

## The Issues of Catchment Boundaries Delimitation in a Suburban Area – the Case Study of Poznań Metropolitan Area, Poland

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### ABSTRACT

The urbanisation and suburbanisation processes are considered to have a detrimental impact on the environment. Increasing the share of the impervious surfaces is one of their main negative effects, particularly in and near the cities, affecting the water relations of basins. It also results in new catchment boundaries formation and, in many cases, changes in the physiographic parameters affecting the accuracy of hydrological and hydraulic calculations of small suburban catchments. This study is an attempt to delimit the catchment boundaries located in the suburban area of Poznań city, Poland, in three variants: according to the Raster Hydrographical Map of Poland and Raster Topographical Map of Poland, digital elevation model, and rainwater sewage system. The analyses were conducted with ArcGIS software, and the results were additionally verified with geodesic measurements on site. This work focuses mainly on the impact of anthropogenic pressure on the catchment shape and the course of its boundaries. The analyses were conducted on the Rów WB stream catchment located in the Skórczewo village, Dopiewo municipality, which stands out within the Poznań Metropolitan Area as the area where the suburbanisation process is the most intensified. This study proved that the agrotechnical and drainage works performed in undeveloped, agricultural areas affected catchment shape and size as much as suburbanisation itself. According to the authors, the suburban catchment boundaries should be regularly updated due to the intensity of the new investments development and additionally verified on site.

**Keywords:** suburban area, suburbanisation, catchment, Poznań Metropolitan Area

### INTRODUCTION

The process of suburbanisation is defined in many ways, mainly as the urbanisation of the areas situated near a city. Therefore, it causes changes in the land cover of those zones by increasing the share of developments; thus affecting the primary functions of those areas (usually agricultural) (Podawca et al. 2019). The new approach to the socio-economic studies indicates that modern suburbanisation is a part of more complex urban transformation leading to metropolisation (Mrozik & Idczak 2015, Podawca & Mrozik 2019). Suburbanisation is also closely related to the population demand for higher life quality in spacious developments of the core city surroundings (Podawca & Pawłat-Zawrzykraj 2017) while still working in the city itself. It leads to the

increase in the commute time and transportation network expansion, thus to the environmental and social conflicts (Zhao 2010). The conversion of the natural land cover to urban fabric may cause habitat and landscape fragmentation, affects biodiversity composition and its extent (Scolozzi & Geneletti 2012, Su et al. 2012, Di Giulio et al. 2009) and results in the pollution of organisms, air, soil, and water (Borowiak et al. 2018, Simon et al. 2011, Liu et al. 2010). An increase of impervious surfaces leads to the rainwater sewage system development and retention drop; therefore, it will eventually lead to local inundations with higher flow peak and its longer duration (Kim et al. 2016, Hawley & Bledsoe 2011). Suburbanization also contributes to the primary agricultural drainage systems demolition. Thus the changes in water relations which are hard to predict and shift

of the catchment boundaries to different location, affecting its shape and size, occur (Przybyła et al. 2011). The environmental assessment of all new developments should include monitoring of the actual catchment boundaries, as according to the European water policy and its main principle of integrated water resources management (IWRM), the core of all actions during planning and decision-making process should be determined by hydrographic catchment areas (Mrozik et al. 2015).

## AIM, MATERIALS AND METHODS

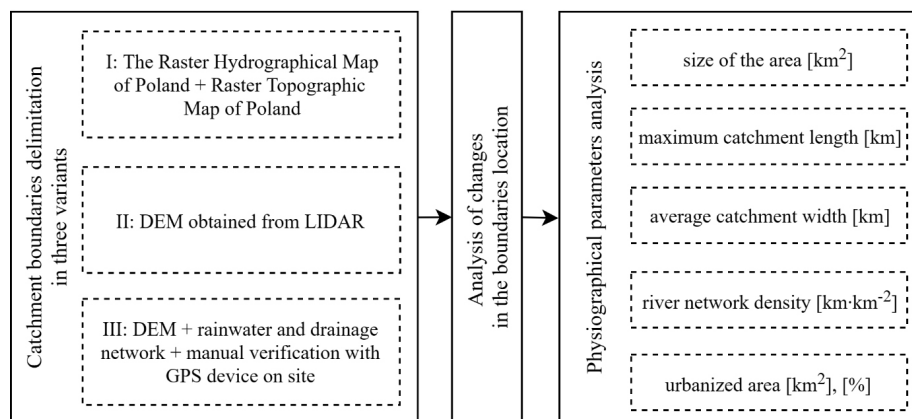
The aim of this research was to determine how the process of suburbanisation affects the local water relations, changing the catchment boundaries position, shape, and size. This study is an attempt to delimitate catchment actual boundaries in a suburban area of Poznań, Poland.

