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Original Research Article

MEASUREMENT OF THE CATCHMENT AREA OF THE RIVERS OF THE KŁODZKO BASIN USING QGIS SOFTWARE

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Abstract

Knowledge of the catchment area is essential for hydrological analyses. With it, it is possible to determine the water flow rate at the cross-section enclosing it. Nowadays, measurement is possible thanks to computer techniques that continue to develop in order to determine its area in the most effective way, i.e. as quickly and precisely as possible. The aim of this paper was to investigate the differences in the resulting catchment areas based on the Digital Elevation Model at different resolutions. One method of calculating catchment areas using the QGIS software and its tools is presented, using the example of a section of the Nysa Kłodzka River and its tributaries. The results were compared to plots made available by IMGW, which were treated as baseline data. Attention was paid to what could cause differences in the results obtained and which model would work best for which case.

Keywords: catchment area, Digital Elevation Model (DEM), QGIS, Nysa Kłodzka

1. INTRODUCTION

A catchment area is an area from which water flows into one common receiving body (e.g. a river, lake or marsh)[1, 2, 3]. As liquid can move both over the land surface and, through filtration, into the ground, a distinction is made between a topographic (surface) catchment area and an subterranean catchment area. The catchment boundary, separating the outflow directions of water into different river systems, is the watershed, defined by the relief of the land (surface) or by the shape of the ground layers influencing the location of the groundwater table (subterranean)[1].

The catchment area is useful, for example, for calculating the flow rate in any section of a controlled river using the extrapolation and interpolation method or for an uncontrolled river using empirical and regional formulas. This paper focuses on surface catchments that can be generated from a Digital Elevation Model (DEM). Historically, a topographic catchment was measured on paper maps.

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Hydrographic maps were and still are produced by teams of cartographers, geographers, surveyors and hydrology and water management specialists based on collected source material and the results of field hydrographic imagery[4]. They come in analogue and numerical versions. Free access to some maps is available through the government website – geoportal [5]. On the same website, files with DEM, i.e. a point representation of the elevation of the terrain, can be downloaded. This model is created and updated by digitising elevation data of the terrain, collected by various techniques, e.g. airborne laser scanning (ALS), photogrammetry, field measurements (e.g. using total station or GPS techniques) or map digitisation [22]. One of the basic types of DEM is the GRID model in the form of a regular grid of squares[6, 7]. This grid can vary in size, the smaller it is (e.g. 1m x 1m), the more accurate it is, but this makes the model itself contain more data and take up more memory. A practical advantage of the grid model is the multitude of existing software tools with which it can be analysed [7, 8]. One of them is Geographic Information System (GIS) software – Quantum GIS(QGIS).

On topographic maps, watersheds are delineated by lines perpendicular to the isoline, drawn along convex hillsides [1, 21]. According to this idea, rainwater will flow towards the watercourse along the slopes according to the direction of the slope. When the natural elevations unambiguously shape the catchment areas, then the watershed is clear [1, 21]. On the other hand, when the course of the catchment boundary is difficult to determine, e.g. in marshy areas or flat and wide areas, the watershed is uncertain [1, 21]. A difficulty in determining the course of surface watersheds is caused by closed basins. These are places where further water circulation takes place through the process of evaporation or infiltration [1, 21]. Complications can also be caused by bifurcations, i.e. situations where water in a watercourse flows in two different directions, resulting in entering two different catchments [1, 21]. In such a situation, the watercourse is crossed by a watershed, which is marked on the map as a water gate [21].

Taking into account the above-mentioned difficulties and other factors cited later in the text, the problem is to accurately determine the catchment area. Often, when looking for information on the area of a given catchment area, different sources give different values. So what could be the source of these discrepancies? It might seem that the more accurate the model used for the analyses, the closer the results should be to the real thing. The aim of this study was to investigate whether the smaller the size of the DEM grids used in the catchment area calculations, the closer the results would be to the baseline surfaces.This paper presents the results of catchment area calculations using Digital Elevation Models of different resolutions and highlights what can cause discrepancies to be obtained. The results obtained were compared to the catchment areas compiled by the Institute of Meteorology and Water Management (IMGW), made available on the website[9].

2. RESEARCH AREA

The area undertaken for the research analysis is the upper catchment area of the Nysa Kłodzka River (a tributary of the second-order Odra [1], closed by a water gauge located in Kłodzko (Fig. 1). The area is located in south-western Poland, near the border with the Czech Republic. It includes the Kłodzko Basin, the Rów Górnej Nysy, as well as the slopes of the Stołowe Mountains, the Bystrzyckie Mountains, the Bardzkie Mountains, the Złote Mountains and the Śnieżnik Massif, whose ridges define the watershed. On the northern side, the catchment area is closed by the Ścinawka Depression. The Kłodzko Basin, together with the Rów Górnej Nysy, is a tectonic trench with a meridional direction, dividing the Sudetes into central and south-eastern parts [10, 11]. Having its source on the slope of the Jelenia River in the Śnieżnik Massif, the Nysa Kłodzka is the main river of the region. In the section from Boboszów to Kłodzko it is symmetrical, flowing in a northerly direction. The more important tributaries are the Goworówka, Wilczka, Bystrzyca, Duna Górna, Biała Lądecka and Bystrzyca Dusznicka, on which hydrological stations are located. The Cieszyca, Duna Dolna and Kamienny Potok, which are Level IV tributaries, are also controlled rivers.

