Global and Complementary (Non-authoritative) Geospatial Data for SDGs: Role and Utilisation

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A report produced jointly by the Task Team on Global Data and Task Team on Alternative Data Sources established in December 2016 by the Working Group on Geospatial Information of the Inter-agency and Expert Group on Sustainable Development Goal Indicators (IAEG-SDGs) with contributions from Mr. Stephan Arnold, Prof. Jun Chen, Mr. Olav Eggers, Prof. Zhilin Li, Ms. Sandra Liliana Moreno Mayorga, Prof. John Mills, and Prof. John Shi. This report was reviewed by members of the working group before being made available to IAEG-SDGs at its ninth meeting in March 2019.

Content

1 Preamble

1.1 Importance of geospatial data to SDGs

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

In principle, reliable geospatial data would be better produced by individual nations. Such datasets could then be aggregated, as appropriate, at regional and global levels and compared to independent international (global) data sources. Certain types of fundamental geospatial data (e.g., elevation and topography, Land Cover, transportation networks, settlements and geographic names) should be collected and provided to underpin the SDG indicators calculation. For a robust comparability, such geospatial data should be provided in a harmonized way regarding for example spatial resolutions, thematic detail and temporal periodicity. However, this is a challenging task for many countries in the world, with clear differences between countries on data richness and capacity to provide long-term consistent data. Some of them may have a shortage of certain types of core geospatial data while others might lack the requisite data capture capacities.

So which data sources should be used? While some indicators need local data all the way down to street and address level, others could benefit from a more regional/global data approach, or a combination of these two approaches could be applied. Furthermore, some SDG indicators are very ambitious and the data and processes which are needed are not yet defined. All in all, we are looking at a data-puzzle of opportunities and limitations to use global data, where it will be difficult to apply a single approach that fits for all data situations in the countries. The way in which the 2030 SDG indicators will be implemented will depend on the individual countries' data availability, policy and developmental priorities, capacity, available data infrastructure and institutional arrangements, among other factors.

One possible solution to some of these challenges, therefore, is to assess the usability of the available global and complementary (non-authoritative) data sources and, if appropriate, utilise them to augment or even provide the much-needed baseline values and to potentially provide default data to inform certain SDG indicators in support of national reporting.

1.2 Scope of this report

This report is produced jointly by the Task Team on Global Data led by Prof. Jun Chen and the Task Team on Alternative Data Sources led by Mr. Stefan Arnold. The task teams were established by the Working Group on Geospatial Information of the Inter-agency and Expert Group on Sustainable Development Goal Indicators (IAEG-SDGs) at its second expert meeting in December 2016. The report was reviewed by members of the working group over a period of time before being made available to IAEG-SDGs at its ninth meeting in March 2019. This report summarizes the results of discussions of the Working Group on Geospatial Information (IAEG-SDGs WGGI) between December 2016 and March 2019.

The results of the respective work of the Task Teams were brought together into this report on Global and Complementary (Non-authoritative) Geospatial Data for SDGs: Role and Utilisation, to discuss how these data sources can be considered as "complementary" to public data from official sources such as from National Statistics Offices (NSOs). The report is structured as follows: Section 2 examines the concepts and historical development of global and complementary (non-authoritative) data; and Sections 3 and 4 elaborate respectively the potential roles and utilisation in informing SDGs.

2 Global and Complementary Geospatial Datasets

This section introduces commonly used and available global and complimentary data types, illustrating their use in monitoring and action-oriented activities at national and local levels.

2.1 National versus international (global) mapping initiatives

National geospatial data refers to the official data products generated by official, authoritative agencies of a nation. During recent decades, many nations have invested substantial human and financial resources in preparing and maintaining their core geospatial datasets, including topography, Land Cover, administrative units, transport networks, settlements, cadastral parcels, hydrography, geographical names, and imagery (UN-GGIM, 2015). Several international organisations, national and regional space agencies, and private companies have developed global and regional datasets to supplement a nation's data infrastructure. This can also assist the development of a Spatial Data Infrastructure (SDI)[1] which in turn can foster interoperability and sharing of data. To increase the global availability of relevant data, the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) has defined 14 Global Fundamental Geospatial Data Themes[2], which will support SDG indicator monitoring. These fundamental data themes are a pre-requisite for harmonised indicator follow-up and will support the creation of a globally agreed "spatial data pool", with a minimum content of information, to be provided by all UN member states.

Some of the most commonly used data products which are available and/ or extracted at the national or global levels (and that will play a significant role in SDGs monitoring) include, among others, topographic maps and digital elevation models (DEMs), satellite image data and a diversity of Land Cover products.

2.1.1 Topographic maps and Digital Elevation Models

Topographic maps contain most of the fundamental data themes and provide information about various features on the land surface. According to the joint survey conducted by the UN-GGIM Secretariat and the International Society for Photogrammetry and Remote Sensing (ISPRS), the authoritative topographic data coverage at the various scale ranges has greatly increased between 1986 and 2012 (Konecny et al., 2015). Today, global coverage is estimated at 30% for 1:25k topographic maps and at 75% for 1:50k mapping. While several countries are capable of updating their national topographic data at one- to two-year cycles, topographic data in some other countries can be anything from 10 to 30 years old.

