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COMPARISON OF THE CATCHMENT AREAS OF THE RIVERS OF THE KŁODZKO BASIN CALCULATED ON THE BASIS OF THE HYDROGRAPHIC MAP OF POLAND AND THE DIGITAL ELEVATION MODEL

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A b s t r a c t

The catchment area is important information from a hydrological point of view. The article addresses the problem of differences between catchment areas measured on the basis of a Hydrographic Map of Poland, surface catchments created on the basis of a digital elevation model and catchments reported in the literature. It describes the hydrographic maps available, including the possibility of using them online. The possibilities of measuring the catchment area using modern software available on the SCALGO Live portal and the tools contained therein are presented, using the example of a section of the Nysa Kłodzka River and its tributaries. The plots made available by IMGW were used as baseline data. Attention was paid to what can cause differences in the results obtained and which method for a given case should prove to be the most practical.

Keywords: catchment area, digital elevation model, QGIS, SCALGO Live, hydrographic map of Poland

1. INTRODUCTION

A catchment is an area from which water flows into one common receiving body (e.g. a river, lake or marsh)[1, 2, 3, 4]. Its surface area is useful for hydrological calculations, e.g. to determine the flow rate of a controlled river using extrapolation, interpolation or of an uncontrolled river using empirical methods and regional formulas [1, 5]. A distinction can be made between the underground catchment and the surface catchment that is the subject of the study. Its boundary is defined by topographic watersheds, delineated by landforms. These form the content of the Hydrographic Map[6]. For Poland, it has been drawn up since the mid-20th century, and the breakthrough year was 1994, when the first numerical maps appeared, which significantly influenced their development. They were performed on the basis of guidelines „*System Informacji o Terenie. Wytyczne techniczne K – 3.4*" ["*Land Information*

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System. Technical Guidance Document K - 3.4"], and next „*Wytyczne Techniczne GIS – 3. Mapa hydrograficzna Polski. Skala 1: 50 000 w formie analogowej i numerycznej*" [„*GIS Technical Guidance Document – 3. Hydrographic Map of Poland. Scale 1: 50 000 in analogue and numerical form."]*. Although the maps had a digital version, this did not ensure that the georeferenced data was consistent and up-to-date. In 2013, the Head Office of Geodesy and Cartography (GUGiK) began work on a new data system as part of the project: „*Model bazy danych przestrzennych dotyczących środowiska przyrodniczego wraz z systemem zarządzania w aspekcie kartograficznych opracowań tematycznych*" [*"Spatial database model for the natural environment with a management system for thematic cartographic studies"*] (**enviDMS).** The main objective was to create a hydrographic data model that would include databases for the topological and cartographic component, as well as to implement a system for managing this hydrographic data. The Project has so far developed 375 sheets of digital hydrographic map at a scale of 1:50 000 and 55 sheets at a scale of 1:10 000 [7].

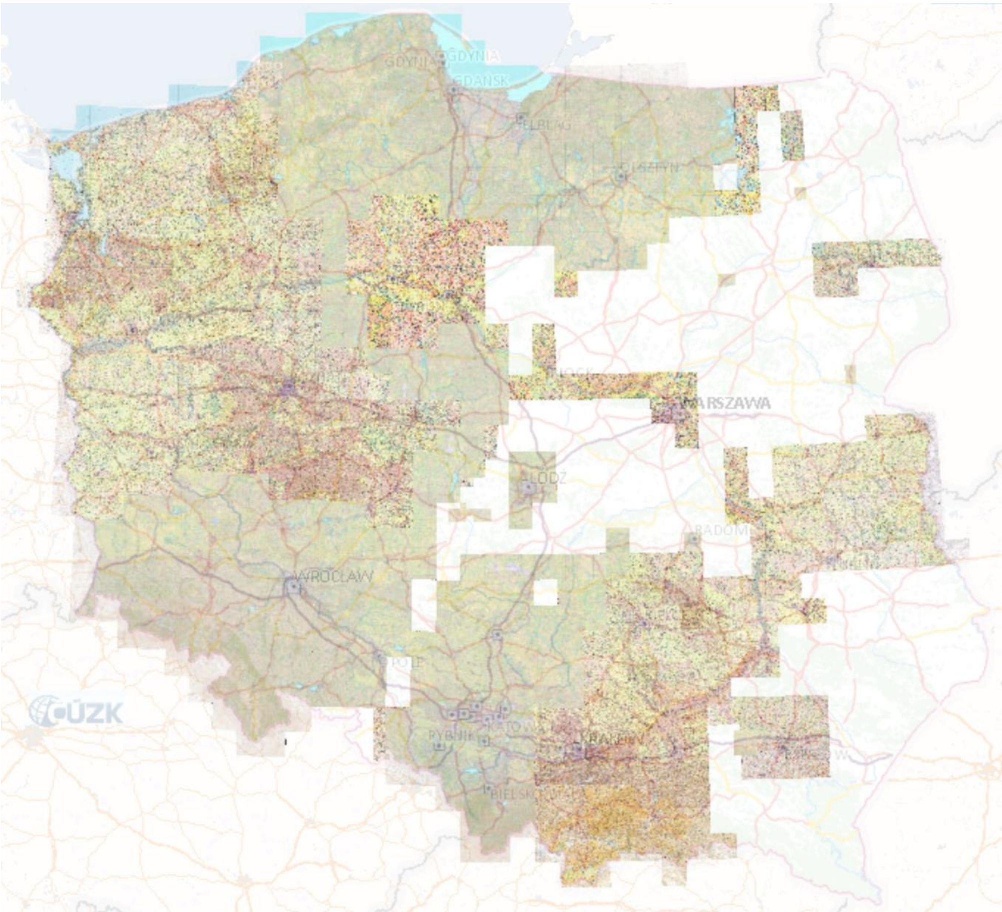

Fig. 1. Sheets of all Hydrographic Maps of Poland, made available through the geoportal[14]: enviDMS 50k – dull color, mainly in the north (Pomeranian and Warmian-Masurian Voivodeships) and south (Lower Silesian, Opole and Silesian Voivodeships) and part of Greater Poland and city of Łódź; enviDMS 10k – also dull color, a few individual sheets, mainly eastern part of the country; Hydrographic Map of Poland made in accordance with technical guidelines K-3.4. and the GIS-3 manual – sharper colour, the sheets are also under the enviDMS layer [14]

It should be noted, that measuring catchment areas on paper as well as digitally is subject to large errors. This error can relate to both the accuracy of the plotted watershed line (the largest map scale is 1:10 000) and the method of calculating the area itself. On maps in analogue versions, it will be the measurement error of the measuring equipment and errors due to the precision of the person taking the measurement. On top of this, map shrinkage must be taken into account. The situation seems simpler on maps in digital versions, but even there the precision of the measurements seems to be far from the desired results. Free map portals, such as the government's geoportal.gov.pl [14], provide maps without vector overlays. The measurement tools available on the portals do not allow for perfect precision (e.g. the function to draw the cursor to the watershed line or the protractor to guide the watershed line perpendicular to the levels is missing). As a result, measurements are taken 'by the look'. With larger catchment areas and a more complicated boundary, such a measurement would definitely be prolonged. With today's access to technology, this method seems very archaic and impractical. Moreover, the maps provided by the geoportal are incomplete - many map sheets are missing, especially in the central and south and north-eastern parts of the country (Fig. 1.). Furthermore, this map ends at the national border, so a hydrographic map of the neighbouring country is required to delineate the catchment areas of border rivers. A prime example is the Ścinawka River, which has its source in the Wałbrzych district, then flows through the territory of the Czech Republic to enter Poland near Tłumaczów.

