CITIZEN SCIENCE:
THEORY AND PRACTICE

Volunteered Geographic Information, Citizen Science and Machine Learning in the Service of Sustainable Development Goals and the Sendai Framework

COLLECTION: CONTRIBUTIONS OF CITIZEN SCIENCE TO THE UN SDGS

REVIEW AND SYNTHESIS PAPER

VYRON ANTONIOU

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ABSTRACT

This paper focuses on two prominent efforts tackling global problems, namely the UN Sustainable Development Goals (SDGs) and the Sendai Framework (SF). To achieve the aims sought by these initiatives or to observe and measure their effectiveness and progress, accurate and up-to-date information is needed. An important part of this information refers to geographic information (GI). GI is the fundamental underpinning element that spans the globe, captures time, and functions as the common denominator of many variables and data from other domains. Herein, several enabling factors related to GI are highlighted, and their intertwining impact is examined relative to the aims of SDGs and SF. These factors are Earth observation (EO) imagery enhanced with the advances in machine learning (ML), citizen science (CS), and volunteered geographic information (VGI). The synergy of these factors can be used to bring, on the one hand, the high-level policies and discourse from a theoretical level down to more practical implementations, and on the other hand, enable individual and localized efforts to scale up easily in both developed and developing countries and produce the desired results.

CORRESPONDING AUTHOR:

Vyron Antoniou

Hellenic Army Academy, GR

v.antoniou@sse.gr

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INTRODUCTION

The natural environment of our planet, our civilization, and our societies need to coexist in harmony both now and in the future. The United Nations (UN) can provide ample evidence and statistics for this observation (UN 2022), which paints a not-so-flattering picture of the current state of our planet and of humankind. There is an urgent need for coordinated action against global problems. Indeed, with the UN in a leading position, countries around the world are trying to coordinate efforts to tackle global problems. However, while theoretical and high-level roadmaps exist, what is largely missing is practical implementation mechanisms to achieve the set goals. This is not to say that there are no stakeholders that take their role seriously and try to honor their international agreements, but rather that the overall outcome falls short of the initial target.

A realistic obstacle is the cost involved to replace long-standing processes and mechanisms with more efficient, sustainable, and safer ones. Moreover, the financial status and capacity of each country positions each of them at a different starting point regarding the investments needed to achieve the desired outcome (Vorisek and Yu 2020). Another set of problems is the competing interests and priorities of countries (Moallemi et al. 2020). For example, while some countries are willing to cut back on energy consumption from fossil fuel and invest more in renewable energy, without harming the pace of their development, others opt to use cheap (and polluting) energy to achieve economic growth. Such factors have created gaps between the aims and goals of high-level policies and what happens on the ground. The gaps might vary from country to country or from goal to goal but what remains common is the lack of practical solutions with straightforward implementation that are easy scaleable at national or global levels.

Despite these issues, several factors that can facilitate the implementation of SDGs are not fully leveraged; GI is one of them (Scott and Rajabifardb 2017). A generic framework based on EO and ML, VGI, and CS will enable stakeholders/countries, despite their different needs and means, to work more efficiently towards the achievement of SDGs and SF aims. Through several examples, this paper shows that the above factors can act as key enablers for the necessary land information and land management capabilities to support sustainability and disaster risk reduction. First, a brief overview of SDGs and SF is given, and their close connection is highlighted. Then, the spatial dimension of the selected factors is described, and several are presented. The examples presented and the role of GI as a common denominator are used to discuss how SDGs and SF can be spatially enabled. The paper concludes with the overall role of GI when supported by individual and intertwined advances of the selected factors.

GLOBAL INITIATIVES

UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS (UN SDGS)

Economic development has been a steady goal for centuries. Only recently has sustainable development been realized as a necessity. In the literature, the concept of sustainable growth and development appeared in the 1960s (Rostow and Rostow 1990) along with the realization that sustainability plays a key role in any kind of true development that interconnects different aspects of a society such as environment, well-being, and economy. Globally, the importance of sustainable development is such that the UN General Assembly adopted and issued in 2015 the Resolution 70/1: Transforming our world: the 2030 agenda for sustainable development (UN 2015a). The UN 2030 Agenda (as it is more commonly known) aims to function as a blueprint for all countries. Since global sustainability cannot be met individually, all countries need to adjust their actions to meet the aims and goals the UN Agenda has set, by the year 2030. The aims of the UN 2030 Agenda are eloquently summarized in 17 individual SDGs (UN 2015a). These goals are further detailed in targets and indicators that further explain the tangible goals that need to be achieved. Following the publication the Agenda, nations started to work towards Goal achievement. It is up to each country to translate the SDGs into national initiatives, plans, and actions as well as to bear the cost associated with their achievement. It is worth noting, though, that the cost for accomplishing the SDGs is estimated to trillions per year, for a 15-year period (UNTT 2015).

THE SENDAI FRAMEWORK (SF) AND DISASTER RISK REDUCTION

The Sendai Framework for Disaster Risk Reduction 2015–2030 (or simply, Sendai Framework [SF]; UN 2015b) is a voluntary, non-binding agreement that recognizes individual countries as the prime player for reducing disaster risk, and in parallel, shares this burden with other stakeholders such as local government, private sector, citizens, local communities, and volunteers. Its main aim is the reduction of disaster risk and losses in lives, livelihoods and health and to strengthen the resilience of economic, physical, social, cultural, and environmental assets of people, businesses, communities, and countries.

In the SF, several factors that undermine disaster risk reduction efforts are recognized. The negative roles of poor land management, unplanned and rapid urbanization, and limited availability and use of technology are highlighted. At the same time, the important role of volunteers, civil society organizations, and academia in planning, preparedness, and effective response is acknowledged, and a call for more active involvement is made. The SF urges all stakeholders to invest in, among other fields, technology and research in order to develop the right systems, processes, and methodologies for early warning systems, preparedness, response, recovery, rehabilitation, and reconstruction, and sets as one of its goals the increased preparedness for response and recovery, which has a direct impact in strengthening resilience.

The SF sets seven global targets to be met by 2030 (in parallel with the UN SDGs), (UN 2015b, p. 12). These targets are further analysed into indicators that measure progress and determine global trends in the reduction of risk and losses. In parallel, SF sets four "Priorities for Action" (UN 2015b, p.14) that apply to global, regional, national, and local levels.

