Global Partnership for Sustainable Development Data

TReNDS
Thematic Research Network on Data and Statistics

Landsat's Earth Observation Data Support Disease Prediction, Solutions to Pollution, and More

A Case Study of Landsat
Prepared by SDSN TReNDS

How can open access to Earth imagery help predict disease spread or identify solutions to toxic waterways? The Landsat program—the longest-standing continuous global record of the Earth's surface through satellite imagery—has enabled these and other solutions in support of people, planet, and prosperity since its launch in the 1970s. Beyond its social and environmental impacts, Landsat is also an economic boon; it has produced annual cost savings in the United States ranging from US$350 million to $436 million for federal and state governments, nongovernmental organizations, and the private sector, as well as an estimated worldwide economic benefit as high as $2.19 billion as of 2011. Landsat is a powerful example of the benefits of long-term investing to build robust data systems for sustained, longitudinal monitoring of environmental, social, and economic conditions.

Context

There are approximately 150 million square kilometers of land worldwide, of which humans occupy or use roughly 80 percent. 40 percent of that is used for the purposes of agriculture, feeding our rapidly growing population; in 2011, the global population reached 7 billion, and it is projected to increase to more than 9 billion by 2050 (United Nations Population Division 2017). As demand grows, our planet's capacity to sustain needed food and fiber production and fresh water supply diminishes (NASA, n.d.). Close monitoring of environmental change is therefore required.

Images of the Earth taken at moderate resolution (each pixel representing an area of about 30 meters by 30 meters) by Earth-orbiting satellites such as Landsat offer the critical capability to observe land use and land use change over time and to compare changes in different parts of the world. Furthermore, this Earth observation data can inform a wide variety of applications "including tracking biodiversity and wildlife trends; measuring land use change such as deforestation; mitigating, and managing the impact of natural disasters, including fires, floods earthquakes, and tsunamis; sustainably managing natural resources, such as energy, freshwater, and agriculture, address emerging diseases and other health risks; and predicting, adapting to, and mitigating climate change" (Anderson et al. 2017).

For policymakers, satellite data better equip them to make policy decisions across geographic scales and to consider the environmental impacts of seemingly local decisions. Keeratikasikorn and Bonafoni describe an example from Bangkok, Thailand in the anthropogenic phenomenon of increasing temperatures in urban areas. Maps of this phenomenon were developed using data from Landsat 8 and then "[supplied] a scientific support for the urban planning policy aimed to integrate urban development and landscape ecosystems"(Keeratikasikorn and Bonafoni 2018).

In 2015, 193 countries committed to an ambitious global agenda to eradicate poverty and achieve sustainable development. The 2030 Agenda for Sustainable Development and its 17 accompanying Sustainable Development Goals (SDGs) acknowledge the importance of considering the local, regional, and global impacts of our land use decisions, if we are to chart a more sustainable development path. For example, five targets (under Goals 2,6,11, 13, 14, and 15) specifically relate to ecosystem management, and tracking their progress will rely heavily on access to time-series Earth observation and land imaging data (Anderson et al., 2017).

Table 1. Earth observation and geospatial information linkages to SDG goals, targets, and indicators

Target Contribute to progress on the Target, not necessarily the Indicator									Goal	Indicator Direct measure or indirect support to the Indicator					
							1.4	1.5	1 No poverty	1.4.2					
						2.3	2.4	2.c	2 Zero hunger	2.4.1					
					3.3	3.4	3.9	3.d	3 Good health and well-being	3.9.1					
									4 Quality education						
								5.a	5 Gender equality	5.a.1					
		6.1	6.3	6.4	6.5	6.6	6.a	6.b	6 Clean water and sanitation	6.3.1	6.3.2	6.4.2	6.5.1	6.6.1	
					7.2	7.3	7.a	7.b	7 Affordable and clean energy	7.1.1					
								8.4	8 Decent work and economic growth						
					9.1	9.4	9.5	9.a	9 Industry, innovation and infrastructure	9.1.1	9.4.1				
						10.6	10.7	10.a	10 Reduced inequalities						
	11.1	11.3	11.4	11.5	11.6	11.7	11.b	11.c	11 Sustainable cities and communities	11.1.1	11.2.1	11.3.1	11.6.2	11.7.1	
				12.2	12.4	12.8	12.a	12.b	12 Responsible consumption and production	12.a.1					
					13.1	13.2	13.3	13.b	13 Climate action	13.1.1					
		14.1	14.2	14.3	14.4	14.6	14.7	14.a	14 Life below water	14.3.1	14.4.1	14.5.1			
	15.1	15.2	15.3	15.4	15.5	15.7	15.8	15.9	15 Life on land	15.1.1	15.2.1	15.3.1	15.4.1	15.4.2	
								16.8	16 Peace, justice and strong institutions						
17.2	17.3	17.6	17.7	17.8	17.9	17.16	17.17	17.18	17 Partnerships for the goals	17.6.1	17.18.1				

