Risk Awareness Maps of Urban Flooding via *OSM Field Papers*- Case Study Santiago de Chile

Carolin Klonner
Institute of Geography, Heidelberg Academy of Sciences and Humanities (HAW), Heidelberg, Germany
Carolin.Klonner@geog.uni-heidelberg.de

Sabrina Marx
Institute of Geography, Heidelberg Academy of Sciences and Humanities (HAW), Heidelberg, Germany
Sabrina.Marx@geog.uni-heidelberg.de

Tomás Usón
Institute of Geography, Heidelberg Academy of Sciences and Humanities (HAW), Heidelberg, Germany
Tomas.Uson@geog.uni-heidelberg.de

Bernhard Höfle
Institute of Geography, Heidelberg Academy of Sciences and Humanities (HAW), Heidelberg Center for the Environment (HCE), Heidelberg, Germany
hoefle@uni-heidelberg.de

ABSTRACT

Urban flooding has been increasing in recent years and therefore new specified methods need to be developed and applied. The rise of Web 2.0 technologies and collaborative projects based on volunteered geographic information like OpenStreetMap (OSM) lead to new dimensions of participatory practices. Thus, citizens can provide local knowledge for natural hazard analysis in a convenient way. In the following, a case study of the Quilicura community in Santiago de Chile -regularly affected by urban floods- is presented. A combination of *OSM Field Papers* and the risk perception of local people is applied in the concept of risk awareness maps including a questionnaire for participants' information. This explorative study is a promising approach for a complementing data source because insight into local knowledge is acquired in a fast way. Results reveal two main streets, which are identified by the participants as prone to urban floods.

Keywords

Natural hazard analysis, Web 2.0, participatory sensing, OpenStreetMap, risk awareness.

INTRODUCTION

Flooding events can be seen as a common part of nature, however, as soon as they affect people and their belongings, they are declared as disasters. These are increasing all over the world (CRED EM-DAT 2014) due to, on the one hand, changing climate conditions and on the other hand, the increasing number of people living in risk areas as well as the impact of human beings on nature (Ebert, Banzhaf, and McPhee 2009). Risk can be defined as the combination of hazard and vulnerability, while the latter can be further divided into exposure and coping-capacity of a certain area (Ebert, Welz, Heinrichs, Krellenberg, and Hansjürgens 2010). Elements at risk such as infrastructure, humans or buildings are exposed to the hazard, yet they are able to cope differently with the threat (Cardona, van Aalst, Birkmann, Fordham, McGregor, Perez, Pulwarty, Schipper, and Sinh 2012; Ebert et al. 2010; Wisner 2008).

There is a variety of flooding types such as fluvial, pluvial or marine flooding. Reasons can be heavy rainfalls, tidal fluctuations and dam failures among others (Wehn, Rusca, Evers, and Lanfranchi 2015). The study at hand focuses on pluvial urban flooding, which can be generated by different causes e.g. when the precipitation intensity is higher than the infiltration capacity of the ground. This mainly happens in areas where the surface is sealed, either artificially by buildings and asphalting, or naturally by hard rock, frozen soil, or crusting in arid areas. The surface runoff is increased if there is a high groundwater level and only little vegetation, which could reduce the surface runoff by interception (Herget 2008). Further, in many areas the drainage system cannot cope with high rainfall in a short time because it is insufficient or poorly maintained and thus, the surface runoff is increased even more. The case study is based in the Quilicura community of Santiago de Chile, which is regularly affected by pluvial urban floods, mainly due to an artificially sealed surface and insufficient drainage system.

In such events, decision making processes are of major importance. Therefore, Morss, Wilhelmi, Downton, and Gruntfest (2005) examined management efforts, information from former floods, the role of technical and scientific information as well as the generation and use of information about flood risk at different geographical scales. In Morss et al. (2005), interviews with floodplain managers revealed that they focus on the perception of flood risk within their community and how citizens view acceptable risk and to what extent they accept management responses. This perception of flood risk can also be regarded as flood risk awareness; that is why the method at hand is termed *risk awareness maps*. The study of Morss et al. (2005) concluded by emphasizing “end-to-end-to-end” research, which interconnects decision makers and focuses on multidirectional communication. Hence, the methods need to be adapted to such personal information and adequate tools for the use by citizens need to be applied. *Participatory sensing*, for example, can be seen as basis for such methods because they allow participants to provide their local knowledge to a broader community but also to gain scientific knowledge themselves, which might lead to higher motivation to take mitigation actions (Burke, Estrin, Hansen, Parker, Ramanathan, Reddy and Srivastava 2006; Enenkel et al. 2014; Ferster and Coops 2014; Morss et al. 2005; Resch 2013; Tulloch 2008). Additionally, it is essential to increase interdisciplinary research for integrated research since most analyses are multi-discipline and discipline centric (Gall, Nguyen, and Cutter 2015; Morss et al. 2005).

So far, most research about crowdsourced geodata and hazard analysis has dealt with the response phase (Horita, Degrossi, Assis, Zipf, and Porto de Albuquerque 2013), although the mitigation and preparedness phase play an important role in disaster risk management, especially with an increasing number of urban flooding events. Therefore, the presented study about risk awareness maps combines social with natural sciences and tries to bridge the aforementioned gaps while focusing on the mitigation and preparedness phase.

STATE OF THE ART

International conventions like the Aarhus Convention (United Nations Economic Commission for Europe (UNECE) 1999) and the European Flood Directive 2007/60/EC (European Commission 2015) promote and require measurements to strengthen public participation and to involve citizens in the flood management cycle (Wehn et al. 2015). Information for the mitigation and preparedness phase about areas which are highly at risk can often be retrieved from official data but in many countries and in remote areas, there are no measurements (e.g. from gauges), any historical data or it is very difficult to collect data via technical sensors in the required resolution for specific cases such as urban flooding. Thus, the risk awareness of people living there can be seen as a means to evaluate parts of the region which should be analysed in more detail. Further, it is also possible to evaluate in how far the people perceive the flood risk in their neighbourhood, e.g. their knowledge of elements at risk, and to increase their risk awareness via the information gathering and the integration into the mitigation phase (Wehn et al. 2015). Such measurements are enhanced by recent developments of mobile computing devices and Web 2.0, which led to tablets and smartphones with integrated global positioning systems (GPS; Goodchild 2007).

