Chapter

Modeling Antecedent Soil Moisture to Constrain Rainfall Thresholds for Shallow Landslides Occurrence

Maurizio Lazzari, Marco Piccarreta, Ram L. Ray and Salvatore Manfreda

Abstract

Rainfall-triggered shallow landslide events have caused losses of human lives and millions of euros in damage to property in all parts of the world. The need to prevent such hazards combined with the difficulty of describing the geomorphological processes over regional scales led to the adoption of empirical rainfall thresholds derived from records of rainfall events triggering landslides. These rainfall intensity thresholds are generally computed, assuming that all events are not influenced by antecedent soil moisture conditions. Nevertheless, it is expected that antecedent soil moisture conditions may provide critical support for the correct definition of the triggering conditions. Therefore, we explored the role of antecedent soil moisture on critical rainfall intensity-duration thresholds to evaluate the possibility of modifying or improving traditional approaches. The study was carried out using 326 landslide events that occurred in the last 18 years in the Basilicata region (southern Italy). Besides the ordinary data (i.e., rainstorm intensity and duration), we also derived the antecedent soil moisture conditions using a parsimonious hydrological model. These data have been used to derive the rainfall intensity thresholds conditional on the antecedent saturation of soil quantifying the impact of such parameters on rainfall thresholds.

Keywords: landslides, soil saturation, geomorphology, hydrogeological risk, Basilicata

1. Introduction

Rainfall-induced shallow landslides are critical issues of scientific and societal interest, causing billions of euros in damages and thousands of deaths every year [1]. A large number of studies investigated the functional relationship between rainfall characteristics and landslide events [2]. One of the main results is the definition of empirical rainfall thresholds associated with the triggering of the shallow landslide, such as total event rainfall, intensity-duration, event-duration, and event-intensity thresholds ([3] and reference therein) [4, 5]. However, these approaches lead to a limited understanding of the geomorphological process and, if used for warning purposes, they can produce a large number of false positives alarms [6]. In fact, rainfall thresholds approach evaluates only the amount of cumulated rainfall and it neglects the primary role of other vital parameters, such as evapotranspiration, soil moisture, rainfall infiltration, soil porosity, and permeability.

In order to consider predisposing hydrological factors on empirical threshold calculation, recent studies have focused on the role of the antecedent daily rainfall in landslides triggering [7–12]. These approaches have found a strong relationship between the hourly rainfall data triggering landslides and the initial soil moisture contributing to improving the predictive accuracy of empirical thresholds. Those results have also stimulated a critical revision of the intensity/duration thresholds in the last few years [6, 13–15]. In particular, Bogaard and Greco [6] introduced the cause-trigger concept for defining hydro-regional thresholds for predicting landslide occurrence, also suggesting taking into consideration the slope water balance. Starting from this new perspective, we aim to contribute to this discussion by evaluating the correlation between antecedent soil moisture conditions and rainfall intensity during shallow landslide events. In particular, we would like to explore better how much the initial saturation degree of soil affects the intensity/duration (I/D) relationships in landslide prediction. For this purpose, it is very important to use reliable databases in the literature or otherwise build a specific one.

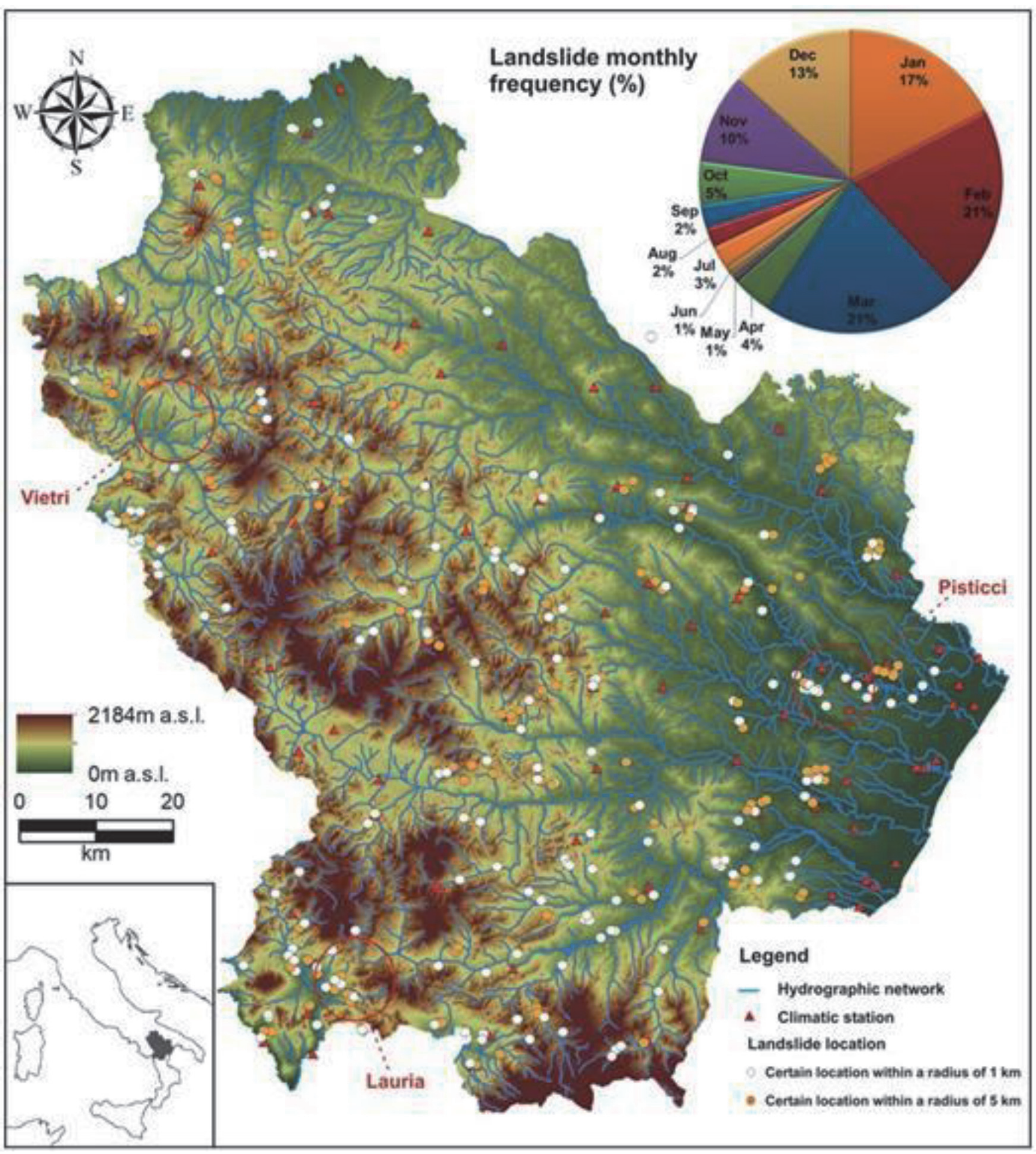

Figure 1.
Geographical distribution of the weather stations and landslide events for the study area. The graph in the inset shows the monthly distribution of landslides in Basilicata from 2001 to 2018.

There are many soil moisture datasets that have been successfully used to calibrate and validate catchment or watershed scale models of infiltration, soil-moisture storage, and in some ways, even to examine the first landslide trigger [16–19].

In this chapter, we addressed this issue by reconstructing and leveraging a dataset of 326 landslide events that occurred in the Basilicata region (southern Italy, **Figure 1**, and Appendix), from January 2001 to March 2018. For each georeferenced landslide, we derived the rainfall event characteristics and antecedent soil moisture conditions using a parsimonious physically-based distributed model applied at the regional scale with a spatial resolution of 200 m and a daily and hourly time scale. This approach allowed us to reconstruct all of the main forcing factors that may have produced a change in the slope stability and to detect the impact of antecedent soil moisture on the rainfall intensity/duration relationship. The numerical simulation has been needed to reconstruct the antecedent soil moisture values not available for the whole study area.

2. Data and methods

This study was carried out within a research agreement with the Civil Protection of the Basilicata region, which supported in part the reconstruction of the list of landslide events used for the analysis. The database was constructed with the primary aim of creating an updated description of the most recent landslides and the associated rainfall events. Therefore, the present section will be devoted to the description of the study area, the methodology adopted to build the database, and the modeling approach used to reconstruct the antecedent soil saturation conditions.

2.1 Study area

Basilicata is a region of southern Italy covering an area of 9.992 km^2 characterized by different topographical and geomorphological contexts, landscape types (47% mountains, 45% hillocks, and 8% plains) and geolithological conditions. The north-western and south-western regions are characterized by mountain landscapes (southern Apennines) with significant elevations of the relief (between 1300 and 2000 m of altitude) and steep slopes, particularly where Mesozoic successions (dolomite and siliceous limestones) outcrop. The eastern region shows a hilly landscape characterized by soft shapes or tabular hills (alternating ridges and valleys in conglomeratic sandstone—clayey—marly), usually with low gradients of the slopes, often modeled in foredeep Plio—Pleistocene units with clayey dominant [20, 21].

Precipitation values are typical of the Mediterranean, with distinct dry and wet seasons [22]. Higher precipitation totals occur during the last autumn-winter period when landslides and floods usually take place (more than 70%). A near real-time hydrometeorological network covers the territory uniformly with a density of one station every 80 km^2. It has been operating over a time interval of about 70 years, providing temperature and precipitation data at the resolution of 10 minutes.

2.2 Landslide and rainfall data

Based on detailed bibliographical research [23–25], which explored all available sources including national and local newspapers and journals, Internet blogs, and the scientific and technical literature, we have collected a database of 326 shallow landslide events (landslide event is a single landslide) from January 2001 to March 2018.

The information collected and stored in the inventory includes (**Figure 1**):

- accurate or approximate location of the landslide event;
- accurate or approximate time, date, or period of the failures;
- rainfall conditions that resulted in slope failures collected from the nearest rain gauge, including the total event rainfall, the rainfall duration, the mean rainfall intensity, and the antecedent rainfall for 2001–2018;
- landslide type;
- a generic description of the lithology.

In addition to this data that is also reported in Appendix in a tabular format, meteorological data and the output of the hydrological model have been used for the subsequent elaborations. In particular, hourly rainfall and temperature data were obtained from the rain gauges of the Civil Protection of the region. The hydrological model proposed on a regional scale considers homogeneous soil moisture conditions in the space and the first meters of depth in the areas affected by each landslide identified in our database.

The regional pedological map is depicted in **Figure 2** with the spatial distribution of landslides (**Figure 2**). This maps provides a nested description of soil classes that indentifies four regions at the first level (soil map of Italy, scale 1: 5,000,000), the 15 provinces, and 75 soil units (scale 1: 250,000). Based on the pedological characteristics of the regions, it was observed that the highest number of landslides (56 landslides) occurred in the soil province n.6. It is also worthy to mention a high number of events occurred on the soil unit 12.4 (33 landslides) and 10.2 (21 landslides). These last two soil units correspond to:

- 12.4—hilly clay soils with steep slopes, badlands, intended for grazing or arable land, with low permeability (Vertic Haploxerepts; Inceptisol);
- 10.2—hilly sandy-conglomerate soils, intended for pasture, vineyards or shrubs (Typic Xerorthents; Inceptisol).

The number of event recorded in each soil unit is described in the histogram of **Figure 3**.

