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DEFINITION OF RUNOFF THRESHOLDS INTEGRATING SATELLITE DATA AND IN-SITU MEASUREMENTS: RESULTS FROM VOINEŞTI EXPERIMENTAL BASIN (ROMANIA)

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EXTENDED ABSTRACT

I processi di runoff sono influenzati da diversi fattori quali la tipologia e le proprietà del suolo, la copertura vegetale, la pendenza dei versanti e le caratteristiche degli eventi pluviometrici. Per la definizione delle soglie di generazione del *runoff*, a diverse scale spaziali e temporali, possono essere utilizzati modelli empirici, concettuali o fisici. L'utilizzo di modelli fisicamente basati consente di comprendere i processi idrologici a scala di bacino o di plot; per la loro applicazione sono richiesti un gran numero di variabili e una calibrazione sito-specifica che spesso ne limitano l'utilizzo. L'approccio modellistico empirico si basa sulla conoscenza di un numero limitato di parametri e per questo viene spesso preferito ai modelli più complessi, specialmente in aree scarsamente monitorate. Inoltre, i modelli empirici, sebbene non includano un collegamento diretto con i processi fisici e idrologici che si verificano nel sistema analizzato, si contraddistinguono per la semplicità e la rapidità di calcolo, nonché per un rapporto costi-benefici vantaggioso. Molti studi hanno evidenziato l'importanza delle condizioni di umidità del suolo antecedenti ad un evento pluviometrico quale fattore critico che regola l'innesco del *runoff*. Purtroppo, il contenuto d'acqua del suolo è un parametro scarsamente monitorato o misurato in modo puntuale, risultando spesso non rappresentativo delle condizioni di umidità a scala di bacino. Per ovviare alla mancanza di dati a terra possono essere utilizzate le stime di umidità del suolo da satellite, testandone però l'effettivo utilizzo in siti sperimentali. In questo contesto il presente studio si propone di studiare empiricamente le soglie di innesco del *runoff* in un bacino sperimentale situato in una regione collinare subcarpatica della Romania, nel comune di Voineşti, distretto di Dâmboviţa. Realizzato nel 1963 e oggi gestito dall'Istituto Nazionale di Idrologia e Gestione delle Acque della Romania, il sito sperimentale di Voineşti è caratterizzato da depositi fluviali continentali pliocenici, prevalentemente sabbiosi, appartenenti alla fase finale di sedimentazione del Bacino Dacico. L'area di studio presenta una piovosità media annua di 700 mm e la maggior parte degli eventi pluviometrici è registrata nel semestre aprile-settembre, con precipitazioni particolarmente rilevanti nel periodo giugno-luglio. Il sito in esame dispone di n. 10 plot, con diverse superfici e copertura di suolo di diversa natura, capaci di raccogliere e quantificare distintamente il deflusso superficiale, sub-superficiale e profondo, grazie ad una serie di canalette superficiali e tubi interrati. Il bacino sperimentale di Voineşti (Figg. 1-2) ha un'area di 0.74 km^2 ed è equipaggiato con 6 stazioni pluviometriche e 8 sonde per il profilo di umidità del suolo ad acquisizione giornaliera del dato (modello PR2/6, Delta-T Device). Le misurazioni di precipitazione, contenuto d'acqua e *runoff*, effettuate nel periodo 2016-2018, sono state integrate con stime satellitari di saturazione del suolo, ricavate dalla missione Sentinel-1 (SSM1km). L'obiettivo specifico dello studio è quello di ottenere soglie empiriche di innesco del *runoff* (vedi approccio di Fig. 4), focalizzandosi su un plot di 600 m^2, caratterizzato da prato naturale che rappresenta la copertura tipica dell'area subcarpatica. A questo scopo, sono stati selezionati 45 eventi di *runoff* e per ognuno di questi sono state analizzate le condizioni di innesco (umidità o grado di saturazione antecedente del suolo e la quantità di pioggia a scala di evento, P).

L'approccio utilizzato si basa sull'impiego di due differenti indici (eq. 2, 3), entrambi espressi in mm: l'*Antecedent Soil moisture Index* (ASI) e l'*Antecedent Degree of Saturation Index* (ADSI), in grado di descrivere le condizioni antecedenti all'evento di runoff in termini di contenuto d'acqua volumetrico misurato a terra (ASI) e di grado di saturazione stimato da satellite (ADSI). La Figura 6a illustra i dati di *runoff* vs. ASI+P, mentre la Figura 6b i dati di *runoff* vs. ADSI+P. In entrambi i grafici è possibile individuare, empiricamente, le soglie d'innesco del runoff, valutabili in ASI+P = 65 mm e ADSI+P = 67 mm. Questo lavoro ha individuato la soglia di innesco del *runoff* sia partendo da dati di umidità misurati a terra (indice ASI) sia considerando stime di saturazione satellitare (indice ADSI), dimostrando l'utilità delle osservazioni satellitari per sopperire alla mancanza dei dati a terra di umidità del suolo. In conclusione, l'approccio qui utilizzato può essere esteso ad altri bacini o plots, considerando la possibilità di integrare diversi prodotti satellitari di umidità del suolo a diverse scale spazio-temporali.

