ReBioClim

D1.2.3
Report on the spatial composition, configuration analyses and assessments of ecosystem services

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Compilation of maps and visualisations, showing existing/planned functions and spatial qualities in the area incl. aspects of connectivity, access to public spaces along the streams in maps of ecosystem services' assessment: e.g. climate regulation, recreation, carbon sequestration, food/energy etc.

1. Summary

To understand the current physical conditions of urban streams and support informed restoration decisions, this deliverable looks at their spatial characteristics. Specifically, we conducted a multi-scalar analysis at three levels: (1) the pilot sites for each city, (2) all stream segments within the four cities, and (3) the sub-catchments that cover all the streams. For each scale, the most relevant variables were selected to calculate and map spatial variations. The resulting maps provide stakeholders with a clear spatial reference to guide the decision-making process.

For pilot sections, ecosystem services including provisioning, regulating and cultural services were analysed and mapped. Every pilot stream was rated to show which stretches already offer good conditions and which ones could benefit from simple restoration measures. For all stream segments within the four cities, spatial features in and around the stream corridors were mapped and analysed for each city. Using these features, we grouped the streams into six types. Each type reflects a different situation, helping identify what kind of local restoration might be suitable in different parts of each city. At the sub-catchment level, we grouped larger sub-catchment areas into five categories. This shows how the wider landscape affects the health of the streams and where broader actions may be needed.

Together, these three levels of analysis provide a clear and easy-to-understand overview of urban stream conditions. They support cities in choosing where to act and what kinds of measures are likely to work effectively for stream restorations.

2. Introduction

ReBioClim Work Package 1 is Challenges and opportunities of Nature-based approaches in urban stream restoration from multiple perspectives. Followed by Activity 1.1 the analysis of institutional and stakeholder perspective on urban stream restoration, Activity 1.2 explores the multi-perspective analysis of the ecological, social-economical and urban-spatial perspectives on urban stream restoration.

In this deliverable D 1.2.3, we particularly focus on the urban-spatial analyses for composition and configuration of ecosystem services. Partners involved in this report include Technische Universität Dresden (LP), Leibniz Institute of Ecological Urban and Regional Development (PP2), Delft University of Technology (PP9), and Poznań University of Life Sciences (PP8).

The urban spatial perspective entails the following approach:

- We **focused on the spatial context of the streams**, that is, on how the spatial configuration of the urban area surrounding a stream influences its current state and potential for restoration.
- In setting up the analytical framework and layers of analysis, we followed **a social-ecological systems approach**, which treats social and ecological aspects on equal footing.
- Following the three high-level objectives of ReBioClim to **promote biodiversity, climate adaptation and improve quality of life**, we structured the variables of our analysis into three corresponding categories.
- Considering that the pilot sites cannot be fully understood in isolation, we chose to adopt a **cross-scale approach** ranging from 100-meter stream segments as analytical units through entire stream networks and to sub-catchments found within city boundaries.
- Considering the scale and spatial focus of the analysis, we do not make direct measurements of Biodiversity, Climate Adaptation and Quality of Life, but **employ spatial proxies** for those and validate with direct measurements only when such measurements exist.

Following this approach, we ask the following research question:

What are the spatial conditions surrounding the streams conductive to restoration potential in the four cases?

In what follows, we present the methodology, report on the results and conclude by discussing the implications thereof.

3. Methodology

We set up a cross-case analytical framework (1) to compare the four ReBioClim cases and identify stream restoration-related differences and similarities, and (2) to extract generalizable patterns that can be applied to other cases, at least in similar Central European cities. We aimed to characterise spatial challenges and potentials across scales, and, within the frame of the main research question, to answer city-level questions like "Where does stream restoration have the highest potential to succeed?", sub-catchment level questions such as "Which sub-catchment has the most need for restoration?", or site-level questions such as "What measures need to be taken on this site to improve its contribution to biodiversity, climate adaptation and/or quality of life?"

3.1. Stream segments (pilot-level analysis)

For detailed analysis on the level of pilot sites, we used 50m stream segments. This provided sufficient level of detail for structural mapping on which the ecosystem services (ES) assessment is based.

From an onsite and ecosystem service (ES) perspective, the pilot streams of the four cities were analysed. IOER (PP02) applied the method of Renner et al. (2018), which has been slightly adapted, to collect onsite data for each 50 m section, covering socio-cultural, ecological and morphological characteristics related to regulating and cultural ES. For details on structural mapping, see the data collection form in the Appendix A. Furthermore, the occurrence of edible plants were mapped also in this 50 m sections and a corridor of 100 m width (50 m on both sides of the stream bank). This edible plant assessment was the basis for the the main provisioning ES (see next chapter). The following Table shows the ES which are included in our analysis. These comprise 1 provisioning ES, 7 regulating ES, and 4 cultural ES (Table 1).

Table 1 Ecosystem Services (ES) included in the analysis (Table by H. John)

ES Group	ES
Provisioning	Wild fruits and herbs
Regulating	Flood regulation
	Low water regulation
	Sediment regulation
	Cooling effect
	Retention of GHG
	Habitat provision / river
	Habitat provision / surrounding area
Cultural	Aesthetic experiences
	Nature experience & tranquillity promoting health, recuperation or enjoyment through passive or observational interactions with the river landscape
	Health, recuperation or enjoyment through active or immersive interactions with the river landscape
	Educational values

3.1.1. Edible plants as provisioning ecosystem service

Regarding the provisioning ES, we focused on food provision. Other provisioning ES did not seem relevant to us for urban areas (e.g. plant biomass and agricultural yields) or take place in other/larger areas (e.g. water provision, which is strongly influenced by the catchment area). For food provision, we developed our own assessment scheme, which mainly addresses edible plants. The idea behind this is to enhance the availability of edible plants along the stream as a kind of nature-based approach to enhance the appropriate ecosystem service. That would help people to become a closer connection to urban nature, to enjoy the stream area, and to contribute to nutrition and health.

The assessment scheme consists of the following steps:

1. As a precondition, we developed a general species list of selected edible plants that are of interest to people, likely appreciated and used to grow in or along urban streams. Another preparation was the delineation of river sections (50 m according to urban river structure assessment) as mentioned above.
2. Using the list of edible plants, we did a survey about the knowledge and appreciation of edible species using posters that have been displayed at several public events of the project. People were asked to use sticking points for several species to mark what species they know and like to eat or to use for several edible products (such as jam, juice, spices) (see Figure 1). Analyzing the frequency of the sticking points, we recorded the most and less appreciated edible species for valuing them within the assessment.
3. Another criterion for the assessment was a differentiation of the selected species regarding their harvesting season: we sorted them as

   -spring species: usable from March until May, which are mostly herbs

   -summer species: usable from June to August, which are late herbs, flowering trees and early fruits

   -autumn and winter species: usable late fruits and frost-resistant plants

For several good reasons, no mushrooms and no root plants were regarded as valuable for this ES. Tables 2 and 3 show the final values of our selected plants and their allocation to the three seasons.

4. Next step was the mapping of the selected and appreciated edible plants in and along the steam sections. This mapping took place as a minimum of 2 times (optimal at all 3 seasons).

5. Using the mapping results, we evaluate the river sections for the ecosystem service provisioning of edible plants.

We also created a memory game for public events to teach people (mainly children) which plant species are edible using a funny way of learning (Figure 2). The allocations to several harvesting seasons and the appreciation of species could also be used to be applied to other project areas if there is not enough time available for doing the voting again. When the assessment has been done, tailored measures can be selected by planting some of the high-appreciated plant species along the urban rivers during the restoration process, making the restored river area more attractive for the public.

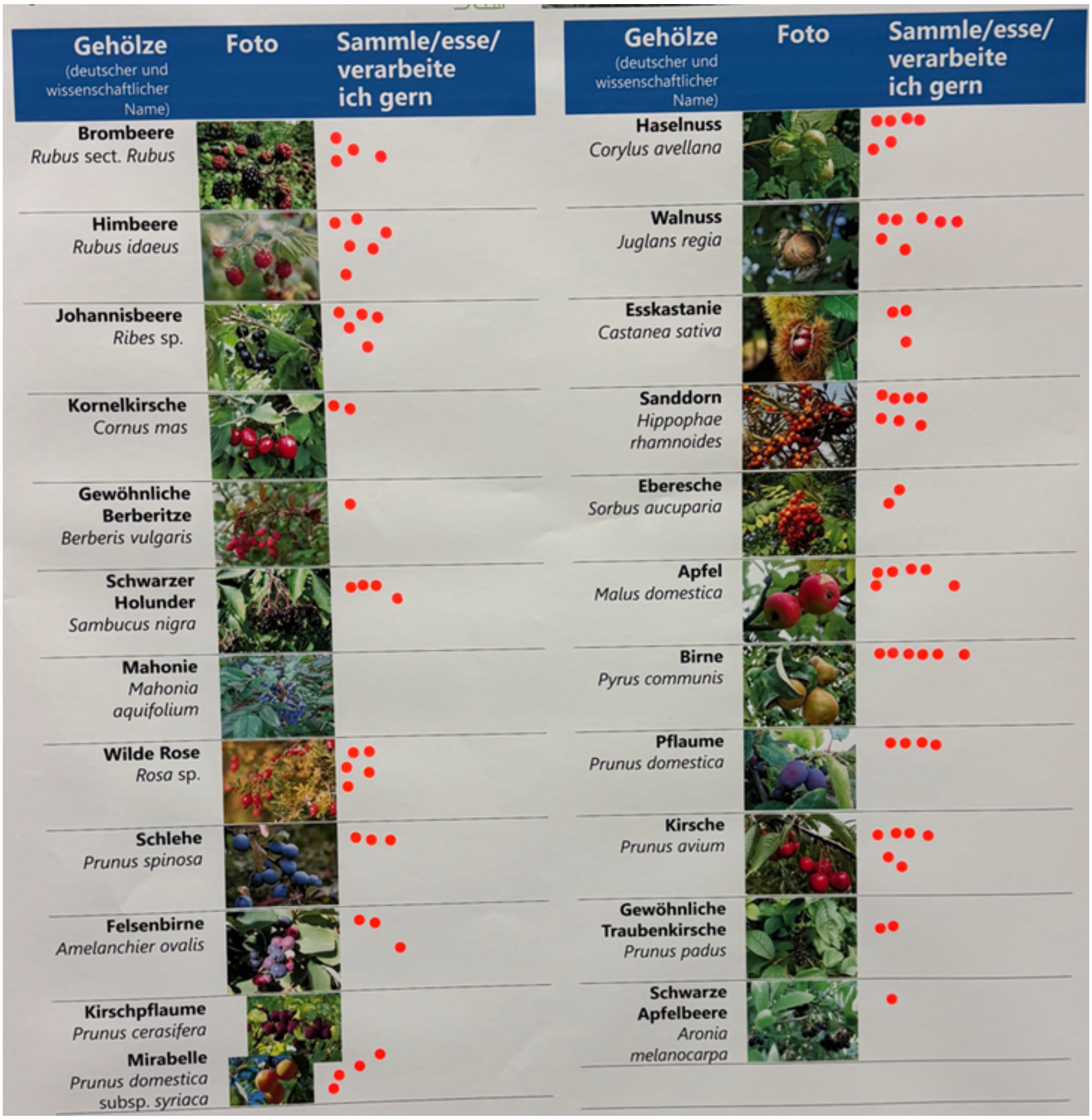


Figure 1 Example of a poster with sticking points marking the appreciated edible plant species (Photo by R.-U. Syrbe)

Tree/shrub	Total votes	Season I.	Season II.	Season III.	Sum I-III
Mirabelle plum	30		3		3
Apple	29			3	3
Walnut	27			3	3
Raspberry	26		3		3
Pear	25			3	3
Elderberry	21		2	2	4
Plum	20			2	2
Hazelnut	19			2	2
Cherry	19		2		2
Juneberry	18			2	2
European Cornel	16		2		2
Sweet chestnut	16			2	2
Blackthorn	14			2	2
Sea-buckthorn	14			2	2
Currants	13		2		2
Wild rose	13			2	2
Blackberry	12		2		2
Mountain-ash	9			1	1
Bird cherry	5		1		1
Black chokeberry	4			1	1

Table 2 Edible tree or shrub plant species, their votes and seasonal allocation for the German study area (Table by R.-U. Syrbe)

Herbs	Total votes	Season I.	Season II.	Season III.	Sum I-III
Wild garlic	31	3			3
Wild strawberry	28		3		3
Chives	27	3	3		6
Water mint	26		3		3
Water cress	22	3	3	3	9
Purple loosestrife	16	2			2
Ground ivy	15	2			2
Ground elder	13	2			2
Common sorrel	12	2			2
Knoblauchsrauke	12	2			2
Daisy	12	2	2		4
Common comfrey	11	1			1
Meadowsweet	10		1		1
Cuckoo flower	10	1			1
Water pepper	9	1			1
Dandelion	9	1	1		2
Lesser celandine	7	1			1
Coltsfoot	7	1			1
European speedwell	6	1			1
Common Loosestrife	6	1			1
Chickweed	5	1	1	1	3

Table 3 Edible herb plant species, their votes. seasonal allocation and overall values (Table by R.-U. Syrbe)

Figure 2 Memory game on edible plants (Photo: R.-U. Syrbe)

3.1.2. Regulating and cultural ecosystem services

For the regulating and cultural ES we used two approaches for the assessment, depending on the availability of further data in a specific pilot area:

- A simple approach, only based on the structural mapping
- An enhanced approach, including further available data

The enhanced approach for the regulating ES is oriented on the RESI-Handbook (Podschun et al. 2018). For the cultural ES we used assessment methods developed for Austrian rivers by Scheikl et al. (2021) and Hayes et al. 2022 and adapted them to our pilot sites and with regard to our data collection form.

