Chapter 12
Comparing Volunteered Data Acquisition Methods on Informal Settlements in Mexico City and São Paulo: A Citizen Participation Ladder for VGI

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Abstract In the early 2000s, Web 2.0 technologies prompted an explosion in geographic data that include Volunteered Geographic Information (VGI), a set of methods that brings user contribution to the center of data acquisition. These methods increase the capacity of community-driven and local initiatives to create geographic information and close existing data gaps in authoritative sources. Informal settlements constitute an example of where a major vacuum exists, as maps are often incomplete, outdated, or imprecise. However, quality issues regarding VGI frequently arise, as do questions on citizen participation and empowerment. This study explores how different VGI approaches support citizen participation and user empowerment, in tandem with the opportunities and limitations of VGI to map informal settlements in Latin America. We propose a VGI comparison framework to evaluate citizen participation in two informal settlement mapping projects in São Paulo and Mexico City. Such a framework includes four categories: (1) required material resources; (2) required geographic information system (GIS) literacy; (3) user agency; and (4) involvement of research subjects. The results demonstrate that higher citizen involvement in São Paulo stems from the inclusion of residents through participatory mapping methods. Conversely, the Mexico City's case demonstrates how crowdsourcing may happen irrespective of and contrary to the goals from those represented in the data. We suggest that VGI is a powerful tool for generating timely and precise data on informal settlements, but research subjects should have agency over geographic information collected about them.

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1 Introduction

From the early 2000s, there was an explosion of available geographical information made possible by Web 2.0 technologies, including Volunteered Geographic Information (VGI). VGI is a set of methods based on users' contributions to the acquisition of geographic information (Goodchild 2007). With the introduction of VGI, consumers of geographic information (formerly passive) can become active data producers. These methods marked Geographic Information (GI) production, which transitioned from being highly technical and opaque to the average citizen to become a synonym of inclusion in an increasingly digital society. This transition took place due to the advent of geotagged big data, characterized by the ubiquitous use of global navigation satellite systems (e.g., GPS), the surge in geo-marketing, and the massive adoption of personal location sensors (Sui et al. 2013b; Yan et al. 2020). Despite the undeniable advantages of the availability of GI, this explosion of data generation brought about problems such as unwanted surveillance and breaches of privacy (Bertone and Burghardt 2017), including commercial use and political misuse of volunteered information (e.g., the Cambridge Analytica scandal) (Sharma 2019), and unwarranted governmental or private surveillance (Ricker et al. 2015).

One response to the privacy and data-ownership concerns is to take control of the means of production, editing, and dissemination of information. Open and free data activism, along with collaborative stances at intellectual production (e.g., collective intelligence, peer-production, co-creative labor), constitute efforts in this direction (Yan et al. 2020). VGI falls within this scope, most notably because of its emphasis on blurring the boundaries between users and consumers of information that create, enlarge, review, and otherwise contribute to the information. Examples of this phenomenon encompass open GI platforms such as OpenStreetMap (Harvey 2013). VGI presents a hybridization of roles between those who record and collect GI, those who use it, and those represented by it. This relationship is not inherently fairer, but the distributed ownership and agency provide active roles to citizens that otherwise would be passive subjects in the different mapping efforts.

This chapter adopts a broad definition of VGI, which includes participatory, collaborative, and open-sourced GI methods. By doing this, we deliberately opt not to break VGI away from techniques such as Public Participatory Geographic Information Systems (PPGIS), as proposed by some authors (Verplanke et al. 2016). Instead, we explore the differences between techniques within a mapping methods spectrum, in which participation is in the center.

This chapter presents a study on the application of VGI to map informal settlements in Latin America. The questions that structure this research are: *(1) How do different VGI approaches support citizen participation and user empowerment? (2) What are the opportunities and limitations of VGI in mapping informal settlements* *in Latin America beyond current authoritative data acquisition procedures?* These questions stem from the realization that authoritative sources such as registries, census, or urban planning documents do not adequately portray informal, illegal, peripheral, or otherwise deprived settlements. A recent stream of community or volunteer-driven mapping experiences made possible by Web 2.0 interaction creates novel GI sources, closing some existing gaps in authoritative data sources. These applications also present issues of empowerment, privacy, and citizenship, on which this investigation focuses. Methods and tools employed within the VGI spectrum directly impact citizen participation and empowerment (Corbett and Keller 2005; Reynard 2018), which are two of its main premises and require clarification. To address these issues and clarify differences in terms of methods and expected outcomes of VGI, we propose a framework for assessing citizen participation in VGI and applying it to two case studies: peripheral urbanization in Mexico City, and participatory mapping in inner-city slums in São Paulo. The novelty in this research resides in our focus on user empowerment as the driver for a user participation ladder in VGI.

This chapter addresses citizen participation and empowerment questions from a comparative perspective in the VGI experiences and research spectrum. The following section provides an overview of the theoretical questions regarding user participation in VGI and the lack of data on informal settlements. The methods section presents a comparison framework for VGI applications based on citizen participation that collects environmental and socioeconomic data in these settlements at varying resolutions. In the results section, we present the analysis of two contrasting case studies using the citizen participation framework. The discussion section reflects on the breadth of the VGI spectrum, notably the empowerment of users, volunteers, and citizens through the VGI applications. It also discusses the potential of VGI to provide high-quality GI about informal settlements in developing countries. We conclude with remarks on the necessity of interdisciplinarity and participatory processes in research and policy development, most notably when socioeconomic inequality is a relevant factor.

1.1 Lack of Information about Informal Settlements

VGI presents advantages to GI's democratization, most notably through a more equitable data acquisition's distribution and by reducing the distance between producers and users of GI. As with other Web 2.0 technologies, it dramatically expands the role of information in everyday life for millions of people, which increases the pace at which data are produced and used (Sui et al. 2013b; Yan et al. 2020), as seen in location-based devices. However, despite the increased integration predominant in the developed world, differences persist across regions and demographics. Overall, men have more facilitated access than women, and developed economies present much better access than less-developed countries (LDCs, as defined by UN-DESA 2021). Men in developed countries would be the upper end of the technology accessibility spectrum, as close to 90% of them have access to the web. At the opposing end, only 14% of women in LDCs have access to it (International Telecommunications Union 2019). This stark contrast exemplifies the differences in place, gender, income, and other socioeconomic factors that determine the ability to access, produce, and disseminate GI (Corbett and Keller 2005; Sui et al. 2013b).