Nowadays, software dedicated to cartographic analysis, based on DEM, such as QGIS or ArcGIS, is used to delineate catchment areas, which significantly streamline the task [8, 9, 10]. Relatively recently, web apps, such as SCALGO Live, have also emerged that also enable hydrological analyses, including catchment measurement [11, 12, 13].

The article describes the possibility of using the Hydrographic Map of Poland online and presents an example of a survey using the tools available on the geoportal. Although this method is unlikely to be used nowadays, it can be useful for estimating catchment areas, e.g. in the absence of knowledge of how to use mapping analysis software. An example of measurement on the SCALGO Live portal is also presented. The results obtained were compared to the catchment areas provided by IMGW, which were taken as baseline, and to the catchment areas generated in QGIS software based on Digital Elevation Models (DEM) of different resolution[1]. The aim of the study was to check whether catchment measurements using tools available on the map portal give sufficiently close results to baseline surfaces. It was also checked how close to baseline surfaces can be obtained using modern measurement techniques with DEM models. The results were analysed, and attention was drawn to the problems that can arise during calculations using DEMs. In conclusion, it was determined whether and to what extent each of the methods can be used for catchment measurements.

2. RESEARCH AREA

The study area is the upper catchment area of the Nysa Kłodzka River in south-western Poland, close to the border with the Czech Republic, closed by a water gauge located in Kłodzko (Fig. 2)[1]. It covers the Kłodzko Land, i.e. the Kłodzko Basin and the surrounding mountains. On the northern side, the catchment area is closed by the Ścinawka Depression. The main river of the region is the Nysa Kłodzka, flowing symmetrically in a northerly direction. 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. [19, 20]

Ongoing and planned developments are likely to affect the boundaries of individual catchments and may lead to the creation of new drainless areas. In 2018, the Kłodzko bypass along National Roads 33 (DK33) and 46 (DK46), with a total length of 9.19km and by 2033 an additional several tens of kilometres are to be built, roads connecting the capital of the Kłodzko region with the Czech Republic, from the south and west [21]. Two reservoirs have been built as accompanying facilities. In addition to the development of road infrastructure, investments were made to improve flood protection in the region. As part of active protection, 4 dry reservoirs were constructed between 2018 and 2023. In total, they can store 15.9m m3 of water with a floodplain area of 233.72ha. In addition, work is underway on passive protection, including the reconstruction of regulatory buildings and bank insurances on the Nysa Kłodzka and its several major tributaries [11]. The completed developments listed above are not included in the hydrographic maps, which in the case under analysis date from 2013 to 2017. In contrast, some of them, by the time of writing, were included on the Digital Elevation Model, which is updated far more frequently - in certain areas of the country almost every year.

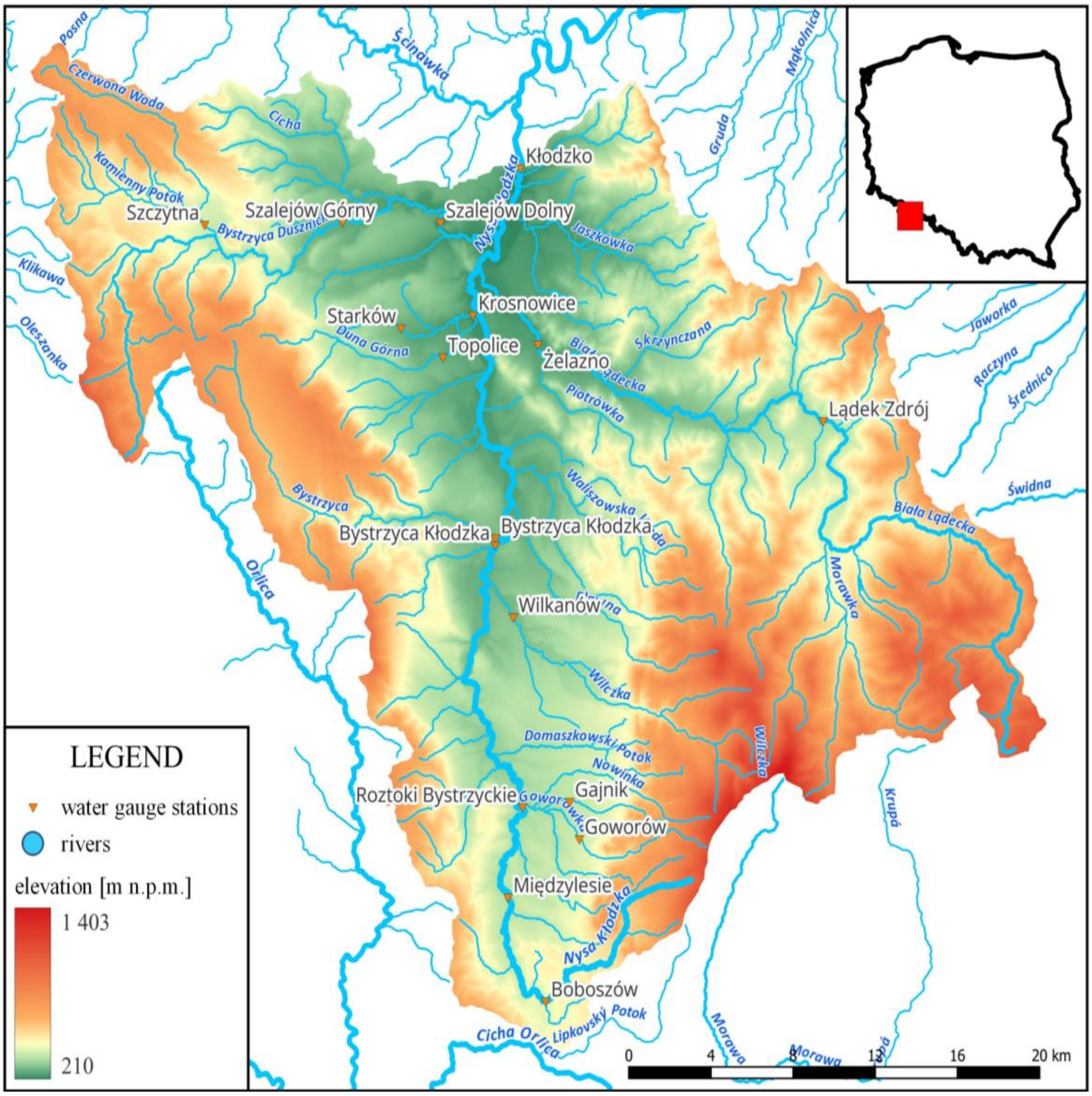

Fig. 2. Kłodzko Basin [1]

