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Engaging global youth in participatory spatial data creation for the UN sustainable development goals: The case of open mapping for malaria prevention

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ABSTRACT

Practitioners bemoan lack of data as one of the biggest obstacles to progress towards global sustainable development goals. This paper explores a scaled-up participatory method developed by YouthMappers, for creating missing geospatial data derived from remotely sensed imagery in order to contribute to persistent data needs in the context of the United Nations Sustainable Development Goals (SDGs). We explore the application of this method to a case related to SDG 3 on Health. We document how our approach centered on creating a global academic network designed to engage and empower university students and their faculty mentors to participate in broader efforts to create open, free spatial data on open platforms to inform humanitarian and development objectives outlined by the funding agency, the United States Agency for International Development (USAID). This approach expressly links supply and demand for geospatial knowledge by connecting specific needs for geographic information to specific development objectives in targeted places where USAID works to end extreme poverty. We discuss the rationale and context for the methodology as it draws from and builds upon prominent literature of participatory GIS (PGIS) and volunteered geographic information (VGI). We demonstrate how the mapping of building and road infrastructure in Mozambique and Kenya was carried out in order to provide information for an insecticide spray campaign to prevent malaria and protect public health. Throughout these efforts, steps are taken to ensure spatial data quality and to offer opportunities for youth volunteer embeddedness in mapping tasks and themes in places where students otherwise would not engage with real world data or connect with peers from different countries. We reflect on the opportunities and challenges for how this scaled-up "remote participatory sensing" approach to spatial data creation can inform development projects in the context of the SDGs.

1. Introduction

Vast amounts of new geospatial data are created and shared daily through online open platforms by volunteer, humanitarian or crisis mapping actors around the world. Typically, these data are created ad-hoc or for immediate use in response to urgent crises or extreme events. Such information contains geographic features and attributes that are critical to building resilient communities and infrastructure over the long term. Meanwhile, advances in research on resilience and vulnerability are hampered by access to reliable data (Barrett & Headey, 2014) and practitioners often bemoan lack of data as one of the biggest obstacles to progress towards development goals (United Nations Independent Expert Advisory Group, 2014; Stuart, Samman, Avis, & Berliner, 2015, p. 51). This situation presents an opportunity to apply open, online, crowd-engaging geospatial tools in relation to producing missing data that can explicitly address locally relevant longer-term development needs. In addition, these data-generating processes may also support research needs in the context of regions and countries challenged by chronic environmental and economic vulnerability.

Indeed the potential for participatory GIS (PGIS) and volunteered

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geographic information (VGI) to inform development goals such as the United Nations Sustainable Development Goals (SDGs) may be something that geospatial practitioners are increasingly aware of, yet represents a novelty within the development community at large. In this article, we document our experience with the creation of an academic network designed to engage and empower students and their faculty mentors, especially in developing regions, to participate in broader efforts to create open, free spatial data on open platforms for humanitarian and development efforts in ways that directly contribute to sustainable development objectives outlined by the funding agency, the United States Agency for International Development (USAID). For the first time, YouthMappers merges the capacity for data and knowledge production in the academic sector with the development and humanitarian actors responsible for implementing tactical interventions, focused on open spatial data creation and engaging students in majoritarian nations.

This research is situated in a long tradition of investigating people's participation in data creation with the goals of empowerment and engagement through geographic technologies (Harris & Weiner, 1998). Studies on Participatory GIS, as it became in the 1990s, focused on the democratization of geospatial technologies and inclusion of the people who were often simply regarded as the objects of study. With continuously expanding access and affordability of the internet in the early- to mid-2000s, people were able to generate data themselves, participate in far-flung communication, and create databases as a collective. Now commonly called "Volunteered Geographic Information", this movement overcame some of the earlier technical obstacles to participation in GIS, but also raised new thorny ethical and data quality issues (Haklay, 2013). Our research in this paper is informed by these debates, and extends them to understanding the purposeful work of scaled up collectives relates to addressing global development objectives.

We describe our methods for the participatory use of remotely sensed imagery to create geographic data that feeds directly into development interventions. In doing so, we consider how the participatory character of these methods relate to the UN's goals because the SDGs currently serve as the dominant development framework. The SDGs are often conceptualized in the context of national level policy-making and international aid discussions while simultaneously attempting to promote local stakeholder engagement. The cross-scalar nature of abstract SDGs justifies the need for a methodological, micro-scale participatory approach that is expressly linked to a particular SDG, yet can directly speak to the broader global framework in question.

In the next section, we explore the potential of PGIS and VGI to inform development framed under the UN's Sustainable Development Goals (SDGs) and we ground this work in the relevant literature. The next section discusses the overall approach of creating a global youth program focused on the fusion of technology and international development. As one example of how this network functions, we introduce a case study of applied mapping related to malaria prevention in East Africa, framed by SDG 3 on Health, to illustrate the results of the data production effort in our first year. We conclude with a reflection on our methodology, suggesting a number of lessons and recommendations for future applications as well as future research on participatory spatial data creation.

1.1. *Positioning participatory geographic technologies in the academic literature*

Open geospatial technologies, and internet mapping in particular, play a role in enabling digital humanitarianism and represent a novel medium for citizen participation in a digital era (Meier, 2015). This field draws upon a long tradition in geography and related disciplines that integrates public participation with geographic information systems (GIS). This work originated in the early 1990s and coalesced around a few key events, for instance, the National Center for Geographic Information Analysis (NCGIA) Initiative 19 meeting in Friday Harbor, Washington in November 1993. A small group of scholars met to respond to growing critiques of the use of GIS, and to map out a more participatory future (Harris & Weiner, 1998). Obermeyer (1998, p. 65) traced the phrase "public participation GIS" to a workshop organized by planners, but cites the NCGIA meeting as the "first formal gathering of scholars to discuss the topic." Brown and Donovan (2014) and Brown, Kelly, and Whitall (2014) further elaborated the concept of PGIS that emerged from NCGIA as a field that necessarily fosters the empowerment of non-governmental organizations, grassroots groups and local communities. The idea of participation leading to empowerment has been advanced by Ardissono, Lucenteforte, Savoca, and Voghera (2014, p. 3) whereby "participatory processes are related to empowerment [because] they are based on a bottom-up decision-making model."

As far back as a decade ago, Dunn (2007, p. 2) characterized the empowering nature of PGIS with respect to the "control and ownership of geographical information, representing local and indigenous spatial knowledge, the democratization of GIS and sustainability." Mukherjee (2015) emphasized marginality and equity while Chingombe, PedzisaiManatsa, Mukwada, and Taru (2015) emphasized local knowledge integration. Other scholars posited a strand of research under the banner of critical GIScience, which initiated a focus "on the social implications of and social biases inherent in the science, technology, and their deployments" of Geographic Information Science fields (Schuurman, 2017). Critical Cartography researchers, along with feminist GIS scholars, continue to actively challenge the limitations of geospatial technology and its multiple uses, and continue to question and redefine its relationship to empowerment.

When geospatial technologies went online through the introduction of open mapping on the web, the nature of access to these tools changed dramatically (Elwood, Goodchild, & Sui, 2010), representing "a paradigmatic shift in how geographic information is created and shared and by whom, as well as its content and characteristics," including, we assert, a concomitant shift in how to understand its potential to engage volunteer mappers. Calafiore, Borges, Moura and Boella (2016, p. 3) recognized VGI as "systems [that] allow collection of data produced by the engagement of large numbers of private citizens without any pre-required Geographic Information Systems," enabling participation of non experts in ways that challenge how knowledge is created. In return, this new way of creating knowledge has been challenged by concerns regarding the quality, reliability, veracity, completeness, metadata, and bias of VGI (Heipke, 2010; Jackson et al., 2013; Elwood, Goodchild, & Sui, 2013; Flanagin & Metzger, 2008; Neis & Zipf, 2012; Goodchild & Li, 2012). As a result of this tension, the subsequent body of scholarship unfortunately tends to construct "the spatial data production activities of states in opposition to bottom-up, amateur, asserted" mapping (Cinnamon, 2015). For efforts like the SDGs that seek to bridge local change and global indicators, this juxtaposition is problematic.

