(Article begins on next page)

Contribution of Geomatics Engineering and VGI within the Landslide Risk Assessment Procedures

Francesco Mancini[1], Alessandro Capra[1], Cristina Castagnetti[1], Claudia Ceppi[2], Eleonora Bertacchini[1] and Riccardo Rivola[1]

[1] DIEF, University of Modena and Reggio Emilia, Italy
{francesco.mancini, alessandro.capra, cristina.castagnetti, eleonora.bertacchini, riccardo.rivola}@unimore.it
[2] DICATECh, Technical University of Bari
claudia.ceppi@poliba.it

Abstract. This paper introduces the potential role played by the methodologies encompassed under the geomatics engineering and VGI (Volunteered Geographical Information) within different steps of a Landslide Risk Assessment (LRA) procedure. In particular, tasks needed within a general risk assessment procedure will be initially discussed and possible contributes geomatics engineering and VGI identified in a general framework where a quantitative characterization of factors such as Hazard, Vulnerability and Exposure is a requirement. As concluded, a LRA procedure benefits of contributions by surveyors in the hazard assessment whereas any crowdsourced data would be a valuable support in the vulnerability/damage assessment. However, as also found in the literature, several limitations related to the potential role of VGI and crowdsourcing in the field of LRA will be highlighted.

Keywords: Landslide Risk Assessment · Geomatics Engineering · VGI

1 Introduction

As stated by several authors in the last decade, the so-called Volunteered Geographic Information (VGI) can be a valuable resource in the evaluation and assessments of risk arising from natural hazards and for a rapid and comprehensive inventory of exposed assets [1,2,3,4,5].

Among the range of possible natural or man-induced disasters, this paper focuses the possible roles played by the methodologies encompassed under the geomatics engineering and the VGI as support to the Landslide Risk Assessment (LRA) procedure. Initially, issues and possible approaches to the quantitative Landslide Risk Assessment (LRA) will be briefly introduced with a short insight to the existing international framework. Successively, a review of useful geomatics engineering techniques, ranging from terrestrial to satellite-based, used in the monitoring of slope failure phenomena will be introduced. Finally, a discussion on the role of VGI and crowdsourcing in the field of LRA will be provided by illustrating main issues arisen after the recent and relevant literature.

2 Landslide Risk Assessment: Quantitative Approaches

As presented by the Centre for Research on the Epidemiology of Disasters (CRED) in its annual statistical review, a total of 330 natural triggered disasters were reported in 2013, which is below the average of the last decade [6]. Globally, all the monitored phenomena caused 96.5 million of victims worldwide (21,610 killed) with a very high percentage (88%) coming from low income economies. The recorded economic damages decreased in comparison to the last decade. Within the wide range of possible natural disasters, the CRED provided a classification that can be found in [1]. In that classification landslides are listed under the geophysical disasters which caused costs the 82% below their 2003-2012 annual average and mostly due to the Sichuan, China, earthquake. In particular, the geophysical disasters accounted for 32 episodes (9.7% of total; 7.1 million victims; 1,166 deaths) worldwide.

Once again, it can be noted that many of the geophysical natural disaster were reported over region belonging to developing countries. Here, deficiencies in existing digital maps and assets inventories could represent a limiting factor whenever a quantitative risk assessment procedure is sought.

With regards to the quantitative analysis of risks related to landslide hazards and investigations on slope failure phenomena, an even bigger interest has been recently showed by the scientific community and stakeholders. In this field, the assessment of damages to properties and assets, both as direct and indirect costs, procedures and methodologies able to predict potential hazards to landslide takes on an increasing importance. Beside this, increasing attention is now placed in the mitigation procedures able to reduce social and economic losses due to landslides by means of effective planning and management processes.

However, in spite of improvements in hazard recognition, prediction, mitigation measures, and effectiveness of early warning systems, worldwide landslide activity is widely reported. Thus, for countries affected by landslide risks an improvement in the effectiveness of funds allocation procedures is a requirement in addition to a careful vulnerability of assets exposed to landslide hazards. Hazard, risk, vulnerability and exposure are some keywords in the LRA procedure. A detailed list of keywords and definitions was provided in [7] by the United Nations International Strategy for Disaster Reduction.

