UDC 551.4+911.2; DOI 10.30970/gpc.2025.1.4883

Topography effect on land cover in a river basin system: Case of Bystrytsia Pidbuzka

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Abstract. Topography is an important factor of land cover. Concurrently, topography and land cover are significant hydrological regime controls of an area, which, for the purpose of water management, is represented as a basin system – a network of subbasins connected by the streamflow. Therefore, this study aims at providing a simple methodology for an automated delineation of a river basin system, and for its subsequent geomorphometric and land cover characterization using available global geodatasets.

As a case, we chose the Bystrytsia Pidbuzka basin system of 500 km², which has a transitional location between the Carpathian Mountains and the Fore-Carpathian Upland in Lviv Oblast (Ukraine). Global digital elevation model (DEM) FABDEM V1-2 with a resolution of 30*30 m was used as a primary geodataset for topography data, while ESA WorldCover V2 2021 with a resolution of 10*10 m was selected as a primary land cover geodataset. Firstly, we automatically delineated the basin system by applying hydrology analysis algorithms to the DEM. Secondly, we used a zonal function to obtain the main geomorphometric indices (mean and standard deviation values of altitude and slope) for each subbasin. Thirdly, an agglomerative cluster analysis was applied on the indices to group the subbasins into several topography classes. We also postprocessed the land cover geodataset and calculated proportions of land cover classes in each subbasin via a tabulate area function. Then, we used the cluster analysis to group the subbasins into land cover classes. Finally, correlation coefficients between geomorphometric and land cover indices of the subbasins were calculated.

The Bystrytsia Pidbuzka basin system consists of 21 subbasins of 4-6th Strahler ranks with the area of 63–5 038 ha, mean altitude of 259–656 m, and mean slope of 0–13°. The subbasins form four distinct topography classes: 1. Flat plain subbasins; 2. Undulating plain subbasins; 3. Transitional plain-mountain subbasins; and 4. Mountain subbasins. The subbasins are also grouped into five classes according to prevailing land cover types: 1. Tree – grass; 2. Tree – grass – arable; 3. Tree – grass – arable – built; 4. Arable – tree – grass; and 5. Arable – grass – tree – built. We found the strongest correlation between altitude and slope indices (0.97) as well as between altitude / slope and tree cover (0.86). The weakest correlation is between slope and built-up areas (-0.17), which can be partly explained by underrepresentation of built-up areas on the WorldCover dataset.

Key words: basin system; topography; land cover; geomorphometry; FABDEM; ESA WorldCover; Carpathian Mountains; Fore-Carpathian Upland.

Вплив рельєфу на наземний покрив у річковій басейновій системі: приклад Бистриці Підбузької

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Анотація. Рельєф є важливим фактором земного покриву. Водночас рельєф і наземний покрив є суттєвими регуляторами гідрологічного режиму території, яку, з метою управління водними ресурсами, представляють як басейнову систему – мережу суббасейнів, пов'язаних русловим стоком. Тому дане дослідження має на меті надати просту методологію для автоматизованого виділення річкової басейнової системи, а також для її подальшої характеристики з огляду на геоморфометрію та структуру наземного покриву на підставі загальнодоступних глобальних геоданих. Як приклад ми обрали басейнову систему Бистриці Підбузької площею 500 км², яка має перехідне розташування між Карпатськими горами та Передкарпатською височиною у Львівській області. Глобальна цифрова модель висот (ЦМВ) FABDEM V1-2 з роздільністю 30*30 м була використана як первинні геодані про рельєф, а геодані ESA WorldCover V2 2021 з роздільністю 10*10 м були обрані як джерело інформації про наземний покрив. По-перше, ми автоматично виділили басейнову систему застосувавши алгоритми гідрологічного аналізу до ЦМВ. По-друге, ми використали зональну функцію для отримання основних геоморфометричних показників (середнього значення та стандартного відхилення альтитуди та ухилу) для кожного суббасейну. По-третє, до цих показників застосували кластерний аналіз та згрупували суббасейни у кілька класів рельєфу. Ми також опрацювали геодані наземного покриву та розрахували пропорції його класів у кожному суббасейні за допомогою функції табулювання площ. Потім ми згрупувати суббасейни за класами наземного покриву за допомогою кластерного аналізу. На завершення, розрахували коефіцієнти кореляції між геоморфометричними показниками та показниками наземного покриву суббасейнів.