Alternatively, we respond to Cinnamon's call to more accurately depict what is "in actuality a vast, shifting, and heterogeneous landscape of spatial data production approaches." Recent literature has begun to demonstrate the complex and nuanced ways that VGI is produced during natural hazard events (Burns, 2018; Haworth, 2018). Our work seeks to develop and improve a conceptualization of Cinnamon's (2015) "continuum [that] could encourage the development of hybridities that harness the benefits of different approaches—including the oversight and quality control of conventional methods, with the speed, low cost, and distributed nature of citizen-based spatial data production." We are doing this through the design and implementation of a method of collaborative action in the applied domain that operates at a global scale: YouthMappers' participatory spatial data creation. This is an important stance if the public in general, and youth in particular, can become important actors and partners to their governments in meeting the SDGs, especially in developing regions of the world.

1.2. The YouthMappers approach as a participatory methodology

YouthMappers is organized as a network of chapters, where groups establish new or affiliate existing student organizations on their home campuses for the purpose of engaging in mapping efforts, shared learning and other forms of peer exchange for data creation that directly responds to development and humanitarian need. In the first two years of the program, the network grew from three US founding universities to 100 campuses in 30 countries, consolidating an international movement of spatial volunteers (YouthMappers, 2018). The program design centers on an arrangement of student organizations in order to leverage a social element at the local context, to improve chances for chapter sustainability, to advance a model of student leadership with faculty mentorship, and to reach greater numbers of youth (Solis, Huynh, Carpenter, Adames and Ojeda, 2017). Affiliation and participation is free, and chapters in good standing (those who participate in network-promoted campaigns and report on them) are deemed eligible for their members to apply for special programming, such as mini-travel grants, research fellowships, leadership workshops, and other benefits. An alumni network has emerged organically from graduating participants.

The volunteered mapping efforts of YouthMappers chapters are undertaken at local and global scales.[1]

YouthMappers volunteers work in places of the world that are under-mapped or effectively unmapped due to lack of available or accessible geographic data, and where progress towards sustainable development goals are especially urgent. Since YouthMappers is publicly funded, project generated data is required to be free and open for use by anyone, a model that is exemplified by the OpenStreetMap platform. The method for creating fundamental spatial data at this scale and scope – and in such remote places where community participatory mapping is not immediately viable – involves crowd digitization of features visible on earth observation imagery. Through a partnership with the USAID GeoCenter, YouthMappers can access high quality, high-resolution donated imagery[2] for campaign projects (Sinton, 2016). Students access the displayed images for digitization over the internet through the Humanitarian OpenStreetMap Team (HOT) Tasking Manager or the TeachOSM Tasking Manager. Students create OSM accounts, log into the Tasking Manager of their choice, and choose a YouthMappers project to work on remotely. Satellite data itself is also available for specific-purpose projects directly through an MOU with the Digital Global Foundation so that the spectral data can also be analyzed directly for requested research or development topics. This "participatory remote sensing" approach is essential to create vector data or for direct utilization of geospatial data in GIS applications and as the base map for further local activities that add attributes and details. The data on OSM itself can be used again by other actors for other purposes, as it becomes available under the Open Data License (ODbL) Share Alike, where users freely share, modify, and use data while maintaining this same freedom for others.[3] Many YouthMappers are finding ways to utilize this data in their own thesis or dissertation research.

While it is possible for single individuals to contribute to this process, global, remote campaigns often attract groups of students who work simultaneously on common tasks. Groups gather on campus in person, and through the network via video conference with other chapters at other universities, or sometimes visit other chapters (Manyungwa, 2017). This social dimension to the effort adds an element of camaraderie and motivation, such as when organized as "mapathons" or "map-offs" where groups may compete to see how much work each has created (Davis, 2018). Importantly, the global level participatory remote sensing campaigns request data that for major actors and are directly connected to the communities that are responsible for, or, are interested in pursuing advances to the SDGs in the humanitarian community, governmental agencies, USAID, country missions, Red Cross, Peace Corps, and others.

The most common digitization tools used by YouthMappers are the iD editor, which OSM's online digitization platform, easy for beginners, and JOSM (Java OpenStreetMap), a more complex, downloadable desktop editor that can be used to map offline. Using JOSM is advantageous for those with poor internet connections, as they can later upload changes. The most common features mapped are roads, which are traced down their center as line features, followed by buildings, which are drawn as area features, rather than points, so that later analysis permits estimation of metrics such as building footprint for post-disaster damage assessments, population estimates, etc. Other common features requested remotely are waterways and land use polygons. From a pedagogical standpoint, the main challenge in data quality seems to stem from the experience level of student mappers with imagery interpretation, rather than with a lack of familiarity with GIS. This is a significant challenge, but also an opportunity for introducing such techniques to students. Virtual interns, who are generally more advanced/experienced students from the network's constituent universities, have worked directly with USAID GeoCenter staff guidance to check the quality of data contributed by the broader network.

Local community participatory mapping adds value to the remote action. This is characteristic of projects that are either student-driven, faculty-led, or donor/government requests, and typically focuses on the generation of detailed features or locally-knowable attributes within a particular area of interest, such as on campus or with nearby populations where fieldwork is possible, or sometimes in the hometowns of participating students. The workflow for such projects might include using hand-held GPSs, smart phones, or other mobile GIS applications to pinpoint or trace data into OpenStreetMap. It might also include tagging or adding deeper detailed attribute data to existing OSM features. This is the Participatory GIS aspect of the project. Field visits to local places where student knowledge is used to capture geographic features or check features mapped remotely by other students, or in some cases, where students train or engage local residents to map or add attributes, are examples of the fusion of PGIS and VGI. Both happen in tandem to produce geographic knowledge. Increasing interest in drone-technology drives exploration of sites with photographic data, but many YouthMappers chapters lack the resources to implement such equipment-intensive, high-bandwidth data collection. Additionally, some students are contributing to open street-level photo repositories, such as Mapillary,[4] using cameras or phones to upload visual data. Typically, these kinds of local activities follow initial desktop mapping activities to tag or name fundamental spatial data on basic infrastructure such as roads, waterways, buildings, land use, and other features.

In its first year, the network made more than twelve million changes or edits to OpenStreetMap.

The pace of contributions peaks around concerted efforts, such as mapathons that are scheduled as part of a data campaign. Because YouthMappers are university students, contributions also tend to peak when classes are in sessions and students are on-campus, particularly in late October/early November with the celebration of GeoWeek.

The edits and changes to OSM tagged by YouthMappers have been made in more than 45 countries, where the locations of largest contributions reflect the various global campaigns (e.g. Mozambique) followed by local efforts initiated by students themselves. The features that are most often mapped remotely are visible infrastructure

[1] http://www.youthmappers.org/projects.

[2] The sources of donated imagery include USAID's NextView license as well as other sources like Bing, Digital Globe, Landsat, Mapbox and others.

[3] https://en.wikipedia.org/wiki/Open_Database_License.

[4] http://www.mapillary.com.

Table 1
Map changes made by members of the YouthMappers network, by categories of highways, buildings, land-uses, and waterways. April 2016–July 2017. Collected using http://resultmaps.neis-one.org/osm-changesets?comment=youthmappers.

OSM Contributions	Map Changes	Monthly Contributors	Change Sets	Highways	Buildings	Land-Uses	Waterways
April, 2016	5,51,425	310	7893	15,061	53,095	440	762
May, 2016	4,11,634	114	2048	9002	41,265	487	349
June, 2016	8,04,091	232	6038	26,089	73,819	1394	596
July, 2016	10,12,915	560	11,428	34,830	91,517	890	988
August, 2016	73,574	15	140	2202	7126	11	86
September, 2016	4,23,383	311	4112	8779	37,988	278	422
October, 2016	9,06,941	885	12,198	26,506	85,429	314	120
November, 2016	11,94,278	845	18,189	29,275	1,45,047	388	197
December, 2016	96,822	63	1138	2484	11,092	66	13
January, 2017	7,22,644	182	6889	19,899	89,564	73	106
February, 2017	11,63,570	299	19,703	26,091	1,52,697	224	174
March, 2017	9,42,233	488	17,008	15,096	1,20,978	199	16
April, 2017	26,19,010	538	47,154	18,886	3,24,122	734	77
May, 2017	5,86,140	349	9299	11,496	70,852	69	31
June, 2017	25,67,792	384	22,275	7396	3,62,293	52	21
July, 2017	16,19,148	175	4105	1649	2,34,311	61	41
TOTALS	***1,56,95,600***	***5750***	***1,89,617***	***2,54,741***	***19,01,195***	***5750***	***5750***

(buildings and roads), as this makes it possible for digitization by students collaborating elsewhere using satellite imagery. Table 1 details the relative number of features created, where buildings are the most common edits to OSM.

