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A simplified methodology for estimating the torrential risk in small, predominantly forested, mountainous watersheds

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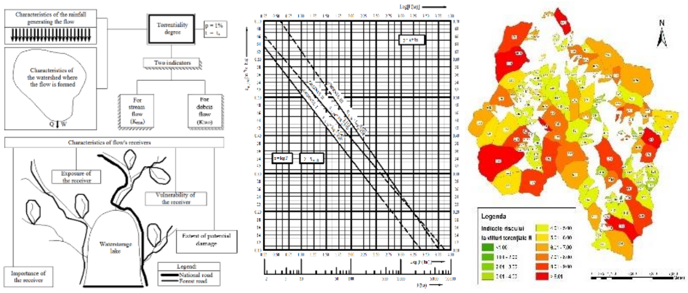
HIGHLIGHTS

- The risk index attributed to the torrentiality degree was joined with the risk index attributed to the characteristics of the receivers.
- The approach enables the creation of digital maps for torrential risk assessment and the informed decision making.

GRAPHICAL ABSTRACT



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ABSTRACT

The described methodology is termed "simplified" because it is not risk that is evaluated, but a torrential risk index associated with the probability of exceeding the maximum discharge of 1%. To this end, the risk index attributed to the torrentiality degree of the watershed was joined with the risk attributed to the main characteristics of the receivers. In order to join the two indexes into a single one, differentiated weights were allocated to six influential factors, and the values specific to each factor were converted to a unique scale (0 to 10), which required the use of correction coefficients for each case separately. Applicable to small (≤2500 ha), predominantly forested watersheds, the proposed methodology refers to one of the most frequent cases of design activity: forest roads are present in the watershed to be managed, the watershed itself may be crossed by other public transport infrastructure and there is a water accumulation downstream that needs to be protected against siltation.

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1. INTRODUCTION

Torrential flows and their consequence - floods - represent, as known, one of the most important risk sources. The fact that these types of events (*i.e.* floods) cause around 70% of the yearly damage and losses worldwide [1] justifies the assertion that "*torrentiality is not consistent with sustainable development*" [2]. On the other hand, in what regards the small, torrential, predominantly forested watersheds, located in the mountainous area of Romania, there is a considerable discordance between the amount of the necessary funds for preventing and fighting torrential flows and the limited financing possibilities from the central public authority responsible for forestry [3]. This is why questions such as the following need a careful analysis: "What should be the order of priority in developing and applying projects regarding torrential watersheds management? To which forestry departments and to which watersheds should the priority be given to justify the limited financial resources?

In response to such questions, we propose a simplified method for the determination, at watershed scale, of a "conventional" level of risk for the 1% exceedance probability [40] computed as a "torrential risk index", depending on which the decision-making authority can proceed to a informed allocation of resources. This means that the available resources should be directed, with priority, in those watersheds where the torrential risk index values are the highest. In other words, if we determine this index for small watersheds in a given territory and if the resulting values are divided into classes (in a convenient way), digital maps can be developed to characterize the priority of interventions in accordance with the "conventional" level of risk.

The method for estimation of torrential risk described herein is convenient because there is a wide variety of opinions and solutions regarding the estimation of the risk caused by extreme pluvio-hydrological phenomena [4-29]. In addition, there are different approaches in this domain explaining the lack of a unitary methodology regarding the determination of the vulnerability of receivers [30-39]. Also, if we refer to the thousands of small watersheds located in Romanian mountainous forested area, we observe that negative effects of torrential flows - considerable in terms of material damage - have a completely different economic and social dimension compared to the effects of floods occurring in the case of the large watersheds of rivers that cross rural and urban areas. Last, but not least, one should take into account the fact that the procedure of preparing natural flood risk maps (stipulated by Government Resolution no. 447/2003) [41] is a very laborious one; furthermore, the boundaries of the floodable zones marked on these maps, that are associated with different exceeding probabilities of the maximum discharge (20%, 10%, 5%, 2%, 1% and 0.1%) are given in detail only for human communities and not for all riverbeds throughout small, elementary watersheds, located, in general, in the mountainous forested area of Romania.

This is the reason why these methodological difficulties could be arguments and challenges at the same time, regarding the rational allocation of available funds and the prioritization of new investments, by a less complex approach that is based on the determination of a *torrential risk index* instead of the rigorous expression of this risk as the *"product of the probability of occurrence of the generating event and the value of material damage and human losses"* [13-15].

2. MATERIALS AND METHODS

2.1. The simplifying assumption

In accordance with the stated purpose, we have accepted the following simplifying assumption: a "*conventional*" level of risk attributed to torrential flows characterized by 1% exceedance probability, in small, predominantly forested watersheds, can be obtained by associating three categories of features involved in the occurrence of the phenomenon (**Figure 1**): features of rainfalls generating torrential flows, features of watersheds where torrential flows are formed and features of flows' receivers.