Басейнова система Бистриці Підбузької складається з 21 суббасейну 4-6 рангів Стралера площею 63–5 038 га, середньою висотою 259–656 м та середнім ухилом 0–13°. Суббасейни згрупували у чотири класи рельєфу: 1. Пласкі рівнинні; 2. Хвилясті рівнинні; 3. Перехідні рівнинно-гірські; 4. Гірські. Суббасейни також поділили на на п'ять класів за переважаючими типами наземного покриву: 1. Дерева – трава; 2. Дерева – трава– рілля; 3. Дерева – трава – рілля – забудова; 4. Рілля – дерева – трава; 5. Рілля – трава – дерева – забудова. Ми виявили найсильнішу кореляцію між показниками альтитуди та ухилу (0,97), а також між альтитудою/ ухилом та деревним покривом (0,86). Найслабша кореляція спостерігається між ухилом та забудовою (-0,17), що частково можна пояснити недостатнім відображенням забудованих територій у геоданих WorldCover.

Ключові слова: басейнова система; рельєф; наземний покрив; геоморфометрія; Карпати; Передкарпаття; FABDEM; ESA WorldCover.

Introduction. Topography is an important factor of local climate, current exogeneous geomorphic processes, soil, as well as of natural and anthropogenic land cover. At the same time, both topography and land cover significantly contribute to the formation of slope and channel runoff and thus are important hydrological regime controls of an area. Therefore, topography and landcover are essential features of river basin (watershed) systems, which provide spatial framework for water management. Unlike topography or geology, land cover is a rather dynamic landscape feature, which is used to sustainably manage hydrological regime and to adapt to changing climatic and economic conditions (e.g., Lenton, 2011). Rather detailed topography (Meadows et al., 2024) and land cover (Xu et al., 2024) geodata are freely available at a global scale now, and they can be used to efficiently characterize basin systems and to assess their sustainability from the perspective of regional and global changes.

Therefore, the goal of this study is to provide a simple methodology for an automated delineation of a river basin system, and for its subsequent geomorphometric and land cover characterization using freely available global geodatasets, geospatial statistics, and cluster analysis. As a case, we selected a basin system of a medium river – the Bystrytsia Pidbuzka – which is representative for the North-Eastern megaslope of the Carpathian Mountains and Fore-Carpathian Upland, and has diverse natural and economic conditions. We hypothesized that topography has a pronounced effect on land cover within the basin system units – subbasins. We also used a deductive approach to environmental classification of the subbasins according to their water-regulating capacity (e.g., Olden et al., 2012).

Study area. The Bystrytsia-Pidbuzka River, a right-hand tributary of the Dnister, is entirely situated within Lviv Oblast, Ukraine (insert map at Fig. 2). The study area covers a river basin of 500 km², with its pour point at the confluence with the Tysmenytsia River. The main channel stretches for 79 km. Both the Bystrytsia-Pidbuzka and its left tributary, the Cherkhava, originate from the Marginal and Dnister Beskydy regions belonging to flysch low Carpathian Mountains. The middle and lower sections of the basin feature broad valleys and undulating interfluves of the Upper Dnister Fore-Carpathian Upland. Elevations range from 255 m at the confluence with the Tysmenytsia in the east to 858 m at Vydilok Mountain on the southwest boundary of the basin. The Carpathian interfluves consist of silty-sandy shale (flysch) covered with relatively thin layer of eluvial-colluvial rocky loam, while the Fore-Carpathian interfluves are made up of old alluvial deposits with colluvial loam on top. The wide valley bottoms are filled with Holocene alluvial loam and lacustrine deposits (peat and silt), with the floodplains and channels composed of sand-pebbles in the upper flow and loam in the lower flow (DHS, 2009; Kruhlov et al., 2024).

According to the Köppen-Geiger climate classification, the macroclimate is of Dfb class – cold, without dry seasons, and with warm summers (Peel et al., 2007). The nearest weather station in Drohobych (altitude 277 m) recorded an average air temperature of -3.4°C in January and +18.1°C in July, and an annual precipitation of 744 mm (Shuber, 2018). Interfluves of the mountainous part of the basin are characterized by predominantly brown forest loam-scree soil (Dystric Cambisol), while for the undulating interfluves of the Fore-Carpathian Plain is typical brownish-podzolic pseudogley soil (Staginc Albeluvisol). Valley bottoms are occupied by alluvial and boggy soils (Luvsiol, Fluvisol) as well as peat (Grunty…, 2019; Transformation…, 2008). Most wetlands have been drained, and natural forest cover has been reduced, especially in the plain part of the basin. Natural ecosystems have been replaced by agricultural fields, forest plantations, and settlements. In the lower flow, there is a hydropower plant with a small reservoir, and the river channel has been canalized and confined by dikes.