Besides topographic mapping activities, and in addition to the national authoritative initiatives, Digital Elevation Model (DEM) datasets have been collected at a global scale with the help of satellite Earth Observation sensors (see Table 1). NASA's Shuttle Radar Topography Mission (SRTM)[3] produced the first Global DEMs with a spatial resolution of 30m to 90m and vertical accuracy of 10-15m. ASTER GDEM, World DEM, and ALOS World 3D are the other Global DEM datasets which have since become

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[1] Such as INSPIRE in Europe

[2] https://undesa.maps.arcgis.com/apps/Cascade/index.html?appid=4741ad51ff7a463d833d18cbcec29fff and E/C.20/2018/7/Add.1

[3] First through the space shuttle Endeavour in 2000, covering latitudes 56°S to 60°N.

freely available or commercially available for a monetary cost. Digital Height Models (or a combination of Digital Terrain and Digital Surface Models) might additionally be useful in the context of urban indicators and can be derived using similar methodologies.

Table 1: Global DEM datasets available for SDGs

Product	Spacing	Vertical accuracy	Year	Remarks
SRTM	30m/90m	10–15 m	2000	Generated by Interferometric Synthetic-Aperture Radar, and covering 56°N to 60°
ASTER GDEM	30m	7–14 m	2009-2011	Generated by ASTER and gaps filled with SRTM
World DEM	12m	2m (rel) 4m (abs)	2014	Generated by TanDEM-X; DSM and DTM commercially available at cost
ALOS World 3D	30m	5 m	2016	Generated by ALOS PRISM; freely available and based on 5 m global DEM which is available commercially at cost

2.1.2 Satellite Image Data

Another main source of geospatial information stems from the large number of satellites, providing data on a great variety of geophysical parameters in many different formats, and spatial and temporal resolutions. Satellite data have several common characteristics which are of interest to the NSOs seeking to integrate such data to their national information system. Satellite image data is becoming increasingly freely and openly available, consistent and comparable, and in a time-series. These factors can further enable and complement traditional statistical methods to derive new datasets and insights, saving time and cost of the survey. Many of the datasets resulting from these satellites are openly available through the Global Earth Observation System of Systems (GEOSS) Common Infrastructure[4] coordinated under the auspices of the Group on Earth Observation (GEO)[5].

While many commercial satellites of very high spatial resolution may not be the obvious source of information for developing countries due to their associated high costs, in recent times high resolution satellite time series image data have been available free of charge, such as Landsat and Sentinel. Major obstacles for the use of such free satellite data however, are often the insufficient spatial resolution (for certain applications or information requirements) and the necessity to process and interpret data before the generation of useable information. This coupled with capacity-related challenges (both human resource and systems) which are prevalent in many developing countries, limit the utilization of such products for information extraction, and in turn SDG monitoring.

Table 2: Some examples of free satellite data which can be useful for SDG monitoring

Satellite	Spatial resolution	Mission objectives	SDG
Sentinel 1	C-band Radar Strip Map Mode: 80 km swath, 5 x 5 m spatial resolution Interferometric Wide Swath: 250 km swath, 5 x 20 m spatial resolution Extra-Wide Swath Mode: 400 km swath, 20 x 40 m spatial resolution	Land monitoring of forests, water, soil and agriculture Emergency mapping support in the event of natural disasters Marine monitoring of the maritime environment Sea ice observations and iceberg monitoring Production of high-resolution ice charts Forecasting ice conditions at sea	SDG 2: Agriculture SDG 6: Water SDG 11: human settlements monitoring SDG 15: Forest, Biodiversity, Land degradation

[4] GEOSS is a set of coordinated, independent Earth observation, information and processing systems that interact and provide access to diverse information for a broad range of users in both public and private sectors. GEOSS links these systems to strengthen the monitoring of the state of the Earth. It facilitates the sharing of environmental data and information collected from the large array of observing systems contributed by countries and organizations within GEO. Further, GEOSS ensures that these data are accessible, of identified quality and provenance, and interoperable to support the development of tools and the delivery of information services http://www.geoportal.org/

[5] The Group on Earth Observations (GEO) is an intergovernmental organization working to improve the availability, access and use of Earth observations for the benefit of society. GEO works to actively improve and coordinate global Earth observation systems and promote broad, open data sharing.

Satellite	Spatial resolution	Mission objectives	SDG
	Wave-Mode: 20 x 20 km, 5 x 5 m spatial resolution.	Mapping oil spills Sea vessel detection Climate change monitoring.	
Sentinel 2	13 spectral bands: four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution. The orbital swath width is 290 km.	Monitoring agriculture, forests, land-use change, land-cover change; mapping biophysical variables such as leaf chlorophyll content, leaf water content, leaf area index; monitoring coastal and inland waters; risk mapping and disaster mapping.	SDG 2: Agriculture SDG 6: Water SDG 11: human settlements monitoring SDG 15: Forest, Biodiversity, Land degradation
Sentinel 3	21 spectral bands 300 meters/1270 km swath	Supporting global land and ocean monitoring services, in particular: sea/land colour data and surface temperature; sea surface and land ice topography; coastal zones, inland water and sea ice topography; vegetation products.	SDG 2: Agriculture SDG 14: Coastal eutrophication SDG 15: Forest, Biodiversity, Land degradation
Landsat 7/8	15m/30m/100m (panchromatic/multispectral/thermal)	Provide data continuity with previous Landsat missions Offer 16-day repeat coverage of the Earth Build and periodically refresh a global archive of sunlit, substantially cloud free, land area and coastal images Make data widely and freely available. As of 2008, Landsat data with standard processing are available at no cost Support Government, international, and commercial communities Promote NASA's EOS interdisciplinary research via synergism with other EOS observations - By orbiting in tandem with NASA's Terra satellite to obtain near coincident observations[6].	SDG 6: Water SDG 11: human settlements monitoring (and multi-temporal comparisons) SDG 15: Forest, Biodiversity, Land degradation

As openly licensed imagery becomes available in higher spatial and temporal resolution and as more automated approaches to extraction of information from such imagery continue to grow, there is increasing impetus for countries to integrate the necessary structures to improve the quality of their data and inform national statistical processes. As an example, the new generation of Sentinel satellites, with its broad variety of spectral bands and relatively high revisit rates (e.g. 5 days by optical Sentinel-2), offer a rich archive to be explored over the coming years.

