

Research Article

Georgiana Vaculisteanu, Mihai Niculita, and Mihai Ciprian Margarint*

Natural hazards and their impact on rural settlements in NE Romania – A cartographical approach

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Abstract: Natural hazards are the most significant threats in rural areas of Romania, while landslides, floods and bank river erosion are the geomorphological processes that impose the greatest risk in the Moldavian Plateau. We have identified 189 of disappeared, displaced and partially affected villages (in the area between Siret and Prut Rivers), using old cartographic materials as primary tool, and overlapping them with the present situation: orthophoto imagery and LiDAR derived high-resolution Digital Elevation Models (DEMs). The main natural hazards that affected the settlements were landslides (63%), floods (26%) and river bank erosion processes (11%) and in 19% of the cases the settlement completely disappeared. We also present seven study cases, three for landslides, three for floods and one for river bank erosion in order to detail how these natural hazards impacted the physical environment of the settlements. In the Moldavian Plateau the mentioned natural hazards played an important role in the dynamics of the settlement network, with variations induced mainly by the socio-political characteristics and not necessarily by the frequency variation of the natural hazard events. Such studies are needed in order to depict the vulnerability and risk scenarios, especially for the back-analysis, but also considering that future climate changes might impose changes in hazard, vulnerability and risk associated to settlements.

Keywords: natural hazards, landslides, flood, bank erosion, rural settlements, abandoned settlements, Moldavian Plateau, old maps

1 Introduction

Natural hazards affect millions of peoples every year around the Globe. Their negative impact register a constantly growing due to the rapid increase of world population, concentration of people and their economic activities and assets, emergence of new vulnerabilities and hazards [1]. As a direct consequence, some scientists are already framing human society in a new "era of catastrophes" [2]. This reality is closely connected with a constant growth of technology in spatial data acquisition, visualization, and analysis [3], communication and media [4], social networks [5], and a general growth of people's sensitivity to the risks associated with natural hazards.

But natural hazards are not only a present day threat for human society. Natural hazards have always been manifested and, as they do nowadays, they have affected human society with serious consequences and fatalities recorded on all continents [6–8]. Unfortunately, sometimes many of these past events are less known, sometimes they were lost in time. This is a characteristic for low magnitude events which affected local and isolated communities. More than that, some totalitarian social-political administrations have tried to reduce the impact of natural hazards and even to use their consequences for different purposes.

The study of the past events constitute a milestone in risk analysis and management, due to their capacity to offer a better phenomenological understanding, in order to evaluate the aftermaths, and to offer a background for the future scenario-based vulnerability and risk assessments. These can really increase the capacity of local communities to improve the level of resilience, to increase the level of preparedness and to find any available solution to mitigate the impact of natural hazards at least at a local scale.

As most of the natural hazards affect large territories (droughts, earthquakes, tsunamis, tropical cyclones), some of them are concentrated in a certain location (landslides, snow avalanche, flash floods) generally in a short temporal scale [9]. In these cases, the local topography

*Corresponding Author: Mihai Ciprian Margarint: Alexandru Ioan Cuza University of Iasi, Iasi, Romania;
Email: margarint.ciprian@yahoo.com

Georgiana Vaculisteanu, Mihai Niculita: Alexandru Ioan Cuza University of Iasi, Iasi, Romania

and the characteristics of landforms can lead to concentration on some areas of the impact of hazards, until reaching thresholds from which damages can be devastating. If these areas are overlapping on highly vulnerable communities, they can decisively affect the structure and functionality of an entire settlement.

Regarding the future impact of natural hazards, climate changes will influence the frequency and the impact of natural hazards in Europe [10–14] and in Romania [15–17]. Changes in precipitation extremes [18–20] will impact river flow [21–23], floods and landslides [24]. In this context it is very important to study past events and their impact on society, in order to build-up vulnerability scenarios. This back analysis can also reveal mistakes that were made in the past by the society, and should be avoided in the future.

The recent availability of cartographic websites such as <https://mapire.eu> [25] or <http://www.geo-spatial.org> [26], remote sensing historical imagery such as Google Earth [27] along with the classic printed maps offer now a real background in identification and mapping the spatial dynamic of settlements. By overlapping with other thematic layers such as high-resolution LiDAR Digital Elevation Models (DEMs), georeferenced aerial photos or Unmanned Aerial Vehicle (UAV) images, new ways in the assessment of hazards and their associated landforms (spatial expansion/mapping, typology, magnitude, consequences), and their impacts are emerging [28–30].

In this study we propose a regional approach of past natural hazards that affected in the last century hundreds of rural settlements in Moldavian Plateau, North Eastern Romania. Due to their geographical location, geological and geomorphological background, this region is exposed to many natural hazards such as climatic (heat waves, droughts, rainstorms, hail, snowstorms), hydrologic (floods), geomorphologic (landslides, river bank and soil erosion) and earthquakes [24, 32–41]. During the last century, this region registered important land use changes, due to agricultural practices, deforestation, technical works for land improvement [42, 43]. Over time, some of these hazards had a strong spatial concentration and triggered the abandonment of parts or even the entire of some undeveloped, vulnerable rural settlements. It is the case of landslides, floods and associated processes of river bank erosion, which affected 189 in the Moldavian Plateau [44, 45].

Thousands of years ago, people used landslide crowns as the best places to establish their settlements with a pragmatic defensive purpose [36]. In the last centuries people preferred to locate the settlements along the slopes, to avoid windy interfluvies or flood plains and to benefit

from the shelter location and water resources [42]. Communist period which Romania passed between 1947 and 1989, has been characterized by a policy of territorial systematization [46, 47], based in certain cases on the aftermaths of natural hazards and forced the inhabitants to move to other places [48]. Along with the individual and social traumas that are unfortunately rarely recorded nowadays, the maps remain at present one of the basic tools that any risk assessor needs to study.

We have identified a number of 189 villages affected by natural hazards, part of them have disappeared or displaced in some cases in regions with high susceptibility to floods and landslides, and worrying is that these phenomena are still happening nowadays. These settlements are classified as: disappeared, displaced and partially affected villages. Some characteristic case studies are discussed in a detailed way, and the paper ends with formulating a series of relevant conclusions.

2 Study area

The Moldavian Plateau is located in the North-Eastern part of Romania; it is a hilly area with a monoclinical geological structure, sedimentary strata, and altitudes ranging between 3 and 794 m above sea level (a.s.l.) [39, 49]. In the Moldavian Plateau steep hillslopes (slopes higher than 5 degree) cover 38% of the surface and floodplains 20%; [39]. The physical-geographic conditions induce a high susceptibility to floods and landslides [39] in the conditions of a relatively high degree of vulnerability of rural communities [50]. Landslides cover almost 19% of the total surface [39]. The study area of the present paper, which is a part of the Moldavian Plateau (24,803 sqkm), located between Siret and Prut Rivers, represents 88% of the plateau surface (Figure 1).

