institutions cooperating within the Human Planet Initiative (HPI)[1] of the Group on Earth Observation (GEO)[2]. We would like to thank GEO for fostering open access to the NASA Landsat satellite image archives – so prominent in our work – and the organisational framework that has helped to establish networks of institutions to advance the use of Earth Observation (EO) for research and policy use.

We would also like to thank all HPI partners for the direct and indirect work that has led to the series of Human Planet Atlases. We would like foremost to acknowledge the partnership with the Center for International Earth Science Information Network (CIESIN) under the former leadership of Dr. Robert Chen with whom the GHSL team has generated the population density datasets. The work of the GHSL team would not have been possible without the European Union Copernicus Programme and the agencies including the European Space Agency that have built and put in orbit the EO satellites such as Sentinel-2 that are the backbone of our data analysis. Thanks to the continued support of European Commission Directorate-General for Regional and Urban Policy (REGIO) since the beginning of the GHSL project, the GHSL data have matured to a level where they supported the negotiations for the harmonised definition of cities, urban and rural areas that is prominently displayed in this Atlas. The GHSL data is today operationally produced under the Copernicus Emergency Management Service supported by the Directorate-General for Defence Industry and Space (DEFIS), and the Directorate-General for European Civil Protection and Humanitarian Aid Operations (ECHO).

We would like to acknowledge the contribution of the map classification and colour scheme created by Duncan A. Smith, Centre for Advanced Spatial Analysis University College London, used in the Atlas for visualising population density[3]. The luminocity3d legend is also available online at luminocity3d.org. Our thanks also go to Adelaide Dura and Fabio Bortolamei for providing customised graphics used within the Atlas, to Andrea Gerhardinger for providing valuable content, and to Niall McCormick for providing a thorough review of the Atlas.

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Introduction

Why an Atlas of the Human Planet?

Urbanisation, societal resilience and sustainability

Urbanisation, a characteristic trait of 21st century human society, is closely linked with both societal resilience and the sustainability of planet Earth.

We are living in an age of fast societal transformation, when humans are also having far-reaching impacts on planet Earth. During the past half-century, the world's population has greatly increased, and most societies have improved their wellbeing and life expectancy. At the same time, the movement of people and goods across regions and continents has also increased, and human activities are significantly affecting our planet's ecosystems and climate. Many people's lives, livelihoods and opportunities are being transformed as human societies adapt to technological and environmental changes. It is likely that many people now live in settlements that are larger than those where they lived during childhood, and mostly in cities rather than in towns or rural areas, with the new challenges and opportunities that this entails.

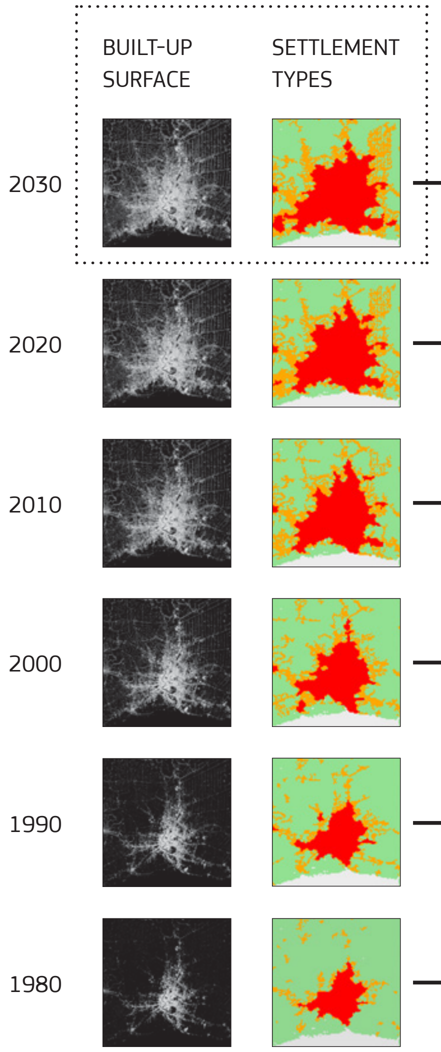
Knowing where people live and work is of key importance for efforts to address current and future societal challenges. Understanding the resilience of societies to hazard impacts and a changing climate, determining the best paths to sustainable urbanisation, as well as implementing major international initiatives such as **Leave No One Behind**[1] or **Early Warnings For All**[2], all presuppose that we have access to detailed information on settlements and population. And that information must be global. This demand for information is addressed by the Global Human Settlement Layer (GHSL), which includes the key variables population density, built-up surface, and settlement types, the latter including cities, towns and semi-dense areas, and rural areas.

This Atlas of the Human Planet 2024, the 6th in a series, showcases the vital relevance of information on population and settlements for addressing a range of societal issues. While the Case Studies that illustrate the Atlas are all local, the activities and processes that happen at given locations can and do have regional or global consequences. Such global impacts on planet Earth and its resources are measured by indicators that are part of International Framework Agreements, for which data on population, built-up surface and settlement types are used in various combinations, and also complemented with information from other thematic areas. The Atlas of the Human Planet 2024 is designed for a non-technical audience, and has a slightly different format from the previous editions (including the images and graphics), as is briefly summarised in the next sub-section.

How to read this Atlas

The Atlas of the Human Planet 2024 presents a collection of Case Studies that describe and illustrate the development of global human settlements, based on GHSL information. Chapter 1 provides the context for the GHSL team's work, and summarises global human settlements as they are today, and how they have evolved over the past half-century. This global overview is complemented by local Case Studies, in Chapters 2, 3 and 4. Cities have physically evolved based on particular construction and planning patterns, and display very different sizes and spatial patterns, as shown in Chapter 2. Geography is still an important constraining factor for the development of most settlements, as shown in Chapter 3. Regardless of where settlements are located, there will always be challenges related to the interaction between natural processes and societies, with some areas that are more exposed than others experiencing disastrous events, as shown in Chapter 4.

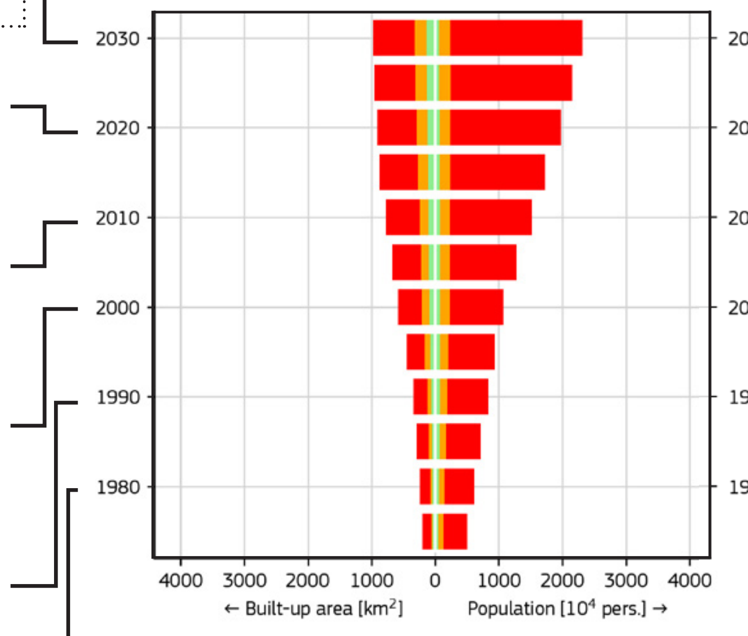
This Atlas is illustrated using some recurrent types of information. The EU's Sentinel-2 satellite images, which provide high resolution and optical remote sensing data covering the globe, continue the Earth Observation legacy that started with NASA's Landsat satellite programme. The most recent GHSL built-up surface products, derived from Sentinel-2 images, are used to measure the land surface occupied by buildings that in turn is used to estimate the density of the population. The GHSL settlement types dataset is an information product derived using the Degree of Urbanisation methodology, which differentiates between **cities, towns and semi-dense areas,** and **rural areas**. Settlement dynamics plots are used to summarise, for Case Study areas, the amount of built-up surface and population in the different settlement types, over the time-frame covered by the GHSL data. Most of the local Case Studies cover an area of 100 km × 100 km. At the end of the Atlas, the Glossary and Reference sections define any specific terminology and cited publications (referred to by superscript numbers) that are used throughout the Atlas.

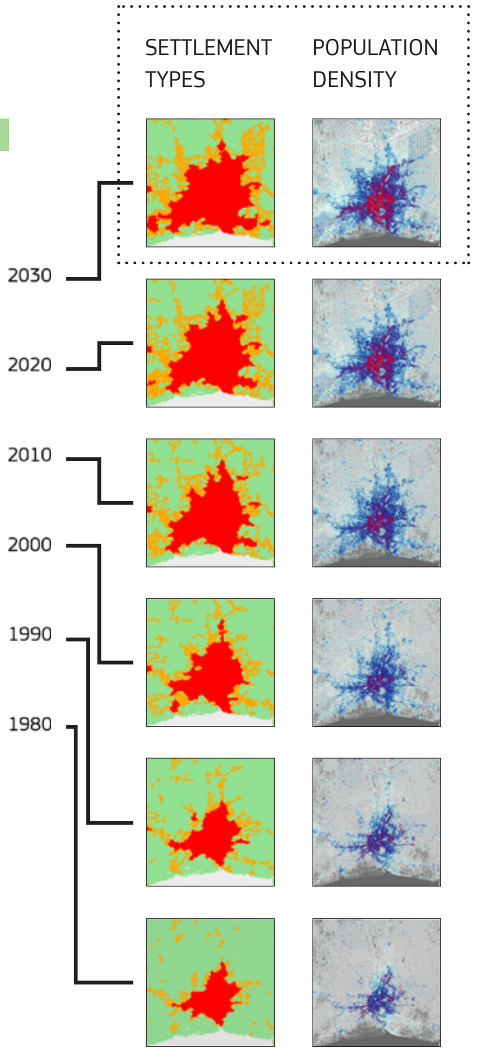


SETTLEMENT DYNAMICS

Bangkok 1975 - 2030

Cities | Towns and semi-dense areas | Rural areas





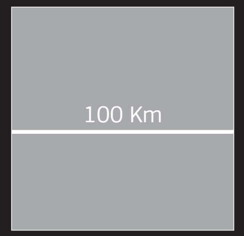
Settlement dynamics plot for 1975-2030

Built-up surface (on the left), and population density (on the right) for the three settlement types, for 1975-2030, at 5-year intervals. The built-up surface and population density values for 2020-2030 are estimated.

GHSL data

Recurrent types of information

The locations of the Case Studies are typically represented as geographical regions of 100 km × 100 km.



Sentinel-2

Sentinel-2 image of Bangkok

Sentinel-2 satellite images provide the most advanced optical remote sensing data covering the globe.

Built-up surface

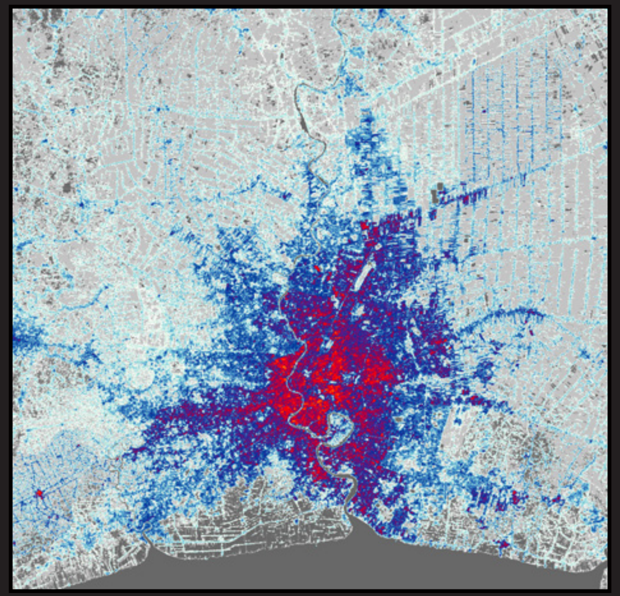
Built-up surface of Bangkok in 2020

Built-up surface measures the area of land occupied by buildings.

Population density

Population density of Bangkok in 2020

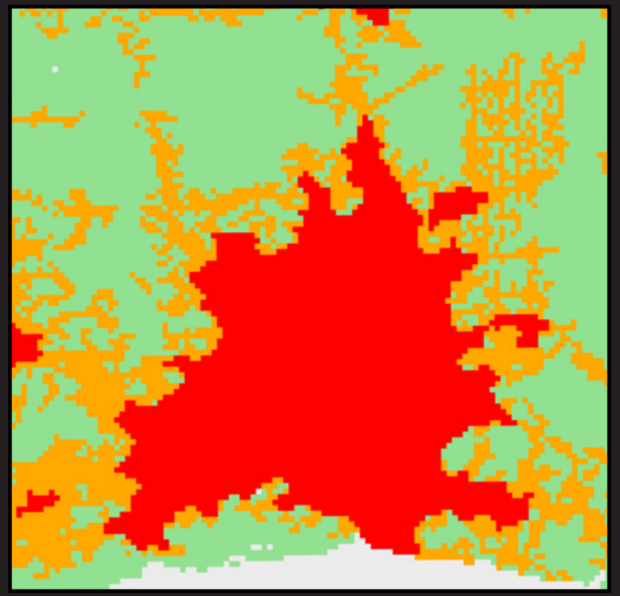
Built-up surface products, derived from Sentinel-2 images, are used to estimate the density of the population.



Settlement types

Settlement types of Bangkok in 2020

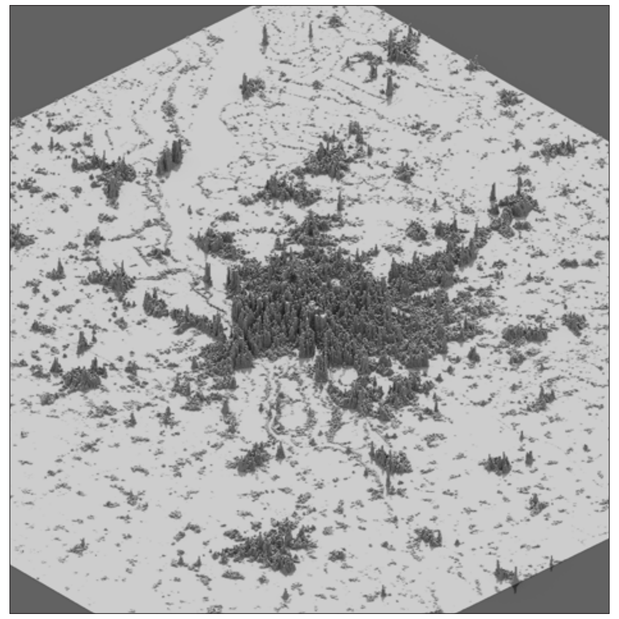
Settlement types is an information product derived using the Degree of Urbanisation methodology.



GHSL products

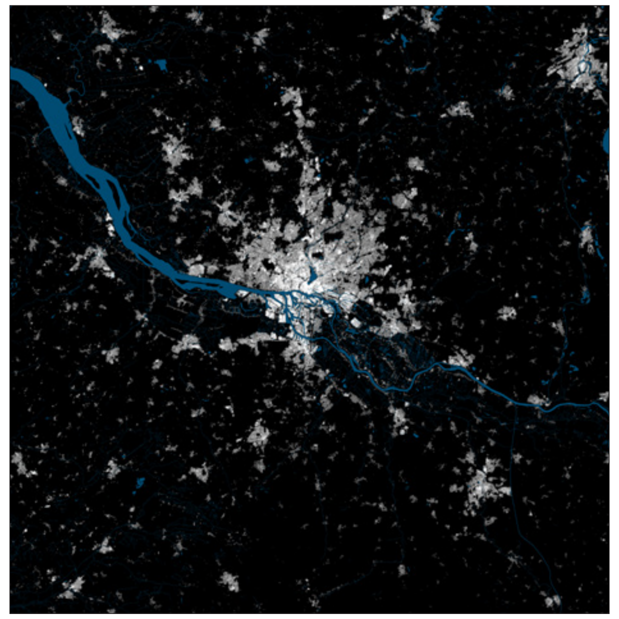
Which geospatial data layers constitute the GHSL products?

The Global Human Settlement Layer (GHSL), and the information that is described and presented in this Atlas, are the result of more than a decade of research on the extraction of information on human settlements from Earth Observation (EO) satellite images, and the integration of data from different sources.
Within the GHSL framework, the first step is the extraction of information for built-up areas (i.e. built-up surface, building height, built-up volume, residential / non-residential classes) from satellite images. Subsequently, population grids are obtained by distributing the residential population collected from national population census data over the built-up areas mapped from the EO data.
These population grids are then used to generate a map of settlement types, which classifies the population grids into **cities, towns and semi-dense areas,** and **rural areas**. The map of settlement types can then be used to generate indicators for comparing urban areas across the world. The images on this page show examples of GHSL products for the city of Hamburg, Germany.



GHSL Built-up volume

GHSL Built-up volume (calculated from built-up surface and building heights) in 3D.

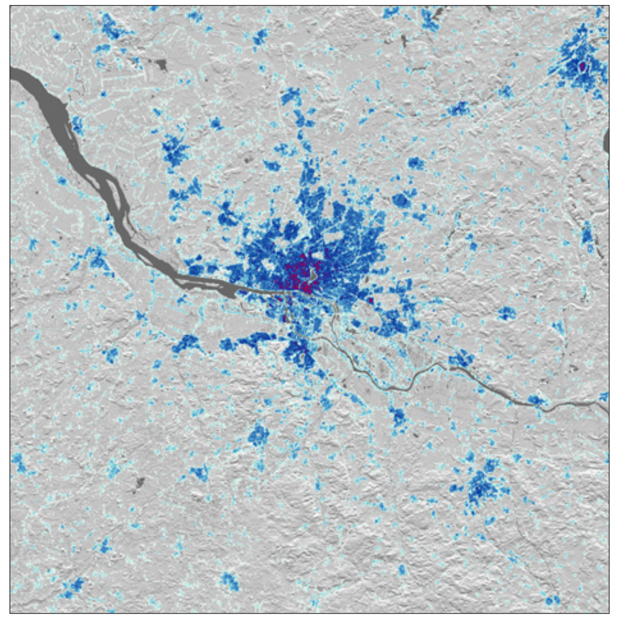


GHSL Built-up surface

Built-up surface extracted from Earth Observation (EO) satellite images for Hamburg, Germany.

Built-up surface map

Higher density built-up
Lower density built-up
Water bodies
Land



GHSL Population

GHSL population (showing presence and density of population) allocated to the GHSL built-up volume data.

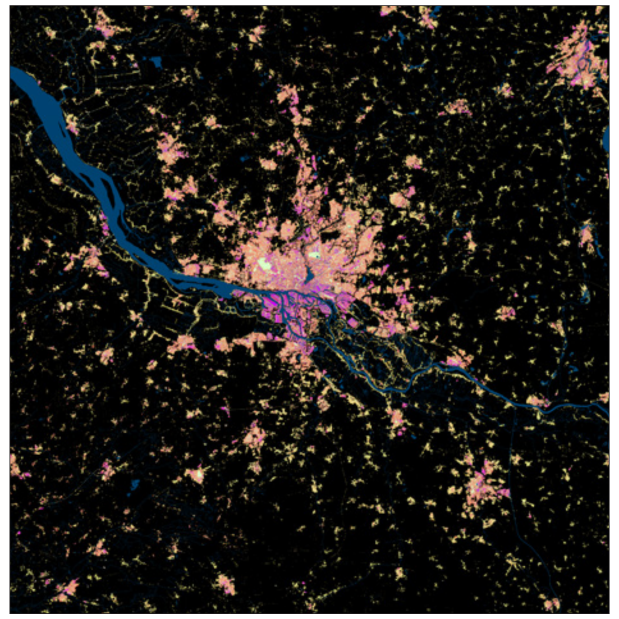
People per hectare

Water bodies
Land

1
2 - 4
4 - 10
10 - 20
20 - 35
35 - 55
55 - 75
75 - 100
100 - 120
120 - 160
160 - 220
220 - 300
300 - 500
500 - 1000
1000 - 2000
> 2000

Sentinel-2

Sentinel-2 composite image for Hamburg, from which built-up information is extracted.



GHSL settlements characteristics

Residential and non-residential built-up areas, building height and vegetation information generate the spatial grid of settlement characteristics.

Residential buildings

1 floor
between 1 and 2 floors
between 2 and 5 floors
between 5 and 10 floors
more than 10 floors

Open spaces

with low vegetation index
with medium vegetation index
with high vegetation index

Non-residential buildings

1 floor
between 1 and 2 floors
between 2 and 5 floors
between 5 and 10 floors
more than 10 floors

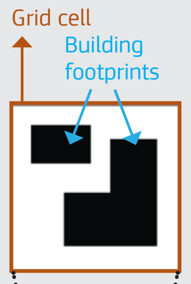
Land
Water bodies

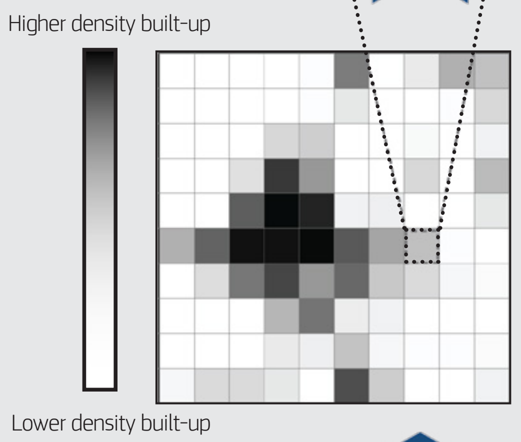
GHSL basic concept

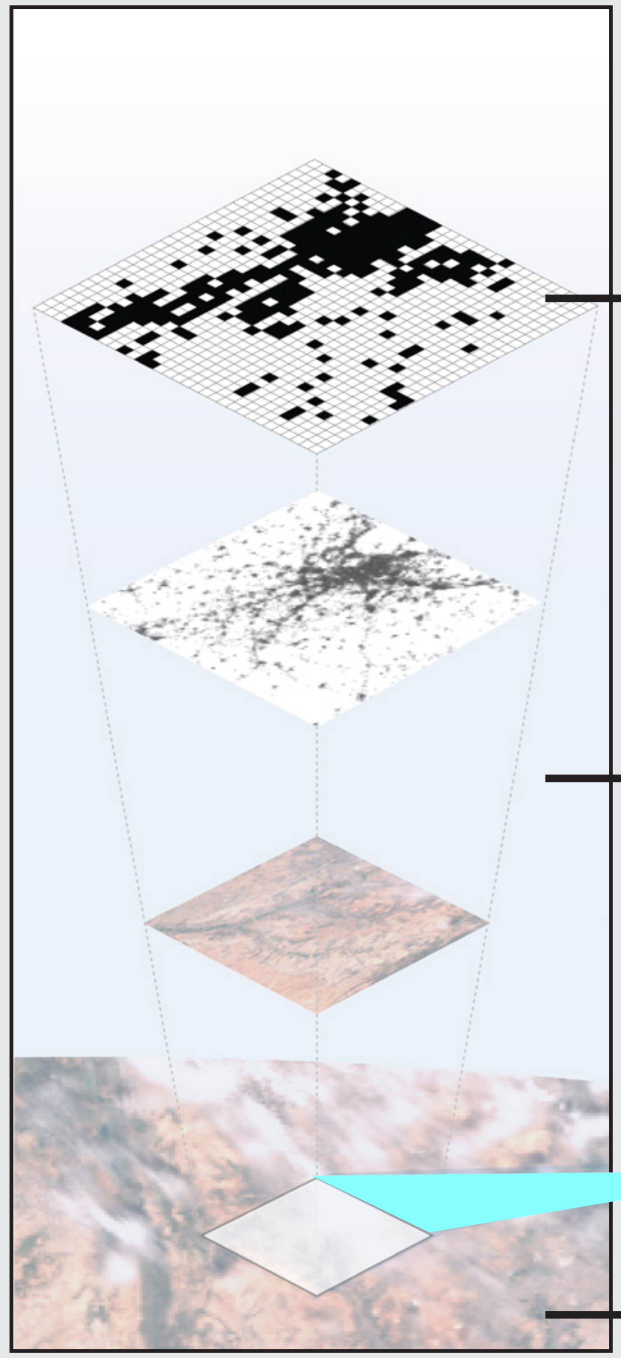
From satellite images of the Earth to built-up surface.

Built-up surface spatial grid

The GHSL built-up surface dataset reports, for each grid cell, the area (in square metres) of land surface covered by buildings. In practice, each grid cell of the GHSL built-up surface spatial grid, displays built-up surface density, that is the ratio between the area of land covered by buildings and the area of land covered by the grid cell.







Built-up surface extraction

Human settlements are characterised by land surfaces covered by constructed, man-made objects, including buildings and associated structures and civil works. The GHSL information extraction methodology measures the built-up surface, namely the physical area of land covered by buildings (also referred as building footprints), in square metres.

Satellite imagery

A satellite image is a digital image taken from outer space which represents an observed part of the Earth's surface. Satellite images contain information about settlements, which can be extracted using image processing operations that use colours, brightness, and texture to separate settlements from other land uses.

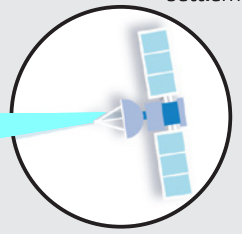
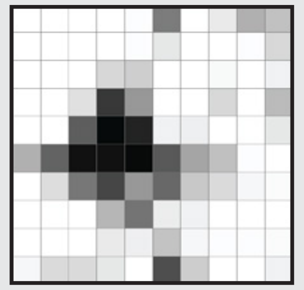


IMAGE ACQUISITION

Earth's land surface

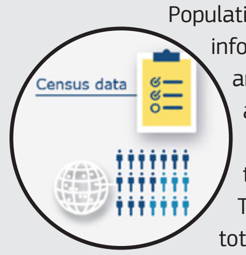
Earth observation (EO) satellites, such as Sentinel-2, regularly collect images of the Earth's land surface, which are used to extract information on different land surface features.

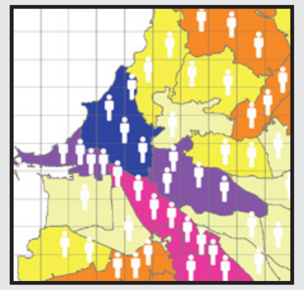
From built-up area to population grid



Input

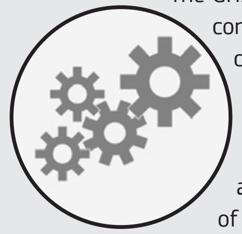
Population census data provide accurate information on the characteristics and number of residents for administrative regions or smaller geographic areas (i.e. "census tracts").
These datasets typically provide a total count for the geographic areas, which vary widely in size and shape, frequently with residents occupying only specific zones of the areas, at different densities.
GHSL procedures use detailed spatial information from the GHSL built-up datasets to generate uniform resident population densities.

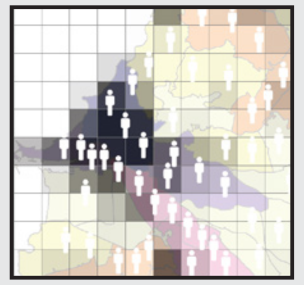




Method

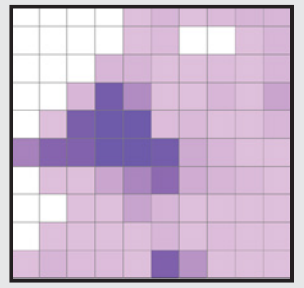
The GHSL methodology is designed to combine information from the population census data with the GHSL built-up datasets, and to downscale the population data into a grid at 100 m resolution (referred as GHS-POP), according to the presence or absence of built-up surface in the grid cell.





Output

The combined information on population and built-up area results in a new GHSL layer (at 100 m resolution), which is independent of administrative boundaries, and which represents population density. In the GHS-POP grid, the grid-cell value represents the absolute number of inhabitants.



The Degree of Urbanisation

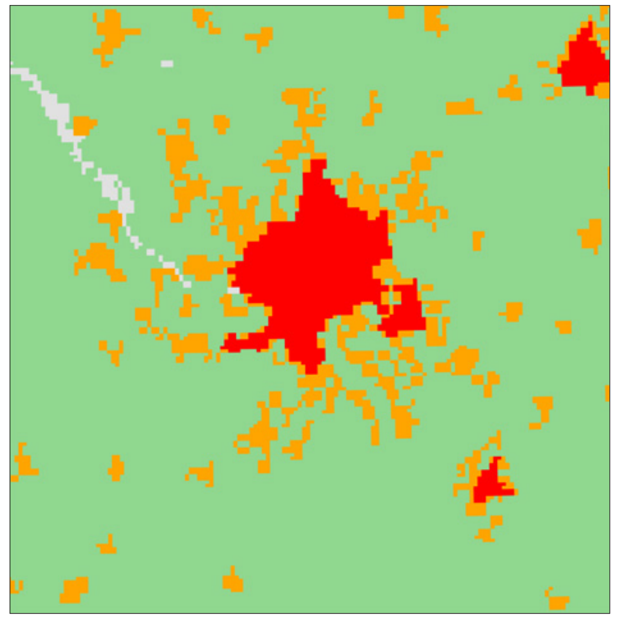
We all have an understanding of what urban and rural areas are. We associate "urban" with larger, densely populated settlements like cities, and "rural" with smaller, more sparse settlements with lower population densities. This urban-rural dichotomy has been used since the 1950s for generating statistics at national level.

However, this classical distinction was based on very different national definitions, making it difficult to generate meaningful global statistics and to compare settlements across regions and countries of the world. Moreover, settlements have grown into complex shapes, forms and sizes, beyond the administrative units, which may be better described using an "urbanisation continuum" concept extending from the largest cities to the smallest villages.

The Degree of Urbanisation (DEGURBA)[3] is a classification methodology that describes this urbanisation continuum. The method delineates **cities**, **towns and semi-dense areas**, and **rural areas** based on population size and density, in a systematic and comparable way across the Earth. It has been developed based on the GHSL datasets, by major international stakeholders (EU, OECD, World Bank, UN-Habitat, FAO, ILO) and has been endorsed by the UN Statistical Commission in 2020, for the international comparison of urban-rural statistics[4].

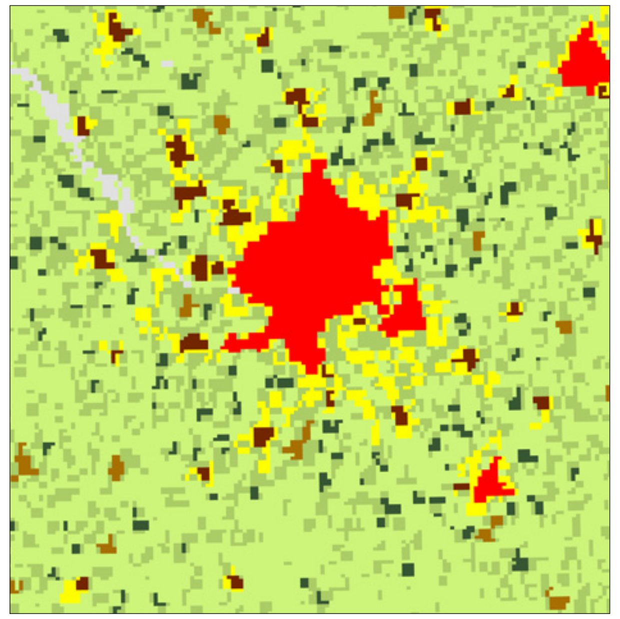
GHSL settlement classification Level 1

Level 1 identifies three settlement types: Cities (Urban centres), Towns and semi-dense areas (Urban clusters), and Rural areas (Rural grid cells).

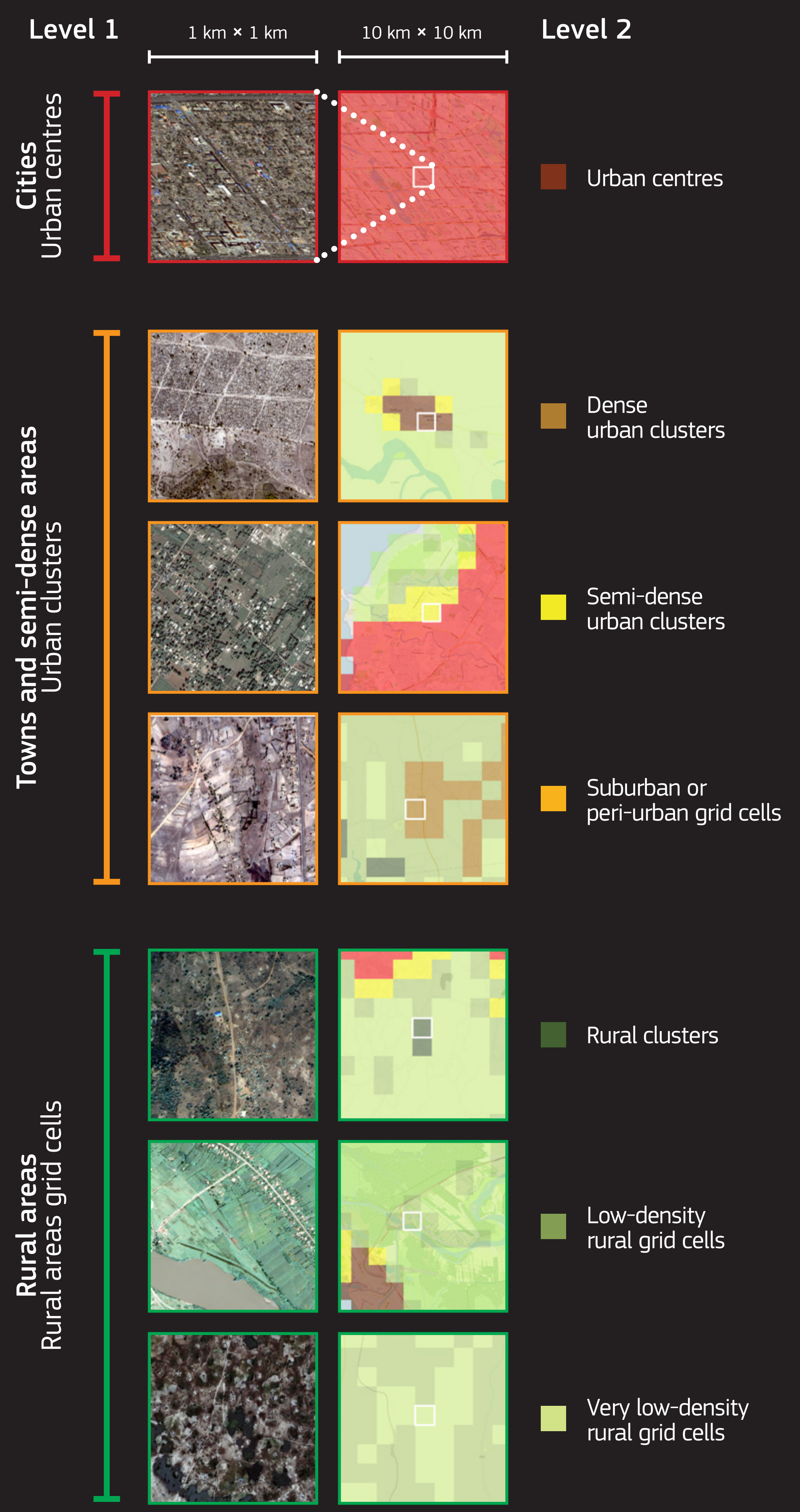


GHSL settlement classification Level 2

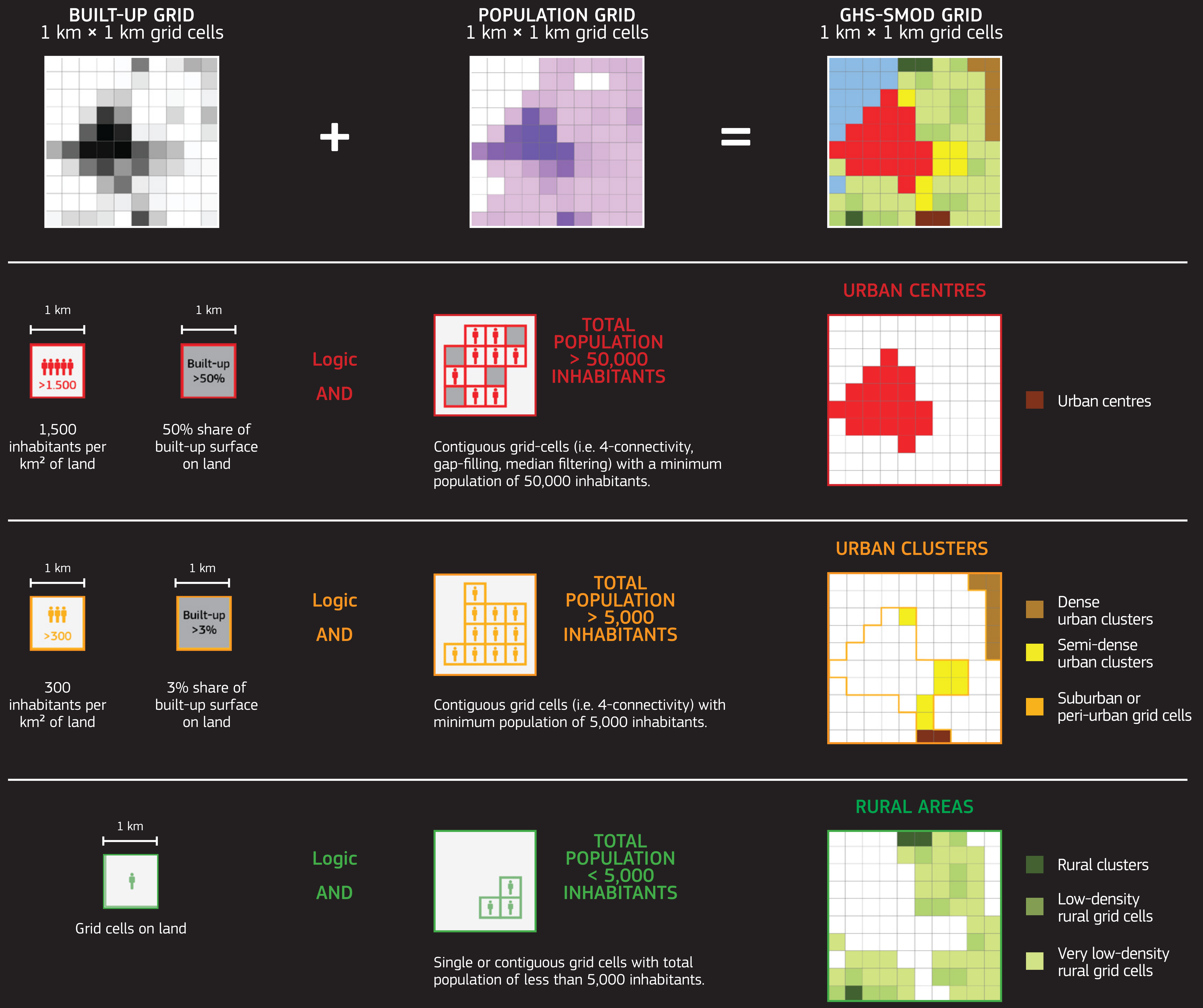
Level 2 identifies seven settlement types: Urban centres, Dense urban clusters, Semi-dense urban clusters, Suburban or peri-urban grid cells, Rural clusters, Low-density rural grid cells, Very low-density rural grid cells.



Settlement classification types



Methodology



Chapter 1

A world of human settlements

Satellite images for measuring human settlements

Human settlements are visible from space. Earth Observation (EO) space initiatives such as NASA's Landsat programme[1] and the European Commission's Copernicus Sentinel programme[2], are continuously recording satellite images of the surface of the Earth. JRC scientists use these images to generate global human settlements maps that provide regular updates of the human presence on planet Earth. The information thus obtained helps to address the most pressing societal challenges of our times.

Settlements everywhere

A multitude of settlements in Punjab (India), which has one of the highest settlement densities in the world.

10 Km

1.1

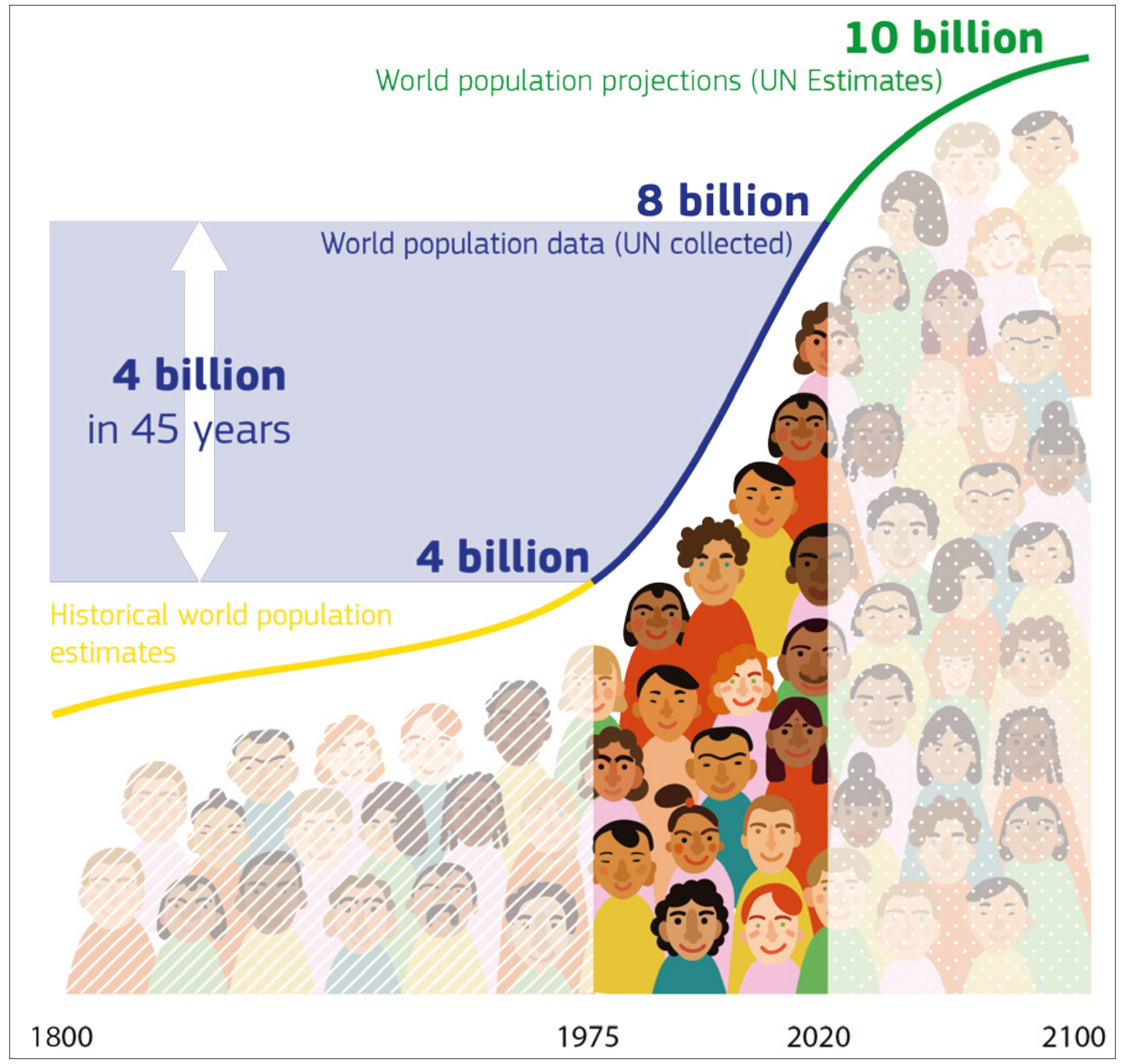
Human settlements around the world

Human settlements define human presence on planet Earth

Human settlements – the locations where people live and work – come in all shapes and sizes in a continuum from rural areas, villages, towns, cities and megacities. Human settlements define human presence on planet Earth. Few regions of the world are uninhabited, whereas high population densities are concentrated in regions of the world more suited to human habitation. The past half century has witnessed the largest and fastest growth in global human population. From 4 billion in 1975 global population has doubled to 8 billion in 2022. To accommodate that growing population, the built-up surface – that made of houses and buildings – has also expanded. The growth of population and built-up surface has been – and continues to be – uneven. For parts of the world, population and built-up continue to expand, in other parts of the world population growth has slowed, and in yet other parts population has started to decline. Global Human Settlement Layer data have been generated to reconstruct the location and sizes of settlements, their share of built-up land, and population densities globally. Built-up and population data are used to develop the Degree of Urbanisation, an agreed methodology to define cities and settlements, and rural areas in a globally harmonised way. Built-up, population density, and settlements type information is typically used in combination with other thematic information to address policy and operational demands.
The size and shape of settlements, the population living therein, their consumption patterns and the trajectories of their developments are at the centre of meeting future global societal challenges. Wellbeing and development come together with environmental concerns elaborated and encoded in the goals and indicators of the International Framework Agreements. Understanding past population growth and the corresponding built infrastructure constructed for shelter and for economic activity can be used to understand future population and built-up growth.

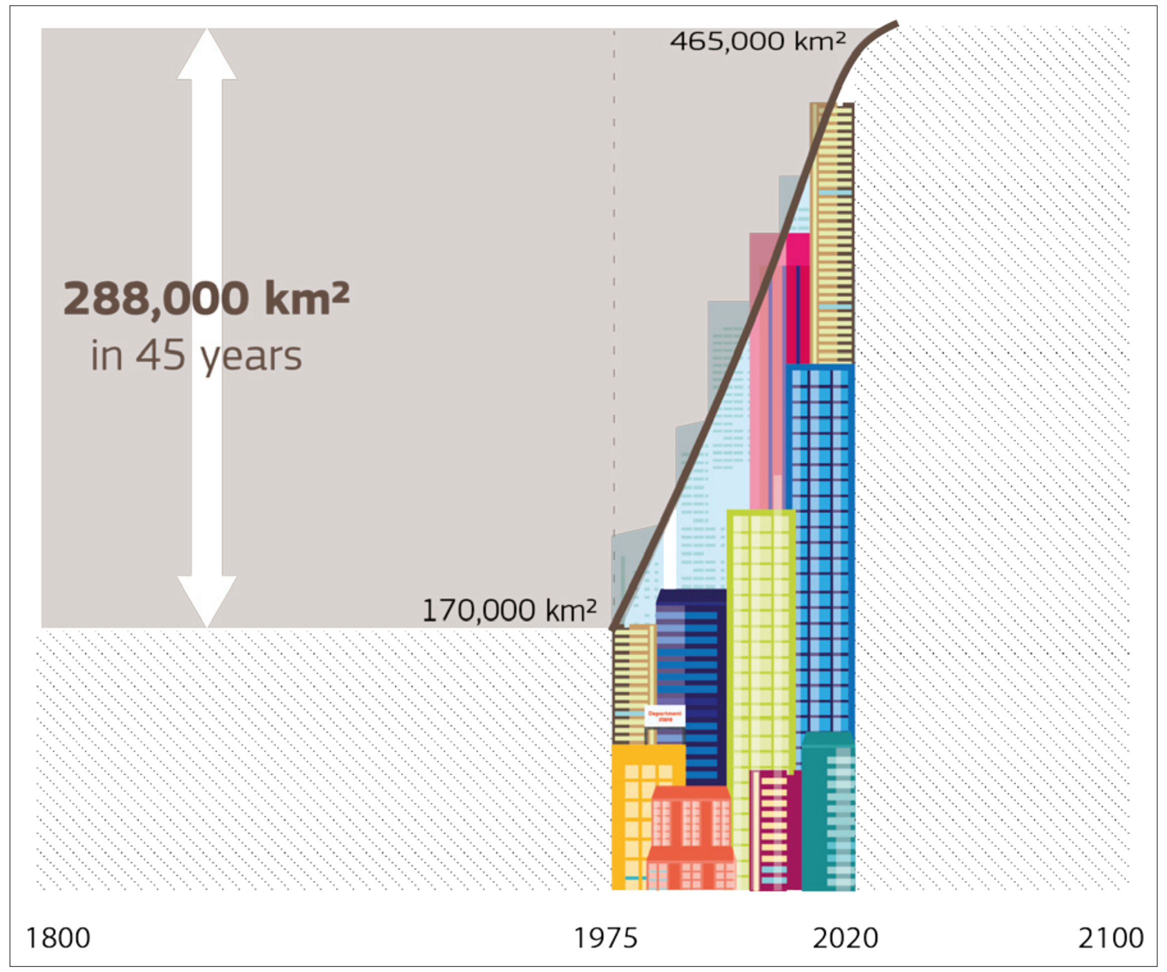
Global population growth

Between 1975 and 2020 the population of the world has grown by nearly 4 billion.



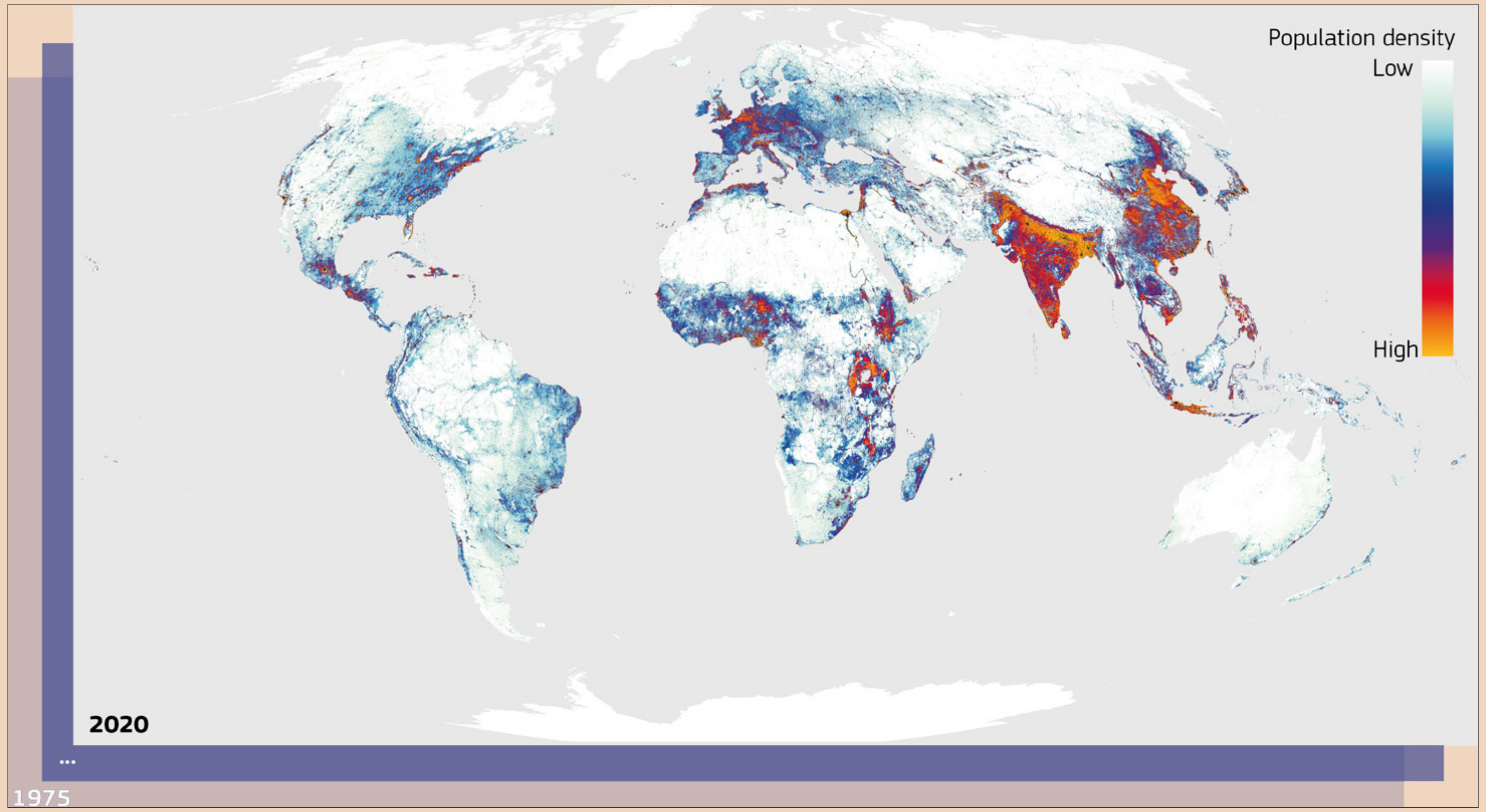
Growth of built-up surface

Between 1975 and 2020 the built-up surface of the world has almost trebeled.



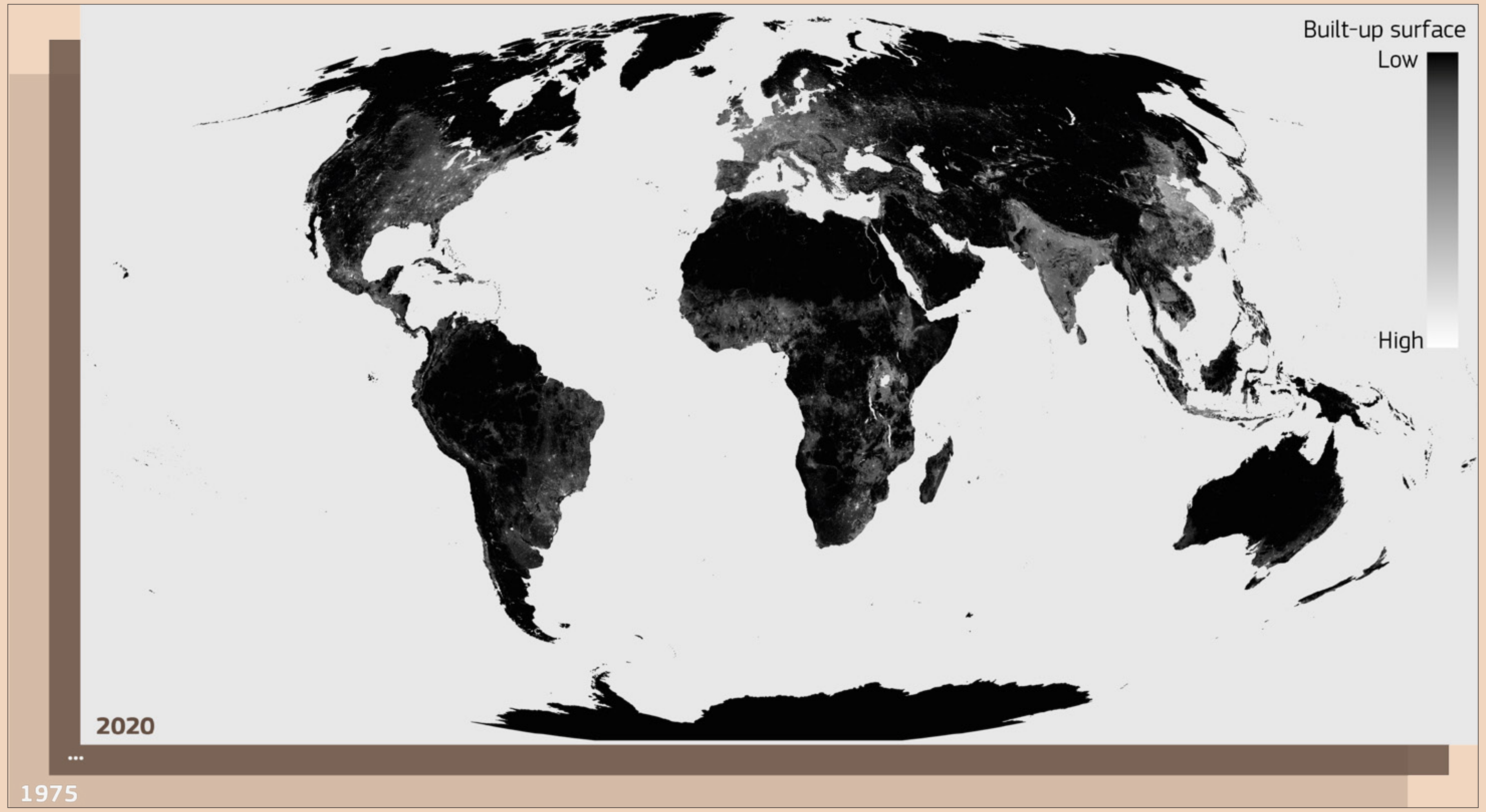
GHSL Population density

World population density maps available from 1975 are used to locate human presence on planet Earth. Population density in 2020 show that few regions of the world are uninhabited although high population densities are concentrated in regions of the world most suited for human habitation.



GHSL Built-up surface

The global built-up surface maps showing built-up surface density available from 1975 are used to reconstruct human presence on planet Earth.

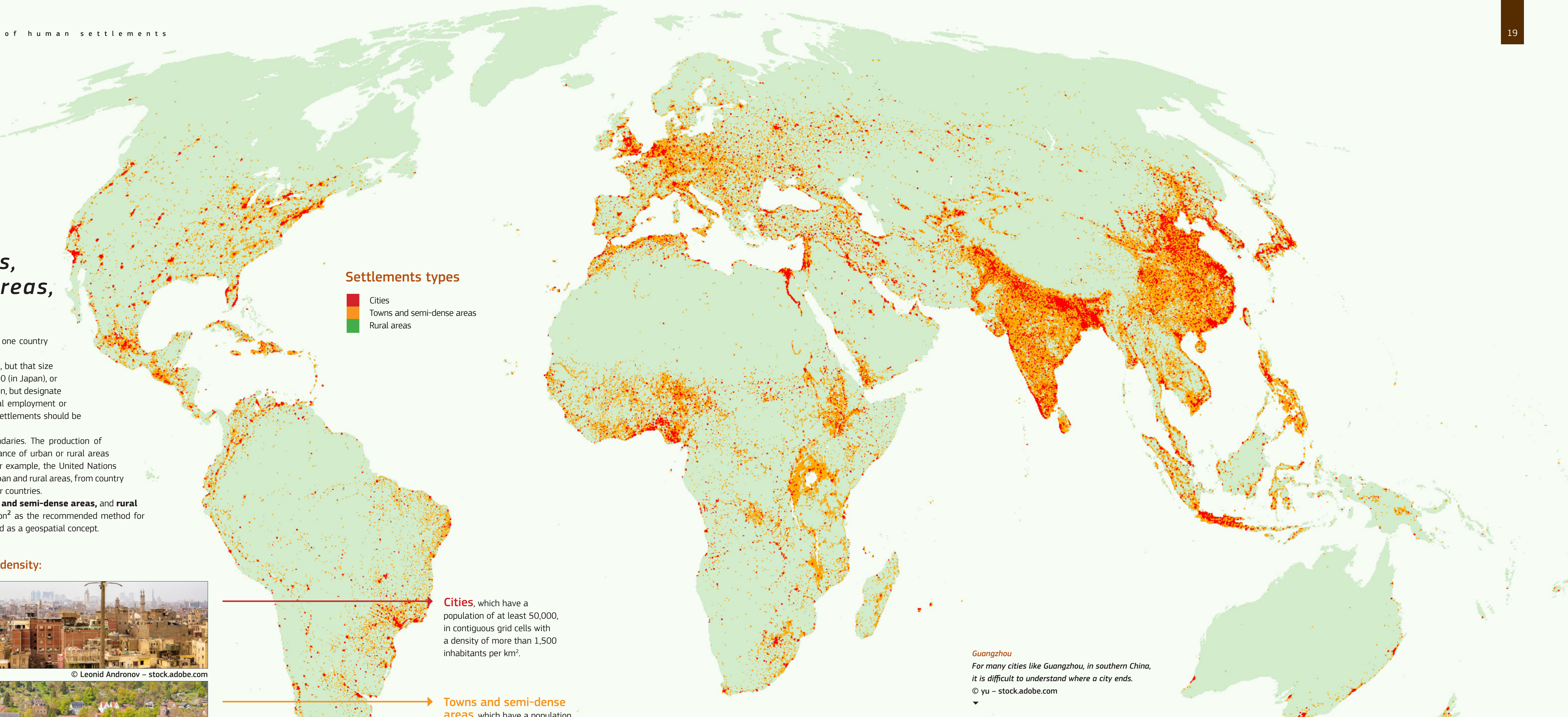


1.2

What is a city and where does it end?

A new definition for *cities, towns and semi-dense areas,* and *rural areas*

National definitions for urban and rural areas differ significantly from one country to another.
Many countries use a minimum population size to define an urban area, but that size may be 200 (in Denmark), 2,000 (in Argentina), 5,000 (in India) or 50,000 (in Japan), or even 100,000 (in China). Some countries do not use a statistical definition, but designate urban areas by administrative decision. In other countries, the sectoral employment or provision of infrastructure and services is used to determine whether settlements should be classified as urban or rural.
This makes it difficult to compare these areas across national boundaries. The production of comparable urban data is the key. If we cannot compare the performance of urban or rural areas across national boundaries, then we cannot meaningfully compare, for example, the United Nations Sustainable Development Goals (SDGs) indicators, which are used for urban and rural areas, from country to country, consequently we cannot learn from the policies used in other countries.
The Degree of Urbanisation[1] is a new global definition for **cities, towns and semi-dense areas,** and **rural areas** that was endorsed by the United Nations Statistical Commission[2] as the recommended method for making international comparisons. It is a people-based definition applied as a geospatial concept.



Three types of settlements, based on a population density:

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Cities, which have a population of at least 50,000, in contiguous grid cells with a density of more than 1,500 inhabitants per km².

Towns and semi-dense areas, which have a population of at least 5,000, in contiguous grid cells with a density of at least 300 inhabitants per km².

Rural areas, which consist mostly of low-density grid cells with less than 300 inhabitants per km².

Guangzhou
For many cities like Guangzhou, in southern China, it is difficult to understand where a city ends.
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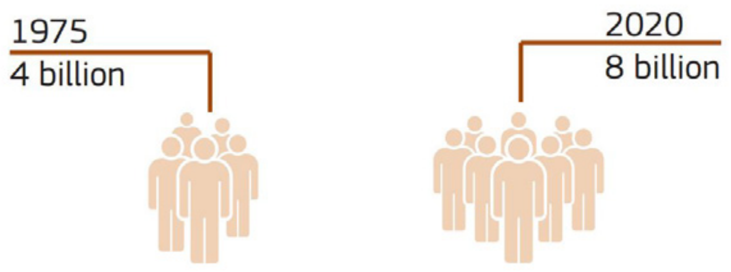
1.3

Eight key facts about urbanisation

The growth of human settlements

Global population in 1975 and 2020



The global population and built-up surface in human settlements have increased significantly over the last 50 years. Using GHSL data we are able to track that growth over time, and to generate global statistics on population and built-up surface.