Laymen and experts are able to collect geodata and distribute them on Web platforms, e.g. via collaborative map projects like OpenStreetMap (OpenStreetMap 2015, Turner 2006). When volunteers share observations of their environment for a specific scientific purpose based on their personal and local experience, the terms *people as sensors* and *citizen science* are used (Resch 2013; Tulloch 2008). In this way, local information and up-to-date maps are available in advance, which is essential for resilience building (Soden, Budhathoki, and Palen 2014). Thus, in natural hazard analysis, additional information gained from local knowledge can complement geodata from traditional data acquisition by authorities or companies (Dorn, Vetter, and Höfle 2014; Enenkel, See, Bonifacio, Boken, Chaney, Vinck, You, Dutra, and Anderson 2015).

A study conducted by See, Comber, Salk, Fritz, van der Velde, Perger, Schill, MacCAllum, Kraxner, and Obersteiner (2013) concludes that in many tasks, e.g. land cover validation, inexperienced are as reliable as experienced participants and they tend to improve to a greater degree and faster. Hence, the authors argue that specific training material and indications might even strengthen this outcome. As there are still challenges related to the quality of data from inexperienced participants (Goodchild and Li 2012), this data should not be seen as a substitute but rather as an important contribution to risk management.

There are different ways of representing our environment, e.g. Dangschat (2014) differentiates between the following: On the one hand, quantitative spatial data such as city maps most often exactly reflect distances and directions and place official institutions and buildings on the geographically correct position based on coordinates. And on the other hand, qualitative spatial data as in mental maps, for example, depend on selective perception, memories and preferences. Furthermore, qualitative spatial data represent the lived space and are socially selective and relational, i.e. they are subject to other persons as well as to the experiences of people (ibid).

Further, Wagner (2007) applied mental models for investigating flash floods and landslides. “Mental models of natural hazards are generally based on personal experience and information assimilated from mass media, peer groups, and responsible agencies” (ibid, p. 671). The results show, among others, that experience has a strong influence on the completeness of the mental models: Inhabitants who experienced many hazards had more accurate and profound mental maps than newcomers. Yet, “it is not enough to measure personal experience only by the number of damaging events experienced but rather also by the local perceptions of those events” (ibid, p. 680 f). Therefore, the method of the study at hand includes not only a questionnaire but also risk awareness maps in which people can indicate their personal perception of flood risk in Quilicura, Santiago de Chile.

STUDY AREA

The city of Santiago de Chile has been a study area of urban flooding in several projects (Krellenberg and Hansjürgens 2014; K. Krellenberg, A. Müller, A. Schwarz, R. Höfer, and J. Welz 2013). Ebert, Banzhaf, and McPhee (2009) see this focus mainly due to Santiago's history of regularly occurring flood events and the authors state that urban growth is still going on, which implies that there is a strong land-use change in urban and peri-urban areas, leading to higher hazard potential due to an increase of population in urbanized regions, more infrastructure and thus, more people at risk.

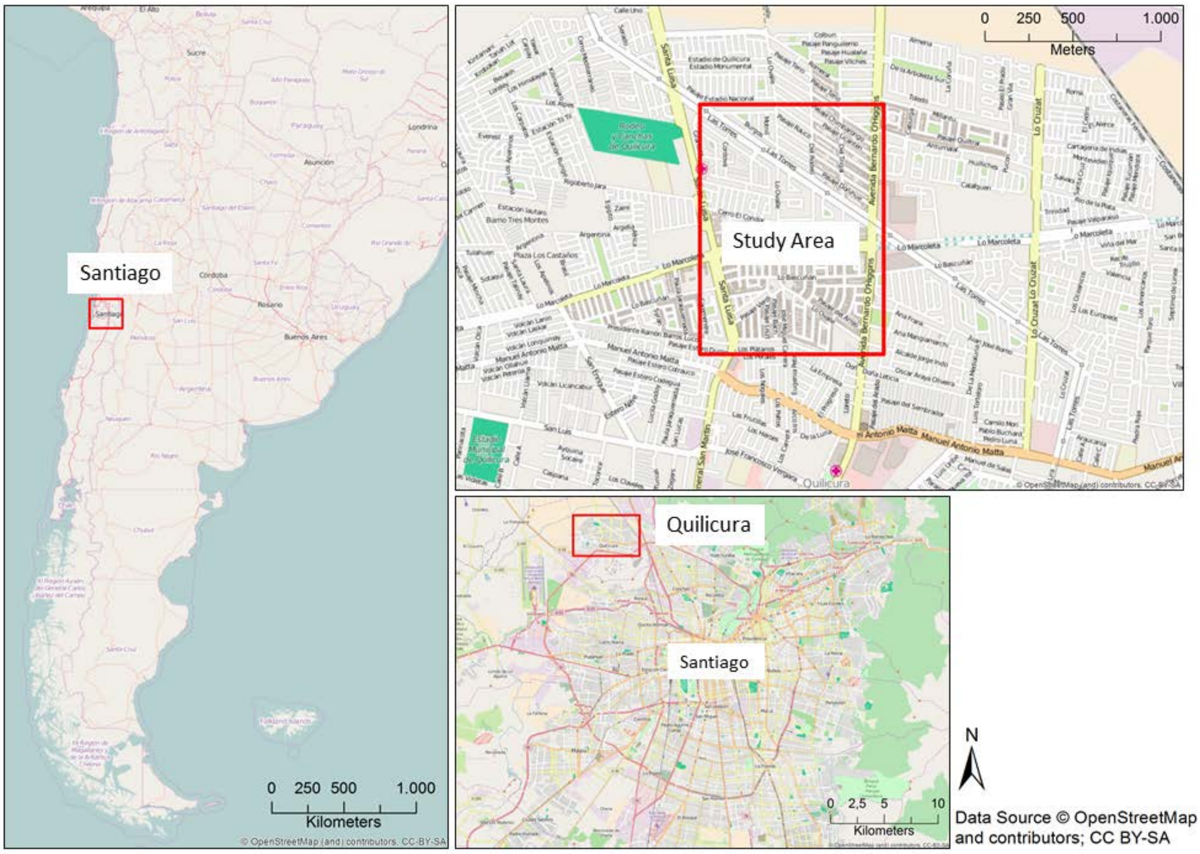

Figure 1. Localization of capital Santiago in Chile, the selected suburb Quilicura and the specific study area extent within Quilicura where the experiment took place (© OpenStreetMap and contributors; CC BY-SA).