Conceptual framework. A river basin system is conceptualized as a transmorphogenic geoecosystem – a geoecological model, which affords studying convergent gravitational flows of water and air. The model is used to study the effect of weather and climate as well as of different landscape structures and processes, including topography and land cover, on properties of the channel runoff at the basin's pour point. Large river basins are usually represented as a hierarchical structure consisting of subbasins linked by the channel runoff. Subbasins are essentially heterogeneous landscape units, and therefore they are characterized as combinations of different hydrotopes (hydrologic response units). The latter are areas with relatively homogeneous landform, soil, and landcover conditions, and thus with similar type of hydrologic functioning (Kruhlov, 2020; Neitsch et al., 2011).

A river basin system can be automatically delineated using topography geodata (a digital elevation model – DEM) and special hydrological modeling algorithms in a geographic information system (GIS) environment. The same topography data afford calculation of geomorphometric indices (mean altitude, slope etc.) of each subbasin via GIS zonal statistics function (Xiong et al., 2022). While the altitude index is a proxy of climate conditions, the slope index implies on the intensity of gravitational processes within a subbasin. A tabulate area algorithm, which is a category of GIS zonal functions, is used to calculate areas and proportions of different land cover categories within subbasins. The land cover categories are delimited and ordered according to the precipitation and soil water retention capacity (from strongest to weakest): tree cover, grassland, arable land, and built-up areas. Proportions of the landcover cover categories afford judging about water-regulating capacity of subbasins – e.g., the larger the proportion of tree cover as the most potent water retention landcover category, the higher is the water-regulating capacity of a subbasin (e.g., Zhang et al., 2017). Cluster analysis can be used to independently classify the subbasins according to two groups of variables – geomorphometric and land cover.

Global geodata. We used two freely-available global geodatasets in the study – FABDEM V1-2 for delineation of the basin system and its geomorphometric characterization and ESA WorldCover V2 2021 for the description of the subbasins from the standpoint of their land cover composition. FABDEM V1-2, which is available at (https://data.bris.ac.uk/data/dataset), is an enhanced version of the global Copernicus GLO 30 DEM (https://spacedata.copernicus.eu/ collections/copernicus-digital-elevation-model) and has a ~30 m horizontal resolution at the equator. FABDEM is corrected for topography distortions caused by tree cover and buildings, and thus, in comparison with the Copernicus GLO 30 DEM, its absolute vertical error is reduced from 1.62 m to 1.12 m for built-up areas, and from 5.15 m to 2.88 m for tree-covered areas (Hawker et al., 2022). In comparison with other global DEMs of the same resolution (Copernicus DEM, NASADEM, AW3D30, and SRTM), FABDEM demonstrates superior accuracy, especially for low-gradient areas with tree cover (Meadows et al., 2024).

ESA WorldCover V2 2021 dataset, which shows global land cover categories for 2021, is produced via automative classification of Sentinel-1 and Sentinel-2 satellite multispectral images and has a resolution of 10 m. The geodataset contains 11 categories of land cover: 1. Tree cover; 2. Shrubland; 3. Grassland; 4. Arable land; 5. Built-up; 6. Bare ground / sparse vegetation; 7. Snow and ice; 8. Permanent water bodies; 9. Herbaceous wetland; 10. Mangroves; and 11. Moss and lichen (https://esa-worldcover.org/en). In comparison with other global land cover datasets of 10-m resolution, such as ESRI Land Use/ Land Cover or Google and WRI Dynamic World, ESA WorldCover has the highest accuracy of 73-84%. The latter varies depending on the land cover class and landscape (Xu et al., 2024).

Material and methods. We processed geodata using ArcGIS Pro (https://pro.arcgis.com) and WhiteboxTools (https:// www.whiteboxgeo.com) software, while cluster analysis was realized via Statistica software package (https://www.statsoft.de/data-science-software/tibco-statistica). The workflow is visualized in Fig. 1. FABDEM V1-2 was the primary dataset used for the basin system delineation and geomorphometric characterization along with the official vector dataset of the river network of Ukraine provided by the State Agency of Water Resources

(SWAR; http://geoportal.davr.gov.ua). DEM data covering the study area were clipped out from the global dataset and projected into UTM coordinates with a resolution of 30*30 m. The river network data were rasterized with the same resolution of 30*30 m and "deepened" into the DEM by 2 m via a local map algebra function. We used WhiteboxTools hydrologic analysis algorithms to produce a hydrologically-corrected DEM as well as derivative flow direction and flow accumulation datasets. After this, we generated watercourse network from flow accumulation data using empirical threshold of 10 ha (111 raster cells) for a minimum catchment area resulting in a stream. The watercourses were assigned Strahler ranks, and subbasins were delineated for the links of 4th order and higher. The subbasins raster dataset was converted into vectors, and small polygons (less than 10 ha), which were mainly modelling artifacts, were eliminated. We assigned unique indices to the subbasins, which reveal their Strahler ranks as well as topology – connectedness via the channel flow. Zonal statistics functions were used to calculate mean values and standard deviations of altitude and slope for each subbasin. The geomorphometric indices were imported into the statistical package, the values were standardized, and an agglomerative cluster analysis with Euclidian metrics was applied to facilitate topographic classification of the subbasins.