1.3. The potential for participatory approaches in geographic technologies to support the UN SDGs

The Sustainable Development Goals (SDGs) are a set of seventeen development objectives set forth by the United Nations for individual countries to as targets to reach by the year 2030 (United Nations (UN), 2015). These goals include: no poverty; zero hunger; good health and well-being; quality education' gender equality; clean water and sanitation; affordable and clean energy; decent work and economic growth; industry, innovation and infrastructure; reduced inequalities; sustainable cities and communities; responsible production and consumption; climate action; life below water; life on land; peace, justice and strong institutions; and partnerships for the goals (United Nations (UN), 2015). While such national scale objectives are typically imagined and implemented in the domain of government and international organization planning and policy-making, local and regional institutions are effective partners in the day-to-day implementation of development plans. The data needed for designing, implementing, measuring and tracking such efforts across the spectrum of the goals are multiple and multi-dimensional. The range of volunteer mapping projects undertaken by YouthMappers contribute to fundamental geospatial data that can inform this spectrum of needed information (Clark et al., 2016) (See Table 2). These are indirect contributions, meaning that the data and analysis conducted could potentially support advances toward an SDG by assisting with data needs for a development project; the contributions are not made in a direct way, for instance, by implementing a development project itself.

One of the applications that YouthMappers has engaged to support SDGs is through event response. Typically, an "event" is a natural disaster response given the origins of the project in the humanitarian relief community. When the devastating earthquakes hit Nepal in early 2015, relief workers traversed roads made digitally visible from satellite imagery onto OpenStreetMap (OSM) by volunteers halfway around the world (Parker, 2015). A year and a half before the disaster, over 100 George Washington University undergraduate and graduate students worked remotely alongside University of Kathmandu students who conducted field surveys to help the World Bank, USAID, and Kathmandu Living Labs to map sections of Kathmandu, focusing on critical infrastructure such as roads, schools, and hospitals in advance of the likelihood of such an event (Lopez, 2013). By the time the earthquake hit, students and faculty had formed a humanitarian mapping society on campus (HMS) and held several Friday night "mapathons," including a remote competitive "Map-Off" with students at Texas Tech University, and George Mason University. Meanwhile, Kathmandu partners validated and attributed the critical infrastructure data created by the students. The subsequent data was destined for earthquake modeling, specifically to predict debris volume, and plan potential "humanitarian corridors" for debris removal and aid delivery. After the earthquake hit, students revisited mapping tasks to help the Red Cross and partners on the ground estimate damaged infrastructure (Dunkins, 2015).

Projects needing data for less urgent but critical development purposes follow a similar approach to event-response tasks. These efforts have arisen either through a global remote campaign, such as those through YouthMappers partners, or through tasks assigned to virtual student interns, or supported through mini-grants from the program to develop local data, knowledge and capacity. Increasingly, student-led initiatives are undertaken and supported by the program through the provision of high-resolution imagery donated by Digital Globe and the management of group tasks using the TeachOSM Tasking Manager.

The program is academic-sector-based and supports university efforts to offer meaningful global learning experiences, to build a socially engaged citizenry, to enhance long-term scientific capacity around the world, and to foster youth exchange and leadership. At the same time, YouthMappers activities also promote formal institutional approaches to open, volunteered mapping in universities, which potentially offer contributions to SDG 4 (education) (Solis, 2005). Faculty are encouraged to incorporate teaching of the open imagery and open mapping technologies and tools in their programs, whether by inserting new modules into existing geospatial technology courses, or following full-semester models that are project-based, service-learning dedicated special topics courses (Solis, 2016). Current efforts are underway to study the adoption of humanitarian crowdmapping teaching in universities of the YouthMappers network (Mueller and Solis, 2017; Solis and DeLucia, 2018). By virtue of the connections with multiple humanitarian, development, aid, and local organizations, the YouthMappers conducting participatory remote sensing offer the possibility of contributions to SDG 17 Partnerships for implementing sustainable development.

Specifically related to SDG 3 (health), YouthMappers undertook an extensive mapping task by adding residential structures in malaria stricken areas of East Africa to OpenStreetMap. These data improve inclusion in malaria spraying campaigns in affected areas but also supports aid organization to more cost effectively plan interventions (Kamanga et al., 2015). Spraying campaigns rely on credible knowledge of residential structures in order to plan for amount of pesticide,

Table 2
Summary of YouthMappers Campaigns and initiatives, April 2016–July 2017, mapped to UN Sustainable Development Goals. See also www.youthmappers.org/projects.

	PROJECT THEME	PARTNERS	DESCRIPTION	LOCATIONS	2 Zero Hunger	3 Good Health and Well-Being	4 Quality Education	5 Gender Equality	6 Clean Water and Sanitation	9 Industry, Innovation and Infrastructure	11 Sustainable Cities and Communities	12 Responsible Consumption and Production	16 Peace, Justice and Strong Institutions	17 Partnerships for the Goals
Global Remote Campaign	**Malaria Elimination**	USAID, Presidents Malaria Initiative, Humanitarian OpenStreetMap Team, Clinton Foundation, Peace Corps, Missing Maps	Malaria prevention and control is a major U.S. foreign assistance objective and critical for ending preventable child and maternal deaths for populations suffering	**Mozambique, Kenya, Mali, Botswana, Rwanda, Zambia, Zimbabwe, Cambodia, Laos, Guatemala, Honduras**		■	■							■
Global Remote Campaign	**AIDS Prevention**	USAID, PEPFAR (President's Emergency Plan for AIDS Relief)	The U.S. President's Emergency Plan for AIDS Relief (PEPFAR) is the U.S. Government	**Tanzania, Uganda, Kenya**		■	■	■						■
Global Remote Campaign	**Flooding Resilience**	World Bank, George Washington University, Red Cross	With support from GFDRR, the Red Cross Red Crescent Climate Centre, George	**Togo, Mozambique, Ethiopia**			■			■	■			■
Global Remote Campaign	**Hurricane Disaster Prevention and Preparedness**	Map the Philippines, NOAH	YouthMappers volunteered data for Map the Philippines (MapPH), an	**Phillippines**		■	■				■			■
Virtual Intern Task Group	**Volcanic Eruption Risk**	USAID GeoCenter and Office of Foreign Disaster Assistance	Sinabung is an active stratovolcano that has had consistent activity since 2010. The volcano poses a significant risk to those living in close proximity. Recent	**Indonesia**			■				■			■
Virtual Intern Task Group	**At Risk Dams and Reservoirs**	USAID GeoCenter, NASA SERVIR	The Lower Mekong Region is a diverse region that shares high vulnerability to flooding. Watersheds cross national boundaries and make planning for large	**Cambodia, Laos, Vietnam**		■	■		■	■				■
Local Capacity Building	**Community Resilience**	Humanitarian OpenStreetMap Team	Communities in the remote region of	**Uganda**			■				■			■
Local Capacity Building	**Lahar Hazard Risk Mapping**	Disaster Assistance	Nevado del Ruiz is an active stratovolcano that	**Colombia**		■	■			■				■
Local Capacity Building	**Peace and Development**	Initatives, Humanitarian OpenStreetMap	In light of the historic peace process underway	**Colombia**			■						■	■
Local Capacity Building	**Food, Economy, and Health**	University of Cape Coast, Texas Tech	The intersection of access to adequate food	**Ghana**	■	■	■				■			■
Local Capacity Building	**Urban Informal Settlements**	USAID, Map Kibera, University of Nairobi	Informal settlement in the large city of Nairobi	**Kenya**			■		■		■			■
Local Capacity Building	**Hazards and Vulnerability**	Bangladesh, Humanitarian OpenStreetMap	Bangladesh is vulnerable and at risk to extreme	**Bangladesh**		■	■							■
Local Capacity Building	**Basic Needs and Infrastructure**	USAID, Texas Tech University	Angola's low level of human development is	**Angola**			■			■	■			■
Local Capacity Building	**Food Insecurity**	Humanitarian OpenStreetMap Team, Khulna University, West Virginia University	This mapping project with Khulna University supported Feed the	**Bangladesh**	■		■					■		■
Local Capacity Building	**Disaster Preparation and Earthquake Response**	Disaster Assistance	In August 2015, Ecuador declared a state of	**Ecuador**		■	■				■			■
Local Capacity Building	**Let Girls Map**	Crowd2Map	Tanzania is one country with a high incidence of	**Tanzania**		■	■	■						■
Local Capacity Building	**Building Open Mapping Capacity for Risk Evaluation**	USAID, Institute of Science and Veterinary Medicine Dalaba, University of Nzerekore, General Lasana Conte University, Fouray Bay College, University of Liberia	Focused on training in remote and local mapping, this project is enabling students to learn to use open tools	**Liberia, Guinea, Sierra Leone**			■				■			■
Student-Led Initiatives	**Illegal Waste Dumping**	Digital Globe, TeachOSM, Federal University of Technology, Akure	Urban waste is one of the major threats to global environment and	**Nigeria**			■				■	■		■
Student-Led Initiatives	**Campus Infrastructure and Access**	Digital Globe, TeachOSM, Esri Panama, University of Panama	The Smart Campus project, carried out with the participation of the	**Panama**			■			■	■			■
Student-Led Initiatives	**Citizens in Informal Settlements**	Digital Globe, TeachOSM, University of Pretoria, Viva Foundation of South Africa	Informal settlements are densely populated, generally unauthorized	**South Africa**			■		■		■		■	■
Student-Led Initiatives	**Promoting Forest Conservation**	University, Costa Rica Corvocado National Park	This project aims to increase public involvement in the	**Costa Rica**			■				■			■
Student-Led Initiatives	**Open Geographic Data for Local Government Disaster Response Agencies**	Digital Globe, TeachOSM, University of Cape Coast	Mapping the greater Cape Coast metropolitan area was initiated as a	**Ghana**			■				■		■	■
Student-Led Initiatives	**Early Warning for Emergency Response**	George Washington University, Humanitarian Mapping Society, Rafael Landivar University	A Geography Masters capstone project at George Washington University presented an	**Guatemala**		■	■			■				■