According to Crozier and Glade [8], the concept of risk refers to a dual components: the likelihood of an adverse happening and its consequences. However, the adverse event has to be recognized and defined as occurrence and consequences triggered by this adverse event. A widely accepted definition of risk is the following: “the exposure or the chance of loss due to a particular hazard for a given area and reference period” [9]. Mathematically, it could be expressed by the multiplication between the probability that a hazard impact will occur and the consequences of such an impact. In particular, the so-called Varnes’ formula defines $R = H \times V \times E$, being H the natural hazard, E the exposure and V the vulnerability.

In 2009 the UNISDR introduces an hazard as “a dangerous phenomenon … that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage”.

Moreover, a particular hazard is quantitatively described by the frequency of occurrence of different intensities for different areas, as determined from historical data or scientific analysis. In this field the contribution of surveyors play a fundamental role because of the ability by traditional and novel methodologies to detect and represent the magnitude and spatial pattern of an investigated phenomenon. Scientific studies/maps, long-term monitoring, historic reports on past incidence of hazards (in particular the location), frequency and severity of the events constitute the wide range of useful products for a hazard assessment procedure. In addition, the UNISDR defines the exposures as "people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses". Exposure is very often referred as "elements at risk". It is strongly connected with the concept of vulnerability which represents the degree of loss to a given element, or set of elements at risk, resulting from the occurrence of natural phenomena with defined magnitude. The degree of vulnerability could be expressed over a scale ranging from 0 (no damage) to 1 (total loss).

In the quantitative risk assessment, hazard, vulnerability, damage and exposure have to be carefully evaluated on a geographical basis at a suitable spatial detail. As found in the relevant literature, several approaches to quantitative risk assessment have been proposed by authors. In Table 1, such methodologies have been summarized.

Table 1. Approaches to quantitative risk analysis as found in literature. The table follows an increasing level of complexity of the methodology. In the definition column, common values are introduced only once (after [10], with modifications).

Risk formulation	Definition	Source
Risk = H x C	C: Consequence (potential worth of loss) H: Hazard	Einstein (1988)
Rs = H x V	Rs: Specific Risk V: Vulnerability	Varnes (1984)
Rt = Rs x E = (H x V) x E	Rt: Total Risk E: element at risk	Varnes (1984)
Rt =∑(Rs x E) = ∑ (H x V x E)	V: Vulnerability	Fell (1994)
Rs = P(Hi) x ∑(E x V x Ex) Rt = ∑ Rs (landslide event 1,…n)	P(Hi): Hazard for a particular magnitude of landslide (Hi) E: total value of elements at risk, Ex: Exposure	Lee et Jones (2004)
R(DI) = = P(H) x P(S/H) x P(T/S) x P(L/T)	R(DI): individual risk P(S/H): Probability of spatial impact P(T/S): Probability of temporal impact P(L/T): Probability of loss of life for an individual hazard	Morgan et al. (1992)
R(PD) = = P (H) x P (S/H) x V(P/S) x E	R(PD): Specific risk property P(H): Hazard P(S/H): Probability that landslide impact the property V(P/S):Vulnerability E: Value of Property	Dai et al. (2002)

During the last 10 years, the increasing availability of geographical data from authoritative sources or crowdsourcing processes has encouraged the use of statistical and multivariate approaches in the challenging task of geographical prediction and hazards/susceptibility to landslide [11]. Investigations related to the landslide susceptibility assessment could be based on qualitative and quantitative approaches (see Figure 1 for an overview of such methodologies).

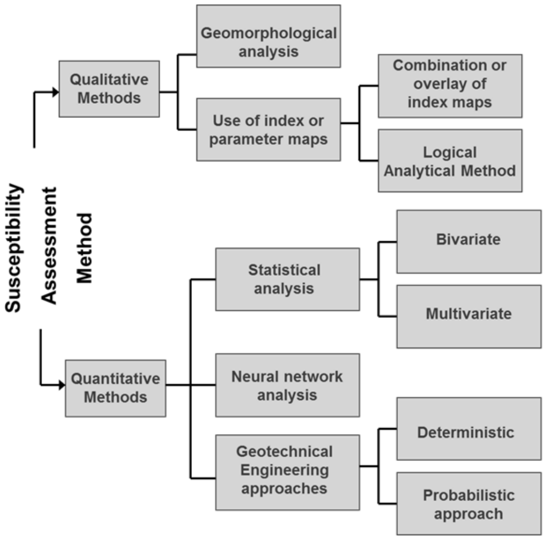

Fig. 1. Classification of qualitative and quantitative approaches in the field of landslide susceptibility assessment

For instance, in the geographical assessment of landslide susceptibility (proneness to landslide) a GIS multivariate analysis could be adopted. In this kind of analysis, all possible causal factors have to be related to landslide occurrence by a selected function.