This Atlas explores how that growth has occurred for selected geographic locations around the world.

*Global built-up surface has expanded at a faster rate than global population. **Towns and semi-dense areas** have seen the fastest growth in built-up surface. The built-up surface of **cities** and **rural areas** grew at similar rates. In 2020, **rural areas** maintain the largest share of the global built-up surface.*

Iceland area
100,00 km^2
(i.e. 102,819 km²)

Global built-up surface 1975
176,000 km^2

Global built-up surface 2020
464,000 km^2

1 Large growth in global population:
The global population has nearly doubled, from 4 billion in 1975 to just under 8 billion in 2020.

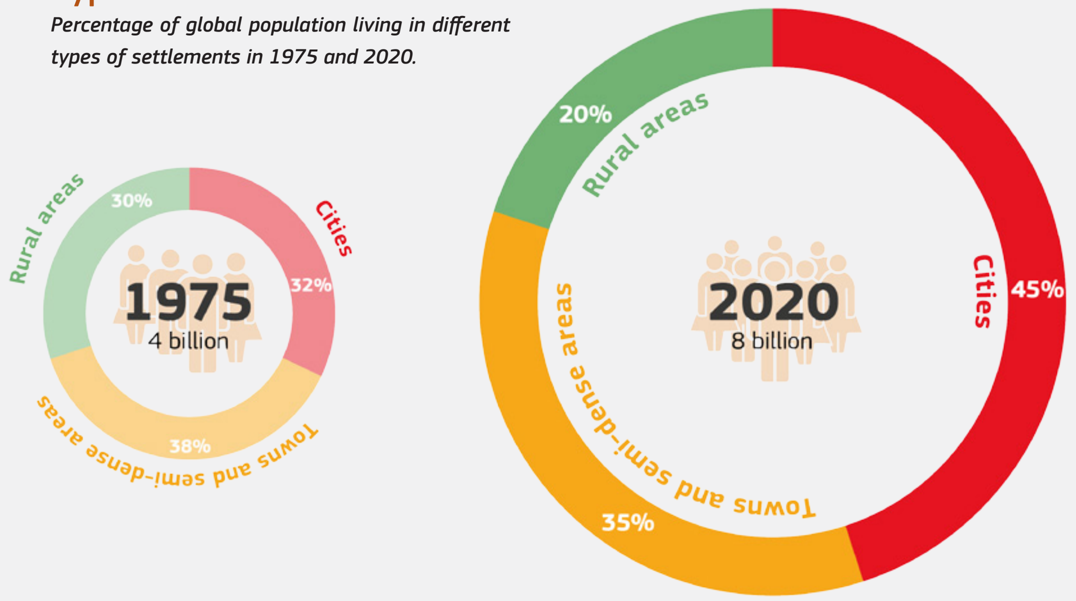
2 Biggest share of people lives in cities:
The percentage of people living in **cities** increased from 32% in 1975 to 45% in 2020. The global population of **cities** in 2020 was 3.5 billion, three times that in 1975 (1.3 billion).

3 Towns and semi-dense areas are much more populous:
While the percentage of people living in **towns and semi-dense areas** remained steady (35%-37%) from 1975 to 2020, the global population of these areas has doubled.

4 Rural areas are also more populous:
While the percentage of people living in **rural areas** decreased from 30% in 1975 to 20% in 2020, the global population of rural areas is higher than at any time in history.

Types of settlements

Percentage of global population living in different types of settlements in 1975 and 2020.



5 Large increase in built-up surface:
The current global built-up surface is almost three times that in 1975. Using the size of Iceland (100,000 km²) for comparison, the global built-up surface was 1.7 times the size of Iceland in 1975, and nearly 5 times the size of Iceland in 2020.

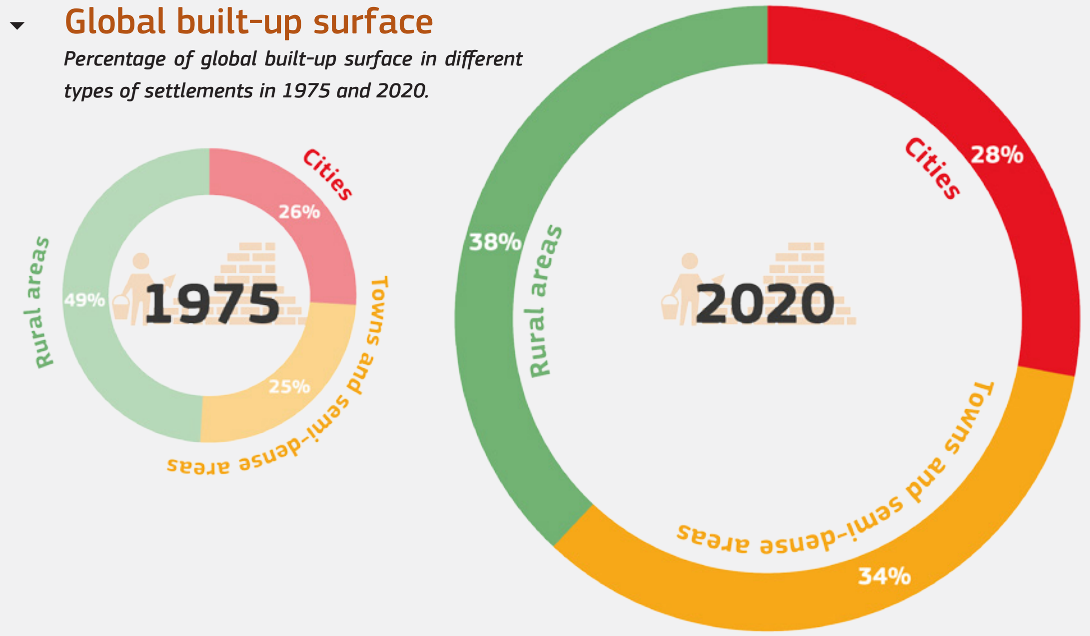
6 Fastest growth of built-up surface in towns and semi-dense areas:
In 2020, the global built up surface in **towns and semi-dense areas** was 3.7 times that in 1975.

7 Significant increase of built-up surface also in cities:
In 2020, the global built-up surface in cities was 2.8 times that in 1975. However, the global built-up surface in **cities** grew at a lower rate than the global population of cities.

8 Rural areas have the most built-up surface:
In 2020, the global built-up surface in **rural areas** was double that in 1975. In fact, despite their much smaller share of the global population, **rural areas** maintain the largest share of the global built-up surface, compared with **cities** and **towns and semi-dense areas**.

Global built-up surface

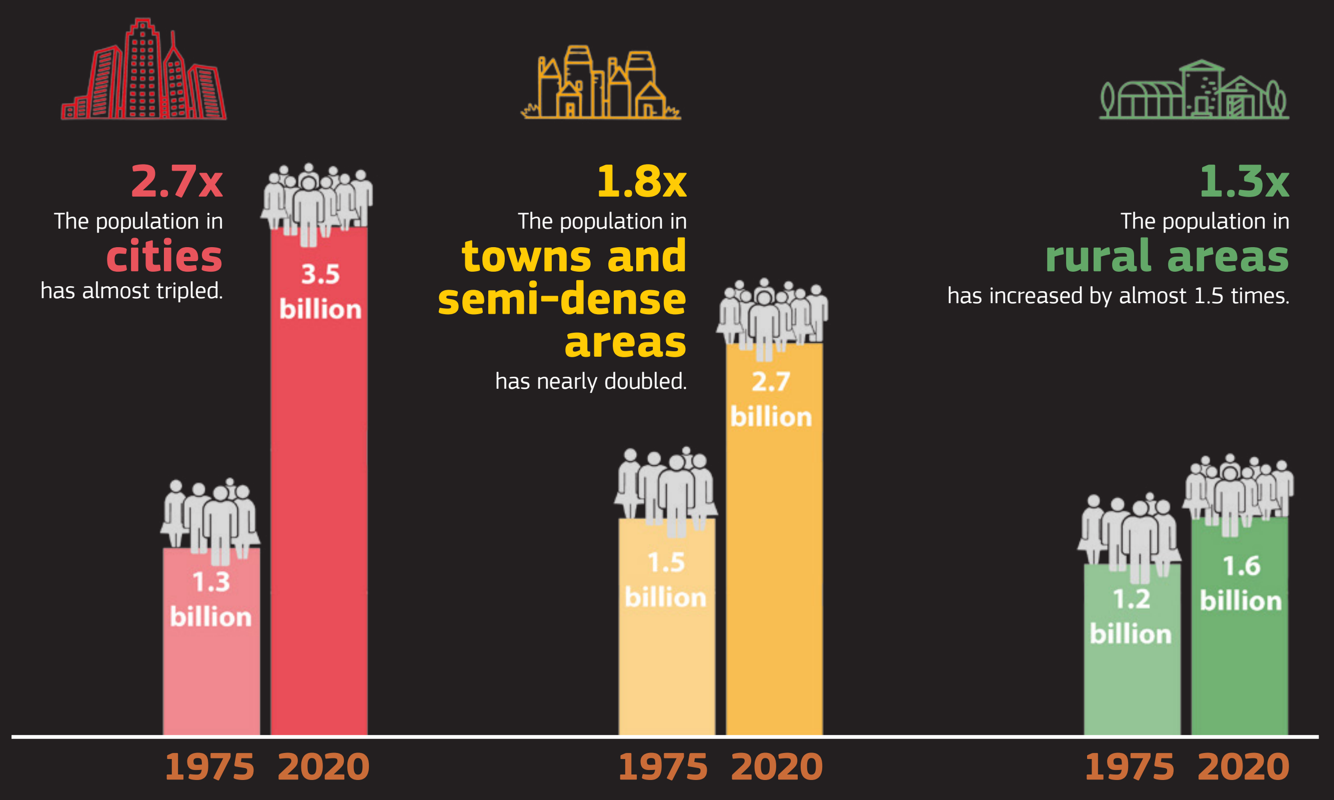
Percentage of global built-up surface in different types of settlements in 1975 and 2020.

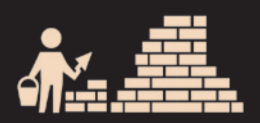


Population growth

Population distribution among different types of settlements in 1975 and 2020.

*Since 1975, the global population of **cities** has grown by 2.2 billion people, **towns and semi-dense areas** by 1.2 billion people, and **rural areas** by 0.4 billion people.*

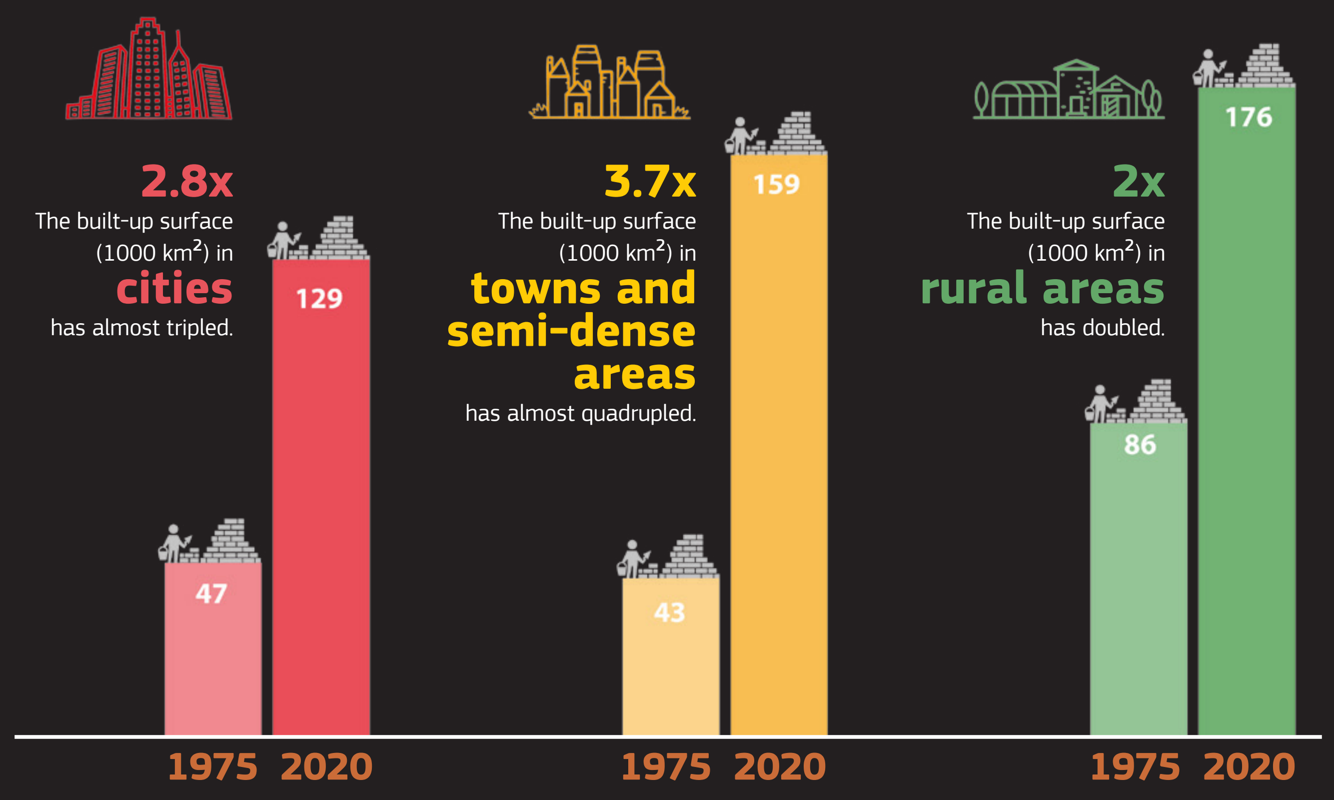




Built-up surface expansion

Built-up surface (in 1000 km²) for the three settlement types, in 1975 and in 2020 (from DEGURBA grids).

The period after 1975 has seen a substantial increase in the area of built-up land.



1.4

Human settlements and sustainability

Human settlements at the core of the post-2015 frameworks for Sustainable Development

A human settlement is a community of people living in a particular place. Living together enables people to work together, to help and protect each other, and to share ideas. This is what has put human settlements at the heart of human development, and has led to the continuous growth of settlements, from the village to the megacity.
Today, the majority of the world's population lives in urban areas. Cities are hubs for culture, science, commerce, productivity, and social, human and economic development. They offer wider opportunities for employment, better access to services, health care and education, and currently produce 80% of the global gross domestic product (GDP).

Human settlements at the heart of human development.

Yet, a growing number of urban dwellers remain marginalised, and are disconnected from those same opportunities. Moreover, urbanised areas consume 75% of energy resources, leading to the emission of 75% of global greenhouse gases. This drives climate change and puts settlements at risk, due to an increase in the number and intensity of natural disasters, and a global sea level rise.

In 2015, all the United Nations members, endorsed a number of international initiatives aimed at addressing the ever-growing sustainability challenges facing our planet, through a set of interconnected international frameworks, namely: the 2030 Agenda for Sustainable

Cities are hubs for ideas, culture, science, commerce, productivity, and social, human and economic development.

Development, with its 17 Sustainable Development Goals (SDGs), working hand in hand with the Sendai Framework for Disaster Risk Reduction, the Paris Agreement, and the New Urban Agenda. Data on cities and human settlements play a pivotal role in implementing and achieving the goals of these international frameworks.

1 Sendai Framework for Disaster Risk Reduction

The Sendai Framework for Disaster Risk Reduction aims to "achieve the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries" by 2030.

2 Sustainable Development Goals

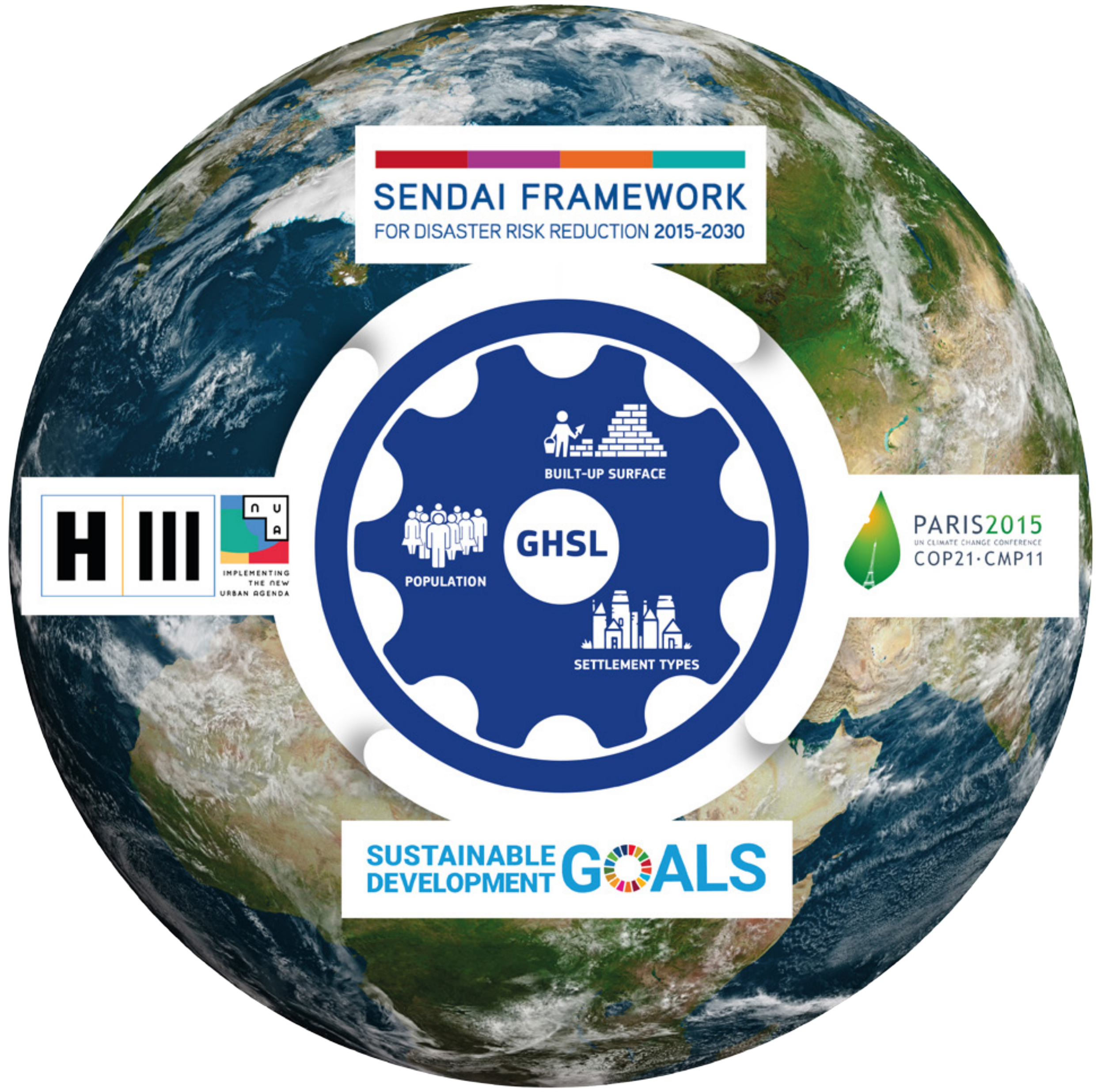
The Sustainable Development Goals are a set of 17 interlinked global goals to achieve a better and more sustainable future for all by 2030. They recognise that ending poverty and other forms of deprivation must go hand in hand with strategies that improve health and education, reduce inequality, and spur economic growth – and all while tackling climate change and working to preserve our oceans and forests.

3 The Paris Agreement

The Paris Agreement's long-term goal is to keep the rise in mean global temperature to well below 2 °C above pre-industrial levels (preferably 1.5 °C), recognising that this would substantially reduce the effects of climate change.

4 New Urban Agenda

Habitat III, the United Nations Conference on Housing and Sustainable Urban Development, was one of the first UN global summits after the adoption of the 2030 Agenda for Sustainable Development. It endorsed the New Urban Agenda, which supports countries and cities in planning and managing cities, towns and villages for sustainable development.



International frameworks and GHSL

Settlments are at the intersection of all societal processes and key to understand societal challenges addressed by the international frameworks.

The transformative promise of the 2030 Agenda for Sustainable Development

The transformative promise of the 2030 Agenda for Sustainable Development with its 17 Sustainable Development Goals – namely "Leave No One Behind" – is reliant on knowing where people are, how they live, and how this has changed over time. According to the assessment of the Group on Earth Observations, all Sustainable Development Goals require information on population distribution, and a mapping of cities and of infrastructures that can be surveyed using information derived from Earth Observation data[1].

"Leave No One Behind" is reliant on knowing where people are, how they live, and how this has changed over time.

The GHSL data provide essential information on population, settlements and the built environment, which is used in the monitoring of the SDG indicators, while the Degree of Urbanisation classification provides a harmonised definition of cities and of urban and rural areas, in order to furnish comparable statistics for the reporting of the SDG indicators.

All Sustainable Development Goals require information on population distribution, and a mapping of cities.

SDGs and Earth Observation

The reporting of all SDG goals relies on some type of information about population and settlements that are in part derived from Earth Observation data.

Supporting the reporting of the SDGs with the Degree of Urbanisation

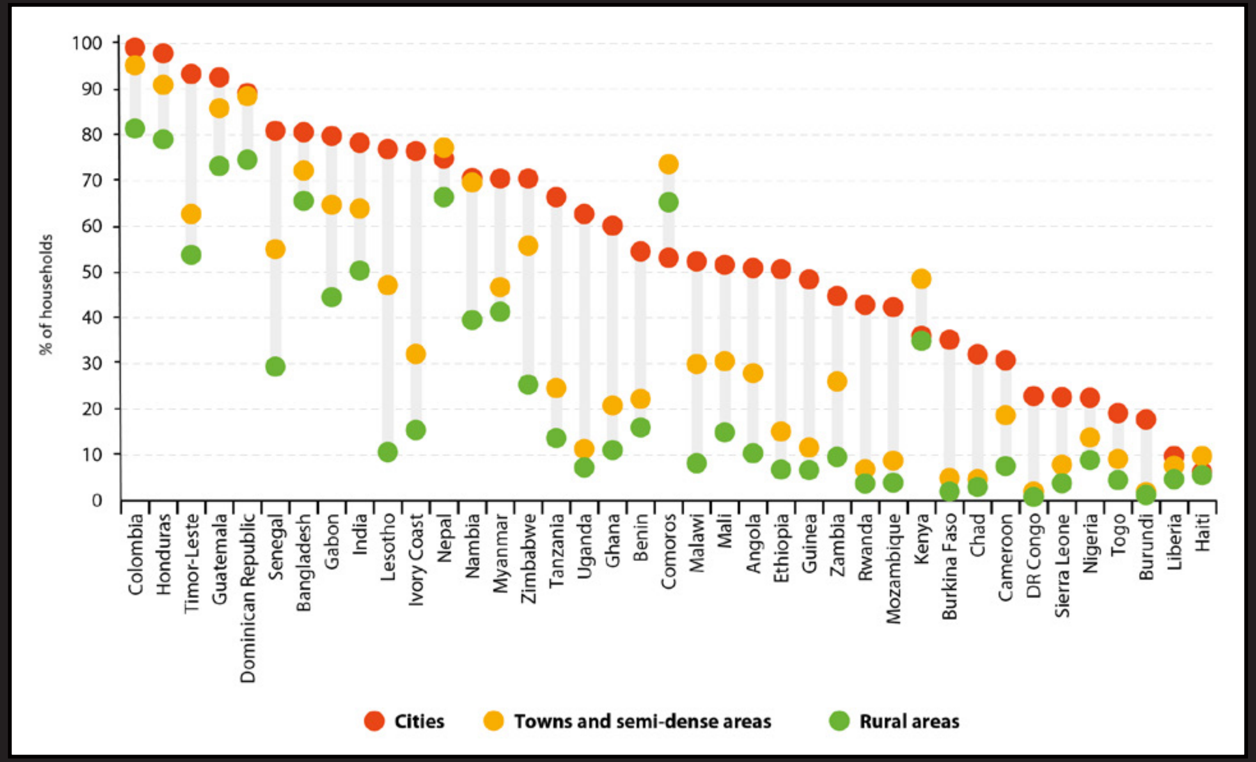
Access to safe drinking water

Share of households having access to safely managed drinking water, by Degree of Urbanisation for selected countries (2010-2016).

Many SDG indicators require a reporting that designates either urban or rural population. The Degree of Urbanisation classification provides - for the first time - a globally accepted and harmonised approach for delineaing urban and rural population shares. This allows comparison of the situation in different countries and facilitates policy interventions that are more targeted.

Many SDG indicators require a reporting that designates either urban or rural population.

Allows comparison of the situation in different countries and facilitates policy interventions that are more targeted.



SDG 11 Sustainable cities and communities

11 SUSTAINABLE CITIES AND COMMUNITIES

Sustainable Development Goal (SDG) 11, titled "Sustainable cities and communities", aspires to "Make cities and human settlements inclusive, safe, resilient and sustainable". The understanding of the process of urbanisation and the capacity to monitor SDG 11, require a wealth of open, reliable, locally detailed, yet globally comparable data, and a fully fledged data revolution.

The GHSL data provide a framework for the analysis of all human settlements, based on their classification according to the Degree of Urbanisation, the method for delineating urban and rural areas. This harmonised approach is essential for the comparable reporting of many SDG indicators, and was endorsed by the United Nations Statistical Commission, at its 51st Session in 2020.

Make cities and human settlements inclusive, safe, resilient and sustainable.

GHSL data provide a framework for the analysis of all human settlements.

SDG 11.3.1 Land Use Efficiency

TARGET 11.3 INCLUSIVE AND SUSTAINABLE URBANIZATION

Target 11.3 of SDG 11, titled "Inclusive and sustainable urbanisation", aims to enhance inclusive and sustainable urbanisation and the capacity for participatory, integrated and sustainable human settlement planning and management in all countries.
One of the two indicators for Target 11.3, Indicator 11.3.1, defined as the ratio of land consumption rate to population growth rate, is designed to measure Land Use Efficiency.
Information from the GHSL contributes to determine all aspects of Indicator 11.3.1.[2] Firstly, the area of interest (i.e. cities) is defined by applying the Degree of Urbanisation method. Secondly, the population growth rate is quantified using the GHSL population grids. Finally, the land consumption rate is calculated by means of the multi-temporal built-up surface products.
GHSL Built-up surface maps available over time are used to generate reliable information on land consumption used to calculate SDG 11.3.1.

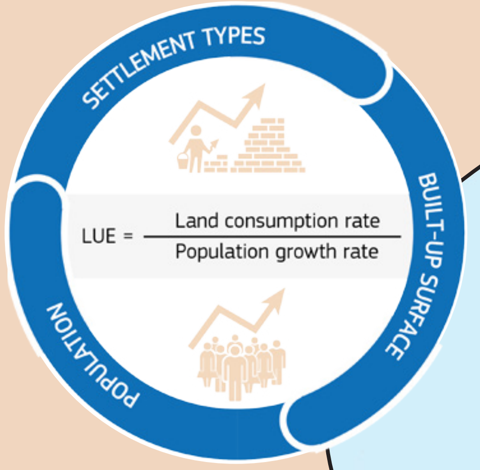
Integrated and sustainable human settlement planning.

The Copernicus Emergency Management Service's Exposure Mapping component is a reliable data source to monitor land consumption for the next decade.

SUSTAINABLE DEVELOPMENT GOALS

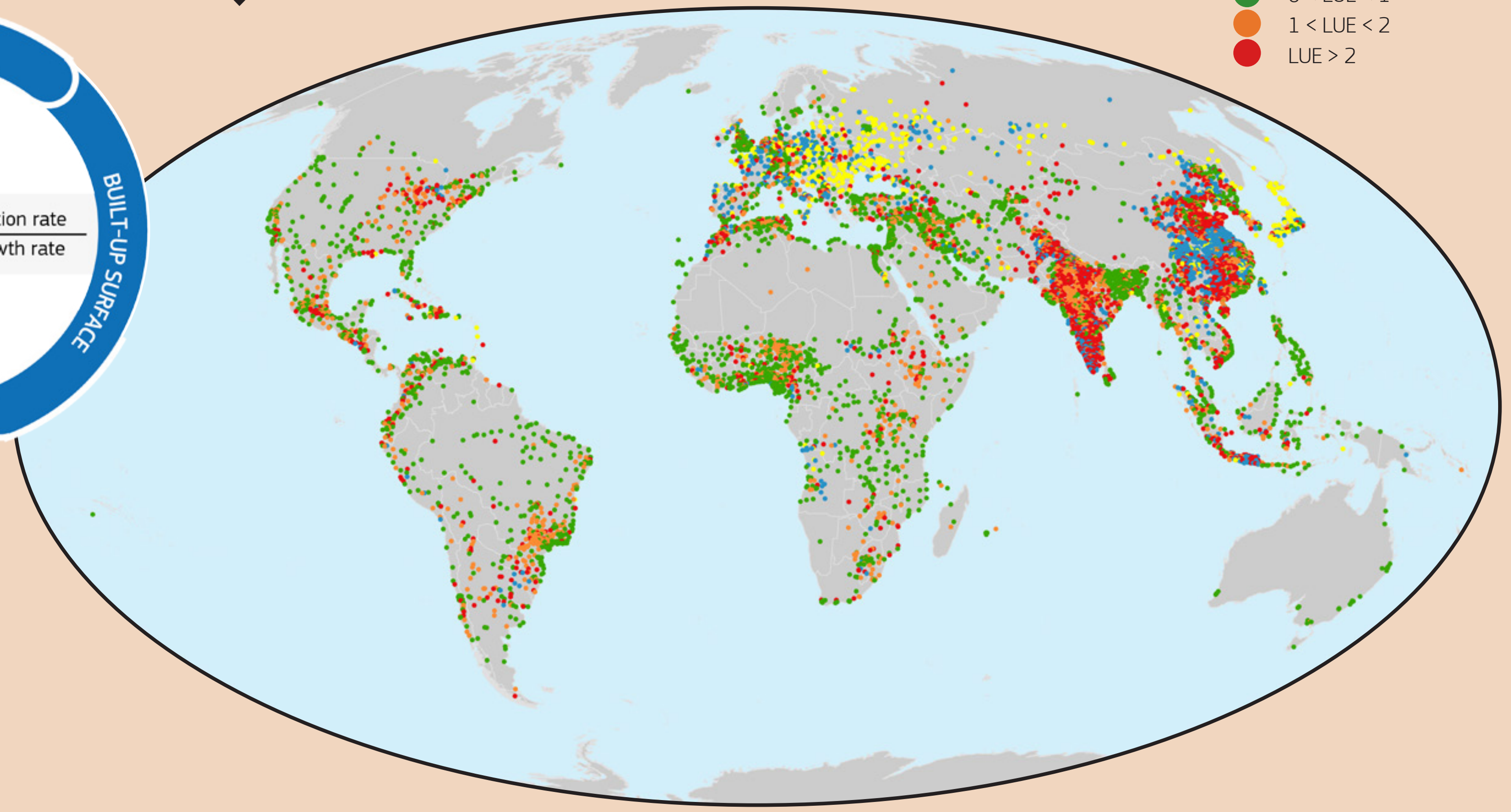
SDG 11.3.1 Land Use Efficiency

SDG 11.3.1 explores the relation between population growth and the expansion of built-up surface.



Land Use Efficiency for all cities, between 1990 and 2015

The map shows Land Use Efficiency for all cities, between 1990 and 2015. Negative values are often related to population decline. Positive values indicate less efficient use of space, with built-up surface increasing faster than population. Values of 0 to 1 indicate a constant growth of population and built-up surfaces[3].



Land
Water

LUE < -1
-1 < LUE < 0
0 < LUE < 1
1 < LUE < 2
LUE > 2

The Paris Agreement

PARIS2015 UN CLIMATE CHANGE CONFERENCE COP21·CMP11

The Paris Agreement is the first legally binding international treaty on climate change. Its overarching goal is to hold "the increase in the global average temperature to well below 2 °C above pre-industrial levels". According to the UN's Intergovernmental Panel on Climate Change (IPCC), crossing the 1.5 °C threshold risks severe climate change impacts, including more frequent and severe droughts, heatwaves and rainfall.
The implementation of the Paris Agreement requires an economic and social transformation to be carried out by countries. In a regular global stocktaking, the UN will assess the collective progress towards the long-term climate goals. This will require large amounts of data.
Information about population and settlements are essential baseline data for the global stocktaking.
GHSL data coupled with the Emission Database for Global Atmospheric Research (EDGAR) help scientists and policymakers to keep track of emission trajectories of cities.

The first legally binding international treaty on climate change.

The Paris Agreement requires an economic and social transformation.

Information about population and settlements are essential baseline data for the global stocktaking.

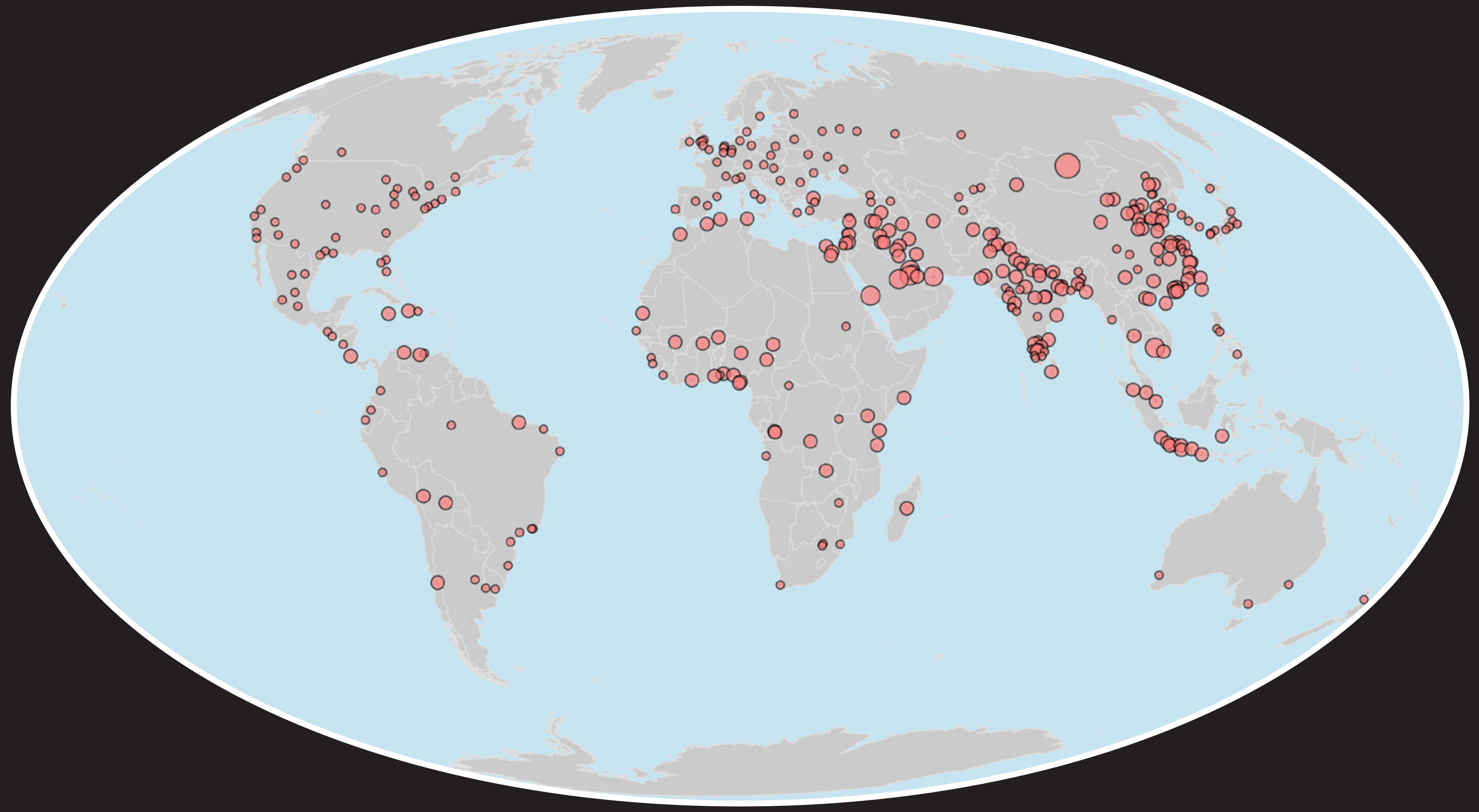
Change of fine particulate matter 1975-2015 (PM2.5)

The map shows the change of fine particulate matter (PM2.5) emissions in cities with more than 1 million inhabitants, between 1975 and 2015[4]. The size of the circles indicates the change. Set against a global increase in PM2.5 emissions, the cities in Asia show the strongest increase in emissions.

Cities above 1 million inhabitants
PM2.5 Emissions
Percentage change 1975 to 2015

Land
Water

1 - 10
10 - 50
50 - 100
100 - 200



International Frameworks

"All people on Earth must be protected by early warning systems within five years."

UN Secretary-General António Guterres, March 23, 2022

SENDAI FRAMEWORK
FOR DISASTER RISK REDUCTION **2015-2030**

The Sendai Framework for Disaster Risk Reduction aims to "achieve the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries", by 2030. The Sendai Framework serves as a roadmap for enhancing the safety and resilience of our communities against the impact of natural disasters.
The first pillar of the Sendai Framework focusses on **Understanding Risk**, and the GHSL data directly support this goal. Indeed, built-up surface and population are essential societal variables for understanding the exposure of people and human settlements to natural and man-made disasters. GHSL provides spatially explicit evidence (in the form of maps) of both of these variables, and represents a concrete effort towards understanding risk on a global scale.

Achieve the substantial reduction of disaster risk and losses.

Built-up and population are essential societal variables for understanding the exposure of people and human settlements.

CEMS is also an important building block for the "Early Warnings for All" initiative of the United Nations.

Early Warnings for All Initiative

Backed by the UN Secretary-General, the Early Warnings for All initiative (EW4All) is a groundbreaking effort to ensure that everyone on Earth is protected from hazardous weather, water, or climate events through life-saving early warning systems by the end of 2027.

GHSL is the Exposure Mapping component in the EU's Copernicus Emergency Management Service (CEMS). CEMS provides geospatial data and images to actors involved in the management of natural or man-made disasters.

CEMS Exposure Mapping

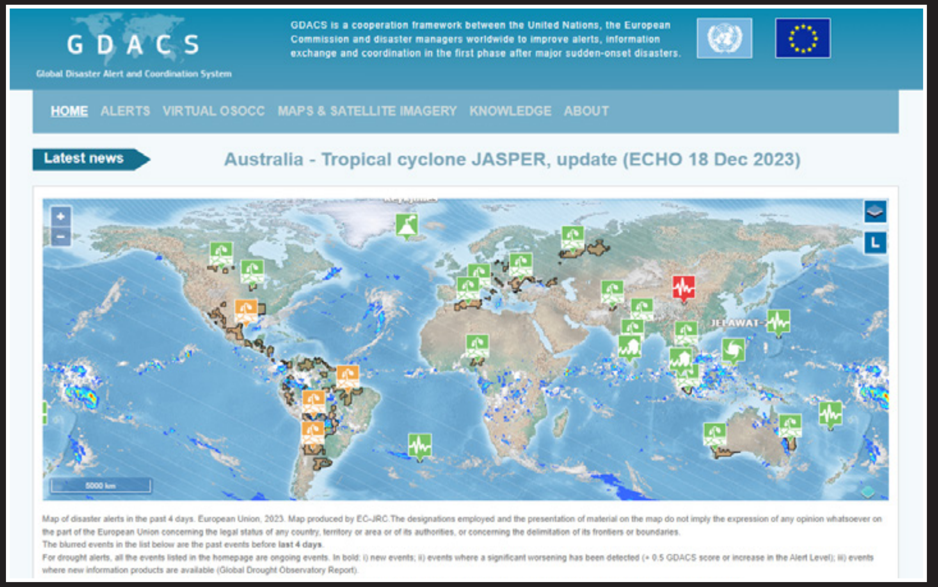
The CEMS Exposure Mapping component provides, through the GHSL, accurate information derived from satellite imagery and census data, on the presence and characteristics of settlements and population.

Visit the platform at:
https://emergency.copernicus.eu/

Global Disaster Alert and Coordination System (GDACS)

GHSL population data are a key part of the Global Disaster Alert and Coordination System (GDACS) of the UN and the European Commission. The key objective of GDACS is to supply disaster managers worldwide with improved disaster alerts, information exchange and coordination in the first phase after major sudden-onset disasters. GDACS and CEMS are important building blocks for the UN's Early Warnings for All initiative.
Below the daily updated global map of hazardous events.

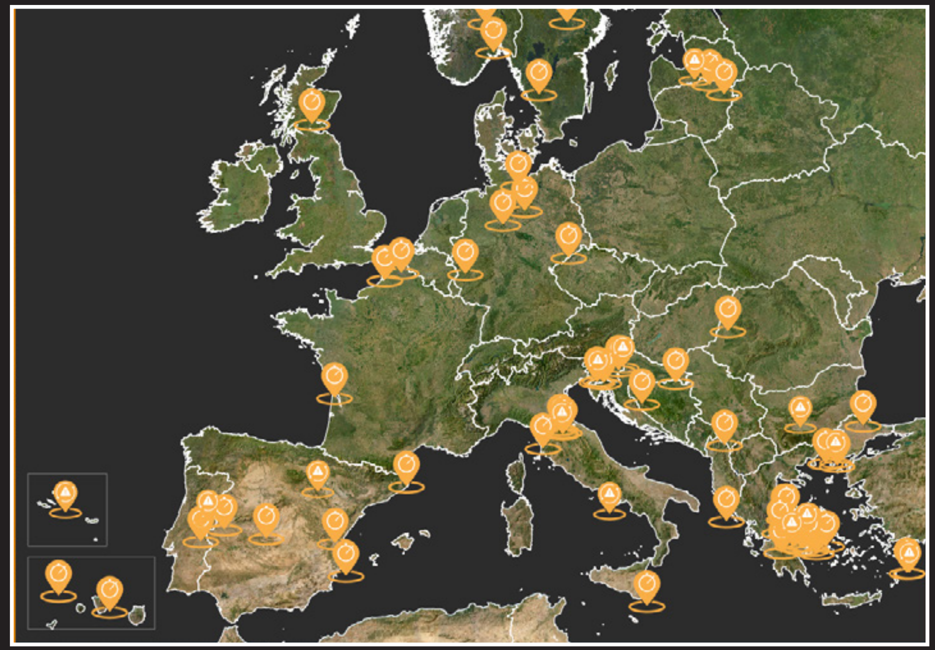
Visit the platform at:
gdacs.org



CEMS On-demand Mapping

The CEMS On-demand Mapping component produces maps in case of natural disasters, human-made emergency situations and humanitarian crises. The GHSL Exposure Mapping data are used operationally to compile such maps, and to estimate affected population. Below the On-demand Mapping activations in Europe during 2023.

Visit the platform at:
https://emergency.copernicus.eu/mapping



Global Flood Awareness System (GloFAS) and Global Flood Monitoring (GFM):

This map, using data from GloFAS, depicts areas where river may overflow based on a 100-year return period estimation, representing a 1% probability for such a flood event to occur.

Visit the on-line platform at:
https://global-flood.emergency.copernicus.eu/

1.5

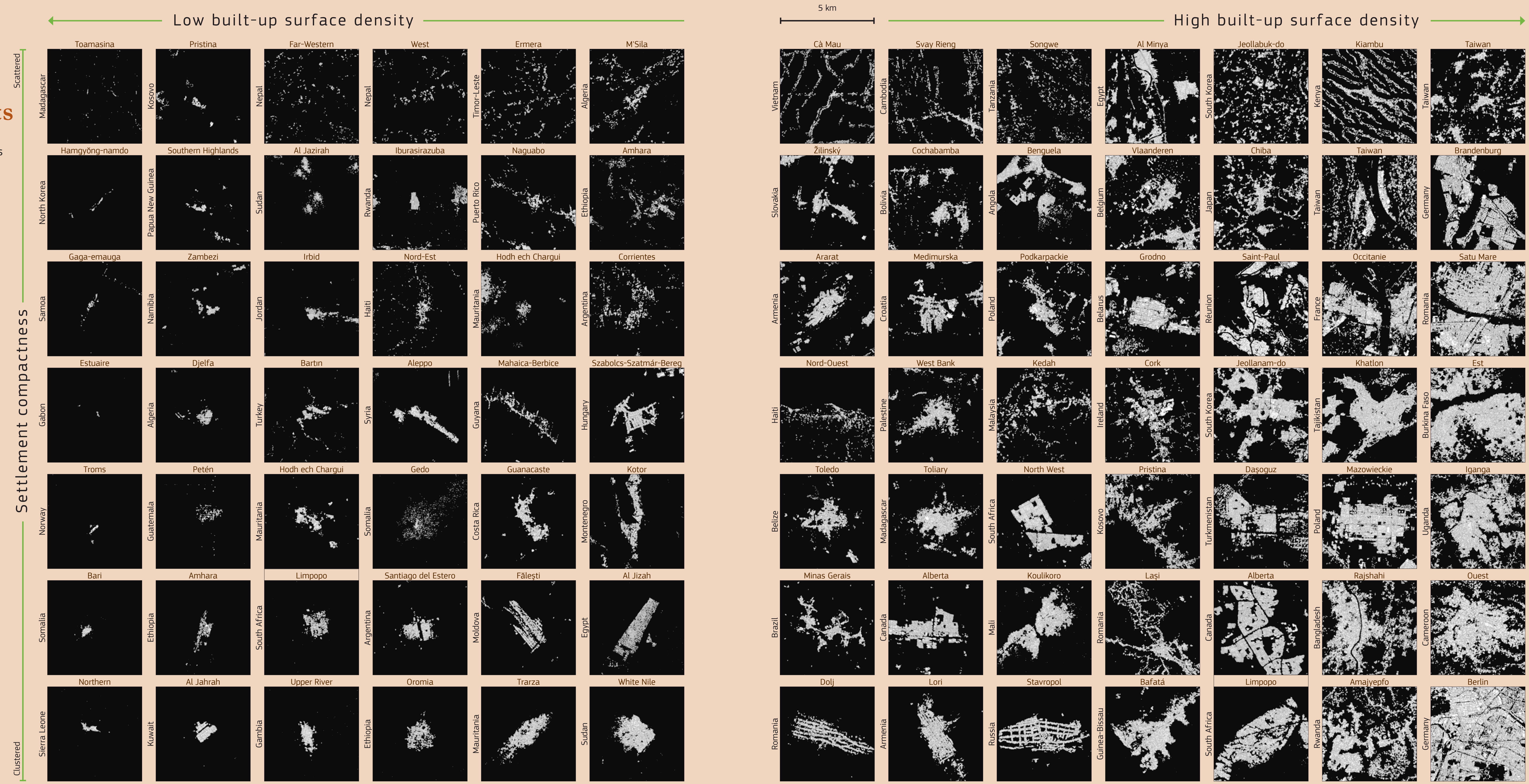
Built-up surface of settlements

Built-up surface is the most conspicuous physical feature of settlements

The built-up surface of settlements defines the human presence on planet Earth. The extent and form of the built-up surface is directly related to how people live, and also determines what the settlements look like. These characteristics can be assessed using GHSL data on population density and the physical morphology of the settlements. At a global level, it is clear that villages and small towns account for less built-up surface than large towns, cities and megacities. There is a wide diversity of aggregated built-up surfaces and settlement types, and it is only with the availability of spatial information such as GHSL built-up surface maps, that we can begin to study, measure and classify that diversity.

Spatial patterns of built-up surface

These 91 GHSL maps show examples of different spatial patterns of built-up surface that are found around the world, classified according to the density (from low to high) and compactness (from scattered to clustered) of the built-up surface. Each map shows the 5×5 km area around each of the settlements, indicating the respective country (left-side), and region or province (top-side).



1.6

Cities

Settlements which concentrate people, infrastructure and activities

Cities are large settlements where the human presence is most evident. Cities have developed over the centuries in order to facilitate economic activities and human interactions, modifying the local and surrounding territory and ecology in such a way that is clearly visible also from satellite imagery. According to the Degree of Urbanisation, there are more than 11 thousand cities worldwide, where a **city** is defined as a settlement with a population exceeding 50 thousand inhabitants, and a population density of at least 1,500 inhabitants per km^2.

Along with built-up surface, high population density is the most conspicuous sign of urbanisation in everyday life. Tokyo, Japan, for example, is one of the world's most populous cities, with over 37 million people living in the metropolitan area. This high-density environment has resulted in unique urban landscapes, such as the city's famous Shibuya Crossing, the world's busiest pedestrian crossing, where the number of people crossing the road can reach up to 3,000 each time the traffic lights change.

▲ *High population density* *Times Square in New York city, USA.* © shantihesse - stock.adobe.com

Population density

High population density brings advantages, such as more efficient use of resources, but exposes the growing population and infrastructure to heatwaves and flooding, for example, especially without appropriate mitigation strategies. Coordinating efforts towards sustainable urban planning, renewable energy use, green building practices, and improving public transport, are essential pathways to ensure the livability of cities in the near future. These efforts will require detailed and updated spatial information that can be provided by the GHSL.

▼ *Mind your step* *The Shibuya Crossing in Tokyo, Japan.*

© Benh LIEU SONG (Flickr), CC BY-SA 2.0, via Wikimedia Commons

▸ **Population density**

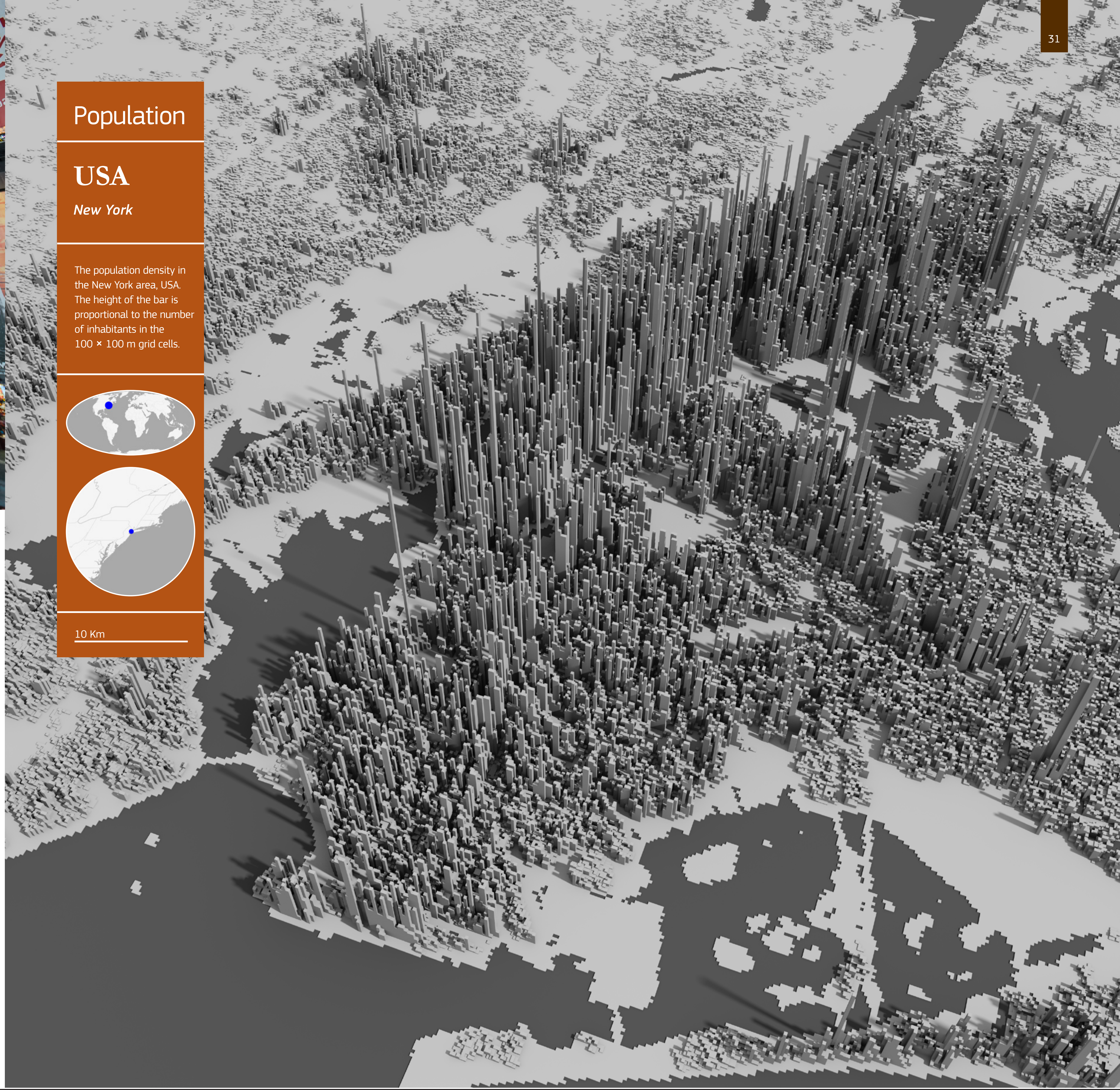
Highest population density is found in high rise residential areas.

Population

USA

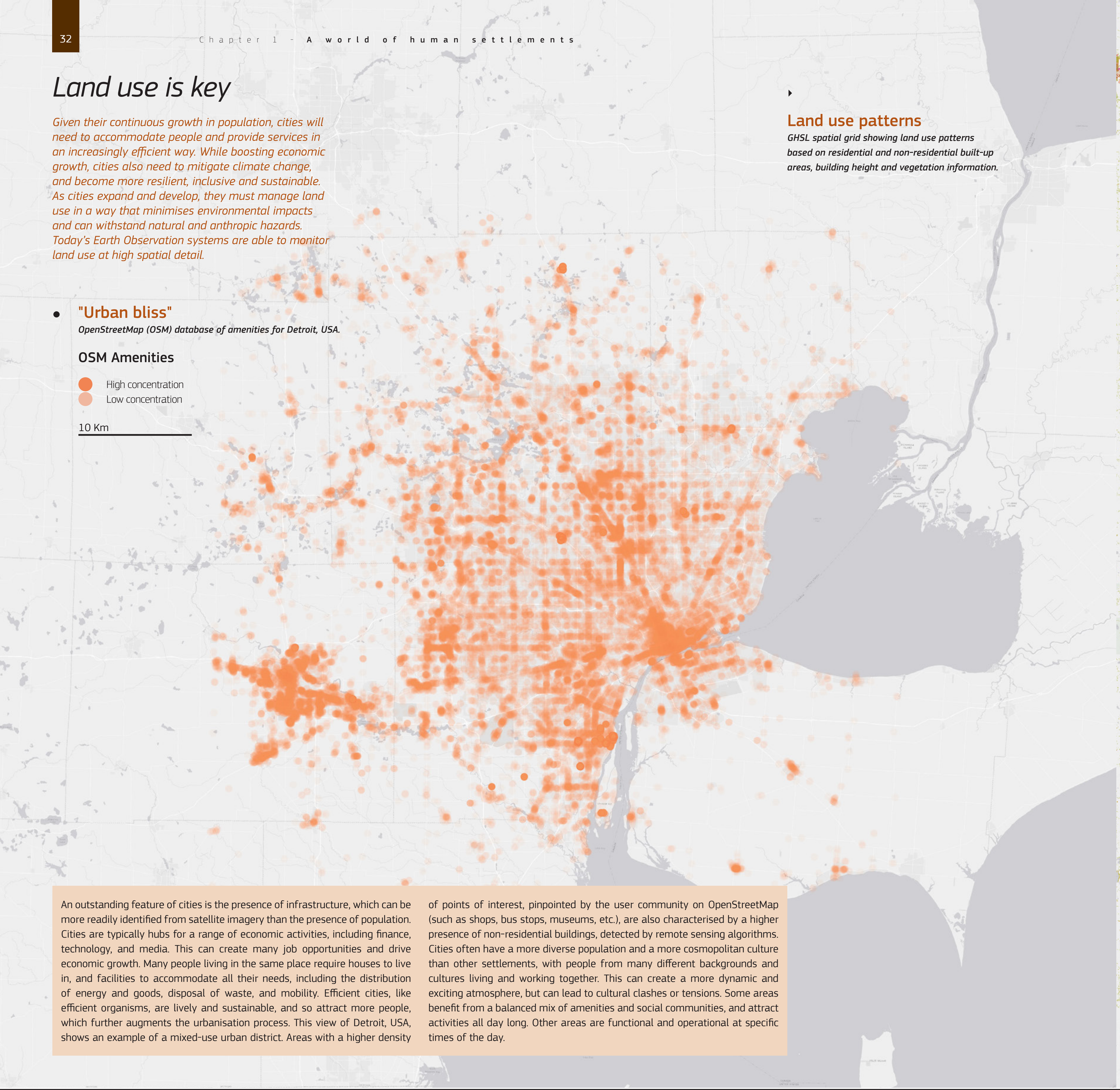
New York

The population density in the New York area, USA. The height of the bar is proportional to the number of inhabitants in the 100 × 100 m grid cells.



Land use is key

Given their continuous growth in population, cities will need to accommodate people and provide services in an increasingly efficient way. While boosting economic growth, cities also need to mitigate climate change, and become more resilient, inclusive and sustainable. As cities expand and develop, they must manage land use in a way that minimises environmental impacts and can withstand natural and anthropic hazards. Today's Earth Observation systems are able to monitor land use at high spatial detail.



"Urban bliss"

OpenStreetMap (OSM) database of amenities for Detroit, USA.

OSM Amenities

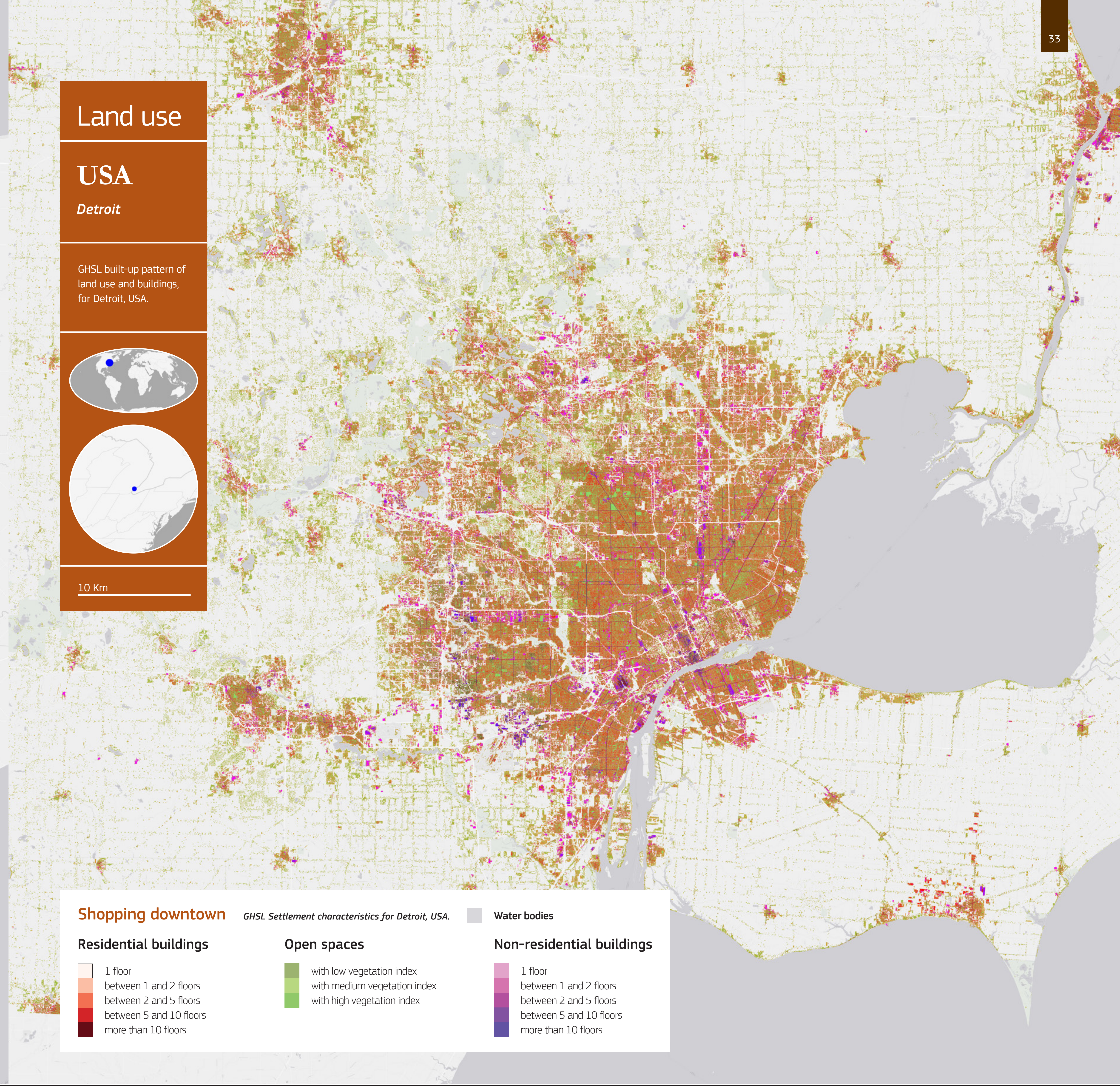
- High concentration
- Low concentration

10 Km

Land use patterns

GHSL spatial grid showing land use patterns based on residential and non-residential built-up areas, building height and vegetation information.

An outstanding feature of cities is the presence of infrastructure, which can be more readily identified from satellite imagery than the presence of population. Cities are typically hubs for a range of economic activities, including finance, technology, and media. This can create many job opportunities and drive economic growth. Many people living in the same place require houses to live in, and facilities to accommodate all their needs, including the distribution of energy and goods, disposal of waste, and mobility. Efficient cities, like efficient organisms, are lively and sustainable, and so attract more people, which further augments the urbanisation process. This view of Detroit, USA, shows an example of a mixed-use urban district. Areas with a higher density of points of interest, pinpointed by the user community on OpenStreetMap (such as shops, bus stops, museums, etc.), are also characterised by a higher presence of non-residential buildings, detected by remote sensing algorithms. Cities often have a more diverse population and a more cosmopolitan culture than other settlements, with people from many different backgrounds and cultures living and working together. This can create a more dynamic and exciting atmosphere, but can lead to cultural clashes or tensions. Some areas benefit from a balanced mix of amenities and social communities, and attract activities all day long. Other areas are functional and operational at specific times of the day.