The climate is temperate continental, with mean annual precipitations ranging between 450 to 750 mm. According to Walter-Lieth plots of meteorological data for Botoșani, Iași and Galați meteorological station stations, from the ECA&D dataset [51] for the 1961-2018, the mean annual rainfall quantities are 566-572 mm, the mean monthly rainfall values lower than 40 mm appear in winter and autumn, the mean monthly rainfall maximum is registered in June or July (up to 90 mm) and the August and September period is semi-arid. During the late spring and the beginning of the summer the maximum rainfall quantity falls, generating floods on the major rivers, while during spring, summer and autumn intense rainfall can cause local flashfloods [40, 52–54]. These floods are related to the

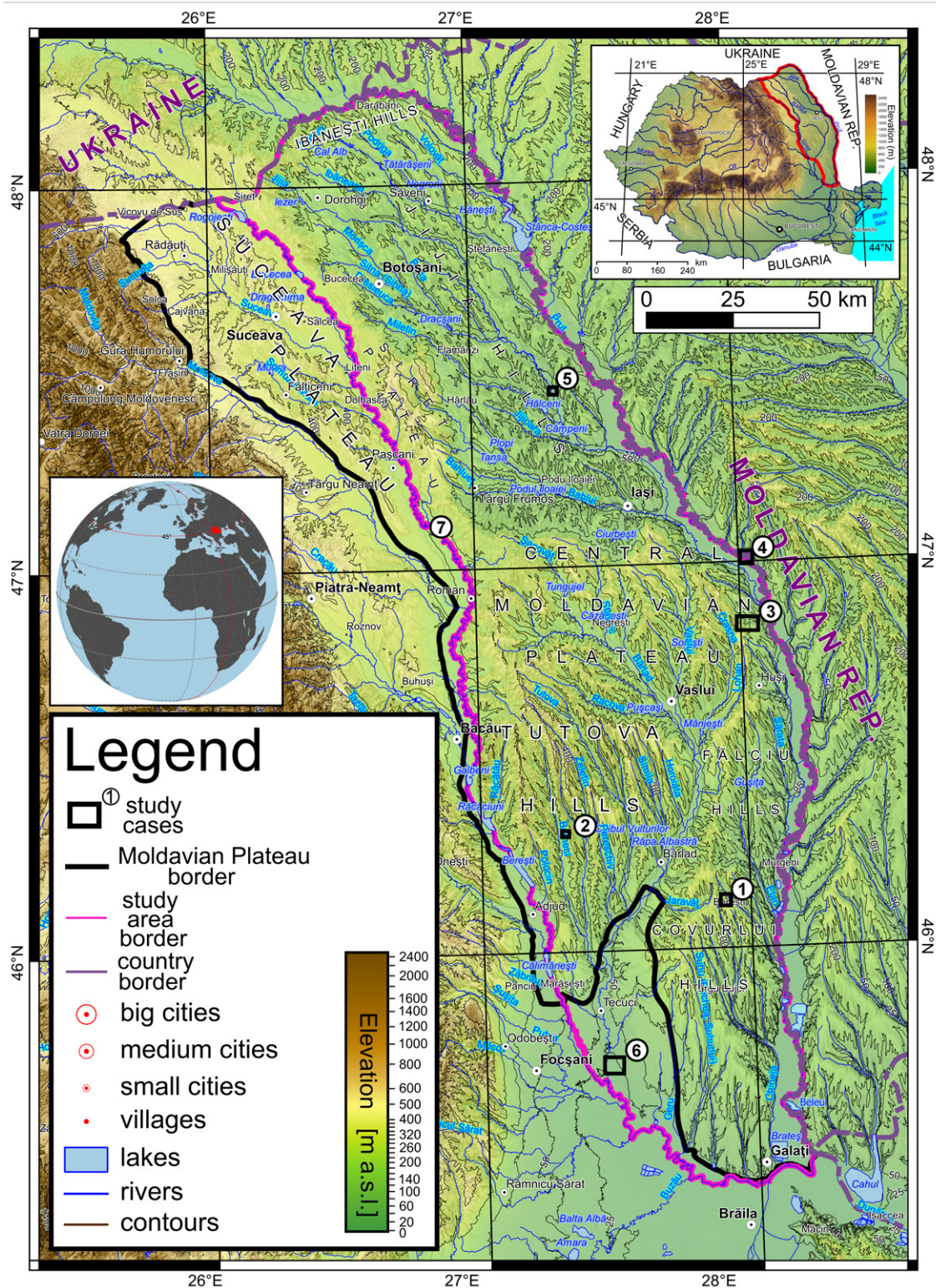


Figure 1: The geographical location of the study area. The numbers from 1 to 6 indicate the locations of study cases, according to the Table 2; 7 - Alexandru Ioan Cuza Village.

circulation induced by the Mediterranean cyclonic circulation, its retrograde movement over the Black Sea and relations with the main anticyclones, convection and blockage conditions and cut-off nucleus appearing over Romania [52, 55, 56]. Usually very big floods were generated by generalized rains during one to three months between May and July [55].

The most quantitatively significant rainfalls that triggered generalized floods both on Siret and Prut catchment were registered in 1504, 1670, 1893, 1897, 1901, 1912, 1914, 1932, 1969, 1970, 1975, 1988, 1991 [55], 2005, 2008, 2010 [57, 58]. On the Siret and Prut tributaries, important floods occurred in the Bârlad basin in 1730, 1846, 1912, 1969, 1985, 1988, in Jijia Basin in 1914 and 1969. In 1969 in the study area the floods were generalized on almost all rivers [54, 55, 59].

The floods before 1960 (when hydrotechnical works were started by the communist regime) generated the biggest losses [53–55, 60, 61]. After 1990, although the mean discharges registered the lowest values [23], important floods with great losses appeared in 1991, 1998, 2005, 2007, 2008, 2010 [54, 61], on Siret the biggest historical flood being the one from 2005 and on Prut the one from 2008. Flashfloods on small river catchments were registered in 1897 and 2010 in Buhaiu catchment [55], in 1991 in Caina catchment [55], in 1991 in Polocin catchment, in 1994 in Huși area, in 1985 in Sacovăț catchment, in 1972 in Zeletin and Berheci catchments, in 1965 in Sitna catchment, in 1979 in Miletin catchment and in 1985 in Bahlui catchment [55].

Landslides in the study area are relict and old [36, 39], with reactivations triggered especially by rainfall events of different durations, during spring, summer or autumn [24, 62, 63]. Because the magnitude and the movement speed of recent events is not high, there are no human losses, but these phenomena generate serious consequences to human settlements and infrastructure [62]. The climate changes scenarios for the study area [24] show that probably the annual rainfall quantities will increase in future, with the increase of the intense rainfall also. This new wet period, at least similar with the 1960–1990 period, will increase the hazard of floods and landslides [24].

River channel migration is an important natural hazard that physically affects settlements located in the floodplains and on terraces, in Moldavian Plateau. The magnitude of the phenomenon is dependent on the size of the river discharge (water and sediment), on its channel morphometry and typology [64] and on the hydrotechnical works. Continuous adjustments between incision with up to 1.5 m, water and sediment fluxes controlled by climatic factors and disturbed by anthropic influences were shown

to exist for Siret River channel in the last 50 years [65]. Siret River showed in the last 60 years rates of up to 15 m/year lateral migration, especially in the sectors with meandered channels [64]. For Prut River both incision and aggradation are recorded downstream of Stâncă-Costești reservoir [66, 67], finalized in 1978. The Prut River showed remarkable rates of lateral migration before the construction of the Stâncă-Costești dam (prior to 1978) of up to 400 m in 80 years in the sectors where the meanders evolved through downstream progression toward cut-off [37]. In the last 36 years, in general the lateral migration greatly reduced, but there are small sectors with rates of 50–80 m migration in this period [37].

