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Assessment of Retention Potential Changes as an Element of Suburbanization Monitoring on Example of an Ungauged Catchment in Poznań Metropolitan Area (Poland)

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1. Introduction

The issue of water resources management gains its importance particularly because of extreme flooding phenomena. In Poland in the last two decades they have proved to be especially severe during year 1997, 2001 and 2010. While comparing it to other adverse weather events, floods cause maximum economic, social and environmental damage (Mrozik 2012). On the other hand, the same time period in Poland was also connected with the intensive suburbanization, which lead to the transformation of permeable surfaces (arable land) into impermeable areas (built-up areas, transportation routes, etc.), resulting in a more rapid run-off of precipitation waters from the catchment, periodical overload of drainage systems and local inundations (Przybyła et al. 2011). Also Petrović stressed that torrential floods, belonging to flash floods appears especially suddenly in small catchments after short duration rains (<24 h) with strong intensity (i>0,5 mm/min) and are the most frequent and disastrous natural hazards (Petrovic et al. 2015, Petrovic et al. 2014).

The observed rate of suburbanization forces monitoring of changes in the spatial development of the commune, which is realised by Central Statistical Office of Poland (Mrozik 2015). Despite the numerous of the proposed indicators to monitor the spatial order (Śleszyński 201) including those relating direct to the environment, it can be noticed the lack

of indicators proposals taking into account the need for monitoring of retention potential change in the hydrographic catchment, which is according to IWRM principles constituted of the primary area for all planning and decision-making activities (Mrozik et al. 2015).

Kundzewicz at al. (2008) argued that precipitation is not adequately simulated by the present climate models. Poland is one of the countries for which climate models largely contradicting future precipitation projections. According to the forecast, it was only a general increase in the frequency and amplitude of extreme events, including floods and droughts (IPCC 2007). In turn, different development scenarios for urbanized areas in Europe based on the IPCC assumptions independently indicated their further expansion at 0.4-0.7% annually, which has been resulted from an over 10-fold greater increase than the development of any other type of land use. A vast majority of this process will occur in peri-urban areas, including considerable areas of Poland (Loibl & Köstl 2008, Nilsson 2013).

The observed and forecasted effects of climate change and developments such as urbanization, suburbanization and peri-urbanization require comprehensive adaptation actions but also monitoring system, especially in the field of water management and spatial planning.

The objective of the study was to investigate the possibility of using the SCS-CN method as an element of suburbanization monitoring to assess the change in retention potential in ungauged catchment in metropolitan areas at the local planning level.

2. Methods

Poznań Metropolitan Area (PMA) is located in Odra river basin, in the water region of the Warta. The delimited by Wielkopolskie Biuro Planowania Przestrzennego PMA comprises 45 communes together with Poznań and covers 6.2 thousand km^2 (approx. 21% area of the Wielkopolska province). The PMA population is 1.3 million, which represents about 39% of province population (Mrozik et al. 2015). It needs to be stressed that currently the PMA is also called as the functional urban area of Poznań.

In order to determine the effective precipitation and potential water retention of the catchment in this study the curve number (CN) meth-

od, originally developed by the U.S. Department of Agriculture Soil Conservation Service (USDA-SCS) (now the USDA Natural Resources Conservation Service – USDA NRCS) was used. SCS-CN is well recognized tool in water management and spatial planning, in which it is dependent on the soil type, land use method and soil wetting prior to the occurrence of precipitation. These factors were comprised in the dimensionless parameter CN, assuming values from 0 (no runoff) to 100 (total runoff). This parameter was functionally connected with maximum potential retention of the catchment (S) expressed in mm:

$$S=25{,}4\cdot\left(\frac{1000}{CN}-10\right)$$

The SCS runoff (Q) (effective precipitation) equation used in the paper were:

$$Q=\frac{(P-0{,}2S)^2}{(P=0{,}8S)},$$

where P means rainfall (mm).

The SCS-CN method categorizes soils into one of four different groups: A (sand, loamy sand), B (silt loam or loam), C (sandy clay loam) and D (clay loam, silty clay loam, sandy clay, silty clay or clay) (NRCS 1986). In this study parameters CN for average moisture conditions were assumed after Nowicka and Wolska (2003).

