Characterization of rainfall events corresponding to forecasted conditions of potential hydrogeological risk

L Khramtsova¹*, M Leonteva¹, M Mobilia², A Longobardi², E Nasyrova¹ and S Aksenov¹

¹Ufa State Aviation Technical University, Department of Fire Safety, Karl Marx, 12, 450000, Ufa, Russia
²University of Salerno, Department of Civil Engineering, Via Giovanni Paolo II, 132, 84084 Fisciano, SA, Italy

E-mail: *khramtsovala@mail.ru, mashuta-l@mail.ru, mmobilia@unisa.it, elinasagitovna@yandex.ru

Abstract. The Italian territory has a high exposure to natural risks including floods and landslides. An early warning system run by the Department for Civil Protection, both at national and regional level, operates to forecasted conditions of potential hydrogeological risk on the basis of forecasted meteorological conditions. The aim of the present paper is to study the relationship between the level of alert issued by the Civil Protection and the characteristics of the associated rainfall events. The case study is a particular area of the Campania region, highly prone to hydrogeological risk. A database of 138 warnings issued during the period 2018-2019 has been analyzed. The warnings were classified using analytical and graphical methods with various criteria. The duration, total rainfall, peak intensity, return period, n-index, BSC-index were used. The results show that there is a clear correlation between the severity of the warnings and the cumulative, peak intensity and the structure of precipitation. No relationship has instead been found between the severity of the warnings and the severity of the rainfall event which, besides the limitation of the case study with a small sample of analyzed events, can be an indication of changing climate conditions.

1. Introduction
The Italian territory has a high exposure to natural risks including floods and landslides. The Department for Civil Protection, with Regional Functional Centers Network, is charged for the management of a network of advanced early warning and alerting centers, the cornerstones of Italy’s preparedness for natural hazards and a best practice worth following. On the basis of the forecast weather events, each Region and Autonomous Province assess critical hydraulic and hydrogeological situations (flooding, landslides, etc...) that could affect their territory. These assessments converge into the Bulletin of national hydrogeological and hydraulic criticalities daily produced by the Department. Consequently, Regions and Autonomous Provinces have to issue alerts for the local civil protection systems, while mayors have the responsibility to activate emergency plans, inform citizens about risk situations and decide the measures necessary to protect the population. In order to indicate the alert level with a simple and intuitive way, a color code has been used: the green color indicates no criticality and/or intense or dangerous phenomena are expected, the yellow color suggests ordinary criticality and locally intense and/or dangerous phenomena are expected, the orange color predicts
moderate criticality and intense phenomena are expected, the red color is used to indicate high criticality and extreme phenomena are expected. In Campania region there are eight warning zones (WZ) and the present research consider as case study the alert area 3(WZ3) including the Lattari Mountains, Picentini Mountains and Pizzod’Alvano Mountains. This area has been selected as it is highly-prone area to hydrogeological risk and where flooding and landslides events occurred indeed rather frequently, especially during the last decade [1-5]. The website of the Civil Protection of Campania region contains an archive of alerts messages from 2018, therefore, the study interval has been from 2018 to 2019 for a total of 138 warning notifications. The aim of this work is to characterize the meteorological events on the base of which the above-said alerts were issued, by means of various criteria including duration, cumulative rainfall, peak intensity, return period, n-index, BSC-index. This analysis allows to potentially identify the characteristics of the rainfall events associated to the different level of alert issued by the Civil Protection.

2. Material and methods

2.1. Case study and data collection

The National Alert System is managed by the National Civil Protection Department in conjunction with local authorities through a network of Functional Centers, Regional Civil Protection Departments and Scientific Competent Centers. The Campania Regional Government originated a Regional Functional Center whose task is to collect, process and exchange all available meteorological and hydrological data, which provides support to local authorities of civil protection for alerts and emergencies. The Campania region (Southern Italy) has been divided into eight warning zones (WZ) in accordance with homogeneity criteria, which take into account the following factors: hydrography, morphology, precipitation, geology, land use, hydraulic and hydrogeological events, administrative boundaries. In the whole territory of a specific alert zone, the effect of rainfall triggering events on the ground is expected to be the same. The subdivision has been carried out with the aim to calibrate the alert thresholds to which the early warning system refers. The rainfall monitoring network consists of 154 rain gauges and one meteorological radar. The non-hydrostatic meteorological model LAMI is used for 3-days ahead weather forecasts of rainfall. The rainfall predictions represent precursors of critical situations. Two types of critical precursors have been defined, a local and a large scale one, which refer to rainfall events effecting respectively only some portions of the alert area and the whole zone. The local precursors are defined for time intervals of 6, 12 and 24 hours while the large scale precursors for a timespan of 24 hours. The threshold values result from a statistical analysis of historical time series of precipitation related to return periods of 2, 5 and 10 years which respectively correspond to yellow, orange and red alerts. These values are compared to predicted rainfalls in order to define the color of alert [6-8]. The eight alert zones of Campania region are (figure 1):

