Potential and Limitations of the Sketch Map Tool in the International Red Cross Red Crescent Movement

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Abstract
In disaster risk management, participatory mapping (PM) closes spatial data gaps in communities by integrating local risk knowledge. The thesis examined the potential and limitations of the Sketch Map Tool (SMT) as a PM tool for community-based disaster risk reduction (DRR) through an International Red Cross Red Crescent Movement case study. The research evaluated the SMT's applicability for community mapping in the Enhanced Vulnerability and Capacity Assessment by the Colombian Red Cross for hazard analysis, capacity assessment, and action planning, using qualitative interviews, surveys, and community maps. A novel classification assessed the SMT as PM method and software within a participatory and collaborative mapping approach, identifying strengths, shortcomings, and recommendations against the backdrop of contextual PM factors. The SMT proved valuable for collecting, visualising, and analysing local spatial disaster risk knowledge as well as collaborative planning, bridging cost-effective and inclusive paper-based data collection with digital data analysis and storage for more efficient community mapping through digitalisation. Limitations arose from shortcomings in the tool's effectiveness as a PM method, interrelating with restrictions and problems of software functions and usability, which if tackled may unfold the SMT's unused potential as adaptable PM method. Future research could test its applicability for other hazards, vulnerability assessments, and ecosystem based DRR. This research establishes the SMT's significance as innovative tool of Participatory Action Research in DRR. With refinements, the SMT shows promise for expanded applications in adaptation planning and holistic disaster risk assessments with forensic approaches by mapping and examining risk drivers and human-nature interactions.

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Summary

Spatial risk data of the most remote and vulnerable communities is often missing (The Centre for Humanitarian Data, 2022), impacting their ability to build disaster resilience (Liu et al., 2018). Communities play a vital role in enhancing risk knowledge by providing local information about hazards, vulnerabilities, and capacities (Sufri et al., 2020). One way this can be achieved are participatory maps, which serve as media for communicating information through the distinct visual language of a certain community (Rambaldi, 2005). By valuing and integrating communities' knowledge and perceptions in disaster risk assessments and reduction plans, analogue and digital participatory mapping methods enable community participation and close data gaps. Is the Sketch Map Tool (SMT)[1], as one example of a participatory mapping tool, a good solution to facilitate this process?

I examined the potential and limitations of the SMT for community mapping in the context of the Enhanced Vulnerability and Capacity Assessment by the Colombian Red Cross for hazard analysis, capacity assessment, and action planning in the community of La Capilla in Soacha, Colombia. Neither the current version of the tool, nor its software usability or usage as participatory mapping method have ever been analysed before regarding its applicability by the International Red Cross Red Crescent Movement and the mapping of other disaster risk related aspects, such as community resources and risk reduction plans.

Through a novel classification I assessed the SMT as participatory mapping method and software, and within a participatory and collaborative mapping approach, using 11 key informant interviews, three qualitative surveys and community maps. I identified strengths, shortcomings, and recommendations against the backdrop of contextual participatory mapping factors. The tool's current software functions, including the generation of printable paper maps with OpenStreetMap data as well as the digitalisation of markings on the base maps (i.e., georeferencing and automatic colour-detection), impact how the solution can be used as participatory mapping method by development agencies.

With the case study, I identified the SMT as valuable for collecting, visualising, enhancing, and analysing local spatial disaster risk knowledge as well as for collaborative planning. Ultimately, I established the SMT's significance as an innovative tool for practitioners and participatory action researchers in the field of disaster risk reduction (DRR). The research shows how the SMT has the potential to be used from risk assessments, via forensic approaches to disasters for identifying underlying causes, to action planning in DRR. Through bridging cost-effective paper-based data collection with digital data analysis and storage, the tool enables more efficient community-based DRR. My evaluation of the SMT's applicability for community mapping acknowledged efficiency gains relating to time, resources, accuracy, and the sustainability of community maps, compared to other participatory mapping methods.

I discovered interconnected shortcomings tied to its effectiveness as a participatory mapping method and software usability due to the current design of the software with its features and functions. Now, the tool's functions are restricted to one base map type and to the recognition of limited colours, one type of markings and the map as sole map feature, which is digitalised.

[1] www.sketch-map-tool.heigit.org/

The language of the user interface as well as the digitalisation process pose additional shortcomings, which lead to limitations of the tool’s applicability.

Enhancements in the software, derived from identified shortcomings and recommendations about potential applications of the tool in the field of participatory mapping, may help to overcome current limitations and unfold the tool's full potential. The recommendations about enhancements and improvements of the solution can be seen as requirements for the further development of the software, which may extend its usage as a participatory mapping method. These include among others the improvement and extension of the digitalisation functions, more base maps and language options, and better user interface design, which would facilitate the tool’s usage by non-experts and a more adaptable and flexible application as participatory mapping method with communities. The tool’s software functions must allow for usage of the tool as a participatory mapping method, which is adaptable to specific community needs and communication styles.

With refinements, the SMT shows promise for expanded applications in investigating root causes of natural hazards in a changing climate by examining risk drivers and human-environment interactions for holistic community-based disaster risk reduction and climate adaptation planning. Future research opportunities include testing its applicability for other hazards, vulnerability assessments, disaster forensic approaches, crisis mapping, climate change adaptation planning as well as the evaluation of its software usability with quantitative metrics.

LIST OF ACRONYMS AND ABBREVIATIONS

AOI	Area of Interest
BRC	British Red Cross
CM	Community mapping
CRA	Community risk assessments
CRC	Colombian Red Cross
DRM	Disaster risk management
DRR	Disaster risk reduction
EVCA	Enhanced Vulnerability and Capacity Analysis
GIS	Geographic Information Systems
GRC	German Red Cross
HeiGIT	Heidelberg Institute for Geoinformation Technology
HOT	Humanitarian OpenStreetMap Team
HRC	Honduran Red Cross
IFAD	International Fund for Agricultural Development
IFRC	International Federation of Red Cross and Red Crescent Societies
IRCRCM	International Red Cross Red Crescent Movement
JAC	Junta de Acción Comunal
KIIs	Key Informant Interviews
LRC	Lebanese Red Cross
MRC	Mozambique Red Cross
N/A	Not applicable
NbS	Nature-based Solutions
NSs	National Societies
OSM	OpenStreetMap
P3DM	Participatory 3-Dimensional Mapping
PAR	Participatory action research
PGIS	Participatory Geographic Information Systems
PM	Participatory mapping
QGIS	Quantum Geographical Information System
SM	Sketch Map
SMT	Sketch Map Tool
SIT	Spatial information technologies
UAV	Unmanned Aircraft System
UI	User interface
VCA	Vulnerability and Capacity Assessment

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1. Introduction

Climate change increases the intensity and frequency of hydrometeorological hazards and weather extremes (IPCC, 2018), leading to humanitarian catastrophes in vulnerable contexts and aggravating existing vulnerabilities and inequities (ibid., 2022). South American populations are highly vulnerable to climatic hazards (ibid.). Economic development, people's vulnerability and coping capacity directly determine risk and exposure to natural hazards, particularly affecting the poorest (IFRC, 2020). But natural hazards do not inevitably lead to disasters when the impact is reduced by preparing and enabling people to cope with them (ibid.). Societies cannot avert hydrometeorological events like torrential rains, but can mitigate or prevent resulting hazards such as floods and landslides that are influenced by human activity by adapting their human-environment system (Becker, 2014). Thus, South American communities can adapt to the changing climate and implement disaster risks reduction (DRR) measures based on the identified risk for a particular location. However, this assessment requires risk data, such as knowledge about past hazards, vulnerabilities, and capacities, which is often incomplete for the most remote and vulnerable populations (The Centre for Humanitarian Data, 2022). The lack of local spatial information impacts a community's ability to build disaster resilience (Liu et al., 2018).

Because various risk conceptions have evolved over time, there is no universal set of characteristics when describing risk. The traditional risk perspective mainly focuses on event probabilities, consequences, and severity of adverse effects, basing risk assessment on quantifiable factors (see Tehler, 2020). But risk is subjective and requires context, integrating human values and risk perceptions (Slovic, 2001). Thus, the voices of the community play an important role in the spatial assessment of all risk components. Participatory maps - analogue or digital, can serve as media for communicating this spatial information through a distinct visual language (Rambaldi, 2005). Communities as mapmakers have "intellectual ownership" over the depicted content and language, by which information, such as local risk knowledge, can be communicated to other actors, such as authorities and development agencies, thereby enabling public participation (ibid., 2005, p. 1).

The International Red Cross Red Crescent Movement (IRCRCM) involves communities through the Enhanced Vulnerability and Capacity Assessment (EVCA) in the assessment and mapping of their risk with the objective to effectively improve disaster preparedness and risk reduction efforts, thus strengthening community resilience (IFRC, 2019). Within the framework, the International Federation of Red Cross and Red Crescent Societies (IFRC) proposes its National Societies (NSs) the usage of community mapping (CM) to identify and visualise community resources, vulnerabilities and hazards as well as to plan community-based projects (IFRC, n.d.-e a).

Residents possess knowledge of past hazardous events, capacities, vulnerable individuals and infrastructure, and potential risk reduction actions, that they can locate in their community. However, paper-based EVCAs and community maps are under or not utilized due to their inaccessibility or illegibility, challenges to update and share, limited user-friendliness or usefulness for decision-making, and potential loss and damage (IFRC, n.d.-b). Thus, the local spatial risk knowledge based on individuals' and groups' experiences and perceptions need to be formalized and analysed digitally during risk assessments (ibid.).

The Sketch Map Tool (SMT) is a local data collection tool developed by the Heidelberg Institute of Geoinformation Technology (HeiGIT) and Heidelberg University, which supports participatory mapping (PM) and risk communication (Universität Heidelberg, 2022). The tool, consisting of a software for generating and printing scale maps and digitalising hand-drawn information, and the usage of the tool as a method for PM have been tested in several countries with different organisations for flood mapping. The solution helps to formalise and visualise local knowledge and thus enables the capturing of individuals' or groups' risk perceptions and experiences about past disaster events (e.g. Klonner et al., 2019; Klonner, Hartmann, et al., 2021a; Klonner, Usón, et al., 2021; Klonner & Blessing, 2019). This research as well as user feedback led to the realisation that the tool needs to be further refined. However, neither the current version of the tool, nor its software usability or usage as PM method have ever been formally analysed regarding potential and limitations for its application by the IRCRCM and the mapping of other DRR related aspects, such as capacities assessments and DRR planning. But for the largest humanitarian network worldwide, namely the IRCRCM, community engagement with participatory approaches in disaster risk assessments and risk reduction is an integral part of the EVCA (IFRC, 2019). Is the SMT, as one example of a PM tool, a good solution to facilitate this process?

The overall aim of the research is to explore the potential and limitations of the SMT in supporting the IRCRCM in the community mapping process in the context of the EVCA. The following two questions unpack the overall aim of the thesis:

1. What are success factors and challenges of PM and thus important contextual factors for applying the SMT for the purpose of community mapping?
2. What are the strengths and shortcomings of the SMT for the purpose of community mapping?
3. Consequently, what are the specific recommendations that would enable the SMT to improve community mapping?

Against the backdrop of general contextual factors of PM, the research explores the strengths and shortcomings as well as recommendations about the enhancement of the tool for identifying its potential and limitations for the IRCRCM. The tool-based case study includes a test of the SMT by the Colombian Red Cross (CRC) within an integrated participatory and collaborative mapping approach, namely the application of the SMT and a Mapathon. The comparison with the previous CM process and outcome of the EVCA for the same community, namely La Capilla in Soacha, Colombia, provides additional findings from an operational perspective. Inspired by case studies about the use of other digital tools in the EVCA (IFRC, n.d.-d) as well as the previous SMT research, the thesis aims to advance the knowledge about PM tools for disaster risk management in general and the use of digital tools, specifically the SMT, for CM in the context of the EVCA.

2. Conceptual Framework

2.1 Disaster Risk, Risk Knowledge and Risk Assessments

Risk can be defined as a “combination of the probability of an event and its negative consequences”, while disaster risk specifies the consequences as “potential [future] disaster losses” in various categories and for a community or society (UNDRR, 2009, pp. 9–10, 25). Exposure is spatially defined and is directly linked to a hazard (ibid., p. 15). It can be represented by the spatial dispersion of elements (potential exposure) intersected with the hazardous zone (hazard exposure) (Kienberger, 2013). The impact of the hazard depends on various factors such as the level of hazard intensity and the vulnerability of the exposed elements. To a varying degree, elements can cope with the impact of a hazard (coping capacity), and decreasing vulnerability (Wisner et al., 2004). Hence, disaster risk is “directly proportional to the magnitude of the hazard, level of vulnerability and exposure, and is inversely proportional to the capacity to withstand the (…) hazard” (IFRC, 2019, p. 4).

Disaster risk knowledge refers to the knowledge of risk components, thereby helping involved actors in assessing risk (Collins et al., 2009; Sufri et al., 2020; UNISDR, 2006). Through understanding the present and imminent risk factors as well as risk drivers and root causes, a risk assessment helps to design DRR actions (IFRC, 2019, p. 4). Quantitative knowledge of the predominant hazards and “patterns of population and socio-economic development” contribute to assessing and mapping disaster risk (UNDRR, 2009, p. 10). With a hazard analysis relevant hazards are identified by location, spatial extent, speed of onset, duration, frequency, and magnitude (Coppola, 2011). Vulnerability and capacity assessments can localise which communities are most vulnerable to a certain hazard by comparing the risk and vulnerabilities with local capacities (IFRC, 2012).

Additionally, it is necessary to analyse contributing factors to other hazards or to human action, that transforms the environment (Turner et al., 1990). Forensic approaches to disasters investigate how dynamic processes or risk drivers such as the population growth, land use processes and patterns, environmental degradation and ecosystem services depletion, as well as poverty and income distribution (cf. Forensic Investigations of Disasters (FORIN) methodology) convert the effects of disaster root causes like development (e.g., inadequate urban and land use planning) into unsafe conditions for communities (Ferreira et al., 2023; German Committee for Disaster Reduction, 2012).

For disaster resilience and DRR, local knowledge for example through volunteered geographic information and PM plays an important role by generating spatial risk knowledge (e.g., Haworth et al., 2018; Reichel & Frömming, 2014). As risk depends on “principles of scale” due to its geographic and temporal distribution (Kienberger, 2013, p. 405), Geographic Information Systems (GIS) support this process by overlaying and analysing spatial layers (Cova, 1999).

2.2 Risk Perception and Risk Communication

People base their risk evaluation on “intuitive risk judgments”, so-called risk perceptions (Slovic, 1987, p. 280). Thus, risk is "socially constructed" with a "multidimensional, subjective, value-laden nature" (ibid., 2001, p. 22). Due to differences in risk judgements risk is perceived and evaluated differently across societies (Sjöberg, 1999a). The public and experts also have varying interpretations of the concepts of risk and its management between (ibid., 1999b).

Risk communication as "any purposeful exchange of information between interested parties" can for example contribute to solving the risk problem jointly through engaging citizens in public risk management decisions (Covello et al., 1986, p. 172). The so-called receiver problems include the imprecise risk perceptions of individuals, while source problems are caused when governments lack the understanding as well as data, which targets specific interests, priorities and worries of individuals and communities (ibid.). Stakeholders' perceptions of preventive measures can be included in a risk assessment with methods of risk communication, ultimately increasing the effectiveness of risk management (Buchecker et al., 2013). Both one-way and two-way communication contributes to the "discursive risk communication on risk perception" and reaching a common assessment of possible prevention measures, and also impacts perceived uncertainties, accepted risk levels, as well as trust in the risk managing institutions (ibid., p. 3020). Thus, the SMT can be viewed as a risk communication tool, focusing on increasing understanding of risk perceptions and risk data through visualising local knowledge on one side as well as on raising risk awareness and discussing associated biases through the participatory process.

2.3 Participatory Community Risk Assessment

Communities play a vital role in enhancing risk knowledge by providing local knowledge about hazards, vulnerabilities and capacities (Sufri et al., 2020). Community-based disaster risk management puts a strong emphasis on these community risk assessments (CRA), which should be applied with a "proactive and situational, dialogical approach" (Wisner, 2013, pp. 440-442). The self-assessment is meant to be proactive because it goes beyond assessing hazard and vulnerability, incorporating the "problem-solving" part through the assessment of capacities (ibid.). It is situational due to its focus on a particular place and group and dialogical because the facilitator is no "expert" but rather "seeks to understand the reality on the ground" through initially basing the CRA on local knowledge (ibid., p. 442). Instead of devaluating and replacing local understanding it is supplemented with "outside knowledge" (ibid.).

Participatory action research (PAR) argues for the "co-production of 'hybrid' knowledge" in disaster risk reduction by incorporating and legitimizing risk knowledge and capacities of local communities, also called endogenous knowledge, and by highlighting its value compared to formally accepted knowledge, so-called exogenous knowledge, of outsiders (McCall & Peters-Guarin, 2012, p. 727). By eliciting and validating local knowledge, that is normally underrepresented in conventional risk assessment outcomes, such as disaster maps and plans, PAR contributes to the integration of "perceptions, values and priorities" of local communities (ibid., p. 739). Development practitioners have created many different guidelines, methods and tools for implementing CRA in particular (e.g., Wisner et al., 2004, pp. 333–342) and PAR in general (e.g., McCall & Peters-Guarin, 2012, pp. 732–734) with PM being the most "wide-spread" visual method (Chambers, 2006, p. 1).

Hazard mapping as well as vulnerability and capacity assessments represent a community-based assessment approach, focusing on multiple or singular hazards (Wisner, 2013). The simple form involves "a census of people and assets at risk, pinpointing some individuals or households who are at extreme risk, and a review of human, financial and technical resources available to mitigate the risk" (ibid., p. 450). While the simpler version normally focuses on preparedness, excluding mitigation plans, the complex form also researches the "root causes" of vulnerability and obstruction of capacity (ibid.). CRA face several technical limitations, such as a "balance (…) between qualitative and quantitative characterization of hazards, vulnerabilities and capacities" due to the low level of formal education of the participants (ibid.). This balance also refers to the expected outcome, which must be meaningful for the community, local plans, and action on the one hand, and fulfil a "minimum acceptable standard of accuracy" on the other hand (ibid., p. 451). Hazard risk maps are a tool for the identification of risk, vulnerabilities and disaster risk management capacities and form the foundation for the development of DRR plans (Vietnam Red Cross et al., 2017). In this process NSs provide technical expertise to the communities and local government with a special emphasis on community engagement and inclusion (ibid.).

2.4 Participatory Mapping

The facilitation of mapping by outsiders is rather new and transformed with acknowledging the ability of local communities to use their means to create elaborated maps (Chambers, 2006, p. 1). Participatory maps became an empowering medium for communities to spatially represent their "socially or culturally distinct understanding of landscape", which often is excluded from "mainstream maps" (IFAD, 2009, p. 7). How PM is conducted by outsiders impacts its effectiveness for community engagement and empowerment as well as for the integration of endo- with exogenous knowledge (Laituri et al., 2023).