The SCS-CN method considers three antecedent moisture conditions (AMC) to indicate the extent of soil saturation, where 'dry' (AMC I), 'average/normal' (AMC II), and 'wet' (AMC III) indicate the difference in saturation based on rainfall over the previous 5 days and season of the year (Miller 2012a, Miler 2012b, NRCS 1986).

The analysis of land cover change was conducted on the basis of a topographic map of 1998 at a 1:10 000 scale (reference system PUWG 1992) and the Urban Atlas based on photographs from SPOT 5 satellite performed on 24/25.09.2007 on the ground resolution of 2.5 m. Pictures were updated with data from topographic maps. The overall process of vectorization with the test of its performance ended 21.10.2009 (reference system WGS1984). The Urban Atlas identifies the following forms of land use:

- continuous urban fabric (S.L. > 80%), discontinuous dense urban fabric (S.L.: 50-80%), discontinuous medium density urban fabric (S.L.: 30-50%), discontinuous low density urban fabric (S.L.: 10-30%), discontinuous very low density urban fabric (S.L. < 10%),
- agricultural,
- industrial, commercial, public, military and private units,
- isolated Structures,
- fast transit roads and associated land ,
- other roads and associated land,
- railways and associated land,
- port areas,
- airports,
- mineral extraction and dump sites,
- land without current use,
- green urban areas,
- forest,
- sports and leisure facilities,
- wetlands,
- water (Mrozik et al. 2012).

As a source of soil data, in this study, the soil map (1:25 000) with soil topology provided by Institute of Soil Science and Plant Cultivation (IUNG) in Puławy were used. Individual steps of the SCS-CN methods were conducted using ArcGIS 10.0 software by ESRI.

Detailed analyses were carried out based on the Skorzynka river catchment covering about 10 km^2. The Skórzynka catchment is located within the rural communes of Dopiewo, Tarnowo Podgórne and the city of Poznań (Fig. 1), covering 21% area of its recipient – the Potok Junikowski strem. Potok Junikowski was defined as a strongly altered water body and it was threatened with failure to reach environmental objectives. Due to the strong morphological changes temporal derogations were forecasted due to a lack of technical facilities and disproportional costs connected with watercourse renaturation (a strongly urbanized area). In the past the Skórzynka channel in the non-urbanized area was artificially deepened and it constituted a part of the land improvement system. At present the watercourse constitutes a recipient of rainwater from the catchment area (Mrozik et al. 2015).

