The Use of Mobile Phones for the Prevention and Control of Arboviral Diseases: A Scoping Review

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Research article

Keywords: Mobile phone, mobile technology, m-health, dengue, Zika, chikungunya

Posted Date: April 23rd, 2020

DOI: https://doi.org/10.21203/rs.3.rs-23817/v1

Version of Record: A version of this preprint was published on January 9th, 2021. See the published version at https://doi.org/10.1186/s12889-020-10126-4.

Abstract

Background: The rapid expansion of dengue, Zika and chikungunya with large scale outbreaks are an increasing public health concern in many countries. Additionally, the recent coronavirus pandemic urged the need to get connected for fast information transfer and exchange. As response, health programmes have -among other interventions- incorporated digital tools such as mobile phones for supporting the control and prevention of infectious diseases. However, little is known about the benefits of mobile phone technology in terms of input, process and outcome dimensions. The purpose of this scoping review is to analyse the evidence of the use of mobile phones as an intervention tool regarding the performance, acceptance, usability, feasibility, cost and effectiveness in dengue, Zika and chikungunya control programmes.

Methods: We conducted a scoping review of studies and reports by systematically searching: i) electronic databases (PubMed, PLOS ONE, PLOS Neglected Tropical Disease, LILACS, WHOLIS, ScienceDirect and Google scholar), ii) grey literature, using Google web and iii) documents in the list of references of the selected papers. Selected studies were categorized using a pre-determined data extraction form. Finally, a narrative summary of the evidence related to general characteristics of available mobile health tools and outcomes was produced.

Results: The systematic literature search identified 1289 records, 32 of which met the inclusion criteria. From the reference lists of included articles 4 records were identified coming to a total of 36 studies. The content analysis identified five mobile phone categories: mobile applications (n = 18), short message services (n=7), camera phone (n = 6), mobile phone tracking data (n = 4), and simple mobile communication (n = 1). These devices were used for surveillance, prevention and management. In general, mobile phone-based studies reported good performance, acceptance by users, usability in downloads as well as feasibility of mobile phone under real life conditions and effectiveness in terms of contributing to a reduction of vectors and disease. It can be concluded that there are great opportunities for using mobile phones in the fight against arboviral diseases as well as other epidemic diseases . Further studies particularly on acceptance, cost and effectiveness at scale are recommended.

Background

Emerging or re-emerging viral diseases such as the most recent coronavirus causing Covid-19 disease or arboviruses transmitted by Aedes mosquitoes causing diseases such as dengue, Zika, chikungunya, yellow fever, represent a significant public health threat in tropical and sub-tropical countries (Kraemer et al., 2019). The rapidly emerging arbovirus infections have reached global scale since the emergence of the chikungunya virus in 2014 and the Zika virus in 2015 in the Americas (PAHO/WHO, 2017). Furthermore, dengue continues to be the most prevalent arbovirus disease, with estimates of up to 400 million infections and around 20,000 deaths per year (WHO, 2018; Paixão et al., 2018). An indication of this concern was the WHO declaring the increase of microcephaly and Guillain-Barré syndrome caused by ZIKV infection, a Public Health Emergency of International Concern (Gulland, 2016).

The transmission, epidemiology and clinical symptoms of dengue, Zika and chikungunya are similar, mainly during the acute phase (the first days of the disease; Paixão et al., 2018) which have produced challenges particularly in the surveillance of these diseases. *Aedes aegypti* (primary vector) and *Aedes albopictus* (secondary vector) transmitting the diseases are widely spread in tropical and subtropical areas (Patterson et al., 2016). Their high adaptability to urban communities (Araújo et al., 2015) favoured by numerous larval habitats (water containers) and the abundance of human hosts (Weaver et al., 2018) have contributed to the geographical expansion of vector populations as well as climate change and other socio-environmental conditions (Wu et al., 2009, Akter et al., 2017).

The key measure for preventing the transmission continues to be vector control since no effective vaccine and no specific treatment are available (WHO, 2009). However, vector control methods have often a limited success rate, not only because of increasing insecticide resistance where chemical methods are used (Nathan, 2013; Barrera, 2016;), but also because of the lack of community participation and the unsustainability of resource intensive vector control in some countries (Lin et al., 2016). The need to prevent the diseases has resulted in new technological innovations including the use of drones with cameras to identify breeding places, computing systems for monitoring and tracking high transmission areas, case tracking of index cases, software for epidemiological surveys and mobile devices for communication and networking (Boger and Low, 2016; Sood and Mahajan, 2017; Sareen et al., 2017; de Souza Silva et al., 2018). These tools may support the management, surveillance, prevention and control of arboviral and other outbreak-prone viral diseases.

One promising tool is the use of mobile phones to support vector control efforts (Bartumeus et al., 2018). These devices are widely used and continuously further developed for several health purposes (Kahn et al., 2010; Klasnja and Pratt, 2012; Kaindoa et al., 2017; Mildon and Sellen, 2019). Their use in the health area is referred to as mobile health (m-health) which is accepted as a component of eHealth. To date, a standardized definition of mHealth has not been established. However, m-Health, according to the WHO, is defined as a medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices (WHO, 2011).

The enormous boom of mobile phones around the world has led to the design of new models with integrated operating systems and other complex functionalities called “smartphones”. Most of these devices are equipped with sensors and modules such as an ambient light sensor, camera, microphone, digital compass, touch-sensitive screen, accelerometer, Bluetooth, Wi-Fi and Global Positioning System (GPS, among others) which has promoted various innovative m-health applications (Labrique et al., 2013; Ventola, 2014). A variety of applications has aimed at supporting disease surveillance (Mtema et al., 2016), promoting health education and behavioral change (Nilsson et al., 2017, Crane et al., 2015), supporting the diagnosis (Meyer et al., 2018) as well as improving the treatment and adherence to medication (Morrissey et al., 2018), among others. Apart from mobile apps, other mobile phone services (e.g. short message services, SMS) have contributed to improving patient compliance and as appointment reminders (Schwebel and Larimer, 2018). In low- and middle-income countries (LMICs), the use of the mobile technology has been an innovative solution to overcome health barriers such as

challenging areas with difficult access, inadequate workforce and restricted financial resources (Folaranmi et al., 2014; Tomlinson et al., 2018).

Despite the potential benefits of mobile phones in health programmes, little is known about their contributions regarding the prevention and control of vector borne diseases, particularly dengue, Zika and chikungunya and no study to date has analysed and summarized the costs or effects in terms of acceptance and effectiveness. Most of mobile phone-based studies have focused on other diseases (Cole-Lewis and Kershaw, 2010; Hoffman et al., 2010; Asiimwe et al., 2011; Hamine et al., 2015) and the few studies addressing arbovirus diseases that deployed mobile technology, have not included an analysis of the health outcomes (de Souza Silva et al., 2018; Culquichicón-Sánchez et al., 2015).