2.3 Reconstruction of rainfall events

The rainfall duration (D) was determined by measuring the time between the moment of the beginning of each rainfall event, which triggered a shallow landslide, considered in the database, and rainfalls ending time. The rainfall ending time was taken to coincide with the time of the last rainfall measurement of the day when the landslide occurred. As suggested by Brunetti et al. [26], the starting time was considered a minimum period without rain (a 2-day period without rainfall was selected for late spring and summer, May–September, and a 4-day period without rainfall was selected for the other seasons, October–April) to separate two consecutive rainfall events. Once the duration of the rainfall event was established, the corresponding rainfall mean intensity I (mm h^{-1}) was calculated dividing the cumulated (total) rainfall (mm) in the considered period by the length of the rainfall period (hours). The full list of events is given in the Appendix of the present

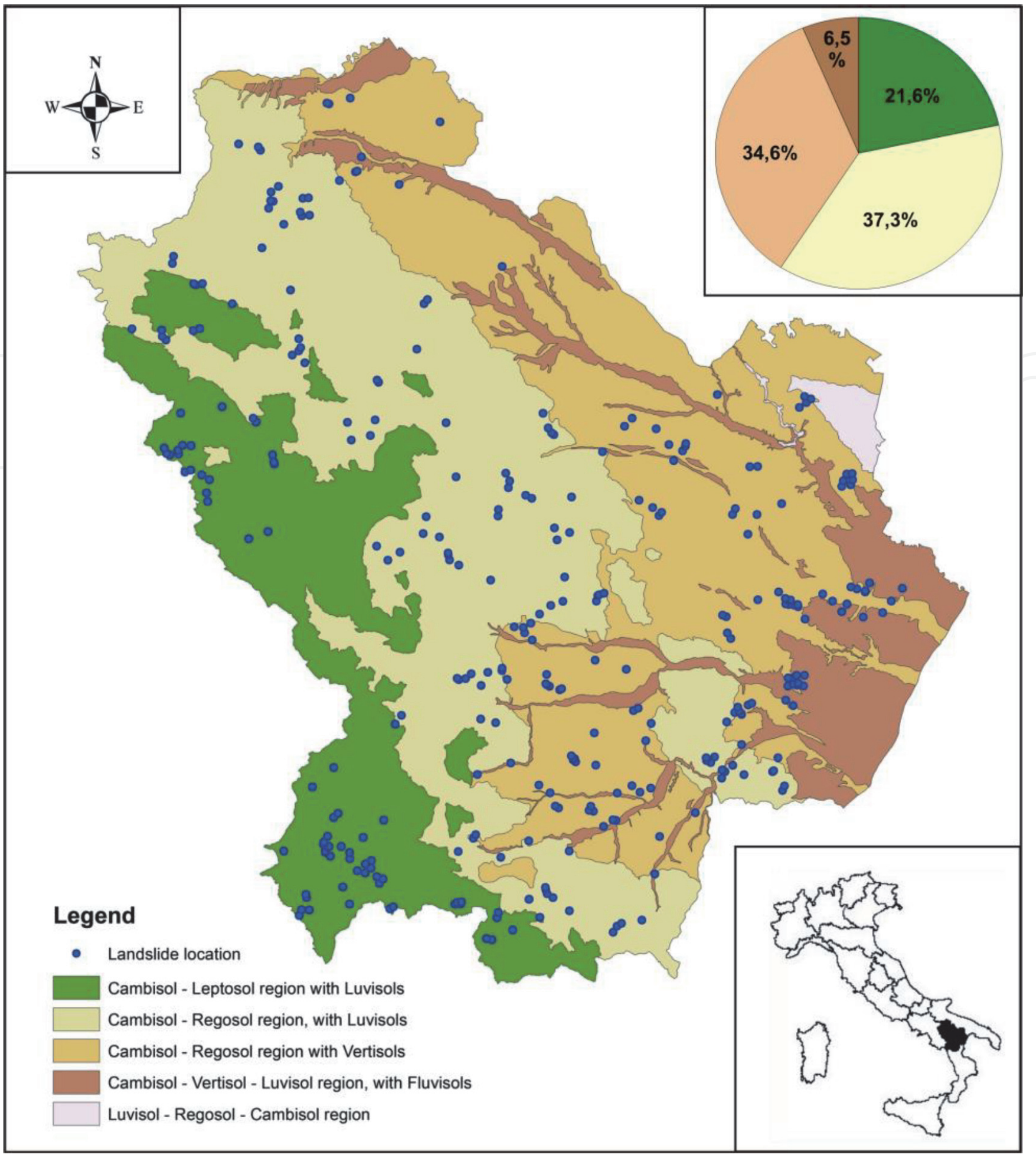

Figure 2.
Pedological regions and shallow landslides distribution over the Basilicata region.

chapter (**Table 1**—Appendix). In recent studies, authors [27–29] have used an approach that provides the seasonality criterion (April-October for the "dry/warm" season and November-March for the "wet/cold" season) to calculate the rainfall events. In this chapter, the proposed method is different from that proposed by Peruccacci et al. [29], because the saturation value and condition are a parameter regardless of seasonality. It provides a more detailed parameter, overcoming the possibility that in the same season, it can have more dry or wet phases.

2.4 Modeling soil water content

Although antecedent soil moisture can be obtained by in-situ measurements at a point scale, measurements on a regional scale are time-consuming and expensive. Recently, more information is available from satellite data, but they are too coarse to provide local estimates of soil water content on a specific landslide [30]. Thus, we used the hydrological model AD2 to describe the temporal evolution of soil water content over the entire Basilicata region using a distributed approach at 240 m spatial resolution.

The AD2 model is a 1D model capable of describing the soil water budget along the vertical direction, but its physically based nature allows to associate physical

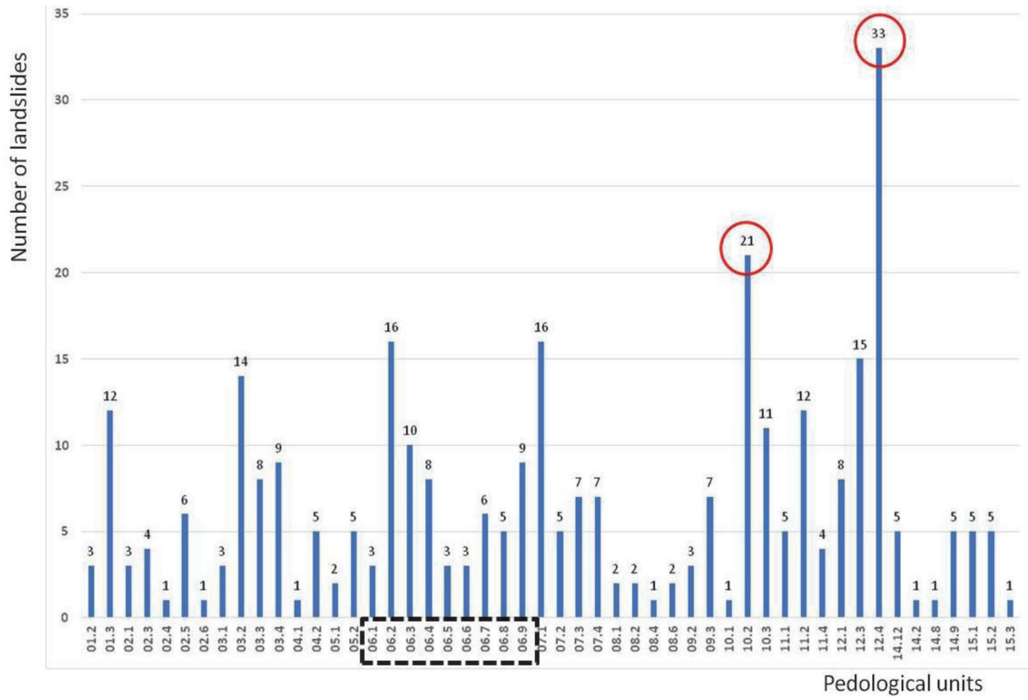

Figure 3.
Histogram with the distribution of the number of landslides in the various regional soil units. Red circles, units with multiple landslides; black dotted rectangle, landslides included in unit 6.

characteristics such as soil texture, land cover, and mean slope to each pixel/location that affects the model parametrization.

The model parameters were obtained from physical maps such as national and regional pedological maps of Italy and Basilicata [31], the III level of the CORINE Land Cover map [32], and the Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM) extracted from HydroSHEDS (hydrosheds.cr.usgs.gov/index.php).

The model was run at 1 h temporal resolution using rainfall and temperature data derived from the rainfall network of the Civil Protection for the period January 1, 2001 to March 28, 2018 [32].

This approach is straightforward and can be easily replicated elsewhere after a simple calibration against the local soil moisture and landslide datasets. It must be stated that obtained values can be affected by several errors due to model structure, parametrization, and climatic data, but at present, such an approach offers a realistic description of the expected relative saturation of the soil providing a synthesis of the state of the system according to the available information on soil texture, antecedent rainfall, and evolution of temperatures. Moreover, several evidences suggesting that the use of a physically based approach allows obtaining more robust outputs [33, 34].

2.4.1 AD2 model structure

Model simulations carried out using at least 1 year of rainfall and temperature data recorded before each landslide event to reach a reliable estimate of the relative soil water content at the date of the considered event. AD2 [34] provides a hydrological prediction that considers several hydrological components such as infiltration, surface runoff, sub-surface runoff, deep percolation, and evapotranspiration. Soil water balance is described by the following Equation [35]:

$$S_{t+\Delta t} = S_t + I_t - R_{out,t} - L_t - E_t, \quad (1)$$

where: S_t is the basin soil water content at the generic instant of time t, which represents a key variable of the model influencing runoff production, leakage, and evapotranspiration; I_t is the infiltration; $R_{out,t}$ is the sub-surface runoff production; L_t is the leakage to the groundwater; and E_T is the actual evapotranspiration.

The infiltration is derived from the difference between the rainfall amount, P_t, and the surface runoff, R_t, at time t (mm):

$$I_t = P_t - R_t. \tag{2}$$

Runoff is calculated using the equation proposed by De Smedt et al. [36], which takes into account the potential saturation of the soil:

$$R_t = \begin{cases} \left(\dfrac{S_t}{S_{max}}\right) P_t \text{ if } P_t \le P_c = \dfrac{S_{max}(S_{max} - S_t)}{(S_{max} - CS_t)} \\ P_t - (S_{max} - S_t) \text{ if } P_t > P_c = \dfrac{S_{max}(S_{max} - S_t)}{(S_{max} - CS_t)} \end{cases} \tag{3}$$

where, S_{max} is the maximum water storage capacity of the bucket, P_c is the critical rainfall producing the surface soil saturation, and C the default runoff coefficient that is parameterized as a function of soil type, soil cover, and slope [37].

The sub-surface runoff production is assumed to be a linear function of the soil water content above the field capacity reference parameter:

$$R_{(out,t)} = \max\{0, c(S_t – S_c)\}, \tag{4}$$

where S_c is the threshold water content for sub-surface flow production, assumed here equal to 0.6 S_{max}, and c is the sub-surface coefficient, which is generally assumed 0.05.

The evapotranspiration is assumed to be a bi-linear function of the soil content and potential evapotranspiration. It may be described by the following equation:

$$E_t = \max\left\{0, \min\left\{\left(\frac{S_t}{0.75S_c}\right)EP, EP\right\}\right\}, \tag{5}$$

where E_P is the potential evapotranspiration, $0.75S_c$ is an estimate of the water content at which the stomata closure starts to reduce the evapotranspiration.

Leakage is computed using the expression derived by Manfreda et al. [38] integrating the power-law function of leakage by Eagleson [39] over a time-step Δ_t:

$$L_t = \begin{cases} 0 & \text{if} \quad S_t \le S_c \\ \left(S_{t-1} - S_{max}\left(\frac{\Delta t K_s}{S_{max}} + \left(\frac{S_{t-1}}{S_{max}}\right)^{1-\beta}\right)^{1/(1-\beta)}\right) & \text{if} \quad S_t > S_c \end{cases}, \tag{6}$$

where L_t is the groundwater recharge in Δ_t, K_s is a parameter that interprets the soil permeability at saturation, and β is a dimensionless exponent.

It must be clarified that all the parameters mentioned in the model equations reported above can be estimated using the existing literature values that associate this parameter to physical features of the area such as soil texture, land use and mean slope using [37, 40, 41].

2.5 Rainfall thresholds

To determine rainfall thresholds for shallow landslide occurrence, we adopted the Frequentist method [26]. The threshold curve is assumed to follow a power law:

$$I = \alpha D^{-\beta} \tag{7}$$

where, I is the rainfall mean intensity (mm h^{-1}), D is the rainfall event duration (h), α is the intercept, and β defines the slope of the power law function. Empirical data were log-transformed to calculate the best-fit line by means of a linear equation $\log(I) = \log(\alpha) - \beta \log(D)$, equivalent to that described above.

Following the methods adopted in previous studies [9, 12, 15], we identified the rainfall events associated with each landslide event and the corresponding degree of soil saturation at the starting time of each event. Including this additional information in the database, it was possible to explore its role in the general behavior of the rainfall events triggering landslides under different initial conditions.

3. Results and discussion

The comparison between the rainfall intensity and the relative saturation before each event is depicted in **Figure 4**. **Figure 4** provides the temporal evolution of the rainfall and relative soil saturation of three different sites (Lauria, Vietri di Potenza and Pisticci; see Appendix) characterized by different lithological conditions during the period from January 1, 2009 to December 31, 2015. This window was extracted from the model simulation to emphasize the seasonal dynamics of soil moisture over the considered sites. Such a seasonality is clearly one of the motivations to conduct this study because such a dynamic strongly affects the hydraulic processes in the soil profile.

It is noticed that most of the different landslide events (reported in the graph with a dark star) occurred after significant rainfall amounts and relatively high or moderate soil saturation degree. When the same rainfall amounts occurred in conditions of low antecedent soil moisture content, they have not produced shallow landslides. This finding aligns with the previous studies [7–15, 42].

This preliminary plot shows that there is an interplay between the antecedent soil moisture conditions and the amounts and the duration of the triggering rainfall. Moreover, it appears how the same degree of soil saturation and rainfall I/D conditions do not necessarily produce the same effects in different geopedological regions.