3 Materials and methods

The main approach of study (Figure 2) was the cartography of the settlements using various cartographic sources, covering the last 100 years. Starting from a list of settlements (the list of Romania localities from <http://www.geo-spatial.org/download/romania-seturi-vectoriale> [68] and the digitized settlements from the RoHGIS project, <http://www.geo-spatial.org/download/rohgis> [69]), we have searched, digitized and flagged the areas where there was a negative difference (disappearance) in the extension of the settlement at a certain temporal level. Beside the settlements from the list, we have fully browsed the topographic maps at a certain zoom level in order to identify missing/disappeared settlements (Table 1). For every settlement, where such a variation in extension have been registered, a digital geodatabase was compiled, and furthermore, additional cartographic and remote sensing data were used to identify the spatial extension of the disappeared/affected settlement and the causes. In order to better understand the topographic background of the location of each settlement, LiDAR high-resolution DEMs were extracted from the database provided by Prut-Bârlad and Siret Water Administrations. Furthermore, the scientific literature and archives were studied in order to identify details about the events that generated the disappearance/resettlement of localities as a part or as a whole. Fieldwork was performed in order to assess the causes of disappearance/resettlement.

4 Results

Natural hazards vary in magnitude and intensity in time and space [70]. Between Prut and Siret Rivers, in an area

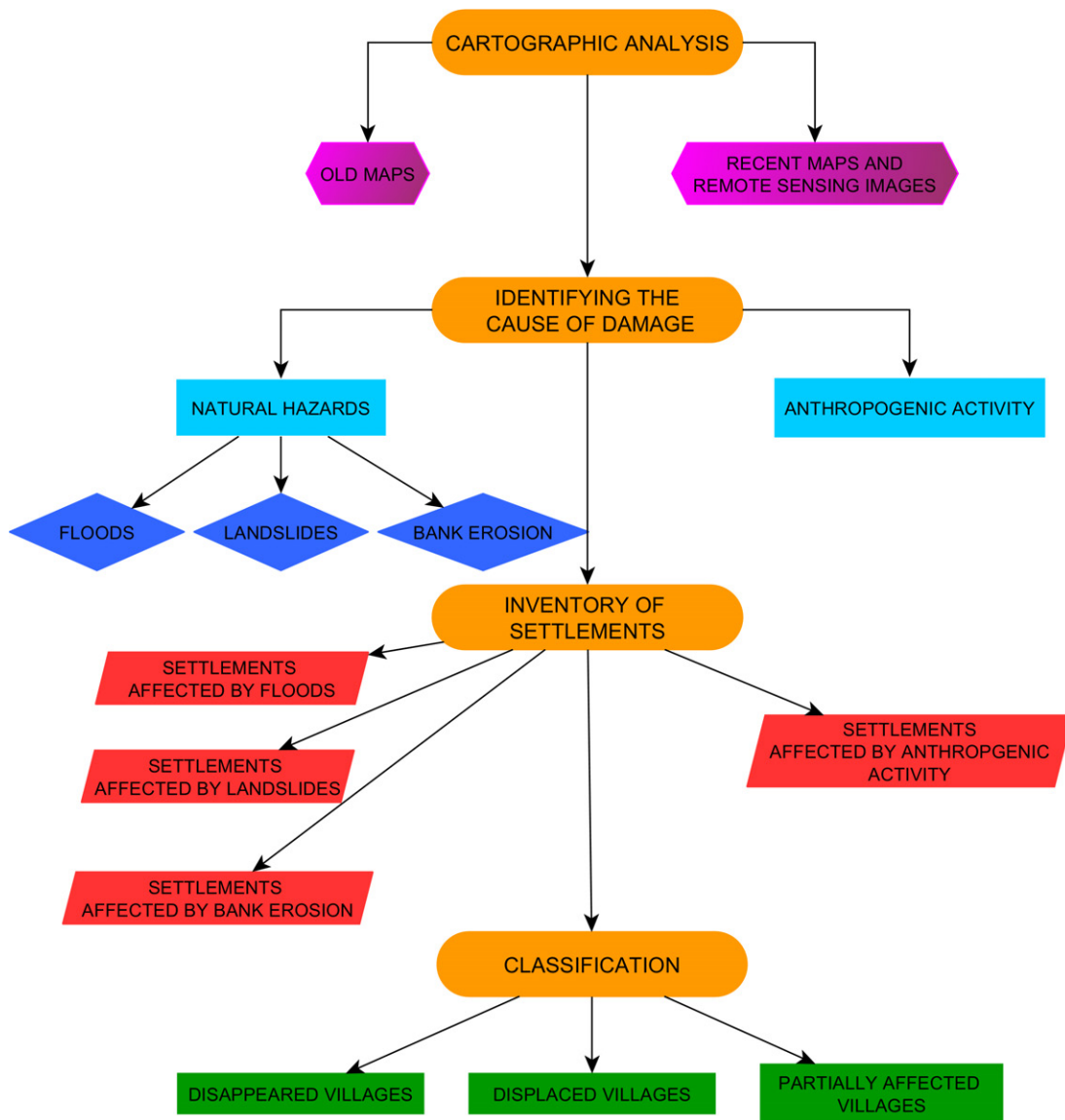


Figure 2: The methodological flowchart used in the study.

Table 1: The cartographic and remote sensing sources used for the cartographic approach indicating the disappearance of the settlements.

No.	Name	Scale/Resolution	Print	Field reference
1	Moldavian Topographic Map	50k	1896	1894-1896
2	Army Plans	20k	1916-1952	1894-1916
3	I st Edition Romanian Topographic Map of Topographic Military Direction (DTM)	25k	1960	1950-1959
4	II nd edition Romanian Topographic Map of DTM	25k	1984	1978-1983
5	I st edition topographic map 1/5000	5k	1961-1966	1957-1961
6	II nd edition topographic map 1/5000	5k	1981-1989	1981-1989
7	LiDAR data	0.5 m		2008/2012

of about 23,000 sqkm, we identified 189 settlements which have been damaged by mass movement processes, floods and bank erosion (Figure 3). Natural causes forced the inhabitants to move, rebuild, repair or abandon their houses but a hazard impact may reach thresholds that exceed the resilience of small rural communities. The cartographic analysis and the final inventory, show us that a total of 20.7 sqkm of built area were totally affected by natural hazard impact.

For a better understanding of the interactions between the natural processes and their consequences on human society, we have chosen and detailed seven study cases (Figure 1 and Table 2).

4.1 Villages affected by landslides

4.1.1 Aldești village

Aldești Village (Figures 1, 4 and 5) is located on Covurlui Hills. Since 1920, till present, the village had suffered a big shifting in matter of build up space and land use; almost a half of the old village being damaged and people forced to move. We identified a retreat of built up area from 40.29 ha in 1920 to 33.77 ha in 1960, determined by intensive mass movement processes and gullies evolution. After 1960, the village registered a gradual extension, the estimated total area in 2010, was 74.6 ha. In case of build-up area, the displacement was the right solution, the village suffered an extension in the opposite direction and the affected region reached values from 18.94 ha (1960-1920) to 14 ha (2010-1960). The displacement was conditioned by huge gullies, followed by some complementary earth processes which are still active. Another factor that influenced the settlement negative dynamic is represented by the demographic aging due to the exodus of young/mature individuals to cities and abroad in the last decades. This state of facts generates a high social vulnerability, a low resilience and in some cases the abandonment of the village.

