LAND USE CHANGES IN THE SUBCARPATHIAN AREA BETWEEN BUZĂU AND SLĂNIC RIVERS, DURING 1990-2006 AND THEIR CONSEQUENCES ON SURFACE RUNOFF

R. COSTACHE[1], *IULIA FONTANINE*[1]

ABSTRACT. – Land use changes in the Subcarpathian area between Buzău and Slănic rivers, in Romania, during 1990-2006 and their consequences on surface runoff. The Subcarpathian area between Buzău and Slănic rivers, located in the south-eastern part of Romania, is one of the most affected areas by the torrential related phenomena. This occurs due to physical-geographical and economical-geographical factors, such as: slope, curvature profile, lithology, soil texture and land use. In order to highlight the influence of land use changes on the accelerated flow, these factors were integrated and worked in GIS environment. The land use changes were obtained and detailed from Corine Land Cover Data by applying and spatially modeling the binary change index and Markov model. By using GIS techniques, the above-mentioned factors were given bonitation scores, according to their influence on the surface runoff. After applying the methodology, mainly taken after Greg Smith (2003), the Flash-Flood Potential Index (FFPI) was obtained for the study area, with values between 10-22 during 1990-2006. During this period, the most important changes in the index values occurred in the central part of the study area.

Key words: land use; Slănic; Buzău; runoff; FFPI

Introduction

The lately global climate change caused forthcoming climate change in the central part of Europe, which includes Romania (*IPPC, 2007*). These changes are visible through the meteorological phenomena severity increase: storms accompanied by torrential rainfall, severe blizzards, severe droughts etc. The Subcarpathian Curvature area is one of the most affected areas by the continental climate character increase.

The importance of delimitating surfaces with high runoff potential consists

[1] University of Bucharest, Faculty of Geography, Bucharest, Romania, e-mail: romulsucostache2000@yahoo.com
[1] University of Bucharest, Faculty of Geography, Bucharest, Romania, e-mail: iulia_ify@yahoo.com

in the fact that the frequency of extreme meteorological events, such as torrential rainfall, has grown significantly much, causing violent and rapid high-floods. Due to these type of studies, measures can be taken more efficiently in order to diminish the severity of flowing phenomena.

The aim of the present study is to analyze, by using specific indexes and GIS tools, the way that land use changed during 1990-2006, and to describe the Flash-Flood Potential Index (FFPI), in the Subcarpathian area between Buzău and Slănic rivers.

Study area

The Subcarpathian area between Buzău and Slănic rivers is located in the central south-eastern part of Romania (fig. 1), in the Curvature Subcarpathians, in the Buzău Subcarpathians section

In terms of lithology, the substrate contains heavy rocks, which increase the runoff phenomenon, in the approach of the Paleogene flysch, located on the contact area between Bocului Hills and Ivănețu (Roşu, 1980), respectively on the contact area to the Curvature Carpathians. The study area is characterized by altitudes between 116 and 876 meters, recorded on Bucului Hills.

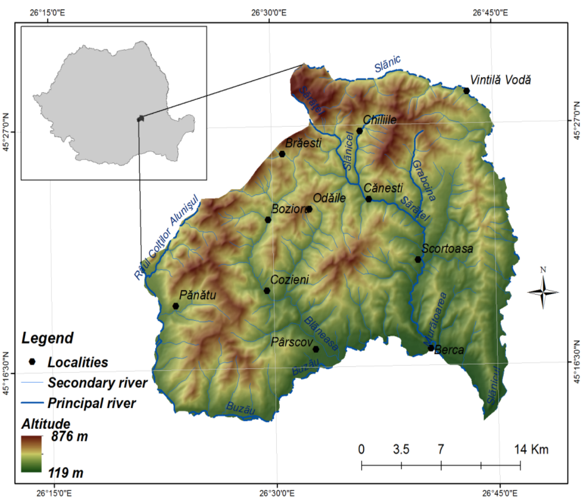

Figure 1. Study area location

The slope has a very important influence on runoff manifestation. The highest values of the slope in the study area exceed 15° and occur in almost 16% of the total area. The highest values correspond especially to hilly sections: Bocului, Dâlmei, Blidişel and Cornetului hills, located on the contact area between the Curvature Subcarpathians and the Curvature Carpathians. The surfaces with high slope values, exceeding 15°, have a high runoff potential (Costache and Prăvălie, 2013). The main climatic characteristics of the study area are the multiannual mean of temperature, which is 8,9°C and the multiannual average sum of precipitation, which is 604 mm/year (*Clima României, 2008*).

