Master of Public Health – Environmental and Occupational Health Sciences

The Integration Between Geographic Information Systems and Community-Based Surveillance for Infectious Disease in Low-Resource Settings: A Scoping Review

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MPH, 2020-2021

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Paris, France
June 2021

Acknowledgements

Gracias infinitas a todas esas personas que han estado involucradas en mi crecimiento como profesional y como persona.

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List of Acronyms and Abbreviations

AFI – Acute Febrile Illness

AFP – Acute Flaccid Paralysis

BU – Buruli Ulcer

CBS – Community-Based Surveillance

CHW – Community-Health Workers

COMBI – Communication for Behavioural Impact

CORPSs – Community-Owned Resource Person

CT – Census Tracts

EO – Earth Observation

EWARS – Early Warning Alert and Response Systems

FGD – Focus Group Discussion

GIS – Geographic Information Systems

GPS – Global Positioning System

GR – Geographical Reconnaissance

HIV – Human Immunodeficiency Virus

IFRC – International Federation of Red Cross Red Crescent Societies

KDE – Kernel Density Estimate

KII – Key Informant Interview

LISA – Local Indicators of Spatial Association

LMIC – Low- and Middle-Income Countries

ODK – Open Data Kit

OSM – Open Street Map

PRA – Participatory Rural Appraisal

PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses

SMS – Short Message Service

SVG – Spatial-Video Geonarratives

TCU – Ten-Cell-Units

VBD – Vector-Borne Disease

VGI – Volunteered Geographic Information

VHF – Viral Haemorrhagic Fevers

VHW – Village Health Workers

WHO – World Health Organization.

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Abstract

Background. Recent epidemics have imposed existential threats to societies given their potential to spread rapidly at an international and global level. Geographic Information Systems (GIS) are useful to the field of epidemiology as it provides a framework to manage spatial data, and opens new ways to investigate health outcomes. The utilization of community assets to engage its members for public health surveillance is not new but it has recently gained interest. This review aims to assess the influence of GIS as a technological tool to implement participatory methodologies for the development of infectious disease Community-Based Surveillance (CBS) interventions in low resources settings.

Methods. This scoping review analysed the role of GIS in the development of CBS systems to tackle infectious diseases in low-resource settings. A dual methodology was developed involving an initial systematic literature review and a second phase of interviews with experts. For the literature review and interviews, an analytical framework was developed to facilitate the data extracting process and analysis.

Results. 25 documents were selected and analysed in the literature review process. The documents were published since 2007 and involved a variety of publications like research papers book chapters, study protocols, and technical guidelines. The review showed experiences from Africa, South and Southeast Asia, and South America. GIS in CBS systems mainly focused on vector-borne diseases, although other diseases included were COVID-19, Buruli ulcer (BU), HIV, and Ebola. The interviews were conducted to six GIS and infectious diseases experts, who reflected on the integration between GIS and CBS based on their implementation and or research background.

Conclusion. GIS supported CBS initiatives should be encouraged and strengthened in low-resource settings in order to improve their infectious disease detection capacity. These systems also highlight the main reflection points to give vulnerable communities the voice they deserve, at the same time that advocates to help reduce the inequality that hinders vulnerable communities to effectively prepare and respond to epidemics, especially in low-resource settings.

Keywords. Community-based surveillance, geographic information systems, community engagement, low-resource settings, epidemiology.

Résumé

Contexte. Les épidémies récentes ont imposé des menaces existentielles aux sociétés étant donné leur potentiel de propagation rapide au niveau mondial. Les systèmes d'information géographique (SIG) sont utiles dans le domaine de l'épidémiologie car ils fournissent un cadre pour gérer les données spatiales et ouvrent de nouvelles voies pour étudier les résultats en matière de santé. L'utilisation des actifs communautaires pour engager ses membres dans la surveillance de la santé publique n'est pas nouvelle, mais elle a récemment suscité de l'intérêt. Cette revue vise à évaluer l'influence du SIG en tant qu'outil technologique pour mettre en œuvre des méthodologies participatives dans le cadre d'interventions de surveillance à base communautaire (SBC) des maladies infectieuses dans les milieux à faibles ressources.

Méthode. Cette revue a analysé le rôle des SIG dans le développement de systèmes SBC pour lutter contre les maladies infectieuses dans les milieux à faibles ressources. Une double méthodologie a été développée impliquant une revue systématique de la littérature et une phase d'entretiens avec des experts. Pour la revue de la littérature et les entretiens, un cadre analytique a été développé pour faciliter le processus d'extraction et d'analyse des données.

Résultats. 25 documents ont été sélectionnés et analysés dans le processus de revue. Les documents ont été publiés depuis 2007 et impliquaient une variété de publications telles que des chapitres de livres d'articles de recherche, des protocoles d'étude et des directives techniques. L'examen a montré des expériences en Afrique, en Asie du Sud et du Sud-Est, et en Amérique du Sud. Les SIG dans les systèmes SBC se sont principalement concentrés sur les maladies vectorielles, bien que d'autres maladies telles que la COVID-19, l'ulcère de Buruli, le VIH et Ebola. Les entretiens ont été menés auprès de six experts en SIG et en maladies infectieuses, qui ont réfléchi à l'intégration entre SIG et SBC en fonction de leur mise en œuvre et de leurs antécédents de recherche.

Conclusion. Les initiatives SBC soutenues par le SIG devraient être encouragées et renforcées dans les milieux à faibles ressources afin d'améliorer leur capacité de détection des maladies infectieuses. Ces systèmes mettent également en évidence les principaux points de réflexion pour donner aux communautés vulnérables la voix qu'elles méritent, tout en plaidant pour aider à réduire les inégalités qui empêchent les communautés vulnérables de se préparer et de répondre efficacement aux épidémies, en particulier dans les milieux à faibles ressources.

1- Introduction

1.1 Infectious Disease Surveillance

Recent outbreaks such as the Influenza A(H1N1) pandemic, Ebola in West Africa, Zika in the Americas, and the current COVID-19 pandemic have imposed existential threats to societies given their potential to spread rapidly at an international and global level. In parallel, infectious diseases remain an important cause of disease burden in several countries, especially low resource, where weak public health systems, lack of infrastructure, and poor access to health services impact health outcomes. Hence, considering geographical disparities, effective strategies to anticipate, detect and respond to infectious threats are deemed necessary to quickly contain and reinforce control and elimination programs (1,2). One important element of the risk of silent spreading of infectious threats is the delay in alerting mechanisms, leading to a deceived understanding of disease estimates, especially in contexts that hinders surveillance systems like conflict, humanitarian crisis, weak health systems, poverty, inequality, and geographical isolation, etc (2). Public health surveillance has customarily relied on passive mechanisms to capture and monitor disease conditions, inducing a level of uncertainty, especially in hard-to-reach communities. A more realistic estimate of disease and health events can be achieved through the improvement in geographical access and engaging interested communities (2,3).

Public health surveillance is defined as “the systematic ongoing collection, collation and analysis of data for public health purposes and the timely dissemination of public health information for assessment and public health response as necessary” (3). Furthermore, a public health surveillance system is based on spatiotemporal information of health events and risks trends, to early detect, understand the impact and direct interventions (4,5). The WHO’s initiative, Early Warning Alert and Response Systems (EWARS), is used to emphasize the importance of the alert component in epidemic preparedness and response initiatives. However, these systems have historically relied on weekly passively collected information, putting aside immediate formal and alternative reporting mechanisms such as event-based surveillance (6). As EWARS should not imply an additional burden to surveillance systems, clear mechanisms for immediate reporting, investigation, and response to infectious disease events should be extrinsically linked to the system, deploying rapid and informed interventions (6,7). Also, surveillance systems are a crucial component of disease control and elimination initiatives. Under the premise of reducing transmission, early detection of health events and risks is fundamental to unfold timely response (5). As defined by Bergquist et al (5) “disease control marks the result of deliberate efforts to reduce disease (e.g. incidence, prevalence, morbidity or mortality) to a level that is locally acceptable, while elimination refers to the interruption of transmission in a defined geographical area”. Examples of the use of effective surveillance systems for elimination have been shown for malaria in Tanzania, and Lymphatic filariasis in China (5).

1.2 Community-Based Surveillance (CBS)

One element that goes beyond traditional epidemiology is community epidemiology, which aims at the cultural comprehension of community social and health assets and knowledge to engage them in their health promotion views (8). A visible component of traditional epidemiology is Community Health Workers (CHW), which normally are members and representatives of their communities, sharing accountability towards their community, but backed and trained by the health system (9).

The utilization of community assets to engage its members for public health surveillance is not new but it has certainly gained more interest in recent years, being useful to address limitations such as the accessibility or lack of resources (3). This approach is now known as Community-Based Surveillance (CBS), and it was defined as “the systematic detection and reporting of events of public health significance within a community by community members” (4). Guerra et al (4) state that the characteristics of a CBS program should be “integration in a formal surveillance structure, be actionable and timely, and have perceived benefits to the community, well-defined reporting mechanisms, a feedback mechanism, and a monitoring and evaluation process”. In addition, CBS systems should clearly state their definition of community, but it is clear that this does not necessarily refer to a group of people living in a determined geographical area (4). Outbreaks in settings with weakened public health systems could escalate, hence, CBS represents an important contribution to rapid outbreak detection and response where routine surveillance is less effective, such as the Ebola outbreak in West Africa (4,10). Due to its usually good sensitivity (although poor specificity), CBS has also been used in elimination programs like poliomyelitis and Guinea worm by engaging key informants and rumor surveillance (4,10). The effectiveness of CBS systems depends on several factors, but most importantly, it should be integrated with the regular surveillance initiatives to ensure reliable supervision and sustainability (10). However, although integrated, CBS does not necessarily mirror traditional surveillance systems, and the decision on its implementation should always depend on the context.

Considering that it is a newly defined methodology, the term CBS has been used to characterize different approaches, some of them not necessarily representing the definition given before. Some authors have used the term CBS to define actions developed with the communities, while others refer to interventions where the communities are passive subjects. There is still a lack of standardization in the terminology to define the active role of community members to detect and report health events in the frame of a surveillance system (3). In a literature review, Guerra et al (4) showed up to six different uses of the term CBS, many of which do not comply with the definition and principles already discussed. Up to 44 unique terms were used to describe methodologies that resemble CBS such as community reporting systems, internet-based participatory surveillance, community event-based surveillance, village-based surveillance, etc.

To make reporting timely and complete, CBS has recently relied on the use of telecommunications technology, coinciding with an increased rate of phone connectivity across countries. Moreover, a surge in the use of the internet has allowed communities to voice their needs and thoughts in several facets (11). The popularity of these solutions, especially mobile devices, has increased in low and middle-income countries (LMIC) in healthcare settings by CHWs, especially in isolated areas. However, it is necessary to ensure proper adaptation of communities and CHWs to this fast-evolving technology environment, but even more, to overcome the challenges in terms of cost, sustainability, accessibility, and in general, justice (3). Because of recent advances, technology has been a recurrent tool to understand the spatial component of epidemiology.

1.3 Geographic Information Systems (GIS)

The technologic revolution and access to spatial information and applications have normalized a way of spatial thinking among people. This change allows understanding several spheres of life in a spatial manner, framing the way we make decisions (12). Based on Waldo Tobler's law of geography where "everything is usually related to all else but those which are near to each other are more related when compared to those that are further away", appealing to the concept of spatial autocorrelation, it is possible to make assumptions on health events within communities (12). As defined by Kost et al (13) "maps can be described as visual representations emphasizing relations between spatial elements". However, these representations can have variable attributes, according to the aim of the map, meaning that "maps do not simply show the world "as it is", but rather constitute a means to describe something in a certain way for others" (13). This adaptability thus, makes mapping useful to both influence people's understanding of a given space, but also to explain how they are involved in that space, making maps an element of democracy (14).