numbers of workers, vehicle fleets and routes, budgets for gasoline and salaries, and other information. Accurate estimates are essential for effectiveness where mosquitos could simply relocate and the malaria vector would not be eliminated. The following section explores this case.

1.4. The case of participatory spatial data creation for SDG 3 health to aid malaria prevention

The prevalence of parasitic diseases like malaria is seen as a huge threat to economic improvement (Madsen, 2016) and sustainable development. The majority of malaria occurrences are in sub-Saharan Africa and Asia (Liu et al., 2015). In 2005, the US Government established a cross-agency Presidential Malaria Initiative (PMI), which includes USAID participation, with the goal of reducing by half, the number of deaths and burden of malaria in 21 countries of sub-Saharan Africa that are at risk (PMI, 2016; PMI, 2017a) (See Fig. 1). PMI's efforts protected about 16 million persons via indoor spraying of more than 4 million houses with insecticides, acquisition of preventive treatment to 21 million pregnant women, distribution of about 42 million long lasting insecticide-treated nets and 57 million antimalarial drugs in 2015 alone (PMI, 2017a). Various United Nations subsidiaries and other organizations like the Clinton Health Access Initiative and the Gates Foundation have been on the forefront of malaria eradication, yet in spite of their endeavors there still exists tremendous child mortality in sub-Saharan Africa where a higher ratio of under five deaths occur (Liu et al., 2015). Poverty in sub-Saharan Africa is correlated with high mortality rates in infants, under 5's and pregnant females, which sometimes are attributed to malaria illness (Worrall, Basu, & Hanson, 2005). The SDG 3 focuses on good health and wellbeing, especially with respect to infant mortality. Malaria elimination is among the expressly set targets, with sights set on full eradication by the year 2030. WHO's aggressive efforts toward malaria eradication have led to setting strategies with targets for elimination implementation from 2016 to 2030. Among the listed targets are (WHO, 2015):

- Reducing malaria case incidence by at least 90% by 2030
- Reducing malaria mortality rates by at least 90% by 2030
- Eliminating malaria in at least 35 countries by 2030
- Preventing a resurgence of malaria in all countries that are malaria free

1.4.1. Implementation considerations on open mapping for malaria prevention

Scaling up infectious disease prevention like malaria requires adequate reach to avoid missing targeted populations (Cohen et al., 2012). Unfortunately, many malaria endemic areas in the world are underprivileged, ravaged by poverty, have no accurate population data in smaller geographic units of resolution or, are completely missing on official maps. Elsey et al. (2016) highlighted flaws and shortcomings when relying solely on census data and household surveys for population enumeration, such as missing/incomplete information, long time

