Flood Citizen Observatory: a crowdsourcing-based approach for flood risk management in Brazil

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Abstract—**The number and intensity of floods have increased worldwide due to climate change, causing more damage, deaths and economic impacts than any other natural disaster. Coping with this type of disaster requires up-to-date, complete and accurate information about the current state of environmental variables. To make a contribution in this context, this paper proposes a crowdsourcing-based approach for obtaining useful volunteer information for the context of flood risk management. Furthermore, an experimental evaluation was performed in order to verify the effectiveness of this approach.**

Keywords- Flood Risk Management; Volunteered Geographic Information; VGI; Crowdsourcing; Citizen Observatory

I. INTRODUCTION

Climate change is increasing the number and intensity of natural disasters around the world [1]. Between 2000 and 2012, natural disasters caused approximately U$ 1.7 trillion in economic losses and affect 2.9 billion people and cause 1.2 million deaths [2]. The occurrence of natural disasters is linked not only to environmental characteristics, but also to the vulnerability of the social system [3]. In this perspective, disaster management (DM) aims to reduce or avoid potential losses and provide assistance to the victims. In particular, spatial information consists of an essential resource in the whole process of DM [4], e.g. to reduce the impacts caused by the disaster or identify its imminence. To accomplish this, information must be reliable, accurate and updated [4], [5].

In particular, floods represent 30% of the natural disasters that occur worldwide, causing more damage, deaths and economic impacts than any other event [6]. In Brazil, floods are intensified during the rainy season, between the months of December and March. Flood Risk Management (FRM) is the process of managing a situation of existing flood risk by controlling the impacts caused by it and being prepared for it [7]. Thus, information about the current state of the environmental variables is needed to allow the simulation of the effects and severity of a disaster [6], [7]. In addition, continuous monitoring of flood risk requires specific local information, such as precipitation and water height, to assess the potential flood risk. However, such information is difficult to obtain in developing countries such as Brazil.

Spatial information obtained from volunteers, so-called Volunteered Geographic Information (VGI) [8], is being used as a data source for disaster management. This is due to the fact that VGI offers a potentially large number of volunteers who act as "sensors", recording important local parameters for DM [9]. In particular, crowdsourcing platforms are used as a tool to assist organizations involved in DM to assist victims of natural disasters, collecting information from volunteers. In the past few years, different crowdsourcing platforms were deployed to map earthquakes (e.g. Haiti 2010), floods (e.g. Pakistan 2010/2011), among other hazards. However, to the best of our knowledge, there is not a crowdsourcing-based approach adapted and empirically evaluated for the reality of the informational needs of floods in Brazil. Thus, this paper proposes and evaluates a crowdsourcing-based approach to obtain useful volunteer information for context of flood risk management in Brazil.

The remainder of this paper is structured as follows: Section II presents the theoretical background for this work. In section III, the crowdsourcing-based approach proposed herein is explained. Section IV presents the empirical evaluation in detail. Finally, Section V concludes the paper and suggests directions for future work.

II. BACKGROUND

In this section, we present the concepts and underlying principles related to this work.

A. Flood Risk Management

Flood Risk Management is the process of managing a situation of an existing flood risk. The main goal is to control a flood, being prepared for it and minimizing its impacts [7]. The FRM comprises actions before, during and after a flood occurs. These actions involve early warning and forecasting scenario, contingency plans and restoration [10].

In the FRM, the preparation phase has as main objective reduce the residual risk through early warning systems and measures that can be taken to minimize the flood impacts. For this, the constant monitoring of the risks and the assessment of the danger, arising from recent information, is required. Every dollar invested in flood prevention reduces in U$ 25 dollars the damage incurred in a natural disaster [10].

Currently, geographic information and related technologies play a fundamental role in all phases of FRM. Natural disasters are typically monitored using different devices such as sensors,

satellites, seismometers, among others. In particular, different information is used in the development of model-based prediction for flood warning systems. In this context, local and up-to-date data is essential for supporting decision-making. A crucial challenge is the availability of data at all points considered strategic. However, volunteer information, as well as sensor data, can be entered in the model for forecasting, since volunteers can act as human sensors [11]. Thus, it is possible to statistically calculate the confidence intervals between the actual and estimated value. This provides probabilistic information for the following iterations of the prediction for the filling of the points where there is no real-time measurement. Still, it is possible to use these data with monitoring data to develop predictive methods correlating the information available. Furthermore, volunteers may provide information about important parameters of local conditions on the verge of occurring a natural disaster. This information can help to provide a more effective and immediate response.