With research and development activities, assessing new methods and approaches of multi-temporal and sensor-fusion approaches, a better interpretation and extraction of SDG-relevant land related information can be achieved through specific application services and products. The concept of providing Analysis Ready Data is being developed where satellite data are processed to a minimum set of requirements and organized into a form that allows immediate uptake with minimum additional user effort. Data Cubes (spatially aligned time series stack of satellite image data) are also being developed with large volume of data and cloud computing capability, which will enable immediate time series analysis and change detection. This way, such data could help to close the information gap in countries with limited national data availability or where mapping activities are scarce.

[6] https://landsat.usgs.gov/landsat-7-data-users-handbook-section-1

2.1.3 Land Cover Datasets

Land Cover is a fundamental geospatial data theme defined as the observable (bio-)physical material at the earth's surface. This can be divided into classes which include all kinds of vegetation (e.g. areas of trees, shrubs, or grasses), non-vegetated natural bare surface materials (e.g. solid or fragmented rocks, gravels, sand, topsoil), water bodies, as well as man-made structures and artificial surfaces, or any combination of the above[7]. The knowledge about the spatial distribution of Land Cover and its change over time is an essential requirement for several SDG indicators[8], such as indicator 6.6.1 (change in the extent of water-related ecosystems over time), indicator 11.3.1 (ratio of land consumption rate to population growth rate), or indicator 15.3.1 (proportion of land that is degraded over total land area). These three indicators were assessed in parallel subtasks within the IAEG-SDG WGGI in 2017.

Many countries have undertaken Land Cover mapping using remote sensing derived data and developed their own national Land Cover products. Whilst some countries have high-quality national Land Cover products, considerable differences exist in terms of their geographic coverage, their spatial and temporal resolution as well as thematic depth (Grekousis et al. 2015; Diogo and Koomen, 2016). Moreover, the rate of updating and accuracy of these products is low or not known in many national products, especially in developing nations (Arsanjani et al., 2016). In addition, no national or specific Land Cover data could be identified in some other countries (Diogo and Koomen, 2016).

Table 3: Global Land Cover datasets

Product	Spatial resolution	Coverage of years	Contents/ overall reported accuracy	Source
GlobeLand30	30 m	2000, 2010	10 classes/ 80.3%	http://www.globeLand30.com
Global tree cover	30 m	Annual (2000-)	One class (forest but with percentage cover)/ unknown	http://glcf.umd.edu/data/landsatTreecover/ FCC: http://glcf.umd.edu/data/landsatFCC/
Global forest change	30 m	Annual (2000-)	Forest canopy cover % / gains / losses	https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html
Copernicus land service: dynamic Land Cover	100 m	Annual (2015-)	10 classes / 74% (2015)	https://land.copernicus.eu/global/products/lc
Forest and non-forest global map	25m	Every year 1993-1998, 2007-2010, 2015-2016	Two classes (forest/non-forest)/ 84% accuracy /L-band SAR	http://www.eorc.jaxa.jp/ALOS/en/palsar_fnf/fnf_index.htm
ESA Land Cover CCI	300 m -1 km	1992-2015 (annual)	22 classes/ 74% (2008-2012)	http://maps.elie.ucl.ac.be/CCI/viewer/download.php
GUF	12 m	2010-2013	3 classes: urban fabric, non-built up land surface, water / unknown	German Aerospace Center (DLR) https://www.dlr.de/eoc/en/desktopdefault.aspx/tabid-9628/16557_read-40454/
GHSL – built up	38 – m	1975, 1990, 2000, 2014	Scale from 0-98 / unknown	Joint Research Center (JRC) of the EU https://ghsl.jrc.ec.europa.eu/datasets.php
GHSL - population grids	250 – m	1975, 1990, 2000, 2014	Number of people per cell / unknown	Joint Research Center (JRC) of the EU https://ghsl.jrc.ec.europa.eu/datasets.php
GHSL settlement model	1 –km	1975, 1990, 2000, 2014	Rural, Urban Cluster, Urban Centre/ unknown	Joint Research Center (JRC) of the EU https://ghsl.jrc.ec.europa.eu/datasets.php

[7] The definition of the theme Land Cover may vary, depending on the point of view from FAO, INSPIRE, OpenStreetMap, Wikipedia and others.
[8] See related: http://www.gofcgold.wur.nl/documents/newsletter/Sustainable_Development_Goals-infobrief.pdf

Product	Spatial resolution	Coverage of years	Contents/ overall reported accuracy	Source
Global Surface Water: Water Occurrence	30 m	1984-2015	0-100% / unknown	https://global-surface-water.appspot.com/
Global Surface Water: Water Occurrence Change Intensity	30 m	1984-2015	High – low / unknown	https://global-surface-water.appspot.com/
Global Surface Water: Water Seasonality	30 m	2014- 2015	1-12 / unknown	https://global-surface-water.appspot.com/
Global Surface Water: Annual Water Recurrence	30 m	1984-2015	0-100% / unknown	https://global-surface-water.appspot.com/
Global Surface Water: Water Transition (First Year to Last Year)	30 m	1984-2015	Permanent, New Permanent, Lost Permanent, Seasonal, New Seasonal, Lost Seasonal, Seasonal to Permanent, Permanent to Seasonal, Ephemeral Permanent, Ephemeral Seasonal / unknown	https://global-surface-water.appspot.com/
Global Surface Water: Maximum Water Extent	30 m	1984-2015	One class / unknown	https://global-surface-water.appspot.com/
Copernicus land service: water bodies	300 m / 1 km	Every 10 days	Sea / water / no water Variable / unknown quality	https://land.copernicus.eu/global/products/wb