Land use

USA

Detroit

GHSL built-up pattern of land use and buildings, for Detroit, USA.

10 Km

Shopping downtown

GHSL Settlement characteristics for Detroit, USA.

Water bodies

Residential buildings

- 1 floor
- between 1 and 2 floors
- between 2 and 5 floors
- between 5 and 10 floors
- more than 10 floors

Open spaces

- with low vegetation index
- with medium vegetation index
- with high vegetation index

Non-residential buildings

- 1 floor
- between 1 and 2 floors
- between 2 and 5 floors
- between 5 and 10 floors
- more than 10 floors

1.7 Towns and semi-dense areas

The most common settlement type

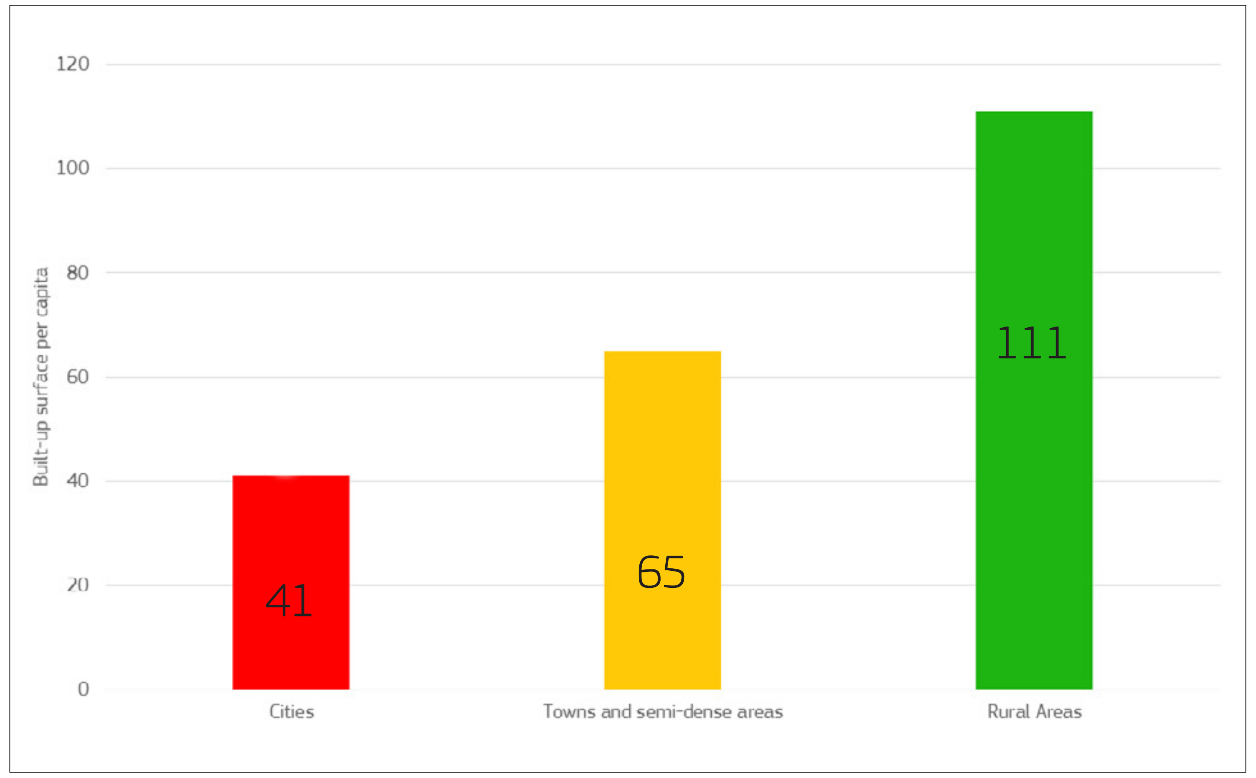
Towns and semi-dense areas generally host fewer people than **cities**, or their population is scattered in a larger space. Towns typically emerge from the environs of infrastructural nodes, trade hotspots or other economic points of interests, while semi-dense areas include suburban and peri-urban areas of larger settlements. **Towns and semi-dense areas** are particularly interesting subjects to analyse, as they may develop into **cities** in the near future.

At global level, each person living in a **city** occupies one-third less building space than a town-dweller.

Compared with **cities**, **towns and semi-dense areas** are less efficient in terms of density of housing and distribution of living space, which are typically spread over a larger land surface. As can be seen from the bar-plot below, at a global level a **city** dweller occupies one third less building space than a **town** dweller, and almost three times less building space than a village (i.e. rural) dweller.

This characteristic of **towns and semi-dense areas**, for example, to some extent compensates for the lower appeal of these settlement types, in terms of daytime opportunities and activities, compared with **cities**. In Paris metropolitan area, for instance, the rate of change between the daytime and nighttime population is particularly dramatic: inside the old, inner beltway (the Périphérique) and along the river Seine to the north, people are attracted by the amenities, facilities and events that concentrate there during daytime. Outside this area, given the cheaper prices for accommodation, and also the diffuse public transport system with fast connections from the centre, people gather at night or return home.

Bar plot of the global built-up surface footprint per capita, for the three main settlement types (differentiate using the Degree of Urbanisation).



Towns

***Towns**, industrial areas and agriculture fields form a mixed landscape along the Oise River, close to Paris.*

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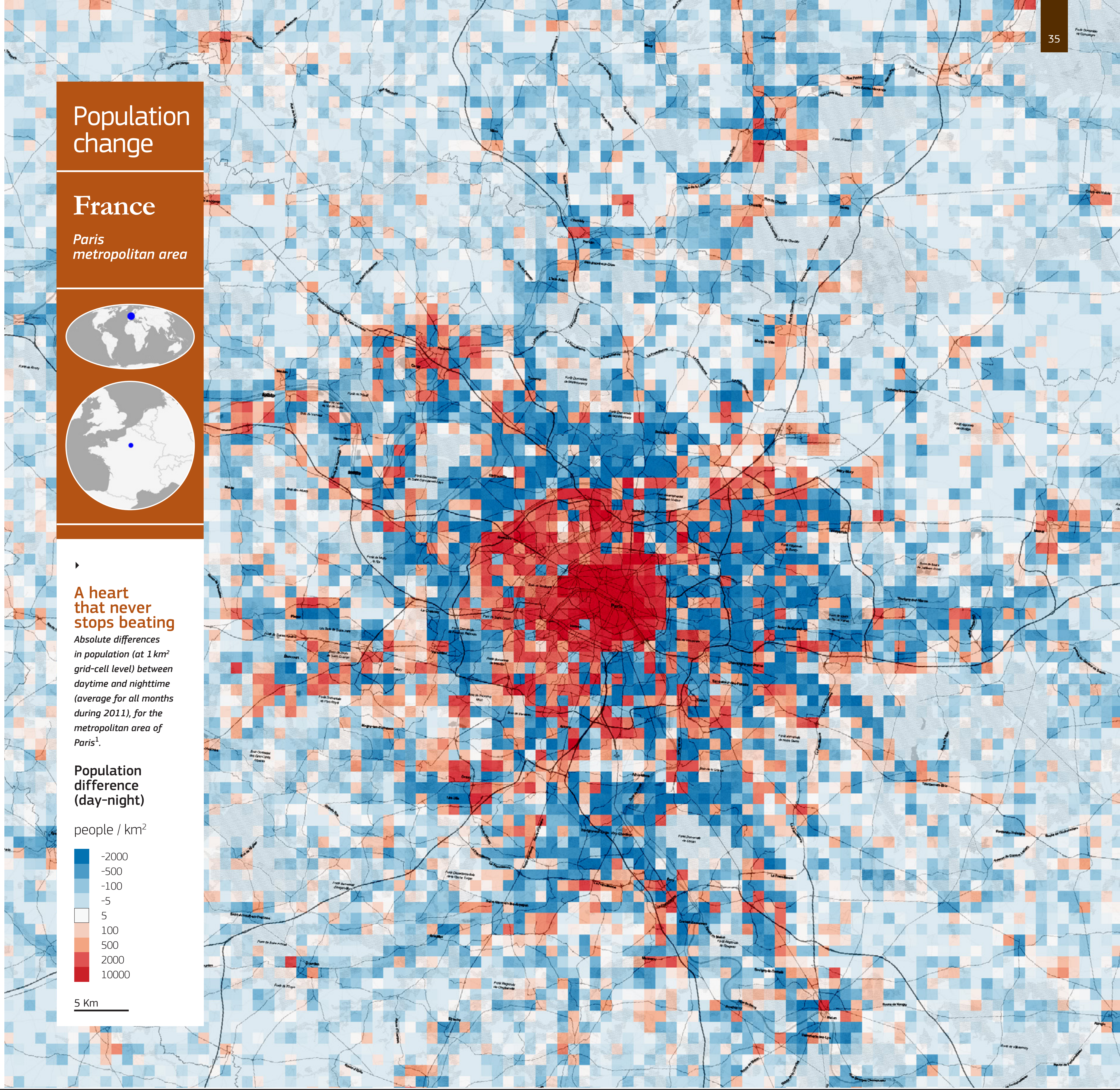
A dynamic sprawl

*At a global level, **towns and semi-dense areas** cover more land area than **cities**, but generally accomodate fewer economic activities. This settlement type is often characterised by rapid urbanisation, which brings with it specific administrative and economic challenges. The less sophisticated administrative capacity of **towns and semi-dense areas** can hamper the development of longer-term strategies and collaboration with private stakeholders, but on the other hand this may also favour "bottom-up" initiatives. Given their global significance, it is important to have a reliable, standardised definition for **towns and semi-dense areas**, which is provided by the Degree of Urbanisation, based on GHSL data (i.e. population size and density).*



A heart that never stops beating

Absolute differences in population (at 1 km² grid-cell level) between daytime and nighttime (average for all months during 2011), for the metropolitan area of Paris[1].

Bad-Freienwelde

Bad-Freienwelde in the region around Berlin. Small towns usually include more green area, and the surrounding natural areas are more accessible.

© Ralf Roletschek, GFDL 1.2, via Wikimedia Commons

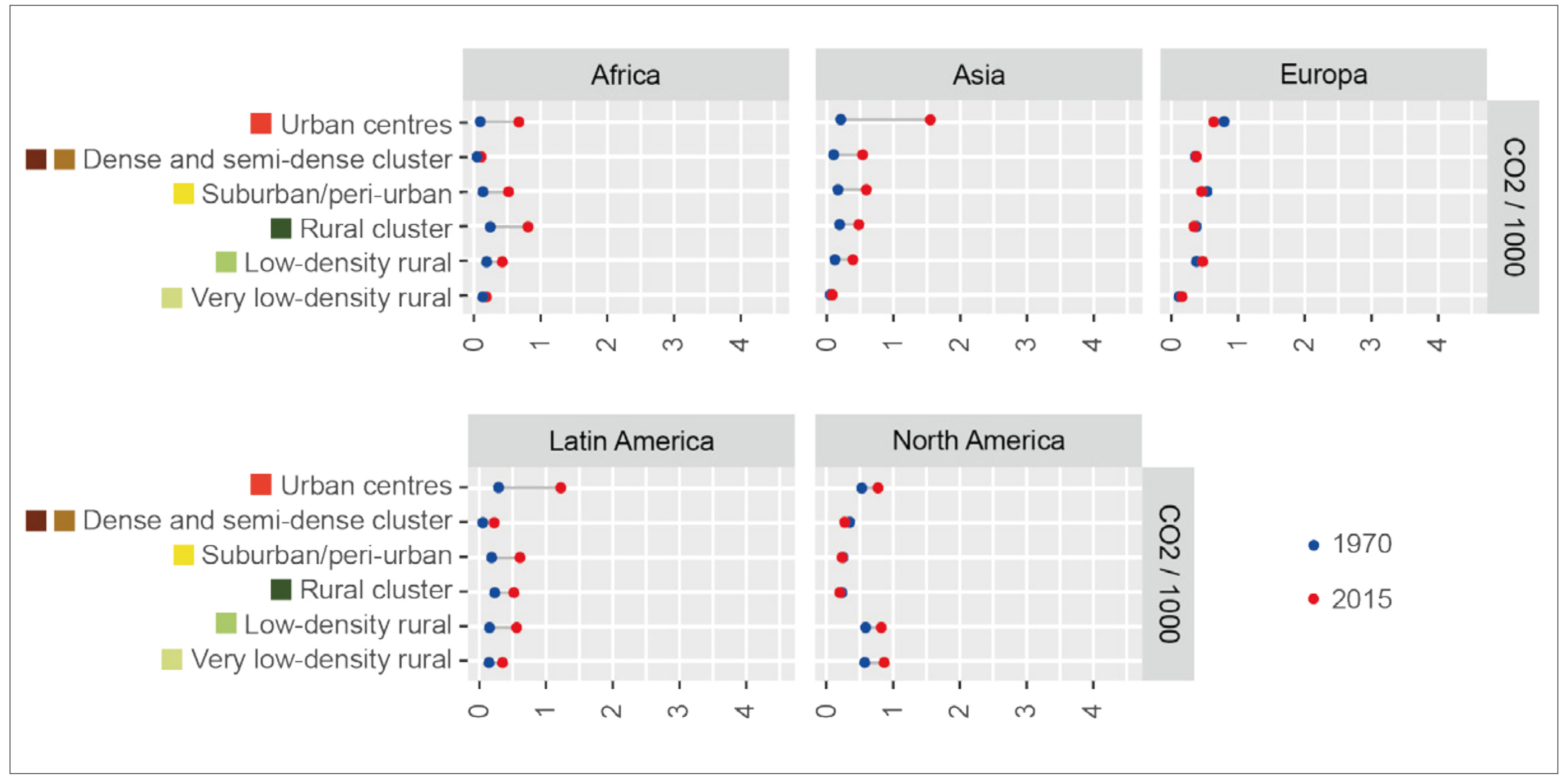
Lower population density settlements such as towns and semi-dense areas often benefit by having larger and more diffuse vegetated areas.

Towns and smaller settlements may have more integrated populations and a stronger community spirit. People are more likely to know each other and to have closer relationships, which can create a strong sense of belonging. In some regions, complementary currencies (i.e. not the national currency, but accepted for use) encourage local trade, by creating a type of parallel market in towns, and reducing vulnerability to the effects of globalisation. Towns that are well planned and "walkable" (or pedestrian-oriented), tend to favour local development and reduced inequalities, creating healthier and wealthier environments, with lower negative climate impacts. Lower population density settlements like towns and suburbs often benefit from larger and more diffuse vegetated areas. Towns that have more tree cover than cities are less sensitive to urban heat island effects and overheating. They also benefit from better air quality, enhanced biodiversity, and better life quality. At the same time, between 1970 and 2015 emissions of pollutants are considerably lower, and have increased much less, in towns compared with cities. Opposite page figures show shows the change in vegetated areas between the **city** and the surrounding **towns and semi-dense areas**, for four different cases. In the coastal cities of Lagos, Nigeria (top left) and Buenos Aires, Argentina (bottom right), the vegetation density identified from satellite sensors increases markedly with the distance from the city centre.

The city of Berlin, Germany (bottom left) shows consistent vegetation both in **cities** as well as in the **towns**, as well as in a group of towns arranged radially around the main settlement. Atlanta (USA) shows more homogeneous vegetation across **cities** and neighbouring **towns and semi-dense areas**.

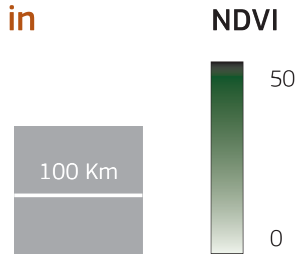
Cities emit more carbon

CO_2 emissions by continent, disaggregated by Degree of Urbanisation level 2[2].



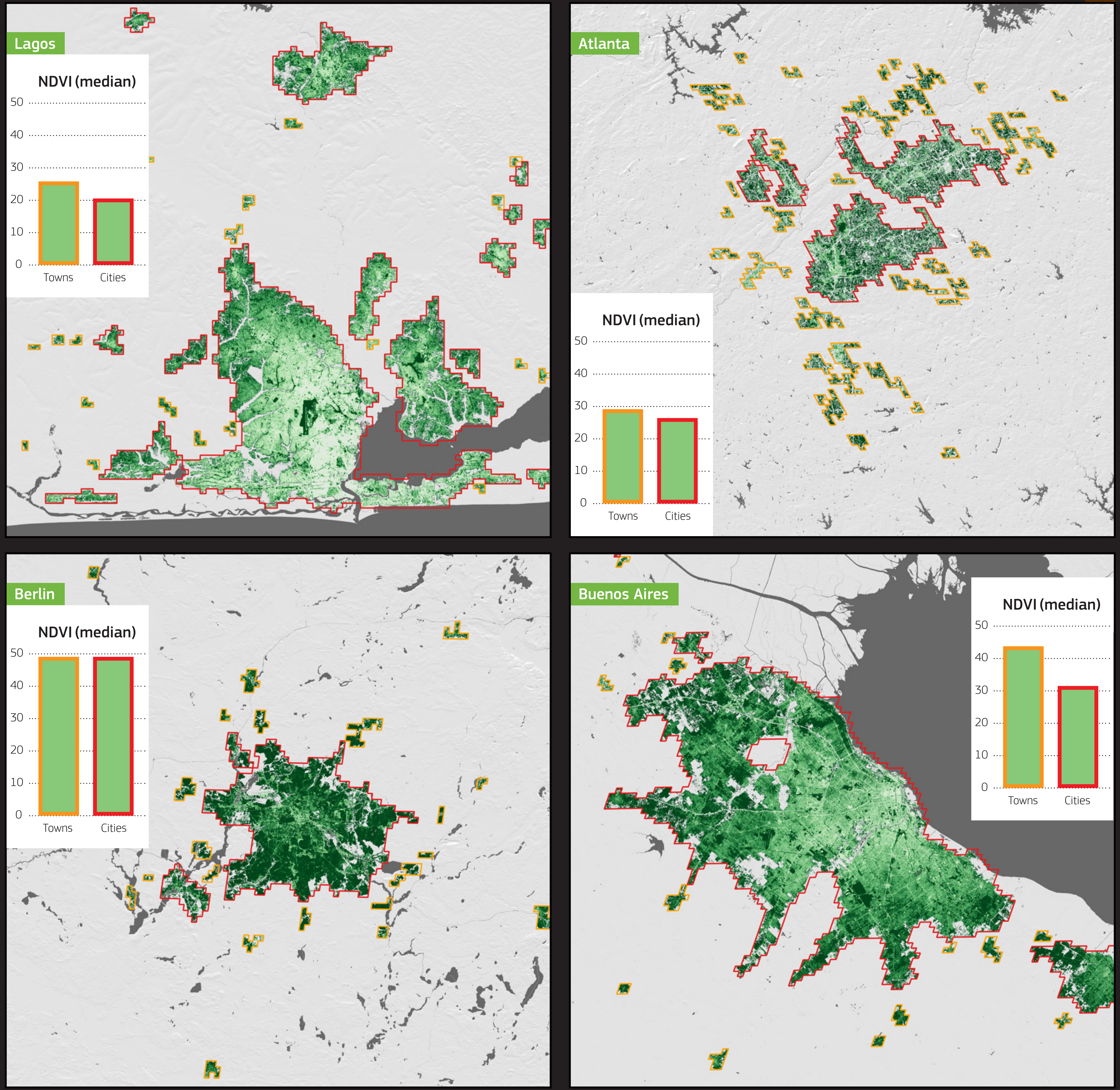
Vegetation density in towns and cities

Satellite-measured Normalised Difference Vegetation Index (NDVI)[3] for Lagos (Nigeria), Atlanta (USA), Berlin (Germany) and Buenos Aires (Argentina).



Green thumbs up

Enhancing greenery in urban areas has several benefits, including: climate change adaptation and mitigation; physical and mental health and well-being; social cohesion and equity (when extended to vulnerable or marginalised areas); economic co-benefits, generated from improved thermal comfort, reducing utility and healthcare costs, and from increased economic value of nearby properties; improved food security, and healthier diets. GHSL data help to identify the less vegetated areas of settlements that need more urgent interventions.



1.8

Rural areas

Sparse settlements are the ones that cover the largest area on the globe

Rural areas are sparsely populated, and people have to cover large distances to move between individual houses or buildings. Despite this shared characteristic, rural areas can be very different across the countries of the world. In many parts of the world, rural areas can have limited infrastructure and restricted access to basic services such as electricity, fresh water, and healthcare. In contrast, in the rural areas of Zeeland, the westernmost and least populous province of the Netherlands, for example, people benefit from all services and are well connected to main towns and cities. In such regions, agriculture can be very diversified and productive, generating income and wealth for the community. The map of Zeeland, shows an exceptional diversity of crop types: in the north, the industrial facilities of the city gradually give way to agriculture, whose continuity is interrupted only by a few villages and individual towns. According to the Food and Agriculture Organization (FAO) of the United Nations[1], the Netherlands was the second leading country for agricultural exports in 2020.

Agriculture can be very diversified and productive, generating income and wealth for the community.

When coupled with renewable electricity generation, land farming has a doubly beneficial impact on society. Solar modules mounted above ground with spaced supports, allow also the operation of normal farm machines.

Agrivoltaics
Field photograph of an agrivoltaics plant in France.
Some rural areas are converting agricultural land into solar farms.
© Jonathan - stock.adobe.com

Feeding the world

Rural areas provide food and resources for societies. Intensive agricultural practices also have a major human impact on ecosystems. Making food systems more sustainable requires the promotion of agroecology practices, in order to reduce the use of synthetic inputs and pesticides, safeguard the soil, and enhance biodiversity. GHSL, through the identification of population areas in rural settings, can help to ensure that development strategies safeguard nature and are combined with health protection measures including protection from pesticides.

A kaleidoscope of crops
Overlay of built-up surface (black) and crop types for the province of Zeeland, the Netherlands[2].

Built-up surface 2018
High density
Low density

Land use and Crop Type
- Water bodies
- Common wheat
- Durum wheat
- Barley
- Rye
- Oats
- Maize
- Rice
- Triticale
- Other Cereals
- Potatoes
- Sugar beet
- Other root crops
- Other non permanent industrial crops
- Sunflower
- Rape and turnip rape
- Soya
- Dry pulses
- Fodder crops (cereals and leguminous)
- Bare arable land
- Woodland and Shrubland (incl. permanent crops)
- Grassland
- Bare land
- Wetlands

Far away land
Rural area in Ethiopia, near Lalibela, in the surroundings of Debre Tabor.
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Economic challenges, including a heavy dependence on agriculture and a lack of diversification, can result in low income levels and vulnerability to fluctuations in commodity prices. Climate change exacerbates these difficulties, as rural areas are more exposed to the impacts of extreme weather events and changing weather patterns, affecting agricultural productivity and livelihoods.

Heavy dependence on agriculture and a lack of diversification, can result in low income levels and vulnerability.

In some cases, infrastructure is noticeably lacking in rural areas. Where the transport network is insufficient, rural areas become isolated from urban areas. The area of Ethiopia presented of this Case Study, covers a surface of only 100 × 100 km, but large rural areas, many villages and some towns are more than three hours distant from main cities.

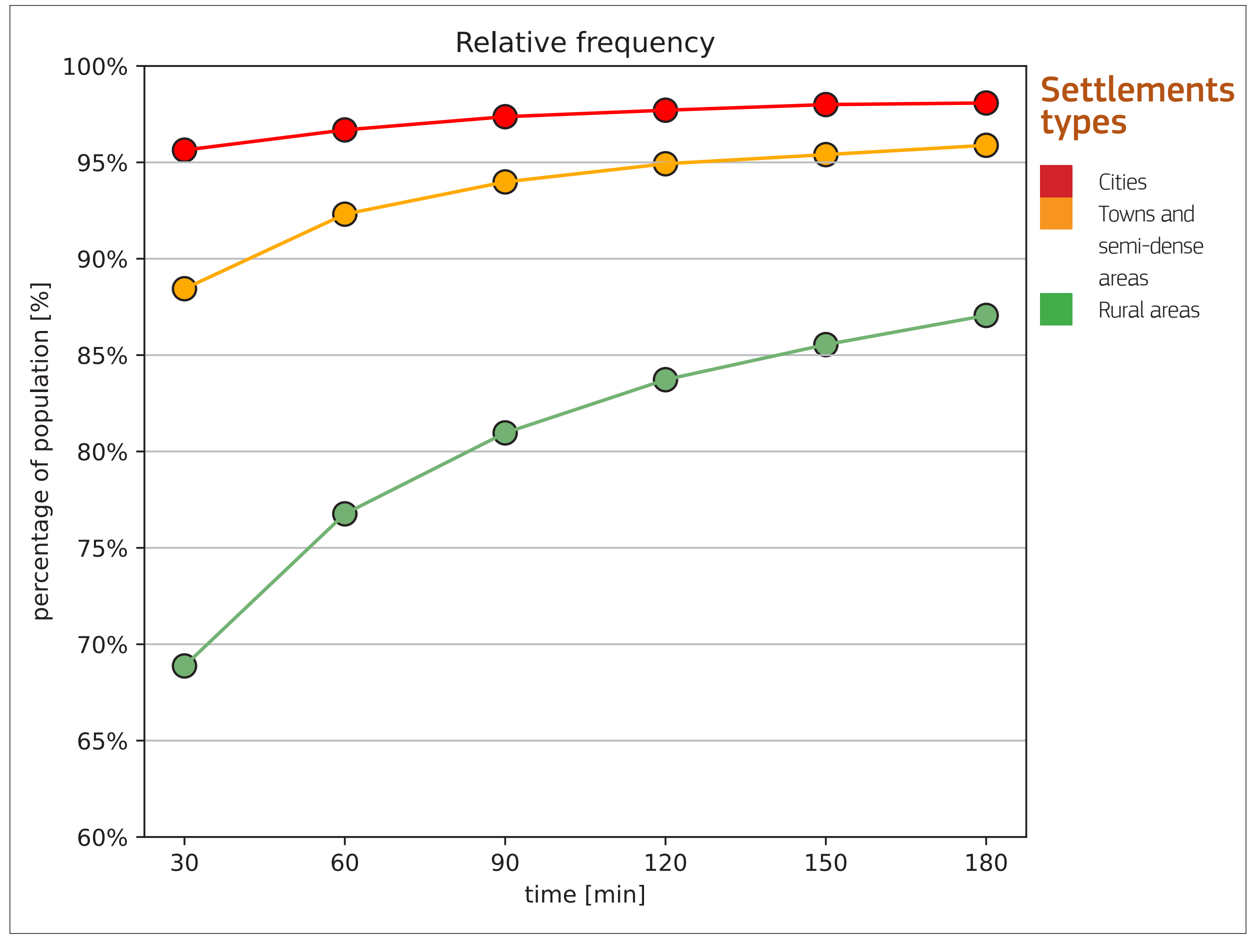
Inhabitants may require a long time to reach basic services, such as health care facilities. One third of the rural population in sub-Saharan Africa, for example, cannot reach the nearest health facility, even for basic medical care, in less than thirty minutes, while 12% unable to do this in less than 3 hours. Comparing travel times with towns and cities, the rural-urban divide that continues to affect this region of the world, emerges in stark detail.

Where the transport network is insufficient, rural areas become isolated from urban areas.

Poor infrastructure is not limited to the transportation sector: inadequate access to technology and digital connectivity also hampers many rural areas' ability to benefit from the advantages of the modern information age.

How long to get to the hospital?

Travel time to the nearest health care facility in sub-Saharan Africa, by share of population and by Degree of Urbanisation[3].



Seeds of inequality

Rural areas are widely distributed around the globe, but the opportunities offered to their inhabitants differ widely according to geography. While some areas are developed, other lack basic infrastructure and services such as safe drinking water, quality housing, education and gender parity. GHSL simplifies international comparisons, by providing a worldwide common definition for rural areas, based on the Degree of Urbanisation. Financial resources and technical assistance to support rural development are essential.

How long to the city?

Travel time to the nearest urban centre in the area of Debre Tabor, in northern Ethiopia.

Road Network

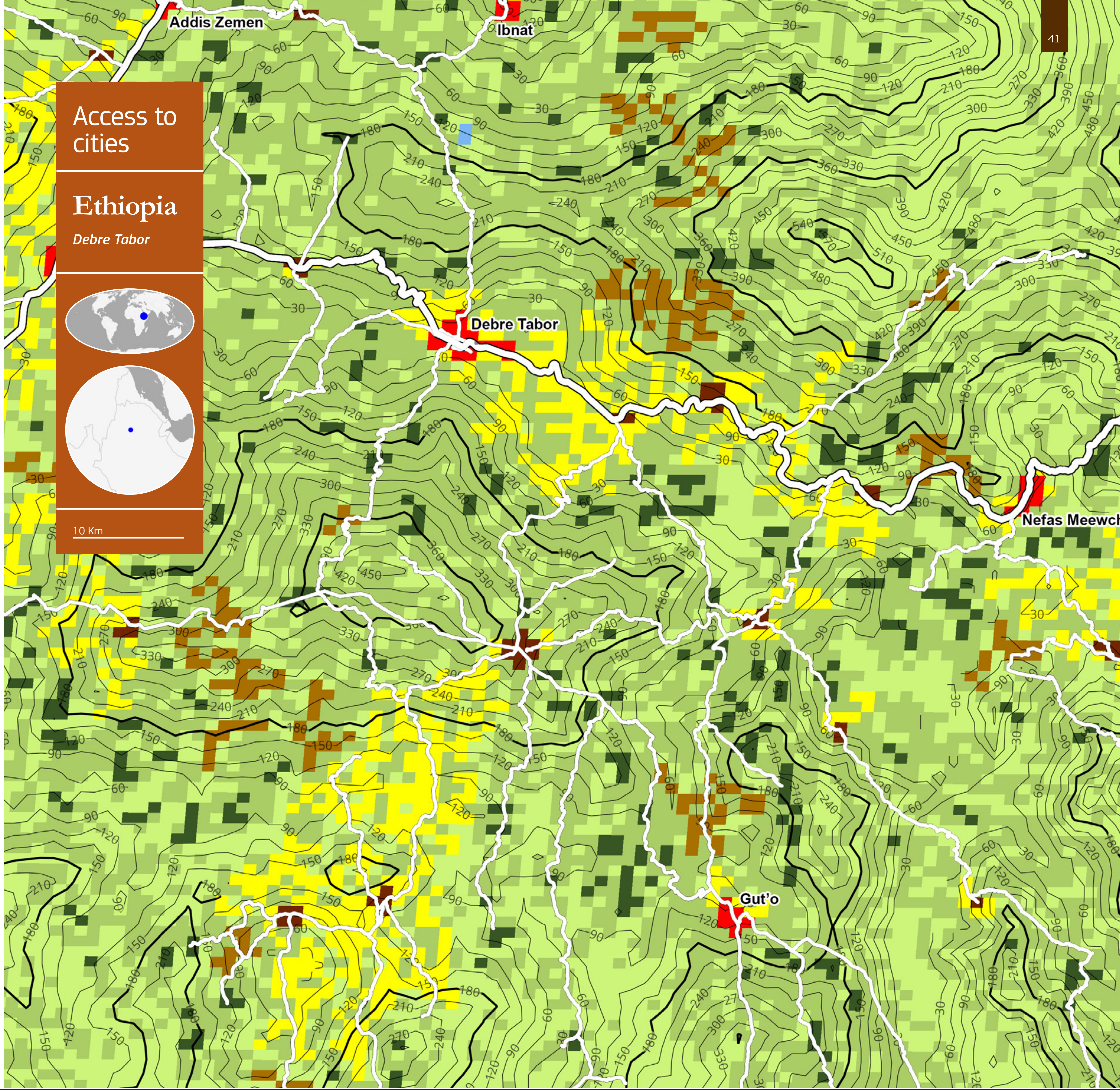
- motorway and primary
- secondary and tertiary

Travel time to the nearest Urban centre in minutes

- 30
- 180

Settlement types in 2020
Degree of Urbanisation

- Water
- Very low density rural grid cells
- Low density rural grid cells
- Rural clusters
- Suburban and peri-uban grid cells
- Semi-dense urban clusters
- Dense urban clusters
- Urban centres



1.9 The growth of cities

Composite of GHSL maps showing the spatial extent of 91 cities around the world.

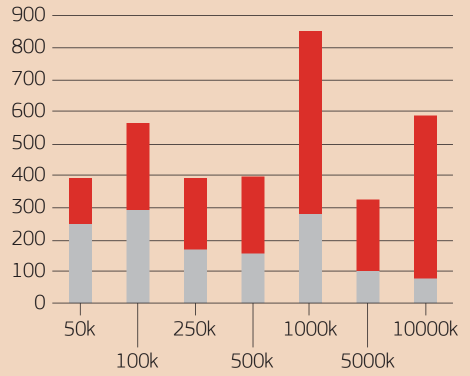
Spatial extent of each city in 1975
Spatial extent of each city in 2020

For a large part of the world, the growth of settlements transforms towns into small cities, small cities into large cities, and large cities into megacities. In 1975, there were over 6,400 cities (i.e. settlements of more than 50,000 people), and that number grew to over 11,534 in 2020. As of 2020, the majority of city dwellers live in cities with a population of 1 to 5 million inhabitants, and in megacities (i.e. cities with more than 10 million people). However, the growth of cities has been constant in all population size classes. To accommodate the growing population, the spatial extent of many cities has also increased.

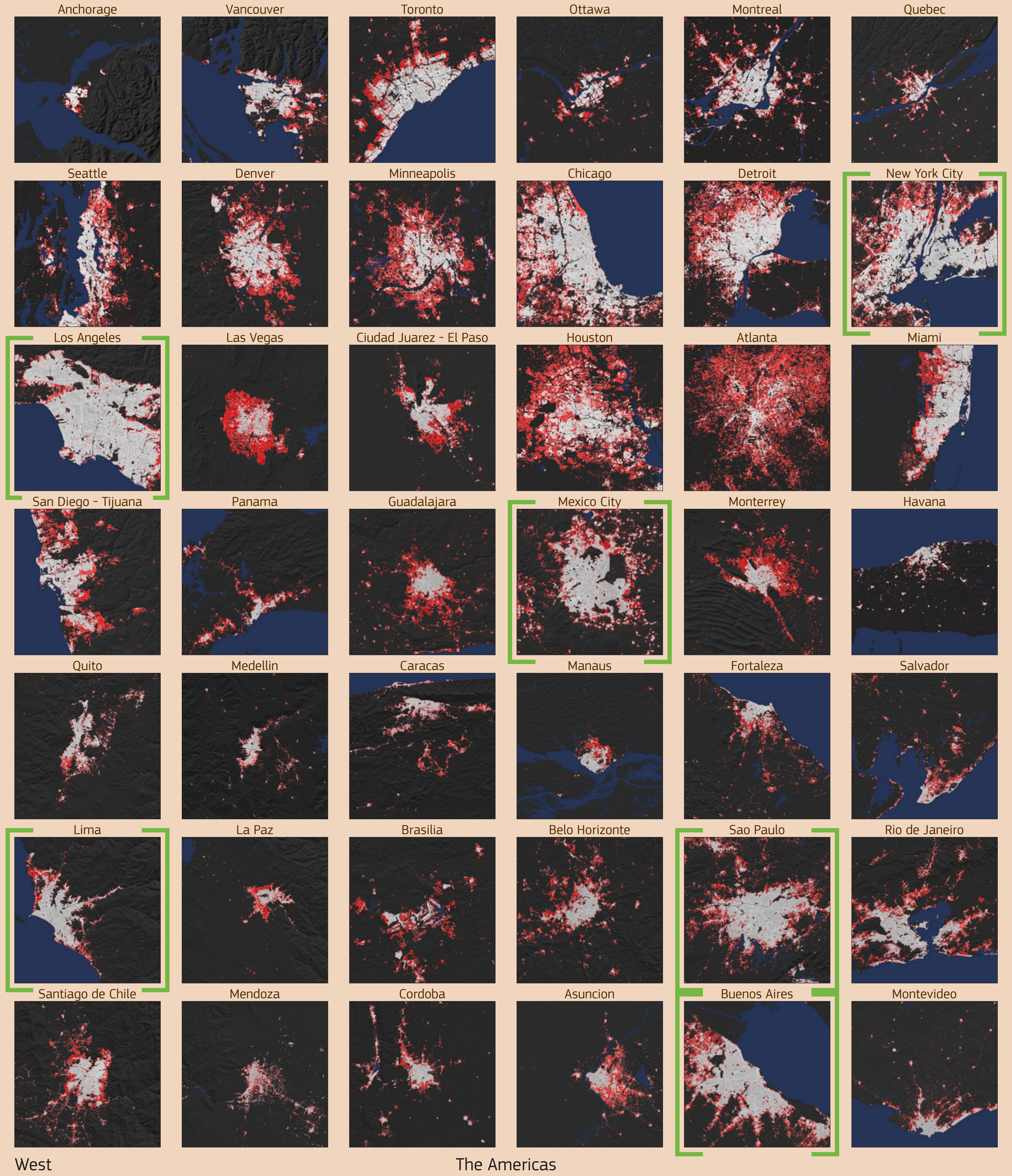
Uneven city growth

The cities in the 1-5 million population size class, and the megacities, have grown the fastest. However, the cities in all other population size classes have more than doubled their population.

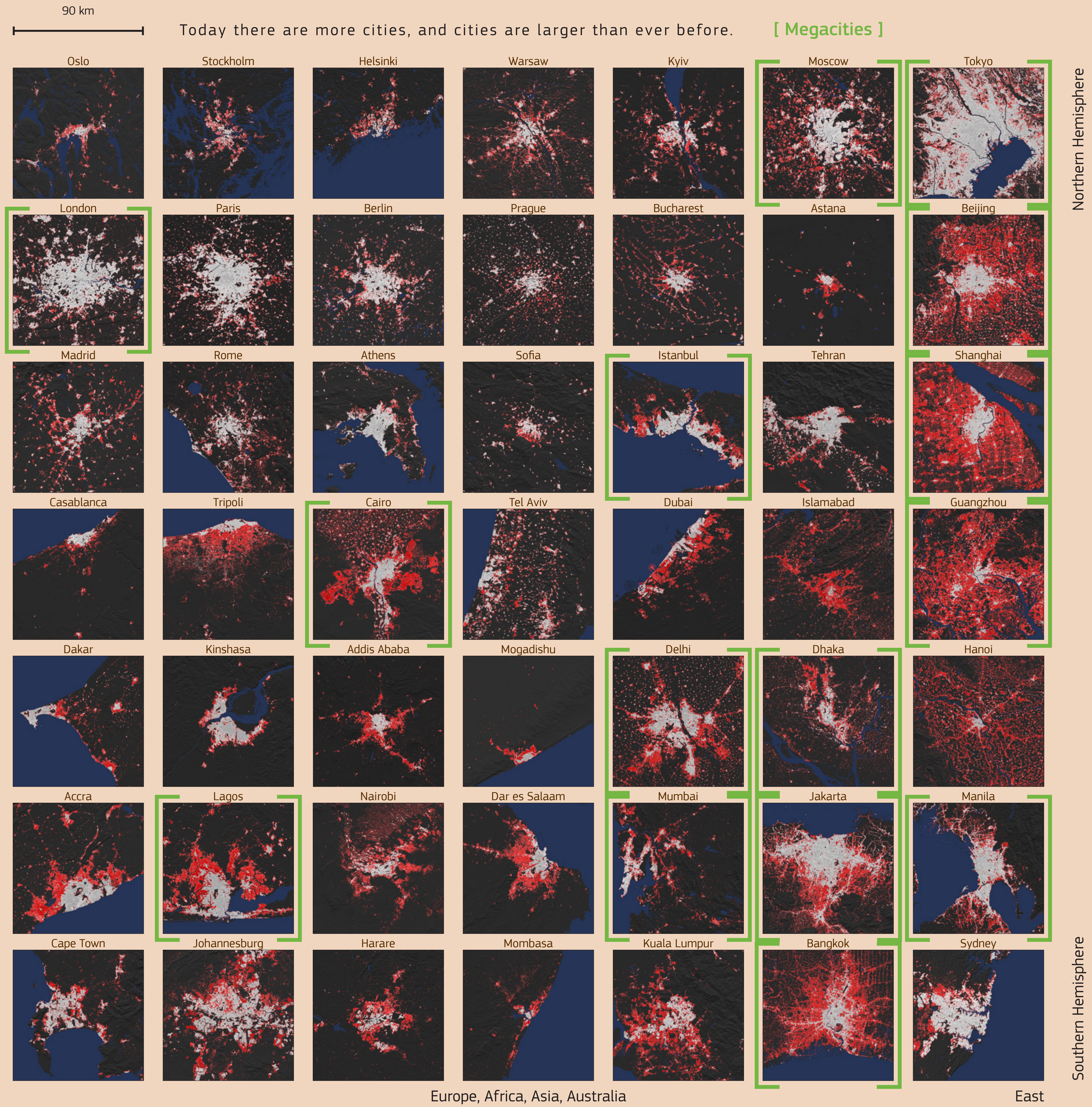
Population in 1975
Population growth 1975-2020



For a large part of the world, cities are continuing to grow, even if that growth is uneven. When cities are grouped into population size classes, those classes show distinct patterns of cumulative population growth. As of 2020, cities with 1-5 million people account for the largest share of the world population living in cities, and show the biggest increase in population over the past half-century. The megacity population size class has grown at the fastest rate, and accounts for the second largest share of world population living in cities. The population size classes for cities with 100-250 thousand, 250-500 thousand, and 500 thousand to 1 million people, have more than doubled in population, and their cumulative population growth accounts for a larger increase in share than the megacity class. Finally, the population size class for cities with 5-10 million inhabitants has more than doubled in population, and includes all the candidate cities to become the next megacities.



Today there are more cities, and cities are larger than ever before. [Megacities]



1.10
Megacities

Megacities are a new feature of urbanisation in the 21st century

Becoming the largest?
Delhi's rapid growth of population and built-up surface is projected to outpace that of other megacities by 2030. Efforts are being made to address the challenges of infrastructure development and housing.
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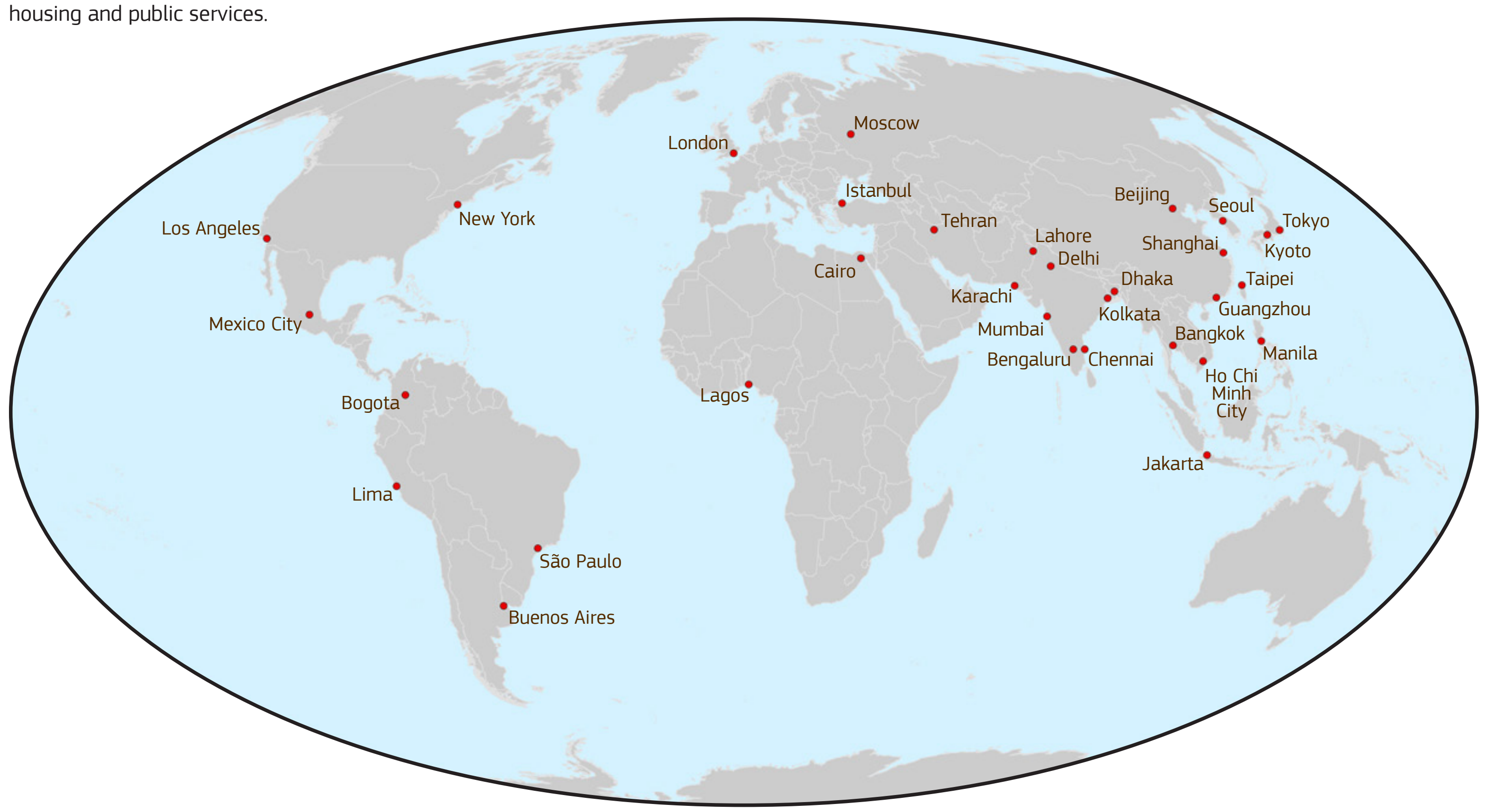
Megacities, which are defined as cities with a population of more than 10 million, are a particular feature of urbanisation in the present century. Continuous population growth within cities, coupled with migration from rural areas as well as from the global hinterland, contribute to the increase in the number of inhabitants that turns large cities into megacities. This spatial expansion into megacities often absorbs and merges adjacent towns and cities. As of 2020 there were 32 megacities[1] in the world, according to the new "Degree of Urbanisation" harmonised definition.
Every megacity has its own characteristic shape, size, and population density, and its own growth dynamics and limitations for further expansion. Asia and the Americas host most of the world's megacities. Asia has the most populous megacity, Guangzhou-Shenzhen, according to the Degree of Urbansation, as well as Jakarta, Tokyo, Shanghai and Delhi, each exceeding 25 million inhabitants. The remaining 27 megacities, with under 25 million inhabitants, occupy a total built-up surface area of up to 800 km². Asian cities such as Mumbai, Karachi, Dhaka, Kolkata, Delhi show higher densities than North American megacities, such as Los Angeles or New York.

Some existing megacities have paused their growth, others have severe limitations to accessing the resources needed for further growth (e.g. Jakarta), while other will continue to expand. Megacities must balance their economic development, innovation regarding environmental concerns, including pollution and waste management, and the quality of life of citizens, including provision of transport, housing and public services.

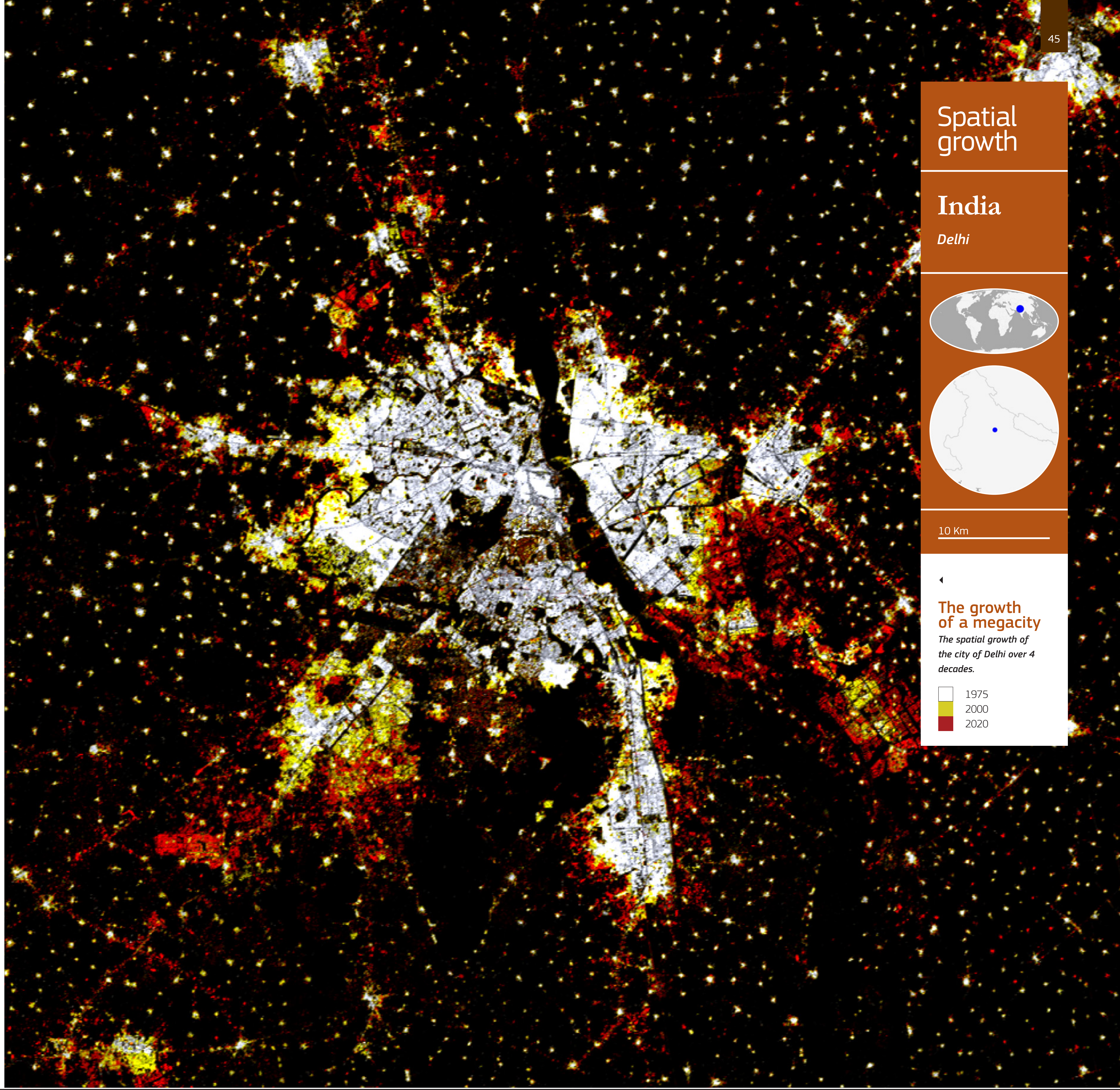
Megacities: opportunities and challenges

Megacities will continue to be a particular feature of the 21st century, especially in the Global South, where the population is still increasing. Megacities bring the opportunities of a larger economy, as well as the challenges of managing the larger entity resulting from the combination of administrative units. The vital processes of urban planning and infrastructure development, assessing resilience and inclusivity require spatial data, and GHSL contributes by providing data on demographics, trends, land use and built-up surfaces.



World's megacities in 2020

Of the 32 megacities that existed in 2020, only seven exceeded 10 million inhabitants in 1975. Today, most of the world's megacities are hosted in Asia and the Americas.



Spatial growth

India

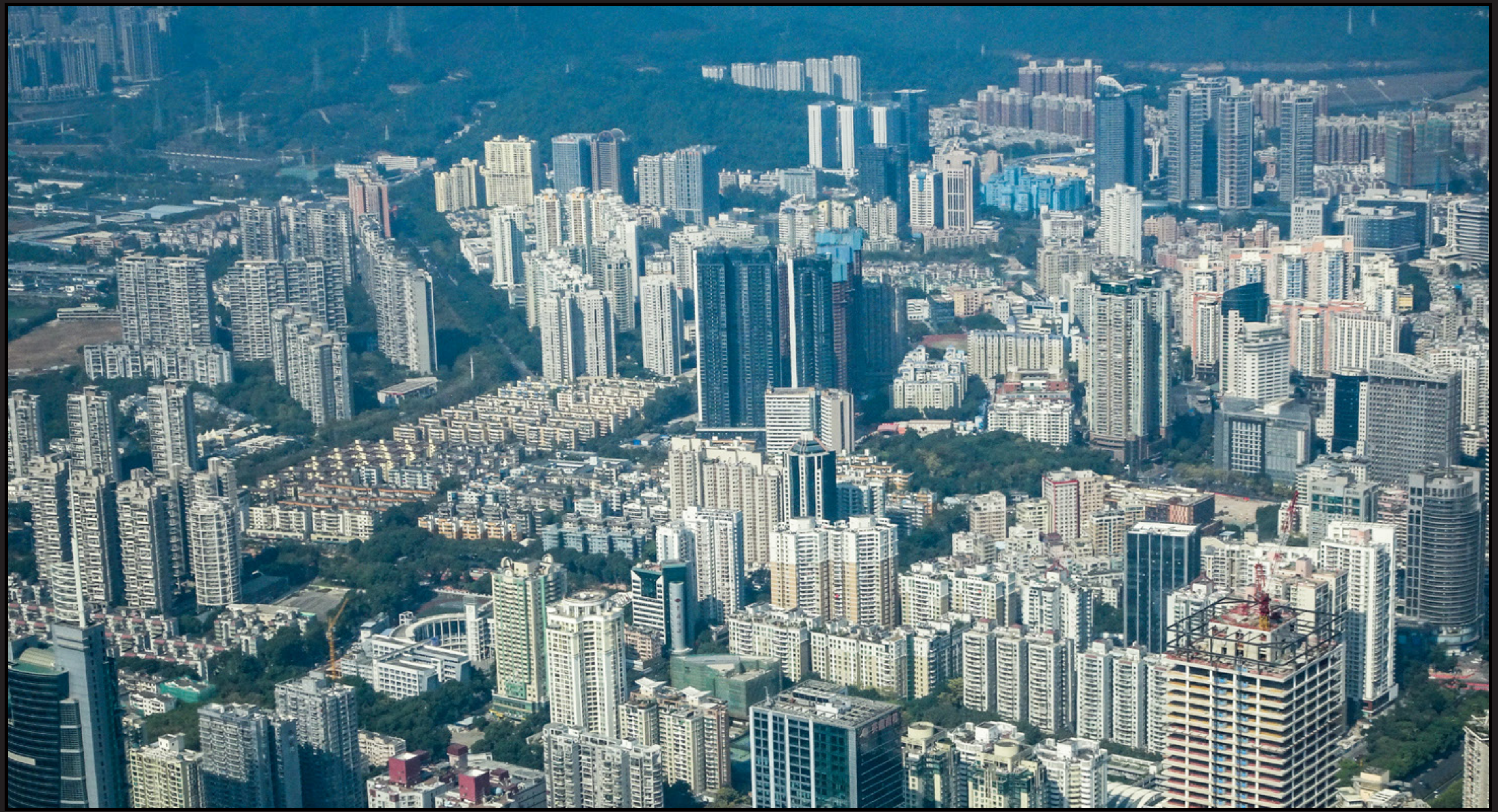
Delhi

10 Km

The growth of a megacity

The spatial growth of the city of Delhi over 4 decades.

1975
2000
2020



Shenzhen city structure
The Shenzhen urban area, seen from the top of the Ping An Tower, in the Shenzhen Financial Centre.

Population vs Built-up surface

Each megacity has its own characteristic population density and built-up surface areas, derived from history, culture and economy.
This plot compares the world's megacities in terms of their population versus physical size.

Spatial growth

China

Guangzhou-Shenzhen

Pearl River Delta metro region

The Pearl River Delta metropolitan region hosts the megacities of Guangzhou-Shenzhen (the most populated), that include also major centres such as Foshan and Dongguan.

20 Km

The growth of a megacity

The spatial urban area growth of the Pearl River Delta.

1975
2000
2020

Amongst the world's largest!

China's demographic and economic development is conspicuous by the changing size of its cities. The horizontal and vertical expansion of Shanghai is a quintessential example of that development.
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Megacities in time

The populations of the world's megacities have grown at different rates and during different epochs. Based on the Degree of Urbanisation, in 1975 there were just seven megacities, in 2000 there were sixteen, and by 2022 there were thirty-two. Of the seven megacities in 1975, Tokyo has maintained a relatively stable and already high population, Osaka has slightly declined, others like Delhi and Shanghai has grown into megacities by 2000.
Their spatial growth has generally followed their population growth, with each city having its own peculiarities. The cities images, the spatial growth of built-up surface of cities occurring between 1975 and 2000 is indicated in yellow, and that occurring between 2000 and 2020 is indicated in red. Megacities with stable population show low spatial growth since 1975, as opposed to those cities with high spatial growth after 1975. A number of cities have grown into a megacity only in the last two decades, such as Ho Chi Minh City. Africa's new megacities, including Lagos, show a continuous and rapid population growth while maintaining a relatively contained space.

Multi-temporal built-up areas

Multi-temporal data on built-up areas, population and settlement types are often used to compute indicators on cities, as input for international framework agreements. When used in combination with information on the environment or human activities, these variables can also be used to address environmental impacts, the demands for resources, and hazard risks (including air and water pollution).

Why GHSL?

GHSL continues to generate updates on built-up and population to monitor the growth or decline of cities as well as to define the contiguous expanding of the limit of the city based on the Degree of Urbanisation.

Megacities over time

Built-up area in:

1975
2000
2020

Water bodies
Land

100 Km

Tokyo
One of the largest megacities

Tokyo has long been considered the largest megacity in the world. Its growth rate has significantly decreased, reflecting the demographic slowdown in Japan.

Shanghai
Biggest population increase

Between 2000-2020, Shanghai experienced the largest population increase of all megacities that is reflected also in its spatial built-up growth.

Ho Chi Min City
Becoming a megacity fast

From a city of 2.5 million in 1975, Vietnam's Ho-Chi-Min City (or Saigon) has turned into a megacity, by quadrupling its population in 45 years. An equivalent growth of built-up surface has followed.

Lagos
Emerging African megacities

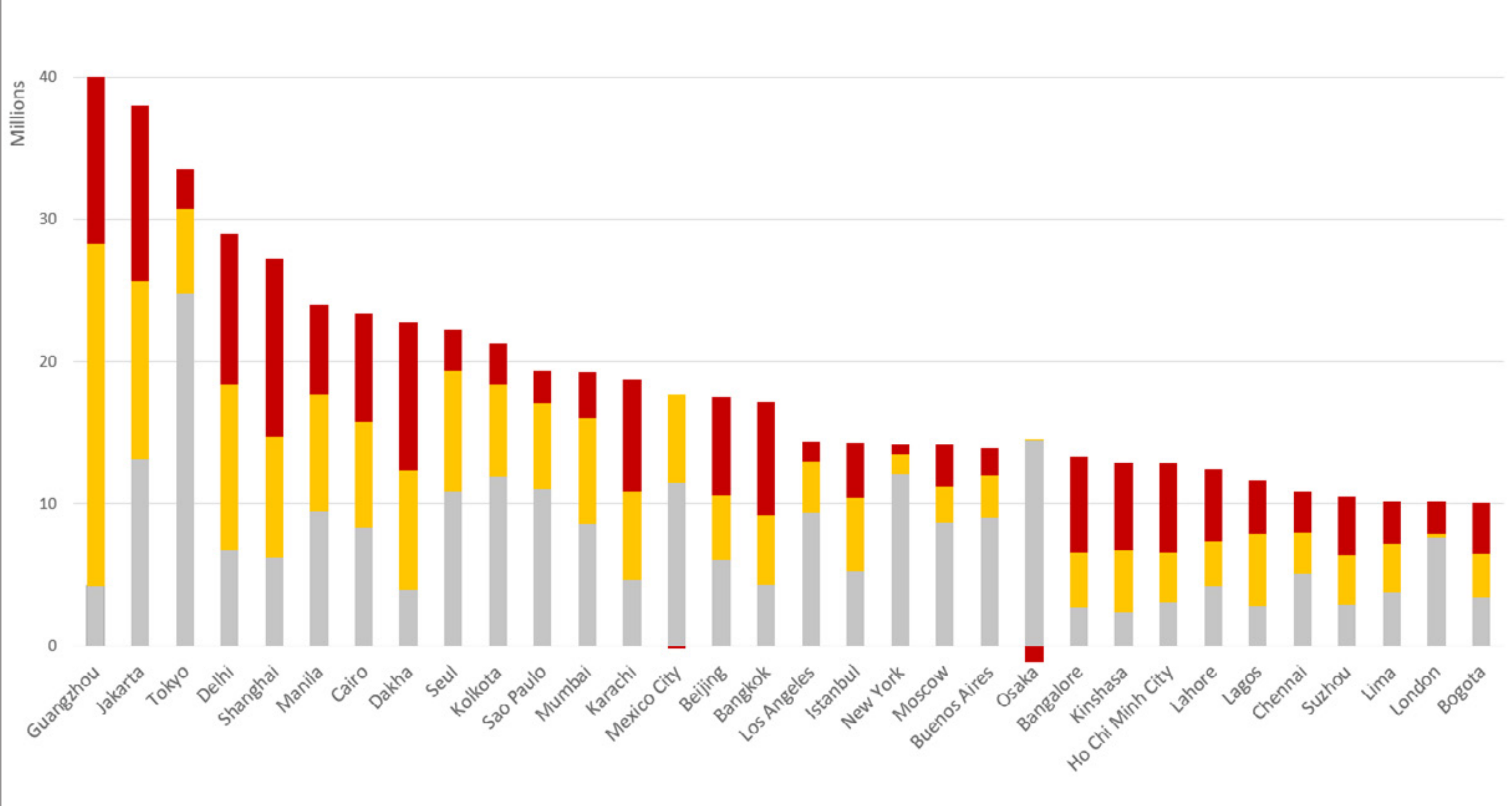
Lagos, Africa's rapidly expanding megacity, experienced its largest population increment between 1975 and 2000. The growth of its built-up surface has been less pronounced than that of its population.