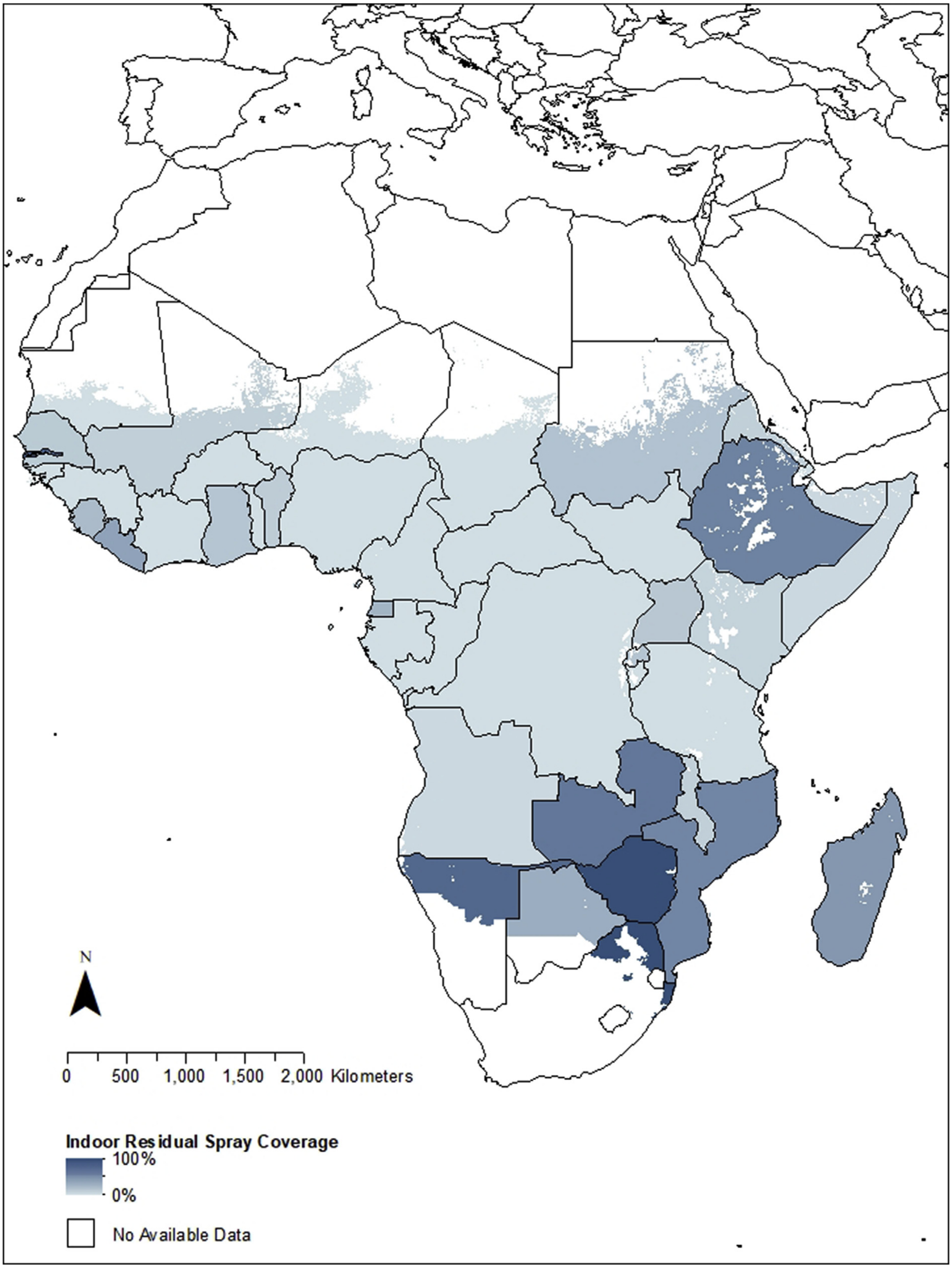

Fig. 1. Indoor Residual Spray Coverage in Africa for 2015. Data source: Malaria Atlas Project, Oxford Big Data Institute.

span between successive census collection, and omission of the poorest population. (Agarwal & Taneja, 2005). A typical census generates data on 10-year cycles, but, if a project requires current data on dwellers' households, or local infrastructure like roads, buildings and other features, a more timely substitute is required to ensure coverage and improve project effectiveness, which remote sensing derived vector information can provide.

1.4.2. Indoor Residual Spraying (IRS)

Over the past decade, there have been cautiously optimistic signs of

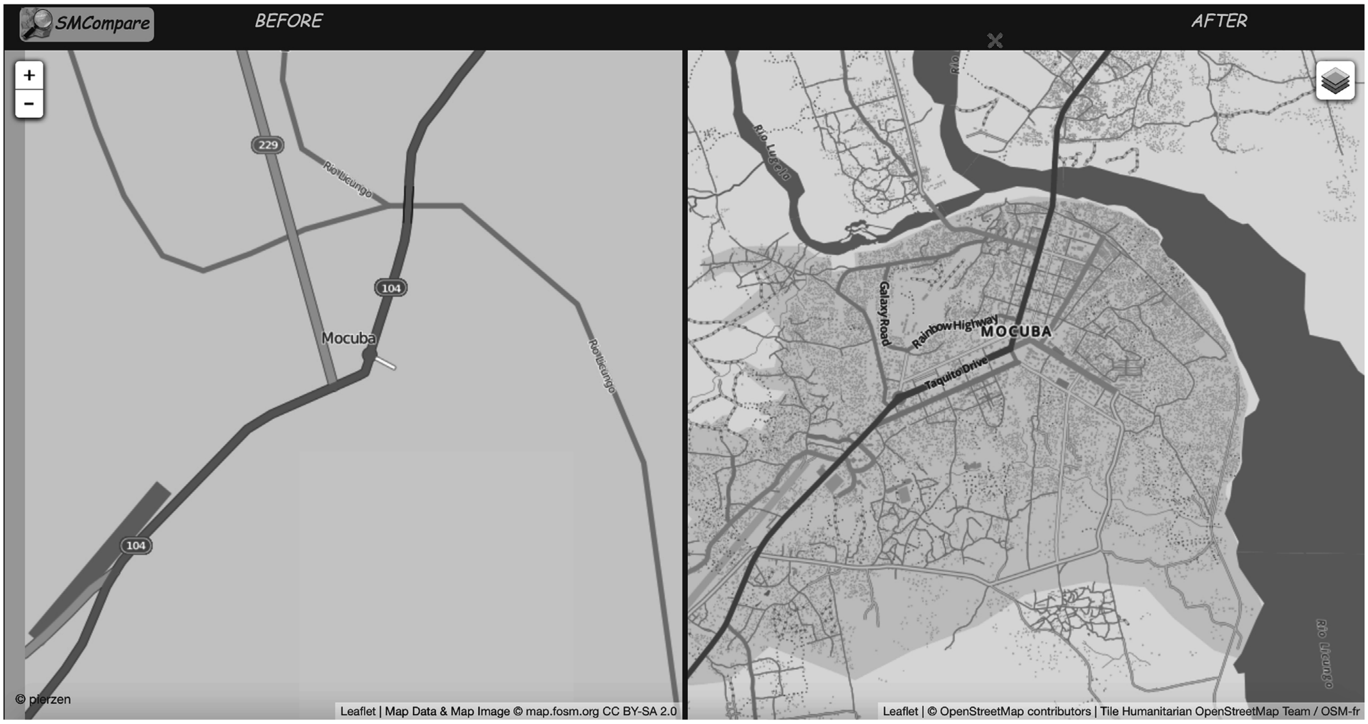

Fig. 2. Comparison of OpenStreetMap in Mocuba, Mozambique, before and after the malaria elimination campaign (2014–2018). Credits: http://pierzen.dev.openstreetmap.org.

a reduction in malaria prevalence in locations in sub-Saharan Africa (O'Meara, Mangeni, Steketee, & Greenwood, 2010). Reasons for the decline may be attributed variously to Indoor Residual Spraying (IRS), more widespread use of insecticide treated nets, and expanded treatment of presented clinical cases of malaria parasites (Bhatt et al., 2015; Pinder et al., 2015). Indoor Residual Spraying (IRS) involves the application of insecticide to the inside walls of a house to reduce breeding of female anopheles' mosquitoes responsible for malaria transmission. Walls are often the resting place of mosquitoes after sucking blood from its host. The latest available data (WHO, 2015) show 90 countries worldwide and 40 in Africa are incorporating IRS as a fundamental measure for exterminating mosquitoes and thus combating malaria (See Fig. 2). Achieving the WHO (2013a,b) recommended 85% inclusion of structures in any sprayed area is an integral part of scaling up vector control. Herein arises a need for spatial data on the actual footprint of all buildings, or at least 85% of them, as well as the roads that reach them, so that implementing partners can factor in vulnerable populations that may not appear on existing maps. Despite promising general reduction of the disease, Bhatt et al. (2015) shows persistence in rates of prevalence in children, aged 2–10 years and areas of persistent continued incidence. These patterns can be compared to the present extent of IRS coverage and bed net distribution coverage. These locations also tend to have poor open, publicly available geospatial data on basic infrastructure– particularly the locations of buildings and roads (Anderson & Chandonait, 2014).

At a local scale, PMI (2017b) reported high levels of malaria epidemic in Kenya Nyanza Province, which forms part of our study area. The study area, Migori District located in Nyanza province, has experienced persistent high prevalence rates, attributed to proximity to the river.

1.4.3. Mapping tasks

Tasks to be mapped were assigned to YouthMappers by the USAID GeoCenter using the Humanitarian OpenStreetMap Team (HOT) tasking platform to coordinate large numbers of remote volunteers. The tasks cover three divisions in Migori County of Kenya and five districts in the Zambezi province of Mozambique. Using these tools, YouthMappers were able to identify and capture building footprints by tracing rooftops, while roads were identified by drawing center lines and tagging the road types according the OSM Wiki with specific tags/classifications for African Roads.[5] YouthMappers members organized mapathons to speed up the mapping process.

The task areas in Mozambique and Kenya focused on the following sites:

> ***MILANGE DISTRICT***: Milange, Derre, Morrumbala, Molumbo, and Quelimane are located near 16°5.810′S, 35°46.325′E, in Milange district in North East, Zambezi province, Central region of Mozambique. Mozambique as a country is endemic to Malaria with about 23 million of its population at risk, where 29% of all deaths in the country are attributed to malaria, of which the most affected are children under 5 years of age (Anderson & Chandonait, 2014). Milange district is one of the most endemic districts in the country (Abílio et al., 2015).
>
> ***MIGORI COUNTY***: Migori county, located in Nyanza province is situated in western part of Kenya. Three divisions were mapped in the county, Uriri, Suna East, Suna West and Rongo. Fully one hundred percent (WHO, 2014) of 48.6 Million (US Census Bureau, 2015) in Kenya's population are at risk of malaria with Nyanza province being most endemic, owing to its close proximity to Lake Victoria as well as being a low-land area (PMI, 2017b).

