CHEMICAL ENGINEERING TRANSACTIONS

VOL. 31, 2013

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet

Guest Editors: Eddy De Rademaeker, Bruno Fabiano, Simberto Senni Buratti

ISBN 978-88-95608-22-8; ISSN 1974-9791

DOI: 10.3303/CET1331151

Vulnerability of Industrial Facilities to Potential Volcanic Ash Fallouts

Maria Francesca Milazzo*[a], Giuseppa Ancione[a], Ernesto Salzano[b], Giuseppe Maschio[c]

[a]Dipartimento di Ingegneria Elettronica, Chimica e Ingegneria Industriale, Università di Messina, Viale Ferdinando Stagno d'Alcontres 31, 98166, Messina, Italy.
[b]Istituto di Ricerche sulla Combustione, Consiglio Nazionale delle Ricerche, Via Diocleziano 328, Napoli, Italy.
[c]Dipartimento di Ingegneria Industriale, Università di Padova, Via F.Marzolo 9, 35131 Padova, Italy.
mfmilazzo@unime.it

Following recent natural disasters, which have had a significant impact on chemical plants, the study of Natural-Technological risks (Na-Tech) has increased worldwide. This work is focused on the study of volcanic Na-Tech events and aims at defining a procedure for the representation of the vulnerability of industrial facilities in areas with the potential volcanic ash fallout using a Geographic Information System (GIS). The methodology has been applied to the area surrounding Mount Etna (Sicily, Italy). Indeed, this volcano has had recently explosive eruptions with consistent ash fallout and is surrounded by a number of industrial installations and also petrochemical plant. This paper is focused on the choice of the most suitable interpolation procedure for the vulnerability mapping in areas where input data is available only for few points, finally comments on the procedure validation are also provided.

1. Introduction

When natural disasters are of concern, it should be expected that, at the same time, those events are able to affect the integrity of urban systems and industrial facilities. A recent survey (Fabiano and Currò, 2012), showed that from 1930 to 2010, nearly 6.4% of the accidents recorded in the downstream oil industry are connected to an enlarged category "Environment". If large amounts of hazardous materials are stored, severe accidents such as fires, explosions or toxic dispersions may also occur. This chain of event is named Natural–Technological scenario (Na-Tech). Na-Tech events have been often neglected in qualitative or quantitative industrial risk assessment (Campedel et al., 2008), but however recent events have forced public authorities and industrial safety managers to cope with this type of risks and to consider them as emergent risks, similarly to those related to new technologies (Krausmann et al., 2011).
The vulnerability of an industrial system may be described by combining the susceptibility (inherent propensity to damage) and the resilience (propensity to deal with the emergency and the recovery of normal activity). When large scale events are of concern, the visualization of vulnerability on specific maps is particularly useful for Civil Protection in order to handle emergencies, particularly if implemented on a Geographic Information System (GIS). Indeed, Lindell and Perry (1996) stated that the level of disaster preparedness is correlated with the level and completeness of vulnerability assessments. It is however worth noting that, in spite of this analysis, Cruz et al. (2004) reported that many countries have high likelihood for the occurrence of disastrous natural hazards but none appear to have implemented Na-Tech vulnerability maps in the Civil Protection plans.
Recently, we have analysed the vulnerability of some industrial facilities to ash fallout, such as storage tanks (Milazzo et al., 2012a) and filters (Milazzo et al., 2012b). This paper aims to develop vulnerability maps for volcanic Na-Tech events as a decision-making tool. Hence, in the first part, a simplified methodology to define the vulnerability of industrial equipment with respect to the ash fallout phenomenon is provided. Finally, the second part of the work focuses on vulnerability representation and shows the

Please cite this article as: Milazzo M.F., Ancione G., Salzano E. and Maschio G., 2013, Vulnerability of industrial facilities to potential volcanic ash fallouts, Chemical Engineering Transactions, 31, 901-906 DOI: 10.3303/CET1331151

comparison between two interpolation–extrapolation methods. The methodology has been applied to Mt. Etna in Sicily (Italy), this volcano has had recently explosive eruptions with consistent ash fallout.