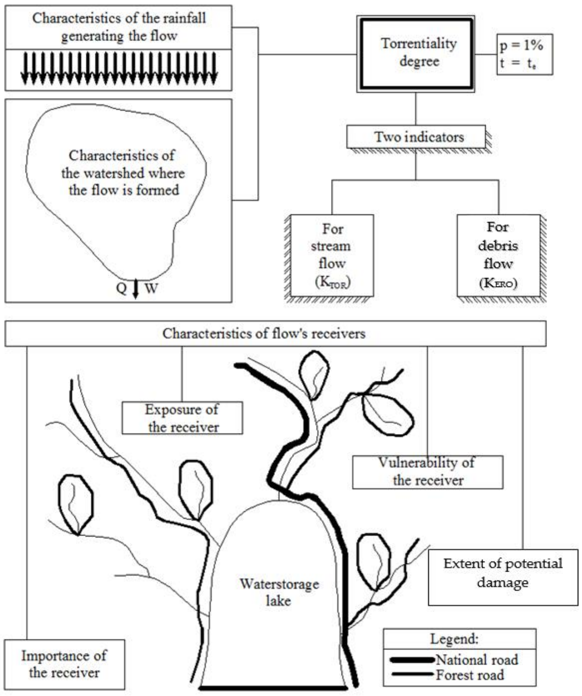

Figure 1. Connection and interdependence of features depending on which the "conventional" level of torrential risk for the 1% exceedance probability, in small, predominantly forested watersheds can be expressed. Source: [9].

The first two categories of features can be coupled and integrated in the expression of the *"torrentiality degree of the watershed"* [42], a synthesizing metric that can characterize the two components of torrential flows: the liquid component and the solid component. Two indicators of the torrentiality degree correspond to these components: the peak discharge for the 1% exceedance probability and the annual average volume of transported alluvia.

2.2. Torrentiality degree

For mapping small watersheds in the forested area of Romania by their torrentiality degree, two methods have been developed and applied until now: the Gaspar's method, introduced in 1967 and revised by the same author in 2002 and the Lazăr-Clinciu's method, introduced in 1995 and recently adapted [21] for GIS technology applications. For both methods, the torrentiality degree of the watershed is defined by means of two coefficients: torrentiality coefficient of stream flow (K_{TOR}) and torrentiality coefficient of debris flow (K_{ERO}). According to the Gaspar's approach, which is one of the well-established methods in the field of torrent hydrology (also known as the method of the active surface, the method of discharge parallelograms, the method of isochrones etc.), the peak discharge for the considered watershed is estimated, for a rainfall associated with the 1% exceedance probability, whose duration (*t*) is equal to the effective duration (t_e). The "effective duration" refers to the interval of rainfall during which, at the same time as the rainfall, there is runoff.

Let *Qmax* 1% ($m^3 \times s^{-1}$) be this discharge. Further on, through the same method and for the same rainfall, the peak discharge is estimated, in two opposed hypothetical situations, regarding the superficial retention capacity of rainfalls: 1 - the minimum capacity and 2 - the maximum capacity. Let $Q_{m1\%}$ ($m^3 \times s^{-1}$) be the maximum discharge corresponding to the first situation and $Q_{M1\%}$ ($m^3 \times s^{-1}$) the maximum discharge corresponding to the second one. By using the three mentioned variables, we can calculate (**Equation 1**) *the torrentiality coefficient of stream flow* as follows [43]:

$$K_{TOR} = \frac{Q_{\max 1\%} - Q_{m1\%}}{Q_{M1\%} - Q_{m1\%}} \quad (1)$$

For categorization purposes, the author recommends a scale consisting of 10 torrentiality classes, where class 1 stands for the minimum torrentiality and class 10 stands for the maximum torrentiality, which are defined as: $0 < K_{TOR} \leq 0.1$; $0.1 < K_{TOR} \leq 0.2$; …; $0.9 < K_{TOR} \leq 1.0$. Denoted by K_{ERO}, this coefficient renders the specific annual average alluvial production, expressed in $t \times ha^{-1} \times year^{-1}$, by taking into account the pluviometric dynamics in the considered area and by applying one of the accredited design methods in Romania: Gaspar-Apostol's method (1985 variant) [44] or the "*limit load method*" [45]. Torrentiality classes of debris flow can be defined, for instance, following this scale [42]: 0-0.5; 0.5-1; 1-2; 2-4; 4-8; 8-16; 16-32; 32-64 and so on. According to Lazăr-Clincu's method, in order to establish the torrentiality degree [46], we determine first "*the hydrologic characteristic*" (K_h), and then "*the transport characteristic*" (K_t); afterwards, in order to convert the results on the scales used for the Gaspar's method, we introduce correction factors for each characteristic, obtaining therefore the torrentiality coefficients (K_{TOR} and K_{ERO}) as follows (**Equations 2-5**):

$$K_h = Q_{max.1\%} / Q_{e.1\%} \quad (2)$$

$$K_{TOR} = 1.43 \times K_h \quad (3)$$

$$K_t = W_a / F \quad (4)$$

$$K_{ERO} = 2 \times K_t \quad (5)$$

The terms used in **Equations 2-5** have the following meaning: $Q_{max.1\%}$ ($m^3 \times s^{-1}$) is the peak discharge for the 1% exceedance probability, calculated through the rational method, $Q_{e.1\%}$ ($m^3 \times s^{-1}$)

- the “*morpho-standard*” maximum discharge, associated with the same exceedance probability, determined by the use of graph version corresponding to the rational method (**Figure 2**), *Wa* (m^3 × year^{-1}) - annual average alluvial transport estimated by the Gaspar-Apostol’s method (1985), *F* (ha) - area of the watershed.