3. METHODS

3.1. Coordinations of water gauge stations

The study compared catchment areas measured with tools available on the geoportal and generated from DEMs with baseline values adopted from IMGW data. Due to the fact that the institute does not make available the coordinates of the water gauge stations placed on its maps, the baseline coordinates were adopted as those read from the maps placed on the geoportal (PL-1992)[1]. 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. [1] Interestingly, the water gauges on the hydrographic map and on the orthophotos do not exactly coincide. For example, the difference in coordinates of the Międzylesie water gauge is about 40m (Fig. 3.).

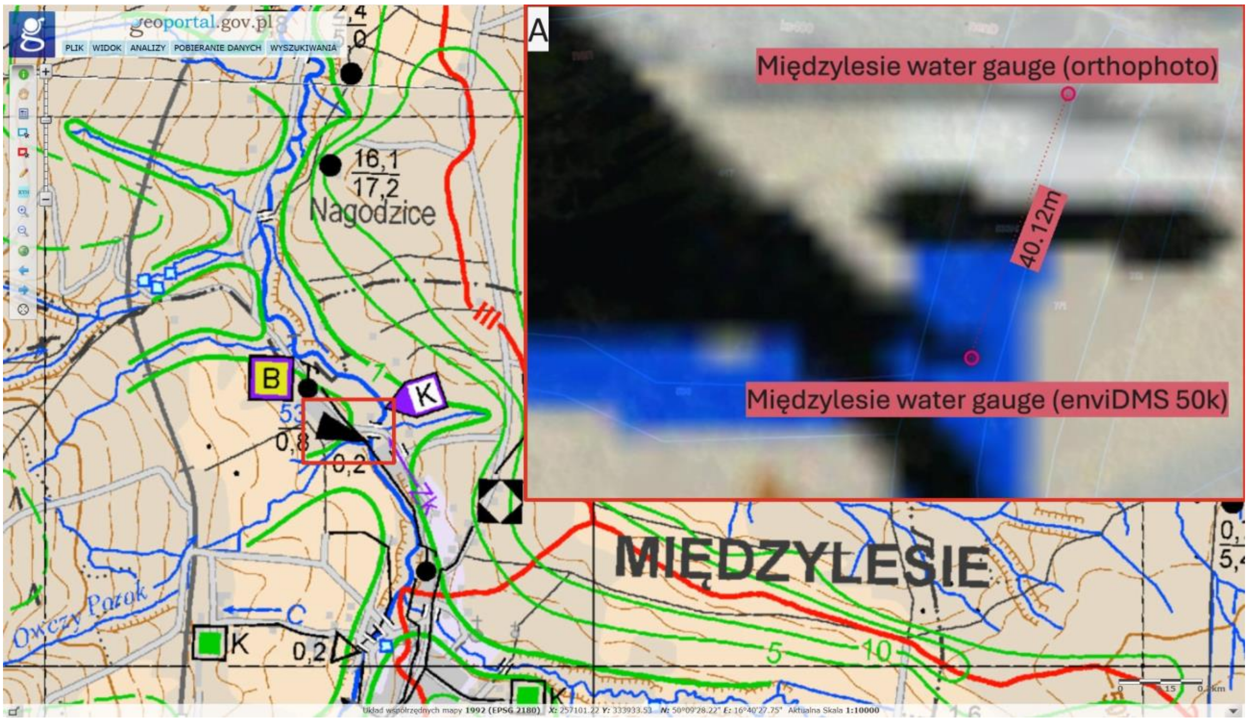

Fig. 3. Difference of approx. 40m between the location of the Międzylesie water gauge on maps; where fig. A – zoom part of Hydrographic maps marked by red frame; black colour is zoom water gauge and blue colour is the river, both layers from Hydrographic maps [14]

The differences in water gauge coordinates between the hydrographic map and the DEM-based models are due to the course of the watercourse in question on the model. [1] Smaller watercourses may not be generated or may be mistakenly replaced by several other watercourses crossing the actual watercourse. Conversely, larger rivers may be broken up into several smaller ones, which can also make catchment measurements difficult or impossible [1]. The differences between the coordinates adopted from the maps and the models based on the Digital Elevation Model are summarised in table 1.

Table 1. 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]		coordinate difference "geoportal vs SCALGO Live" [m]	
			X	Y	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	0.00	0.00
2	Cieszyca	Gajnik	0.00	0.00	0.95	0.02	0.70	-104.30	0.62	57.45	0.00	0.00
3	Goworówka	Goworów	38.67	-20.77	17.88	-1.30	-175.67	-13.65	-211.64	-21.49	38.67	-20.77
4	Duna Górna	Topolice	-	-	22.85	-20.44	-	-	4.43	-106.01	-23.51	-43.79
5	Nysa Kłodzka	Boboszów	0.00	0.00	0.35	-10.64	-32.23	-14.07	-0.70	-68.76	-0.03	-1.57
6	Duna Górna	Krosnowice	0.88	-4.86	-32.28	-91.47	154.28	-1.29	193.92	8.22	-2.00	-4.00
7	Goworówka	Roztoki Bystrzyckie	-0.13	2.00	0.00	0.00	31.28	-43.42	2.76	-55.41	0.00	0.00
8	Kamienny Potok	Szczytna	-0.90	-0.03	0.00	0.00	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	-11.00	5.00
10	Nysa Kłodzka	Międzylesie	-1.34	-0.09	2.40	0.21	-89.86	-3.71	-77.37	-23.14	-9.44	-45.54
11	Bystrzyca	Bystrzyca Kłodzka	0.00	0.00	0.19	-1.78	0.00	0.00	2.42	-29.96	1.71	-2.60
12	Bystrzyca Dusznicka	Szalejów Górny	-15.93	-31.17	0.00	0.00	0.00	0.00	-72.19	101.22	-0.27	-0.31
13	Biała Lądecka	Lądek Zdrój	-0.23	8.45	0.31	8.66	2.73	-56.91	5.65	-68.87	-0.23	0.50
14	Bystrzyca Dusznicka	Szalejów Dolny	0.00	0.00	0.00	0.00	-106.15	-1.70	-100.43	-2.21	1.86	-3.25
15	Nysa Kłodzka	Bystrzyca Kłodzka	-5.35	1.52	2.02	0.02	-74.96	1.85	-36.82	4.10	0.00	0.00
16	Biała Lądecka	Żelazno	5.46	0.81	2.48	0.05	-163.11	-3.85	12.80	0.41	1.57	-7.73
17	Nysa Kłodzka	Kłodzko	-40.29	-58.83	14.02	-0.45	-11.10	-53.99	-	-	-22.35	-15.55

3.2.Measurement of catchment area using tools available on Geoportal

The geoportal has enviDMS50k hydrographic maps for the study area. It was difficult to be precise, as the portal does not have the right tools (such as a protractor) for this purpose. To reduce random error, the measurement was taken 5 times. The exemple procedure is shown in fig. 4 a), b), c). One of the tributaries of the Nysa Kłodzka, Bobosz, is crossed by a watershed on the map. This has to do with bifurcation. An area of approximately 2km^2, located to the east of the watershed gate, was therefore not included in the catchment area of the Nysa Kłodzka.

