Land cover changes in small catchments of and their effects on frequency of flood events in Slovakia

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Abstract The paper is aimed at analysis of the relationship between frequency of flood events and land cover (LC) changes in small catchments that took place in the period 1990-2006. Data on frequency of flood events are from the period 1996-2006. The data source for identification of LC changes was the LC layers of Slovakia from 1990 and 2006 derived by computer aided visual interpretation of satellite images under the CORINE Land Cover Projects. Validity of three statements is tested by the analysis of variance: 1) floods occur more frequently in catchments where some LC change took place than in catchments where no such change occurred; 2) the greater the area of LC changes, the greater frequency of flood events, and 3) flood events occur more frequently in catchments subject to changes supporting surface runoff than in catchments where LC changes supporting infiltration and decreased occurrence of surface runoff prevail. Results of ANOVA and pairwise comparison only confirmed the validity of statement 2.
Keywords small catchments; flood event; land cover changes; analysis of variance; CORINE Land Cover

INTRODUCTION

Increased frequency of high-intensity precipitation events in the of consequence of global warming and land cover/land use (LC/LU) changes (urbanization, deforestation, intensification of agriculture, etc.) have been generally considered the principal causes of frequent flood events in the last two decades. However, the relationships between the climatic change and flood frequency are ambiguous. Certain provable changes such as those in variability of precipitation amount, precipitation intensity and frequency of highly intensive precipitation in some regions cannot be definitely considered the causes of the changed flood discharge culminations. For instance, Robson (2002) reports based on the analysis of 40-year hydrological orders observed in the UK's gauging stations that hydrological data do not confirm an increasing trend of flood discharge culmination values although certain trend is observable in the increased number of days with high discharge and longer duration of annual maximum discharge values.

LC/LU changes influence the condition for transformation of precipitation into runoff. The qualitative impact assessment of urbanization, deforestation or agro-technical practice on size of flood discharge or the volume of flood waves is not a problem (c.f. Smith and Ward 1998, Neaf et al. 2002). For instance, the change of agricultural or forest landscape into an urbanized landscape or the change of forest landscape into agricultural landscape are dramatic changes and the impact of urbanization or deforestation on the discharge process is comparatively easily identified (cf. Calder 1993). Built-up impermeable areas cause formation of rapid overland flow at the cost of the natural retention and subsurface or groundwater flow. The consequence of a rapid runoff into the streams is faster formation of flood waves and the increased volume/size of flood wave discharge culminations.

Nevertheless, LC/LU change impact assessment faces several methodological problems above all in terms of a quantitative expression of the hydrological response on the catchment scale (c.f. De Roo et al. 2000, Hundecha and Bárdossy 2004, Sullivan et al. 2004, Brath et al 2006). As results of the conducted research show (e.g. Wheater 2006), urbanized areas occupy a comparatively small portion of the overall area of catchments and hydrological consequences of urbanization on the level of a catchment scale are not normally significant. A wide discussion in hydrological literature, about the impact of deforestation/afforestation on hydrological cycle has led to controversial conclusions. Andréssian (2004) provided a detailed analysis of this discussion, the origins of which date to ancient time, based on the evaluation of experimental research consisting of a pair comparison of catchments. He reports that deforestation may increase both the volume and discharge of flood waves. However, this impact compared to that of deforestation on annual flow is very variable and in some years it even shows the inverse tendency. Meanwhile, the deforestation/afforestation impact on attributes of floods with a great return period is minimal to none. Research, that has confirmed increased volume and discharge of floods, tends to attribute this impact to the side and accompanying phenomena connected with the deforestation process rather than to forest itself (Calder 1993).