No universal definition of PM exists due to different users, methods and varying applications, which led to multiple terminologies, such as indigenous mapping, counter mapping or CM (IFAD, 2009, p. 6). CM is interchangeably used by the IRCRCM for disaster risk mapping and refers to the process of drawing and visualising community resources, vulnerabilities, and hazards on a map (IFRC, 2019). I will generically summarise these terms under PM as the research includes experiences from actors using the different terminologies.

According to the International Fund for Agricultural Development (IFAD) (IFAD, 2009, p. 6), the overarching theme is that the "process of map-making is undertaken by a group of non-experts who are associated with one another based on a shared interest". Hence, PM is seen as "a map-making process" with the purpose of visualising "the association between land and local communities by using the commonly understood and recognised language of cartography" (ibid.). G. Brown & Fagerholm (2015) relate PM to a process in which *citizens* contribute to creating maps. Both approaches are limited to non-experts, while my research data includes examples of PM, conducted with professors or experts in a learning environment or with local stakeholders with different expertise and in various positions. In the field of PAR in DRR, the PM process has a specific purpose and is inverted to the researcher side. This view limits the process to the "interactive acquisition of local spatial knowledge" about risk (McCall & Peters-Guarin, 2012, p. 727), rather than understanding it as a method for expressing opinions or envisioning change. Thus, I will define PM as an interactive *mapmaking process*, in which *participants* with a *shared interest* contribute their *knowledge* by using the *language of cartography* with the purpose of *visualising the connection between people and land, perceptions, values, and priorities*.

PM as a methodology or process is often separated into *technique, method, tool, media, medium or means of mapping*, such as hands-on mapping on the ground or sketch maps (see Section 2.4.1), as well as the *style or mode of facilitation* – both influencing "who takes part, the nature of outcomes and power relationships" (see Section 2.4.1) (Chambers, 2006, p. 1).

The final participatory map is sometimes referred to as *outcome, output, product, or result* (IFAD, 2009, p. 7). The overall participatory mapmaking process can be partitioned into three distinct phases, namely the "community consultation and/raw data collection" and "data collection and non-digital mapmaking", which take place "on the field" as well as the "data analysis, digital editing, manipulation, etc.", situated "on or off the field" (Rambaldi, 2005, p. 6). I will refer to these phases as *PM* in which participants create a nondigital product - the participatory map, *post-PM,* in which either participants, facilitators or analysts edit and manipulate the output for the creation of a final digital map, and *pre-PM,* which integrates the preparation of the PM including the creation of the medium, such as a scale map.

The production of community maps with a PM approach is supposed to be inclusive and open as well as goal-orientated or planned based around a strategy for use of the *product* (IFAD, 2009, p. 7). The more voices of diverse participants are heard and included, the better the product, representing the collective knowledge of the entire community as well as their agenda (ibid.). Hence, PM products focus on depicting information relevant to the participants' needs and benefit (ibid.). The *content* of the map normally shows local knowledge and information, such as places, symbols, scales and concerned features, thus representing local knowledge systems (ibid.). The visual *language* of the map, with which the mapmaker transports information, consists of "legend items, a combination of symbols (points, lines, polygons and volumes), their variables (hue, orientation, shading value, shape, size, and texture) and interpretation keys" (Rambaldi, 2005, p. 3). The legend with its components: symbols and attributes, namely words describing the signification of the symbols, plays an important role for the map as communication media, and ought to be understandable and agreed upon by the mapmakers due to their ownership over what is "important" (ibid., p. 7). Community maps can have differing scales, which make it possible to display details (e.g., buildings, roads) or a larger extent (e.g., land use, territories, and natural resources) (IFAD, 2009). PM is not restricted to an explicit technique, medium or to formal cartographic standards, however the more the community map is based on them, "the greater the likelihood that they will be seen as effective communication tools" for the outsiders, such as state authorities or development agencies (ibid., p. 7).

2.4.1 Participatory Mapping Tools

IFAD (2009, pp. 13-19) distinguishes between PM tools or techniques in the order of complexity and material requirements. The list starts with hands-on mapping (i.e., ground, sometimes also called ephemeral mapping (Corbett et al., 2006), and sketch mapping on paper), mapping with scale maps and images (i.e., photocopied map or remote-sensed image), and Participatory 3-Dimensional Mapping or Modelling (P3DM) (e.g., 3D scale relief model based on topography). The ranking concludes with mapping with spatial information technologies (SIT) like GIS, multimedia, and internet-based mapping (ibid.).

Sketch mapping was widely applied by development practitioners during the '80s because the priority was given to drawing out community dynamics and facilitating exchange between outsiders and communities (Rambaldi, 2005). Sketch mapping is more elaborate than ephemeral mapping, and both hands-on mapping methods do not include a scale or exact geolocation as participants draw the entire map based on memory (Corbett et al., 2006). These methods are low-cost, technology independent and expected to contribute to better orientation on the map, which is particularly beneficial for non-literate communities (IFAD, 2009). As the results are not georeferenced and the transfer of the maps' content to scale maps is demanding, these maps have limited cartographic accuracy, which impacts the potential to use them as advocacy medium with external actors or for quantitative analysis (ibid.).

Scale mapping is more "complex, demanding and time consuming" and focuses on "courses of action enabling communities to interact efficiently with policymakers", but it was less used due to limited and restricted access to real-scale maps and remotely sensed images of developing countries (Rambaldi, 2005, p. 2). Its target is to create nearly accurate geo-referenced data, enabling the direct comparison and integration with other maps and spatial data (Corbett et al., 2006). As creating scale maps by hand is very time-consuming, the method depends on the availability and affordability of existing, accurate maps at a suitable scale such as satellite and arial images (also called photomaps or orthophotographs (ibid.)), which are beneficial for non-literate communities and people with limited topographic map literacy (IFAD, 2009). Unmanned Aircraft Systems (UAVs), such as drones, nowadays further increase the potential of retrieving remotely sensed data with high spatial and temporal resolution for scale mapping (e.g., Dinko & Nyantakyi-Frimpong, 2023). P3DM has been used both in disaster RA and action planning with for example plotting 3D scale relief models of "hazard-prone areas, vulnerable people and assets, and resources that bolster local capacity (…) to critically appraise disaster risk in (...) [the] immediate environment" and plan DRR measures (Cadag & Gaillard, 2012, p. 105).

The access to spatial data changed in the '90s with the greater availability and affordability of modern SIT like GIS and open online data (Rambaldi, 2005). OpenStreetMap (OSM) and its Tasking Manager platform of the Humanitarian OSM Team (HOT) (Humanitarian OpenStreetMap Team, n.d.) are open-source projects, using a so-called crowd or collaborative mapping approach, in which mapping volunteers improve data availability by remotely tracing map features based on satellite imagery or collecting ground data. SIT aim to place "ordinary people in the position to generate, analyse, manage and exchange georeferenced data (…) to foster social learning and broaden public participation across socioeconomic contexts, locations and sectors" (Rambaldi, 2005, p. 2). In this regard, Participatory GIS (PGIS) describes the involvement of the general public in policymaking or activities of non-governmental, grassroots or community-based organisations through using GIS (Sieber, 2006). In CRA, PGIS has been applied for example for mapping hazards (see e.g., McCall, 2008; Olyazadeh et al., 2017) and vulnerability (see e.g., Kienberger & Steinbruch, 2005; Kienberger, 2013). Digital community maps produced with an integrated participatory and collaborative mapping approach in OSM are found to have a higher information content, accuracy and are easier to update and use and in common compared to conventional CM from CRA (Liu et al., 2018).

Discussions about the superiority of certain mediums or means are beyond the scope of this thesis and are seen as counter effective as strengths of one tool are weaknesses of the other and vice versa (e.g., see Chambers, 2006, pp. 5-6 or IFAD, 2009, Appendix A). Chambers (2006, p. 5) realizes that "different media, processes and power relations fit different applications and lead to different outcomes", while IFAD (2009) stresses that the practical decision for a tool depends on the employment of the map, usable resources (e.g., financial, human and equipment) and the perceived impact on the target group.

2.4.2 Ethical Considerations

When applying PM several ethical issues arise, which may stem from the relationship and interaction between facilitator and participant or the medium. Impacts of PM initiatives can be beneficial or damaging depending on several interrelated, for the facilitator controllable and uncontrollable factors (IFAD, 2009, p. 20). PM takes time from the participants, especially when conducted repeatedly, while the facilitation "is liable to raise expectations of some benefit" (Chambers, 2006, p. 6). The control of the process as well as ownership and use of the extracted information are other ethical concerns. Local knowledge in the form of maps may only benefit outsiders or even harm people, when used against them or triggering conflict in the community, which is often the case when marginalised or vulnerable groups such as women participate (ibid.). McCall (2004) and Fox et al. (2006) among others, highlight the potential of "increased conflict, resource privatization, and loss of common property" when applying spatial SIT participatorily (Rambaldi, 2005, p. 2).

Particularly, the use of SIT poses the danger of exclusion and disempowerment of the people due to the equipment and required training on it, potentially exacerbating the perception that the outsider is more dominant and knowledgeable (Chambers, 2006, p. 6). Facilitators must carefully consider their control over representation and transfer process when using GIS technologies (ibid.). SIT must "be in the position to allow two-way interactions, accommodate and visualise (…) spatial knowledge and stakeholders' perspectives, and to store and display these" (Rambaldi, 2005, p. 4). Particularly, PGIS may raise concerns about data ownership but by giving the data generators authority over access and use of information, outsiders safeguard endogenous knowledge and wisdom from exploitation (ibid., 2006).

Due to the scope of this study, the research does not evaluate the ethical issues arising from the facilitation, or the handling and long-term usefulness of the data for the community in detail. A thorough analysis of the consequences for the community is excluded because the research focus consists of investigating how the method is used by outsiders in an operational environment rather than critically reflecting on "unintended consequences" (Laituri et al., 2023, p. 1). However, the analysis includes if the PM process with the SMT enables or disables community members with diverse backgrounds to participate and facilitators to "genuinely listen to community voices" (ibid.).

3. Materials and Methods

I applied a qualitative research design to gain an understanding through engagement with participants during the data collection for the thesis in Colombia (Creswell, 2013, pp. 22, 47). A case study research strategy was applied as methodology approach (Creswell, 2013, p. 97) by the investigation of actual cases of community mapping by various NS of the IRCRCM, namely the CRC, British Red Cross (BRC), Danish Red Cross, Mozambique Red Cross (MRC), Lebanese Red Cross (LRC), GRC and Honduran Red Cross (HRC). The tool-based case study, namely the application of the SMT, focuses on the previous experience with the second SMT version by the MRC and German Red Cross (GRC) in Honduras and with the latest version (i.e., current SMT version) by the BRC in Nepal. The uniqueness consists of also conducting research on an operational level. Rather than purely extracting data passively, I have studied the implementation of the newest SMT version in a particular context in real-time, namely for the operation of the CRC between March and April 2023, with tangible outcomes (i.e., non-digital Sketch Maps (SMs) created during PM phase, edited digital maps during post-PM phase). Therefore, additional data was collected as the tool was rolled out.

3.1 Integrated Participatory and Collaborative Mapping Approach

The case study includes an integrated participatory and collaborative methodology adapted from Liu et al. (2018) for the collection and management of local disaster risk information as well as for risk reduction planning. As a collaborative mapping approach, the HOT Tasking Manager[2] was used for crowd mapping during a Mapathon. Remote volunteers, the so-called "crowd", collaboratively mapped the Area of Interest (AOI), which consists of the buffered area of the case study site (see 3.2.2), by sketching OSM features visible from Bing satellite imagery.

Regarding the PM approach, the SMT solution was used by the CRC for creating and printing SMs in the pre-PM phase, to collect ground data on these SMs during individual and group mapping in the PM phase, and for later georeferencing the markings in the post-PM phase (see Figure 2 in 3.2.2). The PM product was edited and manipulated to create final maps, using the Quantum Geographical Information System (QGIS) software.

[2] www.tasks.hotosm.org/

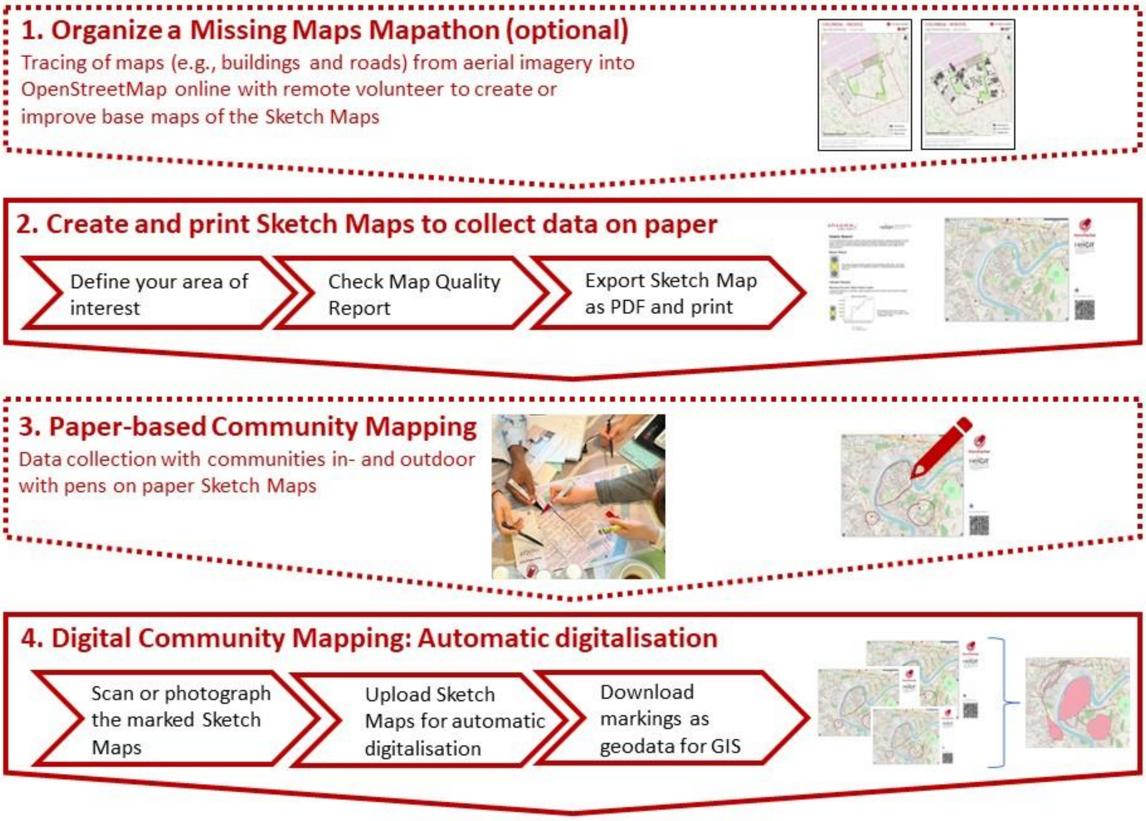


Figure 1. Visualisation of the tested integrated participatory and collaborative mapping approach

3.2 Case Study Description

3.2.1 International Red Cross Red Crescent Movement: EVCA and Community Mapping

The IRCRCM consists of the International Committee of the Red Cross, 192 NSs, and IFRC, that published the EVCA guideline (IFRC, 2019) to follow its objective to support NSs in their development and "improve their programmes, accountability, leadership, policies and systems" (IFRC, 2023). The EVCA guideline includes tools that are part of PAR applicable for DRR (see McCall & Peters-Guarin, 2012, pp. 732–734). These tools can be categorized into participatory research to *analyse risk data* (e.g., participatory disaster risk assessment or EVCA), for *data collection to acquisition knowledge* (e.g., transect walk), for *describing the current situation* (e.g., problem trees; stakeholder analysis), for *verbal information* (e.g., focus group discussions, questionnaires, key informant interviews (KIIs)), for *analysing change (histories)* (e.g., seasonal calendars of livelihood and stresses), for *analysing preferences and evaluations* (e.g., problem and decision tree), for *planning the future* (e.g., strengths, weaknesses, opportunities, threats analysis) and for *PM, PGIS and spatial analysis* (e.g., risk maps) (ibid.). The EVCA mentions the creation of different types of maps during EVCA steps, namely the hazard and exposure map (step 6: Hazard and exposure assessment), vulnerability and capacity map (step 7: Vulnerability and capacity assessment), and "dream" map (step 9: Risk reduction planning) (IFRC, n.d.-f). IFRC provides additional considerations for mapping relating to health, livelihoods, climate, gender and diversity aspects (IFRC, n.d.-g).

For the development of the EVCA and its community mapping guidance for urban contexts (IFRC, 2019) the publications "Integration of climate change and urban risks into the

VCA" (IFRC, 2014) as well as the "Participatory evaluation of the VCA and comparative analysis with the community-based disaster risk assessment (...) methodology" (Miltenburg & Thi Phuc Hoa, 2015) are considerable. Regarding climate change and urban risk, the first highlights that PM should stimulate discussion about the "current processes of change observed by people and causal factors" (IFRC, 2014, p. 70). The latter identified challenges in data precision and reliability of hand-sketched maps as well as lacking data analysis in the Vietnam Red Cross' VCAs, diminishing their usefulness for DRR planning, preparedness and response as well as post-disaster assessments and socio-economic development planning (Vietnam Red Cross et al., 2017). Subsequently, a participatory multi-hazard risk mapping methodology and training was published "for developing, updating and using multi-hazard risk maps for Disaster Risk Reduction in urban context", using different scale maps, but manually digitalising the results in QGIS (ibid., p. 2). Case studies from various NSs about the use of digital tools for community mapping can be found on the EVCA toolbox website, such as crowd mapping with OSM Mapathons combined with mobile-GIS data collection tools such as KoboToolbox[3] on smartphones (IFRC, n.d.-a) or the usage of GIS mapping software and platforms to integrate data from several sources such as mobile-GIS data and PM with scale maps (IFRC, n.d.-c).

3.2.2 Colombian Red Cross: EVCA and Community Mapping in Case Study Location

The integrated mapping approach was implemented by the CRC with the community of the neighbourhood (*Barrio*) La Capilla in Soacha, an autonomous municipality (*Municipio*), located South of Bogotá in the department (*Departamento*) Cundinamarca (see Figure 2) and inhabited by roughly 650,000 people (DANE, 2019). The CRC estimates the population to more than 1,000,000 in the municipality due to significant percentage of migrants in transit. La Capilla is roughly 0.02km² in size and part of the Z Zurich Foundation Flood Resilience project of the CRC, in which an EVCA was conducted between May and August 2022 to gain insights on flood and landslide risks.

[3] https://www.kobotoolbox.org/

Figure 2. Case study location

Soacha is "threatened by flooding caused by frequent and intense rains" which affect households due to the low hydraulic capacity of the sewage networks, the clogging of drains, pipes and overflowing of waterbodies (CRC, 2022b). Torrential floods and housing next to the water basin and on steep hillslopes, which are prone to landslides in the event of heavy rains, as well as improvised constructions pose a high risk in La Capilla (ibid.). The access to the community is difficult due to unpaved roads, and the water bodies and land are contaminated with chemicals and solid waste due to improper waste management (ibid.).