At the urban scale, the most vulnerable areas are frequently under-represented or absent from official sources (Souza 2012; Camboim et al. 2015; Kuffer et al. 2018; Mahabir et al. 2018). Deprived areas, such as slums, squatters, or informal settlements, often miss key geographic features in commonly available data sources (Hachmann et al. 2018). The missing elements may be settlement size, incomplete boundaries, total population, number, and location of buildings and enterprises (Patel and Baptist 2012; Hachmann et al. 2018). Initiatives such as Missing Maps (Scholz et al. 2018) and the Muungano wa Wanavijiji Non-Governmental Organization (NGO) (Lines and Makau 2018) seek to counter these problems and demonstrate the breadth of existing challenges. The lack of cartographic representation of socially vulnerable settlements furthers their symbolic and physical exclusion. The lack of cartographic information may present severe challenges for research and policy, may hinder development and access to fundamental civil rights (Patel et al. 2012), negatively influence self- and outside perception of communities (e.g., in political instances) (Corbett and Keller 2005), and lead to biases against communities (Watson 2009).

In this context, our research helps level off the playing field by increasing data transparency. It provides NGOs, public institutions, international organizations, and researchers with a straightforward way of visualizing irregular settlements' structure and spatial dynamics (e.g., urban expansion) over time. We assume that transparency promotes good governance and fair transactions. When information is not openly available, local elites' incentives for exploitation and opportunistic behavior increase (e.g., due to control of information such as land market dynamics, regulations, and political clout). Currently, available information about the conditions and dynamics of informal settlements is not sufficient or robust, which politicians and local officials routinely mismanage or exploit (Rodriguez Lopez et al. 2017a).

At the community level, the lack of data commonly means underrepresenting a population, its business, culture, and assets (Corbett and Keller 2005), increasing the difficulty to access credit, for example. Land tenure is a critical issue, as the lack of tenure rights often stems from outdated or incomplete registries. These issues may stoke conflicts (Hachmann et al. 2018), sapping long-term agency from communities and endanger small-scale businesses and services (Patel et al. 2012). When population or household data are missing, public infrastructure planning often underestimates the demand for services and investment. Public and private interventions also face increased uncertainty. Planning is less precise, procurement and contracting often occur based on broad assumptions, and projects need longer development cycles, as they compensate for inexistent essential information (Pedro et al. 2017; Pedro and Queiroz 2019). In these cases, the costs for implementing public goods or services increase and public officials often divert resources from the desired results to the initial phases of planning.

From the city management perspective, it is notorious that the lack of information severely hinders urban planning (Zhang 2019). Along with political and economic factors, lack of information and the limited cognition caused by it, fuel a *tabula rasa* approach to design. In this approach, urban master plans and spatial projects often circumvent, exclude, or seek to replace informal settlements entirely (Watson 2009). Strategic policies are frequently ineffective when essential information is missing (Patel et al. 2012), especially when considering the undocumented and dynamic nature of land-use in informal settlements that challenge conventional land-use tools like zoning and cadastral plans (Hachmann et al. 2018). The lack of information may lead to misconceptions, creating myths or partial truths that disrupt public policy effects or make them poorly adapted to the intended population groups (Patel et al. 2012).

The lack of demographic data and GI on informal settlements also has negative public health implications. For instance, coarse spatio-temporal resolutions of health and demographic data challenges the implementation of targeted interventions to prevent or mitigate outbreaks (WHO 2010; Elsey et al. 2016). In addition, the informal settlements' socioeconomic and spatial characteristics exacerbate the risks of communicable and non-communicable diseases (Ezeh et al. 2017; Corburn et al. 2020). Physical and social factors are key health determinants (Barton and Grant 2006). In this sense, combining the georeferenced settlement and health data becomes crucial to plan effective interventions (Friesen et al. 2020). Poor health data (e.g., coarse, lacking precision or outdated) significantly challenge planning and implementing interventions that are critical to tackling urban health inequities.

In this regard, monitoring systems that provide longitudinal data on slums (e.g., NUHDSS in Nairobi, Kenya) play a critical role in health decision-making at the intra-urban scale by providing health data with the appropriate spatio-temporal resolution. Monitoring systems like these can benefit from VGI by integrating local communities' contributions, which may provide critical insights to combat health emergencies like the COVID-19 pandemic, for example. Furthermore, much of the literature focuses on the spatial-time scan (e.g., the nature of the non-linear dynamics), early warning systems (Hohl et al. 2020), or resilience (Scheffer et al. 2001, 2012). At the same time, there is a lack of research addressing changes that affect the structure of social and environmental systems (i.e., irreversible regime shifts). The COVID-19 pandemic, for example, presents regime shifts in many critical areas (e.g., health, social interaction, policy, political debate, among others). VGI could complement existing information and work in tandem with other sources of information to represent system states and processes with increased spatial and temporal resolution. These improvements can play a significant role in the coming decades, notably when considering populations often missing from official sources (e.g., the squatters, slum dwellers, and others).

1.2 Citizen Participation in VGI

This work proposes a description of the broad spectrum of VGI techniques and methods from the perspective of citizen participation, focusing on user agency. This stance emphasizes the "volunteered" in VGI, which is essential in differentiating this group of techniques from other processes of geographic data acquisition. To this end, we must define user agency in the context of VGI. This chapter defines agency as the capacity to exercise control over one's thought process, motivation, and action. This definition encapsulates the cognitive processes of imagining what one wants to implement, being motivated to do so, and believing in one's capacity to implement it without suffering too steep adverse effects or costs in the process (Bandura 2001). In the context of VGI, agency translates into understanding GI to the point of identifying oneself as an agent (either a producer or editor of information) and believing in one's capacity to register or to analyze GI with the available means once the motivation to do so exists. The trade-offs involved in this definition of agency in VGI pitch technical capacity (Robinson et al. 2017), on the one side, and motivation to use or create GI on the other (Verplanke et al. 2016).

The recent evolution in GI effectively demonstrates how decreased technical barriers to data production (e.g., Web 2.0 technologies) sparked a flow of interactive production of information, breaking the virtual monopoly of specialists over GI (Zhang 2019) and creating VGI (Goodchild 2007). In this process, the advent of participatory mapping tools and methods increased users' perceived capacity to create new information by themselves. This capacity increase led to more ambitious goals from users, generating new solutions that further challenged previous restrictions in GI authorship.