The issue of floods became a serious one in Slovakia. Compared with the neighbouring countries where in the last 10 to 15 years extensive territories above all along great rivers were flooded, flood discharges of the great rivers in the Slovakia were rather successfully maintained in the space between the dikes thanks to timely interventions (increased dikes, reconstruction of dike seepage) or by filling the Beša polder in the case of floods in Eastern Slovakia. For this reason, floods in Slovakia were mostly local in rural areas. They occurred mainly on small streams and the material damage was not as disastrous. However, the most tragic flood that occurred in a small catchment was that of July 1998 on the brook Malá Svinka when 50 persons died.

Non governmental organizations often emphasize as far as the causes of increased flood frequency are concerned that it is also due to LC/LU changes in small catchments of Slovakia caused by inadequate practices of forest and farmland management. Solín et al. (2010) tried to answer the question whether LC changes in some way intensify occurrence of flood events by using statistical approach to the analysis of the relationship between the frequency of flood events in small catchments in the period 1996-2006 and LC changes in the period 1990-2006. Some results of the cited paper are also presented in this paper, which consists of three parts. The first part gives information on frequency of flood events in Slovakia in the period 1996-2006; in the second part LC changes that took place in small catchments in Slovakia in the period 1990-2006 are identified and the third parts is involved with the relationship between the identified LC changes and frequency of flood events.

FREQUENCY OF FLOOD EVENTS IN SLOVAKIA IN THE PERIOD 1996-2006

Solín (2008) elaborated detailed subject and spatial analysis of flood events that occurred in the period 1996-2006 in Slovakia. According of the legislation of Slovak Republic, a flood event is defined as the state of the river that requires declaration of the third level of flood activity, which means a state of threat both in the diked and undiked streams. A state of threat is declared if:

a) a distinct temporary rise of the water table of a stream which results in an overflow or there is an immediate risk of overflow,
b) the natural runoff of precipitation water into a recipient is temporarily hindered and the territory is inundated by internal waters,

c) ice or other material blocks the stream and the result is an overflow or an immediate risk of overflow,
d) extreme rainfall inundates the territory,
e) a disorder or crash of water works results in overflow or there exists an immediate risk of overflow.

Information about flood events were collected from several sources: a) reports on floods issued by the Slovak Hydrometeorological Institute, b) reports of press agencies, c) reports on floods processed by the Ministries of Agriculture and the Environment of the Slovak Republic, d) materials of non-governmental organizations, civic associations and regional press. All these sources were accessible via Internet. The data were processed in the GIS.

In the period 1996-2006, flood events occurred in 1,367 municipalities, that is in 47% of the total of 2,928 municipalities in Slovakia (Fig. 1). Flood events occurred more than once in 562 municipalities (41%). From the 1,367 flood stricken municipalities 920 (i.e. 67%) are situated in small catchments (Fig. 2). Flood events were classified into five types (Table 1): river or regional floods (R), flash floods (F), ice jam floods (L), internal floods (V) and water structure break floods (H). Occurrence of river or regional floods and flash floods dominated in the analysed period.

Fig. 1 Spatial distribution of communities that were stricken by flood in the period 1996-2006 (Solín 2008).

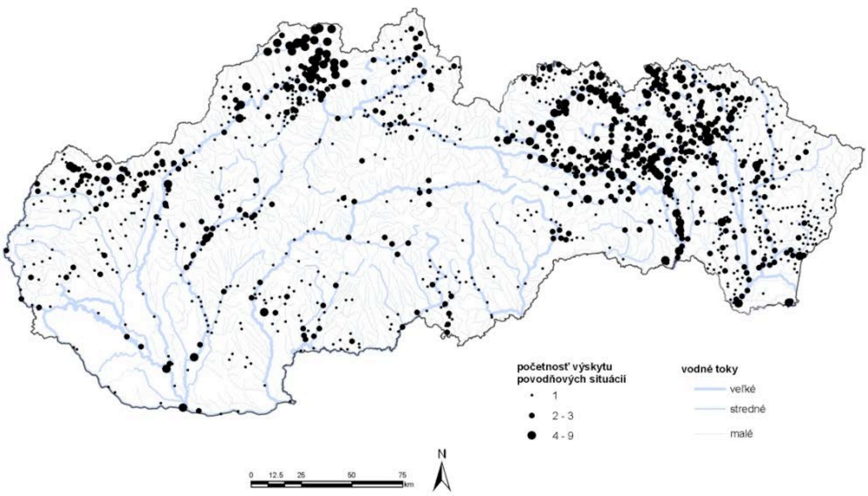

Fig. 2 Share of floods in municipalities located along streams of different size (Solín 2008).

