Journal of Civil Engineering and Architecture 10 (2016) 839-852
doi: 10.17265/1934-7359/2016.07.013

A Method for Developing Seismic Intensity Maps from Twitter Data

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Abstract: Aim of this article, is to present a methodology for extracting macroseismic intensity information and producing seismic intensity maps from VGI (volunteered geographic information). As a VGI source for obtaining and assessing macroseismic observations, the authors chose twitter. Our methodology is validated in two recent earthquakes occurred in Greece: the January 26, 2014 ML = 5.8 in Kefallinia, and the November 17, 2014 ML = 5.2 in Evoikos. Twitter data published within the first 6 h, 12 h, 24 h and 48 h after the earthquake occurrence were analyzed to develop seismic intensity maps. Those maps were evaluated through intensity maps for the same earthquakes, published by international institutes. Evaluation results provide a strong empiric evidence for the credibility of our methodology, the accuracy of the produced seismic intensity maps and accentuate VGI, generated by twitter, as an adequate alternative source for collecting macroseismic information.

Key words: Volunteered geographic information, twitter, seismic intensity, intensity maps, earthquakes.

1. Introduction

Seismic intensity maps visualize seismic intensity in geographic space. Those maps are based on the collection of macroseismic observations and the most common way to collect them is by sharing questionnaires. These questionnaires include questions that can be answered by either selecting multiple choices, or by giving open text answers. The distribution of the questionnaires usually is done through post, e-mail, telephone, radio, TV or by instant distribution [1]. Moreover, questionnaires can be distributed through community approach initiatives such as the "Did you feel it?" Project of the USGS (United States Geological Survey) or the online macroseismic questionnaires of the EMSC (European Mediterranean Seismological Center) in which a citizen can fill a questionnaire accessed through a web site.

Seismic intensity depends from various elements of the seismic movement like the acceleration, speed, period and time length of an earthquake and, moreover, from the structure and history of the ground movement in a building's foundations. Measuring seismic intensity is important because in this way there can be mapped information of previous earthquakes that are connected to disasters.

The authors' motivation is to assess the use of a "phenomenon", as it is described by the researcher who identified it first [2], in the creation of seismic intensity maps. "The phenomenon of VGI (volunteered geographic information) defines the potential that normal citizens (neo-geographers) have to create and share geographic information, or information with geographic reference".

One of the main characteristics of VGI is the high rhythm of produced data, which is sometimes so high that could justify references for "a geography without geographers" [3] and for "wicification of GIS (geographic information systems)" [3]. VGI though, is a more useful tool for a geographer, rather than a replacer. Moreover, regarding production of the VGI

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data, the volume of created cartographic objects in an area is positively correlated to the number of volunteers that contribute, but in a non-linear way [4] and the higher the number of contributors in an area is the better spatial accuracy is [5].

Next, rules and cartographic specifications of spatial data, are usually not followed by neo-geographers [6] and a really disciplined control process to the end part of neo-geographers could "kill" their interest for producing such kind of information [4].

Crowd sourcing and VGI have been highlighted in recent years as an important source of information that can support the natural disasters management [7]. Important factors that empower this opinion are the time precision and the big amount of information that is published during an earthquake, and mainly just after the completion of the event, as a loose or wrong information about natural disasters event could effect to serious consequences [8, 9]. In natural disasters, VGI as a term, is used to describe the spatial data that are created and shared by simple citizens or unofficial entities [7]. A natural disaster takes place when a community has direct effects from a natural event and the damage is so high that external aid is needed [10].

Starbird and Palen [11] highlight the activities of the digital volunteers of the Haiti Earthquake that took place on January 12, 2010 who were organized and published information through twitter.

Moreover, Al-Sharawneh et al. [12] present a methodology for detecting leaders in social media during crisis events, based on credibility criteria. Their method was applied in a dataset consisted of 1,684 thematic tweets about the Victorian forest fire that took place on June 16, 2009 and in which 173 people lost their lives. Some of the very interesting findings of this research, include that 78% of the population are inactive users or listeners, during crisis events.

2 Methodology and Data Used

2.1 Methodology

In this section the methodology is described for extracting macroseismic observations from twitter and creating seismic intensity maps. The methodology is consisted of nine steps (Fig. 1): First step comprises an initial analysis of the tweet dataset. The authors excluded all tweets that have been published after the first 48 h from the time that an earthquake event occurred; Afterwards, in Step 2, the authors proceeded in selecting the tweets, which contain text relevant to macroseismic observations, and from them, the authors further selected, the tweets that contain and geographic reference (Step 3); In Step 4, the authors classified the selected tweets in intensity values, according to the EMS (European macroseismic scale) 98 macroseismic scale. Classification of tweets to intensity grades in the first case study is performed by reading the text content of each single tweet. In this step, some patterns were detected related to certain keywords, contained in tweet texts and values of the EMS 98 macroseismic scale. These patterns are presented in Table 1.

Then those patterns have been applied in the second case study, improving this step in a semi-automated way. In order to apply these patterns, the authors executed various text queries in the text of the tweets, selecting those who contain any of the words of Table 1. The selected tweets were classified with the corresponding intensity values of Table 1.

In Step 5, the authors geo-reference the tweets by adding (x, y) coordinates for every tweet that contains macroseismic observations and geographical reference in its text. For each tweet the authors add the coordinates of the centroid polygon which represents the area that is referenced in the tweet text; Moreover, in Steps 6 and 7 the authors created a layer with all the geo-referenced tweets, it was loaded in a GIS software (Step 6) and the authors proceeded in randomizing the spatial distribution of the georeferenced tweets inside the geographic area-represented by polygon in which they are referred.

