The Earth Observations Toolkit for Sustainable Cities and Human Settlements: overview and progress to date

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1. Introduction

The *Earth Observations Toolkit for Sustainable Cities and Human Settlements* (https://eo-toolkit-guo-un-habitat.opendata.arcgis.com/) represents an ongoing effort to put Earth observations (EO) data and tools into context for analysts in national and city governments, and at local community level. Additional target audiences include policy and decision makers, executive managers and the urban sustainability-interested public. The Toolkit focuses on end user stories that highlight EO applications to improve the timeliness and quality of urban-related indicators, guide policies, and support sustainable urban development. It is a multi-stakeholder partnership that facilitates engagement among local communities, cities, national agencies, and EO experts. It also aims to promote knowledge sharing and collaboration between local communities, cities and countries.

Sustainable Development Goal (SDG) 11, also known as the urban SDG, aims to *make cities and human settlements inclusive, safe, resilient and sustainable.* SDG 11 underscores the importance of subnational and local perspectives for the achievement of sustainable development across regions. The role of cities, human settlements and local communities to meet long-term development objectives and enable tangible improvements on the quality of peoples' lives is further emphasized in the New Urban Agenda (NUA), a universal-in-scope agreement that aims to enhance SDG effectiveness at city, human settlement and community level.

Both the SDGs and the NUA place particular emphasis on high quality, timely and reliable, disaggregated data at the national, subnational and local levels, taking into account the social, economic, and environmental dimensions of sustainable development. The SDG Indicator Framework has an overarching principle of data disaggregation by "income, sex, age, race, ethnicity, migratory status, disability and geographic location, or other characteristics, in accordance with the Fundamental Principles of Official Statistics" (General Assembly resolution 68/261) and to ensure that no one is left behind. Through spatial and thematic disaggregation, EO data can play a significant role to monitor SDG 11 indicators, support city and national-level statistical data infrastructure demands and drive policies and decision making in cities and local communities.

EO data sets provide spatial, spectral and temporal information that can be processed and transformed into variables or high-level products that are useful to produce urban indicators (GEO 2017). National statistical offices, ministries, city governments and local communities have a key role to play in testing the useability of data collected from satellites, airborne sensors or in situ measurements, and EO-mapping products, to address their urban monitoring needs. Such end users can also help provide insights to improve future EO missions and data products for greater utility and customary use in monitoring and decision making.

2. Site Content

The site comprises a catalogue of SDG 11 and NUA-relevant EO data sets – mainly ready-to-use data products – and interactive EO data processing tools that can be filtered by different parameters – such as data type, format, source, spatial scale, temporal resolution, geographic level, keywords, SDG indicator – to help users discern application areas and distinct characteristics for the data and tools. Each data set and tool is openly and freely available, has been peer reviewed, and comes from a federal science agency or a funded partner. It is included in this Toolkit upon recommendation from EO data providers and subject matter experts from the Group on Earth Observations (GEO) Human Planet initiative and the Global Urban Observations and Information initiative. The site also includes use cases outlining how city or national

governments and global research networks have applied EO data to fill monitoring gaps and address reporting needs or guide policy actions.

Supplemental resources include outreach and capacity development material, such as videos, user guides, webinars; as well as a directory of contacts from local and national governments, global research networks, and the EO and geospatial community that are contributing to this activity. EO experts, practitioners, and end users have contributed to the writing and review of the site (see Contributors, https://eo-toolkit-guo-un-habitat.opendata.arcgis.com/) ensuring ongoing relationships between subject matter experts and end users. Recently, and as part of this effort, four working groups have emerged – the *Impact* Working Group, the *Awareness Building* Working Group, the *Bench-learning* Working Group, and the *FAIR Data* Working Group. The primary purpose of these groups is to further improve the usefulness and sharing of this continuously updated resource.