Therefore, causal factors and a reference landslide inventory have to be previously modelled and represented within the GIS environment. Causal factors derived from the elevation model are resumed under the term “morphometric”. Others are relevant to lithology, drainage system, existing infrastructures and anthropogenic source.

Whenever a hazard or susceptibility map is sought, all possible causal factors have to be connected to landslide occurrences following the idea that "the past are the key of the future". A full description of the geographical setting is required through geographical information is a requirements in addition to a landslide inventory where location and description of past occurrences are reported. The acquisition, storage and management of such data greatly benefits of methodologies provided by geomatics engineering.

3 Approaches by Geomatics Engineering in the Delineation of Landslide Hazard

A comprehensive review of possible methodologies adopted by surveyors in the investigation of slope failure phenomena goes beyond the scope of this work. However, in this sections a gallery of some application of geomatics engineering performed in the past by authors to landslide monitoring and hazard assessment well be provided. In this field, methodologies belonging to the geomatics engineering are mainly focused on the challenging task of detecting slow and very slow movements. Among the variety of available techniques the following will be briefly introduced: *real time monitoring by multi sensor approach*, *GNSS (Global Navigation Satellite System)*, *UAV (Unmanned Aerial Vehicle) proximity survey*, *GB-SAR (ground-based radar interferometry)*, *TLS (Terrestrial Laser Scanning)* and *satellite radar interferometry (DInSAR and Permanent Scatterers Interferometry©)*. Beside these methodologies, geomatics could contributes to the LRA by providing geographic data on which *statistical and multivariate approaches to landslide hazard prediction* are based on. Hereafter, all these are very briefly discussed within investigations about slope instabilities and a pros and cons balance provided.

3.1 Real Time Monitoring by Multi-sensor Approach

The integration of various techniques is nowadays more technologically and economically accessible, allowing to identify possible hazard to slope failures at increasing reliability. By the multi-sensor approach, automated Total Stations (ATS), GNSS receivers and clinometers represents the more adopted technologies used.

ATS requires the availability of a suitable site far away from the affected area and several reflectors within the monitored area. Additional reflectors need to be installed in stable positions, serving as control points for data correction. A forced centering device is often used to assure repeatability of ATS positioning, when periodic surveys are required. The inter-visibility between ATS and peripheral prisms could represent a drawback in addition to the stability of both the ATS and control prisms [12]. The latter, in particular, if small displacements are sought. To this purpose, monuments are periodically checked by GNSS surveys in order to avoid misinterpretation of results.

The stability of reference ATS is mandatory and could be achieved by bi-directional clinometer able to tilting movements. It guarantees the stability of the reference frame and the consistency among subsequent observations.

The stability of control prisms is of great concern because their coordinates are used to compute geometric corrections which are then applied to all raw measurements. It is widely known, indeed, that the reliability of ATS measurements is strictly connected to the atmospheric influence on the electronic distance measurements. Errors due to atmospheric refraction can achieve some centimeters of magnitude if no correction is introduced. The monitoring station on Figure 2 was designed by authors to detect potential slope failure phenomena.

Fig. 2. Integrated monitoring system for unstable slopes: master unit at the top; below GNSS benchmark for continuous monitoring, monitoring reflector and reference prism/GNSS respectively

3.2 GNSS (Global Navigation Satellite System)

In the detection of slow and very slow displacements along a slope, the GNSS methodology based on the relative-static positioning was globally used in the last two decades by episodic or continuous monitoring. The designing of a network composed of reference and monitoring points at locations useful to understand and model kinematic phenomena is a requirements. Displacements could be detected at monitoring points (constituting nodes of the network) only and the behavior of stations used as reference carefully characterized within a well-established 3D reference frame. In the GNSS relative positioning the precision is very high and the error model accurately defined but the number of monitoring points is rather low (depending on the spatial point density) and efforts in the field by surveyors significant. Anyhow, GNSS measurements draw the superficial displacement field at variable (but very often reduced) geographical resolution.

In Figure 3 some results provided by the GNSS monitoring over a small village located in Southern Apennines (Italy) are depicted with an indication of landslides bodies as detected after the geomorphological surveys.