Greenough et al (12) define Geographic Information Systems (GIS) as “tools designed to capture, store, manipulate, manage and visualize spatial or spatiotemporal data, and people’s patterns of movement”. Given the high amount of information provided in a single piece, maps as visual data dissemination tools have been deemed useful for several domains including health as reflected by the idiom “if a picture is worth 1,000 words, then a map is worth 1,000 pictures” (15). In public health, environmental and infectious diseases are the areas that have profited the most from spatial sciences. The most notorious historical example of spatial analysis in epidemiology was John Snow’s use of a spatial framework to support the investigation of a cholera outbreak in 1854 in London (12,16). While recently, in 1993, the WHO instituted a Public Health Mapping and GIS program to visualize and locate health trends (17). Recently, under the growing use of satellite data, and an explosion of mapping software and functionalities like Google Earth, the use of mapping processes has increased for several purposes in LMICs, even at small-scale levels (18).

There is, however, an underuse phenomenon of GIS capacity and geospatial data, mainly in humanitarian health and epidemics response, especially in low-resource settings. In certain non-research contexts, the use of GIS is limited to thematic maps, neglecting the importance of geospatial analytics and more advanced spatial modelling (12). Other challenges in incorporating GIS elements in the public health sector in low-resource settings are the lack of financial resources for equipment and software, the lack of training for their use, and the complexity of some GIS software (15). Small scale identification and location of people involved in public health crisis could impose ethical challenges of the growing access to GIS systems (19).

1.4 Mapping as a Surveillance Tool

As stated previously, GIS is useful to the field of epidemiology as it provides a framework to manage spatial data, and opens new ways to investigate links and interactions between health outcomes and environmental factors. This confers epidemiologists the chance to use maps to analyze the relationship between health events and space where they happen. GIS can provide information for planning interventions, monitoring health events, assess outcomes, and report and communicate in the context of epidemics (8). Surveillance-based methods can be problematic, particularly in low-income and/or crisis affected areas. GIS and spatial analysis can help to understand disease spreading patterns and develop ways to measure morbidity that could be used in areas where data is inconsistent and unreliable (20). Currently, GIS for epidemiological surveillance is routinely used allowing a rapid expansion of spatial modelling which in turn becomes more sophisticated and more effective to support surveillance and control strategies (20). GIS in epidemiology and surveillance is also useful to predict and understand the risk based on relevant spatial heterogeneities and hotspot identification, which in conclusion helps to understand the scale of infectious diseases' "ecological niche" (20,21).

From a practical view, the use of public health mapping programs, and the implementation of infectious diseases detection and surveillance technologies have been encouraged by the WHO since the 1990s, being implemented in most countries as of today (16). Caprarelli et al (16) suggest a series of steps for effective GIS use in epidemiology. The first step is to map the data to visualize spatial patterns and formulate a hypothesis. The following step is analysis through data exploration using geostatistical methods. The final step is explanatory which aims to discover cause-effect relationships and make predictions (16). Nowadays, national public health officials began to incorporate spatial and temporal components in their surveillance initiatives, including a range of GIS software for analysing and modelling outbreaks. However, this integration is not commonly seen at the regional or local level especially in low-resource settings (22).

GIS in infectious disease surveillance has an important role in understanding and anticipating the risk. A visible example is its use in vector-borne diseases (VBD) where risk maps are useful to understand the mosquito ecology and distribution, as well as other climatic and environmental factors that impact dengue transmission (23). One of the benefits of these models is the identification of risks at a local level, making them useful for decision-makers and healthcare workers as, from a technologic perspective, dengue risk factors can be easily mapped and tagged by mobile devices (23). An experience in Pakistan developed a dengue monitoring mechanism called "Dengue Activity Tracking System" that works through GPS-enabled mobile application, allowing to capture coordinates and photographs. This allowed submitting real-time information, including maps, into a dashboard accessible to different stakeholders like health authorities (24). An experience in Cambodia in using fine-scale risk maps in malaria, demonstrated effectiveness in identifying residual foci of malaria transmission, encouraging locally adapted malaria interventions targeting identified hotspots, and allowing more efficient use of healthcare resources (25). An acute flaccid paralysis (AFP) monitoring system in Cameroon developed a detailed mapping initiative with mobile phones to improve the program's planning and evaluation. Furthermore, the benefits of this project went beyond as these maps were also used for microplanning as previous hand-drawn maps were poorly accurate. Also, other non-polio programs benefited from the access to these base maps to enrich their public health data (26).

GIS supportive technologies such as remote sensing, unmanned aerial vehicles (drones), and satellite imagery are becoming increasingly available at lower costs allowing access to a range of possibilities to be embedded within epidemiological surveillance initiatives (12). On the other hand, open-source software and web-based mapping tools have been more available and increasingly mobilized for national or regional surveillance systems (5).

1.5 Participatory Mapping

In a passive surveillance process, the individual and communities tend to lose a certain level of autonomy over their health conditions. Participatory surveillance, as well as participatory mapping, provide the citizen decision capacity and democratic potential, especially about surveillance initiatives at a small scale. One example is OpenStreetMap (OSM) which allows everyone to share, view, and edit geographical data (14,18). Crowdsourced mapping has become a strong resource in several areas, although its strength lies mainly during crisis like the Haiti and Nepal earthquakes, and the West Africa Ebola outbreak (11). Crowdsourced mapping in crisis is defined by Hunt et al (11) as “the provision of services by an international and/or online community, who gather, analyse and map critical information related to disaster-affected populations”. Overall, crowdsourcing means decentralised and non-hierarchical work done by volunteers to process high amounts of data from several sources (11). One asset of crowdsourced mapping is that provides community members a unique opportunity to accurately depict themselves and their environment, redefining the discussion around the traditional top-down approach and the power relationship, especially in crisis (11). There are some examples of crowdsourced platforms that provide layers of spatial data on different areas such as OSM, the Missing Maps project, healthsites.io, and the Radiant Earth Foundation. Other examples of infectious disease open-source mapping tools are the Spatial Epidemiology of Viral Haemorrhagic Fevers (VHF) disease visualization, Nextstrain, Microreact, and HealthMap which is a tool for rapid detection of outbreaks (7).

Another form of technological participatory mapping is the use of drones, which although still incipiently used at the community level, allows the possibility of acquiring local spatial information autonomously and more affordably if compared to other remote sense sources (27). Other analog methods such as the use of community map books allow communities to map their assets in place or distantly, also allowing an important level of accuracy through an accessible and cheap methodology (28).

1.6 Objectives

Although there are published experiences on the use of GIS in support of CBS initiatives, there is still a scarcity of studies that focus specifically on this relationship. Being growing trends in infectious disease surveillance, particularly in low resource settings, it is important to understand the links between GIS and CBS, and their complementarity and limitations from a methodological perspective. A thorough analysis of the different methodologies and tools used to potentiate the effectiveness of infectious diseases surveillance efforts at the community level is required, especially from a spatial perspective. It is therefore relevant to compile and document the fragmented available information on the integration between GIS and CBS, especially considering the use of technological tools and its implementation in low resource settings. For this review, the following research question was elaborated "**What is the interaction between GIS and infectious disease community-based surveillance in low-resource settings?**". Hence, based on this question, this review aims to assess the influence of GIS as a technological tool to implement participatory methodologies for the development of infectious disease community-based surveillance interventions in low resources settings.

2- Materials and Methods

2.1 Review Approach

A scoping review was conducted to analyse the role of GIS in the development of CBS systems to tackle infectious diseases in low-resource settings. The PRISMA checklist was followed (**Annex 1**) to provide a more systematic sense of the process even when this is not a systematic review. The methodology involved the definition of a research question, an initial literature and grey literature scanning, a secondary systematic literature search and identification, a relevant study selection, a data retrieval process, and interviews with experts aiming at acquiring key concepts on the use of GIS for CBS systems. As discussed previously, GIS in infectious disease CBS is a relatively new and scarcely studied field, with a diversity of definitions that could limit the depth of the analysis. As for Winter's (9) definition of scoping review, "they aim to provide an overview and organisation of existing knowledge rather than narrow synthesis of a predefined research question"; hence, this was deemed the most relevant methodology to put together the different components and analyse their approaches and difficulties.

This scoping review comprises a dual methodology as it involves a systematic literature search and review at an initial stage and a second phase of interviews with experts (**Fig 1**). During the two phases, no framework was identified in the literature to support the analysis. Hence, an analytical framework was developed to facilitate the data extracting process and analysis for both the literature review and the interviews, as well as to communicate the results (**Fig 2**).