Significant progress has been made in the improvement of the spatial and temporal resolutions, as well as the thematic accuracy, of global Land Cover mapping in recent years (see Table 3). For instance, several 30m resolution global Land Cover datasets have been developed and released, such as the GlobeLand30 (Chen et al. 2015), the first wall-to-wall Land Cover data product for the years 2000 and 2010; a decadal-scale forest cover change product (Hansen et al., 2013); and the global human settlement layers (Pesaresi et al. 2013). Furthermore, annual Land Cover change at global scale has been mapped at moderate spatial resolutions (300 m). One such data product is the European Space Agency (ESA) Land Cover CCI, an annual dataset from 1992-2015 at 300 m-1 km resolution.

Moreover, there is a growing shift towards the use of tools such as Google Earth Engine for SDG monitoring. Several dedicated tools have been developed, such as Trends Earth[9] for SDG indicator 15.3.1 ("Proportion of land that is degraded over total land area"). Ultimately, Land cover maps represent spatial information on different types (classes) of physical coverage of the earth. An extension of static Land Cover maps representing surfaces like forests, grasslands, croplands, lakes or wetlands, dynamic Land Cover maps include transitions of Land Cover classes over time and hence capture Land Cover changes. Land use maps contain spatial information on the arrangements, activities and inputs people undertake in a certain Land Cover type to produce, change or maintain. Four Land Cover datasets will now be explored in more detail.

[9] http://trends.earth/docs/en/

2.1.3.1 Copernicus Global Land Service LandCover100 (CGLS-LC100)

The Copernicus Global Land Service LandCover100[10] will produce annual global Land Cover data from 2015 as an operational activity of the European Commission. The map is provided together with vegetation continuous field layers that provide proportional estimates of vegetation cover for several Land Cover types. This complements other global Land Cover maps, such as the CGLS[11] together with the recently released a Dynamic Land Cover 100m resolution product based mainly on the Proba-V satellite data. The first version of this product[12] includes a discrete Land Cover map and cover fractional layers for four different Land Cover types (trees, shrubs, grassland and bare land) for the reference year of 2015 for Africa[13], with this global data planned to be produced annually.

This product was independently validated at Wageningen University. In collaboration with several regional experts around the globe and the International Institute of Applied Systems Analysis (IIASA), an independent validation dataset was developed using the Geo-Wiki[14] web-application for reference data collection. The validation data is based on a global stratified sampling design based on the Köppen climate layer and population density data (Olofsson et al 2012)[15].

Based on the validation consisting of around 3,600 sample points within Africa, the validation results show that the CGLS-LC100 discrete map has an overall accuracy of 74.3 +/- 1.8 %. In terms of Land Cover types, closed forest and bare/sparse vegetation classes were mapped with relatively higher accuracies, while shrubs and wetlands show relatively lower accuracies.

2.1.3.2 Global Urban Footprint (GUF)

The objective of the GUF project is the worldwide mapping of settlements patterns with spatial resolution of 0.4 arcsec (~12 m). The GUF dataset was created by the Earth Observation Center at the German Aerospace Center. It is available for public use at an aggregated spatial resolution of 2.8 arcsec (75-85m) raster cells. A total of 180,000 TerraSAR-X and TanDEM-X RADAR satellite scenes have been processed to create the GUF. The GUF exhibits a high potential to enhance climate modelling, risk analyses in earthquake or tsunami regions and the monitoring of human impact on ecosystems. Moreover, it can also be employed as basis for monitoring both the historical growth of different settlements, as well as their ongoing and future development. This will allow effective comparative analyses of urban dynamics among different regions of the world (German Aerospace Center 2017).

2.1.3.3 Global Human Settlement Layer (GHSL)

The production of the GHSL project was set up to measure and monitor the global built up environment and its changes for the reference years 1975, 1990, 2000 and 2014. It is supported by the European Commission's Joint Research Centre and its Directorate-General for Regional and Urban Policy, together with the GEO Human Planet Initiative. The two main objectives of the GHSL are:

(a) Build a globally-consistent, multi-scale and detailed representation of built-up areas with free public access through standard protocols; and,

(b) Design and maintain a system/platform/infrastructure supporting the GHSL production. It aims at supporting:

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[10] https://land.copernicus.eu/global/products/lc
[11] The CGLS datasets can be visually explored here: http://viewer.globalland.vgt.vito.be/viewer/
[12] by a consortium consisting of VITO, IIASA, and Wageningen University
[13] The release of the first global dataset for 2015 will be in 2019.
[14] https://geo-wiki.org/
[15] https://www.wur.nl/en/project/Validation-of-the-Copernicus-Global-Land-Service-Dynamic-Land-Cover-product-for-Africa-1.htm)

i) Massive image information extraction from VHR/HR image data repositories;

ii) Global validation exercises;

iii) Integration with other relevant sources; and,

iv) Dissemination of free GHSL information in specific use communities. Nominal target information production scales are 1:10K and 1:50K. 1:500K and other more general scales are derived by aggregation. The GHSL targets international scientific and decision-maker communities addressing regional policies, urbanisation and crisis/disaster management.

Since 2016, the GHSL[16] product has been enhanced significantly by analysis of Radar Satellite Data from the Sensor Sentinel-1.

