

Impact of land-cover change related to urbanization on surface runoff estimation

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Abstract. Civil engineering structures are highly responsible for the negative aspects of urbanization on the hydrological cycle. Due to the land cover change and an increase of impervious areas the risk of flooding can rise significantly. The paper presents the impact of urbanization processes on surface runoff estimation for a small mountainous catchment between 1990-2012.

1 Introduction

Urbanization processes relate to various aspects (demographic, economic, social, spatially-architectural and technical) [1] and are observed throughout Poland. Due to these processes, the local land-cover is frequently changed in a way that increases impervious areas. This phenomenon may have a significant impact on hydrological processes in the catchment [2], [3] and lead to the increased risk of flooding. The changes in land-cover resulting from urbanization processes are predominantly associated with civil engineering structures. Constructions of buildings, roads, and artificially surfaced areas are the main factors responsible for the increase of impervious areas.

The mountainous catchments are naturally characterized by a quick hydrological response, which is one of the primary reasons for flooding [4], but this effect is expected to be increased by the expansions of impervious areas. As a study area, a small 240,4 km² [5] mountainous catchment, the upper Skawa, located in southern Poland was chosen. Within the catchment, six subcatchments can be identified. Due to its mountainous landform and frequent heavy rain events, every year this region struggles from flash floods. The goal of this study is to analyze the impact of urbanization-related to the expansion of civil engineering structures from 1990 to 2012 on surface runoff-estimation. Figure 1 presents the characteristics of the research area.

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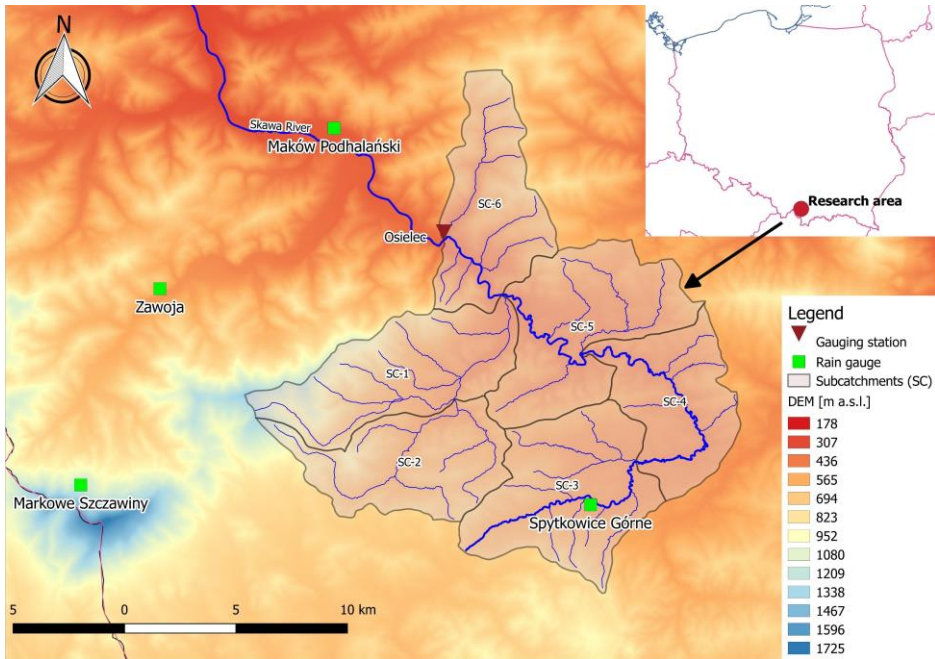


Fig. 1. Research area - the upper Skawa catchment [own elaboration]

2 Material and methods

2.1 Land cover

In the study we use the land cover information created under CORINE Land Cover projects CLC1990 v.18.5 and CLC2012 v.18.5.1. The maps of land cover under these projects were created using satellite images and other ancillary data. The Corine databases are frequently used within various environmental studies, e.g. hydrology [6], [7] as they are freely available data source of significant reliability ($\geq 85\%$). On Figure 2 a comparison of a land cover according to CLC Codes [8] is shown between 1990 and 2012.

