Understanding the impact of Earth Observation for sustainable urban development

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Caribou Space for Development | GAFAG an e-GEOS (ASI / Telespazio) Company | urban development eo4sd

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Executive summary

Earth Observation for Sustainable Development (EO4SD) is a programme from the European Space Agency (ESA) with the overall objective to start the integration of satellite information products & services, as 'best- practice' environmental information, in the planning and implementation of the development projects, programmes and activities of the International Financial Institutions (IFIs), together with their respective developing country partners.

Since 2016, the three-year EO4SD-Urban programme has provided Earth Observation (EO) support to three IFIs, covering 17 IFI programmes in 31 unique cities across 15 countries.

This evaluation was commissioned by ESA to understand the impact of the EO4SD-Urban programme specifically, and the impact of EO for urban sustainability more broadly. The overall objective is to improve the space sector's evidence base and communication of the expected impacts of and learnings from the use of EO products for developing world urban centres. This evaluation is organised into four sections:

- **Section one:** The opportunity for Earth Observation to contribute to sustainable urban development.
- **Section two:** Earth Observation for sustainable urban development—an impact evidence review.
- **Section three:** Evaluation of the EO4SD-Urban programme.
- **Section four:** Recommendations.

— *Opportunities and challenges to achieving sustainable urban development*

- **Urbanisation enables people to benefit from increased productivity** through economic density, accelerated innovation from knowledge spill-overs, greater mobility, and access to employment and services.
- **Poorly planned urbanisation has adverse effects;** on social and economic equality, public health, and the natural environment.
- **Within developing country cities there are several specific challenges:**
  - **Housing and informal settlements:** Uncontrolled expansion marginalises low-income populations in peripheral parts of cities, often in dense informal settlements, limiting access to basic services.
  - **Transport:** Without a good transport network, residents have limited options to access socio-economic opportunities, and suffer from increased congestion, air and noise pollution, and Green House Gas (GHG) emissions.

- **Disaster resilience:** Unplanned settlement can occur near natural hazards—such as hills at risk of landsides—increasing populations' risk, whilst replacing open land with impermeable surfaces, such as pavements, that can exacerbate risks such as flooding.
- **Environment and health:** Poorly planned urban expansion results in the loss of natural habitats, decimation of biodiversity and reduces the productivity of surrounding agricultural land.
- **Access to data:** Urban planning requires access to consistent, regular, and accurate data to carry out urban planning and monitoring. Yet many developing country cities do not have sufficiently robust or integrated data. Traditional sources of urban data—population census and public service records—house data in silos which makes it difficult to observe the interconnections that are vital for an integrated approach to urban development.

— *The opportunity for Earth Observation in sustainable urban development*

- **Earth Observation (EO) is the process of gathering information about the physical, chemical, and biological systems of the planet via remote-sensing technologies.** EO is used to monitor and assess the status of and changes in natural and built environments.[1]
- **Many factors have contributed to the increased interest in EO.** The availability of free and open EO data, increasing data accuracy (spatially and temporally), advances in computer processing power and data analytics.
- **EO attributes improve upon or complement existing data sources.** EO is diverse, affordable, objective, repeatable, continuous, and timely to acquire and process.
- **Actions to address urban challenges are advanced by including EO data.** EO is used in the assessment, implementation, and monitoring of sustainable urban activities.

— *Evidence of the impact of EO in urban development*

- EO is providing benefits within urban development in four overarching areas:
  1. Urban planning and monitoring;
  2. Transport planning and monitoring;
  3. Hazard assessment, early warning, and response coordination; and
  4. Monitoring of environmental issues.
- Insights from public literature have contributed evidence to each of these areas:
  - There is evidence of EO being integrated into city plans, slums assessments, and innovations using EO to enable cities to fund development plans by improving tax revenue collection.
  - Although many of the examples of EO demonstration projects for rail and road were in developed countries, there is an opportunity to transfer these learnings to developing countries.
  - Evidence on the benefits of EO for disaster risk assessments and efficient response is plentiful. In addition, there are EO applications to assess urban building/infrastructure risk exposure.
  - Innovations in satellite sensors enable air quality and surface temperature measurement, and they provide cities with critical environmental information.

1 Wikipedia. 'Earth Observation'. https://en.wikipedia.org/wiki/Earth_observation. Accessed February 2020.

— *Overview of the EO4SD-Urban programme*

- EO4SD-Urban is a three-year programme to demonstrate the application and benefits of EO in the urban context.
- The programme collaborated with 17 IFI programmes, in 31 unique cities across 15 countries.
- IFIs received several urban EO products each; there was a demand for more than what was provided, however, budget limitations meant not all requested products could be provided.
- The EO4SD-Urban programme invested in capacity building through webinars and, to a lesser extent, through city trainings and regional workshops when the opportunity was presented.

— *Impact evidence of the EO4SD-Urban programme*

- **Product quality:** Overall accuracy of the EO products were tested to be between 85%–95% and averaged at 90%.
- **Publications:** 13 IFI publications using EO4SD-Urban products were located, highlighting the utility in research and communications.
- **Guiding planning and investment:** Some IFIs using EO4SD-Urban products demonstrated that EO provided new insights that were previously inaccessible, and these insights and images were a powerful communication tool for policy dialogue. There is also evidence of both IFIs and cities implementing recommendations derived from these insights.
- **Solving data scarcity:** EO is a valuable source of data in data-scarce urban environments. A clear use case of EO in data-scarce contexts, is in the identification and delineation of slums. EO4SD-Urban products were shown to enhance the mapping of slums in Dhaka and provide a cost-effective methodology for assessing the needs of slum populations.
- **Improving disaster resilience:** The EO4SD-Urban portfolio included products that enable cities to assess and respond to disaster risk. Products have been used in Semarang, Indonesia, for housing development decisions as well as in Kolkata, India, for flood risk and response.
- **Enabling time and cost savings:** Clear examples are showcased in reducing the time and costs of city diagnostic visits in Dhaka and Karachi. Also in Kigali, Rwanda, EO was highlighted to save time in the process of collecting data on buildings for property valuation.
- **EO integration within IFIs:** Qualitative insights have shown that some IFI Programme Officers do anticipate integrating EO in urban programmes, with additional programmes using EO now operational or in development, while other IFI Programme Officers highlighted the potential for integration.

— *Progress on increasing and sustaining EO uptake for IFIs and cities*

- **Awareness and demand:**
  - Preceding the EO4SD-Urban project, there has been extensive, historical efforts between ESA and IFIs, via previous initiatives and engagement with IFI interest and advisory groups.
  - Demand was created through the initial ESA 'road-show', at various IFI regional meetings and through the EO4SD-Urban consortiums' strong stakeholder engagement. Sharing of real EO use cases was a powerful way to increase demand. There is now evidence of IFI Programme Officers now promoting EO products within and outside their own organisations.

  - To improve demand there needs to be a clear information gap that the use of EO can be shown to fill.
  - Awareness of the potential of EO for urban development is just beginning. As more demonstrations are shared with programmes and cities, it is expected that demand will increase.

- **Capabilities:**
  - IFI Programme Officers generally noted an increase in understanding the potential of EO for urban development. Tailored capacity exchange visits with cities were not within scope and thus cities were engaged through the IFIs, rather than the consortium.
  - However, a need for greater city-level engagement was consistently referred to as an area for EO4SD-Urban programme improvement.
- **IT infrastructure and workflow integration:**
  - To maximise utility at the city level, the format in which EO outputs are shared needs to consider the current IT infrastructure—bandwidth, storage and processing power—available to the city stakeholders.
  - The continuous use of EO needs to be promoted from the top down. It is unlikely that the cities will use EO if it is not integrated into their workflow and regular tasks.
- **Financial resources:**
  - The availability of financing is rarely discussed in isolation but linked to a need for a convincing case for EO, so that funding can be sourced.

— *Recommendation one: Closing the evidence gap of EO in urban development*

- Across EO urban use cases, there is encouraging and positive evidence on the benefits of EO.
- Some urban use cases, such as hazard assessment, early warning and response, have a longer history with using EO and thus have a more mature evidence base. Other use cases, such as transport planning and monitoring, are just starting to be demonstrated.
- New use cases for urban EO are emerging more quickly than the publication of corresponding impact evaluations. It is a matter of both time and commitment of resources to dedicate to measuring the impact of urban EO products.
- More investment in impact measurement is required to close the evidence gaps and keep pace with emerging use cases. In programmes that are integrating EO as a core data source or service, a robust Monitoring and Evaluation (M&E) framework that both articulates and can evaluate the impact of EO within the urban development sector should be established at the start of the programme.
- Impact evaluations should communicate and quantify the benefits of EO - using language and statistics that the development community are familiar with.
- Impact evidence should be widely shared so that others can benefit from these lessons and results.

— *Recommendation two: Improving the uptake and impact of EO for urban development*

TACTICAL CONSIDERATIONS:

- **Facilitate longer and deeper engagements at the city and IFI level:** In recognition of the more nascent phase of EO in urban, and in the interest of continuing to build momentum, the engagement time on a programme should be lengthened and the amount of interaction at the city level should be increased.
- **Formats of sharing EO outputs:** Depending on the cities IT infrastructure and capabilities, consider the optimal format of sharing EO outputs. The format should encourage rather than deter use.
- **City level trainings:** Consider tailored city training or a more embedded mentorship model to integrate EO practices. City-to-city learning may also be a powerful way to accelerate the demand.
- **Integration with existing programming:** It is crucial that EO tools are used to meet a specific and articulated demand at the city level. A project that already has a long-standing relationship with the city stakeholders was viewed to be more likely to integrate EO within their workflow.

STRATEGIC CONSIDERATIONS:

- **Creating and sustaining demand:** It is critical to continue to create demand by demonstrating and documenting use cases and through ongoing dialogue with IFIs. This could also be achieved by IFI EO 'champions' and the possibility of EO becoming part of the 'urban development tool-kits'.
- **Integration into IFIs operational procedures:** To use IFIs as a platform to scale, EO4SD needs to become relevant for IFI operational task teams, during the short-time frame of project concept to approval. This means being able to provide EO outputs in a matter of weeks, rather than months.
- **Reduce supply costs through streamlining demand:** There needs to be clarity on what EO products are most in demand within IFIs to streamline procurement and reduce supply costs for IFIs.

Background

Since 2010, the European Space Agency (ESA) has sought to demonstrate the benefits that Earth Observation (EO) can deliver for development assistance programmes and operations. ESA's Earth Observation for Sustainable Development (EO4SD) programme aims to initiate the integration of satellite information products as best-practice in the planning and implementation of development assistance programmes of the International Financial Institutions (IFIs), together with their respective city counterparts. Urban Development is one of EO4SD's thematic focus areas.[2]

With more people expected to live in cities, if urbanisation is not well managed, its speed and scale can and is, adversely affecting social and economic equality, public health, and the natural environment. To develop and implement effective strategies for sustainable urban management, consistent and accurate information on the status and development of the natural and built environment is required. EO offers great capabilities for the inventory and analyses of urban areas with high potential to inform and facilitate development assistance in a globally consistent manner.

ESA funded the EO4SD for Urban Development (EO4SD-Urban) programme in May 2016. EO4SD-Urban aims to demonstrate the benefits of EO-based urban products starting in IFI programmes. EO4SD-Urban's goals are:

- To provide convincing demonstrations of the benefit and utility of EO-based information in the urban framework,
- To provide the intended products on a regional basis for up to 40 cities,
- To ensure that the products are user-driven via a strong engagement with IFIs and city stakeholders,
- To provide an operational urban service portfolio offering quality controlled products,
- To provide a technology transfer via capacity building exercises,
- To ensure a robust organisation of service networks with the regional counterparts via dedicated local offices, and
- To develop new business opportunities in urban EO services for the European industry.

The EO4SD-Urban consortium is composed of eight companies, coordinated by GAF AG and including Systemes d'Information a Reference Spatiale (SIRS), GISAT, Egis, the German Aerospace Centre (DLR), NEO, JOANNEUM RESEARCH and, GISBOX.

2 See http://eo4sd.esa.int/ for more information on EO4SD thematic areas.

Since 2016, the three-year EO4SD-Urban programme has provided support to three IFIs, covering 17 IFI programmes in 31 unique cities across 15 countries. Each city was supported through the provision of various EO products. **Annex one** provides a list of the programmes and cities that were supported.

This evaluation was commissioned by ESA to understand the impact of the EO4SD-Urban programme specifically, and the impact of EO for urban sustainability more broadly. The overall objective is to improve the space sector's evidence base and communication of the expected impacts and learnings of using EO products for developing world urban centres.

Public domain sources have been used to provide examples of impact evidence for a variety of EO use cases. These examples were chosen based on the quality of the evidence found and does not reflect favouritism to specific organisations or companies.

This report is organised into the following four sections:

- **Section one: The opportunity for Earth Observation to contribute to sustainable urban development**
  - Provides an overview of the benefits of well-planned urbanisation, while also highlighting several integrated challenges to achieving sustainable urban development.
  - Provides an overview of the advances in the EO sector and the beneficial attributes of EO as a data source.
- **Section two: Earth Observation for sustainable urban development—an impact evidence review**
  - Examines the public domain literature on the impact of EO products for urban development—predominantly in developing countries.
- **Section three: Evaluation of the EO4SD-Urban programme**
  - Provides a succinct overview of the ESA supported EO4SD-urban programme.
  - Highlights how EO4SD-Urban products have been perceived in terms of quality, how they have been used by the IFI programmes and, the potential impact on partner cities.
  - Reviews the assumptions of 'awareness, demand, capabilities, IT infrastructure and financial resources' for a sustained increase in EO uptake.
- **Section four: Recommendations**
  - Reviews the direction of the impact evidence from both the public domain literature review and the insights from the impact evaluation of the EO4SD-Urban programme.
  - Recommendations for closing evidence gaps are shared.
  - Summarises recommendations for improving the uptake of EO within the urban development sector and within IFIs.

The opportunity for Earth Observation to contribute to sustainable urban development

Opportunities and challenges to achieving sustainable urban development

Key points

This section provides an overview of the benefits of well-planned urbanisation, while also highlighting several integrated challenges to achieving sustainable urban development.

- Urbanisation enables people to benefit from increased productivity through economic density, accelerated innovation from knowledge spill-overs, greater mobility, and access to employment and services.
- Poorly planned urbanisation has adverse effects; on social and economic equality, public health, and the natural environment.
- Within developing country cities there are several specific challenges:
  - Housing and informal settlements: Uncontrolled expansion marginalises low-income populations in peripheral parts of cities, often in dense informal settlements, limiting access to basic services.
  - Transport: Without a good transport network, residents have limited options to access socio-economic opportunities, and suffer from increased congestion, air and noise pollution, and Green House Gas (GHG) emissions.
  - Disaster resilience: Unplanned settlement can occur near natural hazards—such as hills at risk of landsides—increasing populations' risk, whilst replacing open land with impermeable surfaces, such as pavements, that can exacerbate risks such as flooding.
  - Environment and health: Poorly planned urban expansion results in the loss of natural habitats, decimation of biodiversity and reduces the productivity of surrounding agricultural land.
  - Access to data: Urban planning requires access to consistent, regular, and accurate data to carry out urban planning and monitoring. Yet many developing country cities do not have sufficiently robust or integrated data. Traditional sources of urban data —population census and public service records —house data in silos which makes it difficult to observe the interconnections that are vital for an integrated approach to urban development.

Over four billion people—more than half the global population—live in cities. This number is expected to increase with a prediction that by 2050, seven in ten people will live in cities.[3] As the dominant habitat for the world's population, how cities evolve, matters greatly.

Urbanisation is a force for positive transformation

With more than 80% of global GDP generated in cities, urbanisation contributes to sustainable growth—if managed well.[4] Compact and dense cities reduce transaction costs, make public spending on infrastructure and services economically viable, and facilitate generation and diffusion of knowledge, all of which are important for growth.[5] People are drawn to cities because they offer more economic opportunities, and when urbanisation is supported by forward looking plans, cities elevate incomes and improve livelihood options. The value of cities extends beyond economic opportunities. Urban areas also offer greater access to education and health services, social mobilisation, and the potential for a higher quality of life.

Box 1: What is a sustainable city?[6]

A sustainable city is a compact, relatively densely populated mixed-use urban form that creates efficiency gains. It combines greater productivity and innovation capacity with lower costs and reduced environmental impact. It provides secure and healthy urban environments where both people and nature can thrive, and offers residents affordable housing, vibrant street life, and safe and high-quality public spaces.

A sustainable city provides inclusive access to health care, education, and jobs at walking distance or reachable by short and convenient transit rides seamlessly integrated with pedestrian and bicycle paths. It harnesses the potential of clean energy and smart technologies to increase well-being, reduces environmental impact, and protects ecosystems. A sustainable city preserves its environmental and physical assets for future generations while enhancing its competitiveness. It also has a local government with the fiscal and administrative capacity to carry out its urban functions with active participation from citizens.

3 World Bank. 'Urban Development: Overview'. https://www.worldbank.org/en/topic/urbandevelopment/overview. Accessed February 2020.

4 Ibid.

5 UN Habitat. 2010. 'State of the World's Cities 2010/2011: Bridging the Urban Divide'. https://sustainabledevelopment.un.org/content/documents/11143016_alt.pdf. Accessed September 2019.

6 Global Platform for Sustainable Cities. 2018. 'Urban Sustainability Framework: 1st ed. (English)'. World Bank. http://documents.worldbank.org/curated/en/339851517836894370/Urban-Sustainability-Framework-1st-ed. Accessed September 2019.

Challenges to achieving sustainable urbanisation

However, if the process of urbanisation is not well planned or managed, the speed and the scale of urban growth can and is, adversely affecting social and economic equality, public health, and the natural environment. Cities are complex habitats and as such their challenges do not occur in silos. For example, failures in the public transport system may lead to more motorised vehicles on the road, increasing air pollution, affecting human health along with rising GHG emissions damaging the environment. These challenges compound both negatively and positively and should be considered holistically.

HOUSING AND INFORMAL SETTLEMENTS

> *In 2012, 883 million people lived in slums[7] and slum populations continue to grow by 10% each year.[8]*

Urban sprawl relates to the uncontrolled expansion of urban areas. It undermines the efficiencies of compact urban living and marginalises low-income populations in peripheral parts of cities, often in dense informal settlements. As informal settlements are often not connected to basic services such as clean water and sanitation, residents in these areas are at greater risk of contracting diseases. Shelters may be poorly constructed and located in areas vulnerable to hazards.

TRANSPORT

> *In Kinshasa (Democratic Republic of Congo), home to one of the world's largest slum population, most people walk an average of 20 to 25 km every day in search of informal work.[9]*

Accessibility within cities is partly determined by the distance between where people live and where people work or access basic services. Without a good transport network, people have few options to access socio-economic opportunities. In the absence of a robust public transport system there may be more vehicles on the road and this contributes to financial, environmental, and public health costs through congestion, air and noise pollution, and GHG emissions.

DISASTER RESILIENCE

> *Developing countries are disproportionally impacted by disasters. The average annual damage from 1980 to 2015 was 1.5% of GDP in developing countries, compared to 0.3% of GDP in developed countries.[10]*

90% of urban expansion takes place in developing countries, and much of it occurs near natural hazards, rivers, and coastlines through unplanned settlements.[11] These areas are prone to floods or landslides and settlements are often not constructed to withstand such hazards. As urban areas develop, buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist become impermeable and dry, increasing risk of flooding. These changes can also cause urban areas to become

7 United Nations. 'Sustainable Development Goal 11: Sustainable Cities and Communities'. https://www.un.org/sustainabledevelopment/cities/. Accessed December 2019.

8 UN Habitat. 2010. 'State of the World's Cities 2010/2011: Bridging the Urban Divide'. https://sustainabledevelopment.un.org/content/documents/11143016_alt.pdf. Accessed September 2019.

9 Wahba, Sameh, and Sarah Xinyuan Lin. 2016. 'Ahead of the next Habitat conference, the urban world we want'. World Bank (blog). http://blogs.worldbank.org/sustainablecities/urban-world-we-want. Accessed December 2019.

10 Moody's Investor Services. 2016. 'Understanding the Impact of Natural Disasters: Exposure to Direct Damages Across Countries'. www.eenews.net/assets/2016/11/30/document_cw_01.pdf. Accessed February 2020.

11 World Bank. 'Urban Development: Overview'. www.worldbank.org/en/topic/urbandevelopment/overview. Accessed February 2020.

warmer than their rural surroundings, forming an 'island' of higher temperatures in the landscape.[12] Prolonged periods of high temperatures increase the demand for energy and water, trigger health issues, and increase air pollution. This combination of challenges exacerbates the risk exposure of urban populations.

ENVIRONMENT AND HEALTH

> *90% of waste is openly dumped or burned in low-income countries. Without improvements in waste management, solid waste related emissions will likely increase to 2.6 billion tonnes of CO2-equivalent by 2050.*[13]

Expansion of urban areas results in loss of natural habitats, decimation of biodiversity and reduces the productivity of agricultural land. Additional environmental degradation occurs when a city's waste disposal and enforcement systems fail to keep pace with urban growth. Low-income countries collect about 48% of waste in cities and much of it is openly burned, impact human and environmental health.

> *In 2016 4.2 million premature deaths, worldwide were attributable to ambient air pollution. About 88% of these deaths occurs in low and middle-income countries.*[14]

Hazards and pollution from waste sites leave people susceptible to health repercussions while emissions from traffic, open fires, and industrial activities affect the air they breathe. Furthermore, biodiverse ecosystems are vital to the effective functioning of city systems—providing water, a natural air filter, and recreational benefits. Decreasing green areas in urban environments negatively impacts the overall population's health and well-being.

DATA FOR SUSTAINABLE URBAN PLANNING

> *City leaders are beginning to understand that data, and the infrastructure to analyse them, will become as important to the well-being of their citizens as the power grid and the transportation system.*[15]

Various policies and frameworks exist from the global level right down to the city level, that aim to guide and measure progress on sustainable urbanisation.

- **Global level:** The United Nations has a dedicated Sustainable Development Goal for cities. Goal 11 aims to "*make cities and human settlements inclusive, safe, resilient and sustainable*".[16] Additionally, there is the is the UN sanctioned 'New Urban Agenda' which serves as a guideline for urban development for the next twenty years.
- **National level:** Countries have National Urban Policies (NUPs) which provide an overarching framework to deal with the most pressing issues related to rapid urban development. The NUP process is comprised of several stages from Feasibility, Diagnostics, Formulation, Implementation, and Monitoring and Evaluation.

12 United States Environmental Protection Agency (EPA). 'Heat Island Effect'. www.epa.gov/heat-islands. Accessed February 2020.

13 Kaza, Silpa, Lisa Yao, Perinaz Bhada-Tata, and Frank Van Woerden. 2018. 'What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050'. World Bank. http://datatopics.worldbank.org/what-a-waste/. Accessed September 2020.

14 Pan American Health Organisation (PAHO). 'Ambient and Household Air Pollution and Health'. https://www.paho.org/hq/index.php?option=com_content&view=article&id=14454:ambient-and-household-air-pollution-and-health-frequently-asked-questions&Itemid=72243&lang=en. Accessed September 2019.

15 Global Platform for Sustainable Cities. 2018. 'Urban Sustainability Framework: 1st ed. (English)'. World Bank. http://documents.worldbank.org/curated/en/339851517836894370/Urban-Sustainability-Framework-1st-ed. Accessed September 2019.

16 United Nations. 'Sustainable Development Goal 11: Make cities and human developments inclusive, safe, resilient and sustainable'. https://sustainabledevelopment.un.org/sdg11. Accessed January 2020.

- **City level:** City authorities adapt the NUPs for their specific context—these are typically referred to as master plans.

The first critical step in urban planning is to establish an understanding of current conditions to:

- Identify priorities for investment,
- Develop a baseline on which to assess change,
- Identify strengths and weaknesses and assets that can be leveraged to support interventions, and
- Identify interconnections, co-benefits, synergies, or trade-offs between city systems that can help guide efficient use of resources.[17]

Yet, many cities, and those who support cities, are challenged at this fundamental point—obtaining relevant, timely, scalable data. Without an integrated approach to accessing and using urban data, developing integrated urban plans becomes very difficult. Traditional sources of urban data—which include population census and a multitude of public service company records—house data in silos which makes it difficult to observe the interconnections that are vital for an integrated approach to work. Data is then often outdated and fragmented.

17 Global Platform for Sustainable Cities. 2018. 'Urban Sustainability Framework: 1st ed. (English)'. World Bank. http://documents.worldbank.org/curated/en/339851517836894370/Urban-Sustainability-Framework-1st-ed. Accessed September 2019.

The opportunity for Earth Observation in sustainable urban development

Key points

This section provides an overview of the advances in the EO sector and the beneficial attributes of EO as a data source.

- **Earth Observation (EO) is the process of gathering information about the physical, chemical, and biological systems of the planet via remote-sensing technologies.** EO is used to monitor and assess the status of and changes in natural and built environments.
- **Many factors have contributed to the increased interest in EO.** The availability of free and open EO data, increasing data accuracy (spatially and temporally), advances in computer processing power and data analytics.
- **EO attributes improve upon or complement existing data sources.** EO is diverse, affordable, objective, repeatable, continuous, and timely to acquire and process.
- **Actions to address urban challenges are advanced by including EO data.** EO is used in the assessment, implementation, and monitoring of sustainable urban activities.

EO satellites gather information about the physical, chemical, and biological systems of the planet via remote-sensing technologies. EO is used to monitor and assess the status of, and changes in, natural and built environments. Many of the actions to address the challenges faced by cities, can be advanced by the inclusion of EO in the assessment, implementation and monitoring of urban activities. In this section the factors that led to a growth in space-derived data are reviewed, and the advantageous attributes that space technology can bring to the urban sector are discussed.

(R)evolution of the EO sector

In August 1959 the Explorer 6 took the first pictures of Earth[18]—60 years later there are over 400 EO satellites in orbit, with hundreds more over the coming years.[19]

With the advancement of technology, commercial organisations are also now involved in the development and use of space technology. Factors that contributed to the increase are, among others, the availability of **free and open satellite data**, increasing data **accuracy** (spatially and temporally), and **improved algorithms** and models for data processing.

- **The costs of commercial data, such as very high resolution data (<1 m) are falling.** Copernicus Sentinel data is provided for free whereas commercial data has a cost. However, prices for commercial EO data are also forecast to fall over the next five years.[20]
- **Spatial and temporal accuracy has increased.** Advances in on-board technologies are constantly improving spatial resolution, measurement accuracy, and frequency of observations. There are a wide range of very high resolution (<1 m) and high resolution (<10 m) satellite missions operated either nationally or commercially.
- **Private sector entrepreneurs are bringing innovation from other industries.** The space sector is undergoing rapid evolution, characterised by a new playing field including the emergence of private companies, participation with academia, industry and citizens, digitalisation and global interaction.[21] New entrants into the EO sector, for example operators of constellations of small satellites such as Planet Labs Inc, are bringing further innovations using small satellites to provide high resolution imagery on a daily update basis.[22]
- **Advances in computer processing power and data analytics.** Major ICT players offer specialised cloud platforms for hosting, managing, and presenting EO data sets and algorithms.[23] Machine learning algorithms that automatically identify objects and land cover are advancing rapidly. Crowdsourcing platforms[24] collect and enhance the reference data to train those machine learning algorithms. High quality ground truth data, to calibrate and test the accuracy of the algorithms, such as traditional development Microdata, is more available.[25] Finally, open-source annotated datasets, and other publicly available resources allow the data to be processed and documented.[26]
- **Specialist companies and organisations in the European EO information services sector (and global equivalents) that create EO applications are proliferating.** ESA and the European Commission have invested ~€250 million in R&D over the last decade to ensure these products are robust and accurate. The European EO information services sector (private companies, government institutes, universities) has grown as a world leader through these investments. These capabilities are not confined to Europe and can be leveraged for challenges in developing countries.

— *Advantages of EO*

18 European Space Agency (ESA). '50 years of Earth Observation'. www.esa.int/About_Us/ESA_history/50_years_of_Earth_Observation. Accessed February 2020.

19 The Parliamentary Office of Science and Technology (POST). 'Environmental Earth Observation'. Westminster, London. No. 566, November 2017. https://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0566. Accessed February 2020.

20 Northern Sky Research. 2019. 'Satellite-Based Earth Observation Market Report'. 11th Edition (EO11). www.nsr.com/research/satellite-based-earth-observation-eo-11th-edition/. Accessed February 2020.

21 European Space Agency (ESA). 'What is Space 4.0?'. 2016. www.esa.int/About_Us/Ministerial_Council_2016/What_is_space_4.0. Accessed February 2020.