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ABSTRACT

Understanding runoff-controlling mechanisms requires hydro-meteorological data derived from experimental plots or catchments. The present study focuses on the Voineşti Experimental Basin (VEB - Romania), which is in the Curvature Subcarpathia and is characterised by outcropping continental fluvial deposits. VEB has different experimental plots built to understand the relations between runoff and its genetic and predisposing factors. The study analysed the monitoring data in a plot of 600 m^2 covered by grassland. An empirical model defined the runoff threshold by integrating ground data and satellite estimations. By identifying 45 runoff events in the 2016-2018 period, it was possible to define a runoff threshold considering the rainfall depth and the antecedent soil hydraulic conditions. Two indices were used based on the previous volumetric water content and the antecedent degree of saturation retrieved by the Copernicus Sentinel-1 mission. By adding the rainfall depth to the soil antecedent hydraulic conditions, a runoff threshold of about 65-67 mm was identified. These findings encourage using satellite moisture products to describe hydrogeological processes in scarcely instrumented areas.

KEYWORDS: *surface soil moisture, runoff, experimental plots, Romania.*

INTRODUCTION

Runoff processes are mainly affected by soil properties, land cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (SITTERSON *et alii*, 2018). As WEILER *et alii* (1998) reported, runoff-controlling mechanisms are generally modelled by rainfall-runoff models developed for distinct time and space scales. Different models (from simplest to complex) can be used, such as empirical, conceptual, and physical (SITTERSON *et alii*, 2018). In general, empirical models require a few parameters, and the run time is fast, even if there is no connection with the physical and hydrological processes occurring in the catchment. Complex runoff modelling involves many interconnected variables, requiring several parameters and a site-specific calibration (SINGH, 2012). Although physical models allow to understand hydrological processes at different spatial-temporal scales, the large amounts of data required to run them limit their usage (UHLENBROOK *et alii*, 2004).

In scarcely ungauged catchments, empirical models are chosen due to their simplicity of implementation, faster computational times, and cost-effectiveness (DAWSON & WILBY, 2001). This is particularly useful in mountain regions where ground-based data over territory are often unavailable (CAMBI *et alii*, 2010; LORENZ & KUNSTMANN, 2012). Many studies have identified antecedent moisture conditions as a critical factor governing the triggering of runoff produced by rainfall events (ZEHE & BLÖSCHL, 2004; JAMES & ROULET, 2009; BERTHET *et alii*, 2009; PENNA *et alii*, 2011; SCHOENER & STONE, 2019; TODISCO *et alii*, 2022). Unfortunately, soil water content in catchments is not generally measured, or spot measurements are present that may be unrepresentative of the water content distribution at the catchment scale (VEREECKEN *et alii*, 2014; ORTENZI *et alii*, 2023). Satellite products of soil moisture estimation can overcome the lack of ground-based data, although testing the results on instrumented basins would be helpful. In this framework, the present study aims to investigate the runoff processes in a hilly region in Romania (Voineşti basin, Curvature Subcarpathian Mountains). In-situ measurements recorded during 2016-2018 (soil moisture content, rainfall, and runoff) are integrated with satellite data, presenting empirical runoff thresholds for natural grassland land cover.

MATERIALS AND METHODS

Geological and meteorological characteristics of the study area

Voineşti Experimental Basin (VEB) is located at an altitude of 500 m a.s.l. in the Curvature Subcarpathians, Romania (45°05'05''N 25°15'09''E - Fig. 1) and has an area of about 0.74 km^2. It is managed by the National Institute of Hydrology and Water Management of Romania. It was implemented in 1963 to establish relations between runoff and its genetic and conditional factors. The main goals of the monitoring in VEB are (*i*) to obtain data for rainfall-runoff mathematical models, (*ii*) to quantify the role of land use on the flow processes, and (*iii*) to study the soil water budget (PETRESCU, 1974; MĂTREAŢĂ, 2009; MINEA *et alii*, 2016; MINEA & MOROŞANU, 2016; MINEA *et alii,* 2022).

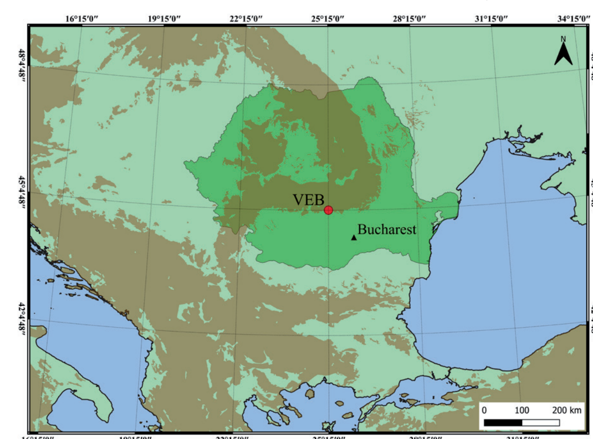

Fig. 1 - Location of the Voineşti Experimental Basin (VEB - EPSG:4326)

In the study area, the outcropping continental fluvial Pliocene deposits belong to the final sedimentation phase of the Dacian basin (JIPA *et alii*, 2007; JIPA & OLARIU, 2009). According to the Corine Land Cover 2018 dataset (CLC), the catchment is covered by 42% natural grasslands, 35% broad-leaved forest, and 23% fruit trees and berry plantations.