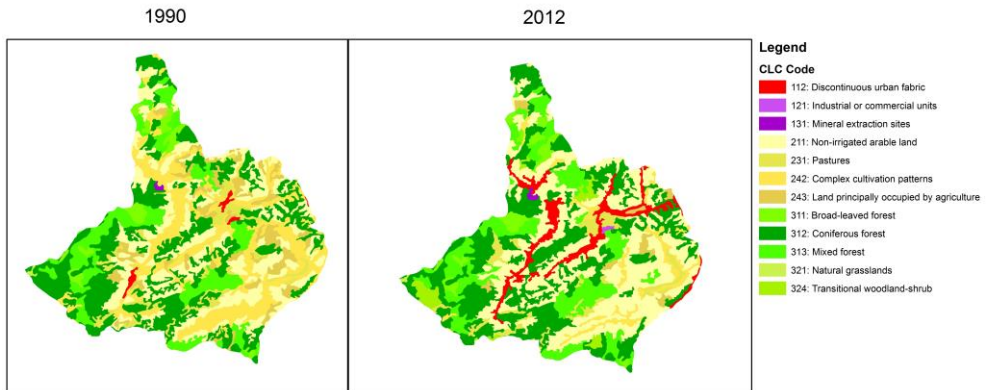


Fig. 2. Land-cover of the upper Skawa catchment in 1990 and 2012 [own elaboration]

In Table 1 areas [km²] and relative areas [%] for 1990 and 2012 datasets are shown according to CLC Codes. Also, the pattern of change between these years is indicated (↑ - increase, ↓ - decrease).

Table 1. Land-cover areas and patterns for CLC1990 and CLC2012 [own elaboration]

CLC Code	1990		2012		Pattern
	Area [km ²]	%	Area [km ²]	%	
112	1,6	0,7%	14,5	6,04%	↑
121	0,0	0,0%	0,3	0,12%	↑
131	0,3	0,1%	0,4	0,18%	↑
211	55,9	23,3%	78,7	32,74%	↑
231	11,3	4,7%	10,8	4,49%	↓
242	48,1	20,0%	10,1	4,19%	↓
243	18,2	7,6%	4,0	1,66%	↓
311	6,9	2,9%	7,5	3,14%	↑
312	67,4	28,0%	72,2	30,04%	↑
313	30,4	12,7%	36,2	15,08%	↓
321	0,2	0,1%	0,2	0,08%	↓
324	0,0	0,0%	5,4	2,24%	↑

Most of the catchment is covered by non-irrigated arable lands as well as coniferous and mixed forests. Between 1990 and 2012 a significant decrease in complex cultivation patterns (CLC Code 242) and land principally occupied by agriculture (CLC Code 243) is observed. In the meantime, we can notice the increase of discontinuous urban fabrics (CLC Code 112) and industrial or commercial units (CLC Code 121) which indicate that the urbanization processes occur within the catchment.

2.2 Surface runoff-estimation

The Soil Conservation Services Curve Number (SCS-CN) developed by the United States Department of Agriculture in 1972 is one of the most popular methods for estimation of surface runoff knowing the amount of rain.

If the total rainfall is greater than initial abstraction, then the surface runoff in SCS-CN method is described as:

$$P_e = \frac{[P - S_p]^2}{P - S_p + R} \tag{1}$$

where:

P_e - runoff [mm], P - total rainfall [mm], S_p - initial abstraction [mm], R - potential maximum retention of soil [mm].

The maximum potential retention of soil (R) is related to the estimated CN value (CN):

$$R = 254 \left(\frac{100}{CN} - 1 \right) \quad (2)$$

The amount of initial abstraction (S_p) is expressed as a fraction of the potential maximum retention of soil:

$$S_p = \mu R \quad (3)$$

where: μ - empirical coefficient based on the CN value (CN < 70, $\mu = 0,075$; $70 \leq$ CN < 80, $\mu = 0,100$; $80 \leq$ CN < 90, $\mu = 0,150$; $90 \geq$ CN, $\mu = 0,200$).

Taking into account eq. (2) and eq. (3) we can notice that the estimated surface runoff eq. (1) significantly depends on the estimated CN value.

2.3 Identification of Curve Number values

The Curve Number (CN) indicates the proportion of rainfall that contributes to surface runoff. Its value is estimated according to the relationship between land cover and hydrologic soil group. Curve number is estimated between 0 to 100. The greater the CN value, the greater proportion of surface runoff. In Table 2 the CN values are presented according to the land cover and hydrological soil group.