Appendix Table B provides an overview of the two approaches. It shows for each ES the parameters used from the structural mapping for both approaches as well as the included further data in the enhanced approach. For the cultural ES "Aesthetic experiences" we also used further data in the simple approach. Here we have used selected results from the questionnaire survey conducted as part of the ReBioClim project.

Besides the analysis of existing and available data, an adaptation of the methodical framework was done. The methods must be focused on the size of the rivers under assessment, on the urban context, and on the purpose of selecting measures for river restoration. The selected methods have been altered, replacing not available data by existing ones and selecting the most important criteria for the purpose of the application in the project. Appendix Table C shows as an example how the existing assessment framework of Hayes et al. 2022 has been adapted to the project. Similar alterations were also made to the methodology of regulating ecosystem services but must be discussed with the project partners much more to fit them into the entire project framework regarding to the other parts of spatial analysis, to the modelling and to the restoration goals.

3.2. Stream segments (city-level analysis and cross-case typology)

For each variable (described in the next section), we chose a segment length (100m, 200m, or 400m) and a buffer radius considered to be most meaningful for their measurement (Figure 3). For 200 segments, all variables were measured along the stream (including sinuosity, total crossings, absolute slope, valley depth), so the buffer is not needed in this segment level. Most of these choices are based on literature, while some we made empirically. For segmentation, we split the streams into 100m units along their centreline, starting from their mouth.

Figure 3 Stream segments and buffers as units of analysis for city-segment analysis.

3.2.1. Variables

The variables related to biodiversity, climate adaptation and quality of life were selected and differentiated based on their effective scale. Specifically, the segment length and the buffer surrounding segments creates a 2-dimensional scale for each segment. Table 4 presents all the variables calculated for the city-level stream segment analysis.

Table 4 Variables used in city-level stream segment analysis, related to the three objectives of the ReBioClim project and their units of analysis, as well as the description of their calculation methods.

Variable	Relevant aspect	Analysed segment length (m)	Analysed buffer radius (m)	Calculation method
Impervious Cover	Bio, Clim	100	100	Ratio of ESA WorldCover class 50 within 100m buffer.
Canopy Cover	Bio, Clim	100	50	Tree cover ratio within 50m buffer of 100m segments; extract ESA WorldCover class 10 and divide canopy area by buffer area.
Green Land Cover Richness	Bio, Clim	100	150	Count distinct green land-cover classes (10,20,30,90,95) within 150m buffer.
Green Land Cover Shannon Diversity	Bio, Clim	100	150	Shannon index of green land-cover types within 150m buffer: $H = -\Sigma (p_i \cdot \ln p_i)$
Land Surface Temperature	Clim	100	100	Mean LST from Ermida et al. (2020) extracted within 100m buffer.
Sinuosity	Bio	200	–	Actual stream length divided by straight-line distance between segment endpoints.
Absolute Slope	Bio	200	–	Absolute longitudinal slope from DTM: elevation difference / segment length.
Total Crossings	Bio	200	–	Count road or path crossings intersecting each 200m segment.
Valley Depth	Clim	200	–	Mean valley depth from DTM cross-sections every 20m (top minus bottom elevation).
POI Accessibility Index	QOL	400	300	Shortest-path distance to Point of Interests (POIs) using sfnetworks (van der Meer et al., 2024); normalized index. POI data retrieved from OpenStreetMap geofabrik POI points.
Transport Accessibility Index	QOL	400	300	Shortest-path distance to transport stops using sfnetworks (van der Meer et al., 2024); normalized index.
Visibility Ratio	QOL	400	–	Ratio of isovist area overlapping with 300m buffer around segments.

Note: *Bio* refers to the aspect of biodiversity, *Clim* refers to climate adaptation, and *QOL* refers to quality of life.

3.2.2. Validation of biodiversity

To indicate climate adaptation and quality of life, the spatial variables are generally sufficient to describe the relevant environmental conditions (Ranta et al., 2021). In contrast, biodiversity is more difficult to capture using only spatial variables. On-site field measurements are therefore necessary to represent biodiversity, particularly for assessing in-stream habitats. In the context of urban streams, the biodiversity of macroinvertebrates is especially important, as these organisms serve as key indicators of the ecological health and biodiversity of stream systems (Lespez et al., 2025).

Considering the limited number of field samples available for in-stream biodiversity assessment, in this section we evaluate whether spatially derived environmental indicators can serve as proxies for biological conditions. To do so, values from selected spatial variables were compared with field-based biodiversity measurements.

Validation of in-stream biodiversity was based on field measurements of benthic invertebrates in the pilot reaches of Geberbach, Teplica and Bila Nisa according to PERLODES protocol (WFD 2001). We combined different core metrices, that were calculated from the taxa lists within the PERLODES evaluation scheme. The indicators were chosen for their relevance in (urban) stream environments (Table 5). All indicators were standardized (0-1) and an overall index as the mean value of all standardized values per site was calculated.

Table 5 Metrics of biodiversity

Indicator	Description
Shannon-Wiener-Index	The Shannon-Wiener-Index is a measure of biodiversity that considers both the number of species (richness) and how evenly they are distributed (evenness). A high index value indicates greater diversity, which is associated with more species and a more even distribution of individuals among those species.
Evenness	Evenness is a measure of how evenly the individuals in a community are distributed among the different species.
1-German Saprobial Index	The type-specific saprobic index assesses the effects of organic pollution on macrozoobenthos. The higher the index, the greater the intensity of organic matter decomposition and the more food is available to macrozoobenthos; increased decomposition activity is inevitably associated with a decrease in dissolved oxygen content. As saprobity increases, the biocoenosis shifts towards taxa that can tolerate deficits in oxygen content. These taxa predominantly belong to the ecological guilds of detritus feeders, fine sediment dwellers, and profundal and potamal dwellers, while the proportion of rheophilic taxa decreases.
German Fauna index (specified for coarse substrate mountain streams)	The index describes the effects of morphological degradation on the macrozoobenthos community of a river section based on water type-specific indicator lists. A high metric value indicates a large proportion of taxa with high morphological requirements in the water body type under consideration and thus also a largely type-specific and near-natural macrozoobenthos community.
Rheo index based on abundances (according to Banning)	This index indicates the ratio of rheophilic and rheobiont taxa to still water species and ubiquists, and highlights disturbances in the biocoenosis of streams caused by changes in flow patterns.
% Feeding type shredder	The metric describes the percentage of individuals that feed on coarse organic matter (e.g. leaf litter, wood). It relates to the functional feeding type of stream organisms. High proportions of shredder organisms is based on the availability of this food resource, e.g. with sufficient tree cover along the stream.
SPEAR-Index	SPEAR (Species At Risk) is a trait based biological indicator that determines the contamination of a stream based on the composition of macroinvertebrate communities.
% EPT-Taxa	The metric calculates the relative abundance of Ephemeroptera, Plecoptera, and Trichoptera taxa based on individuals per square meter. These insect orders mainly comprise species that are intolerant to pollution and have relatively high habitat requirements, both in aquatic and terrestrial environments. The metric primarily indicates the undisturbed nature of the dominant sub-habitats and therefore generally responds to impairments in water quality and water morphology. A high metric value usually indicates undisturbed, structurally rich water bodies.

To test the proxy potential of spatial indicators, six landscape and geomorphological variables were extracted for each sampling location, representing key drivers influencing in-stream biodiversity: (1) green land cover Shannon diversity (shannon_150m), (2) canopy cover (canopy_ratio), (3) absolute slope (absolute_slope), (4) impervious cover (impervious_ratio), (5) number of railway and road crossing structures (total_crossings).

Spearman correlation analysis (Figure 4) shows that several of these spatial indicators have strong relationships with field-measured biodiversity metrics. Shannon diversity, underground length ratio and slope exhibit some of the strongest and most consistent associations across multiple biological indices, while canopy cover, impervious surfaces, road and railway crossings also show notable linkages. Overall, the spatial indicators demonstrate clear connections to the observed in-stream biodiversity patterns and can therefore serve as reasonable proxies.

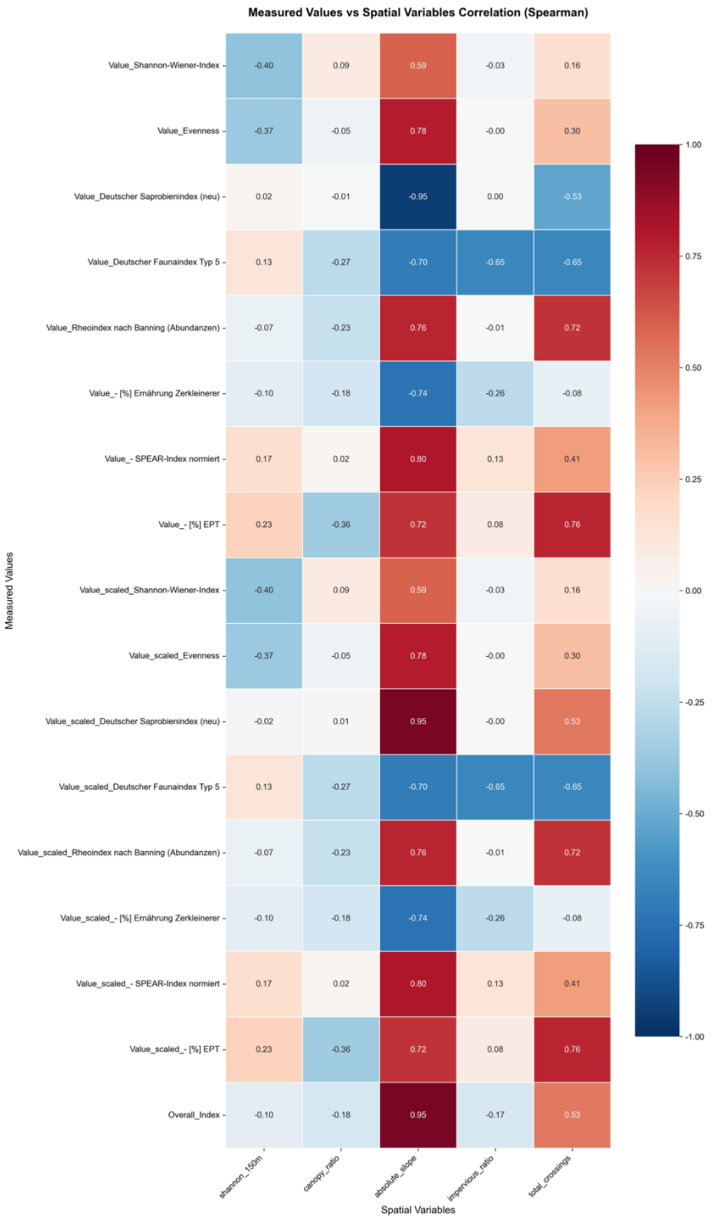


Figure 4 Spearman correlation analysis of measured values and spatial variables.

3.2.3. Typology

To communicate and enable the operationalization of the extracted generalizable patterns, we developed a spatial typology of urban stream restoration using the 100m stream segments as clustering units.

Segments at 100, 200, and 400 m scales were spatially intersected. 200 and 400m segments were assigned to 100m. K-means clustering analysis was conducted across all variables to identify typical combinations. Silhouette score was calculated to determine the optimal cluster number K, and it was found that 6 is the optimal cluster number. These combinations were interpreted as stream typologies, which highlight potential synergies and conflicts among ecological and social variables.

3.3. Sub-catchments (city-level analysis)

In water resources management and in accordance with the EU Water Framework Directive (WFD), all activities related to water resources should take place within catchment areas, which, as natural boundaries, do not correspond to the administrative boundaries of cities.