2. Methodology

The methodology described in this section is a generic and simplified approach for estimating the vulnerability of industrial facilities to volcanic Na-Tech. It has recently been proposed by Milazzo et al. (2012c) and is summarized in the flow-chart of Figure 1. According to this approach, the first step is the definition of the specific volcanic phenomenon and the presence of vulnerable system at a given location around the volcanic crater. Hence, it is necessary to define the potential damage with respect to the physical parameter associated with the volcanic phenomenon. Afterwards, either the threshold limit or the exceedance probability for the physical parameter must be calculated. Finally, an appropriate procedure has to be chosen to interpolate data related to each point of the territory, in order to represent the vulnerability of the system on a cartography.

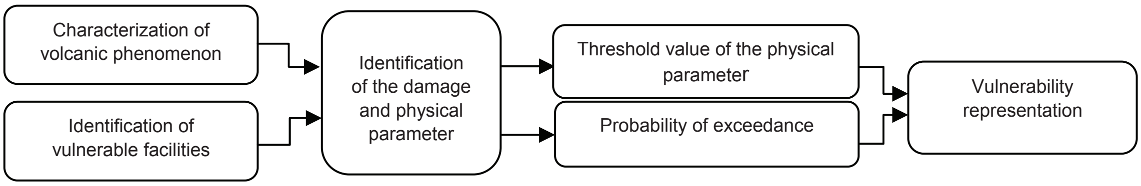

Figura 1: Flow-chart for the representation of vulnerability.

To calculate vulnerabilities a number of simulation maps of the phenomenon are necessary from which the exceedance probability curves of the related parameter are derived for each point in the area. The application of this general procedure is shown in the following section for Mt. Etna, aiming to achieve volcanic Na-Tech vulnerability maps. For this case-study exceedance probability curves are known only for few points, thus this paper is focused on the last step of the approach and aims at the choice of the most suitable interpolation procedure and its validation.

2.1 Characterization of the volcanic phenomenon

Mt. Etna is a volcano located in Sicily (South Italy), it has recently changed the nature of the eruptive style and explosive eruptions with ash emission are more common. The territory surrounding Mt.Etna is characterised by the presence the city of Catania, many small urban centres (as Randazzo, Zafferana, etc.) and agricultural and industrial areas. This volcano frequently is characterized by an explosive activity classified with VEI (Volcanic Explosive Index) equal to 2 or 3, according to Newhall and Self (1982). Among the numerous volcanic phenomena which can potentially damage population and structures, the ash fallout seems the most important for Na-Tech risks (see Milazzo et al., 2013 for more details) and has been analysed in this paper. Regarding the industrial equipment, atmospheric storage tanks, either fixed or floating roof, are considered in the following.

2.2 Identification of the damage and the physical parameter

The physical parameter related to the natural phenomenon of ash fallout causing the damage to industrial equipment is the ash load (kg/m^2) or the thickness of deposit (m). For storage tanks, e.g. the fallout can cause different kinds of damage due to the load of the deposit, classified as:

i) light damage, structural damage and structural collapse for fixed roof tanks;
ii) sinking and capsizing of the roof for floating roof tanks.

2.3 Threshold values of volcanic ash load

The threshold limits of damage used to determine the vulnerability of atmospheric tanks were calculated by Salzano and Basco (2008) and Milazzo et al. (2012a) and are summarized in Tab.1.

Table 1: Critical values for volcanic ash load for the structural damage of fixed and floating roof tanks.

	Fixed roof tanks			Floating roof tanks)	
Damage	Light	Structural	Collapse	Sinking	Capsizing
(Symbol)	(T1)	(T2)	(T3)	(T4)	(T5)
Ash load (kg/m^2)	122	357	714	680	380*

*With an asymmetrical ash distribution causing the immersion of half roof (see Milazzo et al. 2012a).

2.4 Probability of exceedance

Numerical simulations of explosive eruptions produce maps of hourly cumulative value of ash deposits, thus allowing the calculation of the exceedance probabilities for ash load. However, as expected, these simulations are complex and there are very few studies in the open literature. With reference to Mt. Etna, Barsotti et al. (2010) have produced an exceedance probability curve for ash deposit to the ground related to most frequent explosive scenario for this volcano (Figure 2).