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Description of the Data Solution

The Landsat program consists of a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey. To date there have been eight Landsat satellite missions, and a ninth launch is planned for 2020 (U.S. Geological Survey, n.d.).

The sensors on the Landsat satellites generate images with individual pixels that each represent an area of 30 meters by 30 meters. You cannot see individual houses in a Landsat image, but you can detect large, built infrastructure like highways, dams, and office buildings. From a scientific perspective, the 30-meter spatial resolution and 185-kilometer breadth of Landsat imagery fills an important scientific niche because the resulting data provide global coverage every season of the year, yet are detailed enough to characterize human-scale processes such as urban growth, agricultural irrigation, and deforestation. By establishing baseline knowledge of Earth's land areas throughout the last half-century, Landsat allows scientists to evaluate environmental change over time, to better understand the drivers and impacts of change, to model and predict future changes, and to chart these changes in the form of maps.

> **"The foresighted acquisition and maintenance of a global image archive has proven to be of unmatched value, providing a window into the past and fueling the monitoring and modeling of global land cover and ecological change" (Wulder et al. 2012).**

The two most recent Landsat satellites—Landsat 7 and Landsat 8—orbit the Earth at an altitude of 705 kilometers (438 miles), collecting data for a 185-kilometer (115-mile) swath that moves from north to south over the sunlit side of the Earth in a sun-synchronous orbit. Each satellite makes a complete orbit every 99 minutes, completes about 14 full orbits each day, and crosses every point on Earth once every 16 days. The satellites' orbits are offset to allow eight-day repeat coverage of any Landsat scene area on the globe. Between the two satellites, more than 1,000 scenes are added to the USGS archive each day (U.S. Geological Survey, n.d.).

Landsat data are received and downlinked to ground stations worldwide, and are archived at the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, South Dakota. Landsat data products are processed and made available for download to all users at no cost via EarthExplorer, GloVis, and the LandsatLook Viewer.

Implementation

In a 1966 press release, U.S. Secretary of the Interior Stewart L. Udall announced the start of "Project EROS," a program "aimed at gathering facts about the natural resources of the Earth from Earth-observing satellites carrying sophisticated remote sensing observation instruments" (United States Department of the Interior 1966). Secretary Udall named Dr. Pecora to lead the EROS program. USGS's Dr. Pecora stated that the program was "conceived in 1966 largely as a direct result of the demonstrated utility of the Mercury and Gemini orbital photography to Earth resource studies." Although weather satellites had monitored Earth's atmosphere since 1960, prior to the Mercury and Gemini missions there was no appreciation of land imagery taken from space (Baumann 2010).

> **"It was the granddaddy of them all, as far as starting the trend of repetitive, calibrated observations of the Earth at a spatial resolution where one can detect man's interaction with the environment" (NASA, n.d.).**

In cooperation with NASA, the Earth Resources Technology Satellite (later renamed Landsat 1) was launched on July 23, 1972. Additional Landsat satellites were launched in the following decades. Launched in 1984, Landsat 5 collected data for more than 28 years, more than 23 years beyond its original design lifetime. Landsat 7 was launched in 1999 and also continues to operate well past its design lifetime, though in 2003 it experienced an instrument failure that leads to gaps in about 22 percent of its imagery. The most recent satellite – then Landsat Data Continuity Mission, now Landsat 8 – launched on February 11, 2013. Landsat 9 is in development, with launch scheduled for late 2020 (U.S. Geological Survey, n.d.).

Today, Landsat continues to be administered by the USGS in partnership with NASA.