Table 1 Flood frequency by type of flood (Solín 2008).

Year	Type of flood					
	H	L	V	F	R	Total
1996	1			14	112	127
1997	6	3		1	163	173
1998	7			59	1	67
1999	1	9	83	58	202	353
2000				2	164	166
2001	2			296	18	316
2002	7	9	7	93	6	122
2003		11	1	30	17	59
2004	8	11		185	55	259
2005	1	15	1	97	178	292
2006	3	5	22	226	136	392
1996-2006	36	63	114	1061	1052	*2326*

H - water structure break flood.
L - ice jam flood.
V - internal flood.
F - flash flood.
R - river or regional flood.

By overlay of the digital layer of municipalities where flood events occurred in the period of 1996-2006, with that of small catchments (c.f. Solín, Grešková 1999) the digital layer of flood events in small catchments in the Slovakia was produced (Fig. 3). The layer contains 4,587 of small catchments with an area smaller than 150 km^2. If a sole settlement exists in a catchment, then the number of flood events equals the number of flood events of that particular settlement. If there are more settlements in the catchment and numbers of flood in these settlements events are equal, then this number represents the catchment as well. In case the number of flood events differs, the number of flood events in a catchment is represented by the actual biggest number of flood events. It is important to add that some settlement exists in almost every catchment of the basic set. Because the hydrological significant response is considered from the catchment larger than 5 km^2 (HMÚ 1970), only small catchments with an area ranging in size from 5 to 150 km^2 are taken into account (that is 1,678 catchments from a total of 4,587 small catchments).

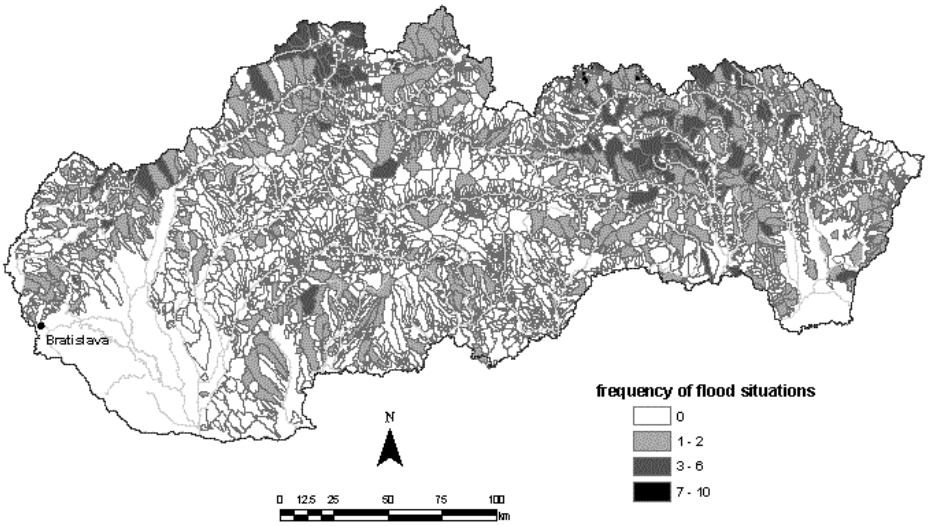

Fig. 3 Frequency of flood events in small catchments in the period 1996-2006.