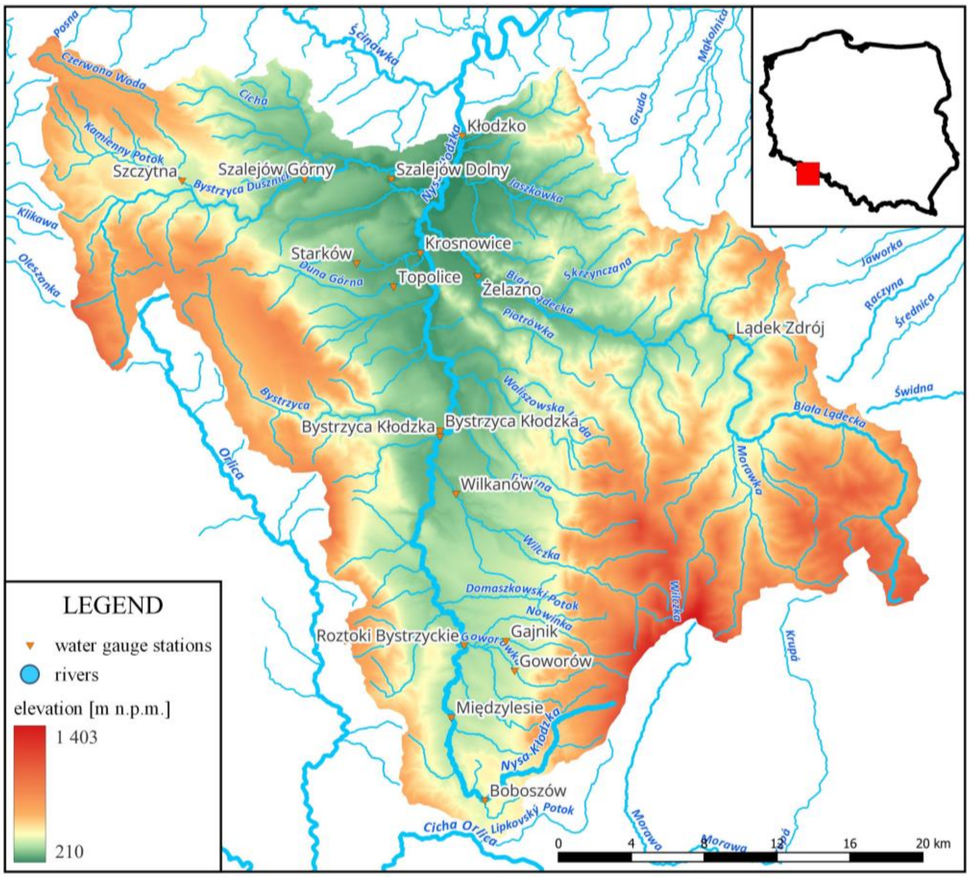

Fig. 1. Kłodzko Basin

3. SURFACE CATCHMENT MEASUREMENTS BASED ON DEM IN QGIS SOFTWARE

3.1. Technical description of QGIS function

As of 2022, a plug-in called 'Wody Polskie – Baza WMS' ['Wody Polskie –WMS Database'] is available for quick access to networked WMS[2] viewing services. The plug-in allows the use of several services, including Mapa Podziału Hydrograficznego Polski w skali 1:10 000 (MPHP10k). In May 2023, the plug-in was updated to version v1.0.2, making around 900 layers available across 30 WMS services. Further updates are planned to give, among other things, the ability to download vector data[12]. With vectorised catchment boundaries, the measurement of catchment areas would be greatly simplified and would be as close as possible to the data provided by IMGW. However, at present, using the plug-in, area measurement is possible using the tools available in the software. This would be done manually by outlining the catchment boundary. However, this solution is impractical, not very accurate and, for larger

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[2] WMS - Web Map Service - services for viewing spatial data (maps) in raster form. In order for the service to work properly, an internet connection is required

catchments, time-consuming. Instead, there are other ways to measure the catchment area by generating it with QGIS software. Over the last few years, modernised methods of generating catchment boundaries on the Digital Elevation Model [13]. One method is to use the available Processing Algorithms. The first step is to import the DEM. For larger areas, it may consist of several raster files that need to be merged together. This can be done using *Raster → Miscellaneous → Merge*. Next, adjust the coordinate system of the model to the system adopted in the project using *Raster → Mappings → Change Mapping*. In the next step, we use the *Fill Sinks (Wang & Liu)* module. This module recognises and fills in the DEM depression surface, creates a flow path grid and a river catchment grid on it, enabling further hydrological analysis[14]. Then we determine the ordinate of the river using the *Strahler order* algorithm[15], resulting in a display of the course of the watercourses on the DEM. It will be possible to compare it with the course of the watercourses on the map loaded in the project (e.g. the mentioned MPHP10k from the plug-in "Wody Polskie - Baza WMS" ['Wody Polskie –WMS Database']) and to determine the coordinates of the cross-sections closing the catchment area, which may slightly differ from the coordinates read from the hydrographic map (Fig. 7A.). The depicted watercourses can be converted into a vector layer using the *channel network and drainage basins* processing algorithm. Then use the *upslope area* function to generate the catchment area. In order to do this, the coordinates of the catchment closure cross-section (defined by the *strahler order* algorithm) must be provided and the method of calculation selected. In this case, the *deterministic 8* method was chosen, which is one of the oldest, and simplest, methods for determining the direction of flow based on the lowest value in one of the 8 neighbouring pixels[14, 16, 17]. To read the catchment area, use the *Volume of Area from the raster* algorithm.

3.2. Measuring the catchment area of the Nysa Kłodzka River up to the Kłodzko water gauge

The analysis was carried out on 4 numerical models with a grid of 1x1m, 5x5m, 25x25m and 30x30m. Apart from the resolution, they differ in the reference system, date and method of acquisition. The 1x1m and 5x5m grid models are drawn in vertical reference frame NMT-PL-EVRF2007-NH and the rectangular reference frame PL-1992. The data of the 1x1m model is from 2023, while that of the 5x5m model is from 2020. They were performed by Airbone Laser Scanning (ALS) and downloaded from the geoportal.gov.pl. The other 2 models are slightly older. The 25x25m model is from 2016, made in the geodetic reference system ETRS89, while the 30x30m model, whose data was collected in 2000 as part of the Shuttle Radar Topography Missions (SRTM), is based on the geodetic reference frame WGS84, and was downloaded from NASA servers [18, 19]. Admittedly, 23 years of difference between the models is quite a long time, but the catchment being analysed is a mountainous catchment where major deformation or migration of rock masses, e.g. under the influence of earthquakes, has not been recorded. Some anthropogenic changes have occurred within the catchment boundaries, such as the creation of several dry reservoirs and roads, but the analysis does not focus on the areas where these changes have occurred or where these changes have not had a major impact on the specific cases analysed. ALS, as the name suggests uses an aerial laser scanning technique. The average vertical error ranges from a few centimetres to 1m, depending on point density and measurement conditions [23]. SRTM uses radio interferometry after measuring terrain height. The average vertical error is significantly higher, ranging between 10-15m depending on the type of land cover [24]. The mapping in the models was changed to the PL-1992 layout. As a result, maps were generated with the catchment areas marked (Fig. 2-5). For a better depiction, the raster layers were converted into vector layers using the command *Raster → Convert → polygonise (raster to vector)*.

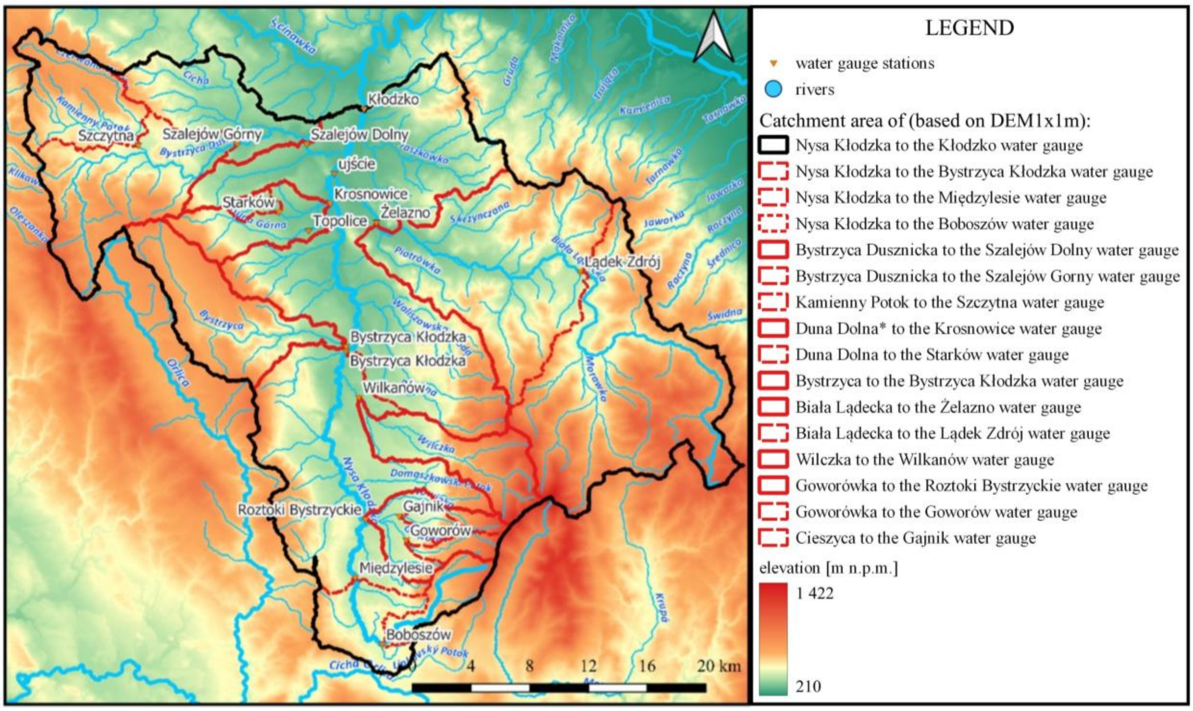

Fig. 2. River basins of the Kłodzko Basin generated on the basis of DEM with a grid of 1x1m in the QGIS programme