B. Volunteered Geographic Information

With the advancement of Internet and mobile devices, users not only start to use the geographic information available online, but also provide it. Formerly, geographic information was created only by official agencies. However, with the increase of interactions made possible by the Web 2.0, the widespread use of devices equipped with GPS (Global Positioning System) and the availability of broadband access to the Internet, geographic information is being produced by people who have little formal qualification. This type of information is called Volunteered Geographic Information (VGI) [8]. Among the advantages associated with VGI, researchers emphasize its use to enhance, update or complement existing geospatial datasets [8].

Recent natural disasters have shown that volunteered information, provided through the Internet, can improve situational awareness by providing an overview of the present situation [9]. This fact occurs because VGI offers a great opportunity to raise awareness due to the potentially large number of volunteers, more than six billion people, that can potentially act as "sensors", recording important parameters for disaster management in a local environment [8], [9].

VGI has been widely used in the context of disaster management. Some examples are the floods in Pakistan in 2010, Queensland in 2010/2011, Thailand in 2011, the Haiti earthquake in 2010, forest fire in France in 2009, among others [13]–[17]. [9] used information provided by the affected citizens by the flood of 2002 in the city of Eilenburg, Germany, to estimate impacts. Furthermore, the use of volunteered information proved essential after the earthquake in Haiti in 2010, because the existing maps of the city of Port au Prince (worst affected area) were outdated and did not contain sufficient information, making it difficult to coordinate the rescuers' activities [18].

Despite the potential of VGI, data quality is a major concern. Information from many individuals can lead to doubts about their credibility [19]. According to [20], the credibility of VGI can be understood as a subjective concept that describes whether a piece of information can be trusted, considering any possible intentional or unintentional omission or exaggeration

error. Moreover, it is not known beforehand how and wherefrom the information will be provided. Another challenge faced refers to the location, because volunteers are in constant movement. Furthermore, VGI is often regarded as poorly structured, documented and validated [20].

In this scenario, different software platforms have been employed in order to collect volunteered information, allowing its visualization and analysis. In particular, these are used as tools to help the victims of natural disasters.

C. Citizen Observatory

Currently, several crowdsourcing platforms support disaster management, enabling the gathering of information from citizens about the affected areas, as well as their analysis and visualization. The term crowdsourcing refers to a way of organizing the work, which involves an information system to coordinate and monitor tasks performed by people [21]. Moreover, this term can be understood as a production model where the intelligence and knowledge of volunteers are used to solve problems, create content and develop new technologies. Using volunteers to perform a specific task, such as environmental monitoring, collectively make a Citizen Observatory (CO), where data can be collected, collated and published [21]. Thus, the term Citizen Observatory can be understood as a software platform in order to obtain volunteered information about a specific topic through different devices (e.g. web browser, mobile application and SMS), and allow their visualization. In this manner, a CO can be used to share information about flood risks, such as water height in the riverbeds or flooded areas.

Different COs were used in the context of flood risk management. In 2011, during the floods in Queensland, the Australian Broadcasting Corporation launched a CO to map the flooded areas [14]. This allowed individuals to send information about the flood through email, text messages, Twitter, or the platform itself, being this information available to anyone with Internet access. Still, other COs were employed during the floods in Pakistan[1] in 2010 and Boulder[2] (USA) in 2013. While these observatories were used to provide information about the impacts caused by floods and their victims, they do not provide information to prevent or minimize the impacts of flood events. In addition, these observatories do not have any kind of integration with Spatial Data Infrastructures (SDI) as they are employed only to obtain volunteered information.

III. FLOOD CITIZEN OBSERVATORY

In order to fill the gaps identified in the previous section, this paper presents a crowdsourcing-based approach to obtain useful volunteered information for the context of flood risk management in Brazil, which includes the definition of mechanisms to help volunteers to better interpret the environmental variables (i.e. the water level). In this section,

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[1] http://pakreport.org/ushahidi/
[2] https://boulderflood2013b.crowdmap/

the interpretation mechanisms developed are presented along with the proposed crowdsourcing platform.

A. Interpretation Mechanisms

Due to the vast extent of Brazilian rivers and inability to provide resources to make measurements of the environmental variables at all required strategic points, four mechanisms were proposed which aim at supporting volunteers to better interpret those variables. These mechanisms were jointly designed by an interdisciplinary team composed of computer scientists and hydrologists. Three different scenarios were considered so the volunteer can interpret environmental variables in various situations, which are described as follows.