Zone 1: Campania Plain, Naples, Islands, Vesuvius;
Zone 2: Upper Volturno and Mortese;
Zone 3: Sorrento-Amalfi Peninsula, Sarno and Picentini Mountains;
Zone 4: Upper Irpinia and Sannio;
Zone 5: Tuscano and upperSele;
Zone 6: Seleplain and upper Cilento;
Zone 7: Tanagro;
Zone 8: Low Cilento.
Figure 1. The eight alert zones within the Campania region.

Zone 3 has been selected as a case study, since it is a flood-prone area where during the last decade flooding and landslides events with more than 50 people affected, have occurred rather frequently (figure 2). WZ3 has an area of 1619 km$^2$ and includes Lattari, Picentini and Avella-Pizzod’Alvano mountains (figure 1).

Figure 2. Number of critical events 1950-2010 year.

The website of the Civil Protection of Campania region contains an archive of risk alerts messages. The study interval has been from 2018 to 2019 for a total of 138 warning notifications if which 68 in 2018 and 70 in 2019. The 20% of alerts in 2018 and the 22% in 2019 are green, the 74% of warnings
in 2018 and the 54% in 2019 are yellow, 6% of alert notifications in 2018 and the 13% in 2019 are orange and no red alerts have been issued during the periods under investigation (figure 3).

Figure 3. Number of warnings by color.

The rainfall data used in the present study, have been recorded at a meteorological station located in the campus of University of Salerno (WZ3). The meteorological station includes a raingauge, a thermohygrometer, a pyranometer and it has a resolution of 5 minutes [9, 10]. The warning notifications emitted by Regional Civil Protection Departments, represent the 50% in 2018 and the 53% in 2019 of the rainy days occurred within the WZ3 during the periods of observation (table 1).

Table 1. Number of warning alerts during the observation period.

| Year | Rainy days | Green Alert | Yellow Alert | Orange Alert | Total Alert | Alerts Occurrence (%) |
|------|------------|-------------|--------------|--------------|-------------|-----------------------|
| 2018 | 136        | 14          | 50           | 4            | 68          | 50                    |
| 2019 | 132        | 23          | 38           | 9            | 70          | 53                    |

2.2. Rainfall events properties

The rainfall events associated to the alerts messages have been characterized according to six parameters: the cumulative rainfall, the duration, the maximum intensity, the return period, the binary shape code and the n-index.

The BSC code is based on a comparison between SRP (Standardized rainfall profile) and USRP (Uniform SRP) for different quantiles τ. SRP is a probabilistic description of the high variability of precipitation over time. The curve expresses the relationship between the non-dimensional depth \( \pi = y_t / P_{ev} \) and the non-dimensional duration \( \tau = t / D_{ev} \) where \( P_{ev} \) is the total cumulative rainfall and \( D_{ev} \) is the total duration of the event, \( t \) is generic time the and \( y_t \) is the cumulative rainfall at time \( t \). More precisely, the 4-digit binary code is determined as follows:

- time values \( \tau_0 = 0, \tau_1 = 0.25, \tau_2 = 0.50, \tau_3 = 0.75, \tau_4 = 1, (\tau_k, \text{ with } k = 0,1,\ldots,4) \) are fixed on the horizontal axis;
- the corresponding USRP areas, \( A^*_k = \frac{1}{2} \tau^2_k - A^*_{k-1} \), with \( A^*_0 = 0 \), are calculated;
- SRP areas \( A_k = \sum_{j=\tau_k-1}^{\tau_k} \frac{y_j-1+y_j}{2} (\tau_k - \tau_{k-1}) \) are calculated where \( y_j \) represents the dimensionless height of cumulative rain corresponding to the abscissa \( \tau_k \);
- the binary code is built on the base of: \( S_k = 1 \) if \( A_k > A^*_k \), else \( S_k = 0 \);
- ultimately, the binary code BSC = \( S_1 S_2 S_3 S_4 \) is obtained.
The BSC allows distinguishing between convective, tropical and stratiform events. During the convective events, large amounts of rain fall during the initial part of the event (such as BSC = 1111 and BSC = 1110 etc.), during the tropical and stratiform events instead, high amounts of rain occur respectively in the middle (BSC = 0110 etc.) and final (BSC = 0011 etc.) part of the event.