4.1.2 Meleșcani Village

Meleșcani Village is located in Tutovei Hills (Figures 1, 5 and 6), and this case can be considered as representative for many small villages affected or that disappeared in this landslide-prone region of Romania [39, 71, 72]. On a recent map (1984 edition) we found this settlement under a changed name – Bostănești Village. The entire settlement is located in a small catchment affected by gullies and landslides (Figures 5 and 6). The most recent buildings

that were identified on the maps dated from 1960, after that, the amplitude of the hazard determined the people to move. The phenomenon also involved a political component, the hazard being used as a reason in order to abolish the village. The principal aim was to obtain agricultural land and to concentrate the population in one open region, easy to supervise. This situation is a common problem for a large part of Moldavian villages. Near to Meleșcani Village, we have identified six more villages with the same fate (Dorofei, Bălănești, Valea Babei, Boboș, Ghionoaia, Ruțetu). The population was forced to move in the neighboring villages and to live in common residences which in rural areas, most of the time, were not connected to the water and sewerage network or gas network.

4.1.3 Podolenii de Jos Village

Podolenii de Jos Village is located in Central Moldavian Plateau (Figures 1 and 7). From 1920 till 1960, the village was in expansion, registering a growth of the total area up to 161% and 174% of the built-up area (Table 2). After 1960, mass movement reactivations forced the inhabitants to leave almost 28.8 ha of the total area and to move downward the catchment (Figure 7)

4.2 Villages affected by floods

4.2.1 Sălăgeni and Cotu București Villages

Sălăgeni and Cotu București Villages are located in Prut River floodplain an area with a high degree of flood susceptibility and a permanent threat of river migration (Figures 1 and 8). The village was progressively displaced, first before 1960 when despite the expansion of the village toward the river channel, a flood forced the population to move. The first impact was coated at 20.67 ha of land and build-up area affected, and the second one, after 1960, had a huge impact (108 ha affected), both villages disappearing from the map of the 1984 edition, due to their merging and displacing to SW beyond the levee. According to a social approach from 1992 the last house in this villages were abandoned in 1972, after 3 years of heavy floods [48].

4.2.2 Iepureni Village

Iepureni Village is located in Jijia Hills on Jijia Valley (Figures 1 and 9), being a representative example for many other villages located along Siret and Prut River tributaries

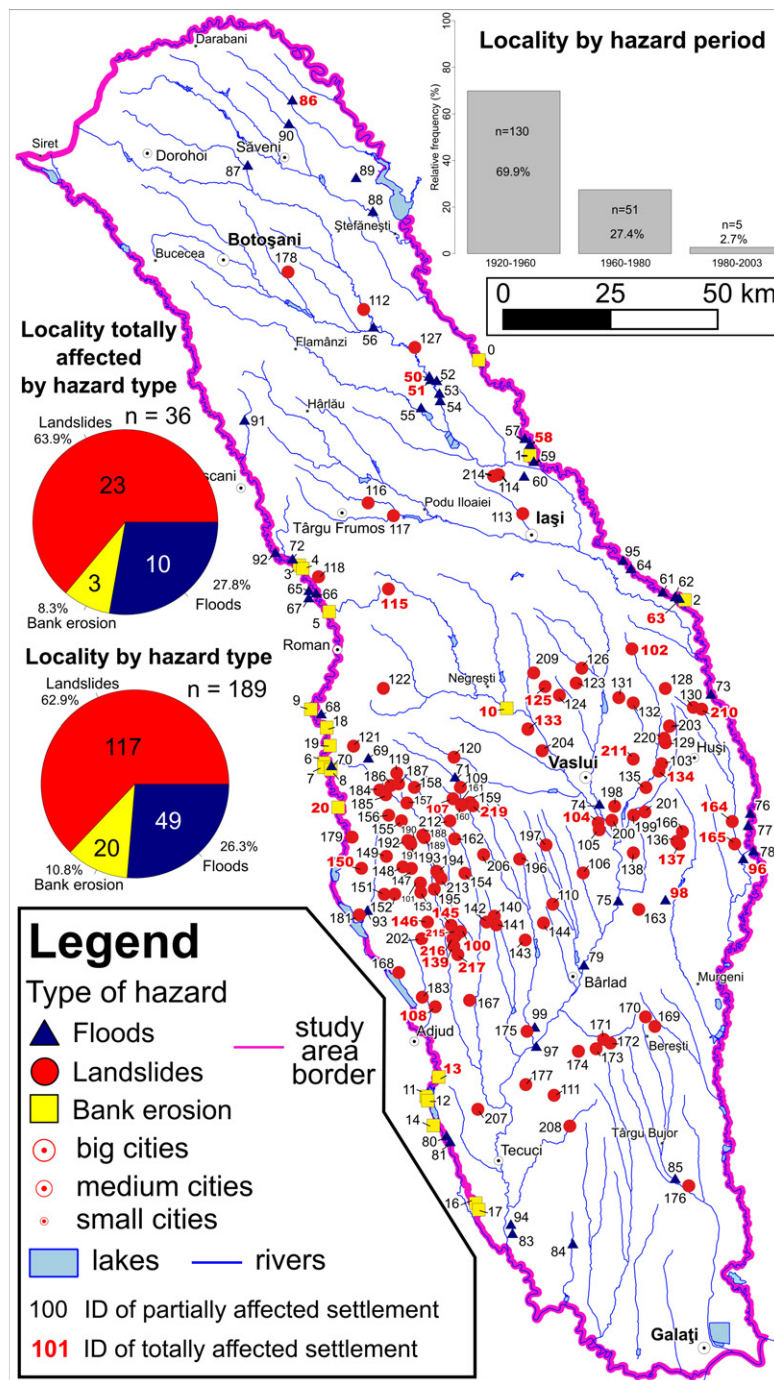


Figure 3: The cartographic and quantitative results of affected, displaced and disappeared settlements.