Of particular interest for this paper are the guidelines for Priorities 1 and 4. In Priority 1, where the focus is on understanding risk, land information holds a key position, and its value and use are acknowledged throughout. The SF highlights the requirement for real-time access to reliable data through the use of both in-situ and EO data from space. Moreover, the advantages of geographic information systems (GIS) are directly mentioned, and their use is considered crucial for collecting, analysing, and disseminating spatial data towards target achievement. For Priority 4, where the discussion is about the response and recovery, the SF focuses on three domains. First, it is social technologies and participatory processes that can provide immediate and effective relief assistance. Voluntary work and community-based organizations need to be developed, strengthened, and included in the disaster response processes before the disaster actually happens. Second, it is land-use planning that is deemed crucial for any effective post-disaster scenario. Finally, it is technical and logistical capacities that ensure better response in emergencies and increase capacity to rapidly evacuate persons who live in disaster-prone areas.

INTERTWINING SUSTAINABLE DEVELOPMENT GOALS AND THE SENDAI FRAMEWORK

There is an inherent connection between SDGs and the SF. All SDGs are related to disaster risk reduction and assume as prerequisite concepts such as risk aversion, disaster impact mitigation, and human life and livelihood safeguards, making all SF targets critical for the achievement of SDGs. The flip side is that progress on SDGs can substantially build the resilience of people and governments in the face of disasters. The SDGs and the SF mark the relationship and mutual dependency between risk management and development (Murray et al. 2017). Each one of the SDGs requires the SF for successful progress and meaningful future (Roberts et al. 2015). Combined, their goal is to leave no one behind (SDGs) and build back better (SF). More on the inherent connection between SDGs and the SF, and specifically how the SF can support each one of the SDGs, can be found in a UNDRR report (2016).

FACTORS THAT CAN ENABLE EFFICIENT AND PRACTICAL SOLUTIONS

CITIZEN SCIENCE

Early examples of citizen science (CS) can be traced back to the 18th and 19th centuries (Silvertown 2009). Today, with the help of several facilitating factors (such as IT, GPS, social networking), which minimize the technological barriers for citizens to actively participate in scientific projects, citizens and scientists are creating a nexus to promote scientific research in several domains. Participation comes in different shapes and forms along all stages of a scientific process (Haklay 2013). It ranges from data collection up to experiment design, data analysis, or dissemination of the results in a collaborative manner with professional scientists (Silvertown 2009; Fraisl et al. 2020). In today's CS projects, active citizens play a crucial part alongside academic and research institutions, industry, public sector, local authorities and communities, governments, and non-governmental organizations (NGOs). The variety of stakeholders and their direct interaction is considered a democratization of science (Irwin 1995) that brings transparency in the processes and the results of scientific projects and aligns scientific research with interests and problems that the public faces, both on local and global scales. Thus, CS is directly beneficial for the people and helps in building better societies (Savan et al. 2003).

Moreover, CS is beneficial for scientists and scientific projects as. For example, any project that requires in-situ data collected from large geographic areas or at a global level needs to drum up support from the public (Silvertown 2009). Especially for environmental projects, citizens' engagement counterbalances the deficit in up-to-date government-collected data (Sheppard and Terveen 2011). Additionally, scientists themselves expand their horizons from ideas developed from the bottom up. Often, the human effort and the computational power that the public can offer through CS projects can easily surpass any laboratory capacity. Examples can be found in projects such as Zooniverse, which is the largest platform of collaborative research; the Cornell Lab of Ornithology, which has a portfolio of CS projects that involve over 400,000 participants actively involved in birdwatching around the world; SciStarter; and the Thriving Earth Exchange. Such initiatives function as an enabling environment for CS projects that focus on several SF goals and SDGs such as Sustainable Cities and Communities (e.g., the Curio project), Climate Action (e.g., the CloudCatcher project), Life below Water (e.g., the Deep Sea Explorers project), Life on Land (e.g., the eBird project), Clean Water and Sanitation (e.g., the Clean Water Hub project), and Risk Mitigation and Community Resilience (e.g., the iseechange project). To maximize these positive effects, research itself is focusing on CS. For example, there is interest in how the general public can get involved in all stages of the research process and how this involvement can be maintained and increased or how citizens can identify sustainability problems and set the research agenda around sustainability challenges (Vohland et al. 2019).

In this context, CS has a key role in supporting SDGs and the SF. It can bridge the gap between data needed and the data that authoritative sources provide for measuring and reporting the progress of SDGs. Citizen-generated data can contribute considerably (c.f. Quinlivan et al. [2020] on water quality monitoring, Amano et al. [2016] on the spatial gaps in global biodiversity information, and Bradter et al. [2018] on habitat suitability). Moreover, CS projects can directly help in the implementation or monitoring of SDGs (Fraisl et al. 2020). Equally important is the case where citizens are setting the agenda and forming the questions to be answered. For example, Fritz et al. (2019) argue that data from CS projects can complement and ultimately improve the SDG reporting process while they can show the way for future research. Further, it is suggested that traditional data sources, for which the responsibility usually lies within National Statistical Offices (NSOs) or other governmental agencies, are falling short of actual needs, mostly due to high costs involved in data gathering and underfinancing. This results in inconsistent or infrequent data collection cycles which can make data outdated. Finally, when data is reported at a national level, the internal spatial variations might go unnoticed or underreported (World Bank and FAO 2011), a deficiency that CS is well suited to address (Hsu et al. 2014).

VOLUNTEERED GEOGRAPHIC INFORMATION

The GI generated by lay people who function as sensors (Goodchild 2007) can complement or replace authoritative sources and eventually underpin SDGs and SF goals. Several intrinsic characteristics make VGI datasets unique (Antoniou 2011) for this case. First is the extended field of scope for which VGI is collected. In many cases, VGI data are used for purposes that go beyond the original scope of data collection (see for example the use of OSM data in creating land use and land cover maps [Fonte et al. 2017], or the use of OSM data in ML processes as training data [Antoniou and Potsiou 2020; Li et al. 2021]). Also, VGI can be a cost-effective workaround for datasets needed to correct, enrich, or complete existing authoritative data. Moreover, VGI datasets can incorporate local knowledge from the volunteer contributors and draw a more accurate picture of the real situation on the ground. Another important characteristic is the timeliness of the data. A volunteer's contribution can be available on the web in a matter of seconds and can be used in planning or situational awareness processes. This time-cycle of data update cannot be matched by any authoritative dataset, which usually follow stiff life-cycle schedules. This explains why governments around the world are researching ways to incorporate VGI in their data production cycles in various sectors and scales (Haklay et al. 2014). This also explains why the SF explicitly refers to inclusiveness, open exchange, disaggregated data, and traditional knowledge when it comes to disaster management (UN 2015b), and states that "special attention should be paid to the improvement of organized voluntary work of citizens" (UN 2015b, p. 13). Indeed, researchers acknowledge that there is a need for a paradigm shift from the top-down authoritative-only flow of data to a more decentralized in-situ data collection that recognizes citizens and local populations as key sources (Challies et al. 2016). This is also important because the cost of environmental data collection, data management, and goal effort monitoring is astonishingly high (Castell et al. 2017), and overwhelms the financial capacities of many countries, especially in the developing world. A step further, VGI can expand its reach from being only a data source to a fertile environment for the development of applications that can be used for disaster management. For example, Ushahidi is an open source software application that enables the collection, management, and analysis of crowdsourced observations through mobile phones or internet (Pánek et al. 2017), and the Humanitarian OSM Team (HOT) is developing a variety of tools.