2.1.3.4 GlobeLand30

GlobeLand30 is an open-access 30m resolution global Land Cover data product that was developed by the National Geomatics Center of China (Chen et al. 2014). It comprises ten Land Cover types, including water bodies, wetlands, artificial surfaces, cultivated lands, forests, shrublands, grasslands, and barren lands, for the years 2000 and 2010. They were extracted from more than 20,000 Landsat and Chinese HJ-1 satellite images with a pixel-object-knowledge (POK)-based operational mapping approach and an overall classification accuracy of over 80% was achieved (Chen et al. 2015). The accuracy of GlobeLand30 had been evaluated by third-party researchers from more than ten countries for all classes or one single class via sample-based validation or comparison with existing Land Cover products (Brovelli et al. 2015; Arsanjani 2016b). Since its release for open access in 2014, GlobeLand30 has been downloaded by more than 8,000 users, and has been used to derive useful information about the status and change of Land Cover, to examine their causes and analyse consequences, and to explore future development scenarios, as well as a variety of other earth observations (Chen et al. 2017a).

2.2 Complementary (non-authoritative) data

The second topic tackled in this report is the issue of complementary data, which are not within the responsibility of public authorities, but rather have their source in Volunteered Geographic Information (VGI), citizen science initiatives or other Citizen Derived Data (CSD).

Here we define some terms as they will be used in the rest of this document. Other sources might define specific terms in a different manner and meaning. This report considers that the term “complementary (non-authoritative) data” is not collected by an official authority or a statistical institution and might not be available for the entire requested area or on a regular time basis. Examples for such complementary data are VGI and CSD, cell phone data, data coming from social media, among other sources.

2.2.1 Volunteered Geographic Information (VGI)

VGI is given freely from a user and/or producer to the community by his or her own will. The producer is commonly working as an individual. One can distinguish between active and passive VGI. The active producer is actively collecting spatial data with the purpose to contribute to a public data domain like OpenStreetMap (OSM) or publishing it through their own channels. In doing so, the volunteering producer collects spatial data or geo-referenced information mostly on a mobile or desktop device, using tailored-to-purpose application software. The producer of VGI in a passive or indirect voluntary role contributes to spatial data pools, for example through tracking functions of mobile devices to

[16] The data can be explored visually under https://ghsl.jrc.ec.europa.eu/visualisation.php#

collect spatial data about a user's behaviour and movement. VGI can have direct benefits for the user(s) who integrate it in their analysis and processes. These can include spatial data providers like land surveying authorities who make use of the procedure by collecting VGI to enhance their own public databases or NSOs through the integration of VGI into spatial data products to inform geocoding.

2.2.2 Crowd Sourced Data (CSD)

In general, CSD can be described as data generated from individuals or about individuals. The term is a more general one, compared to VGI, where VGI is as stated in the name a "volunteered" action of data collection. A substantial part of CSD is – however – not actively volunteered, but automatically collected, either by passive awareness of the individual or even without their knowledge. CSD, depending on its character, can have an objective notation, or be very much biased by subjective perception of the individual who creates the data. Tracking of mobile phone movements in space is unmistakable and objective data and is not subject to interpretation. However, CSD like in social media depends on personal opinions and subjectivity.

2.2.3 Citizen Science

Citizen science can be defined as "scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions" (Oxford English Dictionary, 2019). Data coming from Citizen Science activities cover a broad range of thematic topics throughout the field of research. It is a special form of crowd sourced information, which by tendency does not target to cover a huge area, nor a large number of individuals, but rather aims at solving existing questions and problems from a conceptual point of view. Still the community of citizen science must be considered as a valuable collective that could be triggered to help collecting data for SDG Monitoring purposes, at least in regions where no other data of the needed kind is available.

2.2.4 Geographic extent, temporal dimension

When using complementary data sources with the aim to apply it globally, it may be considered as precondition that such information concerning a specific theme is available for every nation and every reporting reference time window. On the other hand, the question to answer is if it still is of benefit and worthy to use such data if it only is available for certain countries/regions or only for certain periods in time.

2.2.5 Examples of the use and acquisition of complementary data sources

Complementary data sources are used globally to make and inform decision making. This section covers a small set of examples, from various locations, approaches and purposes.

2.2.5.1 Crowd sourced and VGI data in Colombia

Colombia uses a variety of crowdsourcing and VGI techniques across their government, these are discussed in Table 4.

Table 4 Examples of Crowdsourcing and VGI in Colombia

Approach	Description
Using web scraping to update business registers	In 2016, Colombia's NSO conducted the project "Big Data as input for updating statistical Business Register, using web scraping techniques". The aim of the project was to update the Business Registers' records in a more effective and timely manner, using options like web scraping techniques. Data obtained with this method, could be useful not only for updating these registers but for economic surveys conducted by the NSO. This Project focused on the hotel sector, due to its dynamism.
Measuring subjective poverty using	The project addresses the topic of poverty as a social problem. This is traditionally measured through surveys or censuses and defined according to the availability of income; but while these indicators are necessary, they currently are not enough to account for the social development of a nation. As such, this proposed exercise aims to strengthen the analysis of subjective poverty, taking advantage of the

Approach	Description
social media sources	widespread use of social networks, which offer the opportunity to analyse user's self-recognition, since networks like twitter are how people freely express their perceptions according to their environment and social context.
Using citizen generated data to improve mobility	In Bogota, Colombia's capital city, an alliance was established between the city's Secretary of Mobility and the mobile application Waze to promote more efficient mobility through exchange data and its analysis. Waze is a mobile application that leverages the citizens as sensors to monitor traffic through providing turn-by-turn navigation directions - monitoring the user's progression through the city. This is strengthening the capacity of Bogotá to monitor traffic. Bogotá has only 300 sensors to monitor the traffic, but through the alliance with Waze, these sensors are multiplied by a factor of hundreds and thousands throughout the city.