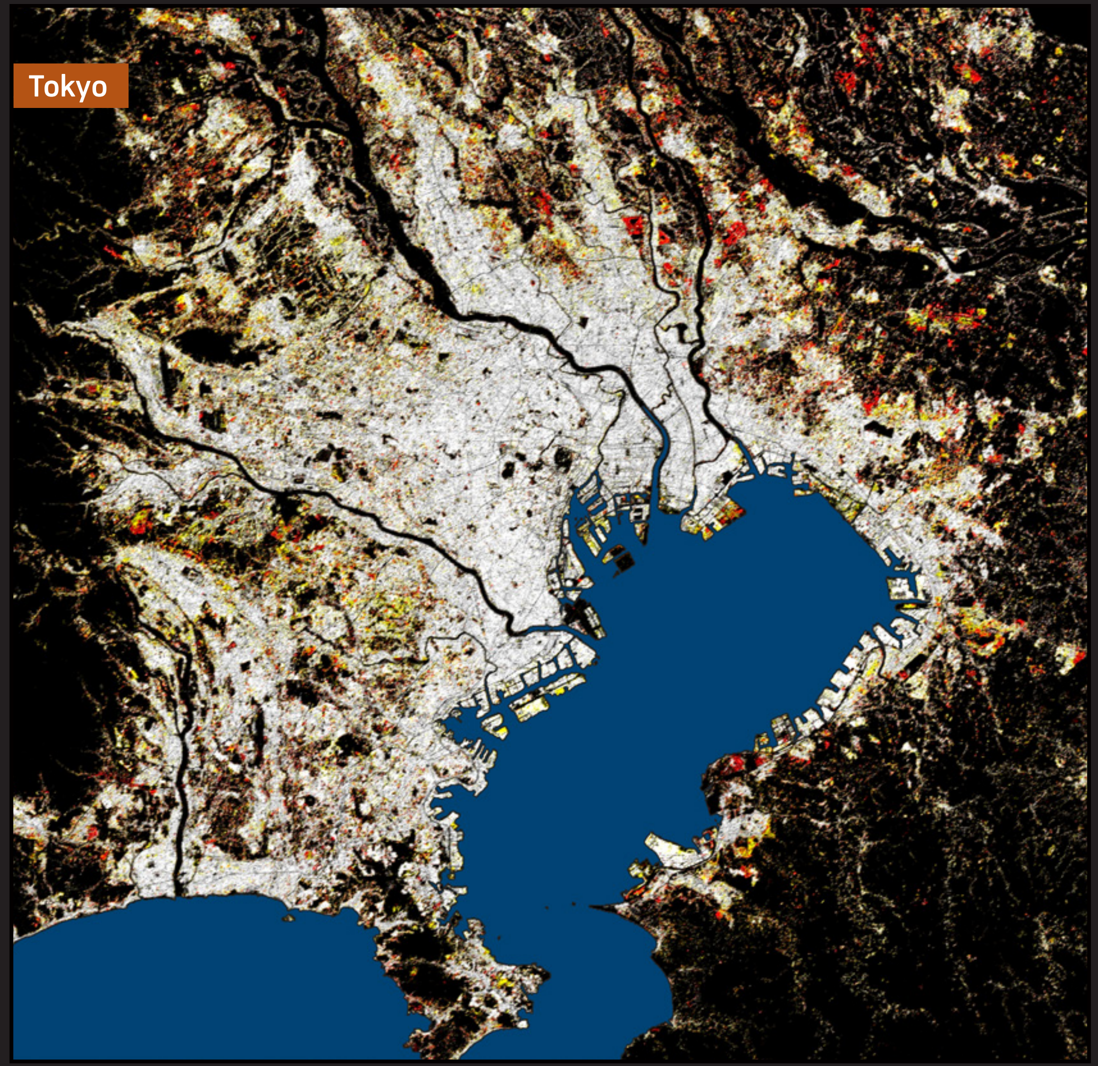
Megacities population increase

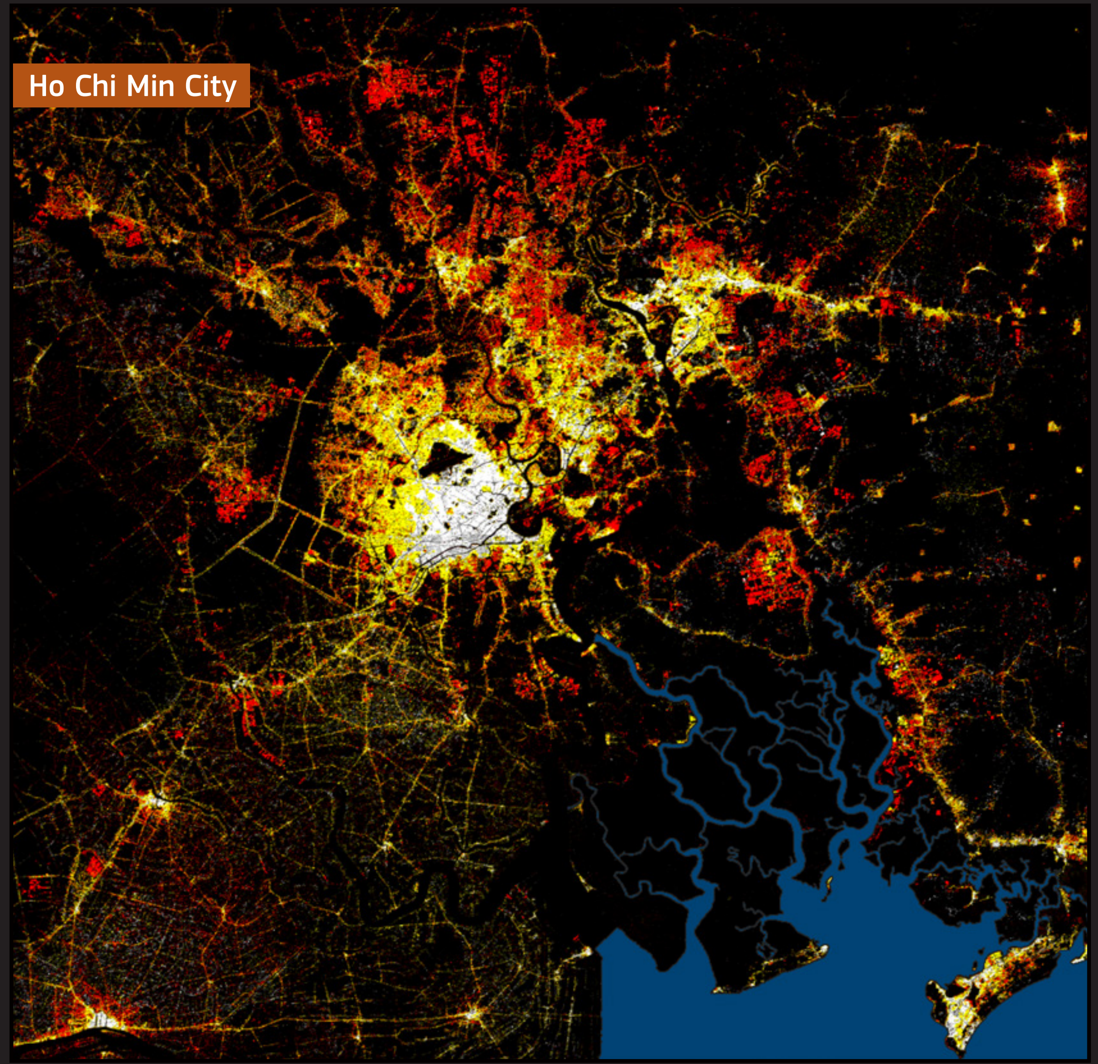
from 1975 to 2000 and 2020

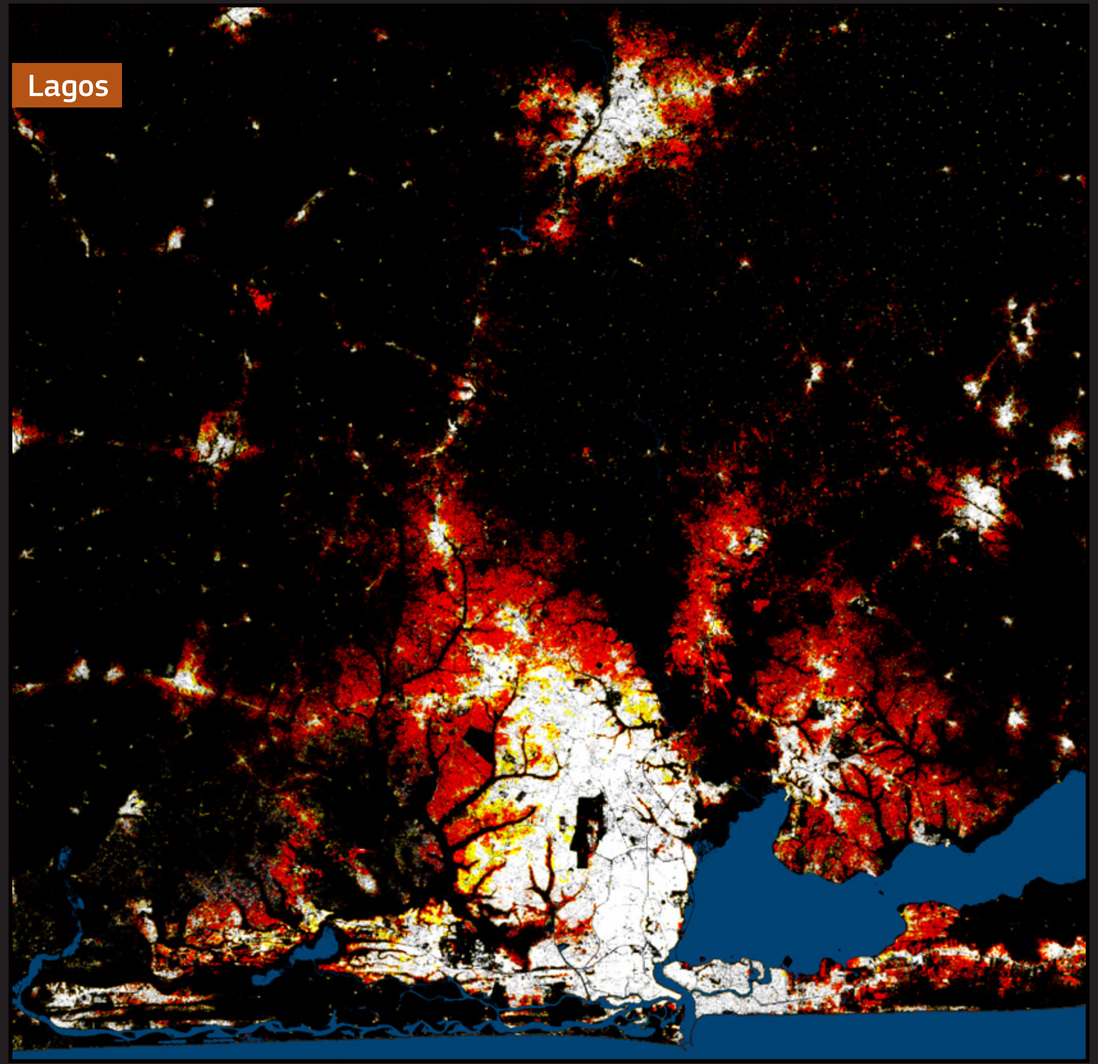
Megacities population has grown at different rates and in different epochs. Here we see population in 1975 (in grey), and population growth during 1975-2000 (in yellow) and during 2000-2020 (in red).

1975
1975 - 2000
2000 - 2020









Chapter 2

Spatial patterns of cities

The unique and shared spatial patterns of cities worldwide

Cities are a unique type of human settlement, differing from the other settlement types not only in their physical shape, size, and population, but also in their spatial patterns of built-up areas. Every city is shaped according to its own geographical features, development history, and economy. Together these characteristics generate a unique spatial arrangement of buildings (including their height and volume) and of open areas, which are the green spaces and the blue spaces (or water features) within the geographical setting. Because cities are often planned and constructed using common planning regulations, some shared spatial patterns can also be recognised in cities across the world. Built-up spatial patterns measured by GHSL (such as the examples presented in this Chapter) can provide a useful input for planning the future development of cities, and to address both urban resilience and future urban challenges.

Spatial patterns of cities

Built-up spatial patterns of settlements come from cultural, historical, economic and development factors that are traditional to communities and societies. ....

2.1 Washington metropolitan area

From planned city to metropolitan area

Emerging metropolitan areas

Many global cities, such as the Washington metropolitan area, are becoming large conurbations as a result of expansion and the incorporation of towns and villages once located on the outskirts. GHSL data offer insights into the temporal evolution of these regions, enables a better understanding of the challenges that a metropolitan area may face, and provides tools for addressing urban resilience.

The Washington metropolitan area is a sprawling urban region centred around Washington, D.C. in the United States, and including parts of the states of Maryland, Virginia, and West Virginia. As the capital city of the United States, it features a diverse range of settlement patterns shaped by historical, economic, and geographical factors.

The core layout and original design principles remain an integral part of the city's identity and urban character.

While its layout was meticulously planned and designed, Washington, D.C. has evolved over time to meet the changing needs of a growing capital city. Nonetheless, the core layout and original design principles remain an integral part of the city's identity and urban character.

Beginning in the mid-20th century, Washington, D.C. expanded with the growth of suburbs in Maryland and Virginia. Such residential development outside the central areas offered a more suburban residential lifestyle compared with that in the urban core. There has been a trend towards mixed-use development, combining residential, commercial, and recreational spaces within the same neighbourhoods.

The Potomac River and its tributaries, and natural features such as hills and valleys, have played a significant role in shaping settlement patterns, by limiting development in certain areas and shaping the road network.

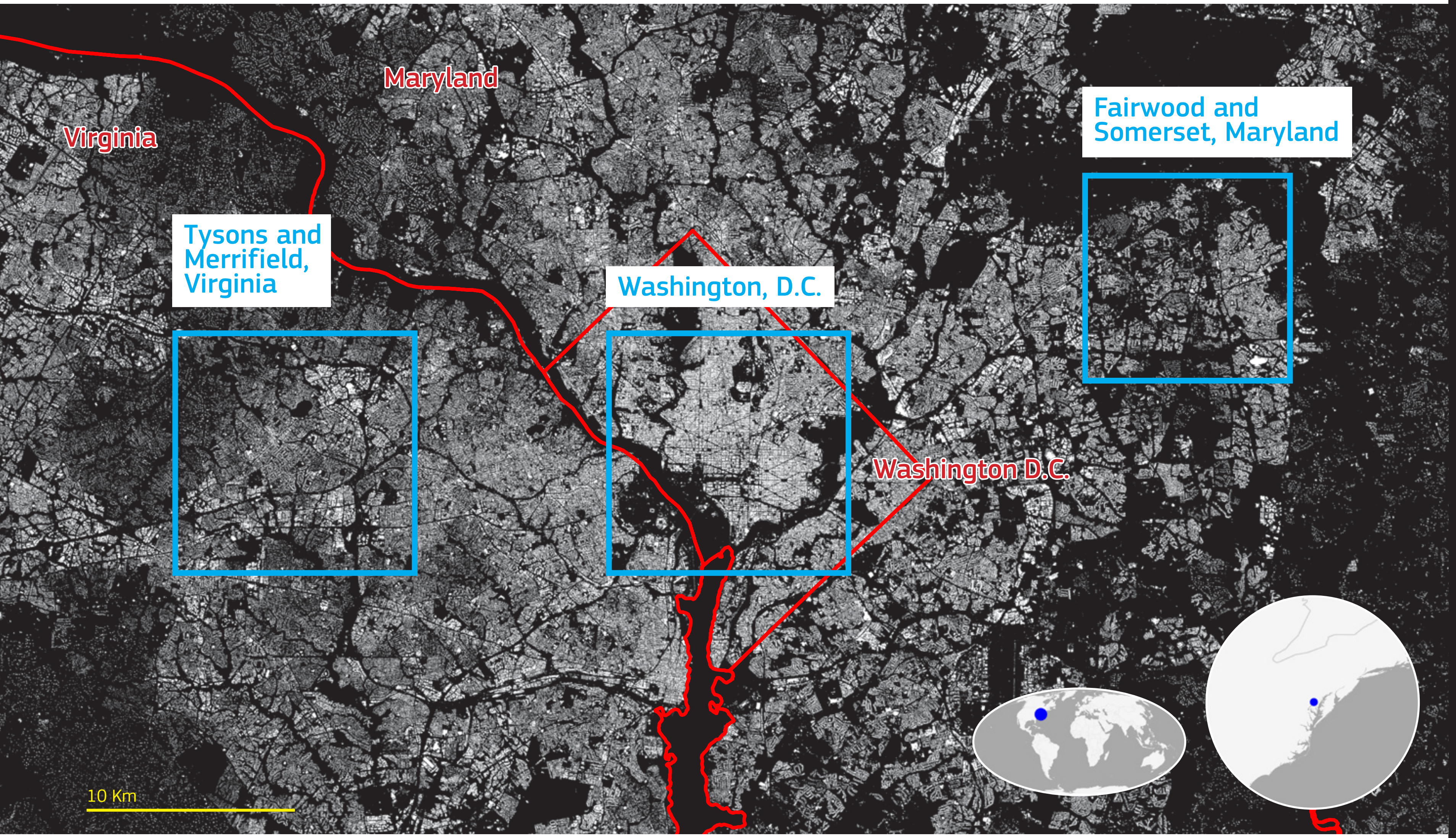
Overall, the settlement patterns in the Washington metropolitan area are characterised by a mix of urban, suburban, and commuter-focused regions, reflecting the area's historical, economic, and geographic dynamics. These patterns continue to evolve, as the area grows and urbanises.

The Washington metropolitan area is just one example of a city that has grown substantially in the 20th century, with transport networks connecting different sections of the city that have specialised functions, including residential, commercial and service sectors.

Washington metropolitan area

Areas of interest — Administrative boundaries

Washington metropolitan area extends beyond the District of Columbia administrative boundaries and includes a number of commercial and residential areas located in Maryland and Virginia (and West Virginia).



Washington, D.C.

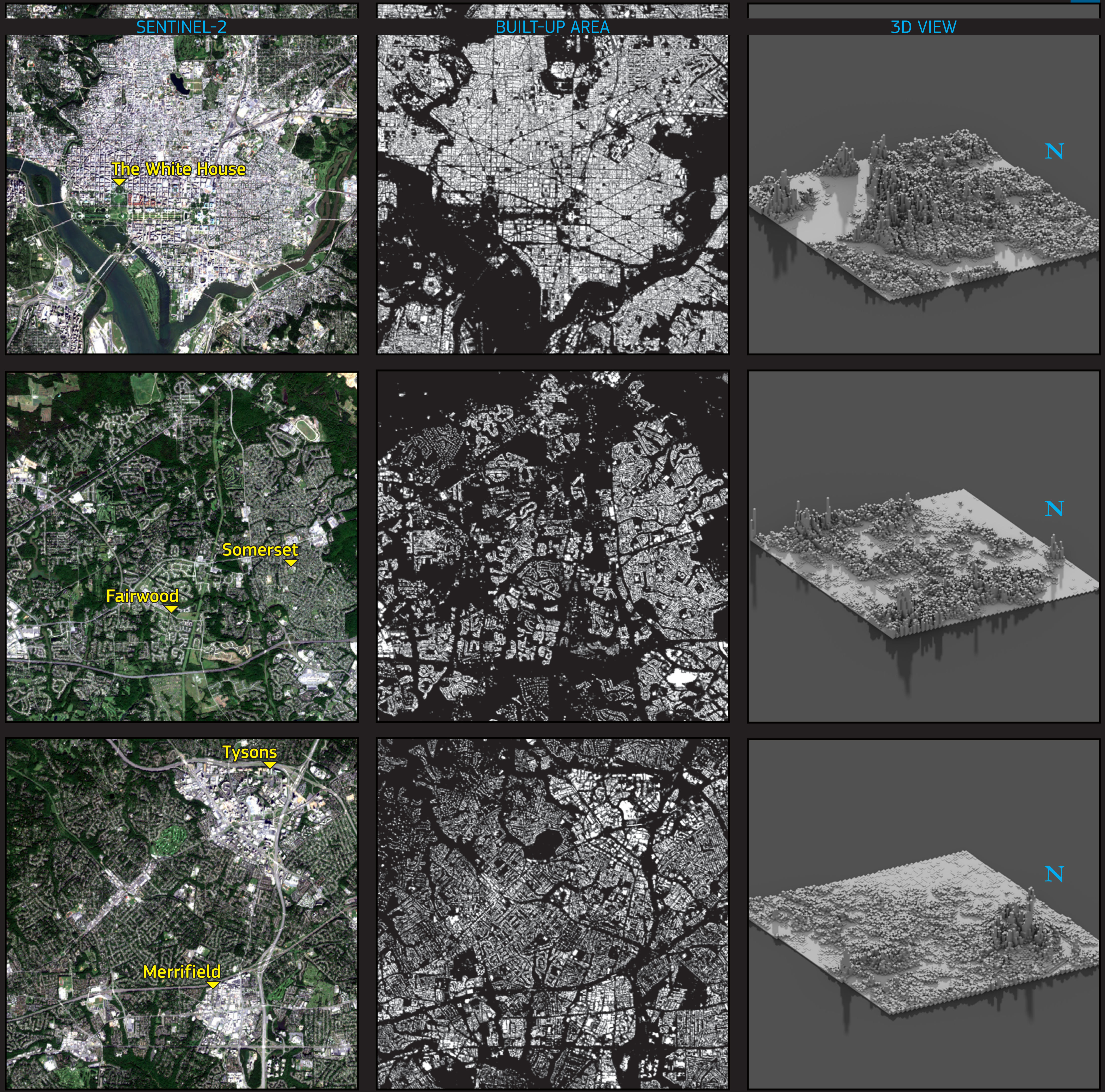
Historically, Washington, D.C. was a planned city. The original layout of boulevards is still visible in the city's structure. The historical buildings serve as the home for federal agencies, international organisations, and cultural centres. The city is known for its unique architectural style including large buildings and iconic landmarks, such as the White House and the United States Capitol.

Fairwood and Somerset, Maryland

Fairwood is a planned community in Prince Georges County, Maryland. It includes residential, commercial and recreational areas. The settlement patterns in this suburban county combine open spaces, traffic infrastructure, mostly low-rise residential buildings, and commercial buildings. North-east of Fairwood, the nearby town of Somerset, in Montgomery County, exhibits more dense settlement spatial patterns.

Tysons and Merrifield, Virginia

Tysons is one of the region's major employment and commercial centres. Located west of Washington, D.C., it is known for its shopping malls, office complexes, and residential developments. It benefits from its prime location along major transportation corridors. Tysons and Merrifield feature higher-rise buildings compared to their surroundings to the west.



2.2 Mexico City

A megacity in the Valley of Mexico

Big cities facing risks

Mexico City faces majors risks as high magnitude earthquakes, water scarcity and subsidence. GHSL data provides high resolution population data to identify areas with the higher exposure to the risks. This information helps policymakers and stakeholders to make informed decisions, reducing personal and economic losses during disaster situations.

Mexico City, one of the largest and most populous cities in the world, exhibits a complex and diverse spatial structure that originates with the early settlements in Mesoamerican history. Early Mesoamerican settlements were built on the shores of a number of lakes covering the floor of the Valley of Mexico. During the colonial period, the lakes were drained to prevent flooding and to favour urban growth. Today, Mexico City is a bustling metropolis that shows a mixture of colonial-era urban spatial patterns, neighbourhoods developed during the 1970s, and areas of luxurious gated communities next to impoverished neighbourhoods. The city still shows some of the original structure of Tenochititlan - the largest city ever in Mesoamerica - and the colonial urban patterns which were incorporated later.

A mixture of colonial-era urban spatial patterns, neighbourhoods developed during the 1970s, and areas of luxurious gated communities next to impoverished neighbourhoods.

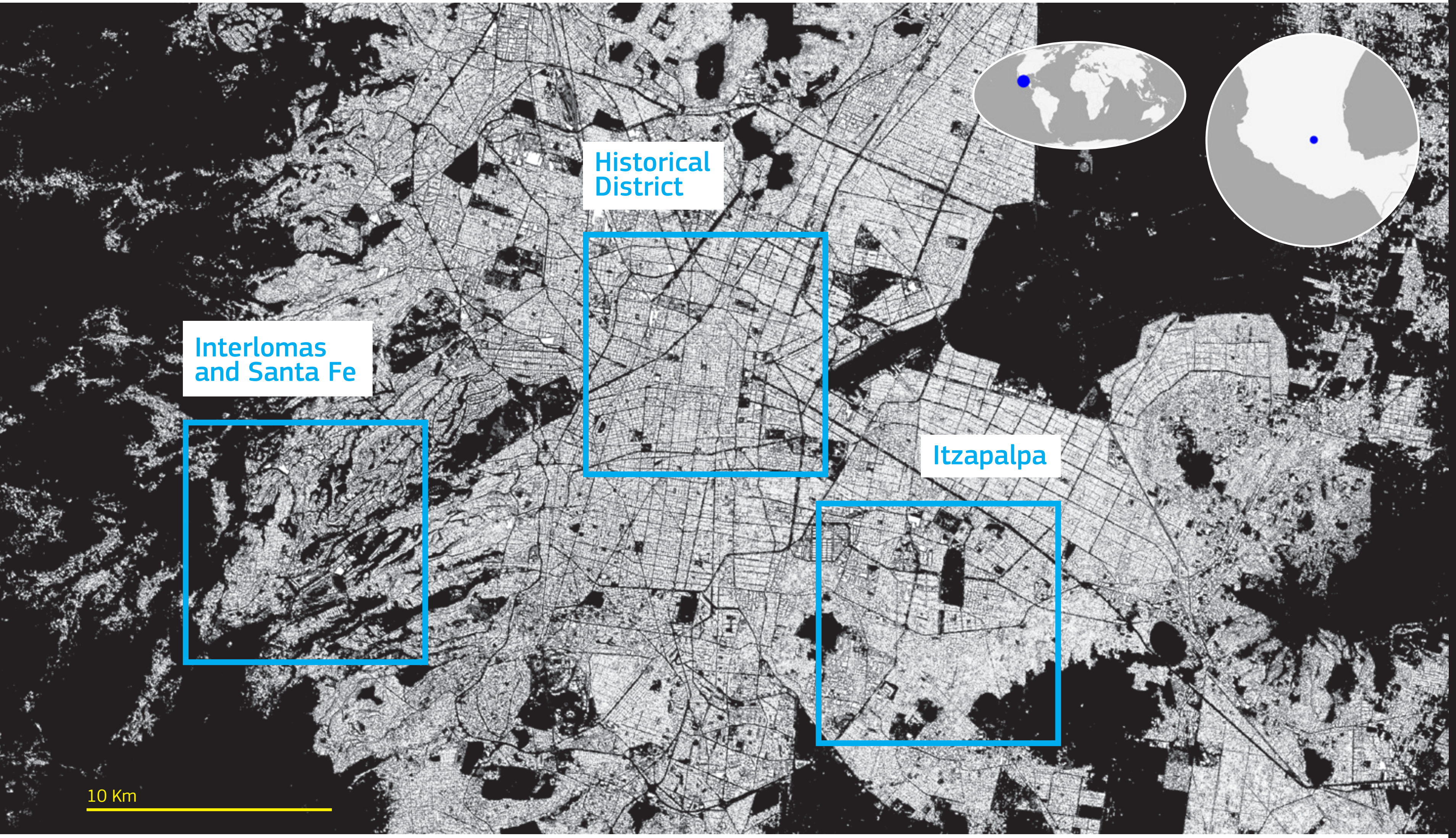
Mexico City is currently grappling with two major issues: subsidence and the high risk of earthquakes. These problems have arisen primarily due to the overexploitation of groundwater beneath the city, a practice that has been exacerbated by climate change and decreased rainfall. Furthermore, Mexico City has experienced a series of high magnitude earthquakes, the most recent occurring in 2017. The depletion of groundwater has significantly impacted the underground stability, increasing the likelihood of more severe damage in the event of future earthquakes. The city's risks and natural hazards are being addressed through a governance structure supported by international institutions. Despite these challenges, Mexico City continues to inspire and attract people from all over the world.

Mexico City is currently grappling with two major issues: subsidence and the high risk of earthquakes.

Mexico City patterns

Areas of interest

Mexico City now includes many of the former isolated settlements scattered in the Valley of Mexico. These can still be identified from the spatial arrangement of built-up patterns.



Historical District

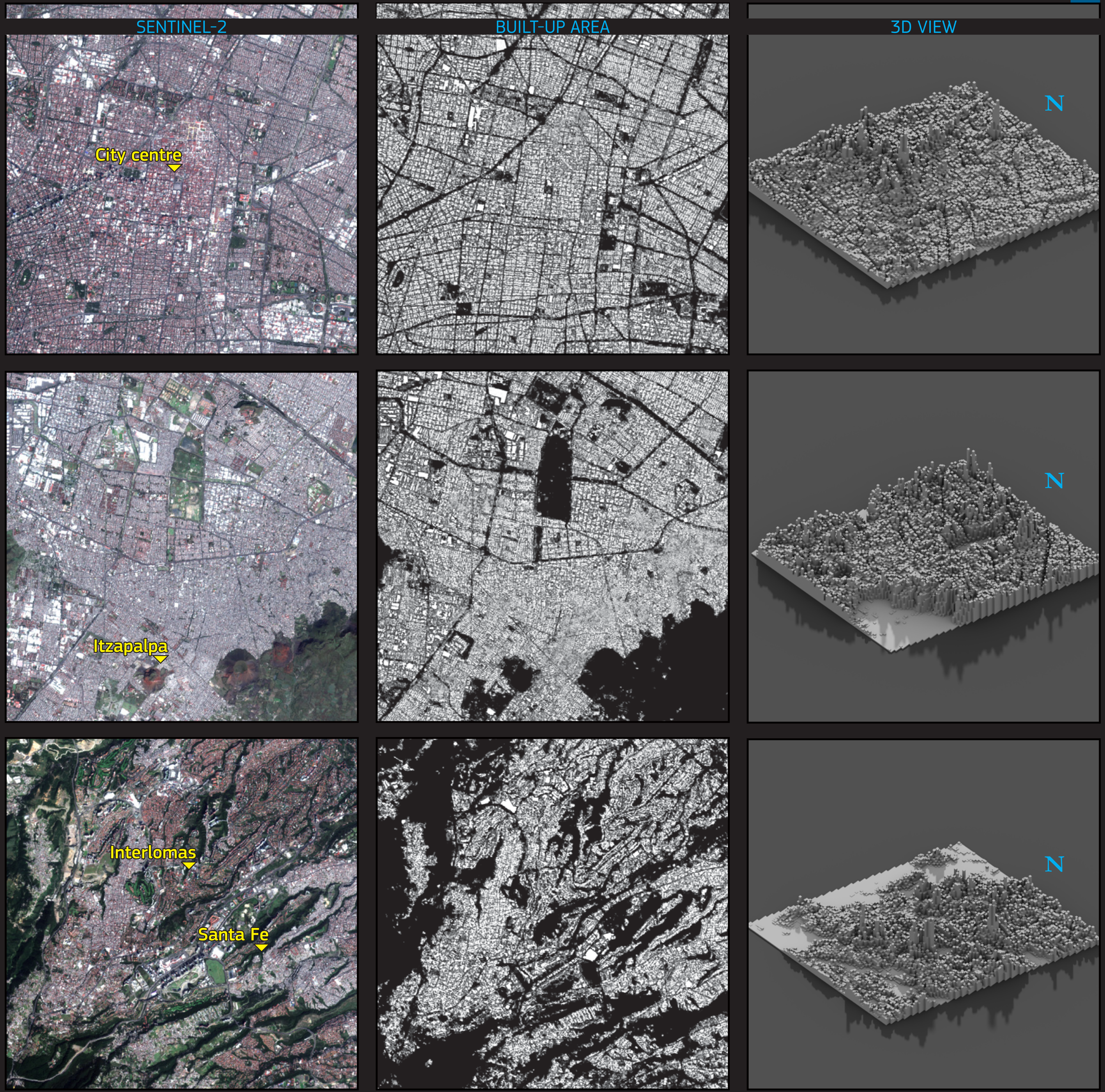
The city centre and outskirts of Mexico City were built on top of the ancient Mexican city of Tenochtitlan. This district features a combination of ancient and colonial urban planning, characterised by rectangular blocks and a street layout centred on significant plazas and landmarks. The surrounding areas present a mosaic of housing areas, green spaces, public monuments, and other amenities.

Itzapalpa

The pre-Hispanic town of Itzapalpa officially became part of Mexico City in 1928. In the 1970s, a significant number of families migrated there from rural areas, leading to a substantial population growth and urban expansion. The area is densely populated and urbanised, with limited open spaces other than the surrounding hills. The total population of Iztapalapa has grown from 10,000 inhabitants in pre-Hispanic times, to 1.8 million inhabitants in 2020.

Interlomas and Santa Fe

Interlomas is an exclusive residential area of gated communities. The area was once covered by woods and small settlements. In contrast, Santa Fe, was an industrial zone in the 1970s, initially established for sand mines purposes. The present-day urban pattern is characterised by affluent residential and business zones (with wider roads and green areas) situated next to disadvantaged neighbourhoods (with narrow streets and denser built-up areas).



2.3 Dar es Salaam

Fast-growing cities in Africa

Dar es Salaam, the capital of Tanzania, is one of the largest cities in Africa with more than 6.9 million inhabitants in 2020. Today it is also one of the fastest growing cities in the country, despite the delayed onset of urbanisation due to the 'rural-first' development policy adopted by the post-independence governments. Since 1975 the city

Since 1975 the city has doubled its built-up area and experienced a tenfold increase in its population.

has doubled its built-up area and has seen a tenfold increase in population. This rapid growth has led to the emergence of sprawling informal settlements that extend outward from the city centre. Such an unplanned development has given rise to a number of issues commonly observed in rapidly developing cities in the Global South. These challenges include profound wealth disparities and widespread poverty leading to a large portion of the population residing in informal settlements without access to basic

Fast growth in highly vulnerable areas

A large part of the city is situated in low elevated coastal areas. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[1], Dar es Salaam is among the twelve major African cities that would face the most severe impacts of rising sea level in the future. Information on the spatial extent of settlements, such as that provided by GHSL, is essential to assess both current and future risks associated with disasters.

amenities such as water and sanitation, traffic congestion, and inadequate provision of services like public transport, schools, and healthcare facilities.
The settlement pattern within Dar es Salaam reflects these challenges, displaying a patchwork of different typologies. Wealthier areas are characterised by low building

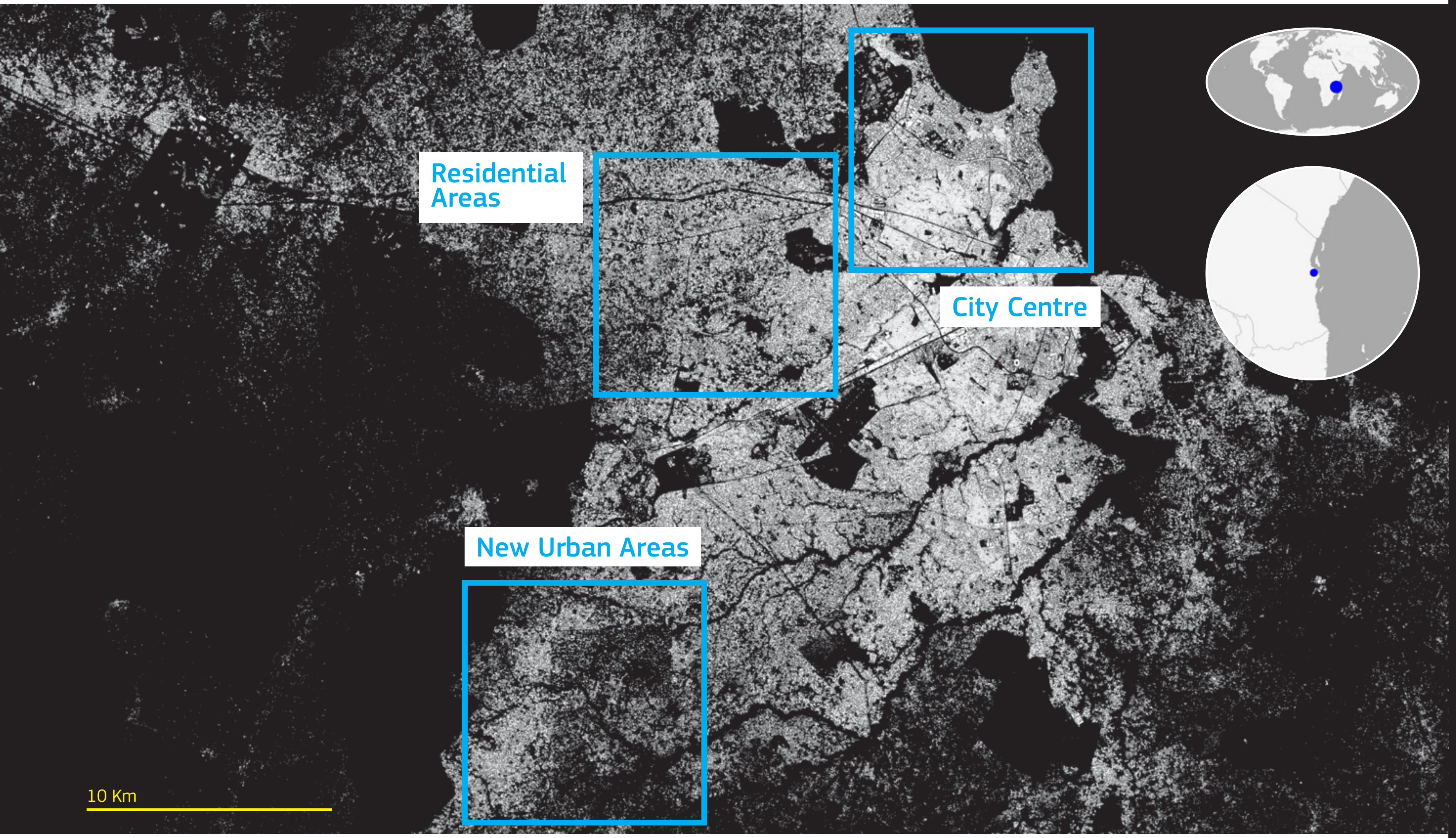
Challenges include profound wealth disparities and widespread poverty.

densities and large open spaces. In contrast, the Central Business District shows a well-planned layout and features tall high-rise buildings. The majority of poorer areas, on the other hand, are characterised by small-sized buildings that are often closely positioned, to the extent that their footprints appear merged when observed from the Sentinel satellites.

Dar es Salaam spatial patterns

Areas of interest

Extracting built-up surface from Sentinel-2 images allows visualising how cities have spatially developed. Dar es Salaam has a denser core but even the sparser buildings are visible along the city limits.



City Centre

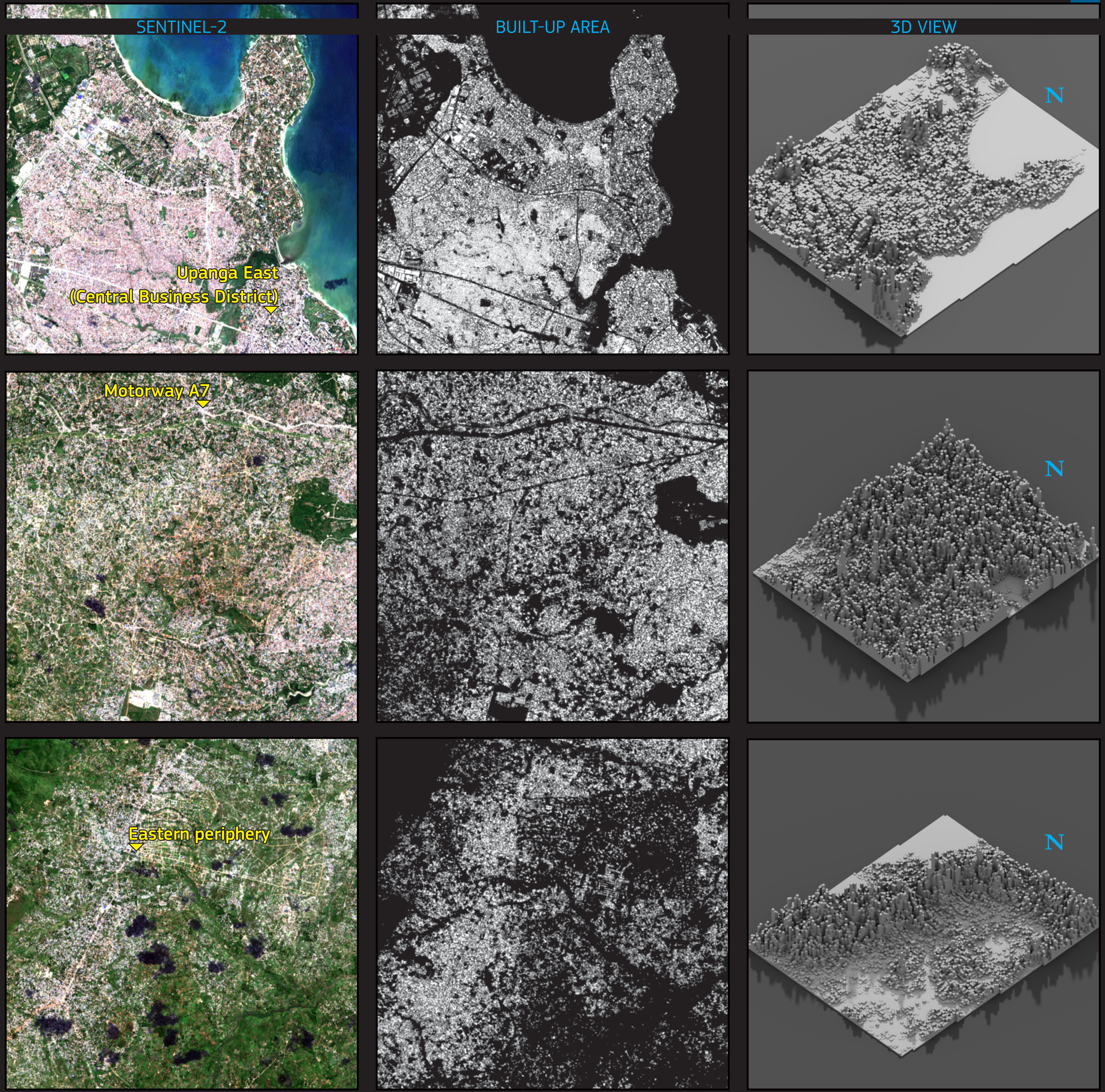
The city centre exhibits a wide range of settlement patterns. The northern peninsula features low building densities and large open spaces typical of affluent neighbourhoods. The central business district is home to the tallest buildings in the city, and the surrounding areas also host high-rise buildings. The city centre also includes large areas of low-rise, high-density settlements.

Residential Areas

In the 1980s and 1990s, the areas surrounding the city centre developed into urban areas. Over time high-rise buildings were constructed to accommodate the growing middle class of Dar es Salaam. The figure shows homogeneous built-up area densities, with a few large open spaces. Clearly visible is the motorway, which cuts through the city from East to West.

New Urban Areas

The city's most recent development is concentrated along three main corridors: northward along the coast, westward and southward. The eastern periphery is transitioning from rural into peri-urban and urban zones. In fact, a distinct building density gradient can be observed from the high-density city centre towards lower density peri-urban areas, and into low density rural settlements.



2.4 Hanoi

A city of nearly five million people

Hanoi, capital city of Vietnam, is located in a coastal area in the northern part of Vietnam along the Red River Delta, a region characterised by flat, low-lying terrain near the coast. The Red River Delta is prone to flooding, especially during the monsoon season, and is considered vulnerable to the impacts of rising sea level and climate change.

Hanoi has experienced a rapid construction boom recently. Skyscrapers, appearing in new urban areas, have dramatically changed the cityscape.

The capital of Vietnam is only the country's second biggest metropolitan area, after Ho Chi Minh City, with more than 4.6 million inhabitants in 2020. Human settlements in Hanoi trace back to the Paleolithic era, and since then its favourable characteristics have attracted continuous habitation.
The modern shape of Hanoi began to form only after 1986, when the government introduced economic reforms aimed at establishing a "socialist-oriented market economy". During the 1990s, Hanoi underwent remarkable transformations, reshaping its transportation and living patterns. This period saw a transition from traditional reliance on walking and cycling to a culture centred around personalised motorised transportation. Simultaneously, the city's urban structure underwent a fundamental change where the traditional concept of living and working in close proximity evolved to create a cityscape where residences are separated from workspaces.
High-rise commercial buildings started to appear ten years later, marking the onset of a rapid construction boom in Hanoi. Skyscrapers have dramatically altered the cityscape, particularly in new urban areas, creating a modern skyline outside the old city. However, as in many other fast-growing cities, this rapid urban development has resulted in the displacement of residential areas in central Hanoi. Consequently, present-day Hanoi is characterised by a densely built-up environment with limited green spaces and open areas.

Rapid urban expansion

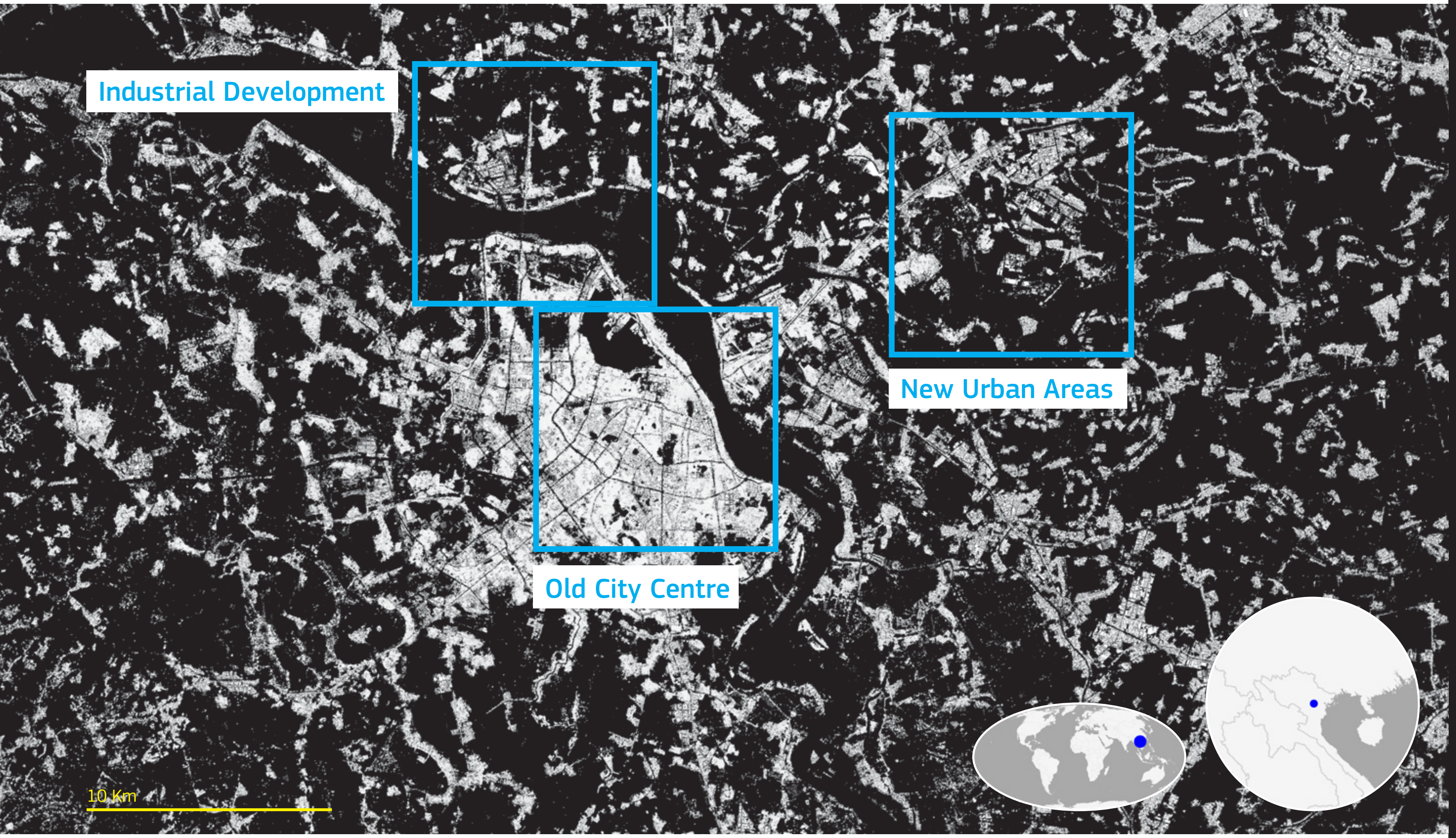
The rapid urban expansion of Hanoi in the last years has significantly altered the city's spatial layout. Insights from GHSL data can assist in identifying urban expansion trends over the past years. And by understanding the historical development of the city, we can better plan and implement future urbanisation strategies.

The capital of Vietnam is only the country's second biggest metropolitan area, after Ho Chi Minh City, with more than 4.6 million inhabitants in 2020.

Hanoi spatial patterns

Areas of interest

Hanoi has developed along the banks of the Red River.
Waterbodies and patches of agriculture are characteristic of its spatial distribution.



Old City Centre

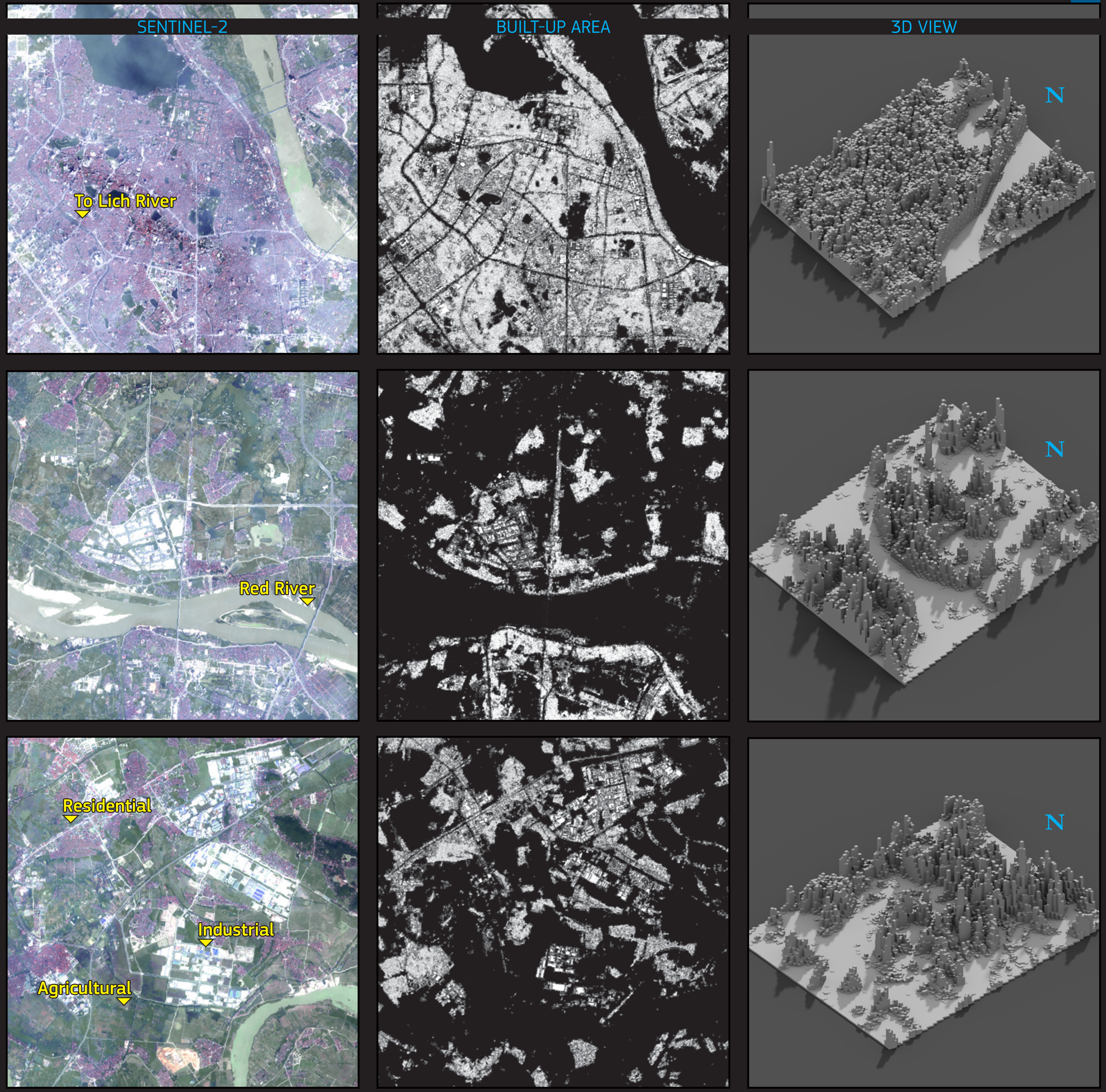
The old city centre of Hanoi combines traditional Vietnamese culture with French colonial quarters. The centre is constrained by the To Lich River and its planned development prevented urban sprawl. The centre shows uniform high-rise apartment blocks and other residential structures. Recently, high-rise skyscrapers emerged in new urban areas outside the old city, marking a shift in the urban landscape.

Industrial Development

The process of urbanisation in Hanoi has been closely linked to industrialisation. Industrial zones were first located in between residential areas. Between the 1960s and 1990s, new zones were established on the opposite side of the Red River. In more recent years, there has been a trend of plants and industries relocating from Hanoi to parks situated in the outskirts or surrounding provinces.

New Urban Areas

As industrial parks gradually move to the outskirts of Hanoi, these now share space with agricultural areas, forming new industrial complexes. The growing need for workers has also led to the expansion of residential areas near these industrial complexes, creating a mixed landscape of agricultural land, residential and industrial areas surrounding the city of Hanoi.



2.5 Paris

A city more than 2000 years old

The 2000-year history of Paris can be traced back from its spatial urban patterns. Paris' core centre on the bank of the Seine began as the small Roman settlement Lutetia. Throughout the Middle Ages, Paris grew to became the largest city in the region and later became a hub of publishing and intellectualism during the 18th century. In mid-1800's, Paris underwent significant urban renewal led by Georges-Eugène Haussmann, the Prefect of the Seine.

Haussmann's impact on the city is evident through the wide boulevards, spacious public areas, and distinctive architecture that define Paris today. The Haussmannian style of

The Haussmannian style of architecture, featuring wide boulevards and circular plazas, remains at the core of Paris' urban organisation.

architecture, featuring wide boulevards and circular plazas, remains at the core of Paris' urban organisation. Currently, the city is divided into 20 arrondissements, each with its own character and distinctive architecture. The Eiffel Tower, the Arc de Triomphe, the Champs-Elysees, and Notre-Dame are some of the most recognisable landmarks of Paris, and these contribute to its unique urban identity.

The arrondissements follow a spiral, starting in the Louvre Museum district in the heart of Paris. The first to eighth arrondissements are densely built-up and house the government buildings and historical monuments. Surrounding the central districts are res-

The Eiffel Tower, the Arc de Triomphe, the Champs-Elysees, and Notre-Dame are some of the most recognizable landmarks of Paris.

idential neighbourhoods, while further northwest along the Seine river, the La Defense area develops in a meandering pattern, housing the skyscrapers in the business district. The Paris of today remains an iconic global city, celebrated for its rich history, culture, and architecture. It is the most populous city of France, and the fourth most populated city in the EU. In recent years, Paris has focused on developing sustainable urbanism, seeking to improve public transportation, reduce pollution, and create more green spaces.

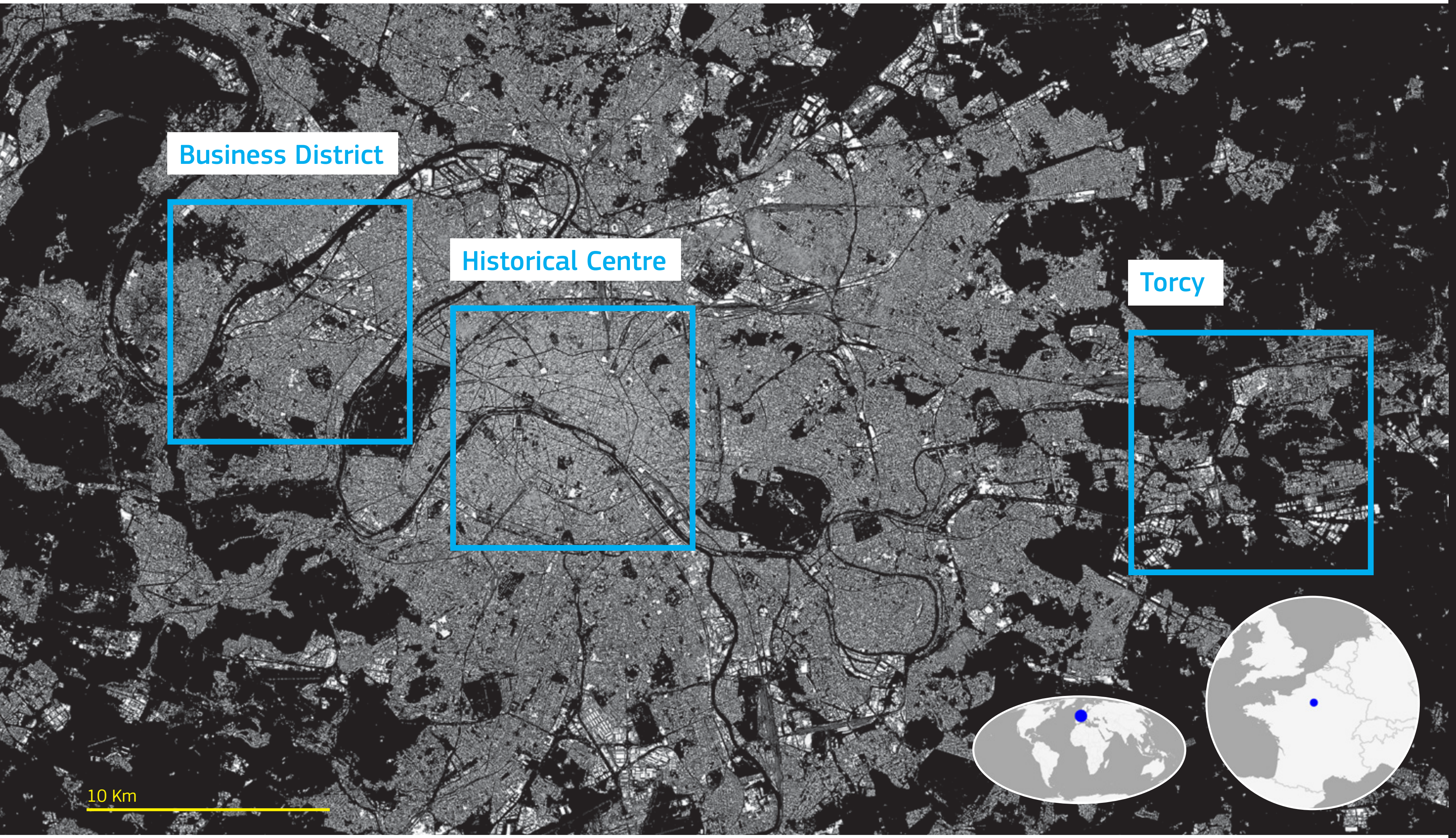
GHSL and spatial patterns

The layout of streets, the location of buildings and landmarks, and the overall design of the city can reveal much about the intentions and priorities of those who built it. The specific architectural styles used can often reflect the historical period or cultural influences that have shaped a city's development. The GHSL data provide an excellent tool to examine these patterns and designs, allowing a deeper understanding of the social, economic, and political factors that have shaped a city and its inhabitants.

Paris spatial patterns

Areas of interest

Paris has grown concentrically from the historical centre along the Seine riverbanks.



Historical Centre

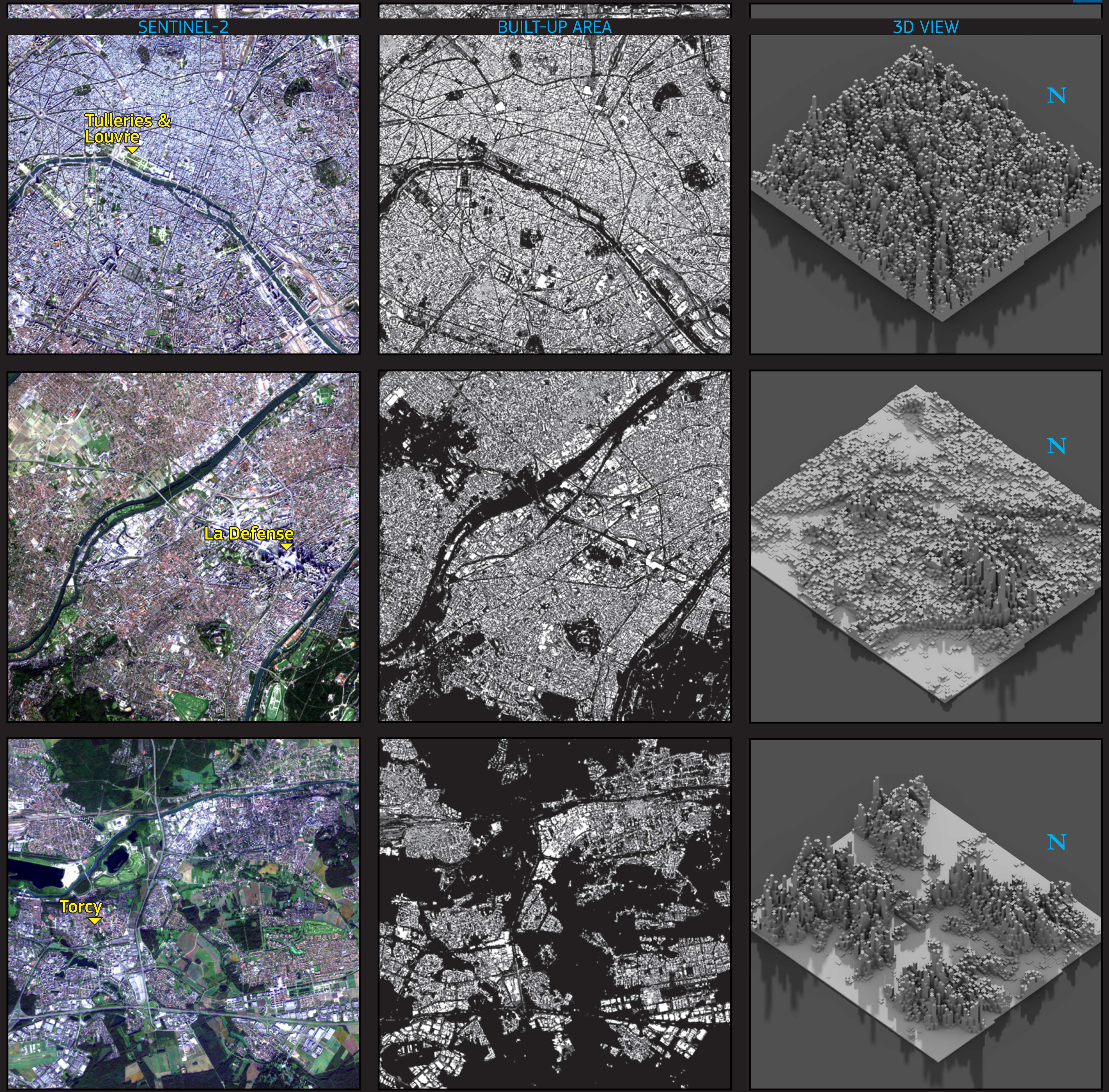
The historical city centre was developed from the 14th to 18th centuries in a radial and linear pattern still visible today. The development of the historical city took place around main focal points: the Seine River, the Louvre Palace, and Le Tuileries. Large squares, long avenues, and impressive monuments characterised it, contributing to its contemporary atmosphere.