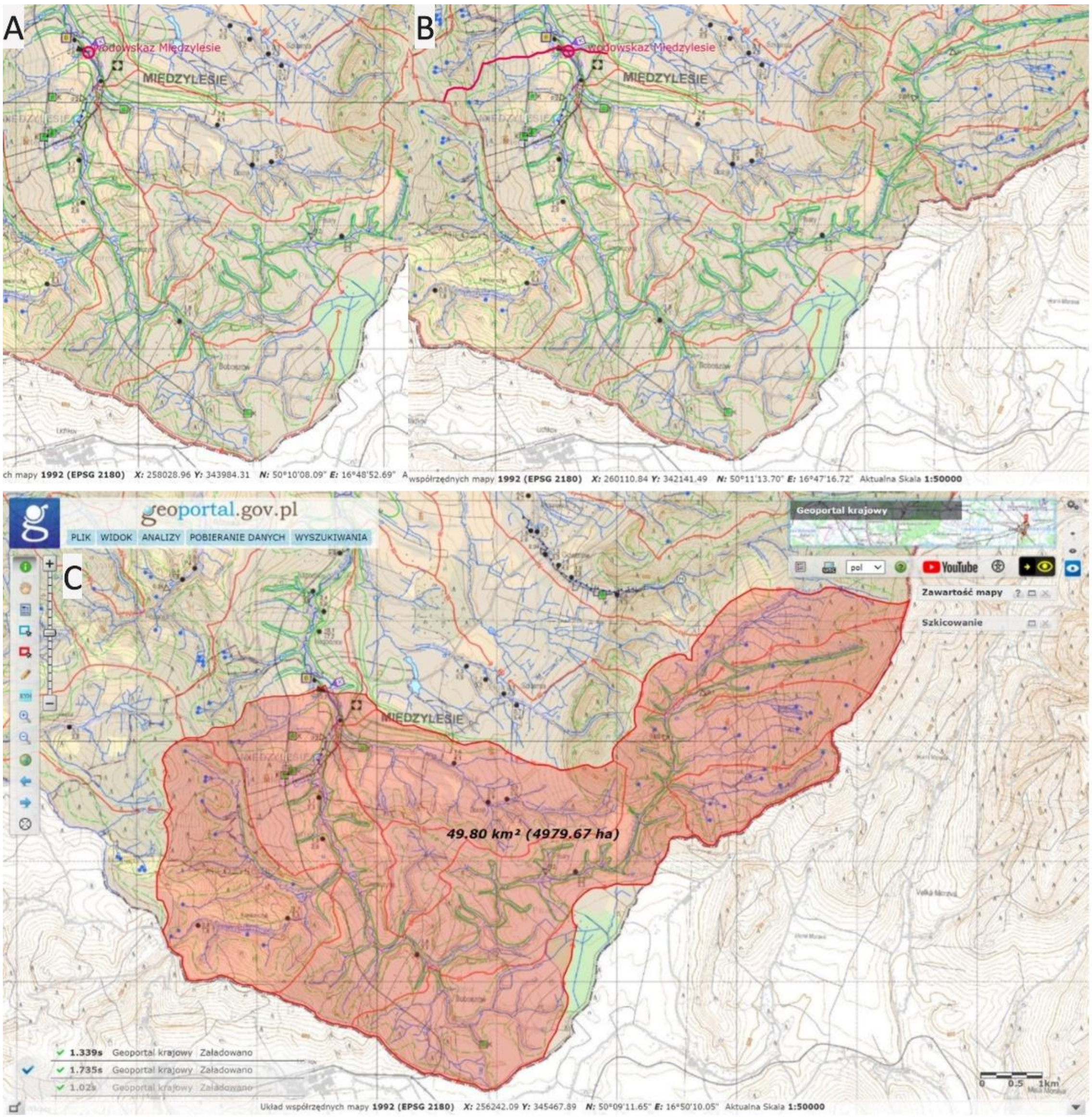

Fig. 4. Measurement of the catchment area of the Nysa Kłodzka River up to the Międzylesie water gauge using tools available on the geoportal [14]: a) marked Międzylesie water gauge on enviDMS 50k Hydrographical Map, b) Staking of the section enclosing the catchment area, c) Catchment area measurement

3.3. SCALGO Live

Derived from Denmark, the web application SCALGO Live was founded with the aim to bring cutting-edge massive terrain data-processing technology to the market[15]. It enables analysis of three-dimensional maps based on a high-resolution (1m or higher) Digital Elevation Model (DEM) [16]. The database covers 9 European countries, including Poland. It is widely used for landform and surface water issues and projects, such as restoration, urban, infrastructure or new development planning. In Poland, the Digital Elevation Model exists in the Kronsztadt 86 system (PL-KRON86-NH) and the European Vertical Reference Frame (PL-EVRF2007-NH). The average difference between the two systems is 0.1659m [17]. SCALGO Live has harmonised the DEM to the PL-EVRF2007-NH, which has been the current state spatial reference system for the territory of Poland since 2012 (Fig. 5.)[16, 18].

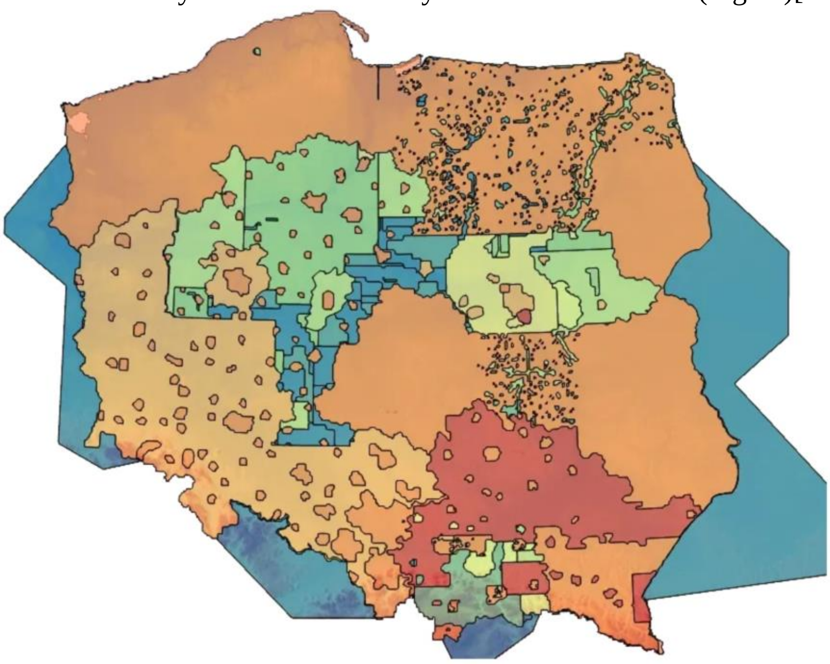

Fig. 5. DEM available on SCALGO Live website [16]