At this level of analysis, spatial data provided by services acting as the central (regional) node of the Spatial Information Infrastructure were used, in this case, in particular, portals related to water management, created by regional/national water resources management agencies. Data on the watershed division was collected, selecting the most detailed available information for analysis. In each country, these included:

Germany – Dresden:

https://luis.sachsen.de/wasser/einzugsgebiete.html?_cp=%7B%22a-9746%22%3A%7B%220%22%3Atrue%7D%2C%22a-9690%22%3A%7B%220%22%3Atrue%7D%2C%22previousOpen%22%3A%7B%22group%22%3A%22a-9690%22%2C%22idx%22%3A0%7D%7D

Czech Republik: Jablonec nad Nisou:

https://voda.gov.cz/?page=rozvodnice-1-radu&views=Zobrazen%C3%AD-vrstev--------------------

Poland - Poznań:

https://dane.gov.pl/pl/dataset/2167,mapa-podzialu-hydrograficznego-polski-w-skali-110

Slovakia – Senica:

https://geoportal.gov.sk/maps/river-basins/datasets?view=-557788,-1242477,38.0986703676

All sub-catchments that at least partially overlap with the administrative boundaries of the analyzed cities were used for the analyses. Individual sub-catchments that did not meet the criteria but were surrounded on all sides by the catchments selected for analysis were also included. To standardize the data, the next step was to aggregate the data by sub-catchment name. Ultimately, 178 sub-catchments were included in the analyses, including 119 in Dresden, 7 in Jablonec, 40 in Poznań and 12 in Senica.

Table 6 Summary of the number of analyzed catchments

Name of the city	Sum of subcatchment areas	Share in the total analysed area	Number of subcatchments	Share in the total number of sub-catchments
Dresden	480,5	34,7%	119	66,9%
Jablonec	130,8	9,5%	7	3,9%
Poznań	559,1	40,4%	40	22,5%
Senica	213,9	15,5%	12	6,7%
Total	1384,3	100,0%	178	100,0%

To better understand the spatial conditions for stream restoration within the catchment, six variables were selected. This group was approved after verification of their intercorrelations.

Table 7 Selected basic statistics and correlation matrix for the indicators used in the study (marked correlation coefficients are significant with $p < 0.05$)

Indicator	Mean value	Standard deviation	SHDI	Sub-catchment area	Share of forest	Share of built-up areas	Share of buildings located in the victinity of 300 m to parks etc.	Forest area per building
SHDI	1,32	0,45	1,00	0,41	0,10	0,09	0,06	-0,15
Sub-catchment area [km2]	8,12	11,96	0,41	1,00	0,08	-0,01	-0,17	-0,06
Share of forest [%]	31,72	24,64	0,10	0,08	1,00	-0,21	0,37	0,30
Share of built-up areas [%]	21,08	19,76	0,09	-0,01	-0,21	1,00	0,01	-0,15
Share of buildings located in the victinity of 300 m to parks etc. [%]	85,34	21,25	0,06	-0,17	0,37	0,01	1,00	0,09
Forest area per building [m2]	21918,78	143142,70	-0,15	-0,06	0,30	-0,15	0,09	1,00

Missing data were removed by case. Therefore, 167 catchments were included in the analysis. The eliminated catchments (1 from the Poznań area, 10 from the Dresden area) represent less than 1% of the total area covered by the analysis. These are primarily forest catchments, devoid of development. Therefore, they could constitute an additional group. However, further data analysis is required in this case.

Cluster analysis was used to identify catchment groups among the catchments in the four analyzed cities. Euclidean distance was used as a measure of similarity, and objects were grouped using Ward's method. Analyses were performed in Statistica. Five indicators were selected for analysis, additionally taking into account catchment area. These indicators were standardized.

Spatial data was obtained from free publicly available databases:

Land Monitoring Service in Copernicus: CLCplus Backbone 2018 (vector), Europe

https://land.copernicus.eu/en/products/clc-backbone?tab=documentation

Geofabrik (OpenStreetMap Data in Layered GIS Format)

https://www.geofabrik.de/

Indicators are grouped according to the project pillars::

Quality of Life:

- Share of Built-up land – based on CLCplus (code 11 and 12)
- Share of buildings located within a buffer of 300 m from the boundaries of forests and parks [%] – based on Geofabric (buildings – code 1500, landuse – code 7201, 7202 and 7211)

Biodiversity:

- Entropy (Shannon Indicator - *SHDI)* – based on CLCplus – all areas except buil-up land)

Climate adaptation

- Share of forest [%] – based on CLCplus (code 21, 22, 31, 32, 33)
- Forest area per building [m2] – based on Geofabric (buildings – code 1500) and CLCplus (code 21, 22, 31, 32, 33)

In the cluster analysis, the catchment area was also included as the sixth parameter.

The visualization of results and spatial analysis were performed in ArcGIS Pro. Each map presenting the indicator includes city boundaries obtained from official national databases and surface water bodies (main rivers and lakes) obtained from European Environmental Agency (Wise WFD Reference Spatial Dataset). The maps were made at a scale of 1:650000. By presenting indicators quantile method (with 4 classes) was used.

4. Results

4.1. Pilot-level assessment of Ecosystem Services

PROVISIONING ES

The assessment results in Table 8 and Figure 5 show exemplarily the values for the provision of edible plants by river sections of the pilot site Dresden/Prohlis. Similar assessments can be used for the three other rivers of the project areas. Preliminary results are the assessment values for the 23 river sections of the Geberbach in Dresden-Prohlis, Germany shown in Table 6. Based on these values, sections can be selected having low values (such as 14. 18, 22, 23, see Tab. 5), and plants should be suggested that might be planted or the river can be prepared for a colonization to reach improved values.

Table 8 Assessment results for the urban stream sections of the Geberbach in Dresden/Prohlis comprising the values for 3 harvesting seasons to an overall final value (Table by U. Kobzeva)

Section	Season I	Season II	Season III	Section value
1	5	8	7	4
2	6	6	0	3
3	4	1	5	3
4	3	4	7	3
5	5	5	12	4
6	6	8	11	5
7	7	10	2	4
8	7	6	10	5
9	7	6	4	3
10	9	5	2	3
11	6	6	4	3
12	5	7	2	3
13	0	7	5	3
14	0	10	4	2
15	0	6	5	3
16	0	6	7	3
17	0	7	6	3
18	0	6	4	2
19	3	7	9	4
20	3	7	9	4
21	3	4	7	3
22	5	2	3	2
23	3	2	3	1

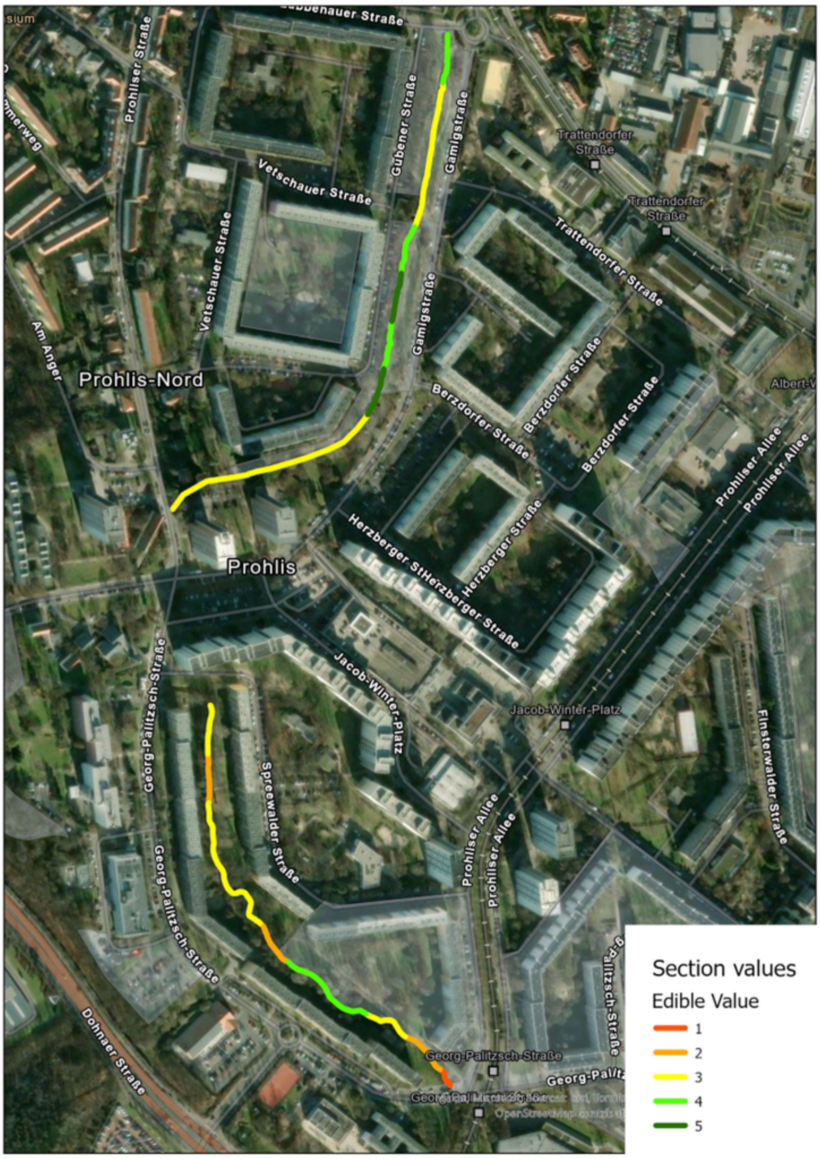


Figure 5 Map of the 50 m river sections along the Geberbach in Dresden/Prohlis with the values of ecosystem service provision with edible plants (map by R.-U. Syrbe)

REGULATING ES

As shown in the overview Appendix Table B, eight regulating ecosystem services have been identified to be assessed as in the project, and the methods are shared by the project partners to apply. Until now, the assessments have been done in Dresden, the following examples show the results. Figure 6 shows the values for the ES habitat provision that is classified as a regulating ES here. The northern part of the river Geberbach in Prohlis is mostly assessed as medium and high values (despite the southernmost sections 11 and 12), thus an improvement should concentrate to these last two sections. Regarding the basic data, we can derive the weakest factors for the assessment, so that the identification of meaningful measures would be easy to justify. Similarly, the southern part of the stream has several more points to address improvements (especially the sections 15, 16, 18, 22, and 23).