VGI can blend ideally with CS projects and EO data to support SDGs (Wu et al. 2020). Examples can be found in monitoring and exploring child wellbeing globally (Dalyot and Dalyot 2018); in the development of a data ecosystem that will enable developing countries to acquire data outside the official data flow to enrich the reporting on SDG indicators (Van den Homberg and Susha 2018) or in the blending of VGI and EO for land cover monitoring to assess dataset accuracy (Stehman et al. 2018). The power of VGI has been also demonstrated when it is put in the service of disaster management and resilience development since VGI, apart from a steady flow of data collection, can also be a valuable event-based data stream, thus providing data that authoritative sources cannot. Examples can be found in improving natural disaster decision-making systems (Zook et al. 2010), collecting data for transportation networks (Sultan et al. 2017), and monitoring meteorological conditions (Sosko and Dalyot 2017).

GEOGRAPHIC INFORMATION AND EARTH OBSERVATION IMAGERY

The past few years have seen a proliferation of EO systems, which has broadened understanding of our planet. Central to this advancement are several successful paradigms of non-private EO endeavors such as those from ESA and NASA. The ESA Copernicus program, with the Sentinel constellation, consists of sensors with low revisiting time and a variety of spatial and spectral resolutions capable of supporting many EO applications. NASA's Earth Observing System includes several missions (such as Landsat, Terra, Aqua, Aura, etc.) with a variety of sensing instruments in orbit and a mission to better understand the main components of the climate system. These remote sensing programs provide EO imagery at no cost, and are key data providers for many CS projects. The role of EO in disaster management, in the implementation of SDGs or the tracking of their progress has been studied extensively (see for example the work of 2018; Anderson et al. 2017; and Kavvada et al. 2020). The UN has acknowledged the importance and role that EO data can play in many aspects of the effort to complete the SDGs, either in measuring and monitoring environmental phenomena or in serving as a backdrop for analysis and research. Of particular interest are the effort to use EO in national statistics for monitoring and measuring indicators relevant to agriculture and land management (UN et al. 2017), the use of EO for monitoring SDG indicators and identifying social gaps at more local scales (Andries et al. 2023), and the use of EO to face challenges in local sustainability (Moallemi et al. 2020), thus supporting the effort to leave no one behind.

However, EO satellite imagery creates huge volumes of data to be managed, which does not leave much room for old practices based on human experts or volunteers who examine imagery scene by scene to take a decision in every step of a workflow. There is a necessity for advanced and automated methods of data management, analysis, and processing (UN 2017). Such advances can be found in the form of satellite imagery Data Cubes and Analysis Ready Data (ARD) (Chatenoux et al. 2021). Both are efficient approaches for storing, organizing, and analyzing large volumes of imagery ready to be used for several applications, including the implementation of ML algorithms.

MACHINE LEARNING

In general, ML has revolutionized the way that massive data volumes are processed and thus the way that valuable information or patterns emerge out of both structured and unstructured GI data. As Wegner et al. (2018) suggest, today, ML allows for the development of geospatial applications that, a few years ago, were beyond reach. ML approaches have been tested in several EO problems and challenges. Examples of technological breakthroughs can be found in satellite image classification and segmentation (Maxwell et al. 2018), artifact reduction (Wegner et al. 2018), and super resolution (Karwowska and Wierzbicki 2022) to name a few long-lasting challenges of remote sensing. Resolving these issues can further promote the efficiency and applicability of EO data to support SDGs and the SF. Indeed, Vinuesa et al. (2020) provide a broad overview on how artificial intelligence (AI) and ML can be a facilitating factor for SDGs by contributing to the accomplishment of 134 targets (which account for the 79% of the total number of targets) across all SDGs and the possible support of 59 targets more. Examples of applying ML on EO imagery to achieve SDGs can be found in poverty prediction by combining nighttime maps with high-resolution daytime satellite images and ML in five African countries, which relates to SDG 1 (Jean et al. 2016) or in forced labor and slavery detection in Rajasthan, India, which relates to SDG 16 (Foody et al. 2019). Also, EO imagery and ML are well positioned to support efforts related to SDG 13 such as drought assessment (Park et al. 2016) or environmental monitoring (Yuan et al. 2020). Regarding SF goals, applications can be found in the field of post-disaster building damage detection (Tilon et al. 2020); in flooding detection (Mateo-Garcia et al. 2021); in climate risk assessment (Zennaro et al. 2021); and in the wildfire prediction (Apostolakis et al. 2022). However, apart from the benefits there is also ongoing discussion regarding ethical issues and the risks that the broad adoption of ML has, especially when it is used in CS projects (Ceccaroni et al. 2019).

DISCUSSION

Society and citizens have a crucial role to play in the achievement of SDGs and SF goals. The factors discussed here have made notable progress both on their own merit and through synergies. CS, VGI and EO with ML can be turned into democratization forces that, on the one hand, can bring to light the needs and aims of common people, and on the other, can provide to them the means to contribute to the solutions needed. This can be a major shift from the passive stance against global problems, which relies mainly on top-down approaches and governmental initiatives.

High-level documents such as UN SDGs and the SF should be the blueprints for action. Such efforts need all the help they can find, and up to now, this help comes mainly from national, academic, and philanthropic initiatives around the world or from the corporate sector through the environment, social, and governance (ESG) standards. What can be a catalyst for more effective action is broader participation of citizens and the help they can provide in several domains, one of which is GI. This is not to say that there has been no progress or that the factors examined have not proved their strength in combating societal and environmental challenges. On the contrary, the strength and effectiveness shown so far justifies the position that the current advances are not the end state but rather are part of their evolution for effective support of the SDGs and SF goals. As shown through the examples highlighted, their combined use multiplies the individual strength of each factor. The nexus that these factors create functions as a generic framework that can enable interested stakeholders, despite their different needs and means, to work more efficiently towards the achievement of SDGs and SF aims. This nexus can be adopted by a broad pool of stakeholders (at all levels of government) and at a global scale as there are no insurmountable obstacles in its adoption. However, each stakeholder can adopt the framework to achieve the goals and aims it deems more pressing. The focus herein is on the spatial dimension of this nexus and its spatial output because GI is the common denominator for many of the SDGs and SF goals.