The role of the antecedent soil moisture condition on the triggering rainfall intensity is clearly shown in **Figure 5**, where the rainfall intensity/duration has been plotted against the simulated antecedent soil saturation of each landslide event. This graph was developed following the trigger-cause concept of Bogaard and Greco [6] and highlights the role of both rainfall dynamics and antecedent soil moisture on the slope stability.

In fact, there is a clear reduction of the rainfall intensity needed to trigger a landslide with the increase of the antecedent soil moisture. In this graph, the data grouped in the function of the rainfall duration trying to explore also the role of this additional parameter on the process. It is observed that the rainfall dynamics also matter, being shorter rainfall events more sensitive to the antecedent soil moisture respect to, while more extended events are less influenced by such parameter.

Similarly, previous studies [7, 8, 12, 43] also found a linearly decreasing trend between the mean rainfall intensity and the initial soil moisture conditions. The slope of the regression functions derived from a different subset of our database changes based on the relative duration of the rainfall events. It is higher for rainfall durations lower than 48 h, while the function becomes almost independent from the relative saturation when rainfall events have longer durations (more than 48 h). This is probably due to the nature of the long-lasting rain events, which are often characterized by a high total amount of rainfall. Results in high values both of the initial saturation degree and of low rainfall intensity that is averaged over longer periods. It must be clarified that the relative degree of saturation has been referred to as the starting time of the triggering rainfall event.

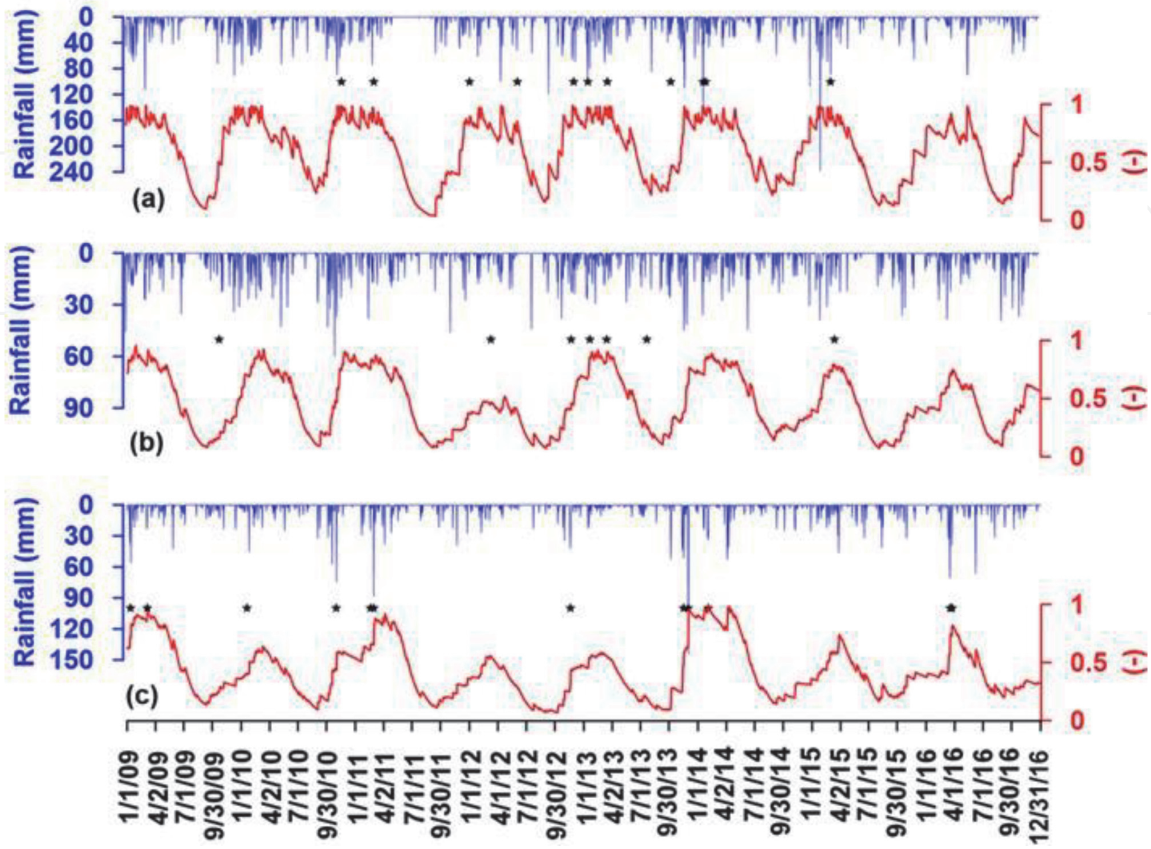

Figure 4.
Daily rainfall (blue) and simulated daily soil degree saturation (red) at (a) Lauria, (b) Vietri, and (c) Pisticci from January 1, 2009 to December 31, 2016. Dark stars represent the data of the occurrence of shallow landslide events in the monitored areas.

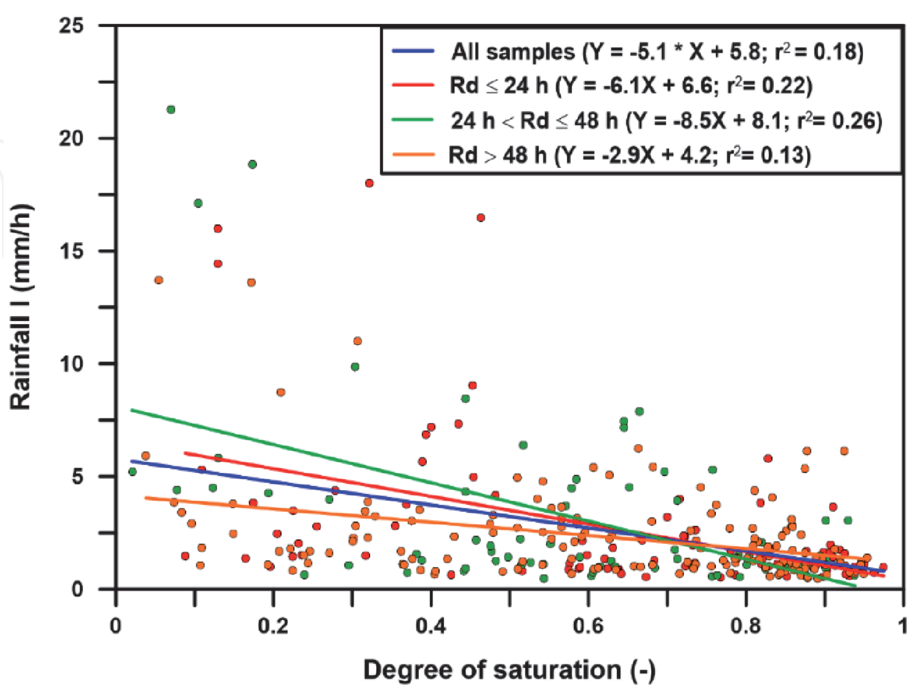

Figure 5.
Mean rainfall intensity/duration and the simulated initial degree of saturation for the 326 landslide events in Basilicata region (southern Italy) from 2001 to 2018.

Figure 6 depicts a clear picture of the dependence between mean rainfall intensity of event of different durations and the antecedent soil moisture, where the rainfall intensity values of the 326 investigated events are associated to the simulated soil saturation degree using a color scale (from blue to yellow starting from lower to higher values of degree of saturation). This graph clearly shows that higher amounts of rainfall intensity are observed in correspondence to lower values of soil saturation and vice-versa. This tendency is not always consistent due to the presence of several spurious data relative to the occurrence of extraordinarily wet events, which resulted in both landslides and floods.

To evaluate the role of degree of soil saturation on the regional mean rainfall intensity/duration function, we have identified two distinguished sub-samples based on the antecedent soil moisture conditions of each event. The two groups were distinguished using a sensitivity analysis, exploiting different antecedent soil saturation values. The selection was made using a subjective selection that tried to identify the most diverse groups of landslides using a given threshold of soil saturation. Therefore, we determined mean rainfall intensity/duration functions (rainfall thresholds) under middle-low antecedent soil moisture conditions that seemed to those that responded better to the data considered (soil degree saturation lower than 0.70), and moderate to high antecedent soil moisture conditions (soil degree saturation equal or higher than 0.70). In this way, it was possible to derive critical rainfall threshold functions conditional on the antecedent soil moisture conditions.

The two functions plotted in the graph (**Figure 6**), which has significantly different slopes. This implies that they must cross somewhere in the space of rainfall intensities and event duration. In the present case, we observed that they cross in a point corresponding to the duration of about 200 h. At such duration, the

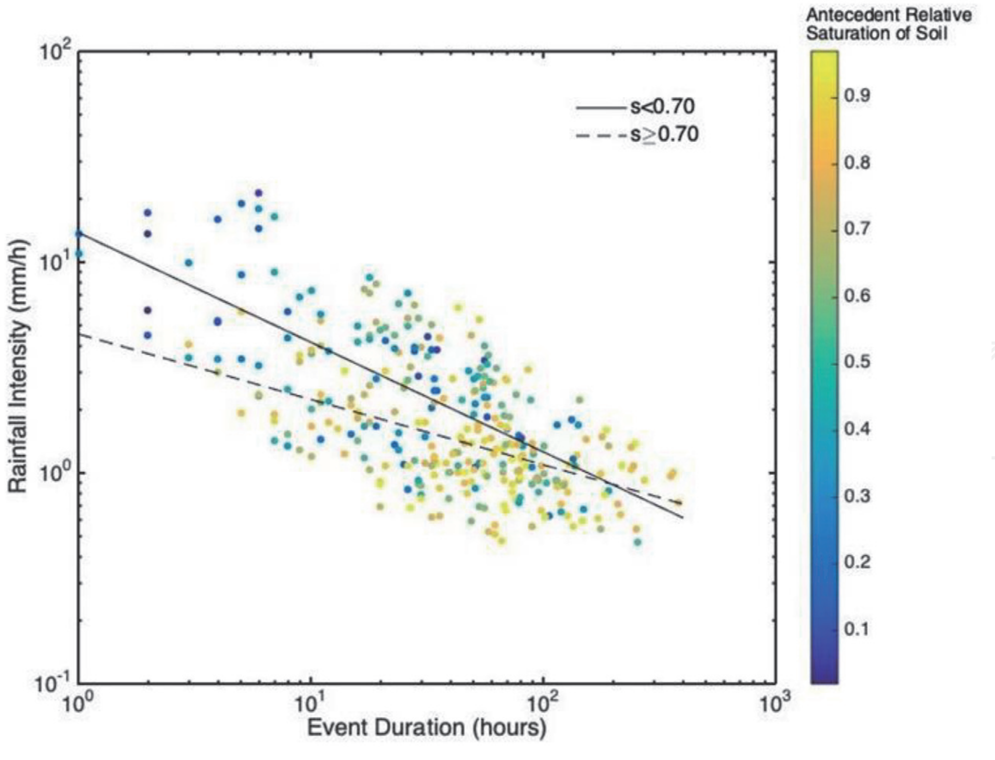

Figure 6.
Rainfall intensity as a function of the duration of the triggering rainfall events for the 326 landslide events recorded in Basilicata region (southern Italy) during the period 2001–2018. Each event is associated with a color that represents the simulated antecedent degree of saturation, whose range is given in the color bar on the right (ranging from 0 to 1). We also included the regression lines estimated for the two groups of events selected based on the antecedent soil saturation conditions. The solid line represents the regression function obtained using the observations with soil degree saturation lower than 0.70, while the dotted line represents the regression function obtained using the observations with degree soil of saturation equal or higher than 0.70.

impact of antecedent soil water content becomes not relevant, and this part of the curve should not be considered.

The proposed approach allows taking into account both rainfall characteristics (intensity and duration) and the antecedent soil moisture state in a specific study area, contributing to foresee a landslide event.

Of course, a methodology like this should be evaluated widely, also taking into consideration the ability of the method to distinguish between true and false alarms. Unfortunately, this field-test is challenging to be implemented in a region like Basilicata with a low density of population (as single possible observators), where a lot of landslide events are not reported or are missing.

4. Final remarks

We have explored the role and effects of antecedent soil moisture conditions on rainfall I/D thresholds triggering shallow landslides by using a dataset built for a region of southern Italy and a distributed modeling approach. By combining rainfall events data with the simulated antecedent soil moisture conditions, it was possible to derive I/D relationships, which can be used to discriminate the triggering conditions for landslides better.

Two distinct degree of soil saturation values [$S < 0.7$ and $S \geq 0.7$] were identified to distinguish different classes of events. Such soil moisture conditions led to two distinct populations of events that identified statistically significantly different rainfall threshold functions. Our results are consistent with those found in the most recent studies on this topic, reinforcing the idea that simulated soil moisture provides better metrics than antecedent rainfall for the predisposing factors of landslide initiation.

