The regional early warning system for rainfall-induced landslides operating in Campania (Italy): performance evaluation of two warning strategies

Michele Calvello[1], Gaetano Pecoraro[1], Luca Piciullo[1]

[1] *Department of Civil Engineering, University of Salerno*
Via Giovanni Paolo II 132, Fisciano (SA), Italy
mcalvello@unisa.it; lpiciullo@unisa.it; gpecoraro@unisa.it

Abstract – **The paper focuses on the evaluation of the technical performance of the landslide warning system operating, at regional scale, in the Campania region. The test area of the case study is one of the eight warning zones adopted by the regional civil protection agency to warn citizens for both extreme rainfall conditions and rainfall-related landslides and floods. The simulations performed herein compare two different warning strategies, which are based on measures of cumulated rainfall over different lengths of time, using rainfall data and landslide occurrences referring to the four-year time frame 2010–2013. The performance evaluation is conducted applying the EDuMaP method [1], which is based on the computation of a duration matrix reporting the time associated with the occurrence of landslide events in relation to warning events, in their respective classes.**

I. INTRODUCTION

Landslide early warning systems (LEWSs) are risk mitigation measures designed to issue timely alerts when the level of risk to which people are exposed is judged to be intolerably high. Warning systems for landslides can be designed and used at different reference scales. Two categories of LEWSs can be defined on the basis of their scale of analysis and operation: "local" systems and "regional" systems. The paper focuses on landslide warning systems operating at regional scale (ReLEWSs), which typically assess the probability of occurrence of landslides, over appropriately-defined homogeneous alert zones of relevant extension, through the prediction and monitoring of meteorological variables.

Following a quite recent national law written on this subject [2] every Italian region, including the two autonomous provinces of Trento and Bolzano, has developed a ReLEWS over its territory, typically within a wider-purpose critical weather conditions warning system. All the 21 ReLEWS follow the national guidelines, yet they have been independently designed and they are independently managed by the regional civil protection agencies. The paper employs the EDuMaP method [1], a method specifically developed to evaluate the performance of regional landslide warning models, to compare the two warning strategies adopted by the warning system operating in the Campania region. The test area of the case study is one of the eight warning zones of the region. Rainfall data and landslide occurrences refer to the four-year time frame 2010–2013.

II. MATERIALS AND METHODS

A. The regional early warning system for rainfall-induced landslides operating in the Campania region

The warning system for rainfall-induced landslides in the Campania region (Italy) is managed by the regional civil protection agency as part of the regional warning system developed to deal with extreme weather conditions and with the so-called "hydraulic and hydrogeological risks", i.e. floods and landslides [3]. The Campania region, which includes 551 municipalities over an area of about 13.600 km^2, is divided into 8 warning zones according to homogeneity criteria which consider the following factors: hydrography, morphology, rainfall, geology, land-use, hydraulic and hydrogeological events, administrative boundaries (Figure 1). The rainfall monitoring network is constituted by 154 rain gauges and one meteorological radar.

Landslide warnings may be issued at two levels, respectively considering: 1) the subdivision of the region in warning zones; 2) the administrative boundaries of the municipalities. Two different warning strategies are adopted in the two cases. In the first case, i.e. when the warnings are issued over one or more warning zones, predicted rainfalls are adopted as precursors of possible hydraulic and hydrogeological critical situations. Two types of critical precursors for each warning zone can be distinguished: local critical precursors, which refer to rainfall events whose spatial characteristics affect only a portion of the warning zone; widespread critical precursors, for rainfall significantly affecting the whole warning zone. The local critical precursors are compared to rainfall intensity thresholds with duration of 6, 12 and

24 hours, while the reference rainfall intensity thresholds for widespread critical precursors refer to a duration of 24 hours. In the second case, i.e. when the warnings are issued over one or more municipalities, the precursor is the rainfall monitored by the network of rain gauges. To this aim, each municipality is "associated" to at least one rain gauge of the network. At the municipal level, six hydrogeological and hydraulic risk scenarios are identified in the system, each one associated to critical rainfall events of different duration. Among these scenarios, only one refers to landslide risk, in particular to the possible occurrence of shallow landslides and debris flows; the other scenarios deal with flood risk. The rainfall precursors associated to the landslide risk scenario are three, they refer to the cumulated rainfall recorded over 24, 48 and 72 hours and they are evaluated for three return periods (2, 5 and 10 years).
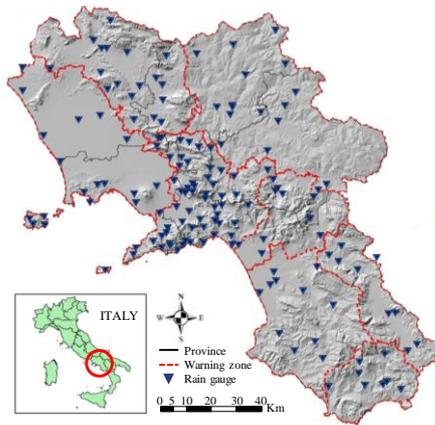