The hydrological network is mainly represented by Buzău and Slănic rivers. Other important rivers are Bălăneasa and Sărățel (fig. 1).

The vegetation has a major importance on surface runoff in the study area. The forest vegetation is represented by a very large number of broadleaf forest species and occupies almost 23% of the total study area (*CLC 2006*). The low weight of the forest in the study area, which has an important role in diminishing the surface runoff potential (*Arghiriade, 1977*), certifies the fact that the area between Buzău and Slănic rivers is highly exposed to torrential associated phenomena.

Regarding the edafic cover, the erodo-soils represent almost 42% of the total area and have a uniform distribution. Another type of soil that occupies a large area is the eu-mesobasic brown soil. Its texture has a major influence on runoff occurrence, because it influences the water infiltration. In this case, the loamy-clay...clay texture of the soil determines a high and very high potential to surface runoff and occurs on 37% of the study area.

In 1990, the types of land use that occupied the largest areas, are: forests (28%), fruit gardens (18%) and grasslands (17%). In year 2006, forests occupied a similar area, of 27%, while grasslands surface had grown to 20% of the total area, to the detriment of transitional areas with shrubs and fruit gardens, causing the increase of the runoff occurrence potential.

Methodology

The study was realized in two main working stages. Firstly, the land use changes during 1990-2006 were analyzed and quantified by using specific indexes which were spatially modeled in ArcGIS 10.1. Secondly, the Flash-Flood Potential Index was calculated and spatially modeled, also by using ArcGIS 10.1.

I. The binary change index (Van Eetvelde and Käykhö, 2009) was calculated and spatially modeled in order to highlight the areas where changes in land use occurred. The index value was obtained by applying the following formula (Van Eetvelde and Käykhö, 2009): ***(NCH%-CH%)/(NCH%+CH%)***, where NCH% means the weight of the total unchanged area, regarding land use, and CH% means the total weight of the changed area.

The Markov Model (Coppedge *et all,* 2007) was used in this study in order to obtain detailed information about the changes in land use, respectively the direction of the changes and the surfaces of each land use conversion.

The first step in obtaining the map of detailed changes was to group the land use types in 7 categories and accord alphanumerical codes for each grouping category: codes between 10-70 for year 1990 and codes between 1-7 for year 2006 (Table 1). The next step was to convert the polygon data to raster data, at a 10 m cell size, by the field containing these codes and gathering the land use raster datasets, by using Map Algebra in GIS environment.

Table 1 Land use codes for 1990 and 2006

1990		2006	
code	Land use	**code**	Land use
10	Anthropic	**1**	Anthropic
20	Agricultural land use and vineyards	**2**	Agricultural land use and vineyards
30	Fruit trees	**3**	Fruit trees
40	Pastures	**4**	Pastures
50	Forest	**5**	Forest
60	Transitional woodland-shrub/ deforestated and Spaces with little or no vegetation	**6**	Transitional woodland-shrub/ deforestated and Spaces with little or no vegetation
70	Water bodies	**7**	Water bodies

In order to spatially model the index, each land use type was given an alphanumerical code and then the polygon data was converted to raster data, according to the field containing the specific codes, at a 10 m cell size.

The next step was to convert the polygon data to raster data, at a 10 m cell size, by the field containing these codes and gathering the land use raster datasets, by using Map Algebra in GIS environment.

In order to spatially model the index, each land use type was given an alphanumerical code and then the polygon data was converted to raster data, according to the field containing the specific codes, at a 10 m cell size. The map of the binary change index was finally obtained by subtracting the 1990 land use raster dataset (fig. 2.a) from the 2006 raster (fig. 2.b).