2.2.5.2 Geo-Wiki (embedded in Project LandSense)

Geo-Wiki[17] is a platform for crowd sourcing VGI, using Earth Observation and Citizen Science data to conduct research that provides innovative, cost effective, and high-quality data to help society achieve the SDGs, developed by IIASA in Austria. This platform provides several Geo-Wiki tools, which were designed to gather crowd sourced geospatial data. Table 5 below discusses these tools.

Table 5 Geo-Wiki Tools

Tool	Description	Website
FotoQuest	An application for mobile devices to collect sample point-based Land Cover and land use information, combined with the option to collect ground truth pictures. A point grid of the European LC/LU field survey 'LUCAS' is integrated in the application software. The application is designed according to a gaming concept, where the user and data collector can gather points and gain in rank when contributing to the data pool.	http://fotoquest.at and Laso Bayas et al (2016)
Crop land capture game and 'Picture Pile'	Gaming applications to collect verified information on cropland or tree cover loss to check the quality of global data products.	https://geo-wiki.org/games/picturepile/
Biomass	The assessment of different biomass data sets	https://application.geo-wiki.org/branches/biomass/
Livestock	A repository for global maps of livestock	http://livestock.geo-wiki.org
Laco-Wiki	Validation tools for regional-scale Land Cover and Land Cover change	https://laco-wiki.net/en/Welcome
AusCover	The validation of Australian maps of Land Cover and biophysical variables	http://auscover.geo-wiki.org

2.2.5.3 Ushahidi

Ushahidi[18] is a platform that enables the collection of reports from the crowd. Ushahidi was developed to map reports of violence in Kenya after the post-election violence in 2008. Since then, thousands have used these crowdsourcing tools to raise their voice. Headquartered in Nairobi, with a global team, Ushahidi claims to be a technology leader in Africa. Ushahidi is a social enterprise that provides software and services to numerous sectors and civil society to help improve the flow of information, primarily elicited from individual citizens. The philosophy is that if marginalized people can easily communicate to those who aim to serve them, then those organizations and governments can more effectively respond to their communities' immediate needs. Fields of application are for example, monitoring of elections, crisis responding, advocacy and human rights, all with real time information postings.

[17] https://www.geo-wiki.org
[18] https://www.ushahidi.com – Ushahidi means "testimony" in Swahili

2.2.5.4 OpenStreetMap

OSM[19] is global map in vector data format, created by people under public participation and free to use under an open license. No formal quality control is employed, however some automation in quality assurance is applied. Quality control relies more on the frequency of updates by users and contributors themselves. Through experimentation by the authors, OSM was found to be high quality for some countries, such as in Germany, the United Kingdom, France, but of lower quality in other areas. The quality of geospatial information also includes factors such as completeness. Here, OSM data availability is another issue; in China as an example, there is more detailed data for urban areas but much less for rural areas. These two factors, quality and availability, need to be considered carefully when OSM is chosen as a main data source in the context of SDG monitoring.

2.2.5.5 Additional sources of complimentary data

Other crowd sourced geographic data can be used as a complementary data source to global products for SDG monitoring.

Table 6 Additional sources of complimentary data

Tool	Description	Website
The Degree Confluence Project	Contains photographs of the intersections of integer latitude and longitude degree lines.	http://confluence.org
Geograph	A concept and open source codebase for a website that curates a comprehensive collection of photographs capturing every part of given region.	http://www.geograph.org
Flickr	An online platform for sharing photographs and tagging with metadata.	https://www.flickr.com
Wikimapia	An open-content collaborative mapping project aimed at marking and describing all geographical objects in the world.	http://wikimapia.org
Wikiloc	A website that allows the discovery and sharing of the outdoor trails for hiking, cycling and many other activities	http://www.wikiloc.com
iSpot and iNaturalist	Mobile applications that assist with identifying the plants and animals.	http://www.inaturalist.org

3 Role of Global and Complementary Data

In general, national datasets are generated by national experts and can be expected to be more accurate and have a better thematic resolution than global products. For instance, on the one hand, national Land Cover is mapped at 2-5m resolution in China, but this level of accuracy and coverage is not present in many other countries. Such data allows the detection of finer-scale Land Cover and land use change processes, such as urban sprawl and landscape fragmentation. On the other hand, international (global) datasets may have higher consistency across space, thereby allowing a better comparability across countries and easier data handling as a single dataset. However, global data sets, if compared with many national Land Cover datasets, where available, may have some limitations such as lower temporal and/or spatial resolution, fewer thematic classes or less geometric/content accuracy.

Regarding complementary data, data quality and continuity are important issues, especially when such data is to be integrated in official reporting cycles. Sometimes, a data collection initiative is started as a crowd source project due to lack of available official data. When successfully and applicably executed, such self-initiated voluntary data collection initiatives can be adapted by administrative authorities and be implemented as an official data collection method. An asset of complementary data is, for use in data quality control purposes, when for example global datasets are

[19] https://www.openstreetmap.org

supposed to be validated over a certain region in a simplified manner. Further, the accuracy of crowd sources data can be measured by the repetitive capture of information for the same location and weighting of congruent matchings. The following sections discuss three roles for Global and Complementary data.