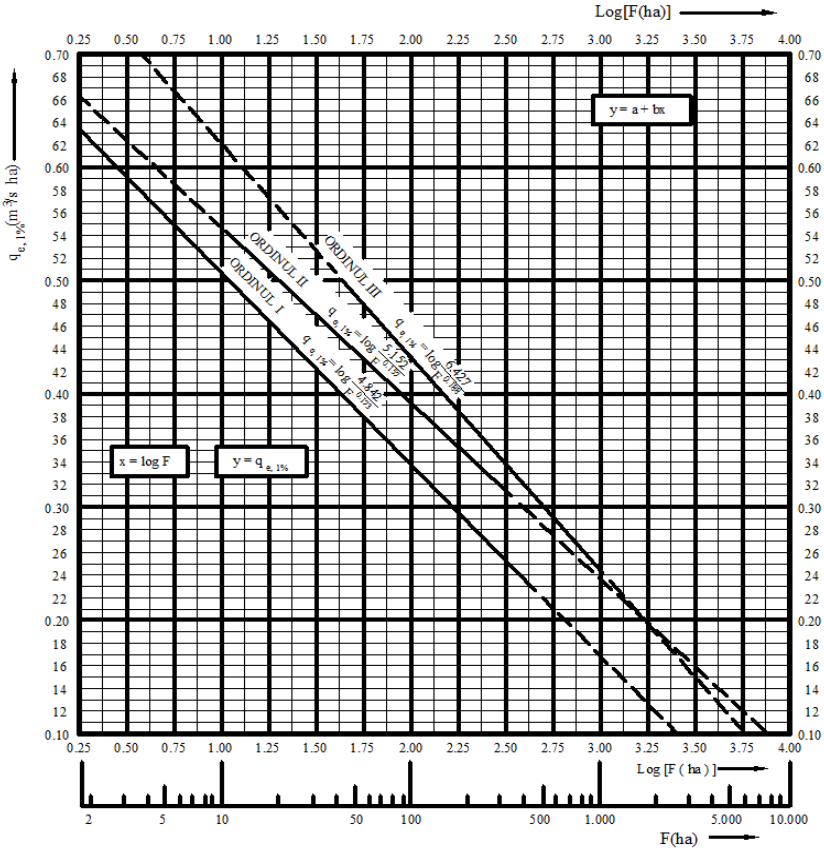

Figure 2. Graph version of the rational method, used to determine the specific maximum morpho-standard discharge ($Q_{e,1\%}$), depending on area (F), in torrential, predominantly forested watersheds, located in the mountainous area of Romania [47]. The F × $Q_{e,1\%}$ product defines the $Q_{e,1\%}$ term in Equation 2.

Torrentiality classes for K_{TOR} and K_{ERO} are defined for the same intervals as for the Gaspar’s method. The “*morpho-standard*” is the maximum discharge calculated in the simplifying hypothesis of a “*morpho-standard*” watershed [47]. According to this hypothesis, superficial retention and water infiltration into the soil are considered null; in other words, the flow coefficient is equal to 1. A preliminary classification of the watersheds can be made with the values of K_h and K_t features. Then, by harmonizing the resulting categories, the torrentiality degree of the watershed is determined (**Table 1**). Should the two characteristics lead to the same category, denoted 1 to 6, the watershed is classified in the torrentiality degree corresponding to the considered category but it is denoted by Roman numerals: I - “*non-torrential*”, II - “*weakly torrential*”, and so on to VI which stands for “*excessively torrential*”.

In many cases, however, it is possible to obtain different classifications of the two characteristics. For instance, for a watershed located in the hills and characterized by forests of medium, or reduced hydrologic quality, but growing on an erosion-resistant lithological substratum (crystalline schists, limestones etc.), hydrologic category 4 and transport category 3 may result.