II. The Flash-Flood Potential Index was created and spatially modeled for the reference years, 1990 and 2006. This index was proposed by Greg Smith in 2003, and was calculated for Colorado river. After, the index was adapted, used and improved by other researchers. In the present study, the index was calculated by integrating five factors that influence the runoff process, by using GIS environment. Morphometric indexes such slope (fig.3.a) and profile curvature (fig.3.b) were derived, in raster format, from the digital terrain elevation model, obtained from a 10 m cell size, by contours interpolation (*obtained from SRTM data*). The other three factors, soil texture (fig.3.c), lithology (Fig.3.d), and land use (fig.2.a, fig.2.b) were firstly obtained as polygon features. The lithology was obtained by vectorizing data from the Romanian Geological Map, at 1:200000 scale (geospațial.org), the soil texture was obtained from the Romanian Soils Map at 1:200000 scale, in digital format (*ICPA*), and land use was obtained from the European Corine Land Cover data for 1990 and 2006. After, the factors in polygon format were converted to raster format, with a 10 m cell size, by using ArcGis 10.1.

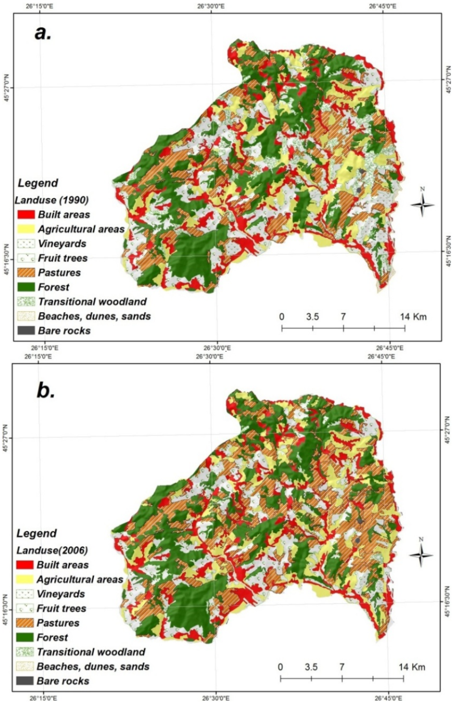

Figure 2. Land use between Slănic and Buzău rivers (a) 1990; b) 2006)

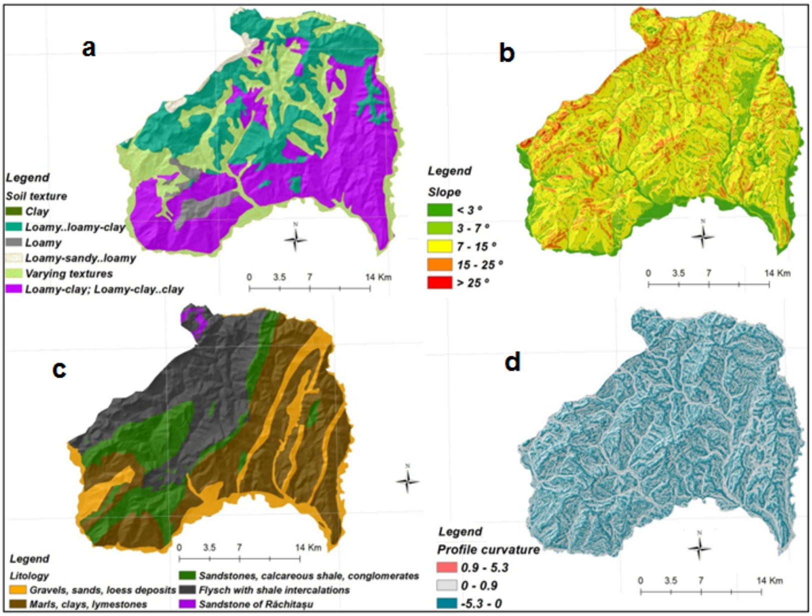

Figure 3. The factors considered for FFPI calculation
(a) soil texture; b) slope; c) lithology; d) profil curvature)

After having obtained the indexes for the two years, 1990 and 2006, classes 4 and 5 of flash-flood potential were separated from the other three classes and gathered in one single class, in order to highlight the most exposed to surface runoff areas. Furthemore, two classes of flash-flood potential were obtained, respectively 0 (which gathered the 1st, 2nd, and 3rd class) and 1 (which gathered the 4th and 5th class) and, finally, the raster for year 1990 was subtracted from the raster representing year 2006.