In this context, the fundamental questions are whether and how the unique characteristics of GI can be leveraged by and integrated in the efforts to achieve the SDGs and SF goals. Better GI (in terms of scope, detail, and currentness) is a prerequisite, but this is challenging for advanced countries and even more difficult for the developing ones with limited economic or technical capabilities (Fritz et al. 2019). Since not all countries start from the same point in their effort to meet these goals, the global challenge that arises is to find ways, methodologies, and best practices that will shorten the road that developing countries have to cover, either by effectively transferring available technologies (Scott and Rajabifard 2019) or by devising new ways to do so. In other words, if the democratization of the access to GI, processes, and services is not achieved, it would be extremely difficult for a global convergence in successfully meeting the SDGs.

This challenge has been recognized by the UN. See for example the decision to establish United Nations initiative on Global Geospatial Information Management (UN-GGIM), and the explicit reference for the role of GI in informing sustainable development policies, including their monitoring and implementation; and the call from the UN Economic and Social Council (ECOSOC) to strengthen the coordination and coherence of global GI management, in capacity-building and norm-setting. Similarly, several aspects of this challenge have been recognized by scholars and researchers under a generic call for geo-enabling SDGs and the SF, and charting a geospatial road to achieve it.

SUSTAINABLE DEVELOPMENT GOALS AND SPATIAL ENABLEMENT

The examples discussed so far, while they have focused on providing answers to small parts of larger problems, present no practical restrictions to scale up and, hence, to be implemented on a national or global scale. The reason is that they have no constraints or dependencies like overwhelming costs or proprietary technologies. Moreover, they provide concrete ways to spatially enable many of the SDGs and SF goals.

Spatial enablement refers to the ability to use GI and spatial technologies, processes, and concepts to enhance decision-making in a cross-cutting manner among several domains. Spatially enabling efforts to achieve SDGs seems like an intrinsic and natural thing to aim for, not least because the UN 2030 Agenda itself recognizes the role of GI in sustainable development. However, this generic call for geo-support is still vague and not eloquently explained (Rabiee 2019). Academics (Scott and Rajabifard 2019) tried to explore the challenges and opportunities to incorporate GI into the global development policy agenda in a more holistic but still theoretical manner. Indeed, at a theoretical level, there is some progress in conceptualizing how geospatial enabling could function in society and in government, as a preamble for geo-enabling SDGs. For example, as Williamson et al. (2007) highlight, a spatially enabled government uses and shares spatial information required for decision-making and policy development. This should be achieved by the development, maintenance, and integration of spatial data infrastructures (SDIs) into daily processes enabling, for example, better land administration and management. In turn, informed policies on land governance and property rights enable governments to address social, economic, and environmental challenges

(Wallace et al. 2006). For a society to be spatially enabled, all levels of governance must first embrace and encourage the collection, processing, and dissemination of spatial information to serve public interest. Consequently, available spatial information can prompt creativity, efficiency, and product and services development (Rajabifard et al. 2010). The spatial enablement of society and government is the fundamental first step to geo-enable the efforts to achieve the SDGs. Then, a roadmap for practical implementation is needed (see also UN-GGIM & World Bank (2018) and Rabiee (2019) who further explain how GI can support SDGs).

THE SENDAI FRAMEWORK AND SPATIAL ENABLEMENT

As discussed, the SF underpins and promotes policies with emphasis on risk management through resilience, preparation, mitigation, response, and aid before, during, and after a disaster. There is rich literature around the definition of resilience (UNISDR 2005), and the mechanisms and phases of disaster management (Carter 1991).

However, when it comes to implementation and tangible action to achieve the SF targets and principles, a common need arises: more and accurate data, much of which is GI. Indeed, this is what is also highlighted by governments or international organizations. For example, the UN notes that the use of EO and GI is vital to address the four priorities set by the SF (UN 2015c). Moreover, the Open Data for Resilience Initiative suggests that access to accurate GI is needed by all involved parties to reach correct decisions. Fundamental to this is GI sharing, and open and transparent processes (Haklay et al. 2018).

The need for GI can be explained by its manifold role in disaster management. GI is needed to provide accurate situational awareness and a common operational picture over an area of interest. The need to plan and operate over the same map is crucial. However, as GI is gathered from multiple sources, there is a need to fuse the information to provide a common GI baseline for all stakeholders. Examples can be found in all major disasters in which multiple operators were involved (Tomaszewski et al. 2015). An interesting case is the 2010 Haiti earthquake where crowdsourcing was the key source of available GI (Zook et al. 2010; Haklay et al. 2018). The fast international response in this case showed the power of crowdsourced GI and the need to create products that can be easily consumed by different end-users. Consequently, the role of crowdsourced GI and its fusion with authoritative data was re-conceptualized in terms of how authorities can better understand, trust, and use crowdsourced GI, which was a major step towards its acceptance by policy makers and planners (Haklay et al. 2018). Similar cases can be found in plans for disaster preparedness. Tomaszewski et al. (2015) note that GIS is considered a key factor and as an integrating technology in the National Response Framework in the United States (US) (US-DHS 2013). In Europe, the Copernicus program is partly dedicated to emergency management, known as the Copernicus emergency management service. This service provides to all involved parties accurate and timely GI, mainly through EO imagery but also by in-situ sources that are part of the service. A step further, the service's mapping component (Copernicus EMS – Mapping) provides worldwide coverage with satellite-based maps and analysis products to the end users. Of course, existing GI data sources and datasets are equally valuable when accessible. For example, cadastre or national spatial data infrastructures (NSDIs) can play a key role in every phase of the disaster management cycle and support of the SF. Such datasets can facilitate tenure, land use, land valuation, land rights management, and zoning information, which, in turn, is valuable information for resilience planning and disaster mitigation preparedness (Rajabifard et al. 2019). Authoritative GI can be further enriched and improved with the active participation of citizens (Basiouka et al. 2015; Rahmatizadeh et al. 2016) and especially with the application of approaches such as gamification, which maximizes motivation, enhances user participation, and maintains engagement (Rönneberg and Kettunen 2021; Apostolopoulos and Potsiou 2022), although caution should be applied as adverse effects on data quality or user de-motivation can be caused by poor gamification design (Eveleigh et al. 2013).