IDENTIFICATION OF LC CHANGES IN SMALL CATCHMENTS IN THE PERIOD 1990-2006

The data source for LC change identification in small catchments were the digital LC layers of Slovakia from 1990 and 2006 derived by computer aided visual interpretation of satellite images under the CORINE Land Cover Projects 1990 (CLC1990) and 2006 (CLC2006) (Feranec et al. 1996, Feranec and Nováček 2009). The CLC nomenclature consists of 44 LC classes (Heymann et al. 1994) out of which 31 were identified in Slovakia. LC classes are clustered into three hierarchic levels. At the first, top level, there are 5 classes, while 15 and 44 classes form the second and third hierarchic levels respectively (Table 2**).** The area of the smallest identified change is 5 ha.

The 1990-2006 LC changes were identified and processed in the GIS and the total area of all LC changes in a small catchments was determined (Fig. 4). LC changes which were recognized are presented in Table 3.

Table 2 CLC nomenclature (Heyman et al. 1994, Bossard et al. 2000)

1 Artificial surfaces

11 Urban fabric
- 111 Continuous urban fabric
- 112 Discontinuous urban fabric

12 Industrial, commercial and transport units
- 121 Industrial or commercial units
- 122 Road and rail networks and associated land
- 123 Port areas
- 124 Airports

13 Mine, dump and constructions sites
- 131 Mineral extraction sites
- 132 Dump sites
- 133 Construction sites

14 Artificial, non-agricultural vegetated areas
- 141 Green urban areas
- 142 Sport and leisure facilities

2 Agricultural areas

21 Arable land
- 211 Non-irrigated arable land
- 212 Permanently irrigated land
- 213 Rice fields

22 Permanent crops
- 221 Vineyards
- 222 Fruit trees and berry plantations
- 223 Olive groves

23 Pastures
- 231 Pastures

24 Heterogeneous agricultural areas
- 241 Annual crops associated with permanent crops
- 242 Complex cultivation patterns
- 243 Land principally occupied by agriculture, with significant areas of natural vegetation
- 244 Agro-forestry areas

3 Forest and semi-natural areas

31 Forests
- 311 Broad-leaved forests
- 312 Coniferous forests
- 313 Mixed forests

32 Scrub and/or herbaceous vegetation associations
- 321 Natural grasslands
- 322 Moors and heath land
- 323 Sclerophyllous vegetation
- 324 Transitional woodland-scrub

33 Open spaces with little or no vegetation
- 331 Beaches, dunes, sands
- 332 Bare rocks
- 333 Sparsely vegetated areas
- 334 Burnt areas
- 335 Glaciers and perpetual snow