VGI is still arguably torn between its contributors' active or passive character (Haklay 2013; Zhang 2019), despite user agency's importance in its evolution. Passive approaches analyze the digital spatial footprint from research subjects (e.g., geotags from social media) independently from their control (Yan et al. 2020). Intermediate approaches include crowdsourcing efforts (e.g., Missing Maps, Wikimapia, and OSM) that help eliminate gaps in mapping, but their goals are not necessarily participation per se, but the data generated by them (Sui et al. 2013a). Direct subject involvement is the mark of active approaches. Participatory mapping and PPGIS (Harvey 2013; Zhang 2019), such as Slum Dwellers International (SDI) and Mapping Kibera, often feature active approaches. These aspects beg the investigation on the levels of citizen participation in VGI, how they relate to empowerment, and the lasting benefits of VGI beyond the data itself.

VGI research seldom measures citizen empowerment, although it is often implicit in VGI campaigns and studies (Corbett et al. 2016). In this sense, it is helpful to make the relationship between citizen participation, empowerment, and VGI explicit. According to Sherry Arnstein (1969), citizen participation is a prerequisite for empowerment, as it assumes active citizen engagement in decision-making and community development processes. Following this line of thought, to empower citizens through VGI, there must be methods, tools, and goals accessible to citizens, even non-specialists. Moreover, as the accessibility of VGI methods increases, there are new opportunities to achieve more plural and representative GI. From a technological perspective, though, accessibility can lead to an oversimplification of the available tools, therefore, constraining the use of the resulting GI. To avoid this contradiction, VGI should adapt its tools and processes to maximize citizen participation in the production, interpretation, and use (or reuse) of GI without compromising the quality of the data. This improvement may enhance citizen participation, and change policy and intervention priorities thanks to more diverse information and better-informed citizens.

We propose to describe the spectrum of VGI between two extremes in user participation: on the one hand, there is technical capacity and access to resources; on the other, there are the users' perceived capacity to exercise control over their GI and the motivations behind its production (agency). The following section presents a framework for comparing and evaluating VGI applications based on their ability to be replicated by ordinary citizens – and thus, to effectively foster citizen participation in the production of GI. Arnstein's "Ladder of citizen participation"(1969) is the inspiration for the framework, as it is a rung-based structure that hierarchically sorts VGI applications in a synthetic index. The latter builds on four assessment categories: (1) user agency in VGI; (2) required material resources to implement mapping; (3) necessary GIS literacy level to achieve results; (4) degree of involvement of research subjects. These four categories encompass criteria shared among most VGI applications and allow comparisons between applications in different contexts.

2 Methods

This section presents the comparison framework for citizen participation in VGI. This framework assesses citizen participation and empowerment in VGI initiatives, providing a novel, multi-dimensional and hierarchically structured comparison tool. Ultimately, the framework aims to improve VGI research and practice by making explicit the resources (e.g., material, informational, and capacity), the agents (i.e., the users, producers, and subjects of GI), and their involvement (e.g., agency and stages of direct participation) in the VGI processes. This framework introduces an innovation by bringing critical factors in GI production to light that are usually subsumed in traditional analysis, revealing the purpose, tools, participation, and empowerment in VGI practices.

Table 12.1 presents the framework and includes 16 criteria. The criteria belong to four categories that describe the tension between technical resources and GIS literacy, on the one hand, and user GI agency and the degree of involvement of research subjects (i.e., people living in the observed area), on the other. Each criterion may receive a value of zero or one, identifying the absence (zero) or presence (one) of that criterion in the case under study. Therefore, each category may receive a value from zero to four points, which adds up to a total VGI Participation Score (VPS). A high VPS (beyond 9 points, for example) would indicate a significant level

Table 12.1 Categories and criteria for the VGI Citizen Participation Score

Categories	Criteria	Categories	Criteria
User GI agency	1. Transparency 2. Editing capability 3. Two-way data flow 4. Control over data format and publication	GIS literacy	5. Specialization 6. Experience 7. Geomatics 8. GIS software
Resources	9. Software license 10. Data license 11. Mobile hardware 12. Human resources	Involvement of research subjects	13. Data collection 14. Data management 15. Data interpretation 16. Usage and impact of data

The criteria add up to a VGI participation score (VPS), which ranges between 16 (total citizen participation) and 0 (no citizen participation)

Table 12.2 Evaluation and interpretation of the VGI participation score

VGI participation score	Interpretation	Examples
13–16	Citizen empowerment	Participation and replication are possible even by the general population. Users have control over data reuse. Little to no resources are prerequisites.
9–12	Significant participation	Overall data controlled by researchers, there may be supervision or mediation by specialists. Non-specialized resources.
5–8	Limited participation	Participation is constrained to predetermined options of agency, technology, and goals. Some specialized resources are necessary.
0–4	Non-participation	Lack of GI knowledge hinders citizen participation, technology, and resources. Users have no control of the results (e.g., veiled GI collection).

of citizen participation in the VGI process (Table 12.2). Researchers analyzing the VGI practices in a particular case may assign a point for each criterion as a qualitative appraisal (e.g., expert opinion).

The qualitative assessment advances on a structured approach to evaluate the processes and practices involved in VGI. By focusing on the process rather than on the resulting data, this framework seeks to distance VGI from a technocratic discourse. Instead, the framework emphasizes the social relevance of GI in the specific context in which it is generated – i.e., to what extent the process and resulting GI contribute or harm people directly related to that context. The analytical categories in the framework highlight the conditions of the data subjects to participate in VGI processes, the degree to which the processes are proposed or designed to work jointly with the subjects (e.g., high, or low dependency on sophisticated techniques, and knowledge transfer potential). These characteristics allow researchers to understand VGI practices and data in connection to the social context that they describe.

Ultimately, the framework seeks to support VGI practitioners and researchers to address more explicitly the purposes and motivations behind data acquisition, utilization, and the degree to which they are accessible and under the control of the subjects described in the data.