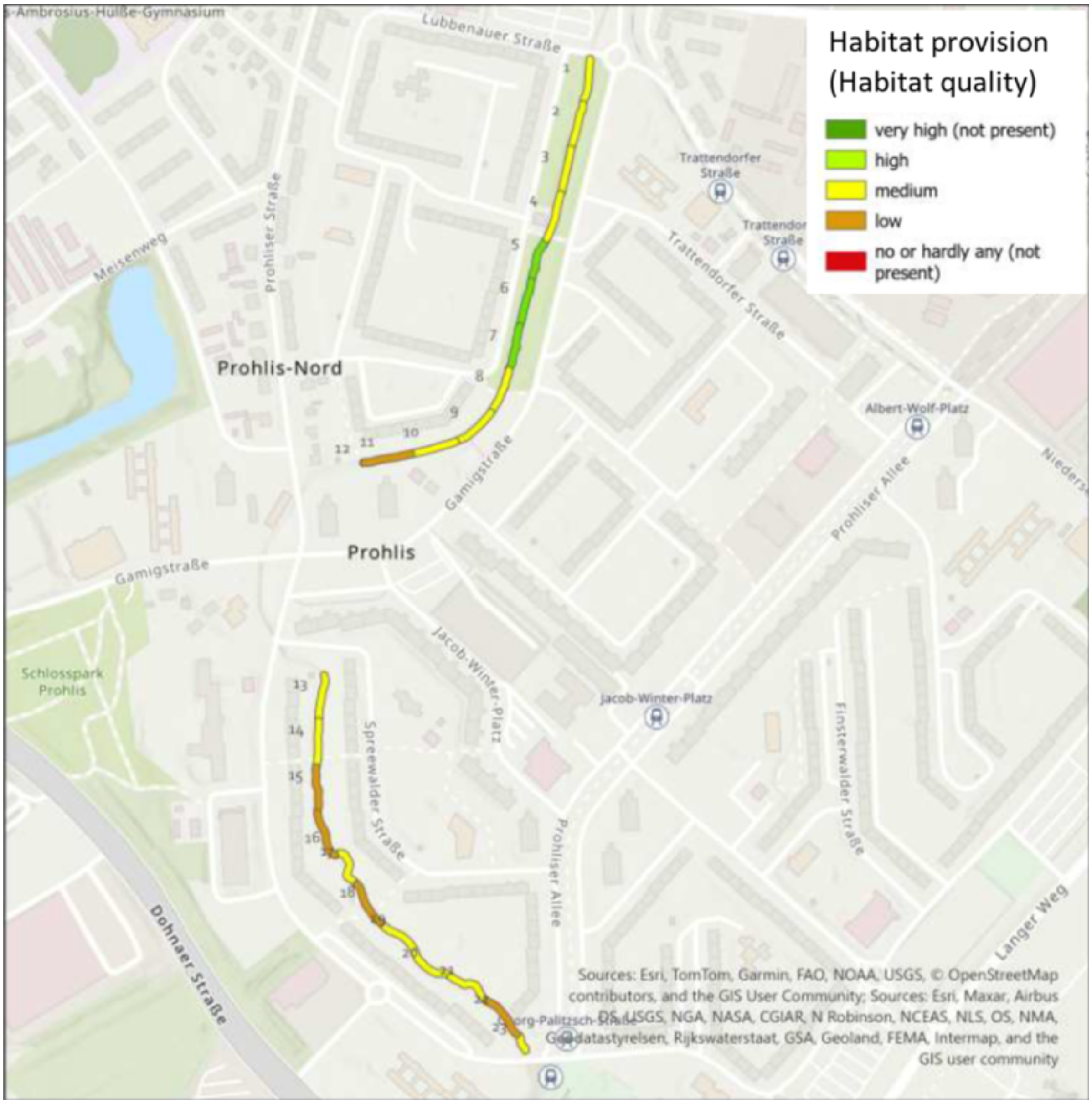
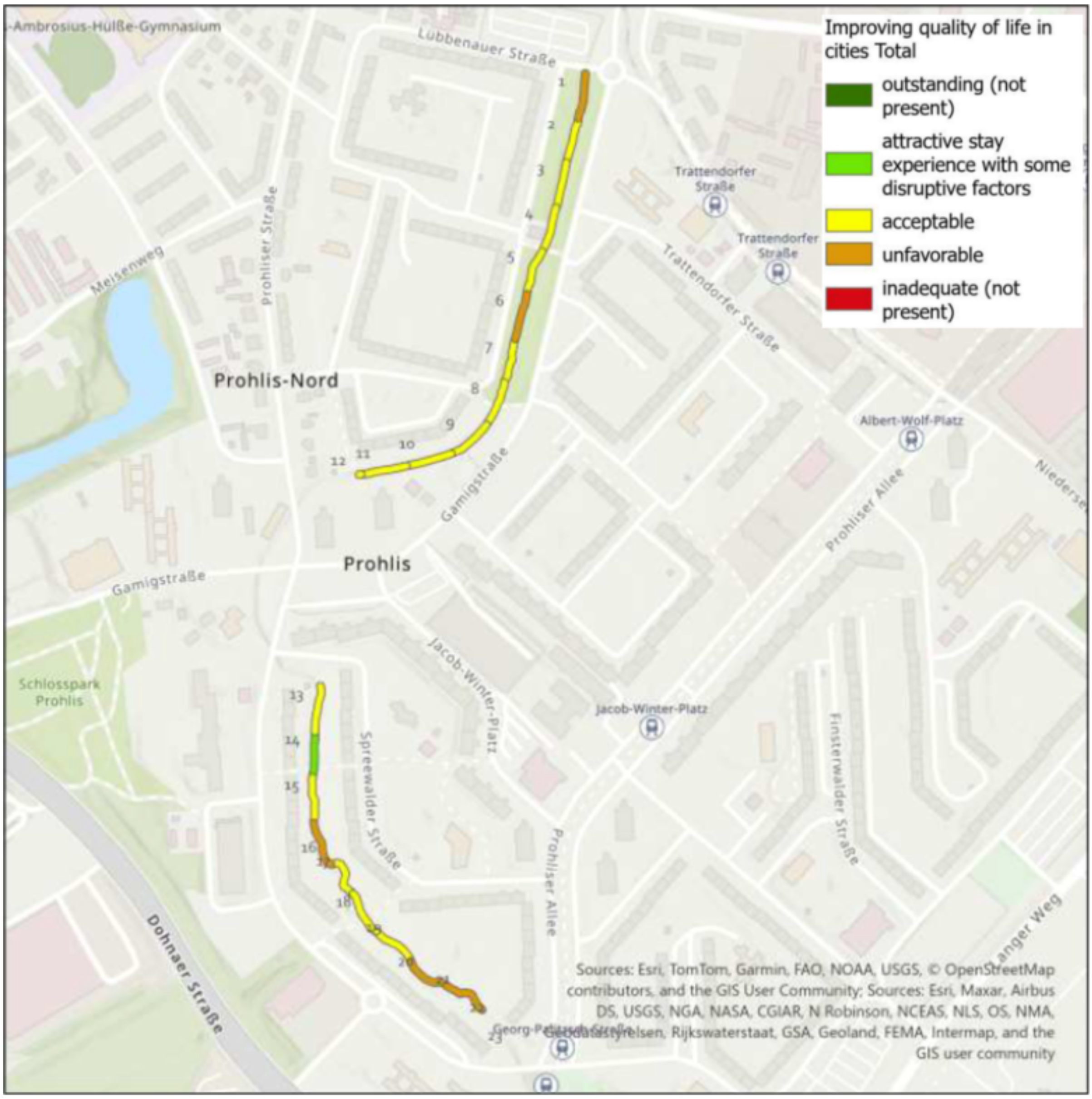


Figure 6 Map of the 50 m river sections along the Geberbach in Dresden/Prohlis with the values of habitat provision/quality (map by participants of the ReBioClim International Student Course 2025)

There are more maps and assessments for the other regulating and cultural ecosystem services available, since the maps look very similar and the long tables are difficult to read and understand in detail, we do not put them into this document, rather use them for decisions and suggestions regarding stream restoration.

CULTURAL ES

The following map ([Figure 7]) shows aggregated information of the cultural ES contributing to the quality of life in the stream surrounding of Geberbach in Dresden/Prohlis.



[Figure 7]: Map of the 50 m river sections along the Geberbach in Dresden/Prohlis with the valuesfor quality of life in the stream surrounding (map by participants of the ReBioClim International Student Course 2025)

Based on the assessment value, measures have been selected for the river sections that are shown [in table 9]. These suggestions are not yet final, since they must be adjusted with the other parts of the spatial analysis and especially double-checked with the trade-off analysis. Following these two steps, more refined suggestions can be derivated from scientific work, which must be discussed with the stakeholders later on, of course before implementation.

[Table 9]: First suggested measures for river restoration based on the ecosystem services assessments for some selected stream sections (Table by the project team)

Section	Desscription of measures	Source

Section 13	Flattening and stabilizing slopes using pile groynes, rootstocks, and natural vegetation; engineering biology methods (willow fascines) for erosion control Planting native trees and shrubs (fluttering elm, black alder, willow, ash) in groups Installation of seating areas, shelters, and rest areas by the water for recreation and relaxation Interactive information and educational boards on water protection, biodiversity, waste issues, QR code connection to engage visitors	LAWA Baden-Württemberg (2023) BUND Sachsen (2024) Umweltbundesamt (2024) Umweltstiftung Lippe (2024)
Section 14	Installation of seating areas, shelters, and rest areas by the water for recreation and relaxation Interactive information and educational boards on water protection, biodiversity, waste issues, QR code connection to engage visitors	Umweltbundesamt (2024) Umweltstiftung Lippe (2024)
Section 15	Floodplain renaturation, unsealing of areas, creation of retention areas for water absorption during flooding Regular waste disposal, removal of pollutants, creation of buffer strips for filtering and pollutant reduction	Umweltbundesamt (2019) Umweltbundesamt (2025)
Section 16	Flattening and stabilizing slopes using pile groynes, rootstocks, and natural vegetation; engineering biology methods (willow fascines) for erosion control Installation of seating areas, shelters, and rest areas by the water for recreation and relaxation Regular waste disposal, removal of pollutants, creation of buffer strips for filtering and pollutant reduction Creation of natural access paths, benches	LAWA Baden-Württemberg (2023) Umweltbundesamt (2024) Umweltbundesamt (2025) Bayern Landesamt für Umwelt (2024)
Section 17	Flattening and stabilizing slopes using pile groynes, rootstocks, and natural vegetation; engineering biology methods (willow fascines) for erosion control Planting native trees and shrubs (fluttering elm, black alder, willow, ash) in groups Anlage naturnaher Zugangswege, Gehölzschnitt, Sitzbänke	LAWA Baden-Württemberg (2023) BUND Sachsen (2024) Bayern Landesamt für Umwelt (2024)

area of action description of measures Source Rest and relaxation facilities Installation of seating areas, shelters, and rest areas by the water for recreation and relaxation Umweltbundesamt (2024) environmental education Interactive information and educational boards on water protection, biodiversity, waste issues, QR code connection to engage visitors Umweltstiftung Lippe (2024)

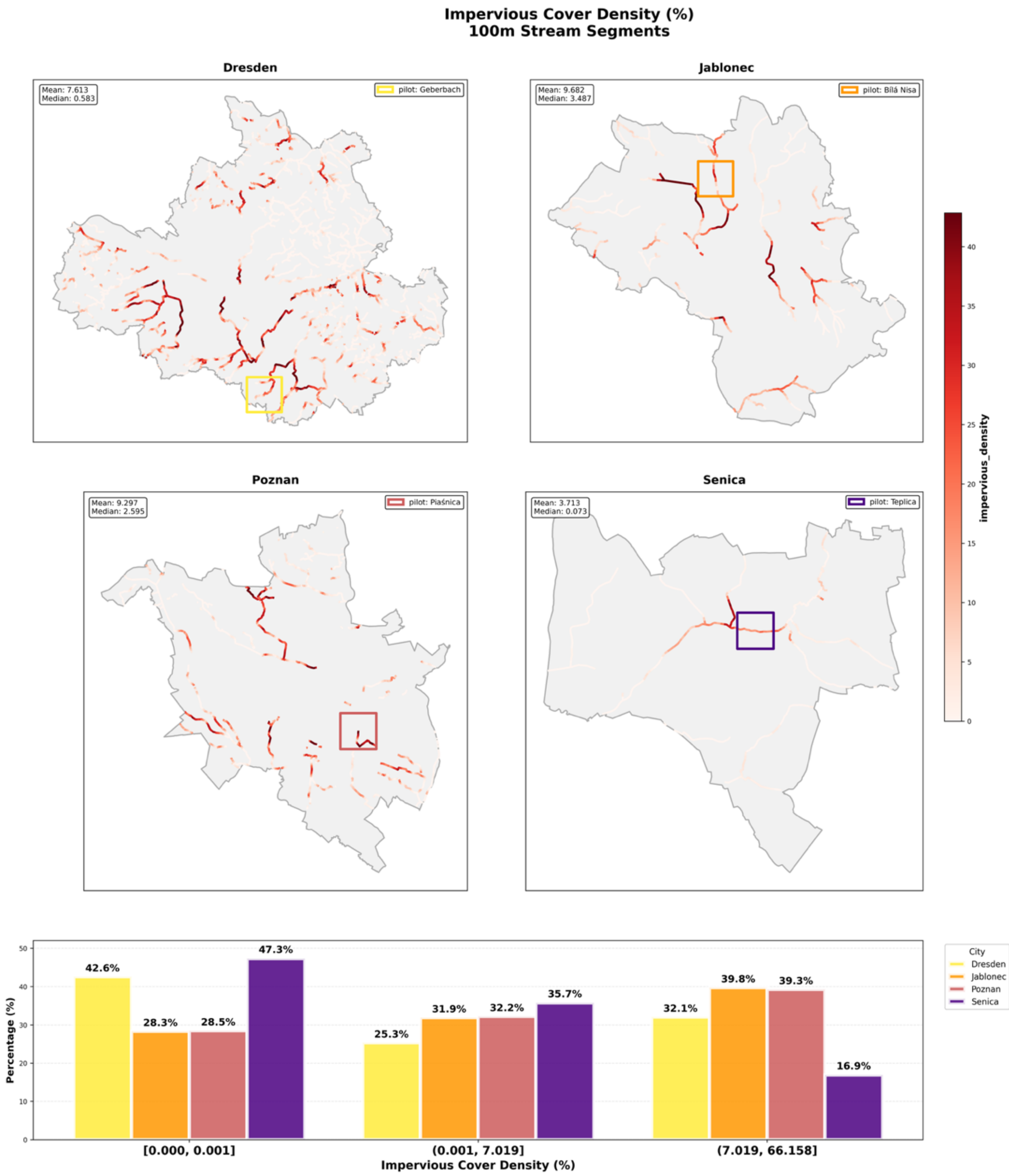
4.2. Segment-scale analysis

All variables were mapped at the 100m segment scale, with the pilot stream highlighted within a coloured bounding box. The maps are followed by a statistical summary based on quantile-classified value ranges. Within each city, the proportions of all quantile classes sum to 100%, meaning that the percentage distribution reflects only that city's own segments. This ensures that the results are easy to interpret, not biased by differences in city size, and comparable across cities.