4 Wetlands

41 Inland wetlands
- 411 Inland marshes
- 412 Peat bogs

42 Maritime wetlands
- 421 Salt marshes
- 422 Salines
- 423 Intertidal flats

5 Water bodies

51 Inland waters
- 511 Water courses
- 512 Water bodies

52 Marine waters
- 521 Coastal lagoons
- 522 Estuaries
- 523 Sea and ocean

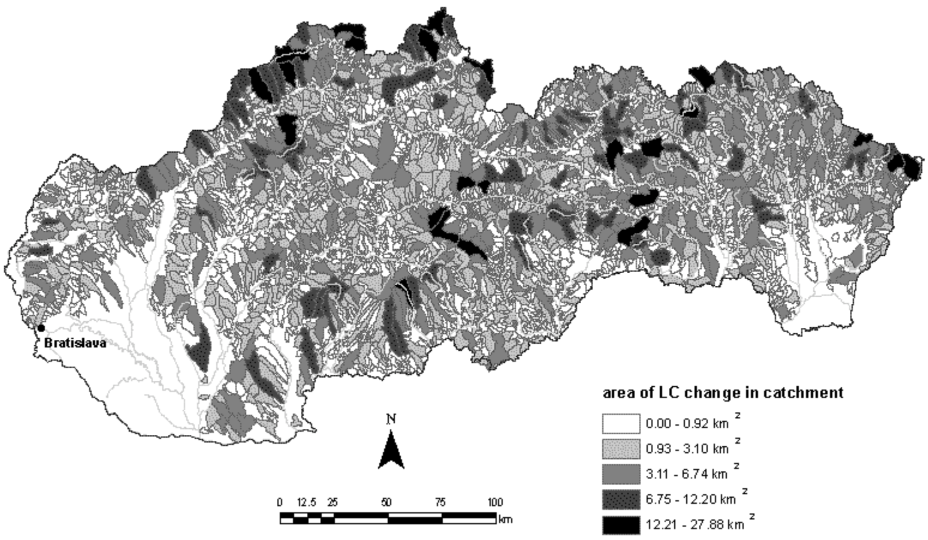

Fig. 4 Total area of LC changes in catchments in the period 1990-2006.

The total area of LC changes in catchments as a rule is the sum of several changes shares of which in total changed area are different. In connection with frequency of flood events, LC changes accelerating or decelerating formation of direct runoff are crucial (Fig. 5 and Fig. 6). LC changes accelerating formation of direct runoff dominated (i.e. those that occupied more than 50% of total changed area) in 558 catchments while changes decelerating the formation of direct runoff prevailed in 646 catchments. The biggest (in terms of an area) of LC changes accelerating formation of direct runoff was deforestation (827 km^2) it means changes of CLC 311, CLC 312, and CLC 313 into CLC 324. Among changes decelerating formation of surface runoff the changes in the framework of agricultural areas (change of CLC 243 into CLC 211), the forestation process represented by the change of agricultural areas (CLC 2) into forest (CLC 3), by the change of class CLC 324 into CLC 311, 312 a 313 and the change of artificial surfaces (CLC 1) into forest (CLC 3) (a result of abandonment of rural settlements because of construction of a drinking water reservoir and the protective zone around it) prevail. The biggest in terms of area are changes of CLC 324 into CLC 311 and CLC 243 into CLC 211.

Table 3 Cross tabulation of LC changes 1990-2006 (km^2).

CLC classes 1990	CLC classes 2006																	
	112	121	122	131	133	142	211	221	222	231	242	243	311	312	313	321	324	Total
112		2.35	1.07	0.10		0.68	35.0	0.24	0.65	9.82	7.56	19.7	2.67	1.04	0.68		2.06	**84.5**
121	1.04		0.15	0.21	0		3.43			0	0.12	0.22	0.26	0	0			**5.56**
122	0.3											0.08						**0.38**
131	0.21	0.07					0.81						0.73	0.29	0.07		1.36	**3.54**
133	0.75									0.38			0.18					**1.31**
142	0.33						0.31			0.53	0.09	0.21	3.19	3.9	1.33		1.66	**11.9**
211	20.9	5.92	2.49	0.58	4.00	1.08		11.5	8.09	73.2	126	86.5	31.5	3.87	7.71	0.16	3.96	**388**
221	0.62	0					24.2		0.39	0.56	1.84	4.11	0.39			0.1	0.11	**32.3**
222	0.39		0.28				15.8	0.79		1.06	1.22	2.34	0.60				0.22	**22.7**
231	3.06		0.18	0.39	0.12	1.20	86.9				26.1	135	71.9	70.1	44.3	1.04	105	**545**
242	1.78				0	0.34	5.03	0.06		1.83		7.8	1.38	0.08	0.07			**18.4**
243	21.4	0.60	0.48	0.08	0.18	2.34	223	1.26	1.89	114	21.1		136	38.5	48.6	0.39	56.1	**666**
311	0.60	0.29		0.08		0.67	10.7		0.21	4.80		11.1		11.6	216	0.30	209	**466**
312	0.26	0.14		0.18		0.67	1.35			6.42	0.14	4.78	10.8		114	0.49	522	**661**
313	0.71	0.69		0.24		1.42	2.48		0.03	2.27	0.05	4.38	96.8	66.0			96.4	**271**
321							0.07			0.35	0.17		2.36	7.38		2.85	14.1	**27.3**
324	0.08	0.32				0.65	2.1		0.05	5.9	0.1	6.8	293	75.8	132	0.53		**518**
Total	**52.4**	**10.4**	**4.7**	**1.86**	**4.30**	**9.05**	**411**	**13.8**	**11.3**	**221**	**184**	**283**	**652**	**279**	**565**	**5.86**	**1013**	