22 Planet. 'Planet Imagery and Archive'. www.planet.com/products/planet-imagery/. Accessed February 2020.

23 For example, Amazon with Earth from AWS, Microsoft with Azure, and Google Earth Engine.

24 For example, MTurk, Figure-eight, and Tomnod.

25 World Bank. 'Microdata Library'. https://microdata.worldbank.org/index.php/home. Accessed February 2020.

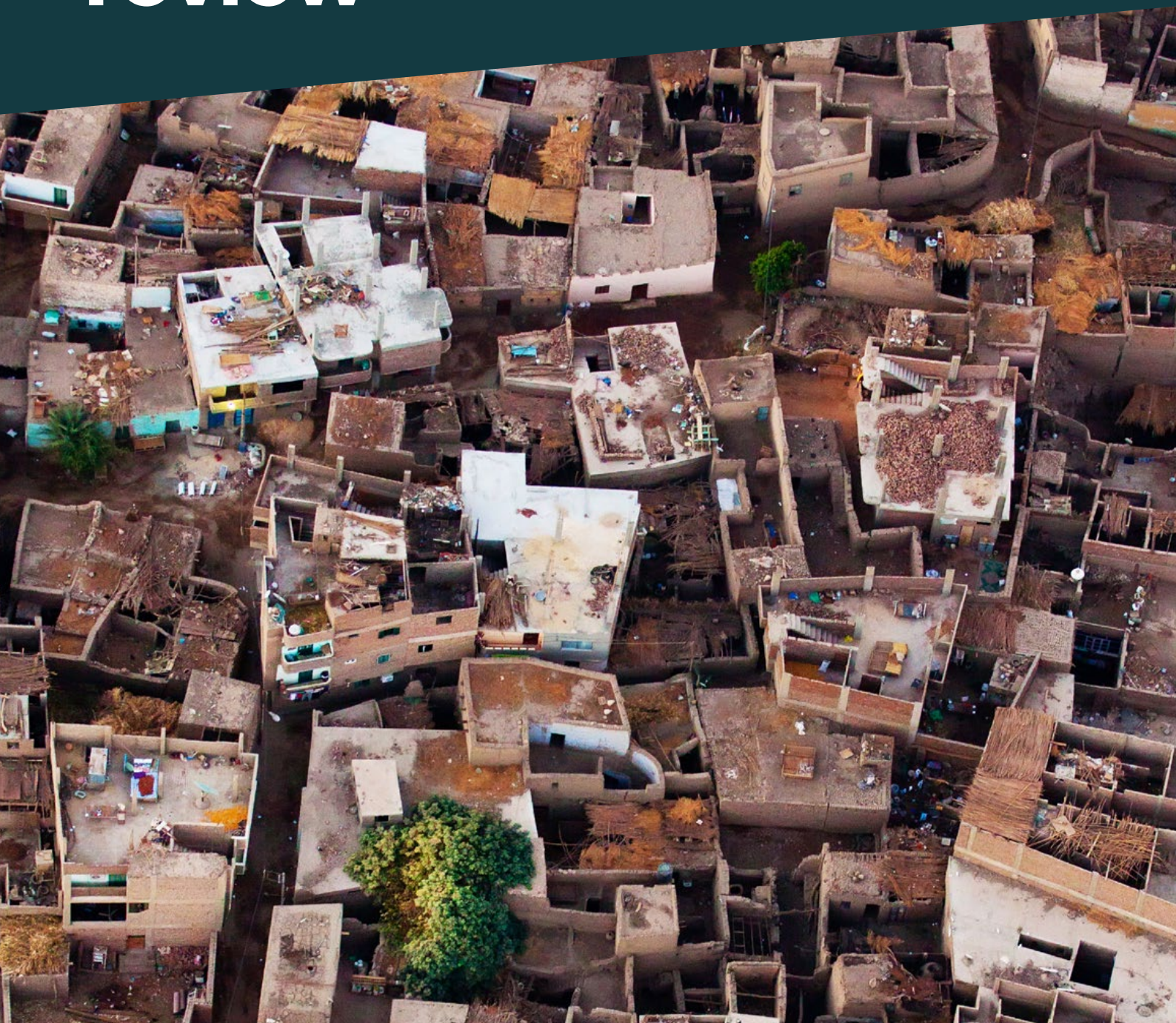
26 Chrieke. 'Awesome Satellite Imagery Datasets'. https://github.com/chrieke/awesome-satellite-imagery-datasets. Accessed February 2020; World Bank, 'World Bank Open Data'. https://data.worldbank.org/. Accessed February 2020; NASA. 'Introduction—Cumulus Documentation'. https://nasa.github.io/cumulus/docs/cumulus-docs-readme. Accessed February 2020; and Development Seed. 'Label Maker: Data Preparation for Satellite Machine Learning'. https://github.com/developmentseed/label-maker. Accessed February 2020.

There are many attributes of EO that can improve upon or complement existing data alternatives such as traditional maps, census data, bespoke surveys, ground observations, or drones:

- **Coverage:** Satellites have global coverage making it possible to consistently monitor vast, remote, and even conflict regions across countries and continents.
- **Objectivity:** Satellite observations derive from the satellite instrument's measurements, which have a known and controlled range of error and are thus less susceptible to many of the biases detected in other measures of the same phenomena.
- **Repeatability:** The nature of satellite observations, being collected along a periodic orbit of the Earth's surface, means that they are repeatable and comparable over time.
- **Continuity:** The continuity of EO data streams allows time to build experience and refine the systems that use the data.
- **Thematic detail:** The range of satellite sensors now available allows for application to a wide range of domains including climate change, agriculture, forestry, urban development, and disaster resilience.
- **Analysis-ready:** Satellite data is organised and processed according to defined industry standards and provided in a form that allows immediate further analysis.
- **Speed:** Increasingly, EO data is available for use soon after acquisition - just days or even hours (near-real time - NRT) later. Enabling stakeholders to receive the EO-derived information they need to act quickly—critical in, for example, disaster scenarios.
- **Affordability:** Along with the increase in commercial satellites, there is also an increase in satellites, such as the Copernicus Sentinel missions, that allow free and open access to data.

To turn EO data into products that enable informed decision-making, processing of the data is required by specialist organisations, like the EO4SD-Urban consortium members. Thus, numerous products have been developed using EO that support solutions for local and global challenges.

Earth Observation for sustainable urban development— an impact evidence review



Evidence of the impact of EO in urban development

Key points

This section examines the public domain literature on the impact of EO products for urban development—predominantly in developing countries.

- EO is providing benefits within urban development in four overarching areas:
  1. Urban planning and monitoring;
  2. Transport planning and monitoring;
  3. Hazard assessment, early warning, and response coordination; and
  4. Monitoring of environmental issues.
- Insights from public literature have contributed evidence to each of these areas:
  - There is evidence of EO being integrated into city plans, slums assessments, and innovations using EO to enable cities to fund development plans by improving tax revenue collection.
  - Although many of the examples of EO demonstration projects for rail and road were in developed countries, there is an opportunity to transfer these learnings to developing countries.
  - Evidence on the benefits of EO for disaster risk assessments and efficient response is plentiful. In addition, there are EO applications to assess urban building/infrastructure risk exposure.
  - Innovations in satellite sensors enable air quality and surface temperature measurement, and they provide cities with critical environmental information.

Against a backdrop of both a rapidly improving data environment and the critical data needs of cities, **it is vital to address the question of how EO supports and improves both the processes and the outcomes for sustainable urbanisation.**

The first step to addressing this question is to hypothesise on what the impact of EO in the urban sector could be. Figure 1 highlights both the role and anticipated impact of using EO within urban development.

Impacts	EO products contribute to the achievement of UN SDG 11 'Sustainable Cities and Communities'			
	SUITABLE HOUSING	**IMPROVED TRANSPORT**	**GREATER DISASTER RESILIENCE**	**IMPROVED ENVIRONMENTAL & HUMAN HEALTH CONDITIONS**
	Compact city growth, adequate public services, and infrastructure for all inhabitants	Extensive, sustainable and affordable transport	Improved mitigation and recovery measures to reduce risk of natural and man-made disasters	Reduction in the environmental risks and conservation of natural ecosystems
	Improvements in sustainable urban planning via enhanced efficiencies in workflow and decision making processes			
IFI and City Outcomes	EO products provide information to identify priorities for investment and to manage cities changing needs			
	IFIs and city authorities have the capacity, IT infrastructure, and financial resources to use EO products			
Outputs	EO supports urban development planning and monitoring	EO supports transport planning and monitoring	EO supports the assessment of various hazards risks, early warnings and response coordination	EO supports monitoring of various environmental issues
Urban Development Challenges	Urban sprawl and informal settlements	Limited and inefficient transport	Vulnerability to disasters	Environmental degradation and population health concerns
	Data for sustainable urban planning			

FIGURE 1: Outcomes and impacts of EO in urban development (Credit: Caribou Space)

EO is well placed to contribute new types of information which form part of the solution to several urban challenges. It helps address data limitations and supports city planners through:

– Information for urban planning by mapping land classes, urban extent, building footprints, and population density;

– Monitoring environmental issues by assessing public green spaces, waste sites, air quality, surface imperviousness, and urban temperatures;

– Mapping different transport classes; and

– Assessment of various hazards risks (flood, landslide, and subsidence) and facilitating early warnings and coordinated responses.

To establish a baseline understanding of the potential benefits of various EO products, a literature review was conducted. The aim was to glean insights on explicit use cases and benefits that EO has had for urban development and highlight the evidence gaps that require further investigation (See Recommendations section on evidence gaps and **Annex three** for methodology).[27]

The following section highlights various forms of evidence on the use of EO products in urban development from public domain literature. Evidence is grouped under the five main categories of urban challenges of: 1. Sustainable urban planning, 2. Informal settlements and access to services, 3. Transport, 4. Disaster resilience and 5. Environment and health.

27 Within the literature review, whilst information on the use cases for EO products in urban development was common, information on long-term impacts was scarce. Thus, in the literature review, while evidence on explicit change due to EO was prioritised, other more implicit change, often in the form of anecdotes and direct quotes were also utilised. Evidence on EO data use cases and impact was prioritised for developing countries. However, where there was limited information this report references examples from developed countries are used.

Evidence of EO benefits in sustainable urban planning

SDG 11.3

By 2030, enhance inclusive and sustainable urbanisation and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.

In developing countries, urban settlement is often informal, and municipal records, when available, struggle to keep pace with rapid changes. A spatially granular lens will improve cities understanding of changes, needs and priorities for investment. EO data is being provided for free via open platforms. There is also evidence of EO being integrated into city plans, particularly for specific, nuanced needs of informal settlements. Furthermore, there have been interesting innovations using EO to enable cities to resource their development plans by improving their tax revenue.

Several open and free base data sets and platforms enable and support sustainable urban planning, specifically for countries who have traditionally lacked access to this data. Furthermore, by aggregating EO data in user-friendly platforms, non-EO experts can access and use EO in their urban development work. Evidence highlights the value of core EO datasets to urban planning. Examples include:

- The ESA Urban-Thematic Exploitation Platform (U-TEP) provides access to EO information, processing tools, and computing resources. The World Settlement Footprint-2015 (WSF) dataset—the world's first map that combines radar and EO data to provide a global overview of human settlements—has been integrated on U-TEP. The WSF-2015 development manager at DLR stated that, *"U-TEP will benefit from the new WSF-2015 data, particularly in view of services for more effective urban planning and service provision, enhanced risk analysis related to natural disasters, or improved assessment of human impact on ecosystems"*.[28]
- The Global Human Settlement Layer (GHSL) (supported by Joint Research Centre - JRC) is one of the core datasets in the GEO Human Planet Initiative and contributes to enabling city authorities to map built-up areas to monitor and plan infrastructure developments. GHSL is currently being used in South Africa to support several legislations including the Spatial Planning and Land Use Management Act, the National Human Settlements Land Inventory Act, the Statistics Act, the Municipal Demarcation Act, the Conservation of Agricultural Resources Act, and the Disaster Management Act and Electoral Act.[29]
- The Africapolis database is a unique database that uses census and EO data. The 2018 edition covers 51 countries and 7,500 urban agglomerations. The data and analyses generated by Africapolis aim to improve African policymakers' and researchers' capacity to better target resources and develop urban policies.[30]

28 Chaturvedi, Aditya. 'ESA combines radar and EO data to create world's first urban habitation map'. Geospatial World. www.geospatialworld.net/blogs/esa-maps-global-urban-habitation-patterns/. Accessed February 2020.

29 Mudau, Naledzani. 'Mapping & Monitoring of Settlements in South Africa'. Group on Earth Observations (blog). www.earthobservations.org/geo_blog_obs.php?id=209. Accessed February 2020.

30 OECD. 2019. 'The socio-economic impacts of space investments'. The Space Economy in Figures: How Space Contributes to the Global Economy. https://www.oecd-ilibrary.org/science-and-technology/the-space-economy-in-figures_c5996201-en. Accessed January 2020.

EO is used to inform and monitor city plans. Evidence from Johannesburg and Dhaka have highlighted the use of EO for informing city plans and tracking urban development interventions. Examples include:

- In 2016, the City of Johannesburg adopted its Spatial Development Framework 2040—an ambitious plan to transform the city into one that is spatially just, efficient, resilient and sustainable. Johannesburg has used geospatial data for analysing inequality and poverty, job-housing mismatch, spatial disconnection, low walkability, and land-use defects. This informed city planning and helped officials prepare development scenario options for the future. The Director of City Transformation and Spatial Planning stated that, *"Satellite technology and geospatial information help track our urban footprint and understand the impact of our interventions"*.[31]

- Dhaka, the capital of Bangladesh, is expected to be one of the five most populated cities in the world by 2025. To understand Dhaka city growth dynamics and forecast its future expansion by the year 2030, a SLEUTH[32] model drawing on historical EO data was used. The model showed that an additional 20% of the metropolitan area will be converted into built-up land by 2030 and a clear spatial trend of sprawl towards the north and north-west. The interpretation of depicting the future scenario as demonstrated by EO will be of great value to urban planners and decision makers for the future planning of Dhaka.[33]

- Examples of how the EO4SD-Urban programme supported IFI's work in city planning is discussed in 'Section three: Evaluation of the EO4SD-Urban programme'.

EO has supported innovations in generating tax revenue for cities to fund urban investment. The technical complexity of ensuring that tax rolls are complete and valuations are current, is often perceived as a major barrier to bringing in more property tax revenues in developing countries. Ensuring property taxes can be collected in fair, low-cost ways requires that automated property valuation methods be based on routinely updated market values. Examples include:

- The UKSA International Partnership Programme (IPP) supported Dakar Change Monitoring project with Airbus Defence and Space using GNSS-based field surveys and high-resolution EO to detect urban change. During the project 90,000 parcels of land were digitised. This data can support more effective property tax collection and ultimately the maintenance of city infrastructure and services. The EO-based methods were calculated to be able to generate additional revenues of £1.6 million and at a cost-effectiveness ratio of £0.37 of cost per £1 of tax revenue collected.[34]

Examples of how the EO4SD-Urban programme supported IFI's work in property valuation for tax revenue generation is discussed in 'Section three: Evaluation of the EO4SD-Urban programme'.

31 Wang, Xueman. 'How geospatial technology can help cities plan for a sustainable future'. World Bank (blog). https://blogs.worldbank.org/sustainablecities/how-geospatial-technology-can-help-cities-plan-sustainable-future. Accessed February 2020.

32 That is, a self-modifying cellular automaton based on Slope, Land use, Exclusion, Urban extension, Transportation, and Hillshade.

33 Pramanik, Monjure Alam, and Demetris Stathakis. 'Forecasting urban sprawl in Dhaka city of Bangladesh'. Environment and Planning B: Planning and Design 0 (2015): 1-16. https://journals.sagepub.com/doi/abs/10.1177/0265813515595406. Accessed February 2020.

34 London Economics and Caribou Space. 2019. 'Economic evaluation of the International Partnership Programme (IPP): Cost-effectiveness Analysis'. Caribou Space. www.spacefordevelopment.org/wp-content/uploads/2019/10/UKSA-IPP-Cost-Effectiveness-Analysis-FINAL-for-web-1.pdf. Accessed January 2020.

Evidence of EO benefits on informal settlements and access to services

SDG 11.1

By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.

A 2016 study highlighted that slum mapping is one of the most recurrent uses of EO in urban development, with approximately 87 published papers in scientific journals in the last 15 years.[35] It should be noted that slum mapping is not a straightforward process, with slum characteristics taking different forms within and between cities that need to be determined for the models to work. However, there is evidence that the accuracy of slum detection is improving. Examples include:

- In a 2017 study, Synthetic Aperture Radar (SAR) images were used to conduct an extensive mapping of slums in Mumbai, India. The results indicated that it is possible to classify the urban landscape by using textural image features with an overall accuracy of **88.6%**. However, a patch-based accuracy assessment highlighted that it is most difficult to detect *small* slum areas in the urban landscape. [36]

EO has been used to provide information that enables authorities to address the specific needs and challenges of slums. Identifying slums and delineating their boundaries at the city scale is a challenge for any city, leading to public authorities underestimating their needs in planning. Applications in Manila and Nairobi demonstrate the efficiency of EO for slum assessments and the benefits for planning. Examples include:

- ESA supported WB with analysis of Metro Manila's slums in 2014. At that time government records were found to be outdated and no comprehensive basis for developing a sample of slum dwellers was available. To address this challenge, ESA supported the application of very high resolution EO data to identify and delineate the slums at scale and in a short time frame. Because of this analysis, the first ever database of 2,500 slums of various shapes and sizes were developed for Metro Manila and was used to develop five distinct slum typologies.[37] Also the number of small "pocket" slums were also found to be significantly underestimated.

- Occupancy rights in the Kibera slum in Nairobi, are ambiguous—since the 1970s, local chiefs and bureaucrats in the Provincial Administration have illegally allocated land titles to individuals, allowing individuals from certain ethnicities to rent out land and control the slum housing market. Tenants rarely hold formal rights and evictions are frequent. Research combined very high resolution satellite images of the slum and data collected from a survey of the inhabitants. The images capture the luminosity reflected by metal roofs and are used as a proxy for housing investment by providing a measure of the age of these roofs. The research found that when the chief and tenants are of different ethnicity, tenants pay rental prices that are 6% to 11% higher. The opposite is true when ethnicity is aligned. These results highlight ethnic patronage and the consequences on welfare. These findings have important implications on urban planning. [38]

Examples of how the EO4SD-Urban programme supported IFI's work in work in slum assessments is discussed in 'Section three: Evaluation of the EO4SD-Urban programme'.

35 Duque, Juan Carlos, Jorge Eduardo Patiño, and Alejandro Betancourt. 'Exploring the Potential of Machine Learning for Automatic Slum Identification from VHR Imagery'. Development Bank of Latin America (CAF). Working Paper No. 2016/13. https://scioteca.caf.com/bitstream/handle/123456789/975/Duque,%20Patino%20&%20Betancourt%20(2016).pdf?sequence=1andisAllowed=y. Accessed January 2020.

36 Weigand, Matthias. 'SAR Image Feature Analysis for Slum Detection in Megacities'. Master's thesis, University of Augsburg and German Aerospace Center. February 2017. https://pdfs.semanticscholar.org/3726/0f9cbf0782ebdeef77259ab2bdcafe498d4e.pdf. Accessed January 2020.

37 Singh, Gayatri, and Gauri Gadgil. 'Navigating Informality: Perils and Prospects in Metro Manila's Slums'. World Bank. http://pubdocs.worldbank.org/en/564861506978931790/Navigating-Informality-Metro-Manila-7-26-17web.pdf. Accessed February 2020.

38 Marx, Benjamin, Tavneet Suri, Thomas Stoker, and Nidhi Parekh. 'Law of the land: Ethnic patronage in Kenya's slums'. November 2018. https://voxdev.org/topic/infrastructure-urbanisation/law-land-ethnic-patronage-kenya-s-slums. Accessed September 2019.

Evidence of EO benefits for transport infrastructure

SDG 11.2

By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons.

SDG 11.a

Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning.

There are numerous examples of EO demonstration projects for rail, road, and even air, however, these were predominantly tested in developed countries. The demonstrations ranged from building railways resilient to disasters in Russia[39] and detecting and forecasting subsidence on railways lines in the UK.[40] However, public domain evidence of use cases within developing countries is also emerging.

There is nascent evidence that EO has supported and positively contributed to providing users with inventories of transport infrastructure in developing countries. Transport infrastructure data availability and quality limits the development of sustainable transport policies, investment strategies, and models of future transport needs. Examples include:

- An ESA EO4SD-Urban project supported the ADB Global Transport Intelligence—Transport Outlook Asia activity. EO contributed to the updated inventory of transport infrastructure, identification of existing gaps, giving the most up-to-date picture of transport infrastructure. The services delivered to ADB had beneficial effect as being highly relevant for future creation of harmonised transportation databases across multiple ADM member countries. According to the ADB Transport Specialist, *"For the same amount of money that we spent for planning previously, we can ask for more and better data* [using EO] *and deliver better services. That's especially important for public transport planning, like for corridors of Bus Rapid Transit systems or even when looking at informal transport"*. Another stated *"One of the major opportunities we had by using satellite imagery analysis is obtaining the data we needed without going into the field…It also allowed us to analyse the land use around the mass transit stations that we are planning. The outcome of the collaboration was very good"*.[41]

39 European Association of Remote Sensing Companies (EARSC). 'Railway line monitoring'. https://earsc-portal.eu/display/EOSTAN/Railway+Line+Monitoring. Accessed February 2020.

40 European Space Agency (ESA). 'LiveLand: Predicting, Monitoring and Alerting of Landslides and Subsidence Affecting Transport Infrastructure'. https://business.esa.int/projects/liveland. Accessed February 2020.

41 Asian Development Bank (ADB). 'Earth Observation for a Transforming Asia and Pacific'. www.adb.org/sites/default/files/publication/231486/earth-observation-asia-pacific.pdf. Accessed February 2020.

Evidence of EO benefits for city disaster resilience

SDG 11.5

By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

SDG 11.b

By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030, holistic disaster risk management at all levels.

Evidence on the use and benefits of EO for both assessing disaster risk and enabling a more efficient response to disasters in urban areas is plentiful. This may have its roots in a longer history of EO being used in disaster resilience. There is evidence on the use and impact of EO in various natural disasters (earthquakes, hurricanes, and landslides), in addition to applications that assess building and infrastructure exposure to disasters.

EO supports earthquake impact estimation and a more effective emergency response. Ground-based seismometers that measure seismic activity are mainstays in determining an earthquake's impact. But these instruments are not widespread, which can lead to incomplete information at critical times. EO applications have provided detailed information on earthquakes' locations in relation to population and infrastructure and scale of surface deformation just days after the earthquake, as shown in Indonesia and Chile. Examples include:

- In 2018, a 7.5 magnitude earthquake struck the Minahasa peninsula in Indonesia and was quickly compounded by a localised tsunami. The event led to over 2,000 casualties, 10,000 injured, and more than 70,000 persons evacuated. The International Charter for Space and Major Disasters was activated, and the first set of images were received within one day. The collection of images enabled the government and army to plan the rescue operations and provided a first estimate of the damages in the city (approximately 5,000 buildings). Based on the images received, an analysis of the state of critical infrastructures was conducted, enabling responders to identify alternative routes to damaged roads.[42]
- RapidEye provides high-resolution EO to crisis management authorities within 12–48 hours through its operation of five EO satellites.[43] In 2010, an 8.8-magnitude earthquake struck Concepción in Chile. RapidEye provided before and after imagery of the city to relief organisations at no cost. These images assisted in rescue and recovery efforts as well as prioritising clean-up and reconstruction activities.[44]

EO has supported the identification of landslide hazards and the response to the aftermath of landslides. EO enables authorities to assess damage, conduct evaluations

42 PwC for the European Commission. 'Copernicus: Market Report—February 2019'. https://www.copernicus.eu/sites/default/files/PwC_Copernicus_Market_Report_2019.pdf. Accessed January 2020.

43 Other providers also do this, for example, the Copernicus Emergency Management Service (EMS) uses satellite imagery and other geospatial data to provide free of charge mapping service in cases of natural disasters, human-made emergency situations and humanitarian crises throughout the world. https://emergency.copernicus.eu/mapping/ems/emergency-management-service-mapping.

44 European Association of Remote Sensing Companies (EARSC). 'Relief after Earthquake damage'. https://earsc-portal.eu/display/EOSTAN/Relief+after+Earthquake+damage. Accessed January 2020.

and prioritise investment in disaster resilience polices. Evidence is highlighted through applications in Armenia, El Salvador, and Panama.

- ESA supported ADB in Armenia to create a priority list of urban investment projects by supplying urban land use/land cover classification and change mapping for four cities, and a landslide inventory and susceptibility map for the city of Dilijan. The ADB Urban Development specialist stated that *"the data from the ESA project delivered to us was quite accurate… Especially the data on landslides was very accurate and allowed us to prioritise some projects above others. Given the overall high landslide risk in Armenia, we now plan to extend these services to other secondary cities in the country"*.[45]
- In 2009, Hurricane Ida brought heavy rains that triggered flooding and mudslides in El Salvador, resulting in almost 200 deaths, leaving thousands homeless and causing more than US$150 million in damage. The NASA satellite images provided by SERVIR mapped the mud flow and assisted officials in understanding the full extent of the hurricane's damage and how it could be avoided in the event of future disasters.[46]
- In 2006, when severe weather caused flooding and landslides in Panama, the SERVIR team provided rain forecasts and damage projections, which prompted life-saving evacuations.[47]

EO supports estimation of asset exposure and hazard identification. For countries to improve their disaster resilience, a clear understanding of risk is required. This comes from an improved understanding of the different dimensions of vulnerability, exposure of persons and assets, hazard characteristics, and the environment. With an improved understanding of risk, investments in risk resilience can be made. The examples below show that EO applications in hazard risk identification has been demonstrated by measuring subsidence in Indonesia and through building and infrastructure exposure measurement in Indonesia, Nepal, Tanzania, and Timor Leste. Examples include:

- As part of the original ESA and World Bank initiative called eoworld. Satellite radar and Interferometric Synthetic Aperture Radar (InSAR) techniques have been used to accurately identify land movement trends in Jakarta in Indonesia with an unprecedented level of detail and accuracy. In Jakarta, pumping water from deep wells is causing the land to sink by approximately 10 cm a year. The information generated by satellites has helped manage ground water extraction and supports regular monitoring of high-rise buildings and coastal defence infrastructure.[48]
- An ESA and World Bank collaboration used EO to pinpoint parts of the Tunisian capital where land was sinking—undermining the city's ability to withstand storms, earthquakes, and extreme weather. The manager of the World Bank's Urban Development and Resilience unit stated that *"the results from the satellite data were stunning…quick, cost-effective and technically sound. They gave us visually impressive products that easily communicated the magnitude of the problem to our counterparts in government"*. Through this information, the Tunisian government has incorporated smart risk mitigation policies into the city's adaptation and resilience plans.[49]
- ESA supported ADB's project to 'climate proof' Timor-Leste's road infrastructure. The project demonstrated how to apply the supplied EO in hydrodynamic modelling. According to the ADB Principal Infrastructure Specialist, *"the project helped ADB in better quantifying climate risks (in particular flood risks) to inform and validate the climate-proofing*

45 Asian Development Bank (ADB). 'Earth Observation for a Transforming Asia and Pacific'. https://www.adb.org/sites/default/files/publication/231486/earth-observation-asia-pacific.pdf. Accessed February 2020.

46 Partnership for Public Service. 'Daniel Irwin: Using NASA technology to solve disaster, environmental conditions'. Washington Post. 18 January 2010. http://www.washingtonpost.com/wp-dyn/content/article/2010/01/18/AR2010011802132.html. Accessed January 2020.

47 Ibid.

48 World Bank. 'High Above Earth, Satellites Help Direct Ground-Breaking Development Work'. https://www.worldbank.org/en/news/feature/2013/08/20/earth-observation-for-development-success-stories. Accessed January 2020.

49 Ibid.

and watershed management activities. It also helped ADB to raise awareness about the impact of climate change and land-use changes in Timor-Leste, with focus on ecosystem services and road infrastructure". The data and services delivered were cited to be better quality and value and easier to obtain than traditional data sources.[50]

Examples of how the EO4SD-Urban programme supported IFI's work in flood early warning and response management is discussed in 'Section three: Evaluation of the EO4SD-Urban programme'.

Evidence of EO benefits for city environment and population health

SDG 11.6

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

SDG 11.7

By 2030, provide universal access to safe, inclusive and accessible, green and public spaces particularly for women and children, older persons and persons with disabilities.

There were insights on the application and use of EO in air quality monitoring and, to a lesser extent, urban heat islands, waste management, and green and open spaces. Several EO products are available to identify and map urban green areas and waste disposal sites. Innovations in satellite sensors enable the measurement of air quality and surface temperature to provide cities with critical environmental information that can support sustainable development interventions.