The first scenario corresponds to a controlled point, i.e. a point where there is an interpretation resource that enables the volunteer to perform the measurement more accurately. In this scenario, there is a water level ruler (Fig. 1, item 1) laid down in the riverbed which supports the measurement of the water level at that point. Rulers were installed in fourteen points located in the five most relevant water streams of the urban area of São Carlos/SP. Each of them has at least two points, one in the upstream and one in the downstream, before the confluence with other streams.

The second scenario corresponds to a semi-controlled point, i.e. a point where there is an interpretation resource for determining the value of the water level in the riverbed in a less precise way. In this scenario there are two types of interpretation resources, a puppet similar to the human figure and multi-color bands (green, yellow, orange and red). The color bands (Fig. 1, item 3) correspond to the hazard index (HI), i.e., the danger which the population is exposed, the risk of human instability. This risk represents the forces exercised on an individual in water currents, i.e., the individual's vulnerability level exposed to floods [22].

In addition, a puppet was proposed to assist the volunteers to determine the water level more easily (Fig. 1, item 2). Thus, the volunteer can use it as a visual resource to determine the water level, because this is painted on the riverbed in some points of the streams of São Carlos/SP city or as imaginary resource, helping to determine the water level at points where there is no available resources. In the puppet, water level measurement is carried out according to pre-defined tags, i.e., ankle, knee, waist, neck and above the head (the whole body). The three proposed mechanisms for the scenarios described above are shown in Fig. 1, item 2.

Finally, the third scenario corresponds to an uncontrolled point, i.e., there is no recourse in the riverbed which could help the volunteers to interpret the water level. For this mechanism, tags (low, normal, high and overflowing) were adopted that are of simple determination and approach to popular knowledge. These tags are commonly cited in Brazilian media to report the water level of a river. Thus, it is expected that the volunteers can interpret this environmental variable more easily.

B. Flood Citizen Observatory

The Flood Citizen Observatory (FCO) (Fig. 2) is a crowdsourcing-based approach that enables the collection of
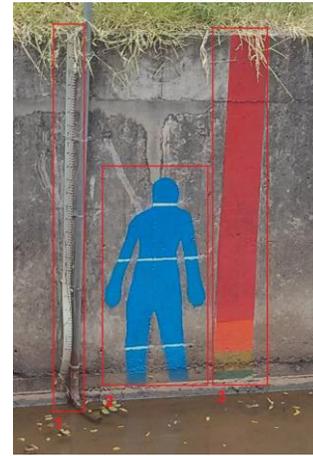

Figure 1. Resources for determining the water height in the river bed

volunteer information. This approach is inserted in a research project about flood risk management called AGORA[3]. Its main objective is to obtain useful volunteer information related to flood risk management, more specifically about flooded areas and water level in the riverbed, in order to provide those information for decision-making. FCO is based on the Ushahidi crowdsourcing platform, which is used worldwide by activists, emergency agencies and citizens to map extreme events [23]. In addition, in this platform, volunteers are considered "human sensors" since these can observe important parameters of flood risk management in a local environment.

In order to facilitate the information provision about flood risk in FCO, the interpretation mechanisms are represented by different categories, whereas the tags for each mechanism are represented by subcategories. Thus, the volunteer can identify, more easily, the category that best represents the observed scenario.

To send a report, volunteers can use both a mobile application and a Web site. Sending a report requires that volunteers provide the following mandatory information:

- **Title:** represents the subject addressed in the report;

- **Description:** represents the observation performed by the volunteer, for example, the water level or flooded area;

- **Category:** represents the mechanism used to interpret the environmental variable, which provides information about the water level in the riverbed;

- **Place's name:** represents the place where from the volunteer is sending the report.

Due to the uncertainty about the credibility of this information, reports are checked before they are made available online. The purpose of this verification is to reduce the number of false or inaccurate information disseminated to the public and emergency agencies.

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[3] http://www.agora.icmc.usp.br

Figure 2. Crowdsourcing platform Flood Citizen Observatory

Thus, before the reports are made available online, the authors of this work approve the reports inserted into the platform. As such, the authors of this study initially play the platform administrator role, checking and approving reports inserted on it. However, it is expected that the emergency agencies involved in flood risk management will play this role.