As mentioned earlier, the catchment areas of some Polish rivers are outside the country's borders. In SCALGO Live DEM also covers some border areas. This service is constantly developing and it is likely that in the near future it will be possible to analyse the catchment area of any river flowing through the territory of Poland. At the time of writing, as with the hydrographic map of Poland, the area of the Nysa Kłodzka catchment can only be measured up to the mouth of the Ścinawka.

The portal uses a nationwide set of hydrological corrections to the GUGiK BDOT10k database, which enables analysis of water flow where rivers intersect with roads and railways. Larger bridges were removed from the DEM, corrections were made for viaducts and tunnels, and culverts on rivers were added. However, it should be noted that some errors in the model may occur, especially for smaller watercourses[16].

Measuring catchment areas with SCALGO Live is very simple and intuitive. From the top panel, select *Point Query,* and next *Watershed*. Then press the mouse button on the point you want to close the catchment area - in this case a water gauge with known coordinates. It can be found on the basis of an orthophoto or topographic map. On the basis of the DEM layer, the programme will generate the catchment area to the point in question (Fig. 6.). The panel on the right will show information regarding the coordinates of the selected point, the area, the land cover and the slope. In addition, it is possible to download the generated catchment area as a vector file, e.g. in shapefile (.shp) or dxf (.dxf) format with user-selectable coordinates. Fig. 7. shows the surveyed catchments measured in this way.

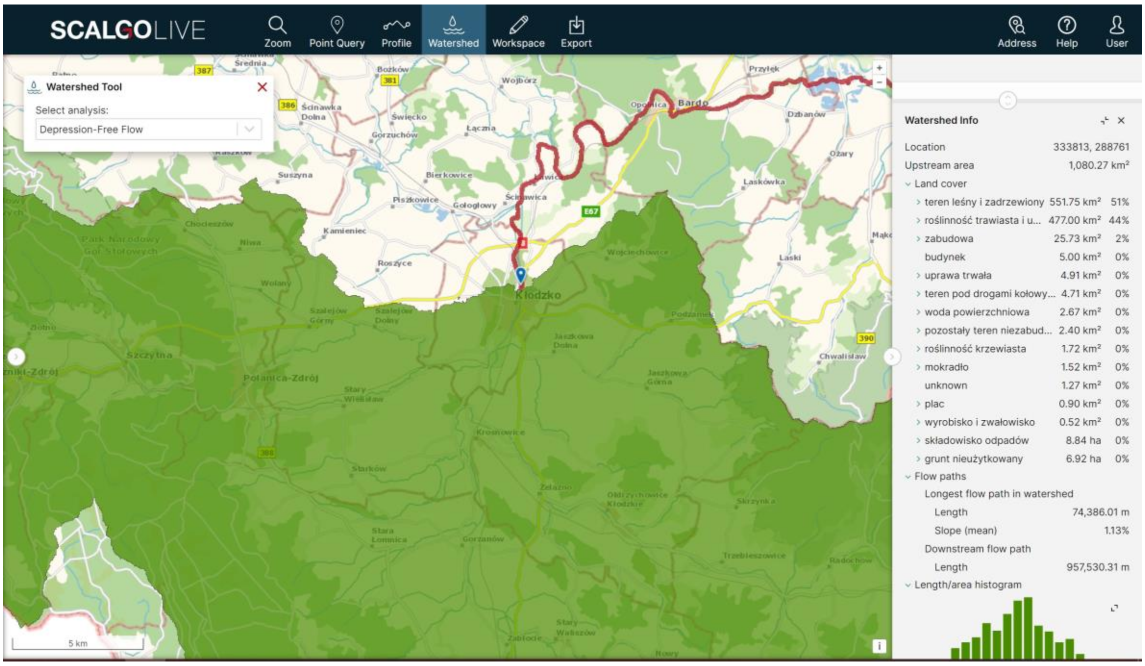

Fig. 6. Measurement of the catchment area to the Kłodzko water level gauge at SCALGO Live

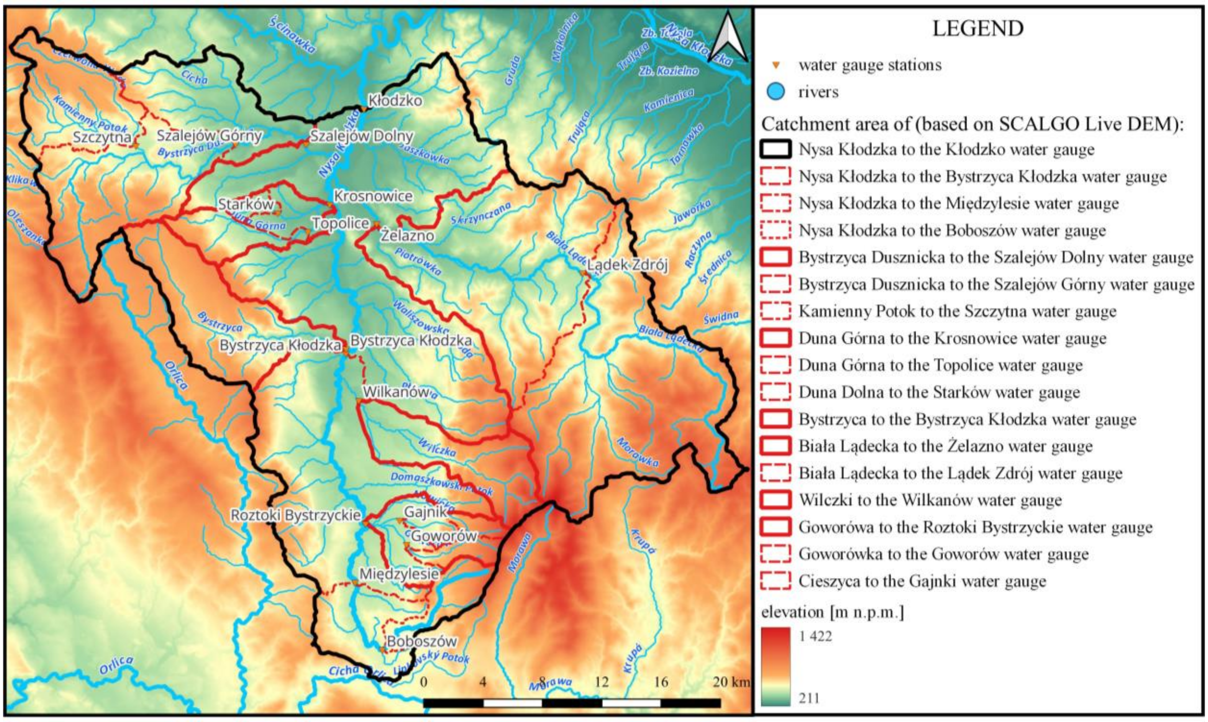

Fig. 7. Catchment areas of rivers in the Kłodzko Basin generated in SCALGO Live

4. RESULTS

Catchment area measurements using the tools available on the geoportal are shown in table 2.