Figure 1. Warning zones and rain gauges employed by the ReLEWS in the Campania region.

B. The EDuMaP method

The "Event, Duration Matrix, Performance method" allows the evaluation of the performance of the warning model adopted within a regional landslide early warning system [1]. The EDuMaP method comprises the following three successive steps: analysis of landslide events (LE) and warning events (WE); definition and computation of a duration matrix; evaluation of the early warning model performance by means of performance indicators.

During the first step, the analyst identifies and classifies the landslide and warning events, according to their spatial and temporal characteristics, by means of a number of model parameters. This step aims at defining the most appropriate LE and WE to be used to assess the model performance. The results of the analysis depend on the values assumed by a series of well-identified parameters (Table 1), which are defined to allow the analyst to make choices on how to select and group landslides and warnings (refer to [1] for details).

The key element of the method is the definition and

computation of a "duration matrix", whose elements report the time associated with the occurrence of landslide events in relation to the occurrence of warning events, in their respective classes. The number of rows and columns of the matrix is equal to the number of classes defined for the warning and landslide events, respectively. Each element of the duration matrix, d_{ij}, is computed, within the time frame of the analysis, ΔT, as follows:

$$d_{ij} = \sum_{\Delta T} time_{ij} \qquad (1)$$

where: i is the number of classes of the warning events; j is the number of classes of the landslide events; $time_{ij}$ is amount of time for which a class i-th warning events is concomitant with a class j-th landslide event.

The final step of the method is the evaluation of the duration matrix based on a set of performance criteria assigning a performance meaning to the element of the matrix. Figure 2 shows the structure of the duration matrix and the two performance criteria that will be used herein to perform the analyses. The duration matrix is based on a subdivision of both warning and landslide events in four classes, indicated with numbers, from 1 to 4, and letters respectively representing the descriptors no, medium, high and very high (for WEs), and no, small, intermediate and large (for LEs). The first criterion employs an alert classification scheme derived from a 2x2 contingency table, thus identifying: correct alerts, CAs; false alerts, FAs; missed alerts, MAs; true negatives, TNs. The second criterion assigns a color code to the elements of the matrix in relation to their grade of correctness, classified in four classes as follows: green; yellow; red; purple.

Table 1. Input parameters for the classification, identification and temporal analysis of landslide and warning events (adapted from [1]).

Parameter	Symbol
Warning levels	W_{lev}
Landslide density criterion	$L_{den(k)}$
Lead time	t_{LEAD}
Landslide typology	L_{typ}
Minimum interval between LE	Δt_{LE}
Over time	t_{OVER}
Area of analysis	A
Spatial discretiz. for warnings	$\Delta A_{(k)}$
Time frame of analysis	ΔT
Temporal discretiz. of analysis	Δt

Alert classification criterion (A)		Landslide events			
		1(no)	2(S)	3(l)	4(L)
Warning events	1(no)	n/a	TN	MA	MA
	2(M)	TN	TN	MA	MA
	3(H)	FA	FA	CA	CA
	4(VH)	FA	FA	CA	CA

Grade of correctness criterion (B)		Landslide events			
		1(no)	2(S)	3(l)	4(L)
Warning events	1(no)	n/a			
	2(M)				
	3(H)				
	4(VH)				

Figure 2. Duration matrix and performance criteria employed herein for the application of the EDuMaP method (adapted from [1]).

III. CASE STUDY

A. Test area and data base

The test area of the case study is the warning zone 3 (WZ3) of the Campania region, which includes 109 municipalities over an area of 1.619 km^2 (Figure 3). The rain gauges monitoring the rainfall in this area are 44. The analysis presented herein uses data on rainfall and landslides recorded, from 2010 to 2013, inside the warning zone 3.

