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# A review about the use of volunteered geographic information for supporting decision-making in disaster management

# Una revisión sobre el uso de información geográfica voluntaria para apoyar la toma de decisiones en la gestión de desastres

# Uma revisão sobre o uso de informação geográfica voluntária para apoiar a tomada de decisão na gestão de desastres

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## Abstract

The frequency of disaster events has highlighted the need to adopt measures that can enable communities to deal with them and reduce the damage they cause. The combination of Spatial Decision Support Systems (SDSS) and Volunteered Geographic Information (VGI) raises numerous opportunities for supporting decision-making, and thus minimizing the impacts of the disaster. However, the literature still lacks research that investigates how this combination has been done until now. In this context, the purpose of this paper is to tackle this problem by employing a review methodology based on the steps defined for the systematic mapping study. The results showed that the use of VGI in decision-making has been growing over the last years. Moreover, the use of collaborative platforms (e.g. OpenStreetMap) still showing up as a promising field of research, mainly because only a few studies in this topic were found in this work.

**Keywords:** Disaster Management, Volunteered Geographic Information, VGI, Crowdsourcing.

## Resumen

La frecuencia de los desastres ha puesto de manifiesto la necesidad de adoptar medidas que permitan a las comunidades afrontarlos y reducir los daños que causan. La combinación de Sistemas de Apoyo a la Decisión Espacial (SDSS, por sus siglas en inglés) e Información Geográfica Voluntaria (VGI , por sus siglas en inglés) brinda numerosas oportunidades para apoyar la toma de decisiones y, por lo tanto, minimizar los impactos del desastre. Sin embargo, la literatura aún carece de trabajos que investiguen cómo se ha realizado esta combinación hasta ahora. En este contexto, el propósito de este trabajo es abordar este problema empleando una metodología de revisión basada en los pasos definidos para el estudio de mapeo sistemático. Los resultados mostraron que el uso de VGI en la toma de decisiones ha ido creciendo en los últimos años. Además, el uso de plataformas colaborativas (por ejemplo,

OpenStreetMap) sigue apareciendo como un campo de investigación prometedor, principalmente porque en este trabajo solo se encontraron unos pocos estudios sobre este tema.

**Palabras clave:** Gestión de desastres, Información geográfica voluntaria, VGI, Crowdsourcing.

## Resumo

A frequência na ocorrência de desastres tem destacado a necessidade de adotar medidas que permitam às comunidades lidar com os eventos, bem como reduzir os danos potenciais. A combinação de Sistemas de Apoio à Decisão Espacial (SDSS) e Informação Geográfica Voluntária (VGI) traz inúmeras oportunidades de apoio à tomada de decisão, minimizando assim os impactos do desastre. No entanto, a literatura ainda carece de pesquisas que investiguem como essa combinação tem sido feita até agora. Nesse contexto, o objetivo deste artigo é abordar esse problema por meio de uma metodologia de revisão baseada nas etapas definidas em um mapeamento sistemático. Os resultados mostraram que o uso do VGI na tomada de decisão vem crescendo nos últimos anos. Além disso, o uso de plataformas colaborativas (e.g., OpenStreetMap) ainda se mostra como um campo de pesquisa promissor, principalmente porque poucos estudos neste tópico foram encontrados neste trabalho.

**Palavras-chave:** Gestão de Desastres, Informação Geográfica Voluntária, VGI, Crowdsourcing.

## 1   Introduction

In the past few years, several natural disasters have affected the communal life of some countries (Haiti in 2010, Australia (Queensland) in 2010-11, Japan in 2011, and the Philippines in 2013) and caused serious damage to all of them. These events can be defined as a disruption of the "local capacity" of a community that has several adverse effects (e.g. loss of life, the spread of disease, financial problems, environmental degradation, etc). Moreover, it leads to difficult circumstances for their members, and the need for assistance at both a national and international level (Jha, 2010; Marcelino, 2007). These facts show the need to carry out relief activities to build some form of resistance against these disasters, i.e. to enable communities to resist, change or adapt, if there is a disaster (Norris et al., 2008).

In this context, Spatial Decision Support Systems (SDSS) which combine geographic information (obtained from official agencies and sensor networks with mathematical models represent an alternative means of predicting outcomes and supporting decision-making in the area of flood management (Hughes et al., 2011; Densham, 1991). Additionally, Volunteered Geographic Information (VGI) can be regarded as a source which can provide updated information, mainly because it is provided by ordinary citizens who live in affected areas. This relies on the use of special equipment (e.g. smartphones, web applications, and mobile text devices) and is sometimes faster than information provided by official agencies (Gao et al., 2011, Gill and Bunker, 2012). When combined, the SDSS with VGI can increase the number of decisions made in the area of disaster management. This is mainly because VGI provides updated information for SDSS, while, at the same time, these systems can integrate and share the information from the volunteers in a standardized way.