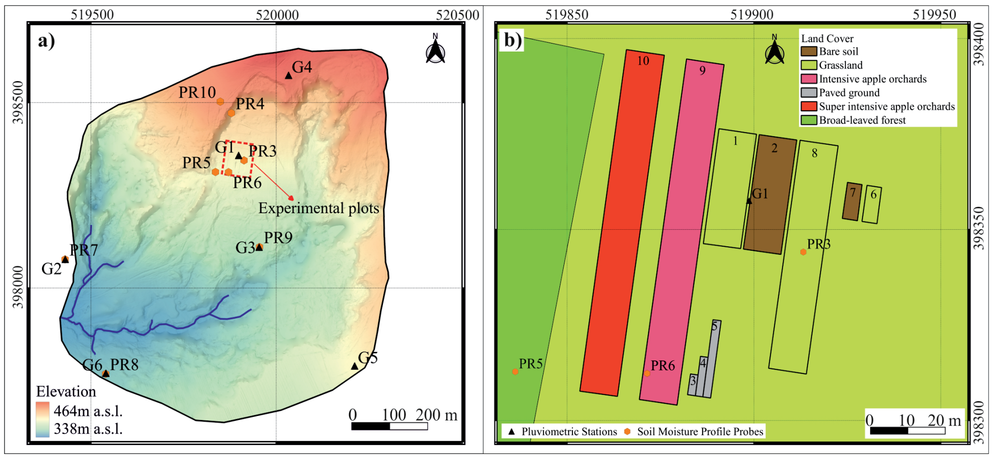

Fig. 2 - Digital Elevation Model of VEB with the location of instruments (a) and detail of the experimental plots (b)(EPSG:31700)

The VEB area is characterised by a moderate temperate continental climate, with an average rainfall of about 700 mm/year, calculated over the 1981-2021 period. Most rainfall events occurred in the warm semester (about 63% during April-September); the highest number of rainfall events was recorded during the June-July period (25%), and the highest maximum rainfall intensity was recorded in August 2005 (higher than 1.25 mm/min). The cold semester (October-March) is frequently characterised by snow periods, with a mean minimum temperature reached in January (-2.2 °C) and an absolute minimum of -22.6 °C in January 1979. During the warm semester, a mean temperature of about 17.3 °C is reached; July is the month of the maximum mean temperature (17.9 °C), with an absolute maximum of 37.3 °C in 2,000 (a dry year).

Characteristics of plots and instruments

The VEB has 10 plots (Fig. 2), with different areas (from 10 to 900 m^2) and different land cover (Table 1). The plots are bounded by concrete walls equipped with collection channels composed of gutters and underground pipes. In the bottom part, shelters containing calibrated tanks with drainage installation to evacuate collected water are present (Fig. 3). The VEB plots allow to collect distinctly the "Hortonian Overland Flow", the "Fast Subsurface Flow" collected at 0.4 m depth, and the "Deep Percolation" collected at 1.3 m, by using underground pipes placed at different depths (Minea *et alii*, 2019). More specifically, for this study, runoff depth means the amount of water stored in the reservoir that collects the shallowest flow (overland flow).

For the analyses of runoff thresholds, plot no. 8 has been selected to investigate grass areas widely diffused in the Subcarpathian Mountains. Jurchescu *et alii* (2019) reported that significant areas are covered with pastures and natural grasslands, favouring slope modelling processes over vast expanses. The shallowest soil layer of plot no. 8 is predominantly sandy soil, with a porosity (*n*) of about 0.45, a dry unit weight (γd) of 14.32 kN/m^3 and a saturated volumetric water content of 0.45 m^3/m^3 (Maftei *et alii*, 2002; Minea *et alii*, 2019). The most predominant particle size fraction is sand (64.8%), followed by clay (17.8%) and loam (17.4%). The soil sample is mainly composed of quartz (41.4%), followed by albite (19.0%), muscovite/illite (18.8%), magnesium iron silicate (12.6%), ferrosilite (7.0%), and vermiculite (1.2%). Soils have a high iron oxide (FeO) content, about 9.4%.

Plot no.	Type of plot	Dimension	Land cover
1	Water budget analysis	30x1 m	grassland
2			bare soil
3	Runoff computation	5x2 m	paved ground
4		10x2 m	
5		20x2 m	
6		10x4 m	grassland
7			bare soil
8		60x10 m	grassland
9		90x10 m	intensive apple orchards
10		90x10 m	super intensive apple orchards

Tab. 1 - Main characteristics of plots

VEB is equipped with 6 rain gauges and 8 soil moisture probes (Delta-T Device profile probe, PR2/6); the reliability of acquisition of the latter is strictly related to the knowledge of soil characteristics (Robinson *et alii*, 1999; Logsdon *et alii*, 2010; Di Matteo *et alii*, 2018; Di Matteo *et alii*, 2021; Ortenzi *et alii*, 2022). Acquiring reliable rainfall depth and soil moisture content data is mandatory to study the slope processes during natural events.