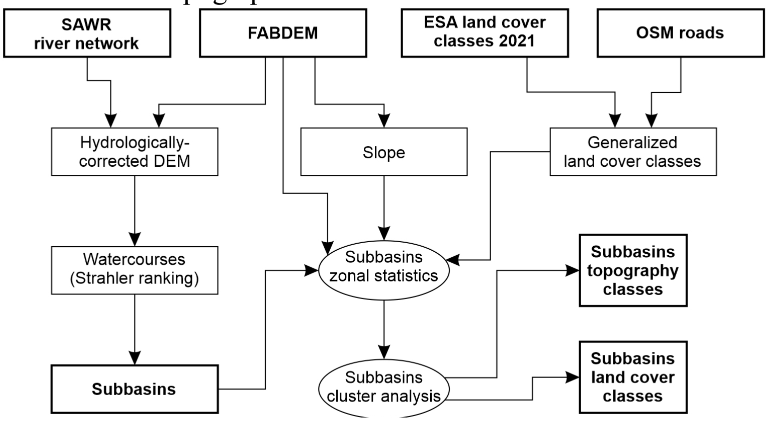

Fig. 1. Geodata processing workflow

Land cover data for the study area were clipped out from the ESA WorldCover V2 2021 dataset and retained original 10*10 m resolution. The clipped dataset contained five land cover classes: 1. Tree cover, 2. Grassland, 3. Arable land, 4. Built-up, and 5. Permanent water bodies. Visual inspection of the geodata suggested underrepresentation of built-up areas and roads, which create impermeable surfaces and hence are important for the deductive classification of the basin system. Therefore, we imported buildings and the main paved road geodata from the vector OpenStreetMap (OSM; https://www.openstreetmap.org), rasterized them and mosaiced with the WorldCover geodataset. After this, we generalized the dataset by eliminating small areas of less than 5 cells – 0.05 ha. Then, we applied a zonal function ("tabulate area") to calculate areas and proportions of land cover classes in each subbasin. The proportions values were imported into the statistical software and analyzed (clustered) in the same way as the geomorphometric indices to classify the subbasins according to land cover structure (see Fig. 1). Finally, we calculated correlation coefficients between the geomorphometric indices and land cover proportions in the basin system.

Results and discussion. The Bystrytsia Pidbuzka basin system has an area of 50 005 ha, the mean altitude of 416 m with a standard deviation of 139 m, and the mean slope of 5.5° with a standard deviation of 5.8°. We delineated 21 subbasins of the 4-6th Strahler ranks with the area varying from 63 ha (SB100) to 5 038 ha (SB431) (Fig. 2; Table 1). Their mean altitude changes from 259 m (SB100) to 656 m (SB622), while the mean slope – from 0° (SB100, SB201) to 13°(SB620). Correlation coefficient of 0.97 reveals very strong interconnection between mean altitude and slope values in the basin system. Standard deviation values of altitude and slope within the subbasins indicate topographic heterogeneity of the latter. Naturally, the most topographically homogeneous are flat subbasins (SB100, SB201), while the most heterogeneous is the mountainous subbasin SB601 with standard deviations of altitude and slope reaching 101 m and 7° respectfully. Agglomerative clustering on the geomorphometric indices afforded delineation of four subbasin classes: 1. Flat plain subbasins; 2. Undulating plain subbasins; 3. Transitional plain-mountain subbasins; and 4. Mountain subbasins (Fig. 3). Flat plain subbasins are located at the NE extremity of the study area belonging to the alluvial-lacustrine Upper Dnister Depression (Kruhlov et al., 2024) and occupy 4 686 ha or 9.4% of the basin system. Their mean altitude is 263 m and mean slope is around 0°. Undulating plain subbasins occupy 19 066 ha or 38.1% in the middle part of the basin system formed by the denudation-and-alluvial Upper Dnister Upland. Their mean altitude and slope are 311 m and 2° respectively. Transitional plain-mountain subbasins have a boundary location between the Upper Dnister Upland and the Marginal Beskydy low flysch mountains belonging to the Carpathians. Their share in the basin system is 11 783 ha or 23.6%, and the mean altitude and slope are 431 m and 6° respectively. Mountain subbasins are completely located in the Marginal and Dnister Beskydy low flysch mountains (Kruhlov et al., 2024). They occupy 14 479 ha or 28.9% of the study area, have a mean altitude of 586 m and a mean slope of 11°.