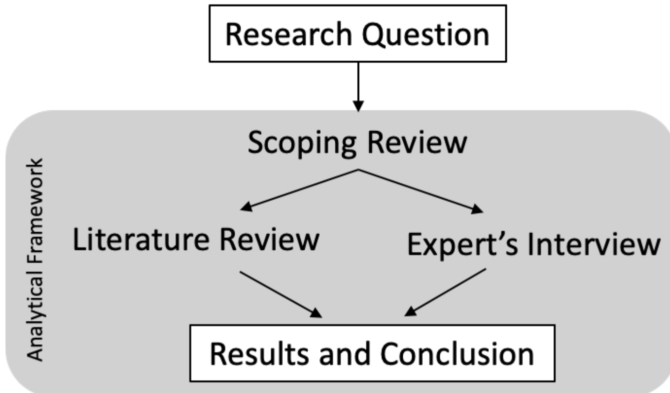

Figure 1. Scoping review's dual methodology

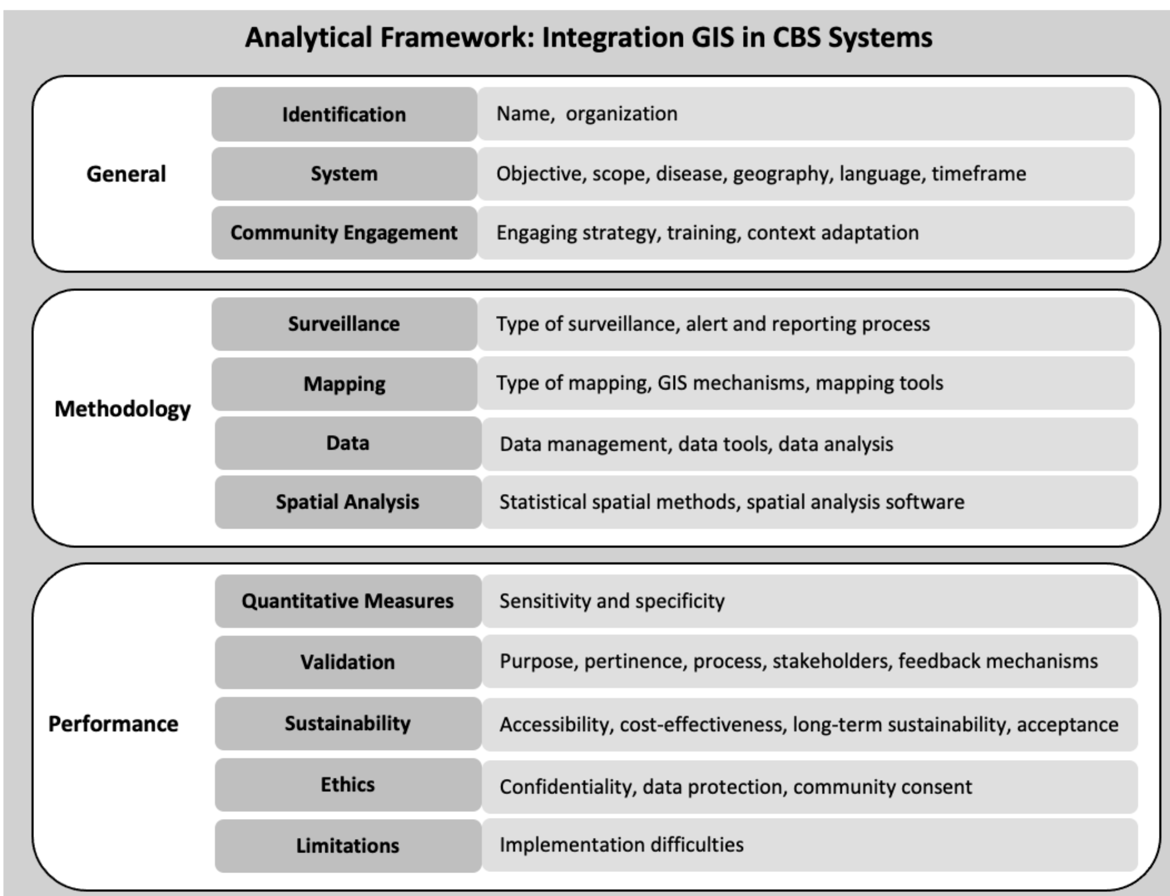

Figure 2. Analytical framework

2.2 Phase 1: Literature Review

2.2.1 Search Strategy

An initial literature and grey literature scanning was developed to define the scope of the research question and to extract potential key terms to use during the literature search strategy. The concepts were divided into three keyword groups: community-based surveillance (community-based surveillance OR population surveillance OR community surveillance OR people centered surveillance OR participatory surveillance OR community-based sentinel surveillance), geographic information systems (geographic information systems OR mapping OR geographical mapping OR participatory mapping OR crowd mapping OR spatial distribution), and infectious disease (outbreaks OR epidemics OR infectious disease). The concept of low-resource settings was not included at this point in the search as it could have returned limited results. Subsequently, using the identified keywords and combined the terms using the Boolean logic, a systematic literature search, including grey literature, was conducted in the following eight bibliographic databases: Web of Science, Embase, Cinahl, Scopus, Pubmed, Epistemonikos, Google Scholar, and Open Grey (**Annex 2**). The search was conducted between March 22nd and April 9th, 2021. A snowballing strategy was implemented to identify further eligible documents not identified during the search. Papers recommended by experts, and relevant references were identified as part of the snowballing methodology. This overall search strategy was chosen given the short timeframe and the characteristics of the topic.

2.2.2 Inclusion and Exclusion Criteria

This review included literature that discusses or refers to a GIS participatory approach for the development of CBS systems in infectious disease. Also, given the expected limited availability of publications that focus on GIS in CBS, literature that is not focused but involves both topics was included. The exclusion criteria included resources that describe GIS without a community-based or participatory component, resources that describe systems developed in high resource settings, resources identified not available in English, French or Spanish, and articles with full text unavailable.

2.2.3 Literature Selection

After scanning by title and abstract, 131 documents were identified out of 2,122 articles resulting from the initial literature search. After duplicates were removed, a total of 115 full manuscripts were screened, and 25 papers were selected for the final review after checking for inclusion and exclusion criteria (**Fig 3**). The articles were stored and documented using the Mendeley Desktop software.

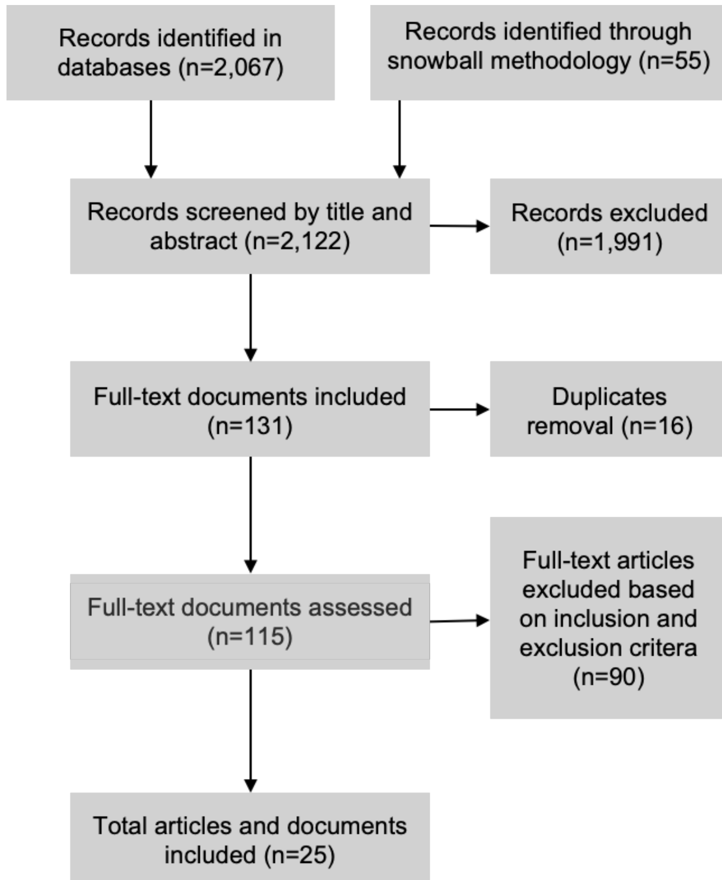

Figure 3. Flow diagram of the search strategy

A quality assessment of the selected studies was not conducted as this is not required in a scoping review, and under the assumption of a low rate of papers that fit the research question. Under the assumption that publications on GIS and CBS might be considerably recent, no year limit was imposed in the search process.

2.2.4 Data Charting Process and Synthesis of Results

Based on the systematic framework, publication details were extracted accordingly using an MS Excel retrieval form to collect descriptive data, but also information about the community-based surveillance initiative, GIS component, and overall features of the systems (**Annex 3**). A systematic analysis of the collected information was done through the retrieval form in order to merge the results and facilitate their display.

2.3 Phase 2: Expert Interviews

A semi-structured qualitative interview with experts was conducted to explore the opinion of persons who have worked in initiatives that involve the use of GIS in CBS systems. The objective was to leverage the results of the literature search by gaining insights from the expert's experience and lessons learnt during the implementation. The systematic framework was used to guide the expert's interview process and standardize these results with those extracted from the literature.

2.3.1 Identification Strategy

Initial purposive sampling followed by a snowballing methodology was used to identify the experts from different relevant and related areas of knowledge but trying to cover two main dimensions: participatory GIS and community-based surveillance. The identified experts were contacted through email (found on papers or their organization's websites) or via LinkedIn. Those who responded were sent an invitation email with further explanation of the initiative, a participant's information sheet, a consent form for their signature, and a scheduled appointment to conduct the interview. A total of 27 experts were contacted of which six responded and finally participated in the interview process (**Table 1**).

Name	Role	Organization
Andrés Garchitorena (AG)	Infectious disease, ecology, and modelling expert	Institute of Research for Development (IRD)
Edward Monk (EM)	Infectious disease doctor and researcher	Médicins Sans Frontières
Florence Fournet (FF)	Infectious and vector-borne disease researcher	Institute of Research for Development (IRD)
Ivan Gayton (IG)	GIS expert	Humanitarian Open Street Map/Médicins Sans Frontières
Johnny Henshal (JH)	GIS senior officer	International Federation of Red Cross Red Crescent
Rupert Allan (RA)	GIS expert	Missing Maps/Médicins Sans Frontières

Table 1. Expert's interview participants

2.3.2 Interview Development

The interviews were conducted online through the Google Meet platform, guided by an interview form created under the guidance of the analytic framework (**Annex 4**). Interviews were recorded after the participant's consent and lasted between 30 minutes to 1 hour. The recorded interviews were transcribed to an interview retrieval form (**Annex 5**) and then analysed through the analytical framework in order to merge with the results of the systematic literature search.

2.4 Ethical statement

This scoping review followed transparent research steps to ensure the validity of the results. An ethical application process was followed through the University of Sheffield to ensure ethical compliance of the research process, and adequate management of the primary data gathered through the interviews.

3- Results

3.1 Selection and Characteristics of Sources of Evidence

The 25 selected articles were reviewed based on the developed analytic framework; general information was extracted to have an overview of the documents (**Annex 6**). Articles were published between 2007 and 2020; 22 papers were research pieces that ranged between ecological studies, case studies, and a review; the other three documents were one book chapter, one study protocol, and one technical guideline. 22 of the documents were written in English while the other three were in Spanish. 13 documents reflected experiences developed at the city or district level, eight at the provincial or state level, and four experiences were not geographically classified, although relating to some geographical areas, especially in the Americas. 10 experiences were developed in Africa, eight in South and Southeast Asia, and three in South America. Overall, the CBS and/or participatory GIS initiatives were developed as components of bigger surveillance or public health systems, 13 were part of overall public health, surveillance, or elimination system, eight were part of a general entomological surveillance or vector control program, and four initiatives stated unique CBS or participatory mapping programs. 16 systems focused on vector-borne diseases, especially malaria and dengue, four systems covered multiple diseases, two of them were developed for COVID-19, and single initiatives were developed for other diseases such as Buruli ulcer (BU), HIV, and Ebola.

The interviews were conducted with six experts who positively responded to the call for participation. Of the six interviewees, five were men. The group was composed of three GIS and three infectious diseases experts. The three GIS experts had a more implementation background, while the infectious disease experts were more focused on research. Although contacted, no epidemiologist participated in the interviews.

3.2 Analysis of Results

3.2.1 Surveillance and Mapping Methodologies

For this scoping review, one of the most common topics associated with the mapping in CBS contexts was VBD, having 10 authors describing methodologies for *Aedes spp.* transmitting diseases such as dengue, Zika, and chikungunya. Dickin (29) described a methodology in which participants from the community were able to draw risk maps with mosquito breeding sites according to their view, these maps were developed in an analog way and ulteriorly digitized. Piedra, Bonnet, and Mora described other methodologies relying on different applications. Piedra (30) discuss the application of GIS methodologies to identify infestation focus by mapping block-level larval indices categorized by type of containers. On the other hand, Bonnet (31) described a two-phase entomological survey in which characterization of potential breeding sites is done through Local Indicators of Spatial Association (LISAs) to analyse spatial concentrations of larvae, this allowed to do descriptive spatial analysis at a household level before and after the intervention. Mora (32) described the use of a web-based GIS system to collect, represent, and visualize spatial data of mosquito breeding sites as part of an entomological surveillance initiative. Ovitraps is an entomological surveillance community-based methodology described by Duncombe (33) who used them to perform a spatial cluster analysis to identify *Aedes spp.* cluster. The International Federation of Red Cross Red Crescent (IFRC) (34) describe seven phases for an ovitraps georeferencing process: 1) work plan development; 2) establishment of a spatial coding system; 3) identification of the type of GPS receptor; 4) definition of the coordinates system; 5) field capturing process; 6) data protection; and 7) data incorporation to a spatial database. VBD surveillance can also be done from a syndromic perspective. In Salvador (Brazil), Kikuti (35) developed a mechanism for CBS of dengue by geocoding patients identified with acute febrile illness (AFI) and evidence of dengue infection within Census Tracts (CT). Wongpituk (36) carried out a dengue surveillance model of risk areas integrating public participation using GIS methodologies, resulting in a dengue risk map relating factors associated with the disease and causes of infection. Other participatory mapping methodologies for VBD surveillance were showed by Krystosik and Palaniyadi. The first introduced the use of Spatial-Video Geonarratives (SVG) where CHW identified disease hotspots and collected insights on their existence, cause, and barriers to control (37). The second utilizes community surveys to map breeding sites and geo-locate them at household levels aiming at understanding people’s perception and knowledge about mosquito protection measures; interestingly, this initiative also collected socioeconomic and environmental variables and related them spatially with mosquito habitats (38).