Business District

Nanterre is a prefecture situated in the western suburbs of Paris. It encompasses part of France's major business district, La Défense, and some of the tallest buildings in the Paris region. These tall towers, built between 1973 and 1982, are intentionally arranged in an irregular, non-grid pattern. The area inside La Défense also intersects with the working-class district and the Nanterre university.

Torcy

Torcy is located in the eastern suburbs of Paris and was developed in the mid-1960s in response to the new towns movement, known as ville nouvelle, which aimed at managing urban expansion. A planned settlement involves strategically planning and designing settlements on unoccupied land to ensure organised and controlled development, as opposed to organic growth without pre-established plans.



2.6 Dubai

Rapid growth in a challenging climate

Dubai defies geography

Dubai defies geography and sets new standards for the contemporary cities. The city will have to address the challenges of a warmer climate in an already hot desert environment, as well as the energy transition challenges of a highly energy-demanding society. GHSL datasets can be used to estimate the city's expansion and population growth. By examining population density, one can gain insights into the demands for energy, water and materials, thereby addressing the future challenges posed by a warmer climate.

Dubai, in the United Arab Emirates, is one of the most modern and rapidly growing cities in the world. Most of Dubai was constructed during the past 50 years. Originally a modest town of fisherman and a regional trading centre, Dubai has now turned into a bustling international hub, home to more than three million people. Its extraordinary development is even more impressive considering its location in a hot desert climate, where for most of the year life is restricted to air-conditioned buildings.

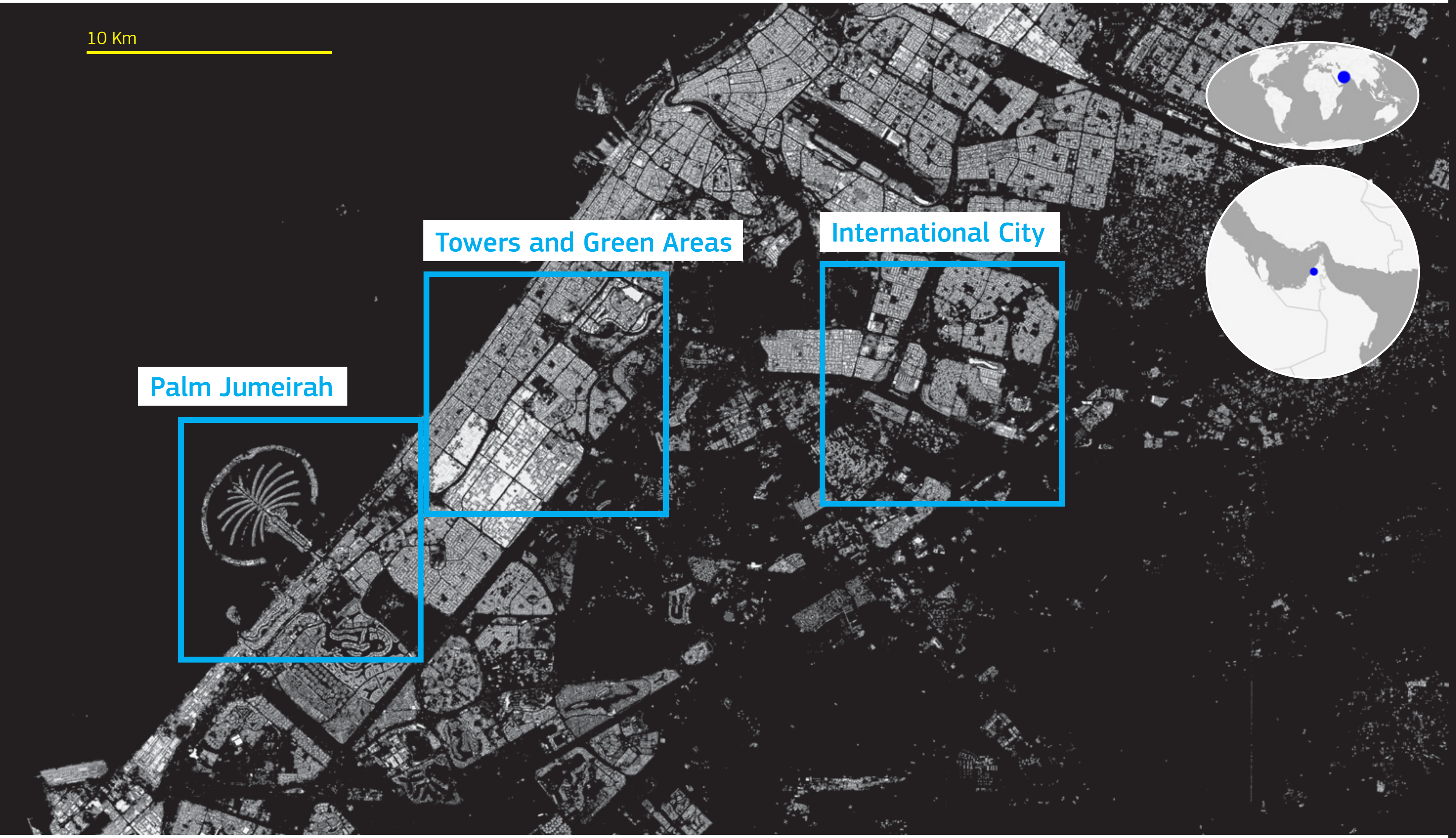
Dubai's spatial built-up patterns reflect its modernity, featuring a large road infrastructure that separates different sections of the city. The peculiarity of Dubai is that many real estate developments occur away from the downtown area, with many gated communities. There is a visible distinction between the very dense built-up old town along the Dubai Creek, the older coastal strip, primarily comprising commercial compounds, and the newer coastline parallel strip, housing a majority of towers and a hotspot of built-up densities in the east near the Marina.

The city now extends over hundreds of square kilometres and continues to expand, serving as a prime example of innovative city design, planning and construction. Furthermore, Dubai remains at the forefront of addressing the challenges posed by its relatively inhospitable climate, actively seeking solutions for adaptation.

Dubai spatial patterns

Areas of interest

Dubai's distinct features and unique spatial settlement patterns can be observed from outer space. The three outlined squares show the Palm Jumeirah , Towers and green areas, and the International City.



Palm Jumeirah

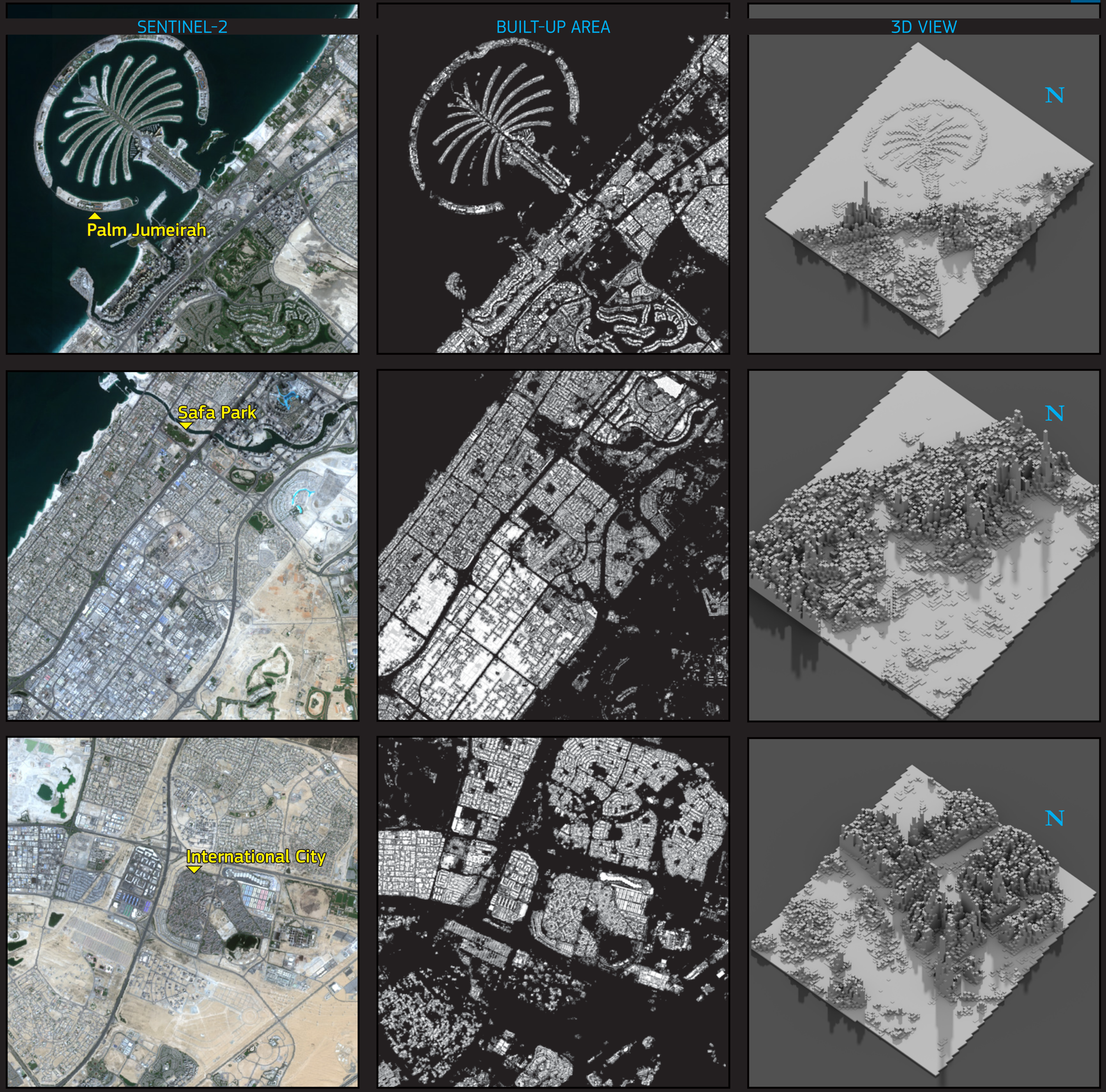
The Palm Jumeirah is a land reclamation project that used rock and sand to extend into the ocean. The area features waterfront apartments, villas, 60 luxury hotels marinas, health spas, shopping malls, restaurants and various facilities. With its shiny skyscrapers, state-of-the-art buildings, and beautiful beaches and sand dunes, Dubai has undoubtedly become an exceptional tourist destination.

Towers and Green Areas

The Dubai towers and green areas city section stand out as the hub of leisure facilities. This area features a dense cluster of towers extending from the shoreline and seamlessly blending with the lagoon's waterbodies, housing recreational and commercial centres. The city sets an example for modern cities by successfully establishing recreational and cultural centres.

International City

Dubai also hosts the International City residential area, which spans over 800 hectares. The spatial layout of this area draws inspiration from traditional carpets designs. Each section of the International City is inspired by architecture from various parts of the world, including France, Russia, China, the United Kingdom, and more. It is now home to a diverse population from around the world.



Chapter 3

Geography matters !

World's diffuse human inhabitation

Human societies tend to settle and prosper in areas with geographically favourable conditions. Societies prefer hospitable climates, fertile lowlands, coastal regions that allow for trade and communication, and locations rich in natural resources. However, settlements can also be found in the most inhospitable locations on Earth. Settlements are shaped partly by topography, with its coastline and mountains, the network of rivers and waterbodies, and partly by the population size to be accommodated, and their economy and societal values. Under current demographic trends, and in the light of challenges related to climate change and globalisation, some places will become more attractive with others losing their appeal. GHSL product provide valuable insights and comparable information about human settlements which are found in geographically diverse settings around the world, such as the examples that are presented in this Chapter.

Settlements in

Vulnerable settlements

Sentinel-2 image of New Orleans, in the Mississippi River Delta.
The city developed as a major transport hub, which must constantly address the challenges of being in a low elevation coastal area exposed to tropical cyclones.

10 Km

3.1 Settlements in Coastal regions

Larger Amsterdam Case Study

The Netherlands

An aerial view of low-elevation coastal areas in the Netherlands.
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Despite only covering around 2.4% of the Earth's land surface, low-elevation coastal areas contain 10% of the world population. Because they host high population densities within a limited space, these unique landscapes present a combination of challenges and opportunities. Low-elevation coastal areas, especially those in large river deltas, have been inhabited since ancient times. Today, many megacities and large cities are found in these large river deltas.

The challenges and opportunities of low-elevation coastal areas

Settlements in coastal areas must find a balance between sea processes (e.g. coastal erosion), land processes (e.g. sedimentation), and the available resources and livelihood opportunities. This balance is reflected in the complexity of settlement shapes and sizes. The settlements adapt to the different land forms and human-modified landscapes, through the use of canals, reclaimed agricultural areas or internal lakes.
The Netherlands is a prime example of a low-elevation coastal area. A significant portion of the country's land area is below sea level. However, the Netherlands has highly sophisticated water management and flood protection systems, which are now considered among the most advanced in the world. Additionally, the country has the highest population density among European countries and some of the most intensive agricultural production. This intensive land use has resulted in a wide variety of settlement patterns.
The larger Amsterdam Case Study shows population distribution and topography of the low-elevation delta area in the Netherlands. It demonstrates the significant part played by Amsterdam in the region's development and historical importance. Amsterdam's strategic location at the intersection of waterways, its access to the North Sea, and its position as a major centre for trade and commerce, have all contributed to its prominence. The newly reclaimed areas exhibit unique built-up spatial patterns that reflect the diverse landscapes found within the broader metropolitan region, encompassing urban, suburban, and rural areas. The total population of the larger Amsterdam is 4.7 million, with Amsterdam accounting for over 3 million of that number.

Balance between sea processes - (i.e. coastal erosion), land processes (i.e. sedimentation) and available resource and opportunities. This balance is reflected in the complexity of settlement shapes and sizes.

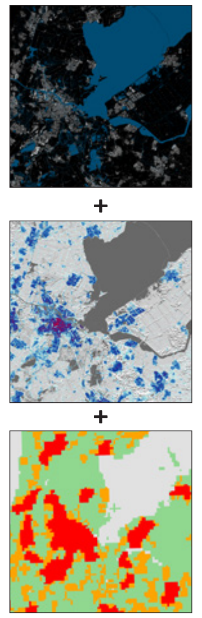
Well protected low-elevation coastal areas

Water management institutions of the Netherlands have developed considerable expertise in water defence technology and sustainable territory management practices that can be exported to other countries. Settlement data for low-elevation coastal areas, such as the data provided by GHSL, are used for implementing water defence measures that address risks associated with storm surges and flooding.

The larger Amsterdam Case Study
Sentinel-2 image

The larger Amsterdam area
Sentinel-2 image covering Amsterdam and the reclaimed agricultural areas of Flevoland to the east. Between the sea and internal lakes, the area is criss-crossed by canals and water bodies.

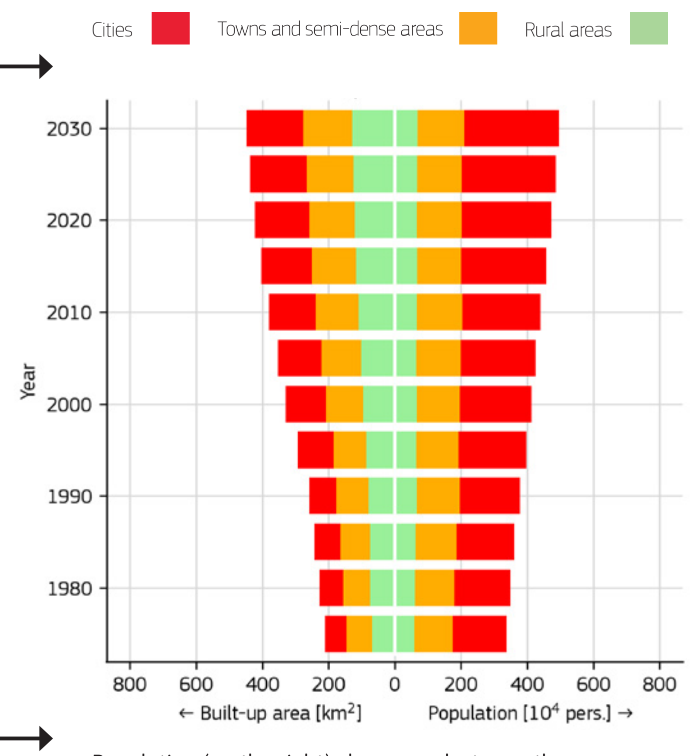
Methodology



Settlement Dynamics extracted from 100 km × 100 km Case Study.

SETTLEMENT DYNAMICS 1975 - 2030

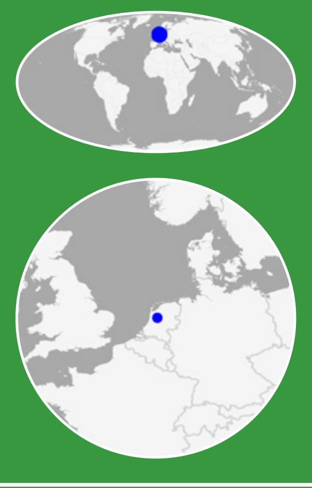
Larger Amsterdam Case Study

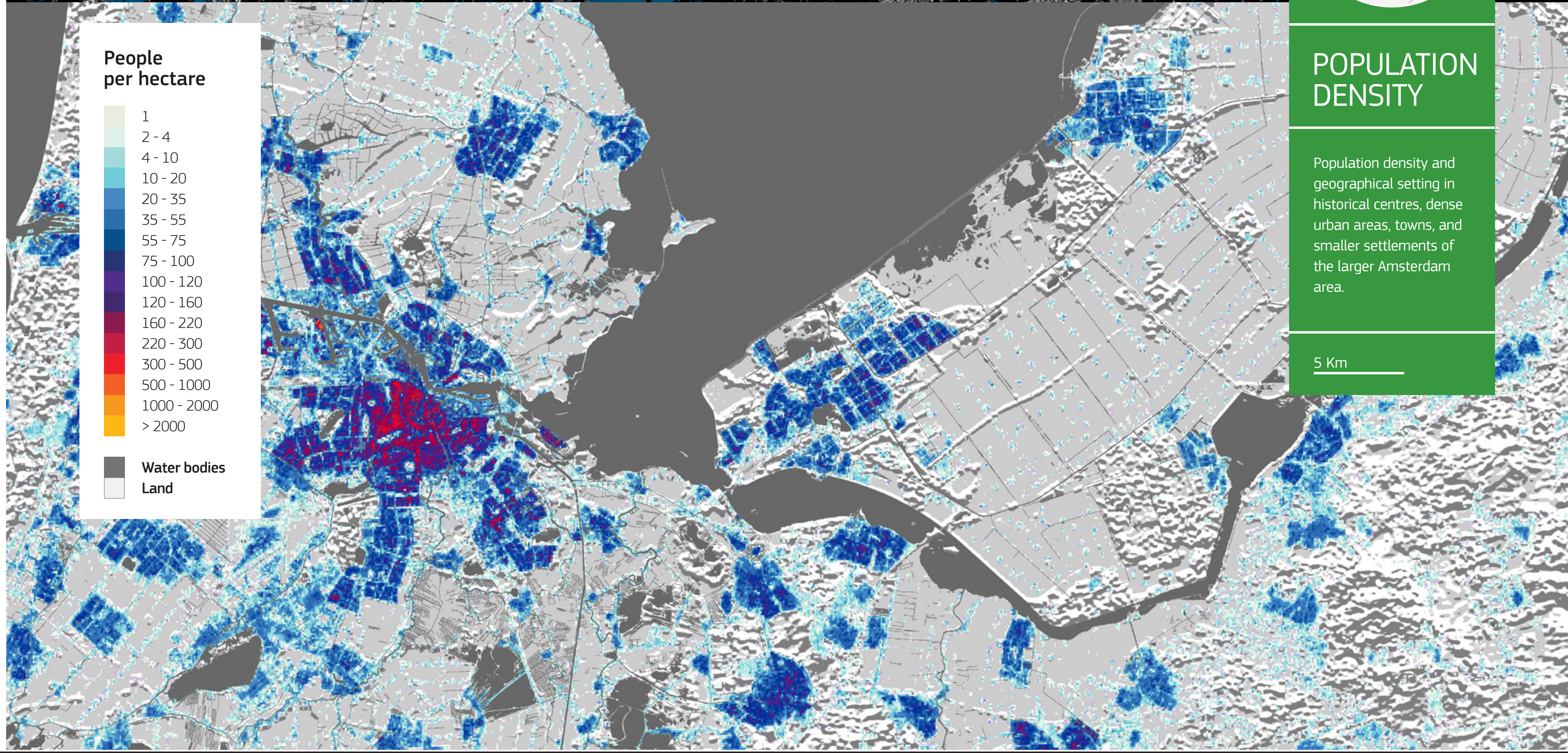


Population (on the right) shows modest growth, distributed fairly evenly between **cities, towns and semi-dense areas**, and (notably, for such a densely populated region) **rural areas**. Built-up area (on the left) has grown steadily for all three settlement types.

BUILT-UP

This image shows the diverse built-up area patterns, ranging from small hamlets in newly reclaimed areas, agriculture fields, to denser urban patterns of Amsterdam shaped around a network of canals.





POPULATION DENSITY

Population density and geographical setting in historical centres, dense urban areas, towns, and smaller settlements of the larger Amsterdam area.

Vulnerable communities in deltas

Barisal Division delta region Case Study

Vulnerable settlements

The settlements on the banks of the canal and river network are very vulnerable to impacts of the storm surges and cyclone winds that affect the coast of Bangladesh more and more frequently.

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Densely inhabited Ganges and Brahmaputra delta region, Bangladesh

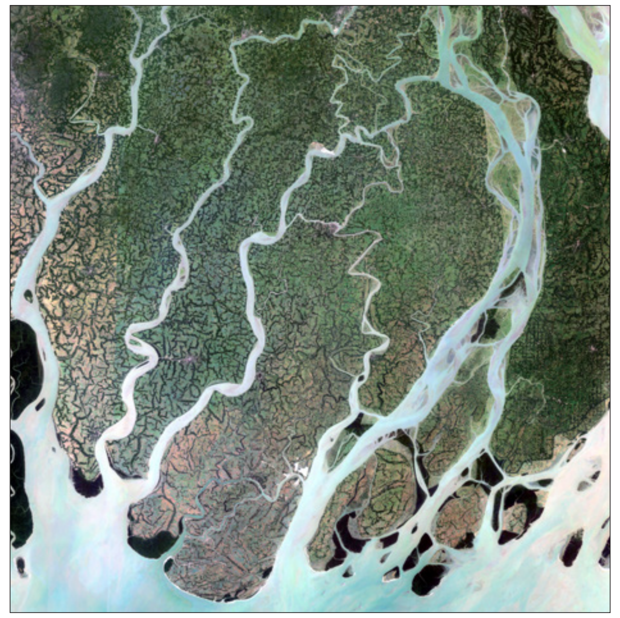
The vast delta region in Bangladesh is characterised by low-lying terrain and a dense network of rivers, making it prone to regular flooding. The Western delta region is home to the Sundarbans Reserve Forest, the largest mangrove forest in the world. In the Eastern delta region, called Barisal Division, the once marshy and forested land has been cleared to make way for agriculture. As a result, this area is densely populated by farming communities. The high population density in a section of the Barisal Division shown in this Case Study can be attributed to the fertile soil and abundant water resources. These riverine communities are in scattered settlements along the canals, primarily in slightly elevated areas. Livelihoods in the Bangladesh delta region are heavily impacted by environmental challenges, including rising sea levels, increased salinity, and vulnerability to climate change. Consequently, there is a growing focus on developing climate-resilient livelihoods in the region. This involves promoting drought-resistant crops, raising livestock that can tolerate saline conditions, and implementing sustainable farming and fisheries practices. Efforts are also being made to address deforestation by protecting and restoring mangrove forests, which provide protection against storm surges, safeguarding lives and property.

Despite these efforts, Bangladesh remains highly susceptible to the impacts of climate change, such as rising sea levels and cyclones. The country faces the challenges of fast population growth, inadequate coastal defences, insufficient infrastructure, and unsustainable land management. It is imperative to prioritise adaptation and resilience-building measures for the long-term protection of Bangladesh's coastal areas and its vulnerable population and environment.

Exposed communities

The vast delta region of Bangladesh is highly vulnerable to natural hazards. Various local, national and international initiatives have addressed the lack of infrastructure and coastal defences. GHSL data have been used in rapid response operations during disasters, and are continuously updated to assess risks and to evaluate the effectiveness of hazard mitigation measures. Population and built-up area projections serve as important tools for estimating future risks and informing decision-making processes.

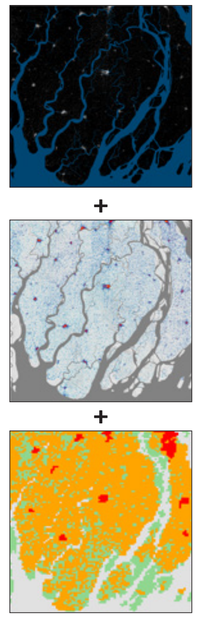
Barisal Division delta region Case Study
Sentinel-2 image



▲ *Barisal Division, Bangladesh*

Sentinel-2 overview of a section of the Barisal Division, Bangladesh, covered by few cities and many rural settlements. Buildings are located under the thin strips of forest, as a last reminder of a once forested area.

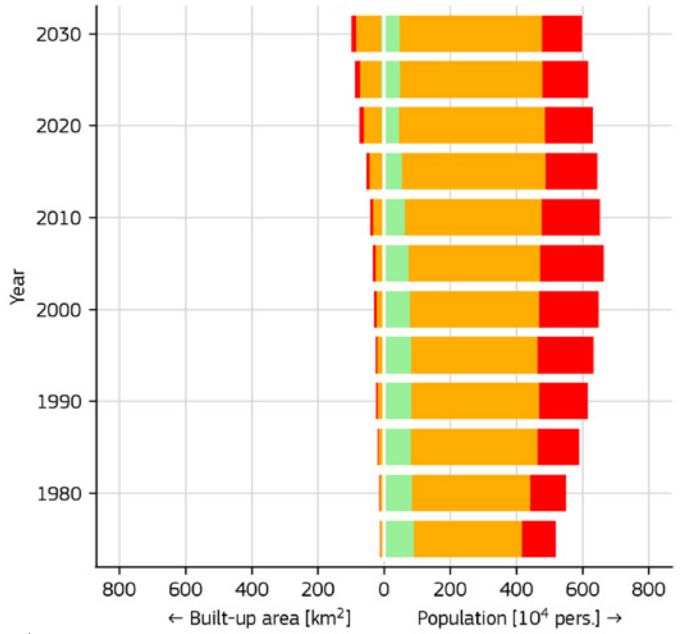
Methodology



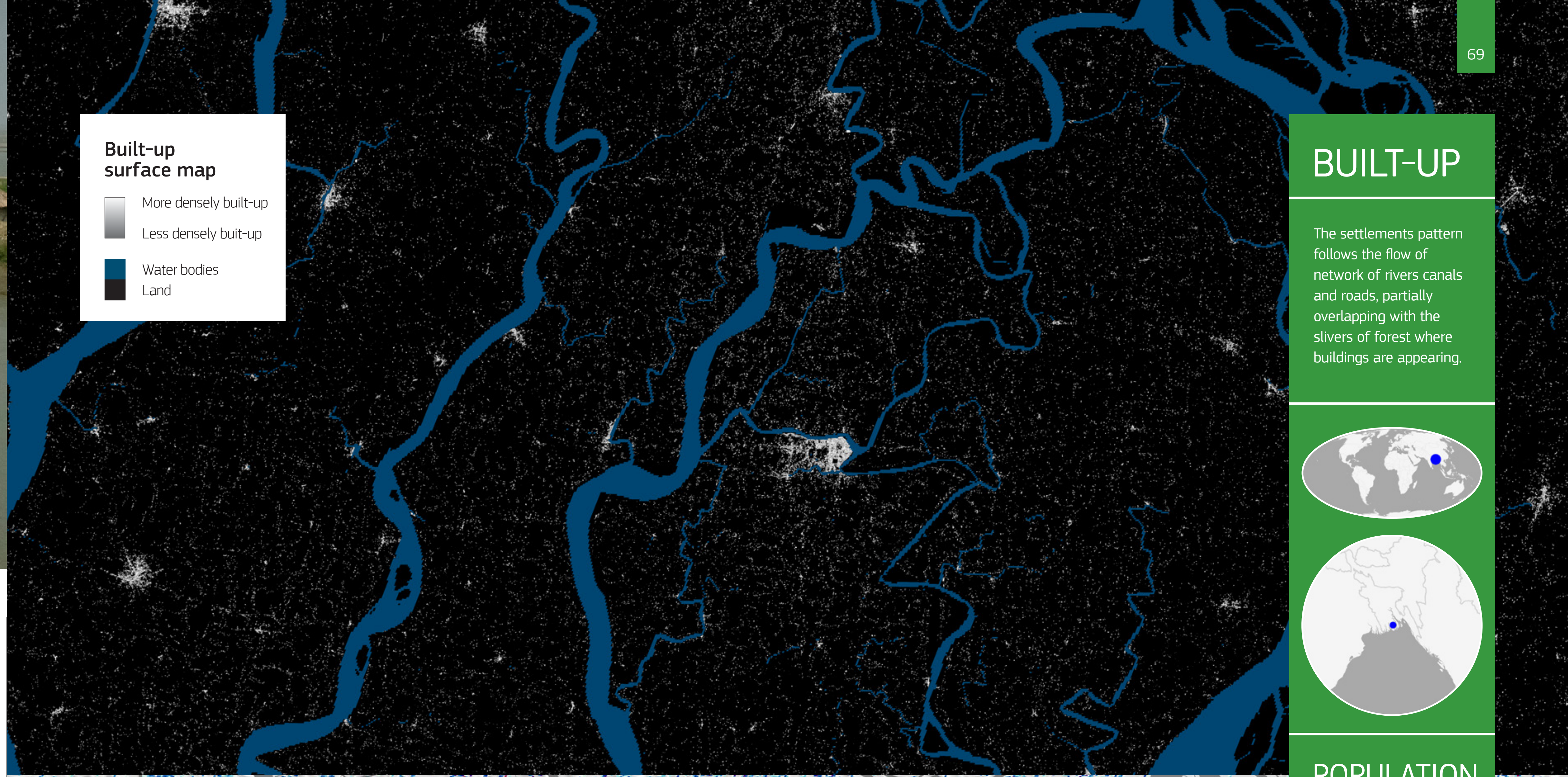
Settlement Dynamics extracted from 100 km × 100 km Case Study.

SETTLEMENT DYNAMICS 1975 - 2030

Barisal Division delta region Case Study



Population (on the right) is around 6 million people, mostly concentrated in **towns and semi-dense areas**. Built-up area (on the left) is very limited for all three settlement types, indicating that the population is concentrated in sparsely developed areas.



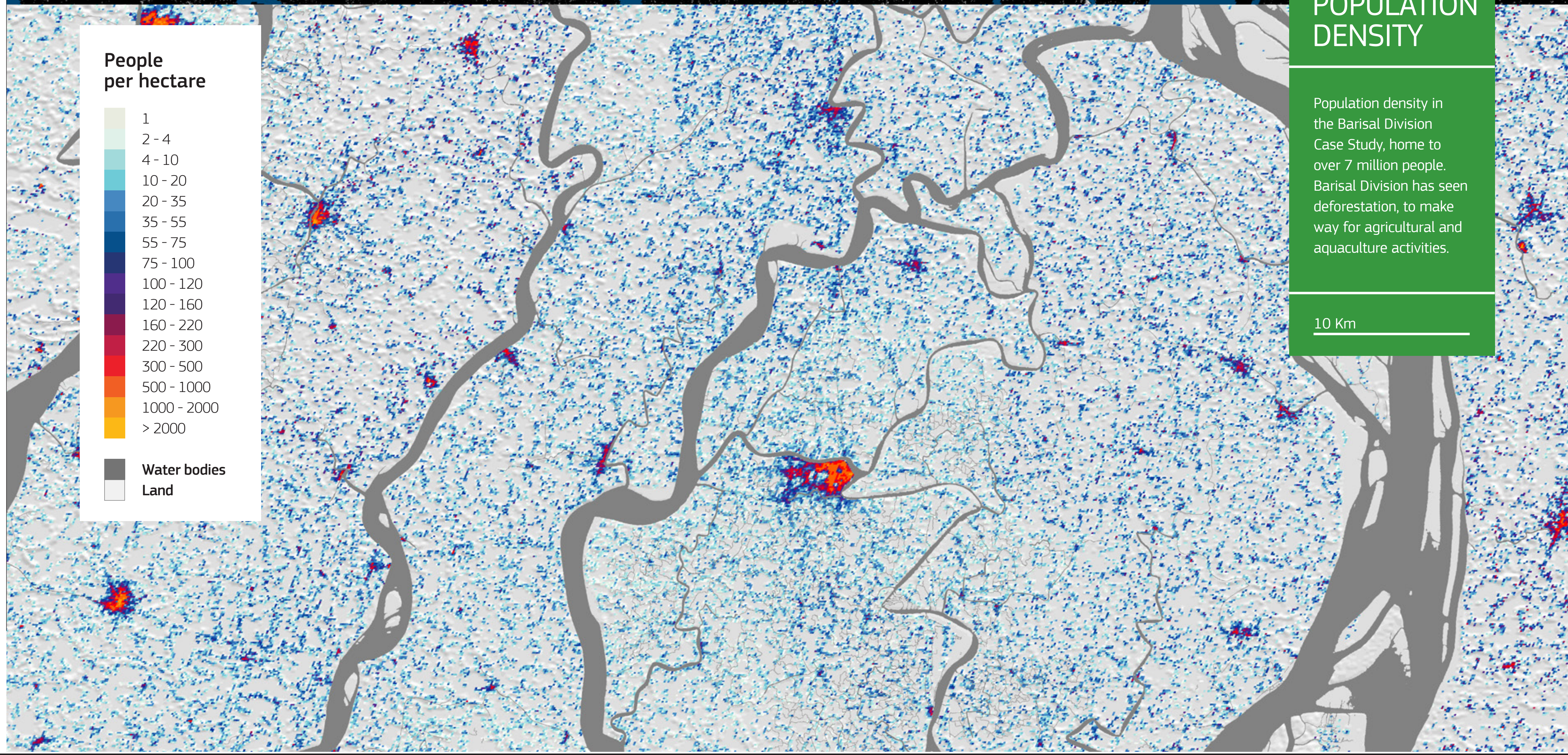
BUILT-UP

The settlements pattern follows the flow of network of rivers canals and roads, partially overlapping with the slivers of forest where buildings are appearing.

POPULATION DENSITY

Population density in the Barisal Division Case Study, home to over 7 million people. Barisal Division has seen deforestation, to make way for agricultural and aquaculture activities.

10 Km



3.2 Settlements in Agricultural regions

Agricultural landscapes have the most varied settlement characteristics

Agricultural landscapes, characterised by extensive cultivated land and significant agricultural productivity, are typically linked to rural settings with low population density. However, agricultural landscapes often encompass not only **rural areas** but also **cities**, and **towns and semi-dense areas**, sometimes hosting remarkably high population densities. The diversity of agricultural landscapes stems from a multitude of factors, such as geography, geology, climate, cultural practices, societal development, and population dynamics, all of which shape the unique characteristics of these landscapes and their food production systems.

Agricultural landscapes often encompass not only rural areas but also cities, towns and semi-dense areas.

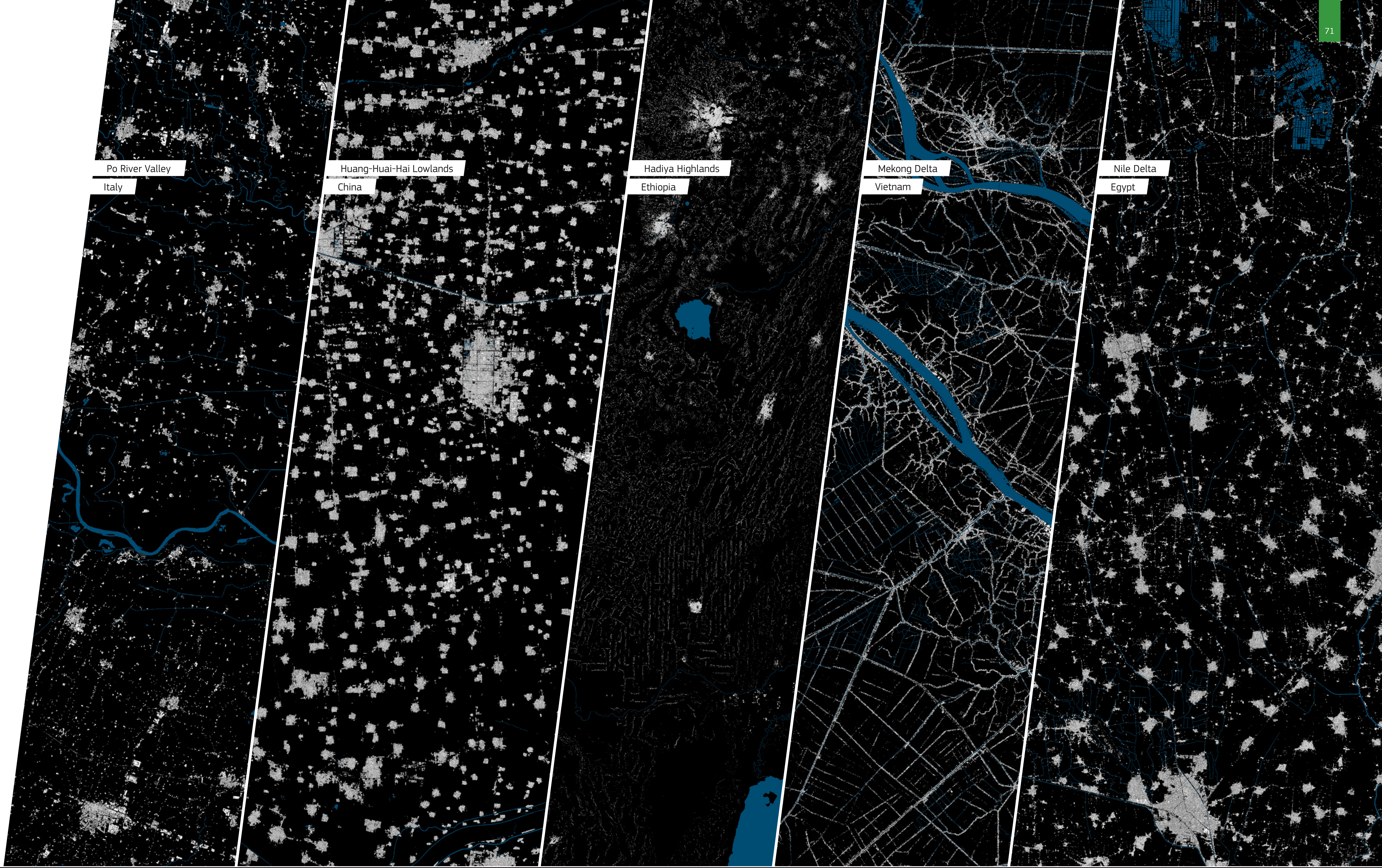
Regions with a historical legacy of food production exhibit the highest population densities, whereas newly reclaimed agricultural landscapes tend to have lower densities. In high-income countries, there is a correlation between higher per capita built-up areas and a more developed food production system, suggesting that the level of urbanisation and infrastructure development is closely tied to the efficiency of the local food production and distribution systems.

It is crucial to understand both historical and current population densities, as well as the quality of existing building stock.

To anticipate future challenges and assess their societal impact, it is crucial to understand both historical and current population densities, as well as the quality of existing building stock. These societal factors are to be analysed in combination with the agricultural land, the food production system as well as the natural resources (including water and natural habitats), and finally the natural and man-made hazards.

Agricultural landscapes challenges

Agricultural landscapes vary significantly in population and settlement density, facing challenges such as encroachment of urban land and high-intensity agricultural land use. Assessing factors like proximity to roads, and the potential risks posed by hazards requires the use of spatial information, such as that generated by GHSL. Over time, GHSL data can also prove valuable in addressing issues like land abandonment and rural population decline, or the risks associated with a changing climate, impacting the livelihoods of communities in agricultural landscapes.



3.2.1

Po River basin

Rural Settlements

The picture shows a rural background characterised by isolated farms nestled among vineyards and crop-fields.

The Po River basin's agricultural landscape

The Po River basin, the vast valley around the Po River in Northern Italy, is characterised by complex agricultural landscapes, where agricultural production and industry coexist. The Case Study shows the Po River basin between Lake Garda to the north, and the foothills of the Apennine Mountains to the south.

The settlement patterns of this region can be traced back over 2,000 years, when the Romans built cities along via Emilia, one of the main arteries where cities were strategically located to be one day's walk apart. Over the centuries, the original forested Po River basin was cleared to make way for agricultural fields, interspersed with settlements of varying sizes.

The Po River Case Study is currently populated by over three million people, with a higher proportion residing in **rural areas**, and **towns and semi-dense areas**.

In more recent history, this agricultural production region has also developed a strong industrial tradition that is reflected in the new spatial patterns of built-up areas. Over the past 50 years, the growth of towns and cities has been slower compared with the expansion of rural built-up areas, which have doubled in size. This spatial growth of built-up areas includes the construction of factories, infrastructure for intensive farming as well as manufacturing and commercial activities. As a result, industry and agricultural production compete for space, water, energy and other resources.

The Po River Case Study is currently populated by over three million people, with a higher proportion residing in **rural areas**, **towns and semi-dense areas**. **Cities**, on the other hand, account for the smallest share of the land. The region faces the challenge to turn high-intensity farming into lower impact farming, with lower-impact farming methods, which can help restore some natural lands and ecosystems, ultimately improving the quality of life for residents. Additionally, policies to restrict built-up areas aim, to limit the fragmentation of natural land that is caused by expansion of infrastructure and built-up areas.

Compact and scattered built-up areas

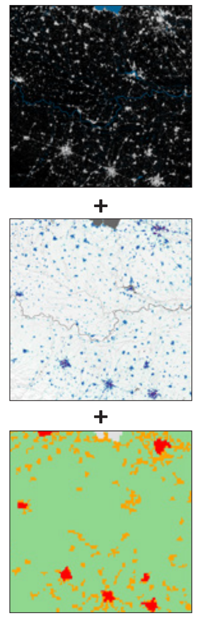
Population density is typically high in older agricultural landscapes, such as the Po River basin, with settlements of various sizes scattered amongst agricultural fields. Policy-makers typically implement land use policies aimed at maintaining compact towns and cities. GHSL data can provide information on the size, shapes, fragmentation and compactness of settlements, in order to assess the impact of these policies.

Po River Case Study
Sentinel-2 image

▲ *Po River Case Study*

Sentinel-2 image of the Po River Case Study, southern Lake Garda, moraines and foothills of the Apennines, and including the cities of Modena, Reggio Emilia, Parma (south), Verona (north-east) and Mantova (centre).

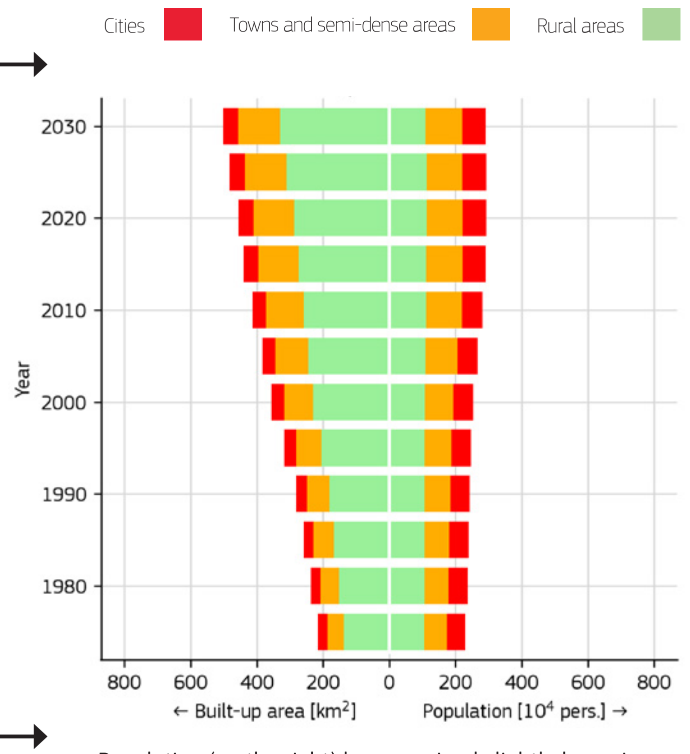
Methodology



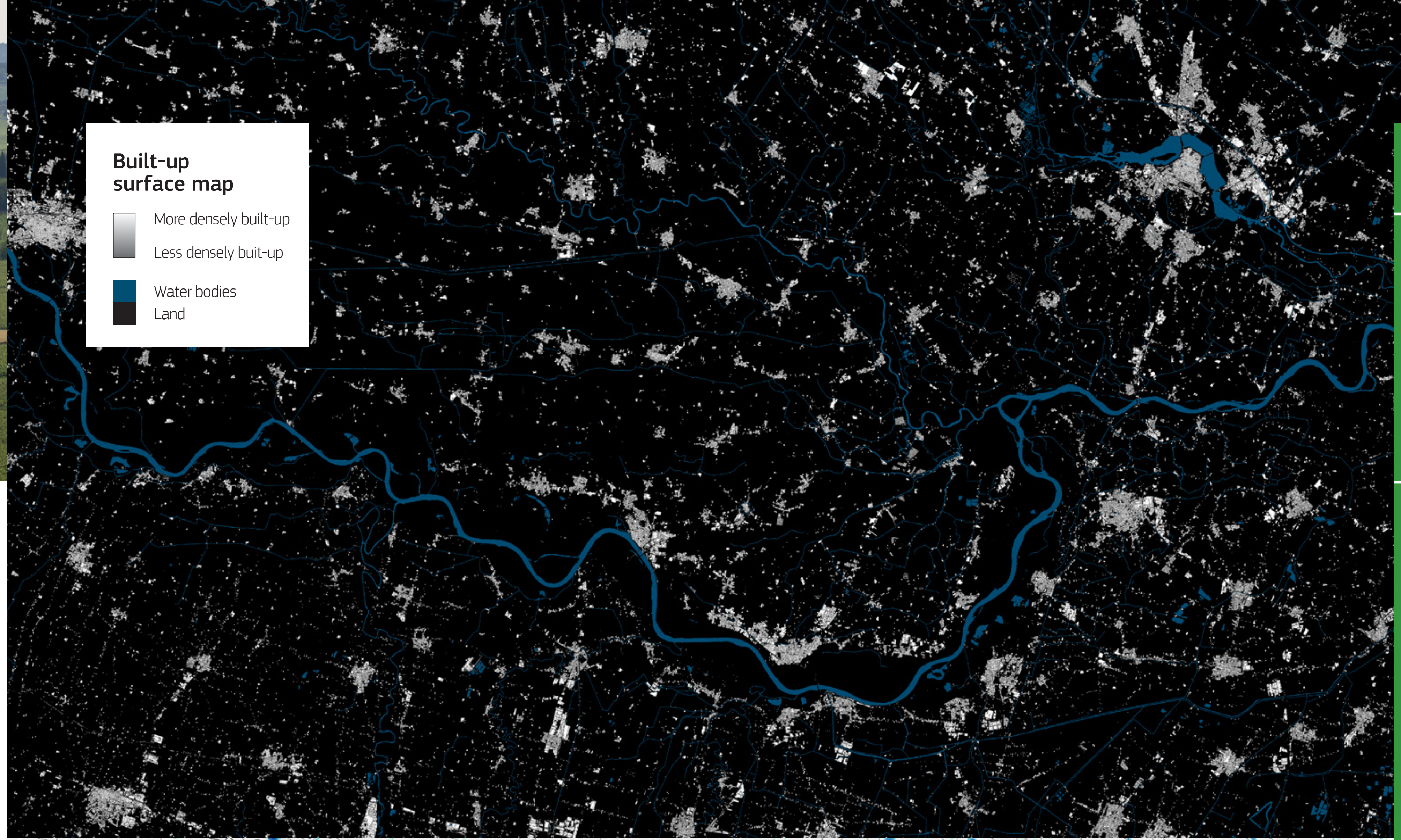
Settlement Dynamics extracted from 100 km × 100 km Case Study.

SETTLEMENT DYNAMICS 1975 - 2030

Po River Case Study

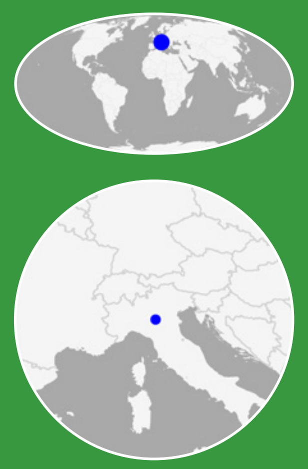


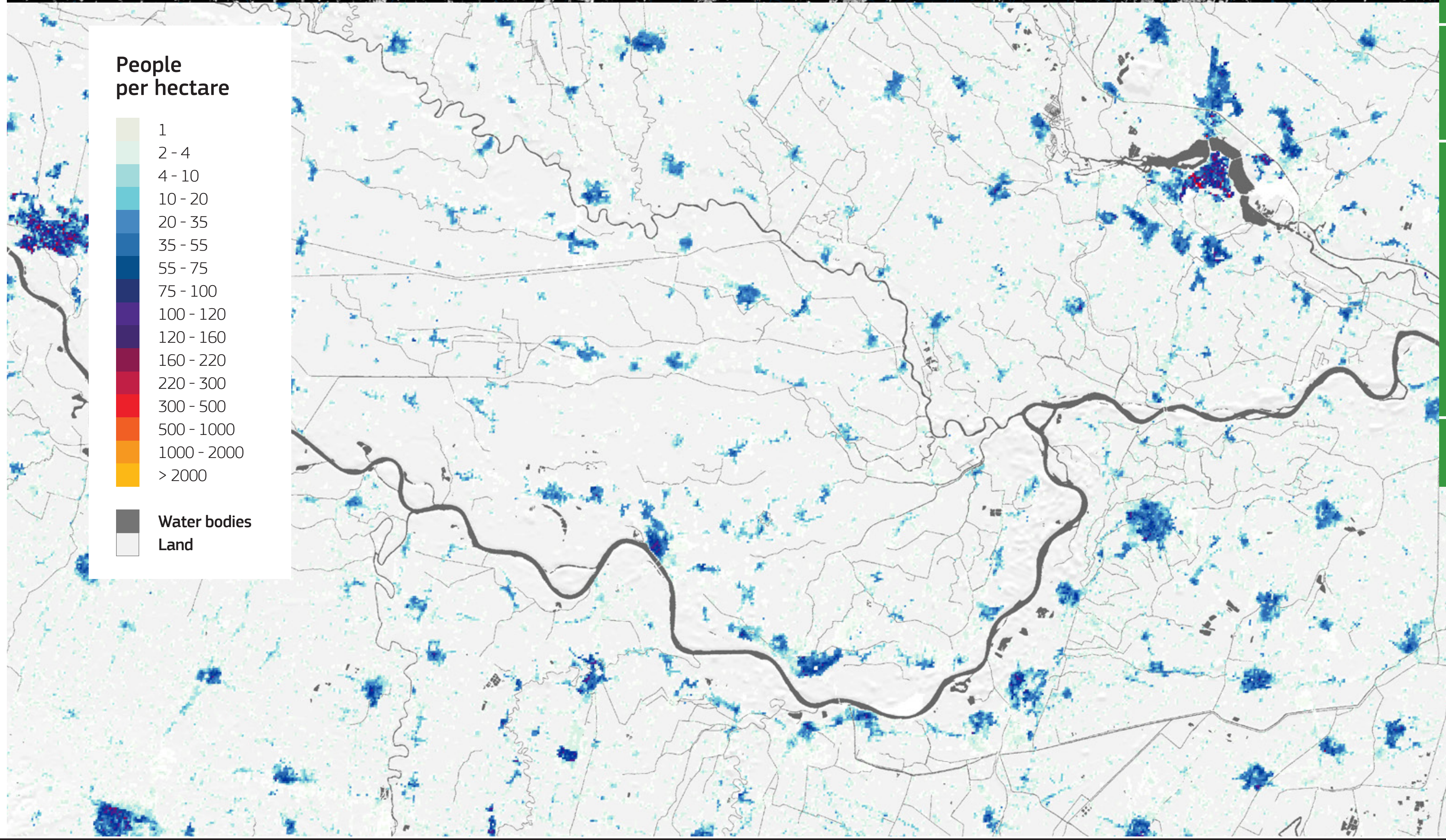
Population (on the right) has remained slightly lower in **cities** compared with **rural areas** or **towns and semi-dense areas**. Built-up area (on the left) has increased constantly in rural areas, and is larger compared with **cities** or **towns and semi-dense areas**.



BUILT-UP

Built-up areas cover a large part of the Po River basin. Rural built-up areas have grown significantly, giving a fine-grain scatter of settlements beside more traditional, compact towns and villages.





POPULATION DENSITY

Population density in the Po River basin reflects settlement patterns. Cities and towns show high population density, while that of smaller settlements is lower, but finely scattered across the area.

10 Km

3.2.2

Eastern China lowlands

Towns in the lowlands

Well-contained rural settlements in the midst of intensively farmed landscapes.

© Wheat field - stock.adobe.com

Agricultural landscapes in eastern China's Huang-Huai-Hai River basin

The agricultural landscapes of the Huang-Huai-Hai River basin in eastern China are renowned for their exceptional fertility and high population density. Settlement patterns in this region have evolved over centuries, with a multitude of villages originally spaced a few kilometres apart, in order to facilitate farming in close proximity. Over time, these settlements expanded and villages turned into towns and cities. Today, the region exhibits a dense pattern of settlements, characterised by distinct boundaries that indicate the implementation of land use planning measures aimed at preserving agricultural land from settlements encroachment.

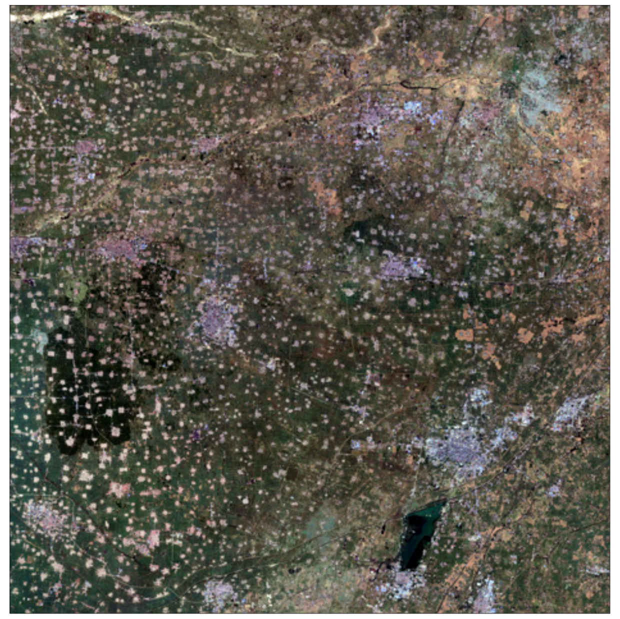
Over 7 million people, with the majority residing in **towns and semi-dense areas**.

The pressure of settlements encroachment on agricultural land remains high due to the increasing demand for housing from a growing and more affluent population, as well as the needs of a dynamic economy. The area shown in the Eastern China lowlands Case Study is populated by over 7 million people, with the majority residing in **towns and semi-dense areas**. While agricultural productivity has increased over time, resulting in higher production per unit area, there has been a simultaneous decline in available agricultural land. Analysis of population trends over time based on the GHSL data reveals that spatial expansion of built-up areas has outpaced population growth, a characteristic trend of a dynamic economy.

Larger settlements

Population density is typically high in old, farmed agricultural landscapes. These areas face the challenge of preserving agricultural land amid the pressure of a fast-growing economy that demands new built-up area infrastructure. GHSL data help in showing populations located in smaller settlements, and assessing the relative proportion of settlements in different size classes. GHSL data also aid in understanding population densities, pressure of settlements on agricultural land-scapes and estimating future population and built-up area growth.

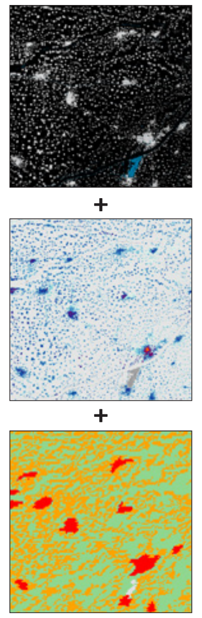
Eastern China lowlands Case Study
Sentinel-2 image



▲ *Eastern China lowlands Case Study*

Sentinel-2 image of agricultural landscapes in the Huang-Huai-Hai River basin east of Shi Jia Zhuang, in Hebei province. This fertile agricultural region is interspersed with a multitude of towns and cities.

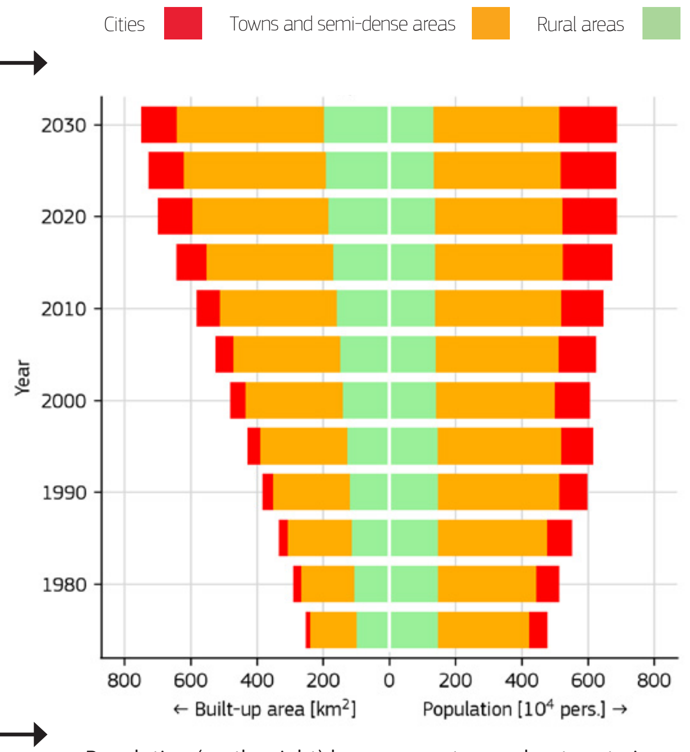
Methodology



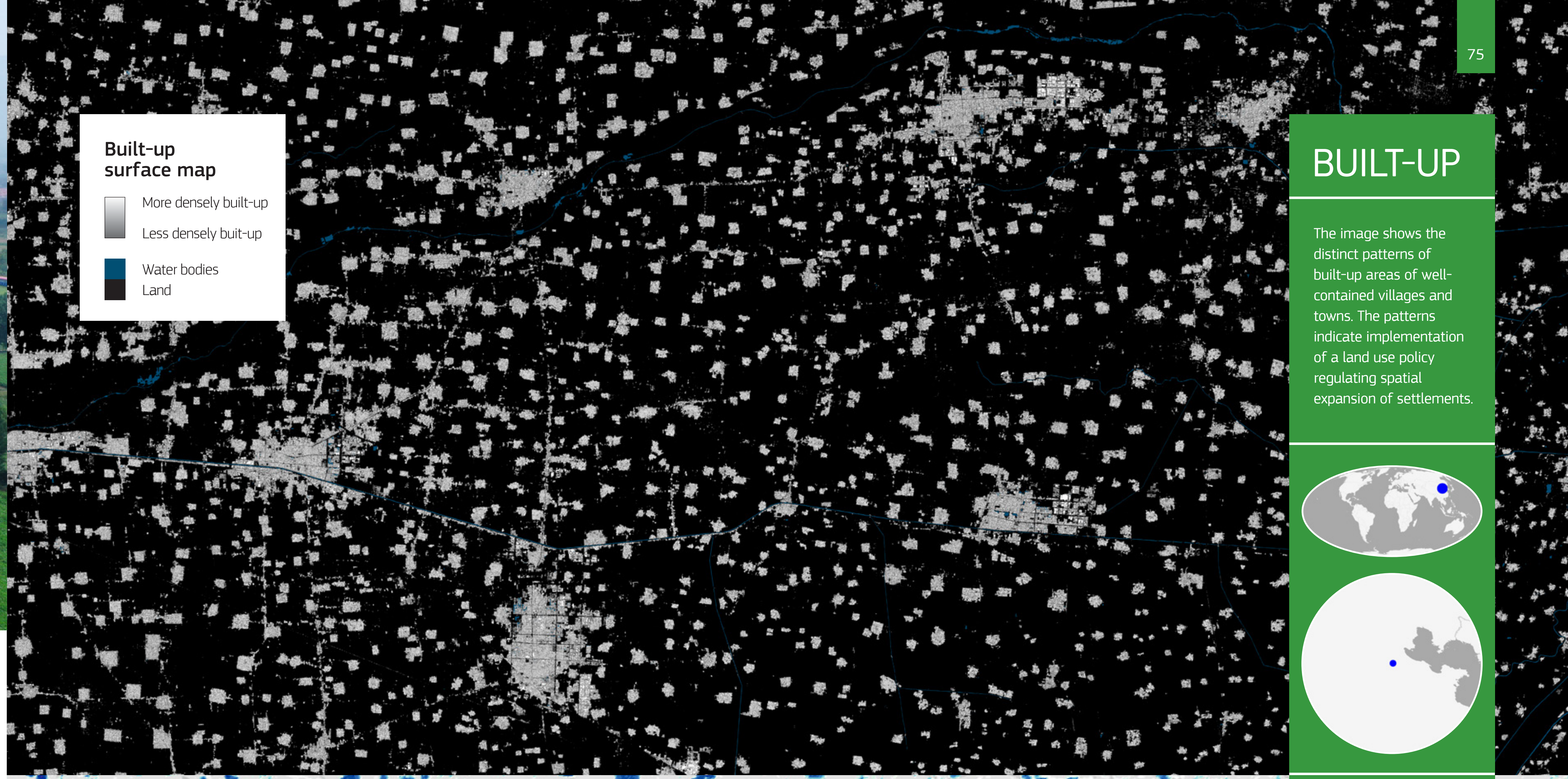
Settlement Dynamics extracted from 100 km × 100 km Case Study.