VPS scores build a ladder of participation and empowerment in VGI, mirroring the example from Arnstein (1969) in creating a hierarchical evaluation of practices that involve communities and tecno-scientific content. In Table 12.2, scores between 0 and 4 fit into the class of non-participation, in which citizen participation is constrained. User agency is limited or nonexistent (e.g., veiled GI collection, absence of derivative uses), required literacy limits the effective use of the application to experts, while the necessary resources curb dissemination or replication by the public (e.g., expensive proprietary software or required coding or geodesy knowledge). Scores between 5 and 8 depict limited participation; they signal that some participation exists but is usually constrained to predetermined options and goals defined independently from data subjects and users. In this class, influence on the agency and goals of VGI still weigh away from citizens. Scores between 9 and 12 mean significant participation. In this class, users generally have high agency levels, controlling data usage and transparency. Applications may still need resources but do not require specialization (e.g., volunteer engagement, free GIS software, mobile phones as GPS data sources). In this class, research subjects have overall control of the data but are not yet at the helm of the mapping process (e.g., external parties may set the purpose of data or custody). Scores between 13 and 16 mean citizen empowerment, which supports open participation and replication of methods by any citizen interested in VGI. The top tier means nearly full user agency (e.g., users know, control, and reuse the data as they wish). There are few prerequisites in GIS knowledge, few necessary resources (e.g., user-friendly applications with very low technical literacy, little to no ground-truthing), and direct involvement of research subjects in knowledge production through VGI.

In the framework, four criteria describe user agency in GI. The first is the capacity for users to know they generate geographic data that are being collected and reused by others. High-ranking applications will provide transparency and fine-tuned control over geographic data and meta-data collection, while low ranking applications will be opaque or even misleading in presenting their data collection methods. The second criteria are the capacity for users to visualize, share and edit data in the application. Low ranking applications will limit user edits, while high-ranking applications will provide practical tools that are easy to master. Next, data flow should be accessible in both directions, meaning users may input and access information in the application, allowing derivative works. Finally, applications should provide complete data in editable formats, avoiding proprietary or simplified formats that limit derivative works to lower quality than the original input (e.g., image formats, data without geolocation).

GIS literacy stems from specialized knowledge, practical experience with GI, proficiency in geomatics, and proficiency in GIS software packages required to obtain and analyze the data. Indeed, these technical aspects may constitute substantial barriers to applying VGI methods, which often require facilitators between the technology and the public (Robinson et al. 2017). In this sense, the user of high-ranking applications could be a layperson, while the tools would only require a cursory understanding of GI (map reading) and GIS software (visualizing or adding information to non-specialized Earth observation platforms). Conversely, in low-ranking applications, the user would need specialized knowledge, and tools would require good cartographic skills and knowledge of geodesy, GIS software, and, if applicable, spatial statistics.

Resources in VGI applications refer to access to software licenses, complete and timely support data (e.g., Earth observation imagery), mobile hardware (e.g., portable GPS devices), and the level of dependence on human resources (either specialized or not) to achieve the necessary results. The costs for licensed software and hardware and volunteers' availability can be highly restrictive to implementing VGI methods (Reynard 2018). On this basis, high-ranking applications would only rely on free software and openly accessible data without the need for on-site data validation or intensive use of human resources. Conversely, low-ranking applications rely on licensed software and data, on-site data collection, and specialized hardware.

Finally, the research subjects' level of involvement in collecting, interpreting, and using geodata is determinant to distinguish different data collection methods (Verplanke et al. 2016). Indeed, the control of research subjects over data is particularly relevant when GI supports social integration through citizen empowerment (Corbett and Keller 2005). In this sense, high-ranking applications would present active research subjects' involvement in geodata collection, management, and interpretation, notably towards the subjects' goals and motivations. Conversely, low ranking applications could exclude the research subjects or implement data interpretation and use without the subjects' knowledge or control.

3 Results

Using the framework of citizen participation in VGI, we compared two VGI projects that mapped informal settlements in Latin America (Table 12.3). In the first case, researchers from the University of Hamburg (Germany) combine human and remote sensing data in a hot spot analysis framework to map informal settlements in Mexico City's fringes. In the second case, the NGO Teto uses a participatory GIS approach to map communities in São Paulo. Both projects aim to fill the gap of authoritative geographic data on informal settlements, resulting in similar outputs, albeit through different methods and with differing purposes. In the São Paulo project, volunteers produced VGI with the communities' consent using a participatory approach. This effort aimed to foster local changes to improve the living conditions in selected informal settlements. The Mexico City project brings two data sources together: VGI and remote sensing data to develop hot spot maps that explicitly aim to conflict between nature preservation and urgent housing needs.

Table 12.3 Comparison of two VGI projects in informal settlements in Latin America. Teto uses a participatory GIS approach to map communities in São Paulo (left). Researchers from the University of Hamburg (Germany, right) combine human and remote sensing to map informal settlements in Mexico City

VGI aspect	São Paulo case	Mexico City case
Volunteer workforce (data agents)	Volunteers of the NGO Teto: Mainly college students and professionals (usually studying or working in architecture, engineering, geography, and urban planning).	Locals file a complaint at the *Procuraduria Ambiental y del Ordenamiento territorial del Distrito Federal* (PAOT). VGI comes from PAOT (September 3, 2015), and the researchers further analyzed it.
Other sources of data (not volunteered)	Raster data: Georeferenced orthomosaic generated from drone images (online GeoTIFF imported in QGIS)/georeferenced VHR satellite imagery openly available online. When available, polygon information on topography, hazards, and other themes.	Raster data: Researchers obtained RapidEye satellite imagery (from the German Aerospace Center) through the German Federal Ministry of Economy and Energy funding. Vector and demographic data from Mexico's National Census 2010 (INEGI 2010), vector data of road systems from OpenStreetMap (OSM 2015)
Data proprietors	Satellite imagery distributed by Google. Drone imagery and resulting maps jointly owned by Teto and the communities where the surveys take place	RapidEye data from the German Aerospace Center. Ecological complaints from PAOT and 2010 census data from Mexico's National Census Bureau (INEGI 2010), both distributed under open access.
Input data	Raster data: Georeferenced orthomosaic generated from drone images (GeoTIFF imported in QGIS)/georeferenced VHR satellite imagery (dynamic XML or URL layer imported in QGIS).	Raster data: RapidEye satellite images, vector data: ecological complaints (PAOT), demographic data (INEGI 2010), road systems (OpenStreetMap 2015)
Site visits required	*In situ* work is required	*In situ* work is not required
Data resolution/ accuracy	Very high resolution (<1 m)	High-resolution satellite imagery (5 m, input)
Tools	QGIS (free, open software)	ArcGIS (commercial software)
Targeted audience/ application	Project designers and advocates in Teto and community members	Government, NGOs, and researchers
Purpose of VGI	To collect settlement data for Teto's development/advocacy projects	To bring to light a conflict between nature preservation and housing needs
Output data	More accurate geographic information: Filling gaps in existing (authoritative) sources, increased resolution, updated information	More accurate geographic information: Filling gaps in existing (authoritative) sources, increased resolution, updated information

3.1 Research in Mexico: Human and Remote Sensing Perspective

Mexico City's rural-urban area lies in the Federal District's southern part. The city depends on water sources outside the urban area (e.g., the Magdalena River south of Mexico City). Land management is especially sensitive in the so-called "preservation zone", where informal expansion may contaminate the water supply (Jujnovsky et al. 2012). The mapping process aimed at creating more transparency in the conflict between nature conservation and housing demand in an unequal society. When conflicts are visible, society can dialogue to develop solutions. Societal dialogue is a critical response to unequal development dynamics (Harvey 2006), especially those that present conflicts between vulnerable groups and common social goods.

