Assessment of flash flood susceptibility potential in Moldavian Plain (Romania)

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Abstract
Concentration of time (Tc) is a frequently used parameter in the evaluation of the hydrological response of different sizes hydrographic basin in case of rainfall events. The present study is innovative, because it has created an index that identifies the small-sized hydrographic basins that are exposed to the risk of flooding. The Moldavian Plain is an area located in the northeast of Romania where the local population is frequently affected by floods and flash floods caused by heavy rainfall events. The main purpose of the current study is to identify the settlements located in the small-sized hydrographic basins, which are associated with low concentration times and powerful surface runoff. The empirical method was applied in order to calculate the Tc for rainfall water, for each drainage basin, for a time class less than 6 hr. Calculations of the runoff water were also done for a theoretical extreme precipitation event, corresponding to the 1% occurrence probability. A total number of 312 basins were identified that are smaller than 30 km², out of which 112 have Tc of less than 6 hr. These basins, in particular, pose flood risk for 12.4% of the villages and towns in the study area.

KEYWORDS
flash flood, Moldavian Plain, subbasin, surface runoff, time of concentration

1 | INTRODUCTION

Floods are considered to be the most devastating extreme natural phenomena, and it has been quantified to cumulate an estimated total damage value of 11 billion dollars, over the span of 70 years (according to EM-DAT, 2019). Since the 1990’s, a constant frequency increase in such events has been recorded, which can be partly correlated with the compensation funds granted for covering material loss, of approximately 40 billion dollars/year (Figure 1).

In Europe, between 1998 and 2009, the economic loss added up to 50 billion euros (European Commission of Environment, n.d.). This trend is a continuously rising one, considering the ever increasing hydroclimatic phenomena frequency that are predicted to occur in the following years, and also an increase in their intensity, in the context of global warming, up to the year 2100 (Reimann, Vafeidis, Brown, Hinkel, & Tol, 2018; Scorzini & Frank, 2017).

Furthermore, anthropogenic pressure on the land and spatial expansion processes for both rural and urban settlements in areas exposed to flood risk, lead to flood vulnerability increase for the population living in these particular regions (Jodar-Abellan, Valdes-Abellan, Pla, & Gomariz-Castillo, 2019; Ortega, Razola, & Garzón, 2014).

Considering flood risk and human exposure, Romania is one of the most affected countries, from the entire European continent (Romanescu, Hapciuc, Minea, &
Iosub, 2018; Romanescu & Nistor, 2011; Romanescu & Stoleriu, 2013, 2014). Inside the country, there are two main areas, characterized by high flood occurrence values: the northeastern and northwestern regions—where floods manifest constantly along the river valleys, by overflowing the flood plains, or through fast runoff events, such as flash floods from steeper slopes, in the mountainous area (Török, 2018).

In addition, there is a spatial and temporal delineation for floods, across Romanian territory, the most vulnerable areas being considered the mountain regions and the subcarpathian region, in association with rainfall values above average, higher slopes, leading to faster flow velocities. The geological and soil characteristics influence runoff positively through low permeability values, and textures that do not favor rainfall infiltration (Iosub, Enea, Hapciuc, Romanescu, & Minea, 2014; Minea, Iosub, Hapciuc, & Buruiiană, 2017).

Spatial and temporal frequency of flood events is associated with the numerous occurrences during spring-summer seasons, when the highest runoff values are caused by torrential rainfall, in conjunction with snowmelt, or solely due to high-intensity rain events during summer time (Corduneanu, Bucur, Cimpeanu, Apostol, & Strugariu, 2016; Marinescu, Stanciu, & Marinescu, 2010).

In the last 20 years, floods have tied record-level values, or even broke historical records, concerning maximum flow rates across numerous river valleys. Particularly in the northeastern part of Romania, the main river systems that drain the region are Siret and Prut, which have surpassed maximum historical flood flow rates in 2005, 2008, 2010, and 2013, both on the main river course, and on numerous tributaries, while in the mountain sectors, several torrents have inflicted significant material damage (Iosub, Enea, Albu, Minea, & Chelariu, 2018; Romanescu, Cimpianu, Mihu-Pintilie, & Stoleriu, 2017).

