Potential of Collaborative Mapping for Disaster Relief: A Case Study of OpenStreetMap in the Nepal Earthquake 2015

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Abstract

In the aftermath of a disaster, there is an urgent need for base maps to support relief efforts, especially in developing countries. In response to this, the OpenStreetMap project has been leveraged to produce maps of disaster-affected areas in a collaborative way. However, there has been little investigation aimed at explaining the collaborative mapping activity itself. This study presents an exploratory case study on how the collaborative mapping activities that followed the Nepal Earthquake in 2015 were coordinated and structured, i.e. how volunteers were organized, and what were the main outcomes of their activity in the context of disaster management. The results show that a large number of remote contributors spread across the world carried out concerted efforts to support the relief work. Moreover, coordination mechanisms were used by local actors to share their knowledge with remote mappers, and, hence, to improve the accuracy of the map.

1. Introduction

The purpose of disaster management is to reduce potential losses and ensure victims are given assistance [1]. Geographic information in particular is essential for disaster management so that action can be taken either to reduce the harmful effects of a disaster or to forecast its imminence. Thus, geographic information must be reliable, accurate and up-to-date [1], [2]. Since there is a shortage of geographic information in developing countries for example, collaborative activities have been carried out to gather geographic information from volunteers. This has important implications in the context of disaster management, since recent natural disasters have shown that Volunteered Geographic Information (VGI) [3] can improve situational awareness [1].

The collaborative mapping activity is essential for disaster management, since it collects a very specific type of data – namely, georeferenced data about features like streets and roads, buildings etc. – and structures this information in the form of a map. The OpenStreetMap (OSM) project has a great potential in disaster scenarios, which was shown when a large number of volunteers provided their support in mapping events after the earthquake in Haiti in 2010 [4,5]. Collaborative mapping in OSM has emerged as a key mechanism through which individuals can provide information about affected areas, thus making a tangible difference to the relief work and the aid agencies without actually being physically present on-site. Collaborative maps have been used by emergency agencies to know where people in need are located and how to assist them [5], as well as to carry out emergency routing [6].

Despite the advantages of collaborative mapping, disaster managers are still frequently uncertain on what they can expect from this collaborative activity, since it is not clear how volunteers can be organized and how this activity is structured in practice. The main purpose of this work is thus to understand (*i*) how collaborative mapping is coordinated, (*ii*) how local knowledge can be incorporated to add details to the map, (*iii*) what are the main outcomes from collaborative mapping and (*iv*) what is the contributors' profile.

The remainder of this paper is structured as follows: Section 2 introduces the theoretical background of this work. Section 3 examines related works. In Section 4, the case study is described. In

Section 5, there is a description of the methodology adopted in this work. Section 6 contains the detailed results. Finally, Section 7 summarizes the conclusions of this work and suggests areas for future work.

2. Background

This section presents an outline of the concepts related to disaster management and OpenStreetMap (OSM) that are used throughout this work.

2.1. Disaster management

Disaster management is a continuous undertaking that aims at reducing or preventing potential losses and ensuring victims are given assistance. This means that it is involves activities before, during and after a natural disaster [1]. The disaster management cycle is divided into four main phases: (*i*) mitigation: action is taken to prevent or reduce the likely occurrence of a natural disaster, to reduce the vulnerability of the local community or to reduce the effects of further disasters [1], [7], (*ii*) preparedness: this involves planning the best way to respond to a disaster situation [1], [8], (*iii*) response: the measures taken immediately after a disaster, and (*iv*) recovery: the measures taken to rebuild what has been damaged after a disaster [1], [7]. Each phase has different information needs for a suitable response. This information helps to improve the resilience of the affected population and assist the emergency services to carry out their tasks.

After a disaster occurs, many people need items, as food, drinking water and medical care and supplies. However, helping the affected population and providing basic supplies is a real challenge since the roads might be blocked or perhaps the area has not been mapped, as is often the case in developing countries. Collaborative mapping comprises a type of activity where the general public provides georeferenced data, like streets, roads and buildings, in the form of a map. An example of a collaborative mapping technology is the OpenStreetMap platform.

2.2. OpenStreetMap

The OpenStreetMap project, founded in 2004, aims at creating a free database with geographic information of the entire world in a collaborative manner [9].