Table 1. Determination of torrentiality degree, based on the classification of the watershed into hydrologic categories (K_h) and transport categories (K_t)

Categories of the hydrologic characteristic K_h (-)		Categories of the transport characteristic K_t ($t \times year^{-1} \times ha^{-1}$)		Characterisation of watershed in terms of torrentiality degree	
1	$K_h \leq 0.2$	1	$K_t \leq 1$	I	Non-torrential
2	$0.2 < K_h \leq 0.3$	2	$1 < K_t \leq 5$	II	Weakly torrential
3	$0.3 < K_h \leq 0.4$	3	$5 < K_t \leq 10$	III	Moderately torrential
4	$0.4 < K_h \leq 0.5$	4	$10 < K_t \leq 20$	IV	Strongly torrential
5	$0.5 < K_h \leq 0.6$	5	$20 < K_t \leq 40$	V	Very strongly torrential
6	$K_h > 0.6$	6	$K_t > 40$	VI	Excessively torrential

In such cases, the torrentiality degree is adopted depending on the nature of the damage that occurred, namely: if the objective is a water storage lake, a catchment for water supply etc., a torrentiality degree denoted by the transport characteristic (level III respectively) will be taken into account, because diminishing the alluvial transport is particularly pursued; but if it comes to the protection of communication infrastructure, industrial sites, or human settlements, then both characteristics are equally important and the torrentiality degree corresponding to the highest category (*e.g.* in the above-mentioned example - torrentiality degree IV), will be adopted.

2.3. Flow receivers

Besides the torrentiality degree of the watershed - that synthetically expresses the magnitude (intensity) of torrential flows and their erosional capacity on conventionally chosen scales - when estimating torrential risk, the characteristics of the objectives tapped and (or) endangered by these phenomena must be taken into account. In other words, *flow receivers* must be considered. Indeed, the "*conventional*" level of torrential risk depends on the importance category of receivers, exposure degree and their vulnerability and on the extent of the (potential) damage caused.

Economic and social importance features can be defined in accordance with the provisions of standards in the hydro-technical field. For instance, in STAS 4273-83 [48], constructions for different purposes are classified by classes of importance from 1 to 4; among these, there are those frequently affected by torrential flows such as the hydro-technical structures for regulation of riverbeds, creating water storage lakes, land reclamation, fisheries as well as the hydro-technical structures associated with industrial sites, human settlements (water supply and sewage), public roads and others. Also, in STAS 5576-88 [49], forestry objectives are designated and classified by categories (also from 1 to 4): forest lands, forest railways, forest roads, forest plant complexes, timber factories, forest warehouses, forest nurseries, workshops for the forestry sector, and other forestry structures. For objectives located near the hydrographic network where the flow occurs, such as the communication routes (roads, railways) or other constructions for economic and social purposes, the exposure degree can be estimated, in a first approximation, depending on the height difference existing between the location of these objectives and that of the riverbed thalweg along which the flow stream moves. If the objective to be protected is represented by a downstream water storage lake, the exposure degree can be differentiated depending on the distance from the mouth of the watershed in which the flow is formed to the location of the dam that created the water storage lake. Receivers that are presented in detail in the existing standards and classified in terms of their economic and social significance, can be ranked, by approximation, on a scale with several values, starting from the characteristics regarding their construction, functionality and use. For instance, the category of receivers that are very vulnerable may include lands located in the proximity of riverbeds (exposed to flooding), slightly improved forest roads, forest cabins, seed warehouses, and workshops for the forestry sector, built in a major riverbed or on the banks of a minor riverbed etc. In the category of receivers with reduced vulnerability can be included the main lines, highways, national and county roads, main forest roads and others. When the objective to be protected is a water storage lake, the vulnerability to a flow that forms in an upstream receiving watershed can be rendered on a differentiated basis, from one watershed to another, depending on the alluvial contribution to the lake per year, or for a certain period, by considering also the "*dead volume*" of the lake. The damage that may be caused by a flow that forms in the watershed subject to analysis is estimated in the hypothesis in which the management operations needed for the protection of a given objective were not carried out. The estimation can be done in terms of monetary value and it can be based on unit cost indexes specific to each of the objectives that could be affected, damaged or destroyed by the flow. If the objectives are only flooded, the problem consists of removing torrential alluvia. For estimating the costs of this operation, one can rely on standardized data [50] which should be updated. Using the same approach, the damage resulting from alluvial contribution to a water storage lake can also be assessed.

3. RESULTS AND DISCUSSION

3.1. Weight allocation for factors

As previously shown, for each watershed, the torrential risk index is obtained by associating two components: the risk index attributed to the torrentiality degree, and the risk index attributed to the characteristics of the receivers. The first index can be expressed depending on the two factors which characterize the torrentiality degree (K_{TOR} and K_{ERO}), and the second depends on four characteristics of the receiver: importance, exposure degree, vulnerability, and value of potential damage. In order to combine these two indexes into one, it is necessary to allocate different weights to the six characteristics that determine the risk level. A possible solution for weight allocation is given in **Table 2**. In a given case, the decision-maker or financer may change these weight values.

As the number of factors used in this approach differs from one index to another (2 and 4, respectively), in their association, the index attributed to the torrentiality degree is used with the weight of 2, and the index attributed to the receiver characteristics is used with the weight of 1.

Table 2. Weight allocation for the criteria on which the torrential risk index is estimated. Source: [9].