Therefore, this scoping review has been undertaken to analyse the use of mobile phones as an intervention tool for arbovirus disease programmes focussing on three arboviral diseases transmitted by Aedes mosquitoes: dengue, Zika and chikungunya. We aimed to identify countries where mobile phone-based studies have been conducted, the type of mobile phone services most frequently used, main purposes of the use of mobile phones as well as to analyse outputs and outcomes regarding performance, feasibility, costs, effectiveness and acceptability.

Methods

Scoping review

The scoping review was conducted based on Arksey and O’Malley’s scoping review framework (Arksey and O’Malley; 2005; Tricco et al., 2018). Additional processual advice, particularly in the identification of relevant studies were used to enhance the selection process of publications (Moher et al., 2009). It has been shown that a scoping review is useful to summarize and disseminate research findings and identify research gaps in the existing literature (Arksey and O'Malley, 2005; Levac et al., 2010). As opposed to systematic reviews, scoping reviews can include a diversity of sources to map the existing literature in a field of interest in terms of the volume, nature, and characteristics of the primary research (Arksey and O'Malley, 2005). This allows researchers to gain a better overview on a broad topic which has not yet been extensively reviewed or is of complex or heterogeneous nature (Mays et al., 2001).

The review team consisted of five co-authors with multidisciplinary expertise in infectious diseases, engineering, epidemiology, knowledge of quantitative-qualitative research methods and research synthesis.

Review Question and Scope

This scoping review was conducted to answer the question “What is the current evidence of the use of mobile phones as an intervention tool for arboviral disease programmes (namely dengue, Zika and chikungunya) in terms of their acceptance, usability, performance, feasibility, cost and effectiveness?”.

Mobile phones are electronic devices used for mobile voice and/or data transmission over a wireless network (Turel and Serenko, 2010). A mobile phone is also called a cellular phone or cell phone, but when it is integrated with advanced features similar to a computer it is called a smartphone. This scoping review included mobile phone, smartphone and other mobile phone services such as mobile applications (mobile apps), short message service (SMS), call detail records (CDR) and other mobile phone sensors. Although there are mobile technology-based studies for different health purpose available, there were only a few studies with a high level of evidence, considering output and outcome dimensions. Therefore, this scoping review was particularly interested in providing information on the feasibility of application in the real world, cost, effectiveness and acceptance indicating whether the mobile technology has a realistic chance to be effective, affordable and socially accepted for the prevention and control of arbovirus diseases.

Search strategy

The search strategy was conducted through online databases (PubMed, PLOS ONE, PLOS Neglected Tropical Disease, LILACS, WHOLIS, ScienceDirect and Google scholar). Search terms were defined that described two categories: 1) mobile phone technology and 2) arboviral diseases (Table 1). Each term was separately entered into the advanced search bar from the online database and then combinations were applied following the basic search structure “mobile phone-based terms” AND “arbovirus-based terms” (as appropriate). Medical Subject Headings (MeSH) were used to ensure an accurate search while this option was available in search command. For Google scholar search the terms “mobile phone” AND dengue Zika chikungunya arbovirus were used to collect a more precise information. A complementary search was performed on Google Web to identify relevant documents in the grey literature (academic reports, theses and dissertations) which were considered to extend the possible small numbers of published articles in scientific journals. Google search was limited to the 100 most relevant hits. Additionally, the list of references of included articles were used to identify additional sources. Online databases and grey literature were reviewed from 2009 to 2019 in order to assess the most recent evidence of this technological tool. The search was updated on January 12, 2020.

Table 1
Search keywords

Category	Keywords
Mobile phone technology	Mobile phone, cellular phone, cell phone, smartphone, mHealth, mobile device, mobile application, SMS, text messaging
Arboviral diseases	Zika, dengue, chikungunya, arbovirus
Time frame	2009–2019

Inclusion and exclusion criteria

Inclusion criteria were mobile phone studies focusing at 1) dengue, Zika and chikungunya and 2) reporting at least one health outcome relating to costs, effectiveness, acceptability and performance. The

review was based on scientific articles using different methodologies (intervention studies, observational studies, pilot studies, qualitative and/or quantitative methods, literature and systematic reviews) as well as grey literature such as academic reports, thesis and dissertations. All articles had to be in English or Spanish published in the last ten years (January 2009 to December 2019). SMS, text messaging, mobile apps or others mobile service involving mobile phone/smartphone were included. Only studies with a full text were considered.

Exclusion criteria were: 1) study protocols, opinion papers, conference proceedings, reflection articles, letters, book abstracts and posters due to the limitation of the information 2) studies without mention of mobile phone and/or its use, 3) studies without evaluation of the effect of mobile phone interventions 4) Other health areas other than arboviral diseases, 4) Non-English and Non-Spanish language. The inclusion and exclusion criteria are summarized in Table 2.

Table 2
Inclusion and exclusion criteria

	Inclusion criteria	**Exclusion criteria**
Study design	Any randomized or non-randomized study, review articles, meta-analysis, academic reports, thesis and dissertations	Opinion papers, conferences, letters, book abstracts, study protocols
Disease	Dengue, Zika, chikungunya	All other diseases or health conditions
Mobile service delivery	Mobile phone as an intervention tool Short message service (SMS) Mobile applications And other mobile services	The use of mobile phones not specifically analysed
Outcomes	Arboviral disease Acceptance and user friendliness, costs, effectiveness, performance and further findings related to health prevention and control	No outcome assessed
Languages	Spanish, English	All other languages

Study selection

All retrieved literature was imported into the program Mendeley©; duplicates were identified and deleted. Titles, abstracts and full texts were systematically screened for the inclusion and exclusion criteria during three phases. The first phase of the title screening was conducted to determinate publications which could be discarded whether the title was not related to the topic. Publications were included in the second screening round whenever their titles were unclear. In the second phase, all abstracts of the publications that passed the first title screening were read to select relevant information for the purpose of the review publications. Publications without abstracts were included in the third screening round. Finally, the third

phase of full text screening was conducted to select publications following the inclusion criteria. By this way only eligible publications in line with the aims of the review were identified for further data extraction. During the study selection, an advisor was consulted in case of doubt whether a publication should be included or not.