Fig. 3 - Panoramic view of the plots (a), with detail of collecting tanks (b)

Satellite soil moisture data

Since 2013, with the European Copernicus Project (Copernicus Global Land Service - CGLS), the European Space Agency has been working on the retrieving of several climate variables with a high spatial and temporal resolution for monitoring processes involving the earth's surface (Bauer-Marschallinger *et alii*, 2018a).

The Sentinel-1 mission consists of a constellation of two polar-orbiting satellites (Sentinel-1A, launched in 2015 and Sentinel-1B, launched in 2016) performing C-band synthetic aperture radar (C-SAR) imaging.

Specifically, the model TU-Wien-Change-Detection is used to derive the relative Surface Soil Moisture of the first 50 mm of soil expressed as a degree of saturation (SSM) (Wagner, 1998). This model retrieves the SSM(t) based on the comparison of the normalised radar backscatter observations at time t ($\theta_{40}(t)$) and the long-term backscatter wettest ($\theta^0_{wet(40)}$) and driest ($\theta^0_{dry(40)}$) soil conditions observations (Eq. 1). Estimation of SSM(t) has some problems in extremely dry conditions, frozen soils, snow-covered soils, flooded areas, and slopes higher than 17°. In these cases, flag values mask the areas where the retrieved SSM(t) value is meaningless.

$$SSM(t) = (\theta_{40}(t) - \theta^0_{dry(40)}) / (\theta^0_{wet(40)} - \theta^0_{dry(40)}) \qquad (1)$$

SAR instrumentation, operating in C-band, is affected by ground roughness and vegetation; in particular, the latter attenuates the radiation emission from the soil by adding its contribution to the recorded backscatter (Wang & Qu, 2009; Barrett & Petropoulus, 2013; Kim *et alii*, 2020; Balenzano *et alii*, 2021). Furthermore, the algorithm that derives SSM(t) values applies a static correction to the vegetation by not considering the vegetation period. The retrieval SSM(t) values are freely distributed (https://land.copernicus.eu/) as SSM1km and describe soil moisture in the top 50 mm depth with a spatial resolution of about 1 km and a temporal resolution of 4-5 days.

Empirical Method To Define Runoff Threshold

Several rainfall events must be identified to define the threshold triggering the runoff empirically. This approach requires the knowledge of antecedent soil moisture conditions and the event rainfall depth (P) which generate the runoff (R). According to Haga *et alii* (2005), antecedent soil moisture condition can be described by the Antecedent Soil moisture Index (ASI, Eq. 4), which is expressed in mm; in this way, it can be added to P, also expressed in mm. After selecting runoff events and plotting R values (mm) vs. ASI+P (mm), the runoff threshold can be identified (Penna *et alii*, 2015; Scaife *et alii*, 2020; Wang *et alii*, 2022). Fig. 4 shows the workflow procedure in order to obtain the runoff generation threshold by analysing several runoff events (R), of which both, the antecedent water content (expressed with ASI) and the rainfall (P), are known.

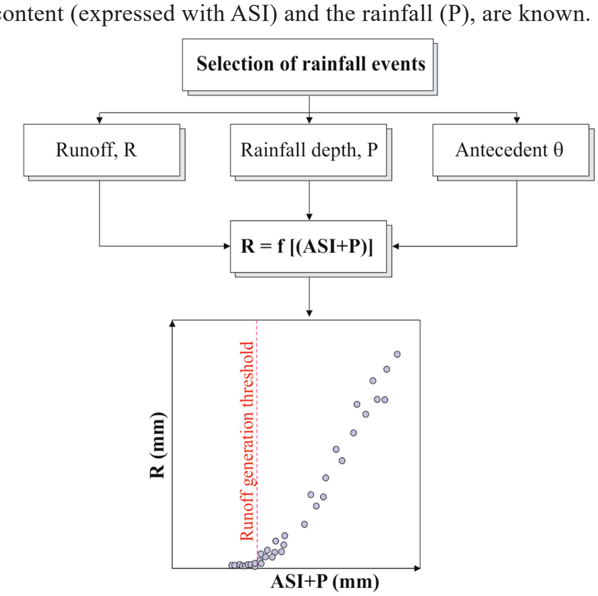

Fig. 4 - Workflow for defining the runoff threshold

As Eq. 2 shows, the ASI considers the volumetric water content measurements (θ) acquired by soil moisture probes at a depth (h).

$$ASI = \theta \cdot h \qquad (2)$$

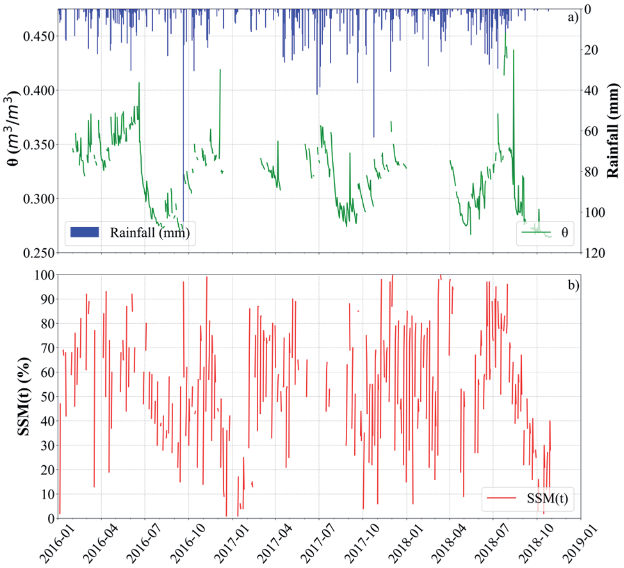

Fig. 5 - Soil moisture trend recorded by PR2/6 probe in PR3 monitoring point (a) and SSM(t) values estimated by Sentinel-1(b), rainfall data refers to the G1 rain gauge