In Step 8 the authors applied the kriging interpolation, a method commonly used in the production of intensity maps [14] and created prediction

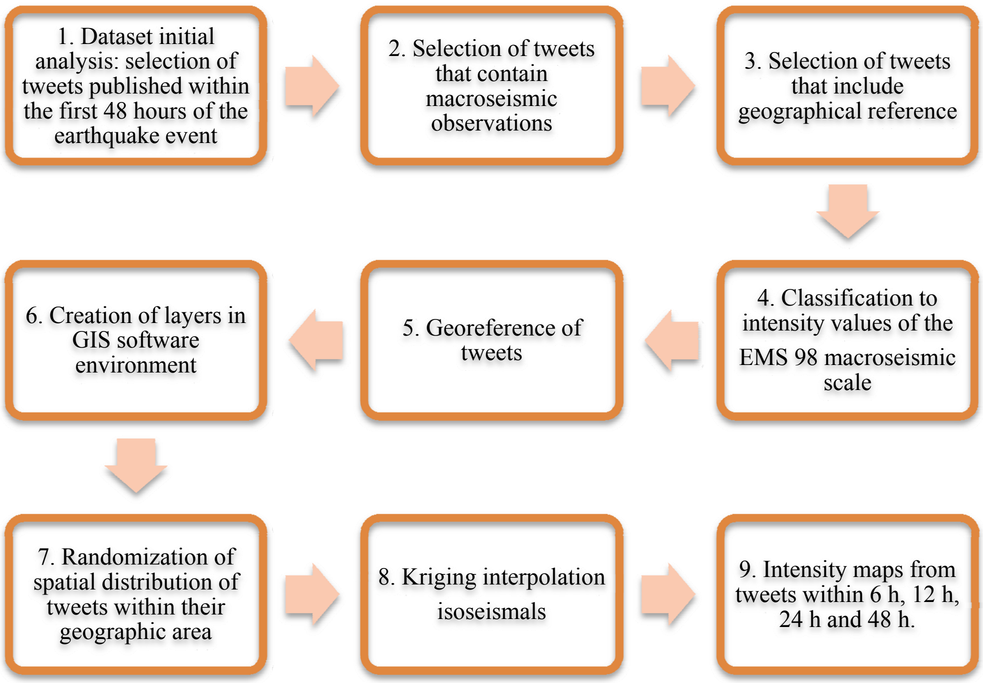

Fig. 1 Methodology diagram.

surfaces from tweets that have been published within 6 h, 12 h, 24 h and 48 h from the time that each earthquake event occurred. Finally, in Step 9 the authors produced four seismic intensity maps, for each case study, from these estimated surfaces.

2.2 Data Description

The methodology is applied in two earthquake events as case studies:

- the Kefallinia, Greece *ML* = 5.8 January 2014;
- the Evoikos, Greece *ML* = 5.2 November 2014.

The dataset for the Kefallinia Earthquake was acquired from the social media data provider—Gnip.[1] The dataset was created by the firehose algorithm and is consisted of 167,989 tweets, that were published from 01-26-2014 until 02-17-2014 and contained any of the keywords: earthquake, richter, Kefallinia or their Greek translations and transliterations. From total, 17,678 of them in Greek language were selected, while 1,721 of total are geo-located tweets. From the geo-located tweets, 245 located in Greece. This ratio of geo-located tweets to total is justified in literature [15].

The second dataset, was acquired by the discover text platform[2] and consisted of 88,128 tweets that have been published from 11-17-2014 until 11-20-2014 and their text contained any of the following keywords: Evoikos, Chalkida (the closest city from the seismic epicenter), earthquake, richter, felt, damages, and their Greek translations and transliterations. This dataset did not contain geo-located tweets, something that was not expected to influence the credibility of the outcome, as geo-located tweets are only 1% of the total dataset. Moreover, the location from which a tweet was published does not necessarily reflect the location of a macroseismic observation, as someone could observe something while moving, and published it afterwards [8].

3. Case Studies of Kefallinia and Evoikos Earthquakes

As stated before, the methodology was applied and validated in two earthquakes that recently occurred in Greece. First is the January 26, 2014 Kefallinia, Greece earthquake (*ML* = 5.8) with epicenter the area of

[1] www.gnip.com.

[2] www.discovertext.com.

Table 1 Pattern-grading outcome from Kefallinia Earthquake case study [13].

Words in tweet (translated)	Intensity value	Word frequency in tweets of Kefallinia Earthquake	Word frequency in tweets of Evoikos Earthquake	Percentage of successful automated classification	Reference that justifies classification
Disruption	VI	2	1	-	"Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors"
Powerful, strong, big	V	31	62	38.7	"The earthquake is felt indoors by most, outdoors by few. A few people are frightened and run outdoors. Many sleeping people awake. Observers feel a strong shaking or rocking of the whole building, room or furniture"
Minor damages	VI	8	0	-	"Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened"
Damages/major damages	VII	76	18	Tweets described no damages	Furniture is shifted and top-heavy furniture may be overturned. Water splashes from containers, tanks and pools
General alert, emergency situation	VII	28	0	-	For general alert most people should be frightened: "Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors"
Felt	III	58	334	97	Weak: The earthquake is felt indoors by a few. People at rest feel a swaying or light trembling; Hanging objects swing slightly
Felt enough, felt strongly	IV	8	20	100	"Largely observed: The earthquake is felt indoors by many and felt outdoors only by very few. A few people are awakened. The level of vibration is not frightening. The vibration is moderate. Observers feel a slight trembling or swaying of the building, room or bed, chair, etc. (…) No damage"
Cracks on roads	VII~VIII	2	0	-	"Minor cracks in ground"
Evacuation	V	53	0	-	No rock fall yet or "minor rock falls"
Windows crack/break	VI	6	0	-	"Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened"
Landslides	VI	7	0	-	"Landslides to massive rock falls (intensity range 6~12)"
Agony	VI	3	0	-	"Many people are frightened and run outdoors"
Fear, terror, panic	VII	6	2	-	"Most people are frightened and try to run outdoors"
Stadium evacuation	VII	9	0	-	"Most people are frightened and try to run outdoors"

Liksouri. The earthquake had effects in the natural and urban environment. The reasons of selecting the Kefallinia Earthquake as a case study are various. At first is, the geography of the area. Kefallinia is an island in the Ionian Sea with no land borders in any of the urban centers of Greece. It is located in the north of Zakynthos, south of Lefkada, and west of Ithaki (Fig. 2). Nearest areas of continental Greece are: the areas of Aitoloakarnania, west Achaia and west Ileia (Fig. 2). Moreover, the earthquake occurred in a non-touristic time period, and the population of the island is 35,801.[3] These two factors were considered significant to evaluate the validity of the method in non-crowded areas.