Finally, a forthcoming extension of this research will aim to carry out a local downscaling to define the relations between I/D and the degree of soil saturation in the smallest territorial contexts characterized by the same climatic and lithotechnical conditions, in which the landslides inserted in our database have developed.

Moreover, it is also important to note that the proposed description of the landslide event may undoubtedly support the development of further studies and models for landslide prediction. In fact, the main results obtained in the present study are the fact that the information about the antecedent relative saturation of the soil may help to distinguish the dynamics of the process better. Therefore, it would be a good practice to include such parameters in all landslide database. This can happen with the support of remote sensing techniques that also allow deriving root zone soil moisture over large areas [10, 41, 44].

Acknowledgements

This work was carried out within a scientific agreement between the Civil Protection Department of Basilicata, the Interuniversity Consortium for Hydrology (CINID), and the University of Basilicata to the start-up the Basilicata Hydrologic Risk Center.

Conflict of interest

The authors declare no conflict of interest.

Appendix

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
1	Rotondella	14/01/2001	4,447,838,6	630,012,0	186,8	26,0	7,18	0,40	Nova Siri SAL	Evalmet web site web site web site
2	Montalbano Jonico	20/01/2001	4,461,333,2	632,500,7	66,6	16,0	4,16	0,48	Montalbano SAL	Civil Protection
3	Pisticci	20/01/2001	4,472,103,8	633,501,3	83,6	34,0	2,46	0,20	Pisticci Scalo SAL	Evalmet web site
4	Rotondella	21/01/2001	4,447,722,3	629,857,3	88,6	52,0	1,70	0,78	Nova Siri Sal	Evalmet web site
5	Tursi	21/01/2001	4,456,520,6	624,987,7	86,2	27,0	3,19	0,70	Tursi SI	Evalmet web site
6	San Fele	09/03/2002	4,518,711,1	545,705,9	23,6	11,0	2,15	0,59	San Fele PC	Civil Protection
7	Lagonegro	12/01/2003	4,441,050,6	565,797,2	148,2	140,0	1,06	0,89	Lagonegro PC	Civil Protection
8	Acerenza	25/01/2003	4,516,566,8	579,515,5	43,0	43,0	1,00	0,20	Acerenza SAL	Civil Protection
9	Nova Siri	25/01/2003	4,444,982,6	631,308,4	80,0	56,0	1,43	0,91	Nova Siri SAL	Civil Protection
10	Pisticci	25/01/2003	4,472,200,4	631,782,9	54,2	48,0	1,13	0,82	Pisticci Scalo SAL	La Nuova Basilicata magazine
11	Castronuovo di Sant'Andrea	04/02/2003	4,449,625,0	600,976,5	33,4	34,0	0,98	0,90	Roccanova PC	Civil Protection
12	Muro Lucano	08/02/2003	4,512,107,1	540,718,1	105,6	172,0	0,61	0,87	Muro Lucano PC	Civil Protection
13	Montescaglioso	09/09/2003	4,490,159,8	640,165,8	21,2	4,0	5,30	0,11	Montescaglioso SAL	Civil Protection
14	Venosa	10/09/2003	4,535,319,9	569,252,5	35,0	8,0	4,38	0,28	Venosa SAL	Civil Protection
15	Craco	12/12/2003	4,467,134,0	623,760,9	117,6	78,0	1,51	0,24	Craco PC	Piccarreta et al., 2004
16	Montescaglioso	26/07/2004	4,490,946,3	640,686,5	31,4	23,0	1,37	0,16	Montescaglioso SAL	II Quotidiano magazine
17	Nova Siri	26/07/2004	4,445,645,0	631,600,0	64,0	4,0	16,00	0,13	Nova Siri SAL	Civil Protection
18	Valsinni	26/07/2004	4,448,638,8	624,031,9	86,6	6,0	14,43	0,13	Nova Siri SAL	Civil Protection
19	Melfi	20/09/2004	4,538,361,1	555,130,7	119,4	81,0	1,47	0,09	Melfi	Civil Protection
20	Montalbano Jonico	13/11/2004	4,460,236,3	634,365,1	67,2	33,0	2,04	0,23	Montalbano SAL	Civil Protection
21	Montescaglioso	13/11/2004	4,491,198,4	641,477,5	126,6	33,0	3,84	0,17	Montescaglioso SAL	Civil Protection

DOI: http://dx.doi.org/10.5772/intechopen.92730

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
22	Pisticci	13/11/2004	4,470,264,9	643,085,0	94,6	34,0	2,78	0,25	Pisticci da Castelluccio SAL	Civil Protection
23	Tricarico	13/11/2004	4,498,622,9	582,231,5	46,2	31,0	1,49	0,32	Albano di Lucania PC	La Gazzetta del Mezzogiorno magazine
24	Tito	24/01/2005	4,493,939,0	556,898,4	40,0	17,0	2,35	0,72	Satriano di Lucania SAL	villasmunta.it
25	Nemoli	26/01/2005	4,435,028,2	568,166,9	76,2	47,0	1,62	0,90	Nemoli SAL	Civil Protection
26	San Fele	22/02/2005	4,518,910,4	546,690,8	77,0	80,0	0,96	0,97	San Fele PC	Civil Protection
27	Bella	23/02/2005	4,512,013,7	545,332,3	59,8	54,0	1,11	0,84	Bella Casalini	villasmunta.it
28	Castronuovo di Sant'Andrea	23/02/2005	4,449,641,7	600,766,2	26,0	30,0	0,87	0,64	Roccanova PC	Civil Protection
29	Picerno	23/02/2005	4,498,702,2	554,494,8	64,8	74,0	0,88	0,90	Balvano PC	villasmunta.it
30	Tito	24/02/2005	4,492,615,5	557,165,5	60,8	55,0	1,11	0,86	Satriano di Lucania SAL	villasmunta.it
31	Calvello	25/02/2005	4,478,560,2	573,724,4	55,4	56,0	0,99	0,94	Laurenzano PC	adnkronos.com
32	Rionero in Vulture	26/02/2005	4,527,555,0	558,531,6	14,2	6,0	2,37	0,72	Venosa SAL	villasmunta.it
33	Potenza	26/02/2005	4,498,664,2	567,834,7	64,4	98,0	0,66	0,87	Potenza PC	La Gazzetta del Mezzogiorno magazine
34	Potenza	26/02/2005	4,504,521,5	572,376,6	64,4	98,0	0,66	0,87	Potenza PC	Civil Protection
35	Sant'Arcangelo	26/02/2005	4,456,637,8	609,566,5	18,6	18,0	1,03	0,68	Roccanova PC	villasmunta.it
36	Gallicchio	27/02/2005	4,460,528,9	596,783,3	21,0	12,0	1,75	0,83	Guardia Perticara SAL	Civil Protection
37	Laurenzana	01/03/2005	4,482,440,8	578,878,4	86,6	148,0	0,59	0,93	Laurenzana SAL	Civil Protection
38	Pietrapertosa	02/03/2005	4,485,954,8	589,868,4	44,6	23,0	1,94	0,73	Campomaggiore SAL	Civil Protection
39	Nemoli	07/03/2005	4,438,133,6	570,116,6	45,8	69,0	0,66	0,93	Nemoli SAL	villasmunta.it
40	Barile	29/03/2005	4,533,072,0	557,767,6	25,8	29,0	0,89	0,64	Venosa SAL	Civil Protection

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
41	Accettura	07/06/2005	4,483,267,3	598,029,9	17,4	5,0	3,48	0,23	San Mauro Forte PC	Civil Protection
42	Terranova del Pollino	24/02/2006	4,426,066,5	610,796,4	79,6	78,0	1,02	0,72	Terranova del Pollino PC	Civil Protection
43	Bernalda	28/02/2006	4,474,473,5	648,787,6	44,0	11,0	4,00	0,72	Bernalda SAL	La Gazzetta del Mezzogiorno magazine
44	Grottole	28/02/2006	4,495,569,9	617,180,7	95,4	176,0	0,54	0,67	Grottole da Serre	La Gazzetta del Mezzogiorno magazine
45	Pisticci	28/02/2006	4,533,072,0	557,767,6	33,8	15,0	2,25	0,67	Torre Accio PC	La Gazzetta del Mezzogiorno magazine
46	Calvello	12/03/2006	4,479,726,4	575,486,3	50,6	29,0	1,74	0,92	Laurenzano PC	Basin Authority of Basilicata (AdB)
47	Montalbano Jonico	12/03/2006	4,472,188,9	640,718,0	37,8	56,0	0,68	0,64	Tursi SAL	Evalmet web site
48	Rionero in Vulture	13/03/2006	4,529,892,8	556,341,5	114,7	70,0	1,64	0,91	Melfi	Civil Protection
49	Venosa	13/03/2006	4,460,626,0	633,605,6	113,2	62,0	1,83	0,84	Venosa SAL	Civil Protection
50	Corleto Perticara	23/03/2006	4,475,673,7	588,722,5	43,6	43,0	1,01	0,83	Guardia Perticara SAL	AdB
51	Ripacandida	24/03/2006	4,529,316,2	560,944,2	30,5	58,0	0,53	0,77	Venosa SAL	Civil Protection
52	Picerno	27/03/2006	4,499,289,0	554,063,1	32,8	9,0	3,64	0,91	Balvano PC	Civil Protection
53	Trecchina	26/09/2006	4,430,915,4	567,168,1	133,0	72,0	1,85	0,63	Trecchina	Civil Protection
54	Rivello	23/10/2006	4,533,947,8	566,654,7	140,2	50,0	2,80	0,35	Nemoli SAL	IFFI Project ISPRA CNR IBAM
55	Maratea	19/12/2006	4,438,301,0	564,922,4	144,6	55,0	2,63	0,74	Maratea PC	infocilento
56	Maratea	04/04/2007	4,473,927,4	630,747,2	31,4	16,0	1,96	0,91	Maratea PC	infocilento
57	Tito	25/11/2008	4,429,377,2	561,850,9	77,4	120,0	0,65	0,43	Picerno PC	Civil Protection
58	Grassano	11/12/2008	4,492,851,3	557,094,7	79,4	16,0	4,96	0,45	Matera PC	La Gazzetta del Mezzogiorno
59	Calvello	05/01/2009	4,480,624,6	572,077,3	35,2	62,0	0,57	0,85	Laurenzano PC	Civil Protection

DOI: http://dx.doi.org/10.5772/intechopen.92730

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
60	Lagonegro	06/01/2009	4,502,711,0	621,802,2	109,8	65,0	1,69	0,88	Lagonegro PC	lucanianet
61	Grottole	13/01/2009	4,469,982,7	634,601,8	87,8	95,0	0,92	0,59	Grottole da Serre	II Quotidiano
62	Montescaglioso	13/01/2009	4,489,561,2	641,250,1	76,6	95,0	0,81	0,52	Montescaglioso SAL	La Gazzetta del Mezzogiorno
63	Pisticci	13/01/2009	4,487,771,2	600,527,1	105,2	114,0	0,92	0,62	Pisticci da Castelluccio SAL	Civil Protection
64	Pisticci	13/01/2009	4,495,207,5	617,127,3	104,6	113,0	0,93	0,62	Pisticci Scalo SAL	La Gazzetta del Mezzogiorno
65	Potenza	13/01/2009	4,499,028,2	571,863,4	17,6	20,0	0,88	0,94	Potenza PC	Civil Protection
66	Laurenzana	14/01/2009	4,477,838,6	584,070,9	38,8	35,0	1,11	0,95	Laurenzana SAL	Civil Protection
67	Acerenza	23/01/2009	4,515,988,0	578,994,5	32,0	28,0	1,14	0,58	Acerenza SAL	Civil Protection
68	Maratea	28/01/2009	4,441,638,3	566,470,6	295,2	185,0	1,60	0,93	Maratea PC	La Siritide website
69	Montalbano Jonico	06/03/2009	4,460,493,9	632,869,2	39,2	34,0	1,15	0,74	Montalbano SAL	Civil Protection
70	Pisticci	06/03/2009	4,429,791,9	561,758,0	40,6	34,0	1,19	0,85	Torre Accio PC	Evalmet web site
71	Tursi	06/03/2009	4,457,119,8	624,774,7	44,4	33,0	1,35	0,82	Tursi SAL	Civil Protection
72	Ripacandida	07/03/2009	4,471,046,5	639,954,0	93,5	69,0	1,36	0,62	Venosa SAL	palazzosangervasio.net
73	Gallicchio	20/03/2009	4,528,878,0	562,300,7	26,2	12,0	2,18	0,67	Aliano SAL	Civil Protection
74	Ripacandida	26/03/2009	4,528,798,8	561,165,2	22,8	36,0	0,63	0,79	Venosa SAL	Civil Protection
75	Tricarico	24/04/2009	4,524,102,2	555,355,7	75,0	135,0	0,56	0,90	Albano di Lucania PC	Civil Protection
76	San Martino D'Agri	28/04/2009	4,455,394,2	587,277,7	22,6	21,0	1,08	0,85	Sarconi SAL	La Gazzetta del Mezzogiorno
77	Vietri di Potenza	22/10/2009	4,500,015,6	596,374,9	11,6	9,0	1,29	0,68	Vietri	Quotidiano del sud, Metauronews
78	San Severino Lucano	18/12/2009	4,430,832,7	596,722,0	12,2	8,0	1,53	0,60	Viggianello SAL	Civil Protection
79	San Chirico Raparo	07/02/2010	4,448,987,6	591,663,1	29,0	5,0	5,80	0,83	Castelsaraceno PC	La Gazzetta del Mezzogiorno
80	Maratea	11/02/2010	4,427,557,0	562,256,5	56,6	76,0	0,74	0,96	Maratea PC	Civil Protection