Table 2. Summary of the area of the catchment of the Nysa Kłodzka and its tributaries measured on a hydrographic map using tools available on the geoportal

lp.	river	water level gauge section	Sample1 [km^2]	Sample 2 [km^2]	Sample 3 [km^2]	Sample 4 [km^2]	Sample 5 [km^2]	**Average area [km^2]**
1	Duna Dolna	Starków	4.21	4.60	4.26	4.65	4.59	**4.46**
2	Cieszyca	Gajnik	6.34	6.09	6.09	6.08	6.03	**6.13**
3	Goworówka	Goworów	7.61	7.63	7.63	7.63	7.60	**7.62**
4	Duna Górna	Topolice	17.54	17.54	17.53	17.54	17.56	**17.54**
5	Nysa Kłodzka	Boboszów	18.51	18.54	18.54	18.53	18.51	**18.53**
6	Duna Górna	Krosnowice	34.55	34.56	34.55	34.55	34.55	**34.55**
7	Goworówka	Roztoki Bystrzyckie	34.65	34.64	34.64	34.63	34.64	**34.64**
8	Kamienny Potok	Szczytna	47.35	47.42	47.40	47.44	47.38	**47.40**
9	Wilczka	Wilkanów	46.57	46.64	46.64	46.62	46.64	**46.62**
10	Nysa Kłodzka	Międzylesie	49.77	49.76	49.58	49.83	49.80	**49.75**
11	Bystrzyca	Bystrzyca Kłodzka	64.69	64.70	64.69	64.68	64.68	**64.69**
12	Bystrzyca Dusznicka	Szalejów Górny	123.84	123.85	123.87	123.84	123.84	**123.85**
13	Biała Lądecka	Lądek Zdrój	162.89	162.85	162.86	162.87	162.64	**162.82**
14	Bystrzyca Dusznicka	Szalejów Dolny	172.98	173.01	173.03	173.02	173.01	**173.01**
15	Nysa Kłodzka	Bystrzyca Kłodzka	260.48	260.46	260.44	260.50	260.42	**260.46**
16	Biała Lądecka	Żelazno	303.36	303.42	303.42	303.15	303.24	**303.32**
17	Nysa Kłodzka	Kłodzko	1080.68	1080.54	1080.65	1080.58	1080.50	**1080.59**

The resulting catchment areas measured using the tools available on the geoportal and read from the SCALGO Live portal are shown in Tab. 3. These data were juxtaposed with the catchment areas generated from Digital Elevation Models of various resolutions in QGIS software [1]. The catchments were ordered in ascending order, based on data from IMGW [7], which were taken as comparative data. 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 3. Summary of catchment areas calculated using different methods and calculation models

lp.	river	water level gauge section	River kilometer [km]	IMGW [km^2]	QGIS (DEM1x1) [km^2]	QGIS (DEM5x5) [km^2]	QGIS (DEM25x25m) [km^2]	QGIS (DEM30x30m) [km^2]	SCALGO Live [km^2]	GEOPORTAL [km^2]
1	Duna Dolna	Starków	3.96	4.35	4.53	4.46	4.05	4.37	4.51	4.46
2	Cieszyca	Gajnik	1.64	5.95	5.94	5.75	4.77	3.70	6.02	6.13
3	Goworówka	Goworów	4.31	7.37	8.10	7.87	7.79	7.99	8.05	7.62
4	Duna Górna	Topolice	3.79	17.41	-	17.58	-	17.60	17.71	17.54
5	Nysa Kłodzka	Boboszów	179.70	18.52	18.01	17.83	18.22	18.41	18.09	18.53
6	Duna Górna	Krosnowice	0.38	32.72	33.94	34.66	33.76	33.78	34.26	34.55
7	Goworówka	Roztoki Bystrzyckie	0.07	34.71	35.73	35.92	41.80	42.90	35.57	34.64
8	Kamienny Potok	Szczytna	0.93	47.15	45.70	47.07	47.08	47.08	46.95	47.40
9	Wilczka	Wilkanów	2.39	47.20	42.18	44.84	44.73	44.91	44.73	46.62
10	Nysa Kłodzka	Międzylesie	172.96	51.40	48.11	48.94	48.76	113.86	49.35	49.75
11	Bystrzyca	Bystrzyca Kłodzka	0.25	64.69	64.4	64.59	64.53	64.79	64.35	64.69
12	Bystrzyca Dusznicka	Szalejów Górny	12.31	123.99	123.26	123.56	123.98	123.41	123.16	123.85
13	Biała Lądecka	Lądek Zdrój	23.04	162.87	162.82	162.78	162.80	163.00	162.84	162.82
14	Bystrzyca Dusznicka	Szalejów Dolny	4.82	173.37	173.09	172.99	171.37	171.28	172.65	173.01
15	Nysa Kłodzka	Bystrzyca Kłodzka	151.38	262.73	260.4	260.18	259.93	325.41	260.63	260.46
16	Biała Lądecka	Żelazno	5.02	303.34	301.9	302.65	302.44	302.41	301.94	303.32
17	Nysa Kłodzka	Kłodzko	130.04	1082.27	1080.1	1079.74	1078.82	1144.64	1080.27	1080.59

As can be seen, the plots for a given gauge cross-section vary depending on the method and grid size of the DEM model. These values were referred to those reported by IMGW [24] and the differences are summarised in Tab. 4. For better illustration, these differences were divided according to a 6-point scale proposed by the author [1]