Todisco *et alii* (2022) introduced a new index, also expressed in mm (Antecedent Degree of Saturation Index, ADSI - Eq. 3), that allows the use of the retrieves of the SSM(t) as a factor to consider the hydrological properties of soils antecedent to the rainfall event.

$$ADSI = (SSM(t) / 100) \cdot h1 \qquad (3)$$

ADSI can be expressed as a function of ASI by introducing the soil porosity (n), Eq. 4.

$$ADSI = (h1/h) \cdot ASI / n \qquad (4)$$

RESULTS

To study the rainfall-runoff response on plot no. 8, the present study considers the change in water content and degree of saturation during 2016-2018. Inside the plot the shallowest soil moisture measurement is carried out at 10 cm depth by using the PR2/6 probe (PR3 in Fig. 2). Fig. 5a shows the trend of the volumetric water content with rainfall recorded at the G1 rain gauge (Fig. 2). In the analysed period θ values ranged between 0.26 m^3/m^3 and about 0.45 m^3/m^3. The maximum value was reached on July 27, 2018, as consequence of a prolonged rainy period (about 316 mm during June-July 2018). It should be noted that θ measurements are not continuous over the period analysed, especially during the winter periods, due to weather conditions that do not allow the acquisitions to be made. Considering the soil porosity (n = 0.45), the soil degree of saturation ranged between 57% and about 100%.

Figure 5b shows the same observation period's SSM(t) trend. Although SSM(t) values are estimated for the first 5 centimetres of the soil, the observations follow the trend of θ values, confirming the capability of Sentinel-1 SSM retrievals to capture soil moisture changes to rainfalls (*e.g.*, Bauer-Marschallinger *et alii*, 2018b). As expected, SSM(t) values vary much more with rainfall events, reacting to the precipitation faster than the water content measurements at 10 cm depth and reaching values higher than 80% during rainy periods. Owe *et alii* (1982) analysed the water content in samples taken at different depths, noting greater variability in the first soil centimetres (up to 2.5 cm) than deeper layers (up to 10 cm). The results of the statistical comparison of SSM1km against in-situ θ observation indicate a value of Spearman rho correlation (*Ø* rho) of about 0.40. This value agrees with the statistical evaluation by Bauer-Marschallinger & Massart (2022) performed on 20 in-situ stations in Romania (RSMN network, *Ø* rho = 0.47).

Forty-five runoff events occurring during no snowfall periods

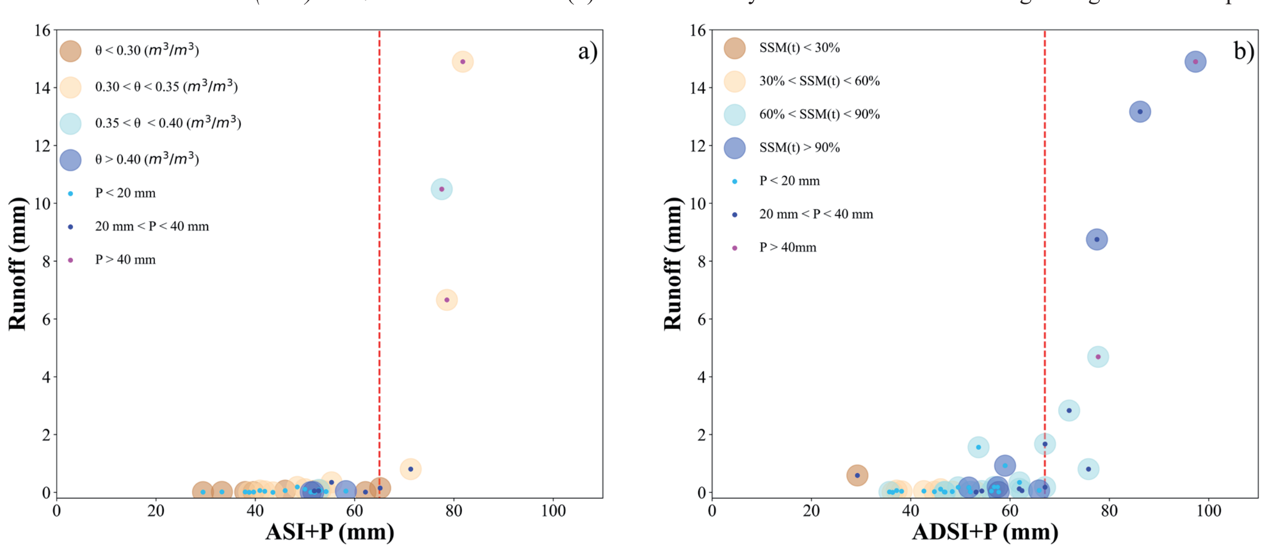

Fig. 6 - - Runoff threshold defined by ASI+P (a) and ADSI+P (b).

have been selected. In detail, 35 events are preceded by an SSM(t) estimation, 27 are preceded by a soil moisture measure (θ), and for only 17 events, both SSM(t) and θ are measured. Many runoff events occurred in June-July, corresponding to the higher concentration of rainfall events. Among the runoff events, the highest occurred on July 9, 2018 (14.9 mm after a rainfall depth of 47.6 mm, preceded by a θ value of 0.34 m^3/m^3 and an SSM(t) value of 99%).

