BABEŞ – BOLYAI UNIVERSITY

FACULTY OF GEOGRAPHY

GEOGRAPHY DOCTORAL STUDIES

NATURAL HAZARDS AND ASSOCIATED RISKS IN TARCĂU RIVER VALLEY

Summary of PhD thesis

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CONTENT

1. INTRODUCTION

The dissertation aims to analyse the natural hazards and the associated risks in the Tarcău Valley, referring only to the hydrological and geomorphological ones on account of their importance in the local dynamics.

The methodology used in the evaluation of the levels of the hazards and risks features the safety of the population and the stability of the economic activities. Consequently, emphasis was given to the inferior sector of the valley due to the density of the population in this area and to the protective measures taken over the last years with an influence on the level of hazard and the vulnerability of the exposed elements.

Key Words: Hydrological hazard, geomorphological hazard, Tarcău Valley, dendrochronology, floodplain, linear erosion.

2. TARCĂU VALLEY – PHISICAL GEOGRAPHICAL FEATURES

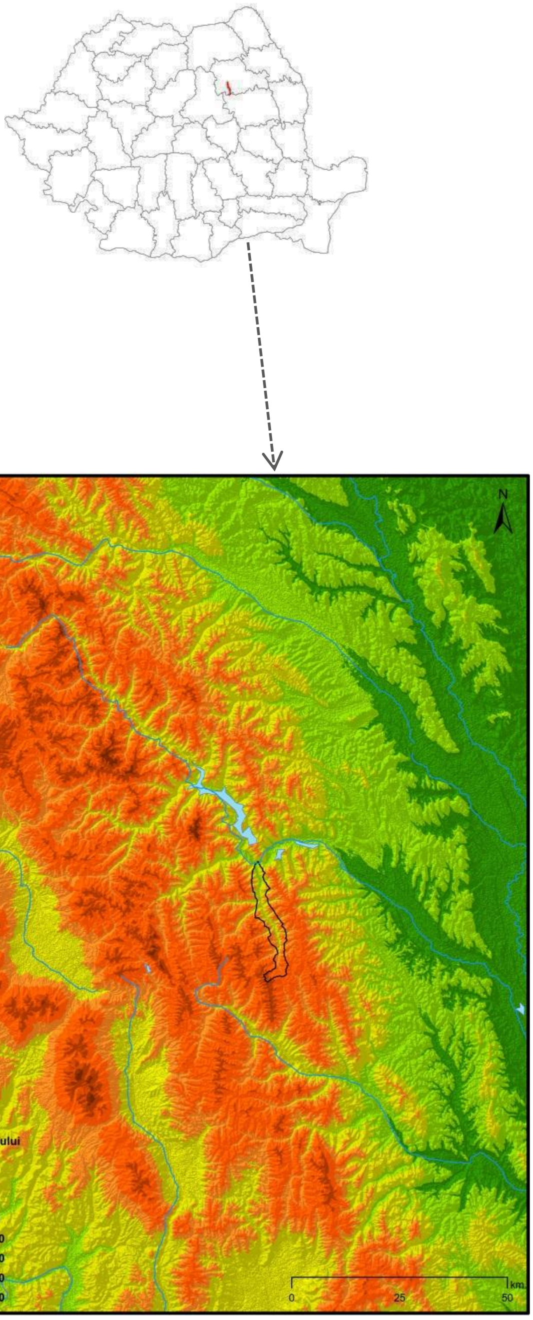
2.1. Geographic location and area limits

Tarcău River, a right side tributary of Bistrița, drains the mountains with the same name from the Transylvanian – Moldavian group of the Eastern Carpathians. Its main course has a length of 33 km and its hydrographical basin has an approximate surface of 392 km^2.

2.2. Geology

The valley is set only on the nappe of Tarcău that consists of Palaeocene-Neocene and Oligocene-Miocene formations. From the first two, predominant is the Tarcău sandstone, over 80%, and is disposed in metric banks of 1.3 m, 3.5m or even over 10 m with interlayers of red and green clay in sub-metric layers. In the Oligocene-Miocene category abounds the Fusaru sandstone, in layers from 0.5 m to 5 m, alternating with levels of clay, diorite sand and siderite limestone, overlapping the inferior dysodile with widths between 250 – 300 m and which include a diverse range of pelitic rocks, from grey or dark-grey clay to the dark clay similar to the dysodile.

For the internal part of the Tarcău nappe the style of the tectonic formations is enforced by the Tarcău sandstone and the Fusaru sandstone, massive rocks, which generates a system of normal straight synclinal and anticline folds, with widths between 2 – 5 km, oriented on a North – South direction on distances for up to 30 km.



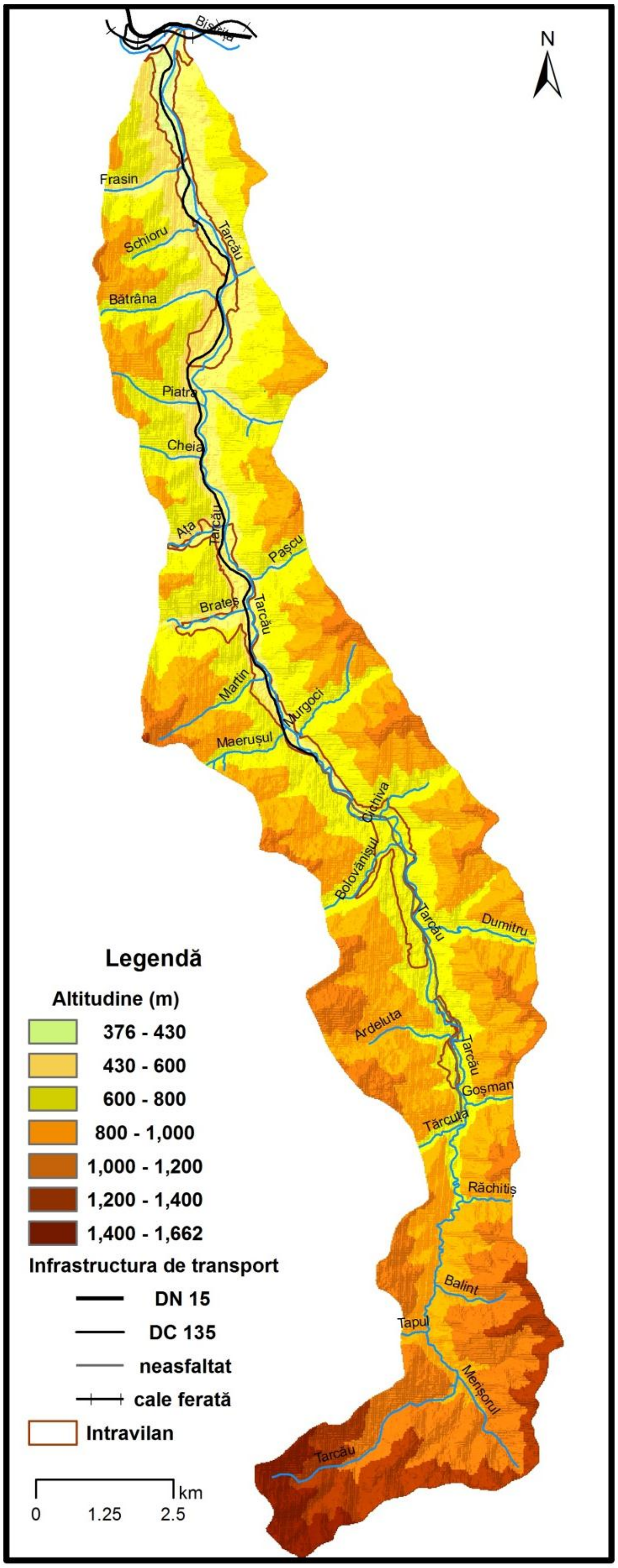


Fig. 1. Location of Tarcău river valley and the neighbouring units.

2.3. Relief

The prevalence of sandstones shapes the slopes with a pronounced declivity (the most common ranging between 15.1 - 35° and 35.1 - 55°), and narrow crests, jagged peaks and shallow saddles.

The valleys shaped in sandstone are also deep and narrow, with breaks in slope, a V shaped cross section and often with canyon shaped beds. The slopes of northern aspect are predominant (15.23%), followed by the ones with a western one, north-western, eastern and north-eastern with almost equal extensions (around 13%). The fluviatile relief presents 7 levels of terraces: the waterside terrace between 2-3 m, the 5-7 m terrace, the 8-12 m terrace, the 15-20 m terrace, the 25-30 m terrace, the 35-40 m terrace.

2.4. Climate

The temperatures registered at Pângărați weather station (365 m) indicate an annual average of 8.4^0 C and a more noticeable variability during the cold season. The average annual thermal amplitude oscillates between 22 - 23^0C, indicating a moderate thermal continentalism (Apăvăloae, in Grasu et.al. 2010).

The annual rainfall value fluctuates around 800 mm (the average for 1991-2011 being 801 mm for the downstream station, Cazaci, and 851 mm for Ardeluța station, situated upstream at 700 m altitude). The highest rainfall is registered during the summer time when the monthly average exceeds 100 mm. The highest monthly rainfall is recorded in June – August, while the minimum is reached in February. The predominant wind direction (45%) is west.

2.5. Hydrology

The hydrological regime of Tarcău river is Eastern Charpathian, marked by its high pluvial supply, the absence of winter floods, by the fact that spring floods start in March and are present until May, which are also completed by other ones between July and August. The two types of water sources in the Tarcău Mountains are: surface (75-85%) and ground water (15-25%) (Ujvari 1972).

2.6. Soils

The high bases concentration in the flysch lead to the forming of cambisols and spodosols. The cambisols can be found between 400 m and 1450-1500 m and are represented by the eutric cambisol and dystric cambisol types. The spodsols occupy limited surfaces, above 1450-1500 m, in the areas with the highest altitude (Grindușu-Tărhăuș crest), at a level higher than the dystric cambisols, with prepodzol as a subtype.