In this case, the data agents are local citizens and researchers. Any resident from Mexico City may file environmental complaints voluntarily in person with the "Procuraduría Ambiental y del Ordenamiento Territorial del Distrito Federal" (PAOT), through the phone, or electronically (e.g., via email or on PAOT's website). Complaints include animal abuse, water misuse, noise, or irregular settlement in the preservation areas, among others. Each complaint generates a record in a database that includes descriptive fields and the geographic coordinates and address of the problem. The researchers included complaints filed between 2002 and 2013 in their analysis, representing the "human sensing" data (i.e., people generating geographic information) (Rodriguez Lopez et al. 2017a).

The research team then combined the "human sensed" data with high-resolution satellite imagery (5 m) from the RapidEye satellites. The German Federal Ministry of Economy and Energy covered the costs of Rapid Eye imagery for that research project (Rodriguez Lopez et al. 2017a). The researchers classified the satellite data into two land cover classes, urban and non-urban, for years 2009 and 2014. Further change-detection analysis described urban expansion (i.e., the difference in urban area between 2009 and 2014) in and around nature preservation areas. The study then quantified urban growth in the protected areas, detecting and highlighting the hot spots of this type of dynamics (i.e., areas in which there was an intense concentration of urbanization). The Getis-Ord Gi* statistic detected the hot spots and provided increased precision for research and policy about the ongoing environmental and social conflict. Finally, the analysis integrated the OpenStreetMap road system (as another VGI source) with census data to assess socioeconomic conditions and the drivers of peri-urbanization (Rodriguez Lopez et al. 2017a; Heider et al. 2018). The analysis output (Fig. 12.1) included the combined hot spots derived from human and remote sensing in a grid of polygons with a spatial resolution of 561 m. The authors published the data, results, and further methodological details under open access (Rodriguez Lopez et al. 2017b).

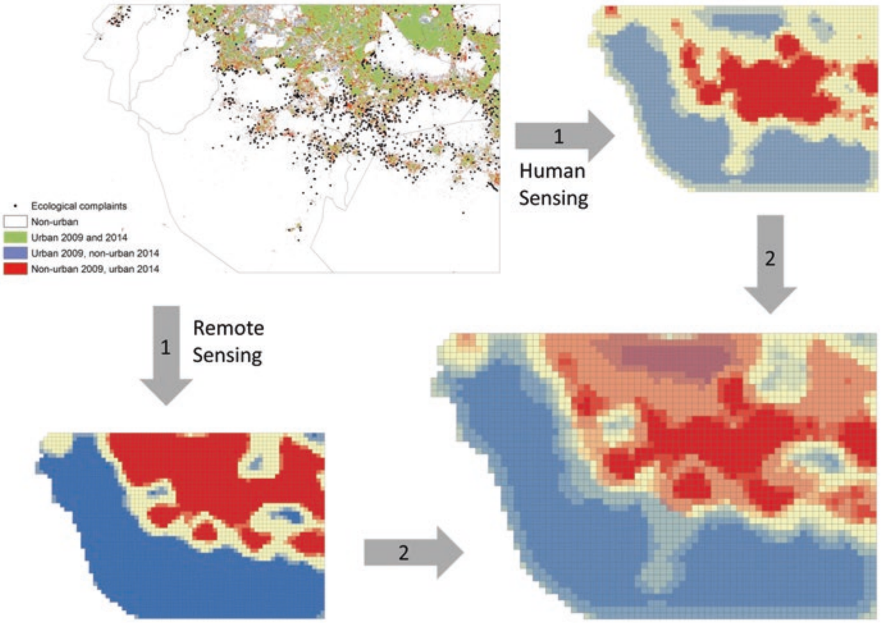

Fig. 12.1 A graphic summary of the hot spot analysis of VGI and remote sensing data in Mexico City and their combination. (**a**) area of interest; (**b**) the human sensing hot spots; (**c**) the remote sensing hot spots; and (**d**) the combined hot spots (human and remotely sensed). Red cells represent hot spots (high concentration of complaints or identified urbanization); blue cells represent cold spots (low concentration of complaints or identified urbanization). The confidence range of the hot spots analysis was 90–99%, source: Rodriguez Lopez et al. (2017a).

The goal of this research was twofold: first, to increase transparency by providing new data to the academic and policy development sectors on this dynamics. This transparency opens the debate beyond local power brokers (e.g., local legislators and public officials involved in land grabbing) and provides evidence to local advocacy groups such as housing rights or environmental NGOs. Second, the research aimed at shining a light on tradeoffs between housing rights and environmental protection policies in an unequal development setting. Within this context, the most vulnerable will suffer from the enforcement of regulations (e.g., expulsion from informal settlements in preservation areas). At the same time, the root causes remain untouched (e.g., lack of land-market regulation or inefficient housing policies), reproducing prejudices in regulatory instances and keeping encroachment-exclusion cycles in place (Zérah 2007). This research followed an ongoing investigation that included Mexican academics who constantly dialogued with local authorities (Rodriguez Lopez et al. 2015). With its results, this dialogue can better address the preservation-housing conflict and provide a more leveled playing field, exposing bias in information (e.g., complaints are more frequent in affluent areas) that stem from the inequality of the social process itself.

3.2 Research in São Paulo: Participatory GIS

Since 2014, Teto has conducted community assessment activities in different informal settlements located in peripheral areas of São Paulo. These activities take place with the community's informed consent and include surveys that combine mapping campaigns and the collection of georeferenced household data to analyze the communities' demographic, socioeconomic, and spatial characteristics. The NGO and the communities use these data to support slum-upgrading projects such as constructing emergency shelters or improving shared open spaces. This process includes a round of discussions on the possible collaborations with Teto that result in a joint agreement regarding the scope of Teto's participation and the necessity of conducting spatial and socioeconomic surveys.