Figures 6a-6b show the runoff vs. ASI+P and runoff vs. ADSI+P diagrams for plot no. 8. Each point is classed for ranges of rainfall depth and SSM or θ. Figure 6b shows clearly that the maximum runoff events occurred when the first centimeters of soil approached the full saturation (SSM(t) > 90%). This result is not observed in Fig. 6a, between runoff (R) and ASI+P; in this case, the maximum runoff event is not preceded by a high value of θ, probably due to the delay of water migration toward the measuring point (10 cm depth). Di Matteo *et alii* (2021) highlighted and described this process in similar sandy soils monitored by the PR2/6 probe in an experimental site in different meteorological conditions.

It should be noted that using both ASI and ADSI indices made identifying runoff thresholds in plot no. 8. In detail, the runoff threshold identified by using the ASI+P approach has a value of about 65 mm (Fig. 6a). Considering the ADSI+P approach based on satellite SSM estimation, the threshold value is about 67 mm (Fig. 6b).

DISCUSSION AND CONCLUSIONS

The results obtained for the VEB plot sustain the empirical methods' capability to establish the runoff thresholds in medium-to-high permeability soils. Using both indices (ASI and ADSI) it was possible to identify runoff thresholds. The use Sentinel-1 SSM1km product, despite at non-daily resolution, made it possible to individuate a sufficient number of events, preceded by a satellite soil moisture estimation, to define the runoff threshold.

Although the physical meaning of ASI and ADSI indices differs, the runoff thresholds derived by the two approaches (ASI+P or ADSI+P) have similar values. As illustrated in the Material and Methods section, the ASI considers θ values, while the ADSI considers the soil degree of saturation. Moreover, the two indices are calculated by considering different survey depths. By considering the shallowest measurement depth of θ obtained by the PR2/6 probe (h = 100 mm), the satellite SSM(t) investigation depth ($h1$ = 50 mm), and the soil porosity measured in plot no. 8 (n = 0.45), the ADSI index for the VEB site results 1.11 times higher than ASI index. In other words, ADSI and ASI values are similar since h1/h ratio is close to the local soil porosity. In this case, no significant changes in soil porosity over time are expected since plot no. 8 is not worked, and the ground cover remains consistently the same (grassland).

In this study, the results obtained comparing in-situ θ observation made by PR2/6 in the PR3 monitoring point and SSM(t) values at a 1 km scale are satisfying overall as they align with the results obtained in the literature (Bauer-Marschallinger *et alii*, 2022). Moreover, the Sentinel-1 SSM1km product seems to record soil moisture changes and reproduces peaks and lows of ground soil moisture.

The employment of free and ready-to-use satellite datasets can implement the strength of empirical models, decreasing the unknown variables in unmonitored areas, at least about water content. The results show that it is possible to overcome the lack of ground-based data by using satellite observations to describe runoff trigger thresholds empirically. In other words, results obtained using satellite data are comparable to those obtained using in-situ data. Moreover, the information obtained in the satellite's first few centimetres of soil makes it possible to make further considerations. According to Wei *et alii* (2020), two runoff thresholds can be individuated: the "generation threshold" (slow response) and the "rise threshold" (rapid response). As shown in Fig. 6b, small runoff activations are present before the identified runoff threshold that represents the rise threshold. Since few runoff events are lower than 2 mm, it remains difficult to identify the generation threshold in the R vs. ADSI+P plot. Further research can acquire new runoff events applying the developed method in other plots having different land use (*e.g.*, plot n. 9): this approach may help also to evaluate runoff threshold considering variations of water content measurement in depth considering the presence of a water content profiler probe (PR-6 in Fig. 2). In conclusion, the approach used here can be extended to other catchments or plots, considering the possibility of integrating different satellite soil moisture products.

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REFERENCES

Balenzano A., Mattia F., Satalino G., Lovergine F. P., Palmisano D., Peng J., Marzahn P., Wegmuller U., Cartus O., Dabrowska-Zielinska K., Musial J. P., Davidson M. W. J., Pauwels V. R. N., Cosh M. H., McNairn H., Johnson J. T., Walker J. P., Yueh S. H., Entekhabi D., Kerr Y. H. & Jackson T. J. (2021) - *Sentinel-1 soil moisture at 1 km resolution: a validation study*. Remote Sensing of Environment, **263**: 112554.

Barrett B. W. & Petropoulos G. P. (2013) – *Satellite Remote Sensing of Surface Soil Moisture*. In: *Petropoulos* G. P. (2013) – *Remote Sensing of Energy Fluxes and Soil Moisture Content.* CRC Press.