However, even with the advances made in these research areas (SDSS and VGI), there is a lack of research in the literature that analyze how these research areas have been combined for supporting decision-making in disaster management, e.g. the activities of disaster management that use VGI as source of information. This paper therefore aims to analyze the existing literature with the aim of identify studies that use different types of VGI as a source of information for supporting decision making in disaster management. This is achieved by employing a review methodology based on the analysis process proposed for the systematic mapping study.

The remainder of this paper is structured as follows. We first introduce the background. Next, we describe the review methodology. The subsequent section discusses the results achieved. Eventually we summarize this work, draw conclusions and suggest future works.

## 2    Theoretical background/Literature review

In this section, we introduce the key concepts of this work starting with disaster management and its characteristics to the conceptualization of VGI.

## 2.1    Disaster Management

During the last years, it has been seeing a growing in the occurrence of natural disasters around the world, e.g., Haiti, Chile, and Pakistan in 2010, Queensland in 2010-11, Japan and Christchurch in 2011, USA in 2012, and Philippines in 2013. The damages caused to Philippines are estimated in close to 7.000 deaths and $USS2.86 billion, it was the worst and deadliest storm that affected the country (data from EM-DAT1).

A natural disaster occurs when a community is struck by a hazard and financial, social, and structure losses and impacts are so large that exceeds the ability of the affected community or society to cope using its resources (De Longueville, 2010). Besides, it can be described as a combination of three elements: exposure to a hazard, the current vulnerability, and capability to deal with the impacts (UNISDR, 2009), i.e. the disaster is determined by a natural hazard (e.g. a floods) that affected and brought several damages for a exposure community (e.g. buildings located close to flooding critical sides); vulnerability can be defined by the social, structural, and economic characteristic of population susceptible to damaging effects (e.g. poor drainage system); and the prevention infrastructures (e.g. evacuation routes) (Bank, 2013).

This growing occurrence has highlighted the needed to adopt measures to increase the power of resilience, change and adaptation of communities affected (Baharin et al., 2009; Mendiondo, 2010; Norris et al., 2008; Poser and Dransch, 2010). In this context, the disaster management presents as an important alternative to achieve this resilience and, as a consequence, avoid or, at least, reduce the impacts caused by natural disasters (Baharin et al., 2009). In general, it is a continuous process composed by some different activities executed before, during and after an event and separated into four main phases: mitigation, preparation, response and recovery, as shown in Figure 1.



**Figure 1: Disaster management (Poser and Dransch, 2010).**

The disaster management defines a set of specific activities to be performed in each of its phases, beginning with those defined for the mitigation phase, whose goal is to eliminate or reduce the probability of disaster (Poser and Dransch, 2010). When the event impact is inevitable, activities are executed to plan the best way to respond to a disaster before it occurs (Vivacqua and Borges, 2012). Then, in the response phase, realized after the disaster, actions defined in the preparation phase are executed. Finally, recovery activities aim to restore vital infrastructure and basic services of the affected communities.

## 2.2    Volunteered Geographic Information

During the last years, tsunamis, earthquakes, and hurricanes have hit various countries and shaken the day-to-day of their societies. This largely irreversible damage affects the coexistence of people, brings difficulties to the EAs, and delay the response processes. This must necessarily be fast and reliable because a slow response based on incorrect data can lead to serious consequences, such as loss of lives (Ostermann and Spinsanti, 2011).

In parallel, the emergence of Web 2.0 and the evolution of mobile devices that allow content creation has become the basis for the emergence of a new paradigm. A new era in which users in general (i.e., citizens) become established as producers of data and information (Niko et al., 2011). This is, in many cases, more detailed and of a higher quality than that provided by official agencies (Elwood, 2008; Goodchild, 2007).

Heipke (2010) proposed the term "crowdsourcing" for this phenomenon which involves content production being carried out by a third party, that is assigned to intelligence and knowledge. It is based on the experience of volunteers, who are independent in the way they use their free time and are located in remote and diverse areas. In a similar context, but more closely linked to geographical issues, Goodchild (2007) coined the term Volunteered Geographic Information (VGI) to name this phenomenon, which was defined as a collection of digital spatial data produced by individuals and non-formal institutions, i.e. by ordinary citizens using appropriate tools to gather and disseminate their views and geographical knowledge on the web. According to Coleman et al. (2009), this volunteerism has a high potential to expand and qualify the amount of information available about the events and experiences of the community members.