Group	Criterion	Characteristic (factor)	Allocated weight
I	Torrentiality degree	Torrentiality of stream flow (K_{TOR})	3
		Torrentiality of debris flow (K_{ERO})	2
II	Torrential flow's receiver	Importance (I)	1
		Exposure (E)	1
		Vulnerability (V)	1
		Value of potential damage (P)	2
		TOTAL	**10**

Because the values of the six factors are expressed, initially, according to specific scales (determined by the different nature of factors), in order to get comparable values for the characteristics used in estimating the "*conventional*" risk level, it is necessary to convert all of these values to a unique scale (for example from 0 to 10), which entails setting and introducing certain correction coefficients for each individual factor.

3.2. Risk index attributed to torrentiality degree

In order to define this index (R_{GT}), we take into consideration the joint influence of the two factors specific to the torrentiality degree (K_{TOR} and K_{ERO}), as well as different weights allocated to these factors and the fact that the assessment scales are different: the first factor (K_{TOR}) is expressed on a scale from 0 to 1, and the second one (K_{ERO}) on a scale from 0 to 64. Consequently, the conversion factors for one and the same scale [0 to 10] will be: 10 for the K_{TOR} factor and 10/64 for the K_{ERO} factor. If the converted values of these two factors (namely 10 K_{TOR} and 10/64 K_{ERO}) are multiplied by the corresponding weights (3 and 2, respectively, according to **Table 2**) and the results are added, we obtain **Equation 6**.

$$3 \times 10 \times K_{TOR} + 2 \times 10/64 \times K_{ERO} = 30 \times K_{TOR} + 0.3125 \times K_{ERO} \quad (6)$$

$$R_{GT} = \sqrt{60 \cdot K_{TOR} + 0.625 \cdot K_{ERO}} \quad (7)$$

Multiplying by 2 the **Equation 6,** as this operation is necessary because, according to **Table 2**, the number of factors that define the torrentiality degree (2) multiplied by the sum of weights allocated to these factors (3+2=5), that is 10, is two times lower than the product of the factors which characterize the receivers (namely: 4 × 5 = 20), and by extracting the square root, we obtain the **Equation 7** for the calculation of the risk attributed to the torrentiality degree.

3.3. Risk index attributed to receiver characteristics

Different values of this index are determined by the different number of receivers identified for each individual watershed, but also by the range of constructive features, layout and functionality of receivers, which gives them a different vulnerability and a different risk level to torrential flows. The following refer to one of the most frequent cases encountered in the design activity: the managed watershed includes forest roads, it may be crossed by other public transport routes (national, county, rural roads, railways etc.) and downstream there is a water storage lake that has to be protected against siltation. Solving the problem is easier if there is one receiver and it becomes more complicated when the number of receivers increases. This is the reason why these two cases will be analyzed in the following.

The first case is that in which the objective to protect is either a public transport route or a water storage lake. In both cases, the risk is attributed to the four characteristics in **Table 2** and the values of the allocated weights are the ones specified in the same table. The differences among the various cases are visible in the way the values of these characteristics are expressed, except for the *economic and social importance* (I) which, according to the relevant standards categorizes the constructions into four classes (1 to 4), in their descending order of importance. But, given that the risk level increases when the category of the importance decreases and that it would be useful to put it on a 0 to 10 scale, in the **Table 3** we have set the values of the conversion factor (*a*).

Consequently, in the formula that estimates the risk attributed to the receivers' characteristics, we will replace the importance category (*I*) with *"the converted value of the importance category"* (I_c), rendered by the product a × I, where "*a*" is the conversion factor. As for the risk level attributed to the *receiver exposure* (*E*), the approach and expression can be differentiated as follows: when the receiver is a *transport route* (regardless of its destination: forest, rural, county, national road), the degree of exposure to the flow formed in the watershed can be expressed depending on the average height difference (weighted by the length of the road) between the road axis and the thalweg of the river transporting the stream of the flow. This will be denoted hereinafter by ΔH_T^D. The smaller this difference is, the higher the risk index attributed to the receiver. It is clear that the most endangered road sections are the ones whose axis run along the river thalweg or very close to it (up to 0.5 m). As the height difference from the thalweg increases (for example up to 5 m), the road sections are less exposed to risk. If the road does not have an axial run but crosses a torrential stream on a bridge, the height difference ΔH_T^D is measured based on the vertical of the bridge span.

If, in a first approximation, we accept the hypothesis according to which, in small, predominantly forested watersheds, the road sections for which the height difference ΔH_T^D is smaller than 5 m are actually exposed to torrential flows, in order to render the value of the risk inducing factor on a 0 to 10 scale, the exposure degree of the receiver will be calculated using **Equation 8**.