[3]Census, 2011.

Second case study is the November 17, 2014 Evoikos Earthquake, a double earthquake that occurred at 23:05 and 23:09 GMT (*ML* = 5.2 for both earthquakes). This case study was selected due to the different characteristics of it. First, geography is different than in the first case study. Evoikos is the name of the sea surrounded by continental Greece area and Evvoia. The epicenter is close to the metropolitan area of Athens, the capital of Greece. Other areas that surround Evoikos Sea are: Voiotia and Fthiotida (Fig. 2). The earthquake did not cause any effects in the urban or natural environment and occurred during night. Those factors were considered as significant to validate the authors' methodology in weak earthquakes, in crowded areas and in time that is expected reduced activity from twitter users.

4. Processing and Results

As described in Section 2, the first steps of the methodology are to select the tweets that have been published within the first 48 h from time of the earthquake occurrence and from them, to further select, the tweets that contain macroseismic observations and geographic reference (Steps 1~3). These steps have been performed by reading and checking the content of every single tweet or by using various text queries. After those steps it was selected 578 tweets related to the Kefallinia Earthquake and 1,040 tweets related to the Evoikos Earthquake.

Next step is about classifying the tweets in values of the EMS 98 macroseismic scale. This process performed for the Kefallinia Earthquake by reviewing all the tweets one by one. Reason for this is the absence of any relevant semi-automated technique or method. Various photos that were embedded as URLs (uniform research locators) within the tweet texts helped significantly to perform accurate grading especially in cases of general observations. From this analysis, some patterns were identified regarding the seismic intensity value in which tweets that contain certain words are classified. The patterns, are presented in Table 1.

Fig. 2 Area names near the earthquake epicenters.

In the next step of our methodology the classified tweets were georeferenced. Geo-reference is performed by adding the geographic coordinates of the polygon centroid that represents the area which is mentioned in the text of each tweet of both earthquakes. After this step, a layer in GIS software was created, visualizing the location of each tweet. In order to have more accurate results when applying the kriging interpolation method, the authors choose to randomize the spatial distribution of the tweets inside the polygon-area which is referenced in each of the texts.

Final step of methodology was to apply the kriging interpolation method that leads to the creation of the final seismic intensity maps. In particular, four maps have been created, for each earthquake from tweets published within 6 h, 12 h, 24 h and 48 h from the earthquake occurrence.

5. Results

In the first map of Kefallinia Earthquake (Fig. 3), created by tweets that have been published within 6 h, are displayed intensity values from I to VIII. The highest values are in the islands of Kefallinia, the north part of Zakynthos and in the south part of Lefkada. High values are observed in the areas of west Aitoloakarnania, north-west Ileia, and west Achaia. Other areas receive values that close to III. Moreover, in the area of Thessaly, there have been observed intensity values I~II.

In the second map of Kefallinia Earthquake (Fig. 4), based on tweets that have been published within 12 h from the earthquake occurrence, distribution of the intensity values is smoother, probably due to the increase in macroseismic observations. The low values in Thessaly have been replaced with value ranges close to III. What is observed though, is that although the highest and high values seem to be located in the same areas as in the first map, in rest areas there seems to be a minor increase of the intensity values which are estimated in a range of III and IV. Similar results are estimated in Fig. 5, which is produced from tweets published within 24 h from the earthquake occurrence. The only difference is that there is a smooth increase in the intensity values in west Greece, particularly in Lefkada, west Aitoloakarnania and west Ileia.

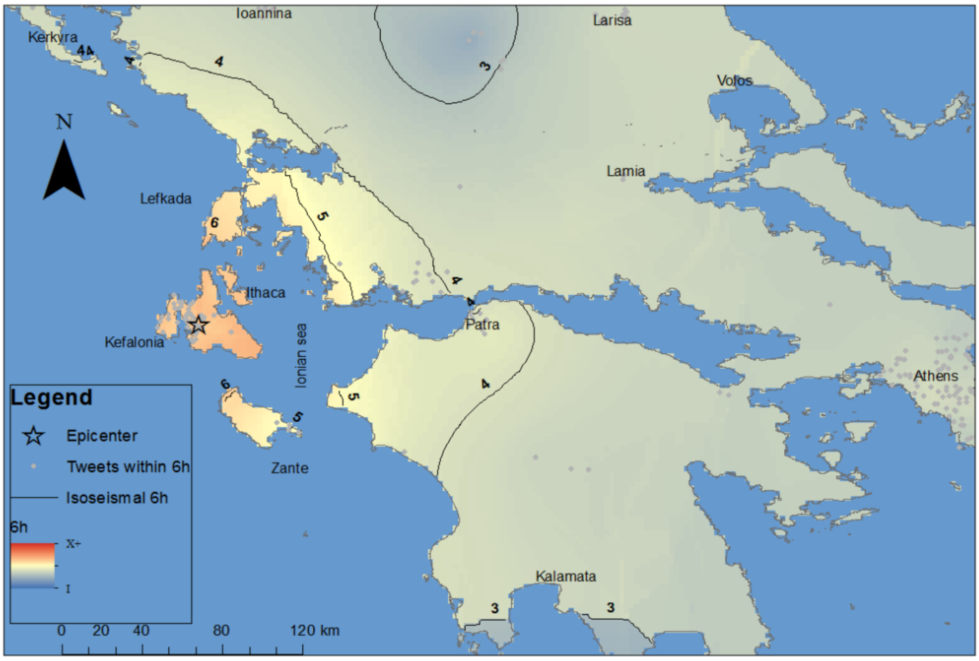

Fig. 3 Intensity map from tweets published within the first 6 h from the earthquake occurrence. The January 26, 2014 Kefallinia Earthquake *ML* = 5.8.