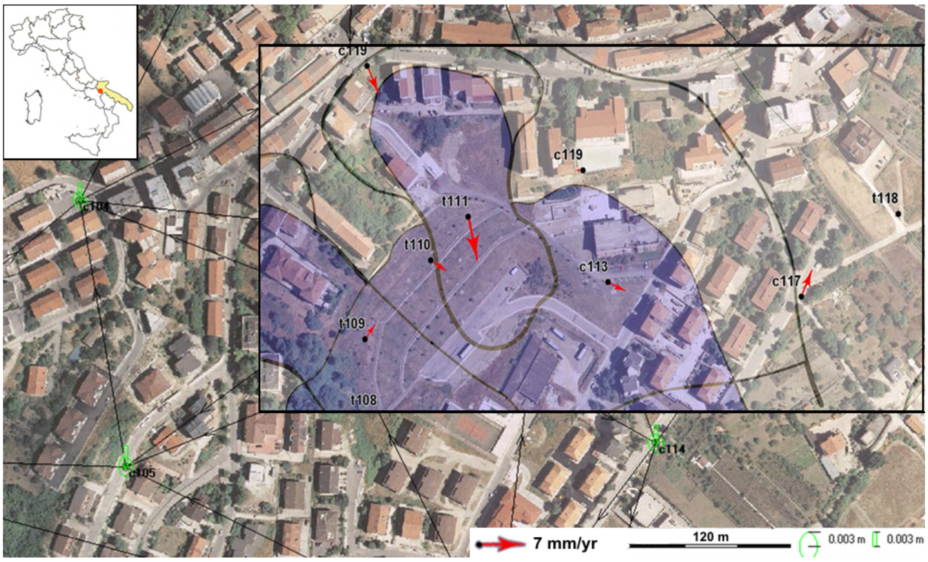

Fig. 3. Displacements over a small portion of the Bovino's (Foggia, Italy) landslide as revealed after the GNSS monitoring. Annual velocities (mm/yr) detected during the year 2009 at network nodes and a delineation of the landslide body are superimposed to the GNSS network geometry and point-specific error ellipses

3.3 UAV (Unmanned Aerial Vehicle) Proximity Survey

More recently, multi-rotors UAV systems have proven to be a very useful tool for very high resolution DSM (Digital Surface Model) and orthophotos generation within geomorphological applications [13,14]. Due to the initial stage of such application to unstable slope, only few applications could be retrieved in the literature. See for example [15] for a cutting–edge investigation of sliding phenomena by UAV systems. These UAV-based methodologies use image collections of unordered, non-metric, aerial images and data analysis based on classical computer vision approaches.

In particular, the flexible surface reconstruction based on the Structure from Motion (SfM) approach is widely used as rapid, inexpensive and highly automated method able to produce 3D information. Besides the good quality of elevation model produced, orthophoto at unprecedented spatial resolution can be produced over hazardous area.

3.4 GB-InSAR (Ground-Based Interferometric Synthetic Aperture Radar)

Spot monitoring campaigns with GB-InSAR allow the rapid assessment of landslide activity [16] even in radar-hostile, partially vegetated slopes and with high contents of humidity (ground and atmospheric). However, solutions could be affected by the processing strategy due to the parameters used (for instance number/timing of raw scenes, coherence of the images over time and space; shape/extent of the area and number or sampling rate of processed scenes. At very low displacement rates (i.e. few mm during the survey period) and with predominantly vegetated grounds, the processing strategy can affect the outcomes significantly. Furthermore, corrections to atmospheric effects could represent an issue whenever a lack of coherence continuity in the scene is present. All these points make the detection of very small displacements very hard.

The installations of GB-InSAR sensor in a suitable place allows the monitoring of slope movements and the possibility to obtain displacement maps in near-real time being also possible to operate at distances of up to few km from the radar sensor. Results can be visualize “on site” through a 2D/3D displacement map thanks to a GIS (Geographic Information System) interface. See Figure 4 for a displacement map from GB-InSAR data collected at Romanoro (Modena, Italy) with displacement (along the LOS) of relevant points (PS) from surveys at 1 hour rate.