Users can supply new data to the project in different ways: (*i*) recording data using a GPS receiver and editing the collected information by using one of the various freely available editors; (*ii*) digitizing data such as streets with the images taken from satellite imagery; and (*iii*) collecting and releasing public sources of current geographic data [11], [12].

The data provided by a user can be classified by using three types of object [11], [13]: (*i*) "Node"- this provides information of the location of a point in the form of latitude and longitude coordinates; (*ii*) "Way"- this is an ordered list of nodes which usually has at least one tag or is included within a relation, such as roads and other areas (polygon); and (*iii*) "Relations" - this defines logical or geographic relationships between the objects. Each object contains additional information such as an identifier, version number, a reference to the user and the date when it was created or last modified.

The creation/edition of an object involves making changes to the map data, for example, adding roads and buildings or changing the names of some of the features. There are many editors that can be used to this end. The top three editors for OSM are [13]: iD[1], Potlatch 2[2], and JOSM[3].

At the time of the writing this article, OSM had approximately 2 million registered contributors [10]. The OSM project initially started by mapping streets and roads [14]. More recently, it has been used for mapping affected areas after a natural disaster (the response phase) [5], and areas at risk of a likely disaster (the preparedness phase) [15]. One example of collaborative mapping which made use of the OSM platform was the collaborative aid given to victims in Haiti after the earthquake in 2010 [5].

According to Zook et al. [5], during a crisis event, the greatest benefit of distributed mapping is that a greater number of maps can be produced in a shorter period of time, allowing scarce technical resources to be diverted elsewhere. The OSM project offers a unique dataset that is global in scale and provides a body of knowledge that has been created and maintained by a very large collaborative network of volunteers [11]. Furthermore, the Humanitarian OpenStreetMap Team (HOT) has been established as a community that brings together traditional humanitarian responders and the OpenStreetMap community to support collaborative mapping tasks, operations and coordination [12]. The main communication channel between them is the HOT mailing list [12].

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[1] http://ideditor.com/

[2] http://wiki.openstreetmap.org/wiki/Potlatch_2

[3] https://josm.openstreetmap.de/

3. Related works

The OpenStreetMap project has been widely investigated in the literature. Neis and Zipf [11] analyzed several contributions to the project made by individuals. They identified 4 types of contributor profiles in OSM: "Senior Mappers" are members that created more than 1,000 Nodes, "Junior Mappers" correspond to members that created at least 10 and fewer than 1,000 Nodes, "Nonrecurring Mappers" are members that created fewer than 10 Nodes, and, finally, members without any edition represent the last group. Moreover, the authors tested whether the Rule for Participation Inequality applied to the community involved in the OSM project [11].

In the context of disaster management, Zook et al. [5] analyzed the way the OSM platform was used in response to the earthquake in Haiti (2010). The authors highlighted the results that were achieved as well as some of the setbacks experienced during the collaborative mapping activity. Neis et al. [6] used the results of collaborative mapping as a support for disaster logistics. They used the OpenStreetMap data as input for the OpenRouteService.org, a platform for emergency routing capable of calculating routes that avoid trespassing affected areas and blocked streets.

In contrast, Soden et al. [15] describe the collaborative mapping that was carried out preventively in Kathmandu (Nepal). The authors explain how collaborative mapping was used in the preparedness phase for mapping points-of-interest (e.g. schools and hospitals). Finally, Eckle and Albuquerque [4] adopt an experimental approach to evaluate the quality of the OSM data contributed by remote mappers since, owing to a lack of time in disaster situations, the data contributed by remote mappers cannot be evaluated by local mappers.

In summary, the studies mentioned analyzed the OpenStreetMap project in the context of general or disaster management, i.e. specifically during the preparedness and response phases. However, none of the studies conducted an in-depth analysis of the assistance provided by the community in the context of a specific event.

4. Case study

Nepal is a country located in South Asia with a population of approximately 27 million people [16]. The Kathmandu Valley, which comprises the capital Kathmandu, and the Lalitpur and Bhaktapur districts, is the most populated part of the country and the most seismically at-risk in terms of population numbers, during an earthquake [15].