Malaria was another VBD targeted by participatory mapping methodologies for surveillance. Kamanga (39) and Fornace (40) discussed experiences of community-level malaria surveillance associated with mapping initiatives in health facilities. Kamanga revealed the provision of community-based diagnostic and treatment as the information was reported via SMS text message to reference health facilities subsequently mapped via Global Positioning Systems (GPS). Homan (41) and Parker (42) exhibited experiences of surveillance in malaria control programs supported by community leaders and other community members. The work presented by Homan highlights the role of community members in household mapping to define groups of clusters denominated "metaclusters", which were used for the planning process in the context of the malaria surveillance program implementation. Parker highlighted the utilisation of mapping field teams composed in part by community members, performing near real-time surveillance and gathering other information such as economic indicators, agricultural development, water sources, etc.

Other diseases can be subject to mapping in community-based surveillance. In the context of COVID-19, Lustosa (43) reported the involvement of community leaders to gather information on Earth Observation (EO)-based data products and based on the data gaps found, several dimensions were summarized such as density, facility, environmental-related data, socio-economic data, etc. Green (44) described a methodology involving the youth, community leaders, and CHW as part of an HIV program. The study involved one stage of developing a digital base map, and through a "dot map" methodology, identify locations positively and negatively associated with HIV in the community. The following step was the development of a photo "scavenger hunt" game for the youth to understand risky behaviour associated with the previously identified spots. Finally, individual interviews were run to map youth daily activities and associate them to the already identified risky spots. Kenu (45) showed an experience on BU where CBS volunteers and CHW developed an active case search supported by a suspected BU patients' geo-location process. The mapping process also supported the identification of features like houses, water bodies, fields/crops, gardens, footpaths, rivers, roads, etc. Finally, Nic Lochlain (46) developed a village-level mapping initiative in the context of the West Africa Ebola epidemic where community surveyors supported by local motorcycle drivers developed mapping activities to improve the Ebola surveillance and response program.

Community mapping for infectious diseases surveillance systems was also discussed by Saran (47) in his review. The paper highlights the integration of infectious disease surveillance and participatory GIS through two methodologies called Volunteered Geographic Information (VGI) which allows retrieving spatial information not collected through satellite imagery or GPS devices, and crowdsourced mapping based on mobile technology. Besides, Dongus (48) highlights the role of Community-Owned Resource Person (CORPs) in conducting a set of sketch maps during their routine activities, followed by a technical mapping to add other attributes through aerial imagery, the results of this mapping were subsequently used for routine surveillance.

Other authors have stated methodologies for participatory mapping in the surveillance of disease risk factors. Munyaneza (49) described the role of CHW in mapping drinking water sources and community data in the frame of a surveillance system in Rwanda. Monk (50) described the use of motorcycle mapping in the context of Ebola in Sierra Leone by defining health facility catching areas. Makful (51) also described the use of Participatory Rural Appraisal (PRA) as a useful methodology.

3.2.2 Community Engagement

In his review, Saran (47) presents Hakay's classification of "citizen science" which provides four levels of engagement within communities "1) crowdsourcing in which citizens with less or no knowledge on activity perform as sensors to complete computing tasks; 2) distributed intelligence where citizens are being trained with skills for interpretation of collected data; 3) participatory science in which citizens decide about research questions and types of data to be collected; 4) extreme, where citizens are fully involved in defining research strategies, data collection, data interpretation, and performing scientific analysis". In this review, the authors highlighted several of these levels of community engagement.

Some of the strategies included the engagement of specific members of the communities. Dickin (29), for example, described the use of COMBI programs involving community leaders and volunteers supporting mosquito larvae cleaning campaigns, while Lustosa's (43) experience included local community leaders and different methodologies for information gathering such as local webinars and videoconferences. As discussed previously, Nic Lochlain (46) developed a methodology to involve local motorbike drivers to support the mapping of extensive areas in the context of Ebola. Bonnet (31) highlighted the role of community leaders in engaging the rest of the community to participate in several activities such as assessment sessions, education activities, and even community theatre. In a similar experience, Munyaneza (49) used CHW to encourage community participation in mapping processes. Along with community leaders, community volunteers' role is also highlighted by authors. Kenu (45) showed an experience where community-based volunteers developed BU active case search through different methodologies including detection through pictures of BU cases. Dongus (48) also states the role in mosquito surveillance of CORPs who were managed by neighbourhood health committees.

The authors also highlighted the role of community methodologies for mapping. The IFRC (34) introduced the definition of social mapping to analyse characteristics about a territory and communicate it visually in a spatial way, aiming at collective decision-making and social and environmental self-understanding. Ansumana (52) presented a mapping experience where long-term residents and local elders supported the improvement of map boundaries which were subsequently revised by local authorities and other stakeholders. Krystosik (37) and Duc Ngo (53) described the role of CHWs, village health workers (VHWs), vector specialists, and other community support programs in the mapping process and the development of participatory mapping activities such as interviews, focus groups, surveys, etc.

The motivation of communities or their habitants is an important element to encourage their engagement in mapping and surveillance initiatives. Kamanga (39) and Green (44) both discussed the role of positive feedback and constant support and accompaniment to community volunteers by stimulating and introducing the element of excitement over new techniques and tools. A similar factor is the role of compensation mechanisms to implementing communities. Nic Lochlain (46) and Kamanga (39) both introduced compensation mechanisms in their initiatives. The first involved the use of affordable local motorbike drivers, part of the local village transportation network. The second one involved compensation for the use of telephone time and small stipends to participating personnel. Another crucial community engagement aspect was the accessibility to the methodologies by adapting them to the local language. Seven authors manifested methodologies adapted to a local language, including Malay, Tenme and Mende, Kinyarwanda, DhoLuo, Vietnamese, and Spanish (29,37,41,44,46,49,53). Language adaptation to methodologies, training, forms, apps, etc, enables a closer relationship among the communities and facilitates the establishment of feedback mechanisms. A final dimension important for the development of participatory methodologies with communities is training. Six authors remarked on the role of training: Nic Lochlain's (46) study involved training of survey teams in data collection and mapping using Open Data Kit (ODK) and OSMand (Automated Navigation Directions), and the engagement of Android smartphone owners to save time and resources. Munyaneza (49) described a low literacy and skills-focused training to CHW, giving extra attention to those identified as having more difficulty in GPS usage. Other authors described a range of training methodologies in a variety of community-based personnel, including Homan which developed training of field workers in basic computing for the use of mobile tablet devices (40,41,50,53).

The experts' interview showed the fundamental role of communities not only as passive subjects but as an active asset to direct the strategy but also to ensure success. One aspect highlighted by the experts was the privileged position that the communities have to map and report their assets and health conditions. Crowdsourcing mapping was also mentioned as an interesting methodology, however, there is still a position of power in this aspect when high resource and low resource settings are compared. Some of the experts stated that clearer and more effective methodologies should be in place to better engage communities and ensure sustainability. The issue of local adaption was also raised, as some experts expressed that there is still a Western view of mapping that neglects communities' ways of representing themselves; although as expressed by MA *"the problem with community-based data is that anyway there is still something needed that is universally orthodox but still easily adaptable".*

3.2.3 Surveillance and Mapping Data Management

Surveillance and mapping data management involved a range of methodologies including surveys, apps, interviews, etc. Nic Lochlain (46) designed a structured survey to be easily implemented in ODK or MS Excel, similar to Kamanga's experience which entered weekly stratified validated data into an Excel form (39). The authors not only highlighted the use of health events data but also demographic information and other important features to understand the communities' profiles (45). Fornace (40) described the use of mobile technology to collect a different range of information such as survey data, GPS coordinates, photographs, and even diagnostic test results, this kind of tools also allows integration between the different structure of questions such as open answers, multiple choice answers, etc, as highlighted by Homan (41).

As mentioned before, risk factors data was constantly used, being entomological surveillance a recurrent example. Piedra (30) suggests the use of GIS apps for epidemic early warning systems with the use of larval sampling and other density measures of the dengue vector. Bonnet (31) on his side, introduces the role of entomological surveys that involved mosquito breeding site geo-location and mosquito indices such as container index (CI) house index (HI), Breteau Index (BI), and pupae per person index; similarly used by Wongpituk (36) who also added data on other environmental variables such as flooding areas, housing areas, distance from reservoirs, among others. Duncombe's (33) experience includes the experience of ovitraps as an important source of entomological data for surveillance.

Spatial data management also involves a series of methodologies described by the authors. A basic mapping model is described by Parker as data is entered from forms into a spreadsheet and then merged with geographic reference points, previously collected and downloaded from a GPS device (42). Palaniyadi described a more elaborated model that adds socioeconomic and environmental variables gathered through structured questionnaires to then add to the database to map the spatial relationship between these variables and mosquito breeding sites. The IFRC (34) highlights the use of narrative and numeric elements, symbols, icons, colors, and textures to facilitate the understanding of socio-cultural and environmental phenomena, which is also discussed by Mora who highlights the importance of having a pre-specified data model that allows gathering the required data (32). Some experiences like Duc Ngo's (53) expressed the use of existing official data to create topographic, demographic, and administrative layers, factors that can be added to the surveillance system and interactive maps can be created to show individual and aggregated household data. Other alternative sources of data can be the transcript of key informant interviews (KII), focus group discussions (FGD's), the "dot maps", and the geo-caching games as data sources to develop several mapping products including heatmaps (29,44). Lustosa (43) also highlights the importance of utilizing data from publications on social media, interviews in local news, sessions with stakeholders and community representatives.

During their interviews, experts highlighted the importance of making people own the data gathering process to make it more effective and agile, including conducting a hotspot (centric first) collection of information. This was reflected by EM's opinion *"neighbours mapping neighbours"*, who also states that it is needed to *"create methodologies to work for and with the end-users"*. FF summon the role of children and adolescent to reach ownership, which also ensures sustainability. Other opinions express the need to have methodologies that are sustainable, accessible, lightweight, and free, which is especially relevant for open-source technology adding the value of avoiding data become a silo. The use of apps, tools, packages for social mobilization, image and photo methodologies were all mentioned by the experts.

3.2.4 Surveillance and Mapping Tools

In the discussion about surveillance and mapping tools, the role of mobile devices such as mobile phones and tablets with access to GPS gained relevance (30,40). Nic Lochlain (46) described the effectiveness of the use of smartphones with Android operative system as they have high market penetration and are compatible with relevant open-source software. ODK has been the most common data management tool found in this review, as it is a tool that allows several mechanisms for data gathering and types of questionnaires adaptable to mobile devices; these features can be performed through functions like ODK-Collect and ODK-Aggregate (41,47,50). Another use of mobile devices was showed by Parker (42) by using GSM (Global System for Mobile Communications) technology to send weekly SMS data reports that were extracted as an Excel file from the receiving phone through open-source tools.

Free access tools such as Google Earth and Google Maps give a good framework for mapping processes in surveillance contexts, other Google-based mobile tools that work offline highlighted by the IFRC are the GPS Status & Toolbox, and Mapa Coordenadas N45, E25. (34). As it was discussed before, the role of crowdsourced mapping is gaining relevance in recent years for several purposes, including epidemiological surveillance. Resources such as OSMand which can be web-based but also compatible with Android smartphones, and Global Administrative Areas (GADM) can be also freely accessible for geospatial data (40,46). Other data collection software capable of mapping offline are GeoODK, Survey123 for ArcGIS, and ePAL (40).