3. EO Application Areas

The information on the Toolkit site is grouped under four thematic areas: Housing, Public Transport, Urbanization, and Public Spaces. These correspond to 4 UN-defined Targets and related Indicators under SDG 11. Targets specify the goals and indicators represent the metrics by which cities and countries aim to track whether these targets are achieved. EO can be of particular value in these topical areas, providing cost and time savings in urban monitoring and indicator calculation – particularly over large areas or data-sparse regions (i.e., areas where conventional data collection techniques are difficult).

Adequate Housing

SDG Target 11.1: *By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums*

About 30% of urban populations in the developing world are estimated to live in slums – settled areas where inhabitants lack access to basic services, adequate housing, and tenure security (Habitat III).

Consistent and reliable data on the location and size of such settlements is a persistent challenge, making these areas and the people living in them invisible to standard assessments of progress on sustainable development and targeted interventions. Medium (1 km-500m) to high resolution (30m -10m) satellite imagery, coupled with methodological and computational advances, can be used to define and map urban areas and settlements in spatiotemporal dimension, and characterize their morphology while also assessing their correlation with socioeconomic variables (Marconcini et al., 2020).

The Toolkit includes a number of EO data sets and tools (e.g., Global Human Settlement Population, VIIRS Plus DMSP Change in Lights, Microsoft Building Footprints) that can assist in understanding the pattern, density, location and distribution of urban slums and deprived settlements at global to regional to national level. For example, the Degree of Urbanization Grid is a software tool, developed by the European Commission's Joint Research Centre, that classifies 1 km^2 grid cells on the basis of population density, size, and contiguity according to the "degree of urbanization" framework into urban centers, towns and suburbs, and rural areas.

The site also illustrates results from an ongoing study to identify strengths and weaknesses for using gridded population data in slums and informal settlements in lower and middle income country contexts. The study, led by Columbia's Center for International Earth Science Information Network and University of Louisville, compares gridded population counts to field-referenced slum data for Lagos and Port Harcourt cities in Nigeria and Nairobi in Kenya. Additional efforts that explore the use of EO data for slum mapping include the IDEAMAPS Network and the SLUMAP project. Visit the *Adequate Housing* thematic page for a full list of related data, tools, and use cases.

Public Transport

SDG Target 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.*

Global open EO data sets are useful for urban planning and to support humanitarian operations through mapping and monitoring changes in public infrastructure, such as roads, bridges, or dams. When combined with local knowledge and ground truth information, they provide valuable insights and support efforts to monitor the status of infrastructures, particularly in support of disaster preparedness and response efforts, urban planning as well as conservation activities. The Toolkit includes a number of relevant EO tools and data sets that can help derive useful metrics, such as the Global Human Settlement-Functional Urban Areas that delineate areas in which at least 15% of the population is commuting to the main urban center of an area. This is relevant for analysis of larger metropolitan areas and their hinterland. The Toolkit also includes use cases that illustrate how satellite imagery has been applied to improve access to public transport. For example, Humanitarian OpenStreetMap Team has been working with local organizations in Indonesia to use satellite imagery, combined with Artificial Intelligence-assisted mapping activities, to map all road networks. This information is crucial for supporting governments and local responders to reach all people as quickly as possible when disasters hit (read more). Visit the *Public Transport* thematic page for a full list of related data, tools, and use cases integrated into the site.

Urbanization

SDG Target 11.3: *By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.*

EO, acquired remotely by space-borne, airborne or in situ sensors and ground-based observations, can be used to characterize the physical properties of urban land cover and land use, and quantify changes in land cover/ land use type and extent. Large archives of satellite data from the USGS/ NASA Landsat and the Copernicus Sentinels, among others, offer unprecedented capabilities for identifying and analyzing patterns of urbanization and disaggregating types of built-up structures (e.g., buildings, road networks). The Landsat collection is an example of freely available, analysis-ready data that offers 30 m spatial resolution and a large temporal extent (since the 1970s).