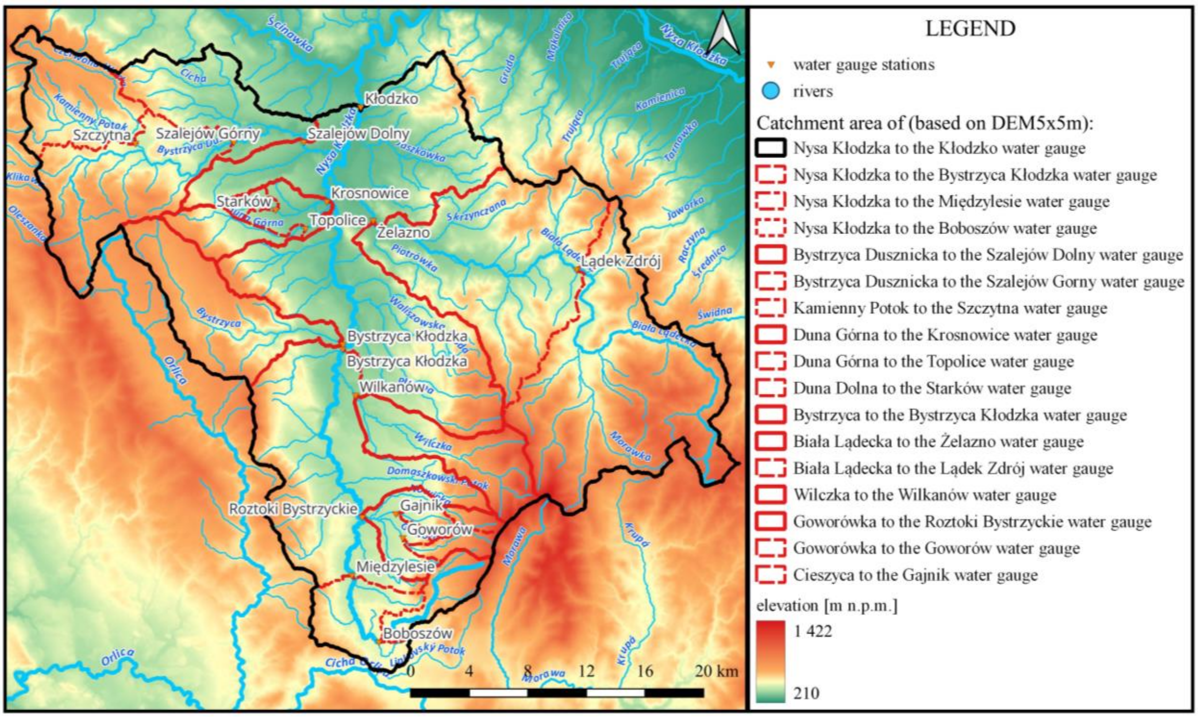

Fig. 3. River basins of the Kłodzko Basin generated on the basis of DEM with a grid of 5x5m in the QGIS programme

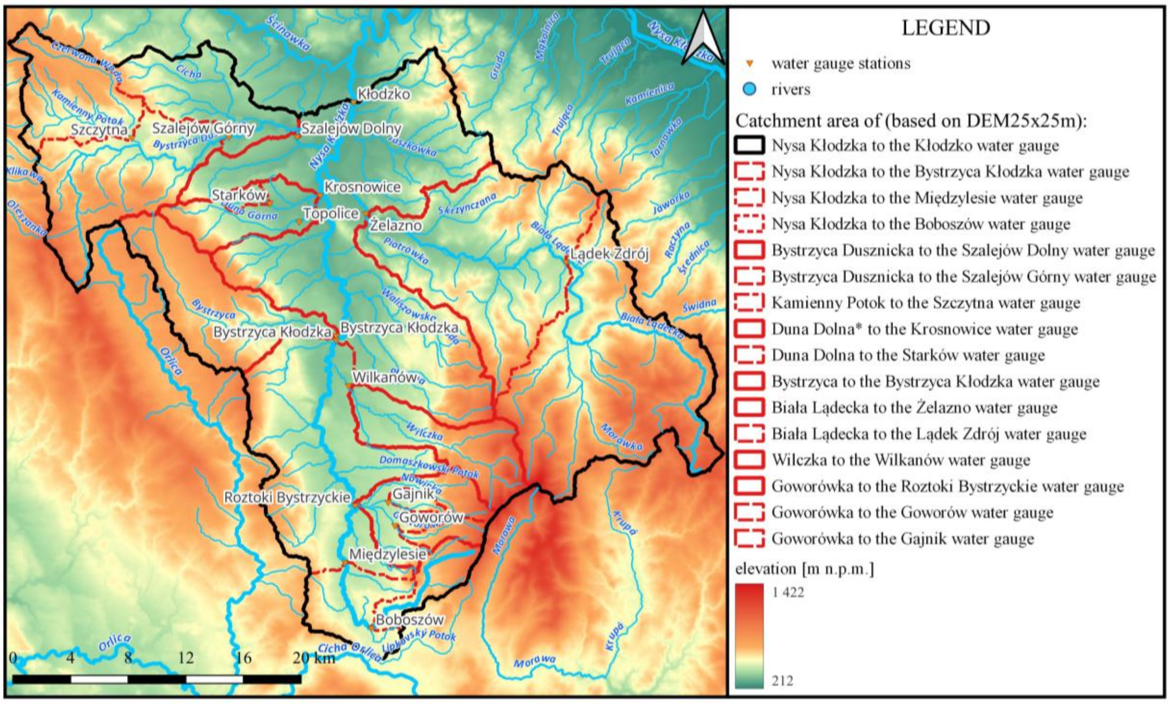

Fig. 4. River basins of the Kłodzko Basin generated on the basis of DEM with a grid of 25x25m in the QGIS programme