At an international level, notable efforts are being made in order to develop a mathematical model which includes as many factors, as possible, that can influence the emergence of floods. Geographic informational systems (GIS) modeling of certain floods, or the delineation of an area that can be affected by hydrological phenomena is very advanced, aiding in this regard the numerous mathematical models, created for calculating the territorial expansion of a river according to its discharge, the water infiltration rate into the soil, land use, and so on (Mei & Anagnostou, 2015). Those mathematical models were later transposed into GIS software that has the purpose of creating a model that depicts results as similar as possible with field readings. The creation of precise maps regarding hydrological risk will generate a more representative image of the inhabited space from certain locations, aiding in avoiding, at early construction stages, the location of several buildings in areas prone to risk or, at the same time, helping to create more efficient management plans than those that are already in use (Devia, Ganasri, & Dwarakish, 2015; Singh & Frevert, 2006; Tschiedel & de Paiva, 2018; Wheater, 2002).

At global level, the directions of flood risk analysis are divided into two categories: concerning the river network, or approaches oriented toward analysing the entire hydrographic basin. Therefore, over the years, two large strategies of flood analysis were developed, the first one involving the hydrographic basin as a whole, which estimates the flow over the entire basin surface; and the second one, associated to hydraulic modeling along the hydrographic network. Regarding the second approach, the simulation is

![Figure 1](image-url)
undergone according to the parameters that define the main course of the river. Mathematical modeling started to gain scientific awareness, by the time computers reached notable technological advancements. Rainfall-runoff models are frequently utilized in simulations of water drainage models, at drainage basin level (Pechlivanidis, Jackson, McIntyre, & Wheater, 2011). Most flood modeling methodologies created at drainage basin level require time factor to be introduced into the equation, one of the most used variants being the Concentration of time (Tc). This factor is defined as the time required by water to flow from the farthest point of a basin towards the outlet; thus, this parameter will highlight the response time of a basin during a rainfall event (Fang, Thompson, Cleveland, Pradhan, & Malla, 2008; Sharifi & Hosseini, 2011; Taghvaye Salimi, Nohegar, Malekian, Hoseini, & Holisaz, 2017).

In the context of 2007/60/EC Directive, that lead toward the modeling of certain flood simulations for the main water courses of the Moldavian Plain, it has been noted that identifying small-sized hydrographic basins that can generate floods is of utmost importance. Once the basins with high response rates in concentrating the water at lowest level of the valley line are identified, the analysis of the flow simulation through the main course of the river can be carried out. This study focuses on the rainfall-runoff simulation at drainage basin level, which has the purpose of identifying the hydrographic basins with a low Tc that can generate floods. One of the fundamental elements of this study is given by the scarcity of the physical database. The first part of the study focuses on the study area the methodology for obtaining the hydrographic basins, and the database used for calculating the runoff concentration time, in basins, according to an extreme rain event. In order to have a broader image on the spatial distribution of the risk that the Tc poses, and the strong surface runoff, the values undergone a process of normalization. The resulting values were spatialized and correlated with information obtained on field, or from local authorities (analysis plans and risk coverage in Iași and Botoșani Counties), in order to validate the model. In Section 4, the article focuses on identifying geological, pedological, and land use patterns that can influence Tc and the result generated from the analysed basins. The results can be used by local authorities, in order to identify the hydrographic basins which are more subjected to such vulnerability, and possibly regulate future construction building permits emitted in the near vicinity of the main river course of those particular areas.

2 | STUDY AREA

Moldavian Plain is located in the historical region of Moldova in northeastern part of Romania at the border with Ukraine in the east (Figure 2). Its landscape is wave-like, with hilly areas, or shaped as low plateaus that are linked to a unitary geological surface, which is fragmented by the hydrological network. Furthermore, the landscape is covered with low plateaus or structural hills, with large, bridge-like formations, at average altitudes of 160–180 m, and they are placed on sandy clays, covered with eluvial clays, which are representative for the entire geographical unit (Ailincăi, Jităreanu, Bucur, & Ailincăi, 2012; Ioniti, Mărgineanu, & Hurjui, 2000; Romanescu & Constantin Stoleriu, 2017).

From a climatic standpoint, the Moldavian region is characterized by multiannual precipitation values between 500 and 670 mm/year (Figure 3a). Greater values are associated with the highest altitudes in the western part, toward Siret valley. Average rainfall values are relatively low, indicating the existence of a relatively dry climate, but characterized by strong torrential rainfall events that occur in the context of atmospheric circulation blocking, on the eastern side of the Oriental Carpathian Mountains, and the forming of retrograde cyclones in the northwestern region of the Black Sea (Prăvăile et al., 2019; Sfica & Minea, 2006). From an administrative point of view, across the Moldavian Plain, there are 144 communes and cities, and 588 towns/villages, adding up to a population count of 950,000 inhabitants, in 2018.