Funding

The United States Government has funded Landsat since its inception. But the relationship between NASA and the institution that legislates that funding (the U.S. Congress) has been turbulent, with ongoing disagreement over the amount of resources required for the Landsat program and available through the U.S. federal budget. The¬Landsat 9 mission is no exception.

"Appropriators [for the Federal Government's FY2014 budget] chided NASA for unrealistic expectations that a Landsat 9 would cost $1 billion, and capped spending at $650 million," according to a report by the Congressional Research Service (Folger 2014). By contrast, $850 million was the approximate cost of building and launching Landsat 8, its predecessor.

Even with funding constraints, NASA and the USGS announced in April 2015 that work on Landsat 9 had commenced, with funding allocated for the satellite in the president's FY2016 budget. At the time of this announcement, they stated that launch was planned for 2023, but was subsequently expedited to December 2020 (Singh 2016). As of April 2018, the launch plan appears on track and a Mission Critical Design Review characterized a 2020 launch as "an aggressive but achievable launch date" (NASA 2018).

Return on Investment

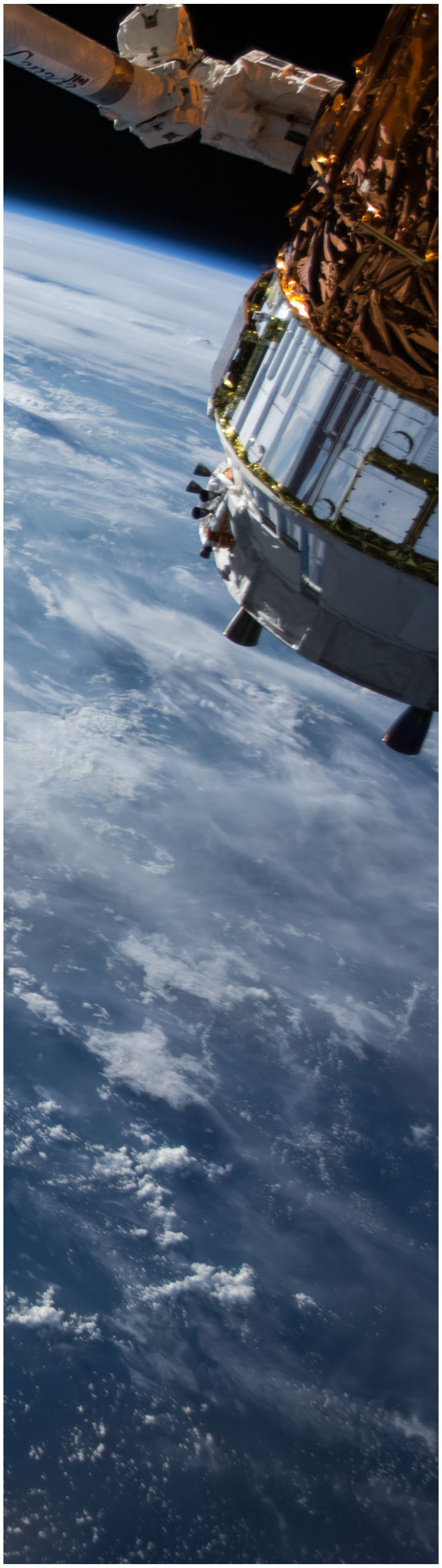
Since 2007, multiple analyses have quantified the economic value of the Landsat program, including studies by the American Society of Photogrammetry and Remote Sensing (National Science and Technology Council 2007) and by Booz Allen Hamilton, which was commissioned to undertake an economic returns study for the USGS

(Adams and Pindilli 2012). In 2013, another analysis by the National Research Council concluded "the economic and scientific benefits to the United States of Landsat imagery far exceed the investment in the system" (National Research Council 2013).

The USGS also published its own analysis in 2013. It included a survey of 11,275 Landsat users on the uses and value of Landsat satellite imagery, 77 percent of whom stated they were dependent on Landsat imagery to do their job. The study also estimated the economic benefit of Landsat data for the year 2011 was an estimated $1.70 billion for U.S. users and $400 million for international users, resulting in a total annual value of $2.19 billion (Miller et al. 2013).