On April 25th, 2015 at 11:56 AM (local time), an earthquake with a magnitude of 7.8 Mw struck the Gorkha district (northwest of Kathmandu) [17]. After this, there were more than 300 aftershocks with a registered magnitude greater than 4 Mw [18], including one with a magnitude of 7.3 Mw on May 12th, causing more than 8,600 deaths and destroying approximately 500,000 buildings [19].

The Kathmandu Living Labs (KLL) is a non-profitmaking organization devoted to the co-creation and implementation of information technology solutions to increase urban resilience and civic engagement in Nepal [20]. After the earthquake, the KLL team, working together with the Humanitarian OpenStreetMap Team (HOT), started to coordinate mapping activities along with the OpenStreetMap community to provide detailed and accurate maps that could enable humanitarian organizations to locate people at risk and provide goods and services to the areas that needed them most [13].

5. Methodology

This work employs both qualitative and quantitative methods to perform an exploratory case study of the collaborative mapping activities, carried out before and after the Nepal earthquake. The objective is to provide a deeper understanding on what a disaster manager can expect from collaborative mapping, how volunteers are organized and how this activity is structured in practice.

We thus aim to answer the following research questions:

1. *How is a collaborative mapping activity coordinated during a crisis situation?*
2. *How does local knowledge improve the accuracy of a map?*
3. *What are the main outcomes from a collaborative mapping activity?*
4. *What is the contributors' profile?*

The authors of this study actively took part as remote mappers and organizers of collaborative mapping activities in the aftermath of this earthquake. The participant observation of the mapping efforts has inspired the formulation of the research questions and supported the analysis of this study.

Furthermore, this study relies upon a mixed methods approach using both qualitative and quantitative methods. In the following sections, each type of method employed is described in detail.

5.1. Qualitative analysis

The qualitative analysis was carried out to determine how a collaborative mapping activity is coordinated and structured, and how local knowledge can flow into the mapping activity to improve the accuracy of a map. The analysis is based on the mailing list from the Humanitarian OpenStreetMap Team and OpenStreetMap Notes.

In an attempt to understand how the coordination was carried out by HOT, we analyzed each e-mail message from the mailing list (sent, forwarded and answered) from April 25th to May 15th. This period was only set for coding messages with material related to the Nepal earthquake. Since we did not found a coding scheme available in the literature for classifying coordination messages from a mailing list, we designed one through a bottom-up approach. First, we created a set of codes (acknowledgement, question, coordination, training, situation report and event call) based on a first screening of messages. During the analysis, two more codes were created (quality and suggestion). The resulting eight codes and a brief description of each one is provided below.

- **Acknowledgement:** message expresses appreciation or gratitude for some job or idea;
- **Question:** message raises a point that has not yet been decided or that it is going to be solved;
- **Coordination:** message decides to integrate the different activities carried out by HOT, for example, definition of tasks for the Task Manager[4];
- **Training:** message gives information and/or instructions to improve the volunteer performance or to help a volunteer attain a required level of knowledge or skill;
- **Situation report:** message gives a report on the team´s activities in the region or provides an overview of the steps taken in a particular activity;
- **Event call:** message makes a call about the mapping events;
- **Quality:** message sets out guidelines on quality control procedures for data;
- **Suggestion:** message recommends a tool or opinion about some subject.

The OpenStreetMap Notes is a source of qualitative information that allows mappers and anonymous users to add comments about a specific point-of-interest on the map, to report an error or to give some additional information [21]. A note is made up of geographic coordinates, a comment, the author's name (which might be anonymous) and its status ("opened", "closed" or "reopened") [21], and it can be either created with OpenStreetMap editors or through an Application Programming Interface (API)[5]. The OSM API allows searching notes by keyword, however due to some limitations, it is not possible to collect all the notes from a very large area and filter them by a creation date. Thus, we designed a tool to extract data produced between April 15th and May 15th 2015 within the Nepal bounding box – i.e. 80.058 (min Longitude), 26.3477 (min Latitude), 88.2015 (max Longitude), 30.4469 (max Latitude). The source code of our tool can be found at: *https://github.com/agora-research-group/osm-notes-export*.