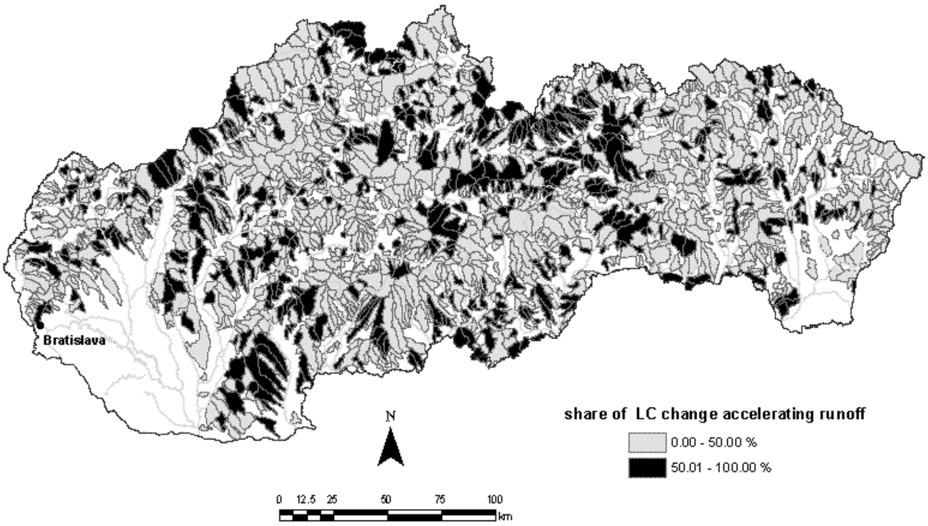

Fig. 5 LC changes in catchments accelerating runoff.

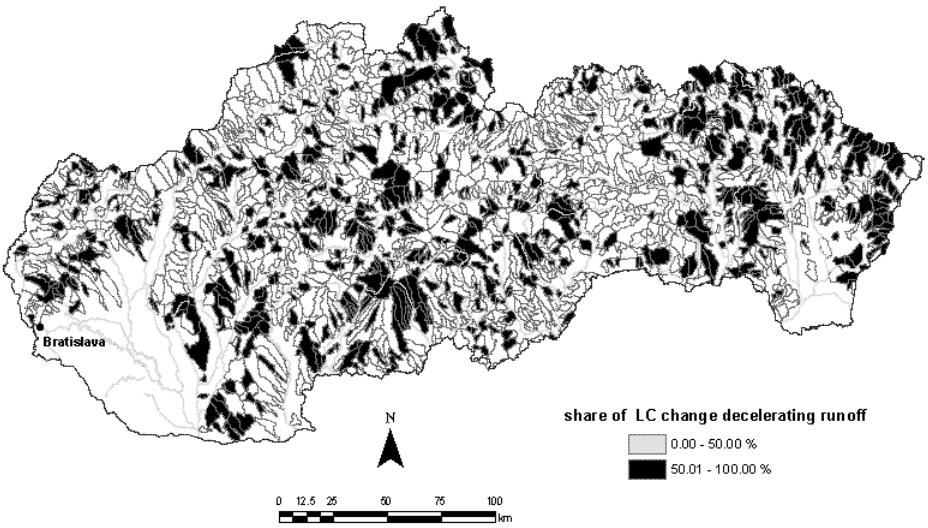

Fig. 6 LC changes in catchments decelerating runoff.f

LC CHANGES IN SMALL CATCHMENTS VS FREQUENCY OF FLOOD EVENTS

Whether the frequency of flood events in small catchments in the period 1996-2006 was also aggravated by LC changes that took place in the 1990-2006 period or not depends on answers to these questions:

- are flood events more frequent in catchments where some change of LC occurred than in catchments that remained the same?
– does frequency of flood events in catchments increases with increasing area of LC changes?
– are floods events more frequent in catchments where LC changes accelerating runoff prevail than in catchments in which LC change decelerating runoff dominate?