To clarify and emphasize the role that GI plays in the SF initiative, one-to-one connections between SF priorities and targets and GI underpinning are given in Tables 1 and 2, respectively.

CONCLUSIONS

High-level documents such as the UN SDGs and the SF have framed the focus of the global community when it comes to combating challenges around the world. The solutions sought need to be feasible and easy to implement in both developing and developed countries. Pre-existing infrastructure, cultural barriers, and adequate funding are just a few factors that can become obstacles to the transferability of a solution that was successful in other cases. In this context, this paper examined factors, advances, and technologies that exist in the geospatial domain and can overcome such

SF TARGET	GEO-ENABLING SF TARGETS
1	*Disaster-related information for affected people or people in danger can be generated through the CS/VGI channels. Rescue and first responder plans and actions can be facilitated from up-to-date (i.e., post-disaster) VGI.*
2	*Accurate GI is needed, especially for disaster-prone areas, to enhance resilience capacity through spatial analysis.*
3	*Use EO and CS/VGI to plan better and resilient development expansion. Use land tenure and administration systems to quickly restore land rights and minimize economic loss.*
4	*Use EO and CS/VGI to map critical, health, and educational infrastructure. Use spatial analysis to enhance resilience and plan evacuation/search/rescue efforts or efficient fall-back scenarios.*
5	*Use CS/VGI in collaboration with authoritative (national or local) efforts to enhance spatial data infrastructures. Use CS/VGI powered with cutting edge technological developments (e.g., ML) to minimize cost for data collection, maintenance, and analysis.*
6	*Use CS/VGI channels to funnel crowdsourced effort to developing countries. Use technological developments (e.g,. ML) to multiply the efficiency of the crowdsourced contribution or the resilience systems developed.*
7	*Use CS/VGI to develop broad networks of citizen sensors that will support any authoritative early warning system and disaster risk information and assessment plan.*

Table 1 How can geographic information enable Sendai Framework Targets?

CS: citizen science, EO: Earth observation, ML: machine learning, Framework, VGI: volunteered geographic information.

SF PRIORITY	GEO-ENABLING SF PRIORITIES
1	*Use EO/CS/VGI to collect data to educate authorities and the public about the disaster risk assessment. Innovative methods (e.g., gamification) can bring concepts such as resilience and disaster risk management to broad audiences.*
2	*Include CS/VGI and innovative technologies to prepare or update policies and guidelines that will improve the overall governance of disaster management. By engaging with the crowd, a more accurate understanding of the needs and requirements of people and local communities can be acquired by the authorities.*
3	*Invest in expanding EO/CS/VGI proliferation to develop a resilient network of up-to-date data collection that can support resilience and disaster reduction planning and action.*
4	*Data from CS/VGI/ML and EO can provide a holistic framework for local, national, or regional preparedness against disasters, while securing a head start for a sustainable recovery, rehabilitation, and reconstruction process.*

Table 2 How can geographic information enable Sendai Framework Priorities?

CS: citizen science, EO: Earth observation, ML: machine learning, Framework, VGI: volunteered geographic information.

obstacles as they have proven their value in numerous cases around the world. Several common characteristics made these factors to stand out. They have all proved their usefulness in a great variety of situations, and they managed to achieve breakthroughs or provide solutions to long-standing problems. They have managed to do so in several types of societies and at several scales, from local communities to the international level, equally efficiently. Importantly, they managed to do so by overcoming bureaucratic processes even when there was minimum or no authoritative funding. Nevertheless, they can work in full accordance and seamlessly intertwine with any other authoritative solution in place. However, the fragmentation of the solutions applied and the lack of a comprehensive framework for their implementation is something that needs to be further considered to maximize impact.

Herein, the focus was on this selection of factors because of their close relationship GI. GI is well positioned to support any sustainable development process. The measurement and monitoring of SDGs and the SF can be achieved only if there is always enough, accurate, and appropriate information available. GI can describe the existing status and progress achieved not least because all goals have either a geographic nature or a very close connection with geography (Scott and Rajabifard 2019) and thus can play a crucial role in the support of SDGs and the SF through their spatial enablement.

COMPETING INTERESTS

The author has no competing interests to declare.

AUTHOR AFFILIATIONS

Vyron Antoniou orcid.org/0000-0002-7365-9995
Hellenic Army Academy, GR

REFERENCES

Amano, T, Lamming, JD and **Sutherland, WJ.** 2016. Spatial gaps in global biodiversity information and the role of citizen science. *Bioscience*, 66(5): 393–400. DOI: https://doi.org/10.1093/biosci/biw022

Anderson, K, Ryan, B, Sonntag, W, Kavvada, A and **Friedl, L.** 2017. Earth observation in service of the 2030 Agenda for Sustainable Development. *Geo-spatial Information Science*, 20(2): 77–96. DOI: https://doi.org/10.1080/10095020.2017.1333230

Andries, A, Morse, S, Murphy, RJ, Sadhukhan, J, Martinez-Hernandez, E, Amezcua-Allieri, MA and **Aburto, J.** 2023. Potential of Using Night-Time Light to Proxy Social Indicators for Sustainable Development. *Remote Sensing*, 15(5): 1209. DOI: https://doi.org/10.3390/rs15051209

Antoniou, V. 2011. User generated spatial content: an analysis of the phenomenon and its challenges for mapping agencies. PhD Thesis, University College London.

Antoniou, V and **Potsiou, C.** 2020. A Deep Learning Method to Accelerate the Disaster Response Process. *Remote Sensing*, 12(3): 544. DOI: https://doi.org/10.3390/rs12030544

Apostolakis, A, Girtsou, S, Giannopoulos, G, Bartsotas, NS and **Kontoes, C.** 2022. Estimating Next Day's Forest Fire Risk via a Complete Machine Learning Methodology. *Remote Sensing*, 14(5): 1222. DOI : https://doi.org/10.3390/rs14051222

Apostolopoulos, K and **Potsiou, C.** 2022. Consideration on how to introduce gamification tools to enhance citizen engagement in crowdsourced cadastral surveys. *Survey Review*, 54(383): 142–152. DOI: https://doi.org/10.1080/00396265.2021.1888027

Basiouka, S, Potsiou, C and **Bakogiannis, E.** 2015. OpenStreetMap for cadastral purposes: an application using VGI for official processes in urban areas. *Survey Review*, 47(344): 333–341. DOI: https://doi.org/10.1179/1752270615Y.0000000011

Bradter, U, Mair, L, Jönsson, M, Knape, J, Singer, A and **Snäll, T.** 2018. Can opportunistically collected Citizen Science data fill a data gap for habitat suitability models of less common species? *Methods in Ecology and Evolution*, 9(7): 1667–1678. DOI: https://doi.org/10.1111/2041-210X.13012

Carter, WN. 1991. *Disaster Management: A Disaster Manager's Handbook*. Manila: Mamta Publication.