EO supports the development of models to measure air quality in cities around the world. This information has been delivered direct to citizens and has also been used by cities to test the impact of various environmental interventions. Examples include:

- The Copernicus Atmosphere Monitoring Service (CAMS) provides consistent and quality-controlled global information related to air pollution, solar energy, and GHG using EO and other sources. In 2017, CAMS helped expand the coverage of the Plumes Air Report—a smartphone application and website which prompts users to adapt their behaviour to air pollution levels—to every city in the world by providing forecasts of the key air quality pollutants. At the end of 2017, the Plume Air Report had been downloaded close to a half million times, with 73% of users saying it has helped them make changes to avoid smog spikes in their cities.[51]
- Sentinel 5-P is a satellite within the Copernicus programme and is dedicated to monitoring our atmosphere. The satellite carries an instrument to map a multitude of trace gases which affect the air quality and therefore human health. The objective is to provide accurate, rapid and timely view of air quality. This is highlighted by the satellite recording a rapid

50 Liveable Cities. 2017. 'Transport sector climate proofing in Timor-Leste'. https://www.livablecities.info/timorleste-climate-proofings. Accessed January 2020.

51 Group on Earth Observations (GEO). 'GEO Highlights: 2017-2018'. http://www.earthobservations.org/documents/publications/2018_geo_highlights_report.pdf. Accessed January 2020.

drop in air pollution in Europe and other regions amidst the COVID-19 pandemic and associated quarantine measures.[52] [53]

- Research during haze episodes over Peninsular Malaysia assessed the value of using EO to provide new datasets to assist in the observation of air quality. 3 km and 10 km MODIS aerosol products were used to provide an overview of the state of fine and coarse particulate matter. They concluded that EO data analysis of atmospheric aerosols remains a great method for estimating haze distribution and can be further used to monitor the atmospheric environment in Malaysia.[54]

EO can support the assessment of urban heat islands in cities. Temperatures can be several degrees higher in cities than in surrounding rural areas. Prolonged periods of high temperatures increase the demand for energy and water, trigger health issues, and increase air pollution. EO has enabled an improved understanding of this phenomenon which makes it possible to develop more efficient alert systems, helping policymakers adopt effective mitigation strategies and improve urban planning.[55] Examples include:

- A study in Kiev, Ukraine, using EO data from Sentinel 3, evaluated the correlation between urban heat island temperature dependence on building density, tree density and population density. Overall the results can inform policy by highlighting the factors that contribute to reducing urban heat island intensity in cities.[56]
- Researchers investigated how to measure the urban heat island phenomena in Bangkok, Thailand. Maps of this phenomenon were developed using EO data from Landsat 8. The researchers stated that their proposed analysis will help determine if the land use plan requires targeted future actions for the Urban Heat Island mitigation or if the maintenance of the current urban development model is in line with the environmental sustainability.[57]
- A study in New Delhi India, again using EO data from Landsat, evaluated the correlation between urbanisation-induced rapid land use/land cover change and Urban Heat Island intensity. The result showed that highly dense sub-districts, built-up areas, and industrial zones were more prone to urban heat island intensity. Overall the results can inform policy by highlighting the factors that contribute to reducing urban heat island intensity in cities.[58]

EO can enable the detection and mapping of illegal waste sites in cities and estimates of household waste generation. With 90% of waste openly dumped or burned in low-income countries,[59] there is a need for adequate information on the location of waste sites so authorities can mitigate illegal dumping practices. EO has supported use cases for the detection of illegal waste sites and the quantification of household waste in cities. Examples include:

- A study assessed the quantity of household solid waste in the City of Da Nang, Vietnam, using a combination of very-high-resolution EO data, field surveys, and solid waste

52 ESA. 'Coronavirus lockdown leading to drop in pollution across Europe'. https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Coronavirus_lockdown_leading_to_drop_in_pollution_across_Europe. Accessed April 2020.

53 ESA. 'COVID-19: nitrogen dioxide over China'. https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/COVID-19_nitrogen_dioxide_over_China. Accessed April 2020.

54 Khaled Ali Ahmed Ben Youssef, and others. 'The development of Air Quality Indices using AOD-Retrieved Images during haze events in Peninsular Malaysia'. 2019. IOP Conference Series. Earth and Environmental Science, 373. https://iopscience.iop.org/article/10.1088/1755-1315/373/1/012027/pdf. Accessed January 2020.

55 United Nations Office for Outer Space Affairs. 2018. 'European Global Navigation Satellite System and Copernicus: Supporting the Sustainable Development Goals'. http://www.unoosa.org/res/oosadoc/data/documents/2018/stspace/stspace71_0_html/st_space_71E.pdf. Accessed January 2020.

56 Shumilo, Leonid et al. 'Sentinel-3 Urban Heat Island Monitoring and analysis for Kyiv Based on Vector Data'. 2019 10th International Conference on Dependable Systems, Services and Technologies. https://ieeexplore.ieee.org/document/8770042. Accessed April 2020.

57 Global Partnership for Sustainable Development Data. 'Landsat's Earth Observation Data Support Disease Prediction, Solutions to Pollution, and More'. https://static1.squarespace.com/static/5b4f63e14eddec374f416232/t/5bacd7f2b208fc85418174 44/1538054151334/CaseStudy_. Accessed January 2020.

58 Pramanik, Suvamoy, and Milap Punia. 'Land use/land cover change and surface urban heat island intensity: source-sink landscape-based study in Delhi, India'. Environment, Development and Sustainability. https://link.springer.com/article/10.1007/s10668-019-00515-0. Accessed January 2020.

59 World Bank. 'What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050'. http://datatopics.worldbank.org/what-a-waste/. Accessed January 2020.

measurements on the ground. The specific generation and composition of household waste correlated positively with the EO data on building type and the spatial location within the city. This assessment of household solid waste generation and composition by building type can help efficiently allocate resources to waste collection throughout the city and improve the rate of waste collection. [60]

- ESA supported the Wastemon project in Italy which provides waste monitoring to improve waste management practices and detect illegal landfills using EO. It was tested by the Environmental Protection Agency of Puglia region, Italy. Over 10 potential illegal waste sites were mapped in the area of interest and the verification results showed the services had an accuracy of 80%. [61]

EO can also support the mapping and assessment of a city's green and open spaces and support in the monitoring of restoring degraded ecosystems in urban areas. Use cases from Sri Lanka and Turkey have highlighted the EO can be an effective tool to map the status of green areas and to understand how and why they are changing. Examples include:

- In a study, Colombo's green space areas were extracted from Thailand Earth Observation System (THEOS) and an environmental criticality map based on population density and percentage green spaces was constructed. The study revealed that 24% of the entire Colombo Municipal Council area consists of green spaces. This study also revealed that 34 of 55 divisions lack the minimum per capita green space recommended by World Health Organization. The research provided recommendations where new green spaces should be established. [62]

- A recent study evaluated the 10-year change in the urban texture in the city of Nevsehir, Turkey, through the integration of very high-resolution EO. The results showed a 23% decrease in urban open-green spaces. The results of the study are expected to guide decision makers in restoring and maintaining green areas in Nevsehir city. [63]

Examples of how the EO4SD-Urban programme supported IFI's work in city environment and population health is discussed in 'Section three: Evaluation of the EO4SD-Urban programme'.

60 Vetter-Gindele, Jannik, and others. 'Assessment of Household Solid Waste Generation and Composition by Building Type in Da Nang, Vietnam'. Resources 8 (2019). https://www.mdpi.com/2079-9276/8/4/171. Accessed January 2020.

61 European Association of Remote Sensing Companies (EARSC). 'Improving waste management practices'. https://earsc-portal.eu/display/EOSTAN/Improving+waste+management+practices. Accessed January 2020.

62 Senanayake, Indishe, Welivitiyage Don Dimuth Prasad, and Nadeeka Manage. 'Urban green spaces analysis for development planning in Colombo, Sri Lanka, utilizing THEOS satellite imagery—A remote sensing and GIS approach'. Urban Forestry & Urban Greening 12.3 (2013): 307-14. www.researchgate.net/publication/259163094_Urban_green_spaces_analysis_for_development_planning_in_Colombo_Sri_Lanka_utilizing_THEOS_satellite_imagery_-_A_remote_sensing_and_GIS_approach. Accessed January 2020.

63 Aklibasinda, Meliha, and Asli Ozdarici Ok. 'Determination of the urbanization and changes in open-green spaces in Nevsehir city through remote sensing'. Environmental Monitoring and Assessment 191.12 (2019). www.researchgate.net/publication/337333144_Determination_of_the_urbanization_and_changes_in_open-green_spaces_in_Nevsehir_city_through_remote_sensing. Accessed January 2020.

Evaluation of the EO4SD-Urban programme

Overview of the EO4SD-Urban programme

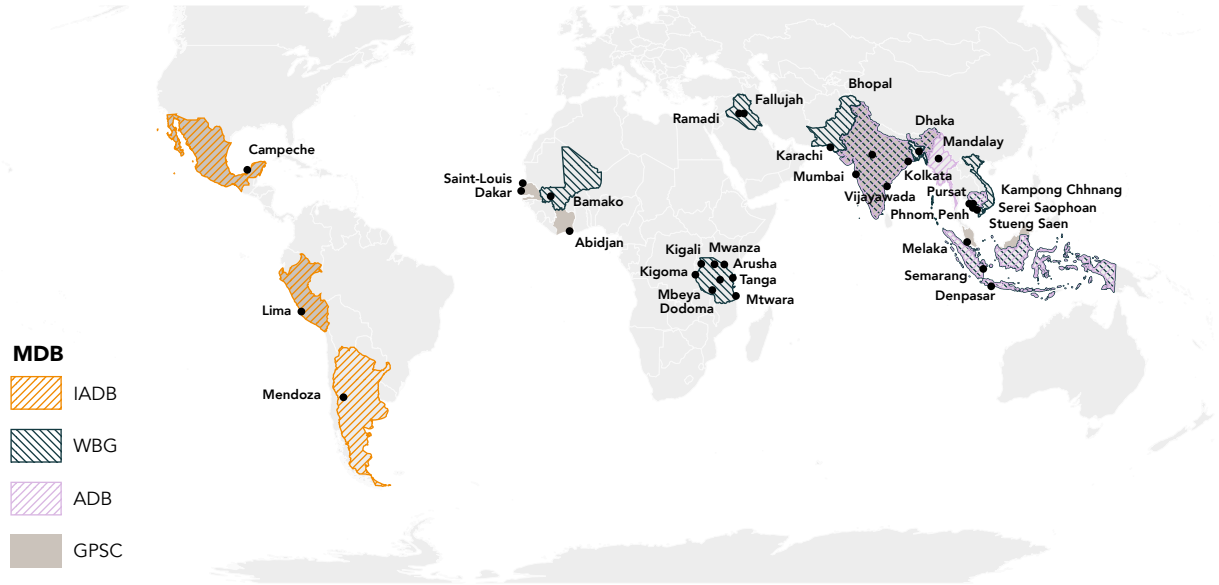
Key points

This section provides a succinct overview of the ESA supported EO4SD-urban programme.

- EO4SD-Urban is a three-year programme to demonstrate the application and benefits of EO in the urban context.
- The programme collaborated with 17 IFI programmes, in 31 unique cities across 15 countries.
- IFIs received several urban EO products each; there was a demand for more than what was provided, however, budget limitations meant not all requested products could be provided.
- The EO4SD-Urban programme invested in capacity building through webinars and, to a lesser extent, through city trainings and regional workshops when the opportunity was presented.

The EO4SD-Urban programme is a three-year programme, initiated in 2016, with the overarching objective of collaborating with IFIs to identify urban programmes to provide demonstrations of the benefit of EO and to mainstream EO into development programmes. The EO4SD-Urban programme developed a portfolio of urban EO products and supported three IFIs, in 31 unique cities (33 in total) across 15 countries, as per Figure 2. See **Annex one**, for a list of the IFI programmes and the EO products delivered.

FIGURE 2: EO4SD-Urban cities (Credit: GAF)



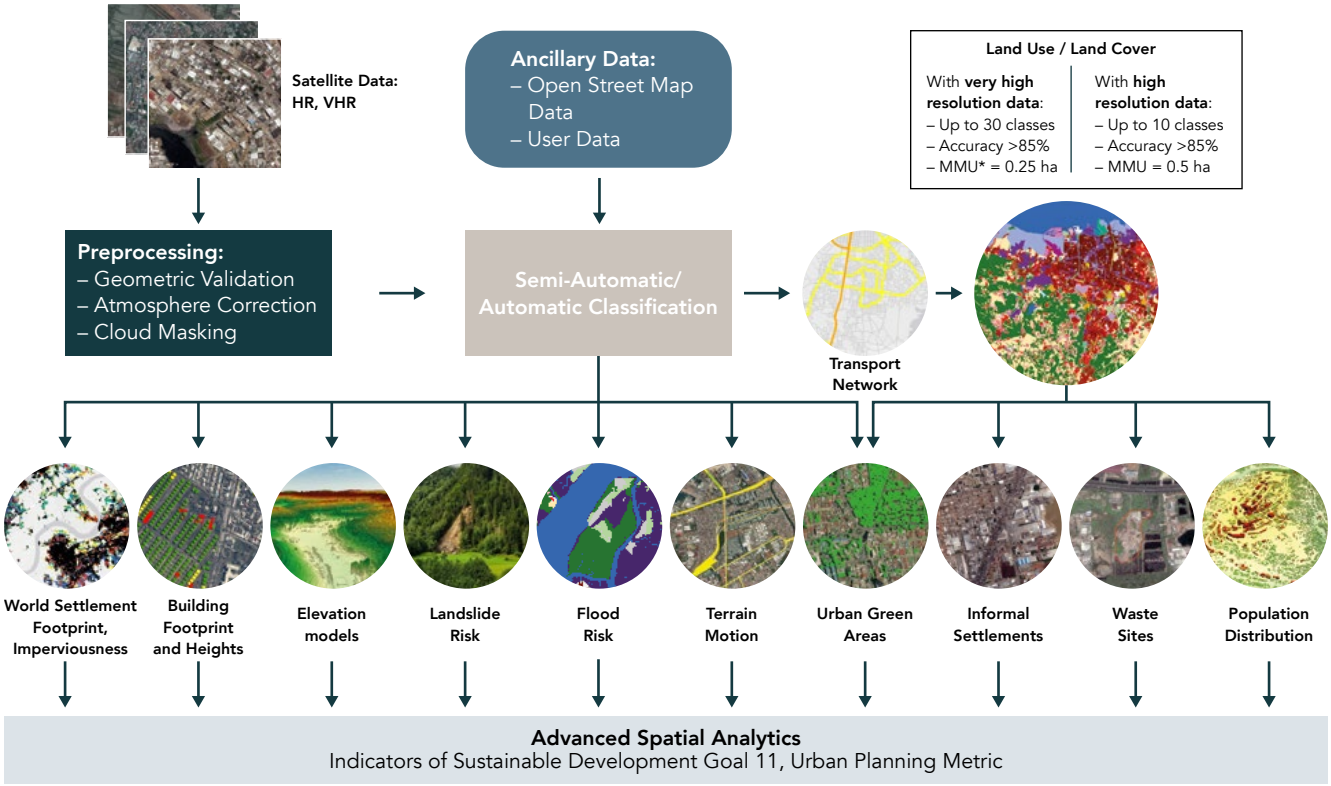


FIGURE 3: EO4SD-Urban EO products Copyright: Abidjan: WorldView-2 © 21.08.2018 DigitalGlobe, Inc., a Maxar company; Denpasar: WorldView-2 © 08.09.2015 DigitalGlobe, Inc., a Maxar company; Semarang: Pleiades © CNES 08.09.2015, Distribution Airbus DS * Minimum Mapping Unit

EO4SD-Urban product portfolio

The EO4SD-Urban programme developed 12 EO products—with various sub-products[64]—for a wide range of urban development challenges. These are described briefly below.

1 **Land use/Land cover and change:** Identifies land use and land cover classes and changes over time.[65] Two different products can be produced: One land use/land cover classification with around 30 classes for the core city area, based on very high-resolution satellite and one complementary land cover classification with around 9 classes for the peri-urban area, based on high-resolution satellite data.

2 **World Settlement Footprint and change:** Identifies and delineates the temporal evolution of urban growth. The product comes with a percentage imperviousness layer visualising the degree of sealed surface.

3 **Transport infrastructure and change:** Identifies different transport classes such as fast transit roads, primary, secondary and local roads.

4 **Urban green areas and change:** Identifies all urban green areas in a city based on high-resolution data.

a **Urban open and green spaces and change:** Very detailed classification of urban green and open spaces (e.g., different park types, squares, etc.) based on very high-resolution satellite data.

64 For example World Settlement Footprint is a main product and World Settlement Footprint Change is a sub-product.

65 Aligned to the Urban Atlas nomenclature. [Copernicus: Land Monitoring Service. 'Urban Atlas'. https://land.copernicus.eu/local/urban-atlas. Accessed January 2020.]

5 **Population distribution and density and change:** Estimation of urban population distribution and density as an important indicator for the assessment of urban growth, and planning for city services.

6 **Waste sites and change:** Identifies the size, location, and change of waste sites and help to detect illegal sites.

7 **Informal settlements and change:** Identifies probable informal settlements and allows the monitoring of the location and extent of these areas in a city.

8 **Flood risk assessment:** Identifies location, intensity, and risk to urban infrastructure and population from flood hazards.

9 **Landslide risk assessment:** Identifies the location and extent of landsides along with areas that are susceptible to landslides.

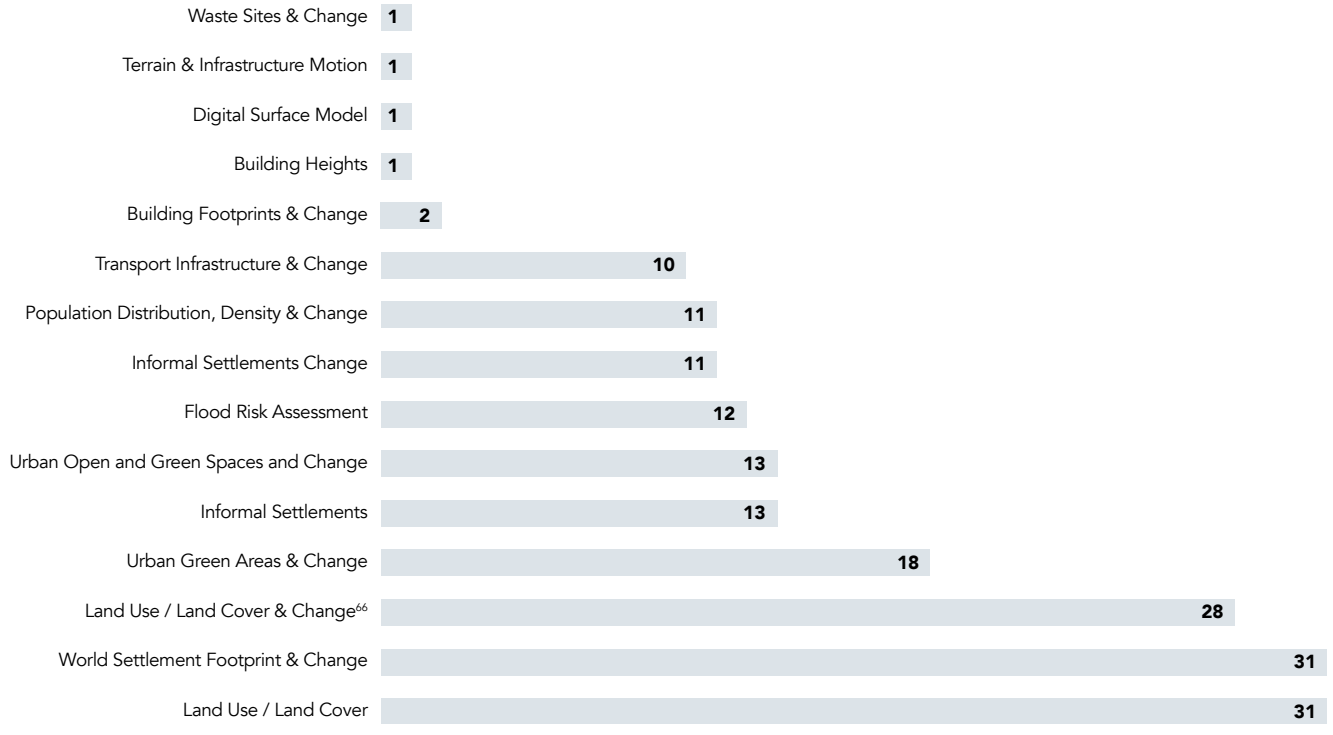
10 **Terrain and infrastructure motion:** Identifies the location and extent of vertical surface movements to highlight areas of subsidence.

11 **Building footprints and heights and change:** Identifying building footprints and their heights allow the clear delineation of the extent of built-up areas, as well as a precise estimation of building heights, which are required for reliably characterising the building volume and making population estimations.

12 **Digital elevation models:** Generation of very detailed digital surface and digital terrain models based on high and very high-resolution multi-stereo satellite data. The datasets are base layers for risk related analysis and different urban applications.

Based on engagement with the IFI Programme Officer, all IFI programmes were provided with a choice from **12** main EO products and several sub-products that could be used to advance their urban programme objectives with their city counterparts. Figure 4 provides an overview on the overall number of delivered products. Note that most programmes requested more products than what was delivered but budget limitations restricted the number that could be provided. Thus, the numbers reflect viable product delivery within a given budgetary framework rather than a representation of actual demand. See **Annex two** for a description of the EO4SD-Urban product portfolio.

FIGURE 4: Number of urban EO products delivered by product type (Credit: GAF)



66 Whereby this is different from the Land Use / Land Cover EO product by showing changes in time.

Capacity building delivered in the EO4SD-Urban programme

The EO4SD-Urban programme was required to invest in continuous stakeholder engagement and deliver various capacity building activities to support the uptake and continued use of EO products. Three capacity building mechanisms were used in the second phase of the programme for both the IFI programme and city level users.

- **Webinars:** 11 webinars were conducted between June 2018 and March 2019 and made available on the EO4SD-Urban website and the World Bank Open Learning Campus (OLC).[67,68] They are also hosted on ADB's K-Learn Platform.[69] The webinars include a balanced mix of technical training and use case examples.
- **City trainings:** Tailored city level trainings for each of the 31 cities was not within the scope of the programme, which was clearly communicated to the IFI Programme Officers at the start of the programme. Thus, a mixture of approaches was used (i.e., in-country if IFI additional funding was available, tele-conferences or, as side events in major meetings). Overall less than a third of cities received targeted support.[70]
- **Regional workshops:** Two regional workshops were held. The first was an ADB supported two-day workshop in Mandalay in March 2019. During the second day, practical training was provided along with use-case presentations for approximately 50+ persons. The second workshop was the city academy as a side event to the GPSC Global Meeting in Sao Paolo, Brazil in September 2019. The two-day training aimed to support city representatives within the portfolio and generate interest for follow-up activities in other cities.

67 World Bank: Open Learning Campus. 'Webinar Series: Earth Observation for Sustainable Development (EO4SD)'. https://olc.worldbank.org/content/webinar-series-earth-observation-sustainable-development-eo4sd. Accessed January 2020.

68 EO4SD. 'urban development'. http://www.eo4sd-urban.info/. Accessed October 2019

69 ADB. 'Earth Observation for Sustainable Development Webinars'. https://events.development.asia/learning-events/earth-observation-sustainable-development-webinars. Accessed April 2020.

70 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 10b: Capacity Building Activities Review. August 2019.

Evidence of impact from the EO4SD-Urban programme

Key points

This section highlights how EO4SD-Urban products have been perceived in terms of quality, how they have been used by the IFI programmes and the potential impact on partner cities.

- **Product quality:** Overall accuracy of the EO products were tested to be between 85%–95% and averaged at 90%.
- **Publications:** 13 IFI publications using EO4SD-Urban products were located, highlighting the utility in research and communications.
- **Guiding planning and investment:** Some IFIs using EO4SD-Urban products demonstrated that EO provided new insights that were previously inaccessible, and these insights and images were a powerful communication tool for policy dialogue. There is also evidence of both IFIs and cities implementing recommendations derived from these insights.
- **Solving data scarcity:** EO is a valuable source of data in data-scarce urban environments. A clear use case of EO in data-scarce contexts, is in the identification and delineation of slums. EO4SD-Urban products were shown to enhance the mapping of slums in Dhaka and provide a cost-effective methodology for assessing the needs of slum populations.
- **Improving disaster resilience:** The EO4SD-Urban portfolio included products that enable cities to assess and respond to disaster risk. Products have been used in Semarang, Indonesia, for housing development decisions as well as in Kolkata, India, for flood risk and response.
- **Enabling time and cost savings:** Clear examples are showcased in reducing the time and costs of city diagnostic visits in Dhaka and Karachi. Also in Kigali, Rwanda, EO was highlighted to save time in the process of collecting data on buildings for property valuation.
- **EO integration within IFIs:** Qualitative insights have shown that some IFI Programme Officers do anticipate integrating EO in urban programmes, with additional programmes using EO now operational or in development, while other IFI Programme Officers highlighted the potential for integration.

Within three years of implementation, the EO4SD-Urban programme supported 17 IFI programmes and covered 31 unique cities in Africa, South America, and Asia. During this time, a variety of use cases for EO data were demonstrated, from diagnostics of city sustainability, improving efficiencies in urban planning, disaster resilience, improving revenue from tax collection, slum identification, and transport planning. This section highlights how these products have been perceived in terms of quality, how they have been used by the IFI programmes, and the potential impact on the cities they work with. Insights have been derived from one-on-one interviews and data from surveys conducted by the consortium during the programme.

Urban EO product and service quality

> *"They have really done an excellent job. I can say at least at a World Bank level, from all interactions. I did find the task team get quite excited about the potential use of this (EO) tool, how this could be useful for our projects".*
>
> **Interviewee—World Bank GPSC programme**[71]

The overall accuracy[72] **of the EO products was between >85%–95%, with an average over 90%.**[73] To promote uptake of and further investment in EO products, users need to see clear value and trust the information provided by the EO4SD-Urban products.

100% of IFIs who responded to a consortium survey highlighted that the EO products provided *"useful and recent data which can be used to the programme"*.[74] While the satisfaction with the products was generally high, a few IFI users provided feedback that they understood late into the project what the products would look like and how they could be used. In response, the consortium simplified their communications to ensure that the user would quickly understand the products and outputs and make clearer decisions on their utility.

Use of EO-derived analysis in external publications

Several IFI programmes have done extensive in-house and external promotion of their EO4SD-Urban engagements. EO products have been used as a data source in publications, conference presentations and internal knowledge transfer sessions. See **Box 2** for a list of publications referencing EO4SD-Urban products.

Various IFI Programme Officers shared their experiences in using EO4SD-Urban products at multiple conferences in addition to holding various information sharing meetings internally. The World Bank has included all EO4SD-Urban data in their online Data Catalogue.[75] The extent and range of the use of EO products in publication suggested a **sense of ownership and clear use of the EO products.**

71 Caribou Space interview. November 2019.

72 The probability that the observation from the EO product is true when compared to the truth on the ground.

73 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 8: Service Demonstration Exercise Specification.

74 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 12b: Service Delivery Utility and Impact Review. August 2019.

75 World Bank. 'Data Catalog'. https://datacatalog.worldbank.org/search?search_api_views_fulltext_op=AND&query=E04sd-%20urban&nid=&sort_by=search_api_relevance&q=search&page=0%2C0. Accessed January 2020.

Box 2: Publications using or about EO4SD-Urban EO data and analytics products

1 World Bank. 2017. 'Urban Development in Phnom Penh'.

2 Ellis, Peter D., Friaa, Jaafar Sadok, Kaw, Jon Kher. 2018. 'Transforming Karachi into a liveable and competitive megacity: a city diagnostic and transformation strategy'. Directions in development; infrastructure. World Bank.

3 Huang Chyi-Yun, Ally Namangaya, MaryGrace W. Lugakingira, and Isabel D. Cantada. 2018. 'Translating Plans to Development: Impact and Effectiveness of Urban Planning in Tanzania Secondary Cities'. World Bank.

4 Mimmi, Luisa, Christian Borja-Vega, Amit Patel, Tanushree Bhan, Tanushree, Hyunjung Lee, Marcia Mundt, Tomas Soukup, and Jan Kolomaznik. 2018. 'Predicting Deprivations in Housing and Basic Services from Space: A Pilot Study in Slums of Dhaka, Bangladesh'. World Bank.

5 Huang, Chyi-Yun, and Isabel Cantada. 2019. 'Challenges to implementing urban master plans – what are we missing?'. World Bank (blog).