The share of artificial surfaces and agricultural areas in the poznański province was calculated with ArcGIS software based on the level 1 classes of the Corine Land Cover database: “1. Artificial surfaces” and “2. Agricultural areas” obtained from Chief Inspectorate of Environmental Protection.

The goal was achieved with three general steps (Figure 1). Primarily, the catchment boundaries were delimited in three variants presented below. Secondly, the impact of changes in the boundaries location on the catchment size and shape was determined, and finally, the difference in physiographical parameters and land cover (with an emphasis on development areas) was analysed. The physiographical parameters studied in this work were: size of the area [ $\text{km}^2$ ], maximum catchment length [km], average catchment

width [km], and river network density [ $\text{km}\cdot\text{km}^{-2}$ ]. The land cover of the chosen catchment was prepared based on Topographic Objects Database BDOT10k in PUWG 1992 coordinate system acquired from Head Office of Geodesy and Cartography in Warsaw. The accuracy of the mentioned database corresponds with that of the topographic map in the scale 1:10,000.

In the first variant (I) of suburban catchment boundaries analysis, the authors studied the boundaries delimited in scale 1:50,000 in PUWG 1992 coordinate system by Polish Institute of Meteorology and Water Management and provided by National Water Management Authority [2005]. Those boundaries were updated to the scale 1:10,000 based on Raster Topographic Map of Poland from 1998 and provided by Main Geodetic and Cartographic Documentation Centre of Poland in PUWG 1992 coordinate system. Secondly, the current topographic catchment area was delimited with (II) digital elevation model (DEM) obtained from airborne laser scanning (LIDAR) at 1 m grid interval and average height error within 0.2 m in PUWG 1992 coordinate system, acquired from the Main Geodetic and Cartographic Documentation Centre of Poland. The analysis was conducted with the ArcGIS 10.5.1 software ArcHydro and Spatial Analyst tools, and included determination of flow direction and flow accumulation of the analysed area after elevation data reconditioning (filling sinks before and after burning streams in the elevation model) [Urbański 2012]. In the third variant (III) the obtained area was revised with the data on the existing rainwater and drainage infrastructure in Poland CS2000 zone 6 coordinate system acquired from District Geodetic and Cartographic Documentation Centre in Poznań and from water



**Figure 1.** Methodology applied to analyse the issues of suburban catchment boundaries delimitation

companies operating within the boundaries of the analysed catchment. Due to uncertainty of some areas, the results were additionally verified by manual elevation measurement with a GPS device on site and improved in the ArcGIS software.

### Study area

The analysis was carried out for Rów WB stream with the length of 7.56 km, which is identified as Dopływ z Dąbrowy (185724 hydrographic code) according to the Raster Hydrographical Map of Poland. It is a recipient of three inflows: WB1 (with the length of 0.59 km), WB2 (2.65 km) and WB3 (1.93 km) streams. It constitutes part of the Wirynka Surface Water Body with the PLRW600017185729 hydrographic identification number. Water quality of the Wirynka river is monitored in Łęczyca control point at 0.7 km of the river by the Voivodeship Inspectorate for Environmental Protection in Poznań [2016]. The monitoring activities are recommended due to the failure in achieving the environmental goals indicated for this river and sensitivity to eutrophication from communal sources pollution. The ecological state of the Wirynka river was determined based on three main types of elements: biological classified as the III class, physicochemical as state below good, and hydromorphological as state below very good. The overall ecological state of the Wirynka river was determined as moderate. The Wirynka river is a tributary of the Warta river and joins it at its 257.7 km. Finally, the Warta river is part of the Oder river basin situated in the western Poland (Figure 2).

The Rów WB stream catchment is located within the boundaries of three rural municipalities of poznański province (Tarnowo Podgórne, Dopiewo, Komorniki) and Poznań city. It is under

great anthropogenic pressure due to the progressing suburbanisation in the poznański province, where according to the Corine Land Cover database, the artificial surfaces increased from 5.0% in 1990 to 9.9% in 2012 to the detriment of the agricultural areas (from 67.9% to 62.1%). Moreover, the urbanized area covered approx. 7.1% of Tarnowo Podgórne, 3.9% of Dopiewo, and 6.5% of Komorniki in 1990 and almost three times more in 2012 in each municipality, indicating their far advanced suburbanisation process.