The subtraction between the two raster datasets was performed in order to observe the areas with high surface runoff potential that changed during this period. The factors were finally reclassified by establishing their bonitation scores according to their influence on surface runoff (Table 2).

Results

By applying the methodology described for the first step of the study, the binary change index value was obtained and also the map of the index values distribution (Fig.4). The index value of 0,56 demonstrates that the area suffered moderate changes regarding the land use (*Stupariu, 2011*).

Table 2. The factors considered for FFPI calculation and their bonitation scores

Parameters	*Types/Values*				
Lithology	*Gravels, sands, loess deposits*	*Marls, clays, lymestones*	*Sandstones, calcareous shale, conglomerates*	*Flysch with shale intercalations*	*Sandstone of Răchitaşu*
Slope(°)	*0-3*	*3-7*	*7-15*	*15-25*	*>25*
Profile curvature			*-5.3 - 0*	*0 – 0.9*	*0.9 – 5.5*
Soil texture	*Loamy-sandy...loamy*	*Loamy*	*Varying textures, loamy...loamy-clay*	*Loamy-clay, loamy-clay..clay*	*Clay*
Land use	*Forests*	*Transitional woodland-shrub*	*Agricultural zones,* vineyards	*Pastures*	*Build areas, bare rocks*
Bonitation score	*1*	*2*	*3*	*4*	*5*
FFPI class (1990, 2006)	10 - 12.4	12.4-14.8	14.8-17.2	17.2-19.6	19.6-22

The results of the binary change index also show that, in 16 years, land use changed on 22% of the total study area, especially in the Sărățel and Bălăneasa river basins (Fig. 4).

Afforestation occurred on a 1641,48 ha surface, almost twice larger than the deforestation surface, which is of 919,76 ha. Though, the afforestations represent only 3% of the total changes in the area, which is not enough for a sustainable management.

By using the Markov model, the map of detailed changes in land use was obtained (fig. 5) and indicates a large number of irregular transitions.

The Markov matrix indicates that conversions into runoff vulnerable areas, according to the land use (conversions into pastures, agricultural surfaces, transitional woodland-shrub/deforested and spaces with little or no vegetation, vineyards and fruit trees) occurred on 14% of the total area, from which the land use conversion into pastures is the most obvious, on 4144.99 ha (Table 3).

Table nr. 3 Markov matrix for land use changes during 1990-2006

2006 (Hectares) 1990	1	2	3	4	5	6	7	Total 2006
10	11	**12** **312,93**	**13** **151,93**	**14** **73,13**	**15** **40,21**	16	**17** **15,04**	**593,24**
20	**21** **47,36**	22	**23** **631,89**	**24** **2239,71**	**25** **399,99**	**26** **117,15**	**27** **23,22**	**3459,32**
30	**31** **28,06**	**32** **780,78**	33	**34** **624,39**	**35** **377,07**	**36** **287,90**	37	**2098,20**
40	**41** **68,56**	**42** **896,99**	**43** **564,56**	44	**45** **427,57**	**46** **94,20**	**47** **8,07**	**2059,95**
50	**51** **122,59**	**52** **143,62**	**53** **109,93**	**54** **542,77**	55	**56** **0,04**	**57** **0,81**	**919,76**
60	**61** **7,90**	**62** **415,26**	**63** **276,38**	**64** **664,99**	**65** **396,08**	66	**67** **345,09**	**2105,70**
70	71	**72** **14,44**	73	74	**75** **0,56**	76	77	15
Total 1990	**274,4**	**2564**	**1734**	**4144**	**1641**	**499**	**392**	**11251**

In order to analyze the way that land use changes (described by the Binary Change Index and the Markov model) influenced the surface runoff potential, during 1990-2006, the Flash Flood Potential Index (FFPI) was calculated and spatially modeled (Fig.6.a; Fig. 6.b) for the two years.

The Flash-Flood Potential Index (FFPI) values for each of the two years are between 10 and 22. For each year, the values were classified in equal intervals, in order to compare the two

years. The last two classes of values (17.2 – 19.6 and 19.6 – 22) are the most important because these characterize the areas with high and very high surface runoff potential.