The rainfall measurements were derived from the regional civil protection agency database which reports the rainfall recorded at each rain-gauge every 10 minutes. The data on landslide occurrences were derived from the project "Franeitalia" [4], an inventory of landslides in Italy retrieved from on-line journalistic sources. The information reported for each record of the landslide database always includes the number of landslides per rainfall event, the source of the news, the site of occurrence and the date of occurrence. For each record the database may also report, if the related information is available: hour of occurrence; landslide characteristics; activity phase; effects on people, structures, infrastructures, cars or other elements; links to related photos or videos. The database reports 2622 landslides in Italy for the years 2010-2013, 213 of which occurred in Campania region. The landslides reported within the warning zone chosen for the case study are 89, yet only 69 of them may be considered, on the basis of an evaluation taking into account the cumulative rainfall of the previous 72 hours, rainfall-induced phenomena.

Figure 4 graphically shows how the information on the times of landslide occurrence, t_L, and on their uncertainty are treated in the landslide database. The time t_L is assigned to a landslide according to how the occurrence is reported in the original source of the information. If only the day of the occurrence is available, t_L is either set to 12:00 am or to the hour where the hourly recorded rainfall is maximum, in case the latter measure is available. In both cases the uncertainty associated with the time estimation is set to 24 hours. If a part of the day—i.e. night, morning, afternoon or evening—is specified, then t_L and its uncertainty are respectively set equal to: 5:00 and 6 hours for the night; 11:00 and 8 hours for the morning; 17:00 and 6 hours for the afternoon; 21:00 and 4 hours for the evening. If more information on the part of the day is available, the following t_L and uncertainty levels may be used: 8:00 and 4 hours for early morning; 13:00 and 2 hours for the late morning; 15:00 and 2 hours for the early afternoon; 19:00 and 2 hours for the late afternoon; 23:00 and 2 hours for the late evening. Finally, if the time is explicitly written, then the associated uncertainty level is set to 1 hour.
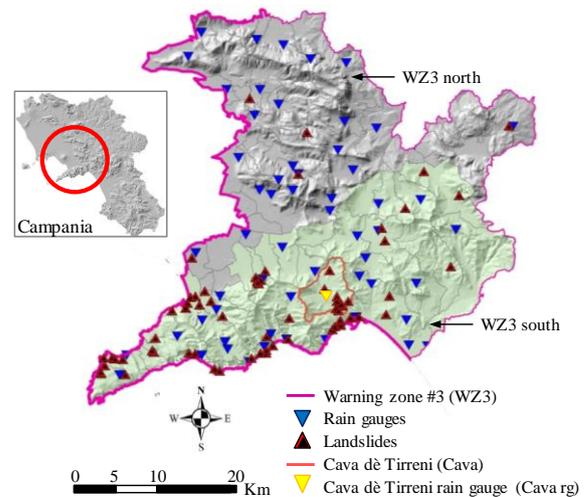

Figure 3. Test area with location of rain gauges and landslides recorded from 2010 to 2013.
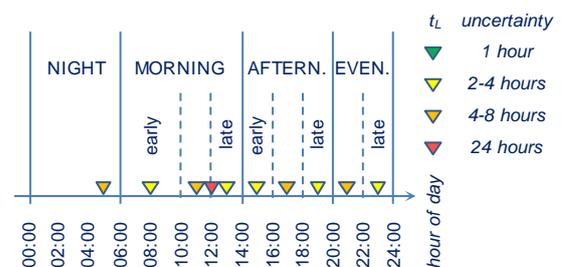

Figure 4. Information on time of landslide occurrence in the landslide database.

B. Events analysis

The assessment of the model performance employing the EDuMaP method requires the preliminary identification of LEs and WEs from analyses carried out on the landslides and warnings databases. As reported in Table 1, ten parameters are needed to carry on this step of the analysis. In this case: the warning levels, W_{lev}, are four, i.e. no warning, class 1(no), attention, class 2(M), pre-alarm, class 3(H), and alarm, class 4(VH); landslide events are grouped in four classes using a fixed landslide density criterion, $L_{den(k)}$, which considers the occurrence of 1 to 2 landslides as a small LE, class 2(S), 3 to 9 landslides as an intermediate LE, class 3(I), and more than 10 landslides as a large LE, class 4(L); the considered landslides, L_{typ}, are rainfall-induced phenomena; parameters t_{LEAD} and t_{OVER} are both set equal to zero; Δt_{LE} is equal to 12 hours; the period of analysis, ΔT, is 2010-2013; the temporal discretization of the analysis, Δt, is equal to 1 hour. Four simulations have

been conducted herein (Table 2) by varying: the area of analysis, A; the rain gauges and the cumulated rainfall considered to define the warnings. Figure 5 graphically shows the WEs and the LEs computed for the analysis "Z3-one", i.e. when the area of analysis is the whole warning zone 3 and the WEs are computed considering the 6, 12 and 24 hours rainfall thresholds of at least one of the 44 rain gauges of the area.