Table 4. Differences between catchment areas according to IMGW and areas measured by different methods and calculation models [1]. Data are highlight in a different colour according to a 6-point scale: (≤|0.5%| - mint green; |0.51%-1.00%| - light green; |1.01%-3.00%| - green; |3.01%-5.00%| - yellow; |5.01%-10.00%| - orange ; >|10.00%| - red)

lp.	river	water level gauge section	River kilometer [km]	IMGW-QGIS (DEM1x1m)	IMGW-QGIS (DEM 5x5m)	IMGW-QGIS (DEM25x25m)	IMGW-QGIS (DEM30x30m)	IMGW-SCALGO Live	IMGW-GEOPORTAL
1	Duna Dolna	Starków	3.96	-4.14%	-2.53%	6.90%	-0.46%	-3.68%	-2.53%
2	Cieszyca	Gajnik	1.64	0.17%	3.36%	19.83%	37.82%	-1.18%	-3.03%
3	Goworówka	Goworów	4.31	-9.91%	-6.78%	-5.70%	-8.41%	-9.23%	-3.39%
4	Duna Górna	Topolice	3.79	-	-0.98%	-	-1.09%	-1.72%	-0.75%
5	Nysa Kłodzka	Boboszów	179.70	2.75%	3.73%	1.62%	0.59%	2.32%	-0.05%
6	Duna Górna	Krosnowice	0.38	-3.73%	-5.93%	-3.18%	-3.24%	-4.71%	-5.59%
7	Goworówka	Roztoki Bystrzyckie	0.07	-2.94%	-3.49%	-20.43%	-23.60%	-2.48%	0.20%
8	Kamienny Potok	Szczytna	0.93	3.08%	0.17%	0.15%	0.15%	0.42%	-0.53%
9	Wilczka	Wilkanów	2.39	10.64%	5.00%	5.23%	4.85%	5.23%	1.23%
10	Nysa Kłodzka	Międzylesie	172.96	6.40%	4.79%	5.14%	-121.52%	3.99%	3.21%
11	Bystrzyca	Bystrzyca Kłodzka	0.25	0.45%	0.15%	0.25%	-0.15%	0.53%	0.00%
12	Bystrzyca Dusznicka	Szalejów Górny	12.31	0.59%	0.35%	0.01%	0.47%	0.67%	0.11%
13	Biała Lądecka	Lądek Zdrój	23.04	0.03%	0.06%	0.04%	-0.08%	0.02%	0.03%
14	Bystrzyca Dusznicka	Szalejów Dolny	4.82	0.16%	0.22%	1.15%	1.21%	0.42%	0.21%
15	Nysa Kłodzka	Bystrzyca Kłodzka	151.38	0.89%	0.97%	1.07%	-23.86%	0.80%	0.86%
16	Biała Lądecka	Żelazno	5.02	0.47%	0.23%	0.30%	0.31%	0.46%	0.01%
17	Nysa Kłodzka	Kłodzko	130.04	0.20%	0.23%	0.32%	-5.76%	0.18%	0.16%

5. DISCUSSION

As stated in an earlier publication [1], the differences in catchment areas are influenced by the accuracy of the coordinates of the point closing the catchment. For DEM-based measurement methods, the deviation from the base coordinates can be determined by the course of the river on the model not overlapping with the course on the map. This was also the case for the analysis of a certain catchment in SCALGO Live. The Goworów water gauge has been bypassed by the Goworówka ‘flowing’ street. The catchment was measured to points downstream and upstream of the water gauge, which coincided with the river on the topographic map (Fig. 8.). The difference in catchment area for the two points was 0.36km^2, resulting in a difference of up to 4.47% for such a small catchment area. Finally, the cross-section located downstream of the water gauge was adopted for the analysis. With reference to Table 6 showing the differences between the coordinates of the baseline water gauge stations and those adopted in the computational models, the SCALGO Live model performed best. In the worst case, the catchment closure point was approximately 46.5m from the point taken as the baseline. This was a smaller distance than the maximum distance at any of the catchment closure points on the models generated in QGIS.

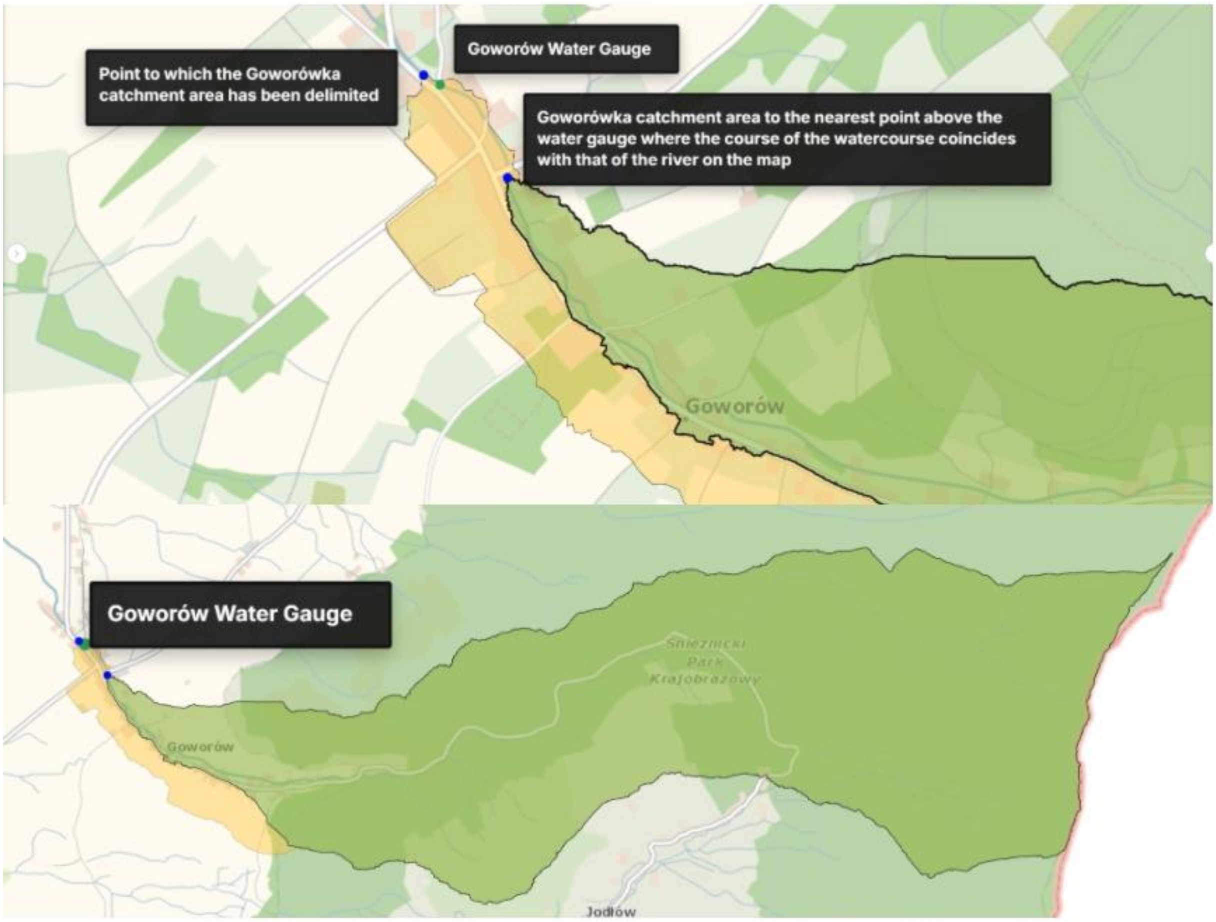

Fig. 8. Course of the watercourse Goworówka generated from the DEM in SCALGO Live; Goworów water gauge was between two points coinciding with the course of the watercourse on the map