Table 3. The converted value of the importance category (I_c)

Standard category (I)	4	3	2	1
Conversion factor (a)	1/4	2/3	2	10
The converted value of the category ($I_c = a \times I$)	1	2	4	10

$$E = \frac{10}{2 \cdot \Delta H_T^D} = \frac{5}{\Delta H_T^D} \quad (8)$$

The factor 2 from the denominator (**Equation 8**) was used because the maximum accepted height difference was 5 m, and the maximum value on the scale is 10. This formula is motivated by the fact that the risk intensity increases when the height difference decreases and vice-versa. More realistic is the hypothesis according to which the receiver's (road's) exposure increases as the height difference decreases, and the depth of the flow (h) increases. The latter can be expressed depending on the peak discharge for the 1% exceedance probability ($Q_{max1\%}$), on the surface of the watershed F (which determines the width of the riverbed, La) and on the riverbed's slope Ia, starting from the well-known relation for the discharge in uniform continuous movement (**Equation 9**).

$$Q = A \cdot C \cdot \sqrt{R \cdot i} \quad (9)$$

To simplify, we accept the equality between the hydraulic radius and the stream depth and, implicitly, the equality between the wet perimeter and the riverbed width. To account for the speed coefficient (C) we use the Manning's relation, by adopting a convenable value (n = 0.1 - mountain rivulets) for the roughness coefficient (n); the riverbed width (La) is expressed depending on the surface (F) according to the literature's recommendations for riverbeds crossing forest areas: La = 0.575 × F0.363 [51], then we obtain the **Equation 10** which can be used to calculate the depth of the stream for a flow generated by a rainfall associated with 1% exceedance probability. Then, starting from **Equation 10**, the exposure degree of receiver can be calculated using **Equation 11**.

$$h_{1\%} = \frac{0.35}{I_a^{0.3}} \cdot \frac{Q_{\max.1\%}^{0.6}}{F^{0.2178}} \quad (10)$$

$$E = \frac{5 \cdot h_{1\%}}{\Delta H_T^D} = \frac{1.75 \cdot Q_{\max.1\%}^{0.6}}{\Delta H_T^D \cdot I_a^{0.3} \cdot F^{0.2178}} \quad (11)$$

In the second case, where the receiver is a water storage lake, the exposure degree can be calculated depending on the distance measured from the lake dam to the watershed where the flow is formed; for example, this distance (D_{bh}) can be calculated as multiples of the lake length (L_{lac}). In this case, the receiver's exposure (E) is very high for watersheds that fulfil the condition $D_{bh} \le L_{lac}$

(they are located on slopes that open directly into the water storage lake) and decreases when watersheds supplying alluvia to the lake are farther from the water plane and implicitly from the location of the lake dam. If we admit the hypothesis according to which the receiver's exposure is low when the upstream watersheds are located at a distance D_{bh} (measured from the lake dam) equal to at least $4 \times L_{lac}$ and to at most $10 \times L_{lac}$, then this characteristic of the receiver, on a 0.1 to 10 scale, can be calculated using **Equation 12**.

$$E = \frac{L_{lac}}{D_{bh}} \tag{12}$$

Placed as a denominator, the distance D_{bh} reduces the exposure degree (E) when it increases. The formula is applicable to the interval: $0.1 \times L_{lac} \leq D_{bh} < 10 \times L_{lac}$. In terms of *receiver's vulnerability* (V) the type of expression differs, depending on its nature. If the receiver is a road, the vulnerability can be approximated according to its type, construction and functional properties. But, given that these properties are also taken into consideration when classifying objectives into importance categories, the "*vulnerability*" characteristic could be rendered by correlating it with the "*importance*" characteristic, starting from the observation that the objectives classified as less important according to the standards are also the most vulnerable to flows. Because we also intend to convert the specific values to a scale from 0 to 10, we will be able to use, in a first approximation, an expression identical to the one introduced for the receiver's importance, namely we will accept the **Equation 13**, where V is the vulnerability, and I_c - the importance category extracted from the specific standard and corrected with the conversion factor.

$$V = I_c \tag{13}$$

When the receiver is a water storage lake, the risk level attributed to its vulnerability could be expressed depending on the annual contribution of alluvia to the lake, originating from the watershed where the flow is formed. The estimation can be done by multiplying the surface of the watershed (F, ha) by the torrentiality coefficient of the debris flow (K_{ERO}, t × year^{-1} × ha^{-1}). Admitting that the maximum values for F and K_{ERO} are of 2.500 ha and 64 t × year^{-1} × ha^{-1}, respectively, and based on the conversion of the values to a 0-10 scale, we will obtain **Equation 14**.

$$V = \frac{625 \cdot K_{ERO} \cdot F}{10^7} \tag{14}$$

Finally, in order to introduce the *influence of potential damage*, it is necessary to determine, right at the beginning, the maximum value of this damage (A), estimated for one of the watersheds in the study area; then the estimation of potential damage is extended to each of the other watersheds for which the torrential risk index is calculated. If the endangered receiver is a road, the estimated length to be destroyed, L_D (in km), is multiplied by the specific unit cost, i_c^D. When the receiver is a water storage lake, the value of the (potential) damage resulting from siltation can be evaluated by assimilating it to the cost of the operation of removing torrential alluvia from the basin. This cost is estimated by multiplying the alluvia flow in the water storage lake (W_L) by the unit price valid for removing, loading and transporting the alluvia to a certain distance (i_c^L). Therefore, the value of the potential damage converted to a scale of 0 to 10 will be that calculated by **Equation 15** in case of a road and by **Equation 16** in case of a water storage lake, where A_L stands for the equivalent value of the most important damage caused by siltation in one of the watersheds in the upstream area of the water storage lake.