Since literature suggests that vulnerability decreases in cases where people are more prepared due to previous flood experience, it is important to include citizens in the flood risk management process, especially in areas like Quilicura, which is one of the suburbs of Santiago with a lot of changes regarding population and built-up areas (Banzhaf, Kindler, Müller, Metz, Reyes-Paecke, and Weiland 2012; Figure 1). A specific part of Quilicura was selected as study area for the experiment according to information about regularly flooded areas provided by local authorities and previous short interviews within the neighbourhood of Quilicura to get a first overview.

METHODS

Risk awareness maps are chosen as a combining method to gather both quantitative and qualitative data via a participatory sensing approach. This follows the demand for more and improved tools for the general public to capture and utilize geographic data in different ways as well as to combine them with professional tools to make collaborations possible (Wilson and Graham 2013).

Due to only little research in this field of applications, an explorative study is conducted to get deeper insights (Stein 2014). A specific experimental design, the "quasi-experiment", is applied to collect the data in the study area (ibid). The sample is already pre-selected by the definition of the study area and participants are randomly selected (ibid), i.e. either someone is already on the street or in front of his property or the researcher asks at the door; in total 14 participants are selected.

Risk Awareness Maps

In order to evaluate the risk awareness of local citizens, the method of *OSM Field Papers* is used, where the OSM data is displayed as a base map (OpenStreetMap Wiki 2015). Via this method, a specific area can be printed as a paper map and people are able to add buildings, attributes, streets or to edit presented data while walking directly through this area. Remotely mapped features can be evaluated in this way. Another advantage is the fact that the data can directly be georeferenced via a QR code for further (GIS) applications (OpenStreetMap 2015). For the study at hand, these *Field Papers* are used in order to assess the risk awareness of residents and thus, the participants are asked to indicate with a marker the specific streets, which they perceive to have a high flood risk, in the provided map (Figure 2). This procedure combines quantitative spatial data from a city map with qualitative spatial data from the mental map, i.e. the perception of risk and local knowledge. In this way it is possible to use the subjective perception of the participants in a GIS analysis because distances and relations are already provided by the *Field Paper*.

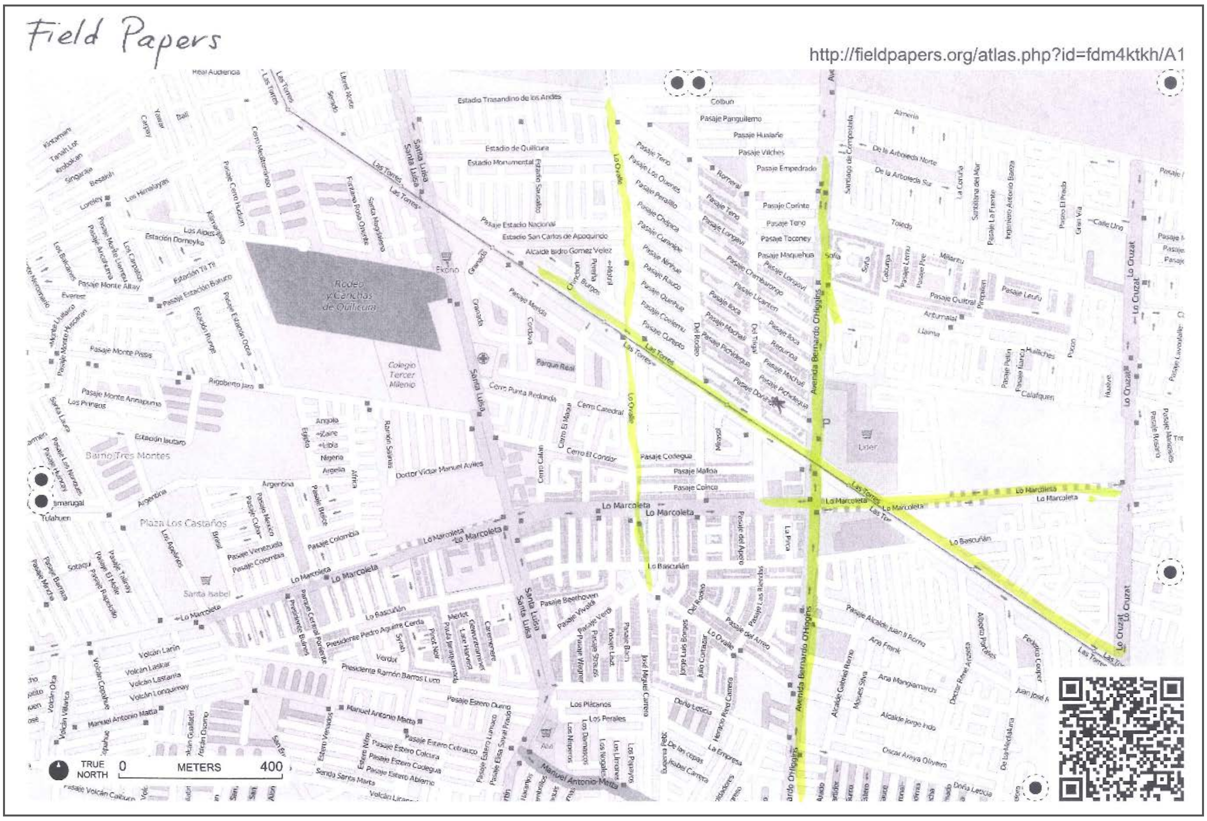

Figure 2. *Field Paper* of the study area in Quilicura, Santiago, with the participant's marking of streets with high flood risk (in yellow). QR code and black dots enable fast georeferencing (Field Papers 2015).