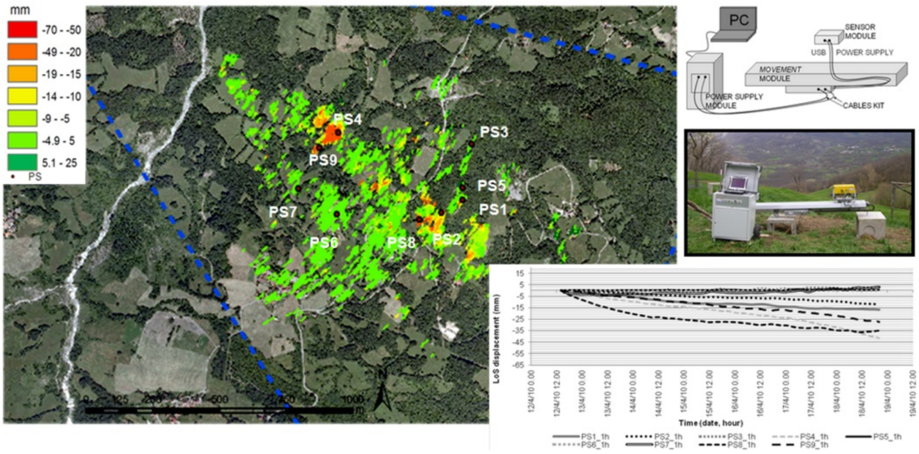

Fig. 4. Romanoro (Modena, Italy) Landslide. 2D LoS (Line of Sight) displacement maps from image processing at 1 hour rate. Some time series of representative points have been reported. In the upper-right insets the radar sensors and its components

3.5 TLS (Terrestrial Laser Scanning)

The main advantage in the use of TLS technique with respect to other geodetic techniques, such as total station or GPS systems, lies in providing a spatially continuous geometric description of the phenomenon. On the other hand the main drawback is the impossibility to exactly identify punctual features, resulting in hard troubles to determine displacements. Despite that, terrestrial laser scanning is widely used to support landslides monitoring and some attempts have been carried out to detect geomorphology changes over time [17].

The main difficulty in comparing subsequent laser scanning surveys concerns the alignment process; the reliability of final results, indeed, is strictly dependent to how properly the multiple point clouds have been aligned. An efficient solution would be the direct alignment, which requests a stable fixed position for the TLS placement at each campaign as well as to fix the orientation by acquiring a specific marker during successive surveys. In the indirect approach, a manual or automatic homologous point's identification in each pair of point clouds is required and a 3D transformation is computed to align point clouds. One more drawback needs to be faced: the vegetation filtering is often required while surveying unstable slopes in order to remove the vegetation and analyze the real ground surface. Once the alignment has been achieved, several strategies are available concerning the surface reconstruction procedure: the multi-resolution meshing approach, based on the Delaunay 2.5D triangulation from each scanning position, proved to be more successful in describing complex local morphologies than grid approaches [18]. See Figure 5 for results of TLS surveys to the Collagna (Modena, Italy) rockslide.

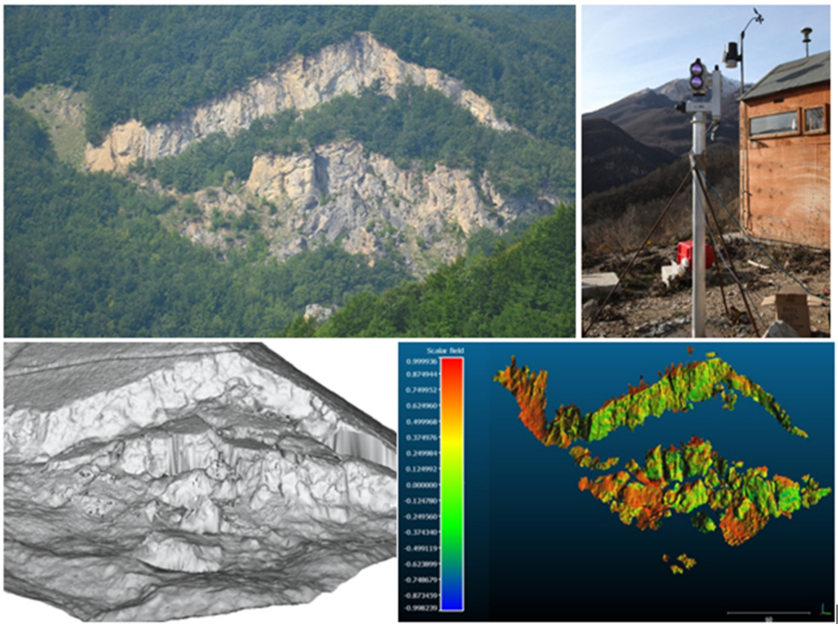

Fig. 5. Results from the Collagna (Modena, Italy) rockslide monitoring (upper left); the laser scanner during surveying (upper right); DTM obtained by integrating airborne and terrestrial laser scanning (bottom left) and morphology changes over the period 2010-2013 obtained by differential TLS surveys (bottom right)