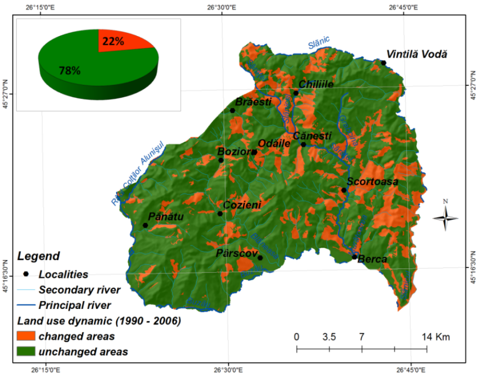

Figure 4. The binary change index of land use during 1990-2006

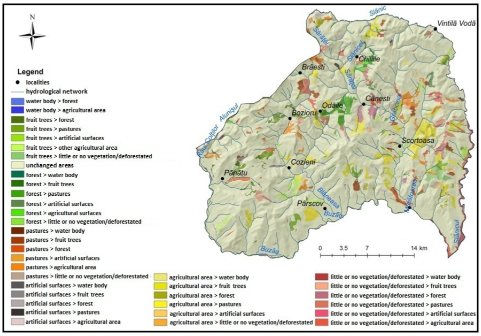

Figure 5. Markov model for detailed changes in land use during 1990-2006

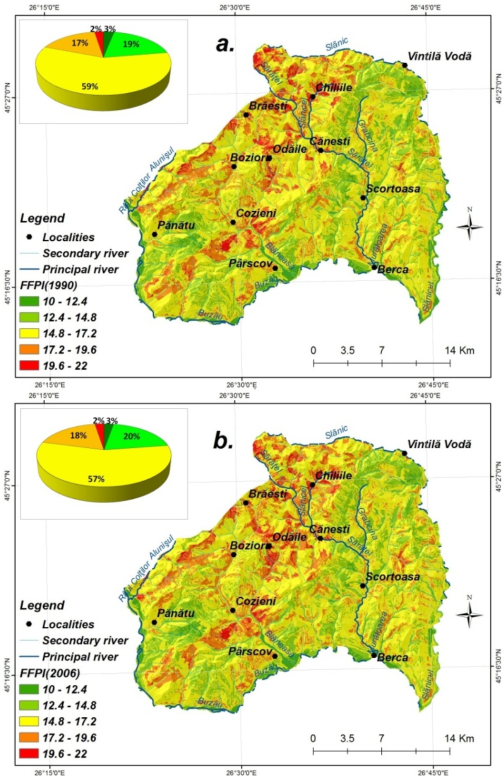

Figure 6. FFPI values for the study area (a)1990; b)2006)

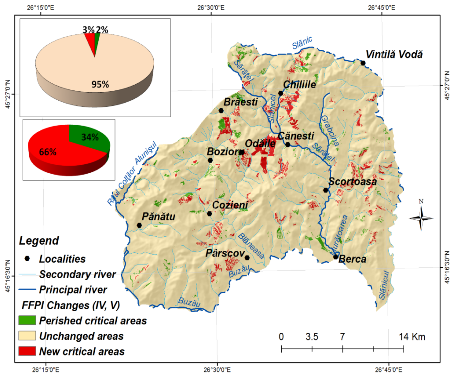

Figure 7. Changes in high and very high FFPI values, during 1990-2000

These areas are generally found on the south-western part of the study area, especially on the contact area between the Subcarpathian area and the Curvature Carpathians. According to the sub-basin repartition, the most affected areas are the upper area of Sărățel basin (Fig.6.a; Fig.6.b) and the central part of Bălăneasa basin. In year 1990, the weight of the last two classes of values was of 19%, and in year 2006 was of 20% of the total study area.

As a result, the weight of the areas with high and very high potential to surface runoff has increased by 1% in 17 years. Though, the spatial changes of the 4th and 5th classes of values within the area are more important. In order to highlight the spatial dynamic of these areas, the two values of the index for each year were finally gathered in two classes of values. In this way, the 1st, the 2nd and the 3rd classes were given the bonitation score 0 and the classes of values for the FFPI between 17,2 – 22 were given the bonitation score 1.