6 Pokhrel, Neeta. 2019. 'Transforming Kolkata, A partnership for a more sustainable inclusive and resilient city'. Asian Development Bank.

7 Asian Development Bank. 2019. 'Two Decade Partnership Helping Bring Kolkata's Urban Services into Modern Age'. Asian Development Bank (blog).

8 Ali, Daniel Ayalew, W. Klaus Deininger, and Michael Wild. 2018. 'Using satellite imagery to revolutionize creation of tax maps and local revenue collection'. Policy Research working paper; no. WPS 8437. World Bank.

9 Hyunji, Lee. 2018. 'Quantifying public spaces for better quality of urban assets'. World Bank (blog).

10 Kaw, Jon Kher, Lee Hyunji, and Wahba Sameh. 2020. 'The Hidden Wealth of Cities: Creating, Financing, and Managing Public Spaces'. World Bank.

11 City Planning Labs. 2018. 'City Planning Labs (CPL): IPDS Framework - Data Pillar'. World Bank.

12 City Planning Labs. 2018. 'City Planning Labs (CPL): IPDS Framework - People Pillar'. World Bank.

EO4SD-Urban products guide urban planning and investment

EO4SD-Urban products have been used in several IFI programmes to guide both IFI and city planning and investment. While policy change is a long-term goal, progressive steps towards policy change has been observed. The stages before policy change where EO products have been supportive are; 1. providing new insights and 2. using these insights to enable dialogue at the municipal and national level.

— *EO provides new insights*

> *"The datasets were very helpful in demonstrating urban expansion for the city in space and time at level of details and at the same time for the whole city, something what is hardly achievable in other means".*
>
> **World Bank—Urban Development in Phnom Penh**[76]

76 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 12b: Service Delivery Utility and Impact Review. August 2019.

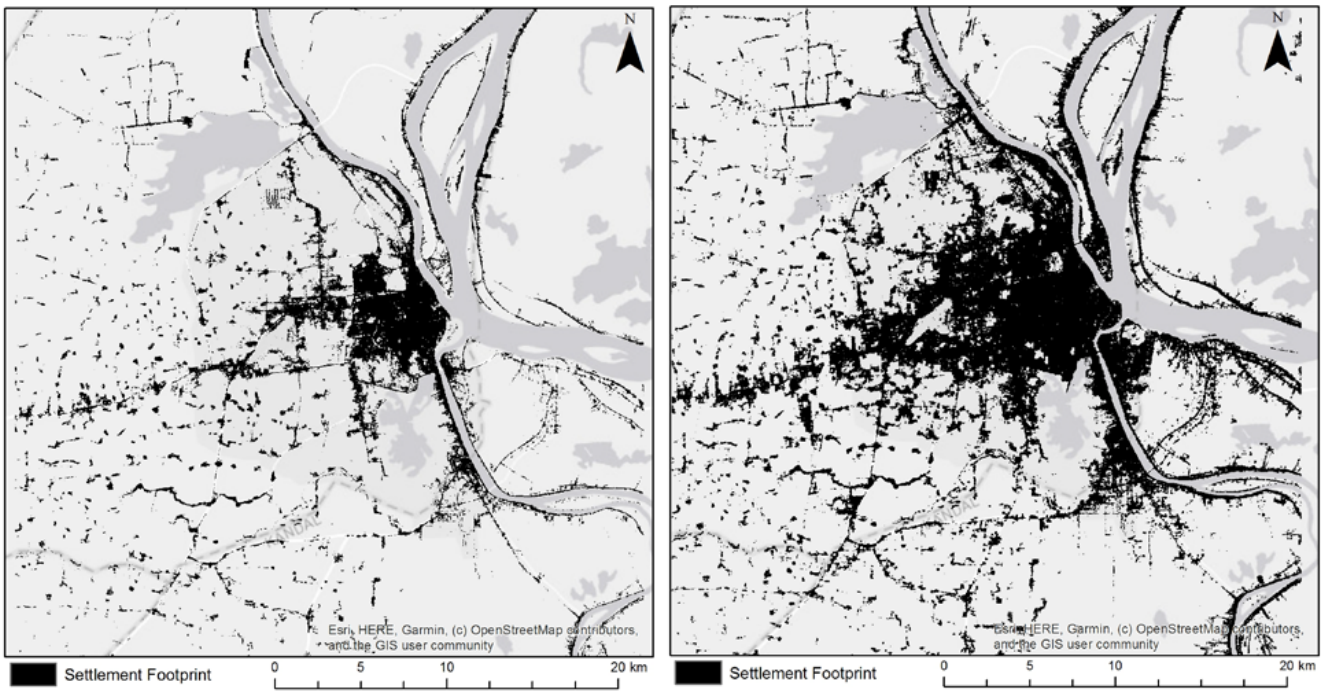
EO4SD-Urban products demonstrated their capabilities in uncovering new insights for the IFI programmes. 100% of IFIs surveyed in a consortium survey highlighted that the EO4SD-Urban products provided them with "new insights compared to before using EO".[77] In the World Bank Urban Planning Study in Tanzania, the insights on land use and land cover *"would not have been possible through other methods or technologies"*.[78]

— *EO as a tool to enable dialogue with cities*

A common thread of feedback shared by the IFIs was the effectiveness of the EO4SD-Urban products in supporting their own engagement with their city stakeholders. EO4SD-Urban supported the World Bank's Social, Urban and Rural, and Resilience (SURR) Global Practice's Urban Development programme in Phnom Penh. The programme was undertaking a rapid diagnostic of Phnom Penh' urban spaces. The diagnostic—now a public report—shed light on the city's challenges and recommendations to achieve sustainable and inclusive growth. The IFI programme lead noted that they *"can understand how the city is growing and the implications of that in wider spatial and temporal context then by any other means possible. Such rapid assessment and support to initial city diagnostic is important and very effective"*. Further to this they shared that the *"results were very helpful in our dialogue with the city on the need for urban planning"*.[79]

Similar statements were echoed by the World Bank GPSC programme in the cities of Bhopal and Vijayawada, India. In both cities, the broad programme objectives were to demonstrate an integrated package of technologies and interventions to assist in investments that will reduce the cities environment impact. EO4SD-Urban provided products on land use/land cover, green areas and World Settlement Footprints.

FIGURE 5: Settlement extent in Phnom Penh 1990 (left) and 2015 (right) (Credit: DLR)[80]



77 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 12b: Service Delivery Utility and Impact Review. August 2019.

78 Ibid.

79 Ibid.

80 Baker, Judy L., and others. 2017. 'Urban development in Phnom Penh'. World Bank. http://documents.worldbank.org/curated/en/286991511862455372/Urban-development-in-Phnom-Penh. Accessed December 2019.

The IFI programme lead noted that *"the urban growth scenario modelling helps cities to identify pathways to low-carbon growth scenarios considering implementing different levers, e.g. policies, technologies, land use, etc"*.[81] In the World Bank Urban Spaces for City Transformation in Dhaka and Karachi the EO4SD-Urban products on land use and trends was cited to provide foundational set of data points that enables both discussion with, and engagement of, local city users. The case below highlights the pioneering methodology for using EO in city diagnostics and the impact of this methodology on city planning and using resources efficiently.

EO4SD-Urban Case Study: Incorporating EO for rapid and objective city-level diagnostics in Karachi, Dhaka, and Lima

Prior to the first engagement with a city, IFIs often require a city diagnostic to jointly identify with the city, priorities for investment. However, few cities have sufficient data, to produce an objective city diagnostic. In these scenarios, consultants are hired to collect data on the ground, speak with various local authorities, and use available city data to piece together a picture of the city and highlight where investments may be made. In a city like Dhaka, where traffic moves at 7 km per hour, this can be a costly and time-consuming exercise.[82]

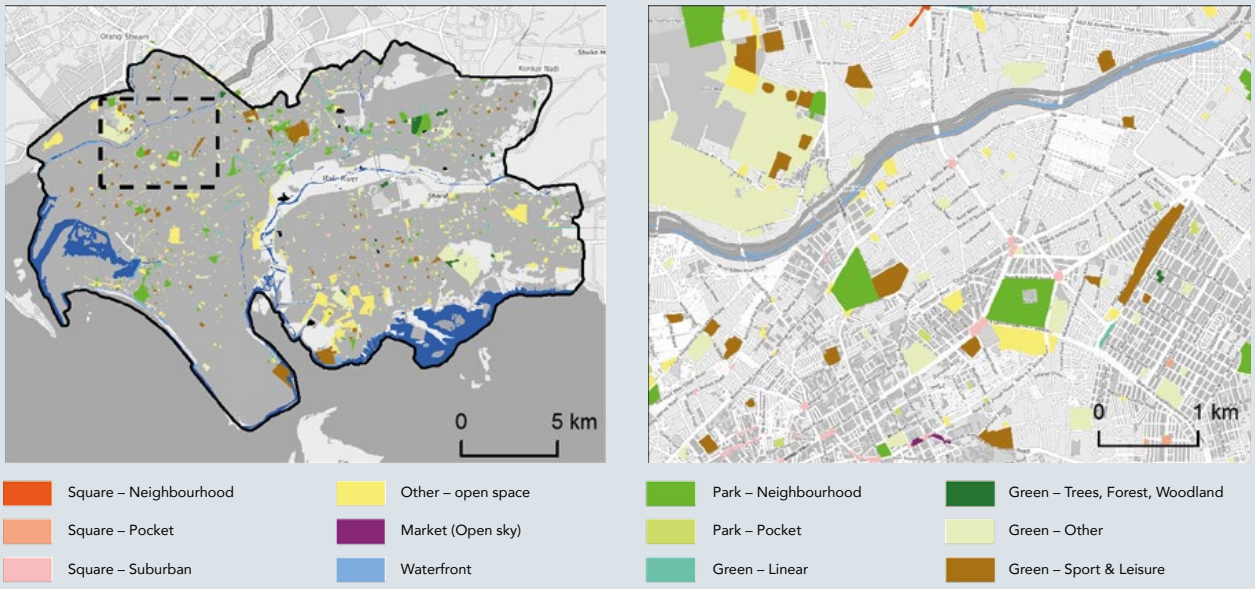
In Dhaka and Karachi, the World Bank conducted a diagnostic as part of broader technical assistance to develop a multisector approach for city transformation. For this diagnostic, the World Bank team engaged with the EO4SD-Urban programme to use EO data in a new city diagnostic methodology.

EO data and various data layers such as street view maps and census data, were used to analyse the patterns of how public spaces were distributed, designed, managed and used.

This approach was highlighted to have been a time saving and objective methodology for assessing priorities for data scarce mega cities.

> *"The government do not have enough data to objectively decide where they want to prioritise. So, it helps. It saves a lot of time, because if we do it manually, and visit the whole city in mega cities like Karachi and Dhaka, it will be extremely time consuming, it would also be very subjective. I think this provides a very good methodology of consistency in trying to analyse a whole city quite quickly"*.[83]
>
> Interviewee—World Bank Dhaka and Karachi neighbourhood improvement project

FIGURE 6: Map of open and green spaces in Karachi based on extended nomenclature - overview and detail maps (Credit: GISAT)



81 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 12b: Service Delivery Utility and Impact Review. August 2019.

82 World Bank. 2017.'A Modern Dhaka is Key to Bangladesh's Upper-Middle Income Country Vision'. Press Release. https://www.worldbank.org/en/news/press-release/2017/07/19/modern-dhaka-key-bangladesh-upper-middle-income-country-vision. Accessed December 2019.

83 Caribou Space interview. January 2020.

The imagery was deemed to be a powerful tool in sharing information about the city to the authorities and to identify priorities for investment which are now operational.

> *"We presented the findings at a conference in Karachi, we were saying things to the city that they didn't know, because they didn't have enough information. That imagery was extremely powerful. I think it helped them decide more convincingly…they realised what was the shortfall in terms of services, as well as urban planning, and spatial development. And it was partially a result of our study on the city".*[84]
>
> Interviewee—World Bank Dhaka and Karachi neighbourhood improvement project

This new methodology for assessing cities was first pioneered in Karachi and was later used in Dhaka and Lima. Notably, after the Karachi pilot, the team became more efficient in implementing the methodology.

> *"The project in Bangladesh was quick because we already knew what we were doing, that's why we could do it pretty quickly".*[85]
>
> Interviewee—World Bank Dhaka and Karachi neighbourhood improvement project

The findings from pioneering this methodology have been distilled into a publication, launched in February 2020 to inspire and enable others working in urban development to implement rapid, cost efficient and objective city diagnostics.[86]

— *Using insights for decisions*

Some IFI programmes are progressing towards influencing stakeholder's decisions. The pathway from insights to action is neither linear nor particularly efficient. There are many hurdles—bureaucracy, politics, competing priorities, capacity, and, ultimately, financial resources. In the short timeframe of the EO4SD-Urban programme, the goal of influencing city planning and policy is long term and requires more than quality data. However, there have been early indications that some IFIs are registering success.

The World Bank's City Planning Labs (CPL) in Indonesia aims to build capacity for integrated, evidence-based spatial planning and investment decision-making and to help cities achieve sustainable and inclusive economic growth. The cities of Denpasar and Semarang were interested in using EO to understand urban growth and vulnerability to risks. EO4SD-Urban products were provided to these cities to assess land use/land cover changes, population density/distribution, and flooding risk. The CPL team then worked closely with the city of Semarang to increase awareness of how EO data can be used to map these occurrences. It was documented that **Semarang's spatial planning department has already used the land subsidence data that was produced from this activity in the preparation of their spatial plan** to support decisions on demarcation of areas unsuitable for housing.[87] It is likely that the dedicated capacity building resources within CPL is one of the drivers for this uptake and integration of EO data.

Another example is the EO4SD-Urban support to the World Bank's Urban Planning study. The case below highlights how the EO-derived insights have enabled the World Bank team to actively engage with both municipal and national officials on improving the effectiveness of urban planning in Tanzania.

84 Caribou Space interview. January 2020.

85 Ibid.

86 Kaw, Jon Kher, Lee Hyunji, and Wahba Sameh. The Hidden Wealth of Cities: Creating, Financing, and Managing Public Spaces. World Bank. 2020. https://openknowledge.worldbank.org/handle/10986/33186. Accessed February 2020.

87 World Bank. 'People'. https://collaboration.worldbank.org/content/usergenerated/asi/cloud/attachments/sites/collaboration-for-development/en/groups/city-planning-labs/file2/jcr:content/content/primary/library/msdi_pillars_andtoo-suFb/people_pillar_ipdsf-k3ov/People%20Pillar_IPDS%20Framework.pdf. Accessed October 2019.

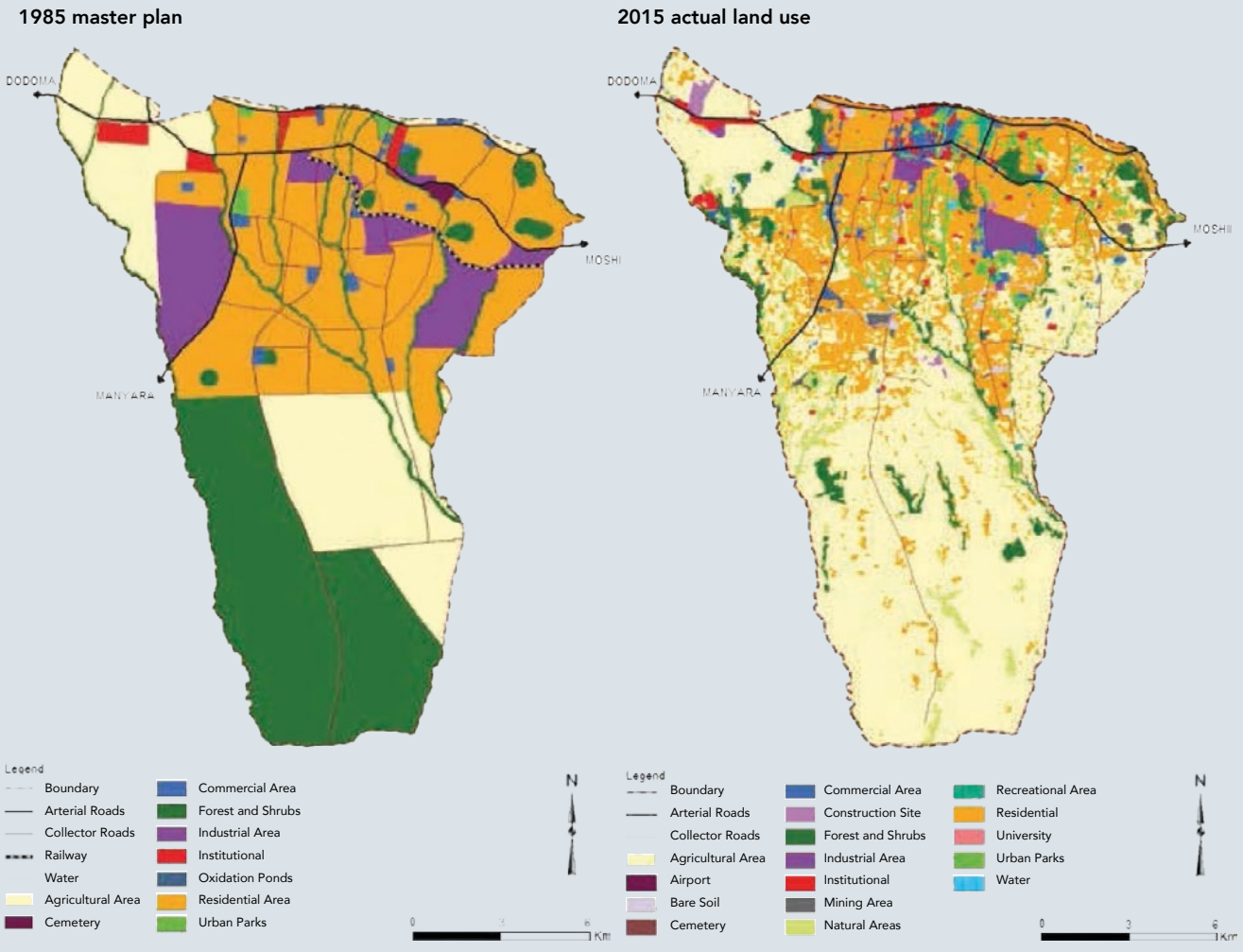
EO4SD-Urban Case Study: EO enables insights on the effectiveness of urban master plans in Tanzania

City master plans are foundational tools in urban planning. They detail a city's present status and are the blueprint for future planning for transport, land use, community services, housing, and economic development. There has been a push to get master plans in place for cities lacking them, but there is less engagement on the question of how effective these plans have been in guiding the development of cities. Evidence on effectiveness is crucial to inform the development of urban planning tools, but also as a means of enabling policy discussion on effective urban planning. To more robustly answer this question, the World Bank conducted a study that investigated the impact and effectiveness of urban planning on city spatial development in seven Tanzania secondary cities: Arusha, Dodoma, Kigoma, Mbeya, Mtwara, Mwanza, and Tanga.

> *"Interviews alone are not a very effective way to demonstrate whether plans are or aren't effective.* ***And so, having the land usage (data) as the basis for that argument, gave it that evidence-base it needed****".*[88]
>
> Interviewee—World Bank Urban Planning Study Tanzania

EO data provided the World Bank team with an objective methodology to extrapolate the effectiveness of master plans. **Using this data, the research team could investigate the degree to which various types of land uses align with previous master plans.** The results of this study, of which EO was data was foundational, were published in February 2019.

FIGURE 7: Difference between 1985 master plan and 2015 actual land use (Credit: GAF AG & Huang et. al., 2018)[89]



88 Caribou Space interview. November 2019.

89 Huang Chyi-Yun, Ally Namangaya, MaryGrace W. Lugakingira, and Isabel D. Cantada. 2018. 'Translating Plans to Development: Impact and Effectiveness of Urban Planning in Tanzania Secondary Cities'. World Bank.

While the consumable output of the EO data was the research, the process of doing the research has become a tool for enabling conversations at the policy level. One of the arguments of the research was the need to decentralise development control and thus enforcement from the municipal level to the ward or sub-ward level. **These insights were presented at the annual meeting of town planners which included the Minister of Lands and the permanent secretary of lands, where decentralising was a core discussion.**

> *"These products enhance the urban planning and capital investment programming processes of cities, as well as inform policy dialogue in Tanzania on urban development. City, regional and national-level planning authorities could substantially benefit from these products as they carry out their respective planning-related reforms".*[90]
>
> Interviewee—World Bank Urban Planning Study Tanzania

The use of EO data has been noted to have also informed future World Bank programmes. The World Bank has now secured funding for a programme that will enable service tax collection using EO data on building footprints, coupled with in-situ data collection. A need for maps of buildings has come directly from the Minister of Finance.

> *"It informed these (tax revenue collection) programmes, it informed the scope of work".*[91]
>
> Interviewee—World Bank Urban Planning Study Tanzania

It has also manifested change in other ways, for example, the Dean of Urban Planning at Ardhi University was involved in the research. **Previously 'urban development control' was not integrated in the Ardhi University's course curriculum, however based on the insights from the research 'urban development control' has now been integrated.**

Overall, the research has contributed to **raising the profile of EO in urban planning** and while this will take time, government authorities have an 'open ear' to further experimentation.

EO4SD-Urban products solving data scarcity in urban environments

> *"Data on land use is scarce in many World Bank client countries...The EO4SD-Urban products are considered as extremely helpful for any rapid urban planning/ spatial planning analysis providing solution where a lack of decent city planning data or even back in time information needed. That is considered as the real benefit of having remote sensing data based products".*
>
> **World Bank Urban Spaces for City Transformation programme in Dhaka and Karachi**[92]

EO products have proven a valuable source of data in data-scarce environments. Access to reliable, current and scalable data is a frequently cited challenge in developing country urban contexts. EO data has been noted to have the right attributes to contribute vital information for city assessments and planning for uses. Two examples from the EO4SD-Urban collaborations—Indonesia and Bangladesh—are shared.

A core objective of the World Bank's City Planning Lab (CPL) in Indonesia was to develop Fundamental Data Sets (FDS). FDSs are core datasets that provide spatial reference, enable

90 Caribou Space interview. November 2019.

91 Caribou Space interview. November 2019.

92 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 12b: Service Delivery Utility and Impact Review. August 2019.

interoperability of geospatial data and applications, and form the common base map that is essential to a city's economic, social, and environmental management and development. These datasets are expected to ease the process of spatial data production, and contribute to resolving common urban data scarcity issues. To acquire such datasets CPL collaborated with the EO4SD-Urban programme to obtain EO data to map urban growth patterns and trace urban expansion over time. Specific analytical products included: Urban land use/land cover, urban extent, transport infrastructure, terrain motion, green areas and flood history analysis. This effort was stated to have provided essential data to understand forces driving spatial growth in the city.[93]

Another clear use case of EO in data-scarce contexts, is in the identification and delineation of slums. For a variety of reasons—political, logistical, and financial—data on slums is often incomplete, unreliable and thus, many slums remain undocumented. This means their needs cannot be adequately assessed and addressed. In the case below, EO4SD-Urban data was shown to enhance the mapping of slums in Dhaka, Bangladesh, and provide a cost-effective methodology for assessing and responding to the needs of slum populations.

EO4SD-Urban Case Study: EO-derived methodologies supporting slum assessments in Dhaka, Bangladesh

A foundational step to improving various social, health, and economic outcomes in slums, is understanding their fabric and specific needs. Data on slums is often elusive and frequently inadequate. Traditionally, household surveys are used to estimate demand for urban services, however, while incredibly useful, these surveys are often expensive, time-consuming and quickly out-dated. There is a clear role for EO data to form a part of the solution to this challenge.

Under the World Bank Water Supply and Sanitation in Rapid Urbanization project, **the team collaborated with the EO4SD-urban programme to devise and test a novel, predictive model that combines spatial characterisation analysis with statistical modelling to identify slum areas and characterise slum deprivation through a case study of Dhaka, Bangladesh.** Two sources of data were combined for this project: 1. In-depth household survey from 2016 and 2. Very High Resolution (VHR) EO data and analytics of informal areas for the whole Dhaka Metropolitan Area produced by the EO4SD-Urban programme.

Several EO-derived indicators were incorporated into a statistical model to predict an index of household deprivation called Slum Severity Index (SSI). The SSI captured the needs of slum residents against several categories. The model provided numerous insights, for example:

- As the distance from central business districts and major roads increases, the lack of water or electricity increases.
- Where the percentage of high density residential urban fabric increases, housing deprivation also increases.
- The indicators for building density (e.g. average dwelling size and distance between buildings) are associated with worsening housing and basic services.

93 World Bank. 'City Planning Labs (CPL): IPDS Framework - Data Pillar'. https://collaboration.worldbank.org/content/usergenerated/asi/cloud/attachments/sites/collaboration-for-development/en/groups/city-planning-labs/file2/jcr:content/content/primary/library/msdi_pillars_andtoo-suFb/data_pillar_ipdsfra-2xOm/Data%20Pillar_IPDS%20Framework.pdf. Accessed October 2019.

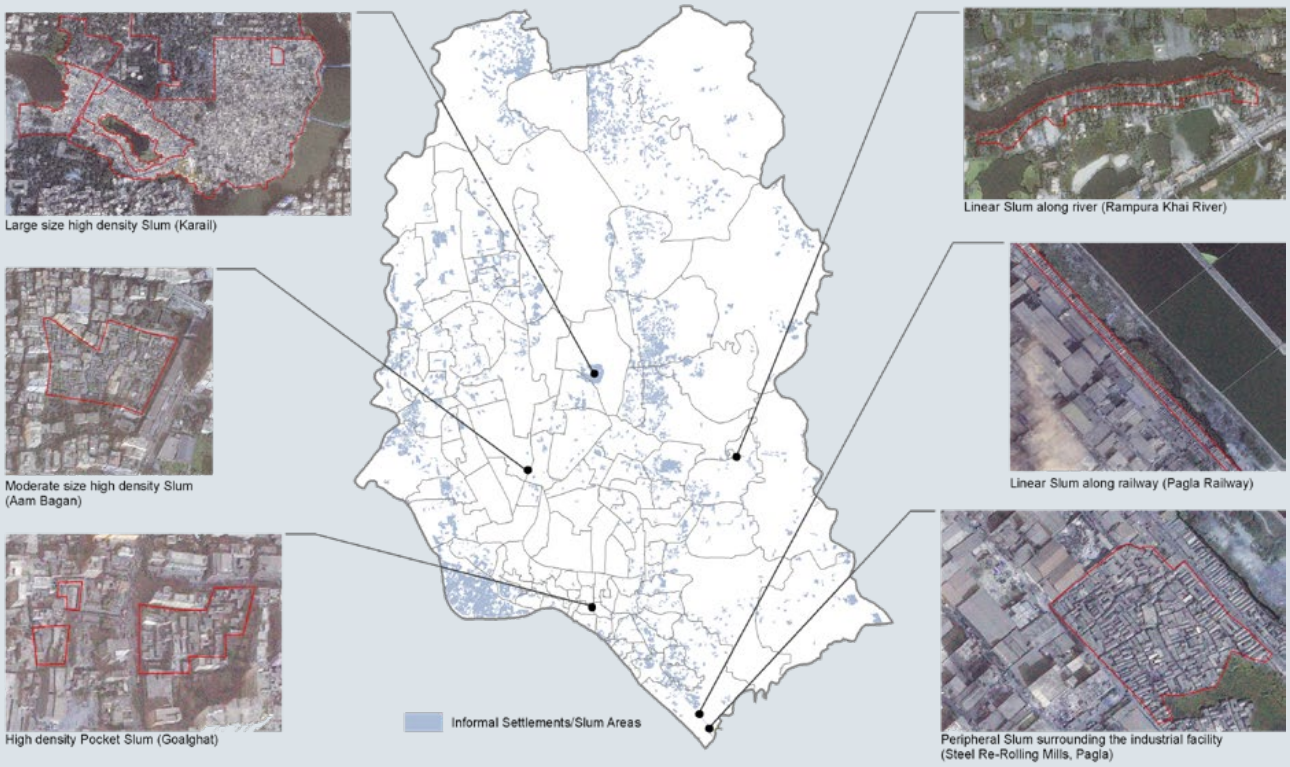


FIGURE 8: Slum mapping and characterisation in Dhaka, Bangladesh
(Credit: GISAT. Satellite imagery: Pleiades © (2017) CNES, Distribution AIRBUS DS)[94]

These findings on the methodology and derived insights have been published.[95] For national governments, this methodology was stated to provide an efficient and cost-effective way to estimate household deprivation and demand for city services nationwide. Given that EO data are available for entire nations simultaneously, there is far less time lag between data acquisition and use in decision-making than traditional survey-based methods.

This analysis and maps have been shared with the city for their planning. Within the World Bank, this engagement has sparked additional discussions and leading to new pilots applying this this methodology.