The VGI has been employed by several technological platforms (e.g. Wikimapia, OpenStreetMap, Mechanical Turk, CloudCrowd, and Wikipedia) as well as to assist the EA and affected communities to perform their activities, mainly those executed in prevention and response phases of disaster (Horita et al., 2013). Through them, various users have generated information on the internet. A study in the USA shows that 35% of these users create content and put it online, and 26-34% of them share this content (Flanagin and Metzger, 2008). In the research field, studies focused on analyzing the impacts of disasters (Poser and Dransch, 2010), the development of frameworks for processing and sharing the information (Goodchild and Glennon, 2010), and the evaluation of the use of social media (e.g., Twitter and Flicker) are evidenced.

## 3    Review Methodology

This section presents the details regarding the review methodology employed in this work. This consists of three activities: (1) definition of research questions; (2) definition of search string; and (3) definition of the search process and study quality criteria.

## 3.1    Research Questions

This work employs the methodology of systematic mapping study described by Peterson et al. (2008). A systematic mapping study is a review approach that has been using by software engineering researchers to obtain relevant studies in the literature. However, different from the systematic literature review (Dyba et al., 2007; Kitchenham and Charters, 2007), it aims to analyze relevant studies in order to give an overview of the topic or theme (Peterson et al., 2008). Then, the state of evidence in specific topics can be deeper investigated using a systematic literature review (Peterson et al., 2008; Budgen et al., 2008).

Since the objective of this work is to identify relevant studies that address the use of VGI as a source of information to support decision-making in the disaster management, the following research questions were defined for being answered:

- RQ1.1: Which activities of disaster management have been using volunteered geographic information as a source of information?

- RQ1.2: Which are the most used types of volunteered geographic information?

## 3.2    Search String

For the definition of the search string, we first identified the main terms associated with the research question. Next, the synonyms of each main terms were identified aiming to obtain all relevant studies. Finally, the synonyms were joined using the Boolean operator "OR" while the main terms using "AND". The search string and its terms are shown in Table 1.

| Keyword | Synonyms |
|---------|----------|
| Decision Support Systems | DSS and Decision-making and Decision model and Decision Support Model and Decision Support |
| Voluntered Geographic Information | VGI and Crowdsoucring and User-generated Content and Social Media and Collaborative Systems and Collective Knowledge and Citizen Based |
| Disaster Management | Crisis Management and Emergency Management and Disaster Response and Emergency Response and Flood and Earthquake and Tsunami and Crisis Situation and Crisis Response and Natural Hazards and Disaster Relief |

**Table 1: Search string**

## 3.3    Search Process and Study Quality Criteria

The search process aims to identify studies that might be relevant for answering the research questions. This involved automated searches in five well-known digital libraries, IEEExplore, ScienceDirect, Scopus, and ISI Web of Science, and AISeL. Therefore, we employed the following three-step search process in each of the mentioned libraries.

- Initial Selection: First, it was selected only studies obtained by applying the search string in the electronic databases.

- Second Selection: The studies returned in the previous step were evaluated according to its title and abstract, and a list containing only those considered potentially relevant was generated.

- Third Selection: Finally, the studies included were fully read and evaluated. An automated tool is used With the aim of facilitate the data extraction. Besides, the quality of each selected studies is performed. For this, it was five criteria that seek to measure the existence of fundamental concepts for the context area. For each question was applied the following scale of values: Yes (Y) = 1 point, No (N) = 0 point, Partly (P) = 0.5 point. Next, the quality of each study is based on the summed of these values. The list of questions is shown in Table 2.

| ID | Description |
|-----|-------------|
| QC1 | IS there a clear statement of the research objectives? |
| QC2 | Were the results evaluated in an unbiased manner? |
| QC3 | Are the results reported clearly? |
| QC4 | Is there a clear background that supports the reserach? |
| QC5 | Is the method used for valiation of the study clear? |

**Table 2: Study Quality Criteria.**

## 4  Results & Discussion

This section first describes the selected studies. Next, the selected studies are summarized to answer the proposed research questions.