3.1 Supplementing National Data

Firstly, global datasets can be used as a supplement to national data. Global datasets with a relatively fine spatial resolution can offer a potential complementarity when reliable national datasets are not available (Arsanjani et al., 2016). It is also possible to integrate national and global datasets for more effective SDGs monitoring, especially if the data have similar spatial resolutions, overlapping temporal resolutions, and comparable (or harmonized) definitions / features. For example, a national forest map of Thailand from the year 2000 was combined with the annual global tree cover maps for the years 2000-2012 to obtain multi-temporal information on forest change and to create a baseline and future estimate of forest change from 2000 to 2020 (Johnson, 2015). In this way, additional useful information has been attained by integrating such complementary national and global Land Cover datasets.

3.2 Covering Trans-Boundary or Cross-Border Areas

Secondly, global datasets can be considered as a good option for measuring and monitoring SDGs indicators at trans-boundary or cross-border areas. Natural disasters, displaced populations, environmental change, water shortages, pandemics, and widespread malnutrition do not stop at national borders or the water's edge (Suresh, 2012). Addressing such issues therefore requires the geospatial datasets covering the trans-boundary or cross-border areas. This can, of course, be realized by collating datasets from different countries, but their integration and harmonization might be extremely difficult due to differences of reference frames, spatial resolution, thematic types as well as periodicity. High quality global datasets will therefore facilitate operations that cover the trans-boundary or cross-border area.

3.3 Supporting global reporting

Thirdly, global datasets can serve as a sound basis for supporting the preparation of global reporting. International agencies may use high quality global datasets to calculate some SDG indicators and send disaggregates at national level to national authorities for review and agreement. Moreover, effective presentation and visualization of the status and trends in SDG indicators is very important for communication with policy makers and end users. This necessitates not only dynamic and multi-dimensional visualization approaches, but also reliable multi-scale (global, continental, national and sub-national) geospatial datasets.

4 Utilisation of global and complementary data

4.1 Use of Global Data

There are several criteria to be considered when selecting suitable global data sources for use in the computation of SDG indicators and national reporting.

4.1.1 Data Quality

The assessment of the quality of data from VGI, Citizen Science and crowd sourcing is an important issue to be considered when it comes to the integration of such data in official statistics. Good quality geospatial data underpins the notions of credibility and authority. ISO defines the quality of geospatial information as the "totality of characteristics of a product that bear on its ability to satisfy stated and implied needs". With respect to complementary data sources, further detail can be found within IIASA assessment of methodologies to assess the quality of VGI by analysing just the manner and content of data contribution itself, without having the possibility to use reference data to check the contributor's data quality (Foody et al. 2016). Other mechanisms to assess the quality of VGI also exist, these are discussed in Senaratne et al. 2017 and others.

This is of an increased relevance when considering the reliability of the SDG indicators. Since many global datasets have been validated by the producers and/or users, it is important to consider relevant accuracy reports and related publications. This will enable a better understanding of their strengths and weaknesses and help the selection of the most appropriate datasets (Arsanjani, et al., 2016a; 2016b). It is possible that some datasets may have accuracy variations across the world and have some classes with higher accuracy than others. It is therefore necessary to conduct a thorough evaluation of the uncertainty of the data (of the classes of interest) before utilisation. It should be noted that here the data quality refers not only to its geometric and thematic accuracy, but also to the temporal aspects. Data sources with reasonably long time series should be selected to ensure consistent analysis of changes to identify trends and progress.

4.1.2 Data Continuity

Data continuity is a fundamental requirement for supporting SDGs. Data providers need to ensure that global data will be available at least until 2030 to establish the baseline data and to keep track of changes from the baseline in the SDG monitoring process. Investment in national systems and processes to integrate new sources of data such as satellite Earth observation data requires a recognised degree of confidence in the continued data availability of supply of data to enable consistent decision making. This is exemplified by Landsat satellite data being available since early 1970 to the present day with the Sentinel satellite series are being planned so that data are available up to 2030 and more.

4.1.3 Data Conversion and Augmentation

Global datasets and national datasets may have different geo-referencing systems. Most international data are geo-referencing to WGS84 ellipsoid with a global map projection. For example, ESA's Land Cover Climate Change Initiative[20] employs a Plate Carree with a geographic Latitude and Longitude representation based on the WGS84 ellipsoid. In contrast, most national data are geo-referenced to a UTM-based coordinate system but possibly with different reference ellipsoids. Therefore, conversion between different geo-referencing systems must be facilitated. Another issue is the data format. For example, most topographic maps are in vector format while most image data are in raster format. Therefore, conversion between raster and vector format must also be facilitated.

4.1.4 Scale and Integration

The available global datasets may vary widely in terms of scale and resolution, thematic details and periodicity. It is likely that some of them might not be in the appropriate scale for a specific SDG indicator. Therefore, aggregation and disaggregation processes are required to translate existing data into multi-scale datasets. Disaggregation is necessary to generate a dataset at a desirable scale, with a more refined thematic content by combining global data and ancillary data sources. For examples, the crowd sourcing data (e.g. OSM and Geo-Wiki) and navigation data (e.g. TeleAtlas and Waze) can provide additional sources of information to distinguish different Land Cover within artificial surface areas. Aggregation is required to downscale high-resolution national and global datasets into desirable scales. This process is also called generalization in cartographic community.

Depending on the SDG indicator being measured, a mix of statistical and geospatial techniques can be adopted to attain the required scale and resolution. For example, for indicators which require data collection at the local level (such as, defining urban and rural areas) and reporting at the national level

[20] https://www.esa-landcover-cci.org/

(such as through the aggregation of locally collected values), representative spatial sampling using statistically sound techniques can be adopted, and continuous monitoring recorded based on the sample. This is specifically applicable for some indicators for SDG 11, where collection of data in all cities in a nation can prove very difficult and expensive, often requiring a method to select a set of representative cities upon which data can continuously be collected and aggregated to achieve national values.