ESA WorldCover geodata contain five land cover classes within the Bystrytsia Pidbuzka basin system: 1. Tree cover, which occupies 26 278 ha or 52.5%; 2. Grassland with a share of 9 654 ha or 19.3%; 3. Arable land of 13 255 ha or 26.5%; 4. Buit-up areas (with roads) of 764 ha or 1.5%; and 5. Water surfaces, which cover 55 ha or 0.1% of the study area (Fig. 4; see Table 1). Visual comparison with a high-resolution satellite image witnessed significant underrepresentation of built-up areas and water surfaces at WorldCover data, and therefore we basically excluded these two land cover classes from the analysis. Agglomerative clustering of the subbasins on the proportions of the land cover categories afforded delineation of five classes: 1. Tree – grass; 2. Tree – grass – arable; 3. Tree – grass – arable – built; 4. Arable – tree – grass; 5. Tree – grass – arable – built (Fig. 5). The tree – grass class encompasses six subbasins and occupies 24.8% (12 397 ha) of the basin system. The subbasins have on average 80.0% of tree cover and 16.2% of grassland, and all belong to the topographic category of mountain subbasins (see Fig. 3). The tree – grass – arable class contains three subbasins and has a proportion of 18.5% (9 240 ha) with an average tree cover of 67.5%, grassland 17.5%, and arable land of 14.3%. These are two transitional plain – mountain subbasins plus a small flat plain subbasin at the lowest flow of the river limited by dykes. The tree – grass – arable – built class consists of four subbasins and occupies 16.3% (8 164 ha). It has an average tree cover of 59.1%, grassland 24.6%, and arable land of 14.1%. Unlike the two previous classes, this one has a significant portion of the area (2.2% on average) under buildings and roads. The four subbasins belong to different topographic classes: undulating plain,

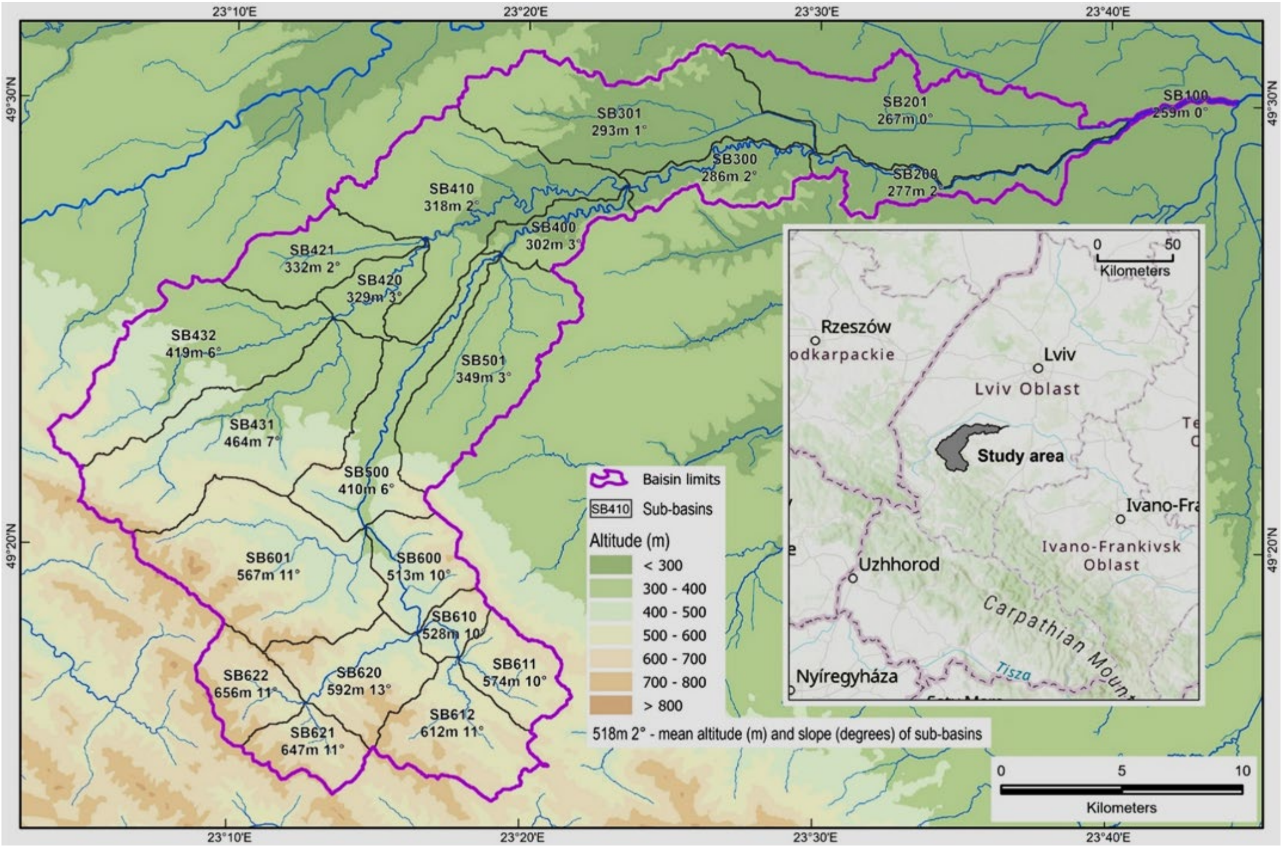

Fig. 2. Bystrytsia Pidbuzka basin system. Location, topography, and geomorphometry