The site was selected because it has been affected extensively from floods, landslides, and torrential floods due to heavy rains year after year (CRC, 2022a). The neighbourhood had to evacuate during major rains in 2009 and 2013 that caused landslides and loss of assets such as furniture and belongings (ibid.). Flooding also disrupted local livelihoods like formal and non-formal businesses, and lead to the permanent relocation of the school and streets behind it, located next to a creek (ibid.). However, government data on flood and landslide risk is outdated and only available on a low spatial resolution, showing La Capilla with a low flood risk even though the recent years have shown differently. The CRC and site represent a good case due to the previous community mapping exercise without the SMT, making it possible to contrast the mapping approach from 2022 with the one using the SMT. The community has social leaders with motivation to participate in projects and the CRC is well respected, which provided a good basis for testing a new PM tool (CRC, 2022b). Additionally, the CRC currently works towards streamlining and digitalising the EVCA, which is why the organisation was interested to test new technologies.

On 11 April 2023, 27 staff members and volunteers of the CRC as well as 6 external persons from YouthMappers Colombia, HOT South America, and OSM participated in the Mapathon, organized by HeiGIT and the GRC. After an introduction in the use of crowd mapping for improving data availability and accuracy with the HOT Tasking Manager, the crowd mapping approach was tested by the participants to trace buildings of the AOI based on satellite imagery. Between 17-19 April 2023, 10 staff members from DRM, and Health, Peace Building, and Education Division of the CRC tested the potential and the limitations of the SMT with 25 community members (residents, members from the community board (*Junta de Acción Comunal* (JAC)), community representative at the city council). Relating to the PM approach, an array of EVCA tools (i.e., mapping, transect walk, focus group discussions) were combined in the context of community mapping to conduct several EVCA steps (i.e., exposure identification (step 6.2), capacity assessment (step 7.2), visioning with the community (step 9.1). As a result, an exposure map based on experiences of historic flood events, a capacities map with resources, and a "dream map" with the aspirations and priorities for community based DRR actions were created (see Figure 3).

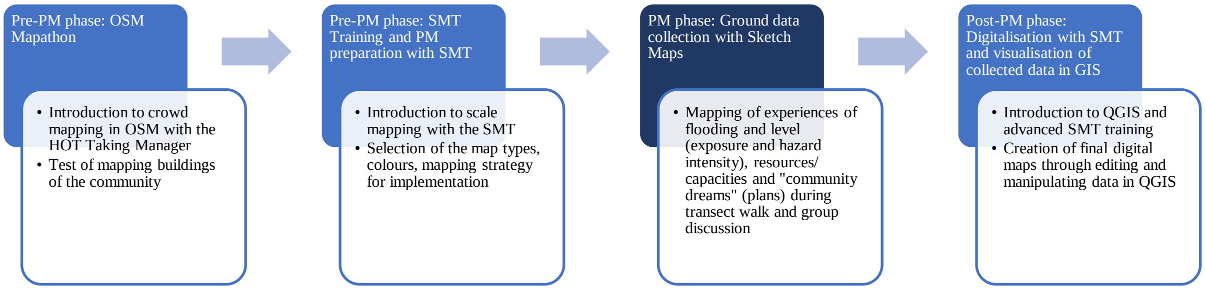


Figure 3. General workflow of the tested integrated participatory and collaborative mapping approach in EVCA (darker blue represents outdoor activities, while light blue indicates indoor activities)

As the crowd mapping did not provide sufficient and reliable data about the building infrastructure, a base map from before the Mapathon was generated and used with the SMT (see Section 4.2 and 4.3). The PM participants freely decided to participate without receiving any benefits as recommended for PM activities (Chambers, 2006, p. 6). They had different levels of map literacy, gender, and household location within the community based on personal observations. All 14 community members participating in the evaluation survey possessed prior experience working on community mapping for disaster risk management (DRM).

3.2.3 Sketch Map Tool

The SMT is a "tool for participatory sketch mapping through offline collection, digitization and georeferencing of local spatial knowledge" (HeiGIT, 2022d). Building on the idea of OSM Field Papers[4], the first prototype of the SMT (2020 until 29 September 2021), was developed in the context of the Waterproofing Data project, which focused on researching new ways for collecting citizen generated data, namely local knowledge about flood data in Brazil (Universität Heidelberg, 2023). Due to its "easy-to-use" handling, it enables "non-experts" to gather and analyse spatial data by georeferencing and colour-detecting markings on scale maps with computer vision methods (HeiGIT, 2022b). The tool recognises red, blue, green, pink and yellow markings, but does not differentiate between different features (i.e., line, point, closed area) and all markings are digitised as polygons with closed circles being entirely filled

[4] http://fieldpapers.org/about

(HeiGIT, 2022c). After the second version (30 September 2021 until 08 December 2022), which was still password-protected, the code was improved and made publicly available with the launch of the most recent third version and website (since 09 December 2022, lastly updated on 22 February 2023), including a new user interface (UI).

The SMT solution can be compartmentalised into two separate but interrelated parts: 1. Open-source online software facilitating the pre- and post-PM phases, namely *preparing PM* (i.e., scale map creation and assessment of the fitness of the OSM base map data for PM) and *post-processing of PM outcomes* (e.g., digitisation of markings on scale maps), and 2. Use of the tool-generated scale maps (i.e., SMs) as a *method* for PM. The first part relates to usage by PM planners, facilitators, or analysts, while the second part involves participants and facilitators. The software consists of several webpages with English text, features, and functions that can be matched to the PM phases (see Appendix A). The tool only generates Sketch Maps depicting the freely available OSM data at a selected scale and does not include a geospatial analysis of the markings. Sketching on these base maps aims at recording and automatically digitalising accurate georeferenced data, which allows users to store and analyse the collected geodata on the computer in a GIS software.

3.3 Data

3.3.1 Data Collection

I gathered primary data through 11 semi-structured KIIs as well as through three maps produced with data that was collected with the SMT, additionally to personal observations. I conducted three qualitative surveys with varying questions depending on the three target groups. In total, 6 SMT training participants from the CRC, 14 community members, as well as 20 PM practitioners and researchers out of which 9 are affiliated with the IRCRCM, responded. Several participants decided to remain anonymous. The findings were complemented with secondary data from the CRC, namely maps produced before this study, and research publications on the SMT. The overview of the research data (see Appendix B) depicts the different data types, data collection methods, as well as basic demographics and background information about the analysed data.

Purposive sampling was applied because key informants were selected based on the organisation, their role, as well as their experience with participatory mapping, community mapping and the SMT (Blaikie, 2010). A snowball sampling strategy was applied because initial interviewees proposed new participants out of their network (Blaikie, 2010, p. 179). The participants' selection focused on informants within the IRCRCM and with SMT user experience to allow the investigation of the research objective. The data collection was stopped as limited new information was found as proposed by the concept of theoretical saturation (Guest et al., 2006). A broad geographic coverage among the participants was achieved because only the Oceanian and Asian regions were missed. However, certain interviewees contributed experiences from these regions as well, which enabled me to derive results for the entire RCRCM.

3.3.2 Data Analysis and Analytic Framework

The raw data of the KII and surveys was analysed with the 6-step thematic analysis as proposed by Braun & Clarke (2006, p. 87 ff.), using the NVivo software. The themes were divided and categorised based on if they relate to the *SMT as a software* including features and functions or if they correspond to applying the *SMT as a PM method* in the specific environment, namely the usage of the OSM scale maps (i.e., Sketch Maps) in the EVCA. Findings were classified as strengths or shortcomings of the SMT, recommendations for the further development of the SMT, or as general PM contextual factors.

Because this tool-based case study is based on the integrated participatory and collaborative mapping approach adapted from Liu et al. (2018), the structure of the main results is also oriented on this research. Thus, the evaluation of the SMT's potential include a comparison of the map content between the community maps, produced by CRC staff with the SMT and QGIS during the case study, and the pre-study EVCA maps from 2022. These include a community map on paper created by participants (PM method: sketch mapping on paper) (see Section 4.1, Figure 4) and a digital version of the community map on Google Earth, which was created by a CRC staff member manually after the PM activity (see Section 4.1, Figure 5). Due to the qualitive research design, the results exclude an assessment of spatial heterogeneity of the maps as well as consistency or accuracy of mapped data (e.g., see Olyazadeh et al., 2017; Zolkafli et al., 2017).

Due to the dual facets of the SMT, namely being a software and PM method with its SMs, the scope of this research, and the available data, no exhaustive evaluation of the software usability was undertaken. This would require more detailed and standardised user feedback, which is collected over a longer testing period, and measuring user interaction and satisfaction quantitatively, for example with a software usability evaluation model (e.g., Dawood et al., 2021). As the SMT is a non-interactive GIS mapping tool, its usability evaluation also differs from that of a standard PGIS software (e.g., Ballatore et al., 2020). While Dawood et al. (2021) and Ballatore et al. (2020) focus on quantifying user feedback, this qualitative thesis research instead utilizes the established themes as a categorisation scheme in the analysis of the findings relating to the SMT as a software (see Section 4.4). Ballatore et al.'s (2020) themes were applied and extended with applicable criteria from Dawood et al.'s (2021) model as described below.

Ballatore et al.'s (2020) framework on the evaluation of the usability of PGIS tools assesses common aspects of perceived usability. The 25 questions in simple English are based on the standardised System Usability Scale (SUS) (Sauro, 2011) and relate to five themes, namely *user interface (UI)*, *spatial interface*, *learnability*, *effectiveness*, *communication*. These represent "complementary dimensions of the usability of a PGIS" applicable for various PGIS domains (Ballatore et al., 2020, p. 13). In comparison to Dawood et al.'s (2021) general model to evaluate the usability of open-source software with quantitative metrics in seven distinct criteria, namely memorability, learnability, accessibility, robustness, effectiveness, satisfaction, efficiency, Ballatore et al.'s (2020) framework focuses on domains of the usability of participatory spatial tools with its specific challenges and requirements. Henceforth, the categorisation includes important distinctions such as the difference between *spatial interface* and *UI*. Thus, Ballatore et al.'s (2020) evaluation scale is more suitable for the analysis of the SMT. However, some aspects are excluded in the analysis because they are not applicable as the SMT is not a PGIS tool but a PM tool. This is aligned with the recommendation to amend the standardised questionnaire and focus on relevant project-specific questions (ibid.).

The *effectiveness* criteria describes "how the system supports the user goals" and incorporates aspects like the inclusion of necessary tools, the reliability of the system, the increased participation in the overall project, the user satisfaction (based on recommendation of the system to others) and the added-value regarding the completion of tasks which are only possible with this system (Ballatore et al., 2020, pp. 12–13). This definition of effectiveness includes several aspects of Dawood et al.'s model (2021) and goes beyond the same-called criteria of effectiveness, which is described as capacity of a system "to empower users in accurately accomplishing specific tasks under a specific context" (Dawood et al., 2021, p. 8) and is measured with the metrics percentage of tasks accomplished, accuracy and completeness. It for example incorporates metrics of the Ballatore et al.'s (2020) satisfaction criteria, such as the user satisfaction with the functionalities and characteristics and their trust in the correct functioning, as well as metrics of the robustness criteria, such as the fault tolerance. Furthermore, Ballatore et al.'s (2020) effectiveness category also relates to aspects grouped under the accessibility criteria in Dawood et al.'s (2021, p. 8) model, that describes if users with "different capabilities such as ordinary users and users with special needs" can complete specific tasks (Dawood et al., 2021, p. 8). In the data analysis, feedback relating to the accessibility metrics flexibility (adaptiveness) and operability of the system are henceforth categorized under the effectiveness theme. Operability in this regard refers to the "necessary functions to facilitate the correct performance of tasks" (Dawood et al., 2021, p. 11). According to Ballatore et al.'s (2020, p. 13) *communication* describes "how the system supports communication with other users and stakeholders". This category includes aspects that are rather applicable to PGIS systems than to a software that analyses PM data, such as the ability of communicating with other participants regarding expressing and exchanging ideas and comments. Thus, communication can be regarded as a secondary "user goal", which is why both criteria are henceforth grouped.

The *UI* consists of "the visible part of the system" and can be evaluated based on the clarity of the terms used in the system including the error messages, the easiness to move through the elements of the system including the return to the homepage, as well as the delay between operations (Ballatore et al., 2020, p. 12-13). As the SMT includes a *spatial interface*, namely the preview of the sketch map, the usability evaluation of the tool includes how the user can interact with the spatial data. Ballatore et al.'s (2020) propose to evaluate the *spatial interface* by the easiness to move to new locations, to zoom in and out, as well as the access to information about what is shown in the map. Furthermore, they include the creation of new spatial content and the time for the visual edits to take effect. *Learnability* describes "how easy it is to learn how to use the system" and includes aspects like the users' confidence to use the system, the remembrance how to execute tasks, the usefulness of help resources, as well as the easiness to discover new features and to correct mistakes by trial and error (Ballatore et al., 2020, pp. 12–13). Ballatore et al.'s (2020) *learnability* category also covers some aspects of Dawood et al.'s (2021, p. 8) criteria of memorability, that describes how the system supports "the user's intuition in using the functions of the system with minimum user memory recall after a substantial time-lapse between visits". As the latest SMT version has not been on the market long enough, it is impossible to evaluate the users' memorability. Aspects such as the understanding of the system's display as well as user support options in case of challenges can be applied in the evaluation of the SMT but are grouped under *user interface* and *learnability*.

3.3.4 Validity

Data triangulation increases data reliability and validity of qualitative research (Golafshani, 2003). The collection of different types of data, namely from the KII and surveys, enabled me to be independent of one data source, investigate recurring themes or dimensions across multiple sources of evidence and triangulate findings (Creswell, 2013, p. 45). During the data collection, questions were selected based on the background and previous answers of the interviewees. Participants without user experience in the SMT were not asked how it could improve the community mapping process because this would risk hypothetical responses and opinions rather than hard data, thereby data contamination was avoided.

Due to the operational nature of the research, the reflection on my interaction with the study object is important. I trained the CRC staff in the use of the tool and supported them during the data analysis in QGIS. However, I was neither actively involved in the selection of the site, hazard, paper formats and colours, the actual test of the tool in the community nor in the creation of the maps and their focus. I limited my involvement with the study object in the way that I only provided general tips on the use of the tool before the implementation and on the use of QGIS during the post-processing of the results that is normally provided to training participants by HeiGIT. Thus, I restricted my influence on the research findings to the extent possible.

The PM was facilitated by local CRC staff as people particularly from vulnerable groups may not freely express their voices due to existing power imbalances when PM is facilitated by an outsider like me (IFAD, 2009, p. 27). I tried to mitigate that my presence would influence "the nature and content of information presented on the map, the validity of the information and how the map is ultimately used" (ibid.). Summarising, the thesis carefully observed the typical PM research pitfall of "transforming [the] map content to meet research goals" because the products - both the PM output and final map, were entirely created by the NS's staff and participants (Laituri et al., 2023, p. 1).

4. Results and Findings

This chapter shows the results of the application of tools by the CRC before the case study (Section 4.1), namely sketch mapping and digital mapmaking with Google products, as well as with the tested integrated participatory and collaborative mapping approach, consisting of crowd mapping (OSM Mapathon), the SMT and GIS software (Section 4.2 and 4.3). The findings provide information about the contextual factors of PM, the SMT's strengths and shortcomings, as well as recommendations for its usage as a PM method (Section 4.3-4.3.4) and regarding its usage as a software (Section 4.4).

4.1 Community Mapping without the SMT

Before the SMT case study, most of the CRC training participants used Google products (i.e., Maps or Earth) for PM, while a minority used physical hand tools. The community map on paper was initially hand-sketched by 48 community members based on their memory (Figure 4). It is used to identify vulnerabilities, capacities and hazards and shows the broad overview of the community with its natural features (e.g., hills (*loma*)) and basic infrastructure (e.g., houses (*casas*), businesses (*empresas*), church (*iglesia*), school (*escuela*), jardin (*garden*), main street (*principal*)). No scale was used by the participants and elements were partially drawn with symbols (e.g., lines, houses, areas) or labelled directly on the map. Sticky notes were used for additional information such as relevant changes in the external environment over time, for example that new migrants were arriving and settling around the community, changing the population distribution and land use pattern.

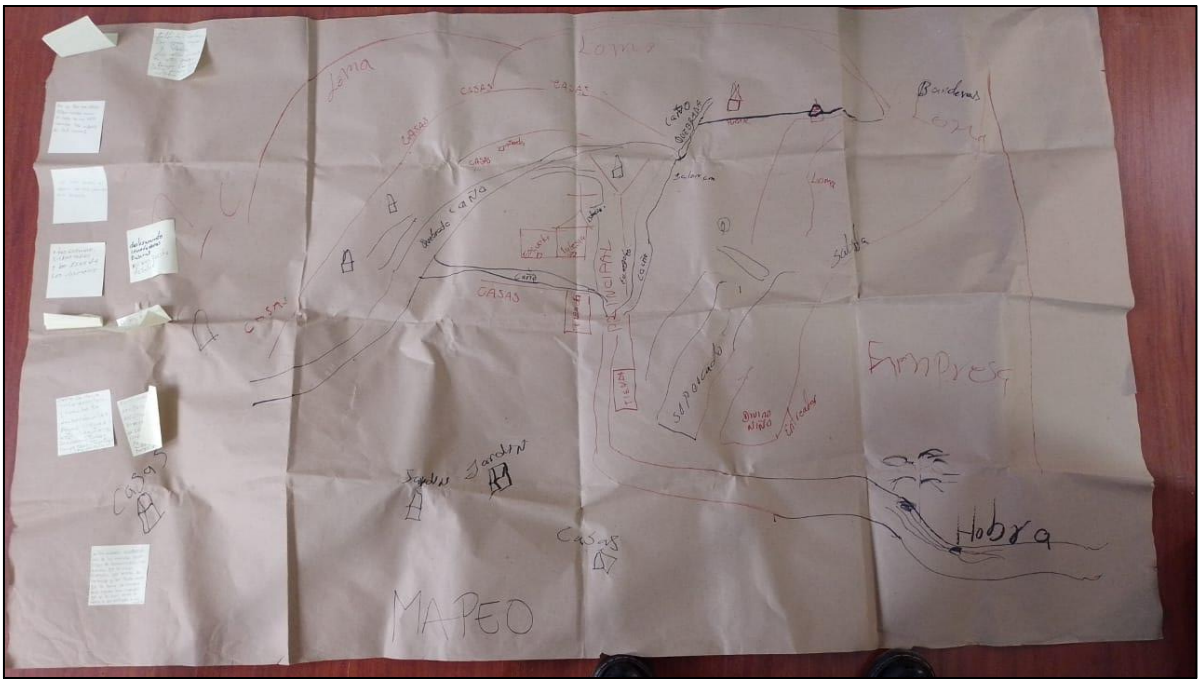


Figure 4. Hand-drawn community map without the SMT on paper

A CRC staff transposed the information into Google Earth and added the observations from the transect walk with the community. The digital community map (Figure 5) includes point locations of the identified main hazards in red colour such as flooding (*inundación*), flash floods (*avenida torrencial*), insecurity (*inseguridad*), landslides (*remoción en masa*) and improper waste management (*basuras*) as well as the resources in blue colour (e.g., shops (tiendas), community action board *(JAC)*, industry (*industria*)). The blue line demarcates the area of intervention of the flood resilience project, while the yellow line represents the estimated community borders.