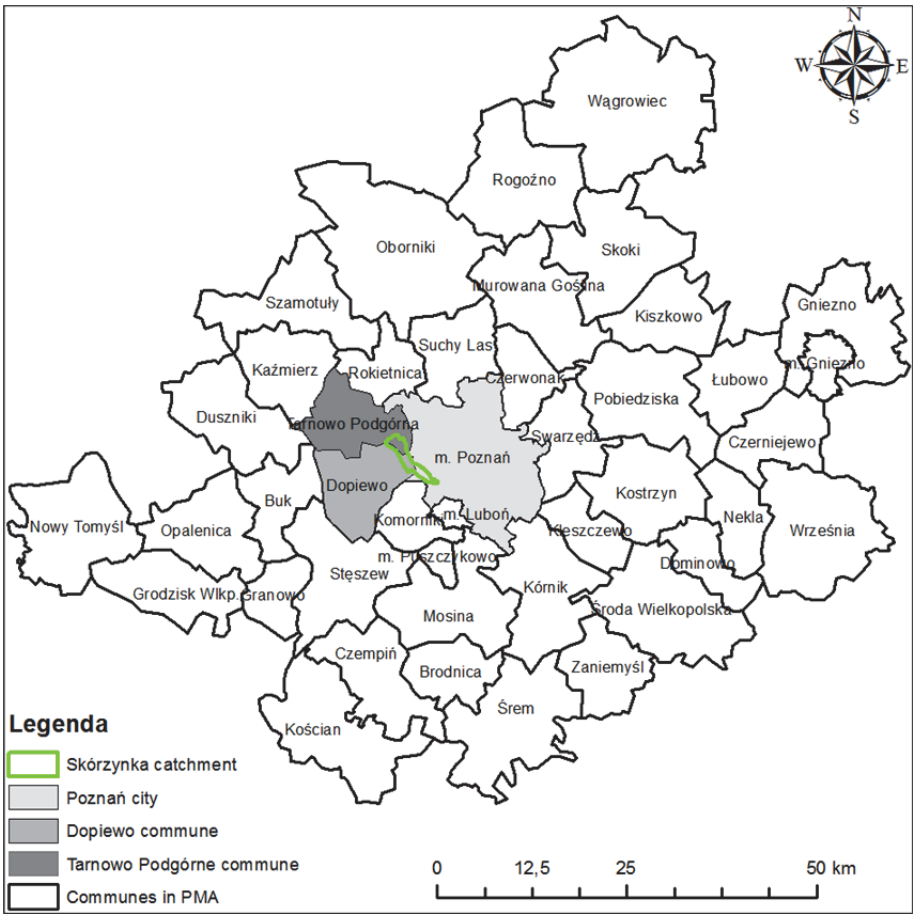

Fig. 1. Skórzynka catchment on the background of communes in Poznań Metropolitan Area
Rys. 1. Zlewnia Skórzynki na tle gmin w Poznańskim Obszarze Metropolitalnym

The climate in PMA is characterized by variability of rainfall in space and time. Based on the climatic data provided by the climatic station of Poznań Ławica from 2000 to 2013, annual precipitation varied from 345 (2003) to 634 (2013) mm with an average value of 532 mm per year, which corresponds to the most arid regions of Europe. More about PMA's hydrologic and climatic characteristics can be found in Mrozik at al. (2015).

3. Results and discussion

The Skórzynka has the snow and rain supply pattern, with one maximum and one minimum in a year. Upon reaching the spring maximum, most typically in March, water stages and flow decrease markedly. A typical phenomenon is connected with the rapid transition from the peak stage to the low-flow stages, which generally begin in June, are stable and typically last until the end of the hydrological year.

In the case of precipitation a characteristic feature is its spatial and temporal variability, hindering conclusive inference. This is confirmed e.g. by the analyses of extreme precipitation in August 2010 (Przybyła et al. 2011). In this study a uniform precipitation level throughout the entire area was used, applicable for very small catchments (up to 10 km^2). The analysis of the change in potential water retention of the Skórzynka catchment was carried out for the years 1998 (topographic map) and 2009 (urban atlas).

In 1998 farmland predominated in the investigated area, covering 46% catchment area. Built-up areas account for 35%. It also needs to be stressed here a particularly low lake density. According to data of 2009 (Urban Atlas), agriculturally utilized areas covered as little as 31% catchment area, which is equivalent to a reduction by 1/3 in comparison to data from 1998. In turn, housing development areas together with service and industrial facilities, vehicle transport routes and railway tracks cover 54% area, which means an increase by over 1/2. It needs to be marked that housing development has appeared also on high quality soils.

To assess the impact of land use change on the potential water retention of the catchment the SCS-CN method was used. The value of CN varies within the range of 25 (forest) – 100 (surface water) (Fig. 2). Its weighted mean for was 72 in 1998 and increased to 76 in 2009 by AMC II (average). The maximum potential retention of the Skórzynka catchment was specified based on the calculated parameters. The results depending on the year and antecedent moisture conditions (AMC) are listed in the table 2. The recorded values for average AMC (II) means decrease of potential water retention of catchment at about 20%, for AMC III it was about 25%.