Questionnaire

The questionnaire aims at collecting further information about personal data of the participants as well as their experience with flood events and the personal perception of severances. Six aspects of the questionnaire are used for the study at hand. The participant's gender, age and the information whether they live exactly at this location or are pedestrians passing by. Furthermore, the time of residence at or knowing of that specific place is recorded. Finally, the problems of flooding both at the location of the interview and at a large scale of the whole district are inquired by using a rating of 1-5 with 1 representing "not affected" and 5 "affected very strongly".

Procedure

Figure 3 describes the steps of the pilot study procedure. First of all, the study area was selected (chapter 3) and the *Field Paper* of OSM was designed accordingly. The DIN A4 (21 cm x 29.70 cm) format was chosen to facilitate the handling in the field. Furthermore, the extent was focused on the North-Central part of Quilicura (Figure 2) based on information from the local government about historic urban flooding. The study was conducted in May 2015. Residents on the street and in their houses were questioned. In order to evaluate possible differences in awareness of people directly living there and people just passing by, the questionnaire includes a corresponding question. After the questionnaire, the people were asked to indicate streets and areas in the map of *OSM Field Papers*, of which they think that they are affected by urban floods. All in all, 14 participants were asked.

Afterwards, the images of the maps were uploaded to the *Field Paper* website and the georeferencing was done automatically via the QR code. In order to find out areas which are marked more often, the indicated streets and areas, e.g. street crossings, were digitized as polygons. An intersection of the polygons was conducted and the number of overlapping polygons at the intersecting areas was calculated. Finally, these results were classified and displayed in a map (Figure 4).

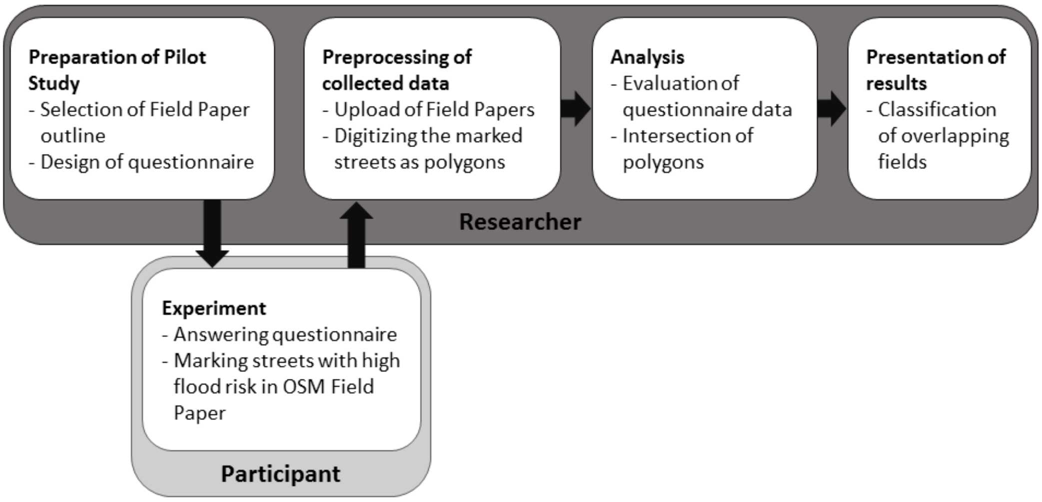

Figure 3. Workflow of the pilot study. Study design developed by researcher; application of *Field Paper* and questionnaire during case study in Quilicura, Santiago de Chile. The indicated streets and areas are digitized during the preprocessing and intersected in the analysis phase; the questionnaire data is evaluated before the results are presented in a classified map of perceived flood risk and an overview table of participants' information.

RESULTS

Risk Awareness Maps

The risk awareness maps were analysed with GIS software. The location of the participants at the time of the experiment as well as their perceived flood risk is shown in Figure 4. The participants marked several streets which were indicated as polygons in the specific layer. Figure 4 displays a map where the polygons of all participants are intersected and categorized according to the number of overlapping polygons, i.e. the number of participants perceiving this area at flood risk. The highest overlap of 7-9 polygons is identified for the red section. The orange parts stand for overlaps of 5-6 and green for overlaps of 4 or less polygons. In the other parts of the selected area of the city none of the participants perceives any flood risk.

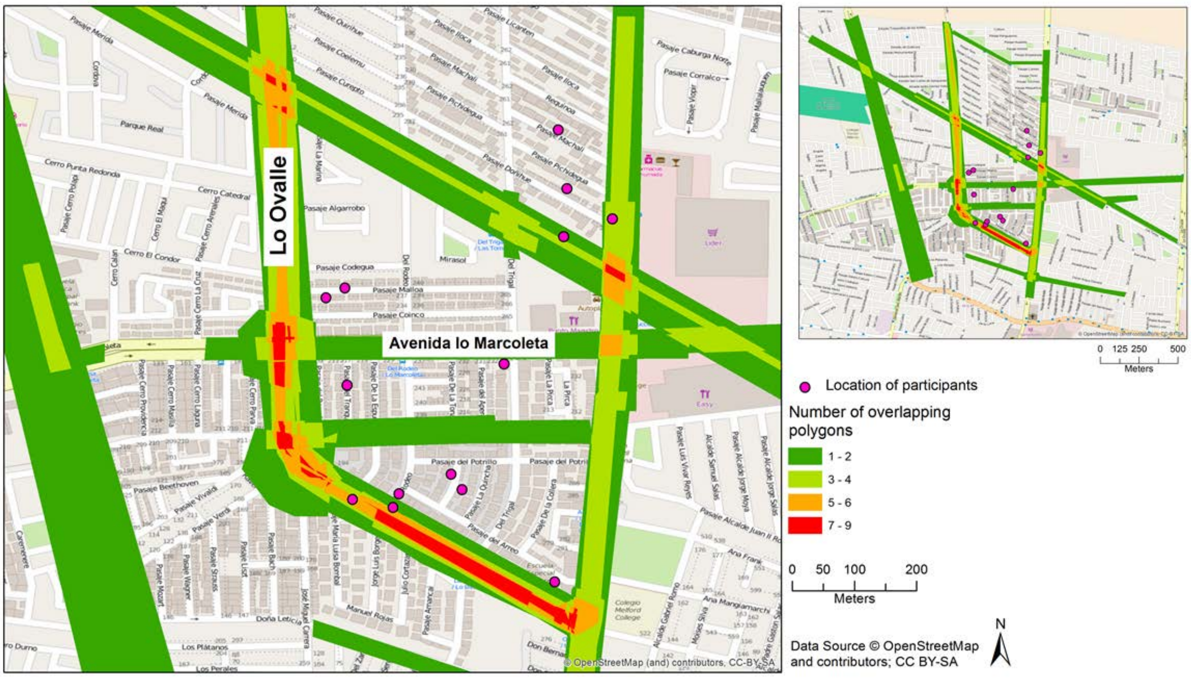

Figure 4. Intersection of the areas at flood risk indicated by 14 participants. Red and orange represent the most perceived flood risk. The street "Lo Ovalle" has the maximum of 7-9 overlays of polygons. Participants' geolocation is marked in magenta.