$$P = \frac{10 \cdot L_D \cdot i_c^D}{A_D} \tag{15}$$

$$P = \frac{10 \cdot W_L \cdot i_c^L}{A_L} = \frac{10 \cdot K_{ERO} \cdot F \cdot i_c^L}{A_L} \tag{16}$$

$$R_{REC}^D = \sqrt{2 \cdot a \cdot I + \frac{5 \cdot h_{1\%}}{\Delta H_T^D} + 20 \cdot \frac{L_D \cdot i_c^D}{A_D}} \tag{17}$$

$$R_{REC}^L = \sqrt{a \cdot I + \frac{L_{lac}}{D_{bh}} + \frac{625 \cdot K_{ERO} \cdot F}{10^7} + 20 \cdot \frac{K_{ERO} \cdot F \cdot i_c^L}{A_L}} \tag{18}$$

If the values of the four terms that define the receivers' characteristics (I, E, V and P) are calculated using the **Equations 15-16**, the value of the risk index attributed to the receiver's characteristics may be obtained by multiplying the values of I, E, V and P by the weights allocated in **Table 2** and by extracting the square root from the sum of the calculated products (**Equation 17** for public transport infrastructure and **Equation 18** for water storage lakes). If the flow formed in a certain watershed affects more receivers (r_1, r_2, … r_n), whether they belong to the same category or not, in order to express the risk index attributed to all receivers it is required to successively determine the values of the risk index attributed to each receiver ($R_{REC}^{r_1}, R_{REC}^{r_2}, ..., R_{REC}^{r_n}$). Afterwards, the obtained individual values (i to n) are summed (**Equation 19**), standing for the risk index attributed to all the receivers.

$$R_{REC} = \sum_{i=1}^{n} R_{REC}^{r_i} \tag{19}$$

$$R_{REC} = R_{REC}^{DF_1} + R_{REC}^{DF_2} \tag{20}$$

$$R_{REC} = R_{REC}^{DF_1} + R_{REC}^{DF_2} + R_{REC}^{L} \tag{21}$$

In the case of two receivers of the same type, for example, that are further included in the same category, such as two forest roads ($r_1 = DF_1$ and $r_2 = DF_2$), the risk index attributed to the receivers can be estimated by the use of **Equation 20**. If we add one more receiver, for example, r_3 - a water storage lake, then the risk index can be estimated by the use of **Equation 21**.

3.4. Risk index attributed to torrentiality degree and receivers' characteristics

The risk index (R) can be expressed, further on, as the product between the risk index attributed to the torrentiality degree (R_{GT}) and the one attributed to the characteristics of the receivers (R_{REC}), or as the square root of this product (**Equations 22-24)**.

$$R = R_{GT} \cdot R_{REC} \tag{22}$$

$$R = \sqrt{R_{GT} \cdot R_{REC}} \tag{23}$$

$$R = R_{GT}^{x} \cdot R_{REC}^{y} \tag{24}$$

In **Equation 24**, x and y stand for the exponents that have to be provided by the decision-maker.

5. CONCLUSIONS

An objective decision-making system designed to rationally allocate available financial resources and to prioritize new investments is essential for the authorities in charge of preventing and fighting torrential flows. This is the reason why, starting from the almost complete lack of natural flood risk maps for this type of watersheds, on the one hand, and taking into consideration the laborious procedures described in the literature for risk estimation, on the other hand, this paper presents the underlying principles and the calculation algorithm of a simplified methodology to estimate torrential flow risk. The following may be concluded:

1. Instead of determining the boundaries of floodable zones, for flows with different exceedance probabilities (20%, 10%, 5%, 2%, 1% and 0.1%), as stipulated in the procedure for drafting flood risk maps, one can estimate, for each watershed, a "*conventional*" flow risk level generated by rainfalls associated with 1% exceedance probability, by associating the risk index attributed to the torrentiality degree of the watershed with the risk index attributed to the characteristics of the receivers;

2. Following the classification and reclassification of the values obtained for watersheds in a certain area, one can generate a digital map of the torrentiality risk index, on the basis of which, available financial resources can be directed towards promoting new management operations in the watersheds for which the torrential risk index has the highest value;
3. It is highly likely that the proposed methodology, although simplified, will lead to comparable results, that differentiate each watershed from the others in the same area, enabling informed decision-making and prioritization of new investments;
4. However, we do not exclude the recommendation according to which, after the use of proposed methodology, a map should be drafted containing the limits of floodable zones for various flow exceedance probabilities and a more precise estimation of the vulnerability of exposed objectives, and of the material damage, should be made.

SUPPLEMENTARY MATERIALS

No supplementary materials were submitted by the author.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

APPENDIX

No appendixes were provided by the author.