The return period is given by:

$$ T = \exp \frac{K_T + 0.0373}{0.517} $$

where $K_T$ is the probabilistic factor of growth given by the ratio between the observed rainfall intensity and the rainfall intensity resulting from site-specific IDF (Intensity-duration-frequency) curves [11].

The parameter n-index is defined as an exponent of the power law relating to the maximum averaged intensity and the duration of the event. It reports the temporal variability of precipitation behavior within the event. N-index value can be found from the following formula:

$$ I(t) = I(t_0) \left( \frac{t_0}{t} \right)^n $$

where $I(t)$ and $I(t_0)$ are maximum average intensities, corresponding to the general time $t$ and the reference time $t_0$. The index ranges bounded between 0 and 1. There are three classes for describing the average regime of the temporal structure of precipitation: regular ($n < 0.5$), effective ($n = 0.5$) and irregular ($n > 0.5$). Regular precipitation is associated with stationary behavior (e.g., orographic precipitation, static cell, etc.), while the predominance of irregular precipitation is associated with abrupt changes (e.g., thunderstorms, etc.) [12-14].

3. Results

3.1. Rainfall events characterization

The analysis of the characteristics of the rainfall events corresponding to the warnings collected in WZ3 suggests that in 2018 the events had a duration ranging between 240 and 1560 minutes while in 2019 between 360 and 1440 minutes (figure 4, a). The intensities in 2018 and 2019 reached maximum values respectively of 94 and 73 mm/h and minimum values of 2 and 3 mm/h (figure 4, b). The cumulative rainfall of the events approached at most 61 mm in 2018 and 78 mm in 2019 and at least 0.5 mm in 2018 and 0.7 mm in 2019 (figure 4,c).
Figure 4. The analysis of the characteristics of the rainfall events 2018-2019. 
a) Maximum/minimum duration; b) Maximum/minimum intensity; c) Maximum/minimum cumulative rainfall.

With reference to the return period, the 88% of the events are ordinary while the 12% are moderate. The minimum return period for both 2018 and 2019 is 1 year while the maximum is 12 years in 2018 and 14 in 2019 (figure 5).

Figure 5. Return period in 2018-2019.
The study of the BSC code of the events highlight that the 11% of events occurred within the two-years period of observation are tropical, the 46% are convective and the remaining part are stratiform. For illustrative purpose, in figure 6 examples of tropical, stratiform and convective events with their respective BSCs for 2018 and 2019 have been proposed.

![Figure 6](image_url)  
*Figure 6. Examples of tropical, stratiform and convective events with their respective BSCs for 2018 and 2019.*

With reference to the n-index, the percentage of regular, effective and irregular rainfall events in 2018-2019 have been shown in table 2.
Table 2. Percentage of precipitation regularity in 2018-2019.

| n-index | Percentage (%) |
|---------|----------------|
| <0.5    | 47.1           |
| =0.5    | 0.0            |
| >0.5    | 19.1           |

In figure 7 an example of n-index estimation for 4 rainfall events.

3.2. Correlation between the rainfall events characteristics and the color of alerts

The results of the analysis show how effectively the color of alerts can be related to the rainfall properties discussed above. Moving from the lowest to the most severe level of alert, the mean cumulative rainfall of the events associated to the warnings increases. It goes from 3.6 mm for events with green alert to 15.6 mm for events with yellow warning to 34.8 mm for rainfall corresponding to orange level of risk. The same happens with the mean peak intensity which assumes lower values, close to 4 mm/h, for events occurred during the green alerts, higher values of about 21 mm/h for events with yellow warning level and still higher values, reaching 27 mm/h, for orange alert events. The events characterized by low and middle potential of danger can be respectively associated to irregular rainfall structure and rainfall with regular patterns, finally the orange alert events correspond to effective precipitation structures (table 3).
Table 3. Rainfall characteristics corresponding to alert colors.

| Rainfall characteristics | Green Alert | Yellow Alert | Orange Alert |
|-------------------------|-------------|--------------|--------------|
| Mean Cumulative rainfall (mm) | 3.6         | 15.6         | 34.8         |
| Mean Peak intensity (mm/h) | 4.4         | 20.9         | 26.5         |
| Mean n-index             | 0.54        | 0.36         | 0.50         |
| (Temporal structure of precipitation) | (Irregular) | (Regular)    | (Effective)  |

A clear correlation between the color of the alert and the severity $T$ of the observed rainfall event has not been found. This is probably due to the model uncertainties related to the assessment of the return period. Also the small sample of events analyzed could have compromised the effectiveness of analysis.