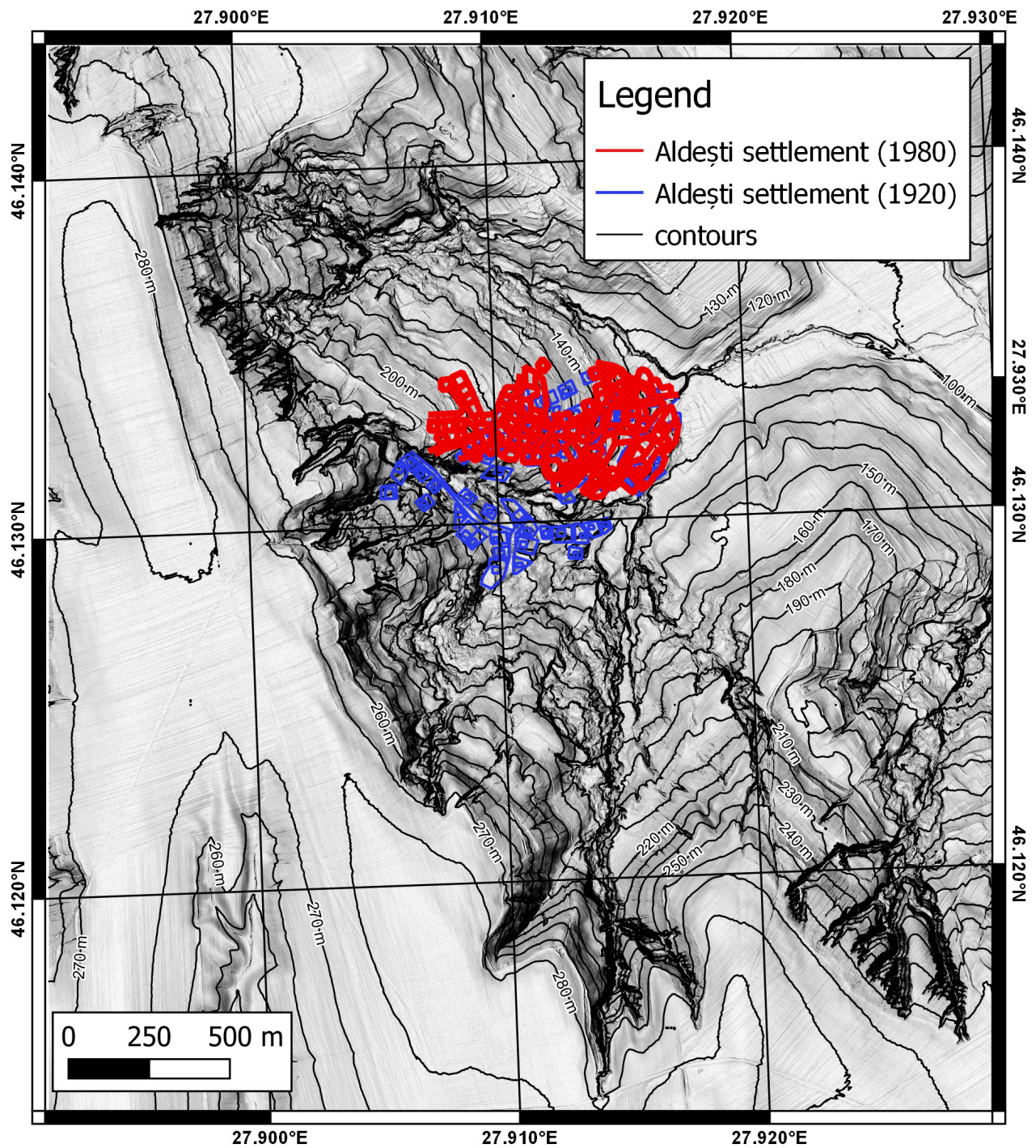


Figure 4: Cartographic representation of the Aldești settlement.

Table 2: The dynamics of the settlement surface for the study cases.

Study case*	Village Name	Area (ha)	Years				
			1920	1960 - 1920	1960	2010 - 1960	2010
1	Aldești	Total	40.29		33.77		74.6
		Build-up	11.57		3.93		20.49
		Affected		18.94		14	32.94
2	Meleșcani	Total	45.71		24.89		0
		Build-up	5.90		2.28		
		Affected		7.76		15.61	23.37
3	Podolenii de Jos	Total	36.74		59.2		99.9
		Build-up	12.51		21.79		6.60
		Affected				28.8	-
4	Sălăgeni and Cotu București	Total	31.21		176.5		56.3
		Build-up	9.13		5.67		1.91
		Affected		20.67		108	128.67
5	Iepureni	Total	27.46		**		11.06
		Build-up	11.49		**		5.29
		Affected				-	9.89
6	Umbrărești	Total	129.7		**		231.9
		Build-up	58.79		**		19.85
		Affected				-	73.2

*the locations of the study cases can be seen in Figure 1

**no data for 1960 regarding the region

**Figure 5:** Aerial (UAV acquisition) and terrestrial photos of Aldești, Meleșcani and Alexandru Ioan Cuza study cases.

and affected by floods. The first location was identified on Army Plans (1:20,000) along to Jijia River channel with a total area of 2746 ha of which 11.49 ha was represented by build-up space. After the intense flood of 1969, the village was moved toward E on the valley hillslope (Figure 9 and Table 2), location which is susceptible to landslide reactivations.

4.2.3 Umbrărești Village

Umbrărești Village is located in Tutova Hills (Figures 1 and 10), along Bârlad River channel. With 231.9 ha as total area in the present, it suffered big changes because of frequent floods. Half of the village (73.2 ha) was displaced and rebuild on the other side of the river channel, in a considered safe area. The last consignment about flood risk impact was in July 2005 when, after several floods in different upstream hydrographic basins, Umbrărești Village was one of the most severely affected [73].