Questionnaire

For the evaluation of the questionnaire we focused on the most important aspects related to background information of the participants and their own perception of urban flooding problems. In a future in-depth analysis the results can be analysed in more detail to gain insight into individual influences of experience, personality etc. on risk awareness.

<table>
<tr><th></th><th></th><th>Age
(Average: 49)</th><th>Years of residence at or knowing of that place
(Average: 14.6)</th><th>Problems of flooding in the community
(1 = not affected, 5 = affected very strongly)</th><th>Problems of flooding at that place
(1 = not affected, 5 = affected very strongly)</th></tr>
<tr><td rowspan="3">People not living at location</td><td rowspan="2">Male</td><td>58</td><td>20</td><td>3</td><td>5</td></tr>
<tr><td>35</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>Female</td><td>48</td><td>12</td><td>5</td><td>5</td></tr>
<tr><td rowspan="11">People living at location</td><td rowspan="5">Male</td><td>19</td><td>5</td><td>4</td><td>1</td></tr>
<tr><td>54</td><td>20</td><td>5</td><td>1</td></tr>
<tr><td>75</td><td>15</td><td>3</td><td>1</td></tr>
<tr><td>27</td><td>14</td><td>3</td><td>4</td></tr>
<tr><td>24</td><td>11</td><td>5</td><td>1</td></tr>
<tr><td rowspan="6">Female</td><td>65</td><td>15</td><td>5</td><td>1</td></tr>
<tr><td>49</td><td>20</td><td>5</td><td>4</td></tr>
<tr><td>53</td><td>20</td><td>4</td><td>1</td></tr>
<tr><td>77</td><td>20</td><td>5</td><td>1</td></tr>
<tr><td>45</td><td>17</td><td>4</td><td>1</td></tr>
<tr><td>50</td><td>13</td><td>3</td><td>1</td></tr>
</table>

Table 1. Overview of the results of the questionnaire with 14 participants. Each row corresponds to one participant.

There are 14 citizens asked either directly at their home (79%) or on the street (21%) (Table 1). The age of the participants ranges from 19 to 77 years with an average of 49 years. Additionally, they are on average living for 14.6 years in this area. The time of residence is important to know as new residents might not have experience with a flooding event and therefore should be excluded. However, since this exploratory study has only a little number of participants, it is not possible to have a statistical evaluation.

Furthermore, there is an equal distribution of male and female participants. Regarding the personal impression of flood severity, there is a significant difference between the specific place of the interrogation and the whole community. Most citizens see the community as affected strongly, whereas at the direct location the perception of flooding varied strongly and the flood affection is either not there (most cases) or it is very strong. The risk awareness maps show a high flood risk in the street "Lo Ovalle" including two crossing sections (Figure 4). These parts are identified by over half (7-9 overlapping polygons) of the 14 participants.

Comparison to local information

Figure 5a and 5b show the areas which are identified by most of the participants as being highly at risk. People already took preventive measures in order to protect their property from flooding in this area (Figure 5c). One explanation of the resulting focus on the bigger streets could be that these streets resemble canals with insufficient drainage capacities and that the surplus of rainwater is collected there from the smaller streets and leads to an even stronger flooding at the crossings. Another explanation might be based on the method itself as it tries to find out the risk awareness of the citizens; thus, the people are probably more affected by flooding on the main roads than on smaller roads and therefore only mark these streets on the map.

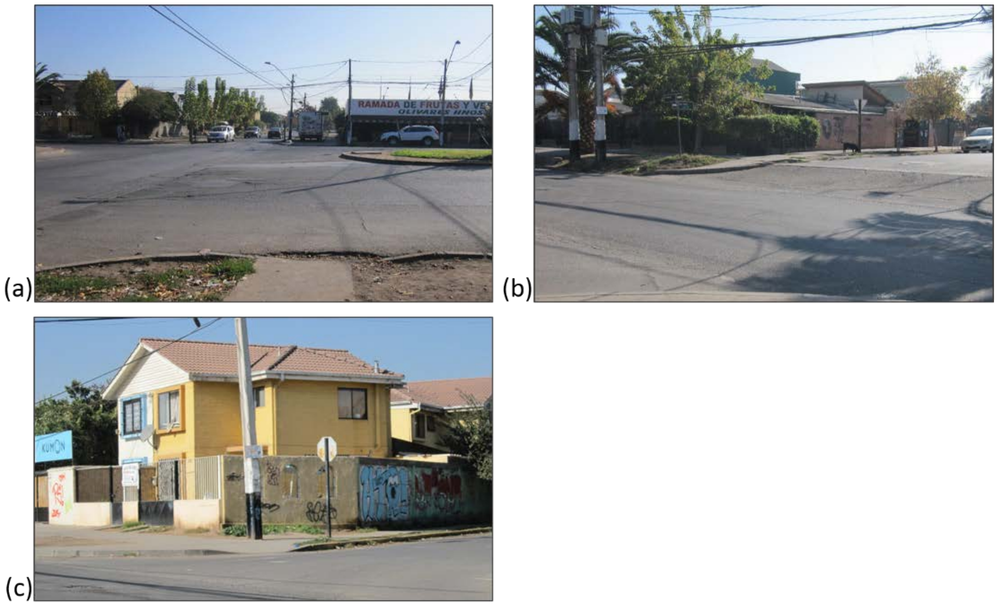

Figure 5. Visual inspection of areas in Quilicura where the participants perceived high flood risk: (a) Crossing of the street lo Ovalle and Avenida lo Marcoleta. The street is on a deeper level as the surrounding area. (b) Crossing of lo Ovalle and one of the smaller roads which is on a higher level- the surplus of rainwater flows directly into lo Ovalle during a raining event. (c) Crossing of lo Ovalle with one of the smaller roads. Preventive measures (small walls) taken by residents (source: C. Klonner, Quilicura 06.05.2015).