> *"I think it's gaining pretty good acceptance in the [World] Bank because,* ***we are developing now, new research programmes applied to precisely analysing household deprivations in slums in other parts of the world****, in Africa, in East Asia as well. So, this was very enriching to start that discussion".*[96]
>
> Interviewee—World Bank Water Supply and Sanitation in Rapid Urbanization project

Following on from the testing of the EO-derived methodology, **in the next phase the World Bank project will be extended and a user-friendly web application will be created to allow for interactive analysis of the resulting integrated spatial data on a web-based GIS platform.**[97] **So that the information is used for decision-making processes for reducing urban deprivations in slums.**

94 EO4SD-Urban Programme. Examples of Informal Settlements/Slum Areas.

95 Mimmi, Luisa, and others. 2018. 'Predicting Deprivations in Housing and Basic Services from Space: A Pilot Study in Slums of Dhaka, Bangladesh'. World Bank. https://www.researchgate.net/publication/325090468_Predicting_Deprivations_in_Housing_and_Basic_Services_from_Space_A_Pilot_Study_in_Slums_of_Dhaka_Bangladesh. Accessed December 2019.

96 Caribou Space interview. December 2019.

97 Mimmi, Luisa, and others. 2018. ' Predicting Deprivations in Housing and Basic Services from Space: A Pilot Study in Slums of Dhaka, Bangladesh'. World Bank. https://www.researchgate.net/publication/325090468_Predicting_Deprivations_in_Housing_and_Basic_Services_from_Space_A_Pilot_Study_in_Slums_of_Dhaka_Bangladesh. Accessed December 2019.

EO4SD-Urban products contribute to improving urban disaster resilience

> *"The fact that without being there, we could look at past flood events, current flood events and then use that to provide early warnings".*
>
> **Interviewee—ADB-Kolkata Environmental Improvement Investment Programme**[98]

The EO4SD-Urban product portfolio included products to assess and respond to disaster risk. These included landslide risk, flood risk, and terrain and infrastructure motion. Coupling these products with land use/cover and informal settlements change, supplies vital information for city disaster resilience assessments.

The use of the terrain motion product by the city planning department in Semarang, Indonesia for housing decisions has previously been highlighted. Another strong example is from the EO4SD-Urban engagement with ADB in Kolkata, India. The case below highlights the application of EO4SD-Urban products into Kolkata's flood forecasting and early warning system.

EO4SD-Urban Case Study: EO paving the way for a more resilient Kolkata

Kolkata is one of the densest megacities in the world, with a population of 14.7 million. The Kolkata Municipal Council (KMC) is mandated to provide and maintain a variety of urban services to the city's inhabitants, however, it has been extremely challenging to keep pace with the rapid urbanisation in the city. To support an integrated approach to urban planning, ADB and KMC have been working in partnership for more than 20 years to improve Kolata's urban services. The most recent investment—Kolkata Environmental Improvement Investment Programme (KEIIP)—aims to increase climate resilience and urban services through investment in water supply, sewage and drainage, and flood resilience and response.

The KMC and ADB partnered with the EO4SD-Urban programme to utilise EO data to analyse problems and improve urban services.

98 Caribou Space interview. November 2019.

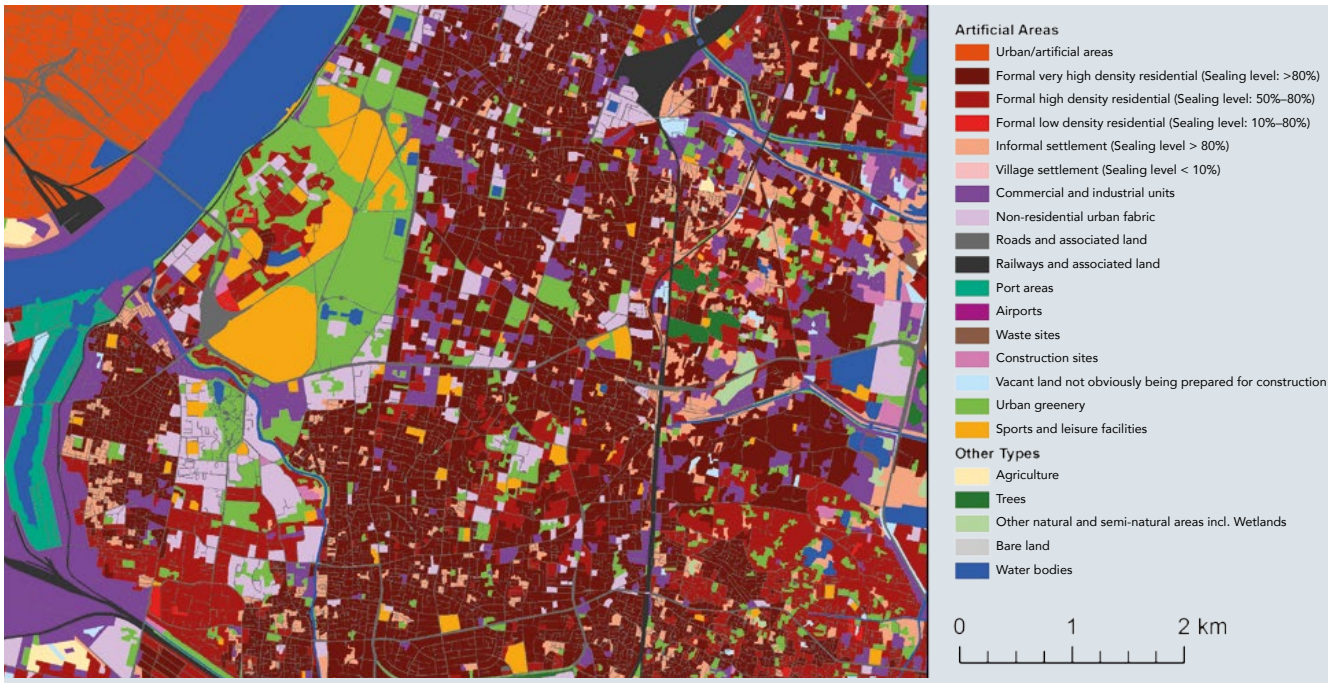


FIGURE 9: Slum mapping and characterisation in Dhaka, Bangladesh (Credit: GISAT)[99]

The data provided by EO4SD-Urban is being integrated into the KMC's flood forecasting and early warning system (FFEWS). The FFEWS has been designed to provide forecasts as well as real-time updates from sensor nodes installed in key points throughout the city. Information generated and disseminated by the FFEWS will enable informed decision making before and during floods. Data on the movement of floodwater in the past is being used and modelled to help identify hotspots and install sensors for flood warnings.

> *"The fact that without being there, we could look at past flood events, current flood events and then use that to provide early warnings".*[100]
>
> Interviewee—ADB Kolkata Environmental Improvement Investment Programme

Additionally, the EO4SD-Urban land-use map is being updated through KEIIP to consider prioritising present and future investments.

The future looks bright for KMC who have now appointed a senior technician as head of the KMC GIS department, alongside continuing ADB investment in training. The training will cover risk maps with archived EO data, and modelling work to illustrate the potential extent of flooding under various climate-change scenarios. Notably, a member of the EO4SD-Urban consortium has been contracted to support these trainings. The maps and training will help the KMC to decide future investments and policy to improve the city's resilience to flooding related to climate change.

99 EO4SD-Urban Programme. Satellite image of land use.
100 Caribou Space interview. November 2019.

EO4SD-Urban products enable time and cost savings

> *"In the context of the regular funding, savings on expert travelling and on-site visits are mentioned as potential regular source of funding for regular geospatial support of diagnostic preparatory work".*
>
> **World Bank Urban Spaces for City Transformation Dhaka and Karachi** [101]

Using EO data has been cited to save money and time for IFIs and cities. This often manifests from reducing the need for in-situ data sources, such as household surveys. In the World Bank's Urban Spaces programme in Dhaka and Karachi, the savings on site visits was noted as a potential source of funding for further investment in geo-spatial work. This is extremely valuable in mega-cities such as Dhaka and Karachi where during a diagnostic visit, it was noted that *"if you had to visit every neighbourhood, that would take months"*.[102]

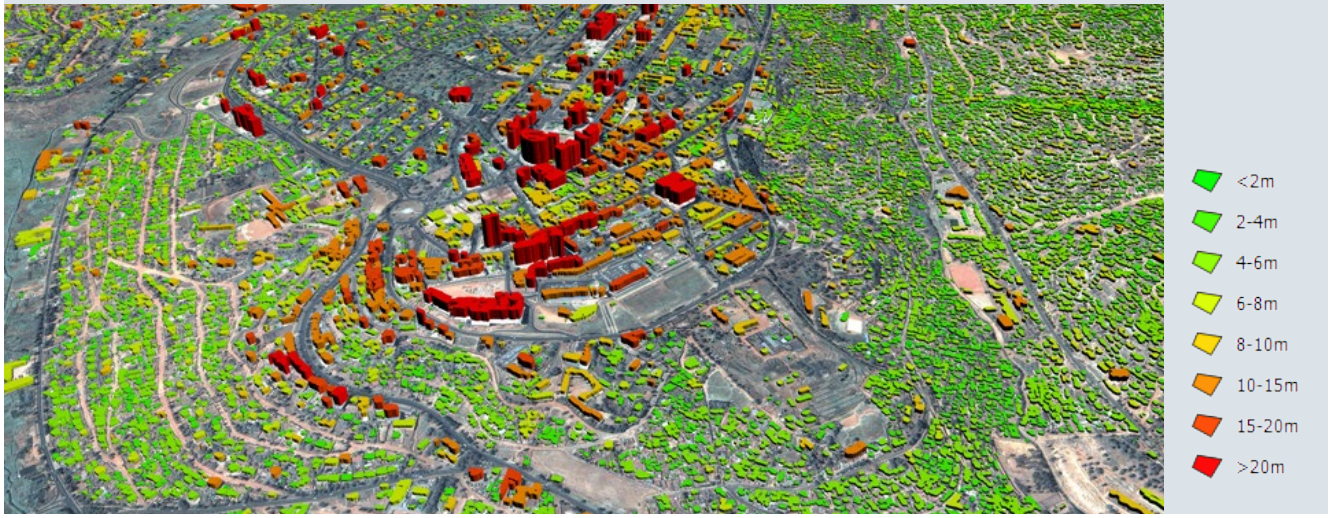
The time and costs savings is further illustrated by the EO4SD-Urban support to the World Bank Development Economics Research Group programme in Kigali, Rwanda. In the case below, EO data was highlighted to save time in the process of collecting data on buildings; the results of the study demonstrate that this methodology could greatly improve the property tax collection process for the Rwandan Government.

EO4SD-Urban Case Study: EO supports improving city tax revenue collection for service provision in Kigali

Realising the potential of cities necessitates the ability to generate resources for urban service provision, that is, to raise funds and use effective delivery mechanisms. Property taxes have been identified as a large source of untapped municipal revenue that could ease the revenue constraints on local governments. Coverage with digital cadastral maps is a necessary precondition if property taxes are to be collected both effectively and fairly, yet only 5% of African and South Asian countries have digital cadastral records.[103] For those countries, the use of digital products based on EO can be transformational.

The World Bank—Development Economics Research Group (DECRG) conducted a pilot study to support the government of Rwanda to improve methods of land valuation. The pilot objective was to assess methods for using existing land transaction data, land cadastral maps and building height data using EO4SD-Urban EO products, to simulate different property values and related tax rates to assist the country with improving the total revenues captured.

FIGURE 10: Analysis of building heights in Kigali, Rwanda (Credit: GAF AG. Satellite imagery: Pleiades © (2015) CNES, Distribution AIRBUS DS)[104]



101 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 12b: Service Delivery Utility and Impact Review. August 2019.

102 Caribou Space interview. January 2020.

103 World Bank. 'Doing Business'. www.doingbusiness.org. Accessed December 2019.

104 EO4SD-Urban programme. Satellite image of building height in high density neighbourhood, Kigali, Rwanda.

The Kigali pilot demonstrated that an EO-based methodology could reduce the cost of establishing and updating tax registers by allowing automated generation of building footprints and, based on building heights, an estimate of total built-up area.

> *"It helps quickly assess tax collection potential of cities and urban centres particularly in developing countries with limited information.* ***Overall, it will thus help avoid costly and time-consuming data collection efforts on property characteristics"***.[105]

The pilot found that 40% of the potential yield of US$4.9 million from current lease fees is collected, suggesting that more efficient collection could heighten returns. Furthermore, moving to a 1% value-based tax would not only spread the tax burden more equally but could also **increase revenue to about US$19.3 million—almost 10 times what is currently collected.**

> *"Using information derived from building heights and footprints substantially improves the predictive power of the hedonic property price function*[106] *that is employed to assess the property tax potential in Kigali city.* ***This approach has a potential to be replicated in other contexts***".[107]

Another use case for the Rwandan Government is to use this dataset to cross check property value declaration and respond if there is a large discrepancy.

> *"People declare the value of their property and they will pay because they haven't done any evaluation yet, so one way of using this (data) is; we give them the (estimated) value of every property, and if people are declaring, they can cross check…if there is a huge gap, they can do something about it"*.[108]

Interviewee—World Bank Development Economics Research Group

These insights were shared with representatives of the Rwandan Government and there has been requests to update the model using 2019 data. There are also plans to replicate this model in several other African cities. For example, in Lusaka, Zambia this EO-based method is at the exploratory phase. In the Lusaka case, there is an additional emphasis on estimating and comparing the current manual method of property valuation with the EO-based alternative in terms of time and cost differences. If this proceeds to the testing phase, the results will be valuable in deepening and expanding the dialogue on the application of such a methodology in developing cities.

EO4SD-Urban demonstrations catalysing integration and replication

> *"This (integration) is the ultimate goal".*

World Bank Urban Spaces for City Transformation Dhaka and Karachi[109]

Insights from the EO4SD-Urban IFI user survey, and interviews conducted by Caribou Space have shown that some IFI do anticipate integrating EO products. The EO4SD-Urban programme's goal was to provide convincing demonstrations of the benefit and utility of EO-based information in urban development. The implicit assumption within this goal was that post demonstration, IFIs and cities would be more likely to integrate, replicate, and expand their use of EO in urban programmes. This section highlights examples of IFI programmes that are interested in or already integrating.

105 Ali, Daniel Ayalew, W. Klaus Deininger, and Michael Wild. 2018. 'Using satellite imagery to revolutionize creation of tax maps and local revenue collection'. Policy Research working paper; no. WPS 8437. Washington, D.C.: World Bank. http://documents.worldbank.org/curated/en/347231526042692012/Using-satellite-imagery-to-revolutionize-creation-of-tax-maps-and-local-revenue-collection. Accessed December 2019.

106 The hedonic pricing method is used to estimate economic values for ecosystem or environmental services that directly affect market prices. It is most commonly applied to variations in housing prices that reflect the value of local environmental attributes.

107 Ali, Daniel Ayalew, W. Klaus Deininger, and Michael Wild. 2018. 'Using satellite imagery to revolutionize creation of tax maps and local revenue collection'. Policy Research working paper; no. WPS 8437. Washington, D.C.: World Bank. http://documents.worldbank.org/curated/en/347231526042692012/Using-satellite-imagery-to-revolutionize-creation-of-tax-maps-and-local-revenue-collection. Accessed December 2019.

108 Caribou Space interview. January 2020.

109 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 12b: Service Delivery Utility and Impact Review. August 2019.

The World Bank Urban Planning Study for Tanzania noted *"there is significant potential to mainstream geospatial technologies* in various areas where World Bank financing and technical assistance are critical".[110] The World Bank team in Tanzania is planning a study on using EO data to map building footprints, coupled with survey work to create a model for that would enable officials to assess and enforce service tax collection. This may also include land use maps to more effectively enforce development control against cities master plans. This was stated to have been procured for execution in the next year.[111]

The ADB Kolkata Environmental Improvement Investment programme has concrete plans to continue using EO data. Funding has been secured for additional work on EO and capacity building with the city partner KMC. The programme lead stated that EO4SD-Urban *"gave us that taste of what is possible and then we engaged SIRS (EO4SD-Urban consortium member) to take it to the next level and that includes training, that includes site visits—to train them on the usage of this 3D model and other analytical work"*.[112] Furthermore, KMC has since appointed a head of GIS and ADB expects that *"in six months' time, things will be moving in the right direction, and all these analytics…would be taken up by KMC"*.[113]

Following on from the slum assessments in Dhaka under the World Bank Water Supply and Sanitation in Rapid Urbanization project, there have been several internal conversations and pilot projects in the pipeline to extend the use of the EO-derived methodology in both Africa and Asia. Along with the public research report, the World Bank team also produced an internal set of guidelines on the assessment methodology and have been working to promote the use of EO internally and elaborate further discussions with the government. They noted the engagement *"opened a whole new set of areas where satellite imagery can be applied and we as a sector are very interested in using this information because, one, it can help reduce costs of data collection, which is very important, and two, it can give us a new perspective of things on how to analyse the problems…and that's the door that we wanted to open with this partnership and I think we accomplished that because now our leadership team is talking about these issues and we're thinking of talking to other colleagues to see how can we streamline this into current activities and projects that we have with many countries"*.[114]

Under the World Bank Urban Spaces for City Transformation project in Dhaka and Karachi, the methodology developed using EO and other data sources for a rapid city diagnostic have been tested further in Lima, Fallujah, and Ramadi. A publication launched in February 2020 aims to showcase and promote the methodology as a tool in urban planning.[115]

Following on from the World Bank Development Economics Research Group's work on property valuation in Kigali Rwanda, further plans to explore this method in several African cities. In Lusaka, Zambia, this methodology is already being explored.[116]

However, integration is not always immediately viable for a variety of reasons. A deeper analysis of the successes and challenges in creating an enabling environment for sustained uptake of EO data amongst IFIs and their city counterparts is explored in the next section.

110 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 12b: Service Delivery Utility and Impact Review. August 2019.

111 Caribou Space interview. November 2019.

112 Ibid.

113 Ibid.

114 Ibid.

115 Kaw, Jon Kher, Lee Hyunji, and Wahba Sameh. The Hidden Wealth of Cities: Creating, Financing, and Managing Public Spaces. World Bank. 2020. https://openknowledge.worldbank.org/handle/10986/33186. Accessed February 2020.

116 Caribou Space interview. January 2020.

Progress on increasing and sustaining EO uptake for IFIs and cities

Key points

This section reviews the assumptions of 'awareness, demand, capabilities, infrastructure and financial resources' for a sustained increase in EO uptake.

- **Awareness and demand:**
  - Preceding the EO4SD-Urban project, there has been extensive, historical efforts between ESA and IFIs, via previous initiatives and engagement with IFI interest and advisory groups.
  - Demand was created through the initial ESA 'road-show', at various IFI regional meetings and through the EO4SD-Urban consortiums' strong stakeholder engagement. Sharing of real EO use cases was a powerful way to increase demand. There is now evidence of IFI Programme Officers now promoting EO products within and outside their own organisations.
  - To improve demand there needs to be a clear information gap that the use of EO can be shown to fill.
  - Awareness of the potential of EO for urban development is just beginning. As more demonstrations are shared with programmes and cities, it is expected that demand will increase.
- **Capabilities:**
  - IFI Programme Officers generally noted an increase in understanding the potential of EO for urban development. Tailored capacity exchange visits with cities were not within scope and thus cities were engaged through the IFIs, rather than the consortium.
  - However, a need for greater city-level engagement was consistently referred to as an area for EO4SD-Urban programme improvement.
- **IT infrastructure and workflow integration:**
  - To maximise utility at the city level, the format in which EO outputs are shared needs to consider the current IT infrastructure—bandwidth, storage and processing power—available to the city stakeholders.
  - The continuous use of EO needs to be promoted from the top down. It is unlikely that the cities will use EO if it is not integrated into their workflow and regular tasks.
- **Financial resources:**
  - The availability of financing is rarely discussed in isolation but linked to a need for a convincing case for EO, so that funding can be sourced.

For the successful adoption and integration of EO products, the IFI and their city stakeholders should have sufficient awareness, demand, capabilities, infrastructure, and financial resources to optimise the use of EO products. This is critical to ensure IFI and city stakeholders can effectively use the products provided, derive value and advocate for additional investments in EO data products for the future. The assumptions surrounding EO sustained uptake are reviewed to understand what is needed to increase and sustain EO uptake in the urban sector.

Awareness and demand for EO products

> *"Having a formal partnership facilitates a lot how you organise and plan the work ahead because you can explicitly identify resources, people, needs and sort of build up a better planning process around it. So, I think the partnership we had for EO4SD is very good. And it helps a lot".*
>
> **Interviewee—World Bank Water Supply and Sanitation in Rapid Urbanization project in Dhaka**[117]

— *Channels for improving demand*

There is evidence that both ESA's initial engagement with the IFIs and the consortium's follow on engagement has raised awareness and, in some cases, the demand for EO products within IFIs. Preceding the EO4SD-Urban project, there has been extensive, historical efforts between ESA and IFIs, via the eoworld initiative (starting 2010), to raise awareness and demand for EO products. In addition, ESA engages with the IFI internal advising bodies, management, interest groups and coordinating units - complementing the EO4SD-Urban project level engagements. Interviews noted that initial demand was created through the initial ESA 'road-show' to IFIs, which were conducted prior to the initiation of the EO4SD-Urban programme. This was referenced by the GPSC and ADB-Kolkata programme. Specifically, IFI Programme Officers stated that learning about the applications in other developing countries was a powerful way to increase their interest and eventual demand. The GPSC team noted that the regional meeting in São Paulo was a success in generating interest for cities. With representatives from 40 countries, the EO4SD-Urban session was noted to have substantial benefits on raising the profile of EO applications in the urban environment. The GPSC lead stated that, *"there was a large session at our plenary meeting that had a lot of bandwidth. People were talking about the projects. So regardless about the actual impact on the ground in those cities, there is a lot of awareness being raised"*.[118]

Some IFI programmes have owned the process of raising awareness of EO potential internally. The World Bank Water Supply and Sanitation in Rapid Urbanization programme in Dhaka, highlighted that they produced an internal set of guidelines on using EO to assess slum status, and they have been actively promoting it to the leadership within the bank as well as colleagues in other World Bank sectors. *"So we're very excited that we have these (internal) sessions where I will participate and share my experience. This is the result that we wanted, concrete discussions about it"*. The World Bank Urban Spaces for City Transformation programme in Dhaka and Karachi, developed a new methodology for conducting rapid city diagnostics. This methodology and findings was published and launched in February 2020 to inspire and enable others working in urban development to implement rapid, cost efficient and objective city diagnostics.[119]

117 Caribou Space interview. December 2019.

118 Ibid.

119 Kaw, Jon Kher, Lee Hyunji, and Wahba Sameh. The Hidden Wealth of Cities: Creating, Financing, and Managing Public Spaces. World Bank. 2020. https://openknowledge.worldbank.org/handle/10986/33186. Accessed February 2020.

— *Matching the tool to the need*

It is crucial that there is a demonstrable link between a stated need and the capabilities of EO tools. In Tanzania, there is an articulated need, at the government level, to improve revenue from tax collection— *"It's a matching of demand and tools. The desire for improved revenue from tax collection is definitely coming from within government here"*.[120] The World Bank has responded through the scoping of a programme that will use EO data on building footprints as part of the mapping exercise to inform tax collection.

— *Sufficient time*

A consistent theme is that awareness of the use cases and benefits of EO products for urban development for both IFIs and city stakeholders, is just beginning. There remains a lot to learn and more time is required for EO to become a mainstream tool within urban development. As more demonstrations are highlighted to programmes and cities, it is expected that demand will increase. The ADB Programme Officer in Kolkata stated that *"We hope that with the flood warning system in place and active, the appetite will grow faster"*.[121]

Institutionally, within IFIs, it was highlighted that time is required for demand to catch up with supply, and at this stage in the application of EO products for the urban development sector, it is a stage that is characterised by 'hand-holding'.

> *"I think you really just need more of the same, but the challenges that you have a supply of know-how but you don't have, among the institution or our clients, an organised demand for that know how. So, that connection only happens with a lot of hand-holding".*
>
> **Niels Holm-Nielsen—World Bank's Global Technical Lead for Resilience and Disaster Risk Management** [122]

Capabilities to use EO products

— *IFI and city knowledge and capabilities*

There has been a change in capacity level for IFI Programme Officers who have directly engaged with the EO4SD-Urban programme. The programme lead for the ADB Kolkata Environmental Improvement Investment Programme stated that *"two years ago, I had no idea what some of these things could do. I'm slowly learning the potential of it"*.[123] The channels through which the capabilities were changed, seem to come naturally through the direct engagement and process of collaboration with EO4SD-Urban rather than specific trainings. One of the Programme Officers in the World Bank Water Supply and Sanitation in Rapid Urbanization project in Dhaka highlighted specific increases in their geo-spatial analytics skills: *"I learned a lot on the process it takes to analyse the imagery and apply filters and algorithms to obtain the image you may want to have. That itself requires a lot of expertise that obviously, I don't have. But at least understanding the process was very useful for me because once you understand the process you can know the limitations of the information that you can derive from Earth Observation and you can understand the potential."* [124]

120 Caribou Space interview. November 2019.
121 Ibid.
122 ESA and World Bank workshop. 21 January 2020.
123 Caribou Space interview. November 2019.
124 Ibid.

However, capacity within IFIs was noted to also be a challenge for the increase use of EO in the urban development. Niels Holm-Nielsen—World Bank Global Technical Lead for Resilience and Disaster Risk Management—stated that *"The main bottle neck is going to be within the institution, within our teams, there are maybe two or three people within each team that have a level of know how to pick up on what you (EO4SD-Urban programme) are offering. We could try to group together our people that have the interest and the skills to helps them help others, to channel a more spread out demand and see how that works"*.[125]

At the city level, while specific and tailored capacity exchange visits at the city level was not within the scope of EO4SD-Urban—the consortium worked to extend knowledge transfer through the development of webinars. The World Bank team in Tanzania noted that *"whenever they would have a webinar training, I would circulate it to our group of (city level) GIS people. I know that several people participated in more than one, so that would be an indicator, that it was worth going back for"*.[126] Feedback collected from the webinars' attendees highlighted that the material quality, utility of examples, and level of technical detail was rated highly.[127] The webinars can be viewed at any time on both the EO4SD-Urban website and the World Bank Open Learning Campus.

Feedback on training and demonstrations at regional meetings was noted to be positive. The EO4SD-Urban training at the GPSC São Paolo meeting aimed to train the city representatives from the already covered cities and generate interest for follow-up activities for other cities. Feedback gathered was broadly positive. An attendee from Sao Jose Dos Campos City Hall stated that the *"training supported me to improve the geographic database management, and the platform to apply in daily use"*.[128]

— *Need for greater city level engagement*

The need for more city level engagement was frequently raised. While the resources and the trainings that were conducted, when there was an opportunity, were deemed useful for those that attended, in the absence of tailored city training they are unlikely to be a major driver for change in knowledge and practices among city level stakeholders. This was noted frequently by IFI Programme Officers in relation to their city stakeholders. The World Bank Metro Mumbai programme noted that *"the products were useful, but their exploitation could be further enhanced if specific training was available"*.[129] This need was echoed by the ADB Second Integrated Urban Environmental Management in the Tonle Sap basin programme, and the Kolkata Environmental Improvement Investment programme. Notably the ADB Kolkata programme is now investing in capacity building activities for the city stakeholder. In the World Bank Urban Planning Study in Tanzania, a minimal level GIS capacity was stated to present within the cities but for ramping up, a *"really intensive programme and the establishment of perhaps a GIS lab"* [130] would be required.

125 ESA and World Bank workshop. 21 January 2020.
126 Caribou Space interview. November 2019.
127 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 10b: Capacity Building Activities Review. August 2019.
128 EO4SD-Urban Consortium. EO4SD-Urban Training Evaluation of the City Academy Training Brazil.
129 EO4SD-Urban Consortium. EO4SD-Urban Deliverable 12b: Service Delivery Utility and Impact Review. August 2019.
130 Caribou Space interview. November 2019.