Data extraction

A data extraction form was designed using a Microsoft Excel® spreadsheet. The following information was extracted for each publication: title, author, year, objective, country, target setting, targeted arbovirus disease, study design, mobile phone services (e.g. mobile app, SMS), purpose of the mobile phone for arboviruses (e.g. disease prevention, surveillance), the target users (e.g. health workers), outcome dimension (costs, performance, effectiveness, acceptability). To determine the categories of mobile phones, patterns were adapted from previous expert interviews and an initial literature search was conducted to develop a better classification for achieving the objectives (WHO, 2011; Labrique et al., 2013, WHO, 2018). Categories were iteratively added if more mobile phone services and purposes were found that did not fit into any previous pattern (e.g. mobile phone tracking data). A final step, the data extraction form was optimized and adjusted for all categories. Each full text was reviewed once it was clearly classified with the extraction form. Following the guidelines for conducting a scoping review, no formal assessment of the methodological quality of the included articles was performed (Arksey and O'Malley, 2005; Levac et al., 2010), however the quality of the papers was defined by the study designs which were eligible for inclusion.

Synthesis

Descriptive numerical and thematic analyses are presented as narrative summaries given the heterogeneity of the literature. From the beginning, we were aware that a non-overlapping categorization of individual technologies was difficult due to the complexity of the mobile technology and its integration with other tools. Therefore, publications dealing with more than one mobile phone category were assigned according to the dominant tool; for instance, if a mobile application uses multiple sensors such as Bluetooth or GPS, it is classified as a mobile app, not as a sensor. A last revision was performed to fit each data of the study in their proper category.

Results

Results of the study selection process

A total of 1289 publications was retrieved for this review, including 1189 from the databases and 100 from Google search. After deleting duplicates, 1013 remained for screening the titles. 301 articles were chosen from the screened abstracts, selecting 82 full-texts eligible for full-text screening and 4 papers were identified from reference lists. As a result, 36 full texts were included for the data extraction. The selection process is shown in the PRISMA flow diagram Fig. 1 (Moher et al., 2009).

Figure 1

Descriptive results of geographic distribution and study designs

The studies included came from twenty different countries (Fig. 2. Geographic distribution of mobile phone-based studies). Eighteen studies were conducted in the American regions (Colombia, United States, Brazil, Guatemala, Peru and Mexico), of which one study was conducted in four countries (El Salvador, Honduras, Dominican Republic and Guatemala). Twelve were conducted in the Asian region (Nepal, Singapore, Sri. Lanka, India, China, Malaysia and Pakistan), four in the Africa region (Kenya and Madagascar) and only two were identified in other regions (Fiji and Spain). Most studies were focussing on urban areas where our target diseases are prevalent, only three were specifically conducted in a rural area. Brazil and United States of America were the countries with the highest number of publications (each one with six), however the studies identified in Unites States were not performed under real-world conditions, but rather under laboratory conditions. Most studies were published in the last three years (n = 22), reflecting a recent increase in the use of mobile phones for the prevention and control of arbovirus diseases.

Figure 2

From 36 identified studies, most of them had a descriptive approach (*n* = 12), of which some provided preliminary results with small groups of people who "tested" the mobile technology in controlled environments and a few studies described their lessons learned after being conducted at a large scale. Some studies included pilot/feasibility studies (*n* = 6), diagnostic test studies (*n* = 6), retrospective studies (*n* = 4), cross sectional studies (*n* = 4), randomized controlled trials (*n* = 3), quasi-experimental studies (n = 2), non-randomized control trial (n = 1), and a qualitative study (n = 1). Regarding our target diseases, the majority of the 36 studies focused on dengue (*n* = 15), six studies on Zika and no study on chikungunya specifically. However, seven publications covered arboviral diseases in general or *Aedes* vectors. Seven studies on the mobile health technology targeted more than one infectious disease including arboviruses.

Mobile phone categories

With respect to the mobile phone technology, we classified each service of a cell phone to identify which type of mobile phone category were most frequently used in terms of our outcomes. Five mobile phone categories were identified: mobile applications (mobile apps, smartphone apps, mobile software), SMS (Short Message Services), mobile phone tracking data (call detail records, mobile phone signals), camera phone (camera module/image sensor) and simple communication service (calls). An overview is presented in Table 3. The most widely used mobile phone category was mobile applications (n = 18). Simple mobile communication (e.g. voice communication) were used less often.

Table 3
Mobile phone categories according to the 36 studies

Mobile phone category	Definition and considerations	Number of hits
Mobile applications	Mobile applications, commonly referred to as mobile apps, are software programs designed to run on a mobile device, such as a smartphone or tablet. Many mobile apps have corresponding programs meant to run on desktop computers. This category comprises mobile apps, iPhone apps, smartphone apps, mobile software and m-learning platforms that were run on mobile phone or smartphone.	18
Short message service	Short message service (SMS) is a service for sending electronic message to and from a mobile phone. Messages are usually no longer than 160 alpha-numeric characters and contain no images or graphics. SMS is also known as text messaging.	7
Camera phone	A camera phone is a mobile phone that can take pictures and record video clips. Most new cellular phones are already equipped with cameras which include an image sensor, the lens and microelectronic mechanical system. Smartphone cameras are used for imagen processing and visual readout.	6
Mobile phone tracking data	mobile phone tracking data are often call detail records (CDR) that log the location of mobile phone users when they make telecommunication transactions, such as a phone call or text message. This category comprises mobile phone signals.	4
Simple mobile communication	Simple mobile phone communication involves the use of mobile phone numbers to allow contact with others including voice communication (e.g. calls).	1

Purpose of mobile phone use in health programmes

To analyse the support that mobile phones are promoting, we noticed that the included studies in this review were focussing on three major purposes: surveillance, disease prevention and disease management which are summarized in Table 4. Three studies were identified for both purposes: surveillance and prevention (Reddy et al., 2015, Lwin et al., 2017; Rodriguez et al., 2018), resulting in 39 studies (including 3 addressing both surveillance and prevention) to be analysed. This review also identified specific aims in each purpose which are presented in Table 4. Some mobile applications were assigned to more than one aim, thus being able to perform a variety of functions such as data collection, health education, geolocation among others (e.g. The App, Mosquito Alert; Palmer et al. 2017). In total the mobile phone-based studies included 25 for surveillance, 7 for disease prevention and 7 for disease-management.

Twenty-five surveillance studies aimed at collecting data and reporting mosquitoes, patients, symptoms, socio-demographic factors and perceptions of the population about the disease (Lozano-Fuentes et al., 2012; Lozano-Fuentes et al., 2013; Tai-Ping et al., 2016; Randrianasolo et al, 2010; Toda et al., 2016; Toda et al., 2017; Kumoji and Khan Sohail, 2019; Ocampo et al., 2019; Eiras and Resende, 2009; Pepin et al. 2013; Sanavria et al. 2017; Palmer et al., 2017; Reddy et al., 2015; Leal-Neto et al., 2017; Olson et al., 2017; Randriamiarana et al., 2018). Others used mobile apps for georeferencing or mapping of users’ locations

or breeding sites visualizing high risk areas for arboviral diseases (Tai-Ping et al., 2016; Palmer et al., 2017; Mukundarajan et al., 2017; Leal-Neto et al., 2017; Hewavithana et al., 2018; Ocampo et al., 2019). Other mobile services were used for estimating human movements through mobile phone tracking data to predict outbreaks or possible risk areas on maps (Wesolowki et al, 2015; Mao et al., 2016; Massaro et al., 2017; Rajarethinam et al., 2019). Another group of devices captured sounds or images of *Aedes* mosquitoes to identify species using the phone camera or running mobile applications (Palmer et al., 2017, Mukundarajan et al., 2017).