IV. EXPERIMENTAL EVALUATION

The approach proposed in this work is aimed at obtaining useful volunteered information for the context of flood risk management through a crowdsourcing platform. An experiment was conducted with the objective of evaluating our approach. In the pursuit of this goal, two questions were formulated by the authors of this work, in order to direct the execution of the experiment. The first question refers to the effectiveness of the platform in obtaining volunteer information for the context of flood risk management. Thus, this question was defined as:

Q1) Is the crowdsourcing-based approach, Flood Citizen Observatory, effective in obtaining useful volunteer information for the context of flood risk management?

The second question was formulated in order to check if the difference between the average of the information provided by volunteers and the average of data acquired from sensors is significant. This is important for if there is a significant difference, volunteered information may not reflect the real state of the environmental variable observed, resulting in erroneous predictions about the flood risk. Thus, the following question was elaborated:

Q2) Is the difference between volunteered information and sensor data significant?

Once they were formulated, for each question was defined a null hypothesis, which the authors wanted to refute with the most possible significance, and an alternative hypothesis,

which the authors intended to prove. Regarding the effectiveness of the crowdsourcing platform (Q1), we intended to refute the statement that the percentage of useful volunteered information obtained by platform is less than or equal to 50% (Null Hypothesis). Furthermore, we attempted to demonstrate that the percentage of useful volunteer information obtained by the platform is more than 50% (Alternative Hypothesis). Volunteered information is considered useful if it can be used for hydrological models or for decision making by emergency agencies. As regards to the difference between the average of the volunteered information and the average of sensor data (Q2), we attempted to refute the statement that the average of the volunteered information is different from the average of sensor data (Null Hypothesis). Furthermore, we tried to prove that the average of the volunteered information is equal to the average of sensor data (Alternative Hypothesis).

After defining the experiment variables, metrics were developed to measure those variables. A criterion was defined in order to determine the usefulness of the obtained information to the context of flood risk management. For this, three different values were assigned to the following grades: 0 (the category does not represent the scenario observed, i.e. the selected category does not match to the report description), 5 (the category partially represents the scenario observed, i.e. the volunteer selected more than one category), 10 (the category completely represents the scenario observed, i.e., the volunteer selected only one category that represents exactly the scenario observed). Thus, the effectiveness of the platform is calculated by the percentage of volunteered information that has grades greater than or equal to five in this criterion. Moreover, the average values of the volunteered information is calculated by summing the values contained in the report description, referring to the water level on the water level ruler, and divided by the number of reports with this information. On the other hand, the average of sensor data is calculated by the sum of the measurements carried out by it during the period of time that the volunteers performed the observations, and divided by the number of measurements taken during this period.

The participants were strategically selected, in order to include participants with different levels of experience and expertise in the area of flood risk management. Before the execution of the experiment, participants attended a training about the crowdsourcing platform and the mechanisms used for the interpretation of the water level in the riverbed. Furthermore, participants were also shown how to insert a new report in the crowdsourcing platform. After the training, all participants were asked to insert reports about the water level observed in the water level ruler of one of the controlled points, and a second report about the water level in the same point as observed with the assistance of one of the interpretation mechanisms to be chosen by the volunteer.

For the analysis and interpretation of the results, three statistical tests were used. First, the Shapiro-Wilk [24] was used to verify the normality of the samples. Then the Levene Test [25] was applied to verify homoscedasticity of the sample, i.e., if different samples have equal variance. Finally, the T Test [26] was applied in order to statistically reject or accept the null hypothesis. According to [27], it is possible to reject the null hypothesis based on statistical test results.

A. Results

The experiment was conducted with ten volunteers (participants), with different levels of experience and knowledge in the flood risk management area (TABLE I), in a point of the watershed of São Carlos/SP city. During the execution of the experiment, the volunteers inserted fifteen reports on the platform.

First, the reports were analyzed regarding to the category selected by the volunteer in order to verify the effectiveness of the approach. For each report, a grade was assigned according to the number of selected categories and if those represented completely, partially or even not represented the scenario observed (see previous section). Among the reports inserted, nine had only one category selected, which completely represent the observed scenario. For these, it was assigned the value 10. Two reports had more than one category selected, which partially represent the observed scenario. For these reports, it was assigned the value 5. Finally, four reports had one or more categories selected, however these did not represent the observed scenario, being assigned to them the value 0. Thus, eleven reports obtained note greater than or equal to five, i.e. approximately 73% of the inserted reports can be used in the context of flood risk management. Thus, the null hypothesis was rejected, i.e., the platform is effective in obtaining useful volunteer information for the context of flood risk management. Since the volunteers attended to a training before the execution, we can assert that the training was sufficient to enable volunteers to produce useful observations for the context of flood risk management in our approach.