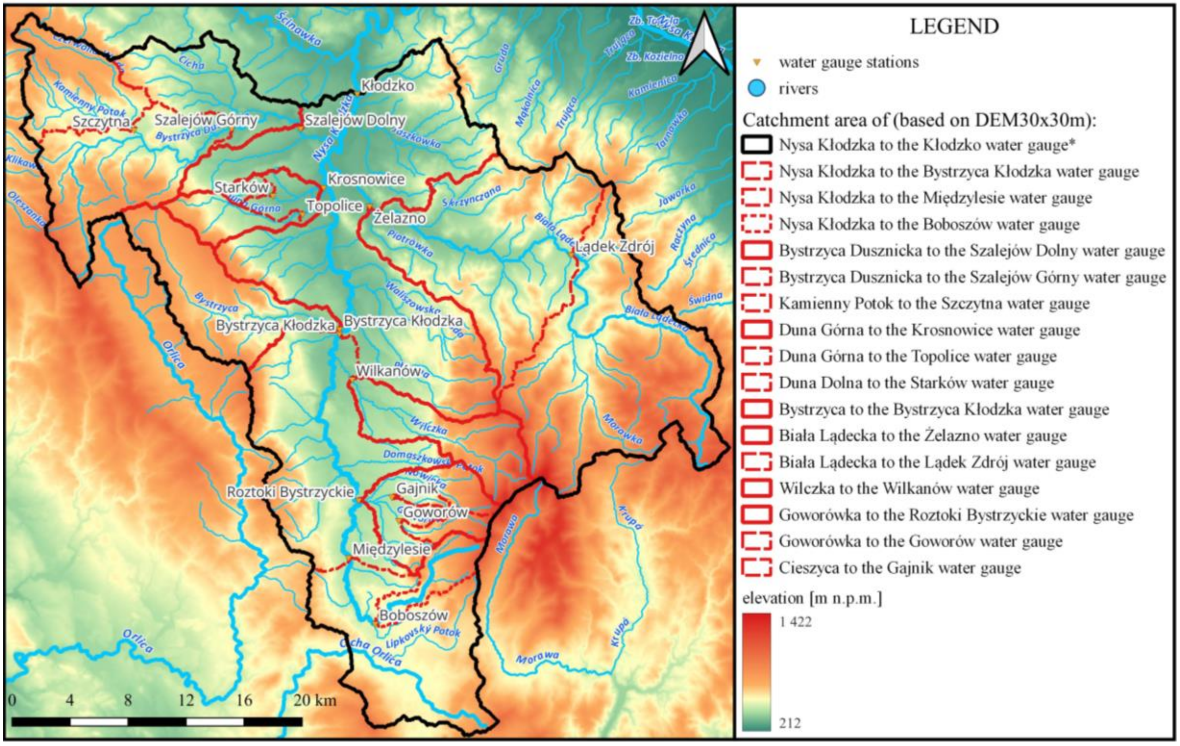

Fig. 5. River basins of the Kłodzko Basin generated on the basis of DEM with a grid of 30x30m in the QGIS programme

4. COMPARISON OF CATCHMENT AREAS

The calculated catchment areas using various methods and calculation models are summarised in Tab. 1. The catchments are arranged in ascending order, based on data from IMGW [9]. Finding some of the water gauges on maps, especially the newer ones, proved to be a problem. Unfortunately, IMGW, apart from marking them on its map, does not provide the coordinates of their location. Therefore, the dark green colour indicates the water gauges identified on the hydrographic map, the light green colour indicates the water gauges found on the orthophoto map, while the water gauges marked in white are the water gauges whose coordinates were estimated on the basis of the IMGW map.

Table 1. Summary of catchment areas calculated using different methods and calculation models

lp.	river	water level gauge section	River kilometer [km]	IMGW [km^2]	QGIS (DEM1x1m) [km^2]	QGIS (DEM5x5m) [km^2]	QGIS (DEM25x25m) [km^2]	QGIS (DEM30x30m) [km^2]
1	Duna Dolna	Starków	3.96	4.35	4.53	4.46	4.05	4.37
2	Cieszyca	Gajnik	1.64	5.95	5.94	5.75	4.77	3.70
3	Goworówka	Goworów	4.31	7.37	8.10	7.87	7.79	7.99
4	Duna Górna	Topolice	3.79	17.41	-	17.58	-	17.6
5	Nysa Kłodzka	Boboszów	179.70	18.52	18.01	17.83	18.22	18.41
6	Duna Górna	Krosnowice	0.38	32.72	33.94	34.66	33.76	33.78
7	Goworówka	Roztoki Bystrzyckie	0.07	34.71	35.73	35.92	41.80	42.9
8	Kamienny Potok	Szczytna	0.93	47.15	45.70	47.07	47.08	47.08
9	Wilczka	Wilkanów	2.39	47.20	42.18	44.84	44.73	44.91
10	Nysa Kłodzka	Międzylesie	172.96	51.40	48.11	48.94	48.76	113.86
11	Bystrzyca	Bystrzyca Kłodzka	0.25	64.69	64.40	64.59	64.53	64.79
12	Bystrzyca Dusznicka	Szalejów Górny	12.31	123.99	123.26	123.56	123.98	123.41
13	Biała Lądecka	Lądek Zdrój	23.04	162.87	162.82	162.78	162.80	163.00
14	Bystrzyca Dusznicka	Szalejów Dolny	4.82	173.37	173.09	172.99	171.37	171.28
15	Nysa Kłodzka	Bystrzyca Kłodzka	151.38	262.73	260.4	260.18	259.93	325.41
16	Biała Lądecka	Żelazno	5.02	303.34	301.90	302.65	302.44	302.41
17	Nysa Kłodzka	Kłodzko	130.04	1082.27	1080.10	1079.74	1078.82	1144.64

As can be seen, the plots for a given gauge cross-section vary depending on grid size of the DEM model. These values were referred to those reported by IMGW [9] and the differences are summarised in Tab. 2. For better illustration, these differences were divided according to a 6-point scale proposed by the author (Tab. 3).

Table 2. Differences between catchment areas according to IMGW and areas measured by different methods and calculation models

lp.	river	water level gauge section	River kilometer [km]	IMGW-QGIS (DEM1x1m)	IMGW-QGIS (DEM 5x5m)	IMGW-QGIS (DEM25x25m)	IMGW-QGIS (DEM30x30m)
1	Duna Dolna	Starków	3.96	-4.14%	-2.53%	6.90%	-0.46%
2	Cieszyca	Gajnik	1.64	0.17%	3.36%	19.83%	37.82%
3	Goworówka	Goworów	4.31	-9.91%	-6.78%	-5.70%	-8.41%
4	Duna Górna	Topolice	3.79	-	-0.98%	-	-1.09%
5	Nysa Kłodzka	Boboszów	179.70	2.75%	3.73%	1.62%	0.59%
6	Duna Górna	Krosnowice	0.38	-3.73%	-5.93%	-3.18%	-3.24%
7	Goworówka	Roztoki Bystrzyckie	0.07	-2.94%	-3.49%	-20.43%	-23.60%
8	Kamienny Potok	Szczytna	0.93	3.08%	0.17%	0.15%	0.15%
9	Wilczka	Wilkanów	2.39	10.64%	5.00%	5.23%	4.85%
10	Nysa Kłodzka	Międzylesie	172.96	6.40%	4.79%	5.14%	-121.52%
11	Bystrzyca	Bystrzyca Kłodzka	0.25	0.45%	0.15%	0.25%	-0.15%
12	Bystrzyca Dusznicka	Szalejów Górny	12.31	0.59%	0.35%	0.01%	0.47%
13	Biała Lądecka	Lądek Zdrój	23.04	0.03%	0.06%	0.04%	-0.08%
14	Bystrzyca Dusznicka	Szalejów Dolny	4.82	0.16%	0.22%	1.15%	1.21%
15	Nysa Kłodzka	Bystrzyca Kłodzka	151.38	0.89%	0.97%	1.07%	-23.86%
16	Biała Lądecka	Żelazno	5.02	0.47%	0.23%	0.30%	0.31%
17	Nysa Kłodzka	Kłodzko	130.04	0.20%	0.23%	0.32%	-5.76%