Ownership and workflow integration

The continuous use of EO products needs to be promoted from the top down and integrated into both the IFI and city's workflow. In the World Bank Urban planning study in Tanzania, they noted that while data that provided by the EO4SD-Urban programme was circulated to the cities, it was the research report that was the consumable item.[131] It is unlikely that the cities will use the EO data as it is simply not integrated into their workflow and regular tasks *"there's nothing that's pulling them to this data because the direct outputs that they get from working with it are different than the outputs that are those that are required by their heads of department"*.[132]

Linked to this integration is the sense of ownership over the EO data. The direct engagement has been with the IFIs and not the cities. Thus, there is an onus on the IFI to support the ownership of the process. This was raised, but is being addressed in the ADB Kolkata programme, through increased financial and technical assistance from ADB and the appointment of a GIS lead in Kolkata Municipal council: *"We are now taking lead in implementing all the GIS components under the project… So, with him (GIS lead) being appointed, I think then comes momentum…we expect that in six months' time, things will be moving in the right direction, and all these analytics would be taken up by KMC"*.[133]

In the World Bank Urban planning study in Tanzania, they noted that increasing the government ownership was a key learning. *"The challenge is really more on our end, how could we be more actively engaging the government, because the government was not a client per se, in the spatial analysis that was provided. …We consumed it, digested it, and then used that as the basis for evidence based policy recommendations. But it would have been ideal to put the government more in the driver's seat as the actual consumer of the data itself"*.[134] This was echoed by the World Bank Water Supply and Sanitation in Rapid Urbanization project in Dhaka which also noted that the government *"need[s] to be empowered to be able to have the technical capabilities to use this information and this approach and these sources of data"*.[135]

City IT infrastructure and EO product format considerations

To maximise utility at the city level the format in which the EO outputs are shared needs to consider the current IT infrastructure available to the city stakeholders. As EO4SD-Urban was mainly sharing map files and analytics—the IT infrastructure required is centred around computer storage and processing power. At the IFI level this was not noted to be a concern. However, file size at the city level was raised as a concern by the World Bank GPSC programme in India, *"I was just worried that some of these files, for instance, just logistically speaking, they're quite large when they were transferred to the Indian cities. I remember there are download issues. So, I wonder, do some of these cities have the right infrastructure? And is this huge file just going to sit on someone's computer and they never open it again?"*[136]

The format in which the EO products are presented should encourage use. A Programme Officer for the GPSC programme shared that while he had experience a few years prior on remote sensing land cover classification when the products were shared they were *"difficult to dissect, besides the high-level numbers"*.[137] It was further noted that in the GPSC programme in Bhopal and the Vijayawada the outputs were very technical documents. And while those cities may have people that can dissect that information and access that information on the

131 Huang, Chyi-Yun, Ally Namangaya, MaryGrace W. Lugakingira, Isabel D. Cantada. 2018. 'Translating Plans to Development: Impact and Effectiveness of Urban Planning in Tanzania Secondary Cities'. World Bank. http://documents.worldbank.org/curated/en/300731546897829355/Translating-Plans-to-Development-Impact-and-Effectiveness-of-Urban-Planning-in-Tanzania-Secondary-Cities.pdf. Accessed December 2019.

132 Caribou Space interview. November 2019.

133 Ibid.

134 Ibid.

135 Caribou Space interview. December 2019.

136 Caribou Space interview. November 2019.

137 Ibid.

computer infrastructure, *"it might be useful to have different types of output information. Some information might be very high level and simple in a graphic form for lay persons to understand and other information still be that very technical level"*.[138]

The World Bank Water Supply and Sanitation in Rapid Urbanization project in Dhaka noted that internally there needs to be education on translating complex technical reports into a format that is understood by key city decision makers: *"The next step is to educate our staff in ways to present this information to decision makers, which is the difficult part because sometimes when you have very technical people analysing the data, you can produce a very nice scientific report… but the key is how you translate and distil that information so that a local politician or a mayor or a state representative can understand this information"*.[139]

Financial resources

IFIs' budget holders need to be convinced of the investment in EO so that their programmes can continue to demonstrate EO applications to the cities. The same scenario is repeated at the city level. Considering the diversity of 17 IFI programmes and their city stakeholders, feedback on financing at each level varies. The availability of financing is rarely discussed in isolation, but deeply linked to providing a convincing case for EO, so that budget can be sourced.

In the ADB Kolkata programme, locating finance at the city level was not seen as a challenge *"I would say in India, the challenge is not actually at the level of finding finances for the particular intervention"*.[140] This was a perspective shared by the GPSC programme in that at the city level *"it's not only the financial, it's really the governance structure"*.[141] The main hurdle to overcome is for the city stakeholders to view EO products as highly beneficial to their work, to continue or start, funding the use of EO data.

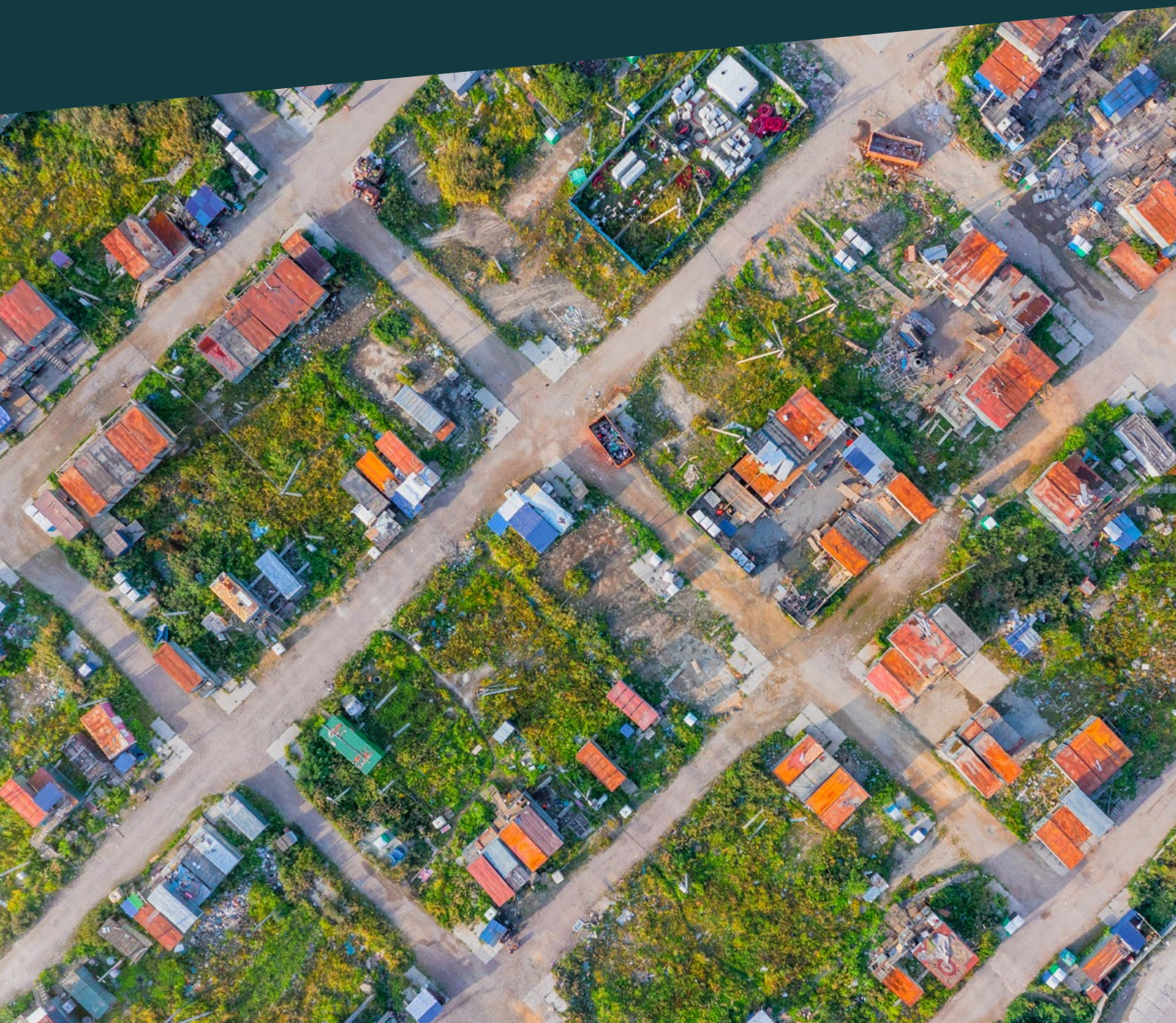
In the World Bank Urban Planning Study in Tanzania, it was noted that the government had procured EO data in the past, but it was not used. Presumably because the *"capacity building and awareness raising wasn't done in a deep enough manner"*.[142] Currently, the financial resources are deemed to be a barrier and thus for the time being, until more awareness and more demonstrations are conducted, the government will likely use free data *"using the imagery, that's available in QGIS, Bing, or Google Maps, because there's not a whole lot of money or resources to buy… I think relying on readily available and free tools is the way forward"*.[143]

As discussed in the ADB Kolkata case study, funding has been secured to continue providing EO services, alongside more city level capacity building. The ADB Kolkata programme also cautioned that due to their funding, EO has a higher chance of integration, which may not be the case in other cities. *"We have a big loan component. So, a lot is happening in KMC, otherwise if you had done this in another city where it was not backed up by a loan, it would have brought nothing to be honest"*.[144]

Overall, the challenge is not about determining whether the coffers are empty or full, but what is needed to prise them open. Strong demonstrations, continued awareness building, initial technical support and enabling countries to own and lead on the use of EO are still required to improve uptake. Interviewees consistently referenced that EO use in urban was 'just beginning'.

138 Caribou Space interview. November 2019.
139 Caribou Space interview. December 2019.
140 Caribou Space interview. November 2019.
141 Ibid.
142 Ibid.
143 Ibid.
144 Ibid.

Recommendations



Recommendation one: Closing the evidence gap of EO in urban development

Key points

This section reviews the direction of the impact evidence from both the public domain literature review and the insights from the impact evaluation of the EO4SD-Urban programme. Recommendations for closing evidence gaps are shared.

- Across EO urban use cases, there is encouraging and positive evidence on the benefits of EO.
- Some urban use cases, such as hazard assessment, early warning and response, have a longer history with using EO and thus have a more mature evidence base. Other use cases, such as transport planning and monitoring, are just starting to be demonstrated.
- New use cases for urban EO are emerging more quickly than the publication of corresponding impact evaluations. It is a matter of both time and commitment of resources to dedicate to measuring the impact of urban EO products.
- More investment in impact measurement is required to close the evidence gaps and keep pace with emerging use cases. In programmes that are integrating EO as a core data source or service, a robust Monitoring and Evaluation (M&E) framework that both articulates and can evaluate the impact of EO within the urban development sector should be established at the start of the programme.
- Impact evaluations should communicate and quantify the benefits of EO - using language and statistics that the development community are familiar with.
- Impact evidence should be widely shared so that others can benefit from these lessons and results.

The question of how EO supports and improves both the processes and the outcomes for sustainable urban development is being addressed. Through the review of ~150 sources of public domain literature and interviews with IFI Programme Officers who used EO4SD-urban products, a clearer understanding of the specific impact that EO data facilitates for urban development is forming.

EO has proven benefits within the urban development sector use cases. As showcased in both the public domain literature section and the impact of EO4SD-Urban section, there is encouraging and positive evidence of the value that EO data is providing to: *Urban planning and monitoring, transport planning and monitoring, hazard assessment, early warning and response,* and *monitoring of environmental issues.*

FIGURE 11: Qualitative review of impact evidence in developing countries by urban use case (Credit: Caribou Space)[145]

Key: NASCENT EVIDENCE BASE EMERGING EVIDENCE BASE MATURING EVIDENCE BASE

New use cases for urban EO are emerging more quickly than the publication of corresponding impact evaluations. Some use cases, such as *hazard assessment*, *early warning*, and *response*, have a longer engagement period with using EO and thus have a more mature evidence base. However, impact evidence on *urban planning and monitoring* and *monitoring of environmental issues* is now emerging. Measuring the impact of EO-based products is a matter of both time and commitment of resources. In comparison to other sectors such as disaster resilience, agriculture, and forestry, the use of EO in urban development is more nascent, however, it is clear from the use cases outlined that there is both value and documented impact in using EO in the urban development sector.

More investment in impact measurement is required to close the evidence gaps and keep pace with emerging use cases. In both EO demonstration projects and in programmes that are integrating EO as a core data source or service, a robust Monitoring and Evaluation (M&E) framework should be established. This is essential if the impact of EO is to be measured and the learnings communicated. The M&E framework should be tailored to the specific needs, set-up, and goals of the demonstration project or programme and be sufficiently resourced.

The M&E framework should contain the following as minimum:

- Clearly articulate the impact that is expected from the use of EO data using the Theory of Change approach.[146]
- Establish robust indicators to both monitor progress towards impact and to evaluate the final impact. This should be accompanied by clear guidance on methodologies to collect and report on the indicators.
- Establish a baseline on the status prior to the EO intervention to assess impact post EO intervention.
- Set up to measure long-term impact. If, for example, a city did implement tailored flood mitigation plans using EO as an input, it would be beneficial to track the longer-term impact on the city.

Impact evaluations should communicate and quantify the benefits of EO—using language and social and economic statistics that the development community are familiar with. Equally, when communicating with the development community members of the EO community should ensure their language is understandable for non-experts.

Document and share findings on the impact of EO for urban development. The urban development community advances its effectiveness through the sharing of knowledge. Impact evidence should be widely shared so that others can benefit from any lessons.

The evidence base within this report is a move toward more coordination and a consolidation of the urban development community's understanding of the actual impact of using EO within the urban development sector.

145 There are sub-use cases within each main use case, thus this is intended to be illustrative and based on the qualitative review of the evidence. Note that this report does not feature all the literature highlighting any given impact.

146 For more guidance see: https://www.betterevaluation.org/en/resources/guide/theory_of_change.

Recommendation two: Improving the uptake and impact of EO for urban development

Key points

This section summarises recommendations for improving the uptake of EO within the urban development sector. These recommendations are derived from discussions with various individuals who have directly engaged with the EO4SD-urban programme.

Tactical considerations:

- **Facilitate longer and deeper engagements at the city and IFI level:** In recognition of the more nascent phase of EO in urban, and in the interest of continuing to build momentum, the engagement time on a programme should be lengthened and the amount of interaction at the city level should be increased.
- **Formats of sharing EO outputs:** Depending on the cities' IT infrastructure and capabilities, consider the optimal format of sharing EO outputs. The format should encourage rather than deter use.
- **City level trainings:** Consider tailored city training or a more embedded mentorship model to integrate EO practices. City-to-city learning may also be a powerful way to accelerate the demand.
- **Integration with existing programming:** It is crucial that EO tools are used to meet a specific and articulated demand at the city level. A project that already has a long-standing relationship with the city stakeholders was viewed to be more likely to integrate EO within their workflow.

Strategic considerations:

- **Creating and sustaining demand:** It is critical to continue to create demand by demonstrating and documenting use cases and through ongoing dialogue with IFIs. This could also be achieved by IFI EO 'champions' and the possibility of EO becoming part of the 'urban development tool-kits'.
- **Integration into IFI's operational procedures:** To use IFIs as a platform to scale, EO4SD needs to become relevant for IFI operational task teams, during the short-time frame of project concept to approval. This means being able to provide EO outputs in a matter of weeks, rather than months.
- **Reduce supply costs through streamlining demand:** There needs to be clarity on what EO products are most in demand within IFIs to streamline procurement and reduce supply costs for IFIs.

> *It was quite a short period of collaboration. So, I very much hope that it would continue so that you can build what has been done…If you stop, it would be, I mean I don't think it's a waste, but it's a pity that you somehow lose that positive momentum".*
>
> **Interviewee—World Bank GPSC programme**[147]

Several considerations for increasing the likelihood of uptake within IFIs and cities were put forward by the IFIs during interviews and workshop discussions. These considerations are outlined below. The first set of considerations are more tactical for future/similar EO4SD-Urban programmes. The second set of considerations are more strategic and relevant to accelerating and scaling EO use in IFI development assistance programmes.

— *Tactical considerations*

- **Longer engagements:** A request to consider increasing the length of engagement was frequently suggested. The collaboration period was noted to be short, and in recognition of the more nascent stage of EO in urban—as well as in the interest of continuing to build momentum—the engagement time on a programme should be lengthened.
- **Deeper city-level engagement:** IFIs highlighted a preference, in the future, to work with fewer cities but increase both the length and depth of each engagement. This would go beyond the city level and include an analysis of the decision makers outside of the city that need to be influenced and brought into discussion on the applications of EO in urban programming. Specifically, ensuring that the authorities at both the city and, when relevant, national level are aware and involved to improve opportunities for ownership of the process.
- **Formats of sharing EO outputs:** During the initial capabilities assessment in phase one of the programme, include a review of the available infrastructure and the impact the infrastructure may have on the delivery of various files and outputs at the city level. If concerns are raised, consider different modalities on how to disseminate this information in terms of technology and final format. Cloud based environments can be used to minimise the need for local IT infrastructure for data storage and processing. For example, via the Urban Thematic Exploitation Platform (uTEP) (see page 22).
- **City-level trainings:** With fewer cities and longer engagement times, the expectation was that cities could benefit substantially. For example, more time could be invested in building relationships with the city counterparts, and a more nuanced understanding of their needs and current processes could be obtained and responded to. This could also translate into more tailored training and ideally a mentorship model to integrate EO practices at the city level. The World Bank GPSC programme did highlight that city to city learning may be a powerful way to accelerate the demand. An anecdote of one of the GPSC cities, Dakar, Senegal, was shared. It was observed that they continued to express a strong interest and demand in the use of EO products, due to observing how Johannesburg, South Africa, was optimising for and integrating EO data in their urban planning and monitoring. Furthermore, the simplicity of imagery was noted to be powerful. Another anecdote of consortium sharing posters of land cover classifications in several cities was cited to have been *"powerful"*.
- **Integration with existing IFI urban programmes:** It is crucial that EO tools are used to meet a specific and articulated demand at the city level. Furthermore, it is important to integrate the use of EO tools in a long-term project. A project that already has a longer-standing relationship with the city stakeholders was viewed to be more likely to integrate

147 Caribou Space interview. November 2019.

EO tools within their workflow. This is clearly exemplified by the leverage illustrated by the long-term ADB Kolkata programme.

— *Strategic considerations*

- **Creating and sustaining demand:** Considering that, comparatively, the use of EO in urban development is at an emergent stage, it is critical to continue to create demand by demonstrating and documenting use cases and through ongoing dialogue with IFIs. While, there are several urban EO champions within IFIs—as evidenced by internal promotion of EO use and IFI publications showcasing the EO methodologies used—this needs to go wider and deeper within IFIs. For example, integration into 'urban development toolkits' and integrating discussions on using urban EO products in conversations with city stakeholders.
- **Integration into IFI operational procedures:** To use IFIs as a platform to scale, EO4SD needs to become relevant for IFI operational task teams. These are the teams that prepare the lending operations. A route to increasing integration is by providing timely information to inform their operational delivery. The project delivery timeframe, where the task teams are expected to go from concept to project approval, is often less than 12 months. The creative part of this process, is only a few months, before the formal concept review. Niels Holm-Nielsen—World Bank Global Technical Lead for Resilience and Disaster Risk Management noted that, *"if the matchmaking between EO service delivery and demand takes several months, EO4SD will remain confined to pilot studies"*.[148] The procedure to connect the service offer with the operational demand needs to be reduced to weeks, rather than months, to influence IFIs operational workflow at scale.
- **Reduce EO supply costs with IFIs:** There is an operational aspect to mainstreaming EO use in the urban development sector. During the January 2020 World Bank and ESA workshop in Washington, DC, Niels Holm-Nielsen—World Bank Global Technical Lead for Resilience and Disaster Risk Management—highlighted that *"the better we become at knowing what products are commonly demanded across multiple task teams, we can reduce the transaction costs. The better we can become at knowing what products have a no marginal replication cost."*[149] The push is to ensure that IFI resources are being used efficiently, for example, while initial costs of a product may be high, this should have wider application across a variety of IFI teams and the costs of updating the product need to be incorporated.

148 Correspondence with Niels Holm-Nielsen. February 2020.
149 ESA and World Bank Workshop. 21 January 2020.

Annexes

Annex one: List of IFI programmes, cities, and countries in EO4SD-Urban

World Bank programmes

PROGRAMME	COUNTRY | CITIES	EO PRODUCTS
Urban Planning Study Tanzania—Impact & Effectiveness of Urban Planning on City Spatial Development[150]	Tanzania: Mtwara, Tanga, Mbeya, Arusha, Dodoma, Mwanza, Kigoma	• Land Use/Land Cover and Change • World Settlement Footprint and Change • Urban Green Areas and Change • Informal Settlements and Change • Transport Infrastructure and Change • Population Distribution and Density Change
Global Platform for Sustainable Cities (GPSC)[151]	India: Bhopal, Vijayawada	• Land Use/Land Cover and Change • World Settlement Footprint and Change • Urban Green Areas and Change
Global Platform for Sustainable Cities (GPSC)	Mexico: Campeche	• Land Use/Land Cover and Change • World Settlement Footprint and Change • Urban Green Areas and Change
Global Platform for Sustainable Cities (GPSC)	Peru: Lima	• Land Use/Land Cover and Change • World Settlement Footprint and Change • Urban Green Areas and Change • Building Footprints and Change • Flood Risk Assessment
Global Platform for Sustainable Cities (GPSC)	Ivory Coast: Abidjan	• Land Use/Land Cover and Change • World Settlement Footprint and Change • Informal Settlements and Change

150 Huang, Chyi-Yun, Ally Namangaya, MaryGrace W. Lugakingira, Isabel D. Cantada. 2018. 'Translating Plans to Development: Impact and Effectiveness of Urban Planning in Tanzania Secondary Cities'. World Bank. http://documents.worldbank.org/curated/en/300731546897829355/Translating-Plans-to-Development-Impact-and-Effectiveness-of-Urban-Planning-in-Tanzania-Secondary-Cities.pdf. Accessed December 2019.

151 Global Platform for Sustainable Cities. 'GPSC 3rd Global Meeting: Catalyzing Sustainable Urban Futures'. 16–20 September 2019. http://pubdocs.worldbank.org/en/635911565815778943/GPSC-3rd-Global-Meeting-Brochure-7-24.pdf. Accessed September 2019.

Global Platform for Sustainable Cities (GPSC)	Senegal: Dakar, Saint-Louis	**Dakar:** • Land Use/Land Cover and Change • World Settlement Footprint and Change • Urban Green Areas and Change • Flood Risk Assessment **Saint-Louis:** • Land Use/Land Cover and Change • World Settlement Footprint and Change • Flood Risk Assessment
Development Economics Research Group (DECRG): Pilot Study "Using Satellite Imagery to Revolutionize Creation of Tax Maps and Local Revenue Collection"[152]	Rwanda: Kigali	• Building Heights • Digital Surface Model
City Planning Labs (CPL)—Indonesia[153]	Indonesia: Denpasar, Semarang	**Denpasar:** • Land Use/Land Cover and Change • World Settlement Footprint and Change • Flood Risk Assessment **Semarang:** • Land Use/Land Cover and Change • World Settlement Footprint and Change • Urban Green Areas and Change • Transport Infrastructure and Change • Terrain and Infrastructure Motion • Flood Risk Assessment
1 National Urban Cadastre and Municipal Support Programme[154] 2 Transforming Cities through Public Space Programme (Urbanscapes Community of Practice)[155] 3 Global Water Practice—Water Supply and Sanitation in Rapid Urbanization—Predicting Slum Dwellers' deprivations from Space[156]	Peru: Lima	• Land Use/Land Cover • World Settlement Footprint and Change • Urban Green and Open Spaces • Informal Settlements
1 Bamako Urban Sector Review: Engine of Growth and Service Delivery[157] 2 Transforming Cities through Public Space Programme (Urbanscapes Community of Practice)[158]	Mali: Bamako	• Land Use/Land Cover • World Settlement Footprint and Change • Urban Green and Open Spaces

152 Ali, Daniel Ayalew, Klaus Deininger, and Michael Wild. 2019. 'Using satellite imagery to create tax maps and enhance local revenue collection'. Policy Research working paper; no. WPS 8437. Washington, D.C.: World Bank. https://www.tandfonline.com/doi/abs/10.1080/00036846.2019.1646408. Accessed December 2019.

153 Collaboration for Development. 'City Planning Labs (CPL)'. World Bank. https://collaboration.worldbank.org/content/sites/collaboration-for-development/en/groups/city-planning-labs/file.html. Accessed September 2019.; Amindarbari, Reza, Andres Sevtsuk, Thalyta Emandya Yuwono. 2013. 'City Planning Labs (CPL): a concept for strengthening city planning capacity in Indonesia'. World Bank. http://documents.worldbank.org/curated/en/731961468041432789/City-Planning-Labs-CPL-a-concept-for-strenghtening-city-planning-capacity-in-Indonesia. Accessed September 2019.

154 World Bank. 'National Urban Cadaster and Municipal Support Project'. https://projects.worldbank.org/en/projects-operations/project-detail/P162278?lang=en). Accessed September 2019.

155 Collaboration for Development. 'The World Bank Urbanscapes Community of Practice'. https://collaboration.worldbank.org/content/sites/collaboration-for-development/en/groups/urbanscapes.html. Accessed September 2019.

156 Mimmi, Luisa M., and Christian Borja-Vega. 2017. 'Predicting slum dwellers' deprivations from space: a pilot study on Dhaka'. World Bank (blog). https://blogs.worldbank.org/water/predicting-slum-dwellers-deprivations-space-pilot-study-dhaka. Accessed December 2019.

157 Urban Sector Review and World Bank. 'Bamako: An Engine of Growth and Service Delivery'. http://documents.worldbank.org/curated/en/154691549486819482/pdf/127221-repl-Bamako-Report-final-v4.pdf. Accessed September 2019.

158 Collaboration for Development. 'The World Bank Urbanscapes Community of Practice'. https://collaboration.worldbank.org/content/sites/collaboration-for-development/en/groups/urbanscapes.html. Accessed September 2019.

1 Emergency Operation for Development Programme—Additional Financing (Iraq)[159] 2 Transforming Cities through Public Space Programme (Urbanscapes Community of Practice)[160]	Iraq: Ramadi, Fallujah	• Land Use/Land Cover and Change • World Settlement Footprint and Change • Urban Green and Open Spaces and Change
1 Dhaka City Neighbourhood Upgrading Programme (Urbanscapes Community of Practice)[161] 2 Transforming Cities through Public Space Programme[162] 3 WB Global Water Practice: Predicting Slum Dwellers' deprivations from Space: a pilot study on Dhaka[163]	Bangladesh: Dhaka	• Transport Infrastructure and Change • Land Use/Land Cover and Change • World Settlement Footprint and Change • Green Areas and Open Spaces and Change • Informal Settlement and Change • Flood Risk Assessment
1 Karachi Neighbourhood Improvement Programme[164] 2 Transforming Cities through Public Space Programme[165]	Pakistan: Karachi	• Transport Infrastructure and Change • Land Use/Land Cover and Change • World Settlement Footprint and Change • Green Areas and Open Spaces and Change • Informal Settlement and Change • Flood Risk Assessment
Mumbai Metro—Phase II Programme[166]	India: Mumbai	• Land Use/Land Cover and Change • World Settlement Footprint and Change • Building Footprints and Change
Advisory Services and Analytics (ASA) Programme: Urban Development in Cambodia[167]	Cambodia: Phnom Penh	• Land Use/Land Cover and Change • World Settlement Footprint and Change • Green Areas and Open Spaces and Change • Flood Risk Assessment

159 World Bank. 'Emergency Operation for Development Project—Additional Financing'. https://projects.worldbank.org/en/projects-operations/project-detail/P161515?lang=en. Accessed September 2019.

160 Collaboration for Development. 'The World Bank Urbanscapes Community of Practice'. https://collaboration.worldbank.org/content/sites/collaboration-for-development/en/groups/urbanscapes.html. Accessed September 2019.

161 World Bank. 'A More Liveable Dhaka City: Dhaka City Neighborhood Upgrading Project'. http://documents.worldbank.org/curated/en/382111568359904697/pdf/Bangladesh-Dhaka-City-Neighborhood-Upgrading-Project-A-More-Liveable-Dhaka-City.pdf. Accessed September 2019.

162 Collaboration for Development. 'The World Bank Urbanscapes Community of Practice'. https://collaboration.worldbank.org/content/sites/collaboration-for-development/en/groups/urbanscapes.html. Accessed September 2019.

163 Mimmi, Luisa M., and Christian Borja-Vega. 2017. 'Predicting slum dwellers' deprivations from space: a pilot study on Dhaka'. World Bank (blog). https://blogs.worldbank.org/water/predicting-slum-dwellers-deprivations-space-pilot-study-dhaka. Accessed December 2019.

164 World Bank. 'Karachi Neighborhood Improvement Project'. https://projects.worldbank.org/en/projects-operations/project-detail/P161980?lang=en. Accessed September 2019.

165 Collaboration for Development. 'The World Bank Urbanscapes Community of Practice'. https://collaboration.worldbank.org/content/sites/collaboration-for-development/en/groups/urbanscapes.html. Accessed September 2019.