Teto's community assessments rely on high-resolution spatial data collected through VGI. The mapping process results in detailed community maps locating the settlement extent and identifying significant features that include each building's footprint and use (e.g., residential or community facility) and primary road access. Data also indicates household locations, basic socioeconomic data (e.g., household members and housing conditions), and household-specific demands for infrastructure (e.g., need for more streetlights or better road access). Teto, its volunteers, and the community collaborate in these activities, and the resulting data supports projects and advocacy initiatives co-developed by the community and Teto.

Teto's volunteers are university students or recent graduates (often from architecture and urbanism) engaged in enhancing living conditions in informal settlements, and are generally much less vulnerable than the informal settlements' population. The volunteers provide technical expertise for the mapping effort, given their university training, even if they are not GI experts. Currently, this is a workaround for the lack of technical literacy in the communities, which are often some of the most vulnerable in São Paulo. The downside of this workaround is that community dwellers rarely participate in the vector data (i.e., point, line, and polygon data, commonly collected with GPS or similar devices) collection process, although their knowledge registers as GI through the interaction with the volunteers and surveys. Community dwellers also join the data validation and interpretation processes, as explained further below.

Vector mapping campaigns have a fixed timeframe, usually lasting eight weekends. Groups of four to six volunteers divide the work in each campaign, with each volunteer covering between 1.5 and 2 ha, depending on the settlement's complexity; hence, the number of available volunteers limits the process. Based on the aerial imagery, the volunteers first manually digitize each building's perimeter in QGIS (a free and open-source GIS software), considering each roof to correspond to one building (step 1 in Fig. 12.2). Teto prefers freely accessible satellite imagery, as its combination with accessible software enhances the replicability of the method. In some cases, private partners (e.g., DroneDeploy and Ponto360) provided higher-resolution drone aerial imagery. Then, the volunteers check the accuracy of the digitized built environment on-site (step 2 in Fig. 12.2). Satellite imagery may be

Fig. 12.2 Teto's mapping process, step-by-step: (1) acquiring drone or satellite imagery; (2) digitizing building footprints, with on-site verifications using Google My Maps; (3) validating GI data to obtain geographic information that may support upgrading projects. Elaborated by the authors, based on Google Earth (2018) and Pessoa Colombo (2019)

outdated or lack resolution; therefore, on-site verification is essential in informal settlements. The Google My Maps platform (which is free but not open) allows the visualization of the digitized building footprints on mobile phones, facilitating on-site verifications. Finally, the surveys collect land use, infrastructure, and demand information (step 3 in Fig. 12.2). Volunteers then georeference the tabular information from the survey into the centroids of the building outlines. This workflow requires each volunteer to use a smartphone and at least one computer per mapping campaign to digitize the final map. In addition, a reasonably good Internet connection is required.

At the end of each mapping campaign, Teto and community leaders organise focus groups that validate and interpret the collected data through a horizontal dialogue with the community (Santos Melo et al. 2021). Community leaders use printed maps to situate geographically specific demands. This way, they turn geographic data into information, which they use to plan future interventions. They use large, printed maps (e.g., in ISO A0 format) in these discussions, which allows more spontaneous annotations (Fig. 12.3). Such discussions based on printed materials are crucial to overcoming technological and material barriers to participation in GI. In this way, local knowledge enhances geographic data. This process

Fig. 12.3 Focus group co-organized by Teto and local community leaders to enhance geographic information. Source: Teto

also allows the co-development of community projects between the NGO and city inhabitants.

The cartographic outputs consist of two features generated in QGIS: a polygon feature containing the buildings' footprints and a point feature indicating the households' locations and non-residential structures. Teto usually manages those datasets, but community leaders can also manage them independently and locally when capacity (e.g., hardware, software, literacy) is available. However, most of the data restitution to communities is through printouts, in the form of reports illustrated by graphs and maps. Therefore, the outputs are high-resolution geo-datasets combining descriptive data of socioeconomic and environmental aspects of the community. Teto uses the outputs to support slum-upgrading projects, as they allow identifying the most vulnerable areas that require more urgent interventions. The type of interventions varies, but the most common are new single-family housing units (replacing shacks with new structures), improved accessibility (e.g., stairs, bridges) and community facilities. In collaboration with the community, Teto then plans and designs all interventions, including the election of beneficiaries in the case of housing projects.

4 Comparison Under the VGI Participation Framework

This section presents the VGI participation scores for the two cases under analysis. We evaluate whether these VGI initiatives attain citizen empowerment or significant participation (at the higher tiers of the VPS score) or are limited in participation or non-participatory at all (at the lower levels of the scale). For this analysis, we start by considering user GI agency and then observe the required GIS literacy, the required resources and finally, the degree of involvement of the research subjects in producing and managing the GI.

Overall, the results show the contrast between the two cases. When comparing VGI participation scores, the Mexico City case attained five out of 16 possible points, representing limited participation. Teto's mapping process in São Paulo shows significant participation with a total VPS of 10 points. Below, we present the assessment of each case under the VPS comparison framework (Table 12.4).

The case study in Mexico comprises data acquisition from locals, georeferencing by the planning authority, and hot spot analysis by an independent research team. This case scores two out of four points in the GIS Agency category. Residents in Mexico City (who may not live in the informal settlements) produce the data through complaints filed over multiple media (e.g., phone, email) and inform a geographic

Table 12.4 VGI participation score calculated within the framework of citizen participation in VGI

Criteria	Case 1: São Paulo	Case 2: Mexico
GI agency	**4**	**2**
Transparency of data usage	1	1
Possibility of data editing	1	0
Two-way data flow or exchange	1	0
Format of data communication or publication	1	1
Tech literacy	**1**	**0**
No formal specialization in GI science	1	0
No practical experience with GI	0	0
No proficiency in geomatics	0	0
No proficiency in GIS software	0	0
Required resources	**2**	**2**
No licensed GIS software	1	0
No licensed data	1	0
No mobile/external hardware (GPS or drone)	0	1
No intense human resources	0	1
Involvement of research subjects	**3**	**1**
Data collection is done by or with research subjects (RS)	0	0
Data management is done by or with RS	1	0
Data interpretation by RS	1	0
Data aims to foster local changes (physical or social)	1	1
TOTAL SCORE	**10**	**5**

location. From that point on, PAOT manages the case with no further user input. In this sense, the data producers have spatial knowledge about the fact but have no data editing or exchange possibilities. However, the researchers published the project's data (including the complaints and results) under open access (Creative Commons License, by attribution – CC BY) to enable dissemination in academia (Rodriguez Lopez et al. 2017b). Open access to the PAOT's database breaks the barriers around the information on these conflicts. The Mexico case scores no points in the tech literacy category because replicating the process, especially the hot spot analysis, requires specialized knowledge in GIS and geomatics. The case meets two criteria in the "required resources" category because the research team used licensed software and remote sensing data for hotspot mapping, limiting participation. However, neither GPS, drone imagery, nor fieldwork was required, widening participation possibilities.