4. Conclusions
The present paper reports the results of an analysis which has aimed at the identification of a correlation between the forecasted severity of the weather warnings of the Civil Protection and the properties of the observed rainfall events. The case study has been set in the warning zone 3 of the Campania region selected as it is a highly-prone area to hydrogeological risk. The period between 2018 to 2019 has been studied and a number of 138 warning issued during this period has been amounted for. The rainfall events associated to the different levels of alert have been characterized in terms of duration, cumulative rainfall, peak intensity, return period, n-index, BSC-index. A clear structure between the severity of the warnings and the cumulative and peak intensity has been found. It has been furthermore concluded that green warnings are associated to rainfall events with irregular structure, while yellow alerts to regular events and orange alerts to precipitation with effective behavior. In terms of correlation with the alert severity, nothing can be said about the return period of the observed events. This is probably due to because the comparisons carried out for a single case study and the model uncertainties related to the assessment of the return period, could have compromised the effectiveness of analysis. Also the small sample of events analyzed could have compromised the effectiveness of analysis. In general, low return periods have been found to be associated to yellow and orange alerts corresponding to severe and moderate rainfall events. This result indicates that, according to the rules adopted from the regional Civil protection Department the considered area is being called to face critical situations even when ordinary rainfall events occur, probably because of the fragile equilibrium of its territory due to the climate and land use changes.

References
[1] Califano F, Mobilia M, Longobardi A 2015 Heavy Rainfall Temporal Characterization in the Peri-Urban Solofrana River Basin *Southern Italy Procedia Engineering* **119** pp 1129-1138
[2] Mobilia M, Califano F, Longobardi A 2015 Analysis of rainfall events driving MDHEs occurred in the Solofrana river basin, Southern Italy *Procedia Engineering* **119** pp 1139-1146
[3] Longobardi A, Diodato N, Mobilia M 2016 Historical storminess and hydro-geological hazard temporal evolution in the solofrana river basin – Southern Italy *Water* **8**(9) p 398
[4] Mysiak J, Testella F, Bonaiuto M, Carrus G, De Dominicis S, Ganucci Cancellieri U, Firus Kand Grifoni P 2013 Flood risk management in Italy: challenges and opportunities for theimplementation of the EU Floods Directive *Natural Hazards & Earth System Sciences* **13**(11) pp 2883-2890
[5] Alfieri L, Salamon P, Pappenberger F, Wetterhall F, Thielen J 2012 Operational early warning systems for water-related hazards in *Europe Environmental Science & Policy* **21** pp 35-49
[6] Pecoraro G, Piciullo L, Calvello M 2017 Regional landslide early warning systems: comparison of warning strategies by means of a case study *Advancing Culture of Living with
[8] Moiraghi M 2007 Civil Protection (Segrate (Milano) p 291
[9] Meire P, Coenen M, Lombardo C, Robba M and Sacile R 2008 Integrated Water Management: Practical Experiences and Case Studies 80 p 363
[10] Longobardi A, D’Ambrosio R, Mobilia M 2019 Predicting Stormwater Retention Capacity of Green Roofs: An Experimental Study of the Roles of Climate, Substrate Soil Moisture, and Drainage Layer Properties Sustainability 11(24) 6956
[11] Krasnogorskaya N, Longobardi A, Mobilia M, Khasanova L F, Shchelchkova A I 2019 Hydrological Modeling of Green Roofs Runoff by Nash Cascade Model The Open Civil Engineering Journal 13(1) pp 163-171
[12] Rossi F, Villani P 1995 Flood evaluation in Campania Region 1470 (in Italian)
[13] Terranova O G, Iaquinta P 2011 Temporal properties of rainfall events in Calabria (southern Italy) Natural hazards and earth system sciences 11 pp 751-57
[14] Robert Monjo 2016 Measure of rainfall time structure using the dimensionless n-index Climate research 67 pp 71-86
[15] Afanasev I, Volkova T, Elizaryev A, Longobardi A 2014 Analysis of interpolation methods to map the long-term annual precipitation spatial variability for the Republic of Bashkortostan, Russian Federation WSEAS Transactions on Environment and Development 10(1) pp 405-16