Bauer-Marschallinger B., Freeman V., Cao S., Paulik C., Schaufler S., Stachl T., Modanesi S., Massari C., Ciabatta L., Brocca L. & Wagner W. (2018a) - *Toward global soil moisture monitoring with Sentinel-1: Harnessing assets and overcoming obstacles*. IEEE Transactions on Geoscience and Remote Sensing, **57**(1): 520-539.

Bauer-Marschallinger B., Schaufler S. & Navacchi C. (2018b) – *Copernicus Global Land Operation "Vegetation and Energy".* Validation report. Issue I2.20.

Bauer-Marschallinger B. & Massart S. (2022) - *Copernicus Global Land Operation "Vegetation and Energy"*. Quality Assesment report, update 2021. Issue I1.00.

Berthet L., Andréassian V., Perrin C. & Javelle P. (2009) - *How crucial is it to account for the antecedent moisture conditions in flood forecasting? Comparison of event-based and continuous approaches on 178 catchments.* Hydrology and Earth System Sciences, **13**(6): 819-831.

Cambi C., Valigi D. & Di Matteo L. (2010) - *Hydrogeological study of data-scarce limestone massifs: the case of Gualdo Tadino and Monte Cucco structures (Central Apennines, Italy)*. Bollettino di Geofisica Teorica ed Applicata, **51**(4): 345-360.

Dawson C.W. & Wilby R.L. (2001) - *Hydrological modelling using artificial neural networks*. Progress in Physical Geography, **25**(1): 80-108.

Di Matteo L., Pauselli C., Valigi D., Ercoli M., Rossi M., Guerra G., Cambi C., Ricco R. & Vinti G. (2018) - *Reliability of water content estimation by profile probe and its effect on slope stability*. Landslides, **15**(1): 173-180.

Di Matteo L., Spigarelli A. & Ortenzi S. (2021) - *Processes in the Unsaturated Zone by Reliable Soil Water Content Estimation: Indications for Soil Water Management from a Sandy Soil Experimental Field in Central Italy*. Sustainability, **13**(1): 227.

Haga H., Matsumoto Y., Matsutani J., Fujita M., Nishida K. & Sakamoto Y. (2005) - *Flow paths, rainfall properties, and antecedent soil moisture controlling lags to peak discharge in a granitic unchanneled catchment.* Water Resour. Res., **41**: W12410.

James A. L. & Roulet N. T. (2009) - *Antecedent moisture conditions and catchment morphology as controls on spatial patterns of runoff generation in small forest catchments.* Journal of Hydrology, **377**(3-4): 351-366.

Jipa D. C., Olariu C., Marinescu N., Olteanu R. & Brustur T. (2007) – *A late Neogene marker sequence in the Dacian Basin (Paratethys Realm). Genetic and stratigraphic significance.* GeoEcoMarina, **13**(1).

Jipa D. & Olariu C. (2009) – *Dacian Basin, Depositional architecture and sedimentary history of paratethys sea.* Geo-Eco-Marina. Special Publication no. **3**, 268 pp.

Jurchescu, M., Kucsicsa, G., Micu, M., Sima, M. & Bălteanu, D. (2019) - *Landslide exposure assessment under environmental change in the Romanian Subcarpathians.* Studia Geomorphologica Carpatho-Balcanica, **53-54**: 59-84.

Kim H., Wigneron J. P., Kumar S., Dong J., Wagner W., Cosh M. H., Bosch D. D., Collins C. H., Starks P. J., Seyfried M. & Lakshmi V. (2020) - *Global scale error assessments of soil moisture estimates from microwave-based active and passive satellites and land surface models over forest and mixed irrigated/dryland agriculture regions.* Remote Sensing of Environment, **251**: 112052.

Logsdon S. D., Green T. R., Seyfried M., Evett S. R. & Bonta J. (2010) - *Hydra probe and twelve-wire probe comparisons in fluids and soil cores.* Soil Science Society of America Journal, **74**(1): 5-12.

Lorenz C. & Kunstmann H. (2012) - *The hydrological cycle in three state-of-the-art reanalyses: Intercomparison and performance analysis.* Journal of Hydrometeorology, **13**(5): 1397-142.

Maftei C., Chevallier P., Ciurea C. & Rosu L. (2002) - *Considerations Concerning the Characteristics of Permeability of the Podzolic soil in Voinesti Catchment*. " Ovidius" University Annals Constantza. Series Civil Engineering, **1(3/4)**: 525.

Mătreaţă S. (2009) - *Influenţa factorilor fizico-geografici asupra scurgerii apei în bazine hidrografice mici cu exemplificări pe râurile din România - The influence of physical-geographical factors on water runoff in small hydrographic basins with examples on rivers in Romania*. Doctoral Thesis, Bucharest, Romani, 341 pp.

Minea G., Adler M. J. & Pătru, G. (2016) - *A hydrometric and hydrological approach test at microscale. Procedia Environmental Sciences*, **32**: 275-280.

Minea G. & Moroşanu G. A. (2016) - *Micro-scale hydrological field experiments in Romania.* Open Geosciences, **8**(1): 154-160.