Table 2. Simulations conducted herein

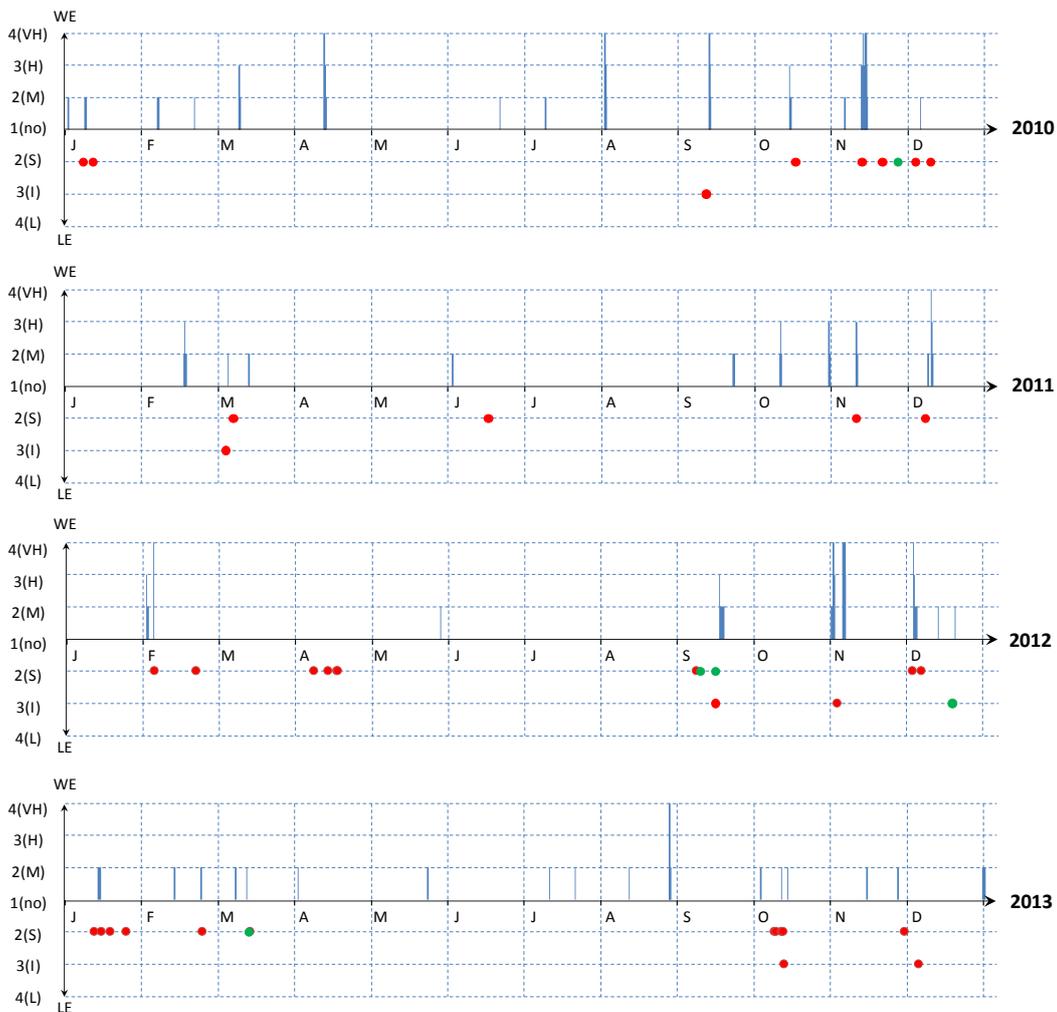| ID	A	rain gauges	rainfall thresholds
C-C	Cava	Cava rg	24, 48, 72 h
Z3s-C	WZ3 south	Cava rg	24, 48, 72 h
Z3-C	WZ3	Cava rg	6, 12, 24 h
Z3-one	WZ3	one of 44	6, 12, 24 h

Figure 5. Landslide and warning events from 2010 to 2013 for simulation "Z3-one" (in green LEs for A=Cava).