In the case of numerical delineation of catchment areas, the size of the DEM grid had the greatest impact on the accuracy and degree of variation in the results [1]. When comparing the accuracy of the DEM-based model results obtained, the SCALGO Live model performed best. The differences were predominantly up to 3.00% and only 2 were found up to 10.00%. More accurate results were only obtained using the tools available on the geoportal. SCALGO Live uses an DEM model with a grid size of 1x1m, so the results would primarily need to be related to those obtained from the 1x1m DEM-based model analysis in QGIS. For areas above 60km^2, comparable results were obtained, with up to 1.00% deviation from the results provided by IMGW. For areas below 60km^2, much closer results to the IMGW data were obtained on the SCALGO Live model. Each of the ten study catchments in this interval was successfully generated (in contrast to the DEM1x1m model in QGIS). In eight cases, the results were closer to the baseline results, of which the accuracy of five was within 3.00% and two more were below

5.00%. The largest deviation was obtained to the Goworów water gauge described earlier, but it was below 10.00%.

The cross sections of Międzylesie, Bystrzyca Kłodzka and Kłodzko on the Nysa Kłodzka are worth noting. The areas counted numerically and through measurements from the Hydrographic Map of Poland are smaller than the baseline areas provided by IMGW by approximately 2km^2. This is due to the phenomenon of bifurcation which occurs on the Bobosz watercourse, a tributary of the Nysa Kłodzka River in the vicinity of Boboszów. On the Hydrographic maps, this area is marked as a water gate and so was not included in the survey. However, this uncertain boundary is not included in the MPHP10k maps on the basis of which IMGW delineates the catchment areas (Fig. 9.)[1, 25].

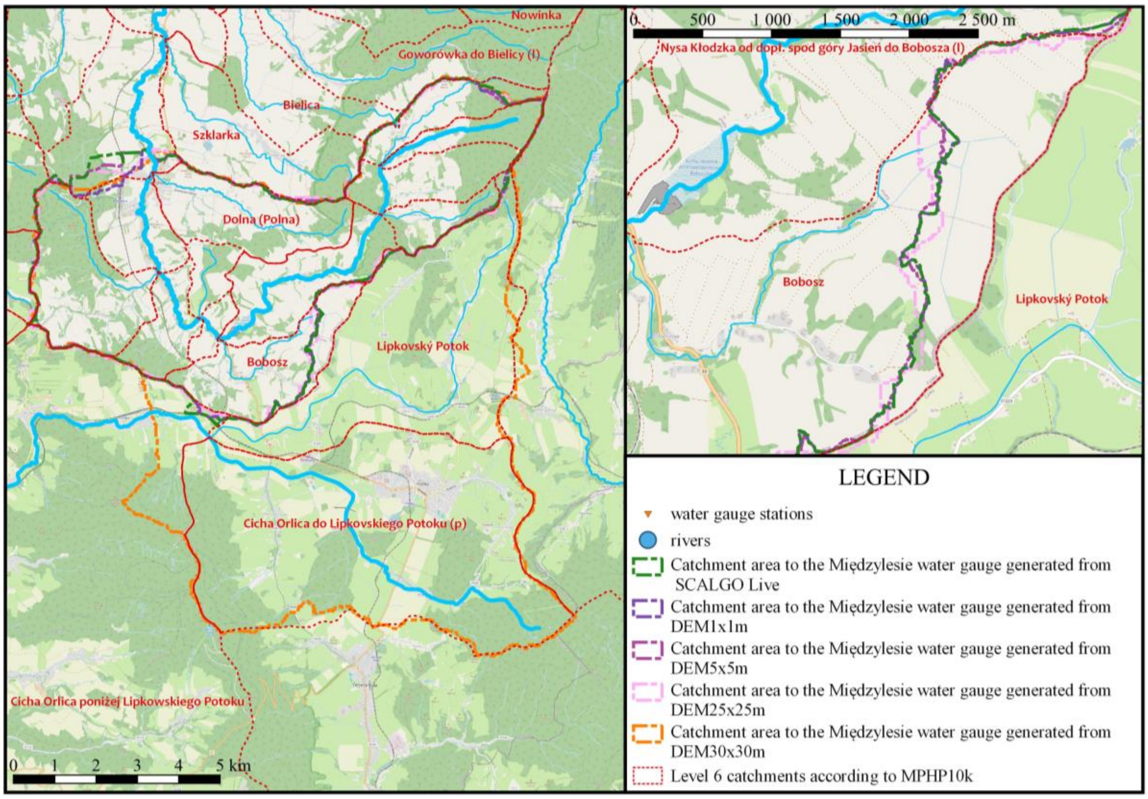

Fig. 9. The Nysa Kłodzka sub-basin and its fragment - the Bobosz sub-basin, on the border of which (according to numerical models) bifurcation occurs. (Source of background map: OpenStreetMap.org)

The announced updates to the plug-in to QGIS 'Wody Polskie - Baza WMS'[1] may prove to be a great facilitation in catchment area measurements. They are to enable, among other things, the downloading of vector layers, which would considerably simplify the measurement of catchment areas, which would be as close as possible to the data made available by IMGW [1, 23]. For the time being, measurements using the layers contained in the plug-in amount to analogous measurements to those described using tools from the geoportal.

6. CONCLUSIONS

Taking into account the results obtained, the analysed area can be divided into two cases in terms of surface area: small catchments (up to 60km^2) and large catchments (above 60km^2, but below 1100km^2). Currently, for the determination of the area of small catchments, measurements using the tools available on the geoportal should be quite sufficient. A limitation may be the availability of map sheets and, over time, unless the maps are updated, also certain investments, such as the construction of hydrological and transport infrastructure, that may affect the watershed. As shown in the example of the Goworów water gauge, in small catchments even a slight shift of the catchment boundary can generate significant deviations from the baseline area. For a large catchment, this method may prove impractical due to the time-consuming nature and the possibility of a mistake resulting in the need to repeat the measurements.

Due to the speed, ease and accuracy of the task, the SCALGO Live portal should work best. With regard to the results obtained from the DEM in QGIS, for both the small and large catchment areas the plots were more similar to the baseline. Due to the fact that it is a web-based application, the calculations will not take up computer memory as would be the case for analyses in QGIS. When analysing catchment areas based on DEMs, the programmes, due to the accuracy and resolution of the grid, may generate some errors, such as the course of a watercourse where it does not actually run or the omission of hills that form a watershed. Errors may be exacerbated on lower resolution models, so some control of the results obtained should be kept in mind.

ADDITIONAL INFORMATION

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

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