2.7. Flora

The characteristic flora for the Tarcău catchment is mainly represented by forest (83%), dominated by the mixture level (spruce, fir, beech), followed by the spruce level consisting of spruces and spruce-fir areas.

2.8. Human elements

The population in the Tarcău Valley is unevenly spread through the villages of Tarcău (1978 inhabitants), Cazaci (518 inhabitants), Brateş (324 inhabitants), Schitu Tarcău (49 inhabitants) and Ardeluța (31 inhabitants), focused mainly in the inferior sector of the valley, where its configuration allows a more extent display of buildings. The most important economic activity is represented by lumbering.

3. METHODOLOGY

3.1.Hazard, risk and associated terms

UNISDR (2009) defines the *hazard* as a dangerous phenomenon, substance, human activity, or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage.” The hazard can be considered as the probability that a particular danger (threat) occurs within a given period of time (Fell R., Ho K.K.S., Lacasse S., Leroi E., (2005).

“Internationally agreed glossary of basic terms related to disaster management” defines the risk as the expcted losses (of lives, persons injured, proprty damaged and economic activity disrupted) due to a particular hazard for a given area and reference period. Most often, risk is considered to be the product between the hazard, elements at risk and vulnerability. (Kleist et al 2006, Papathoma -Köhle et al 2007).

Vulnerability is an intrinsec characteristic of a community that is always there even in quiescent times between events. Determining it means considering the consequences if a certain event impacted particular elements at risk. (Thywissen, 2006).

The elements at risk consist of population, buildings engineering works, infrastructure, environmental features and economic activities in the area affected by a hazard. (Felll, R., Ho, K.K.S., Lacasse S., Leroi E., 2005). Their affectedness largely depends on the preparedness. UNISDR defines it as the activities designed to minimize loss of life and damage, to organise the temporary removal of people and property from a threatened location and facilitate timely and effective rescue, relief and rehabilitation.

3.2. Risk management

Risk analysis starts from the characterisation of the phenomenon that can have extreme manifestations (fig.2). The hazard analysis is then completed by the frequency one that sets the occurrence probability and the return period. The purpose of risk analysis is the estimation of negative consequences upon the society, considering damages or even life losses determined by the potential dangerous natural processes (Douglas 2007, Fuchs 2009). If the risk evaluation is correctly performed, it can be seen in a proper management plan, that can be supported by the local administration's budget and that through implementation leads to a reduction of the risk.

3.3. Methods of risk evaluation

There are two main types of methods used in risk evaluation:

- *quantitative methods*, that use statistic data to perform numerical simulations of the phenomenon's characteristics. According to their results the hazard level is estimated and the extension of areas exposed to risk.
- *qualitative methods* uses qualificatives to appreciate the intensity of the phenomenon, the probability of occurrence, the hazard and the associated risk.

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Risk evaluation methodology used in Tarcău river valley

In the case of Tarcău river valley the hydrological hazard map and the risk one were made based on floods with a return period greater than 100 years, according to the methodology adopted in the Autonomous Province of Bolzano/South Tyrol in 2008 (***2008a). that sets the principles used to obtain the maps included in the regional urban plan. The main concept focuses on saving lives, safety ensuring for the inhabited areas, maintaining the economic activities and supply uninterrupted. The same methodology was used also for the geomorphological hazard, but the elements used to define the hazard level were adapted to the available information.

Table .1. Threshold values for assessing the phenomenon's intensity (modified after BUWAL 1998, quoted by *** 2008a)

Phenomenon	Threshold values	Low intensity	Medium intensity	High intensity
flood, torrential flood	flood <1.5%; torrential flood 1,5 – 15%; < 30% solid material ; < 40 km/h	h < 0.5m h x v < 0.5 m^2/s	h < 0.5 – 2m h x v < 0.5 – 2 m^2	h > 2m h x v > 2 m^2/s
debris flow	slope > 15%, solid material 30-70%, 40->60km/h	-	M<1m sau v<1m/s	M>1m sau v>1m/s
erosion	continuous	d < 0.5m	d=0.5 – 2m	d>2m
h= water depth; h x v= hydrodynamic pressure; d= average thickness of the eroded material , or depth of the eroded banks, measured perpendicularily to the slope, steep bank; M= thickness of deposits				

3.3.1. Hazard map

The hazard categories on the hazard map results from combining the intensity of the phenomenon (table 1) and the occurrence probability (table 2) according to the matrix in fig. 3. In obtaining the three hazard levels, low, high and very high, the existing protection works are also considered

Fenomen	**Intensitate scăzută**	**Intensitate medie**	**Intensitate ridicată**
viitură, viitură torențiala	h < 0.5m h x v < 0.5 m^2/s	h < 0.5 – 2m h x v < 0.5 – 2 m^2	h > 2m h x v > 2 m^2/s
curgere de debris	-	M<1m sau v<1m/s	M>1m sau v>1m/s

Table 2. Occurrence probability expressed in return period (modified after BUWAL 1998 quoted by *** 2008a)

Occurrence probability		**Return period (T_{R})**	
high	100% to 82%	$T_R \leq 30$ years	**very frequent**
average	82% to 40%	30 years < $T_R \leq 100$ years	**frequent**
low	40% to15%	100 years < $T_R \leq 300$ years	**rare**
very low	<15%	$T_R > 300$ years	**very rare**

3.3.2. Evaluation of the specific risk

The specific risk represents the damage caused to an element at risk according to the hazard degree and the vulnerability (fig.3) and it is expressed by the relation $R_s = H \cap V$. To quantify their vulnerability, each element is considered individually, and is attributed one of the four degrees of vulnerability: very high, high, medium, low. The corresponding 4 risk levels are:

- *very high* – indicates the probability of human lives loss and severe lesions, of important damage to buildings, infrastructure, environment and economic activities

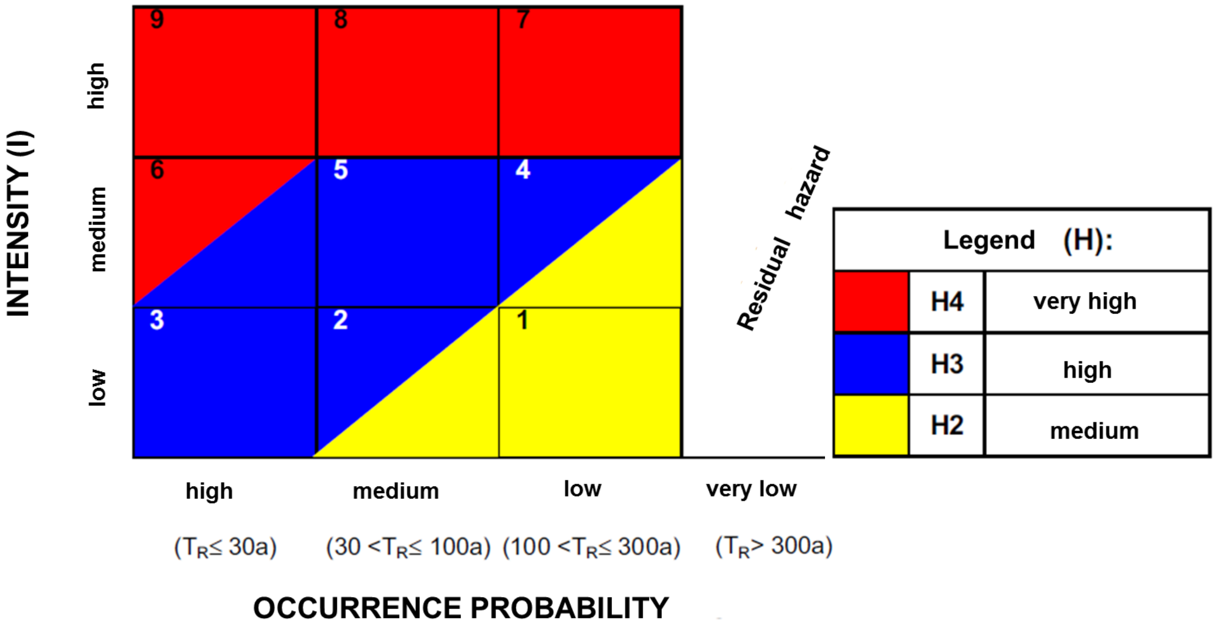
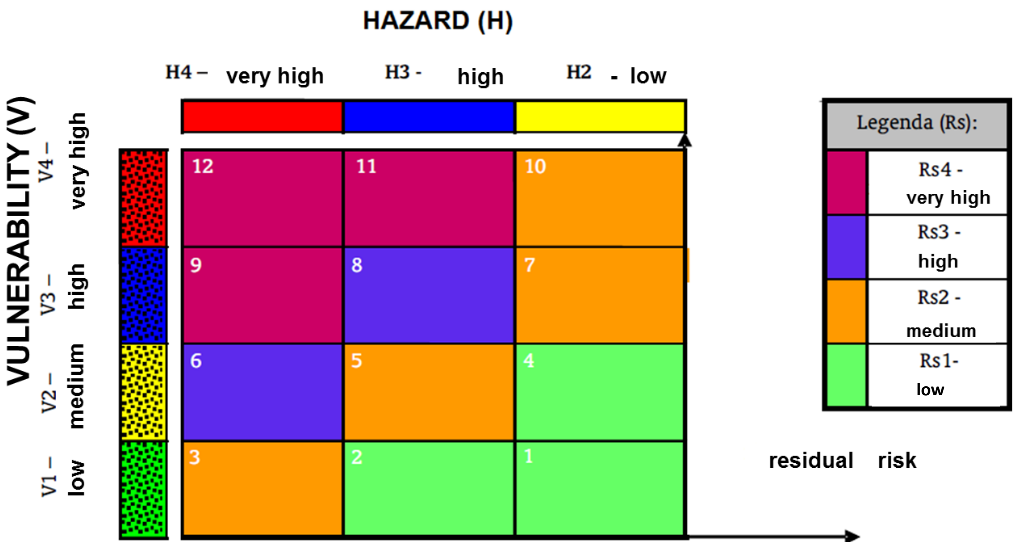


Fig. 3. Matrix used to define the hazard degree for the hydrological phenomenon (modified after BUWAL 1998 quoted *** 2008a).