In total number of 1,678 of small catchments land cover changes occurred in 1,652. Consequently, the number of catchments where no LC changes were identified is very small and comparison of flood event frequency between the two groups would be incorrect. The first question looses sense. With regard to the second question, total LC change area values in catchments were grouped into four classes and each class was represented by arithmetic average of flood event frequency (Table 4). Averages comparatively clearly indicated increasing frequency of flood events with increasing total area of LC changes in catchments.

Table 4 Effects of LC change area on frequency of flood events.

Area of LC changes (km^2)	I area ≤18.6		II 18.6>area≤44.7B		III 44.7>area≤92.5		IV area>92.5	
	$\bar{j}$	*n*	$\bar{j}$	*n*	$\bar{j}$	*n*	$\bar{j}$	*n*
Average/number	*0.358*	1023	*0.696*	412	*0.949*	159	*1.517*	58

As far as the third question is concerned, catchments where LC changes accelerating runoff prevail were grouped in class A and catchments in which LC change decelerating runoff dominate compose class B. Their corresponding frequencies of flood events are quoted in table 5. The arithmetical means of flood event frequency in class A is lower than in class B. Consequently, these values do not indicate the presumed trend of increasing flood events in catchments where LC changes accelerating formation of direct runoff prevail.

Table 5 Effect of LC change type on frequency of flood events.

Type of change	A		B	
	$\bar{j}$	*n*	$\bar{j}$	*n*
Average/number	*0.462*	558	*0.555*	646

A- group of chatchments with LC changes accelerating runoff
B- group of chatchments with LC changes decelerating runoff

Data concerning frequency of flood events and those about LC changes in catchments correspond to a relatively short period of 11 and 16 years, respectively and represent sample observations. As the flood event values are not those of the true population means, it is necessary to test whether the effect of area of LC change classes in catchments on frequency of flood events (Table 4) is systematic or it only causes random variations. Method of analysis of variance and pairwise comparison by method LSD (Fisher's protected least significant difference) was used to test this hypothesis. Value of *F*-test (Table 6) suggests that the effect of total LC change area in catchments on frequency of flood events is statistically significant and a certain systemic dependence exists between frequency of flood events and area of LC changes. Results of pairwise comparison showed that all pair differences between averages of frequency of flood events were statistically significant. (Table 7.)

Table 6 Results of ANOVA

Source of variation	d.f.	s.s.	m.s	*F**	*F* pr
Area of LC change classes	3	125.788	41.929	43.61	<0.001
Residuals	1648	1584.494	0.9615		
Total	1651	1710.2827			

d.f. – degree of fredom
s.s. – sum of square
m.s – mean sum of square
*F** – empirical F value
Fpr – probility of F distribution

Table 7 Results of pairwise comparison

Mean vs mean		t	significant
I	II	-5.907	yes
I	III	-7.07	yes
I	IV	-8.757	yes
II	III	-2.764	yes
II	IV	-5.97	yes
III	IV	-3.776	yes

CONCLUSION

The traditional research at the local level for a single catchment or a pair of catchments, normally puts emphasis on capturing the temporal aspect of changes of flood attributes such as the size of the maximum discharge, the volume and duration of flood wave by comparison of their size before and after the LC change in catchment. In this paper some results of statistical approach to the analysis of the relationship between the frequency of flood events and LC changes is presented. It has been concluded that the frequency of flood events increases with the increasing total LC change area in a catchment and this tendency is clearly distinguishable but there is no difference in frequency of flood events as far as type of LC change (accelerating or decelerating runoff) is concerned.

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