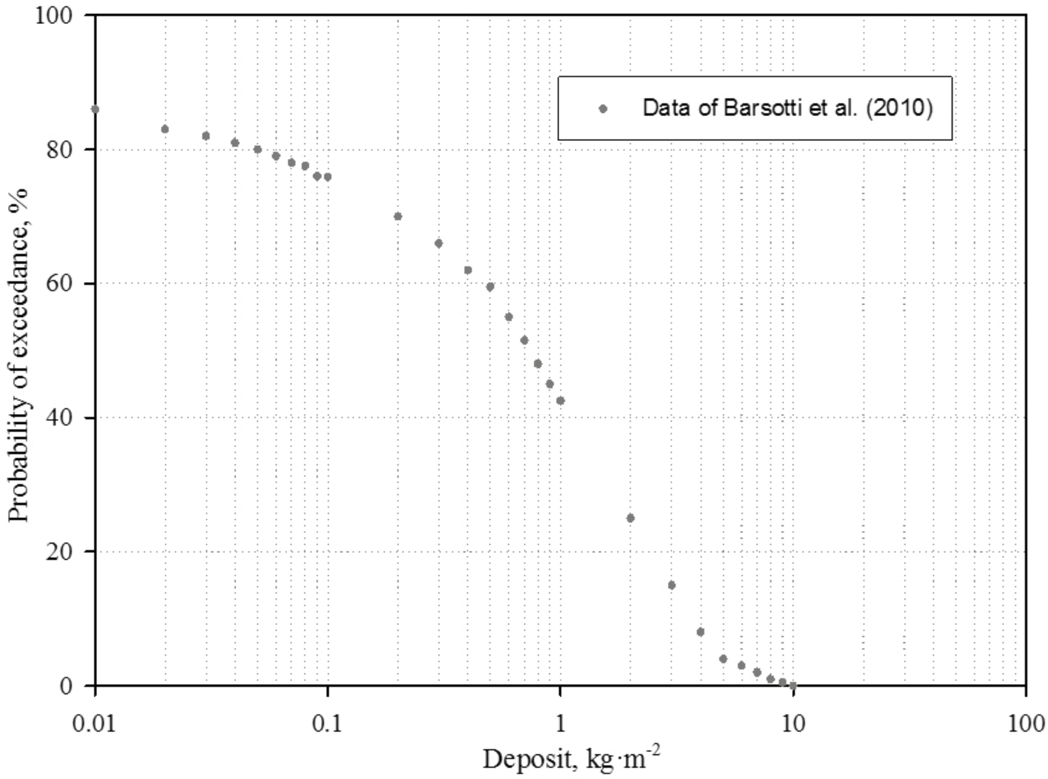

Figure 2: Example of an exceedance probability curve for ash ground fallout as produced by Barsotti et al. (2010).

Starting from the data in Figure 2, maps showing the probability of exceedance for the threshold limits shown of Table 1 are obtained. As already mentioned we knew the exceedance probability curves only for few points, therefore we started our work by using a set of points. In order to achieve our objective we needed to estimate the probabilities also for the points where these are not known, this has been made through a spatial interpolation.

2.5 Vulnerability calculation through spatial interpolation

There are several interpolation procedures, each of them characterized by the time of elaboration, the accuracy, the sensitivity to parameters variation and the degree of smoothness of the interpolated surface. These procedures can be grouped in two main classes: deterministic and stochastic methods (Johnston et al., 2004). Deterministic approaches are based on a correlation among neighbouring points whose parameters have an explicit physical meaning; stochastic methods correlate neighbouring points through a statistical relation (covariance). The class of deterministic methods includes: geometric methods (area interpolation method), Inverse Distance Weighting (IDW) method (named also Point Interpolation Method); finally the class of stochastic methods comprises the Kriging and cokriging methods (Johnston et al., 2004).

In the following, the application and the comparison between two interpolation procedures are shown. The methods applied in this study are the IDW procedure and the Kriging method, respectively. The choice of interpolation method mainly depends on the type of phenomenon to study (in this case tephra fallout), the amount of available data and their spatial distribution and also the results to achieve.