1.4.4. Mapping results: production scale of participatory remote sensing

In order to keep metrics on the edits created by volunteers, we developed a hashtag (also known as a "changeset comment") for tracking our mapping progress: #YouthMappers, and embedded this into the task itself. The data metrics were collected every 30 days using a third-party open source analytic tool, to check the number of contributors, buildings and nodes both created and modified (Neis, 2017).

[5] http://wiki.openstreetmap.org/wiki/Highway_Tag_Africa.

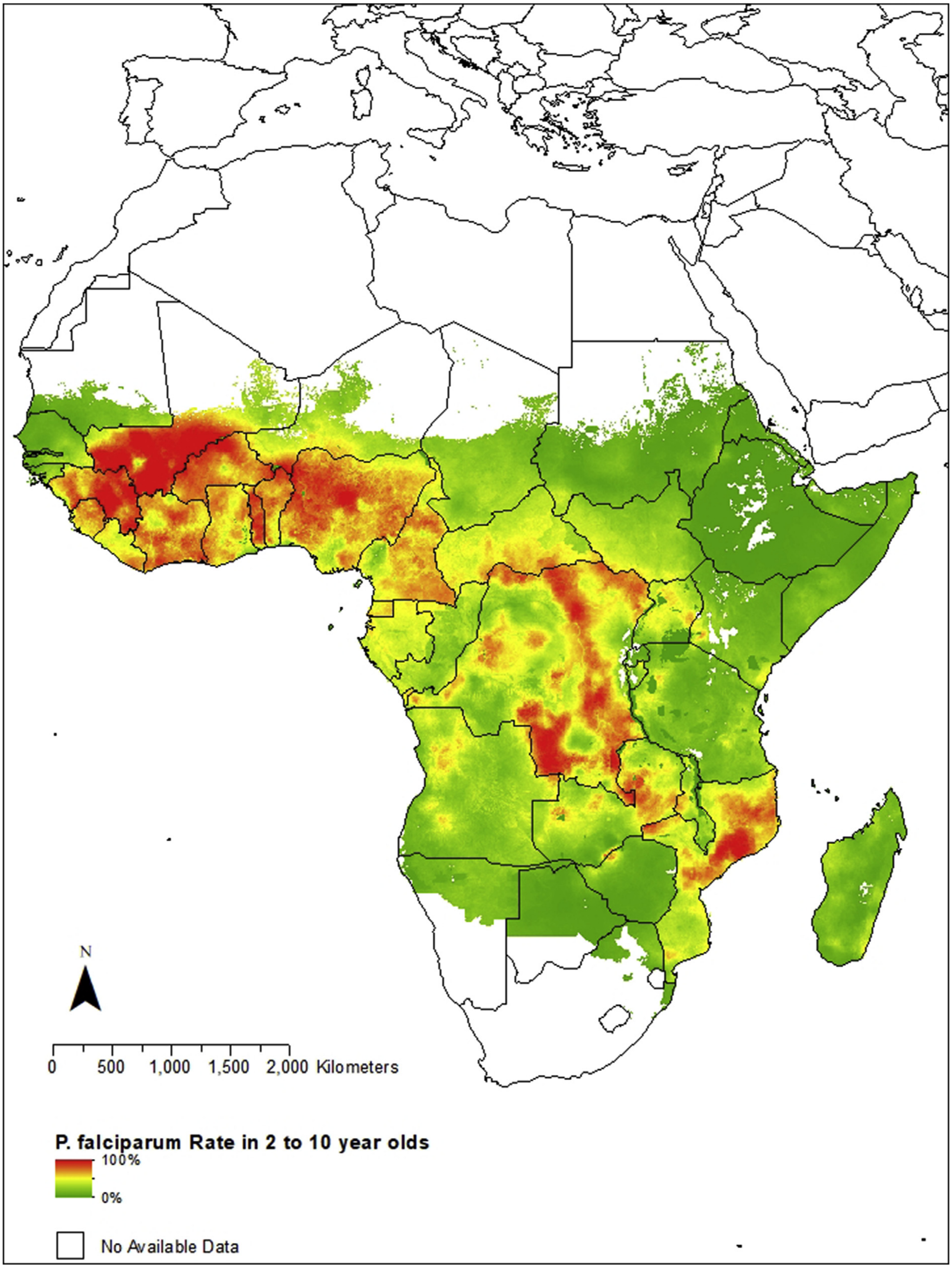

Fig. 3. Rate of incidence of Plasmodium falciparum, species responsible for causing malaria, indicating cases per 1000 people in Africa in 2015. Data source: Malaria Atlas Project, Oxford Big Data Institute.

Data metrics indicate thousands of contributors and millions of map changes made over a period of five months. The map changes comprise all features added in the map which are buildings, roads, water ways, land uses or other features, indicating the level of complexity of the mapping (e.g. the number of nodes for a simple square building would be four corners, but an irregular polygon shaped feature require a higher number of edits.) August recorded the lowest number of contributors because universities are not normally in session during that period.

It is pertinent to note that there were little or no features at all in any openly accessible map of the study areas prior to these mapping tasks (see Fig. 3). To better understand the input of the YouthMappers, the HOT OSM analytics tool[6] was used to visualize and track real time progress. Fig. 4 shows the state of the map features before and after the mapping of a sample of these study areas.

1.4.5. Mapping results: data utility estimates

To understand the utility of this methodology in this applied case, we ask first, does mapping improve the completeness coverage of existing, remotely observed structures relative to projections derived from non-spatial sources like the census, given that spray campaign effectiveness relies on good coverage of the target area? Second, what is the error rate relative to the amount of data produced, and how does this compare between the locations in our study area versus other VGI mapped locations?

As shown in Table 3, we find that the participatory remote mapping in all cases clearly estimates a much larger number of buildings than traditional sources would indicate, as calculated for the Kenya task, where population estimates at smaller spatial units are available. All visible buildings are mapped from satellite imagery, but not all buildings are sprayable structures, e.g. locations where people sleep or reside in the evenings when mosquito vectors for malaria are active. These differences raise additional questions on accuracy that could only be addressed though massive, small-scale field verification, which was not feasible in our study. For the present assessment of the methodology, we can conclude that participatory remote mapping enables an extensive inventory of infrastructure, although the attributes of type of buildings must be completed through other means.

Secondly, given the critical nature of data utility, YouthMappers promotes proactive remote verification of all tasks upon completion. The HOT Tasking Manager allows for a second pass by more experienced users. Using another third-party open source error analysis tool[7] we performed a post-check analysis in order to identify remaining computer-detectable errors. Table 4 compares each task by the number and kind of errors detected within a square kilometer sample digitized in the middle of each of the five mapping tasks in Mozambique and Kenya. As a comparison control, a random number generator of latitude and longitude in the general vicinity of the mapping rendered a list of locations to choose as control. Among them, locations where known YouthMappers or Humanitarian OpenStreetMap Team task activity has been registered were disqualified, as where there was not yet any mapping done. These 8 locations were verified as malaria hotspots on the same order as our tasks using the prevalence map. To control for divergence, we removed the highest and lowest records of errors in the means calculation. The remaining 6 sites were averaged to compare to the tasks. Table 4 shows that YouthMappers tagged tasks in the region overall contained somewhat fewer types of errors than at-large mapping sites. This is likely due to the limited nature of the assignment being to only map buildings and roads. Error rates per building are very similar across all three sample sites (0.0082 in Mozambique, 0.0036 in Kenya, 0.0057 for the control site).

Possible limitations to this error analysis include that control sites were quite limited and may not reflect an appropriate overall quality target. There may be a scale factor in the errors which we did not measure by virtue of using a sample. Also, mappers using the hashtag #YouthMappers may not exclusively represent students, since the tasks were open to HOT users, a flaw in the method of using hashtags in the changeset comments rather than OSM usernames to track errors. Nevertheless, returning to our two original questions, we draw the preliminary conclusion that the participatory remote mapping approach can help scale up the process of revealing missing coverage of infrastructure data, and that the error rate of the results produced with YouthMappers students are at least on par with other VGI volunteers.