### 4.1  Characterization of selected studies

The 13 studies selected in the final selection were equally distributed along of the database (1 per year) with the exception of 2010 and 2012. The first study was published in 2010, after that there is an interest growing process in the use of VGI for decision-making in disaster management from 1 in 2010 to 6 in 2012. In 2013, the low number could explain because this work was conducted until the end of the year. Figure 3 presents the number of studies selected along the years per electronic database.
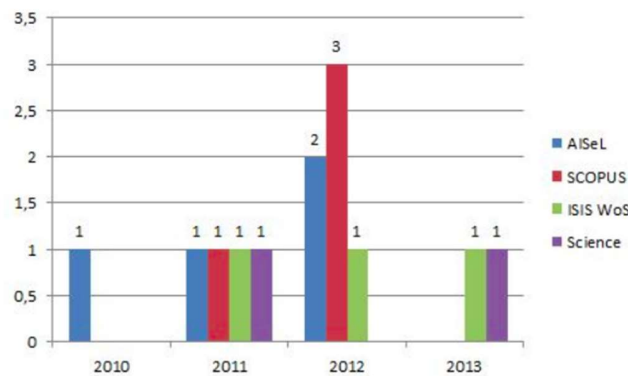


**Figure 3: Selected studies per years**

SCOPUS and AISeL have the same number of studies selected (four studies), they are followed by the ISI Web of Science with three studies and, at last, Science Direct with two studies.

The number of studies at SCOPUS and AISeL could be explained due to the fact that SCOPUS is a well-known integrated repository while AISeL is an important repository from Information Systems (IS) research community having a lot of studies related to DSS and IS for decision-making. Table 3 displays the main information of the studies selected.

| ID | Description | Score | Database | Type |
|----|-------------|-------|----------|------|
| P1 | Oh et al. (2010) | 5 | AISeL | C |
| P2 | Ahmed (2011) | 3 | AISeL | C |
| P3 | MacEacheren et al. (2011) | 5 | SCOPUS | C |
| P4 | Hashimoto et al. (2011) | 3 | ISI Web of Science | C |
| P5 | Yates and Paquette (2011) | 5 | ScienceDirect | J |
| P6 | Erskine and Gregg (2011) | 4 | AISeL | C |
| P7 | Kaewkitipong et al. (2012) | 4 | AISeL | C |
| P8 | Poh et al. (2012) | 5 | SCOPUS | C |
| P9 | Hashimoto et al. (2011) | 4.5 | SCOPUS | C |
| P10 | Elwood (2008) | 4 | SCOPUS | C |

| ID | Description | Score | Database | Type |
|----|-------------|-------|----------|------|
| P11 | Rijcken et al. (2012) | 4 | ISI Web of Science | J |
| P12 | Widener et a. (2013) | 5 | ISI Web of Science | J |
| P13 | Kumar and Havey (2013) | 5 | ScienceDirect | J |

**Table 3: Selected Studies.**

The quality assessment of this work achieved some relevant index, the selected studies scored index over the 3 points in the evaluation having 46,15% classified as Excellent (5 points), close to 69% as Good (4.5 points), and 30,76% were Classified as Medium (4). This fact highlights the relevance and credibility of the studies selected. Besides, 69,23%the studies selected were published in a conference while others 30,77% in a journal. This fact also evidences that this research field still immature and further researches are needed.

## 4.2    Analysis of Research Questions

In this section, we summarize the data collected in selected studies with the aim of answering the proposed search questions.

*RQ1.1: Which activities of disaster management have been using volunteered geographic information as a source of information?*

The selected studies in this work highlight the usage of information provided by volunteers for five purposes in disaster management:

- **Event Forecasting:** Due to the huge number of data shared by volunteers in social media, they have been used to aid to forecast events before or during it strikes an area (Hashimoto et al., 2012). This detection could help in efficiently managing a disaster situation, e.g. identifying the real-time situation in the area (Pohl et al., 2012).

- **Situation Awareness:** To identify the situation awareness presented in the affected areas are essential to support the activities of decision-makers. Social media are becoming important information input to support situational assessment (to produce awareness) in all domains (MacEachren et al., 2011).

- **Prevention:** The prevention activities are important to reduce the communities' vulnerability to a disaster (Rijcken et al., 2012). In this context, the information provided by volunteers using collaborative maps (e.g. OpenStreetMap) or social media has been used to identify the current state of environmental variables and, as a consequence, aid to decision-making in preparedness phase (e.g. planning the land use at the vulnerable locations).