- *high* – describes the possibility of difficulties in ensuring population's safety, the disturbance of the activities in buildings, and of infrastructure, that often lead to the impossibility of using them, discontinuity in social-economic activities and important damages to the environment.
- *medium* – indicates the possible minor damage to buildings, infrastructure and environment, that does not endanger population's safety, the activities in the buildings, infrastructure and environment. The danger is considered to be low even outside the buildings.
- *low* – describes the case when the economic, social and environmental damage is very low.



3.4. Floodplain modeling

In order to obtain the water depth needed in the determining the flood intensity, the flood plain was modeled using HEC-RAS software. The hydrological hazard analysis based one dimensional modeling that leads to hazards map, consists mainly of four stages: data collection, a hydrological one, a hydraulic part and the floodplain calculation (Panayotis et al. 2008). HEC-RAS models the water surface elevation both for steady and unsteady flow in the case of the three regimes: subcritical, supercritical and mixt.

The hydraulic calculations are performed for each cross section, to obtain the water surface elevation, critical depth, energy grade elevation and velocities (Ackerman et al. 2000).The water level computed for each cross section is intersected with the DEM in order to obtain the extension of the floodplain.

HEC-RAS was used to determine the floodplain just for the 4.8 km comprised between Cazaci gauging station and the junction of Tarcău and Bistrița river, based on the 111 cross-sections obtained from personal measurements.

4. DENDROCHRONOLOGY IN STUDYING NATURAL HAZARDS

Dendrochronology is the science of dating tree rings, including investigations of the information content in the structure of the dated rings an application to environmental and historical questions (Kaennel, Schweingruber 1995).

4.1. Sampling and sample analysis

There are two types of samples that can be obtained from a tree: cores (with the help of a Pressler borer) and cross sections (disks). Both are used to measure the tree ring width on the microscope at a precision of 0,001 mm.

4.2. The dendrohydrological study

This kind of study uses the principle process – event – response schematically described in figure 5. Using the growth disturbances identified in the annual rings, the frequency of the determining process can be estimated, while according to the trees' location its spatial extension can be evaluated. The thus obtained frequency would be just a minimum one. The analysed growth disturbances included just traumatic resin ducts and callus tissue, other not being present. The results of the dendrohydrological study are presented in the next chapter.

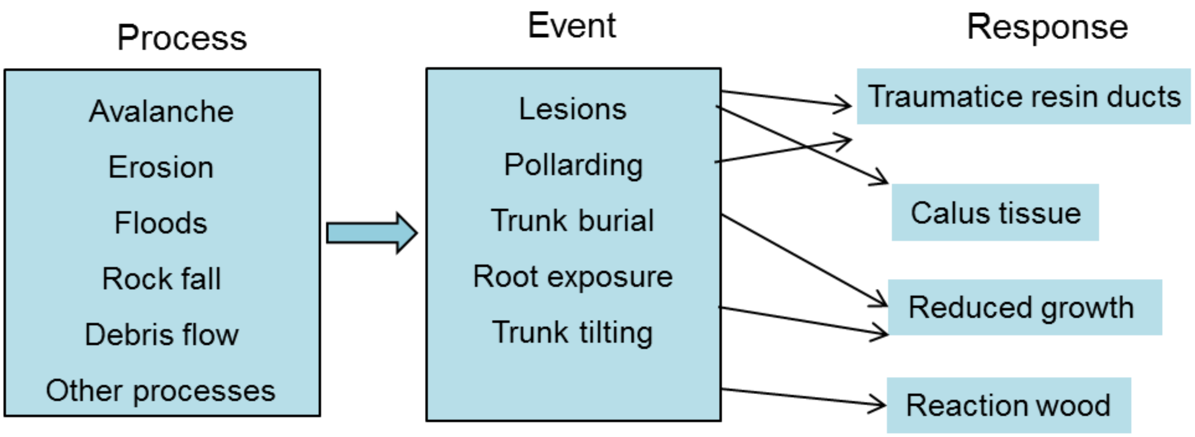


Fig 5. The concept process – event - response (after Schroder, 1978)

4.3. The dendroclimatologic study

4.3.1. Climatic reconstuction

Tree ring width variation is usually non- homogenous, including also the influence of age that determines the diminution of ring width along with ageing. If these variations predominate, the data requires to be standardized, in order to obtain a new detrended series and a more homogenous in time average and variation. Standardization consists in the elimination of long term variations, by dividing the raw values to those estimated by the smoothing function, and thus transforming it into an index series (Kaennel, Schweingruber, 1995). Choosing the smoothing function also depends on the characteristics of the series that has to be indexed, and the user's interest upon the low, medium or high frequency variations. For the series of Tarcău river valley there were used 5 functions, deriving thus 5 dendrochronological series, the stages of the climatic reconstruction being expressed in figure 6. It is performed in 2 main phases: calibration and verification, that require climatic data (monthly temperature and precipitation data) of length exceeding 30 years. *Calibration* consists of identifying the response functions, them representing the statistical relationship that determines the climatic features that influence tree growth. Verification of the reconstructed values is performed using a different set of climatic data than the one used for the calibration.

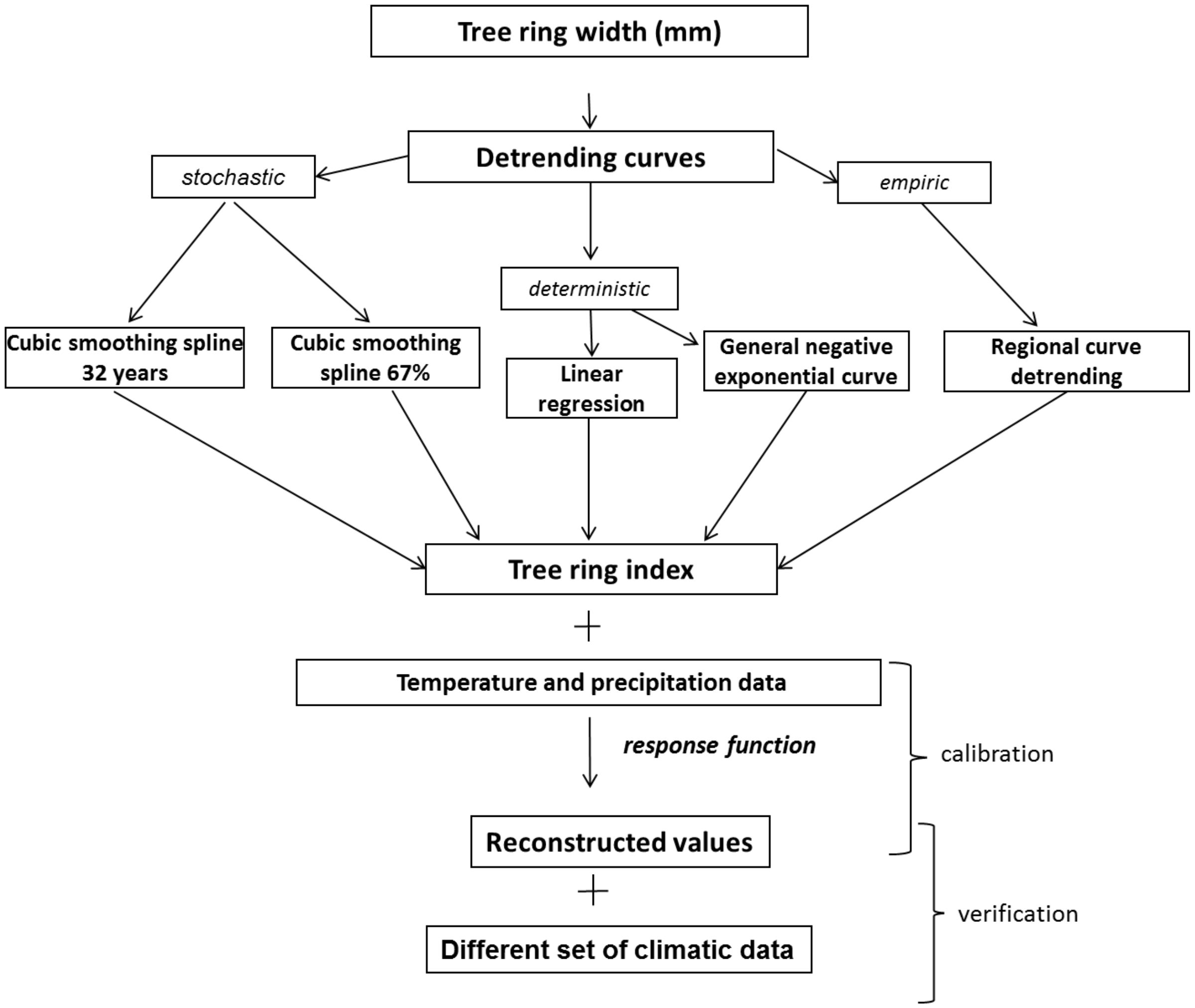


Fig.6. Phases of climatic reconstruction.

The coefficients of the calibration equation are used on a different set of data either from a different temporal interval, either from a different weather station representative to the study area.

The dendrochronologica series of Tarcău has a length of 338 years, covering the interval 1673 – 2011, and the average trees age is of 226 years. The value of 0.234 indicates an average sensibility.

All the 5 growth index series indicate the same response to temperature and precipitation, although small intensity differences can be observed: winter temperatures (Novembre –Decembre –January) and summer precipitation (July) influence the annual growth of tree rings in Tarcău area, the correlation and response coefficients exceeding the 95% confidence interval for these months.

Figure 7 presents the reconstructed winter temperature for the interval 1730 – 2011 using the annual growth indexes obtained with the cubic smoothing spline of 67%, the general negative exponential curve and the regional curve. For the three of them a slight positive trend can be identified.