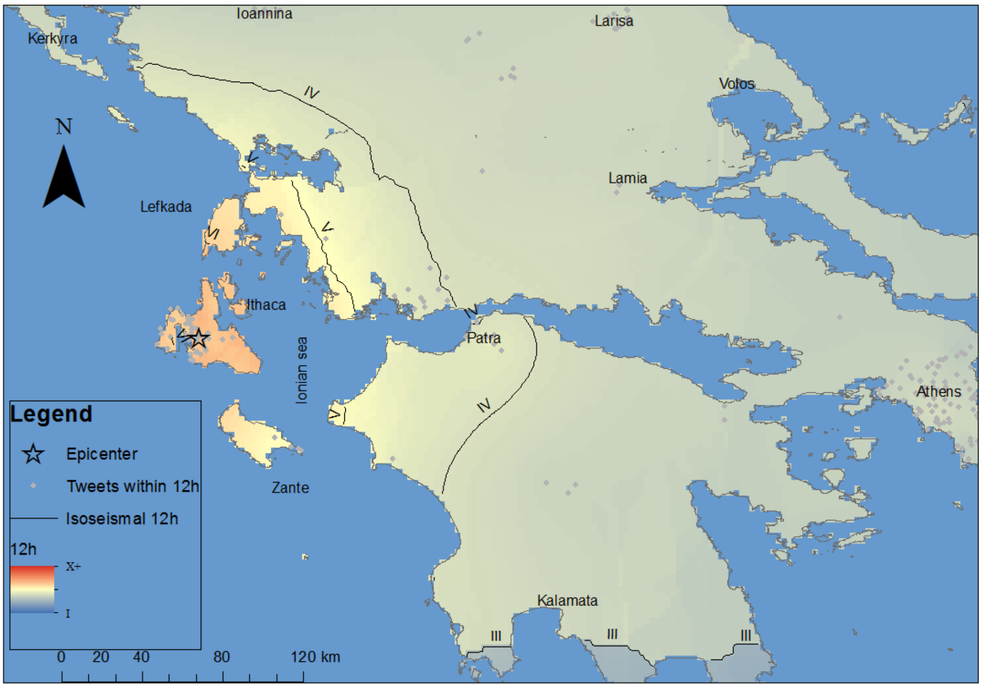

Fig. 4 Intensity map from tweets published within the first 12 h from the earthquake occurrence. The January 26, 2014 Kefallinia Earthquake *ML* = 5.8.

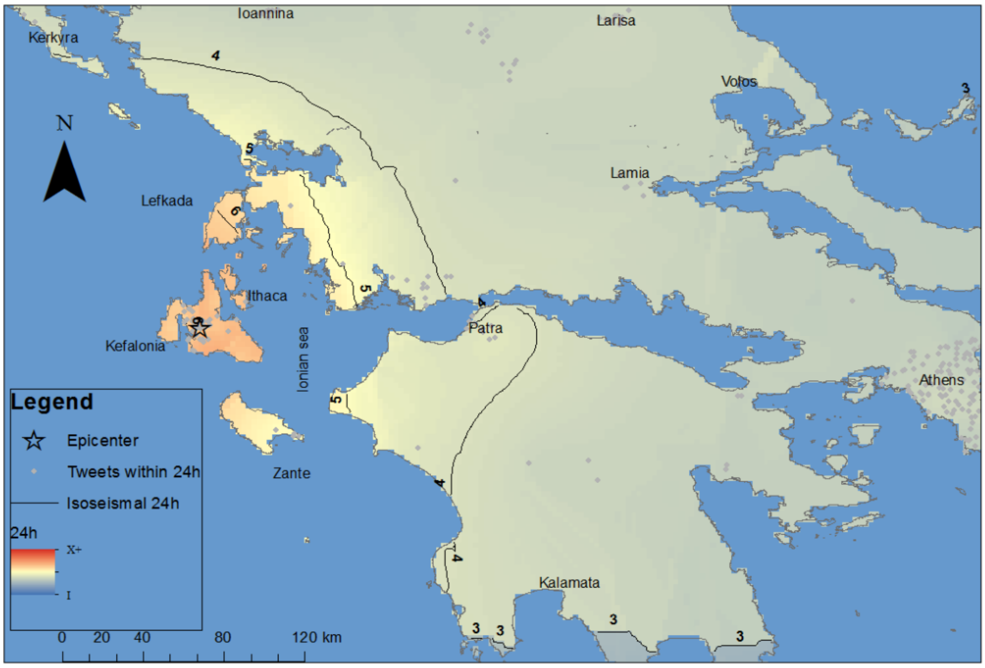

Fig. 5 Intensity map from tweets published within 24 h from the earthquake occurrence. The January 26, 2014 Kefallinia Earthquake *ML* = 5.8.

The final fourth map of Kefallinia Earthquake (Fig. 6), was based on tweets that have been published within 48 h from the earthquake occurrence. The distribution pattern is similar with Figs. 4 and 5. There is a decrease of the high intensity values in west Aitoloakarnania, west Achaia and north Lefkada with the highest intensity values located in the areas of Kefallinia, north Zakynthos, south Lefkada. In the rest of Greece there is a minor decrease or better adjustment of the intensity values, estimated in a range of II~III. This final map seems to be the most accurate map in terms of intensity value distribution and estimation.

In the first map of Evoikos Earthquake (Fig. 7), created by tweets that have been published within 6 h, are displayed intensity values from I to V. The highest values are observed in central and north Evvoia (Chalkida and Aidipsos). Nearby areas (Thiva, Athens) receive values from III to IV and rest of Greece receives values from I to II.