Table 3. Scale of catchment area differences

scarce	≤|0.5%|
little	|0.51%-1.00%|
small	|1.01%-3.00%|
accetable	|3.01%-5.00%|
large	|5.01%-10.00%|
enormous	>|10.00%|

5. DISCREPANCIES IN THE RESULTS OBTAINED

5.1. Accuracy of water level gauge coordinates

Undoubtedly, the differences in catchment areas are influenced by the accuracy of the determination of the coordinates of the point enclosing the catchment. As mentioned earlier, IMGW did not provide the coordinates of the water gauge cross sections, so those read from the maps provided on the geoportal (PL-1992) were used as base coordinates. Eight of them (Wilkanów, Międzylesie, Bystrzyca Kłodzka on the Nysa Kłodzka and Bystrzyca rivers, Lądek Zdrój, Szalejów Dolny, Żelazno and Kłodzko) are marked on the hydrographic map. Another two (Goworów, Boboszów) could be found on the orthophoto map or through the Google Street View tool. The remaining water gauge stations could not be found on the maps, so their location was estimated on the basis of the IMGW map. The differences in water gauge coordinates between the DEM-based models are due to the course of the watercourse in question on the model (Fig. 6, 7.). That means that the course of the watercourse generated from the DEM does not necessarily coincide with the real course.

In the case of the Kłodzko water level gauge on the DEM30x30m model, the programme interpreted the Nysa Kłodzka as separate watercourses (2 major and 3 minor), which join together approx. 3.5km to the north, beyond the mouth of the Ścinawka River (Fig. 6.). Therefore, 5 points of the same altitude were used as the catchment closing cross-section, and the catchment area of the Nysa Kłodzka River up to the Kłodzko water gauge, on the 30x30m model, was the sum of the 5 generated catchments. These rather serious errors may suggest that the algorithm generating the river course is badly tuned to this specific location and should be improved. This could be caused by a sudden, unexpected change in elevation on the DEM. A similar situation can also be seen in Figure 7B.

Based on the DEM, smaller rivers may not be generated at all, and runoff paths may be routed in such a way that the watercourse in question is crossed by them. Such a situation occurred on the DEM1x1m and DEM25x25m models on the Upper Duna (Fig. 7.). At the point of the riverbed, several watercourses were generated on the model, most of which flowed into the branch flowing next to it - the Topolica. For this reason, the catchment area to the Topolice water gauge was not calculated and the Krosnowice water gauge was located above one of the watercourses flowing through the Duna Górna catchment area. The calculation was unlikely to have been influenced by the newly constructed Krosnowice dry reservoir on the Topolica (was built between 2018-2023), which, according to the maps, did not affect the existence of the Duna Górna.

The differences between the coordinates taken from the maps and the models based on the Digital Elevation Model are summarised in Tab. 6. The most similar coordinates were on the higher resolution models (DEM1x1m and DEM5x5m), where the coordinate differences at twelve of the seventeen stations were within a few metres. On the lower resolution models (DEM25x25m and DEM30x30m), the opposite was true - there, the coordinates of two points coincided with the base coordinates, while at the remaining fifteen points the differences ranged from tens to hundreds of metres.

Table 4. Difference in the coordinates of the water gauge cross sections in the different calculation models

lp.	river	water level gauge section	coordinate difference "geoportal vs QGIS (DEM1x1m)" [m]		coordinate difference "geoportal vs QGIS (DEM5x5m)" [m]		coordinate difference "geoportal vs QGIS (DEM25x25m)" [m]		coordinate difference "geoportal vs QGIS (DEM30x30m)" [m]	
			X	Y	X	Y	X	Y	X	Y
1	Duna Dolna	Starków	12.50	4.78	0.00	0.00	29.58	1.16	0.00	0.00
2	Cieszyca	Gajnik	0.00	0.00	0.95	0.02	0.70	-104.30	0.62	57.45
3	Goworówka	Goworów	38.67	-20.77	17.88	-1.30	-175.67	-13.65	-211.64	-21.49
4	Duna Górna	Topolice	-	-	22.85	-20.44	-	-	4.43	-106.01
5	Nysa Kłodzka	Boboszów	0.00	0.00	0.35	-10.64	-32.23	-14.07	-0.70	-68.76
6	Duna Górna	Krosnowice	0.88	-4.86	-32.28	-91.47	154.28	-1.29	193.92	8.22
7	Goworówka	Roztoki Bystrzyckie	-0.13	2.00	0.00	0.00	31.28	-43.42	2.76	-55.41
8	Kamienny Potok	Szczytna	-0.90	-0.03	0.00	0.00	0.00	0.00	0.00	0.00
9	Wilczka	Wilkanów	0.10	-2.82	0.03	0.86	-160.03	4.58	3.58	-143.43
10	Nysa Kłodzka	Międzylesie	-1.34	-0.09	2.40	0.21	-89.86	-3.71	-77.37	-23.14
11	Bystrzyca	Bystrzyca Kłodzka	0.00	0.00	0.19	-1.78	0.00	0.00	2.42	-29.96
12	Bystrzyca Dusznicka	Szalejów Górny	-15.93	-31.17	0.00	0.00	0.00	0.00	-72.19	101.22
13	Biała Lądecka	Lądek Zdrój	-0.23	8.45	0.31	8.66	2.73	-56.91	5.65	-68.87
14	Bystrzyca Dusznicka	Szalejów Dolny	0.00	0.00	0.00	0.00	-106.15	-1.70	-100.43	-2.21
15	Nysa Kłodzka	Bystrzyca Kłodzka	-5.35	1.52	2.02	0.02	-74.96	1.85	-36.82	4.10
16	Biała Lądecka	Żelazno	5.46	0.81	2.48	0.05	-163.11	-3.85	12.80	0.41
17	Nysa Kłodzka	Kłodzko	-40.29	-58.83	14.02	-0.45	-11.10	-53.99	-	-