Table 1. Bystrytsia Pidbuzka basin system. Geomorphometric indices and land cover proportions within individual subbasins (see Fig. 2 and 4)

SB-ID[1]	Area (ha)	R[2]	AltM[3] (m)	AltS[4] (m)	SlpM[5] (deg.)	SlpS[6] (deg.)	Tree[7] (%)	Grs[8] (%)	Arbl[9] (%)
SB100	63	6	259	1	0	0	59.9	22.4	17.6
SB200	1 367	6	277	11	2	2	26.9	27.9	38.3
SB201	4 623	4	267	6	0	1	6.3	18.5	74.1
SB300	1 470	6	286	14	2	3	28.2	29.7	38.1
SB301	4 644	4	293	18	1	2	31.3	18.7	48.2
SB400	987	6	302	17	3	3	36.1	39.4	23.1
SB410	4 515	5	318	23	2	2	37.3	18.6	42.3
SB420	910	5	329	21	3	3	37.8	20.8	40.8
SB421	1 688	4	332	15	2	2	21.7	18.2	58.3
SB432	4 139	4	419	70	6	4	75.2	14.5	9.3
SB431	5 038	4	464	99	7	5	67.4	15.5	16.1
SB500	2 606	6	410	87	6	6	63.1	20.7	13.8
SB501	3 485	4	349	43	3	3	46.7	26.2	25.8
SB600	1 491	6	513	83	10	5	66.5	23.3	6.8
SB601	4 523	4	567	101	11	7	75.0	18.1	5.6
SB610	582	5	528	68	10	4	60.1	28.0	10.0
SB611	1 281	4	574	52	10	5	84.2	14.1	1.3
SB612	2 177	4	612	71	11	5	81.3	14.8	2.7
SB620	2 046	5	592	89	13	6	81.4	14.0	3.5
SB621	1 085	4	647	60	11	5	81.4	16.1	1.5
SB622	1 285	4	656	64	11	5	76.5	20.1	2.6
Whole basin system	50 005	6	416	139	6	6	52.5	19.3	26.5

[1]SB-ID – subbasin index (see Fig. 2 and 3); [2]R – rank according to Strahler; [3]AltM – mean altitude; [4]AltS – altitude standard deviation; [5]SlpM – mean slope; [6]SlpS – slope standard deviation; [7]Tree – tree cover proportion; [8]Grs – grassland proportion; [9]Arbl – arable land proportion.

transitional, and mountain. The arable land – tree – grass class is represented by four subbasins and has a share of 23.5% (11 575 ha) in the basin system. On average, arable land occupies 47.4%, tree cover – 32.0%, and grassland – 19.1%. The subbasins exclusively belong to the undulating plain topography category. The arable land – grass – tree – built class also encompasses four subbasins and occupies 16.9% (8 447 ha) of the basin system. On average, proportion of arable land is 43.4%, of grassland – 28.9%, and of tree cover – 24.4%. This class also has a significant portion of area under buildings and roads – 2.9% on average. From the standpoint of topographic classification, the subbasins fall into the categories of undulating and flat plains.

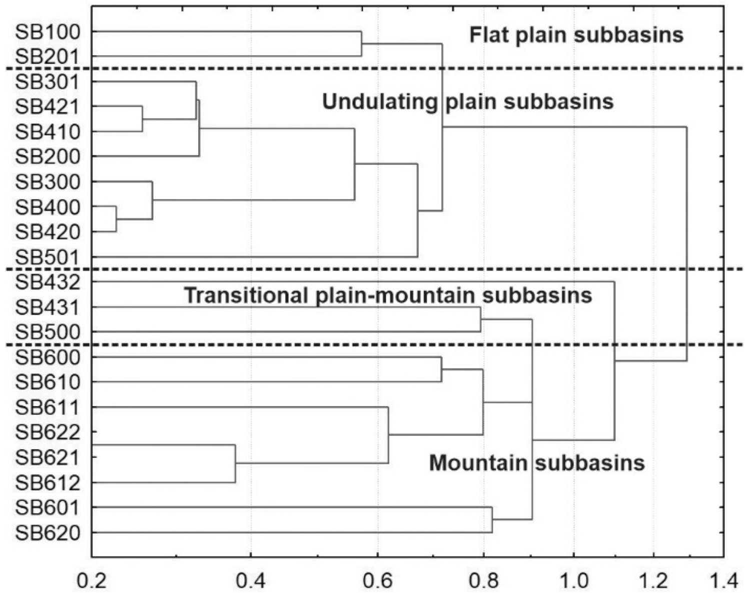

Fig. 3. Dendrogram representing clustering of subbasins on mean values of altitude and slope. The values are provided in Table 1. See also Fig. 2