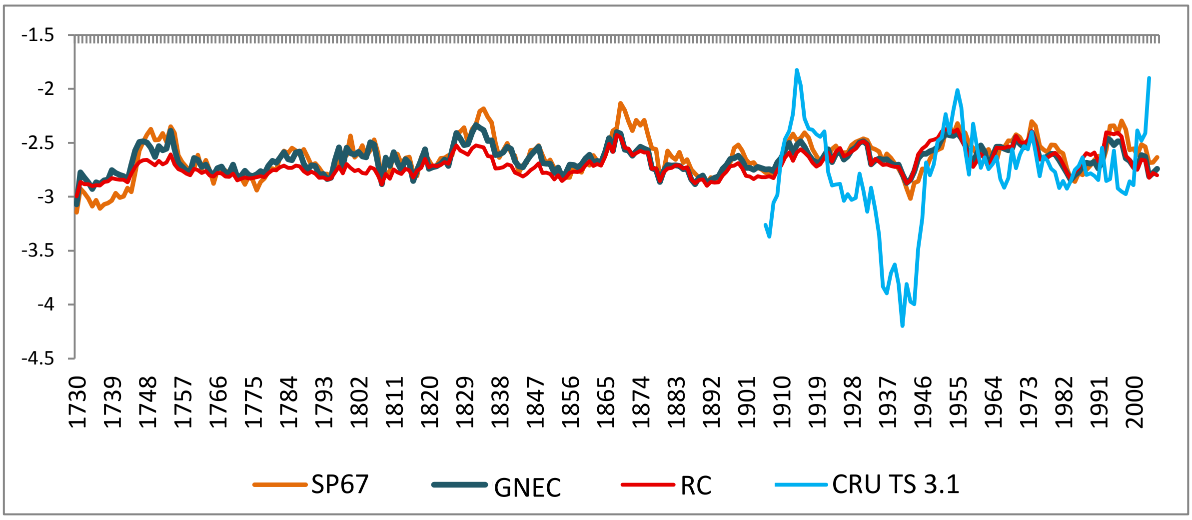


Fig.7. Decadal variation of reconstructed winter temperature (November, December, and January) and of those extracted from the CRU TS 3.1 grid dataset.

The correlation values obtained for the reconstructed precipitation and those extracted from the grid dataset do not exceed the 0.5 threshold, but the results support the hypothesis of increasing precipitation values, reflected in the discharge values. The linear trend calculated for the discharge values measured at Ardeluța gauging station for the period 1976 – 2011 indicate an increase of 0,83 m^3/s of average discharge, value confirmed by a statistical significance of 0.001, and an increase of 1,5 m^3/s of the maximum discharge value, considering that the average multiannual discharge is of 1,15 m^3/s. Also, the precipitation values measured at Ardeluța for the period 1981 – 2011 for the month of July indicate an increase of 33 mm, confirmed by the statistical significance of 0.05.

4.3.2. Pointer year analysis

Using the annual variation of the ring width years with extreme climatic conditions can be identified, either positive or negative, due to pointer years. They can be defined considering two elements (Schweingruber et. al., 1990, Kaennel și Schweingruber, 1995):

- event year or characteristic ring – year when the growth is obviously reduced or increased compared to the average ring width;
- pointer year – event year for which most trees in a stand indicate a characteristic year of the same type (positive or negative).

The relationship between the climatic parameters and the pointer years can be identified by studying the correlations between their variation. Both temperature and precipitation data are analysed for two growing seasons, the current and previous one, the influence of both of them on annual growth being important.

For the dendrochronological series of Tarcău, the pointer years were searched along the interval 1800 – 2011, being identified 12 of them, out of which 5 positive and 7 negative (table 3). The analysis of climatic parameters for these years outlines that the temperature variation during the current growing season is the main factor that influences the radial growth. Negative pointer years have a good correlation with years when summer temperatures drop below the average, while positive ones are associated with hot but not dry summers, precipitation deficit reducing growth.

Tabel 3. Poiter years of Tarcău dendrochronological series

Year	Type
1821	**-**
1873	**+**
1893	**-**
1902	**+**
1927	**+**
1937	**+**
1947	**-**
1948	**-**
1949	**-**
1964	**-**
1996	**-**
1998	**+**

5. HYDROLOGICAL HAZARD AND THE ASSOCIATED RISK

5.1. Hydrological hazard analysis

For Tarcău river, as well as the entire country, mainly pluvial floods occur, followed by those caused by rain falling on snow melting. Over 66% of the annual floods recorded between 1991 and 2011 in Tarcău catchment appear during the summer, 26.19% during the autumn (September and October), while only 7.14% of them occur in springtime. Floods occur every year with very high frequency, but in the last 20 years elevated values of the water flow, which exceed multiannual average, appear in 1991, 1998, 2001, 2002, 2005, 2010 and 2011.

Monthly average precipitation recorded at Cazaci and Ardeluța gauge stations for the summer months in the 1991-2011 period range from 112 mm for August (both stations), and 154.4 mm (Cazaci) and 147.3 mm (Ardeluța) for July. The historical precipitation maximum fallen within 24 hour was recorded on the 12 of July 2005 at Ardeluța (150.7 mm) and it's close to the mean monthly values for that same month. This peak caused the flood with the highest maximum discharge recorded at both gauge stations: 217 m^3/s at Cazaci and 127 m^3/s at Ardeluța. SGA Neamț made the floodplain map for Tarcău catchment based on this historical flood of 2005.

5.1.1. The floodplain

For most of Tarcău Valley the water level does not exceed the banks and if another flood like the historical one of July 2005 should occur, only a few areas downstream of Ața and Tarcău junction would be flooded.

Lunca Lăcătușului was flooded quite often, there is a high number of households (20-25) being exposed, while the left bank was eroded in this section (in 2005 the structure of a house had been affected because of the alluvial deposits underneath the building's foundation were removed). In order to protect this area from future floods some works have been done in the autumn of 2011:

- to clean the riverbed, including the removal of a 40.000 m^3 holm;
- attempts to increase the river's slope;
- a 900 m length and 2 m height protection wall was built on the left bank of Tarcău, elevated with another 1 m of alluvial deposits;
- in the areas where the existent thalweg wasn't that obvious, there was an attempt to shift the thalweg towards the left bank, at the bottom of the protection wall.

Consequently, it was necessary to recalculate the floodplain for the section downstream of Cazaci station, down to junction with Bistrița. Recalculation was done based on 111 cross sections, using the HEC-RAS software. The results reveal that the protection works have been done according to the project and they fulfill their purpose; also, the water level calculated for a flood with a maximum discharge of 217 m^3 does not exceed the top of the protection wall.

5.1.2. The dendrohydrological study

Based on the methodology presented in the previous chapter, samples from 34 spruces found on the right bank on Tarcău were analysed. The lack of trees and especially coniferous ones from the left bank made possible only the study of the right bank. Traumatic resin ducts haven't been identified in 38% of the analysed trees, fact that indicates an undisturbed growth. For the other trees traumatic marks have been identified for the years 1942, 1943, 1946, 1947, 1948, 1953, 1969, 1971, 1973, 1974, 1975, 1986, 1994, 1995, 1998, 1999, 2002, 2005, 2006, 2007. Unfortunately, in most cases, there's a low percent of trees that show the reaction for each particular year, and often, the traumatic resin ducts identified for a year appear in just 1or 2 trees. The only event confirmed by the minimum necessary number of trees is the one in 1994, and their location indicates the right bank nearby Frasin and Tarcău junction.

5.1.3. The hydrological hazard map

The floodplain map was obtained for the historical flood discharge, and based on it, the hydrological hazard map. Taking into account the high intensity, (the water level exceeding 2 m at both gauge stations), and the low flooding occurrence probability, a very high hazard was considered for the entire Tarcău valley. For the section downstream of Cazaci gauge station the hazard level fluctuates between very high for the flood channel and high and medium for areas neighbouring it.

5.2. The risk analysis associated to hydrological hazard

5.2.1. Analysis of elements at risk

The elements exposed to risk can be categorized in a wide variety, from population to built structures, economical activities and environmental elements. For the valley of Tarcău, taking into consideration the damage caused by flooding, only the direct or tangible damage were quantified and no loss of human lives were registered. There are 3 categories of elements affected: dwellings and all their dependencies, transport infrastructure and lifelines.

Table .4. Damages according to the type of element affected, for the years 2004 -2012

Type of elements affected	Percent
dwellings and dependencies	1,12
roads, bridges, footbridges and platforms	98,84
electric lines	0,04

The most important damages were recorded in the case of transport infrastructure. The communal road 135 that links Tarcău valley to the national road network is found on the lower terraces of Tarcău and due to the intensive bank erosion it can be affected during floods. Similar situations can occur at junctions because of the undersized culverts Tarcău's tributaries being channeled under the communal road, and also because of the effect of the solid load transported by the water flow. There is a small percentage households damaged due to the low water level in the inhabited areas and the fact that the houses are located at a larger distance from the river banks, so most frequently only the dependencies are affected. Protection measures for flooding and bank erosion are represented by gabionade and concrete walls.