Castell, N, Dauge, FR, Schneider, P, Vogt, M, Lerner, U, Fishbain, B, Broday, D and **Bartonova, A.** 2017. Can commercial low-cost sensor platforms contribute to air quality monitoring and exposure estimates? *Environment international*, 99: 293–302. DOI: https://doi.org/10.1016/j.envint.2016.12.007

Ceccaroni, L, Bibby, J, Roger, E, Flemons, P, Michael, K, Fagan, L and **Oliver, JL.** 2019. Opportunities and risks for citizen science in the age of artificial intelligence. *Citizen Science: Theory and Practice*, 4(1). DOI: https://doi.org/10.5334/cstp.241

Challies, E, Newig, J, Thaler, T, Kochskämper, E and **Levin-Keitel, M.** 2016. Participatory and collaborative governance for sustainable flood risk management: An emerging research agenda. *Environmental Science and Policy*, 55(2016): 275–280. DOI: https://doi.org/10.1016/j.envsci.2015.09.012

Chatenoux, B, et al. 2021. The Swiss data cube, analysis ready data archive using earth observations of Switzerland. *Scientific data*, 8: 1–11. DOI: https://doi.org/10.1038/s41597-021-01076-6

Dalyot, K and **Dalyot, S.** 2018. Towards the use of crowdsourced GIS data to steferenced child well-being globally. *Social Indicators Research*, 139(1): 185–204. DOI: https://doi.org/10.1007/s11205-017-1714-1

Eveleigh, A, Jennett, C, Lynn, S and **Cox, AL.** 2013. "I want to be a captain! I want to be a captain!" gamification in the old weather citizen science project. In: *First international conference on gameful design, research, and applications*, 79–82. Toronto, Canada on October 2–4. DOI: https://doi.org/10.1145/2583008.2583019

Fonte, CC, Minghini, M, Patriarca, J, Antoniou, V, See, L and **Skopeliti, A.** 2017. Generating up-to-date and detailed land use and land cover maps using OpenStreetMap and GlobeLand30. *ISPRS International Journal of Geo-Information*, 6(4): 125. DOI: https://doi.org/10.3390/ijgi6040125

Foody, GM, Ling, F, Boyd, DS, Li, X and **Wardlaw, J.** 2019. Earth observation and machine learning to meet Sustainable Development Goal 8.7: Mapping sites associated with slavery from space. *Remote Sensing*, 11(3): 266. DOI: https://doi.org/10.3390/rs11030266

Fraisl, D, Campbell, J, See, L, Wehn, U, Wardlaw, J, Gold, M, Moorthy, I, Arias, R, Piera, J, Oliver, J, Masó, J, Penker, M and **Fritz, S.** 2020. Mapping citizen science contributions to the UN sustainable development goals. *Sustainability Science*, 15: 1735–1751. DOI: https://doi.org/10.1007/s11625-020-00833-7

Fritz, S, See, L, Carlson, T, Haklay, MM, Oliver, JL, Fraisl, D, Mondardini, R, Brocklehurst, M, Shanley, LA, Schade, S and **When, U.** 2019. Citizen science and the United Nations Sustainable Development Goals. *Nature Sustainability*, 2(10): 922–930. DOI: https://doi.org/10.1038/s41893-019-0390-3

Goodchild, MF. 2007. Citizens as sensors: the world of volunteered geography. *GeoJournal*, 69(4): 211–221. DOI: https://doi.org/10.1007/s10708-007-9111-y

Haklay, M. 2013. Citizen science and volunteered geographic information: Overview and typology of participation. *Crowdsourcing geographic knowledge*, 105–122. DOI: https://doi.org/10.1007/978-94-007-4587-2_7

Haklay, M, Antoniou, V, Basiouka, S, Soden, R and **Mooney, P.** 2014. *Crowdsourced geographic information use in government*. London: World Bank Publications.

Haklay, M, Antoniou, V, Basiouka, S, Soden, RJ, Deparday, V, Sheely, RM and **Mooney, P.** 2018. *Identifying Success Factors in Crowdsourced Geographic Information Use in Government*. London: World Bank Publications.

Hsu, A, Malik, O, Johnson, L and **Esty, DC.** 2014. Development: Mobilize citizens to track sustainability. *Nature News*, 508(7494): 33. DOI: https://doi.org/10.1038/508033a

Irwin, A. 1995. *Citizen science: A study of people, expertise and sustainable development*. London: Routledge.

Jean, N, Burke, M, Xie, M, Davis, WM, Lobell, DB and **Ermon, S.** 2016. Combining satellite imagery and machine learning to predict poverty. *Science*, 353(6301): 790–794. DOI: https://doi.org/10.1126/science.aaf789

Karwowska, K and **Wierzbicki, D.** 2022. Using Super-Resolution Algorithms for Small Satellite Imagery: A Systematic Review. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. DOI: https://doi.org/10.1109/JSTARS.2022.3167646

Kavvada, A, Metternicht, G, Kerblat, F, Mudau, N, Haldorson, M, Laldaparsad, S, Friedl, L, Held, A and **Chuvieco, E.** 2020. Towards delivering on the sustainable development goals using earth observations. *Remote Sensing of Environment*, 247: 111930. DOI: https://doi.org/10.1016/j.rse.2020.111930

Li, H, Zech, J, Ludwig, C, Fendrich, S, Shapiro, A, Schultz, M and **Zipf, A.** 2021. Automatic mapping of national surface water with OpenStreetMap and Sentinel-2 MSI data using deep learning. *International Journal of Applied Earth Observation and Geoinformation*, 104: 102571. DOI: https://doi.org/10.1016/j.jag.2021.102571

Mateo-Garcia, G, Veitch-Michaelis, J, Smith, L, Oprea, SV, Schumann, G, Gal, Y, Baydin, AG and **Backes, D.** 2021. Towards global flood mapping onboard low cost satellites with machine learning. *Scientific reports*, 11(1): 1–12. DOI: https://doi.org/10.1038/s41598-021-86650-z