In addition to this visual inspection, flood risk maps could be used for evaluation. Flood risk consists of the hazard itself, e.g. the spatial extent, and the vulnerability of a specific area (Morss 2005). However, to the authors' knowledge, there are no up-to-date official flood risk maps on a small scale available for a comparison with the risk awareness maps. Due to this circumstance and to the fact that the risk awareness maps additionally include personal aspects such as the experience of hazards (Wachinger, Renn, Begg and Kuhlicke 2013), a comparison to the personal perception of flood affection at the place of living is used within a focus study area (Figure 6), in which the scale, data acquisition (personal evaluation) and conceptualization of risk are similar. This point-based validation is established on the assumption that people can give more accurate information about flood risk perception if directly asked about their place of living than by drawing their risk awareness in a map of a larger area. Though, this has to be investigated in more detail in future research. Moreover, influencing factors have to be kept in mind such as in how far it is possible to visualize risk awareness in maps.

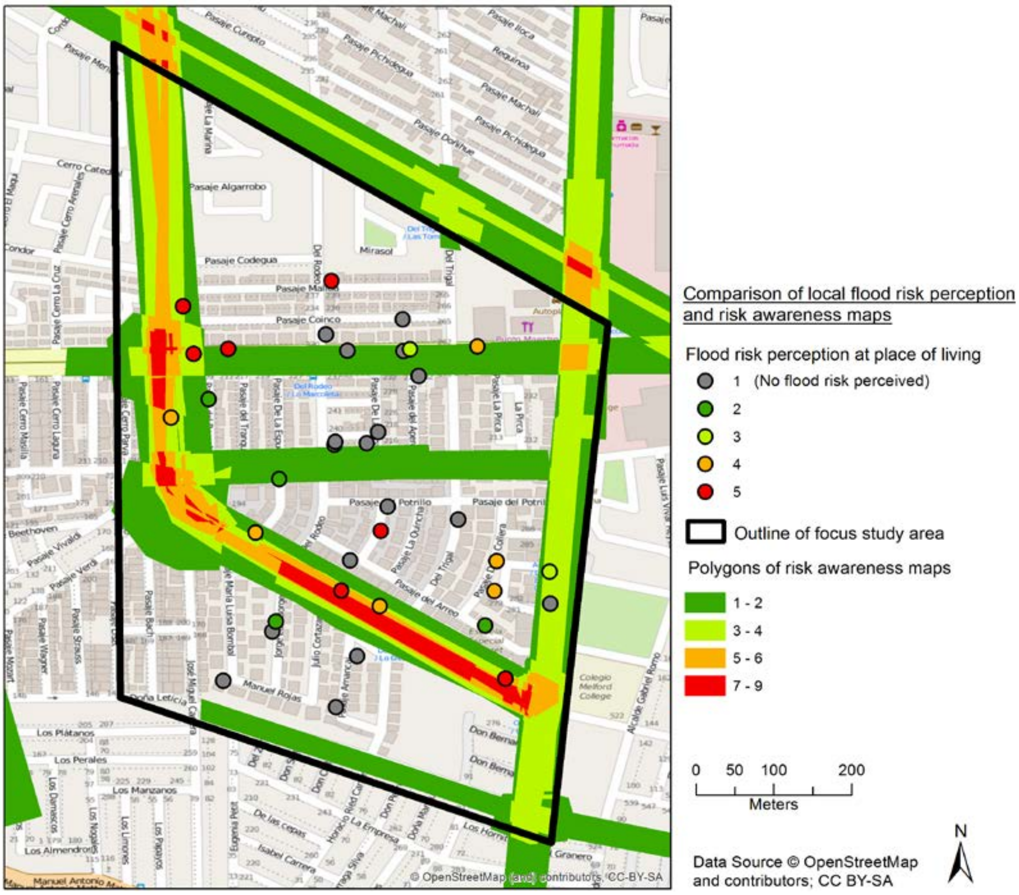

Figure 6. Comparison of local flood risk awareness (36 participants) and risk awareness maps in a focus study area.

Figure 6 shows the locations of 36 local residents who were asked about the affection of their place of living by pluvial floods with answers from not affected (1) to affected very strongly (5): Green to red show perceived risk (19) and grey no perceived risk (17). At 12 locations (63%) there is perceived risk in both datasets- with the highest level in lo Ovalle and the crossing section lo Ovalle and Avenida lo Marcoleta. Hence, 7 locations where residents perceived high flood risk were not considered in the risk awareness maps. On the other hand, 83% (14 locations) correspond in no perception of flood risk with the risk awareness maps, i.e. no polygon areas can be found at the grey locations. This comparison reveals in the same way as the visual inspection of the area that the risk awareness map approach can give some hints for areas which are perceived as strongly affected by floods but that no detailed and general conclusions can be made as some areas might be neglected in the maps.

DISCUSSION

The conducted experiment has to be considered as an initial study. It gives a first insight into the method of risk awareness maps using the *Field Papers* approach based on OSM data and a questionnaire.

In contrast to the presented risk awareness maps, mental maps (qualitative spatial data) are based on a blank sheet on which people draw an image e.g. about their perception of space (Pocock 1972), which allows a subjective view e.g. of the relevance of certain places for specific social groups. Although the participants have more freedom in this approach, the risk awareness maps which are based on the *Field Paper* can be seen as more effective for participatory sensing approaches because, on the one hand, the participants can locate themselves more easily due to the base map and the street names and can give detailed information about certain locations of risk and, on the other hand, the automated georeferencing of the results allows a fast processing of the data and the use of the participant's contribution for further studies.