The high degree of estimated hazard and the extension of the floodplain (which with a few minor exceptions practically does not exceed the flood channel) were taken into

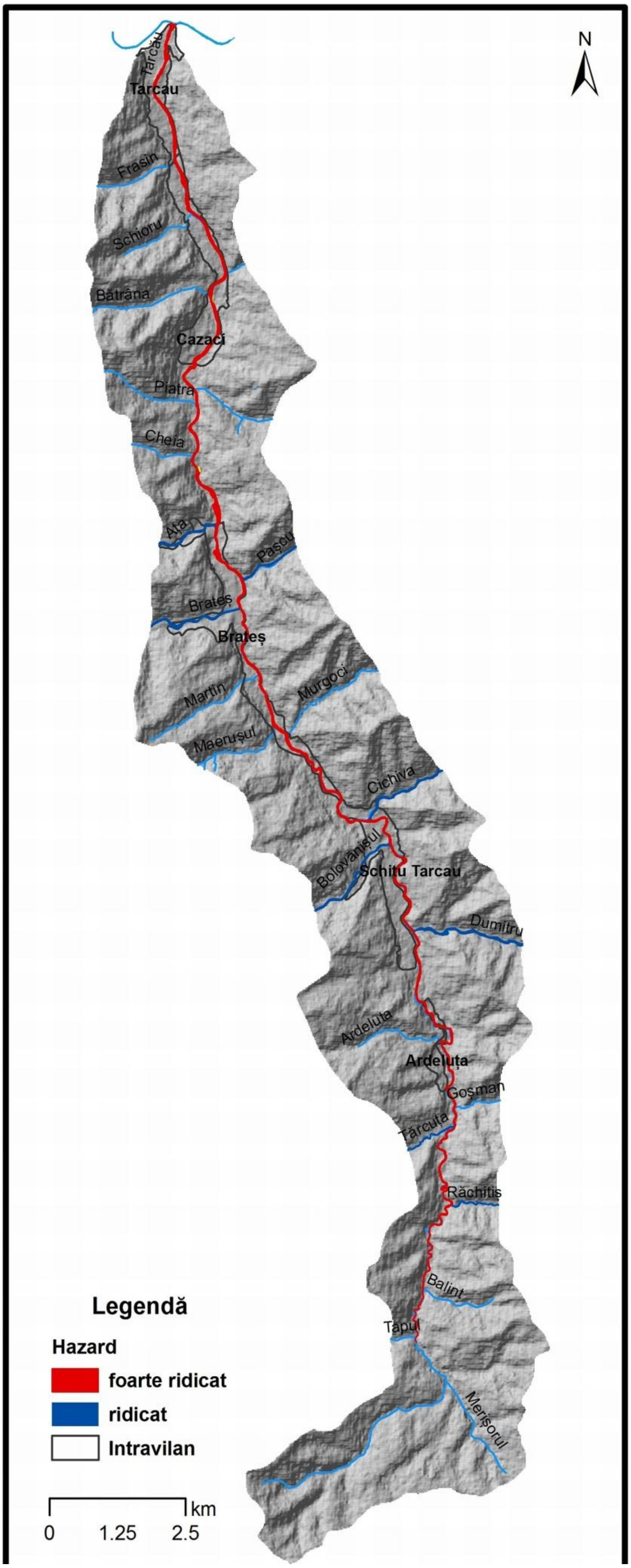


Fig.8. Map of hydrological hazard,   for the valley of Tarcău .

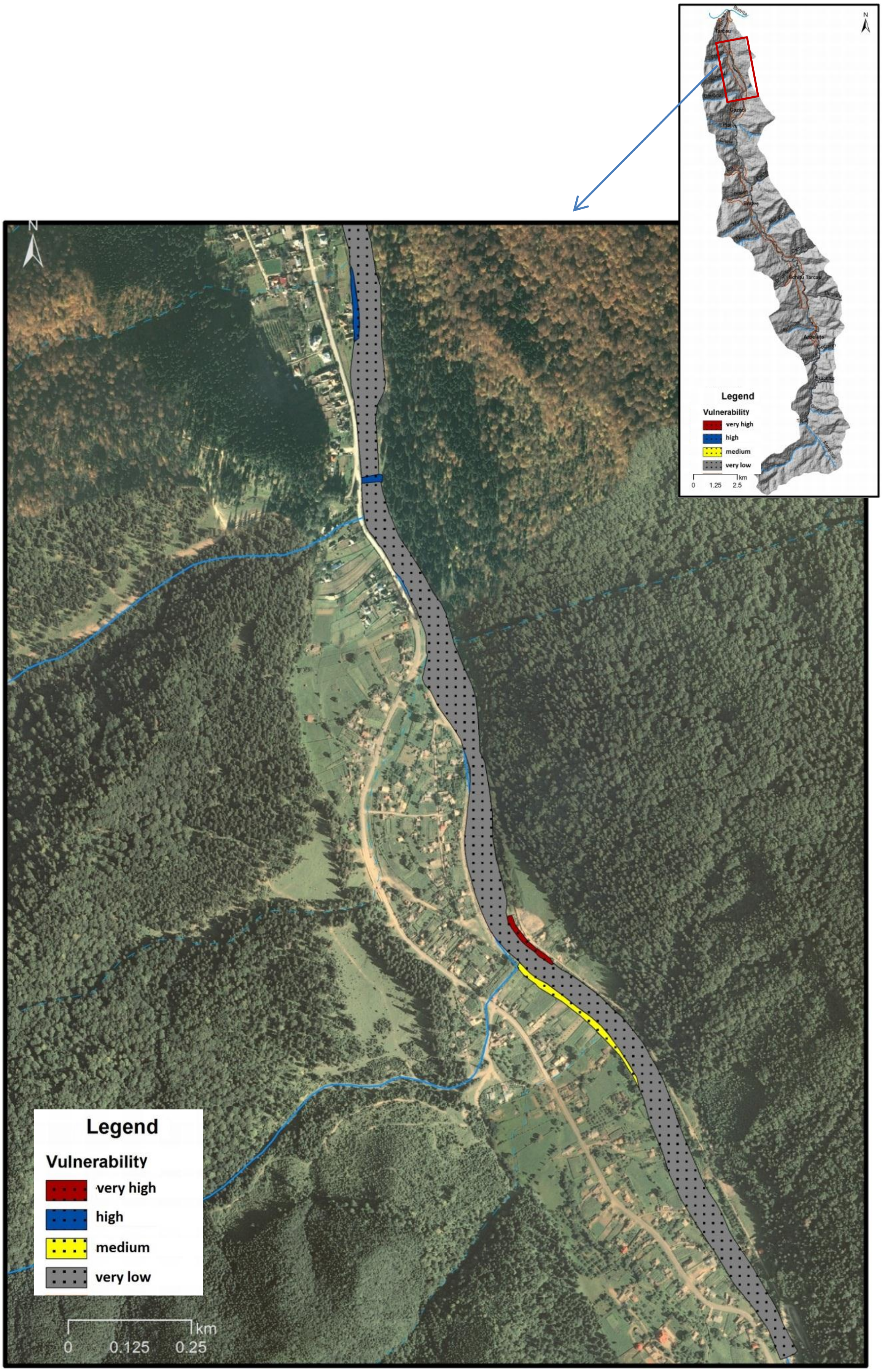


Fig. 8. The vulnerability of elements at risk present in Cazaci village

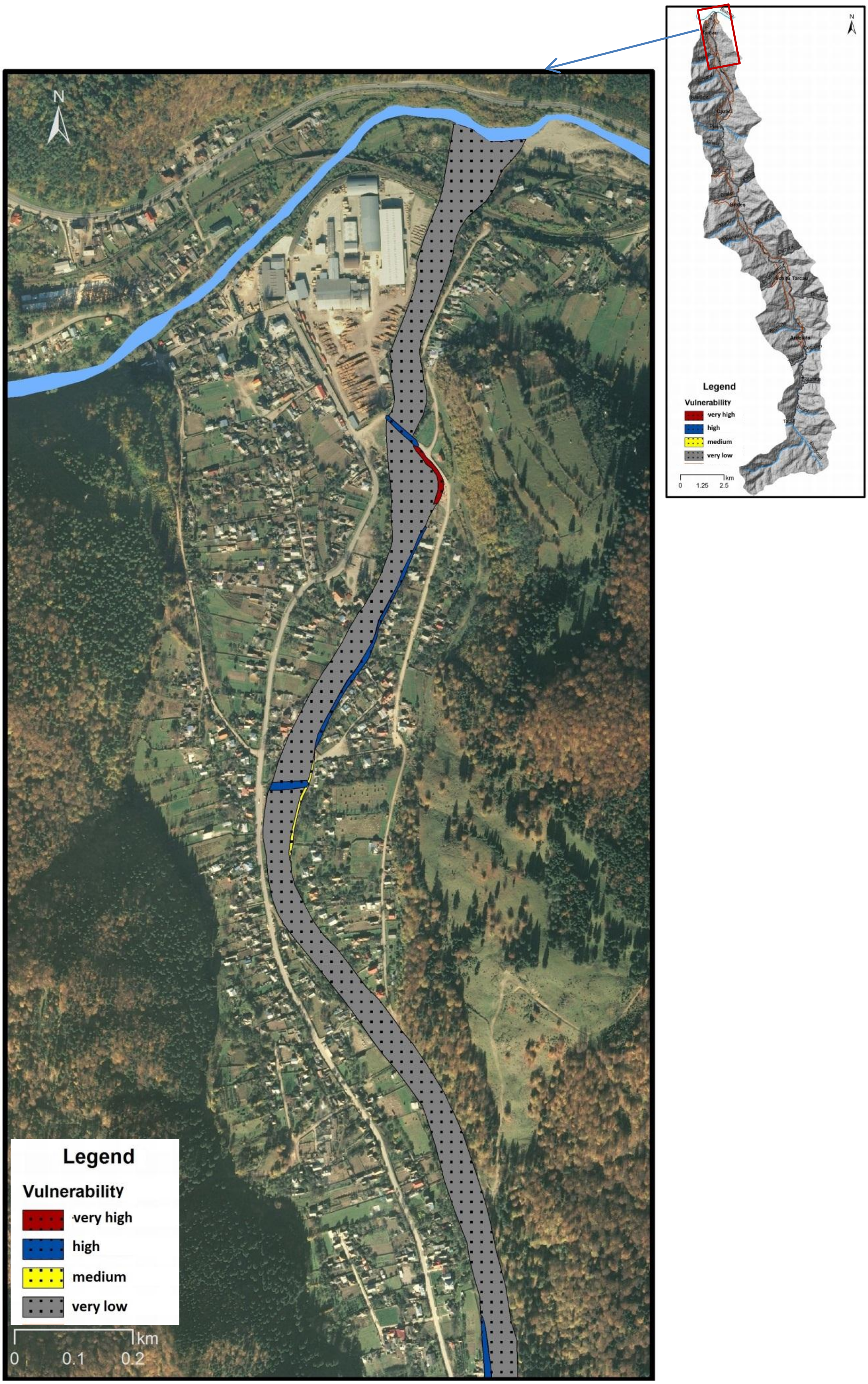


Fig. 9. The vulnerability of elements at risk present in Tarcău village.

consideration when evaluating the vulnerability of elements at risk for the entire valley of Tarcău.