Maxwell, AE, Warner, TA and **Fang, F.** 2018. Implementation of machine-learning classification in remote sensing: An applied review. *International Journal of Remote Sensing*, 39(9): 2784–2817. DOI: https://doi.org/10.1080/01431161.2018.1433343

Moallemi, EA, Malekpour, S, Hadjikakou, M, Raven, R, Szetey, K, Ningrum, D, Dhiaulhaq, A and **Bryan, BA.** 2020. Achieving the sustainable development goals requires transdisciplinary innovation at the local scale. *One Earth*, 3(3): 300–313. DOI: https://doi.org/10.1016/j.oneear.2020.08.006

Murray, V, Maini, R, Clarke, L and **Eltinay, N.** 2017. Coherence between the Sendai Framework, the SDGs, the Climate Agreement, New Urban Agenda and World Humanitarian Summit, and the role of science in their implementation. In: *Global Platform for Disaster Risk Reduction*, Cancun, Mexico on 22–26 May 2017, 24–26.

Pánek, J, Marek, L, Pászto, V and **Valůch, J.** 2017. The Crisis Map of the Czech Republic: the nationwide deployment of an Ushahidi application for disasters. *Disasters*, 41(4): 649–671. DOI: https://doi.org/10.1111/disa.12221

Park, S, Im, J, Jang, E and **Rhee, J.** 2016. Drought assessment and monitoring through blending of multi-sensor indices using machine learning approaches for different climate regions. *Agricultural and forest meteorology*, 216: 157–169. DOI: https://doi.org/10.1016/j.agrformet.2015.10.011

Quinlivan, L, Chapman, DV and **Sullivan, T.** 2020. Applying citizen science to monitor for the Sustainable Development Goal Indicator 6.3.2: a review. *Environmental monitoring and assessment*, 192: 1–11. DOI: https://doi.org/10.1007/s10661-020-8193-6

Rabiee, M. 2019. Spatially Enabling the SDGs: The Social, Economic, and Environmental Impacts of Spatial Enablement. In: *Sustainable Development Goals Connectivity Dilemma: Land and Geospatial Information for Urban and Rural Resilience*, 65–77. Boca Raton: CRC Press. DOI: https://doi.org/10.1201/9780429290626-4

Rahmatizadeh, S, Rajabifard, A and **Kalantari, M.** 2016. A conceptual framework for utilising VGI in land administration. *Land Use Policy*, 56: 81–89. DOI: https://doi.org/10.1016/j.landusepol.2016.04.027

Rajabifard, A, Crompvoets, J, Kalantari, M and **Kok, B.** 2010. *Spatially enabling society: research, emerging trends and critical assessment*. Belgium: Leuven University Press.

Rajabifard, A, Potts, K, Torhonen, MP, Barra, F and **Justiniano, I.** 2019. Leveraging National Land and Geospatial Systems for Improved Disaster Resilience. In: *Sustainable Development Goals Connectivity Dilemma: Land and Geospatial Information for Urban and Rural Resilience*, 81–92. Boca Raton: CRC Press. DOI: https://doi.org/10.1201/9780429290626-5

Roberts, E, Andrei, S, Huq, S and **Flint, L.** 2015. Resilience synergies in the post-2015 development agenda. *Nature Climate Change*, 5(12): 1024. DOI: https://doi.org/10.1038/nclimate2776

Rönneberg, M and **Kettunen, P.** 2021. Enabling citizens to refine the location accuracy of cadastre boundary markers by gamified VGI. *Abstracts of the ICA*, 3: 252. DOI: https://doi.org/10.5194/ica-abs-3-252-2021

Rostow, WW and **Rostow, WW.** 1990. The stages of economic growth: A non-communist manifesto. Cambridge, UK: *Cambridge University Press*. DOI: https://doi.org/10.1017/CBO9780511625824

Savan, B, Morgan, AJ and **Gore, C.** 2003. Volunteer environmental monitoring and the role of the universities: the case of Citizens' Environment Watch. *Environmental management*, 31(5): 0561–0568. DOI: https://doi.org/10.1007/s00267-002-2897-y

Scott, G and **Rajabifard, A.** 2017. Sustainable development and geospatial information: a strategic framework for integrating a global policy agenda into national geospatial capabilities. *Geo-spatial information science*, 20(2): 59–76. DOI: https://doi.org/10.1080/10095020.2017.1325594

Scott, G and **Rajabifard, A.** 2019. SDGs Roadmap. In: *Sustainable Development Goals Connectivity Dilemma: Land and Geospatial Information for Urban and Rural Resilience*, 10–34. Boca Raton: CRC Press. DOI: https://doi.org/10.1201/9780429290626

Sheppard, SA and **Terveen, L.** 2011. Quality is a verb: the operationalization of data quality in a citizen science community. In: *7th International Symposium on Wikis and Open Collaboration*, 29–38. Mountain View, CA on 3–5 October 2011. DOI: https://doi.org/10.1145/2038558.2038565

Silvertown, J. 2009. A new dawn for citizen science. *Trends in ecology & evolution*, 24(9): 467–471. DOI: https://doi.org/10.1016/j.tree.2009.03.017

Sosko, S and **Dalyot, S.** 2017. Crowdsourcing user-generated mobile sensor weather data for densifying static geosensor networks. *ISPRS International Journal of Geo-Information*, 6(3): 61. DOI: https://doi.org/10.3390/ijgi6030061

Stehman, SV, Fonte, CC, Foody, GM and **See, L.** 2018. Using volunteered geographic information (VGI) in design-based statistical inference for area estimation and accuracy assessment of land cover. *Remote Sensing of Environment*, 212: 47–59. DOI: https://doi.org/10.1016/j.rse.2018.04.014

Sultan, J, Ben-Haim, G, Haunert, JH and **Dalyot, S.** 2017. Extracting spatial patterns in bicycle routes from crowdsourced data. *Transactions in GIS*, 21(6): 1321–1340. DOI: https://doi.org/10.1111/tgis.12280

Tilon, S, Nex, F, Kerle, N and **Vosselman, G.** 2020. Post-disaster building damage detection from earth observation imagery using unsupervised and transferable anomaly detecting generative adversarial networks. *Remote sensing*, 12(24): 4193. DOI: https://doi.org/10.3390/rs12244193

Tomaszewski, B, Judex, M, Szarzynski, J, Radestock, C and **Wirkus, L.** 2015. Geographic information systems for disaster response: A review. *Journal of Homeland Security and Emergency Management*, 12(3): 571–602. DOI: https://doi.org/10.1515/jhsem-2014-0082

UN. 2015a. Transforming our world: The 2030 agenda for sustainable development. General Assembley 70 session. [online access at: https://documents-dds-ny.un.org/doc/UNDOC/GEN/N15/291/89/PDF/N1529189.pdf?OpenElement last accessed 28 September 2022].