> **"Satellite imagery has significant potential to provide more timely statistical outputs, to reduce the frequency of surveys, to reduce respondent burden and other costs and to provide data at a more disaggregated level for informed decision making" (Global Working Group on Big Data for Official Statistics, n.d.).**

In 2015, the Landsat Advisory Group of the National Geospatial Advisory Committee undertook a critical review of the value of the Landsat information. The committee consisted of commercial entities such as Google and Esri; federal, state and local government entities; and NGO geospatial information experts. The review considered both past studies and broader applications of Landsat data, such as government mapping, monitoring consumptive agricultural water use, forest change detection, flood mitigation, coastal change, and wildfire risk assessment. The analysis examined 16 decision processes and attempted to quantify the cost of using Landsat to inform these processes versus other methods (National Geospatial Advisory Committee – Landsat Advisory Group 2014; Mitchell 2012). The study found that 16 Landsat applications alone produced savings of $350 million to over $436 million per year for federal and state governments, NGOs, and the private sector (National Geospatial



Advisory Committee – Landsat Advisory Group 2014). The study notes that these savings and others not addressed by the paper will continue to accelerate. The Advisory Committee found that "the economic value of just one year of Landsat data far exceeds the multi-year total cost of building, launching and managing Landsat satellites and sensors" (National Geospatial Advisory Committee – Landsat Advisory Group 2014).

Other assessments estimate the value of Landsat to be far higher. A 2015 report by economists from Colorado State University and the USGS Fort Collins Science Center estimated that the 2.38 million Landsat images freely downloaded in 2011 benefited the U.S. economy by $1.8 billion in that year—almost double the cost of building and launching Landsat 8, as noted by the study authors (Loomis et al. 2015). Their study was based on a Contingent Valuation Method, which estimates users' willingness to pay for non-market goods. For this study, the economists analyzed a 2012 survey with a sample of 13,473 data users. Users were asked if they would purchase Landsat data at a given price. This price was then incrementally revised upwards or downwards depending on if the user said "yes" or "no" to the initial amount. The prices ranged from $10 to $20,000 per Landsat scene. The study found a mean value for established Landsat users of $912 per scene and $367 per scene for new users, whom—one would assume—gave a lower value as they had yet to understand its potential application. Based on these prices, the annual economic benefit for the Landsat scenes obtained in 2011 was calculated at $2.19 billion worldwide (for both U.S. and international data users). This estimate was considered conservative because it did not include downstream users of Landsat data, i.e. data users who did not directly download Landsat data from the USGS but used data or derived products obtained from others.

There have also been attempts to quantify the value of Landsat data for specific industrial sectors; for example, Abhishek Nagaraj at the Massachusetts Institute of Technology looked at how Landsat imagery has contributed to the discovery of new deposits in the gold exploration industry (Nagaraj 2015). Nagaraj finds that between the 1950s and 1990 information from Landsat nearly doubled the rate of significant gold discoveries from the industry. Furthermore, affordable access to the imagery encouraged entrepreneurship as junior firms had lower costs for early-stage experimentation.