4.2.1. Mapping variables in four cities

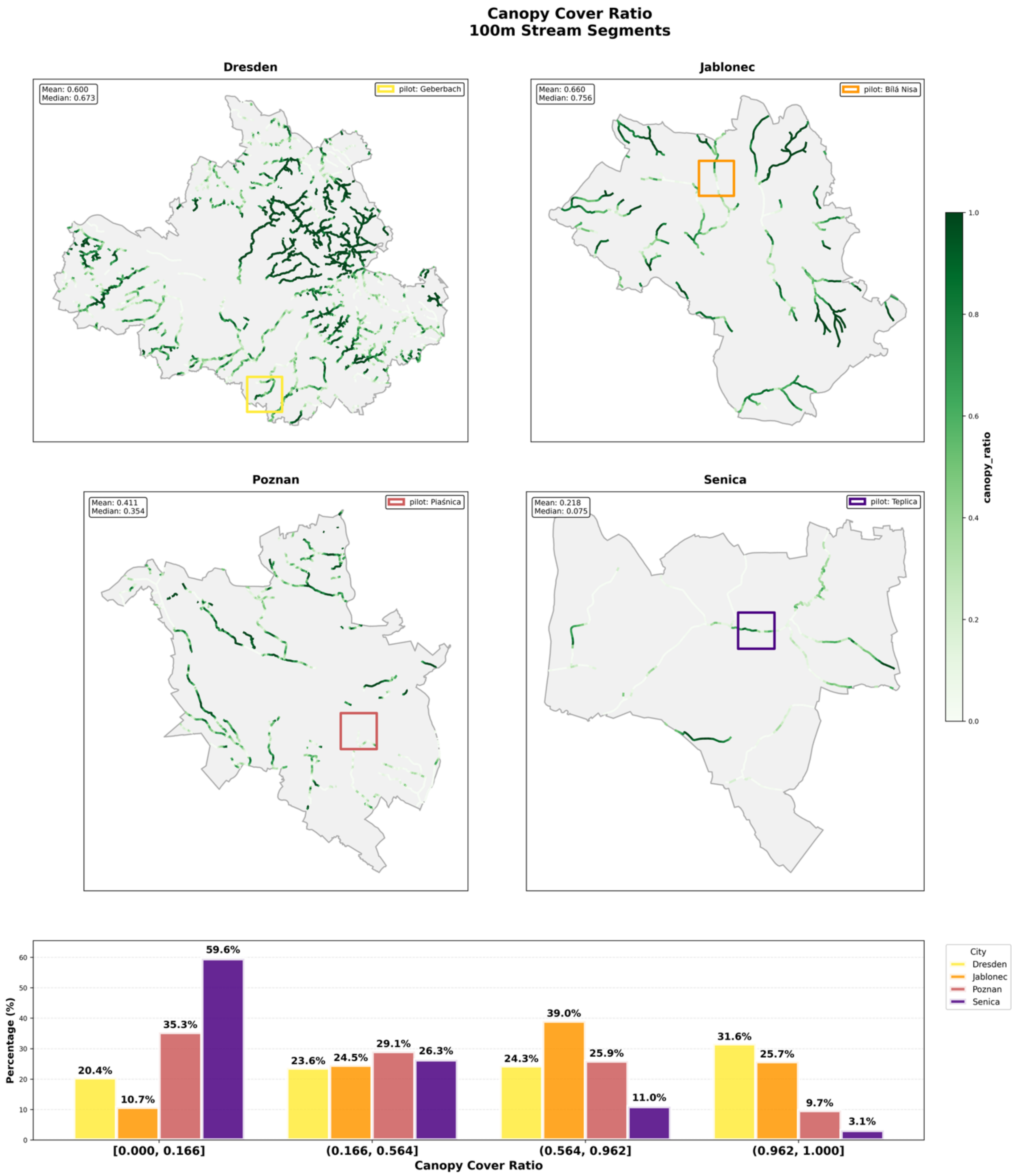
IMPERVIOUS COVER

The quantile distribution shows that many stream segments fall into the lowest range, as imperviousness values are zero. Dresden and Senica have the highest percentage of segments in this class, and Dresden shows large stretches in the northeastern part of the city where stream segments have no impervious area at all.



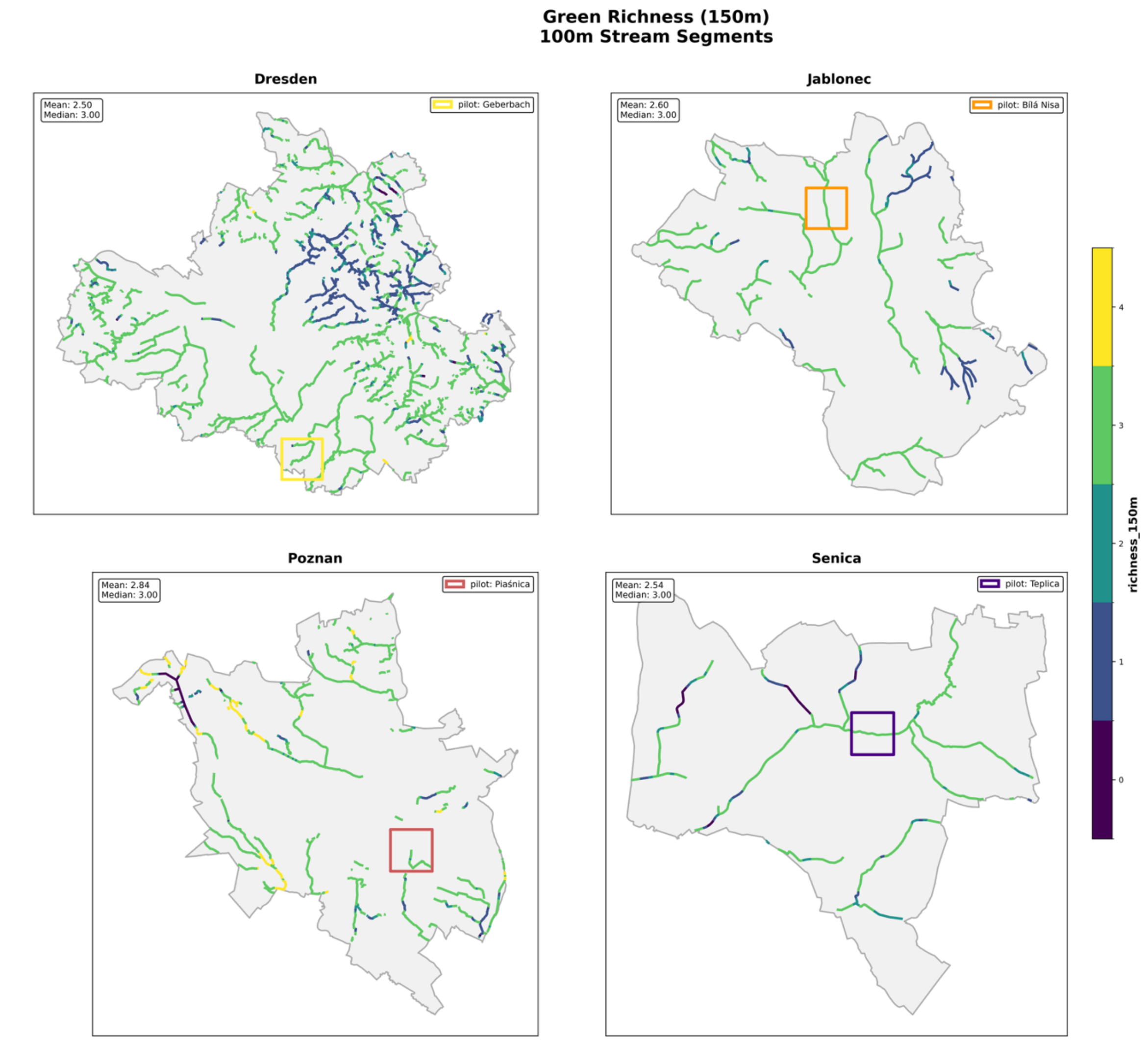
CANOPY COVER

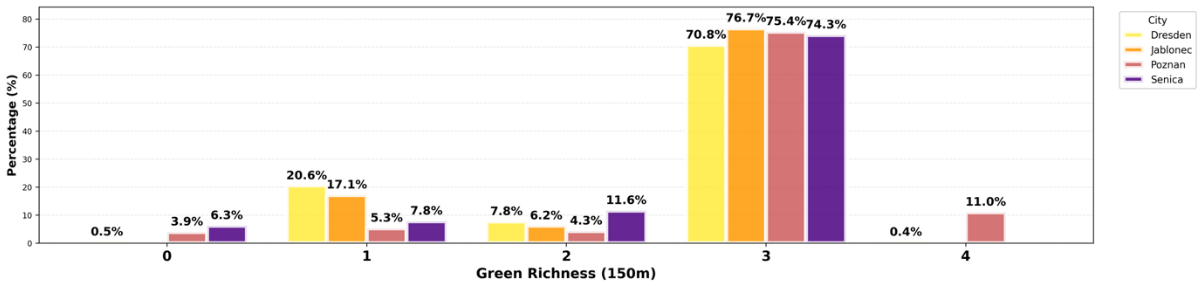
The quantile distribution shows that Senica has the highest proportion of stream segments in the lowest canopy cover range, indicating that most of its stream network is only sparsely covered with trees. In contrast, Dresden has the largest share of highly covered segments, which is consistent with the lower levels of impervious cover observed in the same catchment.



GREEN LAND COVER RICHNESS

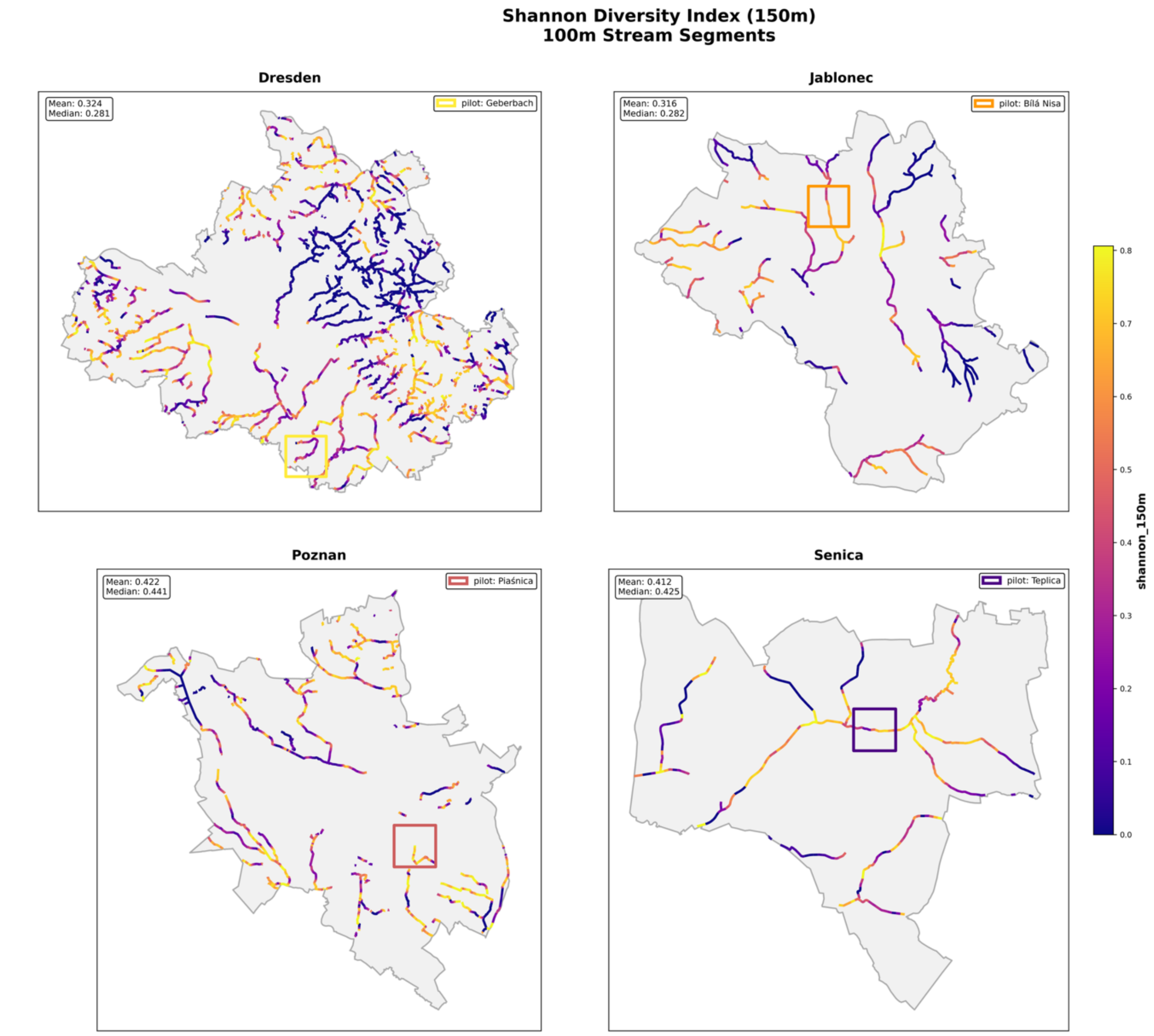
Green richness represents the number of green land-cover types within a 150-m buffer around each stream segment. The results show that Poznan generally has the highest green richness across its stream network, while in all cities most segments contain three types of green cover.