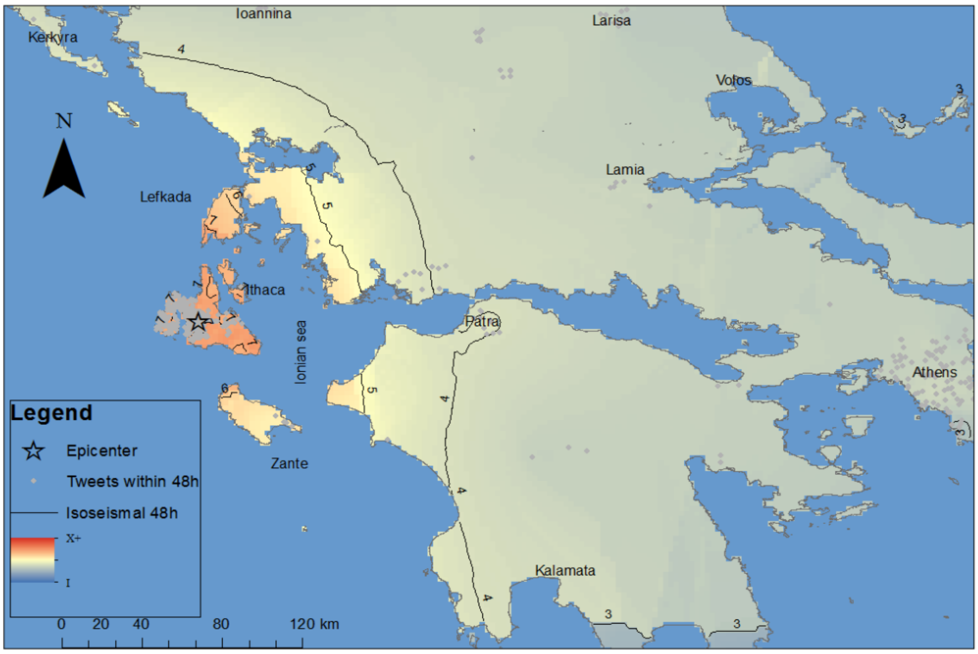

Fig. 6 Intensity map from tweets published within 48 h from the earthquake occurrence. The January 26, 2014 Kefallinia Earthquake *ML* = 5.8.

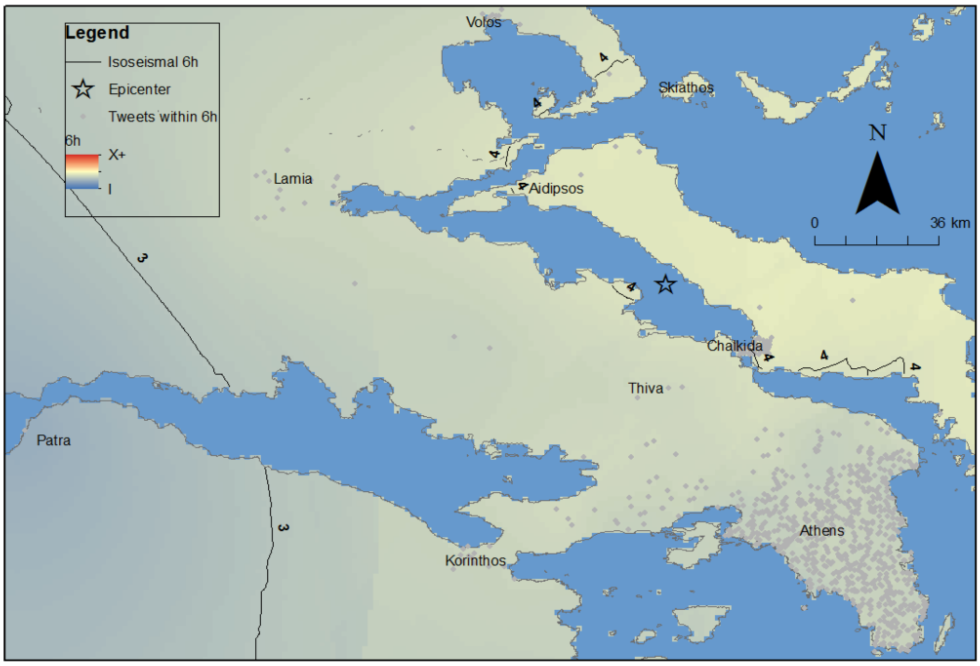

Fig. 7 Intensity map produced from tweets published within 6 h from the earthquake occurrence. The November 17, 2014 Evoikos Earthquake *ML* = 5.2.

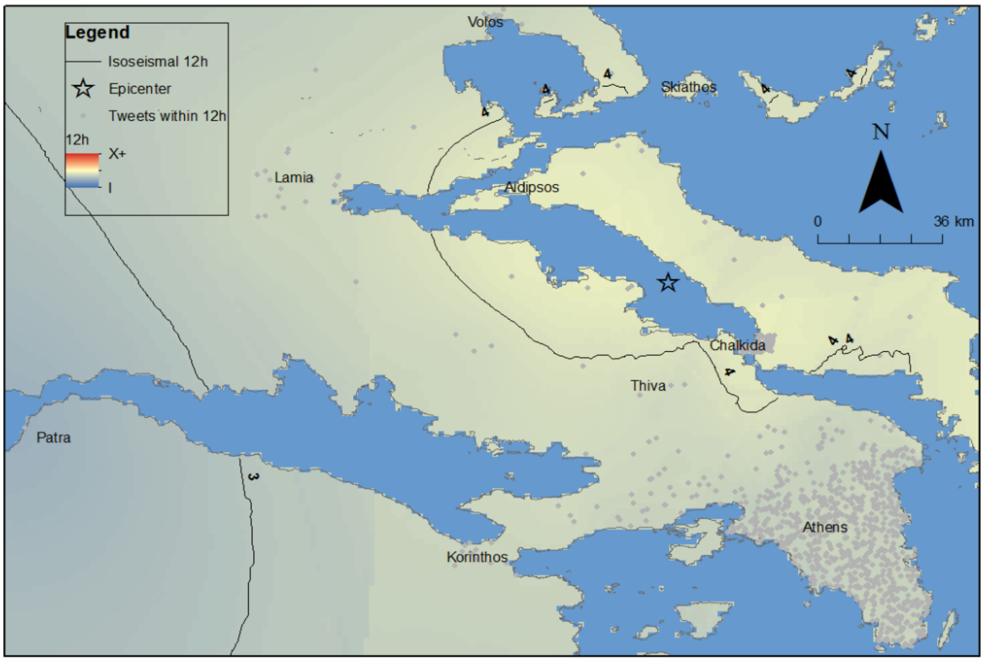

Fig. 8 Intensity map produced from tweets published within 12 h from the earthquake occurrence. The November 17, 2014 Evoikos Earthquake *ML* = 5.2.