The use of GPS devices was reported by 10 authors in this review. Homan (41) described its use by health field workers to track themselves navigating in real-time in their household visits, while Fornace used it to identify landmarks such as clinics and schools in the geo-location process. Monk reported its use to geolocate households during surveys, other uses were to state boundaries and reconnaissance of mosquito breeding sites (38,40,41,50). Other GPS characteristics highlighted by Kamanga (39) were the level of accuracy and the possibility to show an elevation in a healthcare center mapping initiative. The most common GPS brand in the review was Garmin (several models), including the DNR Garmin software to process the information gathered (45,49,52). Another method for mapping reported by authors was remote sensing through aerial photography or commercial satellite-based sources with tools like high or very high-resolution satellite imagery (40,44). Lustosa (43) reported the use of drone imagery for mapping by adding cameras at different angles through EO in COVID-19 in Brazil.

Several software were discussed by authors for dataset mapping process, digitization of analog mapping, and spatial analysis. The most recurrent mapping software were ArcGIS including several of its features with 8 authors reporting its use, and Quantum GIS (QGIS) with five reports.

Other reported mapping tools were Mapbox Studio, MapInfo Professional, MapBasic programming, and GeoODK which can be useful also for epidemiological and other health events data (40,53). ArcGIS offers several packages for mapping and spatial analysis, being the preference of many experts, however, from a sustainability perspective and given the participatory component, an open-source program like QGIS might be more useful and sustainable in CBS initiatives (44). For statistical analysis, R statistical software and several of its packages including GeoR were also commonly used, being reported by 5 authors. R software is also free, open-source, and cross-platform (44). Other software used by authors for spatial statistical analysis included SaTScan, GeoDa, Stata, and Python (31–33,40).

The expert's interviews highlighted once more the role of open-source schemes, however, the solutions should be local first, as the risks of introducing new software and tools within a community should be considered, as expressed by IG *"local people, local devices and open knowledge"*. Experts also agree on the need to develop basic and/or analog tools like printed maps and survey forms for backup. Showing the same trend as in the literature review, interviews highlighted the role of ODK and OSM, but also mentioned other data management tools like Kobo toolbox, DHIS2 which can be used at all levels but easily adapted to the community level, or R Shiny which can be flexible to include GIS spatial analysis.

3.2.5 Spatial Analysis

Spatial analysis in epidemiology is a dimension that potentially increases sensitivity and enhances the results of surveillance systems, including its community-based component. Nine documents involved a certain level of spatial analysis, showing more than a disease or health event spatial localization. Piedra (30) highlights the capacity of GIS to develop spatial statistical analysis in dengue programs by supporting planning, monitoring, evaluation, and decision making, especially after larval density analysis in entomological surveillance, while Krystosik (37) utilized the Kernel Density Estimate (KDE) to map several dengue risk factors to support their visualization. Palaniyadi (38) also shared an experience on mosquito breeding sites density to check on mosquitogenesis conditions in urban settlements. Kenu (45) in his paper on BU elimination, developed buffer zones around places where BU was found, in order to analyse particular characteristics in the surveillance process. Duncombe (33) reported spatial clustering in entomological surveillance by calculating the observed and expected number of mosquitoes in the identified zones; and Bonnet (31) discussed the role of local and global clustering techniques like spatial autocorrelation such as the Moran's index, although the latter can fade local scale spatial heterogeneity. Saran (47) also discussed the role of geographical clustering in COVID-19 surveillance to enable timely prevention and containment measures due to early notification to epidemiologists and decision-makers. Also, Parker (42) included a hotspot definition in the context of a malaria surveillance initiative to classify areas with a prevalence ≥40% compared with the proportion of P. falciparum in positive samples.

During the interviews, the experts have expressed contrasting points of view about the use of spatial analysis in CBS. Some experts say that spatial analysis is not easy to implement in non-research contexts. Even when there is complete data at the community level, the information needed is already known and there is no necessity for sophisticated methods. Other experts acknowledge the challenge of doing spatial analysis in CBS but try to explain some ways to implement it. FF explains the *"use of density analysis with very basic mosquito traps and the use of OSM community to teach how to collect data and put it in the maps, so they can do some hotspot analysis for vector-borne disease initiatives".* Other authors point out the need to incentivise the communities to gather a higher amount of quality data or the use of map books linked with local cluster population density as mechanisms to develop further spatial analysis in participatory surveillance.

3.2.6 Validation of Results

Mapping and surveillance data validation in a community context is needed to make results more reliable and communicate the right information to decision makers. In this revision, 10 documents explain or inform about data or results validation processes. The IFRC (34) highlights the role of metadata to understand the data gathering process and account for the right information for surveillance and spatial analysis; and Makful includes a reliability test in her analysis to determine the level of trustiness of the data gathered (51). Dongus called "technical mapping" to the process of verification and formalisation step from technical experts and community members, after an initial "sketch mapping" (48). Mora developed something similar with the support of epidemiology and nursing students (32). Nic Lochlain (46) defined a two-step validation process where the first element was validation in-place supported by local communities, and the second step was the use of an algorithm developed in R program by matching the GIS information from different sources including the mapping process. Munyaneza (49) reported something similar as it also included a two-step validation by engaging communities and other stakeholders at the district level, but also passing the process through revision by GIS experts. Fornace and Homan reported real-time and in-place quality control of the surveillance mapping process through GPS or web-based monitoring systems (40,41). Another validation mechanism described by Dickin was the use of printed maps revised by community members and other stakeholders such as public health officials, influencers, and key community persons (29).

Experts expressed the importance of community involvement in surveillance mapping as a validation mechanism itself. This is reflected by JH who says that *"the stronger the local mapping community is, the more validation is inherently done".* However, even though they could be resource-pressing, experts also manifested that community validation needs to have quality data and methodologies, as well as constant updates in real-time to avoid ambiguity. This strategy could also be potentially effective in the case of the migrant population. Experts also highlighted the role of crowd mapping such as OSM and Missing Maps as a mechanism of continuous validation, however, this remote validation of data is not 100% effective and, in several situations, does not have a realistic life cycle. For this, some experts suggested the involvement of impartial third parties to validate reported data.

3.2.7 Ethical Dilemmas

Ethical concerns are an important aspect when developing either disease mapping or surveillance activities. However, it was not a recurrent topic for discussions among authors as only 6 made references to it, none of them, however, making insightful reflections. In ethical terms, attention went towards the importance of counting with the communities to develop surveillance initiatives, making it mostly participative, and making communities feel non-invaded. This can be reached, as expressed by some authors through agreeing on a social contract and develop mapping surveillance actions along with the communities after a clear explanation of goals and methodologies (29,45,48). Adapted consent form at the community and individual levels was also an element included in some of the discussions (29,41,48). Another relevant discussed topic was the importance of creating mechanisms for data protection and confidentiality through reliable data storage procedures, taking into account the harm/benefit ratio (34,46).

Expert interviews showed contrasting results. As some experts think that there are no serious ethical implications in mapping communities, it has been clear that adding the element of surveillance adds ethical dilemmas that should be addressed, especially on the use of non-secure data apps or methodologies. Another point of ethical discussion was the level of detail in mapping initiatives, even if communities agree with it, especially when it is possible to map or geo-locate individuals or point houses with higher resolution. Some experts think that data safety is important but overemphasized, especially in low-resource settings. IG sustains that *"people could accept the risks of being identified by the sole fact of them being recognized as existing human beings. The default should be that everyone is counted, with the option for people to opt-out"*. Some experts consider certain situations more sensitive in terms of mapping for surveillance, for example, in security settings where potential unforeseen consequences could be present, or in emergency or epidemic context with their association to stigma and other ways of discrimination; in these situations, the "do no harm" principle should be considered.

3.2.8 Sustainability

Some authors refer to the sustainability in these community initiatives. In terms of spending, Nic Lochlain reveals an overall cost for mapping survey data collection of €3,395, meaning €3.80 per village surveyed, including costs of motorcycle drivers daily rate, fuel, and maintenance; costs also included surveyors' daily worker rate (46). In his community-based initiative, Munyaneza reports an overall cost of US$29,692 for the data collection and mapping process (68% of the cost), training (15%), map validation (11%), and dissemination (6%); this cost was about twice less expensive than the cost of a team of GIS experts. It should be noted that this initiative used proprietary software, which means that costs could be even lower for open-source software (49). Dongus' initiative calculates an average cost of US$24 to sketch and map covering one Ten-Cell-Units (TCU), equalling US$831 per km2, the author considers this initiative to be sustainable, especially in African contexts with low rates of geo-location, as this mapping should be done only once with very small updates (48). Homan states that open-source mobile data collection software is more cost-effective than paper-based mechanisms as it implies fewer field workers and staff to accomplish the surveillance tasks (41). Other sustainability dimensions highlighted by authors were the importance of acceptability at the community level to ensure a successful transition to a sustainable scheme (53), and the important role of children and adolescents to ensure long-term engagement, especially in rural, low-resource environments (44). Fornace (40) also highlighted the importance of extending community-based strategies towards health facility capacities to monitor remote areas and ensure a sustainable link among both dimensions.

Most of the experts interviewed thought that the discussion on sustainability is not necessarily about costs but about ownership, especially through making maps and surveillance initiatives visible and useful for the communities. The role of the community itself is crucial to own and drive the initiatives, but it is also crucial the role of leaders and decision-makers to support and maintain the spirit. As shown in the literature review, another important group highlighted by the experts to ensure sustainability is children's ownership. It is also important to make these initiatives with technology socially sustainable that is open source and open knowledge, to empowering people to drive themselves. EM states that *"plans should be built sustainably from the start, involve local buying, local design, and effective feedback mechanisms".*

3.2.9 Limitations

Among the limitations highlighted by authors, one important identified is precisely sustainability, especially due to lack of motivation, stock depletion, or staff shortages (30,39). Also, the lack of integration of surveillance initiatives with existing local and national programs to ensure coordination was identified as an important obstacle (30). Another limitation was the follow-up and engagement of the migrant population under study, including internal migration at the household level (41). From the technical perspective, one identified limitation is the lack of fine-resolution mechanisms to follow community-level mapping initiatives, especially to validate locations away from recognisable features such as roads and lakes (45,49), but also the fact that sometimes entomological indexes are recorded in spatial units not aligned with CT boundaries (35). Another limitation is the user-unfriendly character of some of the tools and methodologies for mapping and surveillance (30). Dickin also states the lack of accuracy compared to scale when sketch maps were done based on community members' perspectives or interests (29).

Accessibility has been an important limitation reported by authors. Nic Lochlain described the challenges of developing activities under strict curfews and travel restrictions in the context of an Ebola outbreak (46), and Monk found that poorer and isolated communities have more difficulties in enrolling in health systems initiatives (50). Accessibility in terms of personal safety was also a concern among studies (33). Parker discusses the difficulties of running surveillance programs in remote and challenging areas due to conflict, natural disasters, or political disputes (42), which is true, especially when mapping or photographs are recorded as part of the initiative (44).

Experts' interview highlighted the sometimes-recurrent failure during implementation, leaving a gap between theoretical knowledge and community-level implementation, especially due to lack of incentives but also by building tools that the communities cannot maintain. Logistical issues in isolated areas is always a limitation. In terms of financial support, short-term view from donors and investors is a problem to ensure increasing capacities at the community level. EA stated that *"many people over trust technology, but there is not really a replacement for field presence"* to highlight the trend of relying too much on digital resources neglecting the role of communication and coordination in the targeted areas.