Figure 5. Digital community map without the SMT in Google Earth

4.2 Community Mapping with the Crowd Mapping Approach (OSM Mapathon)

The HOT Taking Manager project (#14537) description highlights that "the community [La Capilla] and the CRC have not been able to map the exact extent of flooding and affected infrastructure [in the EVCA] due to the lack of baseline mapping data [in OSM, such as buildings] (…)", which is why the collaborative mapping approach was tested (HOT Tasking Manager, n.d.-a). Figure 6 depicts the progress of tracing buildings in the AOI and buffered mapping area. In total, 6% of the total area has been mapped by 7 crowd mappers (by 6/7/2023) (HOT Tasking Manager, n.d.-b). It is not possible to identify how many mappers were associated with the CRC or external partners participating (i.e., OSM, HOT and Youthmappers Colombia). Overall, 9 out of 68 mapping tasks were started, and 4 of them verified (ibid.).

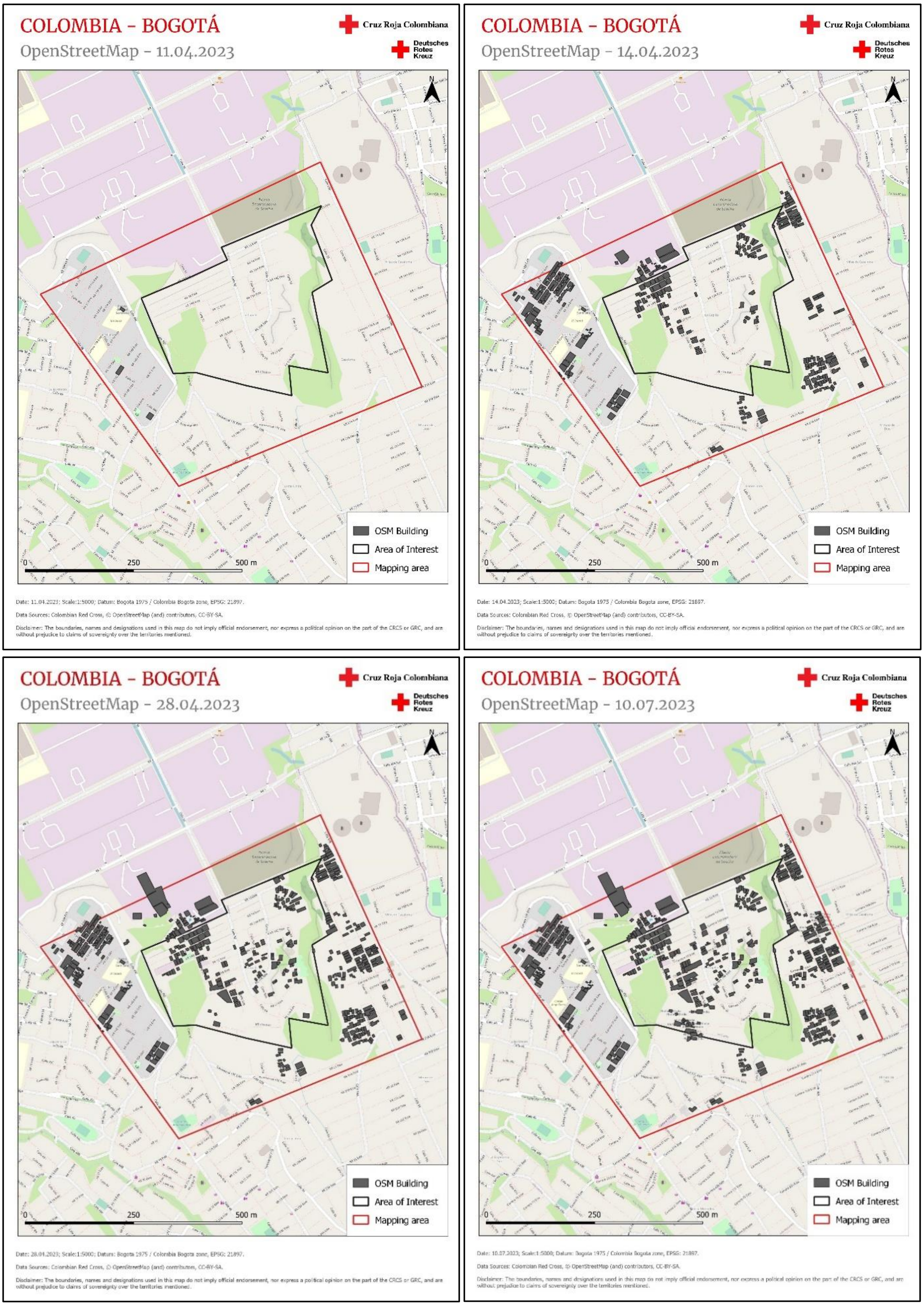


Figure 6. Buildings in the Area of Interest on OpenStreetMap (OSM) before and after the Mapathon (extracted on 11, 14, 28 April and 10 July 2023)

During the Mapathon, several participants from the CRC with little to no experience in crowd mapping mentioned problems in tracing buildings due to initial difficulties handling the tool and identifying the exact extent of the buildings based on the given satellite imagery. More experienced mappers provided feedback that the AOI as an informal settlement was very difficult to map even with more experience because different roofing materials are used for the same building and no standard extent of property and buildings exists. Two months later, the facilitator of the Mapathon from the GRC resumed after consultation with one verifying mapper that “the area was too difficult for beginner and too much rework was needed [in the tasks which were submitted for verification].” Hence, the difficulty level of the project was upgraded. Due to the incompleteness and lacking accuracy of mapped buildings, the CRC abolished the plan to use the newly mapped information as a base map for the SMT test and instead used a base map of the AOI generated before the Mapathon.

4.3 Community Mapping with the SMT as Participatory Mapping Method

Based on the data collection from 13 practitioners that applied the SMT in their work, the tool was mostly used for hazard analysis (10/13) and improving or creating base maps (8/13), then for capacities mapping (3/13) and vulnerability mapping (2/13), and lastly for other types, such as “dream maps” (2/13) or project planning (1/13).

4.3.1 Paper-based Sketch Maps with OSM Scale Maps

The CRC generated and printed SMs in horizontal orientation in large format (A2) for group discussions for mapping capacities and “community dreams” as well as in A4 for a flood hazard analysis for individual mapping on glossy paper. One interviewee, who has multiple-year experience in community mapping within the IRCRCM, saw a strength in the paper-based format because it was good both for participants and facilitators that were reluctant to use technological solutions. One survey respondent with SMT experience highlighted the different paper formats as an advantage compared to other tools. An interviewee from the LRC however stressed the limited options of sketching on paper maps compared to true digital mapping solutions, particularly to take attribute data, describe map elements and collect exact geolocations, which are needed for taking decisions later.

Data quality recured as a general PM challenge in interviews and surveys alike. It was often mentioned in relation to the PM tool and the facilitation of the PM exercise, as well as to aspects of the participation and skills of the participants. However, two interviewees contrasted that data quality aspects such as accuracy, completeness, richness are less important, because the primary focus of PM lies on community engagement.

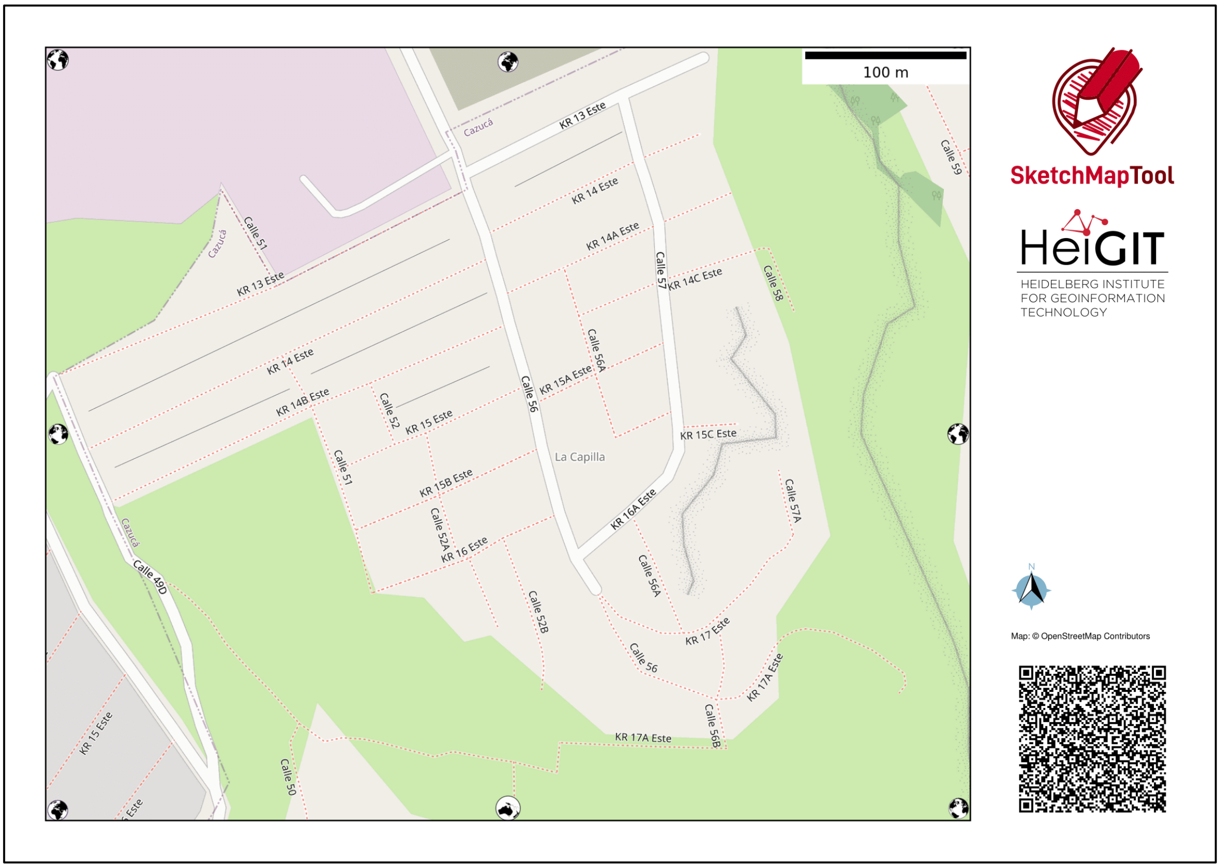


Figure 7. Sketch Map of the case study location

The Sketch Map depicted freely available OSM data of the buffered area of La Capilla at a selected scale with several features, such as roads including names, walking paths, ridges, and green areas (Figure 7). One interviewee stressed that having only OSM data on the scale map "is a trouble" because he normally shows participants different types of base maps. Another interviewee highlighted the ability to orientate with an OSM base map "depends on if the community is map literate or not", while another said that that "satellite imagery sometimes helps people to orientate (…) because they see there's a river and the mountain". This is confirmed by all but one CRC staff, that mentioned that they would like to use satellite imagery as an alternative base map. In total, most of interviewees and half of the survey respondents with SMT experience mentioned more base map options (i.e., satellite imagery, topographic maps, landcover) or the option to upload own data (i.e., drone imageries, previous flood data) as a recommendation. Two of them highlighted the challenge of using this tool in rural areas or Colombian settlements due to the low OSM data coverage, while one interviewee mentioned OSM landcover base maps, which could be useful for mapping risk drivers, such as environmental degradation, and adaptation measures. One survey respondent highlighted the option to include root causes, climate scenarios, and solutions addressing all three risk components, as a recommendation.

4.3.2 OSM Data Quality Report

The OSM data quality report (Appendix D) indicated a medium quality of the underlying OSM data for the AOI since no amenity features are mapped, as well as the Points-Of-Interest indicator is low since the density of landmarks is zero. As this meant that participants probably have difficulties to orientate on the scale map because there are just few features providing orientation, the CRC staff helped participants to first locate themselves or their house on the map before going on the transect walk through their neighbourhood. One interviewee as well as a survey respondent with SMT experience agreed that the analysis of the base map is "really useful" and an added value of the SMT.

Most of the interviewees mentioned that a general PM challenge consists of the map literacy of participants, impacting their ability to orientate and map features. This depended on the participant's background including cultural context, gender, and age, the amount, type and difficulty of information displayed on maps as well as on the PM tool itself. The latter had an impact on the inclusiveness and to which extent a diverse group of people can participate, hence ensuring that their voice is represented on the map. Based on personal observations, some participants had difficulties to orientate on the paper based SMs in the beginning. Some stressed that the scale map was not up to date, showing green areas where people were living now. One survey respondent with SMT experience confirmed the challenge that the generated SMs showed outdated information because the base map was incomplete and not up to date (see Figure 8).

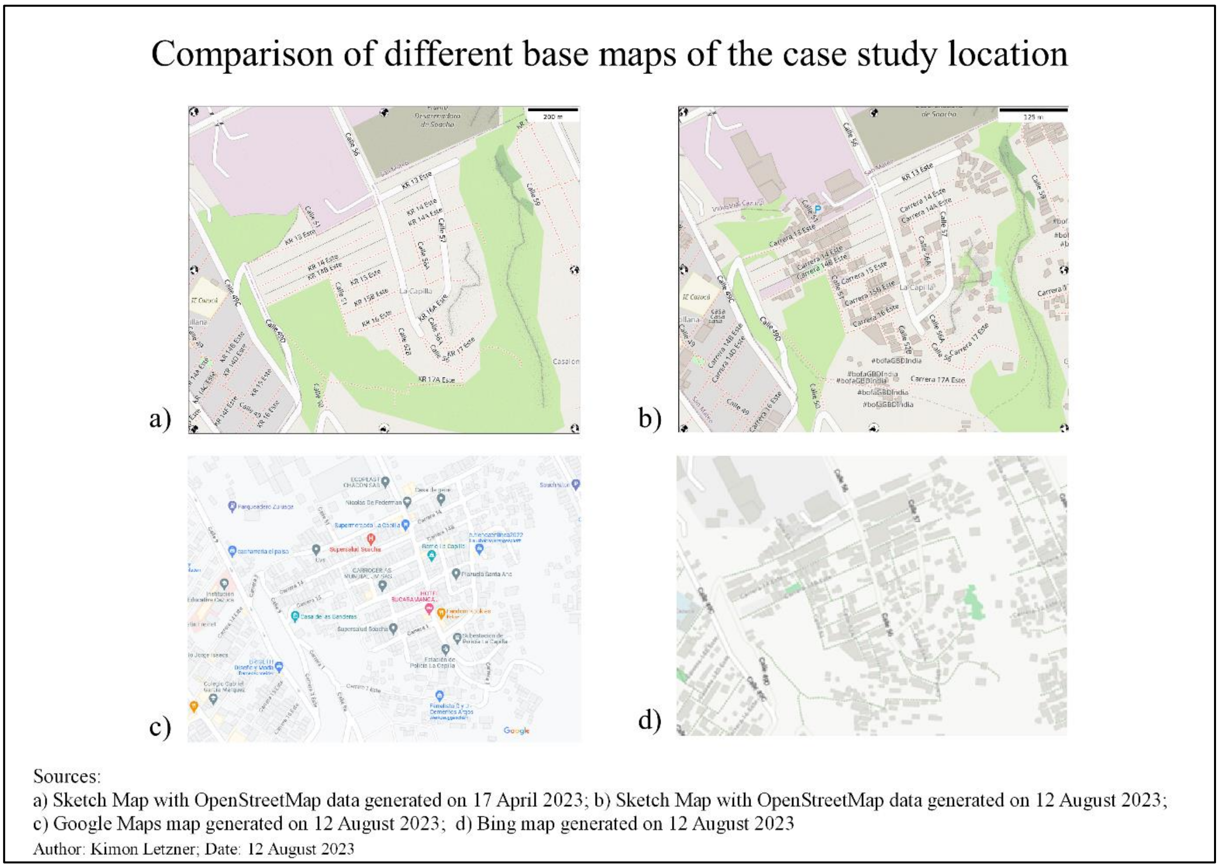


Figure 8. Comparison of different base maps of case study location on OpenStreetMap before the Mapathon (a), after the Mapathon (b), on Google Maps (c) and Bing (d)

Some PM participants were holding the SMs upside down because they mentioned to normally enter the community via the main street from North to South. It was observed that some participants with better orientation skills helped others to orientate or teamed up during the individual mapping exercise. The observations are also backed by the survey responses of the community members as only a few mentioned that the orientation on the map was challenging, out of which one highlighted that this challenge only existed in the beginning.

4.3.3 Hazard Mapping

Before the PM, the CRC tested the colour-detection of the SMT for the recommended colours for making markings (i.e., red, blue, green, pink, yellow). The results of the detection of the different colours were diverse for most colours, with red providing the most accurate and consistent results. The CRC did not identify if the glossy paper, intensity of coloured markers or quality of the pictures led to the varying results. Thus, participants were asked to use thick red fell-pens for markings. The initial idea to use different colours for indicating water height at a location based on the participant's knowledge and experiences was amended as the other colours did not work reliable. Instead, participants were asked to use numbers on a scale from 1-3 based on the context adapted scale from Klonner et al.'s (2021, p. 67), which was printed and shown to the participants (Figure 9). For labelling and numbering, black pens were chosen as this colour is not detected by the software.