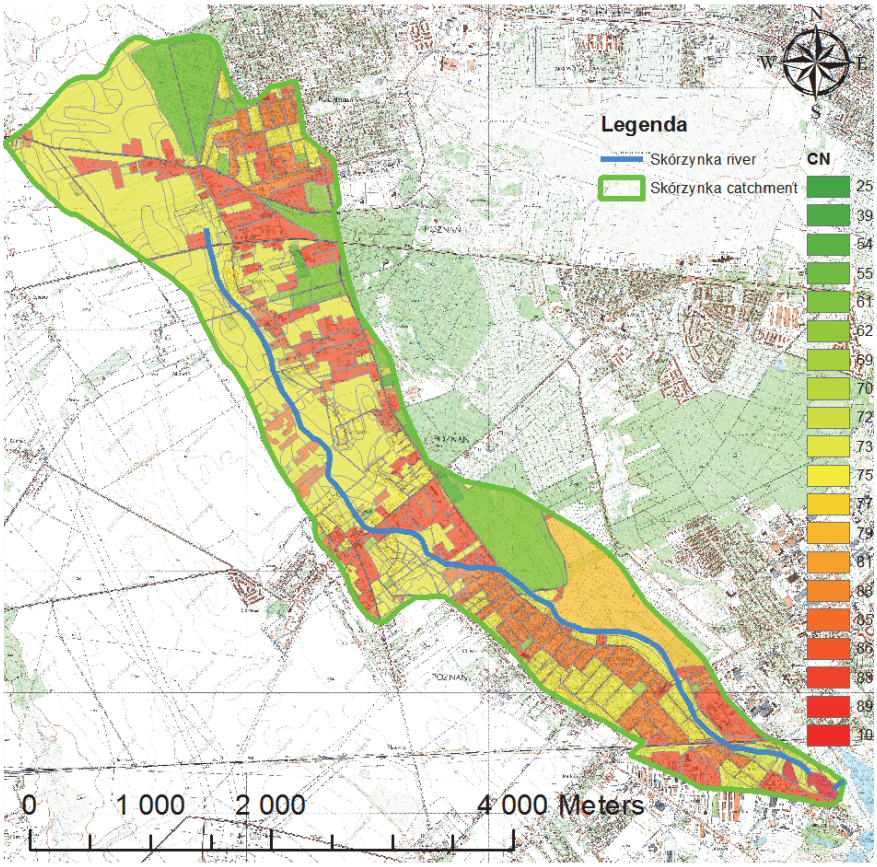

Fig. 2. Spatial distribution of the CN parameter set by Urban Atlas (2009) – shown on a base of topographic map (1998)
Rys. 2. Rozkład przestrzenny parametru CN określony na podstawie danych z urban atlasu (2009) przedstawiony na podkładzie mapy topograficznej z 1998

Time variability of rainfall intensity, in addition to duration and total precipitation, has a major impact on the size of the flood. In order to identify the hazards of extreme rainfall is necessary to determinate effective precipitation. In this paper, calculations were carried out for rainfall event recorded on 17.08.2010 at meteorological station Poznań – Ławica. This is the precipitation about the probability occurrence of once every 100 years. Throughout the 10 years it can be seen as significantly increased effective precipitation in the Skórzynka catchment (Table 2). This is due to primarily intensive suburbanization in rural communes, taking place at the

expense of arable land. Previous studies have shown, that smaller impervious surfaces connected to river network could generate flashier responses than larger impervious surfaces (Meierdiercks et al. 2010). The significance of spatial and temporal changes in land use and land cover for the surface runoff potential stressed also (Deshmukh et al. 2013).

Table. 2. Change in potential water retention and effective precipitation in Skórzynka catchment
Tabela. 2. Zmiany potencjalnej retencji i opadu efektywnego w zlewni Skórzynki

Potential water retention (S) (mm)					
AMC I		AMC II		AMC III	
1998	2009	1998	2009	1998	2009
225	184	99	80	41	31
Runoff (Effective precipitation) (Q) (mm) during the 98 mm rainfall event (17.08.2010)					
AMC I		AMC II		AMC III	
1998	2009	1998	2009	1998	2009
10	15	35	41	61	68

4. Conclusion

In any geospatial study of changes over time, a major challenge is the availability of suitable datasets. This article showed that in small catchment, not covered by permanent monitoring (e.g. state of water), which are subject to intense urbanization processes, application of the SCS-CN method may be useful for evaluating the potential water retention. In addition, it has been shown that urban atlas can be a useful source of spatial land use data for the peri-urban and urban areas at the local planning level.