In the Bystrytsia Pidbuzka basin system, there are strong correlations between the geomorphometric indices and proportions of tree cover and arable land. The tree cover proportion has the same positive correlation coefficients with the mean altitude and mean slope, which equal to 0.86. The arable land proportion has negative correlation coefficients of -0.81 with the mean altitude and -0.84 with the mean slope. Conversely, there is a weak negative correlation between the grassland proportion and the topography – -0.46 with the mean altitude and -0.38 with the mean slope. Even weaker are negative correlations between built-up areas (with roads) and the topography – -0.26 with the mean altitude and -0.17 with the mean slope.

Strong positive correlation between the topography and the tree cover as well as strong negative correlation between the topography and the arable land proportion witness generally sustainable land cover structure in the Bystrytsia Pidbuzka basin system. Mountain subbasins, which have relatively high flash flood and erosion potential are forested by over 60% and contain only a small portion of arable land. Thus, their water-retention and water-regulating capacity is also relatively high and is in line with harsher geomorphic and climatic conditions. Conversely, plain subbasins with low erosion and flash-flood potential are more intensively used for crop production, which decreases water-retention capacity. Low negative correlation between the topography and the grassland proportion is quite expected – grassland, which is associated with non-intensive agricultural land use, is less sensitive to geomorphic conditions. Weak negative correlation between the topography and the built-up area proportion can be explained by two factors. The first factor is geographic reality, which witnesses rather even distribution of settlements across the plain and mountain subbasins. Moreover, in the mountain subbasins, buildings sometimes form denser structures in narrow valley bottoms than in the plain subbasins. The second factor is connected with the WorldCover geodata, which underrepresent areas with dispersed building structures.