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ADB programmes

PROGRAMME	COUNTRY | CITIES	EO PRODUCTS
Future Cities—Mandalay Urban Services Improvement Programme (MUSIP)[168]	Myanmar: Mandalay	• Land Use/Land Cover • World Settlement Footprint and Change • Green Areas and Open Spaces • Informal Settlement
Second Integrated Urban Environmental Management in the Tonle Sap Basin Programme[169]	Cambodia: Kampong, Chhnang, Pursat, Serei Saophoan, Stueng Saen	• Land Use/Land Cover and Change • World Settlement Footprint and Change • Urban Green Areas and Change • Population Distribution and Density and Change • Flood Risk Assessment
Kolkata Environmental Improvement Investment Programme[170]	India: Kolkata	• Land Use/Land Cover and Change • World Settlement Footprint and Change • Urban Green Areas and Change • Informal Settlement and Change

IADB programmes

PROGRAMME	COUNTRY | CITIES	EO PRODUCTS
Emerging and Sustainable Cities Initiative (ESCI)[171]	Argentina: Mendoza	• Land Use/Land Cover and Change • World Settlement Footprint and Change • Waste Sites and Change

168 Asian Development Bank (ADB). 'Project Overview'. https://www.adb.org/projects/47127-002/main#project-overview. Accessed September 2019.

169 Asian Development Bank (ADB). 'Cambodia: Second Urban Environmental Management in the Tonle Sap Basin Project'. https://www.adb.org/projects/50102-002/main. Accessed September 2019.

170 Inter-American Development Bank (IDB). 'Emerging and Sustainable Cities Program'. https://www.iadb.org/en/urban-development-and-housing/emerging-and-sustainable-cities-program. Accessed September 2019.

171 Ibid.

Annex two: EO4SD-Urban products

The following section highlights the 12 main EO4SD-Urban products that were requested and used in the various IFI programmes around the world. It is important to note that while these products can work in isolation, they generate more powerful information for interventions when combined.

Land use/land cover and change

The product can be either produced based on high or very high-resolution satellite data resulting in a classification with around 9 or 30 classes respectively.

Land use/land cover classification based on very high-resolution satellite data.

— *About the product*

The product land use/land cover classification and their related change maps represent a very detailed classification (up to 30 classes) of spatial-temporal land use/land cover patterns for a city area. This product is prepared based on very high-resolution satellite data (spatial resolution between 0.3 m to 1 m) and covers typical land use and land cover classes. The nomenclature follows the established nomenclatures such as continuous and discontinuous urban fabrics, industrial, commercial and public units, road and rail networks, port areas, airports, green urban areas, agricultural land, forests, sport and leisure facilities. The map classes can be adapted to specific urban areas and user requirements. The product comes with a statistical evaluation of the results.

— *Applications*

This product is especially designed for the inner part of the city and serves as a starting point for a range of urban spatial statistical analyses. It can be further used to understand how development trends are positively or negatively impacting specific locations in a city. With such information, urban planners can easily capture infrastructure bottlenecks and spatial structures important to be improved and prioritise activities and investments.

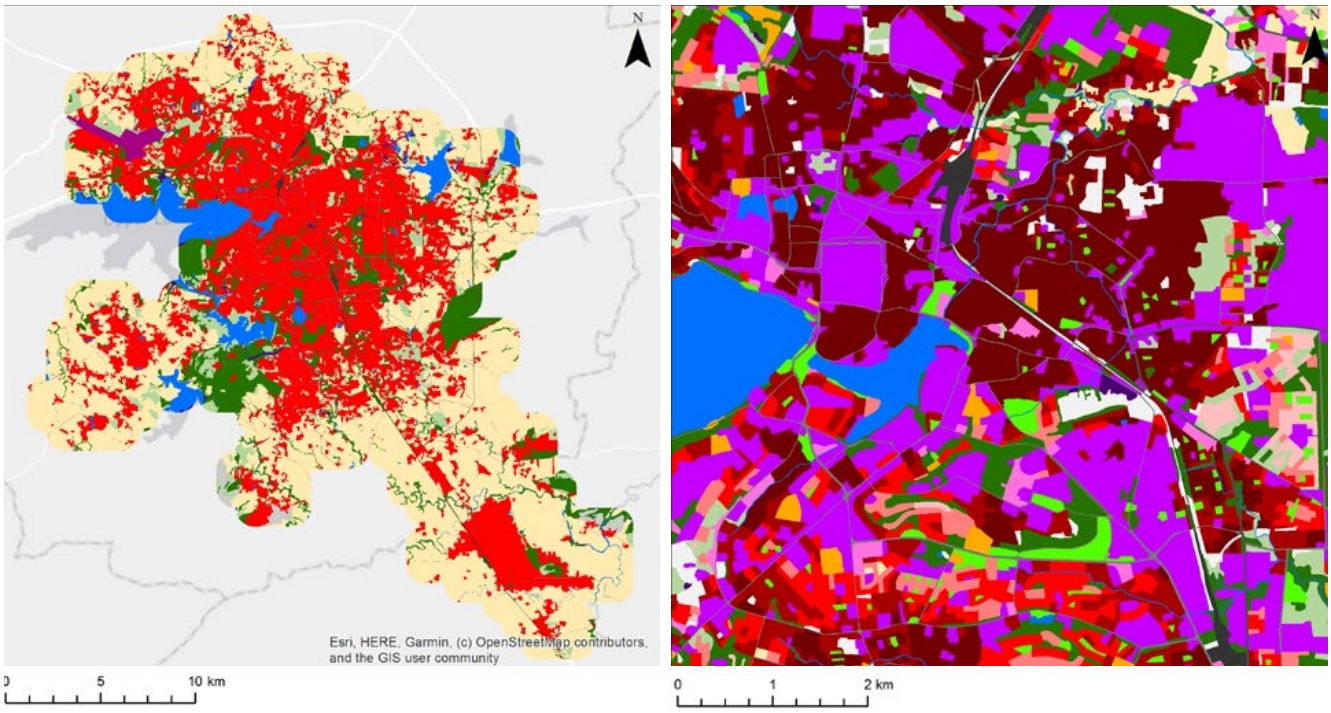

FIGURE 12: Land use/Land cover map produced based on high-resolution (left) and very high-resolution (right) satellite data for Bhopal in India (Credit: GAF AG)

Land cover classification based on high-resolution satellite data

— *About the product*

The land cover classification and its related change maps are prepared based on high-resolution satellite imagery (10 m to 30 m spatial resolution). The classification procedure is a fully automated approach and covers the main land cover classes like settlement area, agricultural, forest, grassland, bare soil, wetlands, and water (up to 9 classes). The map classes can be adapted to the specific urban areas and user requirements. The product comes with a statistical evaluation of the results.

— *Applications*

The product is specifically designed to be applied to larger areas surrounding the city. The classification can be used in combination with the very detailed land use/land cover classification based on VHR satellite imagery. It can be further used to understand how development trends are positively or negatively impacting specific locations in a city.

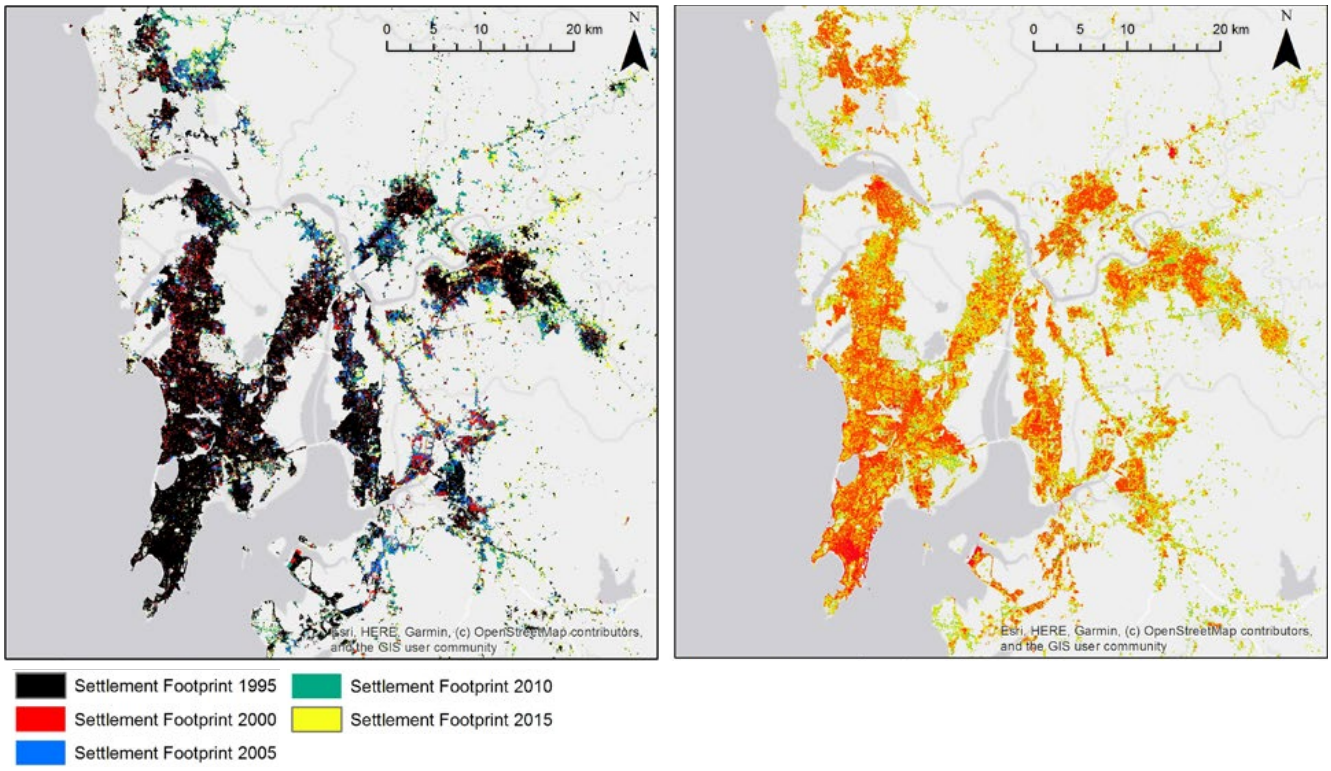

FIGURE 13: World Settlement Footprint for Mumbai, India, (left) and the Imperviousness Layer for the same area (right) (Credit: DLR)

World Settlement Footprint and change

— *About the product*

This product is a globally produced and freely available dataset provided by the German Aerospace Center (DLR). It comes as a binary product showing built-up and non-built-up areas. An intermediate step in the production of this dataset is the generation of a soil sealing/imperviousness layer, showing in percentage the degree of sealed surface.

Uncontrolled urban sprawl has environmental, social and economic impacts on a city and country. To reliably delineate urban growth/sprawl, the built-up area is automatically assessed based on high-resolution satellite imagery (10 m to 30 m spatial resolution). Built-up area maps include the classes built-up and non-built-up and allow the assessment of the growth rate and type of new urban areas.

— *Applications*

Built-up area maps emphasise spatial patterns and intensity of changes, which assist in relevant policy development for management of urban expansion in an effective, efficient, equitable, and sustainable manner for the selected city. The results of this assessment can be the basis for better estimating the future trends and implementing suitable urban planning strategies.

Soil sealing/imperviousness maps help to understand the impact on the environment of urban expansion and development of related technical infrastructures. Mapping the extent of all such areas is highly important as it is related to assessing the risk of urban floods, the area and spatial location of green areas and parks, as well as the reduction of ecological productivity.

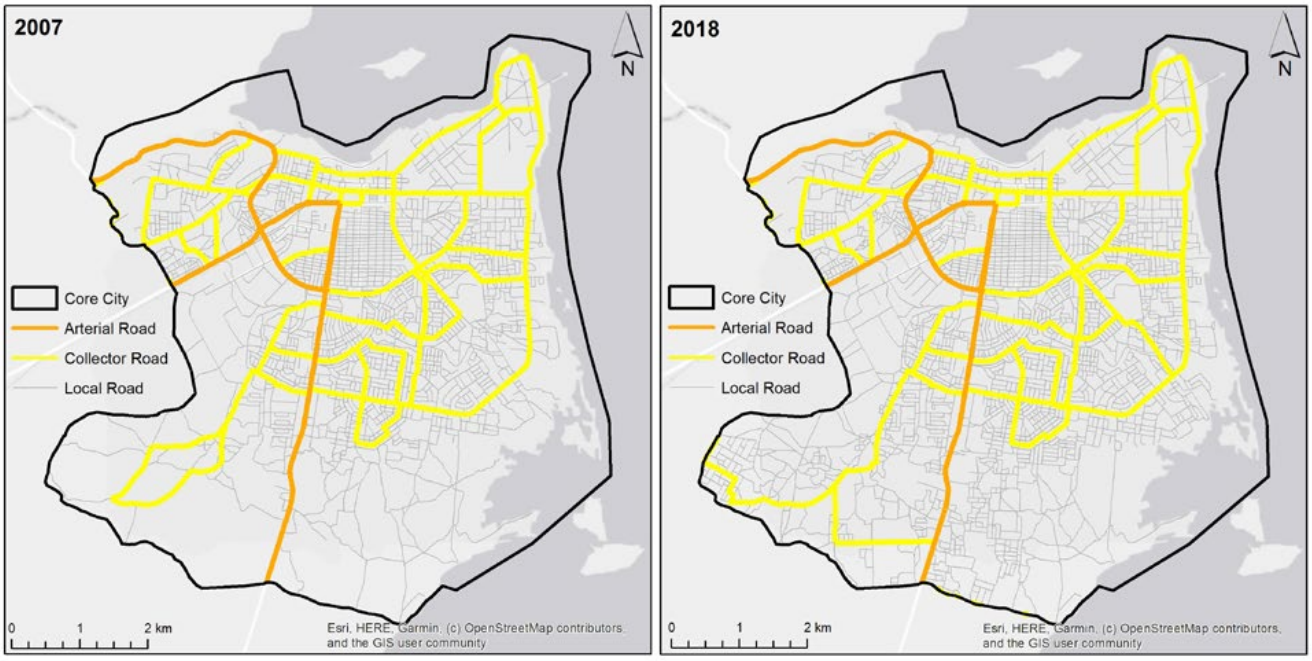

FIGURE 14: Transport infrastructure mapping in Tanga, Tanzania, for two points in time (Credit: GISBOX, GAF AG)

Transport infrastructure and change

— *About the product*

This product covers the mapping of different transport classes such as fast transit roads; primary, secondary, and local roads; railways; port areas and airports; and so on. Additionally, it delineates road width profiles, block areas formed by roads and lengths of street frontage. Basic statistics are provided with the product. The product can be fit to user requirements.

— *Applications*

This product may be used to determine the global city indicator related to kilometres of transportation system per 100,000 population. This indicator is an important tool to assess the city's performance in becoming a sustainable, green and competitive city. This product can also support the important concept of transit-oriented development (TOD), which requires that current transit areas or corridors be identified in order to assess the types of potential land development possible in these areas.

Other applications of the product include identifying the number of lanes in an area to locate potential bottlenecks in a network as well as knowing if a road network is undersized. The product could also be used to derive average pollution models if coupled with 3D buildings.

For an integrated and holistic approach to transport planning, maps showing the actual transport structures help to visualise improvable spatial forms and facilitate the future provision of infrastructure.

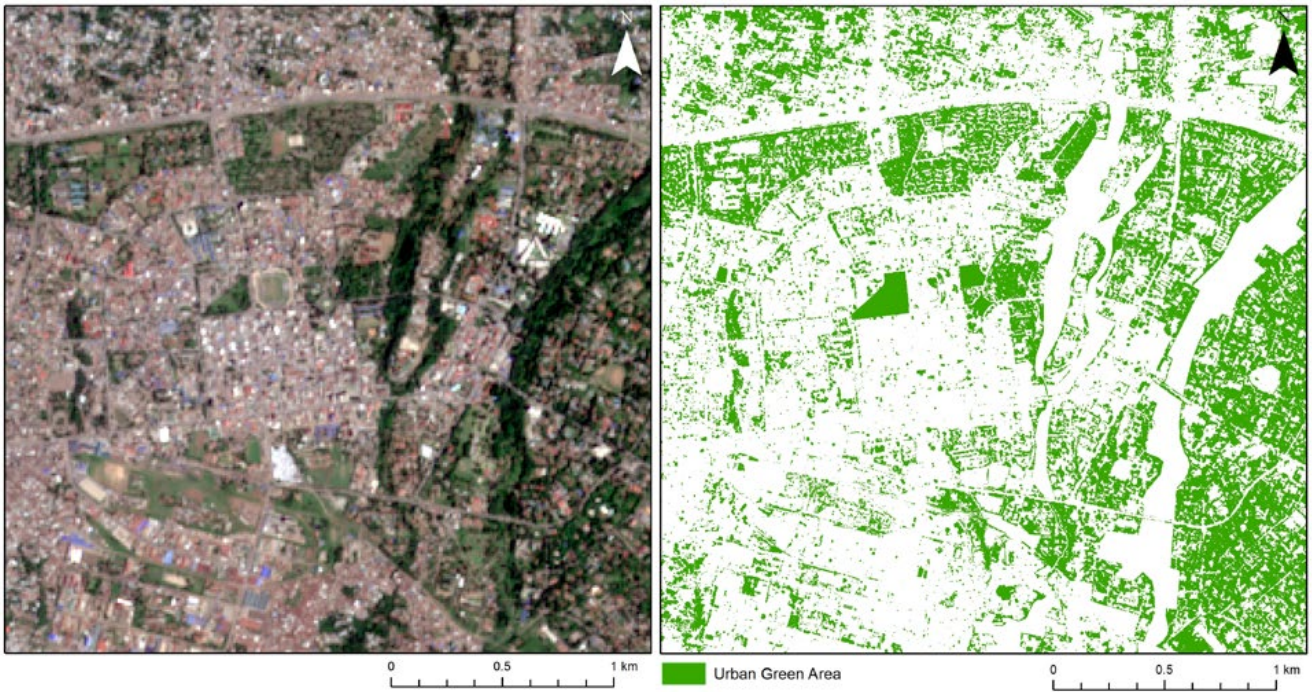

FIGURE 15: Urban Green Areas in an area in Arusha in Tanzania in 2015 (Credit: GAF AG)

Urban green areas and change

— *About the product*

The benefits of having green areas in cities is now an accepted and important component of urban development and planning programmes. The product provides precise spatial information/location and extent of different green areas in the city.

The urban green area product is derived in a fully automatic classification process from multi-temporal high-resolution satellite imagery (10 m to 30 m spatial resolution). The multi-temporal approach allows to minimise the seasonal vegetation effects. The urban green area product includes linear green features such as riverine habitats/woodlands, hedges, and trees, as well as public parks, private gardens, forested areas, and so on. Certain green density classes can be derived from the mapping such as density of green areas per urban block or cadastral parcel.

— *Applications*

The amount of all vegetated areas in a city is of high importance as it is related to the livability of a city, climate resilience, the risk of urban floods, and the reduction of ecological productivity. The amount of urban green areas further is an urban sustainability indicator to assess the actual status in the attainment of the UN Sustainable Development Goals (SDGs). The availability of public green spaces in an urban context is a common indicator for urban planning, and the ratio of population versus the available area of green spaces or the Green Area Ratio (GAR) is an indicator of sustainability.

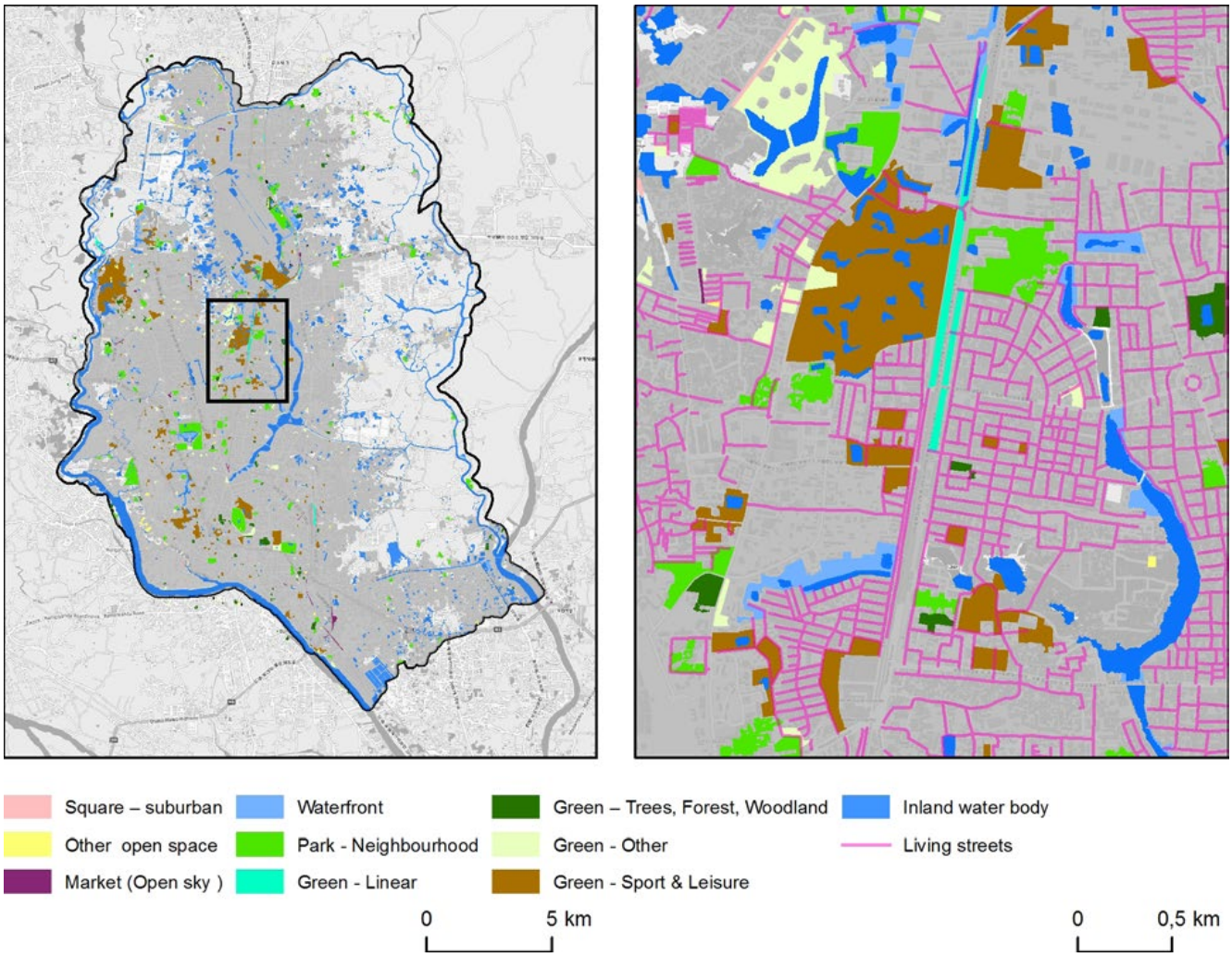

FIGURE 16: Map of open and green spaces with an extended nomenclature - overview and detail maps for Dhaka, Bangladesh (Credit: GISAT)

Urban open and green spaces and change

— *About the product*

Urban Open and Green Spaces is an advanced product providing comprehensive and more detailed typology compared to the Urban Green Area product from EO4SD-Urban portfolio. The product extends delineation and classification to additional classes from open and green spaces nomenclature including: open spaces typology, green and leisure areas typology such as parks of different sizes, streets and public buildings. Mapping at such nuanced detail requires very high-resolution satellite imagery.

— *Applications*

The product aims to support urban livelihood improvement activities as well as monitoring of indicators embedded in the UN Sustainable Development Goals, particularly Goal 11.7 on universal access to safe, inclusive and accessible green and public spaces.

The product allows determination and categorisation of several types of open (public) and green spaces in the city. Apart from providing spatially explicit information about localisation, distribution, and availability of these elements in the city and its districts, additional spatial analytics including connectivity, accessibility, and inclusivity indicators are calculated.

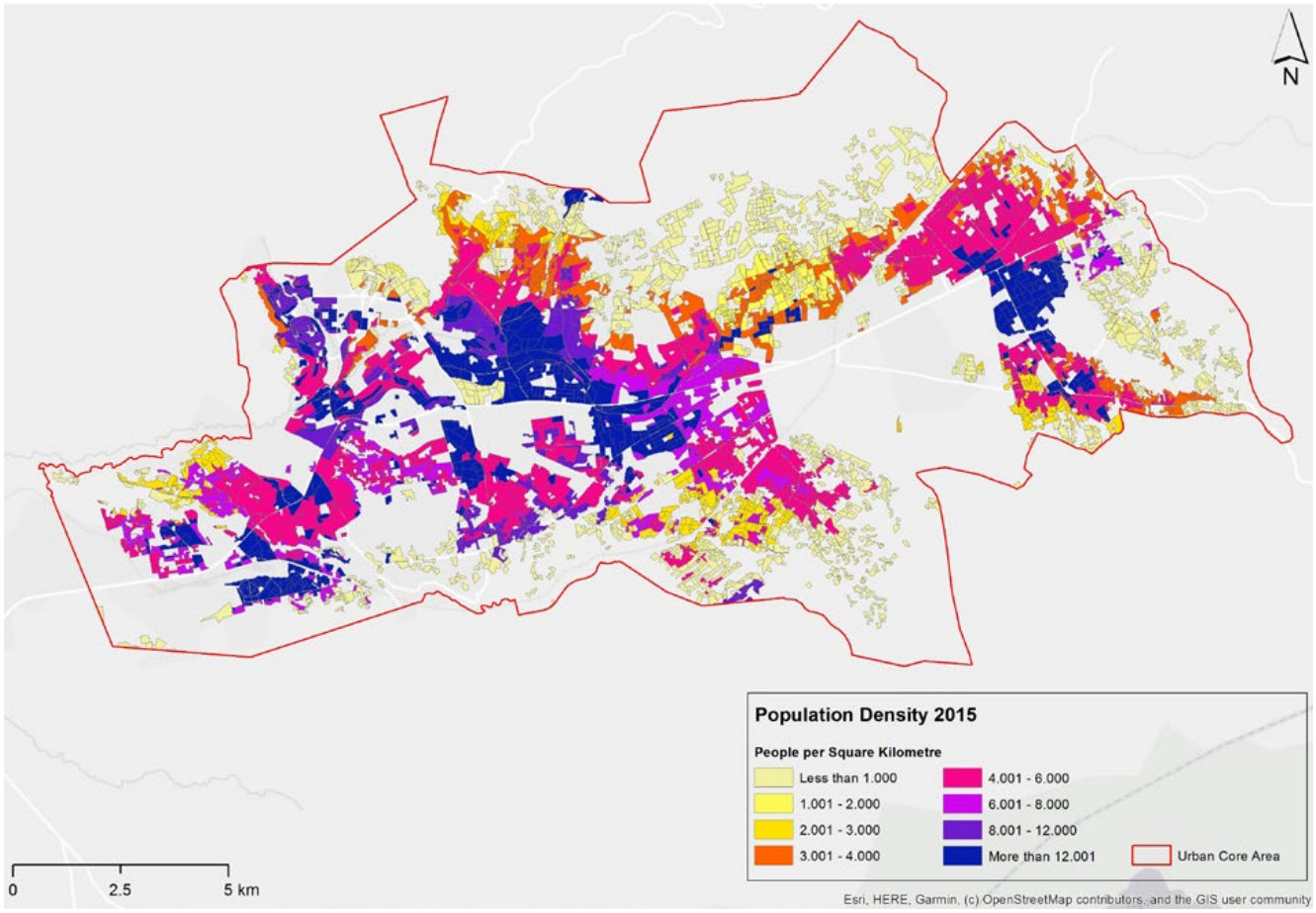

FIGURE 17: Population density in Mbeya in Tanzania for the year 2015 (Credit: GAF AG)

Population distribution and density and change

— *About the product*

Population distribution and density assessments are both crucial variables for sustainable urban development and urban security applications. The product can either be an add-on product to the land use/land cover classification and is then calculated for residential areas or it can be a stand-alone raster product and is calculated per pixel. For the product generation, census data of the city is used and disaggregated by using the mean soil sealing/imperviousness degree for each residential polygon/area.

— *Applications*

The estimation of the urban population distribution and density is an important indicator for the assessment of urban growth and planning for city services. The derived information can be also very helpful in hazard risk prevention and assessment as well as for the definition of special human-related indexes. In addition, the population distribution product can be also estimated for individual urban blocks based on 2D or 3D data. By combining the population product with building heights the Floor Area Ratio can be calculated.

FIGURE 18: The location of a dump site in the larger urban area of Bhopal, India in 2015 (Credit: GAF AG. Satellite imagery: Google Earth)

Waste sites and change

— *About the product*

This product locates and maps different kinds of waste disposal sites. The product focuses on the development of waste sites over time. For mapping the status of the waste site as legal or illegal, ancillary data is needed to make the distinction between both classes.