Between 1969 and 2011, several torrential rainfall events recorded cumulated quantities of over 30–45% of the average multiannual rainfall, in just 1 month (172.1 mm/month, July 1991, at Botoșani weather station; 277.2 mm/month, June 1985, at Iași weather station). Furthermore, the maximum precipitations recorded in a 5-day time interval, vary from 65 to 112.6 mm, the greatest water accumulation values are registered in the southeastern areas, while the minimum values occur in the northwest (Figure 3b).

The highest probability of torrential rainfall events is associated with the monthly interval between May and September, therefore the hydrological regime of the local rivers follows this trend, corresponding with the highest flow rates (Buruiană, Apostol, Machidon, & Buruiană, 2012).

Approximately, 74% of the Moldavian Plain is included in Jijia River drainage basin, which is a right-hand side tributary of Prut River, the remaining 26% being drained by Bașeul, Volovăț, Ghirenia drainage basins.

Jijia’s most important tributaries are Sitna, Miletin, and Bahlui Rivers. The highest occurrence probability for floods on the largest rivers in the Moldavian Plain is during the summer season, mostly in June–July. Some of the largest floods that were recorded on the valleys of these large rivers were registered in 1969, 1979, 1988, 1991, and
Regarding the floods that took place in small drainage basins, in the study area, the years with the highest number of events are 2005, 2008, and 2010, when 72, 58, and 68 villages were affected, respectively, in Botoșani county alone. A total of 1,549 houses were damaged, 499 destroyed, 96 cultural heritage sites and 126 km of national and county roads were flooded, and 216 bridges suffered various degrees of flood impact (PAAR, 2017).
Due to its large extent, in Botoșani county, an average of 28 villages and towns suffered damage from floods each year, both along the main river courses and in the concentration areas of torrents.

3 | MATERIALS AND METHODS

Small-sized drainage basins in the Moldavian Plain are subjected to high flood risk susceptibility, annually several floods following torrential rainfall take place, and impact the local population. The model that was chosen for the analysis emphasizes identifying small drainage basins that have a fast response time in concentrating rain water in the main valley, during torrential events, and generate flash floods. In addition, in order to better understand the phenomenon, surface runoff was included in the analysis. The methodology for identifying the drainage basins with high risk, of less than 6 hr, requires using rainfall data, soil texture, and also morphometrical parameters derived from the terrain model. Hydrological and rainfall data were acquired from Prut-Bârlad Basin Water Administration and Romanian Climatic Data set series, for the 1968–2013 time interval (Dumitrescu & Bîrsan, 2015). The soil texture was extracted from the pedological reference layer 1:200000–1965, land use layer consisted of Corine Land Cover data, provided by Copernicus Mission. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) was downloaded from the National Aeronautics and Space Administration, open-source geo-database.

The selection and delineation of hydrographical basins were semiautomatically carried out in ArcGIS, using the ASTER DEM data set as a spatial base. The smallest basins were selected at a threshold of 1,000 cells, due to the results being more consistent and correlating with the field situation, than at 750, 500, or 250, with respect to the cell size of the DEM used. The Strahler method of hierarchizing hydrographic basins was applied on the aforementioned DEM, and 312 first-order basins resulted, which stand as the base of the current study. All basins are small size, with a catchment area that does not surpass 30 km² (Sharifi & Hosseini, 2011). The analysis was done also on basins of second, third, fourth, and fifth orders of hierarchy, but resulting values for Tc are significantly reduced, being of low relevance for the current study.

Tc estimation was done by applying Soil Conservation Service—curve number (SCS-CN) method, where CN is calculated, based on layers with hydrological soil groups (HSGs) and land use, the values indicating the response type of the landscape, according to previous humidity and hydrological conditions. CN entries have been introduced according to the adapted values for Romania. This index is of high significance, through the increased degree of surface runoff estimation and retained in soil (Chendesch, 2011). The formula for calculating concentration time was applied, as seen below (Fang et al., 2008; McCuen, 2005):

$$Tc = 1.67 \times T_{LAG},$$

where $T_{LAG}$ is defined as the time between the gravity center of the rainfall and the peak of the hydrograph (NRCS, 2010):

$$T_{LAG} = \frac{3.28084 \times L^{0.8} \times (S + 1)^{0.7}}{1,900 \sqrt{I_B}},$$

where $T_{LAG}$ is delay time (hr), $L$ is flow length (m), $I_B$ is average watershed land slope (%), and $S$ is maximum potential retention. $S$ is calculated according to the CN values as follows:

$$S = 25.4 \times \frac{1,000}{\text{CN} – 10},$$

The maximum runoff depth was calculated applying the following equation (Taghvaye Salimi et al., 2017):

$$Q = \frac{(P – 0.2S)^2}{P + 0.8S},$$
where $Q$ is runoff (mm), $P$ is rainfall event (mm), and $S$ is maximum potential retention (mm).