The seven studies reporting on disease prevention interventions aimed at providing information on arbovirus diseases and preventative measures as well as at promoting behavioural change through mobile applications and short message services (Dammert et al., 2014; Reddy et al., 2015, Lwin et al., 2017; Rodriguez et al., 2018; Bhattai et al., 2019). Some studies tested a mobile learning approach to teach about arbovirus diseases to specific population groups (students) using mobile apps or platforms integrated in mobile devices (Patil et al., 2016; Abel-Mangueira et al., 2019).

The seven mobile phone-based studies for disease management aimed at facilitating the contact between health workers and patients for timely diagnosis (Barde et al. 2018) and detecting viruses of dengue, Zika and chikungunya in samples of serum, saliva, blood, urine from humans using platforms that were supplemented by a smartphone camera to acquire real time images or display a visual readout of the assays (Thiha and Ibrahim, 2015; Chan et al., 2016; Priye et al., 2017; Ganguli et al., 2017; Rong et al., 2018; Kaarj et al., 2018; Bhadra et al., 2018).

In summary, the mobile phone technology, mainly taking advantage of mobile applications, has been most frequently used for surveillance purposes including data collection, reporting and geolocation and estimation of human movements. Mobile phone technology focussing at communication between health staff and patients was less explored. There was also a number of mobile applications with multiple purposes for surveillance, prevention and management of arbovirus diseases.

Table 4
Mobile phone-based studies by purpose and mobile technology category

Purpose	Specific aims in mobile phone	Mobile phone category	Application or system' names / Mobile phone projects
surveillance (n = 25 studies)	Data collection and reporting	mobile apps	VECTOS app and mosquito social app; Mobile device with OruxMaps, AutoNavi navigation and Baidu Map; mSOS app; Chaak system; Vigilant-e; Mosquito Alert; Healthy cup; Monitoring app in Fiji, MID system; OlympTRIP; Mo-Buzz,Abuzz.
		SMS	SMS survey in four countries; SMS for sentinel surveillance; SMS for IDSR system in Madagascar
	Geolocation and mapping	mobile apps	Monitoring app in Fiji, VECTOS system; Google maps®app; Mosquito Alert; Healthy cup; Abuzz; OlympTrip; Mo-buzz; mobile device with OruxMaps, AutoNavi navigation and Baidu Map
		Mobile phone tracking data	Two studies using CDR in Singapore; mobile phone signals in China; CDR in Pakistan
	Estimation of human movements	Mobile phone tracking data	Two studies using CDR in Singapore; mobile phone signals in China; CDR in Pakistan
	Capturing vector' photos or sounds	mobile apps	Mosquito Alert; Abuzz; Mo-Buzz
		camera phone	Smartphone for a visual readout tool in USA
Prevention (n = 7)	Health education and behaviour change	mobile apps	Monitoring app in Fiji; OlympTRIP; Mo-buzz
		SMS	SMS conducted in Nepal; SMS conducted in Perú
	m-learning approach	mobile apps	m-learning platform in Brazil; mobile social app in India
Management (n = 7)	Detection of arbovirus and point of care diagnosis	camera phone	Three diagnostic studies using smartphone camera in USA and one in China
		mobile apps	Mobile app for image processing in USA and Malaysia
	Communication between health staff and patients	simple mobile communication	Contact using mobile phone number of patients in India

Among the included studies, we assessed the different target groups or users of the mobile phone technology. Health workers were the main target group for receiving mobile phone services (n = 12). This group consisted of vector control staff, healthcare workers, physicians, practitioners, health managers and other health specialists. The second most frequent group were researchers (n = 11) who conducted

studies that used mobile phone tracking data or designed platforms with smartphone cameras under controlled settings. The third most frequent group was the general public (n = 9), which includes communities and specific population groups (students, athletes, police officers). Three mobile phone interventions targeted both groups, general public and health workers. Only one mobile phone service was designed for patients.

Outcome measurements

This review assessed the following outcome dimensions: performance, acceptance, feasibility, usability, costs and effectiveness (Osorio et al., 2018; Krick et al.,2019). A description is given in Table 5 summarizing the scope of expected outcomes in the 36 studies included.

Table 5
Description of outcome dimensions in 36 studies

Outcome	Description
Performance	Operational characteristics of the mobile phone technology in terms sensitivity, specificity, predictive values, accuracy, completeness, quality data, timeliness and concordance with other tests.
Feasibility	The extent to which the mobile health intervention implemented under real conditions can be successfully used in a specific context
Acceptance	User' attitudes towards the mobile phone technology perceived to be satisfactory.
Usability	Users who are testing the mobile phone technology. This comprises users who downloaded the application/service and used it or active users.
Cost	Monetary effort of the use of a mobile technology in a specific context
Effectiveness	Effectiveness comprises results related to reduce vector densities or disease burden, to predict early outbreaks and improve disease prevention and health behaviours.

The analysis of outcome dimensions (Table 5) showed that nineteen (52%) of all included studies analysed aspects of performance, eleven (30%) of feasibility, five (13%) of acceptance, five (13%) of usability, five (13%) of effectiveness; one of these evaluated cost-effectiveness. Only three (8%) analysed costs or at least estimated prices by mobile phone services (some studies covered several outcomes). Studies on performance of mobile technologies were evaluated in all mobile phone categories particularly when using applications (n = 9). Studies on effectiveness and acceptance were conducted only through mobile applications and short message services (SMS). Studies on feasibility were most frequently carried out through mobile apps (n = 6), followed by mobile phone tracking data (n = 3) and SMS (n = 2). Mobile application technologies represent the only category that analysed usability/user-friendliness (n = 5). Costs have been assessed very rarely in mobile phone programmes.

Table 6 summarizes the number of studies dealing with one or the other dimension. It can be seen that few studies have provided information on acceptance, costs and effectiveness and only a small number on usability/user-friendliness studies were identified. Mobile applications were the only category that included all outcome dimensions.