3.6 Satellite Radar Interferometry (DInSAR and Permanent Scatterers Interferometry©)

Since 20 years, the satellite sensing based on SAR (Synthetic Aperture Radar) technology has been providing valuable information in the field of LRA. Thanks to methodologies such as the Differential SAR Interferometry and, more recently, the Permanent Scatterers Interferometry (PSI©), several generations of radar satellites were used to provide impressive information on superficial slow movements. Depending on the geometry of satellite acquisition, elevation maps and deformation maps could be processed by the Differential Interferometry. Fringes represent differences in elevations or displacements at considerable geographical extent.

The alternative PSI method is based on the statistical analysis of radar response from permanent scatterers with suitable geometry at the ground. A variation in the slant range from satellite to targets among repeated passes is likely due to displacements towards or away from the sensor. Displacements can be solely detected along the so-called LOS (Line Of Sight) and a decomposition of displacements along the purely vertical and West-Est directions is only possible by the combined analysis of ascending and descending orbits. A potential slope will be detected with an opposite sign by the ascending and descending orbits. The methodology is not sensitive to displacements in the north-south direction and over vegetated areas.

4 On the Potential Role of Geomatics Engineering and VGI in the Landslide Risk Assessment Procedure

As stated in section 2, a LRA procedure is a complex task and needs of an integrated approach. According to [19], risk assessment "takes the output from risk analysis and assesses these against values judgements, and risk acceptance criteria". As also introduced in section 3, monitoring of landslide kinematics through methods provided by geomatics engineering is able to address the complex issues of hazard evaluation and support the census of element at risk. However, an exhaustive LRA could also benefit from what has been defined as the community based knowledge. There are several stages at which values and judgments, either explicitly or implicitly, enter in the decision-making process by underpinning consideration of the relevance of estimated risks and the associated social, environmental, and economic consequences. For instance, it happens when the identification of a range of possible alternatives for managing risks are formulated. These types of judgment are relevant to the risk evaluation procedure, where three categories of risks could be identified: acceptable, tolerable and intolerable [20].

Such judgments are, however, strongly influenced by psychological values as well as cultural and social aspects. Hence, a multitude of factors contributes to risk perception, and it may also vary greatly among individuals who are part of the same community. Therefore, the fundamental role played by the "communication of risk" and the related "understanding of risk" by people affected by a given hazard, could not be overemphasized.

Despite adversarial attitude and widespread skepticism about the reliability and involvement of the volunteered information, in the framework of the LRA the role of VGI is unquestionably useful in particular conditions. It is the case of events never occurred before, such as those induced or exacerbated by climate change, in which the role of communities and individuals may be similar to that played by the early warning system. Under some conditions, the landslide phenomenon may assume an evolution from slow to very fast. Only few slopes could be instrumentally monitored and, in the case of sudden development of the sliding phenomenon, there are no terrestrial or satellite-based methodologies able to provide information at the required temporal rates.

In such situations, information collected from citizens living within areas subjected to landslide risk could help in identifying possible precursory phenomena and constitute a potential early warning system for authorities. These kinds of Community-Based Early Warning Systems (CBEWS) could contribute towards a reduction of economic losses after a natural phenomenon occurs and in the mitigation of direct and indirect negative effects on goods, people and properties. The CBEWSs are supposed to be an ideal tool, being able to provide the communities and disaster risk manager with anticipatory information on a potential impending phenomenon and improve the preparedness against adverse phenomena. Detractors of such an approach drive the attention on possible false positive responses from CBEWS and the needs of a reliable procedure able to provide a judgment about the credibility of information from the users.

The VGIs philosophy could support EWS especially in developing countries where inventories, existing data infrastructures and available equipment are not able to cope with a rapid and widespread monitoring of emergency situations. If in certain case, the risk evaluation can be conducted relying on the "hard data" collected by means of instrumental survey and monitoring procedures, a complete LRA needs the implementation of intangible data. The latter could be based on the knowledge by communities about the specific risk. Obviously, an integration between expert and community based knowledge could be also an opportunity. Risk maps developed through collaboration between researchers and affected communities are the simplest way to represent and inform about a specific risk. Beside this, a detailed description of the whole mentioned process would be very useful in addition to guidelines able to support any decisional phase.