3.2.10 Future Development and Research

As part of the rounds of interviews, participants considered that, in general, GIS for surveillance purposes is a fundamental operational and research tool that helps to express the data in a more global and legible form, while reaching a wider audience. However, some express that its use is still incipient and that it must be more integrated with the communities and their dynamics and characteristics, especially in low-resource settings where there is less access to certain resources. AG states that *"the role of CHW or community itself is to provide better epidemiological estimates at a better resolution geographically speaking".*

When asked about further perspectives, experts remarked on the importance of developing effective methodologies to strengthen community engagement and more accurate evaluation mechanisms, especially during crisis. From a technological view, the revolution of open knowledge, and the advances in technology and accessibility in mobile phones are expected to keep impacting community-based initiatives in low-resource settings. AG states that *"other technological tools such as artificial intelligence will be useful to map faster and to develop global maps with resolution enough to observe more detailed local areas"*, yet ethical concerns should be considered. COVID-19 has shaped some of the potential trends in the future, such as a more critical understanding of data from the experts. However, also people have now more ownership and understanding (sometimes biased) of the epidemiology, a situation that could potentially lead to social decohesion.

4- Discussion & Recommendations

4.1 The Integration Between GIS and CBS

This scoping review provided additional insights into the issue of integrating geographic information systems within community-based surveillance initiatives for infectious disease in low-resource settings. Overall, predictive tools such as GIS could be used to improve CBS systems when combining with knowledge of health event risks in a given area (54). In this context, case detection instead of measures of disease frequency are prioritized in higher disease areas which allows also to prioritize health care provision and support (35). Based on a personal implementation experience, a CBS system should be developed in several steps, in which the GIS component is compatible: 1) Assessment of the need for a CBS system, which could be in the frame of an outbreak or elimination initiative; 2) Integration and coordination with existing surveillance or public health systems; 3) Engagement of communities in the process; 4) Development and adaptation of the right methodologies and tools; 5) Sensitization, training and implementation with stakeholders and communities; 6) Development of communication, reporting and feedback mechanisms.

Overall, infectious diseases have different characteristics and transmission mechanisms, hence, different strategies to tackle and prevent. This review has demonstrated the flexibility and adaptability that GIS-supported CBS systems have depending on the needs, as they can be very diverse and rich in terms of methodologies and tools for data gathering and mapping. The methodologies used for CBS and participatory mapping will depend on the disease or health event, geographical area, community perspectives, availability of resources, local culture, and social and safety conditions. In this review, examples of mapping for CBS were observed in both epidemic alert and response, and infectious disease monitoring with control or elimination purposes. A CBS mapping for VBD example is the development, monitoring, and reporting of ovitraps by communities, providing data that allows mapping potential mosquito breeding sites and further analysis. Similarly, CBS systems in malaria contexts allow community-level screening through rapid diagnostic tests, improving the reporting mechanisms, and giving the chance to spatially locate malaria cases. By relying on community-adjusted case definitions, other diseases such as cholera, plague, or VHF, could be potentially monitored, mapped, and applied cluster detection techniques within CBS systems, increasing their sensitivity and posibly specificity. One important element to consider is that CBS is not necessarily developed for disease under syndromic surveillance mechanisms as demonstrated in the VBD example. CBS can monitor risk factors as equal as health outcomes, rumor surveillance or community behaviours are other examples of it; all of them, are prone to be mapped and spatially analysed through different methodologies. The expert's interviews evidenced one important asset of GIS-supported CBS systems, which is their interdisciplinarity, involving persons from different backgrounds integrating different sectors. GIS specialists, epidemiologists, information technology, public health, and community engagement experts can support and provide cross-disciplinary inputs for the development of these initiatives (55).

One important element to highlight is the role of CBS within vulnerable communities with weakened public health systems. Authors, considering its cost-effectiveness in hard-to-reach areas, advocate for long-term comprehensive community surveillance to get important health gains for the population. However, it is important to balance the means to make it more effective and sustainable in time, especially from the volunteers' and CHW's perspectives (56,57). Therefore, comprehensive policies need to be in place, from a global and national perspective, to build up on the structures that allow the implementation of CBS, including access to mechanisms and tools. A study on early warning systems in Rohingya settlements in Bangladesh showed the key limitation of its application due to the low availability of mobile networks in some settlement areas, showing the need for a macro infrastructure to ensure conditions for implementation (58). Macro-level initiatives are needed, but as mentioned in the paper, the role of communities is crucial. In her study on Chagas, Parente (59) discusses the importance of close involvement of stakeholders such as local health authorities and residents in promoting disease control, surveillance, and assistance. GIS in CBS systems gives the communities a voice and a place in the world, helps reducing inequalities, and gives them the chance to show their needs and their struggles aiming a social justice. However, this role needs to be acknowledged and encouraged at all levels.

This review showed several GIS and data management methods and tools, especially open-source as they have a crucial role in community-based initiatives. As they provide the capacity to analyse big amount of data straightforward and accurately, technological solutions such as real-time information updating tools are frequently used to improve the efficacy of mapping processes in surveillance systems, especially in poor settings to improve data-driven responses (21). In parallel, crowdsourced methods aim to bring data, local knowledge, and spatial awareness to potentially complement traditional data sources in surveillance initiatives (22). However, alternative non-technological solutions have the advantages of low cost, reliability, and simplicity, prone to be used in certain contexts or as a backup in case technology fails or is limited (21). One low-tech methodology highlighted during the revision was the use of map books, which are useful tools for community mapping in low-resource settings or at a distant site (28). Map books can be adaptable with the idea of Field Papers (60), which is a web-based mechanism to create printable maps compatible with OSM for editing purposes. Fine-scale maps for surveillance can be greatly improved by mapping exercises at the community level as showed by Curtis's experience on using spatial video techniques to generate base layers for water infrastructure and human activity in cholera surveillance (61). Another strategy to improve fine-scale surveillance is the use of risk maps which can capture spatiotemporal patterns by using micro-level data like household or individual information (1,25). Linked to the use of tools is the factor of capacity building. Training is necessary, especially when community members or CHW are not experts in certain data gathering or mapping methodologies, which is called “spatial illiteracy” (15). However, mechanisms like web-based programs with access to training resources, or implementation through self-owned devices might help to save time and resources from training, as well as to reach system usability and encourage ownership, stimulating sustainability (22,55).

Community surveillance mapping is challenged by the movement of persons, which could potentially hinder its results. One solution could be the identification of hotspots using mobile phone data or social networks, also useful to identify behaviour patterns (19). These migration phenomena could occur on a permanent basis, but also, hence, geo-location through GPS tracking devices and cell phone usage could have potential utility (20). However, this is not without ethical concerns about safety and confidentiality during tracing activities, especially in conflict contexts.

Ethical challenges in infectious disease are complex as many interventions and surveillance methodologies will potentially invade the private sphere of persons and communities, gathering sensitive information on behaviour and personal attitudes (19,21). Mapping in the context of epidemics imposes the ethical challenge of stigmatization, having consequences such as discrimination. Even if the surveillance is done at a hotspot level rather than individuals, communities could still face stigma affecting the local economy, property value, etc. (19). Any type of data gathering activity must accomplish with ethical standards of confidentiality, but also accounting on the “do no harm” principle to guarantee a minimum risk possible to people involved in the surveillance initiative (6). To face some of these ethical dilemmas, community empowerment from a perspective of equity, and negotiation of power relationships becomes important to encourage ownership of the surveillance initiatives. This negotiation should involve not only communities but also other stakeholders having a say in community dynamics (14). Another element to tackle ethical dilemmas at the local level is the harmonization of data management legislation in low-resource settings to balance the health information potentially gathered and protecting data privacy (55).

4.2 Future Perspectives

Efforts should be made, by all sectors, to reduce the inequality gap between high and low resource settings in order to improve accessibility to technological resources for mapping and surveillance at the community level (22). Some of these efforts should be addressed towards increasing the critical mass and level of expertise to support such systems. More consensus in definitions and methodologies, especially in CBS, should be reached, accounting for the particularities of the targeted areas. To guide the literature strategy search, assess the evidence, and help to guide the experts' interview process in this review, an analytical framework that involved different features of the GIS, CBS, and community engagement dimensions was developed. A more adapted analytical framework should be considered in the future to address the integration issue between CBS and GIS, based on further research that better explains the symbiotic relationship between maps and surveillance at the community level. Crowdsourced mapping, among other initiatives, has provided a platform to grow GIS communities and databases even in LMIC, which opens future perspectives for integration with governmental initiatives, including surveillance systems. However, there is still work to be done in terms of information sharing, legal framework, and cooperation mechanisms.

Further research is needed to understand the compatibility of spatial and statistical analysis with CBS systems, clarifying the central role of the communities. Additional analysis is necessary to better adapt the use of technological tools for mapping, analysis, reporting, and visualisation aiming at improving their performance, including aspects such as user-centered design for more efficiency, effectiveness, and friendly use (22). Mapping technologies such as remote sensing and drone imagery could potentially impact the surveillance dimension; better accessibility, and adaptation to community-based initiatives to ensure acceptance and ethical use are needed (27,62). It would also be important to clearly understand how these CBS initiatives are replicated, embedded into other surveillance systems, and understand their life cycle.

4.3 Limitations of the Review

Besides its potential contribution, this scoping review has certainly limitations. First, this review is not exhaustive, and the analysis was difficult due to the quality of some of the evidence gathered, which could be explained as it is a relatively recent topic, but also because it is composed of several sub-domains. Another factor could be the lack of interest in the topics, although the current COVID-19 pandemic could change that trend. No quality assessment was done for this review under the assumption that some sources could be lost, which means that the quality of some of the articles could potentially not be the best. Based on the said limitations, this scoping review intended to leverage the results by adding experts' interviews and developing a broad search strategy to try and capture as many factors involved in this relationship. One limitation about the interviews was the experts' sampling snowballing methodology as it could bias the list of participating experts. Another limitation was the level of response of the interviewees, although somehow the final list seemed balanced, still, some insights from epidemiologist or CBS implementing experts were missing. Related to this, another limitation was the exclusion of community members involved in implementing CBS programs, which could have provided a different point of view of the role of GIS as well as their preferred methods to be engaged and their voice to be heard. Another challenge was the lack of standardization in certain definitions, for example, the term CHW sometimes could fall into a grey area, although some papers stated CHW as a person from the same community, and elected and monitored by community instances. Although French was considered, only articles in English and Spanish were found during the search, potentially excluding useful resources in other languages.

5- Conclusion

Recent public health emergencies have taught important lessons in preparedness systems for epidemic response. In an interconnected world, the improvement of the countries' surveillance and early warning systems is crucial, given the high risk of disease expansion. But surveillance systems are also useful to monitor endemic disease, potentially adding hopes and a global sense of collective victory when disease elimination processes are successful. Another lesson learnt is the role of communities in the genesis of epidemics, but also their central role in overcoming epidemics and their secondary effects, as stated by the expression "epidemics start in the communities and end in the communities". Based on the previous ideas, the obligation to conduct and support disease surveillance initiatives is everyone's task, including the communities. Hence, the strengthening of community structures to support surveillance systems in LMIC should be an obligation of the global health architecture, including power governments and the international community.

Under the previous assumptions, CBS initiatives should be encouraged and strengthened in low-resource settings in order to improve their detection capacity. Considering that epidemiological patterns are better measured and viewed in a spatiotemporal way, the potential role of GIS in these surveillance systems is limitless. This review analysed this interaction and highlighted the main reflection points to improve it, and in some way, give vulnerable communities the voice they deserve, at the same time that advocates to help reduce the inequality that hinders vulnerable societies to effectively prepare and respond to epidemics.