Table 6
Number of studies by mobile phone category and outcome dimensions

Mobile phone category	Performance	Feasibility	Acceptance	Usability	Costs	Effectiveness
Mobile applications	9	6	3	5	1	2
Short message service (SMS)	2	2	2	n.a.	1	3
Mobile phone tracking data	2	3	n.a.	n.a.	n.a.	n.a.
Camera phone	5	n.a.	n.a.	n.a.	1	n.a.
Simple mobile communication	1	n.a.	n.a.	n.a.	n.a.	n.a.
	19	11	5	5	3	5
n.a.=not available						

The variability of mobile phone-based study designs makes it difficult to assess individual interventions or to identify the most effective and socially accepted mobile phone service. In the following the six outcome dimensions for mobile phone programmes will be described in more detail.

Performance

The 19 performance studies provide valuable information on how mobile phone interventions perform in terms of completeness, timeliness, data quality, concordance and predictive value of data collection. Mobile applications such as Vectos apps; Mosquito social apps; Google maps® app; Chaak app, MID system, Vigilant-e app demonstrated good performance for data collection. Regarding completeness of data sets, VECTOS in Colombia achieved to locate 84% of dengue cases (Ocampo et al., 2019) and Google maps® app in Sri Lanka located 93% of dengue patients (Hewavithana et al. 2018). Chaak in Mexico achieved with a mobile application to increase the speed of data transmission reducing the delay time by 19% compared to the pen-and-paper capture method (Lozano-Fuentes et al., 2012). The Chaak application also showed improvements in data quality in terms of reducing errors (the proportion of errors for the pen-and-paper method was 0.23 while the proportion of errors for the mobile method was 0.17; Lozano-Fuentes et al., 2012). Another example is Vigilant-e, a syndromic diary app in Guatemala showing good agreement (concordance) between the collected data by participants and by nurses during home visits (Olson et al., 2017). The Abuzz app developed in the United States for capturing wingbeat sounds highlighted a high sensitivity to identify mosquito species at 10 to 50 mm distance (Mukundarajan et al., 2017). Mobile applications have also demonstrated their potential for the management of arbovirus diseases. Two studies developed point-of-care platforms for detecting arbovirus diseases using a smartphone application and image sensor (Thiha and Ibrahim, 2015; Priye et al. 2017). They showed good performance in terms of speed to acquire images and visualize the tests. With respect to short message service (SMS), few studies were identified to analyse the performance aspect. A study in

Madagascar showed that SMS improved the surveillance data in terms of completeness: 73% completeness in 2014-15 compared to 20% in 2008-9; however, timeliness and data quality remained a problem as 90% of health workers had more than 4 errors during data transmission and only 43% of SMS were received in time (Randriamiarana et al., 2018). In contrast, another study in the same country had better results regarding timeliness and data quality, showing that patient data transmission with SMS was improved by 89% within 24 hours (Randrianasolo et al., 2010). The use of mobile phones and internet were able to facilitate the communication between health workers and patients for the timely diagnosis. In India, vector control staff used the contact mobile numbers for tracking dengue positive patients and consequently, conducting vector control activities within 24 hours plus completing 82% of house visits to these patients (Barde et al. 2018). This paper also identified a promotion strategy for tracking users through mobile phone data based on the Signalling System 7 (SS7) in combination with different datasets and observations of mosquito activities (Mao et al., 2016). The study showed a strong performance identifying three clusters with increased transmission risk in a city of China.

In summary, mobile applications have enhanced diagnostic capabilities and improved data collection and transfer in terms of data quality, completeness and timeliness, becoming a promising tool for surveillance and the management of arbovirus diseases. On the other hand, short message services (SMS) showed a good completeness of disease data transmission, but timeliness and data quality were yet an issue depending on the surveillance procedure and capacities of health workers to use SMS. Mobile phone tracking data (mobile signal SS7) to estimate human movements showed a good performance in terms of predictive values. However, additional studies on mobile signals are needed to validate its prediction capacities for the movement of arbovirus diseases and outbreaks.

Feasibility

Mobile apps interventions have been shown to achieve their aims under real conditions. They were particularly used for recording and transferring entomological information. For example, the VECTOS system aimed to monitor the transmission risk of arboviral diseases in three cities in Colombia. The entomological data (collected by Vectos app) and epidemiological data were analysed in a web platform that successfully identified the level of vector infestation (larval indices), the epidemiological risk and the distribution of disease displayed on maps (Ocampo et al, 2019). Similar results were achieved in China in which android mobile devices using mobile applications (OruxMaps, AutoNavi Navigation and Baidu Map) were able to identify the level of larval/pupal infestation and the most abundant breeding sites (Tai-Ping et al., 2016) demonstrating its usefulness for the surveillance of mosquito habitats. Another example is the Monitoring Intelligent dengue system, a mobile software for submitting ovitrap data which are then analysed in a web database. The system achieved to assess the transmission risk (index of female *Aedes aegypti*) in 2015 showing that mobile apps together with other tools are able to monitor entomological indices (Sanavria et al. 2017). For the early detection of arboviral disease, using a symptomatic approach. OlympTRIP was used. This is an application developed to monitor the health status of users during the Olympic games in Brazil. Although no participants reported Zika, the app proved to be useful for monitoring symptoms in real time such as headache, cough and conjunctivitis (Rodriguez-Valero et al., 2018).

Recent studies using mobile phone tracking data through CDR and mobile phone signals have been conducted in Singapore (Rajarethinam et al., 2019), China (Mao et al., 2016) and Pakistan (Wesolowsiki et al., 2015), demonstrating to be a feasible strategy to assess population movements, map changing population densities and estimate dengue spread. Evidence suggests that mobile applications are feasible and useful for monitoring and tracking mosquitoes and/or disease outbreaks since this mobile phone service can involve other technologies (e.g. web platform, internet, GPS). Additionally, mobile phone tracking data -when integrated with disease surveillance data and environmental data- has the potential to estimate human mobility in order to predict the spread of arbovirus diseases and outbreaks.

Acceptance

The acceptance or user satisfaction of the mobile phone technology for arboviral disease has been assessed in studies conducted in India, Fiji, Guatemala and Nepal. The users from e-Vigilant in Guatemala showed high user satisfaction with mobile apps: 98.8% of families reported that the application was beneficial to them and 96,6% that it was beneficial to the community (Olson et al., 2017). The M-learning app in India showed that 80% of students had a positive attitude and 76% perceived the importance of the tool for learning (Narayan Patil et al., 2016). Although, a study in Fiji showed positive feedback on user-satisfaction, its results depended more on connectivity to the internet. With respect to the acceptability of SMS interventions, dengue preventive messages were assessed only in one study in Nepal where messages were well accepted by the community and stakeholders (acceptability of SMS of 4.4 on a 5-point scale; Bhattarai et al., 2019). In summary, we identified in our review that mobile apps and short message services were well accepted by the general public, but no information on acceptance in health workers was given, although most mobile phone technologies were addressed to this user group. Further studies should analyse the acceptance of mobile phone technologies in health workers.