After the reclassification described above, by using Cartographic Algebra, in ArcGis 10.1, the subtraction between the two reclassified rasters, respectively for 2006 and 1990, was performed. After the subtraction, a new raster was created (Fig.7), which highlights the areas where significant changes occurred regarding the surface runoff potential. On the whole, the changes occurred on 5% of the study area, especially on the upper Bălăneasa basin and Slănicel basin, which is a tributary to Sărățel river.

The most affected localities by the high surface runoff potential are Cozieni, Odăile, Căneşti, Scorțoasa and Chiliile (Fig. 8). In these localities, the appearance of the high and very high potential to surface runoff was recorded on surfaces exceeding 250 ha (Fig. 9).The growth of the incidence and severity of hydric risk phenomena has gravely affected these human settlements.

A good example is represented by the severe flash-floods on the 29th May, 2012, that occurred on several rivers in the study area (ISU Buzău).

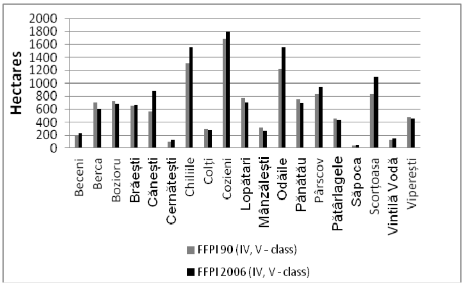

Figure 8. Surfaces with high and very high FFPI values for 1990 and 2006

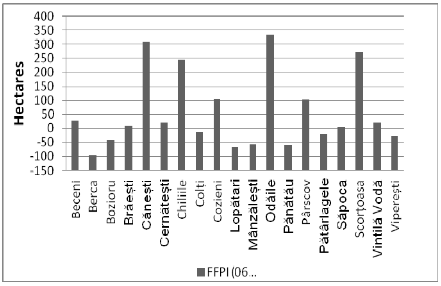

Figure 9. Changes regarding high and very high FFPI values during 1990-2006

These changes occurred especially due to agricultural areas conversion into grasslands which are forthcoming favorable to surface runoff. Regarding the areas where the FFPI values changed during 1990-2006, the weight of the surfaces with high values that appeared is twice higher than the weight of the surfaces with high values that disappeared (Fig.7).

5. Conclusions

The analysis of the environmental changes that reflect the surface runoff potential during 1990-2006 is very important due to the increase of the surface runoff potential in several areas. This causes the increase of the nearest human settlements vulnerability in case of torrential rainfall that would inevitably cause the surface runoff on the slopes and flow accumulation on the rivers found at the base of the slopes where severe flash-floods occur.

The case of 29 May 2012 flash-flood is typical. On this day, accelerated flow on the slopes of the upper basin sectors caused severe flash-flood waves and, consequently, material damage in many localities, such as Vintilă Vodă, Beceni şi Cernăteşti. The most affected localities are found on Slănic river valley.

Regarding the study area, the methodology used for the present study is important because it is related to the main environmental components that influence surface runoff. Generally, the increase of the surface runoff potential occurred on the slopes associated with the central located water courses. By highlighting the areas with a high surface runoff potential, mender measures can be taken by the local authorities, especially by reforesting the vulnerable slopes.

REFERENCES

1. Arghiriade, C., (1977), *Rolul hidrologic al pădurii*, Editura Ceres, Bucureşti.
2. Barredo J.I., (2007), *Major flood disasters in Europe: 1950–2005*. Natural Hazards 42:125–148.
3. Bilaşco Ş., (2008), *Implementarea GIS în modelarea viiturilor pe versanți*, Casa Cărții de Ştiință Cluj-Napoca
4. Bing L, Shao Q, Liu J, (2012), *Runoff characteristics in flood and dry seasons based on wavelet analysis in the source regions of the Yangtze and Yellow rivers*, Journal of Geographical Sciences 22(2): 261-272.
5. Chendeş V, (2007), *Scurgerea lichidă şi solidă în Subcarpații de la curbură*. Teză de doctorat, Academia Română, Institutul de Geografie, Bucueşti.
6. Chunhui L., Zhifeng Y., (2004), Natural runoff changes in the Yellow River Basin, Journal of Geographical Sciences, 14, 4 : 427 – 436.
7. Coppedge, B R, Engle, D M , Fuhlendorf S D, (2007), Markov models of land cover dynamics in a southern Great Plains grassland region, Landscape Ecology, 22: 1383-1393.