The reports related to the water level observed in the ruler were analyzed to verify if the difference between the average of the volunteered information and the average of sensor data was significant. For this, only ten reports were considered, since only those have the value of the water level in the ruler. First, a correspondence between the values observed by the volunteers and the values measured by the sensor was performed. For this, the authors of this work made two observations on different days regarding to the water level in water level ruler at the same point where the experiment was conducted. Each observation was compared to the value measured by the sensor to determine the difference between those values (TABLE II). Thus, it was established that there is a difference of 7 cm between the value observed by volunteers and the value measured by the sensor. This difference was added to each of the observations made by the volunteers before performing the statistical tests.

The Shapiro-Wilk Test was performed to determine whether the samples had normal distribution. The results (TABLE III) showed that the volunteer information does not have a normal distribution, since the value of Sig. (p-value) is less than the significance level[4] adopted (5%). In contrast, sensor data has normal distribution, because the value of Sig. is greater than the significance level.

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[4] The significance level corresponds to the probability of rejecting the null hypothesis, being this true.

TABLE I. PARTICIPANTS' EXPERIENCE IN THE CONTEXT OF FLOOD RISK MANAGEMENT

Experience	Number of Participants
0 month	5
1 month	1
7 months	1
12 months	2
240 months	1

For samples with normal distribution, the most appropriate hypothesis test is the T Test, in its parametric unpaired version. According [26], this test can also be applied to samples that did not have a normal distribution as long as these do not contain to many elements. Thus, this test was selected to determine whether the difference between the average of the volunteer information and the average of sensor data was significant.

To perform the t test, first it was performed the Levene test to analyze the homoscedasticity of the samples, i.e., to analyze if the samples have equal variance. The value of Sig. (p-value) (TABLE IV) shows that the samples do not have equal variance, since this value is less than the significance level. Then, the t test was performed to check whether the difference between averages was significant. The result obtained (TABLE IV) shows that the difference between the averages is not statistically significant because the value of Sig (2 - tailed) is greater than the significance level. Thus, it was possible to reject the null hypothesis. However, it is noteworthy noticing that the water level ruler was not firmly attached to the river bed (Fig. 1), so that the threat cannot be ruled out that this fact may have introduced a bias in the observations of volunteers.

Thus, we conclude that the Flood Citizen Observatory facilitates the provision of useful and accurate information for flood risk management.

V. CONCLUSION

In this work, we propose a crowdsourcing-based approach for obtaining useful volunteer information for the context of flood risk management. In this approach, volunteers are

TABLE II. DIFFERENCE BETWEEN THE VALUE OBSERVED BY THE VOLUNTEER AND THE VALUE MEASURED BY TH SENSOR

Date	Value observed by the volunteer	Value measured by the sensor	Difference
10/02/2014	7 cm	14,12 cm	7,12 cm
12/02/2014	6 cm	13,82 cm	7,82 cm

TABLE III. SHAPIRO-WILK TEST'S RESULTS

		Shapiro-Wilk Test	
Variable Tested	Instrument	Number of elements	Sig.
Water Height	Volunteer	10	0,004
	Sensor	5	0,494

TABLE IV. RESULTS OF THE LEVENE TEST AND T TEST

Variable Tested	Levene Test	T Test	
	Sig.	Sig. (2-tailed)	Mean Difference
Water Height	0,002	0,093	-2,799

considered human sensors, providing information about the environment, such as water level and flooded areas.

Based on the experimental validation, the authors found that this platform is effective in obtaining useful and accurate volunteer information, since volunteers can easily provide information about the water level in the riverbed through the platform categories. This is an important step since in certain regions of Brazil there do not exist water gauges to perform such measurement in real time.

The present work thus fills the gap of empirically evaluated crowdsourcing approaches in the context of flood risk management in Brazil. However, it is necessary to move forward not only in obtaining volunteered information about flood risk, but also in the automated processing of this information to estimate the likelihood of a flood. Additionally, the development of a risk map for the affected population based on the acquired information is an essential goal for future work.

ACKNOWLEDGMENT

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