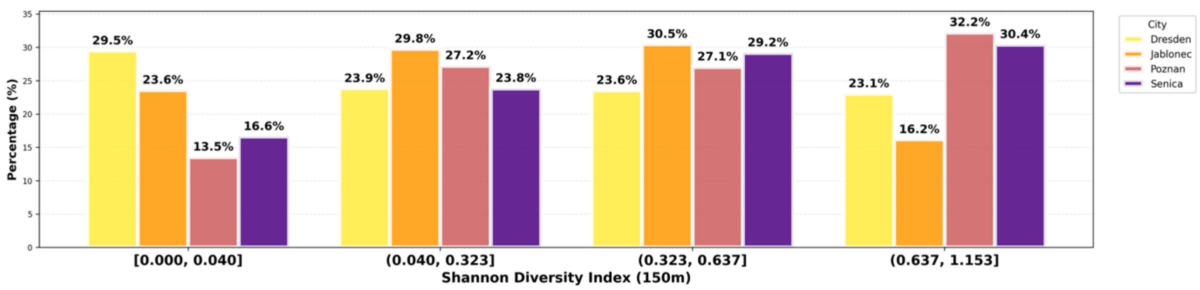




GREEN LAND COVER SHANNON DIVERSITY

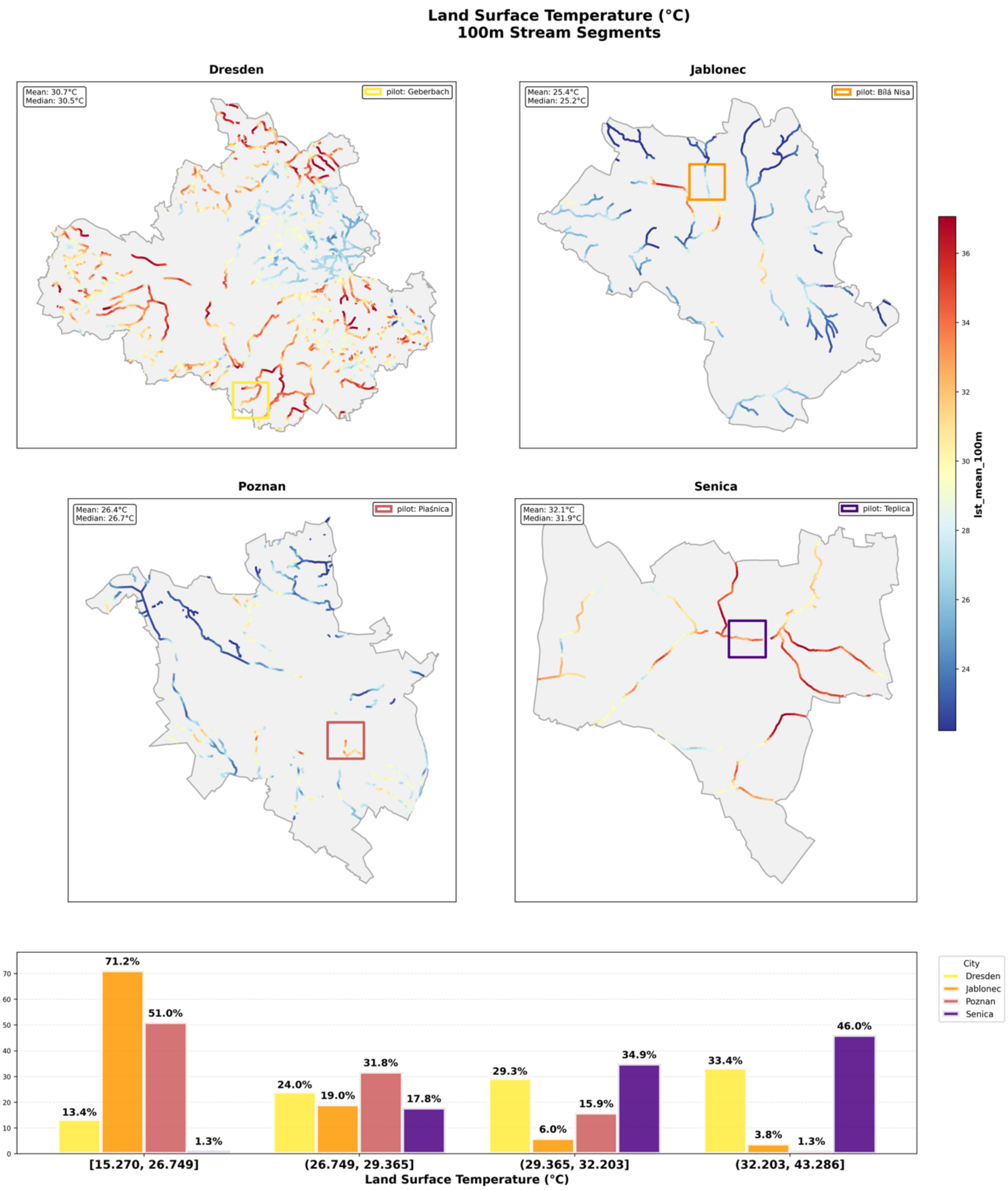
The Shannon diversity index measures the diversity of green land-cover types within a 150m buffer around each stream segment. Poznan and Senica show the highest mean diversity values, indicating more heterogeneous green cover composition. Dresden and Jablonec have lower diversity, suggesting more uniform green cover types along their stream networks.





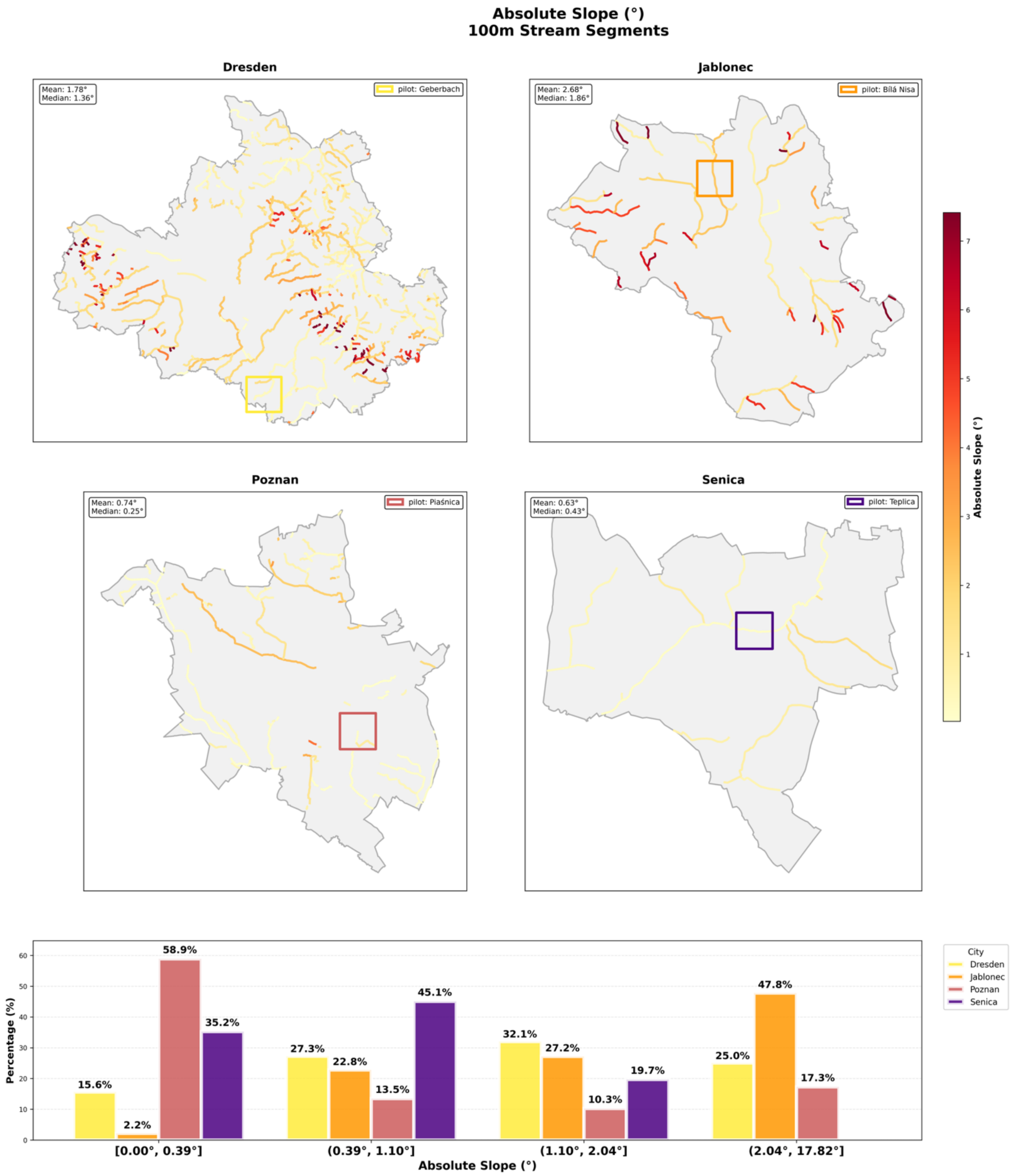
LAND SURFACE TEMPERATURE

Land surface temperature varies considerably across cities, with Senica and Dresden showing the highest mean temperatures (32.1˚C and 30.7˚C respectively), reflecting urban heat island effects. Dresen has clear spatial pattern of LST distributions, where the forested area in the northeastern parts of the city is around 6 ˚C lower than other parts of the city. Jablonec has the lowest mean temperature (25.4˚C), which may be related to its higher elevation and greater green cover.