C. Performance evaluation

Figure 6 shows the duration matrices computed for the four simulations conducted herein. It is straightforward to notice that only the third (Z3-C) and fourth (Z3-one) simulation, both of them referring to a warning strategy based on measures of cumulated rainfall over 6, 12 and 24 hours, produce WEs of class 3 or 4. In particular, only the latter one (Z3-one) shows a significant amount of time in the highest warning class. In both cases, however, the WEs mostly occur when LEs either do not happen or have a small spatial density—i.e. class 2 LEs—.

(C-C)

		Landslide events			
		1(no)	2(S)	3(I)	4(L)
Warning events	1(no)	34935	27	6	0
	2(M)	95	0	0	0
	3(H)	0	0	0	0
	4(VH)	0	0	0	0

(Z3s-C)

		Landslide events			
		1(no)	2(S)	3(I)	4(L)
Warning events	1(no)	34549	305	115	0
	2(M)	92	0	3	0
	3(H)	0	0	0	0
	4(VH)	0	0	0	0

(Z3-C)

		Landslide events			
		1(no)	2(S)	3(I)	4(L)
Warning events	1(no)	34516	347	111	0
	2(M)	78	0	4	0
	3(H)	5	0	3	0
	4(VH)	0	0	0	0

(Z3-one)

		Landslide events			
		1(no)	2(S)	3(I)	4(L)
Warning events	1(no)	33976	327	86	0
	2(M)	458	15	14	0
	3(H)	95	5	6	0
	4(VH)	70	0	12	0

Figure 6. Duration matrices of the four simulations.

Concerning the worst LEs recorded in the period of analysis—i.e. class 3 LEs—in all simulations they mostly occur when the warning level is low, thus indicating errors of the model according to both the employed performance criteria (see Figure 2). This can be easily seen by looking at Figures 7 to 9, which show the results of the four simulations in terms of: relative distribution of CAs, FAs, MAs and TNs according to performance criterion A (Figure 7a); relative distribution of green, yellow, red and purple durations according to performance criterion B (Figure 7b); values of the main positive performance indicators (Figure 8); values of the main negative performance indicators (Figure 9). The meaning of the performance indicators used in the latter two Figures is reported in Table 3. The best results are obtained in the simulation carried out considering only the Cava de' Tirreni territory and its rain gauge. Yet, the results for this simulation (C-C) should be looked at with caution, due to the relatively low number of hours associated to the few LEs recorded, in this territory, within the time frame of the analysis. Also the results related to the other three simulations suffer from the absence of class 4(L) LEs in the test area between 2010 and 2013. However, a relatively large number of hours associated to class 2(S) and class 3(I) LEs allows the analysis to reliably test the performance of the three simulated warning models, at least in relation to these classes of landslide events.
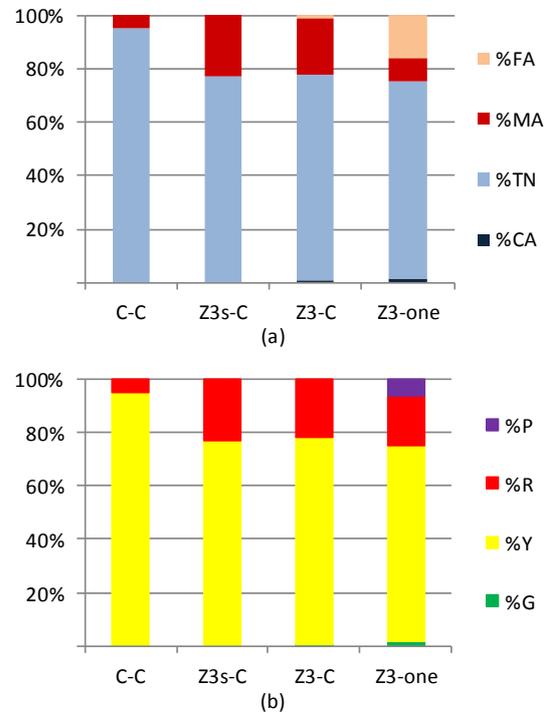

Figure 7. Relative distribution of the terms of the four duration matrices considering the two classification criteria proposed in Figure 2.