2. Discussion and lessons learned

The YouthMappers experience with participatory methodology reflects concerns similar to those expressed in the relevant literature on PGIS and VGI as mentioned above, and provides a unique opportunity to consider these concerns as they relate to the potential for scaling up participation with the purpose of addressing global targets like the SDGs. We explore this set of issues in terms of data quality, data utility, and ultimately data participation.

Technological advancements in web services have indeed increased the scope of human presence in creating and distributing data online (Van Exel & Dias, 2011), and YouthMappers have participated in that reality. Now, more quantities of data and more up to date data are obtainable through VGI than national mapping agencies and authorities are able to produce in traditional ways (Bégin, Devillers, & Roche, 2013; Mashhadi, Quattrone, Capra, & Mooney, 2012; Mooney, Sun, & Yan, 2011). As such, VGI could be considered as an innovation in sustainable development governance with a shift from state dependence to many actors due to urgencies (e.g. disasters) and limited state funds (Agrawal & Lemos, 2007). However, perspectives from the development community justifiably question the quality of OSM data (Currion, 2010; Weingarten, 2010). As one of the leading VGI platforms in the world, OSM has been intensively evaluated to mixed results about quality as defined in various ways (e.g., Haklay, 2010; Haklay, Basiouka, Antoniou, & Ather, 2010; Mooney & Corcoran, 2012; Hacklay, 2013; Foody et al., 2013; Barron, Neis, & Zipf, 2014; Ballatore & Zipf, 2015). For volunteers in humanitarian projects in particular, Porto de Albuquerque, Herfort and Eckle (2016, p. 1) showed that volunteers achieved "satisfactory overall performance (accuracy: 89%; sensitivity: 73%; and precision: 89%)." Likewise, through our work on malaria prevention, we have shown that the scaled up network of students focused on a development purpose related to the SDGs performs at least as good as any OSM volunteer at large. This may be encouraging at the same time that it prods us to research how to not only further improve data quality as traditionally measured, but also how to rethink what is meant by data quality.

Some scholars are seeking alternative quality metrics through such means as "fitness of purpose" tests (Wentz & Shimizu, 2018), in ways that privilege how the data are used over abstract technical attributes of fidelity. For volunteer humanitarian mapping applications such as ours, this means the value of the data and its end use could be a more appropriate parameter that drives tolerance for error or imprecision in VGI data. Thus, data utility remains of utmost interest, but has not yet been fully resolved. Continual monitoring, training and quality control are necessary, as is close communication with development actors who ultimately intend to use the spatial data produced. The design of the methodology in use by YouthMappers accounts for these ties with dedicated attention from USAID and end users of the OSM data created. In practical terms, this means we thoughtfully consider the explicit analytical processes by which open spatial data can influence development decisions, taking advantage of cross-sectoral and international perspectives from the beginning of the process.

However, even with a robust conceptual framework using the highest quality, complete data, identified as having utmost utility, the process of moving towards better decision-making is not automatically guaranteed. Despite increasing amounts of readily available data, or perhaps because of it, a myth has emerged that having data, particularly large data sets, offers better or more advanced knowledge than was previously possible, and this leads uncritically to novel insights based on accuracy and objectivity (boyd & Crawford, 2012). This persistent misconception is likely due in part to the prevailing idea that an uninterrupted chain exists leading from data to information to

[6] http://osm-analytics.org/.

[7] http://osmose.openstreetmap.fr/en/map/#.

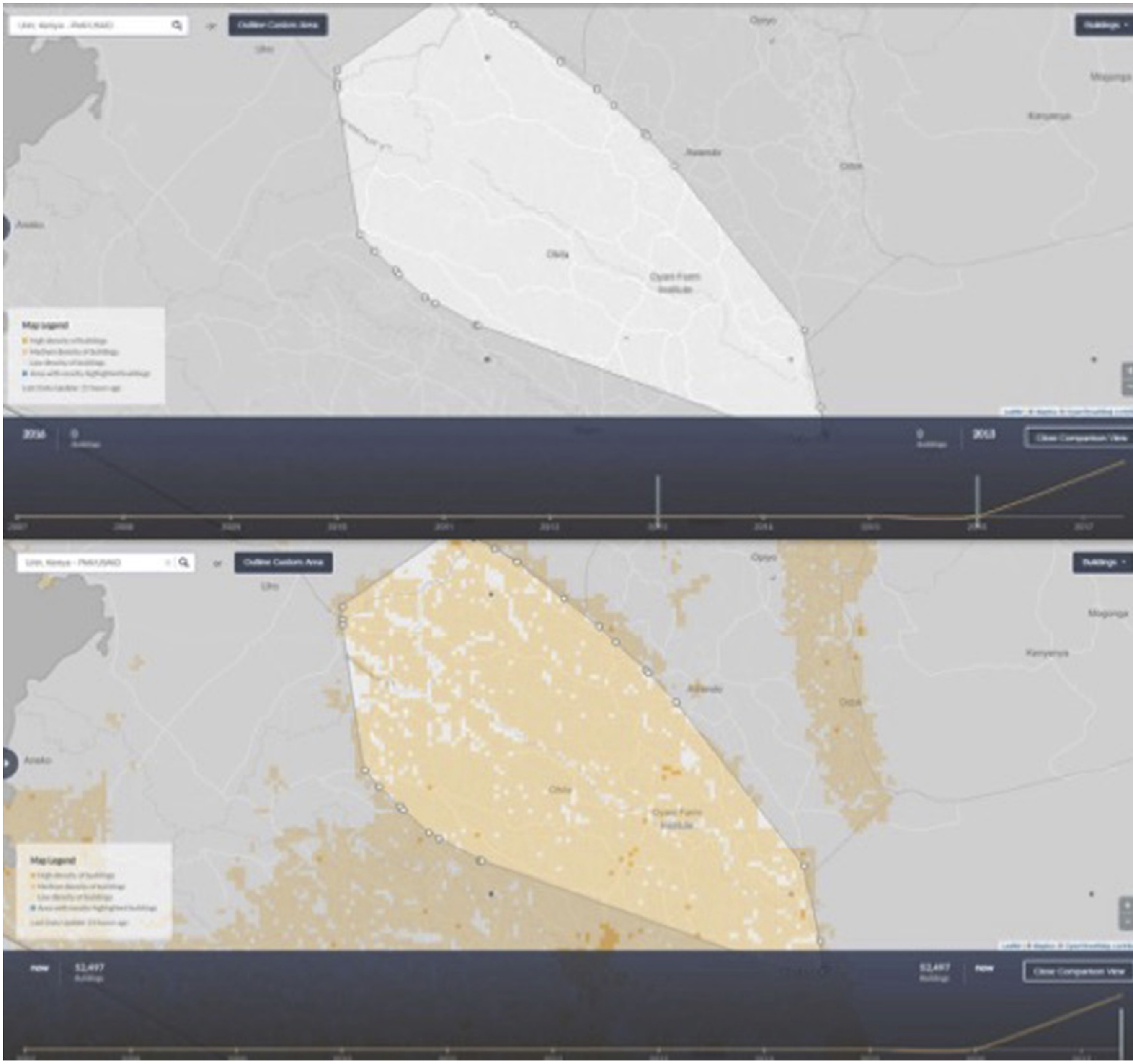

Fig. 4. Uriri Kenya Task before and after mapping (2014–2018). Credits: http://osm-analytics.org.

Table 3
Comparison between estimates of buildings for malaria prevention control derived and counted from OSM.
Source: Migori County public health offices and Abt Associates, Inc.