Usability/user friendliness

Five mobile applications were identified to provide information on the proportion of participants who downloaded the app and subsequently used it. OlympTRIP and Healthy Cup, developed in Brazil showed 75% and 65,7% respectively of active users out of participants who downloaded the app. The participants also reported that OlympTRIP app was user- friendly (Rodrigo-Valero et al., 2018). Similar results were obtained in India where a social application (M-learning) for students reported 73% of active users who accessed the device more than twice a week (Olson et al., 2017). For another application in Guatemala (vigilant- e) it was shown that 78% of targeted users reported weekly their symptoms. In contrast, Mo-Buzz in Sri. Lanka, a mobile-based platform with two versions, one for health staff and the other for the general public, had a low initial use by health staff (only 10%) but then this increased gradually to 76% while it remained low for the general public (Lwin et al., 2017). The authors suggested to increase the uptake of the app by further training of health staff, incentives for the use and strong communication with the general public. In summary, this review evidenced that most mobile applications demonstrated good usability, but that the uptake of this service can require additional promotional and educational efforts.

Costs

Cost calculations were done in different ways. One study described the market costs of a mobile device (Bhadra et al., 2018), others presented the costs of data transfer (Lozano-Fuentes et al., 2013), others

included calculations on staff salary and/or coverage of mobile services (Palmer et al., 2017) and one analysed direct and indirect costs of mobile services (Pepin et al., 2013).

Three studies compared their mobile interventions with traditional methods (Lozano-Fuentes et al., 2013; Palmer et al., 2017; Bhadra et al., 2018). Researchers from Mexico compared the Chaak system demonstrating that the mobile phone-based system did not substantially increase costs compared with the traditional data collection method (cost per household were U.S.$0.10 for the pen-and-paper method compared to U.S.$0.10 to U.S.$2.13 for the Chaak system). Mosquito Alert (mobile application and website) in Spain estimated the costs as 1.23 Euros per km2 per month while ovitraps costed about 9.36 Euros per km2 per month (almost eight times the cost of Mosquito Alert). The authors mentioned that vector surveillance with ovitraps required much effort to be installed and checked by experts so that staff costs were the highest cost components, in contrast, the mobile application costs were mostly associated with community buildings and non-recurring investments in technology (Palmer et al., 2017). Similar economic benefits were demonstrated in a smartphone-read LAMP-OSD assay platform for detecting mosquitoes species indicating in low cost to capture fluorescence signals with a camera phone (<$200) compared with a lab-based qPCR testing (~$30,000 in start-up investment and ~$700 in annual maintenance; Bhadra et al., 2018).

One study analysed cost-effectiveness of the MI-Dengue system in Brazil (Pepin et al., 2013) using multivariate models to estimate the median cost savings per case prevented which was median $58; this saved annually around $364,000 in direct costs (health care and vector control) and approximately $7 million in lost wages (societal effect; Pepin et al., 2013). In summary, although, there is limited evidence on costs associated with the mobile phone technology, examples from Mexico and Spain showed that the use of mobile apps cost less or the same as traditional methods being therefore affordable for disease and vector surveillance. Furthermore, investing efforts in a system that integrates mobile devices, website and a vector surveillance tools can help to reduce case load and thus medical costs.

Effectiveness

Few studies showed effective m-health interventions in terms of reducing the burden of the disease and vector densities through improved dengue prevention and behaviour change and/or, performing as an early warning indicator for outbreaks. The analysis of effectiveness was based on randomized controlled trials which were conducted at large scale. Examples are the Mosquito Alert in Spain (Palmer et al., 2017) and Monitoring Intelligent dengue system (MI-Dengue) in Brazil (Pepin et al., 2013); they used mobile devices and other tools which were effective for dengue surveillance and subsequent action. Mosquito Alert is an app that encourages the public to report mosquitoes through taxonomic surveys and photos taken of the vector to be analysed by experts. Their results showed high detection rates by the app (64% out of 274 municipalities in which tiger mosquitoes were present according to ovitrap plus Mosquito Alert data). However, the system failed to detect *Aedes* mosquitoes in some areas that had positive ovitraps and vice versa. The authors suggest using both approaches together –ovitraps and Mosquito Alert. This study highlighted that this mobile technology provides particularly early warning signals in low endemicity areas where traditional surveillance is limited. MI-Dengue for counting mosquitoes in real time

was the only study that analysed effectiveness of reducing vector density and dengue incidence. Positives results were also observed in MI-Dengue system,-using a website platform-, a mobile device plus traps for mosquitoes and vector control inspections (Pepin et al., 2013; Sanavria et al., 2017)- showed that the system prevented in Brazil 27,191 cases of dengue fever. The authors highlighted that MI-Dengue system was more cost-effective in cities with high levels of mosquito infestation. In summary, the mobile phone technology may be a potential supplement for the control and surveillance of arboviruses diseases.

Short message service (SMS) was the only mobile phone service shown to enhance prevention practices of people related to arbovirus transmission and control. Households exposed to repeated preventative messages in Peru reported an increase in the use of window screening and/or mosquito bednets by 4.5% and a reduction of vector densities (Dammert et al. 2014). A positive effect was also demonstrated in Nepal, where SMS together with a prevention leaflet were sent to the community, which increased knowledge and practice of people towards dengue prevention (Bhattarai et al, 2019). The combination of mobile phone messages with conventional education methods can produce an improved effect in the prevention of arboviral diseases in terms of reducing vector densities in domestic settings (Bhattarai et al, 2019).

Discussion

Overview of findings

This scoping review analysed the use of mobile phone technology for arboviral diseases. Thirty-six publications -which corresponded to the inclusion criteria- described m-health programmes using different mobile phone categories: mobile applications, short message services (SMS), phone camera, mobile phone tracking data and simple mobile communication (Table 3). The aims of these services were for (Table 4):

disease or vector surveillance, (data collection and reporting, geolocation and mapping, human movement estimations)
health education and social mobilization
Detection of arboviruses and point of care diagnosis
communication between health staff and patients

According to previous studies (Osorio et al, 2018 and Krick et al., 2019), six outcome dimensions were analysed. These include (Table 5):

Acceptance of the mobile phone technology
Feasibility (if the technology can be used under “real life conditions”)
Usability (which proportion of target users downloaded and used the application)
Costs (if the technology is affordable and can be financed)
Effectiveness (how much disease incidence or vector density has been reduced)

The issue is that the diversity of study designs does not allow to identify the most cost-effective mobile phone programme for each of the different purposes. However, most projects that involved a mobile phone received positive feedback.