In all three simulations, the efficiency index, Ieff, never exceeds 80%, the odds ratio, OR, ranges between 10% and 20% and the error rate, ER, is always higher than 20%. The values of these performance do not imply a very good performance, yet they cannot be considered very negatively either. The best simulations of this set are the ones using the Cava de' Tirreni rain gauge to define the WEs (Z3s-C and Z3-C). It does not seem to matter much whether the warning strategy is based on measures of cumulated rainfall over 6, 12 and 24 hours or over 24, 48 and 72 hours.
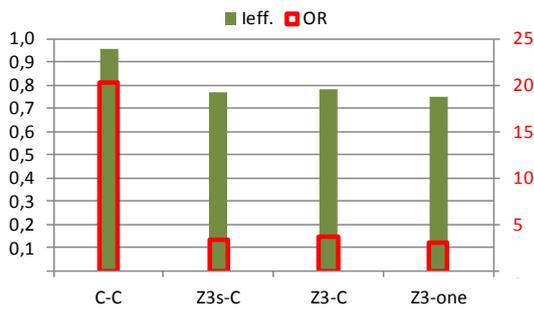

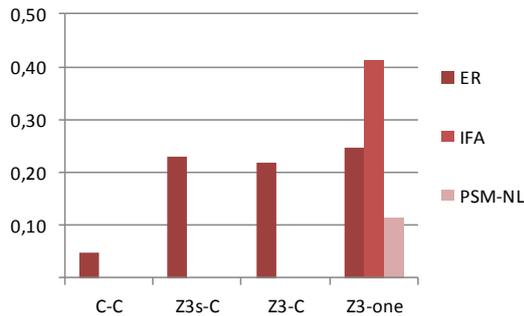*Figure 8. Main positive performance indicators of the four simulations.*

Figure 9. Main negative performance indicators of the four simulations

Table 3. Performance indicators used herein

Indicator	Symbol	Formula
Efficiency index	Ieff	$(CA+TN)/\Sigma_{ij}d_{ij}$ (excluding d11)
Odds ratio	OR	$(CA+TN)/(MA+FA)$
Error rate	ER	$(Red+Pur)/\Sigma_{ij}d_{ij}$ (excluding d11)
Index of severity of false alerts	IFA	$(PUR\&FA)/FA$
Probability of serious no-landslides mistakes	PSM-NL	$Pur/\Sigma_{ij}d_{ij}$ (for i=2-4, j=1)

IV.   CONCLUDING REMARKS

EDuMaP is a method to analyze the performance of early warning models by computing the time associated to the occurrence of landslide events during warning events, in their respective classes. The EDuMaP method has been herein used to evaluate, in a test area, the performance of four landslide warning models derived from the warning system operating at regional scale in the Campania region. To this aim, a 4-year long database of rainfall measures and recorded landslides has been used. The four simulations have compared two different warning strategies, which are based on measures of cumulated rainfall over different lengths of time, within different territories and using different rain gauges. The comparison among the four simulations give some preliminary indications on what rainfall monitoring and warning strategies work better in the test area, yet further work, and other data, are surely needed to improve the reliability of the findings. Nevertheless, the performed analysis highlighted the role of the EDuMaP method in evaluating the effect, in terms of performance, that different operative choices performed by the system managers have on a efficiency of an early warning model for rainfall-induced landslides.

REFERENCES

[1] M.Calvello, L.Piciullo, "Assessing the performance of regional landslide early warning models: the EDuMaP method", Nat. Hazards Earth Syst. Sci., vol.16, No.1, 2016, pp.103-122.
[2] DPCM 27/02/2014, "Indirizzi operativi per la gestione organizzativa e funzionale del sistema di allertamento nazionale, statale e regionale per il rischio idrogeologico ed idraulico ai fini di protezione civile (testo coordinato con le modifiche introdotte dalla Direttiva del Presidente del Consiglio dei Ministri del 25 febbraio 2005 pubblicata sulla G.U. 8 marzo 2005, n. 55)". Italian national law.
[3] D.P.G.R. n. 299 30/06/2005, "Decreto del Presidente della Giunta Regionale della Campania: Il Sistema di Allertamento Regionale per il rischio Idrogeologico e Idraulico ai fini di protezione civile", Bollettino ufficiale della regione Campania, n. speciale 01/08/2005. Italian regional law.
[4] M.Calvello, S.Ferlisi, A.Ruggiero, G.Pecoraro, "Censimento dei fenomeni franosi in Italia da fonti giornalistiche: uno studio pilota", Proc. of IARG, 2013, pp.1-6. In Italian.