Furthermore, in comparison to conventional risk maps, which are based on quantitative spatial data from technical sensors and reflect objective distances and relations, this new method of combination of qualitative and quantitative spatial data in a risk awareness map includes also the knowledge, experience as well as awareness of people living in this area. Thus, if the people are aware of the risk and even are actively mitigating e.g. with flood protection measures, the potential risk is actually much lower than in areas where the normal risk maps might show low risk but in which the citizens are not aware of the danger. This estimation of local risk might be possible with conventional maps if experts go there and collect all the required information; however, this seems difficult to perform as it is very time and cost consuming.

Therefore, the presented approach of risk awareness maps on the basis of *OSM Field Papers* combines the advantages of qualitative and quantitative spatial data for flood hazard analysis. Though, there are still some challenges e.g. the collection of qualitative data is very time consuming. Further, single citizens might not have a good local knowledge leading to wrong deductions. Besides the technical issues, there is also an epistemological side as the question remains in which cases a combination of data sources is more adequate and in which the official data should be preferred. Who can we trust more? Is it possible to develop a certain weighting scheme of local and official data?

Another aspect learned from the pilot study is the fact that a slight change in data acquisition might improve the results. Several participants were not able to understand the map in general as they have not had much experience with map reading or they could not read the streets. Therefore, the follow up experiment will have a longer introductory part to the map itself and the instructions for the drawing task might be more specified. Further, there needs to be additional research regarding the content of the map: Is the handling for the participants easier when the area is displayed at a larger scale and with less information? Or is even more or different information such as landmarks more efficient?

With regard to the quality of the resulting risk awareness maps, one has to keep in mind that such maps are very subjective and influenced by many factors such as experience, age, time of residence in the area or the degree to which a participant is personally affected. Thus, a large number of participants is essential. The strength of such maps can be seen in the provision of complementary local information, especially in cases where there is no other base material available. Furthermore, this initial investigation could be extended to a bigger number of participants as well as a larger study area. For example, during an initiative in the community the *Field Papers* could be distributed to all households. In addition, a larger study area is possible if the extent of the base map is selected on a larger scale during the creation of the *Field Paper*. Though, the comparison to the local perception of flood risk showed that some areas with perceived flood risk might not be identified via the risk awareness maps approach.

A further application of the risk awareness maps can be seen in the approach of Schelhorn, Porto de Albuquerque, Zipf, Leiner, and Herfort (2014). Elements at risk e.g. gained from collaborative maps such as OSM can be combined with hazard maps of the specific area in order to identify places with higher risk (ibid). This method allows a regular update of elements at risk. If there are no official hazard maps available, the risk awareness maps could be used instead. Therefore, the displayed method of the study at hand is applicable in several ways in disaster risk management. Furthermore, if there is not the option to derive elements at risk via the method presented by Schelhorn et al. (2014) because the OSM data are too sparse and no flood model is available, the method of the risk awareness maps can be adapted and people can mark elements at risk in the *Field Paper*. The results of these maps can be used for further analysis in flood management. Additionally, the risk awareness maps and elements at risk maps based on the *Field Paper* can be used for a comparison to existing data about flood risk and elements at risk. Such a comparison identifies the elements and areas at risk which are included in the conventional data but are not perceived by the local citizens. Thus, these identified elements and areas are at an even higher risk.

Within the decision making process, the information of the risk awareness maps can be used as hints for further in-depth analysis of the identified risk areas. Hence, local residents could be informed and protection and monitoring measures could be installed in advance.

CONCLUSION

The user integration provides high potential for the preparedness and mitigation phase and several studies have already applied a combination of crowdsourced geodata in natural hazard analysis (e.g. Dorn et al. 2014; Enenkel et al. 2015). The conducted pilot study in Santiago de Chile can be seen as a first step towards risk awareness assessment via crowdsourcing tools. The easy to use tool of the *Field Papers* is the main advantage. The results can provide insight into areas which should be analysed in more detail e.g. via the installation of monitoring measures such as webcams or via flood modelling based on input data from laser scanning campaigns, local inspection or specified remote mapping. Another aspect for further research can be the documentation and evaluation of the increase of risk awareness and active participation in mitigation measures of the participants taking part in such a mapping approach (Wachinger et al. 2013).

In future, such personal perception may provide a basis for applications especially in areas where ground data is sparse and where data acquisition with technical sensors is very difficult or not possible. Further experiments are essential to include aspects such as cultural background and hazard type as well as to give hints for the development of new geodata collection and analysis methods, particularly for handling individual and local information.

ACKNOWLEDGMENTS

This work was supported by the WIN-Kolleg of the Heidelberg Academy of Sciences and Humanities (HAW). The authors would like to thank Christoph Oberacker for sharing his experience regarding the methods of this research.