The IDW (determinist method) assumes that each measurement has a local influence which decreases with the distance, and is based on the following mathematical function:

$$z_{(So)} = \frac{\sum_{i=1}^{N} w_i \cdot z_{(Si)}}{\sum_{i=1}^{N} w_i} \qquad (1)$$

where:
$z_{(So)}$ is the value to be predicted located in S_o (prediction point); $i = 1, 2, 3, ..., N$ is the number of locations used for the estimation (identification number of the points around the prediction point); $z_{(Si)}$ is the measured value of the variable at a *i*-th location; $w_i=1/d_i^2$ is the weight coefficient of the measured point at a *i*-th location and d_i is the distance of the *i*-th point from S_o.
The Kriging method (stochastic method) is similar to the IDW approach, but it is based on a probabilistic elaboration in order to develop more complex predictive models. The use of the Kriging allows including the estimation of the error and the uncertainty associated with each prediction (Johnston et al., 2003). The correlation is equation (2).

$$z_{(So)} = \sum_{i=1}^{N} \lambda_i \cdot z_{(Si)} \qquad (2)$$

where:
λ_i is the weight assigned to each measured point at the *i*-th location, it is based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement of the measured points.

3. Results

The calculation of the vulnerability has been made using both the interpolation methods, described in the previous section, and a GIS software. Results are iso-probability maps; Figures 3 and 4 show the maps related only to the light damage of fixed roof storage tanks.
Samples usually are not regularly distributed and, even if they were, the sampling would still not be sufficient to operate a detailed tracing of data to achieve iso-probability curves. The construction of vulnerability maps, therefore, must be made through the estimation of the variable values at points where they were not measured.

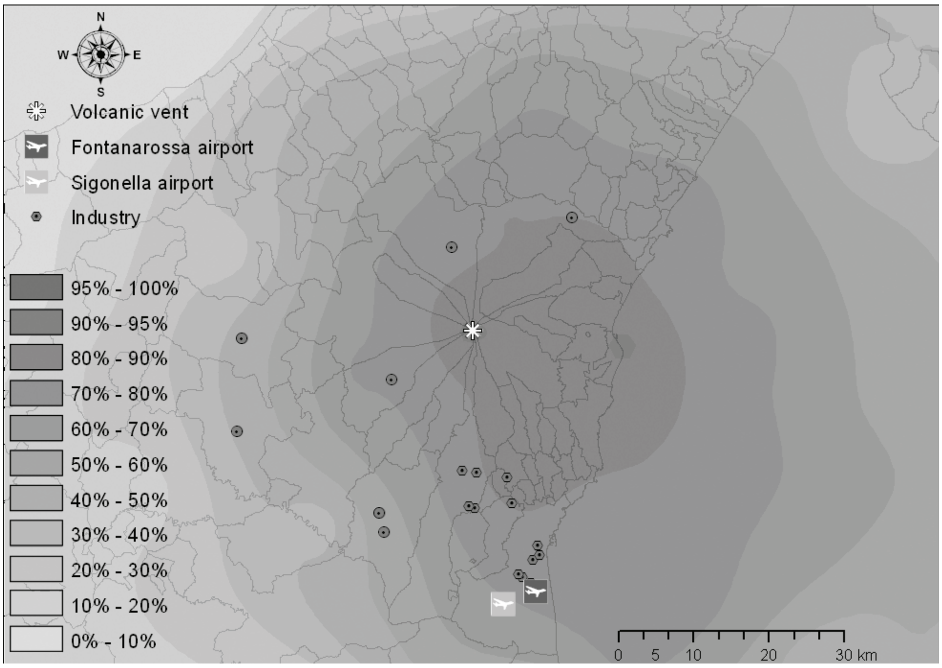

Figure 3: Vulnerability map for light damage of fixed roof storage tanks using the deterministic approach of Inverse Distance Weighting.