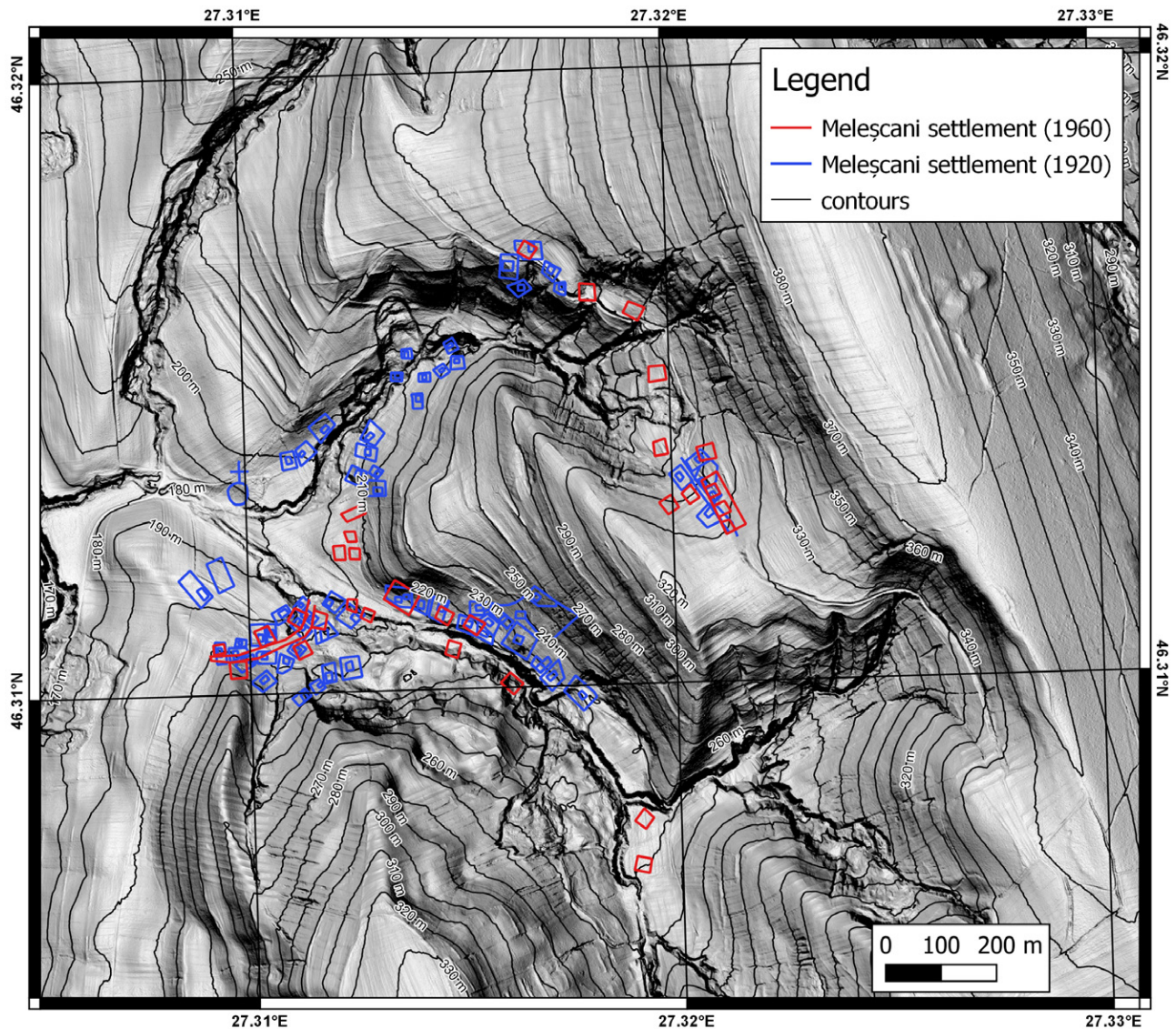


Figure 6: Cartographic representation of the Meleşcani settlement.

4.3 Villages affected by river bank erosion

4.3.1 Alexandru Ioan Cuza Village

Alexandru Ioan Cuza village is located in Suceava Plateau, in the Siret River floodplain (Figures 1 and 5), being affected by river bank erosion. After 1920 the Siret River channel migrated toward East and after 1980 reached the base of the 10 m fluvial terrace and eroded a part of it, destroying several houses. The process is in permanent evolution, several houses being threatened.

5 Discussion

In the study area the fully/partially disappearance/displacement of the settlements was directly conditioned by natural hazards. From a total of 2017 inventoried villages (in the first part of the research), a number of 189 of them were identified as having areas affected by natural hazards, while the rest of 28 being moved by regional (County) administration.

Among the before mentioned hydro-geomorphological processes, the largest number of settlements are affected by landslides (63%), followed by floods (26%), and finally by bank erosion (11%). From 189 settlements, 36 were totally affected and disappeared, while the rest were only

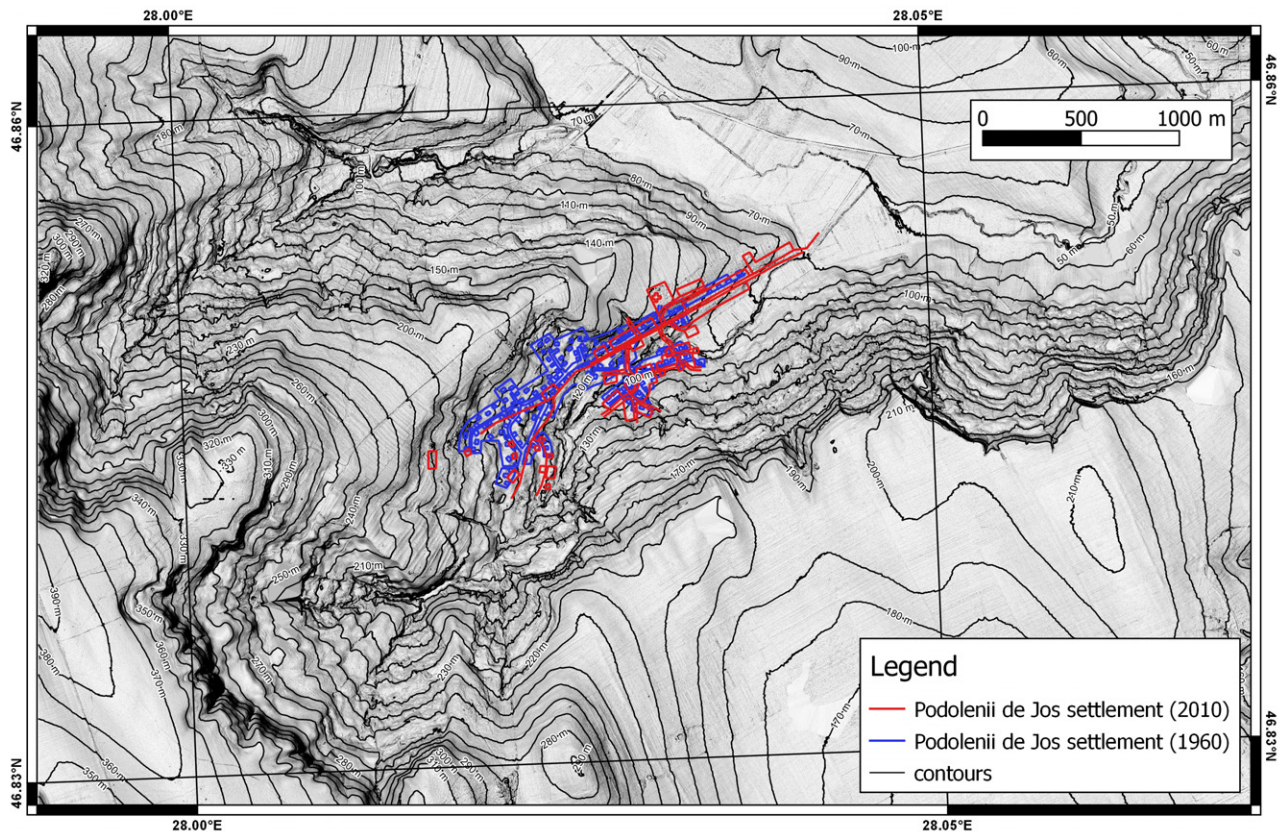


Figure 7: Cartographic representation of the Podolenii de Jos settlement.

partially affected (Figure 3). A number of 32 settlements disappeared and the population was displaced in other localities, while 4 settlements were moved in the vicinity of the initial location. From these totally affected settlements, 64% were due to landslides, 28% due to floods and 8% due to bank erosion. Regarding the temporal phases of hazard activity, we can only use the information given by the availability of the cartographic sources. Thus, we can observe that the frequency decreased toward the present day: 70% of the cases happened between 1920 and 1960, 27% between 1960 and 1980 and only 3% after 1980. This situation is not necessarily the effects of a decrease in natural hazard frequency, but rather is related to evolution of the settlement network, and to the decrease of vulnerability of the society a whole.

In terms of spatial density, the settlements affected by landslides are clustered in two regions with the highest susceptibility (Figure 3): Tutova Hills and Central Moldavia Plateau, as was shown in the literature [39, 71, 72]. In the rest of the study area, the settlements affected by landslides appear in all the physiographical regions. The settlements affected by floods and river bank erosion (Figure 3), cluster mainly along Siret and Prut floodplains and their

major tributaries (Jijia, Bârlad), but these are also cases on smaller rivers.