Vulnerability of villages and towns to floods, inside the first-degree hydrological basins, according to Horton–Strahler classification, is in direct relation to their placement in the greater drainage basin they are part of, the distance to the main river course, and the area of confluence (Figure 5).

In order to generate flash flood risk maps for the towns and villages in the Moldavian Plain, the values obtained from the $T_c$ and runoff depth layers for the drainage basins were required to be normalized, creating a range of risk values from 0 to 1, following the given formulas:

\[
Q = \frac{Q - Q_{\text{min}}}{Q_{\text{max}} - Q_{\text{min}}},
\]

\[
T_c = \frac{T_c - T_{c\text{max}}}{T_{c\text{min}} - T_{c\text{max}}},
\]

where $Q$ and $T_c$ represent the normalized values, $Q_{\text{min}}$ and $T_{c\text{min}}$ are the minimum values of the entire data set, and $Q_{\text{max}}$ and $T_{c\text{max}}$ are the corresponding maximum values. The values vary, according to each analysed parameter. Both risk layers are normalized differently, due to the high values of the runoff depth, which indicate a high flash flood risk, while for the $T_c$ layer, high values are associated with low risk, these layers being in an inverse proportionality relation. The normalized layers were summed up, resulting in a new range, from 0 to 2, which was consequently normalized once more, and classified into three representative classes, which depict low, medium, and high combined flood vulnerability. The delimitation of the third (highest) vulnerability class extends from 1.5799 to 1.97, which correlates with a maximum $T_c$ of 44 min, and the minimum is 21 hr, while the runoff ($Q$) varies from 124 to 111 mm.

4 | RESULTS AND DISCUSSION

The drainage basins in the Moldavian Plain are susceptible to floods and flash floods with different magnitudes, as result of global warming, which contributes to the increase of extreme rainfall events (Croitoru & Minea, 2015). In addition, the degree of forestation is relatively low, and human pressure is correspondingly high, therefore the response time of hydrological basins is modified and population vulnerability increases. Estimation of flood vulnerability for basins and subbasins resulted as an integrated approach of concentration time, rainfall-runoff modeling, and field investigations.

The surface runoff characteristics for the Moldavian Plain area is based on the land use cover type, water infiltration capacity, according to HSGs (Figure 6a,b). Following the hydrological classifications of soils in the Moldavian Plain, a numerical dominance of the B and D hydrological groups is emphasized, counting for 45.3 and 44%, respectively, of the study area. Group B has an average infiltration capacity and moderate water circulation along the pedological profile (Chendes¸, 2011), and it mostly overlaps the western-central area of the plain, and the neighboring hills of Prut River valley, in the north and northeast. The second group, by total cumulated surface area, is Group D, which is characterized by very low infiltration capacity, regardless of the state of humidity, and is associated with soils with fine, clayey texture. Across the Moldavian Plain, these soils are found mostly in its southern half and in the southern part of Prut floodplain, along the river valleys and in the hilly areas of Jijia and Băceu drainage basins. Out of all HSGs, A and C have the least coverage, and can only be found in a very dispersed manner. Soil texture is determined by geological strata, and it also dictates the degree of impermeability of the entire region. From a geological stand point, the Moldavian Plain overlaps sedimentary deposits from the Sarmatian period, composed mostly of compact marlstone, with sand

![FIGURE 5 Methodological workflow for the analysis](image-url)
intercalations, with low infiltration, while the Superior Pleistocene deposits contain clay (Niaças et al., 2019). This substrate favors rapid surface drainage for large amounts of water. Areas where the substrate is poorly permeable are often classified in the “arable fields and pastures,” from a land use perspective, which amplifies the possibility of fast runoff water concentration. Only 12% of the land is covered with forests, and they are most frequently distributed in the areas with soil groups with better permeability. The distribution of villages and towns in the near vicinity of the rivers and potential torrent events determines a high degree of exposure of the local population to floods.