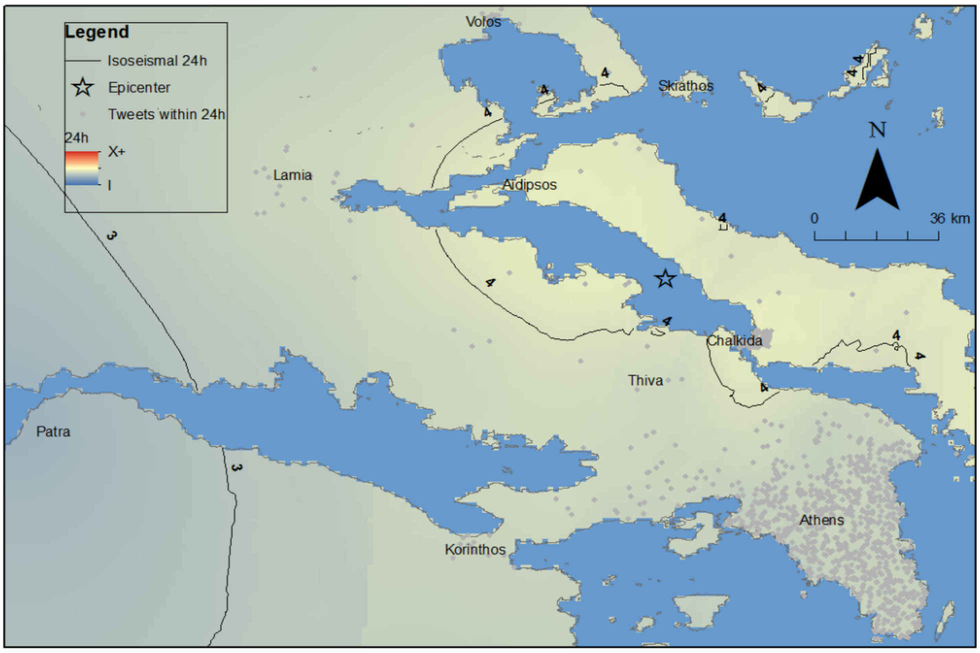

Fig. 9 Intensity map from tweets published within 24 h from the earthquake occurrence. The November 17, 2014 Evoikos Earthquake *ML* = 5.2.

In the second map (Fig. 8), based on tweets that have been published within 12 h from the earthquake occurrence, there is a difference in intensity values in areas near the epicenter. In particular, the higher values, IV~V, are observed in the coastlines around the epicenter, and in south Evvoia. Values from III to IV are observed near Thiva, Lamia, Athens and Volos. Rest of Greece receives intensity values from I to II. In the third map (Fig. 9), based on tweets that have been published within 24 h from the earthquake occurrence, the intensity values and their distribution are similar, as in the second map (Fig. 10).

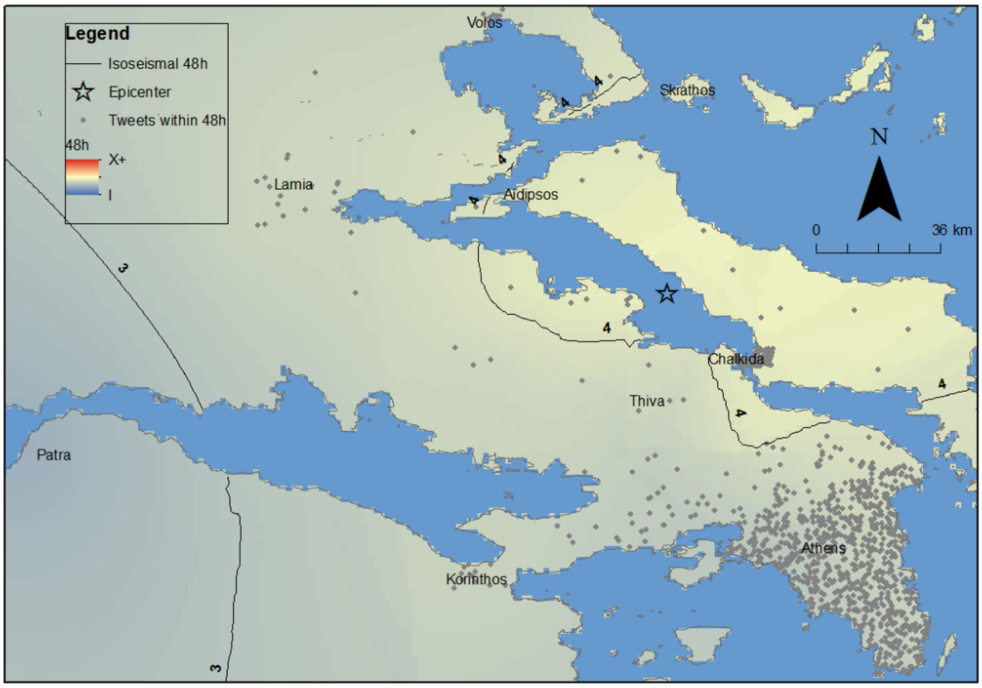

Fig. 10 Intensity map produced from tweets containing macroseismic observations and published within the first 48 h from the earthquake occurrence. The November 17, 2014 Evoikos Earthquake *ML* = 5.2.

Our final map (Fig. 10), based on tweets that have been published within 48 h from the earthquake occurrence, displays higher intensity values in th3e coast areas around the earthquake epicenter and in central and north Evvoia. In south Evvoia and in west Attica, reduced intensity values are displayed, in comparison with previous maps (Figs. 7-9).