### RESULTS

In environmental studies, reports and assessments, as well as planning documents, the catchment boundaries are mainly determined based on the Raster Hydrographical Map of Poland in scale 1:50,000 and updated to the scale 1:10,000 with Raster Topographic Map of Poland [Gudowicz & Zwoliński 2017, Sojka et al. 2017, Kanclerz et al. 2016]. Recognition of the mentioned dataset and its common use by the scientific researchers and engineers is caused by the availability of the data developed with consistent methodology for the whole country and its uncomplicated accessibility. According to the variant I the Rów WB stream catchment (identified also as Dopływ z Dąbrowy) covers an area of 10.73 km<sup>2</sup> with the maximum catchment length of 9.41 km and average catchment width of 1.15 km. The urbanized area is situated in the south-eastern part of the Rów WB stream catchment in the Plewiska village, in the central part in Skórczewo village and in the north-western part in Dąbrowa village. It covers approx. 1.64 km<sup>2</sup>, which represents 15.28% of the catchment (Figure 3, Table 1).

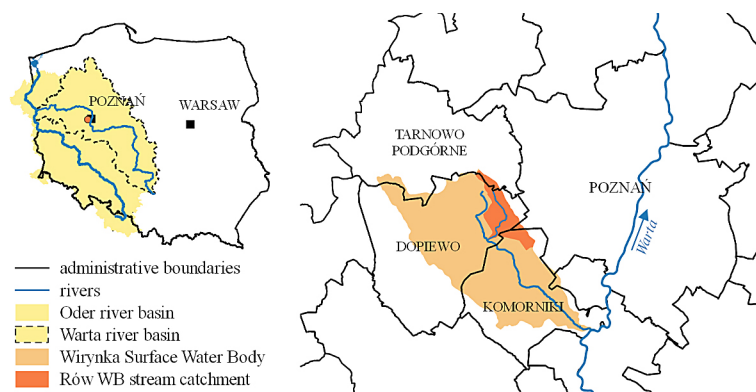
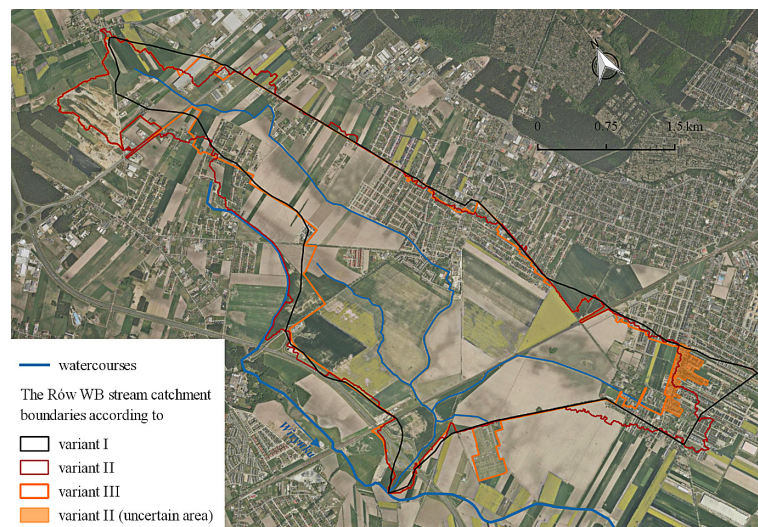


Figure 2. Location of the Rów WB stream catchment

A new approach of topographical catchment boundaries delimitation has recently been considered by scientists as it is more accurate due to the technological progress [Tefera 2017, Wałek 2017, Venticinque et al. 2016]. It is not used commonly as it requires the knowledge of methodology concerning the ArcGIS analysis and the software purchase. It is based on the precise elevation data of the analysed area and includes the spatial analysis of its physiographical conditions with ArcGIS software tools. It features DEM reconditioning, determination of flow direction and flow accumulation. According to this variant, crucial changes were observed to the north and to the west of the catchment. In the northern part, another 0.71 km<sup>2</sup> were included within the catchment area, mainly agricultural lands and grounds under a gravel pit. In turn, in the western part (area of 0.60 km<sup>2</sup>) the location of the boundary moved near the embankment of the Wirynka river. Manual elevation measurements with a GPS device conducted in western part of the catchment showed that the embankment was artificially raised due to yearly

river valley conservation works. Sediments accumulated in the riverbed were settled at one side of the riverbank, changing its natural elevation and shifting the highest point of the local area to the embankment of the Wirynka (Figure 4a). It affected the GIS-based delimitation, creating incorrect catchment boundary. In case of less recognised or larger catchment, those errors may be hard or even impossible to detect.