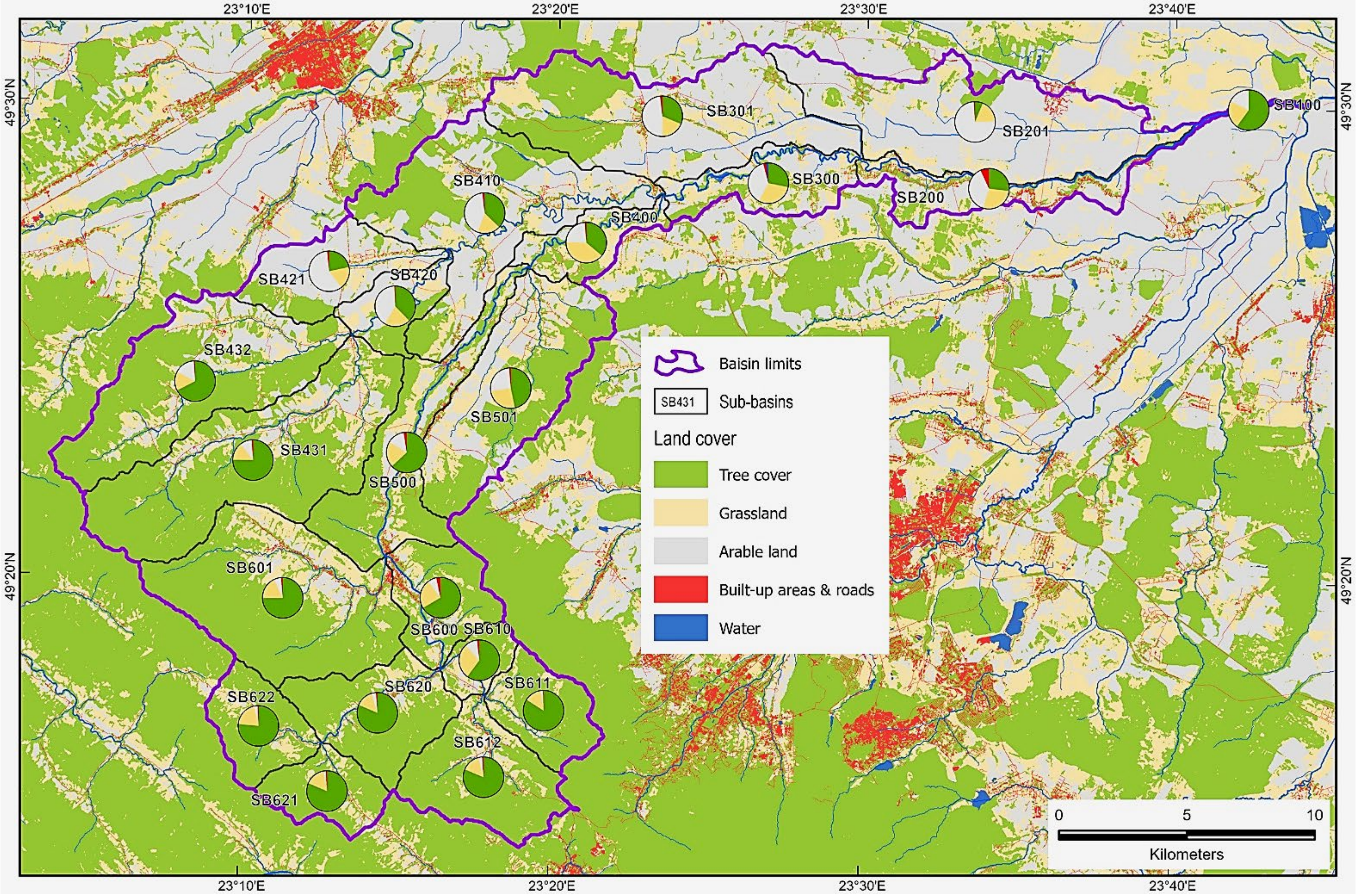

Fig. 4. Bystrytsia Pidbuzka basin system. Land cover structure as of 2021.
Circle charts represent shares of land cover classes within subbasins

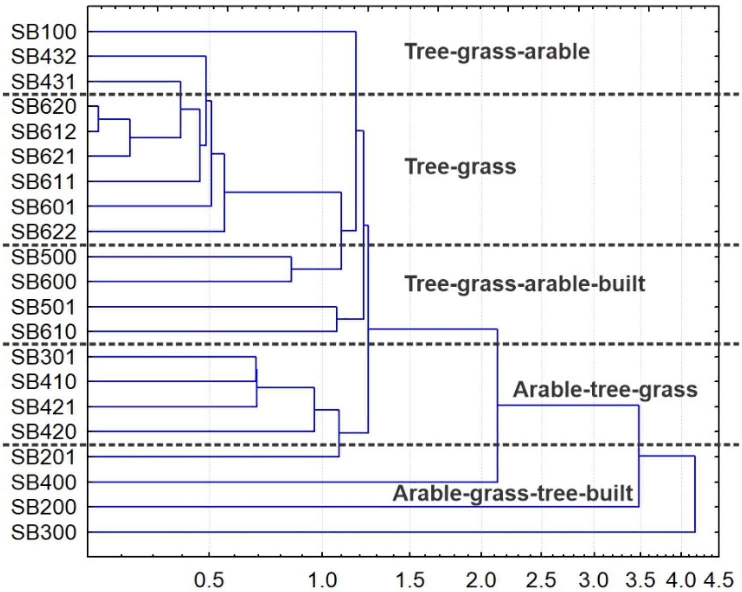

Fig. 5. Dendrogram representing clustering of subbasins on proportions of land cover classes. The values are provided in Table 1. See also Fig. 4

Conclusions. The Bystrytsia-Pidbuzka basin system, despite its relatively small area, has diverse topography caused by transitional position between the mountains and the plains. Tree cover and arable land – two primary land cover classes with, respectively, high and low water-retention capacity – demonstrate strong and sustainable dependance on the topography at a subbasin spatial level. This circumstance gives ground to positively evaluate sustainability of land cover and land use structure in the basin system. This also makes the Bystrytsia-Pidbuzka basin system an interesting model area for further hydrological and geoecological studies in the NE drainage sector of the Carpathian Ecoregion.

FABDEM V1-2 global dataset turned out to be a good geodata source for the delineation and geomorphometric characterization of a basin system at a local and regional levels, including parts of flat terrain. However, additional modification of the DEM by “deepening” of the precisely mapped drainage network improves its accuracy in flat areas. ESA WorldCover V2 2021 geodataset provides generally accurate information, which is very helpful for the assessment of a basin system from the standpoint of water-retention capacity of the land cover. Yet, built-up areas of low density are somewhat underrepresented in this dataset. Zonal statistics, including “tabulate area” function, is crucial for quantitative characterization of a basin system, and its outputs can be efficiently used for further classification of subbasins via cluster analysis.

Acknowledgement. This study was done in the framework of the research project 0121U113567 supported by the Ministry of Education and Science of Ukraine.

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