6. Evaluation through Other Maps

In this section the authors evaluate the results of the intensity maps that have been developed from the methodology. Evaluation is performed, with maps published by international institutes. In particular as comparison maps, the authors choose the intensity maps published by the USGS (Figs. 11 and 12) and the intensity maps published by the EMSC (Figs. 13 and 14).

Regarding the Kefallinia Earthquake, the USGS map (Fig. 11) displays intensity values V~VIII in the two main cities, located in the south-west Kefallinia, Liksouri and Argostoli. The range is consonant with the maps produced by the authors' methodology. In the other areas of Kefallinia and in the north part of Zante, values between V~VI are observed. Smaller intensity values are located in the North West Prefectures of Ileia and Achaia, in west continental Greece and north-west Epirus. In the rest of the country intensity values are estimated III~IV.

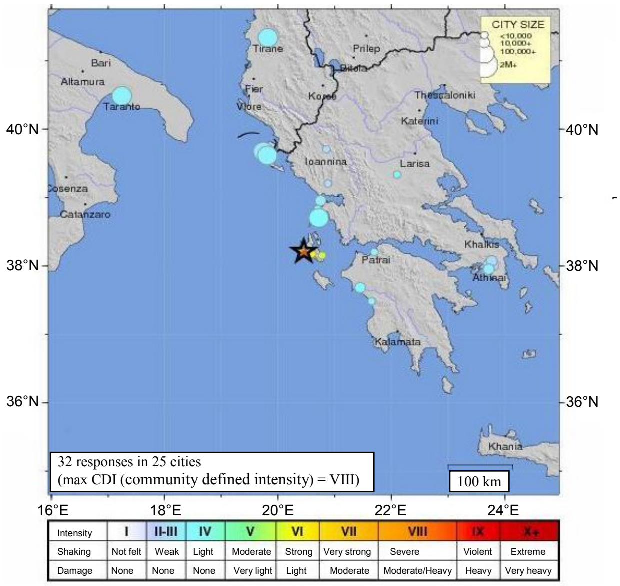

Fig. 11 Intensity map of January 26, 2014 Kefallinia Earthquake in Greece (*ML* = 5.8).
Source: USGS 2014.

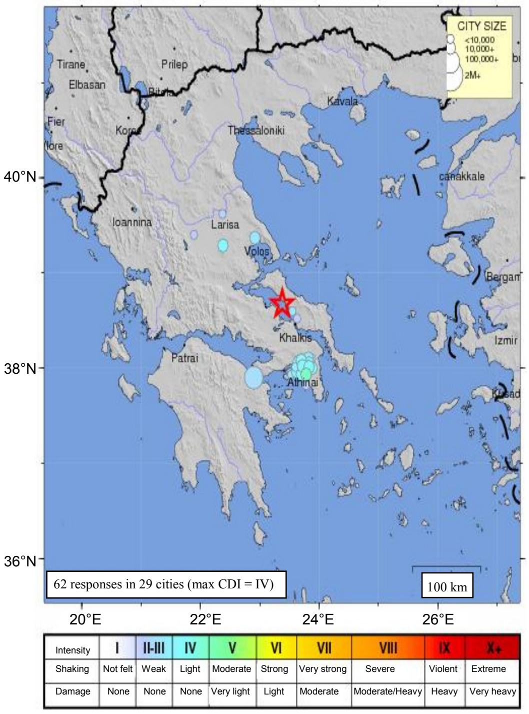

Fig. 12 Seismic intensity map of the November 17 2014 Evoikos Earthquake (*ML* = 5.2).
Source: USGS 2015.

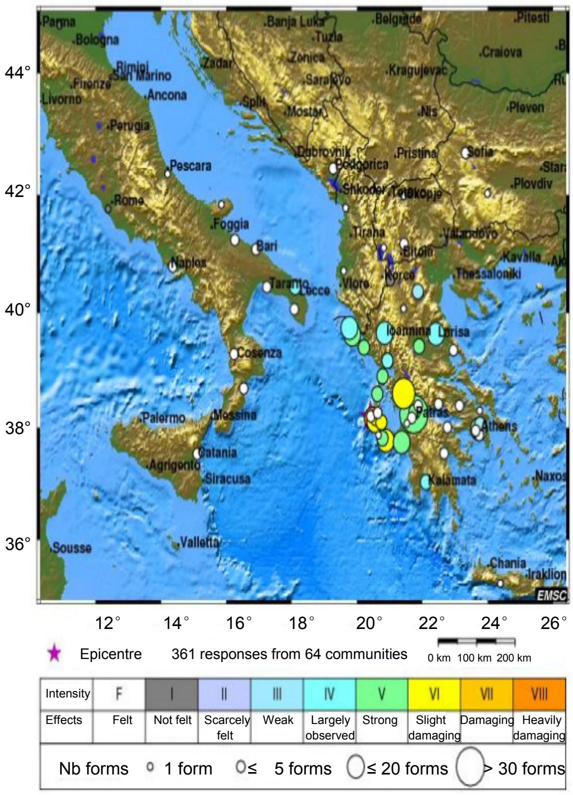

Fig. 13 Intensity map of January 26, 2014 Kefallinia Earthquake in Greece (*ML* = 5.8).
Source: EMSC 2014.

In the EMSC intensity map, a value range between I~VIII is displayed which is consonant to the USGS map and to the maps produced by the authors' methodology. The higher values are located in the islands of Kefallinia and Zante, followed by the areas of west Ileia and Achaia (V). In Attica intensity values are limited to III, in South Peloponisos to II and in Thessaly between III and IV. The spatial distribution of both USGS and EMSC maps are similar with the maps produced by the authors' methodology.

Moreover, the USGS and EMSC maps of Kefallinia Earthquake are based on 32 and 361 observations, respectively, collected by online macroseismic questionnaires while the produced by the authors' methodology maps are based on 578.