The database resulted from the present research shows us just sequentially the interaction between natural hazards and settlements, as where this interaction appeared in the cartographic sources. Many other localities were affected by natural hazards without reaching the required magnitude in order to create consequences that impacted the settlements ability to recover. Often, the impact of natural hazards has given to the authorities the reasons to decide the displacement of the population. Nevertheless, these results show what important role play the natural hazards in the day by day life of the small communities from Moldavian Plateau.

The socio-political changes are also factors that, beside natural hazards, influenced the evolution of settlement network by either favouring or diminishing the effects of natural hazards (Figure 11). For example, the centralization of the localities network was a direct answer to communist doctrine. The traditional rural communities had the tendency to spread into the available space, also in isolated areas prone to negative effects due to natural hazards. Depending on the frequency and the spatial magni-

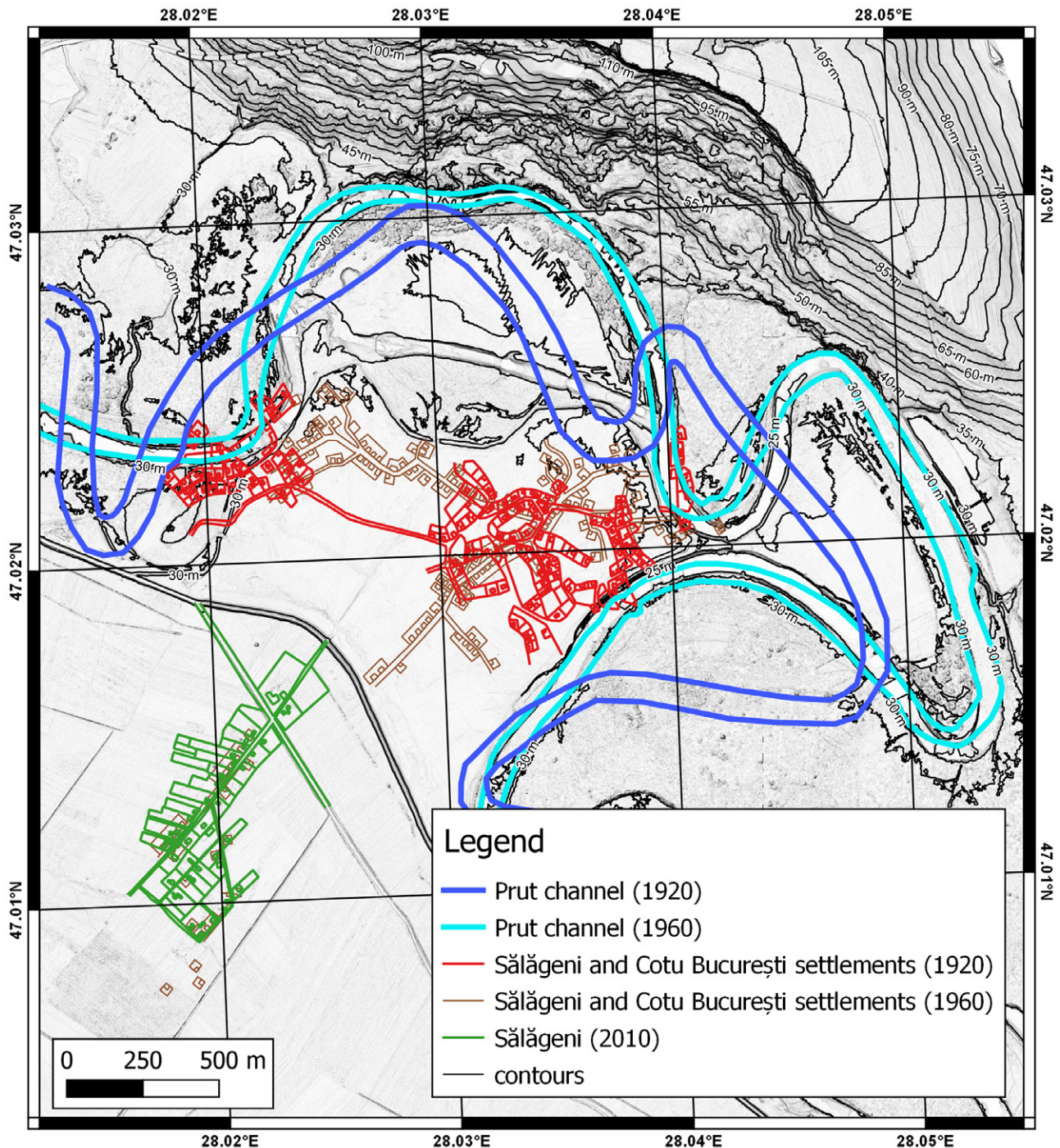


Figure 8: Cartographic representation of the Sălăgeni and Cotu București settlement.

tude of the natural hazard event, the rural community was more or less affected, but in general survived in the same geographical space (it was also difficult to move, because of restrictions imposed by the judicial regime of land ownership). A scattered setting of the landscape was also the outcome to the allotment which took place at each Agrarian Romanian Reform from: 1864, 1921 and 1945. The Re-

form from 1921 was the most radical, the major landowners were expropriated, 6 million hectares were handed over to 1.4 million peasants [74]. After two more decades, in 1945, a new restructuring of agriculture took place. The scattered plots were structured in order to obtain collective farms, peasant associations and co-operatives [74]. Those two were the most significant in matter of land restruc-