Opportunities by mobile phone categories

Mobile applications were the dominant mobile phone category a confirming previous meta-analysis on m-health interventions by Fedele et al, 2017. Given the capabilities of this application and the potential to target various audiences to address specific aims with diverse outcomes (Fiordelli et al., 2013), health projects have taken advantage of this tool to respond to different needs, particularly in disease and vector surveillance. The main use was data collection, reporting, geolocation and capturing images of mosquitoes. In contrast, app-technology for the prevention and management of arboviral diseases was less explored. Although there is limited evidence regarding effectiveness, we identified mobile applications which were combined with other approaches such as capacity building, community involvement, traditional vector control methods and others which were effective and feasible as an early warning systems for arboviral disease outbreaks (Sanavria et al., 2017; Palmer et al., 2017) and thus preventing cases (Pepin et al., 2013).

Short messages services (SMS) have been modestly explored in dengue, zika and chikungunya control programmes (Culquichicón-Sánchez et al., 2015). The aim was mainly disease prevention through health education showing to be effective for reducing vector densities in households and improving preventive practices and knowledge about arboviruses in the population. SMS interventions have also been adapted to the traditional surveillance system to improve early notification of arboviruses, which is similar with other infectious diseases (Déglise et al., 2012). However, more studies are needed to confirm the results obtained so far.

Other opportunities of mobile devices have been tested such as mobile phone-based imaging which has potential diagnostic capacities (Hall et al., 2014). For our target diseases, we found that smartphone cameras as a supplement in diagnostic platforms have the potential of playing an important role in the detection of dengue, chikungunya and Zika patients and identifying mosquito vectors as display images. However, this technology has so far only been tested under controlled conditions and needs further validation studies.

Mobile phone tracking data is one example of how new technologies are overcoming past problems of quantifying and gaining a better understanding of human movement patterns in relation to disease transmission (Buckee et al., 2013). This paper identified also experiences using call details records and mobile phone signals conducted in Asian countries to support surveillance of dengue, chikungunya and Zika (Wesolowsiki et al., 2015; Mao et al., 2016; Massaro et al, 2019; Rajarethinam et al., 2019). The evidence indicates that this data in combination with case and climate data is a feasible strategy for identifying geographical 'hotspots' of dengue.

In general, mobile apps and SMS were usually well accepted by the general public and they also reflected good usability by a large number of active users who downloaded the app. But further studies related to

user's satisfaction and usability are needed to assess its use and acceptance with more accuracy. Cost and financing studies are rare, but the current evidence shows that the use of mobile phone technologies costs less or equal as traditional surveillance methods.

Recommendations

The following recommendations can be given for implementing mHealth interventions for combating arbovirus and other infectious diseases:

Technical requirements

According to the complexity of the mobile phone technology, qualified staff with technological skills (e.g. software developers) will be required to manage the central server and database and other technological needs.

Use of data storage in the mobile phone can be a solution when there is no internet access or intermittent connectivity, thus data can be continuously collected and then transferred when the Internet becomes accessible

Coordination with mobile phone companies will be the enabler to reach private network users.

Mobile phone tracking data should come from those mobile companies which are predominantly used by the population.

Surveillance

Staff turnover, availability of mobile phones, connectivity of the internet, environmental, social and political conditions have to be analysed before starting an m-health programme

Active participation of stakeholders helps to increase the awareness of the importance of improving the data quality through mobile phone technology

Implementing a strategy integrated with existing technologies (mobile app and an appropriate website platform) for monitoring disease and mosquitoes should be flexible

Mobile apps and SMS should be developed in consultation with field staff to facilitate field data collection and analysis.

Promoting the download of mobile applications onto the mobile phones of users can potentially reduce costs and be sustainable for disease surveillance programmes.

Encouraging users to participate in disease or vector surveillance by providing some small incentive and ensuring that the download and use is for free.

Increased communication between general public and health staff can be enhanced by the use of mobile applications for participatory surveillance. This may, however, require personnel to maintain communication with participants.

Use of traditional vector surveillance methods (ovitraps or adult traps) combined with the mobile phone technology can produce better results for early outbreak warming or for hot spots of disease transmission.

Adopting a mobile phone service or application as a tool for strengthening vector surveillance requires Standard Operational Procedures (SOPs) and constant training of health staff.

Use of traditional vector surveillance methods (ovitraps or adult traps) combined with the mobile phone technology can produce better results for early warming information for hot spots of disease transmission.

Social mobilization and behavioural change

Digital media are useful for penetrating multiple social strata, to boost user participation, to improve social engagement and to create and maintain awareness. But for the uptake of the mobile application investment in communication, marketing, and advertising is required.
The combination of the mobile phone technology with conventional educational methods can provide better results for achieving behavioural change in the community.

Limitations

Due to the shortage of randomized trials, this review could not provide much information about the effectiveness of the mobile technology in terms of contributing to reduced vector density and disease incidence. Also, the diversity of mobile phone programmes including different approaches and procedures made it difficult to compare and identify the most effective, acceptable and affordable mobile phone category. However, we described characteristics, purposes and opportunities of using mobile phones in arboviral disease programmes which can be adapted to specific user needs.

Conclusion

This scoping review proves the great opportunities for using mobile phones in the fight against arboviral diseases. Many aims were identified for surveillance, management and prevention of dengue, zika and chikungunya using different mobile phone services. To these belonged mobile applications, short message services, mobile phone data, smartphone camera and even simple voice communication. Positives results of mobile devices were reported in terms of outcome dimensions (performance, feasibility, acceptance, usability, costs and effectiveness). Further studies at a larger scale are required to assess the impact with more precision.

Abbreviations

WHO
World Health Organization
PAHO
Pan American Health Organization
app
application
SMS
Short Message Service
CDR

Call Detail Records

GPS

Global Positioning System

m-health

mobile health

M-learning

mobile learning.

Declarations

Competing interests

The authors declare that they have no competing interests.

Funding

MAC and RCS have a scholarship from Minciencias to support their doctoral studies (grant number 753). We thank Freiburg University by funding the publication of this study.

Author's contributions

All authors contributed to the concept and design of the study. MAC and AK handled a large part of the screening in all stages, interpreted results and wrote the first draft of the manuscript. SRR shared work in all stages of the screening process. MAC, RCS and SDM conceptualised the data extraction form. AK, RCS, SDM and SRR read and provided substantial edits on the manuscript. All authors approval the final version of the manuscript that was submitted.