Corresponding Mapping Task	KENYA	Population	Projected Population	Households	Projected Households	Structures (est.)	Structures (est.)	Structures Added to OpenStreetMap	
	SUBCOUNTY	2016	2017	2016	2017	2016	2017	2015–2017	*% difference*
C.	Uriri	142,844	147,201	26,106	26,902	36,548	37,663	52,497	39.4%
D.	Suna East	119,853	123,509	21,905	22,573	30,667	31,602	57,114	80.7%
E.	Suna West	116,158	119,701	21,229	21,876	29,721	30,627	49,762	62.5%
SUBTOTAL		752,987	775,953	137,618	141,816	192,666	198,541	159,373	59.5%

knowledge to wisdom (Ackoff, 1989; Cleveland, 1982; Cooley, 1980; Frické, 2009; Sharma, 2008; Weinberger, 2010). Now taken for granted, the hierarchy has been abbreviated by proponents of the "data revolution" who give short shift to the process, or conflate the chain altogether, simply as "data to decisions" (UN, 2014; Stuart et al., 2015, p. 51). As Cowell and Lennon's meta-analysis shows (2014:263), "actively cultivating wide stakeholder buy-in" to new approaches "may secure wider support, but not necessarily translate into major influence on decisions". One of the most critical current challenges of harnessing the data revolution related to decision making has to do with the spatial

Table 4
Summary of error analysis on Mozambique and Kenya mapping tasks.

Sample site	A Milange	B Milange	**Mozambique Subtotals**	C Uriri	D Suna East	E Suna West	**Kenya Subtotals**	**YouthMappers Totals**	**Control Sites Average**
Feature Error Share of Total Errors	79.5%	57.7%	**47.7%**	78.9%	82.8%	73.0%	**80.0%**	**68.5%**	**64.8%**
building overlaps	3	2	**5**	8	52	24	**84**	89	52
highway vs building	23	13	**36**	1	9	-	**10**	46	159
almost junction	2	10	**12**	2	19	14	**-**	47	8
bad intersection	25	8	**33**	1	-	1	**-**	35	6
waterway	5	3	**8**	1	-	1	**-**	10	26
other feature error*	-	5	**5**	2	2	6	**10**	15	14
Tag Error Share	20.5%	42.3%	**52.3%**	21.1%	17.2%	27.0%	**20.0%**	**31.5%**	**35.2%**
Tagging	15	30	**45**	4	17	10	**31**	76	144
Number of error types	6	7	**8**	6	5	6	**7**	9	14
Total Errors	73	71	**86**	19	99	37	**155**	241	409
Estimated buildings	4,081	6,446	**10,527**	14,905	24,856	3,831	**43,592**	54,119	71,838
Error Rate/Bldg	0.0179	0.0110	**0.0082**	0.0013	0.0040	0.0097	**0.0036**	**0.0045**	**0.0057**

scale for decision making and governance (Juhola & Westerholf, 2011; Measham, PrestonSmithBrookeGorddardWithycombe, & Morison, 2011). As an effort in collective action, certainly the SDGs are challenged by these same issues of data availability, quality, decision-relevance, and space-time scale.

Yet the online open map can still be where the public, and public institutions meet around data. Geographic knowledge and spatial perspectives can lend innovative frameworks for conceptualizing complex problems and integrating diverse contributions among widely diverse sets of actors. As a visualization technology, participatory mapping can support greater understanding of connections among places, the people living in them, and the phenomenon arising from global change, in ways that people ranging from scholars to youth to policymakers can quickly grasp. But to achieve this, the framework must be explicitly designed in ways that promote “engagement with the crowd versus passive data collection” (Roberts & Doyle, 2017, p. 121). Despite that our approach is designed to accomplish this, we remain concerned about the uptake of YouthMappers data for actual decision-making (Light & Allen, 2015, p. 376). Two issues emerge here. First, because such data pass through so many parties, it is often very difficult to know if such data are used in actual national or international decision-making and if so how much data are actually communicated to decision makers. In the process of policy making, volumes of data are often reduced to specific data points. Additionally, data are only one factor in decision-making. Policy makers have to consider budgets, timelines for implementation and a plethora of other concerns. While we understand that there is not a direct link between creating data and making decisions, there is much to learn about how that process ingests data, how much is used, how it is communicated to non-experts, and how decisions are eventually made. A clearer understanding of how such data affect decision-making in the context of SDGs needs much more clarification and study. Even if our first concern is addressed fully, we then need to know about the interconnections between other sectors that contribute to any given SDG and how these various sectors influence the achievement of a goal. For instance, SDG 3 on health is not simply achieved through health interventions alone. Reducing malaria requires environmental interventions to reduce standing water, education on prevention and treatment, infrastructural development, and many other types of covariate interventions. The role of data in answering these questions are varied, but the ways in which such data come together as a whole to address such complex issues needs further study. How, for instance, does spatial data created in our case study form one point in a complex dataset needed to address SDG 3? What is effective? What is convincing? Further research is needed for future participatory spatial data creation activities to increase their chances at contributing useful data to that will ultimately help decision makers meet the SDGs. YouthMappers is well poised to add to that literature with future research.

Finally, it seems clear that public participation in spatial data creation has empowered citizens to provide knowledge and context to open map resources (Goodchild, 2007), but the notion of “empowerment” in such research remains hotly contested (Corbett, Cochrane, & Gill, 2016). This may be due at least in part to lack of accounting for the social and political practices implied in creating spatial data (Elwood, 2008). For our own work, we must acknowledge concern of the ethics of utilizing unpaid volunteers and mapping in sensitive locations. The use of unpaid volunteers to create data that would otherwise be a task for a paid expert raises several ethical issues including exploitation of the volunteer, employment dampening in the professional field, and reliance on marginalized individuals (e.g. students in the developing world). YouthMappers has tried to ameliorate some of these ethical issues by supporting fellowships, local capacity building grants, and workshops for active students. The use of volunteers can be exploitative if individuals feel compelled to contribute time to tasks, something that the network expressly forbids. Volunteers, however, do act on their own free will and many believe that the networking experience they receive is of significant enough benefit to warrant their free labor. The organizers of the network are cognizant, however, of such dangers and measures are in place for reporting issues. An ethics statement adopted by youth leaders of the network also helps to provide express guidance to the community for these and related concerns (Cowan, McCusker and Solis, 2017).

A related ethics issue, dampening professional employment through the use of volunteers, is certainly a serious concern. This could be a problem should VGI activities *supplant* rather than *supplement* existing data/knowledge. Careful consideration should be paid to ensure that volunteers are not undermining formal employment prospects, particularly in the developing world where such prospects are already few in geographic fields, and opportunities for entrepreneurial activities should be expressly supported.

As a network, YouthMappers has had to decline requests for chapters in countries where volunteer mapping is prohibited by law or presents a significant risk to the volunteers themselves. Chapters are routinely advised not to map sensitive locations, disclose sensitive areas defined either in law or local customs and are forbidden by the projects Institutional Review Board protections on human subjects.

The challenges of growing and nurturing a community that volunteers and participates in these ways go beyond maintaining quality data contributions at the quantities demanded. They also include how to offer critical and meaningful learning experiences through a widely distributed network, how to structure programming in gender inclusive ways that do not underscore colonial histories, and how to sustain the engagement of peers.

3. Conclusion

In this paper, we have proposed a methodological approach in which a multi-university project using PGIS and VGI have helped to support spatial data needs related to the UN's SDGs for developing countries. While the project is relatively recent, it has already built student capacity for mapping and provided data for a variety of development projects aimed at health, poverty reduction, and disaster relief and recovery. It has effectively consolidated a youth movement to contribute to humanitarian and development needs by creating open spatial data at a global scale. Acknowledging the shortcomings identified in our work in this study, and explicitly attempting to design a potential way forward for a quality, embedded approach to participatory remote sensing, we reflect on our experiences with the YouthMappers program and the 'birds eye view' of the place of such efforts in advancing human development. By explicitly teaching and researching this struggle familiar to VGI, PPGIS, we continue to build upon the endeavor to understand how to engage people to use geospatial technologies motivated by sustainable development objectives. We wonder, at what point does the ubiquity of geospatial technologies in the hands of volunteers exceed a threshold that could scale sufficiently to result in a power shift, and might that shift help to accelerate contributions across the SDGs by virtue of such empowerment?

Conflict of interest

The authors have no competing interests to declare.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.apgeog.2018.07.013.

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