— *Applications*

The maps produced show the size, location, and change of waste sites and can help to detect illegal ones. These maps can be used by city planners to establish an integrated sustainable waste management plan. In conjunction with other products (i.e., population density and land use), an estimation of the population that can be affected by hazardous waste and pollution due to these waste sites can be estimated.

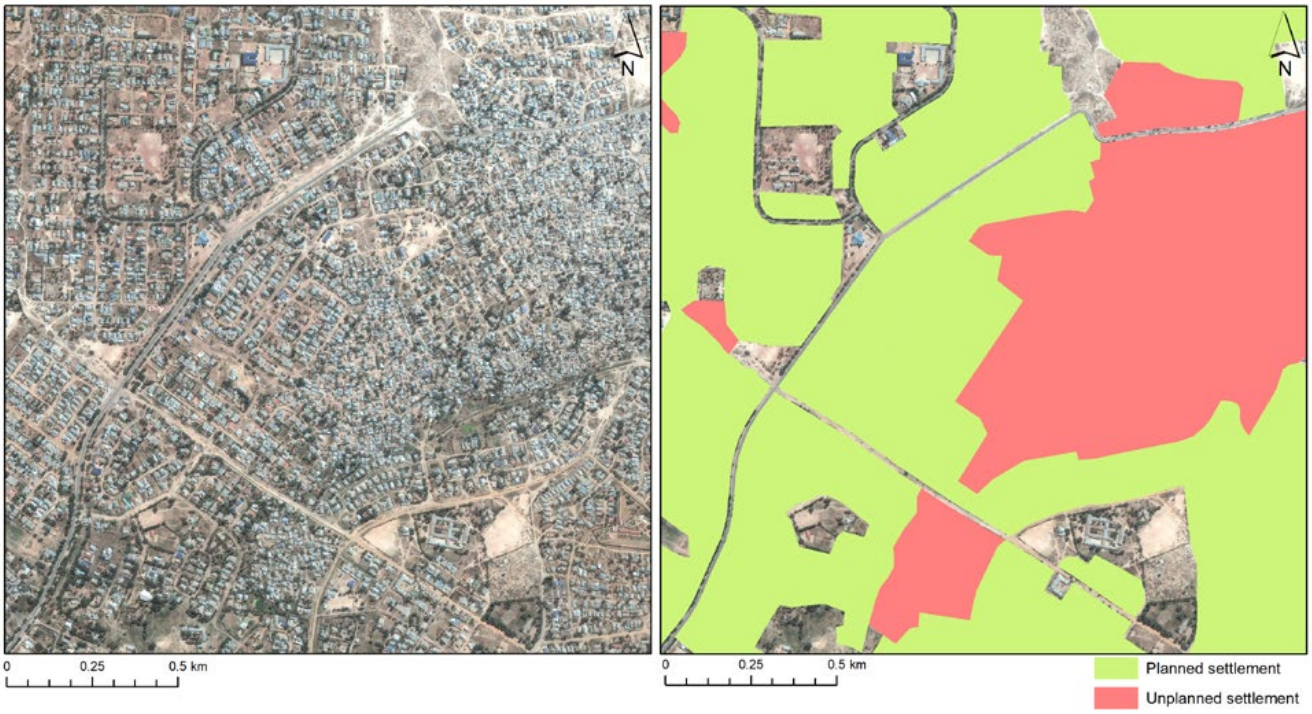

FIGURE 19: Informal settlements mapped in Dodoma, Tanzania, in 2016 to support local urban planning policies (Credit: GAF AG. Satellite Imagery: Pleiades © (2016) CNES, Distribution AIRBUS DS)

Informal settlements and change

— *About the product*

This mapping product includes the detection of the type (phase of development of settlements, e.g., established/permanent or new developments) and extent (in terms of location and area) of informal settlements. Spatial metrics such as compactness, patch size and density of buildings assist in defining these settlements and can be precursors to the application of indicators and deriving settlement typologies. This product is prepared based on very high-resolution satellite data (spatial resolution between 0.3 m to 1 m).

— *Applications*

As most informal settlements are dynamic with frequent population fluctuations, temporal and spatial high-resolution EO data can provide city planners with data and information which would otherwise be difficult to obtain. Especially in developing countries where accessibility is limited, traditional field mapping is difficult as well as time and cost consuming. Therefore, satellite data analysis is a unique planning tool for rehabilitation activities in and around informal settlements. Furthermore, the typology of informal settlements depending on location, construction material, and its spatial patterns (built-up density) are crucial factors for estimating the affected population's vulnerability to natural hazards and the related risks. Planning of improved services and utilities for the informal settlements is also an important use of this product.

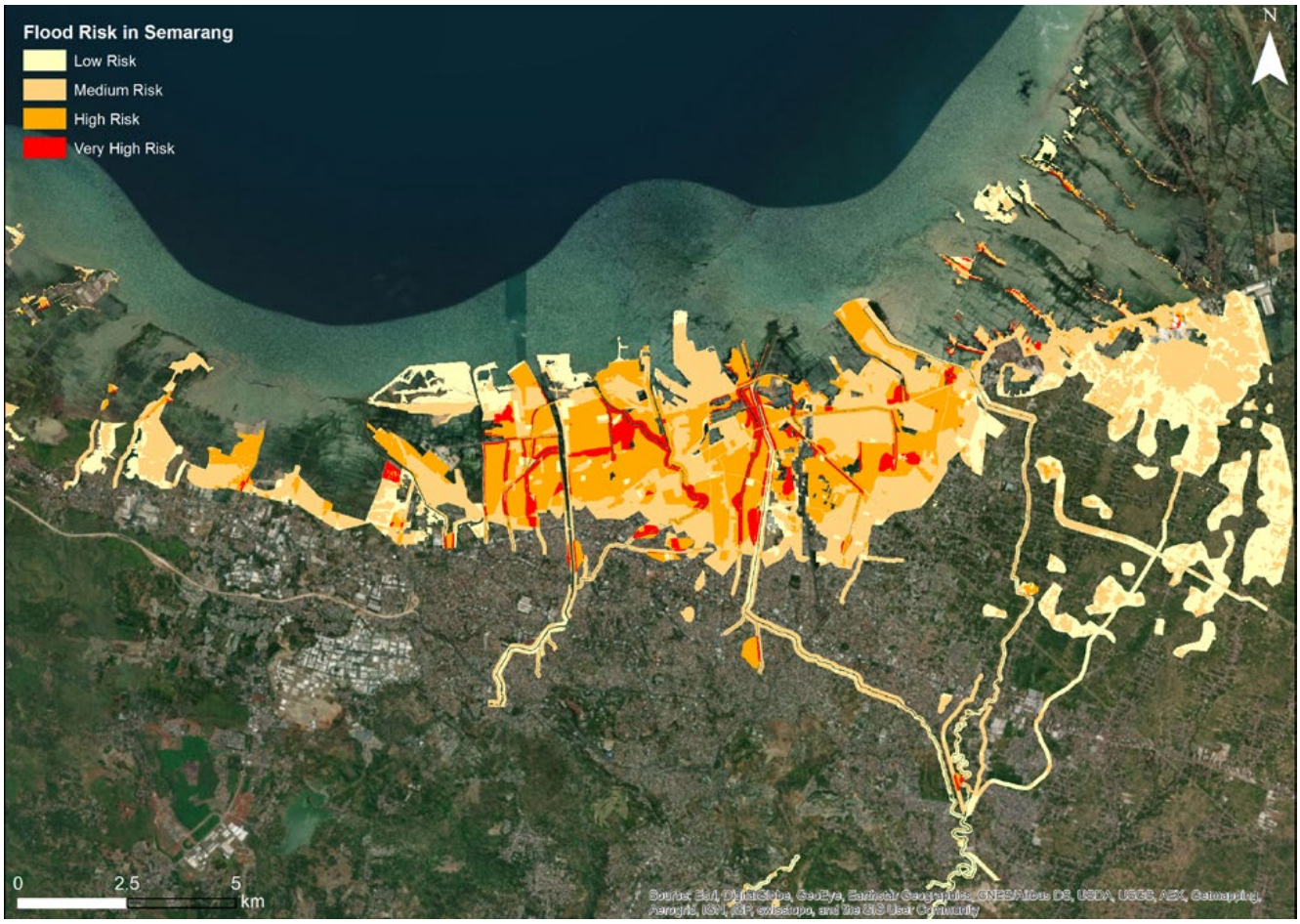

FIGURE 20: Subset of a flood risk map of Semarang, Indonesia (Credit: JR. Satellite imagery: Google Earth)

Flood risk assessment

— *About the product*

This product covers flood hazard maps and flood risk maps. The flood hazard map shows the occurrences of flood events during the past 10 years. The map aims to give an idea about the flood presence in terms of both frequency and extent in the city, and illustrates which part is, in general, flooded more often than other areas. The flood risk map is a combination of flood hazard with land use/land cover (LU/LC) information. Risk is defined as a combination of probability and consequences. A detailed and uniform land-use map is an important prerequisite to perform flood risk calculations since it determines what is damaged in case of flooding.

— *Applications*

Flood hazard and risk maps represent a key input into identification of exposed assets, population, and infrastructure and assessment of flood-related risks. Heterogeneous historic satellite data from archives can be utilised for detection of flood events in the past. Based on data analysis, minimum and maximum inundation extent for a given period and in combination with precise digital terrain model water depth can be calculated.

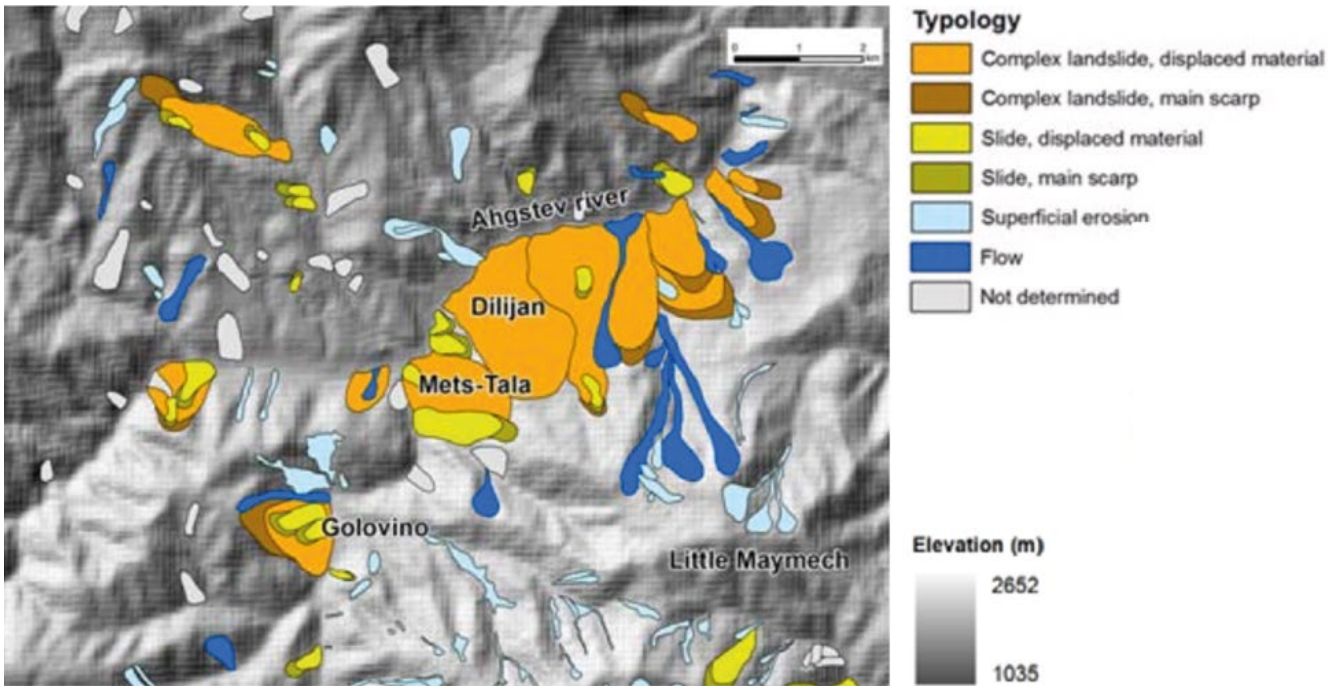

FIGURE 21: Landslide inventory for Dilijan. The landslides are projected on the DEM with a hill-shade effect. Background SRTM DEM © NASA/JPL

Landslide risk assessment

— *About the product*

This product provides landslide inventories, identification and monitoring of landslide-prone areas and hotspots to support risk level estimation and reduction. Furthermore, delineation of landslide extent and damages in support of post-event situation assessment.

— *Applications*

The product can be used for building landslide inventories, definition of risk zones, and estimation of exposed population and existing assets and risk assessment for newly planned built-ups (buildings, infrastructure). The product can further support the engineering of preventive, risk reduction measures and formulation of regulation plans and a post-event situation assessment.

Although not demonstrated in the EO4SD-Urban project, Figure 21 shows a landslide product from a previous ESA programme with ADB. The consortium members Starlab (United Kingdom) and TRE ALTAMIRA (Italy) produced the EO product.

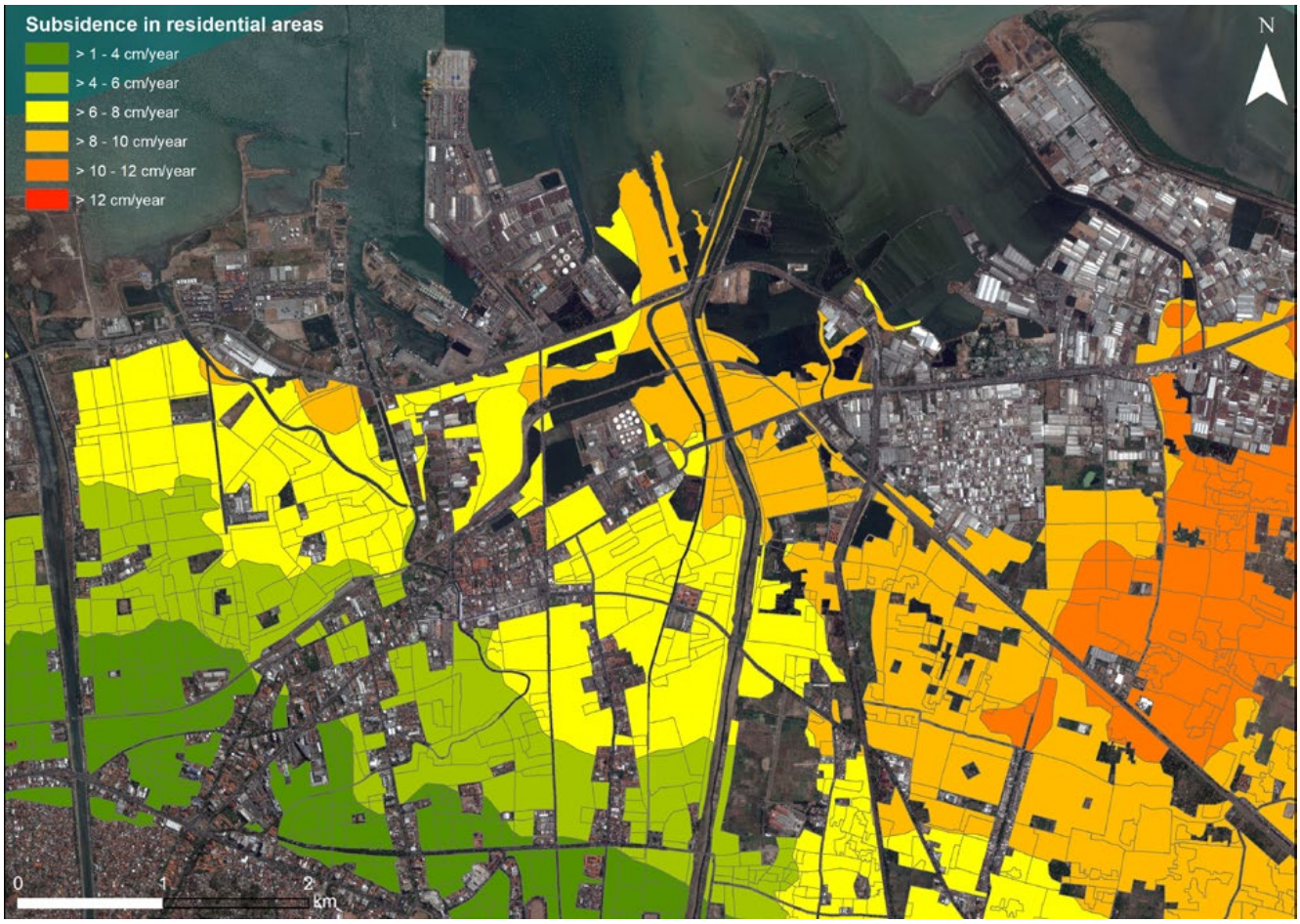

FIGURE 22: Terrain and infrastructure motion product for Semarang, Indonesia
(Credit: JR. Satellite imagery: Pleiades © (2015) CNES, Distribution Airbus DS)

Terrain and infrastructure motion

— *About the product*

This product contains spatially explicit information on land subsidence areas and affected infrastructure. The infrastructure information is generated independently within the land use product and is used as an additional input layer for this product. Thus, there are in total four layers in this product: 1) the raw terrain motion product containing the point-wise information on measured subsidence; 2) the interpolated terrain motion product covering the whole area; 3) the infrastructure motion product with infrastructure (roads, railway, and airport) classified into subsidence classes, and finally 4) the land use motion product with selected generalised land use classes subdivided into subsidence categories.

— *Applications*

The product can be used for monitoring of areas that are impacted by subsidence such as critical infrastructure, buildings, or underground construction sites. It can be further used for earthquake displacement mapping and as an early warning tool.

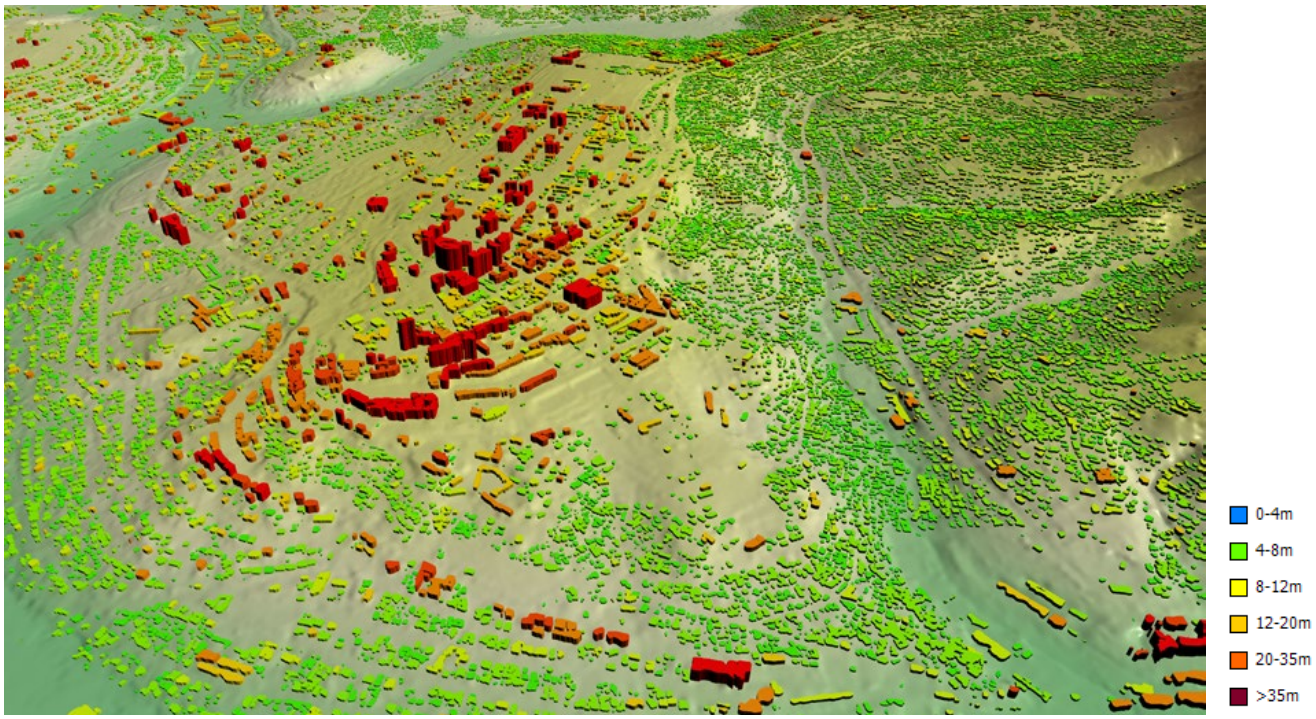

FIGURE 23: 3D building models for the city of Kigali, Rwanda (Credit: GAF AG. Satellite imagery: Pleiades © (2015) CNES, Distribution AIRBUS DS)

Building footprints, heights and change

— *About the product*

Building footprints and the corresponding height information are generated in an automated process. This product is a combination of very high-resolution elevation products and building (block) footprints. The major advantage of this approach is that building heights and footprints stem from the same source data and are geometrically consistent.

— *Applications*

Building footprints can be combined with LU/LC products that distinguish between industrial areas, commercial buildings, residential settlements, farms, public and government establishments, health facilities, and schools, among others. These building type maps allow the understanding of the organisation and spatial distribution of activities, services, and housing within a city and can therefore be used as a tool for managing the city's spatial structure. In combining the building footprint with the building height product, the Floor Area Ratio (FAR) indicator can be derived. The FAR is a key metric for urban planning authorities as many cities use it as a regulatory instrument. Having also the heights of buildings allows the estimation of population and population growth, of the population density, and can support the risk assessment and disaster management plans in a city.

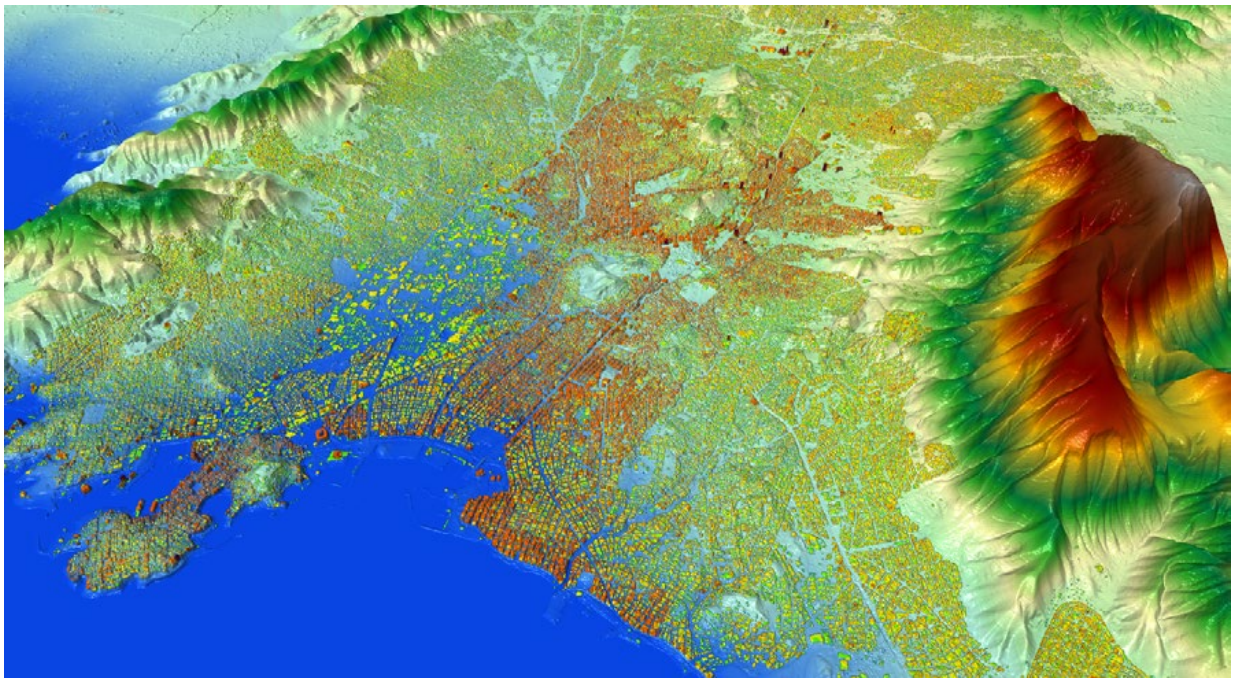

FIGURE 24: Urban Atlas 3D Athens, Greece (prepared within the frame of the local component of the Copernicus Land Monitoring Services (Credit: GAF AG. Antrix Corporation Limited, 2018)

Digital elevation models

— *About the product*

Digital elevation models are composed of digital terrain and digital surface models. The digital terrain model represents the bare earth referenced to a common vertical datum. The digital surface model depicts the elevation of the top of reflective surfaces, such as buildings and vegetation.

The product can be produced based on high and very-high resolution multi-stereo satellite data.

— *Applications*

Digital elevation models are a prerequisite for the automated extraction of building footprints and their heights. As a stand-alone product, it can support the risk assessments and disaster management plans in a city.

Annex three: Methodology

To conduct this evaluation the Caribou Space team relied on the following methods:

1. Public domain literature review that referenced insights on the impact of EO use in the urban sector,
2. Interviews and workshops with individuals at various IFIs who were involved in the EO4SD-Urban programme, and
3. Review of internal EO4SD-Urban documentation.

— *Public domain literature review and limitations*

It should be noted that this was a rapid review and thus cannot claim to have comprehensively captured the field of knowledge on the impact of EO in urban development. However, approximately 150 public domain publications—research reports, academic literature, blogs, and product websites—were reviewed.

Public domain sources have been used to provide examples of impact evidence for a variety of EO use cases. These examples were chosen based on the quality of the evidence found and does not reflect favouritism to specific organisations or companies.

Isolating the impact of EO: The use of EO is just one of many sources of information that is used in an urban environment. Additional information beyond just EO is typically integrated into various models and maps, making it difficult to isolate the precise effects of the use of EO. Studies, when conducted, are rarely engineered to provide detail of whether it was the EO component that contributed to an identified impact.

The level where impact can be detected: Ultimately the effects of integrating EO products into decision making processes accrue to those responsible for developing, funding, and implementing urban plans. If these plans are successful, these benefits are then passed on to the city inhabitants.

Long term impacts not within project control: EO is an information source, and to have impact, actions based on the information is required. For example, knowledge of the hazards in slum areas needs to inform policy. Actions need political will, financial resources, and continued enforcement. These critical elements require both interventions that promote actions and evaluations that measure them.

Limited impact evaluations of EO in urban: A core component in understanding impact is to clearly establish a link between the intervention (use of EO products) and the observed change (at the level of the information user or eventually the urban population). Such rigour is not always viable due to limitations in budget and the ability to gather information on longer-term impact

From the literature review, whilst information on the use cases for EO products in urban development was common, information on long-term impacts was scarce. Ultimately, this scarcity of information affects the confidence with which impact statements can be made regarding EO in the urban sector. Thus, in the literature review, while evidence on **explicit** change due to EO was prioritised, other more **implicit** change, often in the form of anecdotes and direct quotes were also utilised. Evidence on EO data use cases and impact was prioritised for developing countries. However, in some areas limited information was located and thus on occasion some examples from developed countries are used.

— *Internal EO4SD-Urban document review*

Over 50 internal documents were reviewed as part of the evaluation. Key documents to the evaluation included the capacity building review, stakeholder engagement assessments, user utility and impact assessment, and various city operational reports.

— *Interviews and workshops*

Eight one-on-one interviews were conducted with individuals from the World Bank and ADB. Additionally, the evaluation team participated in meetings and workshops with the World Bank and IABD in January 2020 in Washington, DC, where further discussions on the EO4SD-Urban programme were facilitated.

Caribou Space supports organisations to bridge the space and sustainable development worlds by working with governments, space agencies, development agencies, and private sector space companies. Caribou Space provides:

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- **Fund management**: Large scale ODA funds (£100 million plus), and seed stage funds (£4 million plus).
- **Monitoring and Evaluation (M&E)**: Design of M&E systems, delivery of process and impact evaluations, and M&E training.
- **Research, communications, and knowledge sharing**: Conducting research on market opportunities, user needs, use cases, and impact of space solutions, and publicly sharing knowledge of what works, doesn't work, and why. Using diverse communications channels including press and media, publications, social media, conferences and workshops.
- **Programme management**: Delivery of complex, multi-country, multi-million-pound programmes in developing countries.
- **Product strategy**: Supporting strategy for the sustainability and commercialisation of space solutions for developing countries.
- **Economic evaluation**: Quantification of the economic case and impacts of space technology.

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