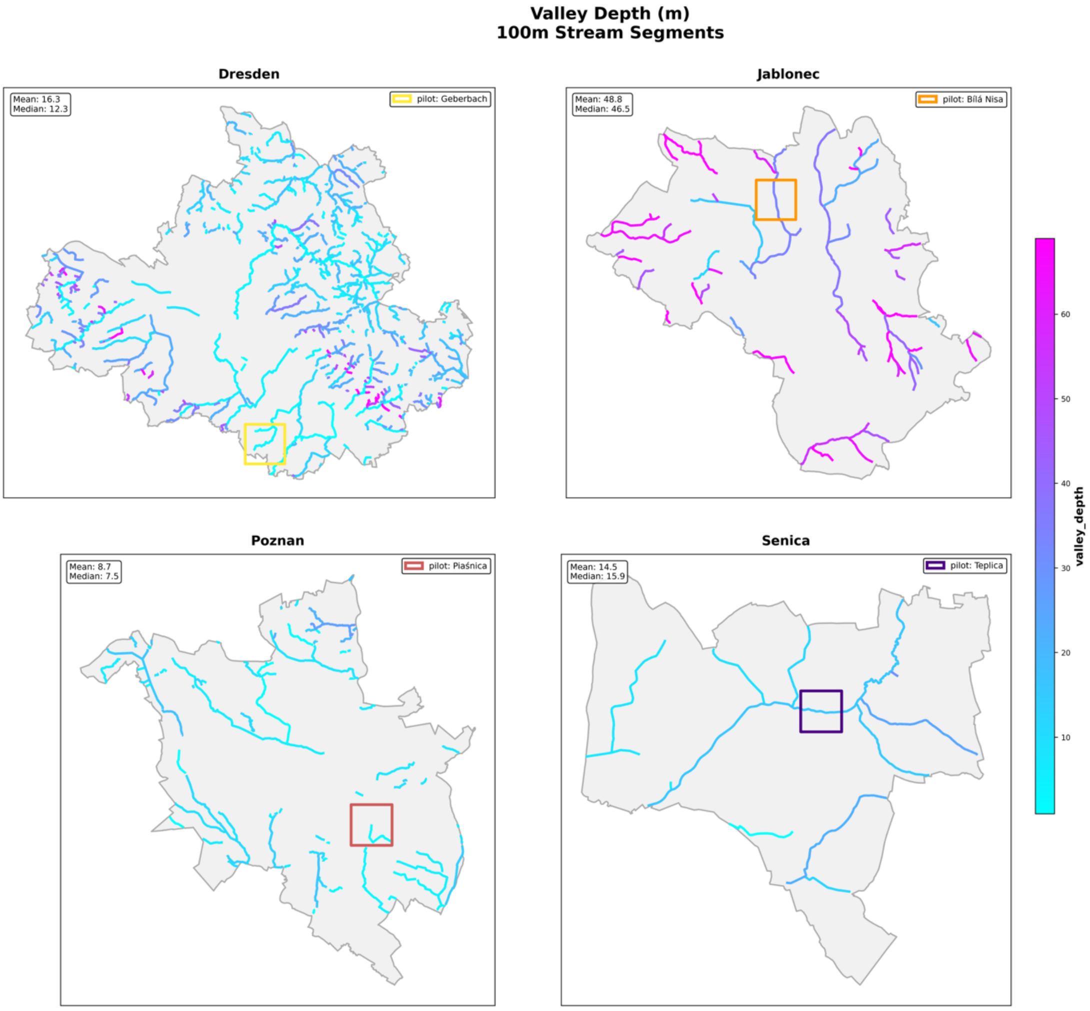
ABSOLUTE SLOPE

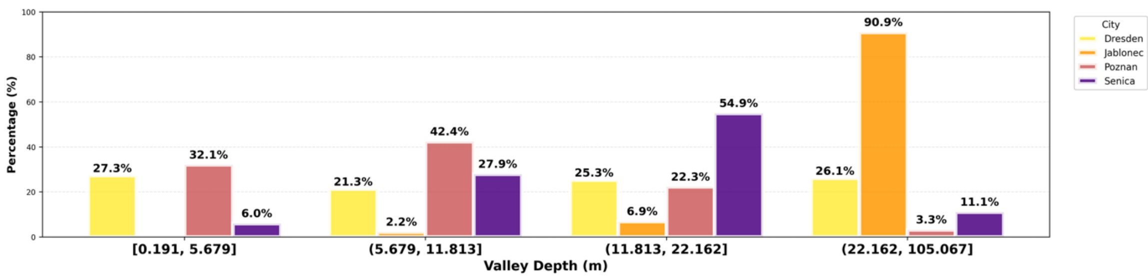
Jablonec exhibits the steepest stream segments with the highest mean absolute slope, reflecting its mountainous terrain. Dresden also shows relatively high slope values, while Poznan and Senica have gentler gradients. The quantile distribution indicates that most segments across all cities fall into the lower slope ranges, with only a small proportion having steep gradients.



VALLEY DEPTH

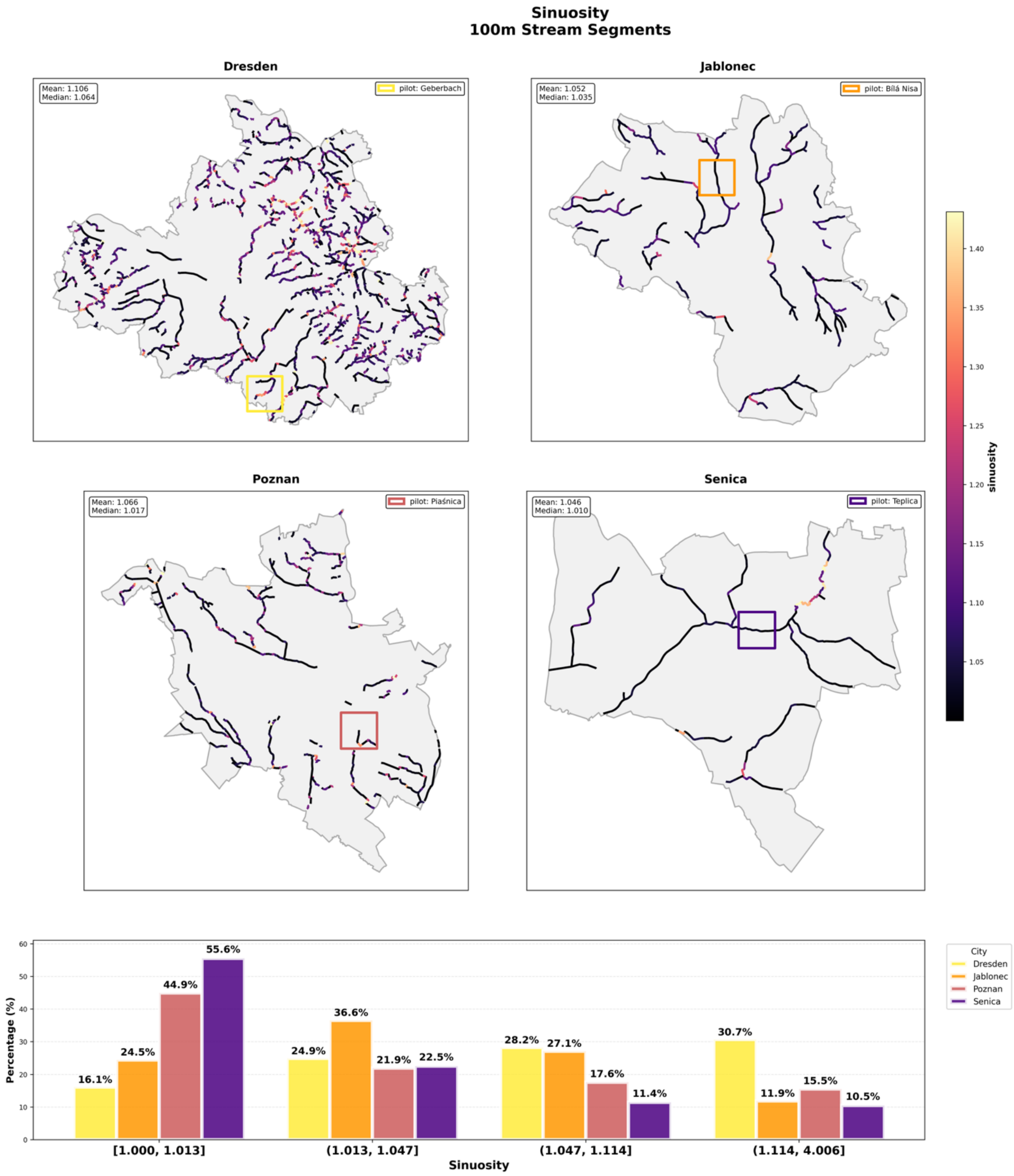
Jablonec stands out with the deepest valleys, averaging 48.8 m in depth, which is consistent with its mountainous topography. Dresden shows moderate valley depths, while Poznan and Senica have shallower valleys. The quantile distribution indicates that most segments in Jablonec fall into higher depth categories, while other cities show more segments in the lower depth ranges.





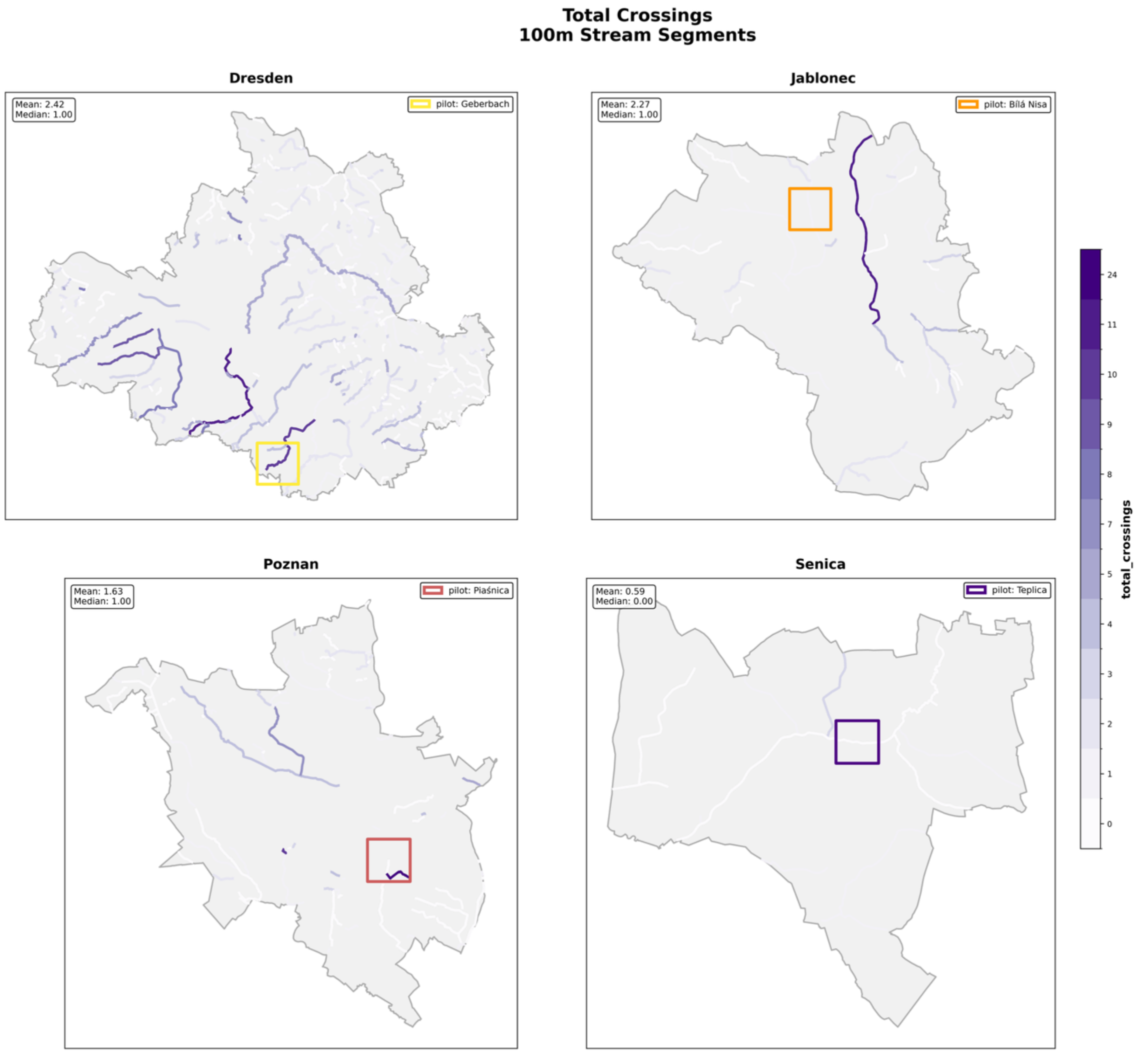
SINUOSITY

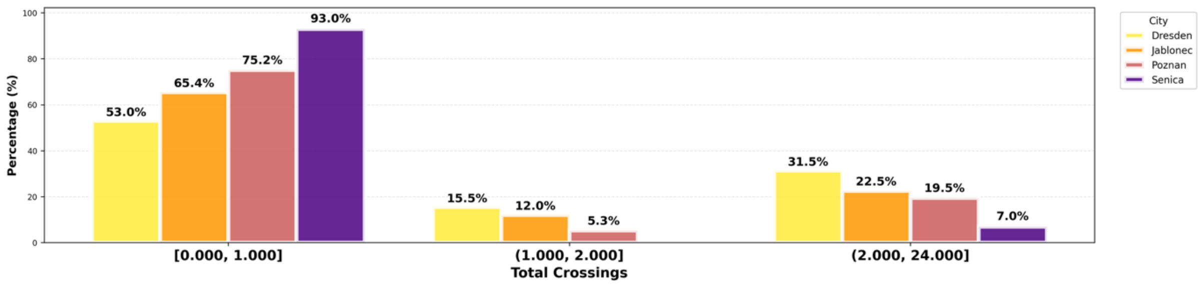
Sinuosity values are generally low across all cities, with means close to 1.0, indicating that most stream segments are relatively straight. Dresden shows slightly higher sinuosity (1.11 mean) with some segments reaching values up to 4.0, suggesting more meandering channels in northwestern green areas. Jablonec has the lowest and most uniform sinuosity (1.05 mean, max 1.38), reflecting its more constrained valley morphology.