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
81	Viggianello	13/02/2010	4,424,622,3	591,954,8	145,8	184,0	0,79	0,93	Viggianello SAL	Civil Protection
82	Latronico	20/02/2010	4,472,103,8	633,501,3	112,2	124,0	0,90	0,85	Castelsaraceno PC	II Quotidiano magazine
83	Tursi	11/10/2010	4,494,906,8	541,098,2	15,8	11,0	1,44	0,22	Tursi SI	Tursi tani.com
84	Ferrandina	02/11/2010	4,485,211,8	627,576,3	63,2	7,0	9,03	0,45	Ferrandina SAL	Civil Protection
85	Grottole	02/11/2010	4,493,102,4	615,427,5	115,2	7,0	16,46	0,46	Grottole da Serre	Civil Protection
86	Matera	02/11/2010	4,502,417,4	634,533,0	61,8	9,0	6,87	0,39	Matera PC	Civil Protection
87	Montescaglioso	02/11/2010	4,454,988,6	623,153,8	45,2	12,0	3,77	0,37	Montescaglioso SAL	II Quotidiano magazine
88	Pisticci	02/11/2010	4,491,414,3	544,109,2	73,4	10,0	7,34	0,44	Pisticci Scalo SAL	Civil Protection
89	Rivello	02/11/2010	4,437,163,0	564,328,3	38,4	10,0	3,84	0,82	Nemoli SAL	Civil Protection
90	Salandra	02/11/2010	4,486,232,1	612,353,1	108,0	6,0	18,00	0,32	San Mauro Forte PC	Civil Protection
91	Tursi	03/11/2010	4,456,064,4	625,339,9	62,3	11,0	5,66	0,39	Tursi SAL	Civil Protection
92	Melfi	10/11/2010	4,491,130,5	640,684,3	55,5	57,0	0,97	0,59	Melfi	II Quotidiano magazine
93	Potenza	11/11/2010	4,539,263,4	551,961,4	78,8	90,0	0,88	0,57	Potenza PC	La Gazzetta del Mezzogiorno magazine
94	Lauria	22/11/2010	4,504,815,2	572,162,3	169,8	140,0	1,21	0,87	Nemoli SAL	La Gazzetta del Mezzogiorno magazine
95	Muro Lucano	02/12/2010	4,440,667,8	573,120,0	135,4	250,0	0,54	0,79	Muro Lucano PC	La Gazzetta del Mezzogiorno magazine
96	Rivello	03/12/2010	4,512,300,7	536,385,6	248,2	271,0	0,92	0,90	Nemoli SAL	II Quotidiano del sud magazine
97	Castelluccio Inferiore	03/01/2011	4,428,643,1	583,828,8	50,8	41,0	1,24	0,86	Viggianello SAL	Civil Protection
98	Alianello	19/02/2011	4,437,455,5	564,407,9	36,8	10,0	3,68	0,57	Aliano SAL	ANAS (National Istitution for Highways)
99	Armento	19/02/2011	4,462,213,4	588,308,3	83,4	52,0	1,60	0,83	Guardia Perticara SAL	Civil Protection

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
100	Bernalda	19/02/2011	4,474,641,9	641,273,3	20,0	10,0	2,00	0,55	Bernalda SAL	Civil Protection
101	Montalbano Jonico	19/02/2011	4,461,782,0	633,367,9	28,4	17,0	1,67	0,48	Montalbano SAL	Civil Protection
102	Pisticci	19/02/2011	4,456,984,3	610,237,7	29,0	49,0	0,59	0,60	Pisticci Scalo SAL	Evalmet web site
103	Tursi	19/02/2011	4,457,443,9	626,287,3	30,8	24,0	1,28	0,39	Tursi SAL	Civil Protection
104	Valsinni	20/02/2011	4,447,737,2	622,905,0	22,8	16,0	1,43	0,59	Nova Siri SAL	Civil Protection
105	Cancellara	01/03/2011	4,509,339,7	577,969,2	42,8	14,0	3,06	0,93	San Nicola D'Avigliano PC	Civil Protection
106	Ferrandina	01/03/2011	4,485,235,5	624,000,0	99,0	19,0	5,21	0,70	Ferrandina SAL	Civil Protection
107	Matera	01/03/2011	4,501,551,8	634,766,1	103,0	23,0	4,48	0,58	Matera Nord SAL	Civil Protection
108	Teana	01/03/2011	4,442,436,7	598,621,8	64,2	21,0	3,06	0,90	Episcopia PC	Civil Protection
109	Bernalda	02/03/2011	4,474,369,9	642,163,4	102,4	21,0	4,88	0,58	Bernaida SAL	Civil Protection
110	Colobraro	02/03/2011	4,449,038,6	620,816,0	78,0	18,0	4,33	0,44	Tursi SI	metapontino.it
111	Grassano	02/03/2011	4,499,277,9	609,377,8	149,7	19,0	7,88	0,66	Grassano SAL	Evalmet web site
112	Irsina	02/03/2011	4,456,172,0	625,292,0	89,4	21,0	4,26	0,19	Santa Marla d'Irsi SAL	pisticci.com
113	Montalbano Jonico	02/03/2011	4,471,789,5	633,568,6	153,6	24,0	6,40	0,52	Montalbano SAL	Evalmet web site
114	Pisticci	02/03/2011	4,449,746,0	630,633,3	81,4	18,0	4,52	0,65	Pisticci Scalo SAL	II Quotidiano, Evalmet web site
115	Rotondella	02/03/2011	4,518,058,7	611,730,4	126,6	17,0	7,45	0,65	Nova Siri SAL	Civil Protection
116	Tricarico	02/03/2011	4,496,864,3	597,934,1	31,4	15,0	2,09	0,82	Albano di Lucania PC	vigilfuoco.it
117	Tursi	02/03/2011	4,460,225,2	632,086,0	152,0	18,0	8,44	0,44	Tursi SAL	Evalmet web site
118	Valsinni	02/03/2011	4,472,089,5	632,234,9	129,2	18,0	7,18	0,65	Nova Siri SAL	Evalmet web site
119	Laurenzana	03/03/2011	4,478,608,5	582,713,6	81,6	63,0	1,30	0,90	Laurenzana SAL	Evalmet web site
120	Lauria	05/03/2011	4,432,403,8	572,113,3	97,8	114,0	0,86	0,84	Nemoli SAL	Civil Protection

DOI: http://dx.doi.org/10.5772/intechopen.92730

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
121	Grottole	05/05/2011	4,447,270,2	625,680,9	62,8	102,0	0,62	0,94	Grottole da Castellano	provincia di Matera
122	Laurenzana (riatt.)	05/05/2011	4,481,944,5	581,225,0	149,8	210,0	0,71	0,78	Laurenzana SAL	ANAS
123	Bella	07/10/2011	4,512,353,3	546,253,8	94,2	5,0	18,84	0,17	Bella Casalini	Civil Protection
124	Muro Lucano	08/10/2011	4,511,194,6	540,805,5	127,6	6,0	21,27	0,07	Muro Lucano PC	La Gazzetta del Mezzogiorno magazine
125	Matera	06/11/2011	4,502,097,8	635,438,5	34,2	2,0	17,10	0,10	Matera PC	Civil Protection
126	San Fele	06/12/2011	4,515,972,5	551,039,6	23,8	30,0	0,79	0,44	San Fele PC	Civil Protection
127	Latronico	15/11/2011	4,437,998,4	586,199,8	65,0	44,0	1,48	0,89	Episcopia PC	Civil Protection
128	Stigliano	25/12/2011	4,473,739,4	605,248,1	46,6	8,0	5,83	0,13	Stigliano SAL	Civil Protection
129	Lauria	06/01/2012	4,431,454,0	572,485,4	41,6	46,0	0,90	0,82	Nemoli SAL	Civil Protection
130	Rivello (2)	20/01/2012	4,436,157,6	558,533,0	16,6	10,0	1,66	0,80	Nemoli SAL	Civil Protection
131	Savoia di Lucania	04/02/2012	4,490,321,5	547,596,1	57,2	79,0	0,72	0,37	Vietri	Civil Protection
132	Craco	08/02/2012	4,470,541,6	622,549,9	37,4	24,0	1,56	0,38	Craco PC	Civil Protection
133	Rapone	10/02/2012	4,521,844,9	542,278,7	20,1	17,0	1,18	0,53	San Fele PC	Civil Protection
134	Montemurro	11/02/2012	4,461,336,3	583,827,5	118,6	254,0	0,47	0,54	Grumento Nova	Civil Protection
135	Avigliano	12/02/2012	4,509,076,7	560,722,3	29,8	39,0	0,76	0,61	Avigliano PC	Civil Protection
136	Bernalda	23/02/2012	4,475,260,0	643,993,1	52,4	42,0	1,25	0,48	Bernalda SAL	Civil Protection
137	Castronuovo di Sant'Andrea	23/02/2012	4,448,673,1	604,075,0	95,4	50,0	1,91	0,48	Roccanova PC	basilicatanotizie.net
138	Chlaromonte	23/02/2012	4,499,219,0	647,309,0	100,4	45,0	2,23	0,51	Noepoli PC	basilicatanotizie.net
139	Montalbano Jonico	23/02/2012	4,461,399,7	632,113,0	46,8	43,0	1,09	0,51	Montalbano SAL	Civil Protection
140	Tursi	23/02/2012	4,456,338,6	624,326,0	53,8	43,0	1,25	0,63	Tursi SAL	Civil Protection

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
141	Pietrapertosa	24/02/2012	4,440,620,5	607,006,8	39,2	39,0	1,01	0,61	Campomaggiore SAL	Civil Protection
142	Vietri di Potenza	08/03/2012	4,495,336,2	543,776,2	10,0	7,0	1,43	0,50	Vietri	Quotidiano del sud, Metauronews
143	Avigliano	09/03/2012	4,507,355,3	561,591,1	31,4	18,0	1,74	0,71	Avigliano PC	Civil Protection
144	Rivello	14/04/2012	4,436,142,6	554,613,5	118,0	30,0	3,93	0,71	Nemoli SAL	Civil Protection
145	Rapone	18/04/2012	45,873,9	542,457,0	50,6	KO	0,56	0,76	San Fele PC	Civil Protection
146	Avigliano	20/04/2012	4,509,561,9	561,009,0	20,4	33,0	0,62	0,76	Avigliano PC	Civil Protection
147	Rivello	21/04/2012	4,435,386,6	565,318,9	256,8	192,0	1,34	0,71	Nemoli SAL	Civil Protection
148	Lauria	06/06/2012	4,432,952,2	570,399,6	58,2	11,0	5,29	0,76	Nemoli SAL	Civil Protection
149	Teana	23/06/2012	4,442,695,5	598,168,9	29,6	3,0	9,87	0,30	Episcopia PC	Civil Protection
150	Lavello	01/09/2012	4,545,949,2	568,245,9	20,8	4,0	5,20	0,02	Lavello SAL	Civil Protection
151	Venosa	02/09/2012	4,460,329,4	633,421,4	141,0	32,0	4,41	0,08	Venosa SAL	Civil Protection
152	Castelluccio Inferiore (3)	03/10/2012	4,427,492,7	587,471,1	9,0	2,0	4,50	0,12	Viggianello SAL	Civil Protection
153	Rotonda	29/10/2012	4,423,198,3	588,915,1	111,2	28,0	3,97	0,27	Rotonda SAL	Civil Protection
154	Campomaggiore	20/11/2012	4,491,247,0	590,935,1	66,8	106,0	0,63	0,24	Campomaggiore SAL	Civil Protection
155	Pisticci	20/11/2012	4,533,376,1	575,381,2	73,8	67,0	1,10	0,54	Pisticci Scalo SAL	pisticci.com
156	Roccanova	20/11/2012	4,453,378,3	603,847,3	96,2	90,0	1,07	0,30	Roccanova PC	Civil Protection
157	Vietri di Potenza	20/11/2012	4,494,560,8	543,083,9	27,0	29,0	0,93	0,44	Vietri	Quotidiano del sud, Metauronews
158	Lauria	04/12/2012	4,472,662,9	632,178,6	220,0	152,0	1,45	0,80	Nemoli SAL	regione.basilicata.it
159	Barile	08/12/2012	4,532,258,7	556,671,8	26,1	12,0	2,18	0,46	Venosa SAL	Civil Protection
160	San Severino Lucano	17/01/2013	4,430,496,6	596,772,9	175,6	177,0	0,99	0,85	Viggianello SAL	Civil Protection
161	Lauria	18/01/2013	4,434,754,0	571,329,9	268,0	180,8	1,49	0,79	Nemoli SAL	Civil Protection
162	Savoia di Lucania	18/01/2013	4,491,704,0	544,971,0	87,6	93,0	0,94	0,68	Vietri	Civil Protection