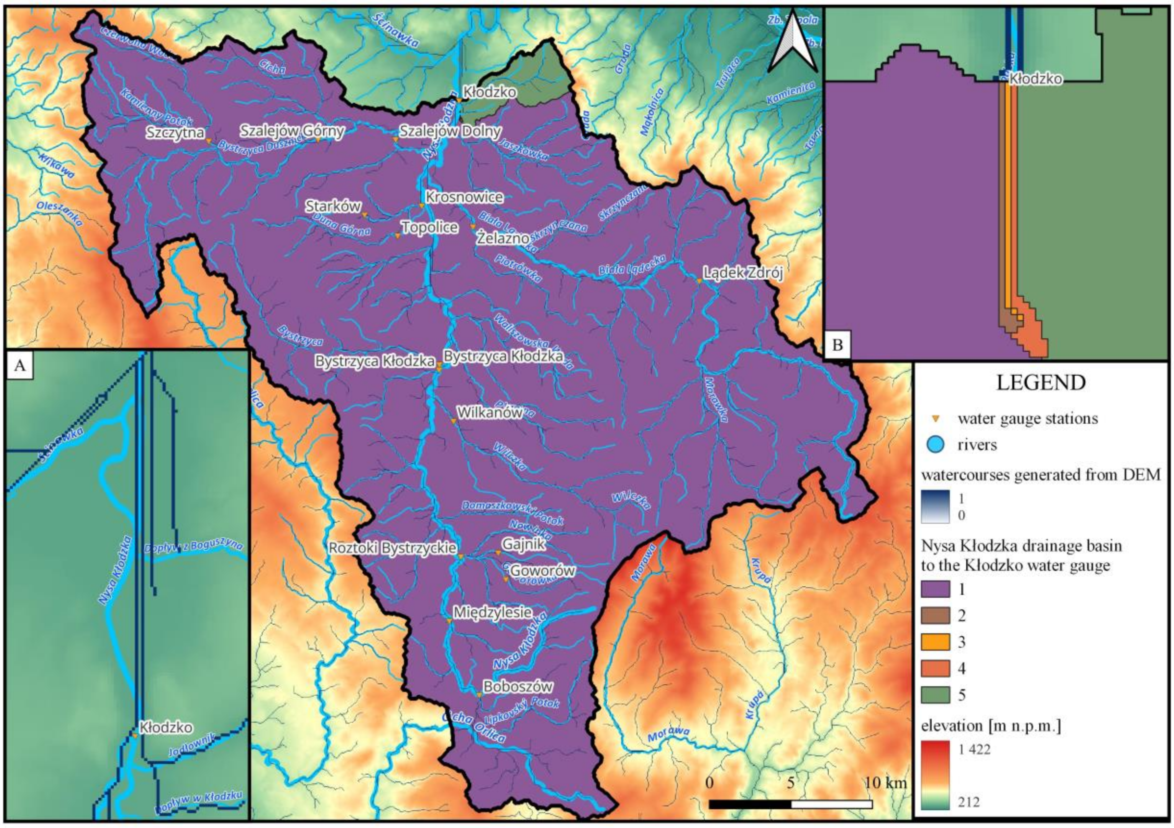

Fig. 6. Catchments of the Nysa Kłodzka River up to the Kłodzko water gauge generated for the DEM30x30m model in the QGIS programme: A - comparison of the course of the Nysa Kłodzka from Kłodzko to the mouth of the Ścinawka River on the topographic map and on the DEM30x30m model, B - generation of the catchment area of the Nysa Kłodzka to the Kłodzko water gauge based on DEM30x30m

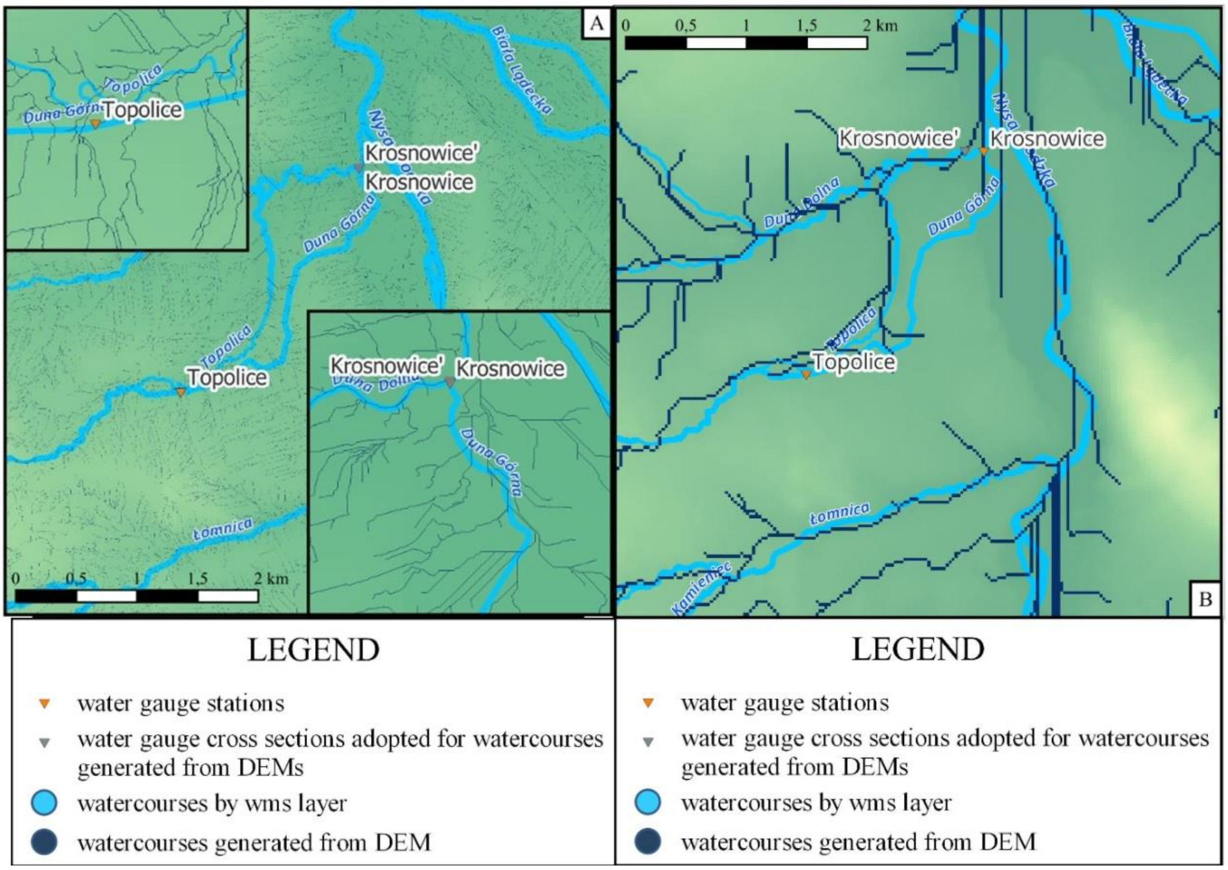

Fig. 7. The course of watercourses generated on the DEM in QGIS software: A - DEM1x1m model, B - DEM25x25m model

5.2. Grid size of DEM

When delineating catchment areas numerically, the grid size of the DEM had the greatest impact on the similarity to underlying data and degree of variation in the results. On the lower resolution models (DEM25x25m, DEM30x30m), these discrepancies from the values reported by IMGW were the greatest (from a few hundredths to even a few hundred percent!). These deviations applied to catchments of smaller rivers as well as larger ones. In the case of the Nysa Kłodzka, even the European watershed of the Łaba River is exceeded (Fig. 8.). Analysing the results from Tab. 2, based on the assumed degree of similarity between the catchment areas and the baseline catchments shown in Tab. 3, a clear difference can be seen between the similarities with the underlying catchment areas of catchments up to 60km^2 and catchments above this value. Differences in catchments larger than 60km^2, with the exception of the DEM30x30m model, were small at best (1.15% for DEM25x25m) and even little (up to 1.00% for the DEM1x1m and DEM5x5m). By far the differences were greater in catchments up to 60km^2. The most similar results were achieved on the DEM5x5m model, for which acceptable deviations predominated, with only 2 out of 10 proving to be large. In contrast, for the highest resolution model, DEM1x1m, the results varied widely, including the case where the catchment closed by the water gauge at Topolice could not be generated. This is quite surprising, as the highest accuracy model was expected to produce results that were closest to the benchmark values. Clearly, the largest amount of data in the model significantly affected the calculation time, which was incomparably longer than the other models, and the size of the result files, which were also several times larger. Given these factors, due to hardware limitations, the calculations had to be performed on hardware with a better CPU and more RAM. The lower-resolution models fared the worst, with large and enormous differences dominating. This may have been due to the fact that certain topographic objects, such as canals or hills that form a watershed, were not included on the rasters [20].