The involvement of research subjects is particularly complex in the Mexico case. In our appraisal, the Mexico case scores only one point because only part of the research subjects is involved in data collection and under conflictive circumstances with other residents. The locals do not manage or interpret data, the other criteria in the framework. PAOT collected the complaint data, and it was not available to citizens as aggregate information, which in turn creates a conflict in information as PAOT might use the data to foster physical or social changes independently from the goals of all inhabitants in the area. Furthermore, the locals who file the complaints may do it motivated by protecting the preservation area (which is a common good), but against the housing need of those in the informal settlements in the region. The opening of the data potentially allows more groups to see this conflict, even if limited to an academic audience. The open data, combined with the analysis of the conflict, can foster debated social action. They are, nonetheless, independent from the research subjects and do not contribute to this score.

In summary, the hot spot mapping project in Mexico City reached limited participation with a score of 5 out of 16 due to the high level of tech literacy required for the analyses, costly resources (software and data), and the lack of research subjects' involvement. However, transparency of data usage and availability in open access publications enable a medium ranking in GI agency.

The case study in São Paulo scores four out of four points in the GIS Agency category. Both data producers and users are fully aware and have control of GI's collection, management, and publishing. The research subjects also enforce their interests and data privacy concerns, controlling the shared GI content. In terms of tech literacy, the case study scores only one point. Neither data users nor data producers need any formal specialization, but previous experience with GI dramatically facilitates the work. In this sense, Teto's volunteers act as VGI facilitators, building the bridge between the community and the use of GI tools and methods. Regarding material resources, the São Paulo case meets two criteria: the data and software are freely accessible, but the method demands on-site verification, which requires mobile hardware for geolocation and also generates transportation costs. Besides these requirements, human resources affect the geographic extent of the output.

Regarding the involvement of research subjects, São Paulo's case merits three points. While Teto's volunteers collected part of the data without the active contribution from research subjects (community dwellers), the latter oversaw the process and maintained control over data retrieval, reproduction, or deletion at any time. At the end of each mapping campaign, the community validates the data and employs it to support its projects. The digital data are stored and managed by Teto, but data are also shared with community leaders or organizations when capacity is available (e.g., personal computers).

The São Paulo project achieves significant participation thanks to community involvement. The participatory approach is visible in the maximum rating of four in GI agency and three out of four in the involvement of research subjects. However, tech literacy for professional remote sensing and the required fieldwork resources were still high within the mapping process, leading to one and two points in these categories, respectively. The total VPS is 10 out of a possible 16, highlighting gains in agency and research subjects' involvement. The participatory approach shows compromises with the technical and resource requirements for working in GI, especially when little to no preliminary data are available.

5 Discussion

This chapter asked how different VGI approaches support citizen participation and user empowerment and what are the opportunities and limitations of VGI in mapping informal settlements in Latin America beyond authoritative data sources. To address the first question, we argue that, despite its qualities, VGI also presents potential issues to informal communities, notably regarding privacy (Elwood 2010; Sharma 2019), ownership over information (Hachmann et al. 2018; Zhang 2019), and changes in political power (Corbett and Keller 2005). Due to privacy and political power concerns, this framework makes explicit the resources and agents in the VGI processes. It decouples the relationship between data producer and data subject, revealing inherent potential conflict and cooperation. Therefore, it provides critical insights in VGI beyond data quality by potentially illuminating conflicts, considering processes (rather than products) and their societal implications. It brings light to critical factors in GI production that are usually subsumed in traditional analyses, highlighting the purpose and tools and the participation and empowerment of the agents involved in VGI.

From this perspective, the framework contrasts the case studies to reveal the importance of control over information by those represented in it. In Mexico City, observation from distant and anonymous complaints separates the data producers from their subjects. In addition, although the research team published their work in an open-access journal, their findings are hardly accessible for informal settlement dwellers and more likely to remain inside academia. In São Paulo, users have veto power over information dissemination. The decoupling of this framework provides opportunities to expand previous research, in which crowdsourced methods (also called passive or contributed) and participatory (named active or volunteered) approaches are often at odds (Harvey 2013; Zhang 2019). At the same time, the technological compromises in the São Paulo case (e.g., the necessary facilitation from the NGO staff) widen the discussion on the empowerment potential from VGI. By keeping the mapping outputs aligned with the communities' interests, this approach preserves a critical aspect of agency, where external resources collaborate to produce VGI, even if community members seldom collect vector data themselves (Hachmann et al. 2018).

When considering empowerment (Corbett and Keller 2005; Cochrane and Corbett 2018), the low VPS scores of the Mexico case in the agency and the research subjects' involvement indicate a potential decrease in the community's socio-political power. The detection if this characteristic demonstrates the capacity of the framework to assess these dimensions. The decrease in power stems from a conflict of interests in which the interest of data producers (i.e., locals who complain about informal settlements) is opposed to the interest of research subjects (i.e., locals who live in informal settlements). The framework exposes this contradiction, as it makes the agents and subjects of VGI explicit. This disclosure is a noticeable advancement from previous research, which often omits the data subjects. In this sense, VGI practices that inform and provide control to the data subjects over GI about them provide enhanced empowerment. These features are present in the São Paulo case, where collaborative and participatory VGI initiatives provide local inhabitants with control over GI about their settlements. This increased control creates new political representation capacity (e.g., advocacy for land tenure rights) and supports more precise settlement improvement plans (e.g., housing, infrastructure) than other information generation methods.

The second research question examined the potential and limitations of VGI to provide information for research and policy development in informal settlements. Our results show that VGI can offer unedited GI on informal settlements at varying spatio-temporal resolutions, in line with previous research (Beukes and Mitlin 2014; Bolay et al. 2016; Hachmann et al. 2018; Lines and Makau 2018). VGI provided the location and quantity of land cover changes over a large region in Mexico. Considering the undocumented and dynamic nature of land-use in peri-urban informal settlements, volunteered sources of GI such as the PAOT are valuable complements to conventional ones. For instance, PAOT provided timely information on environmental changes in peri-urban settlements that would otherwise remain invisible to authorities. In São Paulo's case, VGI covered a much smaller extent but at a more detailed spatial resolution. This in-depth mapping allowed tracing building footprints, a piece of information that is often nonexistent for informal settlements but vital for slum upgrading projects (Hachmann et al. 2018).