Acknowledgements

We gratefully acknowledge the team of the Centre for Medicine and Society, Master Programme Global Urban Health at Freiburg University for their encouragement and support on this work. We thank Johanna Yañez from the State Health Institute (IDS) for hosting the study team. MAC and RCS also thank Minciencias, Colciencias and State of Norte de Santander from Colombia for supporting our doctoral studies.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

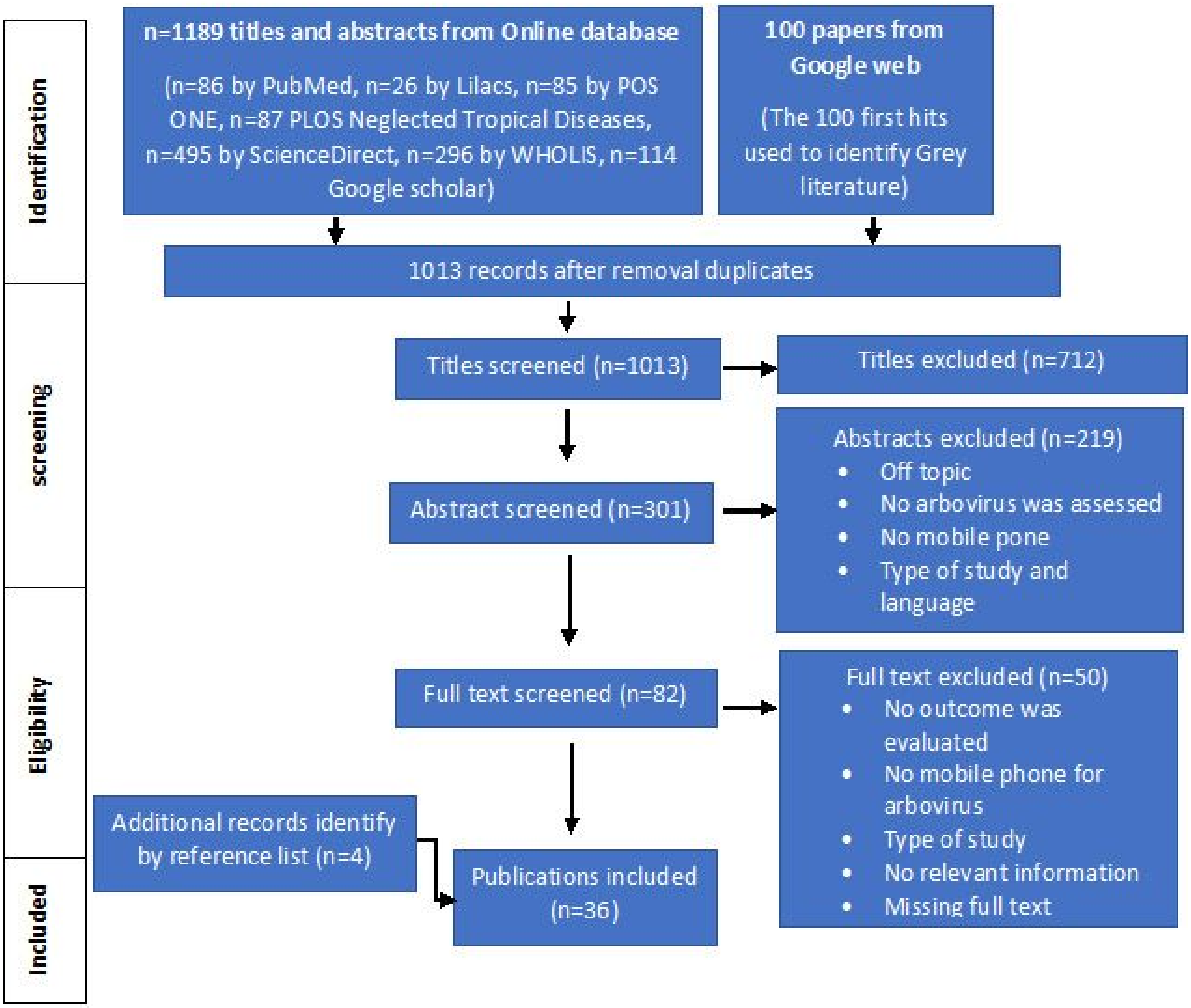

Figure 1

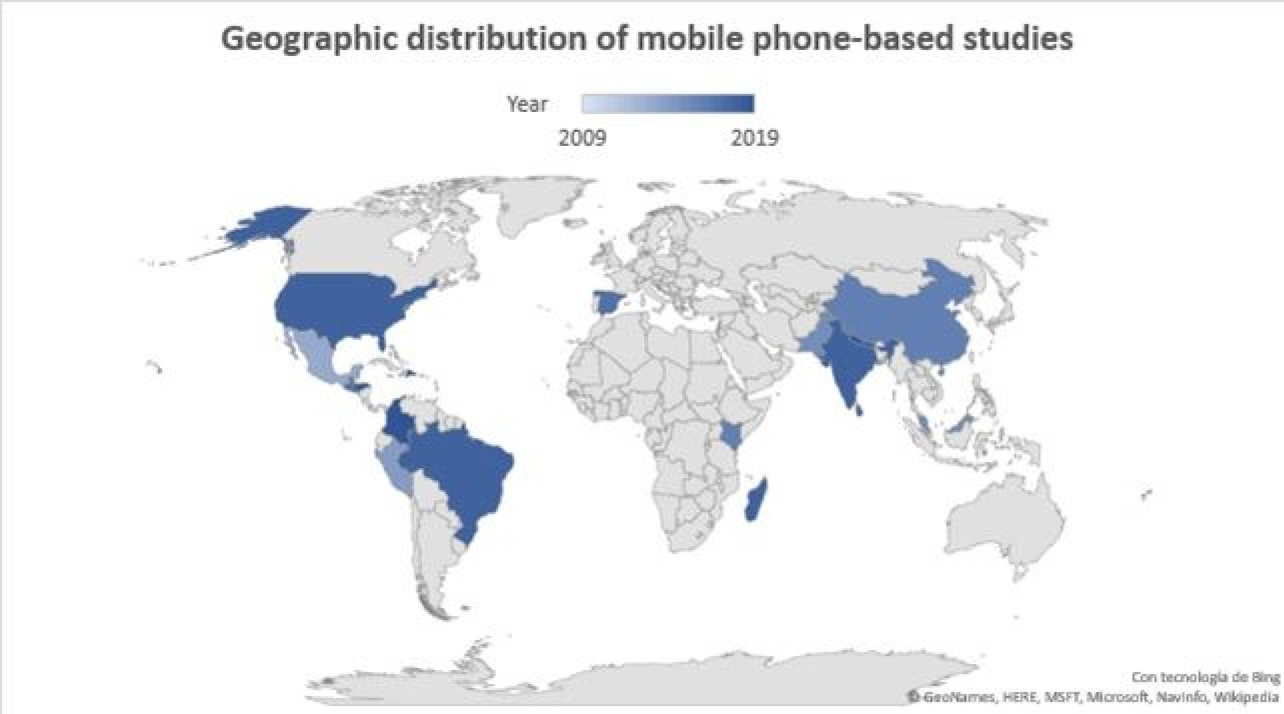

Figure 2

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