Due to the above motivations, the LRA could greatly benefits from massive information coming from crowdsourcing, technical and/or scientific knowledge and VGI. In the hazard assessment procedures surveyors coming from professional or scientific communities can be a primary source of knowledge by providing the extremely wide variety of data and results on the magnitude and extent of monitored phenomena. Open problems are related to the way surveyors can disseminate data, results and knowledge about surveyed hazards. A common practice about dissemination of data would be required by taking also into account issues related to the data heterogeneity (arising from different methods, production stage, etc.) and varying level of uncertainty of observation and results.

In view of future implementations of VGI systems as a tool for risk assessment to natural phenomena, some open questions have to be faced. A first one is related to the minimum level of skillfulness and knowledge required by contributing people while a second relies with the amount and reliability of available information, especially over highly vulnerable areas with poor dataset or within regions where geographical database are not in use. Several other task have to be faced thoroughly: the willingness by users to contribute, difficulties in the access to knowledge by potential contributors (critical for poor qualified group of people), the credibility of contributors and reliability of contributions and to the need of a long-term maintenance of initiatives. Nevertheless, the introduction of the VGI concepts could be a solution for some of the issues arisen in this paper. For instance, it is a shared opinion that the conceptual match between elements at risk and VGI is an applicable framework.

5 Conclusion

In the scientific community involved in the field of risk assessment related to natural disasters is a common thought the VGI could be a solution for some of the tasks. In particular, the Landslide Risk Assessment procedure may benefit from the use of VGI and crowdsourcing in the strengthening of existing Spatial Data Infrastructures and "authoritative" or "conventional" data and whenever data are missed in the investigated areas.

Nevertheless, limitations to the use of VGI in the natural disaster can be found in recent literature. Firstly, some gaps in the use of VGI for natural hazard assessment must be filled as well as the need for more robust case studies and experimental research to support this promising field [1]. Manfré et al. [2] introduced the needs of a training for involved volunteers and minimum number of volunteers. Another key aspect was introduced in [21] by Camponovo and Freundschuh who discussed the need for more research on the quality of the categorization (i.e., attribute data) of volunteered emergency data. Coleman [22] stated that the VGI is not the ultimate solution to all geospatial data updating and maintenance challenges now faced by mapping organizations. The contribution of the scientific community in this field could be placed in the establishment of a rigorous framework and workflow able to provide reliable results and reduce the uncertainty of basic information used in the Landslide Risk Assessment procedures.

References

1. Horita, F.E.A., Degrossi, L.C., de Assis, L.F.G., Zipf. A., de Albuquerque. J.P.: The Use of Volunteered Geographic Information (VGI) and Crowdsourcing in Disaster Management: a Systematic Literature Review. AIS Electronic Library (AISeL) (2013)
2. Manfré, L.A., Hirata, E., Silva, J.B., Shinohara, E.J., Giannotti, M.A., Larocca, A.P.C., Quintanilha, J.A.: An Analysis of Geospatial Technologies for Risk and Natural Disaster Management. ISPRS Int. J. Geo-Inf. 1(2), 166-185 (2012)
3. Schelhorn, S.J., Herfort, B., Leiner, R., Zipf, A., de Albuquerque, J.P.: Identifying Elements at Risk from OpenStreetMap: The Case of Flooding. In: Proceedings of the 11th International ISCRAM Conference. University Park, Pennsylvania, USA (2014)
4. Horita, F.E., de Albuquerque, J.P.: An Approach to Support Decision-making in Disaster Management Based on Volunteer Geographic Information (VGI) and Spatial Decision Support Systems (SDSS). In: Proceedings of the 10th International Conference on Information Systems for Crisis Response and Management. Baden-Baden, Germany, pp. 12-15 (2013)
5. Poser, K., Dransch, D.: Volunteered Geographic Information for Disaster Management with Application to Rapid Flood Damage Estimation. Geomatica 64(1), 89-98 (2010)