By drawing on the extracted data, we applied the same coding scheme of the mailing list to identify the information reported during a crisis situation. During the analysis, we created two more categories ('accuracy' and 'out of context'). The 'accuracy' code is related to the notes that represent the local knowledge of a volunteer. The 'out of context' code was used when it was not possible to interpret the content of a note.

Moreover, we obtained the registration date, the number of created nodes and the first and last edition date, through an existing web service [22] that returns user profile information from its username, so that mapping activities of the author of the note can be identified.

5.2. Quantitative analysis

The quantitative analysis was carried out to analyze the main outcomes of the collaborative mapping activity and the profiles of the contributors. We analyzed the number of new members, active contributors (users that actively contribute to the OSM project), edited objects (Nodes, Ways and Relations) and member's activities. We limited the data extraction to the period from April 15th to May 15th and to the Nepal area. This period was chosen to determine the main outcomes of collaborative mapping before and after the disaster.

The analysis was based on the OpenStreetMap Full History Dump, a file that contains the editing history of the OpenStreetMap database and which is released every week by the Planet OSM[6]. We used the Osmium[7] tool to retrieve data in a certain period of

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[4] http://tasks.hotosm.org/

[5] http://wiki.openstreetmap.org/wiki/API

[6] http://planet.openstreetmap.org/planet/full-history/

[7] http://wiki.openstreetmap.org/wiki/Osmium

time and the Osmosis[8] tool for extracting georeferenced data from the Nepal area. From this data, we extracted the number of contributors (through the user's identifier) from the last modification made on Nodes, Ways and Relations. For each contributor, we obtained his/her mapping activities through the web service [22] and we classified which member was new. The total number of active contributors was extracted for each day through a request for another existing web service [10], which returns the number of active contributors of the previous day. Finally, the number of edited objects was defined by counting which objects were modified during the period studied.

We analyzed the modified nodes distribution to create a density map that assists to identify which areas were mapped before, during and after the earthquake. Nodes were clustered with a Kernel Density Estimation algorithm using the Heat Map plugin of QuantumGIS[9]. The kernel bandwidth, a distance of influence between points, was delimited to 5 kilometers, what generated "hotspots" of mapping activities.

6. Results

In the next sections, we examine the results achieved for each of our research questions in turn.

6.1. Coordination of collaborative mapping activity

Since the Humanitarian OpenStreetMap Team brings together traditional humanitarian responders and the OpenStreetMap community, we investigated the HOT mailing list to understand how the coordination of the collaborative mapping activity in Nepal was carried out. This entailed analyzing 882 messages sent, forwarded and answered during the period from April 25th to May 15th 2015.

According to the data shown in Figure 1 the most representative codes found were "Coordination" and "Question", accounting for 65% of the total number of messages exchanged between members of HOT. From the following messages, a first attempt of coordinating collaborative mapping activities can be observed. This was designed to align the attempts made to map the affected areas and to assist the team on-the-ground.

"We started an international skype communication and gather infos."
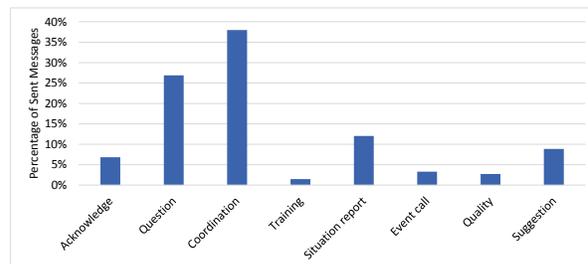
Date: April 25, 2015

"KLL is getting ready to be the local link for mapping. Hope we can start the work soon. There are issues with internet and electricity."

Date: April 26, 2015

"I'm trying to validate a square in Banepa east of Kathmandu.The imagery is about 5 meters out of alignment, but it is consistent.Was the area mapped earlier using different imagery?"

Date: April 26, 2015

Figure 1. Distribution of messages by category

Approximately 05 hours after the first message, a remote member sent a coordination message to give instructions about the first collaborative mapping task:

"[...] please contact and ask him [KLL Director Dr. Nama Raj Budhathoki] to contact me individually. We need infos to coordinate. First task is ready http://tasks.hotosm.org/project/994. I give instructions to avoid to trace every paths in the fields. This make more difficult to read maps. Other activators, please do not hesitate to edit and complete the job instructions."