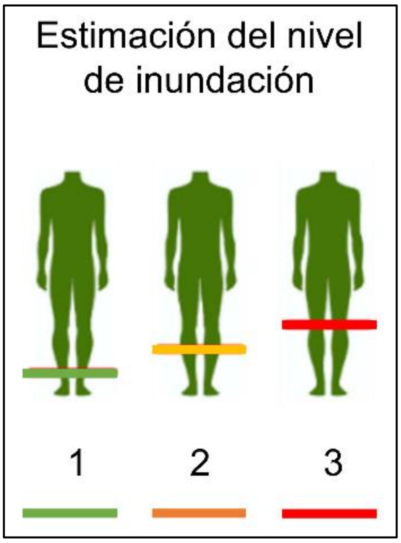
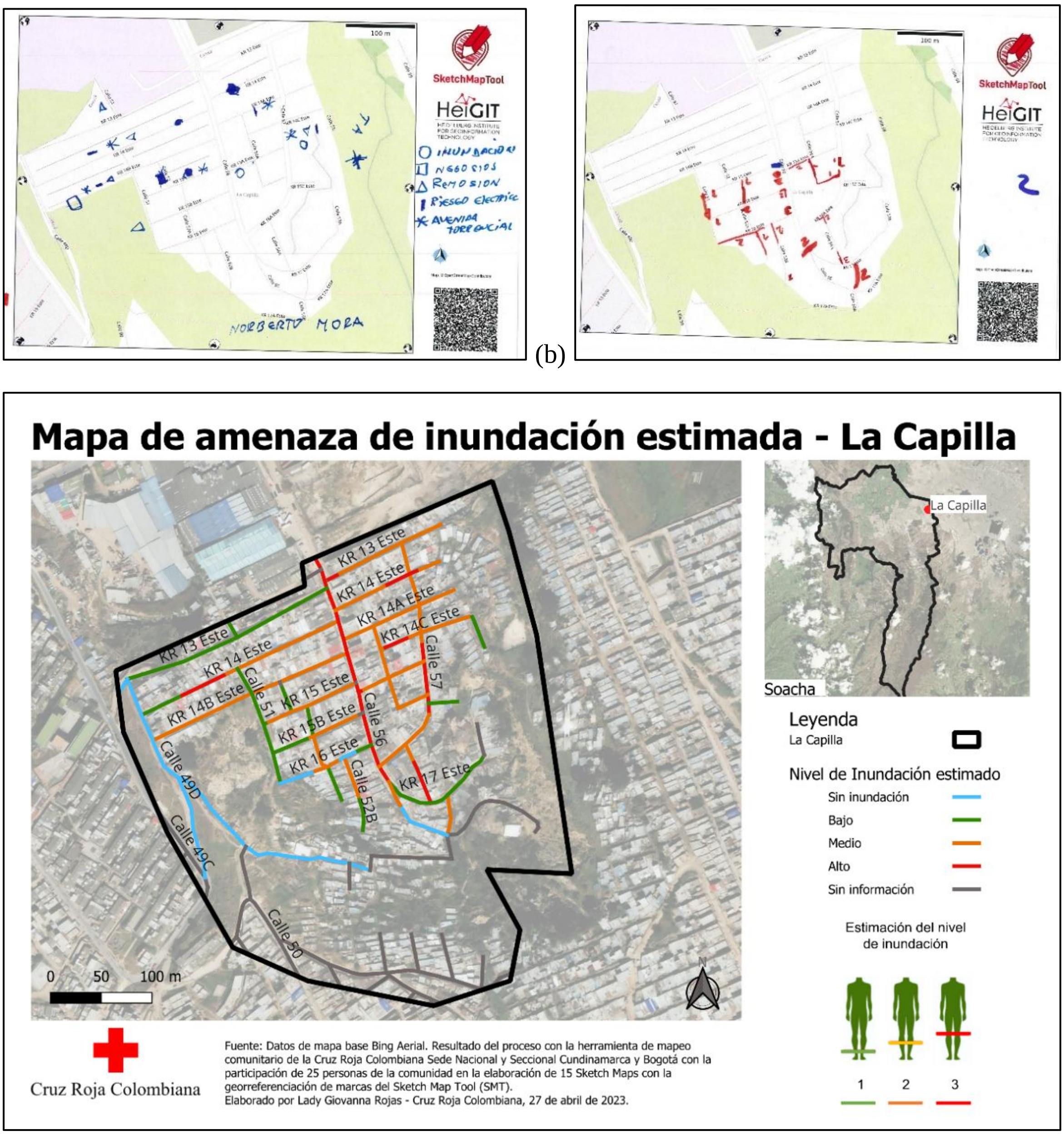


Figure 9. Scale for estimated flooding height, showing the image of a person with flood level markings (1 to 3) (adapted from Klonner, Usón, et al., 2021, p. 67)

For the individual mapping of the local knowledge and experiences of flooding and flood level estimation, the participants split into groups based on their residential zone and went on a transect walk, after staff informed each group individually about the mapping topic and methodology. In total, 15 individual SMs were created (see Appendix E). The resulting SMs lacked uniformity in used symbology, colours, and map content. Participants mapped other hazards using different symbols, differentiated between various water-related hazards like wastewater (*agua grises*), flooding (*inundaciónes*), flash floods (*avenida torrencial*) (Figure 9a), or indicated water flow directions with arrows. Others did not indicate the estimated water height level, used different colours without creating a legend on the side of the map or already started to map other topics, such as capacities. Figure 9b shows the example of a SM, when participants used lines to highlight road segments and numbers to indicate knowledge and experience of past flood events and perceived water height.

The challenge of not having clear instructions as well as to agree on conventions to use was also highlighted by two community members and backed by a survey respondent with SMT experience, who stressed the need to clarify mapping purpose with the participants and colleagues. A practitioner highlighted that a general PM challenge consists of the communication skills of facilitators, which use complicated or technical terminology. Another interviewee confirmed in an interview that there was a need to define a clear strategy for the data collection and analysis. They proposed to note down the methodology about how data is created on each SM to keep track of the metadata that relates to the SM like participants, date, time, topics, conventions, instructions, or questions.

Afterwards, the CRC used the individual SMs to manually assign the OSM road segments the respective water height levels (Figure 9c). The SMs were not digitised with the SMT, because it was not feasible to overlay and compare the individual perceptions due to limited comparative data for each line or point due to missing uniformity in the mapping conventions. The final analytic product of the SMs showed a more detailed flood hazard analysis compared to the previous community map, since the past flood extent is described as lines or street areas in comparison to points, as well as information about the hazard intensity is depicted.



(a) (b) (c)

Figure 10. Flood hazard map (perceived flooding and water height estimation): Example of two Sketch Maps produced by participant (A and B), final flood hazard map produced by CRC staff based on the data collected on Sketch Maps (C)

4.3.4 Capacities Mapping and “Community Dreams”

Figures 10 and 11 show the two SMs created during group discussions as well as the resulting maps created by CRC staff. Regarding the ability to orientate, two interviewees mentioned that group discussion around a table and drawing with pens on paper maps were success factors in their work.

In both cases (see Figure 10a and 11a), participants created a legend on the side of SM, defining the attributes which are numbered on the map. Lines were used to indicate for example access routes as capacities or paved streets and canalisations as “community dreams”. Points were drawn to highlight locations (e.g., pharmacy as resource, or library and medical centre as “community dreams”). Symbols (i.e., triangle, square) were used to show access to basic services (i.e., gas, water, and electricity) as capacities, while polygons displayed the demarcation of areas or items relating to a larger extent or topic (e.g., legalisation of neighbourhood and green spaces as “community dreams”). One interviewee highlighted that for PM in general it could be useful to provide participants with a set of possible attributes (e.g., legend, stickers, etc.) particularly for difficult topics, while another interviewee disapproved of the idea because the development of the legend and thinking about what element are important is an important part of the process.

The two SMs were digitised with the SMT and after the import to QGIS, the staff corrected features as the tool detected additional markings, which were not drawn, did not show polygons for some areas, which were not filled completely, and since lines were not drawn and detected on the actual road. Additionally, post-processing steps were needed for example to manually assign attribute values to the corresponding features and to find centroids of the digitised points, which are given out as polygons by the tool. The CRC staff categorized the features based on the type of resources (i.e., physical, human, infrastructure) and sector of “dream” (i.e., education, recreation, health) on the final maps. In total, 20 additional capacities were identified with the SMT compared to the previous community mapping (see legend of Figure 10b) and the SMT enabled a first spatial representation of the “community dreams” (see Figure 11b).

4 out of 6 CRC training participants mentioned that they intended to use the SMT in the future for complementing and enriching other tools in the EVCA as well as to collect spatial information and visualise areas at risk. However, three interviewees highlighted that data ownership and security are general PM challenges. One of them emphasized that PM should not be used to “mine data” and another said that participants needed to explore themselves how to make use of the data for the sustainability and long-term impact of projects. The feedback from the community survey highlighted two other challenges when applying PM in general. Taking part in such type of activity required knowledge about the entire place to put it on the map and time. A practitioner described particularly paper-based PM methods as “time-consuming”, while another highlighted the importance of enabling diverse age and gender group, which have varying time availability, to participate due to their differing local knowledge.

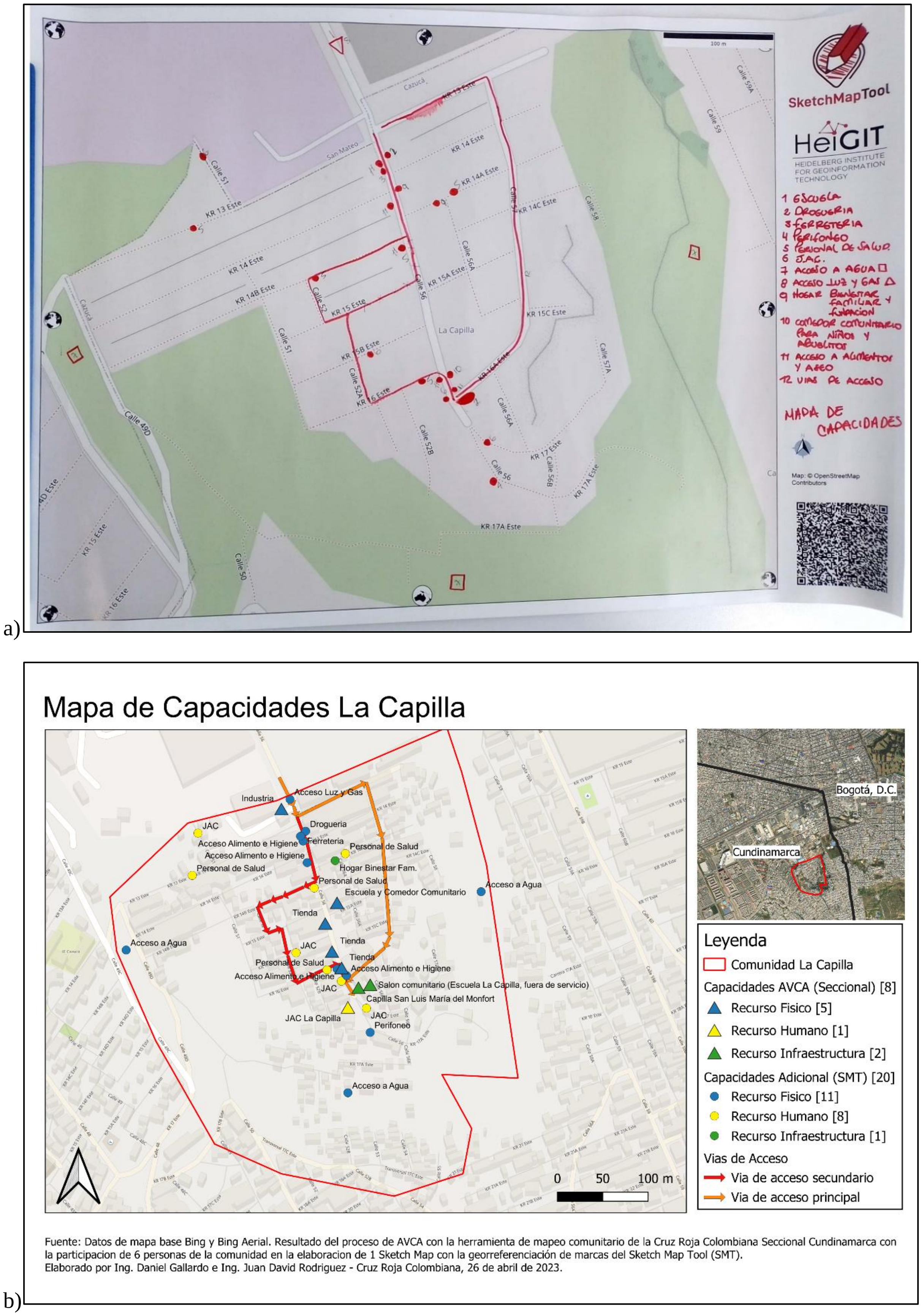


Figure 11. Capacity map (mapa de capacidades) a) Scan of the Sketch Map produced by participants in group discussion b) Capacity map produced by CRC staff based on the data collected with the SMT

a) b)

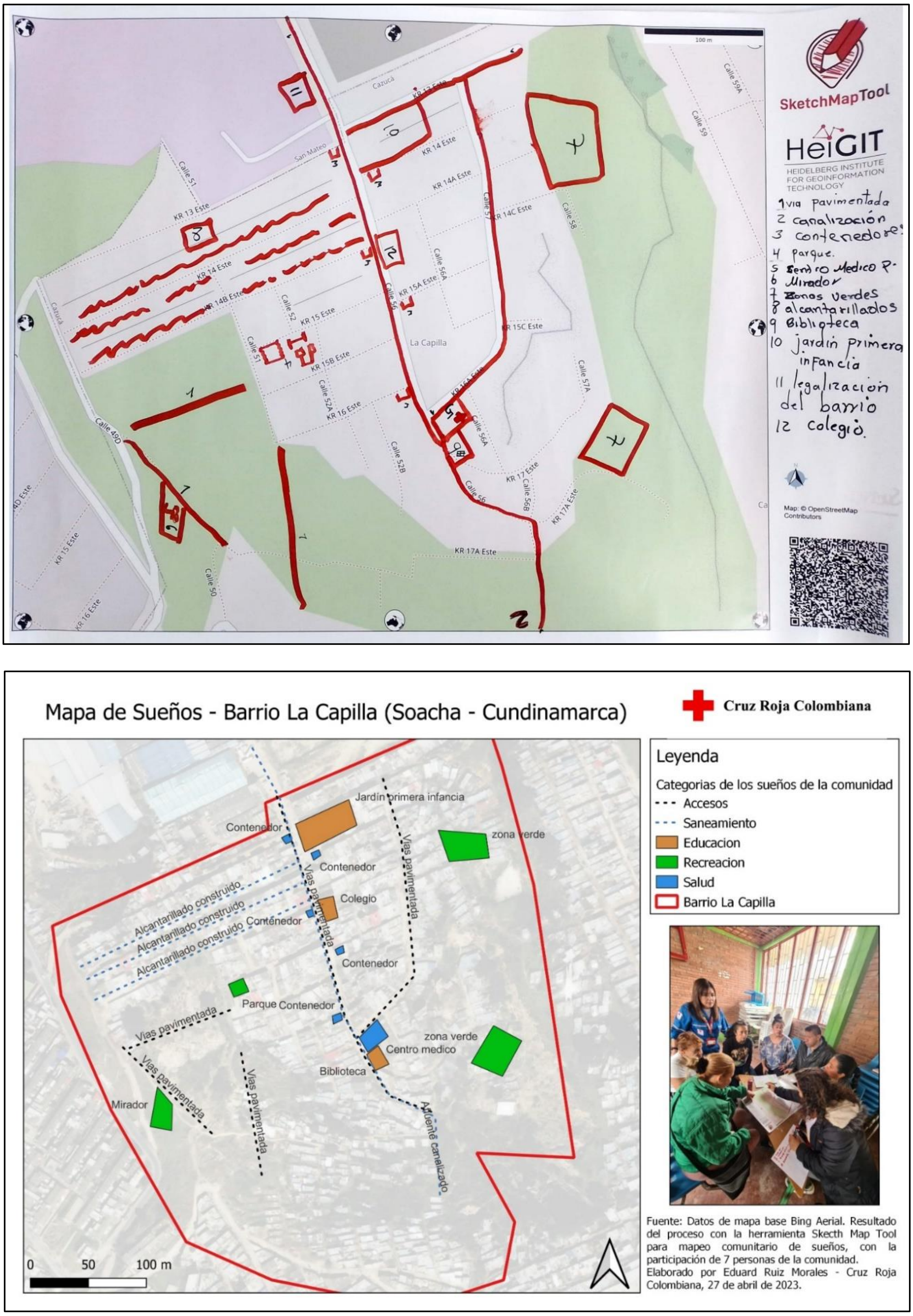


Figure 12. “Dream map” (mapa de los sueños) a) Scan of the Sketch Map produced by participants in group mapping b) “Dream map” produced by CRC staff based on the data collected with the SMT

One participant particularly commented regarding the “dream mapping” group discussion and stressed the challenge of "reaching agreements between everyone [and having] focus on reality”. Disagreement among the participants was also mentioned as a general PM challenge. Two experts working for IFRC highlighted the potential to use PM as an experiential, explorative learning tool. They proposed that community mapping could become a more in-depth and integrated analysis by overlaying risk components, including root causes, climate scenarios as well as natural features of the surroundings to identify Nature-based Solutions (NbS) for DRR. Thus, PM had the potential to visualise the relationship how the environment and risk interact, with the outcome that maps become solutions rather than "dreams".

4.4 Community Mapping with the SMT as Software

4.4.1 Effectiveness and Communication

Two interviewees with experience in the SMT highlighted that the georeferencing function of the tool saved time compared to the manual digitisation of PM results, which was described by a GRC staff as "a relief". This is also backed by the survey findings as several survey respondents with SMT experience highlighted the usefulness of the tool for analysing PM data and creating digital maps. The automatic georeferencing and colour-detection function saved time and the analysis of PM results was "easy and quick" due to the "integration with QGIS, enabling more digital analysis options as well as the production of analytical products (maps)". However, half of the CRC staff mentioned in the evaluation survey that the digitisation of the SMs was problematic. Some reasons were provided such as that the uploading of the pictures required a very good image quality, that it was unclear which colours worked best, and that colours should be detectable. This is in line with the findings from interviews and of the survey, in which all but one respondent with SMT experience mentioned that the colour-detection needs improvements such as more colours or the correct recognition of the pre-defined colours. Three interviewees also mentioned shortcomings when digitizing SMs due to the need to manually correct features.

Several interviewees stressed that the tool should be able to detect features like they are drawn on the map, meaning that points should be digitised as point features and lines as line feature respectively instead of digitalising all features as polygons. Two interviewees and two survey respondents additionally emphasized a possible improvement by having the software link colours on the map to the corresponding legend attributes by recognizing characters and symbols. Half of the CRC respondents wished the geodata results to be also provided as KML or PDF file additionally to the two existing data formats (i.e., GeoJSON, GeoTIFF).

Another insight was that one CRC respondent mentioned that "information should be made available to the community and to other organisations" and that "the tool should be able to share and work with maps generated by other people and/or with other institutions in the future". Similar, an interviewee, who used the tool extensively for the MRC, wished to have had the option to directly upload SM results into the OSM editor, and saw a strength in the software being open source. Another respondent would like to use a mobile version to work digitally on a tablet and for example select the areas together with the community.

4.4.2 Spatial Interface

One interviewee and two survey respondents were missing a grid function, which would enable users to split an overview map into more detailed maps. One interviewee from the Red Cross in Honduras, emphasized that "due to the spatial layout of communities [being sparsely populated], it's really difficult to print out everything on one map because everything would be so small, and you don't see the footpath anymore". This impacted the ability of people to orientate and connect the pieces to another. Other individual recommendations from the survey were the selection of an AOI via defining a bounding box with coordinates and an editable base map to highlight certain aspects or change the North-South orientation. An interviewee from the LRC however emphasized that they do not include other data in the initial map to not influence the mapping process because the "main idea is to see aspects of risks from the point of view of the community (…) [basically] to see what the hidden capacities are".