EXTENDED ABSTRACT - REZUMAT EXTINS

Titlu în română: *O metodă simplificată pentru estimarea riscului torențial în bazinete mici, predominant forestiere.*

Introducere: *După cum se știe, persistă de multă vreme o considerabilă discordanță între valoarea fondurilor necesare pentru prevenirea și combaterea viiturilor torențiale în aria forestieră a țării și posibilitățile limitate de finanțare de care dispune autoritatea publică centrală care răspunde de silvicultură. Iată de ce, ca răspuns la întrebarea: „Care ar trebui să fie ordinea de prioritate în dezvoltarea și aplicarea proiectelor de amenajare a bazinelor hidrografice torențiale?", se propune o metodologie simplificată pentru determinarea, la scară de bazin hidrografic, a unui indice al riscului la viituri torențiale, în funcție de care autoritatea decidentă să poată realiza o alocare rațională a fondurilor de investiții. Aceasta înseamnă ca resursele financiare disponibile să fie direcționate cu prioritate către amenajarea acelor bazine hidrografice torențiale care au fost identificate, în urma aplicării metodologiei, cu indicele de risc cel mai mari mare.*

Materiale și metode: *În construcția metodologiei a fost adoptată următoarea premisă simplificatoare: o măsură "convențională" a riscului indus de viituri torențiale în bazine hidrografice mici, predominant forestiere, poate fi obținută prin asocierea celor trei categorii de caracteristici implicate în producerea fenomenului și anume: caracteristicile ploilor generatoare de viituri torențiale, caracteristicile bazinelor în care se formează viiturile torențiale și caracteristicile receptorilor viiturilor torențiale. Primele două categorii de caracteristici se pot cupla împreună în expresia ,,gradului de torențialitate a bazinului", care se definește cu ajutorul a doi coeficienți specifici: coeficientul de torențialitate a scurgerii lichide (K_{TOR}) și coeficientul de torențialitate a scurgerii solide (K_{ERO}).*

Rezultate și discuții: *Pentru exprimarea indicelui de risc indus de gradul de torențialitate (R_{GT}), se procedează la reunirea coeficienților K_{TOR} și K_{ERO}, după ce, în prealabil, coeficienții respectivi sunt convertiți la aceeași scară (0-10) și sunt multiplicați prin dublul ponderilor alocate (3 pentru K_{TOR} și 2 pentru K_{ERO}). Relația stabilită (7) se redă în partea de prezentare a rezultatelor. Privitor la indicele de risc indus de caracteristicile receptorilor (R_{REC}), metodologia propusă s-a dezvoltat numai pentru unul dintre cazurile frecvent întâlnite în activitatea de proiectare: cazul în care viiturile torențiale periclitează drumuri forestiere și/sau alte căi de comunicație terestră, iar imediat în aval există un lac de acumulare. Patru caracteristici ale receptorilor sunt reflectate în expresia cotei de risc induse de aceștia: importanța economică și socială (conform clasificării din standardele de specialitate), gradul de expunere la viiturile torențiale, vulnerabilitatea în fața viiturilor torențiale și valoarea pagubei (potențiale) estimate. În cazul unui receptor din categoria drumurilor, indicele de risc se exprimă conform relației 16 în funcție de: un factor de conversie a categoriei de importanță a drumului, diferența de nivel dintre axa platformei drumului și talvegul văii (calculată ca o medie ponderată pe lungimea căii), adâncimea curentului viiturii la probabilitatea de depășire de 1%, lungime estimată a fi scoasă din funcțiune în urma producerii viiturii și costul unitar specific al operațiunii de reabilitare a căii. În cazul lacului de acumulare, indicele de risc indus de caracteristicile obiectivului se exprimă prin relația 17 în funcție de: un factor de conversie a categoriei de importanță a acumulării, lungimea lacului de acumulare, distanța măsurată de la barajul acumulării și până la bazinul în care se formează viitura, suprafața bazinului, coeficientul de torențialitate a scurgerii solide și costul unitar specific pentru excavarea, încărcarea în mijloacele de transport și transportarea aluviunilor la o anumită distanță. Pentru estimarea riscului indus de toți receptorii, se determină succesiv indicele de risc al fiecărui receptor, după care valorile individuale obținute se însumează. În final, indicele de risc R indus (simultan) de gradul de torențialitate și de caracteristicile receptorilor se exprimă prin rădăcina pătrată a produsului dintre cei doi indici specifici (R_{GT} și R_{REC}).*

Concluzie: *în urma aplicării metodologiei propuse pentru bazinele dintr-un anumit teritoriu, prin clasificarea și reclasificarea valorilor R astfel estimate, se poate genera o hartă digitală a indicelui de risc la torențialitate, în baza căreia resursele financiare disponibile pot fi direcționate către promovarea de noi lucrări de amenajare în cazul bazinelor identificate cu indicele de risc torențial cel mai mare.*

Cuvinte cheie: *metodologie simplificată; risc torențial; risc; grad de torenţialitate; caracteristicile receptorilor, bazinete mici.*

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