5.2.2. Vulnerability of elements at risk

The elements existing in the riverbed are actually the elements that could be considered at risk, thus bridges being the only ones we can relate to in this case. Consequently, a new class of vulnerability is created, complementary to the matrix in the methodology chapter, that being the very low vulnerability, represented in grey for the riverbed. Practically, the absence of human elements in the riverbed would imply a susceptibility analysis of the riverbed to bank erosion. The lack of information necessary to perform it and obtain a valid conclusion, led only to a very low vulnerability hypothesis.

Due to the riverbed configuration upstream of Ața river the water level in a flood does not exceed the banks. The vulnerable elements downstream of Ața include: 1 bridge, 2 footbridges, 2 village roads, 3 chalets, dependencies and crops.

Each element's vulnerability was classified using information about previous damages, whenever they existed, and also from the perspective of possible physical injuries and of safety, considering the population that may be affected. The high and very high vulnerability prevail, being assigned to transport infrastructure or households and dependencies.

5.2.3. The risk associated to hydrological hazard

The Specific risk is established using the formula $R_s=H\cap V$, and the risk map is obtained by crossing the hazard map with the vulnerability one. Taking into account the categories of hazard and vulnerability identified for the analysed areas, they are combined into the matrix shown in figure 4 to reveal the risk level. Same as in the vulnerability case where the very low class was created, residual risk class was inserted to show the situation where very low vulnerability intersects very high hazard, both found in Tarcău riverbed. With a small number of vulnerable elements, very high hazard prevails. It consists mainly of infrastructure elements as bridges, footbridges and village roads. A high and very high risk is assigned to these elements due to the probability of them being affected, and disturbance or even closing down the traffic leading to temporary isolation of a smaller or larger number of people depending on the event's location. There are also a few areas where a large number of dependencies and crops are exposed to a medium or high risk, depending on the situation.

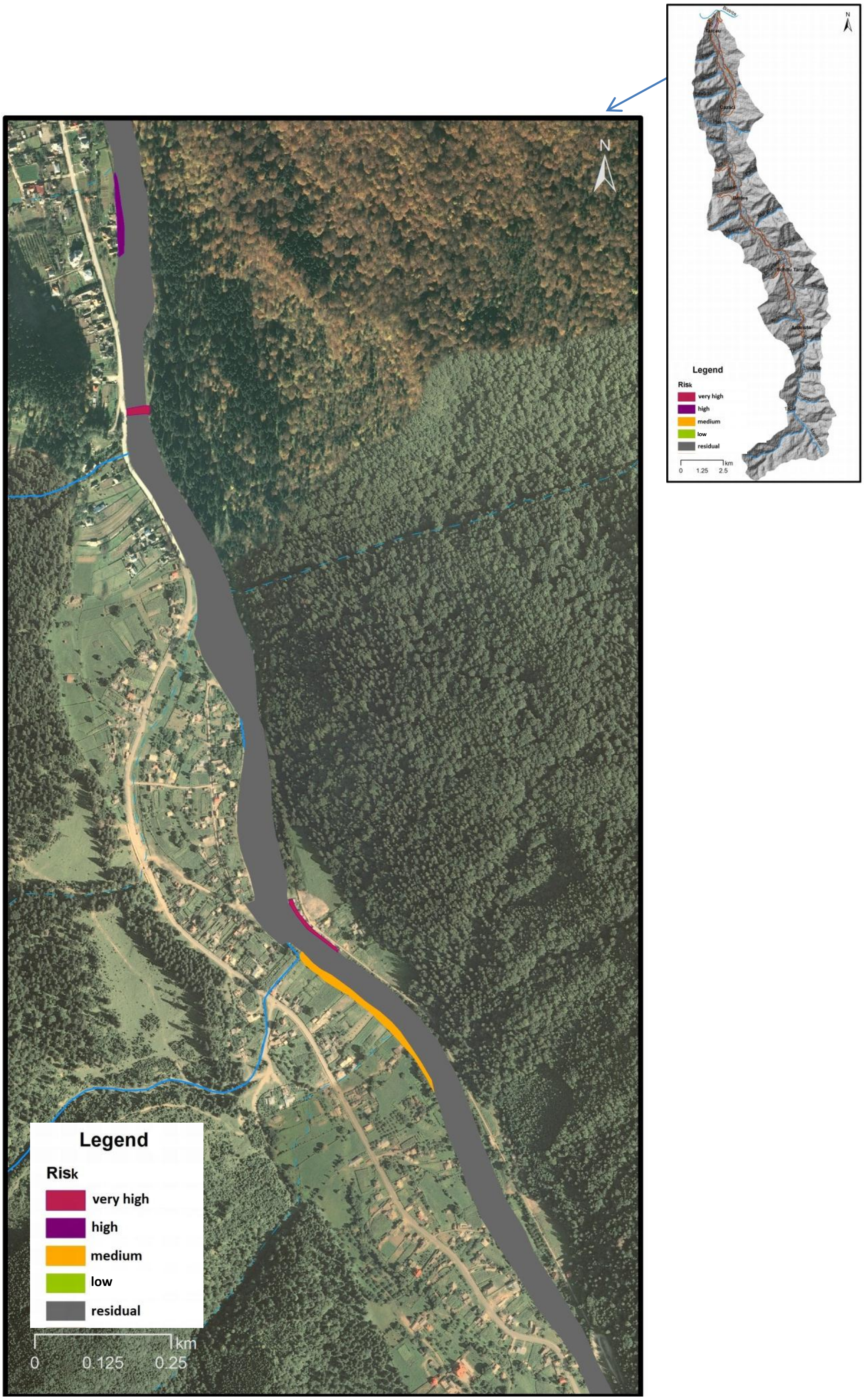


Fig.11. Map of risk associated to the hydrological hazard for the village of Cazaci.

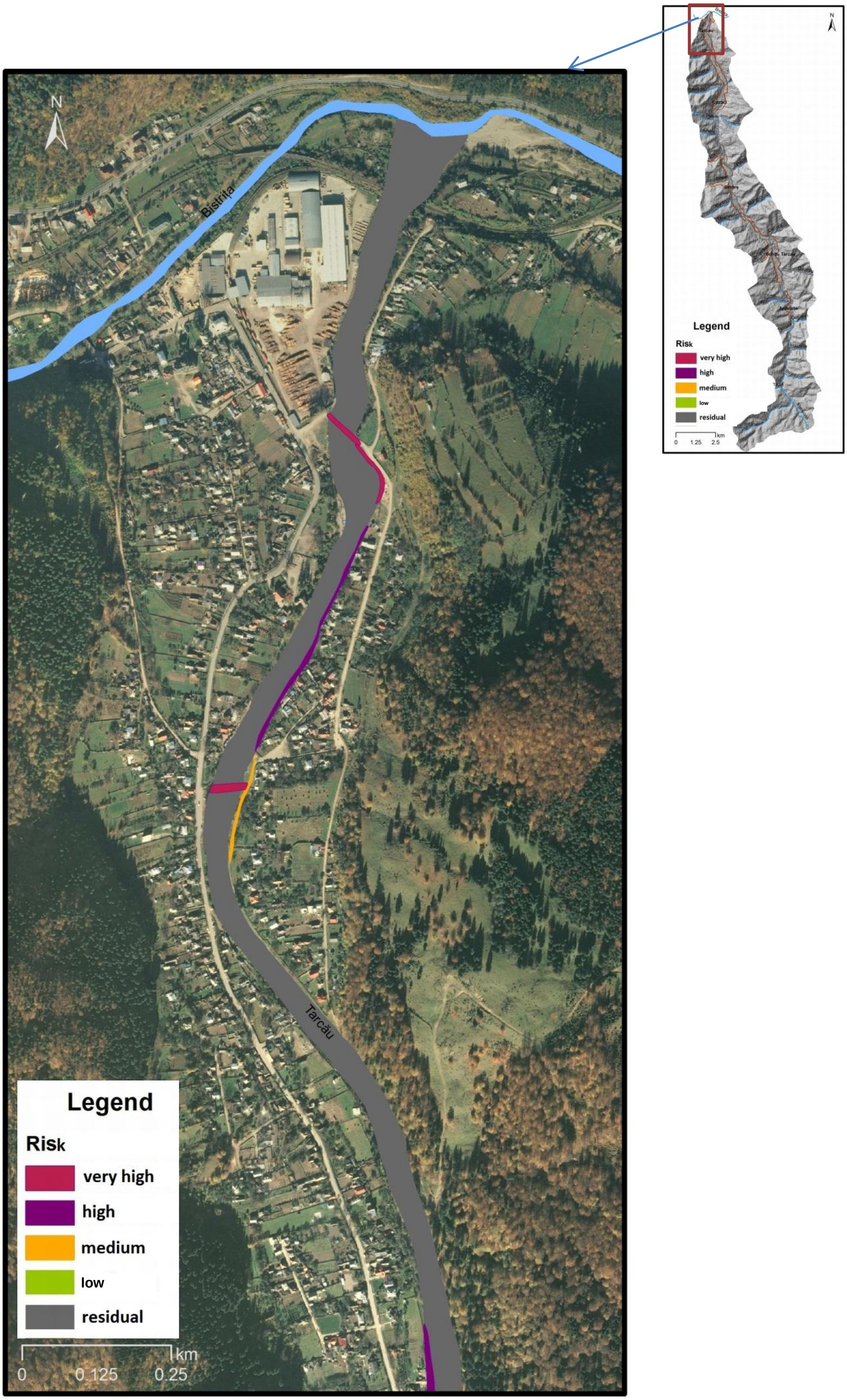


Fig. 12. Map of risk associated to hydrological risk for the village of Tarcău.