UN. 2015b. Sendai framework for disaster risk reduction 2015–2030. [online access at: https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf last accessed 28 September 2022].

UN. 2015c. Earth Observations in Support of National Strategies for Disaster-Risk Management [available online at: http://www.un-spider.org/sites/default/files/White_paper_Earth%20observations%20for%20DRR.pdf last accessed 28 September 2022].

UN. 2017. Earth Observations for Official Statistics [online available at: https://unstats.un.org/bigdata/taskteams/satellite/UNGWG_Satellite_Task_Team_Report_WhiteCover.pdf last accessed 28 September 2022].

UN. 2022. The Sustainable Development Goals Report [online available at: https://unstats.un.org/sdgs/report/2022/The-Sustainable-Development-Goals-Report-2022.pdf last accessed 28 March 2023].

UN. Australian Bureau of Statistics; Queensland University of Technology; Queensland Government; Commonwealth Scientific and Industrial Research Organisation; European Commission; National Institute of Statistics and Geography; Statistics Canada. Earth Observations for Official Statistics, 2017. [online available at: https://unstats.un.org/bigdata/task-teams/earth-observation/UNGWG_Satellite_Task_Team_Report_WhiteCover.pdf last accessed 28 March 2023].

UNDRR. 2016. Implementing the Sendai Framework to achieve the Sustainable Development Goals. [online access at: https://www.unisdr.org/files/50438_implementingthesendaiframeworktoach.pdf last accessed 28 September 2022].

UN-GGIM and **World Bank.** 2018. Integrated geospatial information framework a strategic guide to develop and strengthen national geospatial information management. [online access at: http://ggim.un.org/meetings/GGIM-committee/8th-Session/documents/Part%201-IGIF-Overarching-Strategic-Framework-24July2018.pdf last accessed 28 September 2022].

UNISDR. 2005. Hyogo framework for action 2005–2015 [online access at: https://www.unisdr.org/2005/wcdr/intergover/official-doc/L-docs/Hyogo-framework-for-action-english.pdf last accessed 28 September 2022].

UNTT. 2015. Working Group on Sustainable Development Financing [online access at: https://sustainabledevelopment.un.org/content/documents/2096Chapter%201-global%20investment%20requirement%20estimates.pdf last accessed 28 September 2022].

United States Department of Homeland Security. 2013. National Response Framework. 2nd ed. [online access at: https://www.hsdl.org/?view&did=735934 last accessed 28 September 2022].

Van den Homberg, M and **Susha, I.** 2018. Characterizing data ecosystems to support official statistics with open mapping data for reporting on sustainable development goals. *ISPRS International Journal of Geo-Information*, 7(12): 456. DOI: https://doi.org/10.3390/ijgi7120456

Vinuesa, R, Azizpour, H, Leite, I, Balaam, M, Dignum, V, Domisch, S, Felländer, A, Langhans, SD, Tegmark, M and **Nerini, FF.** 2020. The role of artificial intelligence in achieving the Sustainable Development Goals. *Nature Communications*, 11(1): 1–10. DOI: https://doi.org/10.1038/s41467-019-14108-y

Vohland, K, Sauermann, H, Antoniou, V, Balazs, B, Göbel, C, Karatzas, K, Mooney, P, Perelló, J, Ponti, M, Samson, R and **Winter, S.** 2019. Citizen science and sustainability transitions. *Research Policy*, 49(5): 103978. DOI: https://doi.org/10.1016/j.respol.2020.103978

Vorisek, D and **Yu, S.** 2020. Understanding the cost of achieving the Sustainable Development Goals. [online access at: https://openknowledge.worldbank.org/server/api/core/bitstreams/06eb043e-3b06-5547-bfa4-56f4c1202c23/content last accessed 24 March 2023]. DOI: https://doi.org/10.1596/1813-9450-9164

Wallace, J, Williamson, IP, Rajabifard, A and **Bennett, R.** 2006. Spatial information opportunities for Government. *Journal of Spatial Science*, 51(1): 79–99. DOI: https://doi.org/10.1080/14498596.2006.9635066

Wegner, JD, Roscher, R, Volpi, M and **Veronesi, F.** 2018. Foreword to the Special Issue on Machine Learning for Geospatial Data Analysis. *ISPRS International Journal of Geo-Information*, 7(4): 147. DOI: https://doi.org/10.3390/ijgi7040147

Williamson, I, Rajabifard, A and **Wallace, J.** 2007. Spatially Enabling Government–An International Challenge. In: *International Workshop on Spatial Enablement of Government and NSDI–Policy Implications*, Seoul, Korea on 12 June 2007, pp. 1–12.

World Bank & FAO. 2011. Global Strategy to Improve Agricultural and Rural Statistics [online access at: http://www.fao.org/fileadmin/templates/ess/documents/meetings_and_workshops/ICAS5/Ag_Statistics_Strategy_Final.pdf last accessed 28 September 2022].

Wu, B, Tian, F, Zhang, M, Zeng, H and **Zeng, Y.** 2020. Cloud services with big data provide a solution for monitoring and tracking sustainable development goals. *Geography and Sustainability*, 1(1): 25–32. DOI: https://doi.org/10.1016/j.geosus.2020.03.006

Yuan, Q, Shen, H, Li, T, Li, Z, Li, S, Jiang, Y, Xu, H, Tan, W, Yang, Q, Wang, J, Gao, J and **Zhang, L.** 2020. Deep learning in environmental remote sensing: Achievements and challenges. *Remote Sensing of Environment*, 241: 111716. DOI: https://doi.org/10.1016/j.rse.2020.111716

Zennaro, F, Furlan, E, Simeoni, C, Torresan, S, Aslan, S, Critto, A and **Marcomini, A.** 2021. Exploring machine learning potential for climate change risk assessment. *Earth-Science Reviews*, 220: 103752. DOI: https://doi.org/10.1016/j.earscirev.2021.103752

Zook, M, Graham, M, Shelton, T and **Gorman, S.** 2010. Volunteered geographic information and crowdsourcing disaster relief: a case study of the Haitian earthquake. *World Medical & Health Policy*, 2(2): 7–33. DOI: https://doi.org/10.2202/1948-4682.1069

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