REFERENCES

1. Banzhaf, E., Kindler, A., Müller, A., Metz, K., Reyes-Paecke, S. and Weiland, U. (2012) Land-use change, risk and land-use management, *Risk habitat megacity*. Heidelberg: Springer, 127-154.
2. Burke, J., Estrin, D., Hansen, M., Parker, A., Ramanathan, N., Reddy, S. and Srivastava, M. B. (2006) Participatory Sensing, *Proceedings of the Conference on Embedded Networked Sensor Systems*, Boulder, Colorado, USA.
3. Cardona, O.D., van Aalst, M.K., Birkmann, J., Fordham, M., McGregor, G. , Perez, R. , Pulwarty, R.S., Schipper, E.L.F. and Sinh, B.T. (2012) Determinants of risk: exposure and vulnerability, In Field, Barros, Stocker, Qin, Dokken, Ebi, Mastrandrea, Mach, Plattner, Allen, Tignor and Midgley (Eds.), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, Cambridge University Press Cambridge, UK, New York, NY, USA, 65-108.
4. CRED EM-DAT (2014) The International Disaster Database: Natural Disaster Trends, retrieved 08.09.2014 from http://www.emdat.be/natural-disasters-trends.
5. Dangschat, J. S. (2014) Räumliche Daten, In Baur and Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung*, Springer VS, Wiesbaden, 973-979.
6. Dorn, H., Vetter, M. and Höfle, B. (2014) GIS-Based Roughness Derivation for Flood Simulations: A Comparison of Orthophotos, LiDAR and Crowdsourced Geodata, *Remote Sensing*, 6, 2, 1739-1759.
7. Ebert, A., Banzhaf, E. and McPhee, J. (2009) The influence of urban expansion on the flood hazard in Santiago de Chile, *Proceedings of the Urban Remote Sensing Event, 2009 Joint*.
8. Ebert, A., Welz, J., Heinrichs, D., Krellenberg, K. and Hansjürgens, B. (2010) Socio-environmental change and flood risks: the case of Santiago de Chile, *Erdkunde*, 64, 4, 303-313.
9. Enenkel, M., See, L., Bonifacio, R., Boken, V., Chaney, N., Vinck, P., You, L., Dutra, E. and Anderson, M. (2015) Drought and food security - Improving decision-support via new technologies and innovative collaboration, *Global Food Security*, 4, 51-55.
10. European Commission (2015) The EU Floods Directive, retrieved 28.07.2015 from http://ec.europa.eu/environment/water/flood_risk/.
11. Ferster, C. J. and Coops, N. C. (2014) Assessing the quality of forest fuel loading data collected using public participation methods and smartphones, *International Journal of Wildland Fire*, 23, 4, 585-590.
12. Field Papers (2015) Field Papers, retrieved 15.09.2015 from http://fieldpapers.org/.
13. Gall, M., Nguyen, K. H. and Cutter, S. L. (2015) Integrated research on disaster risk: Is it really integrated? *International Journal of Disaster Risk Reduction*, 12, 255-267.
14. Goodchild, M. F. (2007) Citizens as Sensors: The World of Volunteered Geography, *GeoJournal*, 69, 211-221.
15. Goodchild, M. F. and Li, L. (2012) Assuring the quality of volunteered geographic information, *Spatial Statistics*, 1, 110-120.

16. Herget, J. (2008) Hochwasser, Sturzfluten und Ausbruchsflutwellen, In Felgentreff and Glade (Eds.), *Naturrisiken und Sozialkatastrophen*, Spektrum Akademischer Verlag, Berlin, Heidelberg,165-172.
17. Horita, F. E. A., Degrossi, L. C., Assis, L. F. F. G., Zipf, A. and Porto de Albuquerque, J. (2013) The use of Volunteered Geographic Information and Crowdsourcing in Disaster Management: a Systematic Literature Review, *Proceedings of the AMCIS 2013*, Chicago, Illinois.
18. Krellenberg, K. and Hansjürgens, B. (Eds.) (2014) *Climate Adaptation Santiago*, Springer-Verlag, Berlin, Heidelberg.
19. Krellenberg, K., Müller, A., Schwarz, A., Höfer, R. and Welz, J. (2013) Flood and heat hazards in the Metropolitan Region of Santiago de Chile and the socio-economics of exposure, *Applied Geography,* 38, 86-95.
20. Morss, R. E., Wilhelmi, O. V., Downton, M. W. and Gruntfest, E. (2005) Flood Risk, Uncertainty, and Scientific Information for Decision Making: Lessons from an Interdisciplinary Project, *Bulletin of the American Meteorological Society,* 86, 11, 1593-1601.
21. OpenStreetMap (2015) OpenStreetMap, retrieved 17.03.2015 from www.openstreetmap.org.
22. OpenStreetMap Wiki (2015) Field Papers, retrieved 07.08.2015 from http://wiki.openstreetmap.org/wiki/Field_Papers.
23. Pocock, D. C. D. (1972) City of the mind: A review of mental maps of urban areas, *Scottish Geographical Magazine*, 88, 2, 115-124.
24. Resch, B. (2013) People as Sensors and Collective Sensing-contextual Observations Complementing Geo-Sensor Network Measurements, In Krisp (Ed.), Advances in Location-Based Services, Springer, Berlin, 391–406.
25. Schelhorn, S. J., Albuquerque, J. P., Zipf, A., Leiner, R. and Herfort, B. (2014) Identifying Elements at Risk from OpenStreetMap: The Case of Flooding *Proceedings of the 11th International ISCRAM Conference*, University Park, Pennsylvania, USA.
26. See, L., Comber, A., Salk, C., Fritz, S., van der Velde, M., Perger, C., Schill, C., McCallum, I., Kraxner, F. and Obersteiner, M. (2013) Comparing the Quality of Crowdsourced Data Contributed by Expert and Non-Experts, *PLoS ONE,* 8, 7, e69958.
27. Soden, R., Budhathoki, N. and Palen, L. (2014) Resilience-Building and the Crisis Informatics Agenda: Lessons Learned from Open Cities Kathmandu, *Proceedings of the 11th International ISCRAM Conference*, University Park, Pennsylvania, USA.
28. Stein, P. (2014) Forschungsdesigns für die quantitative Sozialforschung, In Baur and Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung*, Springer VS, Wiesbaden, 135-151.
29. Tulloch, D. L. (2008) Is VGI participation? From vernal pools to video games, *GeoJournal*, 72, 3-4, 161-171.
30. Turner A. J. (2006) Introduction to Neogeography, O'Reilly, Sebastopol, CA.
31. United Nations Economic Commission for Europe (UNECE) (1999) Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters. Aarhus Convention. 2161 UNTS 447; 38 ILM 517 (1999), retrieved 28.07.2015 from http://www.unece.org/env/pp/treatytext.htm.
32. Wachinger, G., Renn, O., Begg, C. and Kuhlicke, C. (2013) The Risk Perception Paradox—Implications for Governance and Communication of Natural Hazards, *Risk Analysis,* 33, 6, 1049-1065.
33. Wagner, K. (2007) Mental models of flash floods and landslides, *Risk Analysis*, 27, 3, 671-682.
34. Wehn, U., Rusca, M., Evers, J. and Lanfranchi, V. (2015) Participation in flood risk management and the potential of citizen observatories: A governance analysis, *Environmental Science & Policy,* 48, 0, 225-236.
35. Wilson, M. W. and Graham, M. (2013) Neogeography and volunteered geographic information: a conversation with Michael Goodchild and Andrew Turner, *Environment and Planning A,* 45, 1, 10-18.
36. Wisner, B. (Ed.) (2008) *At risk: natural hazards, people's vulnerability and disasters,* 2. ed. reprint (Twice), Routledge, London, New York, NY.