Even in relatively affluent cities like Mexico and São Paulo, data on the built environment and dwellings in informal settlements are approximate at most and, at times, inconsistent. This lack of precision and completeness leads to sub-informed decision-making (Pedro et al. 2017; Pedro and Queiroz 2019), which is especially harmful to spatial interventions (Hachmann et al. 2018), risk management (Goodchild and Glennon 2010), and health policy (Elsey et al. 2016; Corburn et al. 2020). VGI can arguably foster synergistic opportunities and prevent unnecessary problems during interventions in these areas by providing locally sourced, updated, and fine-scale data. Despite the lack of focus of the framework on data quality assessment, it still provides a relevant contribution to the methods available for mapping, analyzing, and understanding informal settlements (Kuffer et al. 2016; Kuffer et al. 2018), especially from the community perspective or at the local scale (Hachmann et al. 2018; Williams et al. 2019).

Although VGI can provide data on informal settlements with high spatial and temporal resolutions, it presents limitations. From a scientific perspective, limitations in the replicability of methods and reproducibility of results challenge VGI-related research in general. As VGI initiatives employ participatory practices, the solutions tend to be context-specific, as in São Paulo. Crowdsourced methods, with lessened empowerment, provide massive, at-a-distance data collection but are easily biased and may contradict the interests of those represented in the data, as we show in Mexico City. The lack of access to volunteered data (sometimes inevitable due to ethical considerations) often hampers reproducibility. The replicability of methods is susceptible to the evolution of VGI sources and data formats (Ostermann and Granell 2017). In Mexico and São Paulo's cases, both VGI datasets contain personal data of some kind and demand editing before sharing, limiting the reproducibility of results.

Regarding replicability, both cases relied on tools and methods discussed in previous publications (Rodriguez Lopez et al. 2017a; Pessoa Colombo 2019) and are highly replicable. Nevertheless, their replicability relies on moderate-to-high levels of tech-literacy and material resources, limiting their assimilation by lay audiences from a practical perspective, as the framework exposes. This problem reflects very different approaches regarding the public's active involvement in knowledge production within the VGI spectrum (Hachmann et al. 2018; Zhang 2019), which the framework brings to light and helps discuss. This problem is central in contexts where GI is supposed to promote the empowerment of marginalized communities. This centrality is true for informal settlements, but is a general problem of a society's relationship with technology in unequal development conditions. Therefore, the active participation of citizens in the production of VGI and the transfer of knowledge and GI tools remain critical aspects in VGI research (Corbett and Keller 2005).

6 Conclusions

This chapter provided a comparison framework highlighting the "volunteered" side of VGI. This framework reveals user agency and citizen participation as critical aspects in GI acquisition, management, and dissemination. Even though much of the literature assumes an intrinsic association between VGI, participation, and empowerment, we observe far more complexity in this relationship than previously thought. The framework makes a clear distinction between passive and active participation in VGI. Specific forms of VGI may not include participation from those mapped (i.e., the research subjects) and may even be at odds with their interests, as shown in Mexico.

The framework also shows the implications of the differences in participation intensity and data contributors' composition. Differences among the authors and subjects of data may feed specific biases into the resulting GI. These biases are present in VGI and authoritative sources, albeit for divergent reasons, but often result in the under- or derogatory representation of vulnerable populations. This framework provides tools to assess the GI acquisition processes, considering these biases and the restrictions vulnerable populations face to access methods and tools to produce information. To do so, this framework differentiates VGI practices along with their agency levels, considering the data producers, on the one hand, and data subjects, on the other. This differentiation aims at increasing the precision with which research and policy understand and use VGI as a resource to achieve "people-truthing." The framework provides increased precision to this aim, indicating that VGI practices ranking high in VPS may work as *grass-roots* data validation. A critical reflection is that VGI projects geared at vulnerable populations need facilitators to overcome the existing technological barriers to participation (e.g., expertise and resources). More research could foster collaboration in the data collection stage of VGI, which currently depends on relatively sophisticated geospatial technologies.

We must also recognize the many limitations of this framework despite its potential relevance. First, this framework does not integrate traditional data quality assessment practices (e.g., completeness and accuracy), limiting its comparison to a qualitative measure. Second, other limitations arise from analyzing only two cases, which are far from exemplifying the whole spectrum of VGI. Even if these cases provide evidence for the framework's initial design, more examples will refine the methodology and possibly lead to adjustments in the score (e.g., weights for each criterion). Third, the cases do not stem from a comparative research design. A more systematic and structured set of cases could provide increased precision and critical insights. Given these shortcomings, further research should include more systematic comparisons that range across a more comprehensive set of case studies. Research would benefit from regional diversity, including variations in socio-political systems, data landscapes, and participatory traditions.

This chapter highlighted some of the significant limitations to research and policy and revealed an overall lack of timely, complete, and precise GI on informal settlements. We propose that VGI will play a central role in filling these gaps, given the importance of informal settlements for future development, the multiplicity of actors involved, and the necessity for self-reliance and determination in these communities. Therefore, further research should encompass an information environment that integrates authoritative, open, and volunteered sources of information to the top of their potential. This approach means moving VGI beyond the physical description of the environment into other dimensions of geographic information where local participation is critical, notably on land-use conflicts (as seen in Mexico City), slum-upgrade projects (as shown in the São Paulo case), and even public health.

Informal settlements face extreme social vulnerability and exposure to risks that their own socioeconomic and spatial characteristics increase. Because VGI allows obtaining updated, longitudinal information on populations, it can provide timely and precise data to support spatio-temporal analyses on health emergencies. In health research, VGI can also foster community empowerment by shifting priorities towards marginalized populations' unmet needs. In this direction, our future research efforts will focus on how the COVID-19 pandemic exposed spatial and social vulnerabilities that are yet unaddressed by VGI research. We aim to address these problems with open, authoritative, and volunteered information sources that together provide timely and fine-scale data on vulnerability, impact, and social behavior in the pandemic context. We expect future research will provide GI science with an integrated approach to identifying spatial and temporal tipping points. This contribution will help decrease uncertainty in decision-making during present and future public health emergencies when considering the specific social and spatio-temporal features of cities in the Global South.

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