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List of Annexes

Annexes

Annex 1 – PRISMA Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	X
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	X
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	X
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	X
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	X
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	X
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	X
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	X
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	X
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	X
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	X
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	X
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	

Section and Topic	Item #	Checklist item	Location where item is reported
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	X
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	X
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	X
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	X
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	X
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	X
Study characteristics	17	Cite each included study and present its characteristics.	X
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	X
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	X
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	X
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	X
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	
Reporting	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	

Section and Topic	Item #	Checklist item	Location where item is reported
biases			
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	X
	23b	Discuss any limitations of the evidence included in the review.	X
	23c	Discuss any limitations of the review processes used.	X
	23d	Discuss implications of the results for practice, policy, and future research.	X
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	X
Competing interests	26	Declare any competing interests of review authors.	X
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71 For more information, visit: http://www.prisma-statement.org/

Annex 2 – Search Strategy by Database

Web of science: (community based surveillance OR population surveillance OR community surveillance OR people centered surveillance OR participatory surveillance OR community based sentinel surveillance) AND (geographic information systems OR mapping OR geographical mapping OR Participatory mapping OR crowd mapping OR Spatial distribution) AND (outbreaks OR epidemics OR infectious disease)

Embase: ("community based surveillance" OR "population surveillance" OR "community surveillance" OR "people centered surveillance" OR "participatory surveillance" OR "community based sentinel surveillance") AND ("geographic information systems" OR mapping OR "geographical mapping" OR "Participatory mapping" OR "Spatial distribution") AND (outbreaks OR epidemics OR "infectious disease")

CINAHL: ("community based surveillance" OR "population surveillance" OR "community surveillance" OR "people centered surveillance" OR "participatory surveillance" OR "community based sentinel surveillance") AND ("geographic information systems" OR mapping OR "geographical mapping" OR "Participatory mapping" OR "Spatial distribution") AND (outbreaks OR epidemics OR "infectious disease")

Scopus: (community based surveillance OR population surveillance OR community surveillance OR people centered surveillance OR participatory surveillance OR community based sentinel surveillance) AND (geographic information systems OR mapping OR geographical mapping OR Participatory mapping OR crowd mapping OR Spatial distribution) AND (outbreaks OR epidemics OR infectious disease)

Pubmed: (community based surveillance OR population surveillance OR community surveillance OR people centered surveillance OR participatory surveillance OR community based sentinel surveillance) AND (geographic information systems OR mapping OR geographical mapping OR Participatory mapping OR crowd mapping OR Spatial distribution) AND (outbreaks OR epidemics OR infectious disease)

Epistemonikos: (((“community based surveillance”) OR (“population surveillance”) OR (“community surveillance”) OR (people centered surveillance”) OR (“participatory surveillance”) OR (“community based sentinel surveillance”)) AND ((“geographic information systems”) OR (mapping) OR (“geographical mapping”) OR (“participatory mapping”) OR (“spatial distribution”)) AND ((outbreaks) OR (epidemics) OR (“infectious disease”)))

Google Scholar: "community based surveillance" OR "population surveillance" OR "community surveillance" OR "people centered surveillance" OR "participatory surveillance" OR "community based sentinel surveillance" AND "geographic information systems" OR mapping OR "geographical mapping" OR "Participatory mapping" OR "Spatial distribution" AND outbreaks OR epidemics

OpenGrey: “community based surveillance” OR “participatory surveillance” AND “geographic information systems” OR “Participatory mapping” OR “crowd mapping”

Annex 3 – Sample of the Studies Retrieval Form

General		Surveillance			Geographic Information System				Performance				Remarks conclusion
Identification	System	Methodology	Community engagement	Data management	Methodology	Mapping tools	Spatial analysis	Mapping validation	Overall performance	Ethics and confidentiality	Sustainability	Limitations	

Annex 4 – Expert's Interview Form

The Integration Between Geographic Information Systems and Community-Based Surveillance for Infectious Disease in Low-Resource Settings: A Scoping Review

Semi-structured interviews with community-based surveillance and GIS experts:

Aim:
This scoping review aims to assess the role and impact of GIS as a technological tool to implement participatory methodologies for the development of community-based surveillance interventions, especially during the rolling out of epidemic early warning systems in low resources settings.

Introduction of interviewer
Introduction of interviewee
Ask permission to record the session

Start recording

1. Start each interview stating
- Date, time and place
- Name of the research
- Aim
- Presentation of the expert
- Informed consent:
    - Questions or comments?
    - Purpose of the interview.
    - Request permission to be named in the paper

2. Development of the questions:
    - How do you see/evaluate the use of Geographic Information Systems for overall surveillance activities? Any experience?
    - How do you rate the importance of the community having a central role in disease mapping during surveillance activities (including access, acceptability, training, etc)? Any experience?
    - Under your point of view, what are best data collection and gathering methodologies for participatory or community-based mapping during surveillance activities (for example the role of crowd mapping)? Any experience?

- Under your point of view, what are those useful and usable data collection and mapping tools during community-based surveillance activities? Any experience?
- Do you consider more complex spatial analysis can be done in participatory mapping for surveillance (such as hotspot and coldspot detection, buffering, density analysis, clustering, spatial autocorrelation, etc)? Do you think it could be useful? Any experience?
- Are there necessary mechanisms to validate the community mapping in surveillance initiatives? What is the best way to do so?
- What do you consider are the main ethical concerns in the community-based mapping process for surveillance? How to address them? Open source?
- How do you evaluate the element of sustainability of the mapping component in a community-based surveillance system?
- What do you consider are the main limitations in the community-based mapping process for surveillance? How to address them?
- What do you consider should be the main focus for future development and research in the community-based mapping process for surveillance?
- Final remarks?

3. Thank the expert and close the interview saying the time.

Stop recording.

Annex 5 – Sample Interview Retrieval Form

Identification	Overall evaluation	Central role of community	Data management methodologies	Data and mapping tools	Complex spatial analysis	Validation mechanisms	Ethical aspects	Sustainability	Limitations	Future development and research	Final comments

Annex 6 – Summary of Selected Studies

Year/Authors	Type	Name	Location	Aim	Scope	Disease	Conclusion
2007/Dongus et al	Research paper / Ecological study	Participatory mapping of target areas to enable operational larval source management to suppress malaria vector mosquitoes in Dar es Salaam, Tanzania	Dar es Salaam (Tanzania)	To describe a community-based participatory mapping procedure that can be used to overcome the challenges described above, and allows the integration of the valuable knowledge of community members	Entomological surveillance system	Malaria	The participatory mapping approach developed in Dar es Salaam enables complete coverage of targeted areas with mosquito larval habitat surveillance and control through comprehensive spatial coverage with community-derived maps. It can be fully integrated into an operational malaria control programme which takes local administrative or other suitable structures into account. The proce- dure is simple, straightforward, and low cost. It requires only minimal technical skills and equipment.

2010/Ansumana et al	Research paper / Ecological study	Enabling methods for community health mapping in developing countries	Bo district (Sierra Leone)	To develope and use participatory methods to provide a low-cost solution to address mapping issues in Bo, Sierra Leone, and to begin populating a GIS with population statistics that can be used to address many community issues	Overall surveillance system	Multidisease	This paper demonstrates that a participatory mapping approach can mitigate some of the challenges inherent to mapping in low-resource areas and can be a first step toward implementing GIS for public applications, such as disease surveillance, the determination of the preferred location of public services, and the man-agement of future outbreaks.
2010/Kamanga et al	Research paper / Ecological study - Case study	Rural health centres, communities and malaria case detection in Zambia using mobile telephones: a means to detect potential reservoirs of infection in unstable	Choma and Namwala districts (Zambia)	To combine the process of positive diagnoses in rural health centres (passive case detection) to help detect potential outbreaks of malaria and target interventions to foci where parasite	Passive surveillance system	Malaria	Enrolling rural health centres to provide timely information on the occurrence of malaria cases to central health authorities will provide critical data enabling rapid deployment of specific interventions.

		transmission conditions		reservoirs are likely to occur			Timely information will improve management of the national malaria control programmes and could enable targeted deployment of specific drug intervention to prevent transmission of malaria and reduce the expansion of the disease into a previously controlled area
2013/Dickin et al	Research paper / Qualitative study	Mosquitoes & vulnerable spaces: Mapping local knowledge of sites for dengue control in Seremban and Putrajaya Malaysia	Putrajaya and Seremban municipalities (Malaysia)	To use a participatory mapping approach to identify spatial perceptions of risk to dengue at a community scale	Entomological surveillance system	Dengue	Resident perceptions of some vulnerable areas, such as green spaces, differed from the views of local public health staff could influence the actions of residents to adequately destroy breeding sites. This highlights the need to understand local knowledge of mosquito

							breeding in order to enhance co-operative efforts with vector-control workers, and increase the effectiveness of dengue prevention efforts at a local scale in Malaysia
2013/Duncombe	Research paper / Ecological study	Characterising the spatial dynamics of sympatric Aedes aegypti and Aedes albopictus populations in the Philippines	San Jose village, Muntinlupa city (Philippines)	To explore coexistence patterns and spatial clusters of Aedes populations and to predict vector density across the study area in order to identify high and low risk transmission zones at a fine spatial scale	Entomological surveillance system	Dengue	Mosquito density maps identify potential high and low risk dengue fever transmission zones for directing prevention and control activities, and may be used to advocate the development of targeted local-level surveillance such as spatial decision support system (SDSS) for integrated dengue fever management in the Philippines.

2014/Kenu et al	Research paper / Ecological study	Application of geographical information system (GIS) technology in the control of Buruli ulcer in Ghana	Eastern and Greater Accra region (Ghana)	To use Geographical Information System (GIS) technology to show the spatial distribution and hot spots of Buruli Ulcer in Greater Accra and Eastern Regions in Ghana.	Overall surveillance system	Buruli ulcer	The goal of the study was to determine the spatial distribution of the disease in the communities along the Densu river. The GPS maps generated clearly show where the cases were coming from, the clustering nature of the disease and the risk level per population of the districts. In addition, this study has clearly shown that BU cases were not present upstream of the Densu river but rather were only seen from the point where the river was contaminated and flowed slowly.

2014/Munyaneza et al	Research paper / Ecological study	Leveraging community health worker system to map a mountainous rural district in low resource setting: a low-cost approach to expand use of geographic information systems for public health	Burera district (Rwanda)	To describe the use of community health workers' (CHW) supervisors to map villages in a mountainous rural district of Northern Rwanda and subsequent use of these data to map village-level variability in safe water availability.	Publich health system	Multidisease	Existing national CHW system can be leveraged to inexpensively and rapidly map villages even in mountainous rural areas. These data are important to provide managers and decision makers with local-level GIS data to rapidly identify variability in health and other related services to better target and evaluate interventions.
2014/Palaniyandi M, Anand PH, Maniyosai R	Research paper / Ecological study	GIS based community survey and systematic grid sampling for dengue epidemic surveillance, control, and management: a case study of Pondicherry Municipality	Pondicherry Union Territory (India)	To study the socioeconomic and environment in the two different cultural regions of south India and for mapping dengue and chikungunya transmission segments in the study region, hence, develop a GIS based decision making tool for dengue vector control,	Vector control program	Vector-borne diseases	Socioeconomic and environmental condition in the study region, estimates for identifying the socioeconomic and environmental key variables associated with dengue and chikungunya epidemics, visualising the risk of epidemic

				dengue epidemic surveillance, control and management at the national level			and vulnerable areas, estimates the population at risk of exposure to the epidemic, prioritization of areas/wards / blocks for vector control and management, GIS based spatial solution for vector control and management and a protective measures against dengue vector biting, and to be calling attention to the importance of dengue transmission at work, schools and other public spaces.
2015/Homan et al	Research paper / Ecological study	Innovative tools and OpenHDS for health and demographic surveillance on Rusinga Island, Kenya	Rusinga Island (Kenya)	In 2012 a health and demographic surveillance system (HDSS) was initiated on Rusinga Island, western Kenya, to facilitate a large malaria control trial, the SolarMal project. This paper describes the computer-	Overall surveillance system (focus on malaria - entomological)	Malaria	This novel method of HDSS implementation demonstrates the feasibility of integrating electronic tools in large-scale health interventions

				based HDSS developed for this project.			
2015/Kikuti et al	Research paper / Ecological study	Spatial Distribution of Dengue in a Brazilian Urban Slum Setting: Role of Socioeconomic Gradient in Disease Risk	Salvador State (Brazil)	To examine whether specific characteristics of an urban slum community were associated with the risk of dengue disease. Estimation of the spatial distribution ofsymptomatic dengue in an urban slum community in Salvador, and assess whether group-level demographic, socioeconomic, and geographic factors influenced dengue distribution.	Unique community system	Dengue	Implementation of sentinel health unit-based enhanced surveillance for dengue is feasible and may be employed to obtain high quality information on disease trends and circulating serotypes as well as increase opportunities for timely detection and intervention during epidemics, which may not be achieved by passive surveillance