6. Guha-Sapir, D., Hoyois Ph., Below R.: Annual Disaster Statistical Review (2013). The numbers and trends. Brussels: Centre for Research on the Epidemiology of Disasters (2014)
7. United Nations International Strategy for Disaster Reduction (UNISDR): Terminology on Disaster Risk Reduction. United Nations (2009)
8. Crozier, M.J., Glade, T.: Landslide Hazard and Risk: Issues, Concept and Approach. In: Glade, T., Anderson, M., Crozier, M.J. (eds.) Landslide Hazard and Risk. pp. 1-40.John Wiley and Sons (2005)
9. Varnes, D.J., IAEG. Landslide Hazard Zonation - A Review of Principles and Practice. Commission on Landslides. Paris, UNESCO, pp. 60 (1984)
10. Duzgun, H.S.B. Lacasse, S.: Vulnerability and Acceptable Risk in Integrated Risk Assessment Framework. In: International Conference on Landslide Risk Management and 18th Vancouver Geotechnical Society Symposium (2005)
11. Mancini, F., Ceppi, C., Ritrovato, G.: GIS and Statistical Analysis for Landslide Susceptibility Mapping in the Daunia Area (Italy). Nat. Hazards Earth Syst. Sci. 10(9), 1851-1864 (2010)
12. Castagnetti, C., Bertacchini, E., Corsini, A., Capra, A.: Multi-sensors Integrated System for Landslide Monitoring: Critical Issues in System Setup and Data Management. Eur. J. Remote Sens. 46, 104-124 (2013)
13. Mancini, F., Dubbini, M., Gattelli, M., Stecchi, F., Fabbri, S., Gabbianelli, G.: Using Unmanned Aerial Vehicles (UAV) for High-resolution Reconstruction of Topography: The Structure from Motion Approach on Coastal Environments. Remote Sens. 5(12), 6880-6898 (2013)
14. Bertacchini, E., Castagnetti, C., Corsini, A., De Cono, S.: Remotely Piloted Aircraft Systems (RPAS) for High Resolution Topography and Monitoring: Civil Protection Purposes on Hydrogeological Contexts. In: SPIE Remote Sensing, pp. 924515-924515. International Society for Optics and Photonics (2014)
15. Turner, D., Lucieer, A., de Jong, S.M.: Time Series Analysis of Landslide Dynamics Using an Unmanned Aerial Vehicle (UAV). Remote Sens. 7(2), 1736-1757. (2015)
16. Corsini A., Berti M., Monni A., Pizziolo M., Bonacini F., Cervi F., Ciccarese G., Ronchetti F., Bertacchini E., Capra A., Gallucci A., Generali M., Gozza G., Pancioli V., Pignone S., Truffelli G. (2013). Rapid Assessment of Landslide Activity in Emilia Romagna Using GB-InSAR Short Surveys. In: Landslide Science and Practice. vol. 2, p. 391-399, BERLIN:Springer, ISBN: 9783642314452, Rome, 3-7 October 2011
17. Corsini, A., Castagnetti, C., Bertacchini, E., Rivola, R., Ronchetti, F., Capra, A.: Integrating Airborne and Multi-temporal Long-range Terrestrial Laser Scanning with Total Station Measurements for Mapping and Monitoring a Compound Slow Moving Rock Slide. Earth Surf. Proc. Land. 38, 1330-1338 (2013)
18. Castagnetti, C., Bertacchini, E., Corsini, A., Rivola, R.: A Reliable Methodology for Monitoring Unstable Slopes: the Multi-platform and Multi-sensor Approach. In: Proceedings of the SPIE, Earth Resources and Environmental Remote Sensing/GIS Applications V (2014).
19. Fell, R., Ho, K.K.S., Lacasse, S., Leroi, E.: State of the Art Paper 1-A Framework for Landslide Risk Assessment and Management. In: Proceedings of the International Conference on Landslide Risk Management, Vancouver, BC, Canada (2005)
20. Fell, R.: Landslide Risk Assessment and Acceptable Risk. Canadian Geotechnical Journal 31, 261-272 (1994)
21. Camponovo, M.E., Freundschuh, S.M.: Assessing Uncertainty in VGI for Emergency Response. Cartogr. Geogr. Inf. Sci. 1-16 (2014)

22. Coleman, D.J.: Potential Contributions and Challenges of VGI for Conventional Topographic Base-mapping Programs. In: Sui, D. Elwood, S., Goodchild, M. (eds.) Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice. Springer Science+Business Media, Dordrecht (2013)