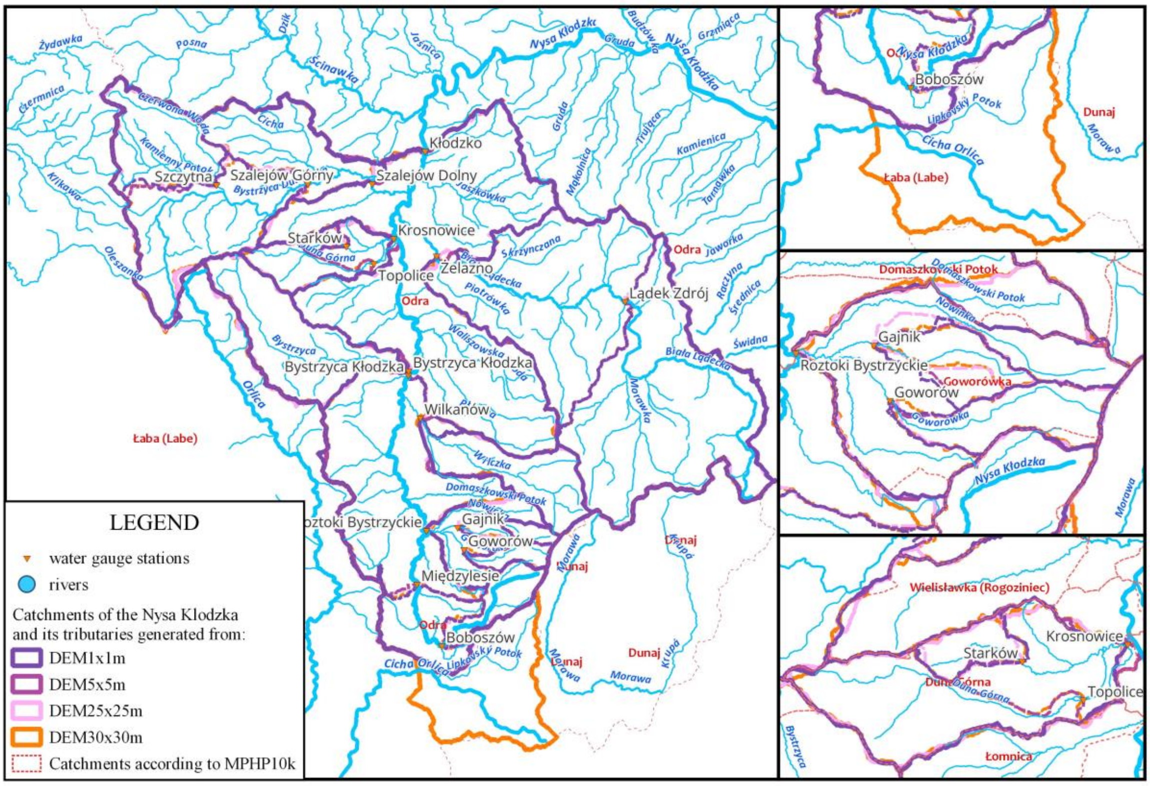

Fig. 8. Overview of the Nysa Kłodzka drainage basin and its tributaries, generated on the basis of the DEM

5.3. Bifurcation

Bifurcation is a phenomenon in which water in a riverbed flows in opposite directions. This phenomenon also occurs in the study area - in the channels of the Bobosz river, a tributary of the Nysa Kłodzka, just downstream of the Boboszów water gauge. It is marked on the Hydrographic Map as a gate in the watershed, so the area behind it should not be included in the survey. This was also the case when generating catchment areas based on DEMs of 1x1m, 5x5m, 25x25m. However, the situation is different at MPHP10k, where the area is included in the Bobosz catchment (Fig. 9.). It amounts to approximately 2km^2 - which would agree with the calculations, as this is how much the areas of the Nysa Kłodzka catchment area at the cross-sections Międzylesie, Bystrzyca Kłodzka and Kłodzko differ between the IMGW data and the areas according to measurements from DEM1x1m, DEM5x5m and DEM25x25m.

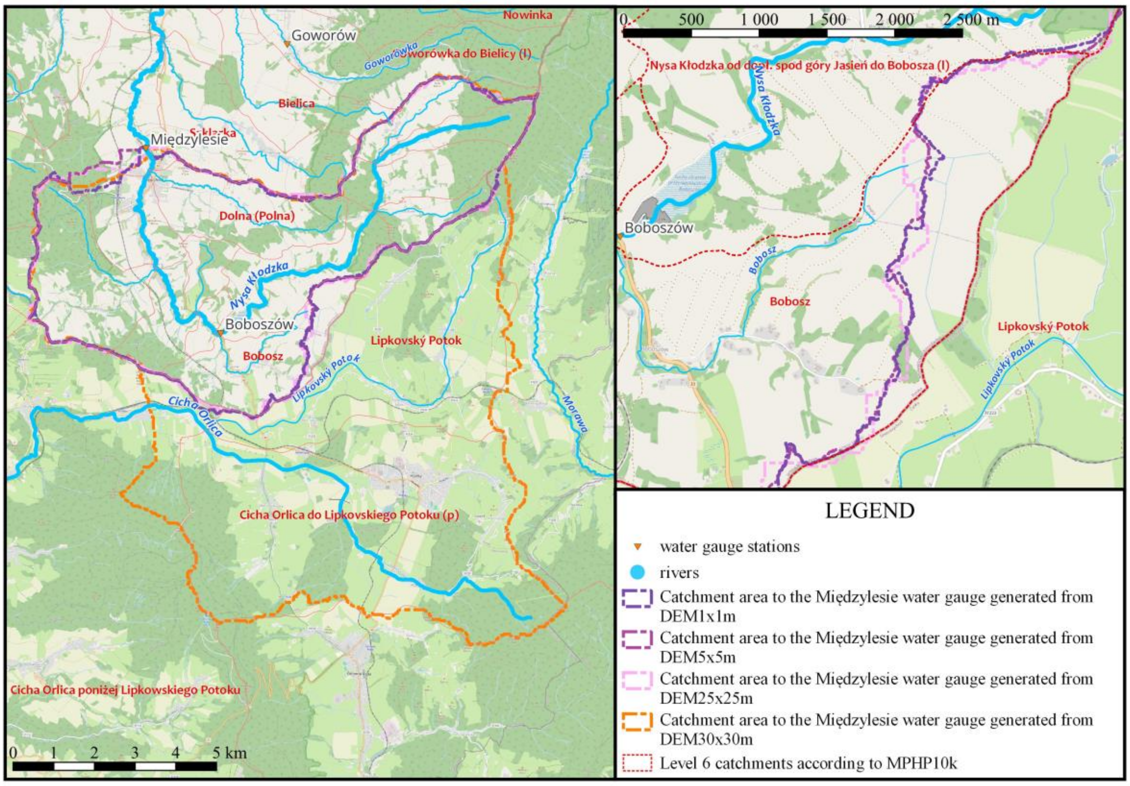

Fig. 9. The Nysa Kłodzka sub-basin and its fragment - the Bobosz sub-basin, on the border of which (according to numerical models) bifurcation occurs. (Source of background map: OpenStreetMap.org)