Minea G., Ioana-Toroimac G. & Moroşanu G. (2019) - *The dominant runoff processes on grassland versus bare soil hillslopes in a temperate environment-An experimental study.* Journal of Hydrology and Hydromechanics, **67**(4): 297-304.

Minea G., Ciobotaru N., Ioana-Toroimac G., Mititelu-Ionuş O., Neculau G., Gyasi-Agyei Y. & Rodrigo-Comino J. (2022) - *Designing grazing susceptibility to land degradation index (GSLDI) in hilly areas.* Scientific Reports: **12**(1), 9393.

Ortenzi S., Mangoni M. & Di Matteo L. (2022) - *Estimating moisture content and hydraulic properties of unsaturated sandy soils of Tiber River (Central Italy): integrating data from calibrated PR2/6 probe and hydraulic property estimator.* Italian Journal of Groundwater, **11**(1): 17-25.

Ortenzi S., Cencetti C., Marchesini I., Stelluti M. & Di Matteo L. (2023) - *Performance of rainfall and soil moisture satellite products on a small catchment in Central Italy.* Italian Journal of Engineering Geology and Environment, **1**: 99-111.

Owe M., Jones E. B. & Schmugge T. J. (1982) - *Soil moisture variation patterns observed in hand county, South Dakota.* Journal of the American Water Resources Association, **18**(6): 949-954.

Penna D., Tromp-Van Meerveld H. J., Gobbi A., Borga M. & Dalla Fontana G. (2011) - *The influence of soil moisture on threshold runoff generation processes in an alpine headwater catchment.* Hydrology and Earth System Sciences, **15**(3): 689-702.

Penna D., Van Meerveld H. J., Oliviero O., Zuecco G., Assendelft R. S., Dalla Fontana G. & Borga M. (2015) - *Seasonal changes in runoff generaation in a small forested mountain catchment.* Hydrological Processes, **29**(8): 2027-2042.

Petrescu M. (1974) - *Stabilirea de relaţii între ploaie-infiltraţie, scurgere lichidă şi solidă pe suprafeţe reduse de versant - Establishing relationships between rain infiltration, liquid and solid runoff on small slope surfaces.* Studii de Hidrologie XLII (Extras) - Hydrology Studies – NIHWM: 119-129.

Robinson D. A., Gardner C. M. K. & Cooper J. D. (1999) - *Measurement of relative permittivity in sandy soils using TDR, capacitance and theta probes: comparison, including the effects of bulk soil electrical conductivity*. Journal of Hydrology, **223**(3-4): 198-211.

Scaife C. I., Singh N. K., Emanuel R. E., Miniat C. F. & Band L. E. (2020) - *Non-linear quickflow response as indicators of runoff generation mechanisms.* Hydrological Processes, **34**(13): 2949-2964.

Schoener G. & Stone M.C. (2019) - *Impact of antecedent soil moisture on runoff from a semiarid catchment.* Journal of Hydrology, **569**: 627-636.

SINGH, V.P. (2012) - *Computer Models of Watershed Hydrology.* Highlands Ranch, CO: Water Resources Publications: 1114 pp.

Sitterson J., Knightes C., Parmar R., Wolfe K., Avant B. & Muche M. (2018) - *An overview of rainfall-runoff model types.* United States Environmental Protection Agency, EPA/600/R-14/152.

Todisco F., Vergni L., Ortenzi S. & Di Matteo L. (2022) - *Soil Loss Estimation Coupling a Modified USLE Model with a Runoff Correction Factor Based on Rainfall and Satellite Soil Moisture Data*. Water, **14**(13): 2081.

Uhlenbrook S., Roser S. & Tilch N. (2004) - *Hydrological process representation at the meso-scale: the potential of a distributed, conceptual catchment model*. Journal of Hydrology, **291**(3-4): 278-296.

Vereecken H., Huisman J. A., Pachepsky Y., Montzka C., Van Der Kruk J., Bogena H., Weihermüller L., Hrbst M., Martinez G. & Vanderborght J. (2014) - *On the spatio-temporal dynamics of soil moisture at the field scale.* Journal of Hydrology, **516**: 76-96.

Wagner W. (1998) - *Soil moisture retrieval from ERS scatterometer data.* European Commission. Joint Research Centre, Space Applications Institute.

Wang L. & Qu J.J. (2009) - *Satellite remote sensing applications for surface soil moisture monitoring: A review*. Front. Earth Sci. China, **3**: 237-247.

Wang S., Yan Y., Fu Z. & Chen H. (2022) - *Rainfall-runoff characteristics and their threshold behaviors on a karst hillslope in a peak-cluster depression region.* Journal of Hydrology, **605**: 127370.

Wei L., Qiu Z., Zhou G., Kinouchi T. & Liu Y. (2020) - *Stormflow threshold behaviour in a subtropical mountainous headwater catchment during forest recovery period*. Hydrological Processes, **34**(8): 1728-1740.

Weiler M., Naef F. & Leibundgut C. (1998) - *Study of runoff generation on hillslopes using tracer experiments and a physically-based numerical hillslope model*. IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences, **248**: 353-362.

Zehe E. & Blöschl G. (2004) - *Predictability of hydrologic response at the plot and catchment scales: Role of initial conditions.* Water Resources Research, **40**(10): W10202.

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