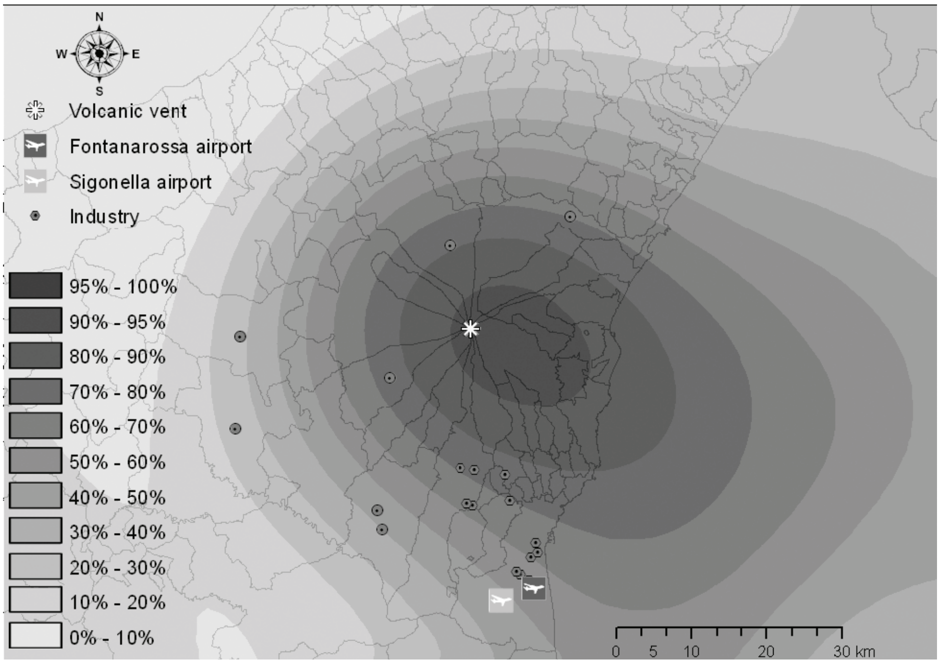

Figure 4: Vulnerability map for light damage of fixed roof storage tanks using the geostatistical approach of Kriging.

It is important to associate each prediction with an error that is the difference between the true value and the estimated value. In this study, errors have been assessed by cross validation, which consists in the estimation of the value of the variable for the points where they are known. This allows to compare the predicted value with the observed value and the error is the difference between the estimated value and the measured value (Johnston et al., 2004).

The validation procedure consists in plotting in Cartesian graph the predicted value as a function of the measured value, as shown in Figure 5. The fitting of the data gives a line, whereas its slope allows to comment about the applicability of the interpolation method. The model is applicable if the slope of the line is about 1.

The blue lines of Figure 5(a) and 5(b) are obtained by fitting the data for the case-study for both the interpolation methods. The slope is ≅ 1 by using the Kriging approach. That demonstrates a good applicability of the model. On the other hand, the application of IDW method does not give a good agreement of data.

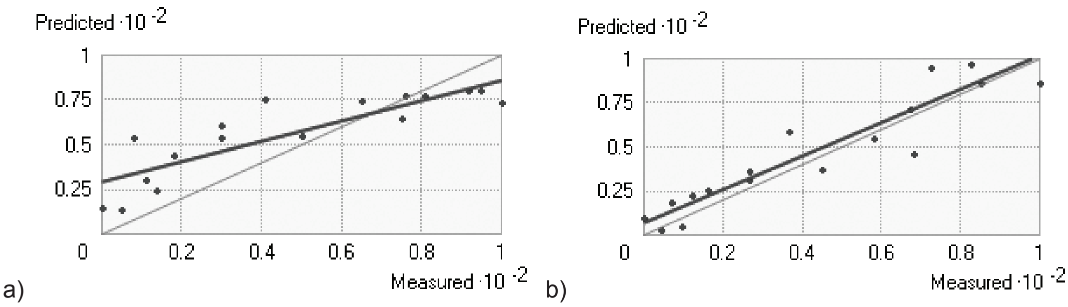

Figure 5. Validation of the IDW and Kriging methods of the vulnerability map related to the threshold limit for ash fallout by using ArcGis Software (Johnston et al., 2004).

Some considerations can be made about the interpolation methods. The IDW technique allows a quick calculation, but results are not very accurate. The geostatistical approach requires a greater number of parameters for an accurate estimation and the data-processing is time-consuming, but it provides more details. The Kriging attenuates the local variability of the variable, it can provide estimates that may exceed the minimum and/or maximum of the measured values, whereas the deterministic methods always produce estimates within the range of values sampled (Liebhold et al., 1993).