6. GEOMORPHOLOGICAL HAZARD AND THE ASSOCIATED RISK

6.1. Geomorphological hazard analysis

Forms resulting from linear erosion (gullies and torrents) stand out in the valley of Tarcău, along with falls. Their formation and the development of these elements is linked to a series of factors: climatic, geomorphological, lithological, biogeographical, and the human one. Maybe the most important one which leads to intense activations are the precipitations. In his studies on Pângărați catchment Radoane N. (1980) assigned a high importance to rainfall that exceeds 50 mm/24 h. The events recorded in Tarcău valley for which the exact occurrence date is known, and daily precipitation values are available are few, but they also indicate values over 50 mm/24 h.

The human intervention is a result of forest exploitation activities. Although the completely deforested areas are not extensive, the constant lot exploitation affects the terrain's integrity and slope stability. Very often, the water flow follows forest roads or the marks left by the dragging of the exploited wood, and thus small gullies often appear.

Large gullies are scarce since the hardness of the substratum and the low quantity of deluvium formed above it are limiting the deepening of the erosive geometry up to a gully's size. The gullies present on high terraces are a particular case. There is a series of gullies upstream and downstream of Gloduri torrent (on a 35-40 m terrace), which cut the scarp of the terrace and their advance regressively on the top of terrace.

The methodology used in hydrological hazard analysis was adapted to develop the hazard, vulnerability and risk map in the case of geomorphological processes also. The information necessary to establish the phenomenon intensity according to Tyrolian methodology's threshold values are missing. That and the impossibility to determine a return period for each one lead to 3 new types of hazard determined by using previous information: low, medium and high hazard. The matrix used to combine the vulnerability and hazard degrees to obtain the risk levels was preserved.

The protection measures implemented for the areas flooded by Tarcău river reduced the vulnerability of the exposed elements but in this situation the measures were not effective, being incorrectly executed or incomplete. Their effect is almost null and even if the solid load is captured behind the protection wall, the water's erosive action upon the road is not removed. This means that the communal road and the households nearby are likely to be flooded each time there's a heavy rain or a fast snow melting.

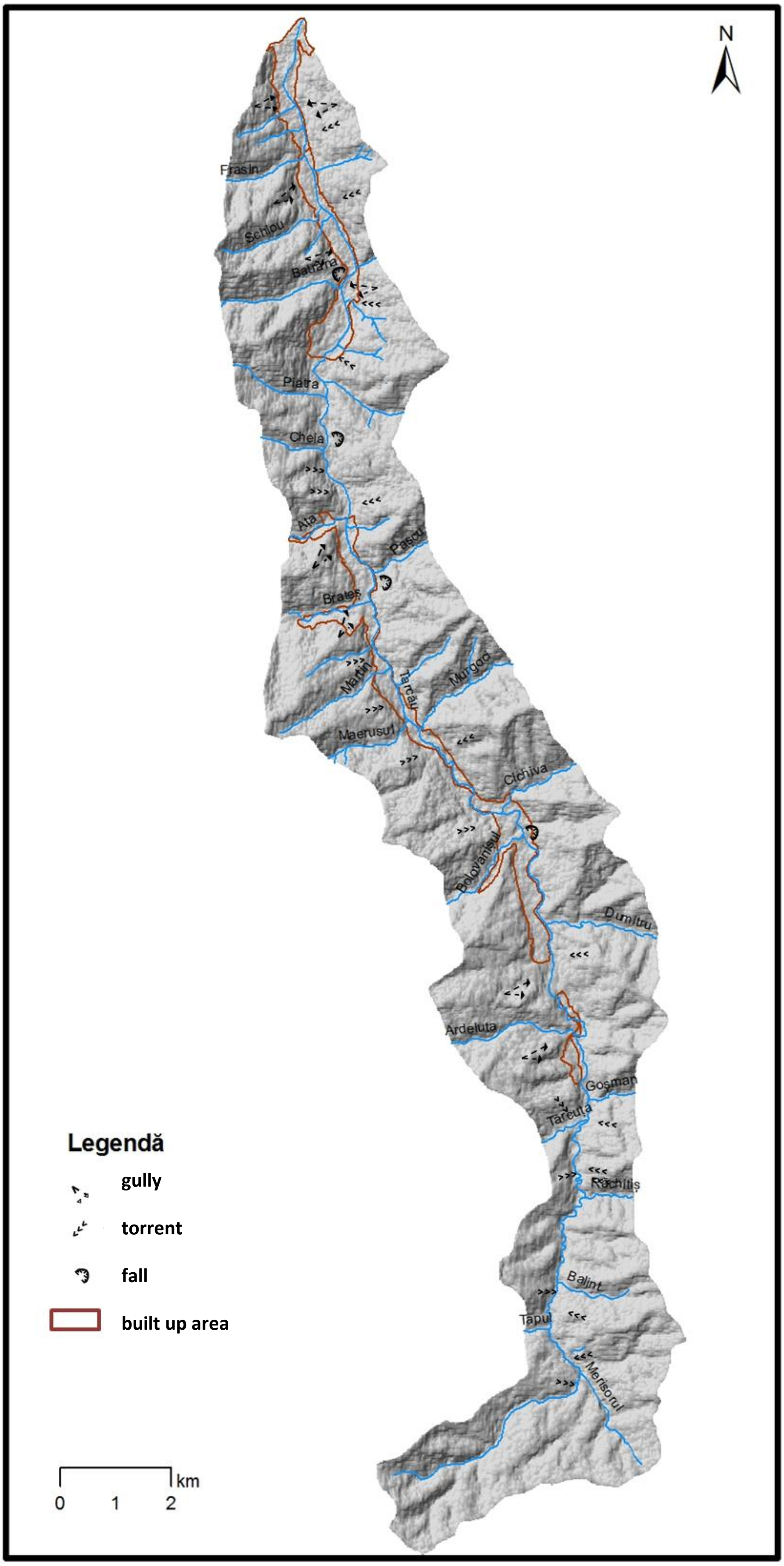


Fig.13. Map of contemporary slope geomorphological processes in Tarcău river valley.

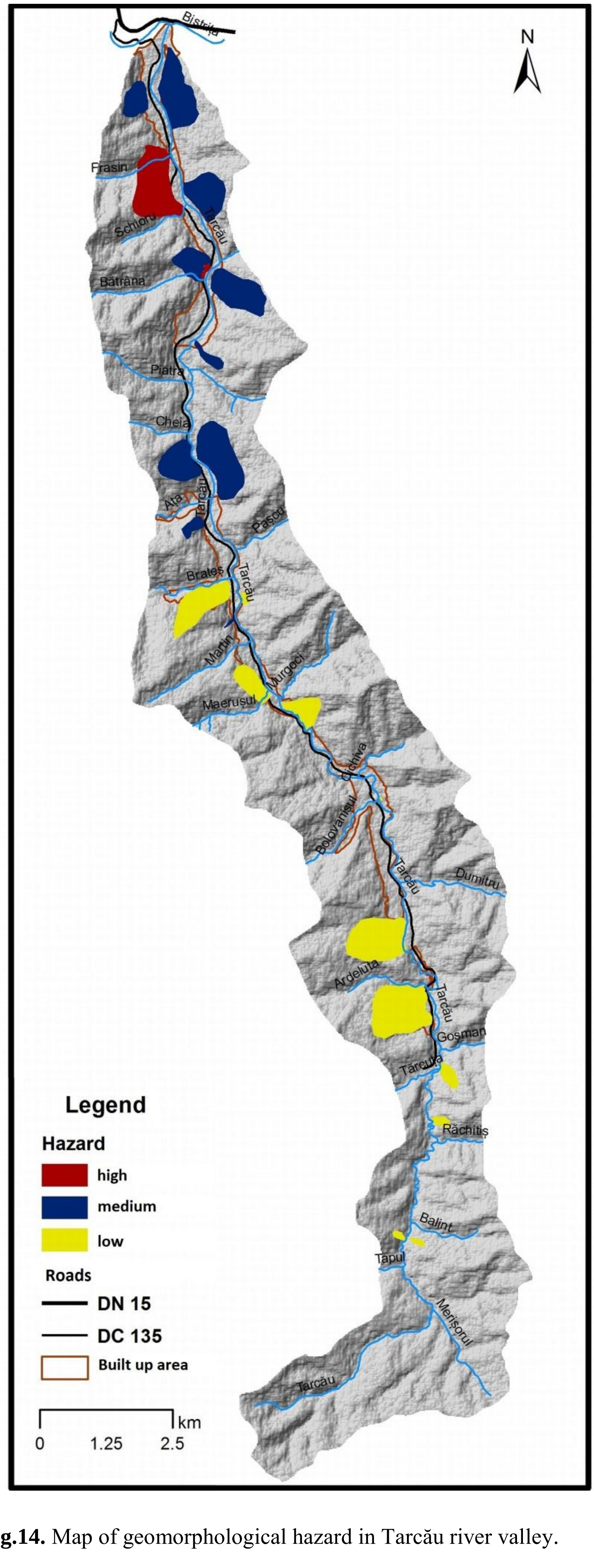


Fig.14. Map of geomorphological hazard in Tarcău river valley.

6.2. Analysis of the risk associated to geomorphological hazard

The vulnerability of the elements at risk was estimated using the damages caused by the geomorphological processes in the previous years to the transport infrastructure, it being the only element affected. Four degrees of vulnerability were established - very low, low, medium and high:

- the forested areas were classified as having a very low vulnerability, the transport infrastructure not being present there ;
- in the situation where the dwellings are not damaged but only their dependencies the vulnerability is considered to be low;
- the areas where elements at risk include secondary roads are assigned a medium vulnerability. We refer mainly to the road on Tarcău's right bank, which follows the former mountain train route, and ca be used as an alternative access route for some areas when DC 135 is partially closed;
- to the communal road 135 a high vulnerability is assigned.