SETTLEMENT DYNAMICS 1975 - 2030

Eastern China lowlands Case Study

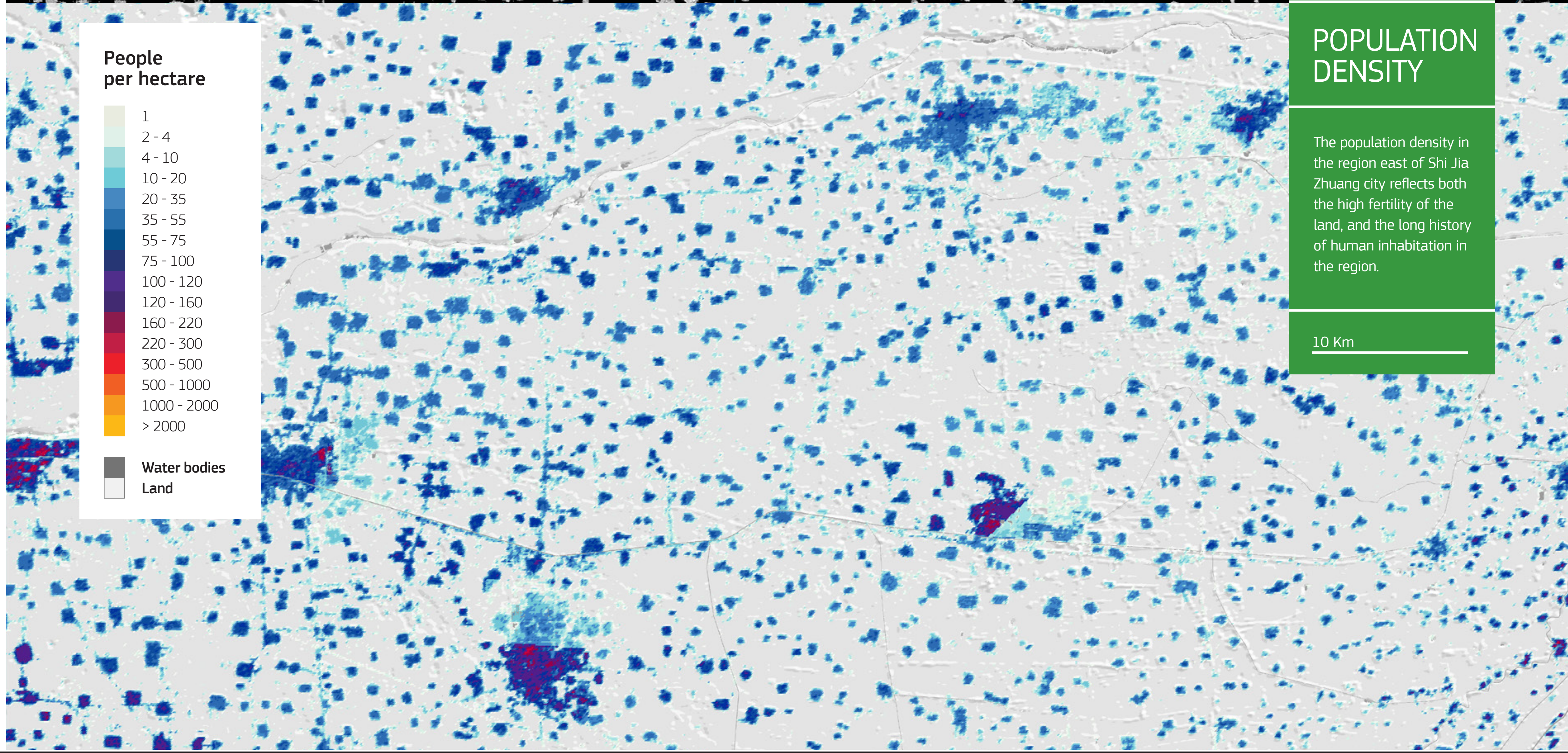


Population (on the right) has grown at a moderate rate in both **cities** and **towns and semi-dense areas**. Built-up area (on the left) has increased significantly in **towns and semi-dense areas**.



BUILT-UP

The image shows the distinct patterns of well-contained villages and towns. The patterns indicate implementation of a land use policy regulating spatial expansion of settlements.



POPULATION DENSITY

The population density in the region east of Shi Jia Zhuang city reflects both the high fertility of the land, and the long history of human inhabitation in the region.

10 Km

3.2.3
Hosaena, southern Ethiopia

Hosaena
Population has increased significantly to nearly 3 million people. This is attributed to high fertility rates, and is expected to continue. However, built-up area growth rate is comparatively slower.

Agricultural landscapes in the Ethiopian Highlands

The Great Rift Valley of Ethiopia is known for its relatively mild climate, which is a result of its elevation. The Ethiopian Highlands Case Study shows an area between Butajera in the northeast and Hosaena in the southwest. Although Hosaena is not a major city, it has seen some urban development over the years. The city is located in a mountainous region with lush green hills and valleys that are characterised by agricultural fields and forests.

Agriculture plays a significant role in the local economy. The fertile land surrounding Hosaena is used for growing crops such as coffee, maize, teff (an Ethiopian staple grain), and various vegetables. Livestock farming is also common in the area. Many farmers in the Hosaena area practise subsistence farming, where they grow crops primarily to feed their families. This type of farming involves a mix of different crops and small-scale livestock keeping. Traditional farming methods, such as oxen for ploughing, and relying on manual labour, are still prevalent in some parts of the Hosaena area. In certain areas, farmers may use irrigation techniques to grow crops, especially during dry seasons, to ensure a more reliable food supply.

The majority of the 4 million people who live in the area today, are scattered across settlements, towns and villages along topographic features and transport routes. The population has significantly increased over time due to high fertility rates, and this growth is expected to continue. While the area does produce some cash crops like coffee and khat, a large portion of the agricultural production is for local subsistence farming. It is important to address the sustainability of livelihoods in a subsistence agricultural area that may be vulnerable to crop failure caused by drought events, by considering both climatological and societal factors.

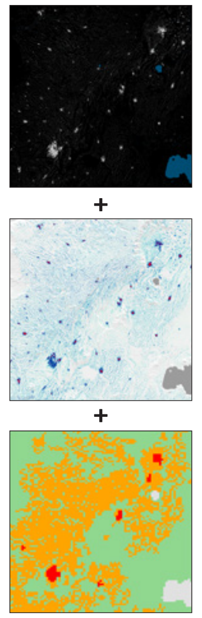
Settlements in subsistence agriculture landscapes

Subsistence agriculture remains the primary means of livelihood in many agricultural regions, including the Great Rift Valley. Food security assessments rely on both climatological and socio-economic data, which provide insights into food production, as well as societal information such as population and accessibility of settlements which define the demand for food. In fact, GHSL population data are used to identify vulnerable population, and the population projections are used for anticipating future food demands.

Ethiopian Highlands Case Study
Sentinel-2 image

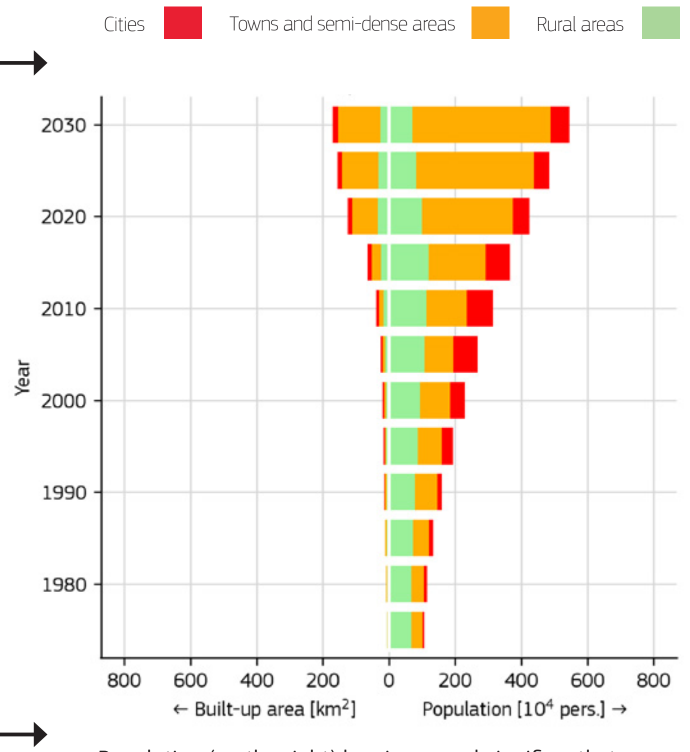
▲ *Ethiopian Highlands Case Study*
Sentinel-2 satellite image for the Ethiopian Highlands Case Study in the Great Rift Valley, from Hosaena to Butajera. The region is characterised by higher-elevation land and is densely populated and extensively farmed.

Methodology

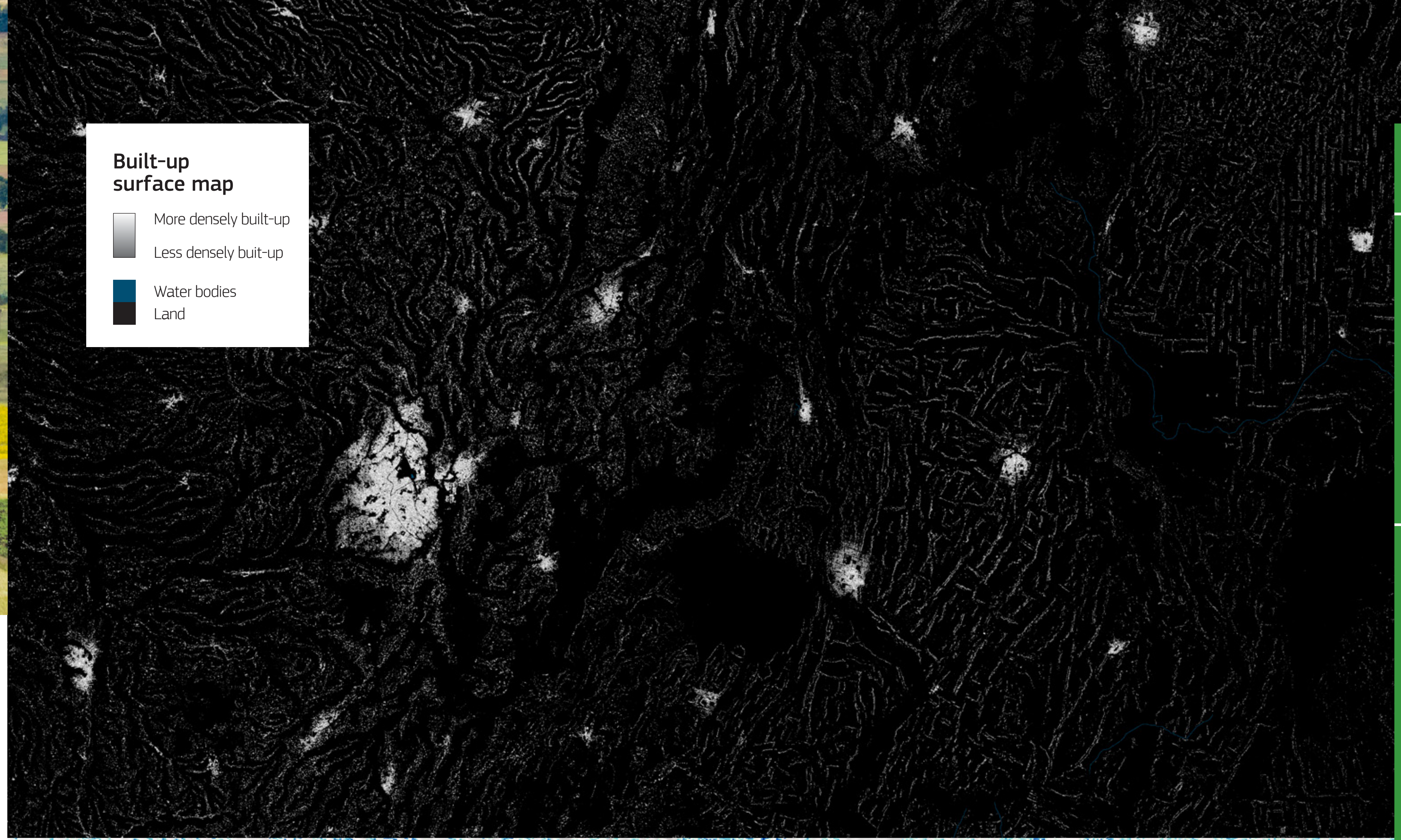


Settlement Dynamics extracted from 100 km × 100 km Case Study.

SETTLEMENT DYNAMICS 1975 - 2030
Ethiopian Highlands Case Study

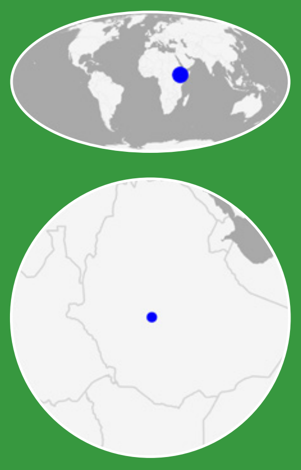


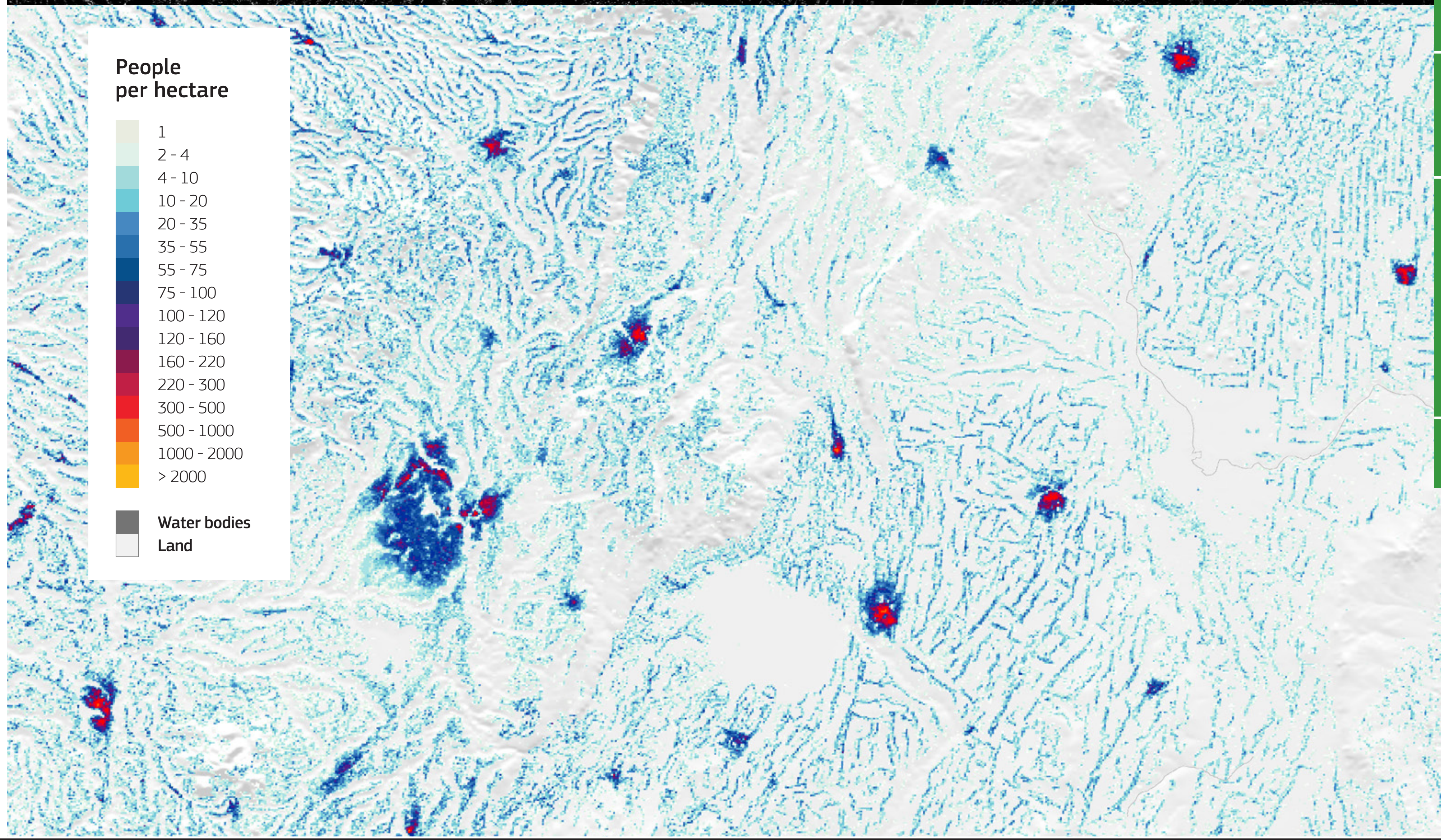
Population (on the right) has increased significantly to nearly 4 million people in 2020. This is attributed to high fertility rates, and is expected to continue. Built-up area (on the left), in contrast, has grown at a relatively much slower rate.



BUILT-UP

Settlements in Hosaena follow the topography and valleys, and are often located alongside roads. This creates a distinct linear pattern that is commonly observed in other regions of Africa with similar topography and economic conditions.





POPULATION DENSITY

Population density is relatively high in this area, with scattered settlements located along the valleys and the two larger population centres.

10 Km

3.2.4

Asian deltas: the Mekong, Vietnam

Can Tho, Mekong region

Can Tho is one of the main cities in the lower part of the Mekong delta region.

High fertility and livelihood opportunities, combined with high environmental risks

The Mekong delta region in southern Vietnam is a crucial agricultural region in Southeast Asia, responsible for over half of Vietnam's production capacity and the majority of its exports. However, it faces numerous environmental pressures, including climate change-induced sea level rise, land subsistence, reduced sedimentation, riverbed mining, and destruction of natural habitats.

The Mekong delta Case Study is centred around the city of Can Tho in the Mekong delta region, and is populated by over 7 million people. It is a highly intensive farming region, with settlements situated along a dense network of managed waterways. Recurrent and severe flooding can occur due to seasonal monsoon rains, high tides, and storm surges, affecting both larger and smaller settlements. Saltwater intrusion is also a significant issue in this delta region, particularly during the dry season.

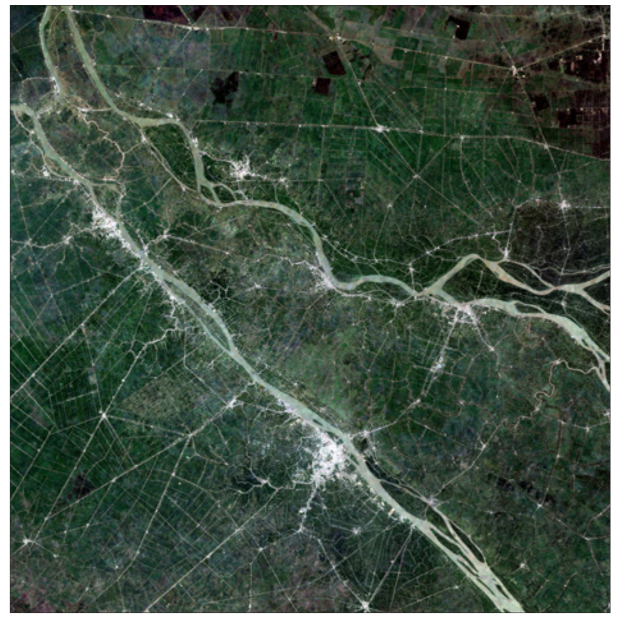
Efforts to address these environmental challenges in the Can Tho area and the broader Mekong delta region, include sustainable land use planning, reforestation, mangrove restoration, improved water management practices, and climate change adaptation measures. International organisations and the Vietnamese government are actively involved in projects aimed at enhancing the resilience to these environmental risks of the delta region and its communities.

The GHSL data are used to assess natural hazard risks and to estimate population growth in the region.

Mekong delta region

Asian large-river deltas, such as the Mekong, offer a combination of livelihood opportunities through fertile agricultural land and abundant water resources. However, they also face the risks associated with powerful hydrological processes, including rapid and intense water discharge from monsoon rains and sea level surges. Human settlements are situated at the interface of these dynamics, and assessing risks requires the integration of both environmental and societal data.

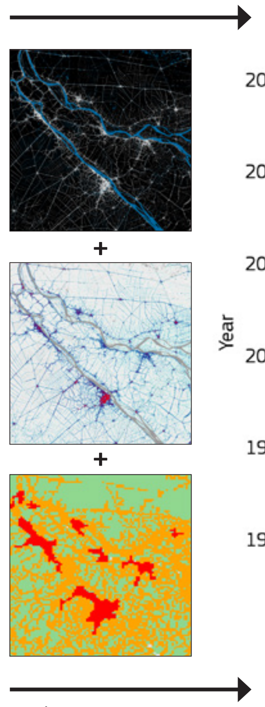
The Mekong delta Case Study
Sentinel-2 image



The Mekong delta

Sentinel-2 image of the Mekong delta Case Study centred around Can Tho (southern Vietnam). This area is intensely cultivated and settlements are located along the roads that border the dense network of canals.

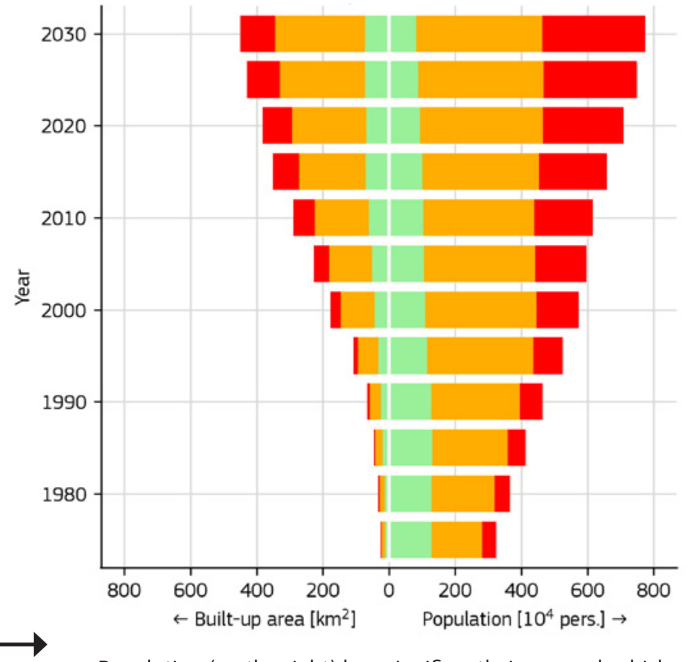
Methodology



Settlement Dynamics extracted from 100 km × 100 km Case Study.

SETTLEMENT DYNAMICS 1975 - 2030

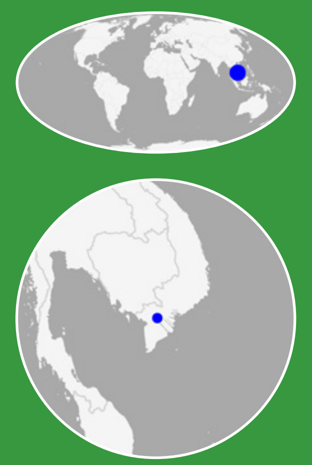
Mekong delta Case Study

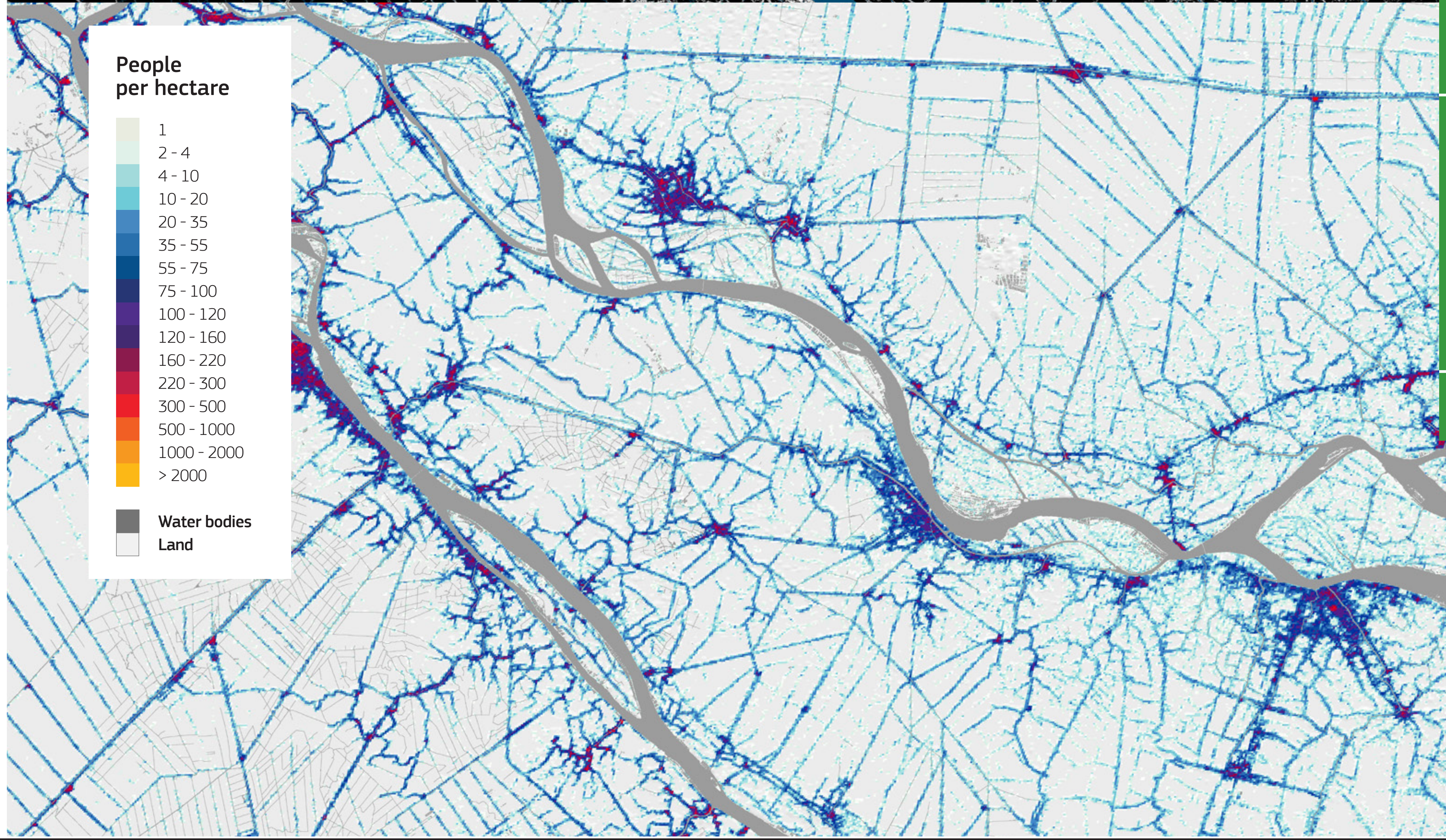


Population (on the right) has significantly increased, which can be partly attributed to the available opportunities in the region, and to high fertility rates. Built-up area (on the left) has grown at a slower rate.

BUILT-UP

Settlements along the region's dense network of artificial canals and rivers create a geometric pattern characterised by straight and curved lines. This pattern is unique to the Mekong delta region.





POPULATION DENSITY

The Can Tho area in the Mekong delta region is densely populated, with most settlements located along roads running alongside both artificial and natural canals. The area has relatively few towns.

10 Km

3.2.5

The Nile delta region

Fewer rural settlements

Over time, many rural settlements in the Nile delta region have expanded and became towns and cities. The population of towns and cities outnumbers that of rural settlements.

Longest inhabited, now most densely populated agricultural landscape

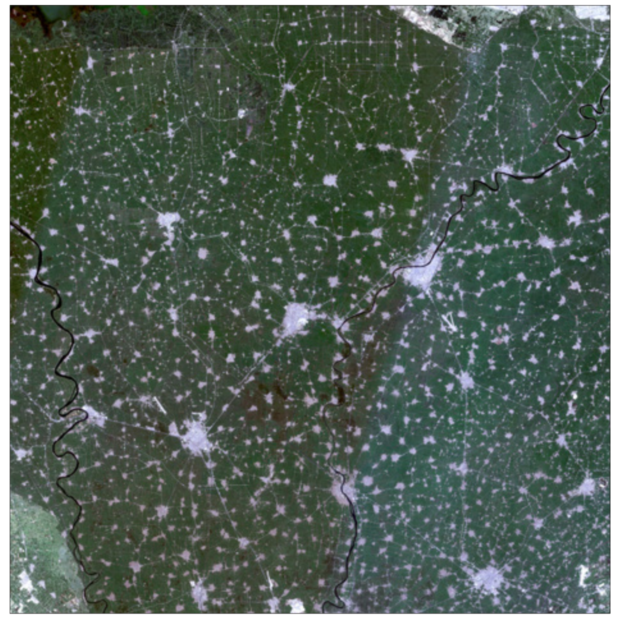
The Nile delta region in northern Egypt is known as one of the most fertile agricultural regions globally. It has a rich historical significance as a major food production area in the Mediterranean region, and is home to a significant portion of Egypt's population. The spatial patterns of settlements in the delta can be traced back thousands of years, when the region supplied grains across the Mediterranean. Over time, the spatial size of settlements has increased, particularly in the last half-century, due to rapid population growth. As a result, built-up areas now cover an important fraction of the delta's land.

The Sentinel-2 image shows the Nile delta Case Study located between Cairo and Alexandria. At the centre there are three large cities - Tanta, El Mahalla, and Mansoura - which are surrounded by a number of towns and villages. The total population in this area exceeds 20 million, making it one of the most densely populated regions in the world. The spatial growth of built-up areas and settlements has primarily occurred at the expense of agricultural land. Over the next 30 years, the population of Egypt is expected to increase by approximately 30 million people, leading to an even higher demand for space, water, and resources.

Highest population density

The Nile delta region is characterised by its dual nature as both an agricultural production area and a highly urbanised region. This Case Study shows that while agricultural land remains the primary land use, the proportion of built-up areas is among the highest in the world. Achieving sustainability here requires a careful balance between hydrological processes, given its low elevation and coastal location, and the intensity of societal demands. Meeting this sustainability challenge requires the use of appropriate datasets and modeling techniques.

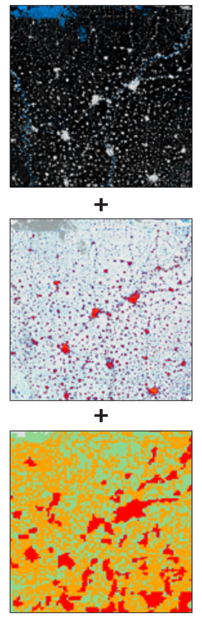
Nile delta Case Study
Sentinel-2 image



▲ *Nile Delta region Case Study*

Sentinel-2 image of the Nile delta Case Study, south of Alexandria. This low elevation region has served as a breadbasket for thousands of years, and has been inhabited since prehistoric times.

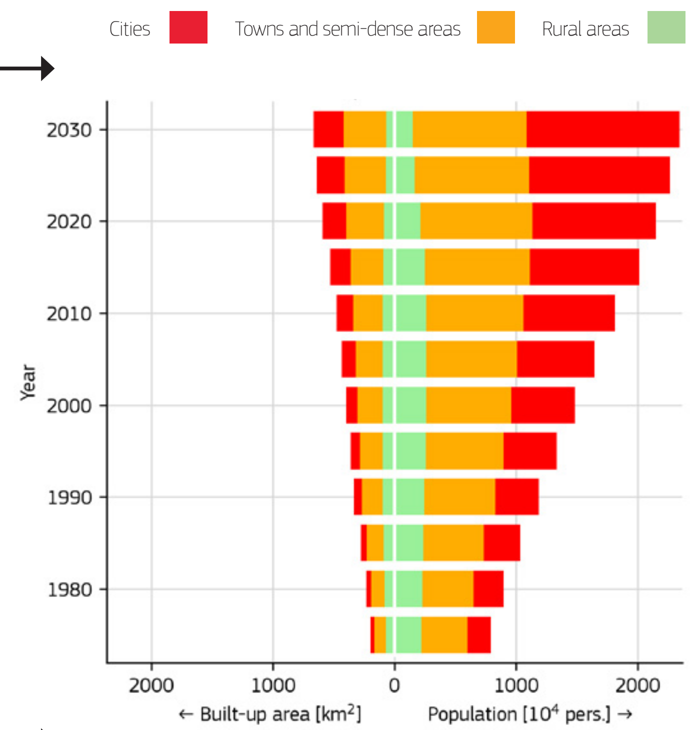
Methodology



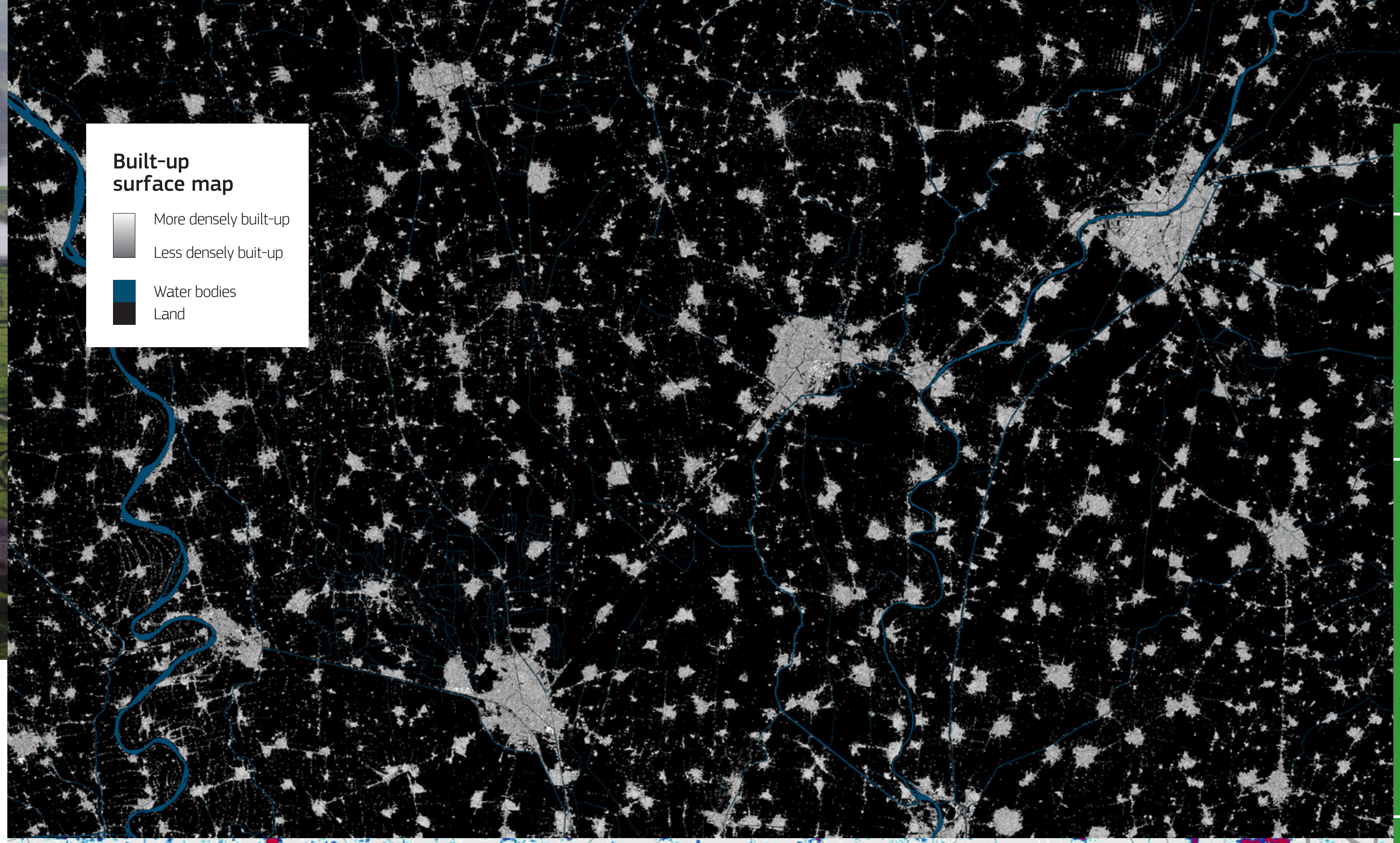
Settlement Dynamics extracted from 100 km × 100 km Case Study.

SETTLEMENT DYNAMICS 1975 - 2030

Nile delta Case Study

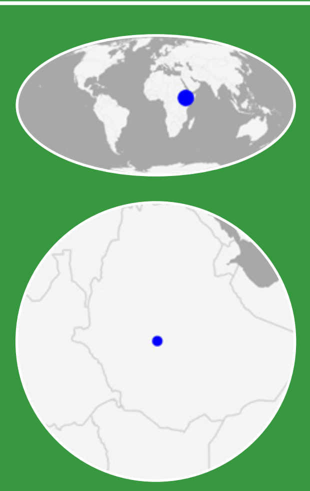


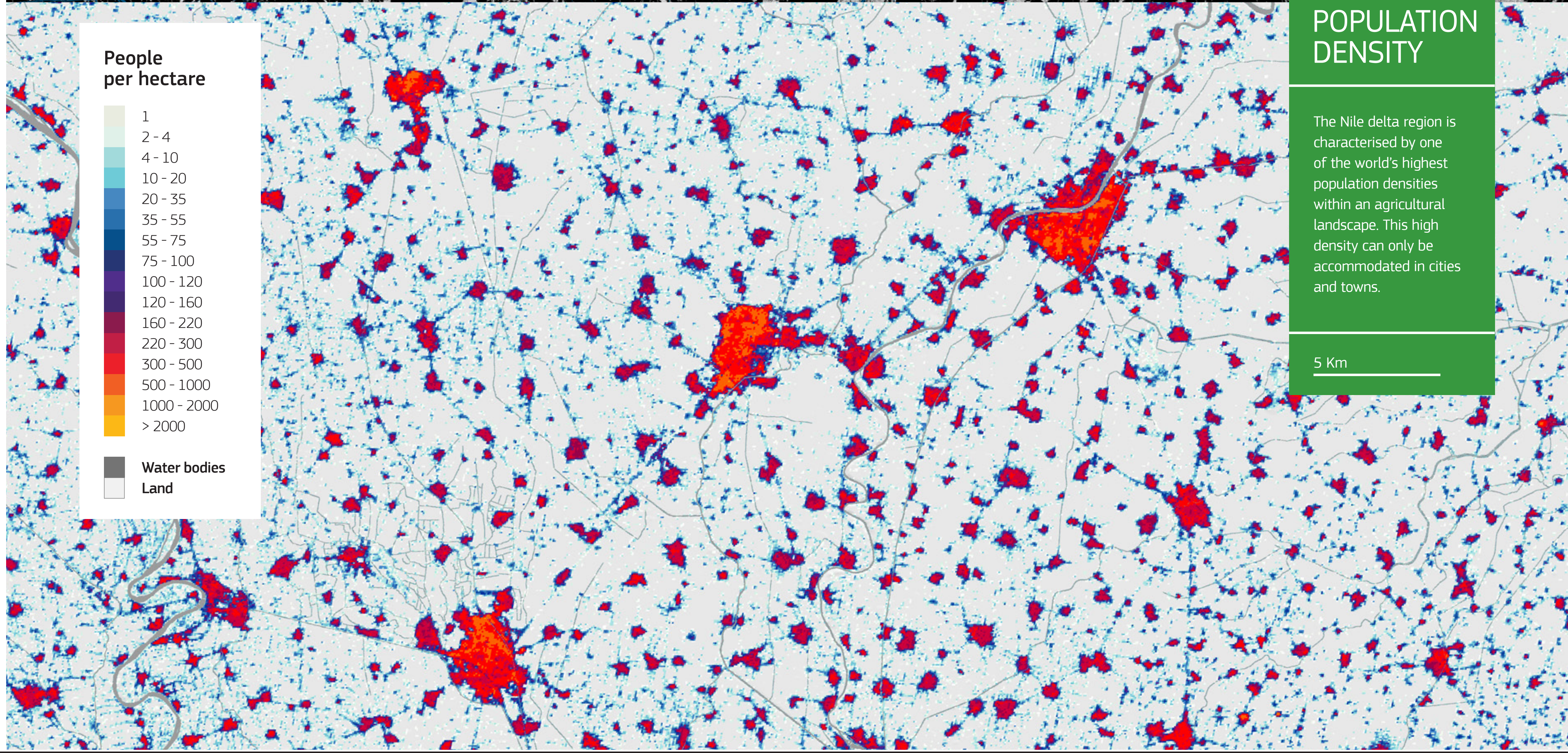
Population (on the right) has soared to 20 million people by 2020, with a signification proportion of people living in **cities** and in **towns and semi-dense areas**. Built-up area (on the left) has also increased, though less significantly.



BUILT-UP

The built-up area patterns in the Nile delta region are unique, due to their size and density. The proportion of land occupied by built-up area is only slightly lower than that used for agriculture.





POPULATION DENSITY

The Nile delta region is characterised by one of the world's highest population densities within an agricultural landscape. This high density can only be accommodated in cities and towns.

5 Km

3.3 Settlements in

Mountainous regions

Topography shapes settlements in hilly and mountainous regions

One billion people live in hills and mountain regions as of 2020.

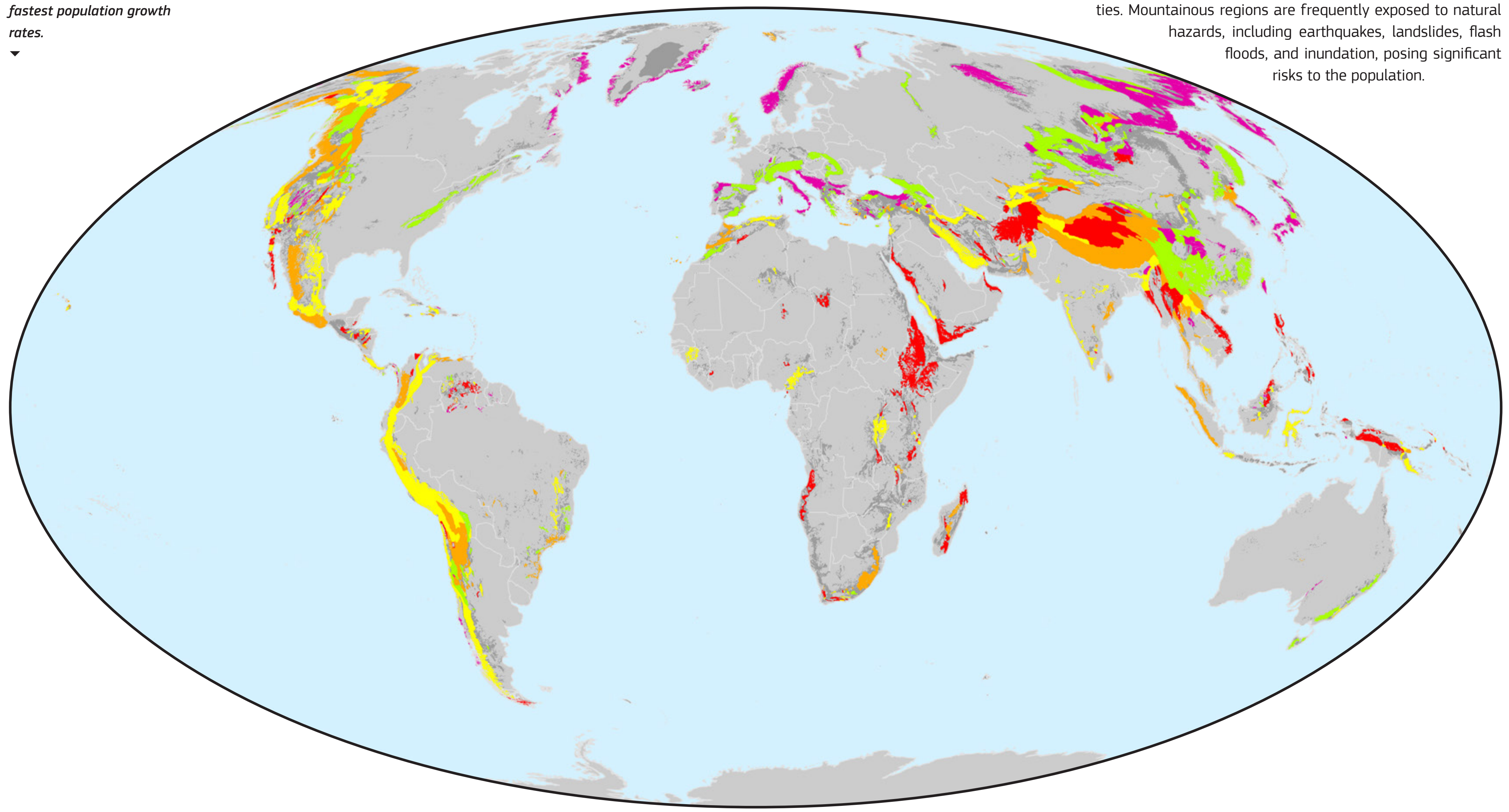
World mountains

Mountainous regions are home to approximately one billion people[1]. Mountainous and hilly areas in the tropics show the highest population density, and experience the fastest population growth rates.

Population change (%) in mountainous areas

1975 - 2020

- 0
- 0 - 50
- 50 - 100
- 100 - 200
- > 200
- Other mountain ranges
- Lowlands



Mountainous regions, which include high peaks and deep valleys, hilly regions and elevated plateaus, cover a significant portion of the land masses of the Earth. It is estimated that one billion people lived in hilly and mountainous regions in 2020, with population density varying greatly depending on factors such as climate, available resources, ruggedness and accessibility. Some mountainous regions, such as the Himalayas and the Andes, are known for their fertile soil, water access, abundant resources, and large populations. Similarly, hilly regions in the tropics, such as the Ethiopian Highlands, offer fertile soil, access to water, and a more hospitable climate compared with the nearby lowlands, resulting in dense human inhabitation.

Population dynamics in mountainous regions follow different trajectories. For example, European mountainous areas show stable or declining populations, while mountainous areas in low-income countries experience population growth. Some mountainous regions, like the Andes, are highly urbanised and feature cities with populations exceeding one million people, such as La Paz in Bolivia, Quito in Ecuador, or Bogota in Colombia, located on flat areas within the mountain ranges. However, a significant part of population in mountainous areas lives in smaller settlements located on foothill slopes or in deep valleys, where dwellings are typically less resilient to the impact of hazards. Livelihoods in these areas are more challenging, often leading to migration of populations from mountains to lowlands in search of better opportunities. Mountainous regions are frequently exposed to natural hazards, including earthquakes, landslides, flash floods, and inundation, posing significant risks to the population.

SENTINEL

Nepal

Kathmandu Case Study

The Sentinel-2 image shows Kathmandu, capital of Nepal, in the Himalayan foothills. Also shown are the 8,000 metres high mountain range (upper right) and the foothills, hills and lowlands (lower left).

10 Km

Kathmandu Valley

The Kathmandu Valley in the Himalayan mountains of Nepal, which comprises the three districts of Kathmandu, Lalitpur, and Bhaktapur, is a metropolitan area with a population exceeding 3 million people (in 2020). The population growth rate in the Kathmandu Valley has been steadily increasing over the years, driven by factors such as rural-to-urban migration, natural population growth, and inward migration from other parts of Nepal and neighbouring countries.

The population growth rate in the Kathmandu Valley has been steadily increasing over the years.

The hills surrounding the Kathmandu Valley have been inhabited for centuries, with people living in villages and settlements scattered across the hillsides. In recent years, urbanisation has led to the development of residential areas on some of the hills, with many people building homes and apartments in these areas. Despite this development, much of the hill areas around Kathmandu remain rural, with local communities still practising traditional farming and agriculture.

The rapid population growth in the Kathmandu Valley raises concerns about various challenges including increased pressure on infrastructure, services, and resources, as well as environmental degradation. The government of Nepal has implemented various policies and programmes to address these issues, aiming to promote sustainable urban development and to improve the quality of life in the Kathmandu Valley.

In 2015, a devastating earthquake of magnitude 7.8 struck

Retrofitting existing buildings to withstand seismic activity, enforcing building codes and regulations.

Nepal, affecting Kathmandu and its surrounding areas. The earthquake caused extensive damage and loss of life and resulted in the collapse of numerous buildings, including historical temples and monuments, and significant infrastructure damage.

To mitigate the vulnerability to earthquakes, the Nepalese government has implemented several measures, including retrofitting of existing buildings to withstand seismic activity, enforcing building codes and regulations, and conducting public education campaigns to raise awareness about earthquake safety.

Earthquake damage

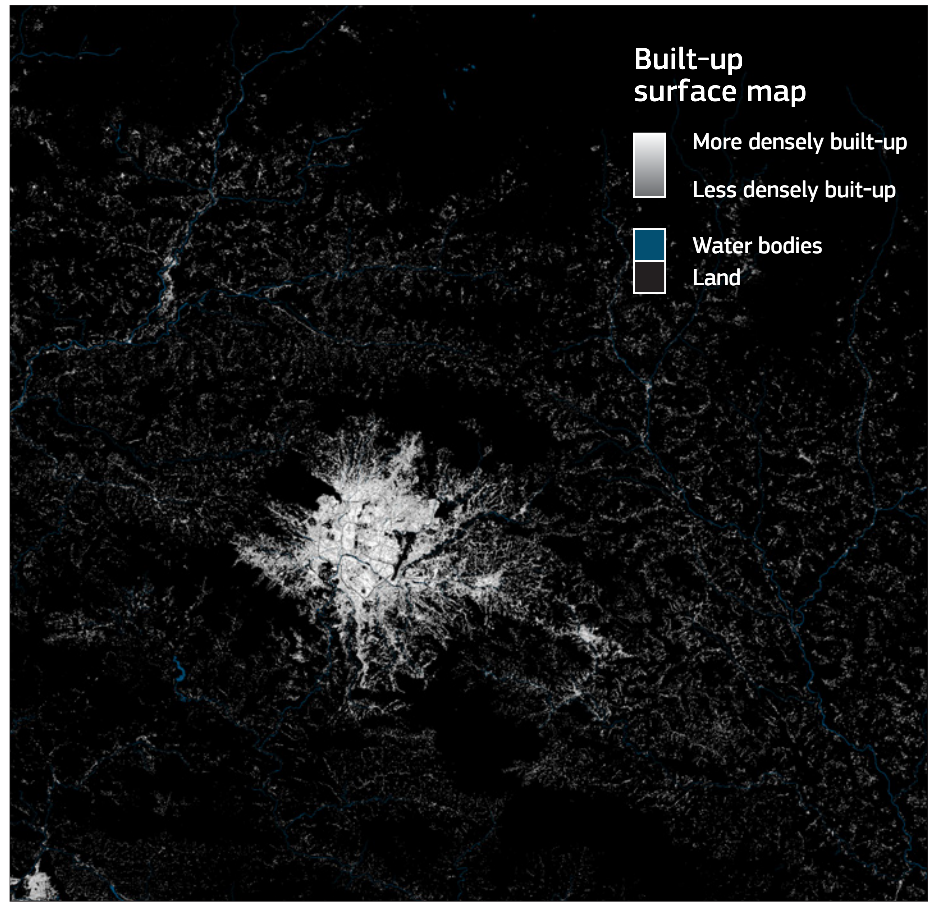
The 2015 earthquake in Kathmandu caused severe damage to buildings, not only in the Kathmandu metropolitan area, but also in the surrounding towns and villages.

Kathmandu and surrounding foothills

The Kathmandu Valley is surrounded by a densely populated rural area that is interspersed with towns and villages.

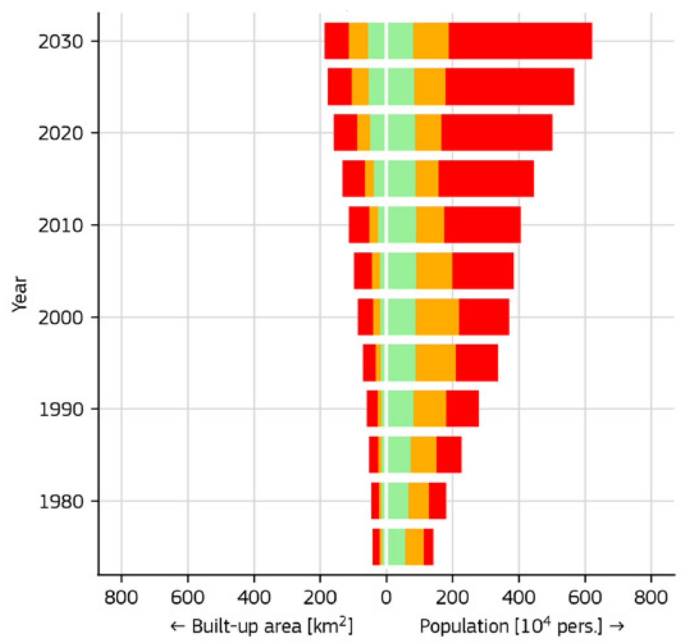
Built-up in the Kathmandu Case Study

The mountainous landscape of the larger Kathmandu area includes the districts of Kathmandu, Lalitpur, and Bhaktapur and many villages scattered in the foothills around the city.



SETTLEMENT DYNAMICS 1975 - 2030

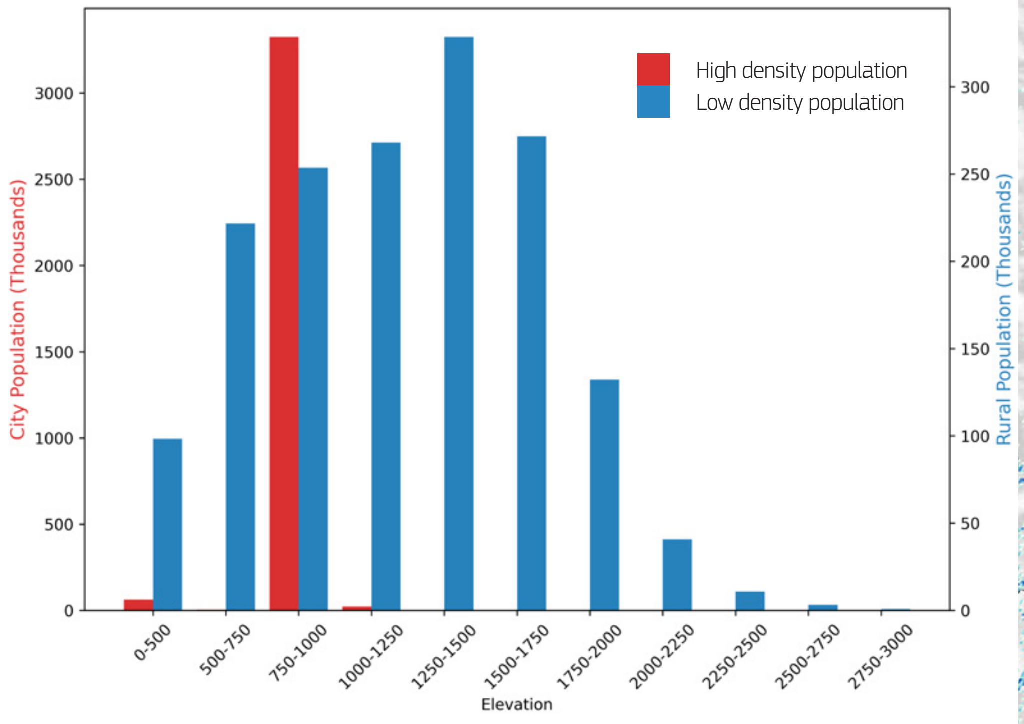
Kathmandu Case Study



Population (on the right) has grown significantly, mostly concentrated in the **cities** of the greater Kathmandu Valley, but also in the surrounding **towns and semi-dense areas** and **rural areas**. Built-up area (on the left) has grown more modestly, mainly in **cities**.

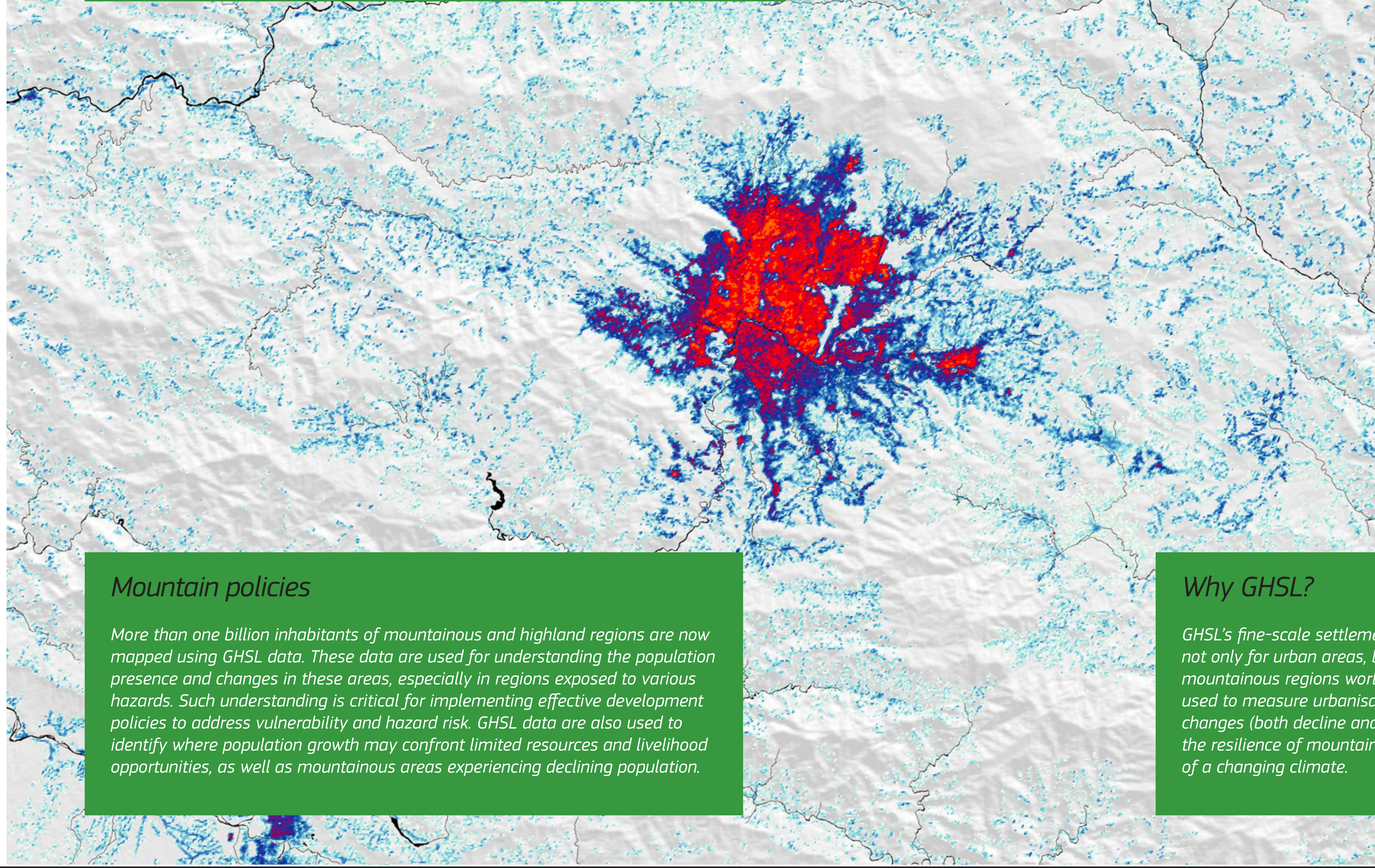
Settlements and elevation

The population of cities (in red) is concentrated in the large valleys, at low elevations, while rural settlements (in blue) are found at much higher elevations.



POPULATION DENSITY

The Kathmandu metropolitan area has undergone rapid population growth, resulting in the merging of three separate cities - Bhaktapur, Lalitpur and Kathmandu - into a single large metropolitan area.



Mountain policies

More than one billion inhabitants of mountainous and highland regions are now mapped using GHSL data. These data are used for understanding the population presence and changes in these areas, especially in regions exposed to various hazards. Such understanding is critical for implementing effective development policies to address vulnerability and hazard risk. GHSL data are also used to identify where population growth may confront limited resources and livelihood opportunities, as well as mountainous areas experiencing declining population.

Why GHSL?

GHSL's fine-scale settlements data are available not only for urban areas, but also for rural mountainous regions worldwide. These data are used to measure urbanisation trends, population changes (both decline and growth), and to assess the resilience of mountain communities in the face of a changing climate.