4.4.3 Learnability and User Interface

Regarding the UI and learnability, one interviewee working for the GRC with several NSs in Central and South America, highlighted that the English interface and supporting material is a shortcoming of the tool for its application by NSs in the region. The majority of interviewees with experience in the tool described the software and process as "intuitive", "straight-forward" or "very easy" due to their background, partially in GIS. However, one person stressed that "other people do not see it like that" for example due to the technical language (e.g., terms like georeferencing, vector, raster) and the limited explanations about why to use it (e.g., use of different colours). One Spanish-speaking interviewee for example had problems with the QR code detection and either did not understand the error message or how to solve the problem. One CRC staff also mentioned that they would like to have a Spanish version and a "floating button" as an "instruction tool" to provide help for each step.

Three other interviewees emphasized the "technological challenge for NSs" to use the tool "properly" or to the "full potential" as "you need people with some GIS skills" for example to use and analyse the digitised SMs and include additional layers. One survey respondent highlighted that the user-friendliness of the process including the data analysis depended on the access to GIS software, with which most people feel "uncomfortable". It was they stressed that NSs would need more human resources to implement the tool "more systematically".

In this regard, one interviewee proposed [HeiGIT or GRC] to offer a service to NSs that are lacking these skills. A majority of interviewees with experience in the tool highlighted that the training needs to be hands-on but with varying levels depending on participants' (GIS) background. In this regard, one interviewee mentioned the opportunity to include the SMT content in an existing WhatsApp training with videos, which targets the communities and enables them to use the mapping tool themselves.

5. Discussion

This research identifies key contextual factors of PM and how they interrelate with PM tools, providing a contextual framework (see Figure 13) for the application of the SMT by the IRCRCM for CM. The choice of tool impacts the required time, which on the other hand is an important factor for the participation and inclusiveness, with the objective to achieve diverse representation. The tool directly influences how participants can orientate and contribute quality data depending on their knowledge and skills, namely their map literacy. The tool directly impacts the data richness and accuracy and contributes to how data is used, owned, and secured. Facilitators with their skills can moderate group dynamics and alleviate negative effects of tools on the participants by guiding participants through the process, which ensures data quality and usage of the data by the participants for more sustainability in PM projects.

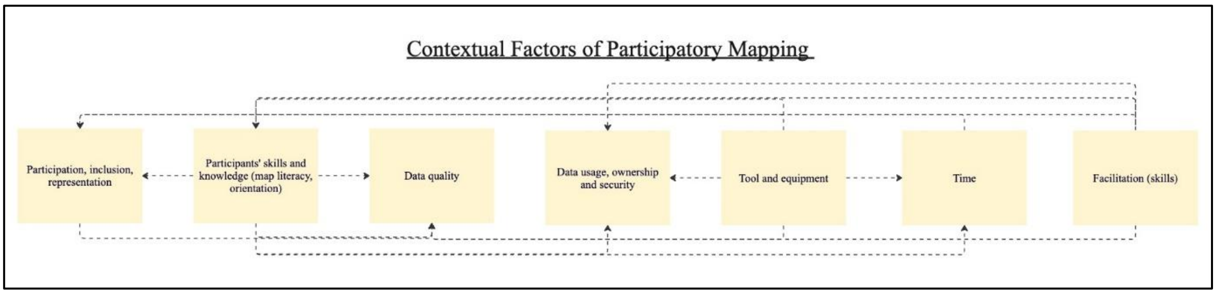


Figure 13. Visualisation of PM factors

The integrated participatory and collaborative approach has provided scientific findings about combining Mapathons and the SMT first-time. Improving the base map to subsequently increase the level of detail for scale mapping on SMs (e.g., individual buildings) was tested but only partially implemented due the difficulty of the mapping task and quality of satellite imagery. Requirements for applying the approach are the availability of high-resolution remotely sensed images for urban unplanned settlements as well as the mapping skills, local knowledge and size of the “crowd”. The case study confirms the importance of ground-truthing remotely mapped information and involving local volunteers and communities in this process (IFRC, n.d.-a). Overall, crowdsourcing approaches, such as the tested approach with a Mapathon, represent a promising example of how NSs can increase the data availability required for risk assessments in vulnerable and isolated locations (Freebairn et al., 2020). This can also be useful for participatory risk mapping with the SMT as the initial base maps can be improved if required.

The results of the evaluation of the SMT can be categorized by understanding the SMT as a PM method or as software with overlapping elements. Elements relating to the software usability are structured according to effectiveness, spatial interface, communication, and user interface and learnability. The strengths of the SMT represent potential for the CM process of the IRCRCM given the above-mentioned contextual factors are considered. Shortcomings are influenced by the contextual factors and represent current limitations to use the SMT for CM. Several explicit recommendations are identified that may contribute to unfolding unused potential for the usage of the tool for CM through further development of the SMT. Figure 14 summarises findings about the SMT and their interrelation based on the categorisation (for the detailed overview see Appendix C).

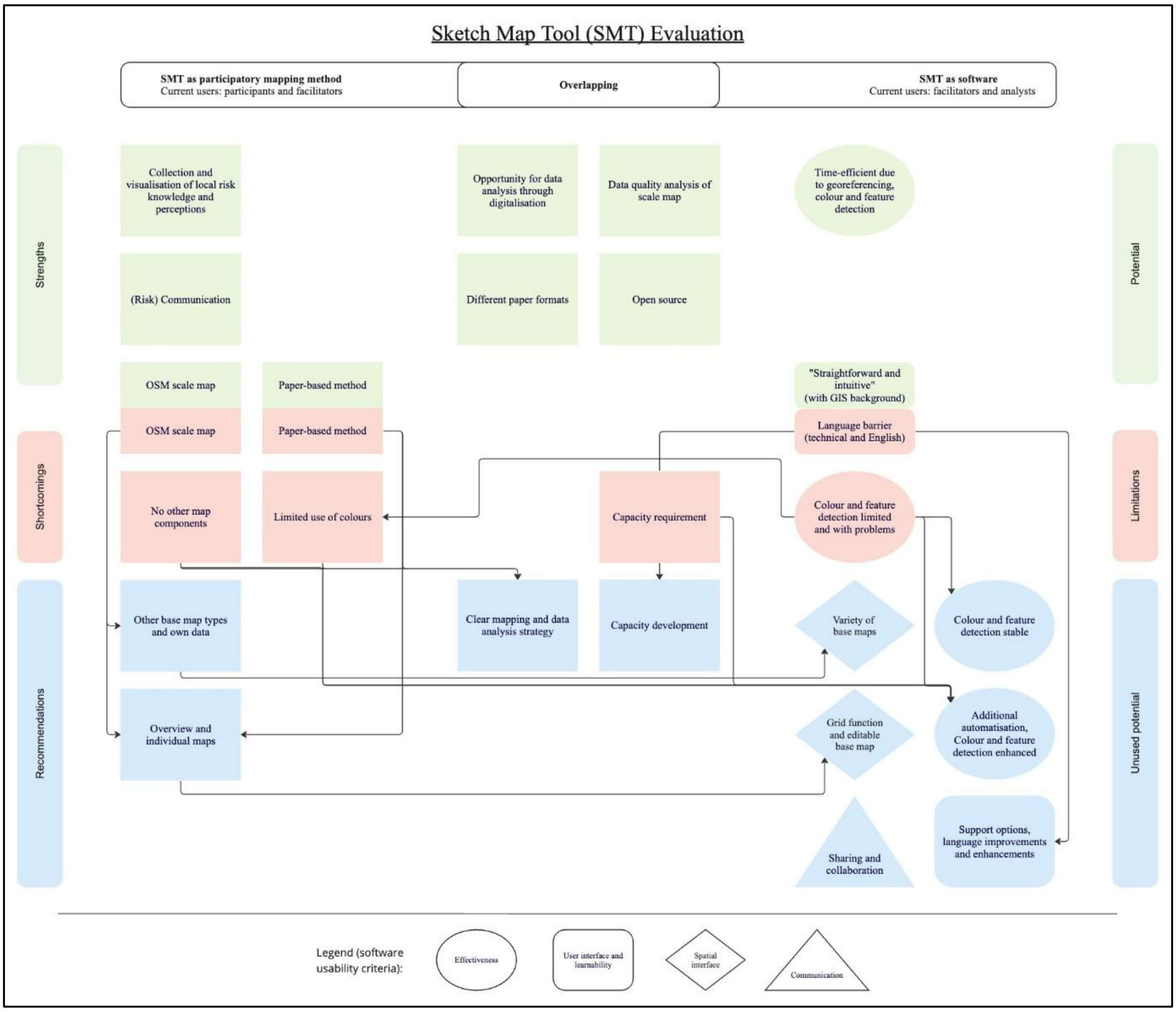


Figure 14. Visualisation of shortcomings, strengths, and recommendations for the SMT and their interrelation, categorized by SMT as PM method and as software (software usability)

The research overcomes persisting research limitations about the SMT because it has either been analysed as a method for PM or based on parts of the workflow of the first prototypes, but never as software and PM method combined and for its usefulness for a particular process of an organisation, namely the IRCRCM. Thereby, the thesis overcomes Laituri et al.’s (2023) critique that current PM research focuses on products instead of the process and results of the process for stakeholders.

The findings show that the SMT as a PM approach can be applied to gather and visualise risk knowledge and perceptions, namely local geospatial knowledge and experiences about past flood events by identifying hazard extent and intensity, about community capacities as well as preferences for action planning. Against the backdrop of unavailable historic impact data, the SMT has proven to have potential to integrate local communities and risk knowledge through the approach of PM (Klonner, Hartmann, et al., 2021b). The research has proven that the SMT as a method enables the integration of perceptions about elementary flood risk component (i.e., hazard characteristics like exposure and level of hazard intensity, community resources serving as capacities) of community members in NS’s EVCA process, ultimately informing flood mitigation (Klonner et al., 2018). However, it was not investigated whether the approach can also be used to capture other risk elements such as probability, consequences, or vulnerability characteristics.

The application of the SMT by the CRC confirms that the SMT facilitates two-way risk communication and trust between stakeholders (Klonner, Usón, et al., 2021), namely through the interaction between the local actors CRC, JAC, residents, and a city council member. In addition to Klonner & Blessing's (2019) research about risk perception and elements at risk, the case study shows that SMs have the potential to be used for the identification of community resources and risk drivers, as well as for DRR and adaptation planning.

The spatial investigation and information exchange during the group discussions facilitated a dialogue between the citizens, authorities and CRC about dynamic processes and community plans including their detailed geolocations. The use of SMs facilitates social participation and co-production of a holistic understanding of disasters' risks, its drivers and root causes and it contributes to defining areas for DRR interventions. The rehabilitation of green spaces on high-exposure zones, on which people have settled densely in times of high population growth due to improper land use and urban development planning serves as an example for the potential of forensic investigation of disasters with SMs. However, non-spatial risk information, such as disaster root causes are at risk to be overlooked if only spatial features are mapped but they can be noted on the side of the SM as general risk factors during the discussion as proposed by IFRC (2019). As such, this case study expands the existing knowledge of how the tool can be applied within the scope of DRR (cf. Klonner, Hartmann, et al., 2021, p. 15), providing an example for its potential for the required social involvement in participatory forensic approaches to disasters (Ferreira et al., 2023).

Thus, the SMT is applicable by practitioners and the different paper formats, particularly the large SMs in group discussions, have proven to be an "easy-to-use method" for RCRC staff, that has the potential for exchanging, collecting and automatically visualising detailed local knowledge (Klonner & Blessing, 2019). While Klonner et al. (2019) state that the previous OSM data evaluation with the "ohsome tool"[5] supports the application of PM methods such as the SMT without expert knowledge, the research highlights the limitation of the current report, which consists of a less detailed version with limited elaborations of the results and possible conclusions. Another limitation in this regard consists of the software's user interface with its rather technical language and sole availability in English.

The main functions of the open source tool, namely the automatic georeferencing and colour detection, bear the potential for fast processing of PM data and efficient use in analytic digital products for community-based DRM by the IRCRCM (Klonner & Blessing, 2019). This saves time and increases the richness of the spatial local knowledge. As such, the SMT provides a new potential for using scale maps in PM due to the strengths compared to approaches where result are manually transposed as applied by Bustillos Ardaya et al. (2019) and the Vietnam Red Cross et al. (2017). However, limitations exist in the paper-based method and single scale map with sometimes outdated or limited OSM data and no other map components. Furthermore, the functions are not without any problem and limited in terms of number of colours and feature types that are currently being detected. The data collection and post-processing requires a clear mapping and data analysis strategy as well as capacity, namely technical skills of NS staff or

[5] https://heigit.org/big-spatial-data-analytics-en/ohsome/

within the communities for ensuring their empowerment of the usage and analysis of the data in the long-term. To harness the full potential of the tool, GIS knowledge and skills are required to process the PM results and produce analytic outputs in GIS.

The research confirms that the paper-based approach has the potential for including marginalised and diverse groups in this process, that may lack technological literacy or internet access (Klonner & Blessing, 2019). It also reaffirms the recommendation of previous SMT research (Klonner et al., 2018; Klonner, Usón, et al., 2021) to include residents in the SMT activity as their risk knowledge and awareness is higher, thus providing more detailed information compared to pedestrians.

The large-scale SMs, displaying the neighbourhood and streets, has proven to be useful for urban flooding as proposed by Klonner et al. (2018) and Klonner & Blessing (2019), providing additional and more precise results regarding flood extent and intensity, and geospatial locations of capacities and community development plans compared to CRC's previous CM. The final analytic output, namely the different thematic community maps, confirms the potential that spatial information captured with SMs can supplement non-existing, outdated, or low-resolution official data, such as flood risk maps and models of local authorities, through the EVCA process (Klonner, Usón, et al., 2021).

As the case study represents the first test of the newest version of the SMT by practitioners, it provides a detailed evaluation of its usability as requested by Klonner, Hartmann, et al. (2021) within the EVCA process of a NS. The findings confirm the assumptions regarding improvements required from the perspective of the IRCRCM. In addition to the different OSM map styles, the option to separate an AOI using a grid tool, the enhancement of the automatic data processing like an analysis of overlapping markings, and additional explanations in the data quality report (Klonner, Hartmann, et al., 2021, p. 15), the research identifies possible further improvements.

The UI and process seems to be intuitive for people with GIS background, but is difficult to understand for non-experts, hindering the users' learnability and thus the tool's application within the entire IRCRCM. GIS capacity development as well as language improvements and enhancements and additional support options could potentially expand its potential. The planned automatic evaluation of markings has additional potential to facilitate the usage of the tool by non-experts by digitalising analysis steps of the data without using GIS. For unfolding unused potential regarding the tool's effectiveness, the colour and feature detection needs to function stable and enhancements such as the recognition of more colours, feature types, and additional map components, like legend and metadata of the mapping activity.

The tool could potentially expand its functions by image recognition, using artificial intelligence and machine learning, to read text from a title line and legend template, consisting of empty fields for symbols or colour-coding and lines for the corresponding attributes, that are filled by participants. During the digitalisation process, text would be linked to corresponding colours or shapes on the map and provided as attribute value or metadata in the downloadable geodata, thereby expanding the tool's potential to be used by non-experts as more steps are digitalised and a clear data collection and analysis strategy exists. The intellectual ownership of the map "language" and its spatial content via the legend would remain in the hand of the participants (Rambaldi, 2005, p. 6) as they were to define what to communicate and how. If users, namely PM planners will be enabled to select, highlight, or label certain features on the base map within the SMT before printing, the community should be integrated in this task during the pre-PM phase, so that the map "language" is based on an agreed and defined vocabulary, "bridging communication barriers among actors having different backgrounds, perspectives and communication pattern" (ibid., p. 1). This is also the case for the definition of the map purpose via the title and legend explaining the base map as the OSM symbology and visualisation may be ambiguous and not objectively understandable, particularly for participants without previous geographic experience.

Other improvements that could unfold potential is the collaboration and sharing option within the software, such as the direct integration of SMT results into OSM but data security and ownership issues must be considered as the differentiation between public and sensitive data and knowledge is critical (Liu et al., 2018).

The SMT scale map not only impacts the precision of results and depends on the flood type (i.e., river flooding and base map with overview of area; urban flooding and base map with higher level of detail such as street level) (Klonner et al., 2018; Klonner, Usón, et al., 2021), but if the SMT is to become a tool for holistic risk assessments and action planning in DRR. The research provides indication that the combination of different base map scales for one area with the help of a grid function and the option to use other thematic base map types such as satellite and drone imagery, landcover or climate change models could contribute to harness the SMT's potential. These functions would for example enable depicting detailed information on a household or neighbourhood level as well as understanding the association of the community with the area around them in a multi-layered way. It potentially contributes to better orientation of the participants and the ability to explore the interconnection of unsafe conditions, its disaster root causes and dynamic processes, such as environmental degradation or population growth with aerial imagery. These functions could potentially also be useful for interlinking, contrasting and validating local knowledge with scientific "outsider" knowledge such as scientific data on climate change, land use, and the status of ecosystems as proposed by IFRC (IFRC, n.d.-f).

The research is restricted to testing the SMT in one urban community in Colombia due to limited time and financial resources. Because of the restrictions of testing the SMT in one geographical area (i.e., urban) and one hazard (i.e., flooding), the possibility of deriving generalizations for the entire country, other disaster contexts or organisations is possibly limited. Research limitations also exists regarding its usefulness for vulnerability assessments in the EVCA context. Future research could focus on testing its suitability for other hazard types, vulnerability assessments, as well as in the context of forensic approaches to disasters and ecosystem based DRR. Conventional EVCAs and CM often lack the integration of these approaches according to an interviewee, who is currently reviewing the EVCA for IFRC as a consultant.

Additional usages of the SMT beyond the EVCA within the IRCRCM seem possible. As a humanitarian network the IRCRCM is involved in impact assessments, which require gathering local impact data for creating or validating crisis maps. As the effective response to disasters depends on identifying the spatial extent and impact of hazards, the SMT could be evaluated as a crisis mapping tool in comparison or combination with other volunteered geographic information or visual interpretation of aerial imagery (e.g., Vavassori et al., 2022).

In addition to using mobile data collection tools for improving OSM data (IFRC, n.d.-a), the SMT could be tested either to provide input for Mapathons or to validate data from Mapathons on the ground and to collect additional information with a paper-based method. Due to the missing comparison between the use of base maps with and without buildings the research was not able to investigate if a more detailed base map improves the precision of for example hazard extent or geolocation of capacities. Thus, future research should test the integrated participatory and collaborative mapping approach entirely by evaluating the usage of the SMT with two different base maps, namely one before and one after a Mapathon. The approach could also be tested with UAVs or high-resolution satellite imageries that could potentially be generated in collaboration with local partnerships, such as iMMAP and YouthMappers.

Further limitations exist in evaluating the software's usability using quantitative data. As the latest SMT version has not been on the market long enough to conduct a long-term study, evaluating specific metrics about the users' memorability of performing tasks after substantial time is impossible (Dawood et al.'s, 2021). Thus, a quantitative study could assess the software usability of the SMT with metrics such as in Dawood et al.'s (ibid.) research or a standardised questionnaire to collect user feedback. The latter could potentially build on the proposed distinguishment of the usage of the tool as a PM method and as a software and use adjusted questions based on the Likert scale from Ballatore et al. (2020).