The main elements at risk are the roads, followed by dependencies, but in a much smaller proportion. The same as in hazard, the medium or high vulnerability areas are found mainly in the lower sector of the valley, where the human elements are much more frequent.

The degree of risk for each particular area is obtained by combining the information available on the hazard map with the one on the vulnerability map. The areas with high vulnerability in Cheia and Tarcău junction, Batrâna and Tarcău junction and the sector between Schioru creek and Frasin, are therefore identified as 3 areas with very high risk. Considering the isolated location of medium and high risk areas and their small surface, we can conclude that there's a low risk associated to the geomorphological hazard in Tarcău Valley.

Last but not least, we must take into account that hydrological and geomorphological extreme phenomena often occur simultaneously in space and time, large amounts of precipitation triggering their occurrence. Therefore, managing one of these extreme processes must not exclude the other.

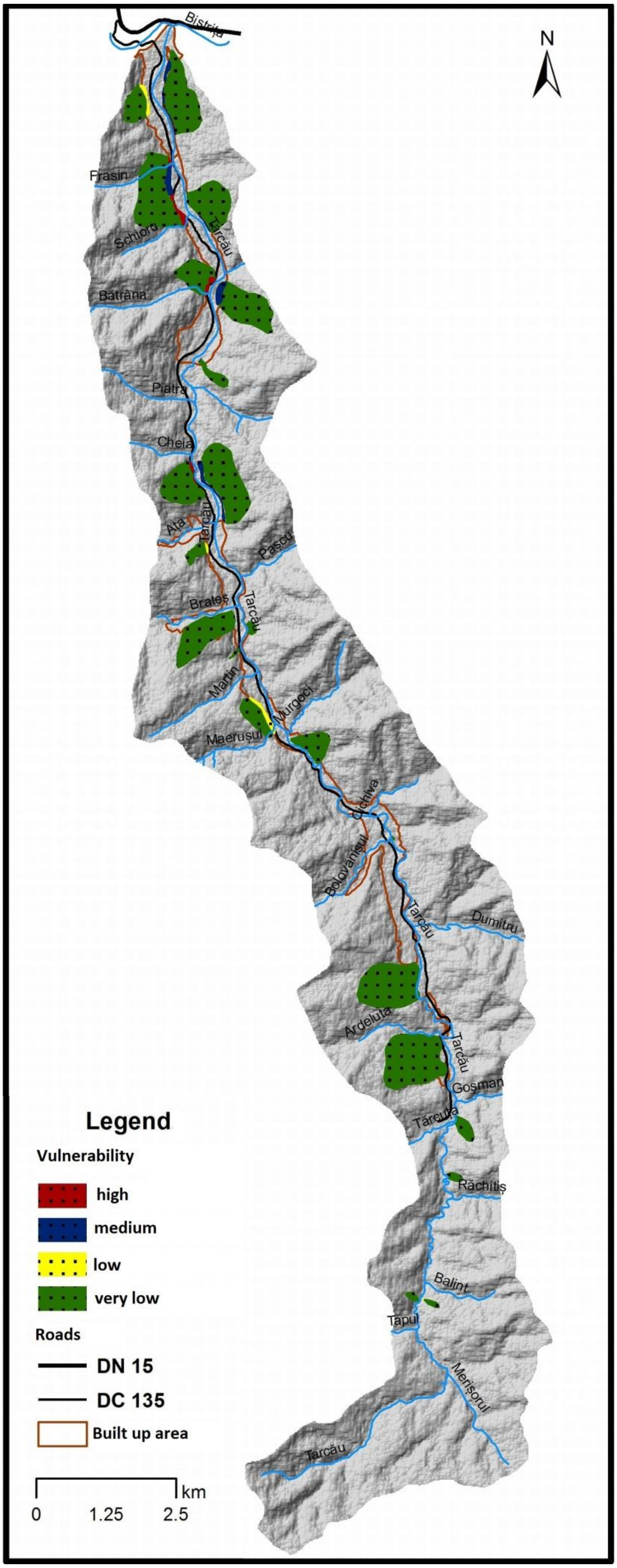


Fig.16. Map of vulnerability of the elements exposed at the risk associated to the geomorphological hazard for the Tarcău river valley.

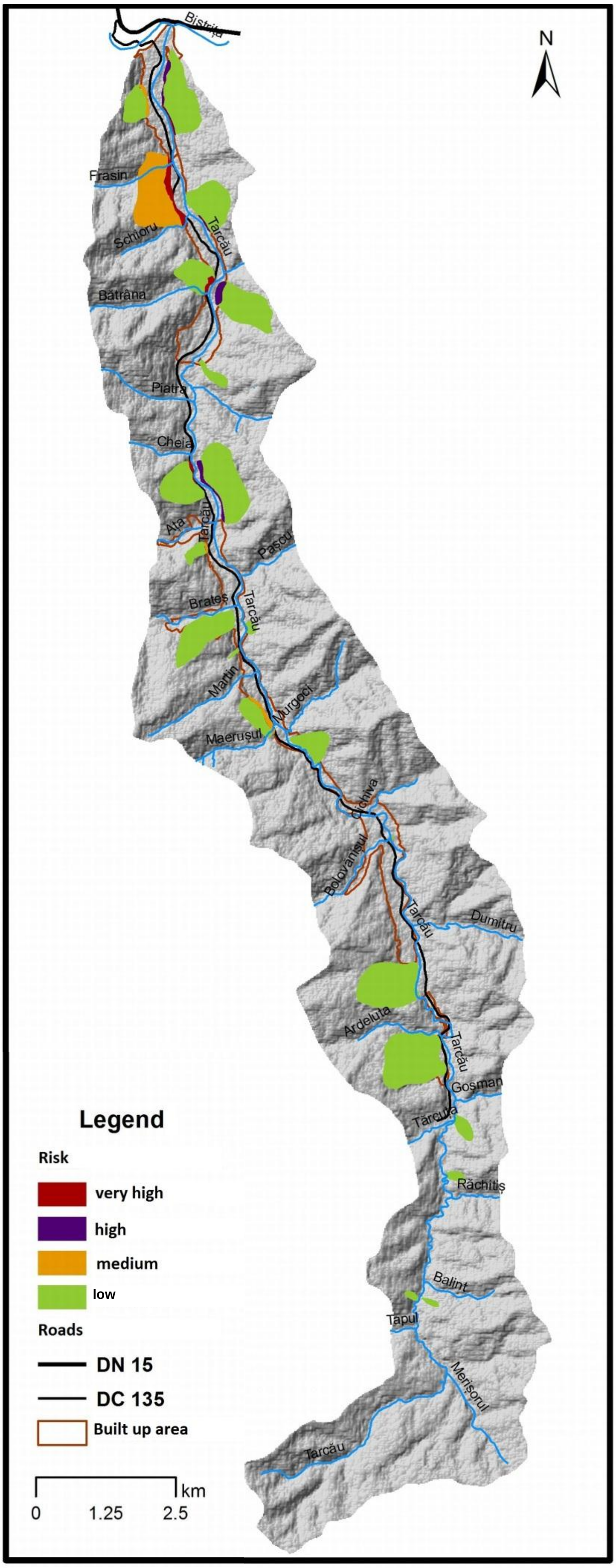


Fig.17. Map of risk associated to the geomorphological hazard in Tarcă river valley.

7.CONCLUSIONS

In an attempt to capture the individuality of the studied area, methodologies conceived for mountain areas were applied and results interpretation was performed by analyzing the output data, although this data was not always sufficient.

Floods are the main extreme phenomenon, but along with slope linear erosion they highlight precipitations' role in the occurrence of extreme phenomena in Tarcău river valley. Their quantity, intensity and spatial distribution determine the manifestation of hydrological and geomorphological processes.

The geological substratum and the forest coverage are the other two important elements that control the evolution of different processes in the studied area. The presence of thick layers of massive sandstones influences both the river bed and the slopes. The river bed overlaps a syncline that determines high banks, limiting thus the flooded areas, while for the slopes it ensures stability, accentuated declivity and fragmentation.

A high percentage (83%) of Tarcău's catchment is covered in forest that implies a high rain interception, reducing thus the concentration time in the case of floods, and the erosive power of the water that reaches the soil. Its influence can be seen in the activity of geomorphological processes that is more intense in the deforested areas.

Also, the extension of coniferous forests, allowed the use of trees as indicators of the dynamics of the climatic and hydrological phenomenon. The results of dendrohydrological study, confirm the reduced extension of the flooded areas, and thus a reduced water depth on the overbanks that is used to establish the hazard's degree. The dendroclimatological study indicates climatic stability, with a slight positive trend reflected in the higher values of the climatic parameters for the last century.

The results of the risk analysis indicate an overall very low (residual) and low risk associated to the hydrological hazard and a low risk induced by the geomorphological hazard, and just in small areas high level of risk induced by both types of hazards. This degrees of risk result either from the combination of a high level of hazard and a very low vulnerability as in the case of the hydrological phenomenon, or from low levels of both parameters as in the case of the geomorphological ones. Although the hydrological hazard is very high, it induces a residual and low risk, due to its extension just in the river bed where the human elements exposed at risk are very few, but also due to the protection works that reduce the vulnerability of the elements at risk.

On the contrary, in the case of geomorphological processes, the absence of protection works, or the inefficiency of some of them allow intense manifestations whose consequences are reflected in the medium and high vulnerability of roads. Therefore, other measures to reduce the negative effects generated by the solid material deposited on the road should be considered.

According to the one dimensional floodplain modeling, the elements at risk exposed to hydrological hazard, are just small crop areas, household dependencies, elements of transport infrastructure. However, considering the recent river bed calibration, the absence of last year's floods that would confirm the estimated water depth in the new river bed configuration, no new flood protection measures should be planned for these vulnerable areas.

It results that the transport infrastructure is the main element at risk associated to both types of hazard. Depending on its future vulnerability also, measures of reducing it should be considered because the maintenance costs are too high and the valley's connectivity to the national infrastructure is low, reduced to the communal road only.

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