4. Conclusions

In this paper, a procedure for the estimation of the vulnerability and the construction of relative maps for volcanic Na-Tech risks has been showed. The objective is to provide local authorities and planners with useful tools for planning emergencies connected to volcanic Na-Tech risks.

The procedure requires the knowledge of the exceedance probability for ash fallout at each location of the territory around the volcano and threshold limits of the parameter causing the damage with the associated eruption phenomenon. The method is also useful when the exceedance probability is known for a limited number of points. In this case, an interpolation procedure is necessary and the choice of the interpolation model is the critical step of the whole procedure.

Acknowledgements

This research has been supported by the MIUR funded project PRIN 2008 entitled "Analysis of potentially critical scenarios on industrial installations and the infrastructure of Eastern Sicily and of health risks associated with explosive eruptions of Etna".

References

Barsotti S., Andronico D., Neri A., Del Carlo P., Baxter P.J., Aspinall W.P., Hincks T., 2010, Quantitative assessment of volcanic ash hazards for health and infrastructure at Mt. Etna (Italy) by numerical simulation. J. Volcanol. Geoth. Res., 192, 85–96.

Campedel M., Cozzani V., Garcia-Agreda A., Salzano E., Extending the Quantitative Assessment of Industrial Risks to Earthquake Effects, Risk Analysis, 28, 5, 1231-1246 (2008).

Cruz A., Steinberg L.J., Vetere Arellano A.L., Nordvik J.P., Pisano F., 2004, State of the Art in Natech Risk Management: NATECH: Natural Hazard Triggering a Technological Disaster. ISDR International Strategy for disaster Reduction. EUR 21292 EN.

Fabiano B., Currò F., 2012, From a survey on accidents in the downstream oil industry to the development of a detailed near-miss reporting system, Process Safety and Environmental Protection 90, 357-367.

Johnston K., Ver Hoef J.M., Krivoruchko K., Lucas N., 2003, Using ArcGis Geostatistical Analyst. Arcgis9. ESRI.

Krausmann E., Cozzani V., Salzano E., Renni E., 2011, Industrial accidents triggered by natural hazards: an emerging risk issue, Natural Hazards and Earth System Sciences, 11, 921–929.

Liebhold A.M., Rossi R.E., Kemp W.P., 1993. Geostatistics and Geographic Information Systems in applied insect ecology. Annual Review of Entomology, 38, 303-327.

Lindell M.K., Perry R.W., 1996, Addressing Gaps in Environmental Emergency Planning: Hazardous Materials Releases During Earthquakes. Journal of Environmental Planning and Management. 39(4) 529-543.

Milazzo M.F., Ancione G., Lister D.G., Salzano E., Basco A., Maschio G., 2012a, Analysis of the effects due to fallout of ash from Mt. Etna on industrial installations. Chemical Engineering Transactions, 26, 123-128, doi: 10.3303/CET1226021.

Milazzo M.F., Ancione G, Lister D.G., Salzano E, Maschio G., 2012b, Potential damage to filtration systems due to volcanic ash fallout, Proc. of the 11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012, 7, 5379-5387, Helsinki, 24-29 June 2012.

Milazzo M.F., Lisi R., Ancione G., Lister D.G., Maschio G., 2012c, Vulnerability maps for industrial facilities in areas with the potential volcanic ash fallout, Proc. of the 11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012, 7, 5388-5397, Helsinki, 24-29 June 2012.

Milazzo M.F., Ancione G., Basco A., Lister D.G., Salzano E., Maschio G., 2013, Potential loading damage to industrial storage tanks due to volcanic ash fallout, Nat. Haz., 66, 939-953, in press, doi: 10.1007/s11069-012-0518-5.

Newhall C.G., Self S., 1982, The Volcanic Explosivity Index (VEI): an estimate of the explosive magnitude for historical volcanism. Journal of Geophysical Research. 87, 1231–1238.

Salzano E., Basco A., 2008, A preliminary analysis of volcanic Na-Tech risks in the Vesuvius area, Proc. of the ESREL 2008, 4, 3085-3092, Valencia, 22-25 September 2008.