In the southern part of the catchment, a similar manner of conservation works of the Rów WB stream tributary (the WB2 stream) was conducted, creating artificial embankments (seen also on the orthophotomap and elevation map), raised even 1 m above neighbouring terrain elevation. The flow direction analysis of this area showed explicitly that ploughing direction is perpendicular to the WB2 stream course, which may cause high water runoff and further intensify water erosion in the future (Figure 4b, Figure 5). Therefore, according to this variant the Rów WB stream catchment covered a total area of 11.67 km<sup>2</sup> with the maximum catchment length of 9.89 km and

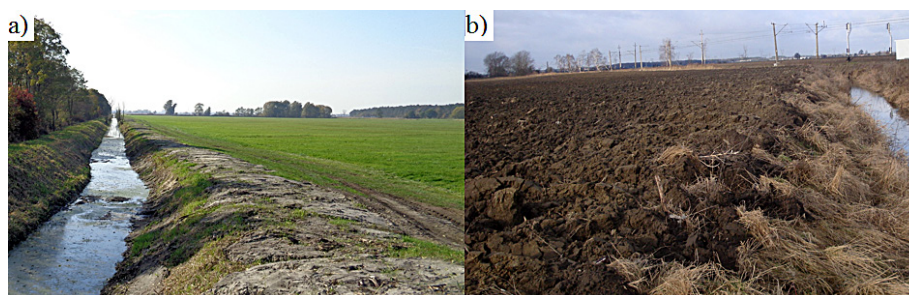


**Figure 3.** An attempt to the Rów WB stream catchment boundaries delimitation

**Table 1.** Comparison of chosen parameters of the Rów WB stream catchment delimited in three variants

Parameter [unit]	Variant I	Variant II	Variant III	
			without the uncertain area	with the uncertain area
Area [km <sup>2</sup> ]	10.73	11.67	9.87	10.29
Maximum catchment length [km]	9.41	9.89	9.89	
Average catchment width [km]	1.15	1.18	0.95	0.94
River network density [km·km <sup>-2</sup> ]	1.19	1.09	1.29	1.24
Urbanized area	[km <sup>2</sup> ]	1.64	1.63	1.51
	[%]	15.28	13.93	15.30
			15.30	15.55



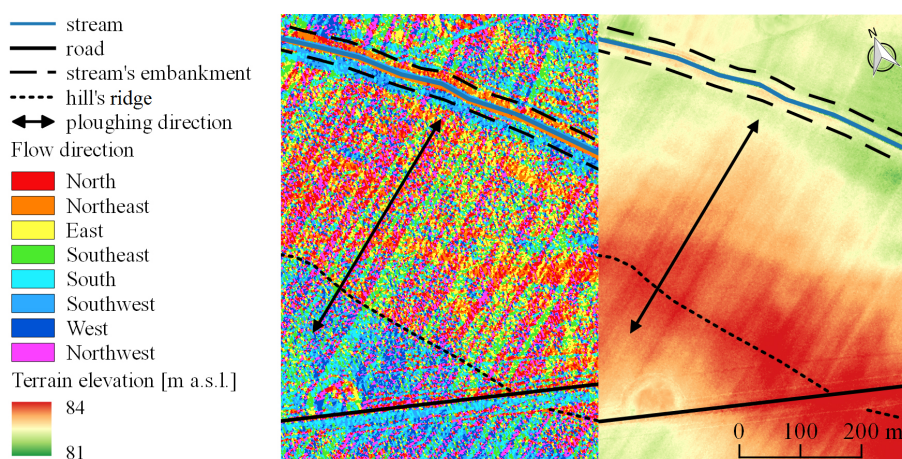


**Figure 4.** Impact of a) conservation works on riverbanks and b) ploughing direction on landform

average catchment width of 1.18 km. An increase in the catchment size caused inclusion of approx. 0.03 km<sup>2</sup> of the urbanized area.