3.4 Settlements in

Arid environments

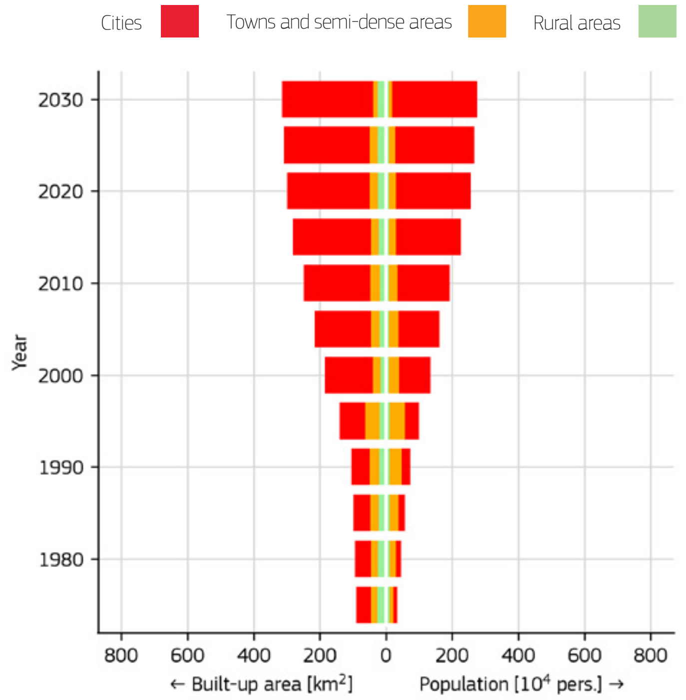
Las Vegas Case Study

Human settlements are also to be found in environments with hot desert climates. One example is Las Vegas, in the south-western United States, which was built in the mid-1800s as a communication hub on the early railway system interconnecting the United States. The presence of Las Vegas Springs, providing water to the Las Vegas Valley metropolitan area, where the city is located, has been crucial in supporting the growing population and in promoting agriculture in the region. Over the past fifty years, Las Vegas has undergone significant growth and has transformed into a prominent tourist destination. The advent of air-conditioning technology has played a pivotal role in making life feasible in desert-like environments, revolutionising the way people live, work, and find comfort indoors. This advancement has fundamentally changed the lifestyle of both residents and visitors, allowing them to enjoy the city's amenities, while escaping the harsh desert climate.

However, desert cities face challenges regarding water resources due to a changing climate. Decadal droughts in North America's Great Plains have resulted in decreased water flow in the Colorado River and reduced water from Lake Powell, which is today the main water source for the city. In addition, the increasing water demand from the population and tourism industry may require innovative ways to supply this most precious resource.

SETTLEMENT DYNAMICS 1975 - 2030

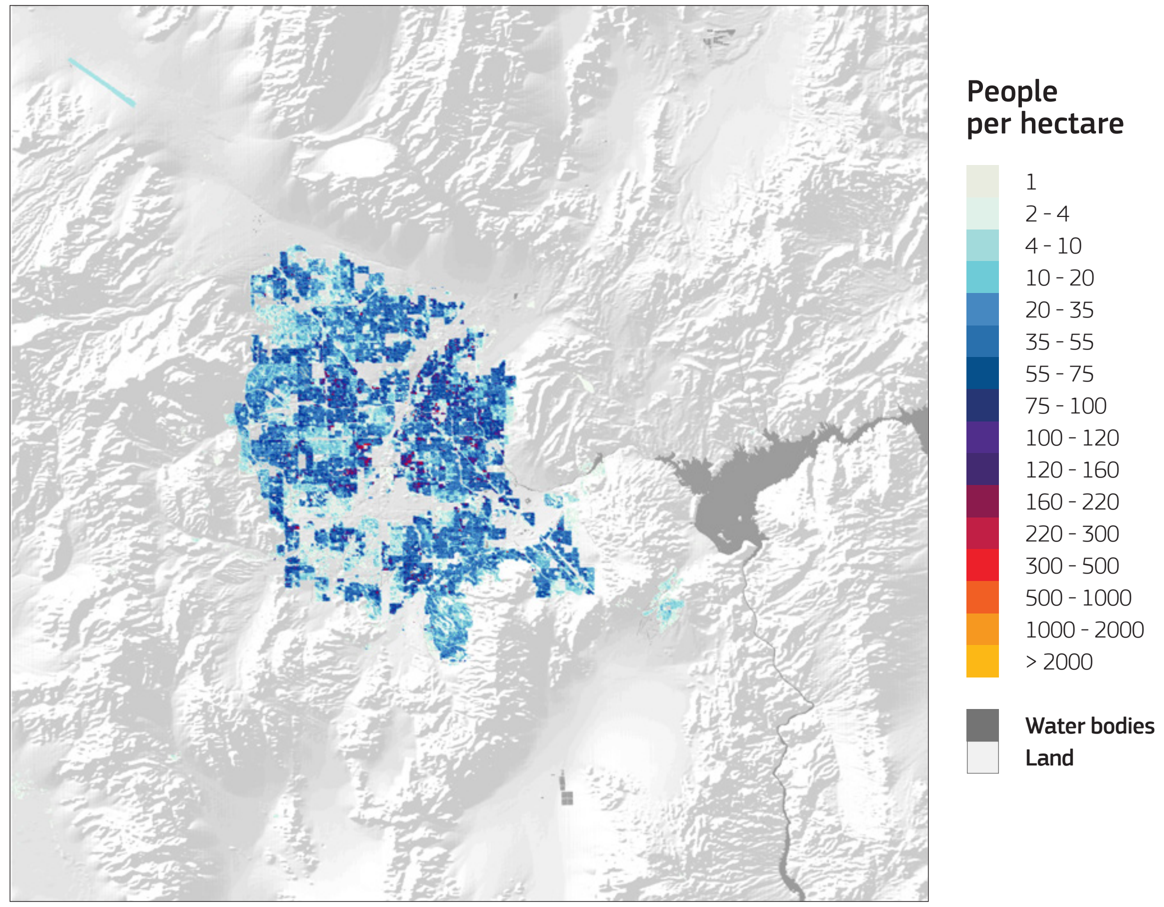
Las Vegas Case Study



Both population (on the right) and built-up area (on the left) have grown continuously over the past 50 years, mostly concentrated in **cities**.

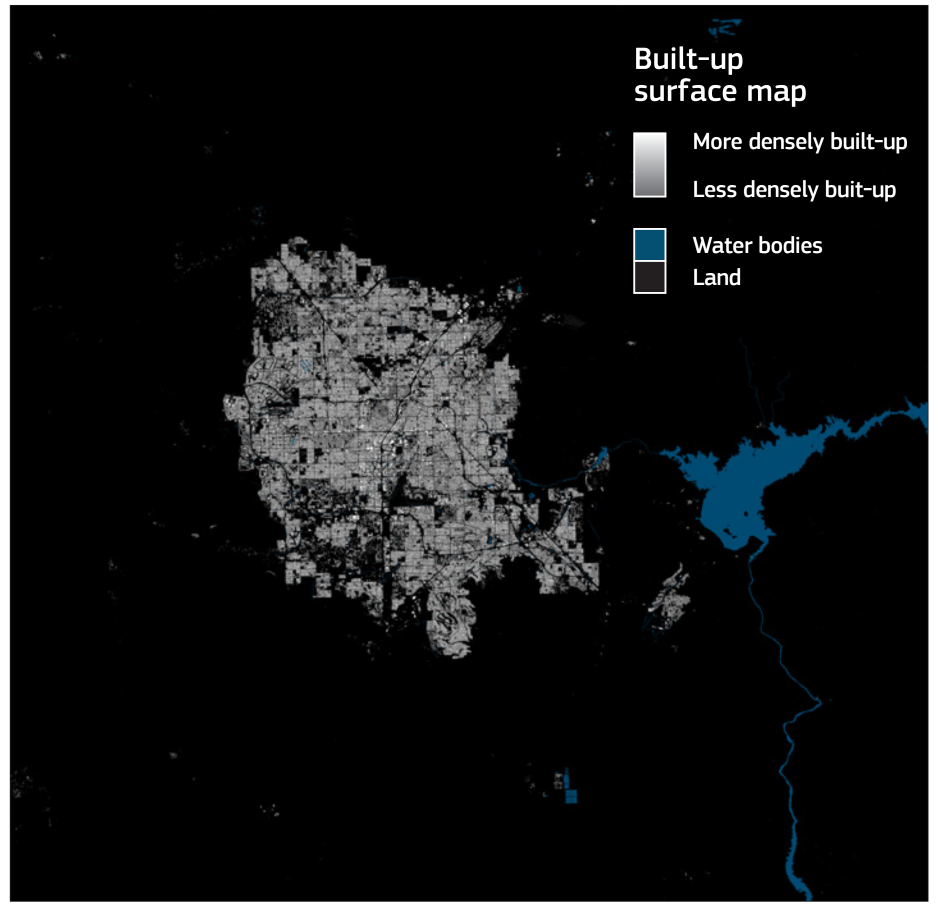
Population density, Las Vegas

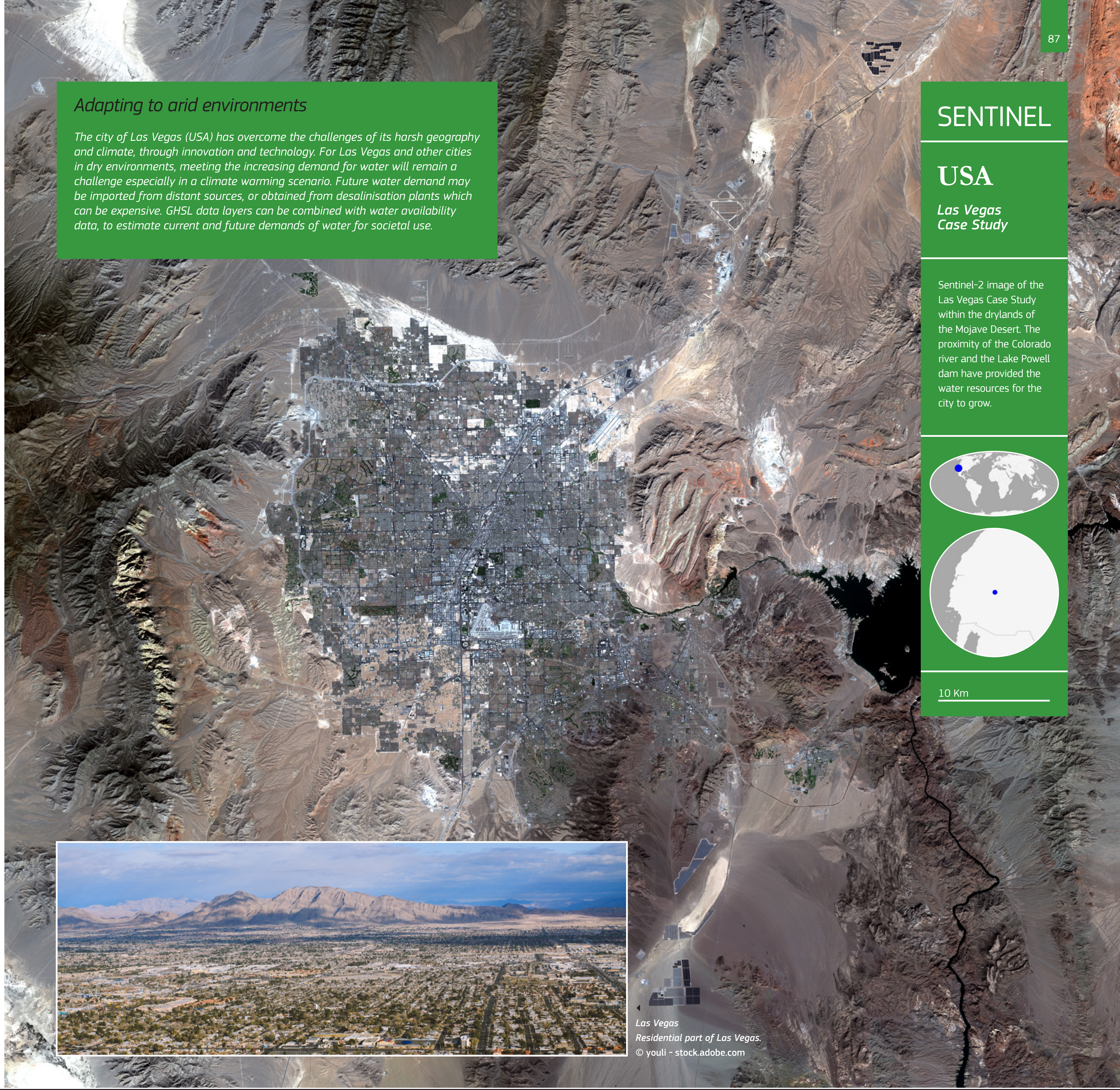
Las Vegas can continue to expand also due to the availability of accessible land. However, Lake Powell and the Colorado River may not be able to supply future demands of water for the city.



Built-up surface, Las Vegas

Las Vegas' built-up surface patterns follow a regular layout of roads, residential areas, and tourist attractions. This is characteristic of a modern city, with cars the primary mode of transportation.





Adapting to arid environments

The city of Las Vegas (USA) has overcome the challenges of its harsh geography and climate, through innovation and technology. For Las Vegas and other cities in dry environments, meeting the increasing demand for water will remain a challenge especially in a climate warming scenario. Future water demand may be imported from distant sources, or obtained from desalinisation plants which can be expensive. GHSL data layers can be combined with water availability data, to estimate current and future demands of water for societal use.

SENTINEL

USA

Las Vegas Case Study

Sentinel-2 image of the Las Vegas Case Study within the drylands of the Mojave Desert. The proximity of the Colorado river and the Lake Powell dam have provided the water resources for the city to grow.

10 Km

Las Vegas
Residential part of Las Vegas.
© youli - stock.adobe.com

3.5 Settlements in Natural protected areas

Settlements are typically restricted in natural protected areas

Human societies often transform natural lands such as forests, grasslands, and wetlands, into human-modified landscapes for various purposes, including agricultural, mining and human settlements. In these human settlements, the land is modified to accommodate human habitation. However, in densely built settlements, particularly larger ones, the natural land is often completely modified into artificially built-up land.
To preserve natural lands and ecosystems, authorities in most countries have established protected natural areas that limit or restrict human activities. The growth of settlements within these protected areas is typically limited or discouraged. In fact, the presence, size and proximity of human settlements in protected areas serve as indicators of the pressure on natural land. The GHSL information, combined with the world protected areas database, helps us understand the impact of human activities and societal pressures on these areas.
Regional and international initiatives help preserve these areas, such as the Virunga National Park, which hosts some of the most endangered species.

Settlements are direct indicators of the modification of natural habitats. Settlements and the proximity to settlements serve also as indirect measures of the impact on natural and semi-natural ecosystems, such as subsistence farming and timber harvesting. For instance, the high-value natural ecosystem of the Virunga Park is at risk of being used by low-income communities with high fertility rates, for whom

The presence, size and proximity of human settlements in protected areas serve as indicators of the pressure on natural land.

protected areas may be the only resources that can support their livelihoods. Promoting alternative livelihoods, such as tourism to the protected areas involving the local communities, can provide an alternative source of income and decrease the pressure on protected lands.

▲ *Mountain gorilla*
© Gregoire Dubois - all rights reserved

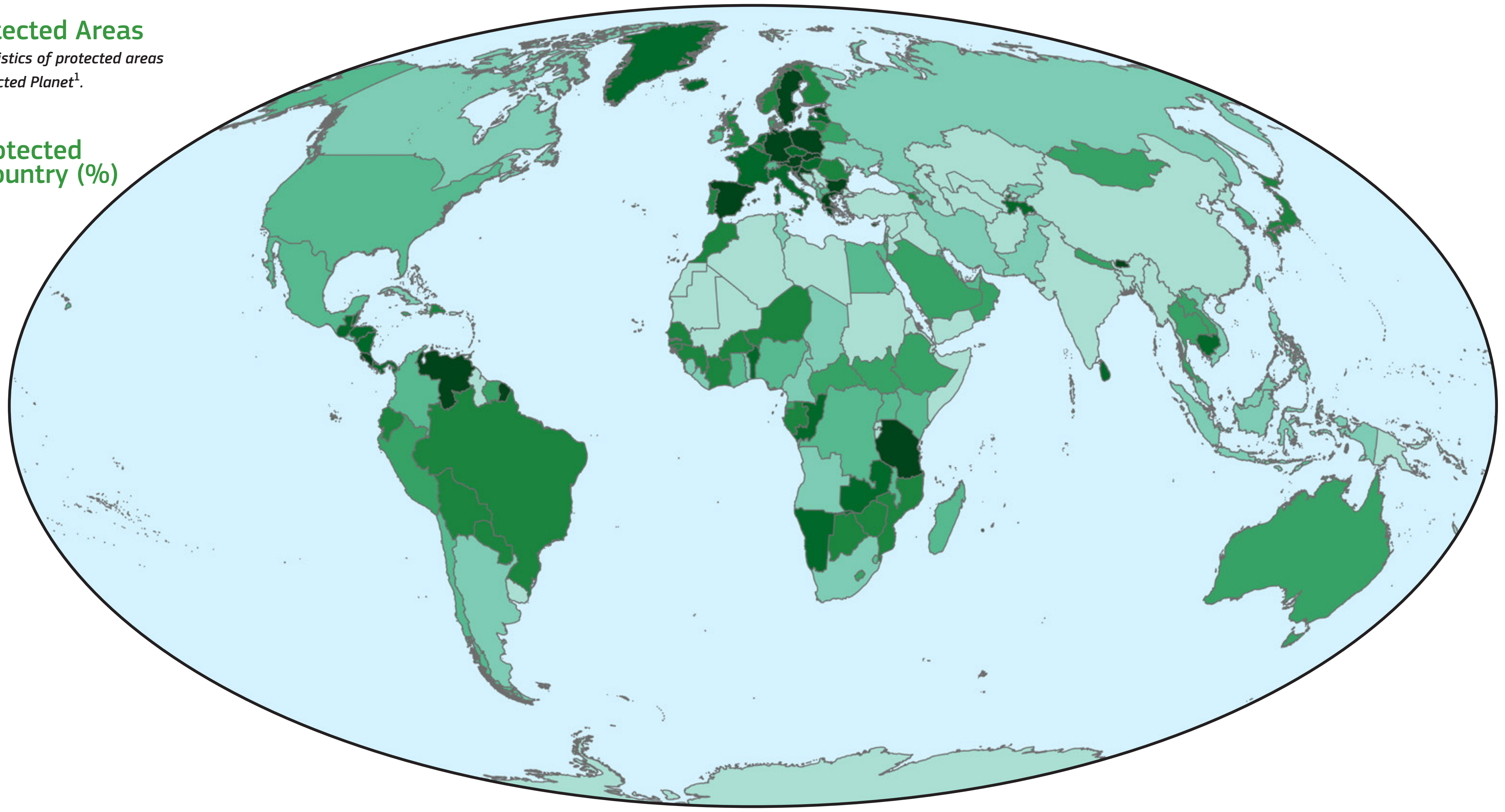
The habitat of the mountain gorilla is confined to the higher slopes of the Virunga Mountains, which are located within the boundaries of Virunga National Park.

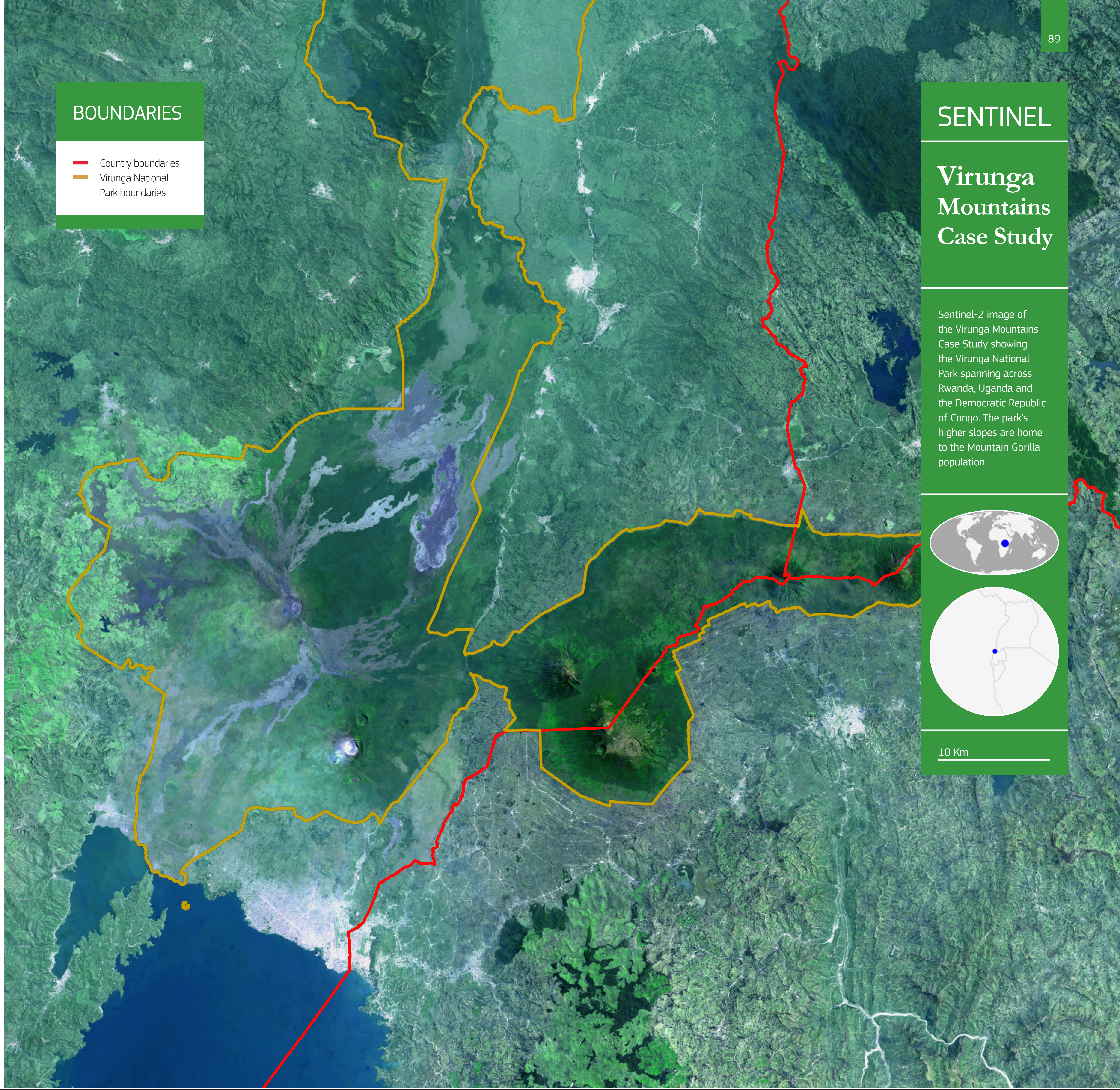
World's Protected Areas

Global coverage statistics of protected areas available from Protected Planet[1].

Share of protected areas per country (%)

- < 10.5
- 10.5 - 15.5
- 15.5 - 20.5
- 20.5 - 25.5
- 25.5 - 35
- 35 - 50
- > 50





SENTINEL

Virunga Mountains Case Study

Sentinel-2 image of the Virunga Mountains Case Study showing the Virunga National Park spanning across Rwanda, Uganda and the Democratic Republic of Congo. The park's higher slopes are home to the Mountain Gorilla population.

10 Km

Virunga National Park

Virunga National Park stretches across the borders of the Democratic Republic of Congo, Rwanda, and Uganda, and is surrounded by densely populated and intensely cultivated areas. Despite these challenges, the park has been successful in protecting its natural resources. It is particularly renowned for its efforts in protecting the mountain gorillas, an icon of the world's most endangered species, which live within the park's boundaries. The park not only serves as a sanctuary for wildlife, but also provides livelihood opportunities for local communities. By offering alternative sources of income, the park helps to prevent encroachment on natural areas by providing viable alternatives for the local population.

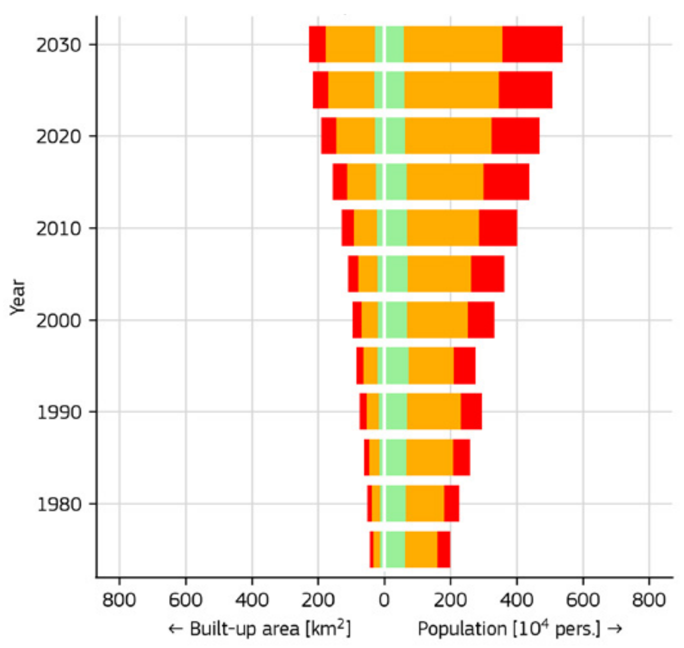
While settlements have been kept outside the park's limit, timber harvesting within the park has emerged as a significant challenge for its preservation. This poses a threat to the park's ecosystem, and requires careful management and conservation efforts.
The population in the foothills of the Virunga Mountains has expanded significantly between 1975 and 2020, and is expected to continue increasing due to high fertility rates. This growing population, coupled with the already high demand for resources, against a background of conflict, will further strain the park's resources and necessitate sustainable management practices to ensure its long-term preservation.

Settlements and parks

Information provided by GHSL data layers can be used to inform decision-makers about population pressure and expansion of the built-up area. This can guide the development of policies aimed at preserving natural protected areas. Restricting human settlements within these protected areas is essential to maintain ecological balance, protect endangered species, and preserve natural landscapes. To achieve that goal, it is crucial to provide alternatives to subsistence farming for the local population.

SETTLEMENT DYNAMICS 1975 - 2030

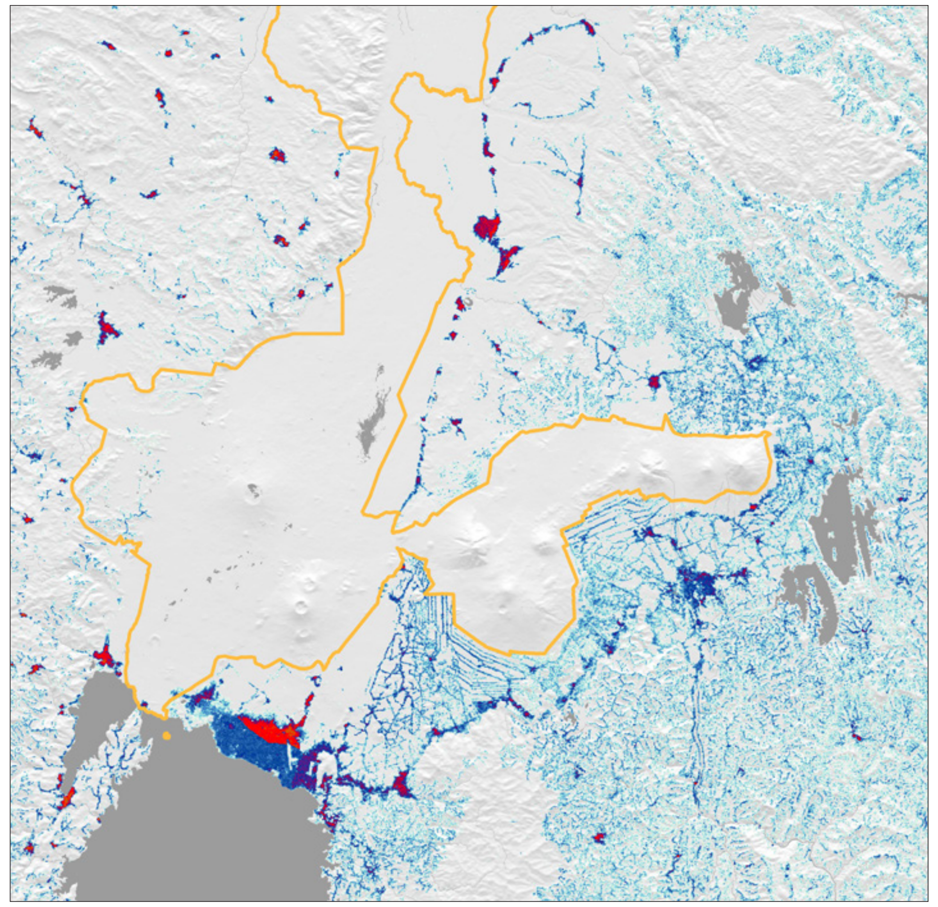
Virunga Mountains Case Study

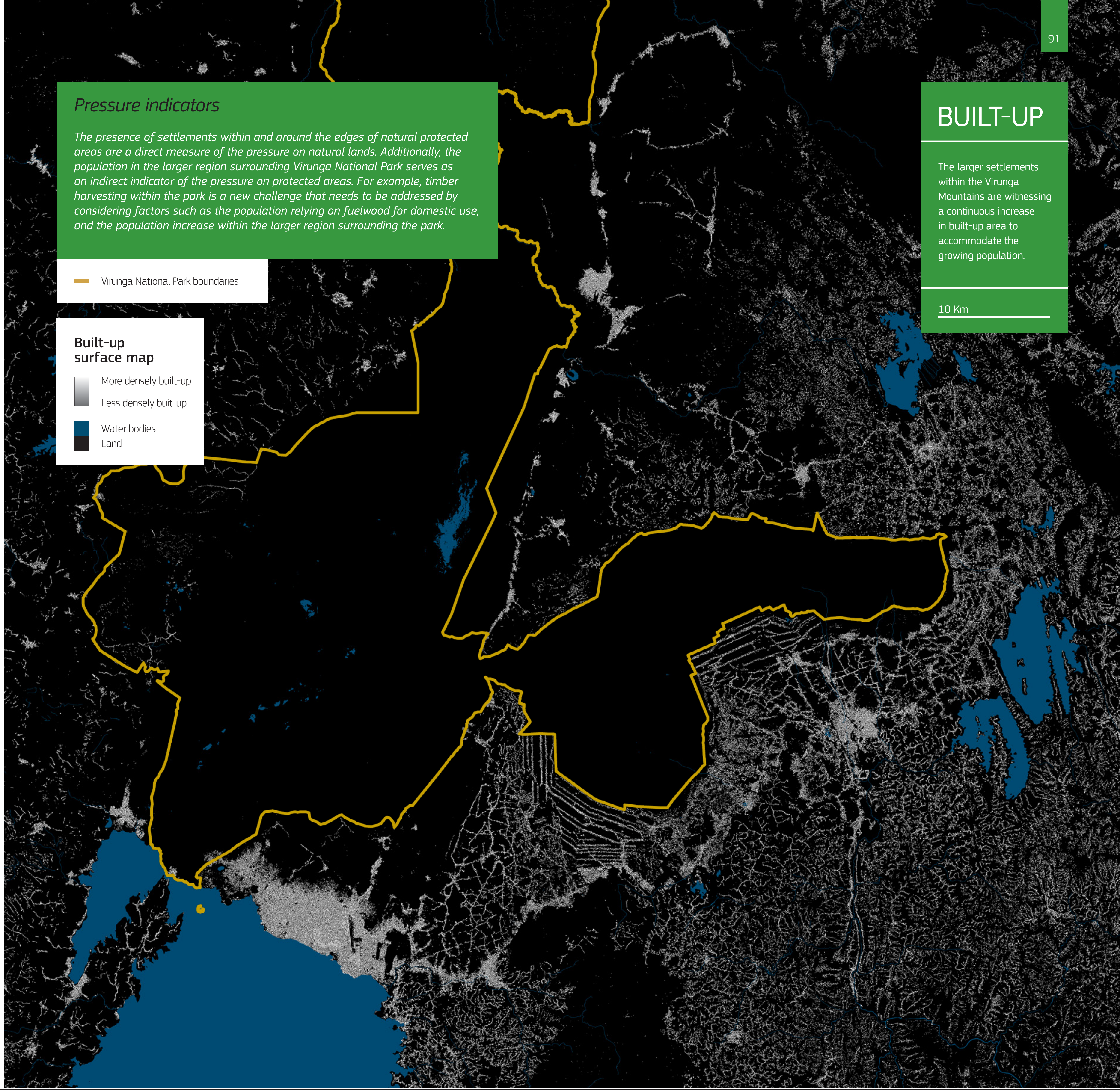


Population (on the right) in the area surrounding Virunga National Park is high, and increasing rapidly, reflecting the trends of a society with high fertility rates. Built-up area (on the left) has grown more modestly.

The landscape of Virunga Mountains
High population density at the edge of the park.

Virunga Mountains Case Study
Virunga National Park is located in a mountainous and hilly region. As the population continues to grow, settlements are starting to appear on the steeper slopes and closer to the park's boundaries.





Pressure indicators

The presence of settlements within and around the edges of natural protected areas are a direct measure of the pressure on natural lands. Additionally, the population in the larger region surrounding Virunga National Park serves as an indirect indicator of the pressure on protected areas. For example, timber harvesting within the park is a new challenge that needs to be addressed by considering factors such as the population relying on fuelwood for domestic use, and the population increase within the larger region surrounding the park.

BUILT-UP

The larger settlements within the Virunga Mountains are witnessing a continuous increase in built-up area to accommodate the growing population.

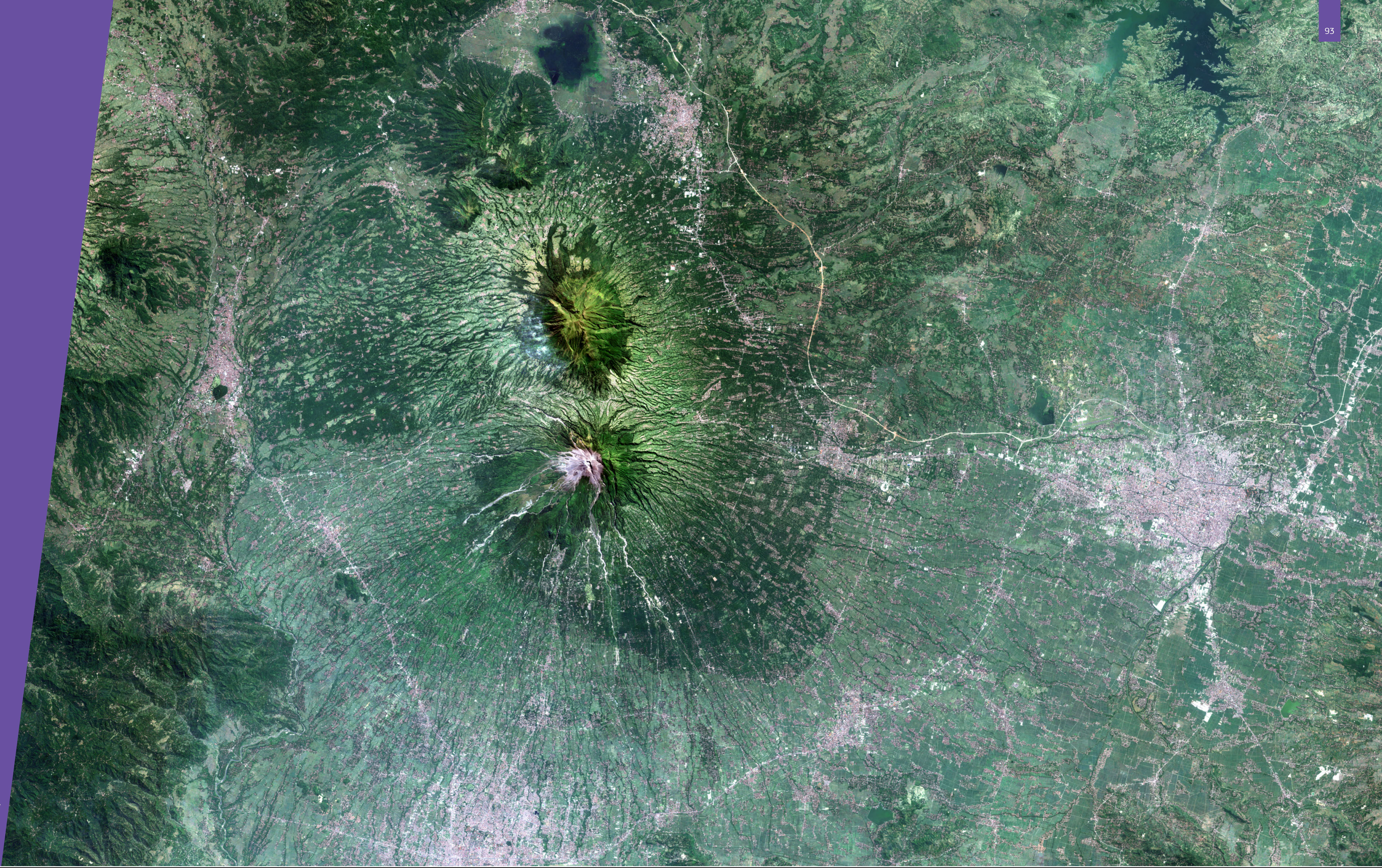
Chapter 4

Living in hazardous areas

Settlements vulnerable to hazards

Some settlements are more vulnerable than others to impacts of natural hazards. This depends on hazardous hydrological, geological or biological processes at a given location as well as characteristics of the built-up environment of these settlements. The global provision of data on built-up areas and population density, such as the examples of GHSL products described in this Chapter, is also operationally used to quantify exposure to hazards, including generating early warnings, impact assessment, supporting emergency aid and reconstruction, and quantifying disaster risks.

Settlements and



Mount Merapi, Sumatra

Sentinel-2 image showing the settlements developed around the Mount Merapi, an active volcano located in Sumatra.

10 Km

4.1 Settlements and Floods

For civilizations throughout history, rivers have offered an essential lifeline critical to their survival and prosperity. Along with providing clean water, they also offer fertile land for agriculture. Despite being a basic necessity for human life, water can also be exceedingly destructive. Rivers can cause significant damage and loss of life during periods of flooding.

Rivers can cause significant damage and loss of life during periods of flooding.

The Sendai Framework for Disaster Risk Reduction advocates for "the substantial reduction of disaster risk and losses in lives".

To prevent damage and conduct post-assessment disaster management in human settlements, it is crucial to recognise the size of settlements and the number of people at risk. In 2015 the Sendai Framework for Disaster Risk Reduction 2015-2030 was adopted. It advocates for "the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries."

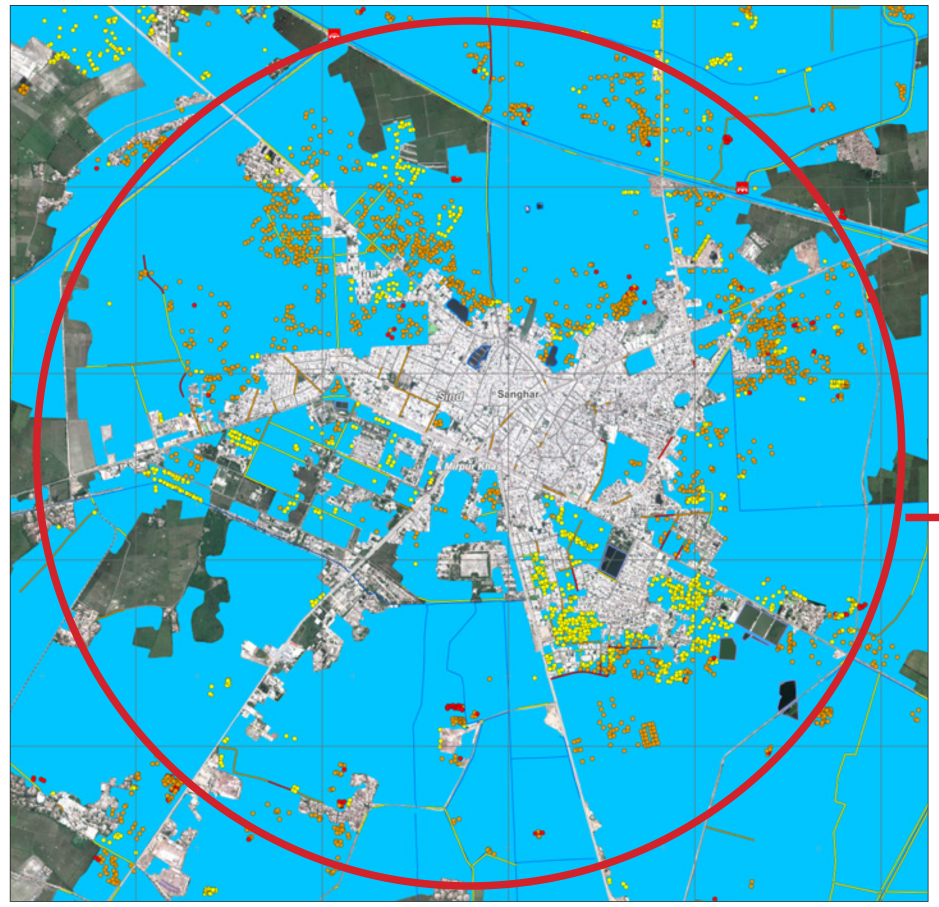
The unplanned establishment of settlements in flood-prone regions coupled with climate change have led to a global surge in floods.

In the period ranging from 1998 to 2017, more than 2 billion people worldwide were affected by floods, resulting in property damage, loss of life, and destruction of vital infrastructure, including schools and hospitals. The situation is worsened by inadequate planning and lack of early warning systems, as well as a lack of awareness that compounds the vulnerability of those who live in areas near floodplains. The unplanned establishment of settlements in flood-prone regions, coupled with climate change, have led to a global surge in flood damage, which disproportionately impacts vulnerable communities living in developing countries.

How can GHSL help?

Using data about the location of people and buildings in flood prevention, can help to enhance resilience and minimise the catastrophic damage often caused by these natural hazards. Knowing where people live and which buildings are located in flood-prone areas allows policymakers, planners, and emergency responders to develop strategies that mitigate the risks of flooding and potentially save lives.

EU humanitarian aid
EU humanitarian aid reaches survivors of devastating floods in Pakistan. Trucks from the EU's partner Cesvi offload relief items.

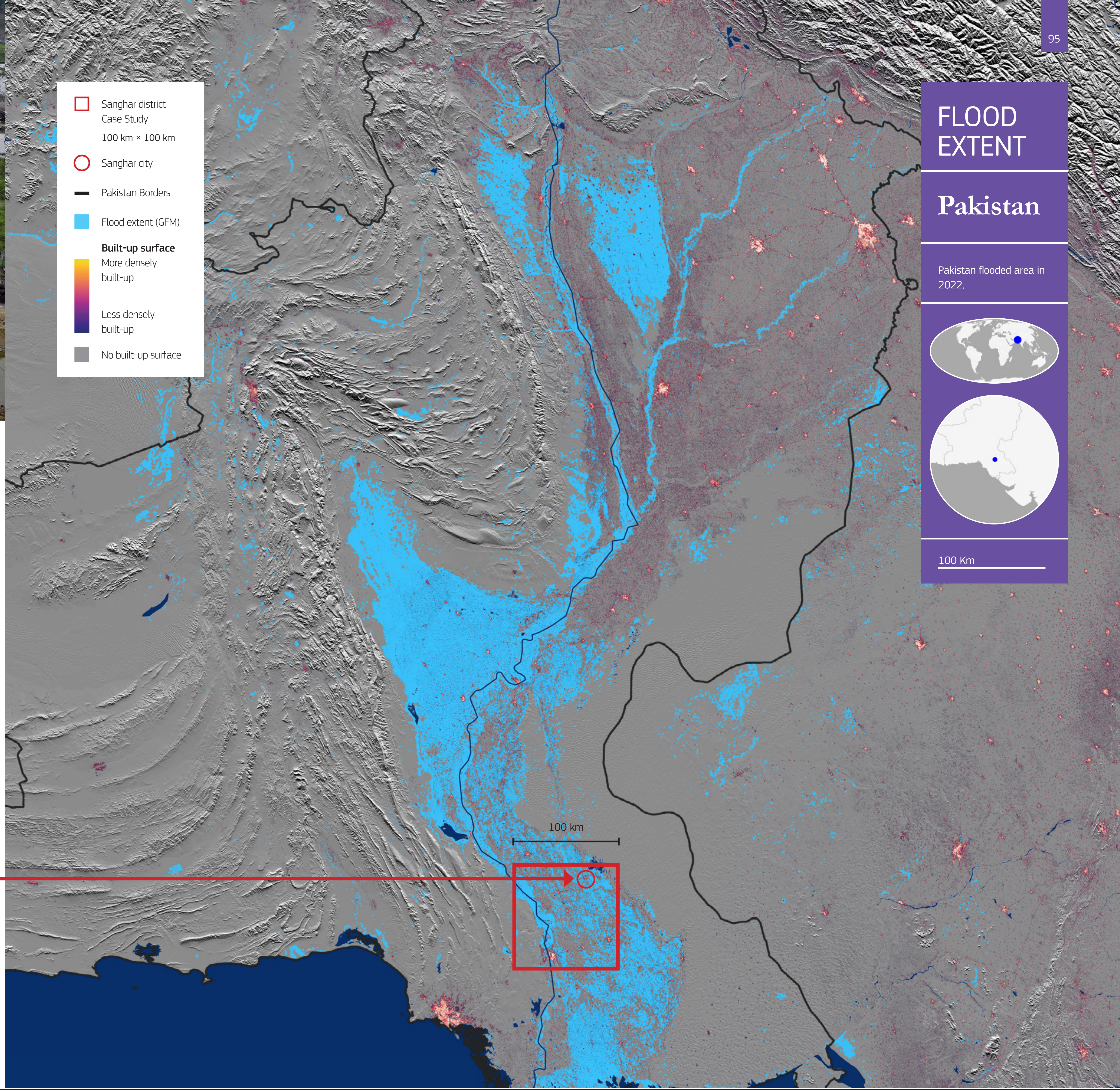


Sanghar city (Pakistan)

Situation of the floods in the city of Sanghar as of 11/09/2022, where GHSL data were use to estimate affected population. Copernicus Emergency Management Service (© 2022 European Union), [CEMS activation 631] Sanghar-Pakistan: Grading-Overview map 01.

Sanghar district Case Study 100 km × 100 km

Sanghar city (CEMS activation location)



Floods in Pakistan in 2022 caused by monsoon rain

The floods that occurred in Pakistan between June and October of 2022 had devastating consequences, including the loss of 1,739 lives and significant physical damage and economic losses. The disaster was caused by heavier than usual monsoon rainfall and melting glaciers, both of which have been linked to climate change. The severe impact of this flood

The disaster was caused by heavier than usual monsoon rainfall and melting glaciers, both of which have been linked to climate change.

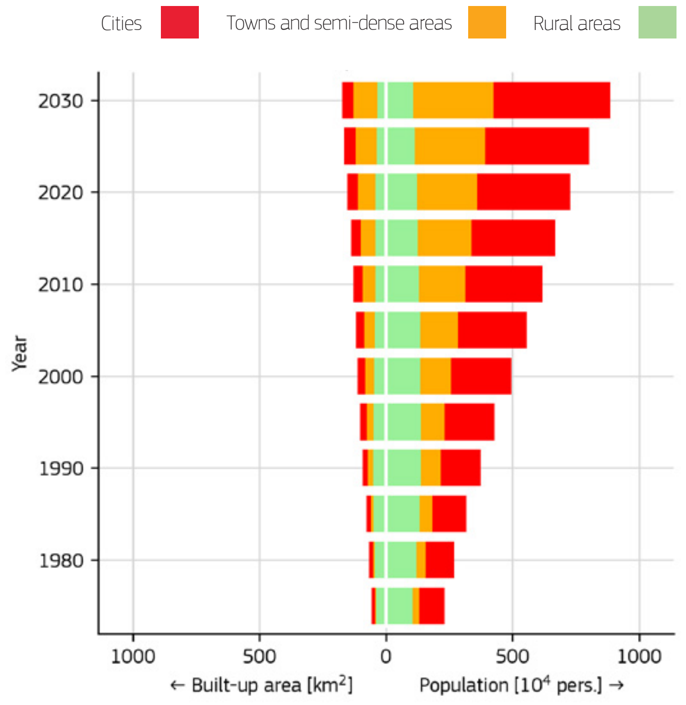
led to a state of emergency being declared in Pakistan on 25 August 2022, and it has been recognised as one of the deadliest and costliest natural disasters in recorded history, and the most fatal flood since the 2020 South Asian floods.

On 10 September 2022, the Copernicus Emergency Management Service (CEMS) Mapping component was activated to monitor and assess the extent of the floods in various cities. The CEMS mapping provides rapid response to emergencies, providing maps and data related to the disaster's severity, infrastructure damage, and the number of people affected. The population component of the GHSL data, is utilised to calculate the number of people potentially exposed to the disaster.

The population component of the GHSL data, is utilised to calculate the number of people potentially exposed to the disaster.

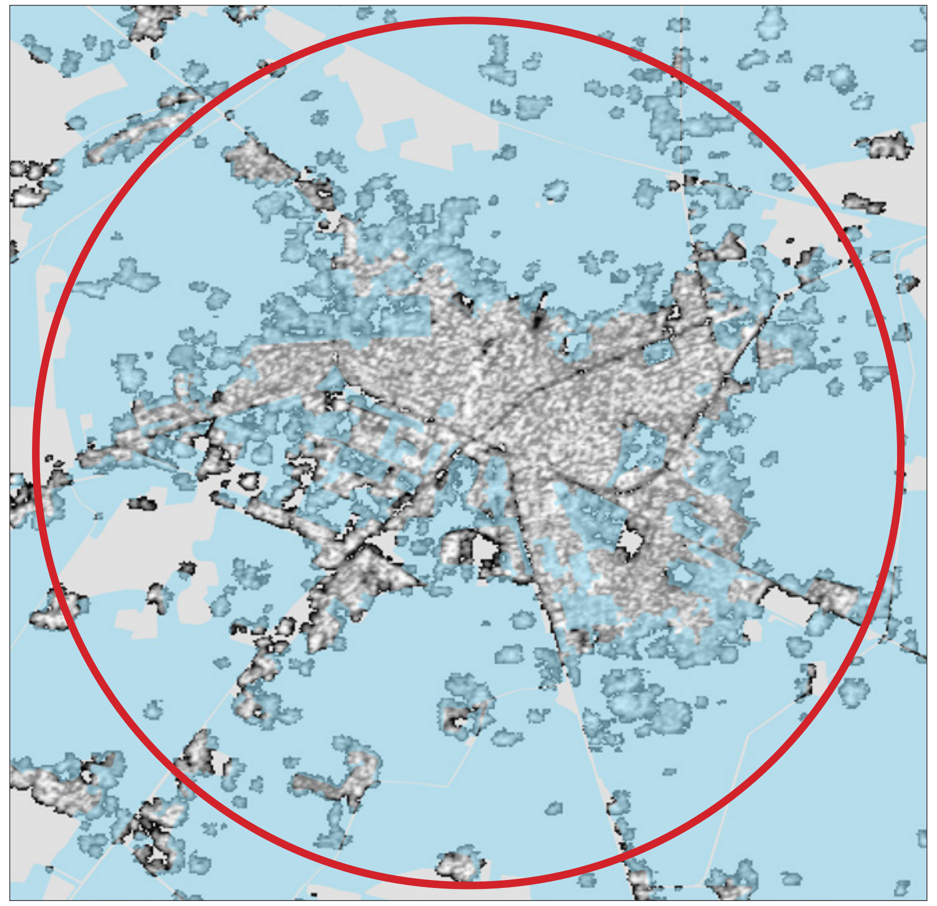
During the disaster, the satellite-based Global Flood Monitoring (GFM) component of CEMS provided regular near real-time updates on the spatial extent of the floods.

SETTLEMENT DYNAMICS 1975 - 2030
Sanghar district Case Study



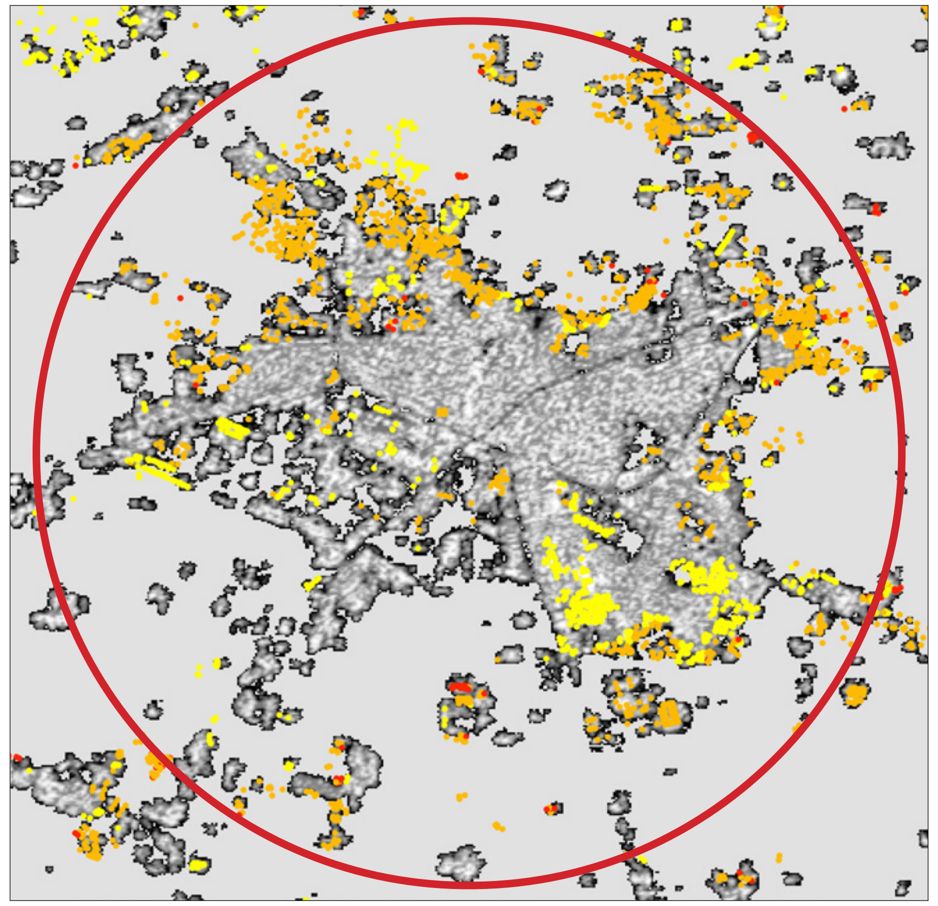
Flooded area in Sanghar

Almost 40% of the population of Sanghar was affected by the floods. The Figure shows the extent of the event, derived from satellite imagery by visual interpretation by CEMS Mapping team.



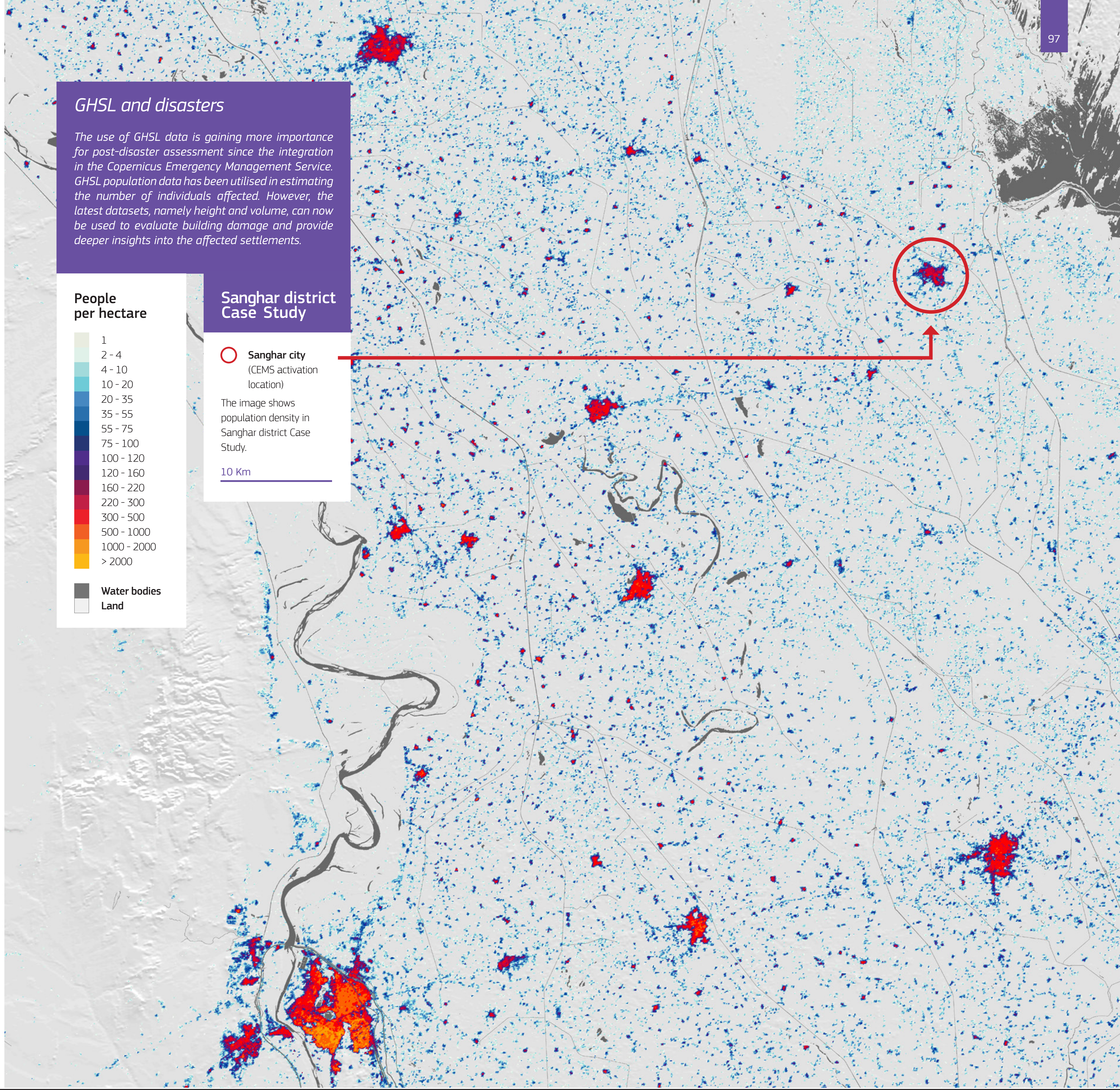
Damage assessment, Sanghar

The Figure shows the damage assessment of the buildings in Sanghar, derived from satellite imagery by visual interpretation by CEMS Mapping team.



GHSL and disasters

The use of GHSL data is gaining more importance for post-disaster assessment since the integration in the Copernicus Emergency Management Service. GHSL population data has been utilised in estimating the number of individuals affected. However, the latest datasets, namely height and volume, can now be used to evaluate building damage and provide deeper insights into the affected settlements.



4.2 Settlements and
Earthquakes

Earthquake in Syria and Türkiye in February 2023

Throughout history, earthquakes have been a persistent challenge for human societies living in seismically active areas. In some instances, earthquakes have had a significant impact on societies, causing destruction that led to their decline or collapse. Today, our understanding of earthquakes has advanced significantly, and we have learned to assess the risks of earthquakes to occur. As a result, many countries are

> Many countries are creating emergency preparedness plans to support communities affected by these natural disasters.

developing building codes and urban planning strategies to better withstand earthquakes, as well as creating emergency preparedness plans to support communities affected by these natural disasters. However, not all regions have access to this knowledge and information, and it is not always disseminated to policymakers and engineers.

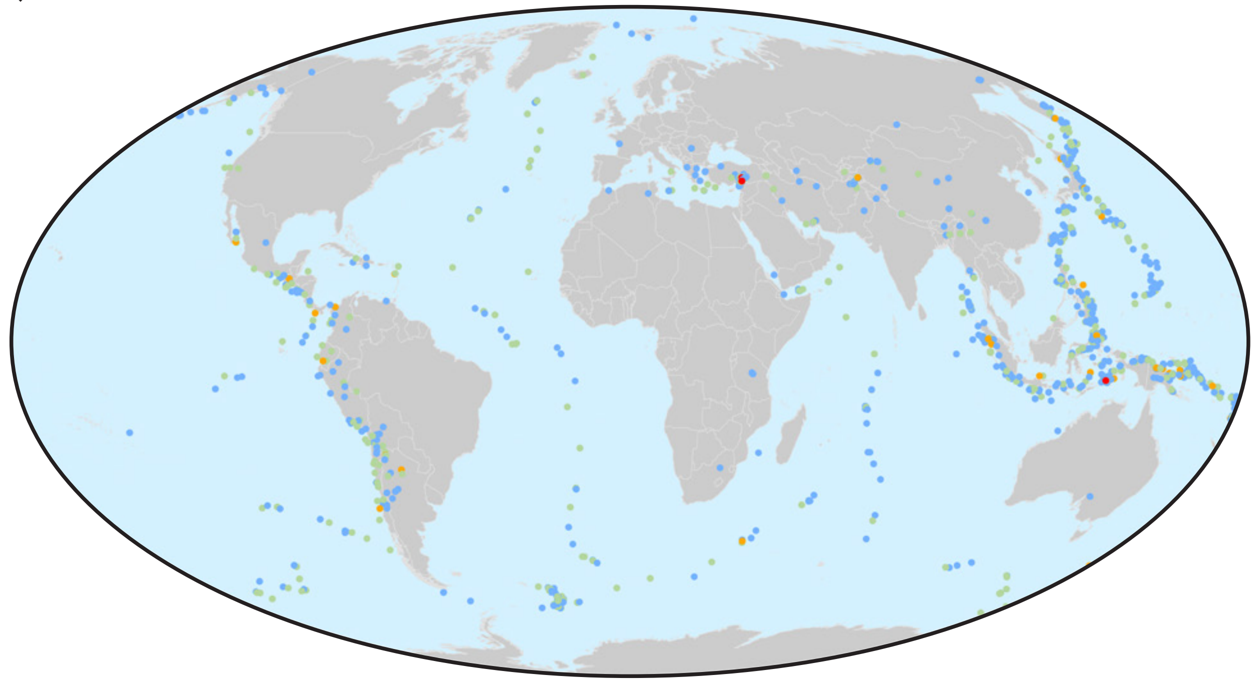
The increasing population and urbanisation in areas prone to earthquakes pose ongoing challenges for disaster management. Between 1998 and 2017, seismic events resulted in a cumulative toll of nearly 750,000 fatalities worldwide, accounting for more than half of all the natural disaster-related deaths. During this period, earthquakes also affected over 125 million people, causing injuries, displacement, homelessness, or evacuation during the emergency response phase of the disaster. These statistics highlight the importance of implementing effective disaster preparedness and mitigation strategies to minimise the impact of earthquakes on human populations.

> The importance of implementing effective disaster preparedness and mitigation strategies to minimise the impact of earthquakes on human populations.