Date: April 25, 2015

It is important to highlight that existing and new mapping tasks are coordinated through the communication between a team on-the-ground (Kathmandu Living Labs) and members of the mapping community, since only the former knows how volunteers can help in the humanitarian undertaking.

Once a mapping task was discussed between members on the mailing list, this was published on the Task Manager, a platform that shows the progress of mapping jobs and manages evaluations of the work done on the map. Thus, remote mappers could watch the progress of collaborative mapping activity without necessarily sign the mailing list.

When a new task is set, an email is sent to the mailing list and the remote mappers can collaborate with each other to accomplish it. In the Task Manager, each task was classified according to the level of experience of a mapper, since critical areas and

validations were designated for experienced mappers, while other areas were designated for novice mappers.

The complete process of collaborative mapping activity is presented in Figure 2.
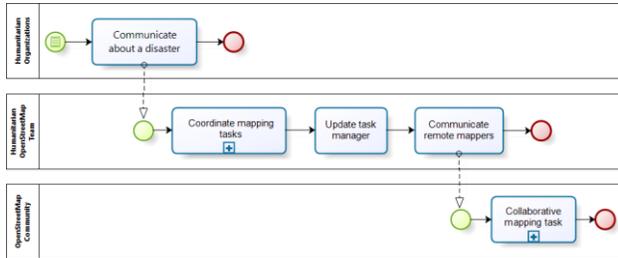
Figure 2. Coordination process of the collaborative mapping activity

6.2. Coordination with local actors

In a disaster situation, aerial images are used by remote individuals to map affected areas. However, this data does not provide further information about the conditions of a point-of-interest. In these cases, local residents are the best source of information, since they have enough local knowledge to improve the details of the map. OpenStreetMap Note is a simple kind of aid since it allows users to create a small report about a specific location, and a source of local knowledge or information.

From the notes extracted in the time interval from April 15th to May 25th and for the Nepal area, 701 notes (a change of status is also considered a note) were analyzed, although only 230 relevant notes were classified, 215 of them being notes related to the Nepal earthquake.

The analysis of the authors´ notes found that 69 registered users had created notes with relevant material during the study period. Of these, 41 users were created after the earthquake (new members) and 26 users had no editions on the map, that is, these accounts were only used to manage the notes. We believe that these users did not alter the map because they: (*i*) had little or no technical knowledge to edit the map; (*ii*) had little or no experience with editors; (*iii*) encountered difficulties with the training material (learnOSM[10]); (*iv*) did not have enough time to edit the map correctly; or (*v*) used other tools that had drawbacks with regard to editing, such as mobile applications like OSMAnd[11]. However, their contributions are useful for map improvement, since most notes refer to information in terms of "accuracy" and "situation report" (Figure 3). This proves that notes

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[10] http://learnosm.org/en/beginner/
[11] http://osmand.net/

are useful for local knowledge or information sharing and, hence, for the improvement of a map since a lot of valuable information can be passed on to humanitarian aid organizations:

"Nagarik Community Teaching Hospital Hospital Gatthaghar(opposite to sajha petrol pump), Bhaktapur, Nepal Phone: +977 984-1214747."
Category: accuracy; Date: April 27, 2015

"Roja Cold Store (Convenience Store) This area is known to locals as 'Itali Chowk' and local buses recognize this stop as 'Anmol Hospital'."
Category: accuracy; Date: April 26, 2015

"Shelter - People took refuge at this school's open space from the earthquake."
**Category: situation report; Date: April 26, 2015**

"Hyatt Hotel is supplying assistance to many foreigners and members of Rangjung Yeshe Institute in their tennis courts here. This is their main rally point."
Category: situation report; Date: April 27, 2015

6.3. Outcomes of collaborative mapping

Since direct data extraction about all the members or stages of registration is not possible in the OSM project [11], we could not calculate the real number of new registered members before and after the earthquake. Instead, we could only analyze the number of new registered members who edited an object in Nepal.
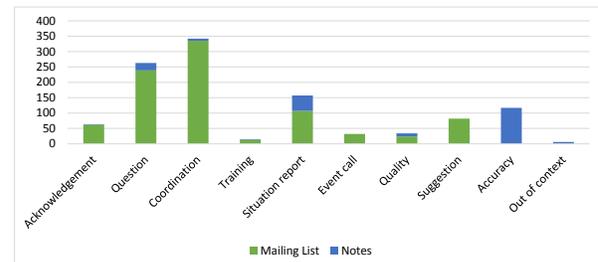