8. Costache R, Prăvălie R, (2013), *The potential of surface runoff manifestation obtained on the basis of the digital elevation model*. Case study: The Subcarpathian sector of Buzău catchment, (in press) Studia UBB, Geographia.
9. Costea G., (2013), Deforestation process consequences upon surface runoff coefficients. Catchment level case study from the Apuseni Mountains, Romania, Geographia Technica, Issue no. 1/2013: 28-33.
10. Fontanine Iulia, Costache R, (2013), Using GIS techniques for surface runoff *potential analysis in the Subcarpathian area between Buzău and Slănic rivers, in Romania*. Cinq Continents 3 (7): 201-214.
11. Gaume E, Livet M, Desbordesc M, Villeneuve J-P, (2004)„ *France, flash-flood on 12 and 13 November 1999*, Journal of Hydrology 286: 135–154.
12. I. Pătru-Stupariu, (2011), *Peisaj şi gestiunea durabilă a teritoriului*, Editura Universității din Bucureşti
13. IPCC, (2007), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, Cambridge University Press.
14. Koutroulis Aristeidis G, Tsanis Ioannis K, (2010), *A method for estimating flash flood peak discharge in a poorly gauged basin: Case study for the 13–14 January 1994 flood, Giofiros basin, Crete, Greece*, Journal of Hydrology 385, 150–164.
15. Marchi L, Borga M, Preciso E, Gaume E, (2010), *Characterisation of selected extreme flash floods in Europe and implications for flood risk management*, Journal of Hydrology 394: 118–133.
16. Mătreață, M, Mătreață Simona, (2010), *Metodologie de estimare a potențialului de producere de viituri rapide în bazine hidrografice mici*, Comunicări de Geografie, Vol. XIV, Editura Universității din Bucureşti, Bucureşti.
17. Prăvălie R, Costache R, (2013), *The analysis of the susceptibility of the flash-floods genesis in the area of the hydrographical basin of Bâsca Chiojdului river*, (in press) Forum Geografic.
18. Van Eetvelde, Niina Käyhkö, (2009), *The applicability of quantitative techniques for assessing spatio-temporal patterns of landscape changes*, European IALE Conference 2009, Salzburg, Austria Symposium 6 – The third and fourth dimensions of landscapes.
19. Villarini G, Krajewski W F, Ntelekos A, Georgakakos K P, Smith J A, (2010), *Towards probabilistic forecasting of flash floods: The combined effects of uncertainty in radar-rainfall and flash flood guidance*, Journal of Hydrology 394: 275–284.
20. Yu J, Yang C, Liu C, Song X, Hu S, Li F, Tang C, (2009), *Slope runoff study in situ using rainfall simulator in mountainous area of North China*, Journal of Geographical Sciences 19:461 – 470.
21. Zaharia Liliana, Minea G., Toroimac Gabriela Ioana, Barbu R., Sârbu I., (2012), *Estimation of the Areas with Accelerated Surface Runoff in the Upper Prahova Watershed (Romanian Carpathians),* Balwois, Republic of Macedonia.
22. Zanon F, Borga M, Zoccatelli D, Marchi L, Gaume E, Bonnifait L, Delrieu G (2010), *Hydrological analysis of a flash flood across a climatic and geologic gradient: The September 18, 2007 event in Western Slovenia*, Journal of Hydrology 394: 182–197.

23. Zhang Y, Zhang S, Zhai X, Xia J, (2012), Runoff variation and its response to climate change in the Three Rivers Source Region, Journal of Geographical Sciences 22(5): 781-794.
24. Zoccatelli D, Borga M, Zanon F, Antonescu B, Stâncalie G., (2010), *Which rainfall spatial information for flash flood response modelling? A numerical investigation based on data from the Carpathian range, Romania*, Journal of Hydrology 394: 148–161.
25. *** (2008), *Clima României*, Administrația Natională de Meteorologie, Editura Academiei Române Bucureşti