Table 2. CN values according to land cover and hydrologic soil group [based on: [9]]

CLC Code	Land cover	Curve numbers for hydrologic soil group			
		A	B	C	D
112	Discontinious urban fabrics	54	70	80	85
121	Industrial or commercial units	85	90	92,5	94
131	Mineral extraction sites	77	86	91	94
211	Non-irrigated arable land	65	76,5	84	88
231	Pastures	30	58	71	78
242	Complecs cultivation patterns	30	58	71	78
243	Land principally occupied by agriculture	78	83	86	88
311	Borad-leaved forest	30	55	70	77
312	Coniferous forest	36	60	73	79
313	Mixed forest	30	55	70	77
321	Natural grasslands	39	61	74	80
324	Transitional woodland-shrub	30	55	70	77

The hydrologic groups in Table 2 are defined as follows: A - low runoff potential, B - moderate infiltration, C - slow infiltration, D - high runoff potential. Within the study area, the hydrologic soil group values vary between B and C.

3 Results

The CN values are estimated separately for every subcatchment. Therefore, for each subcatchment we multiply the area of land cover (Table 2) by its corresponding CN value (Table 3). Finally, a single CN value is calculated for each subcatchment. Based on the CLC 1990 and CLC 2012 the CN values were calculated. The results are presented in Table 3.

Table 3. Curve Numbers based on CLC 1990 and CLC 2012 [own elaboration]

Subcatchment	CN (based on CLC 1990)	CN (based on CLC 2012)	Pattern
SC-1	57,43	61,46	↑
SC-2	65,21	64,21	↓
SC-3	69,03	69,70	↑
SC-4	80,90	72,36	↓
SC-5	78,51	70,56	↓
SC-6	75,51	70,87	↓

Non-significant changes in CN estimation are observed for subcatchments SC-2 and SC-3. In subcatchment SC-1 a small increase of the CN value is observed which means a slightly greater value of the runoff potential. However, for the rest of the subcatchments, we observe a significant decrease in the estimated CN value based on CLC 2012 regarding CN valued estimated based on CLC 1990. Therefore, the runoff potential in subcatchments SC-4, SC-5 and SC-6 estimated basing on CLC 2012 is lower than the one calculated based on CLC 1990.

4 Summary and conclusions

In this study, we analyzed the impact of land cover change related to urbanization processes on the surface runoff estimation. The performed calculations lead to the following conclusions:

- the urbanization processes related to the expansions of civil engineering structures seem to have no significance consequences resulting in an increase the runoff potential for the analysed subcatchments,
- estimated unified CN values for subcatchments can be used in semi-distributed hydrological models (e.g., HEC-HMS).

It is worth to notice that we can counteract the adverse effects of urbanization on hydrological cycle at the level of civil engineering structures. For example, the structural health monitoring of the building [10] or expert systems [11] may be applied in a way that will help in the collection of rainwater and limit the surface runoff on the impervious areas.

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References

1. B. Jałowiecki, M.S. Szczepański, *The city and space in the sociological perspective* (Warsaw, Wydawnictwo Naukowe Scholar, 2009)
2. R. DeFries, K.N. Eshleman, *Hydrol. Process.*, **18**, 2183–2186 (2004)
3. E. Salvatore, J. Bronders, O. Batelaan, *J. Hydrol.*, **529**, 62–81 (2015)
4. F. Fabry, A. Bellon, M.R. Duncan, G.L. Austin, *J. Hydrol.*, **161**, 415–428 (1994)
5. P. Gilewski, M. Nawalany, *Sensitivity of hydrological response of small mountainous catchment to the spatial resolution of precipitation field* (*Geophys. Res. Abstr.*, **20**, 2018)
6. B. Koulov, G. Zhelezov, *Sustainable mountain regions: Challenges and perspectives in Southeastern Europe* (Springer International Publishing Switzerland, 2016)
7. E. Martin et al., *Surv. Geophys.*, **37**, 223–247 (2016)
8. Y. Heymann, C. Steenmans, G. Croissille, M. Bossard, *CORINE Land Cover. Technical Guide.*, Off. Publ. Eur. Communities (1994)
9. M. Ozga-Zielińska, J. Brzeziński, *Applied hydrology* (Warszawa, Wydawnictwo Naukowe, PWN, 1997)
10. A. Al Sabouni-Zawadzka, *Arch. Civ. Eng.*, **60**, 517–534 (2014)
11. A. Węglarz, P. G. Gilewski, *MATEC Web of Con.*, **117**, 1–7 (2017)