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
163	Vietri di Potenza	18/01/2013	4,432,069,0	573,009,3	87,6	93,0	0,94	0,73	Vietri	Quotidiano del sud, Metauronews
164	Sant'Angelo le Fratte	19/01/2013	4,494,125,0	541,429,1	99,6	101,0	0,99	0,63	Tito PC	Fonti Cronachistiche
165	Lagonegro	21/01/2013	4,488,383,1	547,262,1	266,8	244,0	1,09	0,80	Lagonegro PC	La Siritide
166	Episcopia	25/01/2013	4,445,478,1	562,707,3	366,6	362,0	1,01	0,87	Episcopia PC	basilicatanotizie.net
167	San Severino Lucano	03/02/2013	4,429,936,5	596,946,0	28,2	26,0	1,08	0,90	Viggianello SAL	Civil Protection
168	Armento	13/02/2013	4,462,461,3	590,367,6	12,0	10,0	1,20	0,73	Guardia Perticara SAL	Civil Protection
169	Balvano	13/02/2013	4,500,024,3	543,479,7	34,4	31,0	1,11	0,74	Balvano PC	Civil Protection
170	Avigliano	24/02/2013	4,508,495,2	559,778,8	18,4	27,0	0,68	0,95	Avigliano PC	Civil Protection
171	Vietri di Potenza	14/03/2013	4,437,619,1	594,262,1	44,8	49,0	0,91	0,89	Vietri	Quotidiano del sud, Metauronews
172	Castelluccio Inferiore	15/03/2013	4,428,429,2	584,348,2	136,0	214,0	0,64	0,84	Viggianello SAL	Civil Protection
173	Lauria	21/03/2013	4,495,266,6	544,987,6	339,2	353,0	0,96	0,82	Nemoli SAL	youtube
174	Castelluccio Inferiore	10/04/2013	4,428,714,4	584,450,1	12,2	3,0	4,07	0,83	Viggianello SAL	Civil Protection
175	Muro Lucano	10/07/2013	4,510,677,3	541,344,5	59,2	53,0	1,12	0,36	Muro Lucano PC	Civil Protection
176	Vietri di Potenza	21/07/2013	4,493,924,6	541,919,0	13,8	4,0	3,45	0,32	Vietri	Quotidiano del sud, Metauronews
177	Accettura	21/08/2013	4,428,008,9	574,521,3	27,4	25,0	1,10	0,19	Campomaggiore SAL	accettura online
178	Atella - Filiano	21/08/2013	4,517,964,3	559,520,9	43,6	5,0	8,72	0,21	Atella PC	Civil Protection
179	Bernalda	07/10/2013	4,474,073,6	643,387,8	190,4	56,0	3,40	0,08	Bernalda SAL	Quotidiano del sud, Evilmet
180	Montalbano Jonico	07/10/2013	4,461,773,7	634,506,4	84,2	2,90	2,90	0,10	Montalbano SAL	Civil Protection
181	Montescaglioso	07/10/2013	4,490,286,3	641,544,0	135,2	35,0	3,86	0,07	Montescaglioso SAL	Civil Protection
182	Pisticci	07/10/2013	4,487,593,1	594,710,1	105,6	57,0	1,85	0,11	Torre Accio PC	Evalmet web site
183	Lauria	11/10/2013	4,470,914,4	645,919,6	43,4	51,0	0,85	0,39	Nemoli SAL	infopinione.it
184	Bernalda	16/11/2013	4,472,586,8	647,193,6	148,4	136,0	1,09	0,37	Metaponto	Gazzettino.it

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
185	Chiaromonte	16/11/2013	4,433,677,5	571,261,9	238,2	132,0	1,80	0,22	Noepoli PC	La Siritide
186	Pisticci	16/11/2013	4,472,993,9	631,724,0	157,0	135,0	1,16	0,24	Pisticci Scalo SAL	Civil Protection
187	San Fele	22/11/2013	4,518,881,1	545,411,7	109,8	82,0	1,34	0,42	San Fele PC	Civil Protection
188	Guardia Perticara (3)	24/11/2013	4,468,838,7	592,161,9	103,6	115,9	0,90	0,61	Guardia Perticara SAL	Civil Protection
189	San Severino Lucano	24/11/2013	4,429,132,5	594,345,3	133,8	100,0	1,34	0,58	Viggianello SAL	lapretoria.it
190	Laurenzana	26/11/2013	4,440,683,6	606,559,5	89,0	94,0	0,95	0,61	Laurenzana SAL	Civil Protection
191	Valsinni	26/11/2013	4,446,786,7	622,424,8	193,0	115,0	1,68	0,25	Nova Siri SAL	Civil Protection
192	Miglionico	30/11/2013	4,492,223,8	627,675,2	20,0	8,0	2,50	0,48	Ferrandina SAL	Civil Protection
193	Chiaromonte	01/12/2013	4,479,622,4	582,489,7	65,0	25,0	2,60	0,85	Episcopia PC	Fonti Cronachistiche
194	Craco (7)	01/12/2013	4,470,341,9	623,096,0	156,4	29,0	5,39	0,61	Craco PC	Civil Protection
195	Gallicchio	01/12/2013	4,489,127,2	591,325,4	95,6	20,0	4,78	0,54	Aliano SAL	Civil Protection
196	Ginestra	01/12/2013	4,531,394,8	562,130,8	89,5	23,0	3,89	0,32	Venosa SAL	Civil Protection
197	Pomarico (4)	01/12/2013	4,486,804,1	631,164,0	128,6	26,0	4,95	0,51	Ferrandina SAL	Civil Protection
198	Potenza	01/12/2013	4,496,760,3	571,166,4	63,2	25,0	2,53	0,60	Potenza PC	Civil Protection
199	Savoia di Lucania	01/12/2013	4,490,996,4	546,572,9	125,6	51,0	2,46	0,63	Vietri	Civil Protection
200	Tricarico	01/12/2013	4,497,852,6	597,122,7	114,8	32,0	3,59	0,55	Albano di Lucania PC	Civil Protection
201	Armento	02/12/2013	4,449,866,2	621,395,1	120,0	57,0	2,11	0,81	Guardia Perticara SAL	Fonti Cronachistiche
202	Bernalda	02/12/2013	4,473,912,5	643,362,6	221,3	49,0	4,52	0,74	Bernalda SAL	Civil Protection
203	Cirigliano	02/12/2013	4,472,564,9	599,264,5	162,0	56,0	2,89	0,59	San Mauro Forte PC	Civil Protection
204	Colobraro	02/12/2013	4,461,913,3	596,895,9	140,7	26,0	5,41	0,68	Sinni a Valsinni SI	emmenews
205	Garaguso/Grassano	02/12/2013	4,545,101,3	565,137,4	150,0	52,0	2,88	0,47	Grassano SAL	La Gazzetta del Mezz
206	Grottole(3)	02/12/2013	4,494,492,3	616,732,9	186,8	57,0	3,28	0,48	Grottole da Serre	Civil Protection

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
207	Guardia Perticara	02/12/2013	4,494,394,2	605,039,5	120,0	57,0	2,11	0,81	Guardia Perticara SAL	Civil Protection
208	Lavello	02/12/2013	4,459,823,2	599,087,0	130,0	57,0	2,28	0,30	Lavello SAL	Fonti Cronachistiche
209	Missanello	02/12/2013	4,462,814,9	590,380,8	138,6	55,0	2,52	0,54	Aliano SAL	Fonti Cronachistiche
210	Montalbano Jonico	02/12/2013	4,457,687,7	626,816,0	174,8	28,0	6,24	0,66	Montalbano SAL	Civil Protection
211	Pietrapertosa	02/12/2013	4,484,995,6	589,793,9	168,8	54,0	3v13	0,57	Campomaggiore SAL	Civil Protection
212	Pisticci	02/12/2013	4,466,906,3	594,785,7	167,2	33,0	5,07	0,63	Pisticci Scalo SAL	Civil Protection
213	Rivello	02/12/2013	4,436,644,0	564,876,7	42,2	38,0	1,11	088	Nemoli SAL	Civil Protection
214	Senise	02/12/2013	4,445,683,3	609,339,4	83,0	37,0	2,24	0,81	Noepoli PC	Civil Protection
215	Accettura	03/12/2013	4,488,048,3	593,820,9	211,4	58,0	3,64	0,57	Campomaggiore SAL	La Gazzetta del Mezzogiorno
216	Accettura, Salandra	03/12/2013	4,481,543,0	598,406,7	197,8	63,0	3,14	0,59	San Mauro Forte PC	La Gazzetta del Mezzogiorno
217	Ferrandina	03/12/2013	4,436,089,0	624,424,9	161,0	59,0	2,73	0,51	Ferrandina SAL	Civil Protection
218	Ginestra	03/12/2013	4,531,331,9	561,335,0	128,5	56,0	2,29	0,32	Venosa SAL	Civil Protection
219	Montescaglioso	03/12/2013	4,489,336,0	639,955,0	224,2	56,0	4,00	0,54	Montescaglioso SAL	Pellicani et al., 2016
220	Trivigno (4)	03/12/2013	4,490,716,4	583,663,1	196,0	88,0	2,23	0,55	Albano di Lucania PC	Civil Protection
221	Tursi	03/12/2013	4,472,751,0	632,461,7	138,6	66,0	2,10	0,58	Tursi SAL	Evalmet web site
222	Viggianello	04/12/2013	4,427,183,0	589,852,6	74,8	61,0	1,23	0,85	Viggianello SAL	Civil Protection
223	Sarconi	26/12/2013	4,457,355,0	632,845,6	26,0	11,0	2,36	0,85	Sarconi SAL	Civil Protection
224	Aliano	21/01/2014	4,463,968,1	603,952,3	88,4	52,0	1,70	0,83	Roccanova PC	Fonti Cronachistiche
225	Calvera	21/01/2014	4,454,657,0	574,796,0	193,6	69,9	2,81	0,86	Episcopia PC	La Siritide
226	Castronuovo di Sant'Andrea	21/01/2014	4,450,030,0	600,486,2	87,4	60,0	1,46	0,83	Roccanova PC	Civil Protection
227	Rivello	21/01/2014	4,436,820,3	566,903,7	114,8	41,0	2,80	0,86	Nemoli SAL	Civil Protection