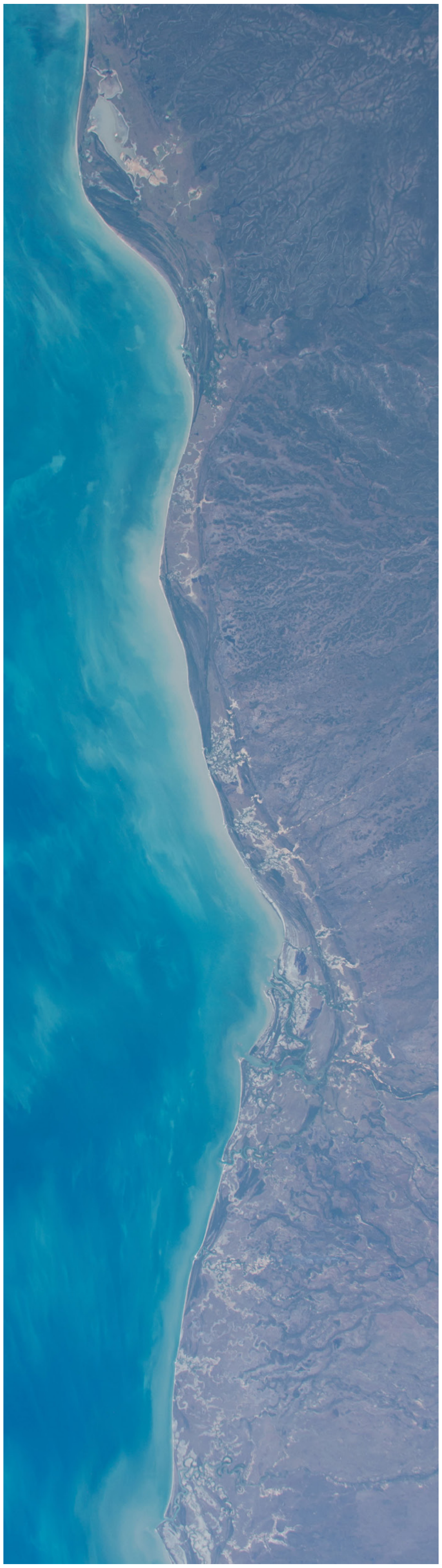
Social and Environmental Impacts

Since Landsat's inception in 1970, data from its missions have had considerable impact on research and science and on resultant policy. The same 2012 survey analyzed by Loomis et al. asked about perceived environmental and societal benefits and impacts from projects that used Landsat. It found that "[…] more than 80 percent of users saw environmental benefits, including improving or enabling long-term planning or monitoring, protecting or improving environmental conditions, and maintaining or improving ecosystem services. Almost 90 percent saw improvements in decision-making through better communication of concepts using Landsat imagery. More than three-quarters cited supporting enforcement of regulations or policies and reducing human risk or increasing human safety as benefits. Close to 70 percent of users also saw some resolution of disputes or reduction in conflicts as a result of projects using Landsat" (Miller et al. 2013). The following section considers just three applications of Landsat and the associated benefits.

1. Implications for human health

Landsat measurements can help decision-makers pinpoint and minimize environmental health risk. For example, they can highlight agriculture or urbanization trends that might pollute waterways or show changes in vegetation growth that might affect habitats for disease-carrying animals and insects.

By way of example in September 2000, the Yemen Ministries of Agriculture and Irrigation and of Health reported an outbreak of Rift Valley fever (RVF) disease in humans and livestock in the El Zuhra district, located on the western coastal plain of Yemen. Experts from across Yemen, the WHO, and the U.S. Naval Medical Research Unit 3 (based in Cairo) subsequently confirmed this (Balkhy and Memish 2003). Large-scale flooding in semi-arid areas and the pooling of water in shallow depressions on the Earth's surface (and resultant



changes in vegetation) can illustrate areas at high risk for the spread of RVF; the disease spreads through bites from infected mosquitos, and these areas are appropriate habitats in which mosquitos can thrive (Centers for Disease Control and Prevention, n.d.). Other spatial monitoring and reporting tools—such as ground-based sensors and radiometers—can capture these kinds of depressions, but the terrain in Yemen was too complex for these tools. Landsat 7 data was therefore used to compare changes in vegetation between May and September 2000. As reported by NASA, "Landsat data in combination with aerial surveys revealed numerous areas along the coastal plain and neighboring areas that were conducive to the transmission of the RVF virus. This enabled the surveillance teams to much better target disease control operations to areas at highest risk of disease than would have been possible using ground surveillance methods in this region of complex topography" (NASA, n.d.).

2. Enabling environmental management

In the United States, scientists from the Carnegie Institute for Science used Landsat 5 imagery to better understand the causes of toxic freshwater algal blooms in Lake Erie—which borders the U.S. states of Ohio, Pennsylvania, and New York—and the Canadian province of Ontario. According to lead researcher Jeff Ho, Lake Erie provides drinking water for 11 million people, and yet the quality of the water supply has been steadily declining (Carnegie Institution for Science 2017). This is generally attributed to phosphorus run-off from fertilizers and as such in 2016 the bi-national International Joint Commission set new phosphorus targets, but as Ho and Michalak's 2017 study (Ho and Michalak 2017) set out to demonstrate, that is only part of the problem. Ho and Michalak's study used historical Landsat imagery to trace changes in algal blooms since 1984, more than doubling the historical record and dramatically boosting their ability to understand trends and causes. These new data have strong policy implications as they clearly highlight the extent to which phosphorus run-off needs to be curtailed and the length of time it will take for the lake to recover. According to Michalak, "The path ahead for Lake Erie is clear—we have to reduce the amount of phosphorus flowing into the lake. And we will need to be patient to give the lake time to recover."