CN values range from 42 to 98, with an average value of 78. The entire area of the Moldavian Plain is considered to have very high potential for surface runoff, 96.5% of the CN values, surpassing 60 points (Table 1). Approximately half of the total area is characterized by values between 81 and 90, indicating strong slope runoff, while being associated to the C and D HSGs, and also to agricultural land, from a land use perspective. This emphasizes the fact that the largest influence, for calculating CN was attributed to the soil groups which determine the high (but not extreme) values, while also being moderated by several vegetation categories. The smallest values correspond to the central region, and are distributed along an alignment, where there are mostly A- or B-class soil groups, with low infiltration and also high forest coverage. The highest, maximum CN values follow a pattern given by the inhabited areas, due to their high runoff degree, and implied impermeability. Therefore, it is considered that this type of land use has a larger significance in the CN calculation workflow (Figure 7a).

For the SCS-CN, a representative precipitation quantity was chosen, corresponding to a 1% occurrence probability: 125 mm. The modeling process was undergone with the theoretical assumption that rainfall distribution for the chosen value was uniformly distributed, across the entire study area, as a conventional measure for comparative relevance between small drainage basins. Surface runoff has correspondingly greater values in the areas where CN values are also larger, as seen in Figure 7b. Runoff in large quantities is directly determined in the hilly region, by the rapid concentration of water, in the form of torrents, which raise the water level significantly along the main river course. Land use categories also influence the runoff, considering the preponderance of agricultural lands or built-up areas, in the

**TABLE 1** Relative surface area for curve number (CN) classes and surface runoff

| CN     | %   | Q 125 mm | %   |
|--------|-----|----------|-----|
| 42–50  | 3.1 | 90.95–97.76 | 2.3 |
| 51–60  | 0.4 | 97.76–104.57 | 1   |
| 61–70  | 21.5| 104.57–111.38 | 11.2|
| 71–80  | 25.1| 111.38–118.19 | 34.5|
| 81–90  | 46.7| 118.19–125  | 51.1|
| 91–98  | 3.2 | —        |     |

Note: Q 125 mm—surface runoff depth values for a 125 mm rain event.
extra-Carpathian area, while enhancing water velocities, due to roughness values. Soil cover is mostly fine textured and does not allow the infiltration of large amounts of water. Therefore, the runoff total volume is also positively influenced by the soils characteristics. Strong runoff is specific for 96.7% of the Moldavian Plain, out of

**FIGURE 7** Distribution of curve number values (a) and surface runoff values for a 125 mm rain event (b)

**FIGURE 8** Basins susceptible to flash floods, with low concentration times and vulnerable villages
which, over 50% of the areas indicate very strong values, of over 118 mm.

Following the steps of the methodological workflow that calculates the water concentration time, resulted in identifying subbasins with a surface smaller than 100 km$^2$, which are associated with concentration times smaller than 6 hr. According to the given methodology, a rapid runoff concentration is correlated with a higher degree of flood vulnerability of these particular areas. Therefore, the vulnerable areas can be correlated with the villages located there, and the human settlements situated in the risk area are identified.

The analysis performed on the Moldavian Plain took into account 312 hydrological subbasins, of first order according to Horton–Strahler classification, out of which, seven torrential catchments were identified as generating very small concentration time, of less than 1 hr. Out of these basins, the lowest concentration time registered is specific to a torrent which reached a theoretical record value of 26 min. Values that range from 1 to 6 hr are characteristic to 36% of the analyzed subbasins. Their surface varies between 6.4 and 17.8 km$^2$. This concentration time is significantly fast, giving the villages and towns located downstream little time to acknowledge the threat and to properly prepare. The spatial distribution is

**FIGURE 9** Flash flood risk distribution in small drainage basins, in the Moldavian Plain
relatively grouped, with high densities in the northern and northeastern part, which overlaps the upper and central basin sectors of Jijia River; in Miletin River basin and in the southern extremity, at the contact with Bârlad Plateau. The total, cumulated surface they cover is 918 km², which amounts to 12% of Moldavian Plain area.

Depending on the Tc in the aforementioned 312 first-degree drainage basins, one can estimate the degree of susceptibility to flash flooding for the villages and towns. In conjunction with their placement inside the drainage basin, in order for them to be susceptible to flooding, they are required to be located in the near vicinity of the main river channel, and next to the confluence with the tributary rivers. After applying the mentioned approaches, 73 villages and towns were identified as highly vulnerable to flooding, in case of severe rainfall events (Figure 8).