Overall, the identified improvements bear the opportunity for the IRCRCM to collect and visualise information on the interaction of the human-environment system on various scale maps (type and scale) to understand underlying causes and risks stemming from natural hazards in a changing climate as well as to plan adaptation, such as NbS, in dialogue with communities and other stakeholder. The study provides a first glimpse on how the SMT has the potential to be used by various divisions of NSs from risk assessments, via forensic approaches to disasters for identifying underlying causes, to action planning in DRR. Similar, to Cadag & Gaillard's (2012, p. 107) findings about P3DM, the SMT solution provides an "enabling environment" for disaster risk assessments, the identification of local and scientific DRR strategies and the integration of these into action plans. The existing SMT has unused potential to become another method that encourages knowledge exchange, namely facilitating "interpretation, assimilation and understanding of geo-referenced data by making them visible and tangible to everyone" and "incorporating both local and scientific knowledge through a two-way dialogue in DRR" (ibid., p. 100).

6. Conclusion

The research represents the first evaluation of the SMT's potential and limitations regarding its application as a PM tool by the IRCRCM for community mapping in the context of the EVCA. The case study identifies important interrelated contextual factors of PM (i.e., tool and equipment; time; facilitation skills; data quality; participants' skills and knowledge including map literacy and orientation; participation, inclusion and representation; data usage, ownership and security). It explores how the SMT can be used in an integrated participatory and collaborative approach within the EVCA. The exploration involves utilizing the SMT in group discussions and transect walks for hazard and exposure mapping, capacity mapping and visioning with the community by the creation of three corresponding maps (i.e., hazard map, capacity map, "dream map"). The research proposes a new classification of analysing the SMT for varying target audiences as a PM method, and software with software usability criteria, which enables a structured analysis of its strengths, shortcomings, and recommendations. Against the backdrop of general contextual factors of PM, the tool's strengths translate into potential, while shortcomings currently represent limitations for its application by the IRCRCM. Recommendations are identified that provide indications that the tool bears unfulfilled potential that could be harnessed with its further development.

Within the IRCRCM several methods and tools are used for PM. While each has its strengths and shortcomings (e.g., IFAD, 2009, Annex A), the tool must fit to the needs of the community and to what "makes sense to the local way of communicating about risk" as mentioned by one interviewee. I identify the SMT as an innovative tool for the spatial analysis of the different categories of PAR for DRR. It has proven to be useful for PM, the data collection to acquisition knowledge and analyse risk data (i.e., identification of exposure and hazard intensity, community resources), for facilitating verbal information (i.e., group discussions), and for planning the future (i.e., community plans). Additional applications of the SMT seem plausible in the context of PAR for DRR and for other EVCA tools but require further testing. Using the SMT for PM may contribute to analysing change (histories) in vulnerability or livelihood over time (e.g., EVCA tools: historical visualisations of underlying causes or livelihood zones), for capturing verbal information (e.g., EVCA tool: via questionnaires) or for visualising situations and evaluations (e.g., EVCA tools: problem trees or stakeholder analyses).

The case study proves that the SMT with its low-cost, paper-based method for data collection and digitalisation software for data analysis is useful for ensuring diverse community participation and a more efficient use of PM data for disaster RAs in the context of the EVCA. Thus, mapping on SMs mitigates the danger of exclusion and disempowerment, usually mentioned regarding SIT equipment (Chambers, 2006, p. 6). The tool exploits the benefits from ordinary sketch and scale mapping such as the low investment and the independency on technology, while overcoming its obstacles, because it provides the ability to digitalise georeferenced results. Transferring the maps' content to a digital format provides the potential to compare and integrate local knowledge with other spatial and scientific data, as well as to use the outcome as advocacy medium with external actors or for risk assessments. Thereby, the SMT provides a potential to mitigate the challenges of sole analogue CM. To harness the full potential of the tool, GIS knowledge and skills are required to process the PM results and produce analytic outputs in GIS. The availability and restriction to OSM data as the only scale map on the SMs, currently represents a limitation, but the case study identifies the integrated participatory and collaborative mapping approach as a possible solution.

The thesis has proven that the SMT can be applied by the IRCRCM to collect geospatial risk knowledge within the EVCA framework, thus improving the precision of community maps, namely through investigating exposure and hazard intensity as well as geolocation of resources. Its usage is not limited to community-based disaster RAs and include community engagement in spatial DRR action or solution planning. With the identified improvements of the existing tool and enhancements of its functionalities (see recommendations in Figure 14 in 5.), the SMT has untapped potential for more applications by the IRCRCM. It may help to identify risk drivers and investigate root causes for a more holistic assessment of risks with disaster forensic approaches or support climate change adaptation planning by visualising and analysing human-nature interactions.

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Appendix A: Table with functions and features of the Sketch Map Tool

PM phase	**Functions**	**Features**	**Website**
N/A - Homepage	General website interface	Home, About, Help and Code button with GitHub logo leading to the code on the GitHub website (GIScience, 2023) and a SMT logo leading back to the Homepage on the top; Privacy policy and Imprint button and HeiGIT logo leading to the HeiGIT website	https://sketch-map-tool.heigit.org/
N/A - About page	Providing information about the tool, project, former and current sponsors and partner organisations, learning material, related publications	Text with hyperlinks and embedded video	https://sketch-map-tool.heigit.org/about
N/A - Help page	Providing printable help resources (i.e., step-by-step instructions, FAQs)	Text with step-by-step instructions and Frequently asked questions (FAQs) that folds out when clicking on step or question; Print icon; Additional information section which is not updated yet	https://sketch-map-tool.heigit.org/help
Preparation	Selection of PM phase on the Homepage	Two buttons on the bottom to initiate either the creation of a SM or the digitisation of a SM	https://sketch-map-tool.heigit.org/
Preparation	Selection of an area of interest (AOI) on a base map containing current OSM data with different page layout options	Spatial interface and preview layout of the SM; a search field and zoom button; Buttons to select paper layout (i.e., format: A4, A3, A1, Letter, Tabloid; orientation: portrait, landscape)	https://sketch-map-tool.heigit.org/create

Preparation	Generation of the Sketch Map for download in Portable Document Format (PDF)	Download button	https://sketch-map-tool.heigit.org/create/results/...
Preparation	Generation of a data quality report for the OSM base map of the selected AOI with the help of the *ohsome quality analyst* (HeiGIT, 2022a) downloadable as PDF	Download button; Report evaluation with a traffic light system based on four data quality indicators (i.e., mapping saturation of major roads, currentness of major-roads and amenities, density of landmarks)	https://sketch-map-tool.heigit.org/create/results/...
Post-processing	Upload of pictures or scans of the marked SMs for processing of results	Drag and drop field or manual browsing to choose file(s) in PNG and JPG file format; max. total upload size restricted to 500 MB; Upload button	https://sketch-map-tool.heigit.org/digitize
Post-processing	Generation of geodata (i.e., raster or vector data) of the colour detected and georeferenced SMs (vector results of markings are generated as polygons)	Button to download georeferenced markings in GeoTIFF or GeoJSON format	

Appendix B: Table with overview and classification of research data

Data	Type	Description of data	Number	Demographics/Background information
Semi-structured interviews	Primary	Key informants	11	- Occupation: 8 practitioner, 2 practitioner and researcher, 1 researcher - Organisational type: 1 anonymous, 1 consultancy, 1 research institution, 6 affiliated with IRCRCM, 2 NGO - 4 with SMT experience - 6 with job experience in Colombia
Qualitative surveys	Primary	I) Community members II) CRC staff (SMT training participants) III) Key Informants	I) 14 II) 6 III) 20	I) Residents of Soacha who participated in the test of the SMT in their community, interviewed by CRC staff who filled out a Spanish questionnaire in simple language relating to general challenges and success factors of PM, strengths, and shortcomings of the SMT; II) Training participants from the CRC, evaluating the SMT after the first training day, filled out an English/Spanish questionnaire relating to problems and recommendations about the SMT; III) English/Spanish questionnaire relating to general challenges and success factors of PM, strengths, shortcomings, and recommendations of the SMT - 12 not anonymous, 8 anonymous - 9 Practitioner, 4 Researcher, 3 PM participant - Affiliation with IRCRCM: 9 affiliated (i.e., 1 IFRC, 8 RCRC NS) - Geographic coverage: Europe (RC: 1 German, 1 British, 1 Danish), South America (RC: 5 Colombian - HQ and regional, 1 Colombian and 1 Mexican consultancy, 1 Colombian Ministry of Environment and Sustainable

				Development affiliated non-profit corporation in research and consultancy, 1 international (independent consultant) - Experience with PM: 16 direct, out of which 15 used PM in risk assessment, 4 not direct
Maps	Primary	I) Sketch Maps II) Community maps (post-study)	I) 18 II) 3	I) created during the test of the SMT by the CRC in Soacha, Colombia - thematic topics: 15 historic hazard and exposure map on urban flooding (see Appendix E), 1 capacities map, as well as 1 “dream map” II) produced by CRC staff after the advanced SMT workshop in QGIS
Maps	Secondary	I) Paper community map (pre-study) II) Digital community map (pre-study)	I) 1 II) 1	I) hand-drawn sketch map produced by community during EVCA community mapping in 2022; II) produced by CRC staff in Google Earth based on PM activity in the aftermath of the EVCA community mapping in 2022;
Research publications	Secondary	Journal articles		- Findings from the application of the SMT/method in Brazil, Germany and Chile

Appendix C: Table with shortcomings, strengths, and recommendations for the SMT

Analytic framework	**SMT as PM method** Current users: participants and facilitators	**Overlapping**	**SMT as software** Current users: facilitators and analysts
Strengths	**Collection and visualisation of local risk knowledge and perceptions:** enhancing risk knowledge; improvements in extent and intensity of flood hazard; location, number, and type of capacities; geolocation of "community dreams"	**Opportunity for analysis through digitalisation of PM data:** "easy and quick"; creation of analytic products through integration of PM data in GIS	**Effectiveness:** time-efficient due to georeferencing, colour and feature detection
	Paper-based method: low-cost and low-tech data collection, decreasing threshold for participants and facilitators to use solution	**Different paper formats**: suitable for individual and group mapping, and diverse mapping objectives	**User interface and learnability:** "straightforward and intuitive" for people with GIS background
	OpenStreetMap scale map: open source; enables spatial orientation and OSM data can be improved with crowd mapping approach; geolocation and relation of mapped features	**Data quality analysis of scale map:** OSM report, analysing suitability for PM	
	(Risk) Communication: two-way; valuation and integration of endogenous knowledge; building of trust; dialogue about disaster risk reduction measures	**Open source**	
Shortcomings	**OpenStreetMap scale map:** base map with OSM data is only option; sometimes limited or outdated data, possibly impacting the	**Capacities:** knowledge in English and GIS required for usage of software and analysis of PM data	**User interface and learnability:** language barrier due to technical terms and explanations, and English as only language option,

	orientation of participants		lacking explanations/guidance
	No other map components: missing legend, title, or descriptions, leading to differences in content and mapping conventions		**Effectiveness:** detection of colours and features not functioning problem-free; limited colours detectable; all markings digitalised as polygons; quality of image critical for QR-code detection and execution of functions
	Use of colours: limited, impacting the amount and clarity of information captured		
	Paper-based: limited data accuracy and richness		
Recommendations	**Scale map:** other base map types and own data (1. satellite; 2. drone; 3. topographic, landcover, historic hazard data, and climate scenarios) for better orientation and diverse mapping purposes	**Clear mapping and data analysis strategy:** include legend, metadata, and methodology for analysis of PM data	**Spatial interface:** allow other base map types and upload of own data; grid function; editable base map
	Overview and individual maps: for better orientation; ability to map surroundings, root causes, spatially dispersed communities	**Capacities:** develop practical instructions, training, or services, targeting different audience (facilitator, analyst, community members) and levels (GIS); enable communities to use the tool without facilitator for sustainable use of PM products	**Communication:** Sharing and collaboration with others; connection with OSM Editor; mobile version
			Effectiveness: 1. colour detection functioning stable and for more colours; 2. feature detection enhanced for legend, and line and point features; 3. other data formats and additional digitalisation of steps for automatic data analysis
			User interface and learnability: user interface and training material in other languages; less technical language; help button for

			instructions of each step

Appendix D: OSM Data quality report La Capilla

ohsome quality analyst

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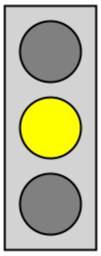
Quality Report

The sketchmap fitness report consists of four data quality indicators (mapping saturation of major roads, currentness of major-roads and amenities, density of landmarks). The report tells you whether you should expect potential problems when using OSM-based Sketch Maps for the Area-of-Interest.

Report Result

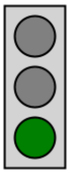


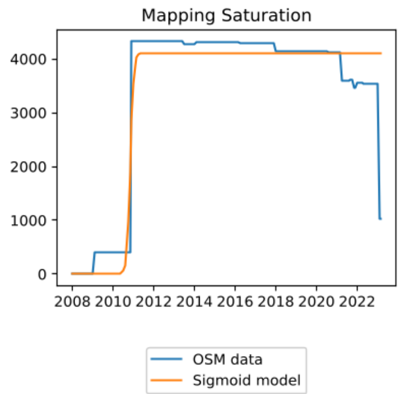
The report indicates medium quality of the underlying OSM data. You should inspect the results for the individual indicators to identify potential data quality concerns.

Indicator Results

Mapping Saturation (Major Roads Length)

Calculate if mapping has saturated. High saturation has been reached if the growth of the fitted curve is minimal.

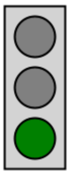


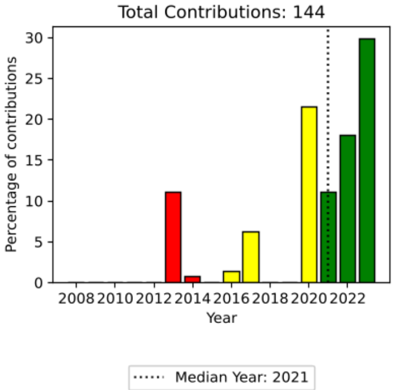


The saturation of the last 3 years is 100.0%. High saturation has been reached (97% < Saturation ≤ 100%).

Currentness (Major Roads Count)

Ratio of all contributions that have been edited since 2008 until the current day in relation with years without mapping activities in the same time range. Refers to data quality in respect to currentness.

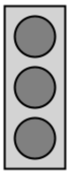




In the last 3 years 59.03 % of the elements were edited the last time. In the period from 4 to 7 years ago 27.78 % of the elements were edited the last time. The remaining 13.19 % were last edited more than 8 years ago. The median currentness of the 144 features (Major Roads Count) is 2 year(s). It is likely that most features are up-to-date.

Currentness (Amenities)

Ratio of all contributions that have been edited since 2008 until the current day in relation with years without mapping activities in the same time range. Refers to data quality in respect to currentness.

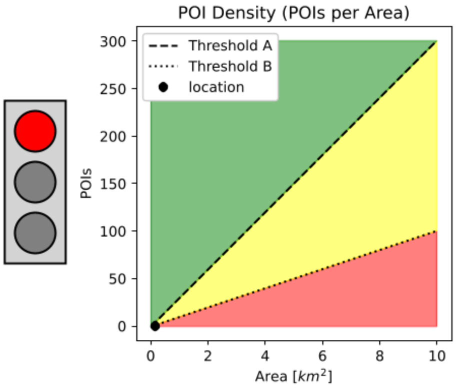


The creation of the Indicator was unsuccessful.

In the area of interest no features matching the filter are present today.

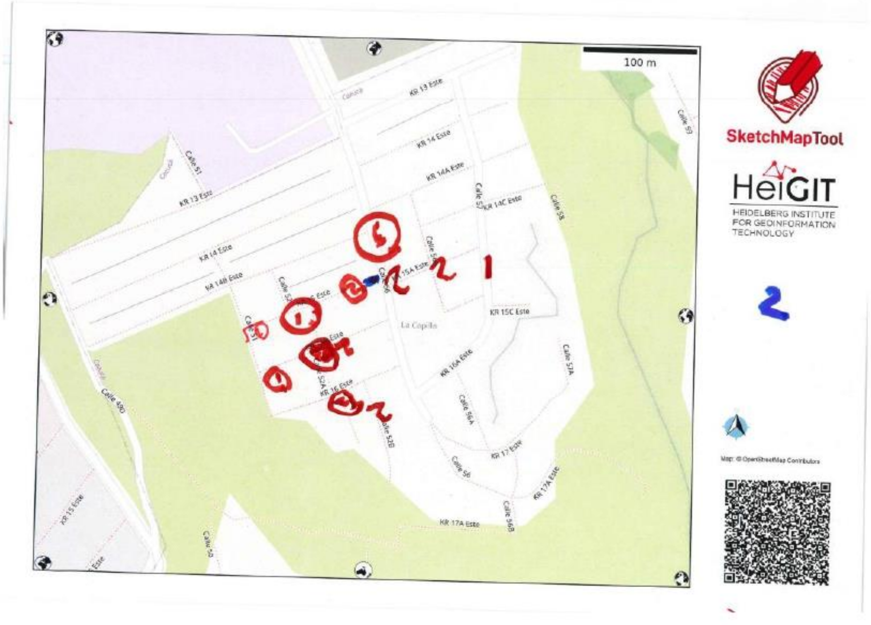
POI Density (POI)

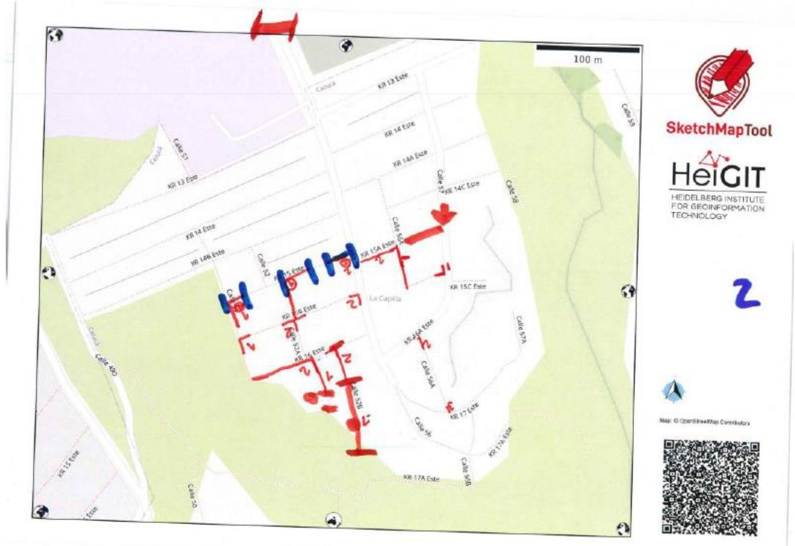
The density of Point of Interests (POI). It is calculated by the number of features divided by the area in square-kilometers.