Regarding the Evoikos Earthquake, in the USGS map (Fig. 12) intensity values between II~IV are displayed. The value range is consonant to the range of the produced by the methodology maps (maximum value in the raster is 4.6). Maximum values are located in Chalkida, in Volos, in south of Larisa and in Attica. Intensity values II~III are observed in Korinthos in contrary to the produced by the methodology maps in which the values are between III~IV. In the EMSC intensity map (Fig. 14) the intensity value range is between I~V. Highest values are located in the area of Voiotia and Attica (IV). In Korinthos intensity value IV is displayed which is consonant to the maps produced by the authors' methodology and in contrary to the USGS map. In Attica the value range is between II and V which has minor differences from the USGS map and is consonant from the maps that were produced by the methodology. In the EMSC map it is noticed that there is absence of macroseismic observations in the closest to the earthquake city center, Chalkida while in the maps produced by the methodology there are up to 96 observations. The USGS and EMSC intensity maps are based on 62 and 308 macroseismic observations that have been collected through online questionnaires while the produced by methodology maps is based on 1,040.

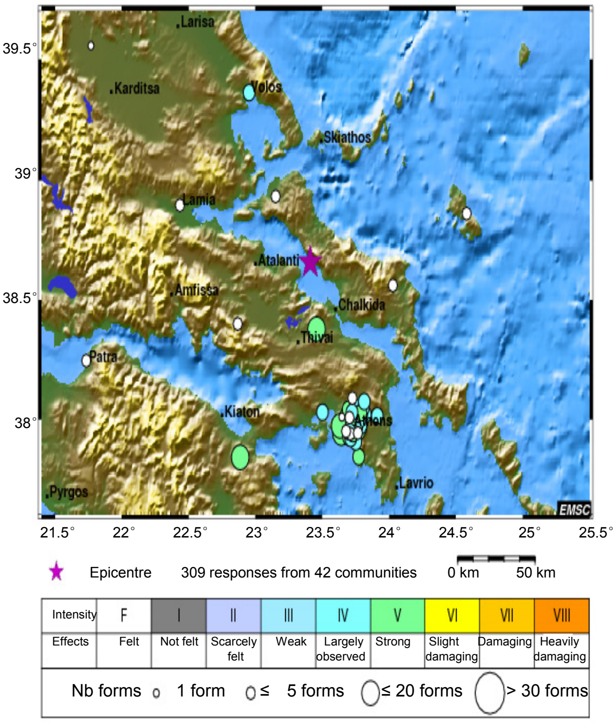

Fig. 14 Seismic intensity map, of November 17, 2014 Evoikos Earthquake (*ML* = 5.2).
Source: EMSC 2014.

7. Discussion and Conclusions

As can be seen in Section 5, credible intensity maps were developed by macroseismic observations that have been extracted from tweets. The positive evaluation results highlight the authors' methodology as a credible alternative for the development of seismic intensity maps. Main benefit of the methodology in respect to other methods, is the production rhythm of the macroseismic information.

While applying methodology there were various concerns. These concerns had to do with that earthquakes could happen any time (24 h per day, 7 days per week) in different locations with the epicenter to be located close or away from urban centers. Moreover, while filling a questionnaire a scientist can collect more structured and accurate information in contrary to a tweet in which a volunteer publishes whatever he wants in a short message without taking into consideration the macroseismic extensions of this tweet. For instance, it is difficult to find a tweet containing information about the floor the user was when an earthquake was happening, although there were a few tweets mentioning even that detail. One more concern was about the spatial distribution of the macroseismic observations as the VGI data, are created in ubiquitous way, in contrary to the questionnaires, the spatial distribution of which, can be manipulated.

For these reasons, it was chosen two completely different earthquake cases. The first case is related to an earthquake with multiple effects in the urban and physical environment, happening at midday, in a non-crowded area, during a non-touristic period, and in a geographic area consisted of islands. The second earthquake had no effects in the environment, occurred during night, in a geographic area close to the metropolitan area of Athens, capital of Greece. In both cases the number of macroseismic observations collected is quite high.

Another conclusion of this research is that the higher the number of macroseismic observations published from tweets is, the better and more precise the development of the seismic intensity map is. This conclusion is relevant to literature, regarding the validity of Linus Law to volunteered geographic information [5] in which the spatial accuracy of VGI is increased when the number of neo-geographers is increased within a square kilometer.

Another issue was about the re-tweets. A re-tweet is the revision of the same information from different twitter users. During literature review it was found that in a crisis event, the users of social media are taking roles of leaders and listeners [12]. Leaders are those which express opinions and publish information. Retweets can be a way to measure the credibility of an information, as the more an information is re-tweeted by multiple users, the more trust there is to the user that published the initial info. Thus, it was decided to include all retweets in the analysis, and to count them equally to the original ones, weighting in that way the credibility of the macroseismic observations created by the leader users.

Another issue, met mostly in the 2nd case study of Evoikos Earthquake, was the major heterogeneity in the spatial distribution of the observations, as 75%~80% of total have been located in the metropolitan area of Athens. VGI characteristics disallow the reduction of the observations as the more the observations are the more correct the information is. With continuous revisions of kriging interpolation, and after various tests in the parameters and the volume of observations, it was noticed that the estimated values are not significantly influenced from this heterogeneity of the distribution.

Various concerns were also raised regarding the classification of the tweets to intensity values according to the EMS 98 macroseismic scale. There were various observations difficult to be classified to a certain intensity grade, such as “strong earthquake” or “very strong earthquake”. These issues have been overcome by classifying each tweet one by one and by collecting simultaneously various information from the same VGI source, such as photos or videos. Moreover, the creation of patterns related to the association between keyword and scale grade, the correctness of which is proven empirically, when was applied in the 2nd case study of the Evoikos Earthquake, consists an unofficial “verbal behavior” of twitter users in Greece when they publish earthquake information.

Concluding, twitter is highlighted as a suitable VGI source for extracting macroseismic observations due to the high production rhythm of volume of earthquake relevant tweets and the authors’ methodology is empirically proven as credible for the development of seismic intensity maps.

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