6. CONCLUSIONS

Undoubtedly, the announced updates to the QGIS plug-in 'Wody Polskie - Baza WMS' ['Wody Polskie –WMS Database'] may prove to be a great help in catchment measurements. Today, however, it is necessary to use other methods to measure catchment areas. When analysing the magnitude of deviations in the case study catchments can be divided into large (with an area of more than 60km^2) and small (with an area of less than 60km^2). For large catchments, the deviations from the baseline plots for the accurate models (DEM1x1m and DEM5x5m) do not exceed 1.00%, and for the less accurate models (DEM25x25m and DEM30x30m), with minor exceptions, barely exceed 1.00%. For smaller catchments, the magnitude of the deviations varies. The best results were achieved on the DEM5x5m model, which was dominated by deviations of up to 5.00% from the baseline results, in no case exceeding 10.00%. In the context of the whole study, the DEM5x5m model also gave the closest results to the baseline, proving that the most detailed models do not always perform best in all computational methods. In addition, some technical issues arose during the calculations on the DEM1x1m model, resulting in the need to use hardware with a better CPU and containing more RAM. In contrast, the results obtained on the DEM30x30m model were sometimes very close to the baseline values, as well as being up to twice as high, as exemplified by the apparent error in crossing the European watershed of Łaba. In a way, the results may be influenced by the age of the collected data, but this would need to be investigated on DEM files of the same grid size and on smaller catchments, which will be the subject of future research. In this case, however, the Łaba river has been flowing there for considerably longer, so there is no reason to find fault with the data acquisition history, but at most with the method and accuracy of the measuring equipment used. Based on the above analyses, the use of this model is discouraged.

An interesting observation is that the catchments delineated to the cross sections marked on the hydrographic map on the DEM1x1m, DEM5x5m, DEM25x25m models are smaller than the baseline catchment areas. There are too few points in the analysis that has been carried out to move towards concrete conclusions. However, if calculations were to be carried out for a larger number of water gauge points marked on the hydrographic map and the relationship persisted, it would be possible to make the bold claim that the catchments calculated using the method described are smaller than in reality, with the result that the calculated flow rate, e.g. by interpolation, may be underestimated.

It should also be emphasised that the method described did not always succeed in generating a watercourse on the model or the watercourse did not coincide with the actual site. Therefore, when carrying out the surveys, the surveyed river network should be checked against the state on the map to be sure to what extent the model can be used. In this case, a different measurement method could prove to be a solution, which is the subject of further research.

ADDITIONAL INFORMATION

The source of the data is the Institute of Meteorology and Water Management -State Research Institute.

REFERENCES

1. Bajkiewicz-Grabowska, E and Mikulski, Z 1999. *Hydrologia ogólna [General hydrology].* Warszawa: Wydawnictwo Naukowe PWN
2. Langbein, WB and Iseri, KT 1960, *General introduction and hydrologic definitions*. Washington: US Government Printing Office.
3. De Graff, JV 2018. Catchment. In: Bobrowsky, PT, Marker, B (eds) *Encyclopedia of Engineering Geology. Encyclopedia of Earth Sciences Series*. Berlin: Springer, 106-107.
4. Główny Geodeta Kraju, 2005. Wytyczne Techniczne GIS-3. Mapa hydrograficzna Polski skala 1:50000 w formie analogowej i numerycznej [GIS Technical Guidance Document – 3. Hydrographic Map of Poland. Scale 1: 50 000 in analogue and numerical form.]. Warszawa: Główny Urząd Geodezji i Kartografii
5. https://www.geoportal.gov.pl, accesed: 11.03.2024-09.08.2024
6. Guth, PL, Van Niekerk, A, Grohmann, CH, Muller, J P, Hawker, L, Florinsky, IV, ... & Strobl, P. 2021. Digital elevation models: Terminology and definitions. *Remote Sensing*, **13(18)**, 3581.
7. Moore, ID, Grayson, RB and Ladson, AR 1991. Digital terrain modelling: a review of hydrological, geomorphological, and biological applications. *Hydrological processes*, **5(1)**, 3-30.
8. Croneborg, L, Saito, K, Matera, M, McKeown, D, van Aardt, J 2020. Digital elevation models: A guidance note on how digital elevation models are created and used-includes key definitions, sample terms of reference, and how best to plan a DEM-mission. Washington DC: World Bank.
9. https://hydro.imgw.pl/, accesed: 11.03.2024-09.08.2024
10. Kondracki, J 2001, Geografia regionalna Polski [Regional geography of Poland]. Warszawa: Wydawnictwo Naukowe PWN

11. Staffa, M 1994. Kotlina Kłodzka [i Rów Górnej Nysy][Kłodzko Basin [and Rów Górnej Nysy]]. Wrocław: IBIS
12. https://www.wody.gov.pl/aktualnosci/3451-kolejna-wersja-wtyczki-qgis-wod-polskich-gotowa-do-pobrania, accesed: 11.03.2024-09.08.2024
13. Romero-Zaliz, R and Reinoso-Gordo, JF 2018. An updated review on watershed algorithms. *Soft computing for sustainability science*, 235-258.
14. Wichmann, V 2007. *SAGA-GIS Module Library Documentation (v2.1.3). Module Fill Sinks (Wang & Liu)*
15. Kamboj, V, Kamboj, N and Sharma, AK 2020. A review on general characteristics, classification and degradation of river systems. *Environmental degradation: Causes and remediation strategies* **1**, 47-62.
16. O'Callaghan, JF and Mark, DM 1984. The extraction of drainage networks from digital elevation data. *Computer vision, graphics, and image processing* **28(3)**, 323-344.
17. Tarboton, DG 1997. A new method for the determination of flow directions and upslope areas in grid digital elevation models. *Water resources research*, **33(2)**, 309-319.
18. Van Zyl, JJ 2001. The Shuttle Radar Topography Mission (SRTM): a breakthrough in remote sensing of topography. *Acta astronautica*, **48(5-12)**, 559-565
19. https://www.earthdata.nasa.gov/sensors/srtm, accesed: 01.07.2024-31.07.2024
20. Zhang, W and Montgomery, DR 1994. Digital elevation model grid size, landscape representation, and hydrologic simulations. *Water resources research*, **30(4)**, 1019-1028.
21. Chormański J. et al., eds. Podręcznik dla uczestników szkolenia: wykorzystanie kartograficznych opracowań tematycznych w postaci cyfrowych map hydrograficznych opracowanych w ramach Projektu enviDMS. Główny Urząd Geodezji i Kartografii, 2017.
22. Paszotta, Z and Szumiło, M 2006. Źródła błędów numerycznego modelu terenu pozyskanego metodami fotogrametrycznymi [Sources of error in the digital elevation model obtained by photogrammetric methods] *Geodesy, cartography and aerial photography* **67**.
23. Haase D and Frotscher K 2005. Topography data harmonisation and uncertainties applying SRTM, laser scanner and cartographic elevation models. *Advances in Geosciences*, ***5***, 65-73.
24. https://www.usgs.gov/, accesed:28.01.2025