The density of landmarks (points of reference, e.g. waterbodies, supermarkets, churches, bus stops) is 0.00 features per sqkm. It is probably hard to orientate on OSM-based sketchmaps of this region. There are just few orientation providing features available, you should explore, if participants can orientate properly.

Appendix E: Sketch Maps of the community members in La Capilla, Soacha, Colombia

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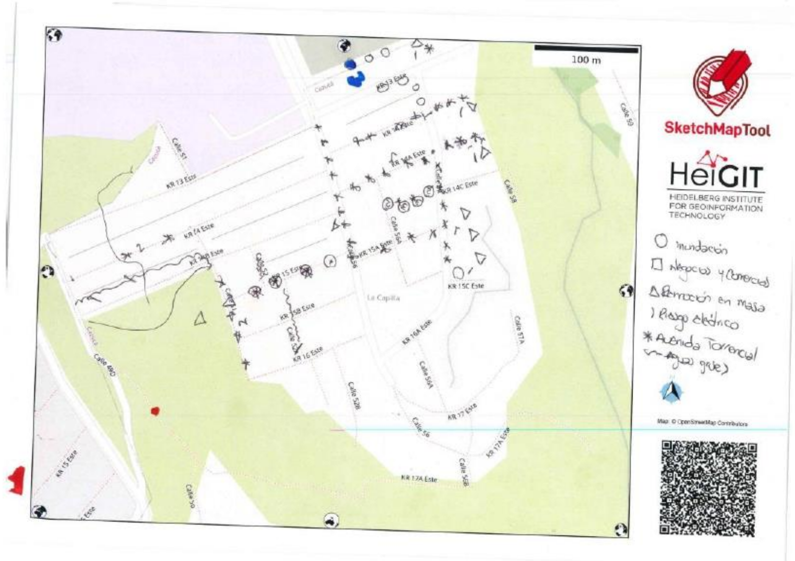
Map: © OpenStreetMap Contributors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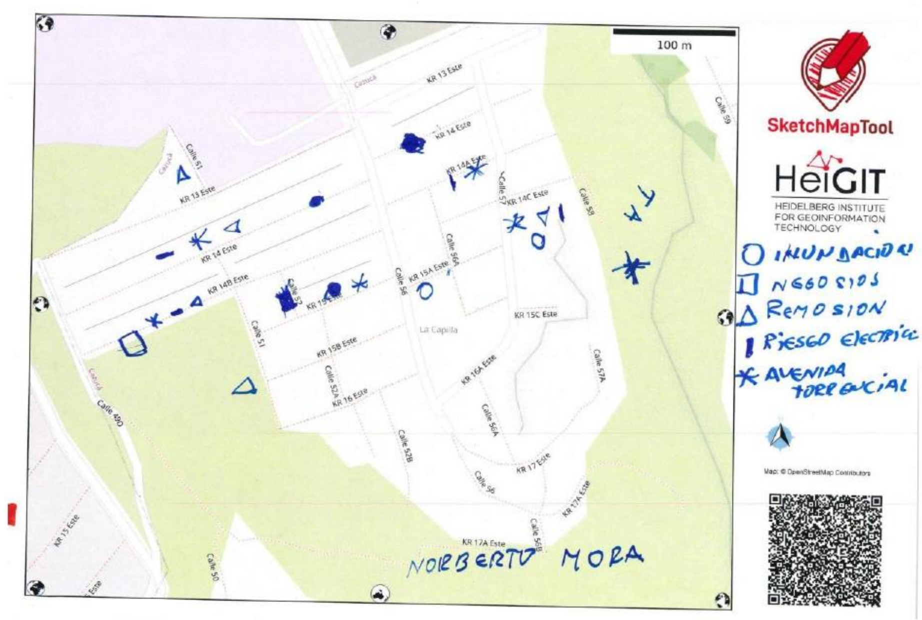
Map: © OpenStreetMap Contributors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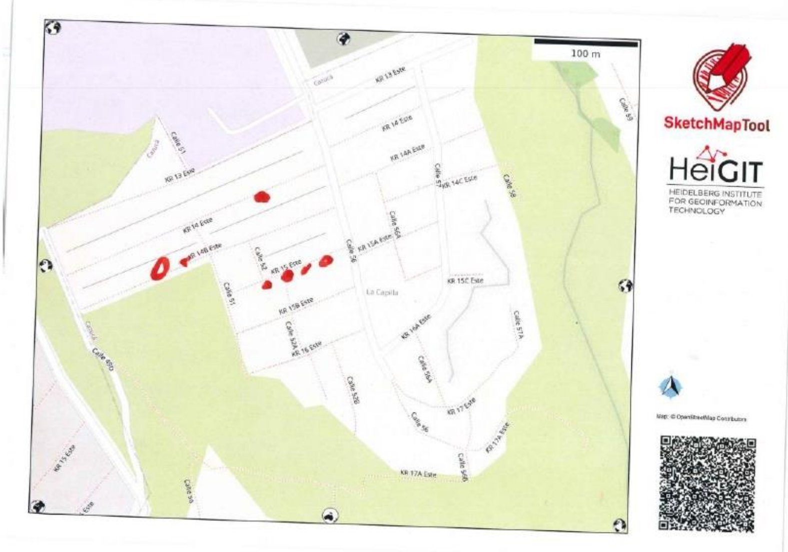
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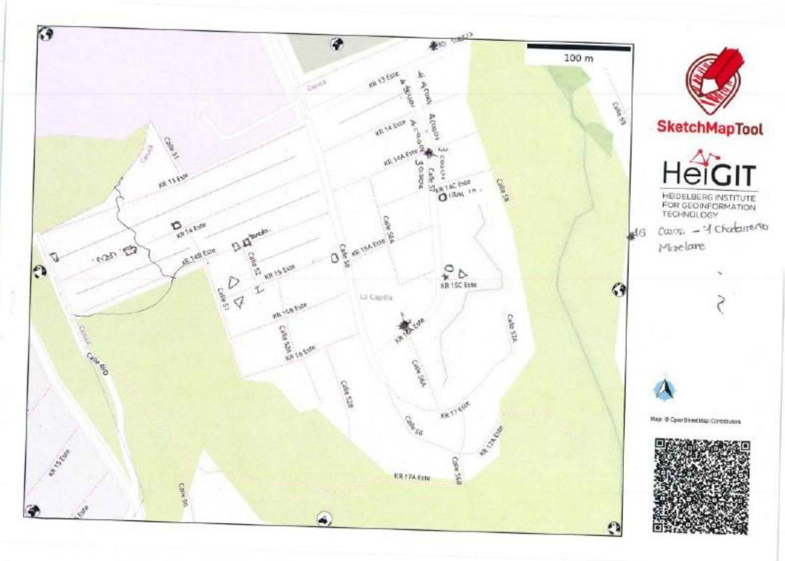
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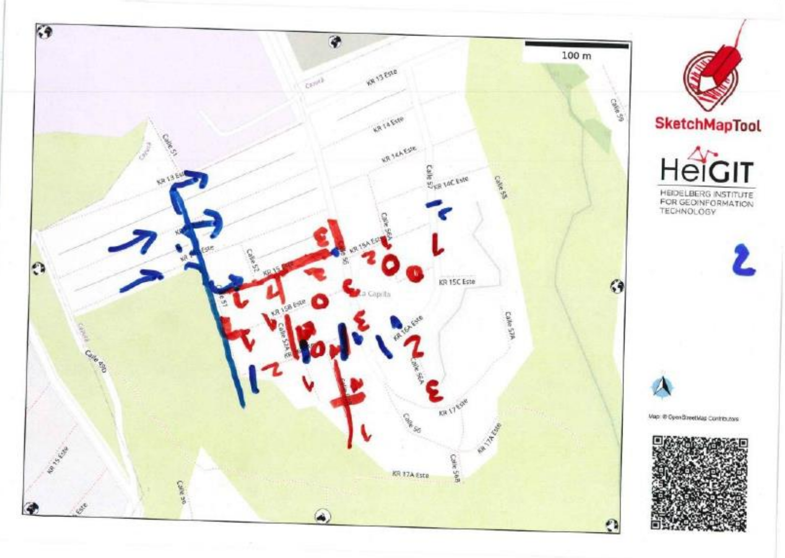
La Capilla
Map: © OpenStreetMap Contributors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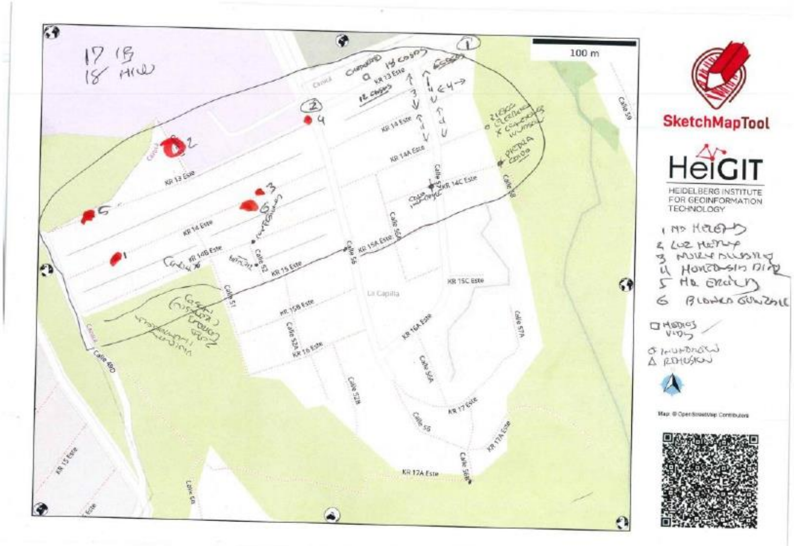
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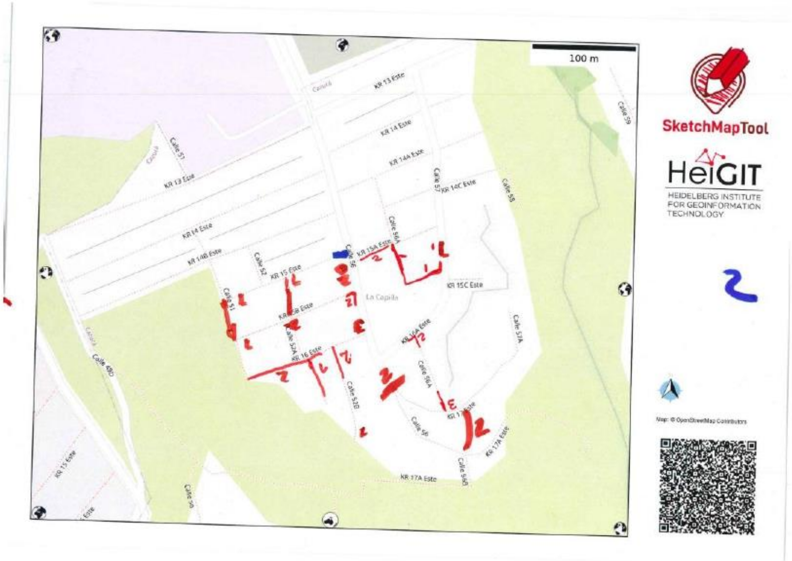
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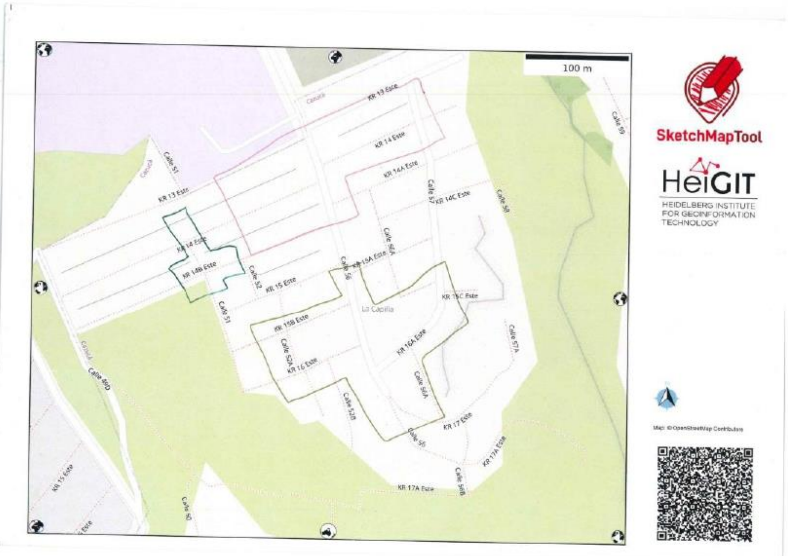
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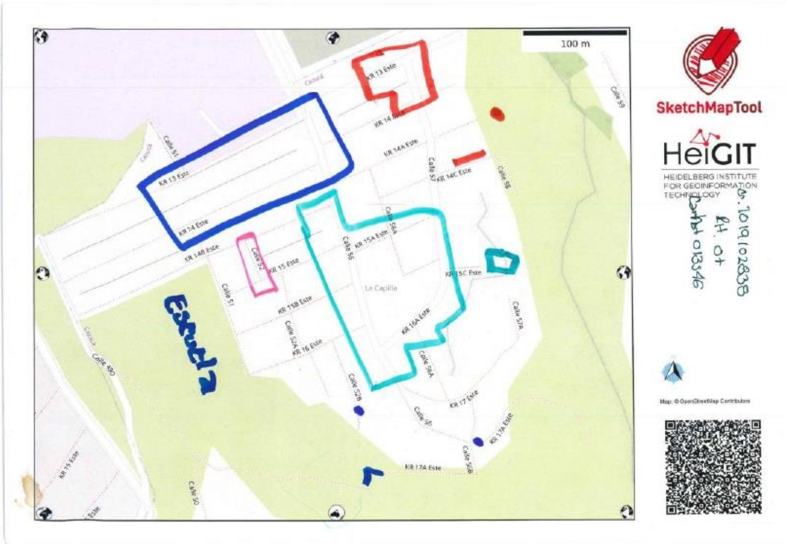
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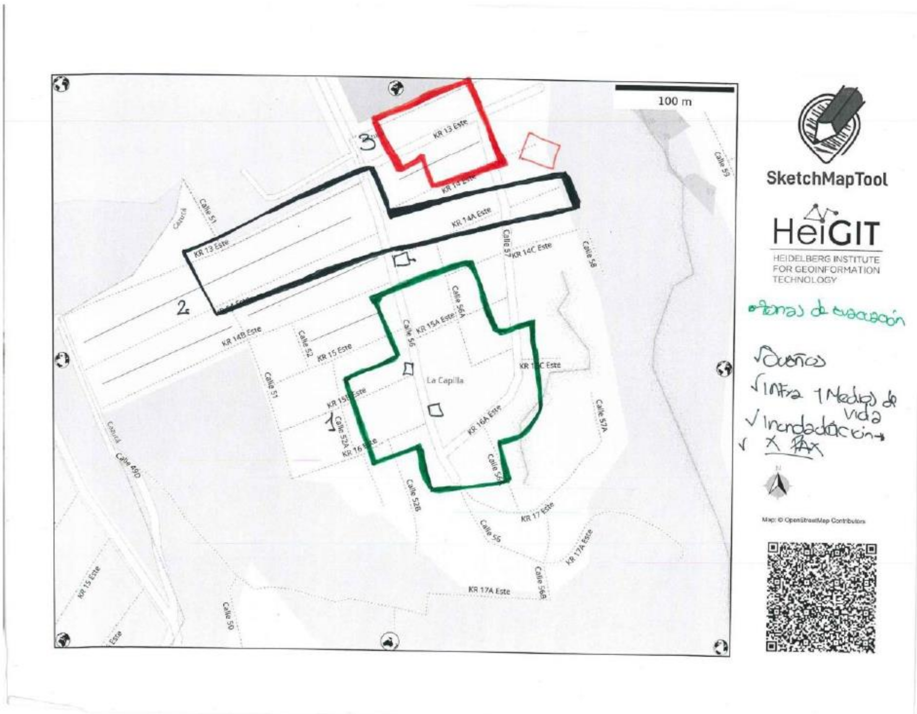
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√ Dueños
√ Infra + Medios de vida
√ Inundación
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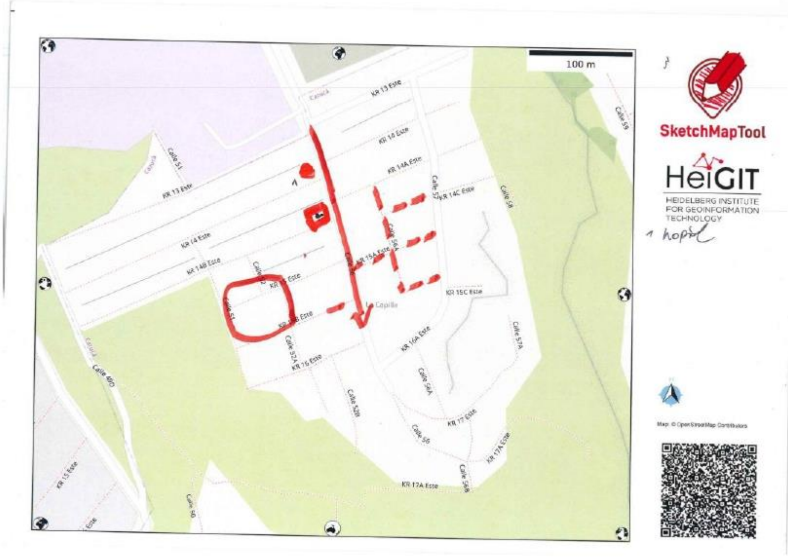
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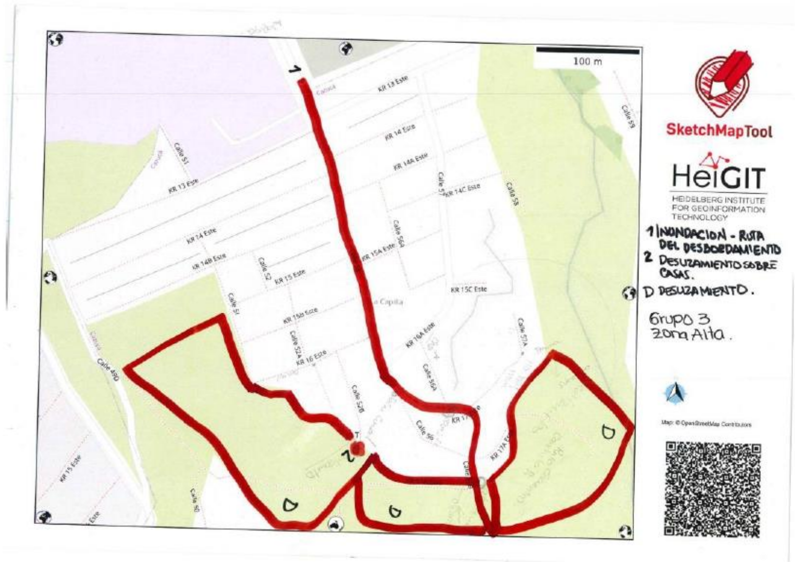
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2 DESLIZAMIENTO SOBRE CASAS.
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