- **Evacuation:** During an evacuation, the current state of the environmental variables are essential to guarantee its efficiency and accuracy (Gottumukkala et al., 2012). For example, if there is a tree blocking the road as soon as decision-makers (or even the community) known this fact, they will have more time to analysis an alternative route. In this context, the information shared by volunteers located in the affected areas has been helping to update these environmental variables (e.g. traffic flow).

- **Supply Chain:** The processes of the supply chain during disaster relief efforts have several unstable variables as well as a set of environmental factors associated. Because of this, the proliferation of social media creates research opportunities to find the best ways to integrate both the efforts of relief agencies and communities' actions in the event of large scale disasters (Kumar and Havey, 2013).

Figure 4 presents the distribution of these purpose of usage in the phases of disaster management. The mitigation and recovery were removed because there is not any study which uses information from volunteers to support the activities of these phases. Besides, Hashimoto et al. (2012) did not specify in

which phase of disaster management they are developing their analysis while Gottumukkala (2012) conducted their study focusing on activities of preparedness and response phases.
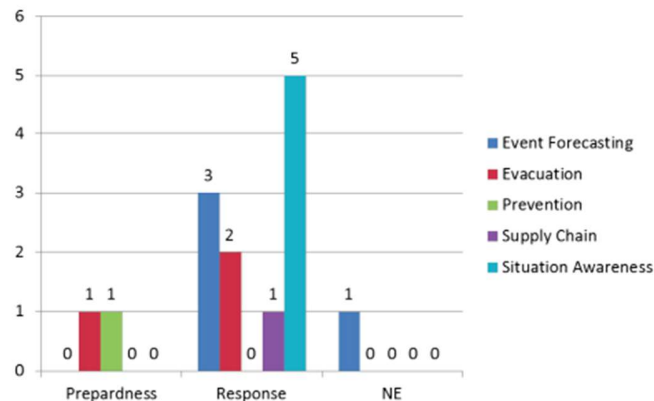


**Figure 4: The use of VGI per phase of disaster management.**

Figure 4 also evidenced that the number of studies conducted for the response phase is higher in comparison to those performed for preparedness. This fact could be explained because this phase has received a lot of attention from volunteers (Horita et al., 2013). Besides, most of the interesting analysis of communities reaction in case of a disaster are performed in this phase. For example, we could understand how the community deals with the routes alternatives in case of evacuation or how the members close to an affected area share the information through their peers.

*RQ1.2: Which are the most used types of volunteered geographic information?*

In this work, we separated VGI according to its collaborative activities: (1) information sharing through social media (e.g. Twitter), (2) collaborative mapping (e.g. OpenStreetMap), and (3) collaborative analysis (e.g. citizen observatories) (Degrossi et al., 2013). Thereby, Table 4 presents the separation of the number of information from volunteers used to support decision-making in disaster management.

As expected, social media was the most found type of VGI (with 11 studies). This might be because this platform is widespread in the communities not only for professional activities but also for personal activities. Therefore, citizens are used to it. Although a few studies were found in collaborative mapping and collaborative analysis, these areas might grow in the next years, mainly because of their potential in providing real-time and useful spatial information.

| Type | Number of studies | % |
|------|-------------------|---|
| Social Media | 11 | 84,62% |
| Collaborative Mapping | 1 | 7,69% |
| Collaborative Analysus | 1 | 7,69% |
| Total | 13 | 100,00% |

**Table 4: Most used types of volunteered geographic information.**

## 5   Conclusion

This paper employs a review methodology for analyzing the use of VGI as a source of information to support decision-making in disaster management. The results showed that the field of research has been growing over the last four years, although further research is still needed. In this manner, the use of collaborative mapping and collaborative analysis raises as a promising research area, mainly because of the intensive use of OpenStreetMap and Ushahidi. Moreover, it was identified a few studies for supporting the activities during the preparedness phase (e.g. early warning or planning of resource allocation) and none study for

the mitigation and recovery phases of disaster management (e.g. reconstruction or land-use planning). Finally, it might be emphasized the potential of taking a top-down approach rather than a bottom-up approach, which was the common approach found in this work. This is in line with a recent group of works (Vieweg et al., 2014) that acknowledge the importance of identifying information needed prior to data analysis.

Due to the time to conduct this work, some essential threats could be highlighted. The final number of studies selected is really low and could not be used to generalize the results. The inclusion of more electronic databases and synonyms could solve this fact and increase the quality of the results. Furthermore, during the extraction process, some information described in the study were difficult to analyze and understand. To achieve this problem, the opinion of one more reviewer could be essential to reduce biases and understanding problems.

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