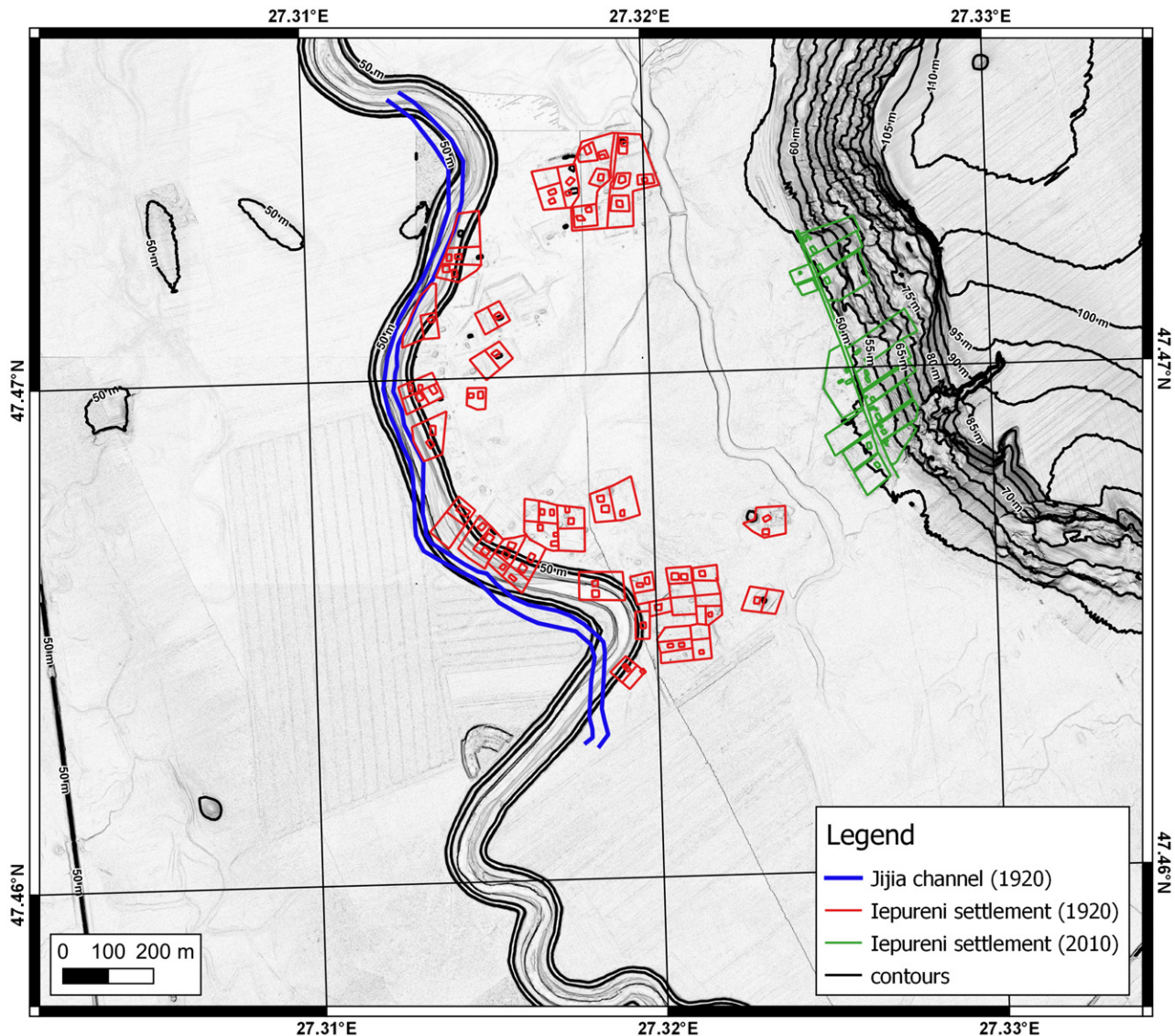


Figure 9: Cartographic representation of the Iepureni settlement.

turation and settlement centralization, in case of disappeared and displaced villages, some important decisions according the resettle represent a political approach which has used the natural hazards from the region as a perfect excuse intended to promote land systematization. This is why mainly during the communist regime, spatial planning decisions in order to centralize the settlement network generated controlled resettlement (this is why there was a high frequency of resettlement between 1920 and 1960). In this way, the natural hazard impact was considered, when resettlement decisions were made. Beside the negative part of the forced resettlement, we can support a premise which assumes the positive influence of the cultural landscape restructuring. In some cases, the access

to the principal roads or to hospital services was difficult, therefore, the society become more vulnerable.

Taking into consideration the natural and anthropogenic factors, the spatial and temporal scale over which natural hazards impact upon the natural environment cover many orders of magnitude [9]. In Moldavian Plateau are some regions where the traces of the impact still there, and the value of the resilience is coated at low amplitude. Even if the economic losses are not huge, the social impact still there, people are without houses and the land use is sometimes irreversible affected.

The analysis of past natural hazard events is crucial as far as the assessment of temporal frequency is concerned, but also for hazard purposes [75–77] and to highlight the creation of vulnerability scenarios.

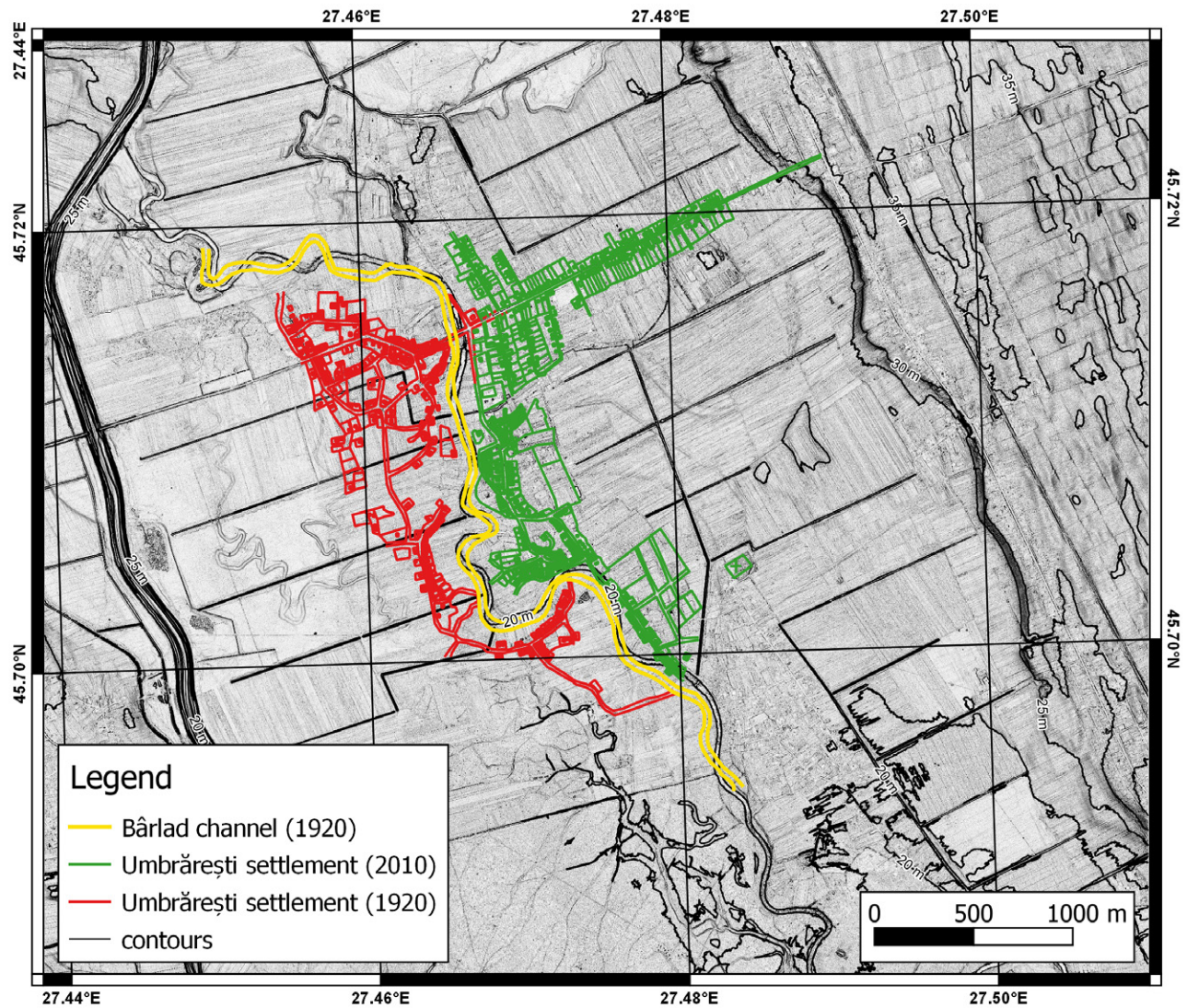


Figure 10: Cartographic representation of the Umbrărești settlement.

thors have used the computational facilities given by the infrastructure provided through the POSCCE-O 2.2.1, SMIS-CSNR 13984-901, No. 257/28.09.2010 Project, CER-NESIM (L4). The authors acknowledge the data providers in the ECA&D project (data and metadata available at <http://www.ecad.eu>).

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