Figure 3. Comparison between the amount of messages on the mailing list and the notes by category

On the basis of the full history dump, we were able to create a list of new registered members before and after the earthquake. This was carried out by retrieving the registration date from all users who edited an object in Nepal. The results show that until April 24th (before the earthquake) only 43 new members were editing objects in Nepal. However, comparing with the number of new members after April 25th (after the earthquake) a sharp difference in the number of new members

could be identified (Figure 4). After the earthquake, 4,287 new members registered in the OSM project. This difference could partially be explained by the fact that crisis situations can encourage volunteers to join humanitarian schemes.
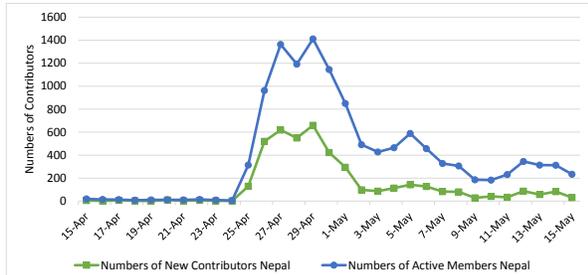
Figure 4. Number of new and active members

In the light of this result, we analyzed the number of active contributors, since there is a widespread misconception that users must be registered before they can retrieve OSM data [11]. Thus, a member might be registered in the OSM project, but not actively edit any object. The results in Figure 4 show that before the earthquake the number of active contributors was less than or equal to twenty per day. However, after the earthquake, we found there was a sharp rise in the number of active contributors. April 25th to May 1st was the period with most active contributors, 7,238 members were active, which is an average of 1,034 contributors per day. The increase in the number of active contributors can partially be explained by mapping parties organized in Bangalore[12] (India) on April 26th and in Barcelona[13] on April 28th, and the collaborative mapping calls sent through the Humanitarian OpenStreetMap Team mailing list:

"First task is ready: http://tasks.hotosm.org/project/994. I give instructions to avoid tracing every paths in the fields.
This make more difficult to read maps. Other activators please do not hesitate to edit and complete the job instructions".
Date: April 25, 2015.

"We are looking to host a mapping hackathon at San Francisco State University in the next few days for the #NepalEarthquake effort […]"
**Date: April 30, 2015.**

"I've been running trainings at Stanford all week. I can help coordinate and possibly teach, next week. Let me know what days/times you have in mind."
Date: April 30, 2015.

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[12] http://bit.ly/nepal2015-mapathon-bangalore

[13] http://bit.ly/nepal2015-mapathon-barcelona

Furthermore, the question remains how long after the registration, could a new member start editing an object. Based on the information retrieved from the OSM database, it was possible to determine the date of the first edit made by a new member. The results in Figure 5 show that approximately 75% of all members first edited an object on the same day that they were registered in the project. This lack of an interval between the registration and first edit date can be explained by the urgent need for digital maps during crisis situations, since emergency services need maps to provide better relief for the affected population.
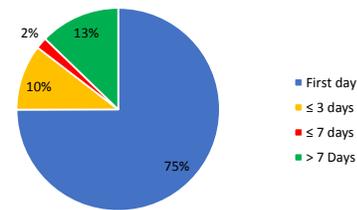