DOI: http://dx.doi.org/10.5772/intechopen.92730

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
228	Senise	21/01/2014	4,444,739,2	610,507,1	52,0	50,0	1,04	0,84	Senise SAL	Civil Protection
229	Latronico	22/01/2014	4,436,079,5	583,979,5	194,9	70,0	2,77	0,86	Episcopia PC	La Siritide website
230	Lauria	22/01/2014	4,444,641,2	597,413,0	267,2	86,0	3,11	0,86	Nemoli SAL	Fonti Cronachistiche
231	Guardia Perticara	24/01/2014	4,469,389,1	594,580,2	103,6	128,0	0,81	0,85	Guardia Perticara SAL	Civil Protection
232	Maratea	28/01/2014	4,427,583,9	561,128,4	234,6	218,0	1,08	0,93	Maratea PC	Civil Protection
233	Francavilla in Sinni	30/01/2014	4,433,285,2	569,276,0	247,8	238,0	1,04	0,86	Episcopia PC	regione.basilicata.it
234	Guardia Perticara	02/02/2014	4,467,955,0	593,670,0	46,4	46,0	1,01	0,95	Guardia Perticara SAL	Coldiretti webpage
235	Potenza	02/02/2014	4,496,094,5	568,378,3	12,4	7,0	1,77	0,91	Potenza PC	Civil Protection
236	Tursi	02/02/2014	4,436,149,4	600,183,4	30,6	36,0	0,85	0,86	Tursi SAL	oltrefreepress.com
237	Accettura	03/02/2014	4,482,603,0	600,241,7	105,6	77,0	1,37	0,79	San Mauro Forte PC	accettura online
238	Castelluccio Inferiore	03/02/2014	4,428,421,9	583,511,5	272,6	381,0	0,72	0,78	Viggianello SAL	castelluccioinferiore.comune.news
239	Gallicchio	03/02/2014	4,460,176,1	597,304,5	88,0	67,0	1,31	0,92	Roccanova PC	Civil Protection
240	Latronico	03/02/2014	4,438,541,9	586,536,2	47,6	68,0	0,70	0,94	Episcopia PC	Civil Protection
241	Pisticci	03/02/2014	4,458,130,1	631,793,0	62,4	68,0	0,92	0,87	Craco PC	Fonti Cronachistiche magazine
242	San Giorgio Lucano	03/02/2014	4,441,730,4	618,593,4	60,2	74,0	0,81	0,94	San Giorgio Lucano SAL	Civil Protection
243	Aliano	04/02/2014	4,462,662,3	608,499,5	94,6	81,0	1,17	0,92	Roccanova PC	Civil Protection
244	Gorgoglione	04/02/2014	4,471,971,5	597,509,0	86,2	74,0	1,16	0,95	Guardia Perticara SAL	basilicata24.it
245	Guardia Perticara (2)	04/02/2014	4,468,759,4	593,490,1	91,8	85,0	1,08	0,95	Guardia Perticara SAL	Civil Protection
246	Missanello(2)	04/02/2014	4,459,645,8	598,794,7	96,6	81,0	1,19	0,79	Aliano SAL	Civil Protection
247	Noepoli	04/02/2014	4,473,633,7	637,169,5	101,6	74,0	1,37	0,90	Noepoli PC	La Siritide
248	Sant'Arcangelo (3)	04/02/2014	4,454,767,9	612,151,0	94,6	81,0	1,17	0,92	Roccanova PC	Civil Protection
249	Cirigliano	05/02/2014	4,476,117,9	599,525,8	124,8	90,0	1,39	0,79	San Mauro Forte PC	sassiland

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
250	Sarconi	09/02/2014	4,473,389,5	604,347,8	22,4	30,0	0,75	0,93	Sarconi SAL	Civil Protection
251	Stigliano	09/02/2014	4,438,261,8	613,374,0	105,6	98,0	1,08	0,78	Stigliano SAL	Civil Protection
252	Armento	25/03/2014	4,461,174,2	591,120,8	17,4	14,0	1,24	0,81	Guardia Perticara SAL	Civil Protection
253	Guardia Perticara	25/03/2014	4,455,948,6	575,716,1	30,8	16,0	1,93	0,81	Guardia Perticara SAL	Civil Protection
254	Montemurro	27/03/2014	4,462,003,7	585,867,7	18,2	20,0	0,91	0,89	Grumento NOva	Civil Protection
255	Stigliano	27/03/2014	4,473,506,8	604,550,1	12,0	4,0	3,00	0,68	Stigliano SAL	regione.basilicata.it
256	San Severino Lucano	06/04/2014	4,429,371,0	597,800,0	68,0	49,0	1,39	0,89	Viggianello SAL	sanseverinolucano.com
257	Rionero in Vulture	12/04/2014	4,530,903,2	556,997,1	29,1	16,0	1,82	0,74	Melfi	Civil Protection
258	Chiaromonte	16/04/2014	4,470,704,8	595,848,0	21,0	13,0	1,62	0,87	Noepoli PC	Civil Protection
259	Montemurro	17/04/2014	4,460,278,1	587,345,4	13,2	7,0	1,89	0,83	Grumento Nova	Civil Protection
260	San Severino Lucano	30/04/2014	4,439,756,0	605,195,5	37,4	47,0	0,80	0,87	Viggianello SAL	Civil Protection
261	Calvello	24/07/2014	4,427,437,3	600,212,2	11,0	1,0	11,00	0,31	Laurenzana SAL	Civil Protection
262	Rivello	08/11/2014	4,435,948,7	554,641,6	53,4	19,0	2,81	0,30	Nemoli SAL	Civil Protection
263	Rionero in Vulture (2)	31/12/2014	4,530,984,6	556,617,6	14,0	6,0	2,33	0,43	Melfi	Civil Protection
264	Brienza	30/01/2015	4,481,683,5	553,437,4	89,8	24,0	3,74	0,76	Brienza PC	Civil Protection
265	Chiaromonte	30/01/2015	4,442,083,4	603,091,6	36,8	53,0	0,69	0,58	Senise SAL	Civil Protection
266	Senise	30/01/2015	4,444,603,9	607,201,7	36,8	53,0	0,69	0,58	Senise SAL	La Siritide website
267	Castelsaraceno	31/01/2015	4,435,933,3	568,128,3	157,6	36,0	4,38	0,81	Castelsaraceno SI	Civil Protection
268	Lagonegro	31/01/2015	4,429,110,9	594,311,5	284,9	53,0	5,36	0,87	Lagonegro PC	Civil Protection
269	Latronico	31/01/2015	4,435,217,2	590,205,7	164,9	61,0	2,69	0,78	Episcopia PC	Civil Protection
270	Lauria	31/01/2015	4,448,327,7	565,843,8	263,8	43,0	6,13	0,88	Nemoli SAL	meteoweb.eu
271	Nemoli	31/01/2015	4,427,708,0	574,027,3	263,8	43,0	6,13	0,92	Nemoli SAL	Civil Protection

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
272	San Costantino Albanese	31/01/2015	4,432,781,2	612,691,0	61,6	80,0	0,77	0,49	Terranova del Pollino PC	Civil Protection
273	San Martino D'Agri	31/01/2015	4,454,871,1	589,437,1	73,2	34,0	2,15	0,74	Roccanova PC	meteoweb.eu
274	Viggianello	31/01/2015	4,447,312,7	586,781,1	164,0	61,0	2,69	0,81	Episcopia PC	meteoweb.eu
275	Montemurro	04/02/2015	4,461,149,4	584,066,8	144,6	132,0	1,10	0,54	Grumento Nova	Fonti Cronachistiche magazine
276	San Severino Lucano	06/02/2015	4,426,488,0	595,925,0	315,8	240,0	1,32	0,82	Viggianello SAL	regione.basilicata.it
277	Trecchina	08/02/2015	4,428,416,7	568,127,6	344,0	248,0	1,39	0,95	Castrocucco	Fonti Cronachistiche
278	Lauria	06/03/2015	4,434,254,5	570,436,9	99,2	82,0	1,21	0,86	Nemoli SAL	La Siritide website
279	Tricarico	06/03/2015	4,497,116,3	597,635,0	40,4	40,0	1,01	0,66	Albano di Lucania PC	tricarico news
280	Vietri di Potenza	12/03/2015	4,494,061,7	543,185,2	9,6	5,0	1,92	0,84	Vietri	Quotidiano del sud magazine
281	Terranova del Pollino	16/03/2015	4,425,194,1	607,145,4	85,2	120,0	0,71	0,84	Terranova del Pollino PC	basilicatanotizie.net
282	Salandra	18/03/2015	4485066v9	613,268,6	13,8	20,0	0,69	0,72	San Mauro Forte PC	Civil Protection
283	Montemurro	25/03/2015	4,461,303,7	585,075,4	31,4	62,0	0,51	0,88	Grumento Nova	rainews
284	Colobraro	26/03/2015	4,449,328,3	620,218,2	30,2	9,0	3,36	0,76	Sinni a Valsinni SI	Civil Protection
285	Ferrandina	27/03/2015	4,472,778,5	627,699,5	99,2	72,0	1,38	0,80	Ferrandina SAL	youreporter
286	Calvera	28/03/2015	4,445,756,6	595,749,2	80,6	128,0	0,63	0,90	Episcopia PC	Civil Protection
287	Castronuovo di Sant'Andrea	28/03/2015	4,449,432,7	600,769,2	83,4	80,0	1,04	0,91	Roccanova PC	Civil Protection
288	Chiaromonte	28/03/2015	4,441,944,5	603,702,8	71,6	78,0	0,92	0,73	Noepoli PC	Civil Protection
289	Colobraro	28/03/2015	4,451,661,8	625,343,5	78,5	77,0	1,02	0,76	Sinni a Valsinni SI	La Gazzetta del Mezzogiorno magazine
290	Grottole	28/03/2015	4,495,416,1	614,736,1	107,2	123,0	0,87	0,64	Grottole da Serre	Civil Protection

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
291	Terranova del Pollino	28/03/2015	4,424,299,8	606,589,5	142,4	129,0	1,10	0,86	Terranova del Pollino PC	Civil Protection
292	Anzi	06/04/2015	4,484,904,3	579,311,8	31,6	66,0	0,48	0,89	Laurenzana SAL	Civil Protection
293	Sasso di Castalda	12/06/2015	4,482,734,2	556,250,0	178,8	76,0	2,35	0,59	Brienza PC	Civil Protection
294	Grassano	11/08/2015	4,498,091,9	608,264,6	106,2	28,0	3,79	0,15	Grassano SAL	Civil Protection
295	Grottole	11/08/2015	4,497,727,3	612,882,2	86,0	35,0	2,46	0,15	Grottole da Serre	meteoweb.eu
296	Matera	11/08/2015	4,500,866,1	633,780,7	54,3	51,0	1,06	0,11	Matera PC	Civil Protection
297	Melfi	11/08/2015	4,538,822,6	554,831,5	11,8	2,0	5,91	0,04	Melfi	Civil Protection
298	Salandra	11/08/2015	4,487,314,1	610,376,5	21,8	26,0	0,84	0,22	San Mauro Forte PC	Civil Protection
299	Venosa	20/10/2015	4,537,376,0	569,867,0	22,8	15,0	1,52	0,24	Venosa SAL	Civil Protection
300	Chiaromonte	31/10/2015	4,442,678,8	603,349,5	108,0	51,0	2,12	0,30	Senise SAL	Civil Protection
301	Gallicchio	06/01/2016	4,460,397,1	596,927,3	10,6	3,0	3,53	0,39	Aliano SAL	La Siritide website
302	Rotonda	13/02/2016	4,423,399,8	588,125,9	117,0	91,0	1,29	0,77	Rotonda SAL	Civil Protection
303	Picerno	15/02/2016	4,500,954,0	549,546,0	93,2	103,0	0,90	0,51	Balvano PC	Civil Protection
304	Venosa	18/02/2016	4,535,187,4	568,991,4	10,7	8,0	1,34	0,38	Venosa SAL	Civil Protection
305	Castronuovo di Sant'Andrea	13/03/2016	4,449,163,2	601,141,5	120,6	50,0	2,41	0,87	Roccanova PC	Civil Protection
306	Terranova del Pollino	14/03/2016	4,425,609,1	607,819,7	63,4	46,0	1,38	0,79	Terranova del Pollino PC	Civil Protection
307	Ferrandina	16/03/2016	4,472,610,0	638,594,0	101,0	150,0	0,67	0,40	Ferrandina SAL	youreporter
308	Sant'Arcangelo (2 eventi)	16/03/2016	4,452,238,1	611,364,0	145,6	48,0	3,03	0,38	Aliano SAL	Civil Protection
309	Colobraro	17/03/2016	4,449,758,6	620,171,4	321,4	144,0	2,23	0,63	Sinni a Valsinni SI	Civil Protection

ID	Municipality	Date	UTM N	UTM E	H (mm)	D (h)	I (mm/h)	Antecedent soil saturation	Weather station	Sources
310	Pisticci	17/03/2016	4,482,354,3	626,252,6	72,1	26,0	2,77	0,57	Torre Accio PC	youreporter
311	Stigliano	17/03/2015	4,472,596,0	604,150,0	238,2	142,0	1,68	0,36	Stigliano SAL	Civil Protection
312	Salandra	18/03/2016	4,485,538,3	613,656,0	156,6	192,0	0,82	0,41	Salandra SI	Civil Protection
313	Pisticci	25/03/2016	4,471,998,1	633,051,0	47,0	18,0	2,61	0,73	Torre Accio PC	Civil Protection
314	Sant'Angelo le Fratte	26/03/2016	4,487,108,9	547,444,0	35,8	33,0	1,08	0,68	Tito PC	Civil Protection
315	Miglionico	26/07/2016	4,492,210,7	626,535,0	13,6	1,0	13,60	0,17	Ferrandina PC	Quotidiano della Basilicata magazine
316	Lavello	11/09/2016	4,545,245,7	564,838,8	31,8	19,0	1,67	0,21	Lavello SI	vulturenews
317	Genzano	21/09/2016	4,521,410,4	590,384,9	19,4	6,0	3,23	0,33	Genzano SAL	Civil Protection
318	Maratea	10/10/2016	4,426,721,0	560,774,8	113,4	70,0	1,62	0,27	Maratea PC	Fonti Cronachistiche
319	Colobraro	23/01/2017	4,447,990,5	622,489,0	127,2	68,0	1,87	0,57	Sinni a Valsinni SI	Civil Protection
320	Campomaggiore	25/01/2017	4,490,127,7	591,486,1	67,2	67,0	1,00	0,67	Laurenzano PC	Civil Protection
321	Senise	25/01/2017	4,445,316,4	612,080,5	113,0	91,0	1,24	0,52	Noepoli PC	trmtv.it
322	Avigliano	08/03/2017	4,510,867,0	560,723,4	53,6	31,0	1,73	0,86	Avigliano PC	basilicata24.com
323	Montemilone	15/07/2017	4,542,486,2	581,337,0	27,4	2,0	13,70	0,05	Montemilone PC	vulture news
324	Viggianello	05/03/2018	4,426,435,3	589,650,4	123,0	197,0	0,62	0,87	Rotonda	Civil Protection
325	Rivello	07/03/2018	4,436,820,1	565,132,1	208,0	360,0	0,58	0,88	Lagonegro PC	Civil Protection
326	Laurenzana	28/03/2018	4,479,367,5	582,543,4	108,2	192,0	0,56	0,83	Laurenzana	Civil Protection

Table 1.
Rainfall-triggered landslides in Basilicata during last 20 years.