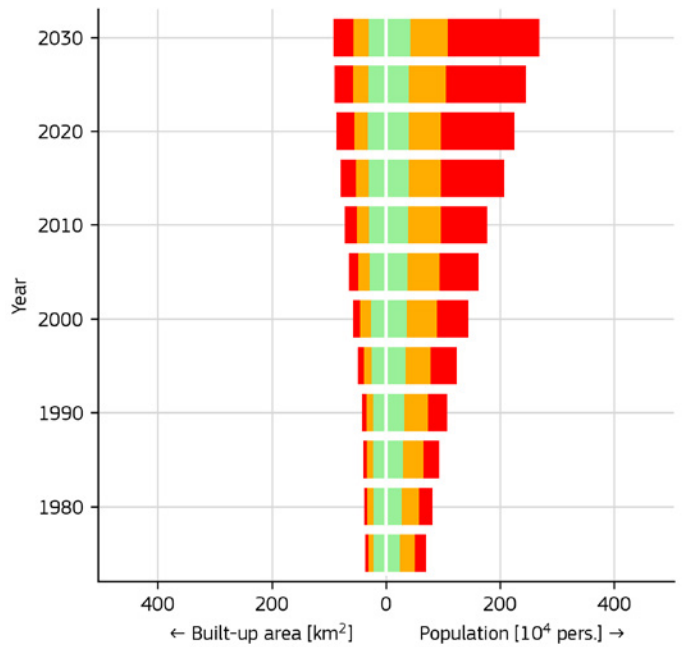
On 6 February 2023, one of the most powerful earthquakes recorded in the region struck the southeastern region of Türkiye and the northwestern region of Syria, which is recognised as one of the most seismically active areas globally. Türkiye has been taking various measures to mitigate and respond to earthquakes, and this event serves as a further reminder of the importance of implementing effective disaster preparedness and mitigation strategies, as mentioned above.

Global earthquakes
2023

Earthquakes recorded between January and June 2023 by magnitude (moment magnitude scale or Mw).

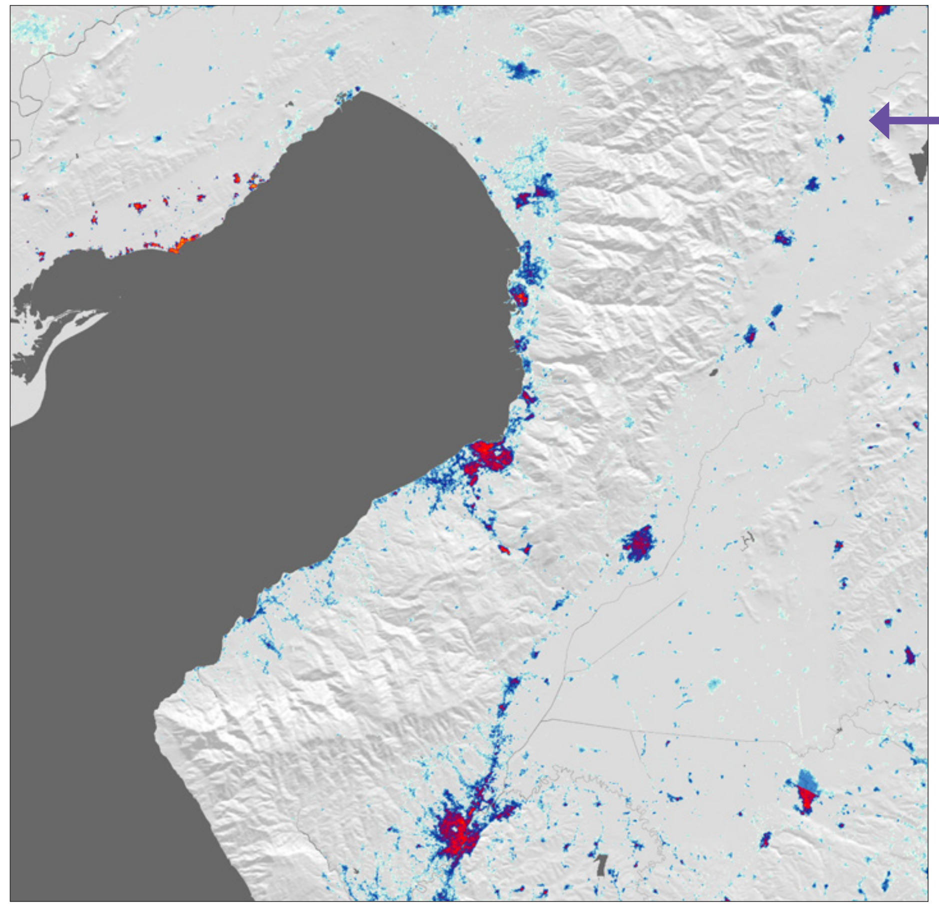


SETTLEMENT DYNAMICS 1975 - 2030
2023 Anatolian Earthquake Case Study



Population in the affected area

Population density in the 2023 Anatolian Earthquake affected area. Population is concentrated along the Anatolian fault, the epicentre of the earthquake, and along the coastline.



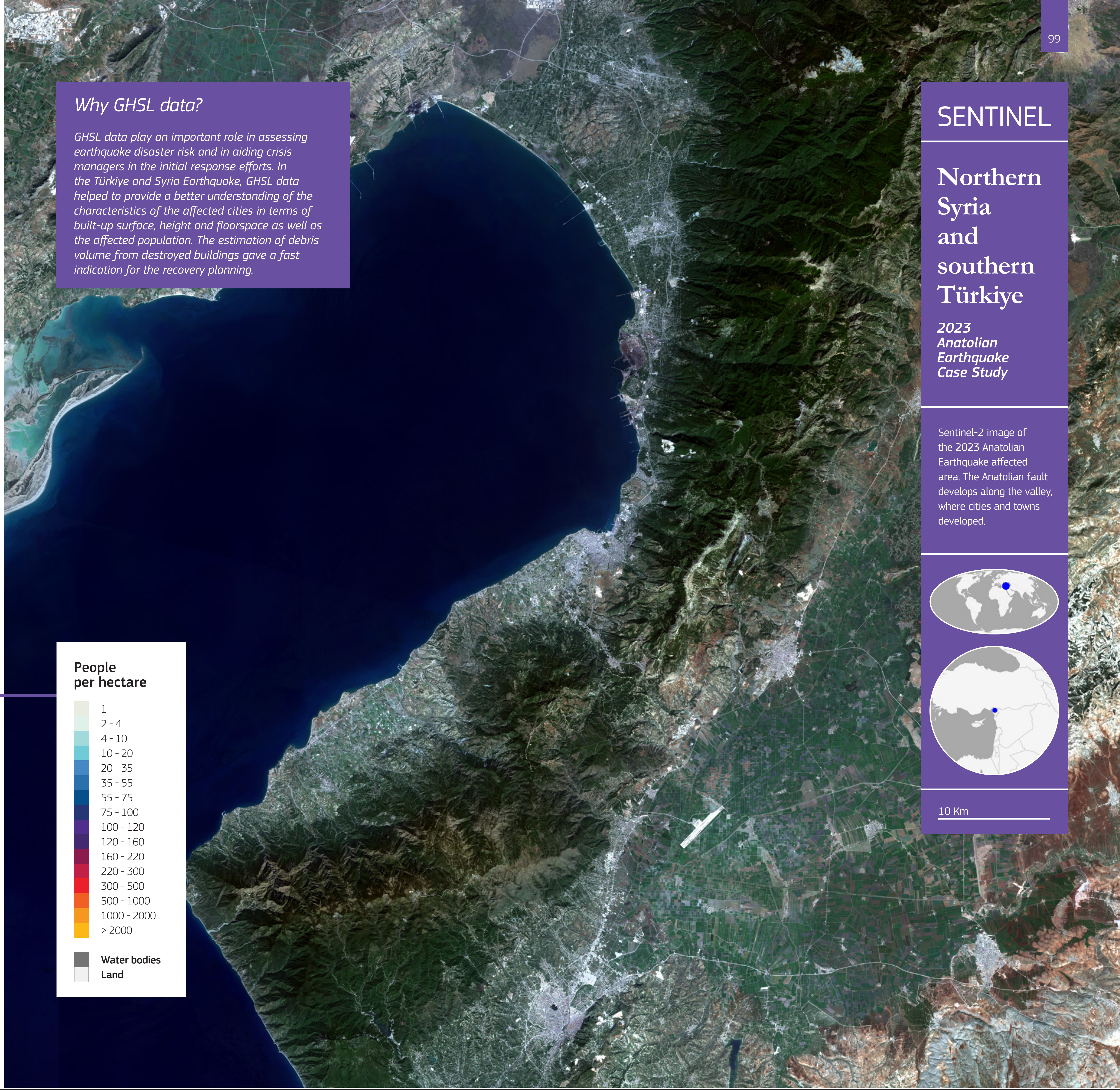
People per hectare

1
2 - 4
4 - 10
10 - 20
20 - 35
35 - 55
55 - 75
75 - 100
100 - 120
120 - 160
160 - 220
220 - 300
300 - 500
500 - 1000
1000 - 2000
> 2000

Water bodies
Land

Why GHSL data?

GHSL data play an important role in assessing earthquake disaster risk and in aiding crisis managers in the initial response efforts. In the Türkiye and Syria Earthquake, GHSL data helped to provide a better understanding of the characteristics of the affected cities in terms of built-up surface, height and floorspace as well as the affected population. The estimation of debris volume from destroyed buildings gave a fast indication for the recovery planning.



SENTINEL

Northern Syria and southern Türkiye

2023 Anatolian Earthquake Case Study

Sentinel-2 image of the 2023 Anatolian Earthquake affected area. The Anatolian fault develops along the valley, where cities and towns developed.

10 Km

Key data

Free and open global access to valuable information, such as GHSL data, can enhance rapid response efforts in the face of hazards and natural disasters. This data provide crucial details regarding the affected population and their geographic location, which can help optimise the distribution of rescue teams and resources. Additionally, such information on population and building characteristics is essential in the development of effective emergency plans and urban planning strategies.

EU's earthquake response
Buildings collapsed after the earthquake in Gaziantep, Türkiye. The Emergency Response Coordination Centre, EU member and participating states and Turkish authorities rapidly mobilised assistance.
© European Union, 2023 (photographer: Lisa Hastert), CC BY-ND 2.0 Deed, via Flickr

Türkiye is a highly seismically-active region due to the presence of the East Anatolian and North Anatolian fault zones. On 6 February 2023, a 7.8-magnitude earthquake struck with an atypical 7.5-magnitude aftershock occurring nine hours later. The epicenter of both seismic events was located in the East Anatolian Fault Zone.

On 6 February 2023, a 7.8-magnitude earthquake struck with an atypical 7.5-magnitude aftershock occurring nine hours later.

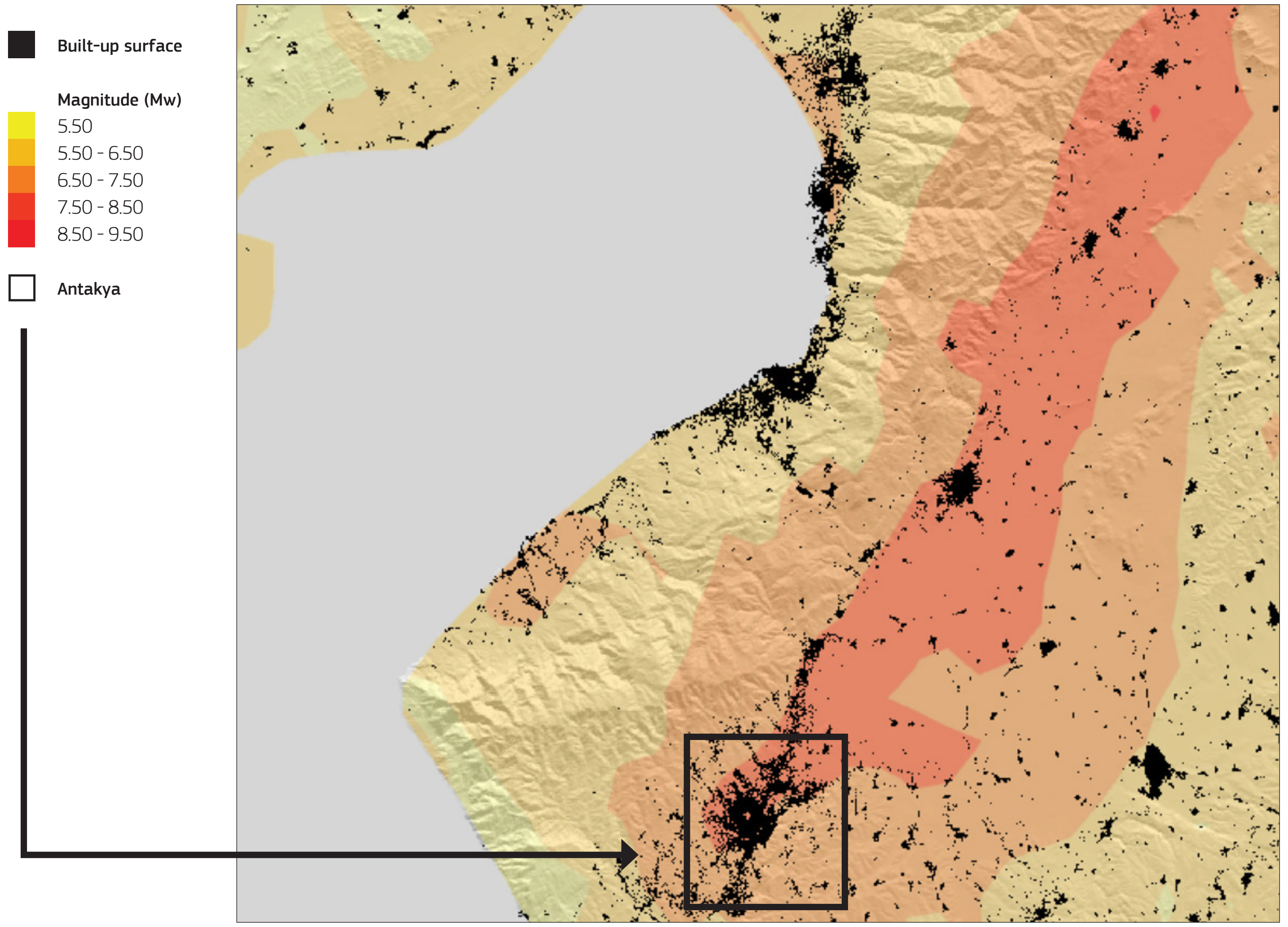
As of 19 February 2023, over 830,000 buildings were either destroyed or damaged in Türkiye alone as a result of these seismic events. In Syria, over 1,100 buildings collapsed or were at risk to collapse in areas under government control. In the areas not under governmental control, more than 8,900 buildings were partially or entirely destroyed, resulting in over 11,000 people being left homeless.

GHSL data provide a quick estimation of the potentially affected population and a characterisation of the settlement structure in the affected area.

In destructive events, such as the one described, rapid response is critical for saving lives. In the immediate aftermath of an event, GHSL data provide a quick estimation of the potentially affected population and a characterisation of the settlement structure in the affected area. This information is embedded in the operational Mapping of CEMS and facilitates a rapid emergency response, which is essential in minimising casualties in such events.

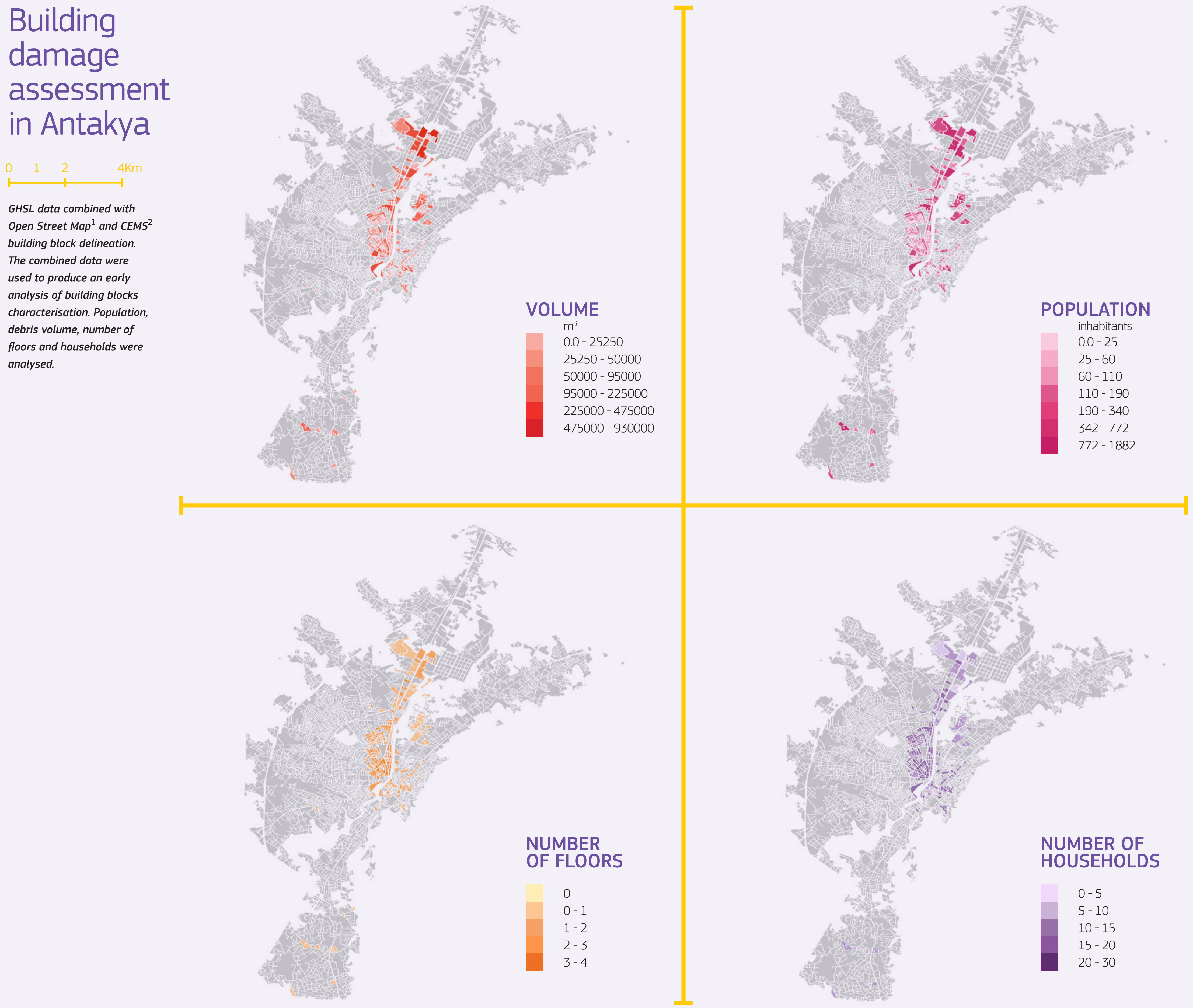
Earthquake magnitude map

Magnitude map of the earthquake occurring in Türkiye and Syria in February 2023. Antakya was one of the most devastated cities, sustaining damage to cultural and historical sites.



Building damage assessment in Antakya

GHSL data combined with Open Street Map[1] and CEMS[2] building block delineation. The combined data were used to produce an early analysis of building blocks characterisation. Population, debris volume, number of floors and households were analysed.



4.3 Settlements and

Tsunamis

Indian Ocean Tsunami that hit Banda Aceh in 2004

Tsunamis are catastrophic ocean waves, usually caused by a submarine earthquake, an underwater or coastal landslide, or a volcanic eruption. While they are relatively infrequent events, they can be extremely devastating when they do occur. Two of the most powerful tsunamis in recent history were the Indian Ocean Tsunami of 2004 and the Great East Japan Earthquake and Tsunami of 2011. These events caused widespread destruction and loss of life in the communities and towns affected. The Indian Ocean Tsunami caused over 230,000 deaths and extensive damage to infrastructure, homes, and businesses in multiple countries around the Indian Ocean. The Great East Japan Earthquake and Tsunami exceeded many protection infrastructures and caused loss of life, despite Japan being prepared with infrastructure and tsunami alert systems.

Two of the most powerful tsunamis in recent history were the Indian Ocean Tsunami of 2004 and the Great East Japan Earthquake and Tsunami of 2011.

Early warning systems have been established around the world to help prepare for and prevent the devastating effects of tsunamis, under the Sendai Framework.

One important aspect of early warning systems is the number of people that need to be evacuated and their spatial distribution.

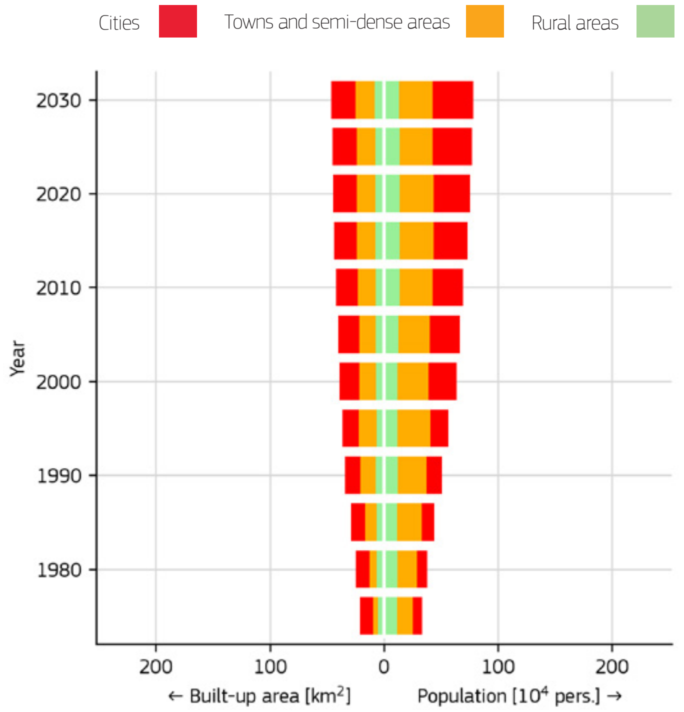
As tsunamis cannot be predicted, early warning systems have been established around the world to help prepare for and prevent the devastating effects of tsunamis, under the Sendai Framework. These systems use a variety of techniques to detect the onset of a tsunami and issue warnings to coastal populations in order to evacuate to safer areas. One important aspect of early warning systems is the availability of population estimates, which provide insights on the number of people that need to be evacuated and their spatial distribution. Low-lying areas near tectonic fault zones are carefully mapped and models are generated to estimate possible new tsunami-related coastal inundations. Overlaying model outputs and population distribution also gives valuable information for disaster prevention plans.

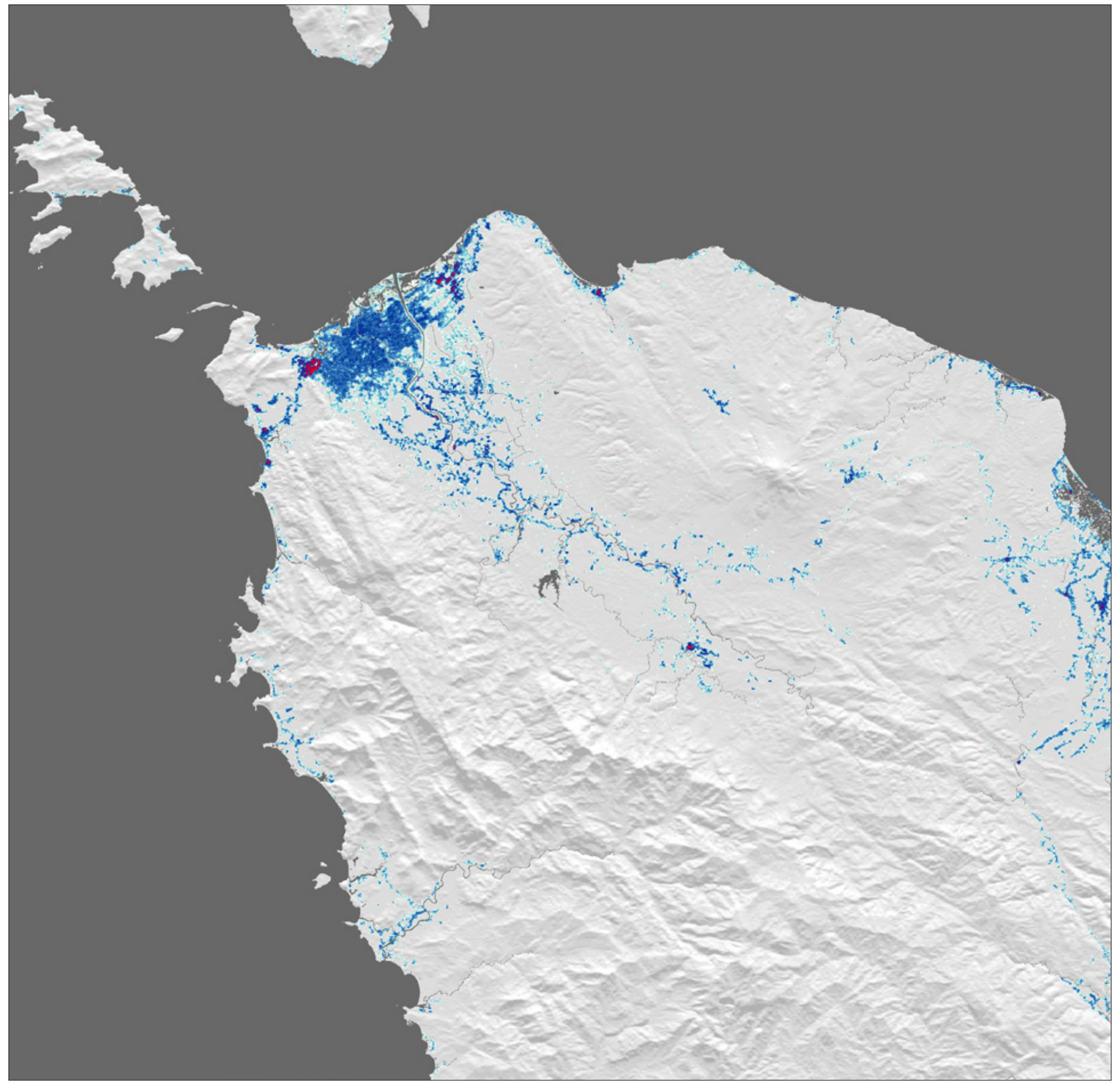
Population matters !

GHSL population data play a crucial role in the development and operation of early warning systems. Experts can identify population demographics and distribution, and use this information to assess how they may be impacted by potential hazards and risks. Additionally, population data is essential for the development of effective early warning systems, enabling communities to better prepare for and respond to a range of potential threats and hazards.

SETTLEMENT DYNAMICS 1975 - 2030

Banda Aceh Case Study





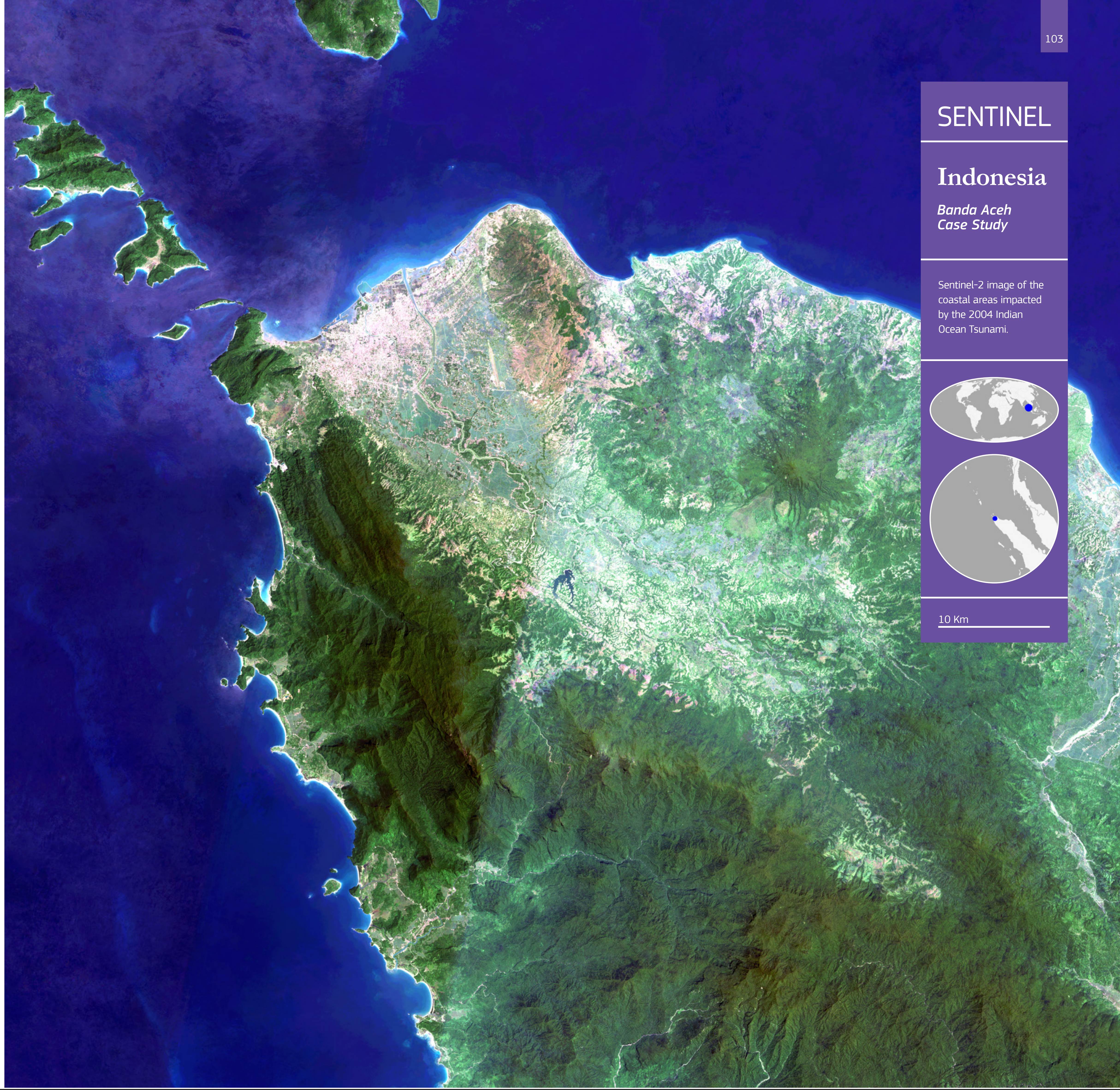
Population distribution

Population map based on GHSL data over the northern Sumatra island.

People per hectare

- 1
- 2 - 4
- 4 - 10
- 10 - 20
- 20 - 35
- 35 - 55
- 55 - 75
- 75 - 100
- 100 - 120
- 120 - 160
- 160 - 220
- 220 - 300
- 300 - 500
- 500 - 1000
- 1000 - 2000
- > 2000

- Water bodies
- Land



SENTINEL

Indonesia

Banda Aceh Case Study

Sentinel-2 image of the coastal areas impacted by the 2004 Indian Ocean Tsunami.

10 Km

Before the tsunami

Quickbird high resolution image over Banda Aceh before the tsunami impact.

Ship in the port

The ship was moored in the port.

The city of Banda Aceh suffered the largest number of deaths.

A major earthquake struck off the west coast of northern Sumatra, Indonesia, on 26 December 2004, producing a massive tsunami with waves up to 30 metres high. This resulted in the widespread devastation of coastal communities along the Indian Ocean. The disaster had a direct impact on Aceh (Indonesia), Sri Lanka, Tamil Nadu (India), and Khao Lak (Thailand), causing significant disruptions to living conditions and trade. The city of Banda Aceh suffered the largest number of deaths. The tsunami caused extreme destruction in the northwestern areas of Banda Aceh and the wave inundation spread 3-4 kilometers throughout the city. Homes, except for reinforced concrete ones with brick walls, were swept away or destroyed. The flow depth was at the level of the second floor in the city centre, and the debris piled up along the streets and in the ground-floor storefronts. Footage showed that the Aceh River was flowing backward, carrying debris and people from destroyed villages up to 40 kilometers inland.

The importance of built-up data

Experts are able to assess the amount of infrastructure damage by detecting the settlements in pre-disaster and post-disaster imagery. GHSL data provide additional support to the pre-disaster assessment by characterising the built-up area existing in the affected area. This information allows experts to accurately determine the extent of the damage caused by the disaster and helps inform mitigation and recovery efforts.

Physical damage and exposure

The physical damage from tsunami impacts can be quantified by comparing pre-disaster and post-disaster imagery. GHSL data provide additional support to the pre-disaster assessment by characterising the built-up area. GHSL data also allow crisis management practitioners to assess disaster risk, plan reconstruction and deploy early warning systems.

After the tsunami

Quickbird high resolution satellite image over Banda Aceh after the tsunami impact. The coastline appears completely changed after the wave retracted.

Empty destroyed port

The tsunami moved the ship two kilometres inland.

After the tsunami struck the coast, the port of Banda Aceh was destroyed and flooded, and infrastructures were wiped out. The tsunami wave affected the coastline, as well as settlements and agricultural fields several kilometres inland.

The tsunami's wave carried a ship moored in the port two kilometres inland. Today, the ship remains in the location it was found after the tsunami, and it has become a memorial of the disaster.

Tsunami memorial

The image shows the ship that landed on the roof top. It was left in that location as a memorial of the disaster.

4.4 Settlements and Volcanoes

Living on the slopes of Mount Merapi

Volcanoes are typically found at the edges of tectonic plates, with many of them being active and some posing significant dangers to nearby populations. Although volcanic eruptions primarily affect a limited geographical area of a few kilometres around the volcano, the resulting smoke and ash plumes can impact faraway regions. The smoke, ash, and gases released during a volcanic eruption can reach the upper atmosphere and have global impacts on the climate and weather

Long-term volcanic activity can make certain areas unsuitable for human settlements.

patterns or pose significant risks to air traffic. At the same time, volcanic eruptions can contribute to the creation of fertile soil for agriculture and can be harnessed as a source of geothermal energy for electricity production. Moreover, volcanoes can also boost local economies through tourism. However, volcanic eruptions can be highly destructive, resulting in the loss of human lives. Long-term volcanic activity can make certain areas unsuitable for human settlements. Nearly 1,500 volcanoes around the world are considered potentially active, although the actual number varies based on criteria used. Currently, the Global Volcanism Program of the Smithsonian Institution considers around 50-60 volcanoes as undergoing eruption at any given moment.
Approximately 8% of the Earth's population resides within a

Currently, the Global Volcanism Program considers around 50-60 volcanoes as undergoing eruption at any given moment.

distance of 100 kilometres from a volcano that has experienced at least one significant eruption[1]. This puts a sizable portion of the world's population at risk of being directly impacted by volcanic activity, highlighting the importance of ongoing monitoring and research efforts to understand and mitigate the risks posed by volcanic eruptions.

Population and volcanic risk

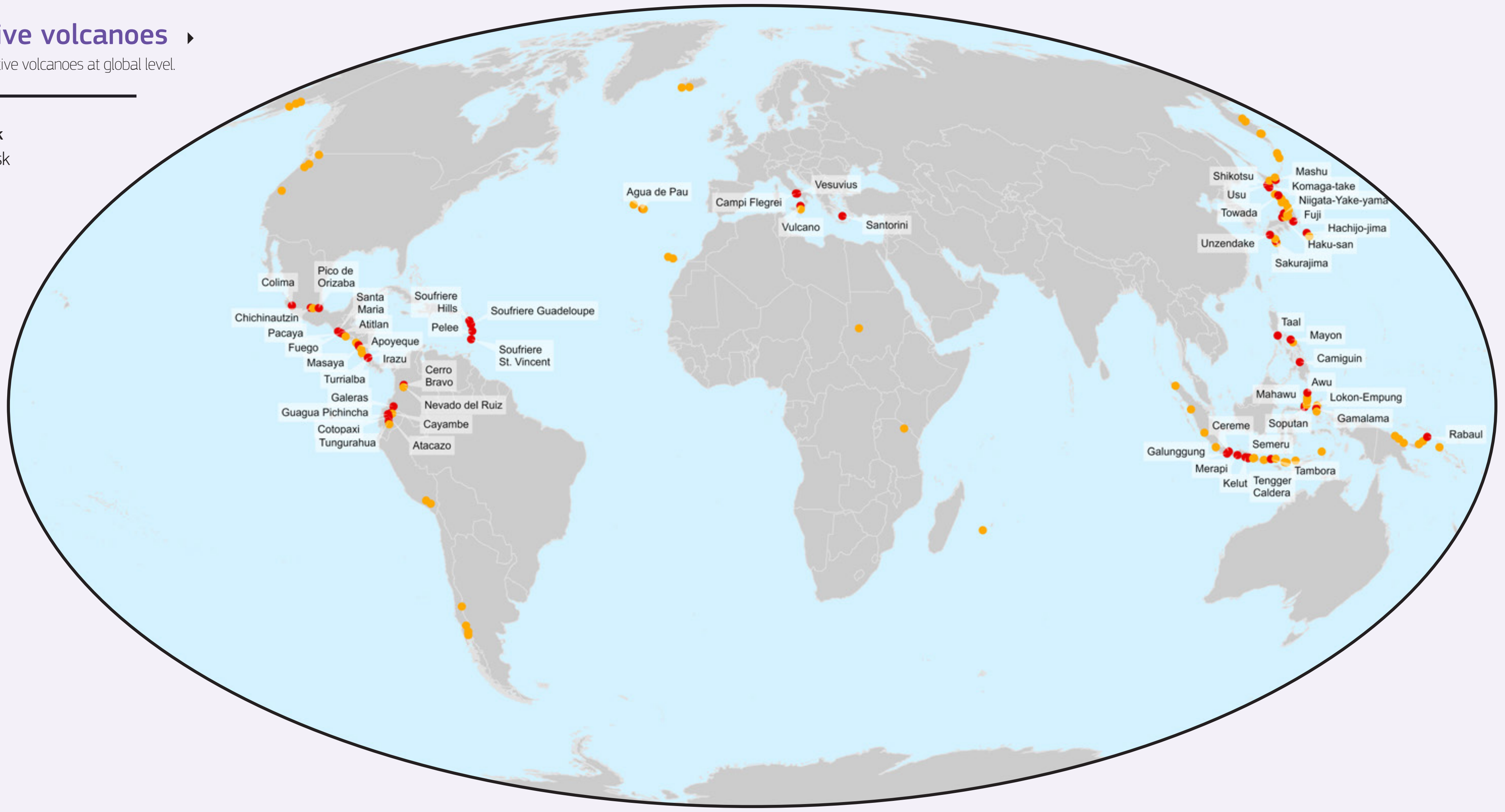
The level of potential risk posed by a highly active volcano is not solely determined by its activity level, but also by the presence or absence of nearby population. By assessing the number and distribution of settlements and population in proximity to a volcano, experts can better evaluate the overall level of potential risk. Risk assessment is essential in developing and implementing effective evacuation plans to protect communities situated on or near the slopes of a volcano, which are most at risk in the event of an eruption.

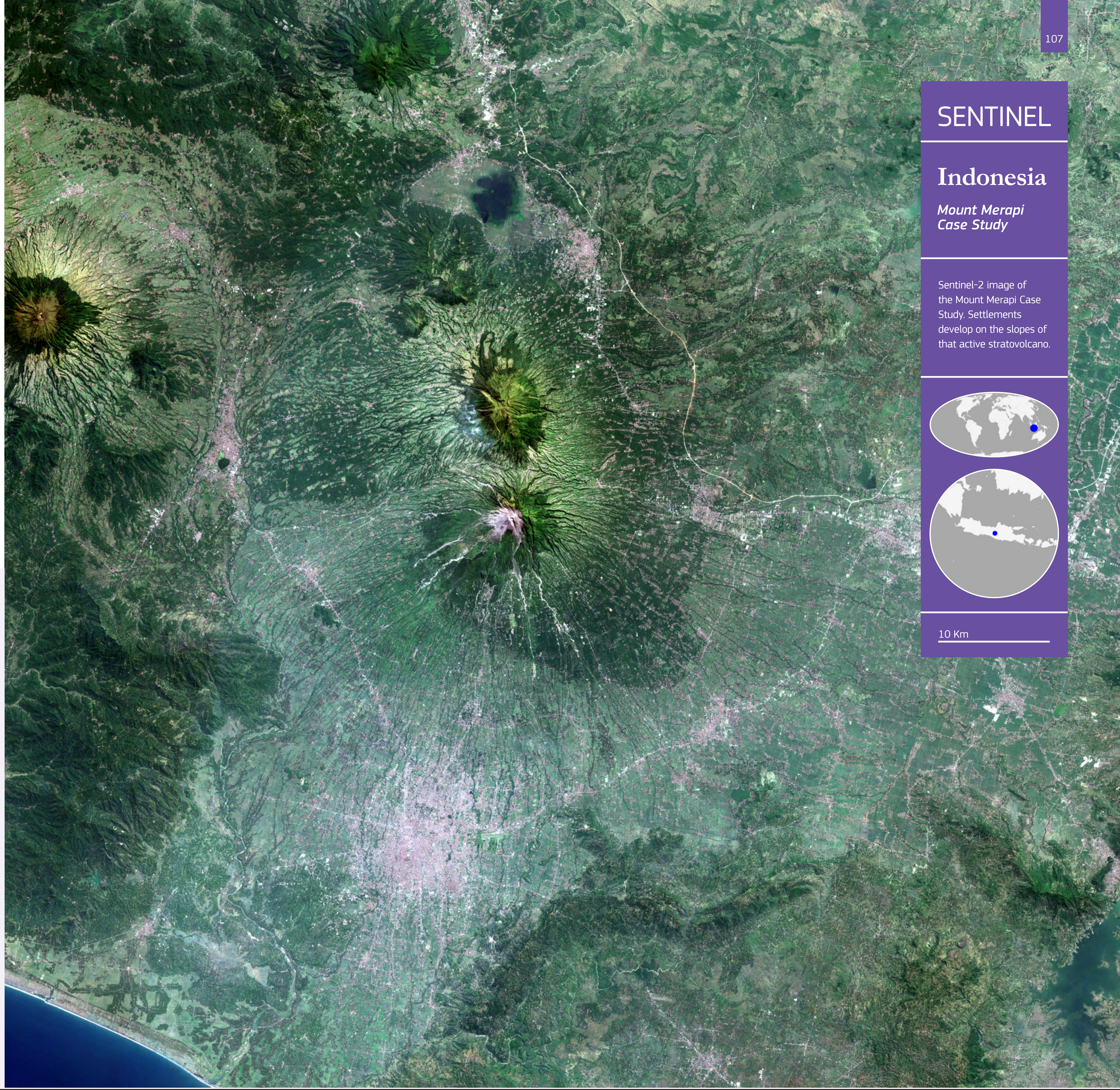
▲ *Mount Merapi* © herukru - stock.adobe.com
Mount Merapi, in Java (seen from Spot Riyadi). Settlements are spread around the volcano, hence the importance of evacuation plans and early warning systems.

Global active volcanoes ›

Level of risk of the active volcanoes at global level.

Level of risk
Moderate risk
High risk





SENTINEL

Indonesia

Mount Merapi Case Study

Sentinel-2 image of the Mount Merapi Case Study. Settlements develop on the slopes of that active stratovolcano.

10 Km

Mount Merapi, located on the island of Java in Indonesia, is an active and highly hazardous volcano with a long history of eruptions, resulting in significant damage to property and countless fatalities over the past millennia.

In March 2023, the volcano began a series of increasingly severe eruptions that produced avalanches of hot, poisonous gas and lava referred to as lahars.

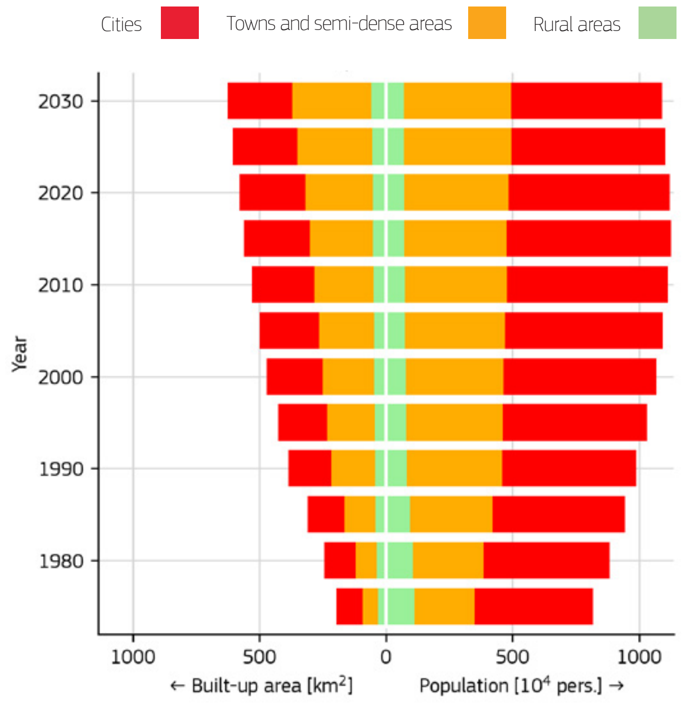
Over time, the surrounding region has become densely populated, with urban centres situated on the lowlands surrounding the volcano, and the volcano's fertile slopes attracting farmers. In March 2023, the volcano began a series of increasingly severe eruptions that produced avalanches of hot, poisonous gas and lava referred to as lahars. In response, authorities suspended tourism and mining activities on the slopes. The eruptions generated large columns of smoke that produced numerous pyroclastic flows, which cascaded down the volcano's heavily populated slopes, causing widespread destruction. The flows constituted Merapi's most significant lava flow since authorities raised the alert level to the second-highest in November 2020.

Magelang district, Yogyakarta

Back in November 2010, the region was covered in ash, as eruptions persisted, forcing thousands to seek shelter. Rivers were swollen by seasonal rains, ash and debris from the mountain.

SETTLEMENT DYNAMICS 1975 - 2030

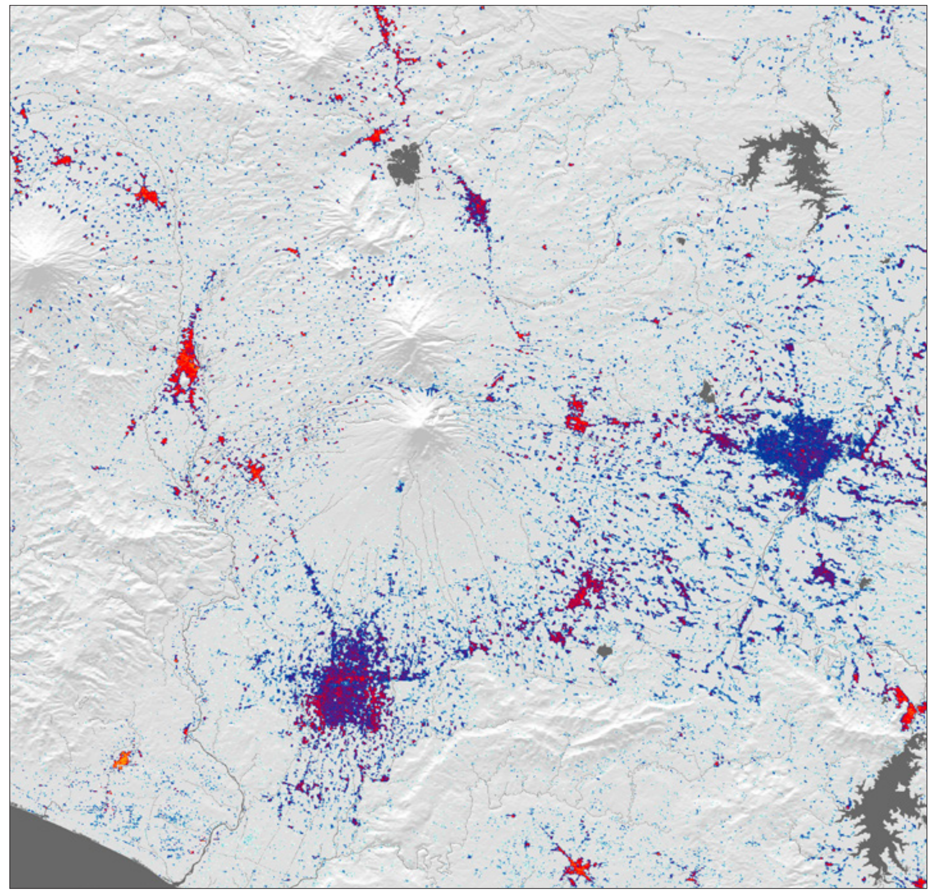
Mount Merapi Case Study



Population and built-up in rural areas have remained relatively unchanged, while the population and built-up in **cities,** and in **towns and semi-dense areas** has increased.

Population in 1975

The population in 1975 residing in close proximity to the volcano was significantly lower than in 2020.



1975 → 2020

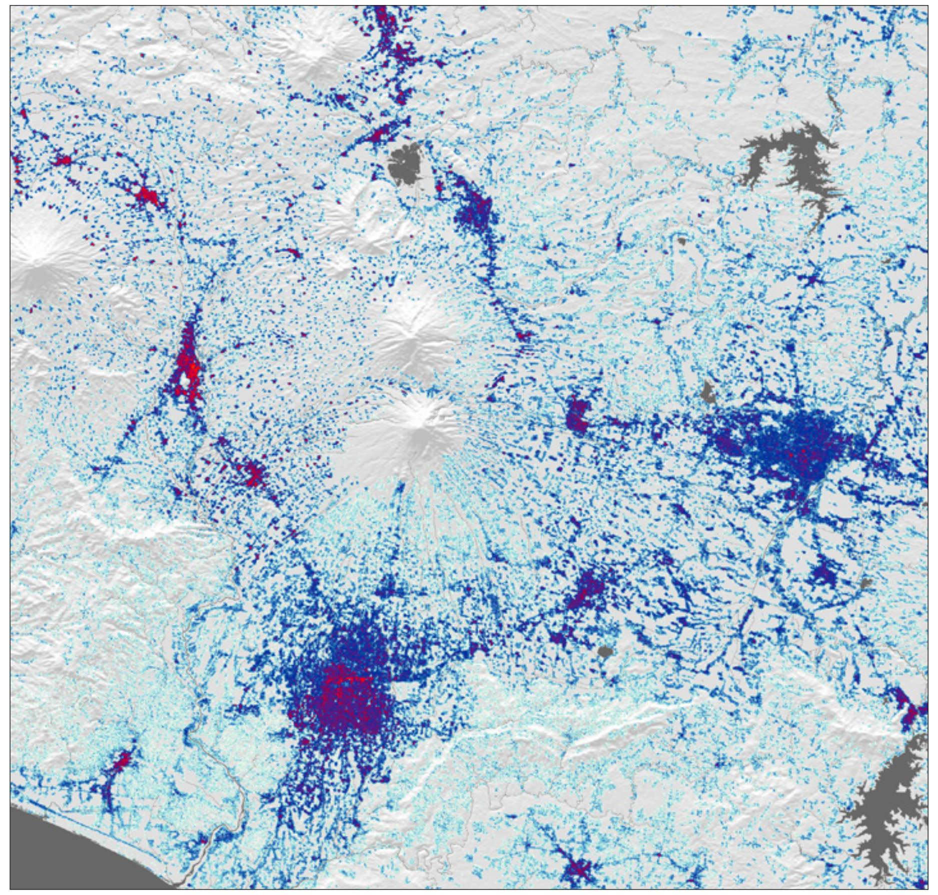
People per hectare

- 1
- 2 - 4
- 4 - 10
- 10 - 20
- 20 - 35
- 35 - 55
- 55 - 75
- 75 - 100
- 100 - 120
- 120 - 160
- 160 - 220
- 220 - 300
- 300 - 500
- 500 - 1000
- 1000 - 2000
- > 2000

- Water bodies
- Land

Population in 2020

The population residing in close proximity to the volcano has significantly increased over the past half a century, resulting in an increased number of people exposed to volcano's hazards.



Settled on the slopes

Monitoring volcanic activity is critical in areas where settlements are growing on the slopes of a volcano. Real-time monitoring and early warning systems are essential to alert nearby communities of potential dangers and ensure a timely evacuation. Overall, a multi-pronged approach that brings together accurate monitoring, effective urban planning, appropriate civil management, and citizen engagement is necessary for effective disaster risk reduction and management in eruption-prone areas.

Built-up surface map

- More densely built-up
- Less densely buit-up
- Water bodies
- Land

BUILT-UP

Indonesia

Mount Merapi Case Study

Human settlements are found on the volcano slopes. Fertile soils attract communities closer to the volcano despite the high risk of eruptions.

10 Km

GLOSSARY

Copernicus: Copernicus is the Earth Observation (EO) component of the EU's Space programme. Copernicus is managed by the European Commission, and includes the Sentinel satellite missions (e.g. Sentinel-1 and Sentinel-2), developed by the European Space Agency (ESA), which collect images on the global environment.
https://www.copernicus.eu/

Copernicus Emergency Management Service (CEMS): As one of six information services of Copernicus, CEMS supports all actors involved in the management of natural or man-made disasters, by providing geospatial data and images, for informed decision-making. CEMS includes three components for the On-Demand Mapping, Exposure Mapping, and Early Warning and Monitoring, for disaster events anywhere in the world. The CEMS Exposure Mapping component, for example, provides highly accurate and continuously updated information on the presence of human settlements and population, with the Global Human Settlement Layer (GHSL) datasets. CEMS is managed directly by the European Commission's Joint Research Centre (JRC).
https://emergency.copernicus.eu/

Emergency Response Coordination Centre (ERCC): At the heart of the EU Civil Protection Mechanism, the ERCC coordinates the delivery of assistance to disaster-struck countries.
https://civil-protection-humanitarian-aid.ec.europa.eu/what/civil-protection/emergency-response-coordination-centre-ercc_en

European Space Agency (ESA): ESA is responsible for the development of the space segment component of the Copernicus programme, and operates the Sentinel EO satellite missions, including Sentinel-1 and Sentinel-2.
https://www.esa.int/Applications/Observing_the_Earth/Copernicus

Food and Agricultural Organization (FAO): The FAO is the specialised agency of the United Nations (UN) that leads international efforts to defeat hunger, and that collects global food and agricultural statistics.
https://www.fao.org/home/en/

Global Disaster Alert and Coordination Service (GDACS): GDACS is a cooperation framework between the UN, the European Commission and disaster managers worldwide to improve alerts, information exchange and coordination in the first phase after major sudden-onset disasters. The service provides alerts on hazardous events and their severity, and on the potential of a disastrous event.
https://www.gdacs.org/

Global Human Settlement Layer (GHSL): As the Exposure Mapping component of CEMS, GHSL provides open and free data and tools for assessing the human presence on the planet Earth, through time-series of global information on built-up areas, population, and human settlements.
https://human-settlement.emergency.copernicus.eu/

Intergovernmental Panel on Climate Change (IPCC): The IPCC is the intergovernmental body of the UN for assessing the science related to climate change.
https://www.ipcc.ch/

Landsat: The Landsat programme consists of a series of EO satellite missions, jointly managed by the US National Aeronautics and Space Administration (NASA), and the US Geological Survey (USGS). Since 1972, Landsat satellites have continuously acquired images of the Earth's land surface and provided an interrupted data archive on natural resources and the environment.
https://landsat.gsfc.nasa.gov/data/

National Aeronautics and Space Administration (NASA): NASA is the US government agency responsible for science and technology related to air and space.
https://www.nasa.gov/

NDVI: The Normalised Difference Vegetation Index (NDVI) is a satellite image-derived measure of vegetation density and health. Values close to one indicate high vegetation density; values close to zero low vegetation density

New Urban Agenda: The New Urban Agenda was adopted at the UN Conference on Housing and Sustainable Urban Development (Habitat III) in Quito, Ecuador, on 20 October 2016. This international framework aims to address urban challenges and promote inclusive, safe, resilient, and sustainable cities.
https://unhabitat.org/about-us/new-urban-agenda

OpenStreetMap (OSM): OpenStreetMap is a collaborative mapping project that allows users to create and edit detailed, open-source maps of the world.
https://www.openstreetmap.org/about

Paris Agreement: The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. The Paris agreement goal is implementing measures that will limit the warming of the planet.
https://unfccc.int/process-and-meetings/the-paris-agreement

Sendai Framework for Disaster Risk Reduction 2015-2030: The Sendai Framework was the first major agreement of the post-2015 development agenda and provides UN Member States with concrete actions to protect development gains from the risk of disaster. This international framework aims to assess disaster risk and to reduce and mitigate impact of hazards.
https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030

Sentinel-2: Sentinel-2 is a polar-orbiting, multispectral high-resolution EO satellite that provides optical imagery of the Earth's land surface. The first Sentinel-2 satellite was launched in June 2015. Sentinel-2 is part of the Sentinel family of satellite missions that were developed by ESA as part of the Copernicus programme.
https://sentinels.copernicus.eu/web/sentinel/home

Sustainable Development Goals (SDGs): The SDGs (or Global Goals) are a set of 17 world development goals that were created by the UN in 2015. The SDGs provide an international framework agreement that defines a set of agreed global sustainable development goals to promote the prosperity and sustainability of the planet Earth.
https://www.globalgoals.org/

GHSL-SPECIFIC TECHNICAL TERMINOLOGY

Building: Any roofed structure erected above ground for human use.
Built-up area: The land area of villages, towns or cities covered by buildings.
Built-up surface: The area of land covered by buildings.
Built-up volume: The product of built-up surface and its height.
Degree of Urbanisation (DEGURBA): The Degree of Urbanisation (DEGURBA) is a methodology for delineating Cities, Towns and semi-dense areas, and Rural areas for the purposes of international statistical comparison, which was adopted by the United Nations Statistical Commission in March 2020. With the DEGURBA methodology, the urban-rural continuum is classified into different settlement types. Specifically, DEGURBA uses the GHSL spatial grids (1 x 1 km resolution) of population and of built-up surface, to generate the classified spatial grids of settlement types (called GHS-SMOD). The DEGURBA methodology is also used to classify administrative or statistical spatial units into the different settlement types.
Non-residential area: Built-up surface that is exclusively for non-residential use.
Residential area: Built-up surface that is dedicated primarily for residential use.
Settlement dynamics plot: The settlement dynamics plot shows the values for built-up surface and population over time, for the land area of a Case Study. The built-up surface and population density values are provided for the three settlement types: cities; towns and semi-dense areas; and rural areas. In this Atlas, each settlement dynamics plot covers the time-span 1975-2030, at five-year intervals. The 2025 and 2030 estimates are based on an extrapolation from the 1975-2020 figures.
"Urban" versus "Rural": Urban and rural settlement types are differentiated b ased o n specific combinations of resident population density, built-up surface density, and population size, observed at a definite spatial generalisation scale, according to the Degree of Urbanisation.

THE GLOBAL HUMAN SETTLEMENT LAYER (GHSL) DATASETS

The GHSL datasets are a set of global spatial grids (i.e. digital maps) of the human presence on the planet Earth. The GHSL spatial grids shown in this Atlas are listed in the Table below.

GHSL VARIABLE	GHSL DATASET	DESCRIPTION OF GHSL DATASET
Built-up surface	GHS-BUILT-S	Spatial grid reporting the area of land covered by buildings (in square meters), for the period 1975 to 2030, at 5-year intervals. Available at spatial resolutions: 10 x 10 m; 100 x 100 m; 1 x 1 km.
Built-up surface non-residential	GHS-BUILT-S-NRES	Spatial grid of the non-residential built-up surface. Spatial resolution: 10 x 10 m.
Built-up volume	GHS-BUILT-V	Spatial grid of the total volume of buildings in each grid cell. Spatial resolution: 100 x 100 m.
Built-up characteristics	GHS-BUILT-C	Spatial grid combining residential and non-residential built-up surface, several vegetation types, and further subdivided based on building heights.
Population	GHS-POP	Spatial grids of residential population, for the period 1975-2030, at 5-year intervals. Available at spatial resolutions: 100 x 100 m; 1 x 1 km.
Settlement types	GHS-SMOD	Spatial grid of classified settlement types (i.e. cities, towns and semi-dense areas, and rural areas), produced based on the Degree of Urbanisation methodology, for the period 1975-2023, at 5-year intervals. Spatial resolution: 1 x 1 km.
Land fraction	GHS-LAND	Land fraction derived from Sentinel-2 composite, Open Street Map data, and the high-resolution Copernicus global surface water map.
Satellite-measured surface reflectance	GHS-Sentinel-2	Global, cloud-free, pixel-based, composite, created from the Sentinel-2 data archive (Level L1C), available in Google Earth Engine for the period January 2017-December 2018.

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https://earthobservations.org/organization/work-programme/geo-human-planet

[2] The Group on Earth Observation (GEO) is a volunteer collaborative intergovernmental body aiming to advance the use of Earth Observation to address societal challenges.
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INTRODUCTION

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CHAPTER 1
A world of human settlements

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[2] Copernicus is the Earth Observation component of the European Union's space programme, looking at our planet and its environment, and with a dedicated family of Sentinel satellites.

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Living in hazardous areas

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Atlas of the **Human** Planet 2024

We live today in an age of fast societal transformation, when humans are having far-reaching impacts on planet Earth. During the past half-century, the world population has doubled to over eight billion people, and most human societies have improved their well-being and life expectancy. At the same time, the movement of people and goods across regions and continents has also increased, and human activities are significantly affecting our planet's ecosystems and climate.

Knowing where people live and work is of key importance for efforts to address major current and future societal challenges. Such efforts include understanding the resilience of societies to the impacts of hazards, both natural and man-made, and to the effects of a changing climate, determining the best paths to sustainable urbanisation, as well as implementing major international initiatives such as Leave No One Behind[1] or Early Warnings For All[2]. Realising these efforts presupposes that we have access to detailed information on human settlements and population, and that information must be global. This demand for information is addressed by the Global Human Settlement Layer (GHSL) spatial database, which includes the key variables of population density, built-up surface, and settlement types, the latter including cities, towns and semi-dense areas, and rural areas.

This Atlas of the Human Planet 2024, the sixth in a series, showcases the vital relevance of information on population and human settlements for addressing a wide range of societal issues. This Atlas is designed for a general, non-technical readership, and makes extensive use of graphics and images. The aim is to inform the widest possible community about the use of science and data to address major societal issues.

Many people's lives, livelihoods and opportunities are being transformed, as human societies adapt to technological and environmental changes. Understanding these changes through the use of data generated by scientific analysis, as described in this Atlas, can guide policy-makers and empower everyone, in making better choices for our common future.

Publications Office of the European Union