4.1.5 National ownership

To secure progress towards the goals of the SDG's, it is essential that national governments are also involved in the processes surrounding the implementation and use of global data sources. The custodians will have an important role to play, and in cases of unavailability of national data sources, they will most likely look at securing information from global data sources. Pursuing this path, processes will have to be set up so that the information flow secures national involvement. Some of these processes could be set up as internet-based services, where custodians and the national authorities share the data related to the monitoring process, and interactively agree to the results and finding in relation to the indicators.

4.2 Data management and organization of complementary data

Other than authoritative data, complementary data sources in most cases are generated outside the control of official authoritative data production processes. Some issues that are normally expected from authoritative data, are not necessarily inherent in complementary data production processes.

4.2.1 Synchronization, Steering, Coordination

VGI and CSD both have no centralized point of contact or responsible entity to synchronize, steer and tie together such initiatives on a higher (international) level, in contrast to authoritative data providers. However, within the growing community of CSD, some initiatives have organized themselves and coordinated their actions among each other[21].

4.2.2 Standardization and Interoperability

The interoperability[22] and comparability of CSD is a crucial issue, that either enables users world-wide to make use of such data, or – in its absence – hampers the usage of the data, like-wise with non-interoperable authoritative data. VGI, Citizen Science, and similar forms of CSD are created outside the constraints and restrictions of standards, and the data producers can act freely according to their own priorities and individual data specifications, if there are any. Still, some initiatives exist to bring some sort of steering into the community of crowd sourced data producers.

Within the Open Geospatial Consortium (OGC)[23], a Domain Working Group on Citizen Science has been established. There are a large and increasing number of active citizen science projects around the world involving the public in environmental monitoring and other scientific research activities. According to this working groups purpose, *"the OGC Citizen Science DWG is motivated to support*

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[21] Examples of these associations include the Citizen Science Association (CSA, routed in the USA), the Australian Citizen Science Association (ACSA), the European Citizen Science Association (ECSA), and possibly similar initiatives in other regions of the globe.

[22] For more information on interoperability see Data Interoperability: A Practitioner's Guide to Joining Up Data in the Development Sector https://unstats.un.org/wiki/display/InteropGuide/Home

[23] OGC is an international not for profit organization committed to making quality open standards for the global geospatial community. These standards are made through a consensus process and are freely available for anyone to use to improve sharing of the world's geospatial data.

citizen science by providing a forum for increasing understanding and demonstration of the benefits brought by using open standards and best practices. As such, the OGC Citizen Science DWG will support the development of improved interoperability arrangements for the citizen science community".

A connection point like a standard institution, where information about many different initiatives comes together, can be of great help to identify existing and even trigger new data production initiatives that might help to provide SDG-relevant spatial data[24]".

VGI is not necessarily standardized in the capture of data, but when provided publicly, a limited list of standards should be fulfilled to provide a minimum of interoperability. Harmonization and standardization of spatial data capture is not only an issue of complementary data, but also for any kind of authoritative data producers. Also, in authoritative processes, human individuals are at work and have their own subjective interpretation of data capture rules.

An important aspect of integrating information from multiple data sources and connected nomenclatures is the need for a paradigm shift from classification towards characterization of landscape. This is further complicated by existing nomenclatures mostly containing a mixture of Land Cover and land use classes, where neither nomenclature addressed in comprehensive and unambiguously separated manner, reinforcing the need for clear definitions for each of these concepts. In response to the ambiguity, the EIONET Action Group on Land Monitoring in Europe (EAGLE) concept[25] (Arnold et al. 2013) describes land units under a more object-based perspective and characterizes them with properties. The step of classification is supposed to be the latter follow-up step, which can be flexibly applied based on the Land Cover components, land use attributes and further characteristics which are to be stored on an intermediate metadata level[26].

5 Summary

As the topics of global data and especially complementary data are expansive fields, this report has addressed the background and current issues from a generic perspective. However, it must be stressed that the exemplars and cases discussed are by no means exhaustive. In summary, it can be stated that both global and complementary data (and their integration) can be a crucial input for the calculation of SDG indicators where fit-for-purpose authoritative data are not available, regardless of the circumstance. However, it is urged that a case-by-case approach be adopted to decide where global and complementary data are to be integrated or not. Decision makers are also counselled to consider whether it is better to have some data or no data for an indicator. The phenomenon of Crowd Sourced Data and Volunteered Geographic Information has many potential uses but ultimately has a large potential to inform and augment current SDG indicator production and analysis. As the SDGs are a politically highly recognized issue, now is the time of opportunity to try to involve the CSD and VGI communities in the collection and provision of data for SDG indicator calculation and ultimately support the mission of leaving no-one behind.

[24] See also for example "A Guide to the Role of Standards in Geospatial Information Management http://ggim.un.org/documents/Standards%20Guide%20for%20UNGGIM%20-%20Final.pdf, prepared cooperatively by representatives of OGC, ISO/TC 211, and IHO. Partly discussed in this document are emerging needs to address new technologies and opportunities to be leveraged such as crowd-sourcing of geospatial information and big data analytics and how standardization could be achieved by a community who would focus on delivering geospatial information from SDI environments into the Web of data.

[25] See also http://ggim.un.org/meetings/2016-1st_Mtg_IAEG-SDG-Mexico/documents/2-1 Stephan Arnold.pdf

[26] See also https://land.copernicus.eu/eagle/

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