Vulnerability degree for potential flash floods in the Moldavian plan is quantifiable, due to the normalization process, and classifying the resulting values ranging from 0 to 1 into relevant classes: the larger the value, the more vulnerable to flash floods, that particular basin is. In order to emphasize the values of risk in a more comprehensible manner, the cumulated risk map is classified into three classes: low, medium, and high (Figure 9).

An approximate area of 48% of the study area is not exposed to flash floods, caused by small hydrographic basins with low concentration times, while 27% of the area is in the medium risk category, and 26% (~2,000 km²) are associated with the high risk of flood occurrence. The main cities that correspond to the high flash flood risk class, are Iași and Botoșani, and the total number of villages and towns that partially or completely overlap risk areas is 254, out of the 588 identified ones (43% of the total number of settlements in the study area). Consequently, 33% of the specific surface of all villages and towns are vulnerable to flash floods. Furthermore, over 70% of the area exposed to high flash flood risk is covered by arable land, 10% by pastures, and the 10% by urban and rural settlements, while the remaining 10% includes the rest of the land use classes, altogether.

Even if a large number of villages and towns are exposed to flash flood risk, the potentially affected population is not that numerous, considering the fact that the majority of the Moldavian Plain has population densities of 380 inhabitants/km².

Another relevant socioeconomic objective is the road network, which can cause direct, medium-term economic dysfunctions, on certain sectors, in case of flash floods that can potentially damage roads, as well as bridges associated with them.

In the analysis, two categories of roads were taken into account: both national and county roads. The high-risk category encompasses 344 km of county roads, which, if damaged, would mostly interrupt local activities for small size villages, therefore smaller values of economic losses; and 134 km of national roads, which would pose greater impact, at a regional level (Table 2).

5 | CONCLUSIONS

The methodology we have chosen can be easily applied on other hydrographic basins from the temperate region. If this formula should be applied elsewhere in the world, some changes are necessary, in order to adapt the physicogeographical parameters to the regional specificity. Due to the abundance of methods of calculation of the Tc, available on the scientific market, the results are different from one method to another, so it is important to choose a method that fits best to the targeted geographical area.

From the climatic, geological, and soil cover point of view, the study area is quite homogenous and therefore, we have used the same formula for the calculation of the Tc in the entire area, if we want to expand the study area by including different geographical regions, more factors must be taken under consideration and a different formula must be applied for the calculus, in order to compensate the differences between of parameters values.

Following the steps of the methodological workflow that calculates the water concentration time, resulted in identifying subbasins with an area smaller than 100 km², which are associated with concentration times smaller than 6 hr.

A total number of 312 first-degree drainage basins were identified, with catchment areas that do not surpass 30 km². The Tc for the aforementioned basins varies between 26 min and 58 hr, out of which 7 basins have concentration times of under 1 hr, while 105 basins vary between 1 and 6 hr.

Almost 12% of the entire surface area of the Moldavian Plain is defined by basins that indicate high susceptibility for flash flood events. Seventy-three villages and towns are located in one of these risk areas, and are in the proximity of river courses and/or the confluence with a tributary river.

Cumulated runoff water quantity indicates the amount of precipitation that dictates concentrated flow values, which were calculated for a theoretical simulated rainfall event of 125 mm. Results emphasized that strong runoff is specific to 96.7% of the Moldavian Plain, out of which over 50% of the areas indicate very strong values, of over 118 mm.

Analysis on concentration time and runoff values indicates different situations that depend on the scale for which the study is performed, and the DEM that is
utilized. In the current study, a coarser terrain model was used, due to the large extent of the study area, and the corresponding threshold values for basin delineation were higher; while for more accurate scale analysis, which would require more detailed terrain models, such as LIDAR (Light Detection and Ranging), the results would be more complex, with high degrees of detail for semipermanent runoff on steeper slopes.

Flash flood risk calculations for the Moldavian Plain indicate that 26% of the area is exposed to high risk values, out of which 70% is covered by arable land, 10% by pastures, 10% by built up areas, and 10% with other, cumulated land use classes.

Population exposure to risk analysis resulted in identifying 254 villages and towns located in the high-risk area (43% of the total number of settlements), and over 478 km of vulnerable national and county roads.

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**DATA AVAILABILITY STATEMENT**

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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