(Ho and Michalak 2017) The Landsat data have enabled scientists, conservationists, and policymakers to see the extent of the problem and the scale of the solution required.

3. Creating a culture of open access to data

Another important impact of the Landsat program is its contribution to open data and open science. In 2008, the U.S. Government made all Landsat data openly available for purchase. After this decision, an average of 53 Landsat scenes per day were being downloaded, with users charged approximately $500 per scene (Anderson et al. 2017). In 2012, the government agreed to make all of the data openly available and free of charge. Since this revised data policy, an average of 5,700 scenes per day are downloaded and, as of 2016, more than 40 million Landsat scenes had been downloaded in total (Anderson et al. 2017). As a direct result of the policy shift, one study estimates that the use of Landsat data within academic and scientific articles has increased by 69 percent (Mishra 2015).

> **Landsat imagery is an essential "national asset" which has made and continues to make critical "contributions to U.S. economic, environmental, and national security interests" (Marburger 2005).**

According to Miller et al.'s 2013 survey of Landsat users, the average number of scenes obtained from all sources annually per user more than doubled after the policy change, whereas the average amount spent annually on Landsat imagery per user decreased by 78 percent (Miller et al. 2013). Although the policy did render Landsat imagery free through the USGS, some users continued to purchase imagery from other providers, "possibly to obtain imagery which has been processed beyond what is provided by the USGS" (Miller et al. 2013).

Like Landsat, other geospatial data providers around the world are sharing data free of charge, including the European Commission's

Copernicus program (FDC, n.d.) and Geoscience Australia (Foong 2012). The Landsat example has also helped drive efforts to promote more open and free data access under the auspices of the Group on Earth Observations (GEO), a voluntary intergovernmental network of Earth observation data providers and other participating organizations established in 2005 (Group on Earth Observations, n.d.).

Ongoing Challenges

Operating costs and political support

In spite of its immense value to research, science, and policy, Landsat faces a number of challenges to its ongoing operation and replication. As satellites are highly specialized technology, the Landsat satellite missions are costly. Although the satellite design and engineering is constantly improving, the lifespan of a satellite is limited by fuel capacity and maintenance issues (NASA, n.d.). (This issue has decreased in significance over time; since the 1970s, the average operational lifetime of an Earth observation mission has tripled to today's average mission length of 8.6 years, which enables more stable and continuous observations from the same sensor over many years (Belward and Skøien 2015).) Several of the Landsat missions have operated well past their baseline design lifetimes. Nevertheless, securing budget for Landsat 9 has been a tense political battle, with the return on investment for this program and its further iterations perhaps viewed less favorably by some politicians in comparison to other proposed programs for the U.S. federal budget. This hurdle has jeopardized the current Landsat open data policy. U.S. Government officials are reportedly considering whether to reverse the policy to allow recovery of Landsat's operational costs from users (Popkin 2018).

Access to and interpretation of the imagery

Although Landsat has seen a surge in use since 2008, especially the open data policy was fully implemented, there are still considerable barriers to the use of the imagery, including the lack of availability of technical expertise to understand and interpret the results. According to Miller et al.'s 2013 survey, many users still purchase the data in

a more interpretable format than the USGS provides, in part due to the lack of technical expertise to process the data. These technical issues may also hinder the use of Landsat for a range of simple SDG-relevant measurements; for example. For example, only in 2018 has the Government of Colombia (which has high statistical capacity) started to use Landsat imagery to monitor urban sprawl and urban land use, even though the imagery has been publicly available for more than a decade.

To help countries access and interpret Earth observation and related geospatial data for SDG monitoring, the United Nations Committee of Experts on Global Geospatial Information Management (UNGGIM) is leading the Working Group on Geospatial Information, under the Inter-Agency and Expert Group on SDG Indicators. The Working Group has agreed to provide in-depth analysis, recommendations, and advice on the development of methodologies for a subset of indicators. It will also undertake methodological work in a variety of cross-cutting themes including data disaggregation, national and sub-national reporting, and other data issues (e.g. citizen science, crowdsourcing data, and volunteered geographic data) to facilitate countries' better use and interpretation of Earth observation data (Anderson et al. 2017). To ensure more widespread uptake and use of these data, particularly in countries with limited resources, additional international investments are needed in statistical capacity with a specific focus on geospatial monitoring and Earth observation.

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