2016/Green et al	Research paper / Ecological study	Participatory mapping in low-resource settings: Three novel methods used to engage Kenyan youth and other community members in community-based HIV prevention research	Muhuru Bay (Kenya)	To describe the development of three innovative mapping methods for engaging youth in formative community-based research: 'dot map' focus groups, geocaching games, and satellite imagery assisted daily activity logs.	Unique community system	HIV	With cheaper, more widely available hardware, easy to use platforms like OpenStreetMap with current high-resolution satellite imagery, and free and robust analysis tools like QGIS and R, it is possible for participants in low-income communities to participate in every aspect of these initiatives. There will still be barriers to accessing computers and building computer literacy and technical skills for analysis, but barriers to this type of community-based participatory research have never been lower

2016/Piedra R, Sanchez Z	Book chapter	Aplicaciones de los sistemas de información geográfica en la vigilancia y el control del dengue	Not geographically restricted (experiences from Latin America)	To provide updated information on the applications of GIS in dengue surveillance and control., introduction of its fundamental concepts and some of its applications in dengue surveillance and control are illustrated in support of decisions at the regional, national and sub-national levels. A model is proposed for the implementation of GIS in the surveillance and control of dengue in an urban area.	Overall surveillance system	Dengue	GIS technology enables the production of high-quality, detailed maps relatively quickly and easily. In turn, maps are a fundamental instrument for communicating useful information to those involved in the dengue program, to decision-makers, as well as to all stakeholders, including community members. The ability to present additional information linked to the map can be very helpful to program staff and community members in identifying problems and finding solutions

2017/Krystosik et al	Research paper / Ecological study	Community context and sub-neighborhood scale detail to explain dengue, chikungunya and Zika patterns in Cali, Colombia	Cali (Colombia)	Dengue, chikungunya, and Zika research in Colombia has generated considerable geo graphic investigations, mostly focused on spatial and temporal patterns of either mosquito intensity or human case data. However, there is still a need for greater understanding at a granular sub neighborhood scale that incorporates specific features such as houses, streets, standing water and other environmental risks	Overall surveillance system	Vector-borne diseases	This study has revealed the types of risks present at a geographic scale not commonly analyzed with regards to dengue or other mosquito-borne diseases. The combined spatial video and spatial-video geonarratives approach not only can be used to identify potential risks, but also, when overlaid with actual disease cases, can be used as an ongoing data resource to determine what was happening inside each hotspot, what it looks like, and how it is described.

2017/Parker et al	Study protocol	Scale up of a Plasmodium falciparum elimination program and surveillance system in Kayin State, Myanmar	Easter Kayin State (Myanmar)	To describe the establishment of the scale up elimination project in Easter Kayin State.	Elimination initiative	Malaria	This protocol illustrates the establishment of an elimination project and operational research in a remote, rural area encompassing several armed groups, multiple political organizations and a near-absent health care infrastructure. The establishment of the project relied on a strong rapport with the target community, on-the-ground knowledge (through geographic surveys and community engagement), rapid decision making and an approach that was flexible enough to quickly adapt to a complex landscape

2018/Fornace et al	Research paper / Ecological study	Use of mobile technology-based participatory mapping approaches to geolocate health facility attendees for disease surveillance in low resource settings	Rizal and Palawan (Philippines) and Kulon Progo Regency, Yogyakarta, (Indonesia)	To assess the use of Android tablet-based applications containing high resolution maps to geolocate individual residences, whilst comparing the functionality, usability and cost of three software packages designed to collect spatial information	Infectious disease surveillance system	Malaria	Results demonstrate the utility of this approach to develop real-time high-resolution maps of disease in resource-poor environments. This method provides an attractive approach for quickly obtaining spatial information on individuals presenting at health facilities in resource poor areas where formal addresses are unavailable and internet connectivity is limited.

2018/Mora J, Díaz C, Cruz-Roa A	Research paper / Ecological study	Sistema de Información Geográfica en la Web (WEBGIS) para el Apoyo a la Vigilancia Entomológica de Aedes Aegypti	Not geographically restricted (Colombia)	A web application was obtained that allows the creation of infestation maps from information shared by the community in a collaborative way. Said information is validated by experts with the aim of only having accurate information at the time the web application builds the infestation maps.	Entomological surveillance system	Vector-borne diseases	Through community collaboration and technological resources, tools can be built on which society relies to solve its problems. The ability of WebGIS to receive and store data from external sources allowed through CrowdSourcing provided information to process and build infestation maps. Infestation maps as a support tool are very useful because they allow us to identify easily possible areas of incidence of the Aedes aegypti mosquito.

2018/Nic Lochlainn et al	Research paper / Ecological study	Improving mapping for Ebola response through mobilising a local community with self-owned smartphones: Tonkolili District, Sierra Leone, January 2015 Laura	Tonkolili and Bombali districts (Sierra Leone)	To explore the feasibility and cost to mobilise a local community for this survey, describe validation against existing mapping sources and use of the data to prioritise areas for interventions, and lessons learned	Unique community system	Ebola	Involving local community and using accessible technology allowed rapid implementation, at moderate cost, of a survey to collect geographic and essential village information, and creation of updated maps. These methods could be used for future emergencies to facilitate response.
2019/Duc Ngo et al	Research paper / Ecological study	Addressing operational challenges of combatting malaria in a remote forest area of Vietnam using spatial decision support system approaches	Phu Yen Province (Vietnam)	To examines the development of a spatial decision support system (SDSS) to address operational challenges for combatting malaria in a priority remote forest area of Vietnam including locating active malaria transmission, guiding targeted response, and identifying mobile	Overall decision support system	Malaria	Results from this study demonstrated that SDSS approaches can support the implementation of specialized surveillance in priority forest areas. This approach moves beyond the routine reporting and display of malaria data to providing interactive geo-spatial decision support tools to

				and high-risk populations.			facilitate active surveillance operations and investigation. Utilizing these tools enabled malaria programme personnel to locate malaria transmission locations in near real time.
2019/International Federation of Red Cross Red Crescent (IFRC)	Technical guidelines	Guía Metodológica dirigida al manejo de herramientas y técnicas para la geolocalización y georeferencia de lugares de importancia para la accion comunitaria contra el Zika, dengue y Chikungunya	Not geographically restricted (Experiences from Central America)	To contribute to the management of tools and techniques for the geolocation and georeferencing of places of importance for community action against Zika, dengue andcChikungunya	Unique community system	Vector-borne diseases	Determining processes for a successful management, dissemination and awareness at the institutional level, decision makers and communities; deepening the analysis of breeding sites known as breeding sites and registration of vector monitoring tools such as ovitraps, in this case of Aedes aegypti, a mosquito that transmits the

							Zika virus, Dengue, Chikungunya and other diseases
2019/Makful M	Research paper / Ecological study	The effectiveness of Geographic Information System training for surveillance officers in the Sukabumi district	Sukabumi district (Indonesia)	To understand the effectiveness of Geographic Information System (GIS) training for health surveillance officers in the Sukabumi district by analyzing the results of training competence measurements	Overall surveillance system	Multidisease	The effectiveness of GIS training for surveillance is based on the competencies of knowledge, skill, self-concept, and motive. Among the relationships between age, education, and gender, only knowledge and educational level are related. Evaluating the participants' reactions means measuring their satisfaction. A training is considered effective if it is enjoyable and satisfying for the participants so that they are

							motivated to learn.
2019/Monk et al	Research paper / Ecological study	Determination of true patient origin through motorcycle mapping: design and implementation of a community defined geographic infrastructure surveillance tool in rural Sierra Leone	Kailahun and Kenema (Sierra Leone)	To describe the design and implementation of an in-field method for the determination of true patient origin and demonstrate its feasibility through proof of concept in rural Sierra Leone	Overall surveilance mapping system	Multidisease	Although GPS technology is widely available, accurate records of geographic community organisation are often lacking in LMIC settings. Where new technology replaces or advances existing systems, it is vital not to neglect gaps that remain or develop in basic infrastructures, especially as they are relied upon to a greater extent during periods of emergency and a key component of epidemic preparedness.

2020/Bonnet et al	Research paper / Case study	Impact of a community-based intervention on Aedes aegypti and its spatial distribution in Ouagadougou, Burkina Faso	Ouagadougou (Burkina Faso)	To determine the spatial distribution of a community-based intervention for dengue vector control using different entomological indices. The objective was to evaluate locally where the intervention was most effective, using spatial analysis methods that are too often neglected in impact assessments.	Vector control program	Dengue	The contribution of spatial methods for assessing community-based intervention are relevant for monitoring at local levels as a complement to epidemiological analyses conducted within neighbourhoods. They are useful, therefore, not only for assessment but also for establishing interventions. This study shows that spatial analyses also have their place in population health intervention research.

2020/Lustosa Brito et al	Review - Case study	The Spatial Dimension of COVID-19: The Potential of Earth Observation Data in Support of Slum Communities with Evidence from Brazil	Salvador State (Brazil)	To discuss how the EO-based (earth observation) datasets can potentially support a risk assessment of COVID-19 from the spatial dimension.	Overall surveilance mapping system	Covid-19	Extensive data gaps exist in the location and the physical, environmental, socio-economic, and demographic characteristics of slums. This prevents effective responses that are tailored to the needs and realities of the communities. Therefore, we explored the potential of EO data, which can provide urgently required base data. However, available global spatial datasets are not sufficiently equipped to be fully operational for local responses. The locally very rich open data repository, available for many cities in Brazil, has enormous potential for

							answering key questions. Such questions are related to physical (e.g., the location of high densities) risks, access to services, environmental risks, and open spaces and would allow for updating the very outdated census data
2020/Saran S. et al	Review - Case study	Review of Geospatial Technology for Infectious Disease Surveillance: Use Case on COVID-19	Not geographically restricted	To discuss on the increasing relevancy of geospatial technologies such as geographic information system (GIS) in the public health domain, particularly for the infectious disease surveillance and modelling strategies.	Infectious disease surveillance system	Covid-19	Geospatial applications and dynamic modelling algorithms could offer a well-timed solution to all time historic challenge of humankind in understanding the disease outbreaks, vulnerabilities to population health and adaption of upcoming generation

2020/Wongpituk K, Kalayanarooj S, Nithikathkul C	Research paper / Mix methods	Geospatial Analysis of DHF Surveillance Model in Si Sa Ket Province, Thailand using Geographic Information System	Si Sa Ket province (Thailand)	To investigate the issues and develop a surveillance system or model for DHF with the help of community participation and Geographic Information Systems (GIS). Also, to analyze the relationship between constituents that anticipated to the case of the disease.	Vector control program	Dengue	GIS technologies applied to investigate surveillance data through correlation of spatial analysis of geographical and environmental practices, which are prominent in disease-prone areas. It suggested ways to develop risk maps analysis model and can be used to elaborate the relationship between outbreaks of Dengue with 10 factors, spatial the result has valuable information and techniques that can be used for prediction and prevention of DF and DHF.