The conducted analyses allow to conclude that the SCS-CN method can be used as an element of suburbanization monitoring to assess the change in retention potential in ungauged catchment in metropolitan areas at the local planning level.

With the use of the SCS-CN method for catchment Skórzynka in years 1998-2009, a decrease of potential retention (about 20%) and increase of effective precipitation (about 17%) has been demonstrated. These results may be a decision criterion for local authorities in the proper creation of spatial policy, especially in water resources management and preventing local floods and droughts.

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Ocena zmian potencjału retencyjnego jako element monitoringu suburbanizacji na przykładzie niekontrolowanej zlewni w Poznańskim Obszarze Metropolitalnym (Polska)

Streszczenie

Rozwój miast skutkuje znacznymi zmianami użytkowania terenu i powiązań funkcjonalnych pomiędzy obszarami miejskimi i wiejskimi. Zmieniające się relacje pomiędzy użytkowaniem obszarów miejskich i wiejskich prowadzą do zmian jakości życia mieszkańców, środowiska i świadczeń ekosystemów, w tym zasobów wodnych. Zmiany te są najbardziej widoczne na obszarach podmiejskich.

Różne scenariusze rozwoju obszarów zurbanizowanych w Europie oparte na założeniach IPCC wskazują niezależnie na ich dalszą ekspansję w granicach 0,4-0,7% rocznie, co jest wynikiem ponad dziesięciokrotnie wyższym niż rozwój jakichkolwiek innych typów użytkowania. Oznacza to, że nasilenie tego procesu będzie szczególnie widoczne na obszarach podmiejskich, w tym na znacznych obszarach Polski.

Obserwowane intensywne przekształcania terenów użytkowanych rolniczo na tereny zabudowane i zurbanizowane zmuszają do zastanowienia się nad wpływem suburbanizacji na gospodarowanie wodami zwłaszcza w kontek-

ście zjawisk ekstremalnych, z których w Polsce w ostatnich dwóch dekadach szczególnie dotkliwe okazały się powodzie w 1997, 2001 i 2010 r. Szczególnego znaczenia nabiera potrzeba monitoringu zjawiska suburbanizacji w kontekście jej wpływu na gospodarowanie wodą w zlewni rzecznej będącej zgodnie z zasadą IWRM podstawową jednostką planistyczną w planowaniu w gospodarowaniu wodami.

Celem pracy była ocena możliwości zastosowania metody SCS-CN jako elementu monitoringu procesu suburbanizacji poprzez zwymiarowanie zmian w potencjalne retencyjnym niekontrolowanych zlewni rzecznych na terenach podmiejskich w miejskich obszarach funkcjonalnych (metropolitalnych).

Szczegółowe analizy w pracy wykonano na przykładzie zlewni Skórzynki położonej w granicach gmin wiejskich Dopiewo i Tarnowo Podgórne i miasta Poznań stanowiących rdzeń Poznańskiego Obszaru Metropolitanego (POM) (określanego obecnie jako Miejski Obszar Funkcjonalny Ośrodka Wojewódzkiego) Ogółem według delimitacji zaproponowanej przez Wielkopolskie Biuro Planowania Przestrzennego POM obejmuje 45 gmin wraz z Poznaniem (w tym 15 miast powiatowych i 15 pozostałych miast).

Do oceny zmian potencjału retencyjnego i opadu efektywnego wykorzystano metodę SCS-CN. Zmiany zagospodarowania terenu oceniono na podstawie mapy topograficznej z 1998 r. w skali 1: 10 000 oraz urban atlasu bazującego na zdjęciach satelitarnych SPOT5 o rozdzielczości terenowej 2,5m z roku 2007. Dane dotyczące gleb pochodziły z mapy glebowo-rolniczej w skali 1: 25 000 wykonanej przez IUNG w Puławach. Wszystkie analizy wykonano przy użyciu oprogramowania ArcGIS 10.0 firmy ESRI. Dane opadowe pochodziły ze stacji Poznań-Ławica.