The Toolkit includes a number of free and open data sets that capture impervious surface extent and change. Multi-temporal information layers on built-up area presence — such as the Global Human Settlement-Built-Up Presence (GHS-BUILT), derived from Landsat's image collection, which maps pixels as built-up when a pixel intersects with a building or is part of a building, and the Global Human Settlement Built-Up (GHS-BUILT-S2) information layer, derived from a Sentinel-2 image mosaic, which maps the probability that a pixel is built-up — can be used to analyze urbanization, map population or analyze exposure to natural hazards. They also provide one of the two inputs (land consumption rate) for SDG indicator 11.3.1, ratio of land consumption rate to population growth rate.

The Toolkit also includes tools that facilitate the production of indicators linked to the evolution of built-up surfaces and population (e.g., SDG indicator 11.3.1). As an example, Trends.Earth Urban Mapper, an online interactive platform developed by Conservation International in partnership with NASA, provides access to a pre-computed time series of impervious surface indicators that are available globally at 30 m resolution. Users can define 3 threshold values – impervious surface index, night time lights index, and water frequency index – that are used by the tool to estimate the built-up extent for the area of interest. Once the urbanized areas are defined, users can then upload their own population data sets or make use of global gridded data (the tool provides access to the Gridded Population of the World V4 (GPWv4, CIESIN, 2016) as a reference) to compute indicator 11.3.1. Visit the *Urbanization* thematic page for a full list of related data, tools, and use cases integrated into the site.

Open Spaces

SDG Target 11.7: *Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities*

SDG 11 acknowledges the key role public spaces play in achieving inclusive, safe, resilient, and sustainable cities. Green spaces offer opportunities to advance well-being, bring down city temperatures, support biodiversity conservation and restoration, and contribute towards energy savings and improved health and

air quality. EO can provide useful data that help with decisions relating to delimiting the extent of built-up areas in cities and support efforts to derive meaningful indicators, such as the average share of built-up area of cities that is open space for public use for all (SDG indicator 11.7.1) or the average distance to open spaces.

The site includes a list of relevant EO data sets and tools that can help end-users derive useful metrics, including in support of the NUA. Examples include the Global Human Modification of Terrestrial Systems dataset, which provides a cumulative measure of human modification of terrestrial lands and their estimated impacts across the globe at a 1-km resolution, and the Global Urban Heat Island dataset, which estimates the land surface temperature within urban areas and the temperature difference with surrounding rural areas in a 10 km buffer around the urban extent. In addition, the Human Built-up and Settlement Extent (HBASE) and Global Man-made Impervious Surface (GMIS) Data Visualization and Access Tool allows users to view and download a global estimate of fractional impervious cover derived from the 30 m Global Land Survey (GLS) Landsat dataset for the target year 2010 in addition to a complementary estimate of global urban extent derived from the same Landsat data. Visit the *Open Spaces* thematic page for a full list of related data, tools, and use cases integrated into the site.

Population as Key Input for SDG 11 Indicators and the NUA

EO data and imagery indirectly support the generation of disaggregated maps of global, regional or national population data, complementing census data and filling in data gaps. Gridded population datasets provide key inputs for a range of indicators that measure change in urban-related characteristics with respect to population growth or other demographic-related parameters (TReNDS SDSN, 2020). Online tools, such as the POPGRID Viewer, enable the evaluation of key differences in gridded population products. To identify strengths and weaknesses for using gridded population data sets in monitoring urban-related parameters, it is important that EO experts work together with city and country-level end-users to compare different gridded population counts with field-referenced data estimates and assess their applicability and accuracy in addressing local to national monitoring needs.

4. Conclusion

The *Earth Observations Toolkit for Sustainable Cities and Human Settlements* is a 'live' resource; its structure, style, components, and content will be continuously updated as new information becomes available and based on targeted user feedback e.g., captured through the Working Groups' activities, focused interviews, projects and case studies. We plan to focus on impact, outreach and capacity development, bench-learning across levels and data access and exchange issues in order to refine and improve our approach to serving user needs and promoting sustainable cities and human settlements through Earth observations. We invite you to share your feedback via our Contact page and consider submitting a case study, tool or other relevant information for publication on the Toolkit via our Contribute page.

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