Author details

Maurizio Lazzari[1], Marco Piccarreta[2], Ram L. Ray[3] and Salvatore Manfreda[4*]

1 CNR-ISPC, Potenza (PZ), Tito Scalo, Italy

2 Interuniversity Consortium for Hydrology (CINID), Potenza, Italy

3 College of Agriculture and Human Sciences, Prairie View A&M University, Prairie View, Texas, USA

4 Department of Civil, Architectural and Environmental Engineering, University of Naples Federico II, Naples, Italy

*Address all correspondence to: salvatore.manfreda@unina.it

References

[1] Hong Y, Adler R, Huffman G. Evaluation of the potential of NASA multi-satellite precipitation analysis in global landslide hazard assessment. Geophysical Research Letters. 2006;**33**: L22402. DOI: 10.1029/2006GL028010

[2] Marc O, Stumpf A, Malet JP, Gosset M, Uchida T, Chiang SH. Initial insights from a global database of rainfall-induced landslide inventories: The weak influence of slope and strong influence of total storm rainfall. Earth Surface Dynamics. 2018;**6**:903-922

[3] Guzzetti F, Peruccacci S, Rossi M, Stark CP. The rainfall intensity-duration control of shallow landslides and debris flows: An update. Landslides. 2008;**5**:3-17

[4] Lazzari M, Piccarreta M, Capolongo D. Landslide triggering and local rainfall thresholds in Bradanic Foredeep, Basilicata region (southern Italy). Landslide Science and Practice. Vol. 2. Early Warning, Instrumentation and Modeling. Springer Series. Margottini C, Canuti P, Sassa K, et al, editors. In: Proceedings of the Second World Landslide Forum; Rome (ITALY); 3–9 October 2011; 2013. pp. 671-678

[5] Segoni S, Piciullo L, Gariano SL. A review of the recent literature on rainfall thresholds for landslide occurrence. Landslides. 2018;**15**:1483-1501. DOI: 10.1007/s10346-018-0966-4

[6] Bogaard T, Greco R. Invited perspectives: Hydrological perspectives on precipitation intensity-duration thresholds for landslide initiation: Proposing hydro-meteorological thresholds. Natural Hazards and Earth System Sciences. 2018;**18**:31-39

[7] Crozier MJ. Prediction of rainfall-triggered landslides: A test of the antecedent water status model. Earth Surface Processes and Landforms. 1999; **24**:825-833

[8] Glade T, Crozier MJ, Smith P. Applying probability determination to refine landslide-triggering rainfall thresholds using an empirical “antecedent daily rainfall model”. Pure and Applied Geophysics. 2000;**157**:1059-1079

[9] Godt JW, Baum RL, Chleborad AF. Rainfall characteristics for shallow landsliding in Seattle, Washington, USA. Earth Surface Processes and Landforms. 2006;**31**:97-110

[10] Brocca L, Ponziani F, Moramarco T, Melone F, Berni N, Wagner W. Improving landslide forecasting using ASCAT-derived soil moisture data: A case study of the Torgiovannetto landslide in Central Italy. Remote Sensing. 2012;**4**: 1232-1244. DOI: 10.3390/rs4051232

[11] Coe J. Regional moisture balance control of landslide motion: Implications for landslide forecasting in a changing climate. Geology. 2012;**40**(4):323-326. DOI: 10.1130/G32897.1

[12] Ponziani F, Pandolfo C, Stelluti M, Berni N, Brocca L, Moramarco T. Assessment of rainfall thresholds and soil moisture modeling for operational hydrogeological risk prevention in the Umbria region (Central Italy). Landslides. 2012;**9**:229-237. DOI: 10.1007/s10346-011-0287-3

[13] Mirus BB, Rachel I, Becker E, Rex I, Baum L, Joel I, et al. Integrating real-time subsurface hydrologic monitoring with empirical rainfall thresholds to improve landslide early warning. Landslides. 2018;**15**:1909-1919

[14] Mirus BB, Morphew MD, Smith JB. Developing hydro-meteorological tfor shallow landslide initiation and early warning. Water. 2018;**10**:1274. DOI: 10.3390/w10091274

[15] Valenzuela P, Domínguez-Cuesta MJ, Mora García MA, Jiménez-Sánchez M.

Rainfall thresholds for the triggering of landslides considering previous soil moisture conditions (Asturias, NW Spain). Landslides. 2018;**15**:273-282. DOI: 10.1007/s10346-017-0878-8

[16] Torres R, Dietrich WE, Montgomery DR, Anderson SP, Loague K. Unsaturated zone processes and the hydrological response of a steep unchanneled catchment. Water Resources Research. 1998;**34**(8): 1865-1879. DOI: 10.1029/98WR01140

[17] Baum RL, McKenna JP, Godt JW, Harp EL, McMullen SR. Hydrologic monitoring of landslide-prone coastal bluffs near Edmonds and Everett, Washington, 2001–2004: U.S. Geological Survey Open-File Report 2005–1063; 2005. p. 42

[18] Ebel BA, Loague K, Montgomery DR, Dietrich WE. Physics-based continuous simulation of long-term near-surface hydrologic response for the Coos Bay experimental catchment. Water Resources Research. 2008;**44**:W07417. DOI: 10.1029/2007WR006442

[19] Napolitano E, Fusco F, Baum RL, Godt JW, De Vita P. Effect of antecedent-hydrological conditions on rainfall triggering of debris flows in ash-fall pyroclastic mantled slopes of Campania (southern Italy). Landslides. 2015;**13**:967-983. DOI: 10.1007/s10346-015-0647-5

[20] Pieri P, Tropeano M, Sabato L, Lazzari M, Moretti M. Quadro stratigrafico dei depositi regressivi della Fossa bradanica (Pleistocene) nell'area compresa fra Venosa e il Mar Ionio. Giornale di Geologia. 1998:318-320

[21] Lazzari M, Pieri P. Modello stratigrafico-deposizionale della successione regressiva infrapleistocenica della Fossa bradanica nell'area compresa tra Lavello. Genzano e Spinazzola. Mem. Soc. Geol. It. 2002;**57**(1):231-237

[22] Piccarreta M, Pasini A, Capolongo D, Lazzari M. Changes in daily precipitation extremes in the Mediterranean from 1951 to 2010: The Basilicata region, southern Italy. International Journal of Climatology. 2013;**33**(15):3229-3248. DOI: 10.1002/joc.3670

[23] Lazzari M. Note illustrative della Carta Inventario delle Frane della Basilicata centroccidentale. Lagonegro: Editore Grafiche Zaccara; 2011. p. 136

[24] Lazzari M, Gioia D. Regional-scale landslide inventory, central-western sector of the Basilicata region (southern Apennines, Italy). Journal of Maps. Published Online. 2015;**12**(5):852-859. DOI: 10.1080/17445647.2015.1091749

[25] Lazzari M, Gioia D, Anzidei B. Landslide inventory of the Basilicata region (southern Italy). Journal of Maps. 2018;**14**(2):348-356. DOI: 10.1080/17445647.2018.1475309

[26] Brunetti MT, Peruccacci S, Rossi M, Luciani S, Valigi D, Guzzetti F. Rainfall thresholds for the possible occurrence of landslides in Italy. Natural Hazards and Earth System Sciences. 2010;**10**:447-458

[27] Vennari C, Gariano SL, Antronico L, Brunetti MT, Iovine G, Peruccacci S, et al. Rainfall thresholds for shallow landslide occurrence in Calabria, southern Italy. Natural Hazards and Earth System Sciences. 2014;**14**:317-330. DOI: 10.5194/nhess-14-317-2014

[28] Piciullo L, Gariano SL, Melillo M, Brunetti MT, Peruccacci S, Guzzetti F, et al. Definition and performance of a threshold-based regional early warning model for rainfall-induced landslides. Landslides. 2016b;**14**:995-1008. DOI: 10.1007/s10346-016-0750-2

[29] Peruccacci S, Brunetti MT, Gariano SL, Melillo M, Rossi M, Guzzetti F, et al. Rainfall thresholds for possible landslide occurrence in Italy. Geomorphology. 2017;**290**:39-57. DOI: 10.1016/j.geomorph.2017.03.031

[30] Ray RL, Jacobs JM. Relationships among remotely sensed soil moisture, precipitation and landslide events. Natural Hazards. 2007;**43**:211-222

[31] Basilicata Region, Ufficio Produzioni Vegetali e Silvicoltura Produttiva - Dipartimento Agricoltura, Sviluppo Rurale, Economia Montana, Carta Pedologica della Basilicata—S.EL. CA srl—Firenze. 2006. Available from: http://www.basilicatanet.it/suoli/cartine/carta-pedologica.zip http://dati.regione.basilicata.it/catalog/dataset/carta-pedologica ttp://www.soilmaps.it/download/csi-BrochureSR_a4.pdf

[32] Corine Land Cover. 2012. Available from: http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/corine-land-cover/corine-land-cover-2012/view

[33] Ruiz-Pérez G, Koch J, Manfreda S, Caylor KK, Francés F. Calibration of a parsimonious distributed ecohydrological daily model in a data scarce basin using exclusively the spatio-temporal variation of NDVI. Hydrology and Earth System Sciences. 2017;**21**:6235-6251. DOI: 10.5194/hess-21-6235-2017

[34] Manfreda S, Mita L, Dal Sasso SF, Samela C, Mancusi L. Exploiting the use of physical information for the calibration of the lumped hydrological model. Hydrological Processes. 2018;**32**(10):1420-1433. DOI: 10.1002/hyp.11501

[35] Farmer DL, Sivapalan M, Jothityangkoon C. Climate, soil and vegetation controls upon the variability of water balance in temperate and semi-arid landscapes: Downward approach to hydrological prediction. Water Resources Research. 2003;**39**:2

[36] De Smedt F, Yongbo L, Gebremeskel S. Hydrologic modelling on a catchment scale using GIS and remote sensed land use information. WIT Transactions on Ecology and the Environment. 2000;**45**:295-304

[37] Liu YB, Gebremeskel S, De Smedt F, Hoffmann L, Pfister L. A diffusive transport approach for flow routing in GIS-based flood modeling. Journal of Hydrology. 2003;**283**(1–4):91-106

[38] Manfreda S, Fiorentino M, Iacobellis V. DREAM: A distributed model for runoff, evapotranspiration, and antecedent soil moisture simulation. Advances in Geosciences. 2005;**2**:31-39. DOI: 10.5194/adgeo-2-31-2005

[39] Eagleson PS et al. Climate, soil, and vegetation. Climate, soil, and vegetation. Water Resources Research. 1978;**14**(5):705-776

[40] Rosano R, Manfreda S, Fiorentino M, Sole A. Sviluppo ed Ingegnerizzazione di un Applicativo Software per la Modellazione Idrologica a Scala di Bacino, 29° Convegno di Idraulica e Costruzioni Idrauliche: Editoriale Bios; 2008

[41] Manfreda S, Brocca L, Moramarco T, Melone F, Sheffield J. A physically based approach for the estimation of root-zone soil moisture from surface measurements. Hydrology and Earth System Sciences. 2014;**18**:1199-1212. DOI: 10.5194/hess-18-1199-2014

[42] Lazzari M, Piccarreta M, Manfreda S. The role of antecedent soil moisture conditions on rainfall-triggered shallow landslides. Natural Hazards Earth System Science Discussion. 2019:1-11. DOI: 10.5194/nhess-2018-371

[43] Baum RL, Godt JW. Early warning of rainfall-induced shallow landslides and debris flows in the USA. Landslides. 2009;**7**(3):259-272

[44] Baldwin D, Manfreda S, Keller K, Smithwick EAH. Predicting root zone soil moisture with soil properties and satellite near-surface moisture data at locations across the United States. Journal of Hydrology. 2017;**546**:393-404. DOI: 10.1016/j.jhydrol.2017.01.020