Figure 5. Interval between the registration and first edit date

To give a better overview of the members' activities, we analyzed the number of object types edited before and after the earthquake. The largest group of edited objects is the Nodes type. The results show that 97,082 Nodes were edited before the earthquake, representing 0.84% of all edited Nodes, and 11,395,286 Nodes were edited after the earthquake, representing approximately 99% of all edited Nodes. The second group with the highest number of edited objects is the Ways type. The results show that there were 9,363 Ways, representing 0.57% of all edited Ways, and 1,624,774 Ways, representing 99.4% of all edited Ways, were edited before and after the earthquake, respectively. Finally, the smallest group of edited objects is the Relations type. A total number of 451 Relations, representing 14.8% of all edited relations, and 2,594 Relations, representing 85.2% of all edited relations, were edited before and after the earthquake, respectively. Figure 6 shows the total number of objects edited before and after the earthquake.
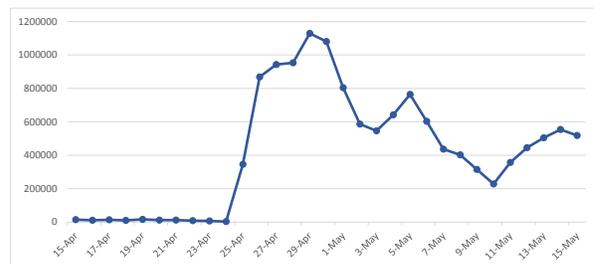
Figure 6. Number of edited objects
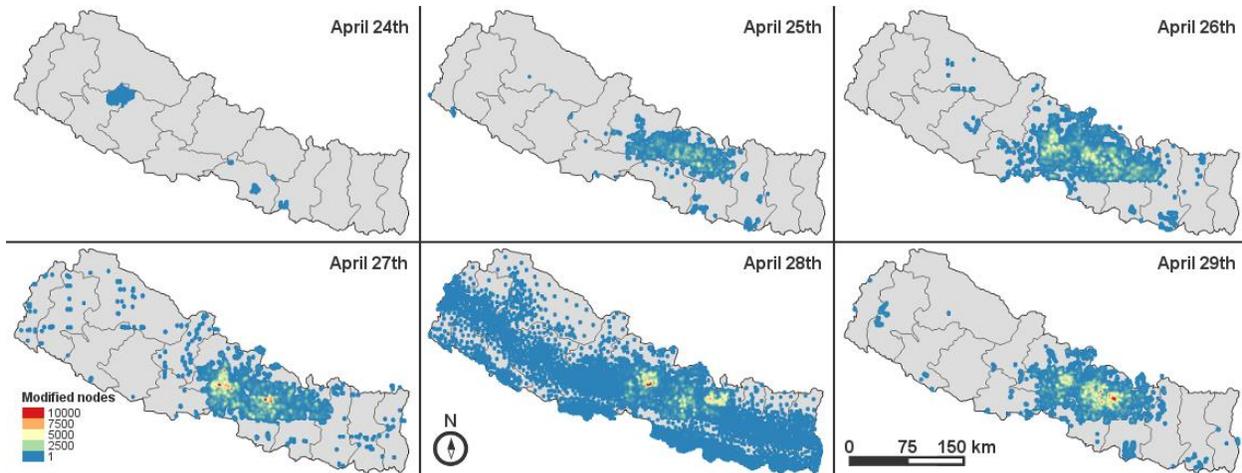
Figure 7. Spatial distribution of the collaborative mapping activity in Nepal before and after the earthquake of April 25th 2015

The areas where the collaborative mapping activity was more intense during the period from April 24th to April 29th have been highlighted (Figure 7). The Kathmandu Valley is the area with the highest number of individual contributions.

The sharp increase of edited objects after the earthquake can be is directly attributed to the increase of active contributors in the same period. Thus, it can be concluded that crisis situations not only acts as a motivating factor for volunteers to join humanitarian campaigns, but also to contribute to them. Other factors that encourage users to contribute might be the chance to learn a new technology, self-expression or a belief that geospatial information should be freely available to everyone [11]. Moreover, the sharp increase of edited objects might be attributed to the mapping parties organized after the earthquake, as we described in detail above. Finally, the sharp rise is due to the coordination carried out through the HOT mailing list.

It is worth noting that a large number of objects were edited from April 26th to May 6th. After this period, the number of edited objects, (apart from the objects from the Relations type), decreases with time, and only began to increase again after the aftershock with a magnitude of 7.3 Mw on May 12th. We believe that this phenomenon may be related to the involvement of volunteers, i.e. after a certain period of time, this involvement declines and, hence, the number of edited objects also decreases.

6.4. Contributor profile

Another point that we analyzed is related to the members' profiles, since the Humanitarian OpenStreetMap Team defines tasks that are suited to

either experienced and non-experienced mappers, as we can see on the messages sent to the mailing list:

"[...] We would surely need a validation process that let's focus on the less experienced contributors. I wonder if such information could be extracted from the Task manager - Tasks completed by contributors less then xx months of experience? [...]"