Dzięki metodzie SCS-CN wykazano dla zlewni Skórzynki w okresie 11 lat dla przeciętnych początkowych warunków wilgotnościowych spadek potencjalnej retencji (o 20%, tj. z 99 na 80mm) oraz wzrost opadu efektywnego (o 17%, tj. z 35 na 41mm) wyliczonego dla ekstremalnego zdarzenia opadowego odnotowanego 17.08.2010 r.

Wykonane analizy pozwalają stwierdzić, że metoda SCS-CN jest użytecznym i pożądanym narzędziem monitoringu procesu suburbanizacji w niekontrolowanych zlewniach położonych w obrębie obszarów metropolitalnych w celu oceny zmian potencjału retencyjnego zlewni.

Uzyskane wyniki mogą stanowić kryterium decyzyjne dla lokalnych władz we właściwym kreowaniu polityki przestrzennej, zwłaszcza w zakresie kształtowania zasobów wodnych oraz przeciwdziałania lokalnym powodziom i suszom.

Abstract

The development of the cities results in significant changes in land use and functional connections between urban and rural areas. The changing relations between the use of urban and rural areas lead to changes in the quality of the inhabitants' lives, of the environment and ecosystem services, including water resources. Those changes are the most visible in peri-urban areas.

Different scenarios of the development of urbanized areas in Europe based on the IPCC assumptions indicate their further expansion at 0,4-0,7% per year which is over 10 times higher score than any other land use. This means that the intensity of this process will be particularly visible in peri-urban areas, including considerable areas of Poland.

The observed intensive transformations of arable lands into built-up and urbanized areas make one think about the influence of suburbanization on water management, especially in the context of extreme phenomena, out of which the most afflictive over the two last decades were floods in 1997, 2011 and 2010. Monitoring the process of suburbanization gains importance in the context of its influence on water management in the river catchment which, according to the IWRM principle, a basic planning unit are in water management planning.

The objective of this paper was evaluation of the possibility of using the SCS-CN method as an element of monitoring process of suburbanization through sizing the changes in the in water retention potential of ungauged catchments on peri-urban areas of metropolitan areas.

Detailed analyses were carried out based on the Skorzynka river catchment located within the rural communes of Dopiewo, Tarnowo Podgórne and the city of Poznań which are the nucleus of Poznan Metropolitan Area (PMA) (currently defined as the voivodeship urban functional area of Poznań). Altogether, according to the delimitation proposed by the regional planning office Wielkopolskie Biuro Planowania Przestrzennego (WBPP), PMA comprises 45 communes together with Poznań (including 10 cities – centres of district and 15 other small cities).

To the assessment of potential water retention and effective precipitation the SCS-CN method was used. The changes in land use were estimated on the basis of a topographic map from 1998 at a 1:10 000 scale and the Urban Atlas based on satellite photographs from SPOT 5 satellite on the ground resolution of 2.5 m from 2007.

Data on soil were obtained from soil and agricultural maps at a 1:25 000 scale performed by Institute of Soil Science and Plant Cultivation (IUNG) in Puławy. All analyses were performed using ArcGIS 10.0 software by ESRI. The information about precipitation based on the data from the climatic station of Poznań Ławica.

Thanks to using the SCS-CN method a 20% decrease of potential water retention (99 to 80mm) in the 11-years period for Skórzynka catchment in average antecedent moisture conditions (AMC II) has been demonstrated. Also, a 17% increase of effective precipitation (35 to 41 mm) calculated for extreme rainfall event observed on 17/08/2010 was shown.

The conducted analyses allow to conclude that the SCS-CN method is a useful and desirable tool used to monitor the process of suburbanization in ungauged catchments located within metropolitan areas in order to assess the changes of potential water retention.

The obtained data may be a decision criterion for local authorities in the proper creation of spatial policy, especially in the sphere of water resources management and preventing local floods and droughts.

Słowa kluczowe:
potencjał retencyjny, Poznański Obszar Metropolitalny,
monitoring suburbanizacji, metoda SCS-CN, zlewnia niekontrolowana,
monitoring, planowanie w gospodarowaniu wodami

Keywords:
retention potential, Poznań Metropolitan Area, suburbanization monitoring,
SCS-CN method, ungauged catchment, planning in water resources management