The topographical and actual boundaries of the catchment may differ due to various ground permeability conditions of the area and as a result of rainwater sewage system and drainage system construction. They require precise field studies, thus are laborious. Ground permeability in different soil layers and, therefore, the direction of the underground runoff, may be both difficult to determine, while the data on the location of the rainwater sewerage network should be easily obtained from the local council or respective water companies. Moreover, in the suburban area where the development process is fast occurring and water infiltration is heavily disturbed or even terminated [Mrozik 2016, Yang & Zhang 2011], the location of the rainwater sewerage system is more significant for the catchment delimitation. In the analysed area, approx. 26.63 km of the rainwater and 0.02 km of the combined sewage system was constructed until the first half of 2018. The research exposed two uncertain areas, the first of them as a result of bifurcation. It covers an area of 0.14 km<sup>2</sup> and is located in the east of the

catchment where the rainwater from the sewage network is discharged directly to the Wirynka river, while during heavy rain partially also to the tributary of the Rów WB (the WB2 stream), confirmed also on the site. The volume or share of rainwater redirected to the Rów WB stream was not the subject of this study, thus was not established. The other uncertain area of 0.28 km<sup>2</sup> is located in a western part of the catchment in a dip between a dual carriageway No. S11 and a local road built on the ridge of a hill. Due to the lack of access to the carriageway rainwater network scheme it was impossible to unequivocally determine if the rainwater at this location is directed to the stormwater sewage system and then to the Rów WB stream tributary or redirected to the Wirynka river. The analysis indicated that the linear artificial constructions mainly affect the course of boundaries in the suburban catchment. This is particularly visible in the north-eastern part of catchment, where the border is marked by regional road 307 and from the north by ul. Batorowska. Furthermore, the obtained results showed that the Rów WB stream catchment covers an area of 9.87 km<sup>2</sup> or 10.29 km<sup>2</sup> (with the uncertain area). The share of the urbanized areas decreased



**Figure 5.** Flow direction and terrain elevation changes due to stream conservation works and ploughing direction

to 1.51 km<sup>2</sup> or 1.60 km<sup>2</sup> respectively, representing 15.30% or 15.55% of this catchment respectively. The maximum catchment length based on boundaries according to this variant is equal to the maximum length pursuant to previous variant, whereas the average catchment width decreased to either 0.95 km or 0.94 km respectively.

On the example of the Silka catchment, Wałek [2017], indicated that the use of topographic maps and Hydrographical Map of Poland is insufficient to determine the catchments boundaries and the surfaces determined on their basis differ significantly from the real catchment area generated using DEM and the corrected BDOT and GESUT databases.

## CONCLUSION

It was established that the determination of the suburban catchment boundaries and its size for the purposes of the engineering and scientific projects may lead to the discrepancy between the obtained results and the actual state of the catchment if based only on the Raster Hydrographical Map of Poland or hypsometric map (variant I) as those are burdened with the low accuracy error, especially in the case of smaller objects.

The analysis showed that the catchment boundaries in the rural area are mainly shifted by the drainage network which affects flow direction of the rainwater, and conservation works performed on rivers and ditches, changing the natural elevation of their embankments. The automatic or semi-automatic GIS-based methods (variant II) do not distinguish the errors caused by artificial elevation changes and lead the catchment boundary alongside the highest ridge of the area, in this case the river embankments. Those errors can be manually revised only if the catchment was sufficiently recognised by the researcher.

In turn, in the areas with higher development ratio, impervious surfaces and thus rainwater infrastructure network is of the higher significance in that matter. It requires a thorough analysis as the rainwater system may be designed with the bifurcation, operating differently under certain rainwater volume conditions. It was proven in the variant III that fast occurring changes in the land cover in suburban areas, for example linear and territorial investments, may affect the shape of catchment boundaries and shift them to a different location. Therefore, the necessity of regular

updates of the suburban catchment boundaries was confirmed. However, the precise catchment delimitation required prominent involvement of the researcher, and included time-consuming field surveys and office work, but the obtained results were also the most satisfying. This is later reflected in the results of hydrological and hydraulic analyses of such small catchments.

Delimitation of the precise topographic catchment boundaries location should include the analysis of the digital elevation model, rainwater and drainage infrastructure network, and be improved with the observations and measurements conducted on site. It should be noted that in each variant, both the size of the area of the studied catchment and their spatial range changed. For some catchments, such changes in their spatial range, despite even small differences in the size, may have a significant impact on the outflow coefficients for the hydrological modeling purposes.

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