Date: April 27, 2015.

"[...] I will ask on the Missing Maps platforms that people not contribute if this is their first time mapping. It might be good to put a note on the description and instructions on the tasks: EXPERIENCED MAPPERS ONLY [...]"

Date: April 27, 2015.

In Figure 8, the green column represents members who contributed with map editions and the blue column, the members who created notes in the study period. In both, their group classification depends on the number of Nodes created.
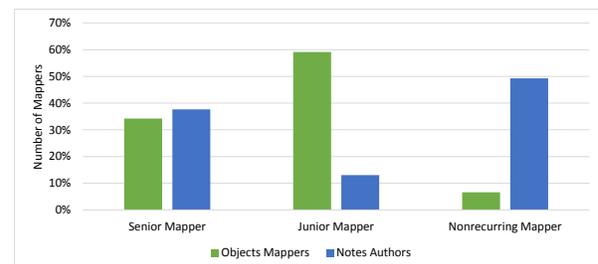
Figure 8. Distribution of active contributors based on their node editions

As can be seen in Figure 8, the "Junior Mappers" is the largest group with map editions, due to the large

number of new members registered after the Nepal earthquake.

In contrast, "Nonrecurring Mappers" and "Senior Mappers" contributed more with notes, due to the fact that experienced users either reply to or close the notes created by beginners.

7. Discussion and conclusions

This paper presents the results of an exploratory case study on the collaborative mapping efforts of the OpenStreetMap (OSM) community in response to the Nepal earthquake of April 25th 2015. This enabled us to understand better how the collaborative mapping activity in the aftermath of a disaster is coordinated and structured. Thus, this study complements existing studies which are focused on the mapping activity of the OSM community which is not related to disasters [9][11][14] and analyses of the data produced by the OSM during crisis that is solely focused on the data produced and disregards the coordination activities [4] [5] [6].

The HOT mailing list is the main communication channel employed. This list effectively works as a "virtual crisis control room", enabling the coordination of hundreds of volunteers throughout the world, HOT coordinators and disaster managers of humanitarian organizations. Hence, it is important that disaster managers and emergency agencies know about the mailing list, since coordination activities and prioritization of tasks are carried out on it.

An important finding of our study is to reveal that OSM Notes are another important coordination mechanism. They act as an instrument to connect remote mappers to local actors. Nonrecurring mappers on-site use specific mobile apps to create notes for sharing local knowledge about geographic objects with remote mappers and humanitarian aid organizations. As a result, OSM Notes help remote mappers improve the maps with rich details and local knowledge contained in the notes. To the best of our knowledge, this source of information has not been explored by previous research studies on OSM, and thus consists of an important a direction to be explored by the scientific community in future studies, in order to further understand how the communication is established between local actors and remote mappers.

An expressive response of the community is the main result of the collaborative mapping activity in Nepal, whereas a large number of objects were created after the earthquake. It is worth noting that community participation was not restricted to the most affected areas, spreading across the country. This can be explained by the coordination activity carried out through the mailing list and Task Manager.

Generally, in the context of disaster management, geographic data is created/edited by mappers that do not have experience on mapping activities, i.e. the so-called 'junior mappers'. In contrast, OSM Notes are created/edited by senior and nonrecurring mappers, since the later use this mechanism to answer questions about the mapped areas based on local knowledge and, hence, the former can improve the accuracy of OSM data. The high frequency of Nonrecurring Mappers is explained by the fact that it is not necessary to be a registered user to create notes.

In previous studies (e.g. [11]), the contributors' profile was considered as a whole and not in the context of disaster management. In the context, a challenge that must be faced is related to the lack of experience of most mappers, since this could have an impact on data quality. Therefore, further research is needed to verify if and how the contributor profile affects data quality.

This study was able to provide a concrete account of the high potential of the concerted collaborative mapping activity of the OSM community for supporting disaster relief. Despite this significant result, the scope of the study did not include a deeper investigation of the real usage of OSM maps and data by disaster responders in the field. This is an important issue to be explored in future studies, so as to further expand our knowledge on collaborative mapping in the context of disaster management.

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9. References

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