TOTAL CROSSINGS

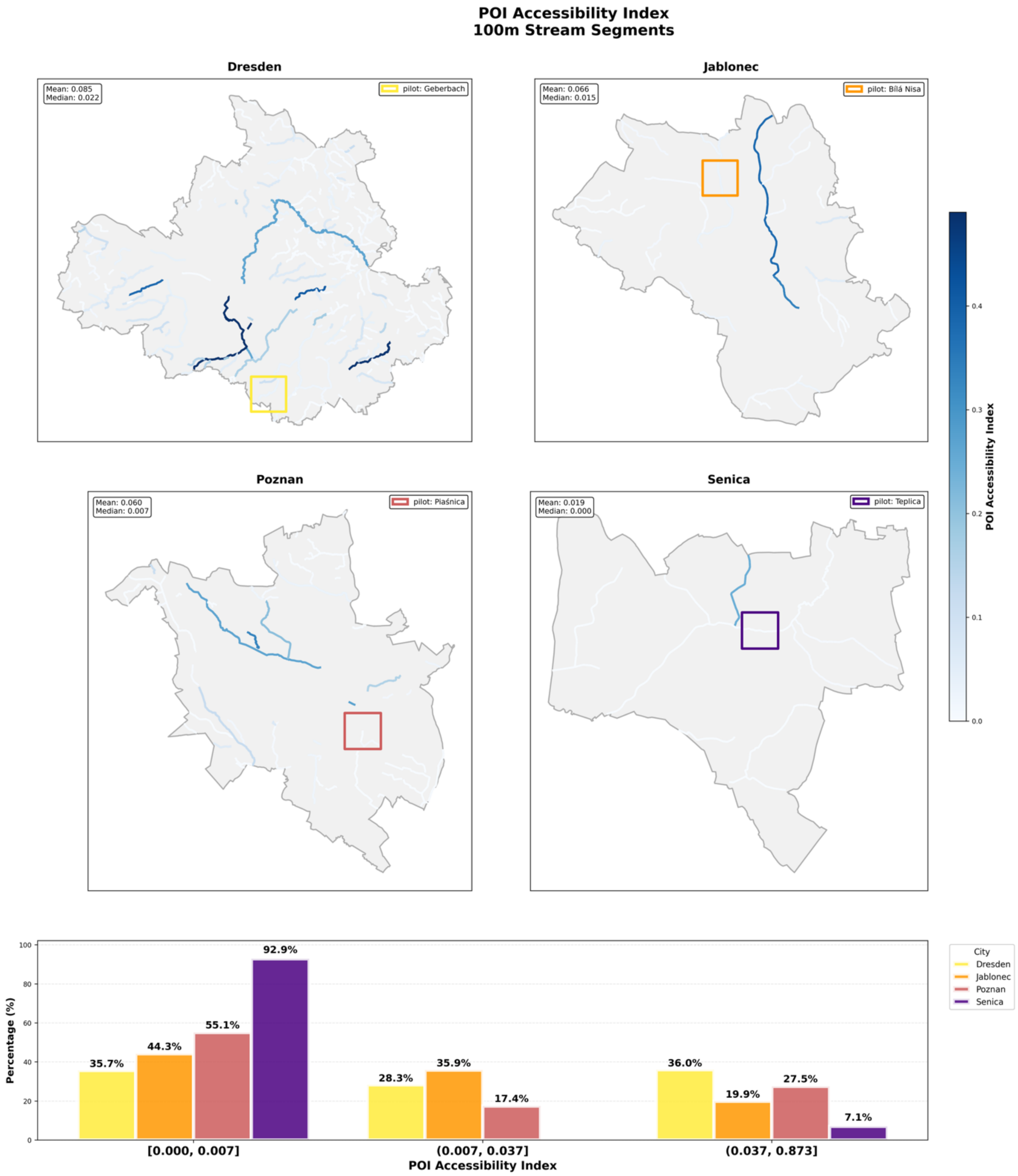
The number of road and railway crossings varies significantly across cities. Dresden and Jablonec show the highest mean crossing counts, reflecting their more dense transportation infrastructure. Poznan has moderate crossing density, while Senica has the lowest, with over half of its segments having no crossings at all. The quantile distribution shows that most segments across all cities fall into the lower crossing categories, with only a small proportion experiencing high crossing densities.





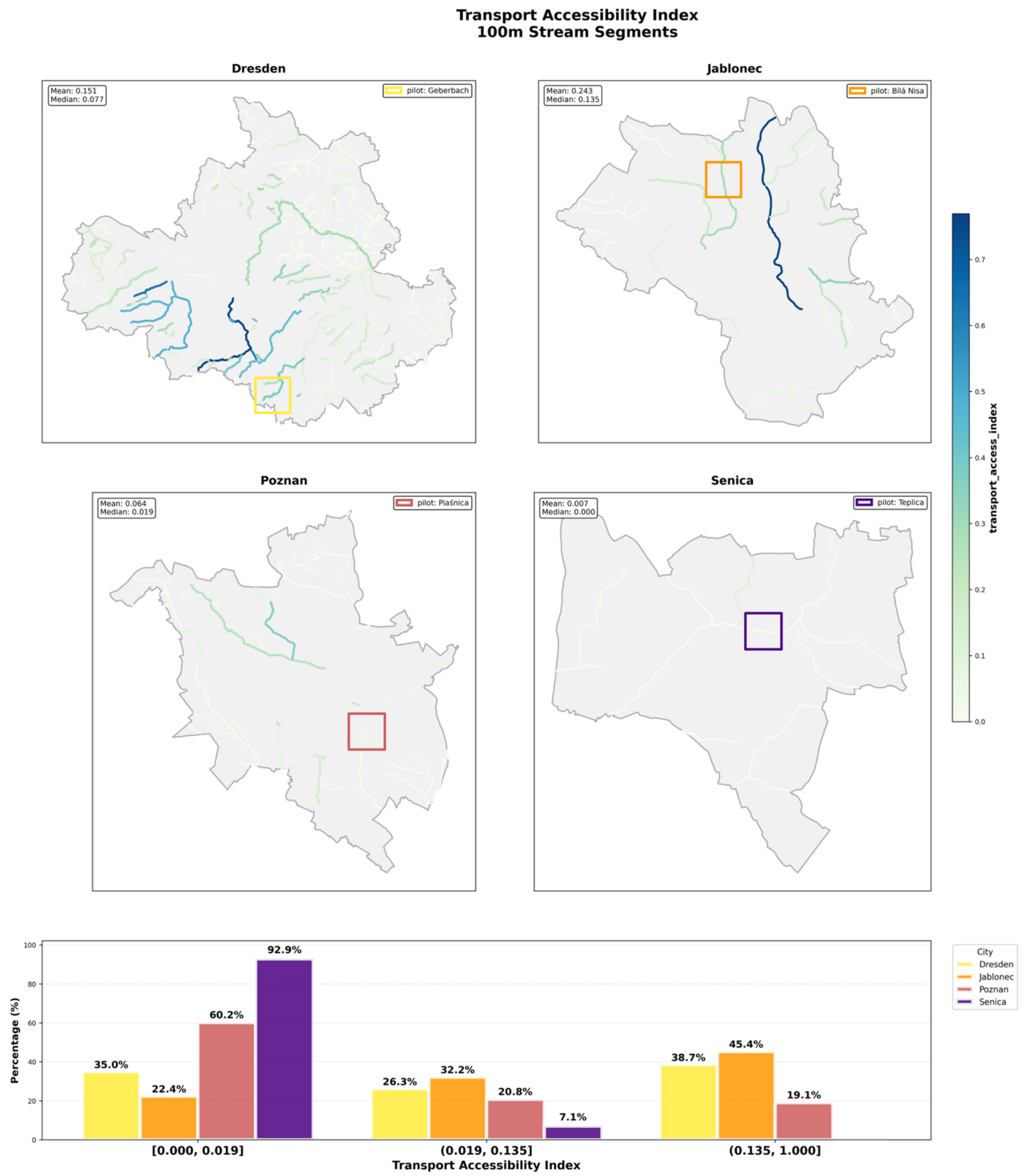
POI ACCESSIBILITY INDEX

POI accessibility shows relatively low values across all cities, with Dresden having the highest mean index and Senica the lowest. The quantile distribution reveals that most stream segments in all cities fall into the lowest accessibility ranges, indicating limited proximity to points of interest. This pattern suggests that urban streams are generally located away from major activity areas.



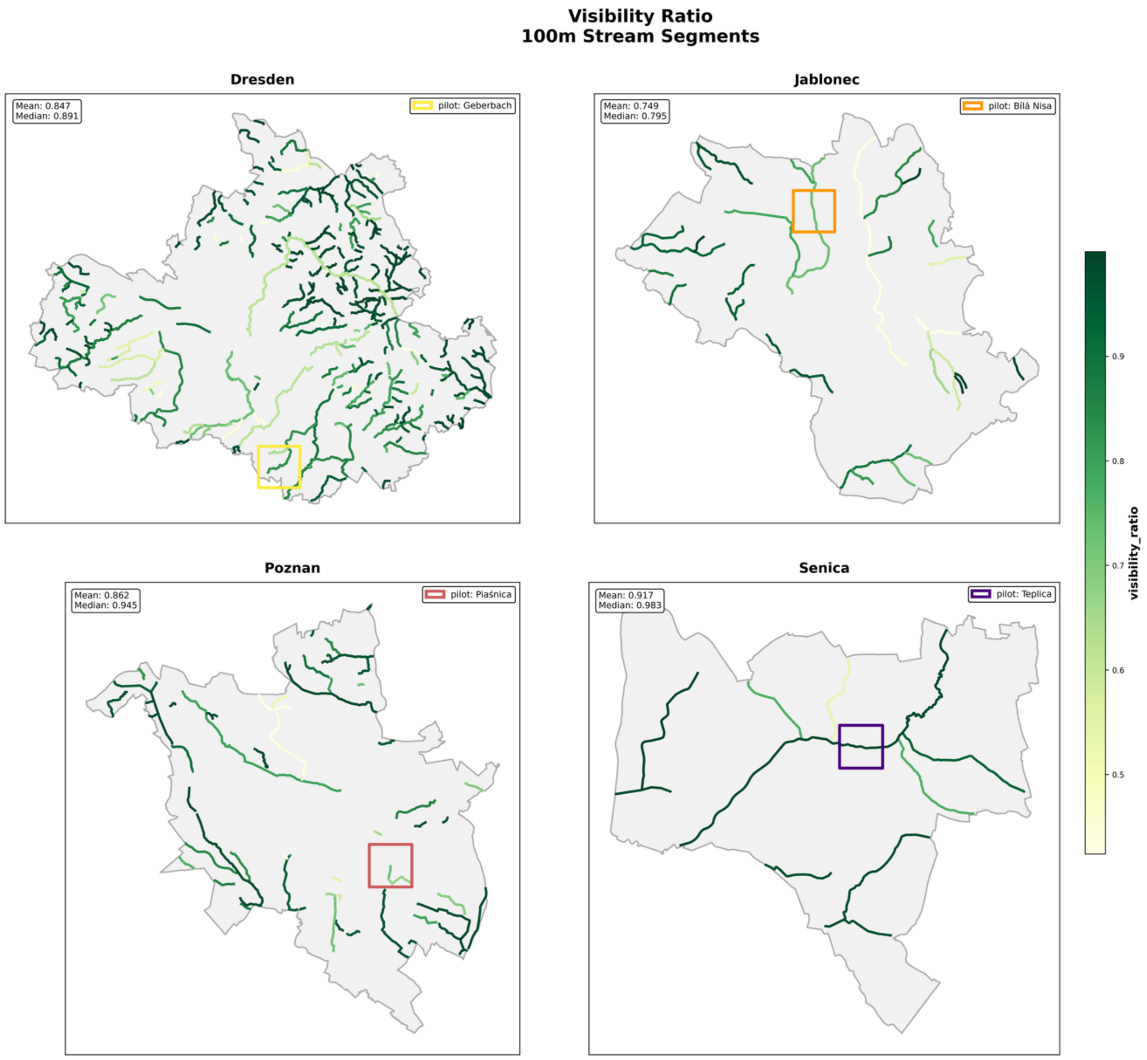
TRANSPORT ACCESSIBILITY INDEX

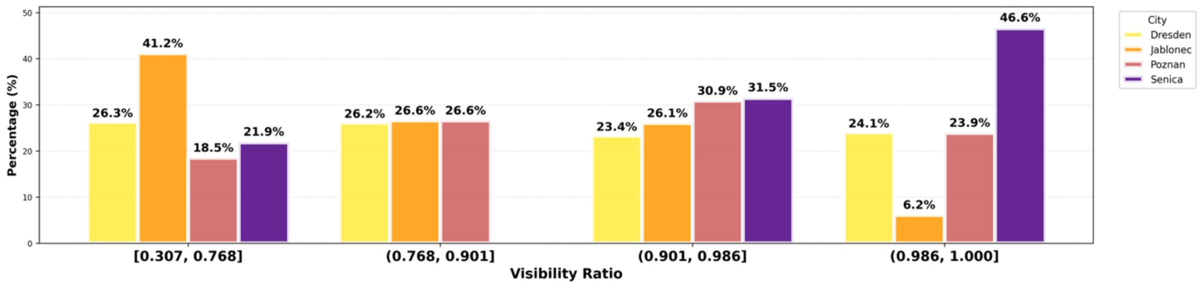
Transport accessibility exhibits clear differences between cities. Jablonec has the highest mean transport accessibility (0.24), followed by Dresden (0.15), while Poznan and Senica show much lower values (0.06 and 0.007 respectively). The quantile distribution indicates that most segments in Senica have zero transport accessibility, reflecting its more rural character. In contrast, Jablonec and Dresden show a greater proportion of segments with moderate to high accessibility, suggesting better integration with transportation networks.



VISIBILITY RATIO

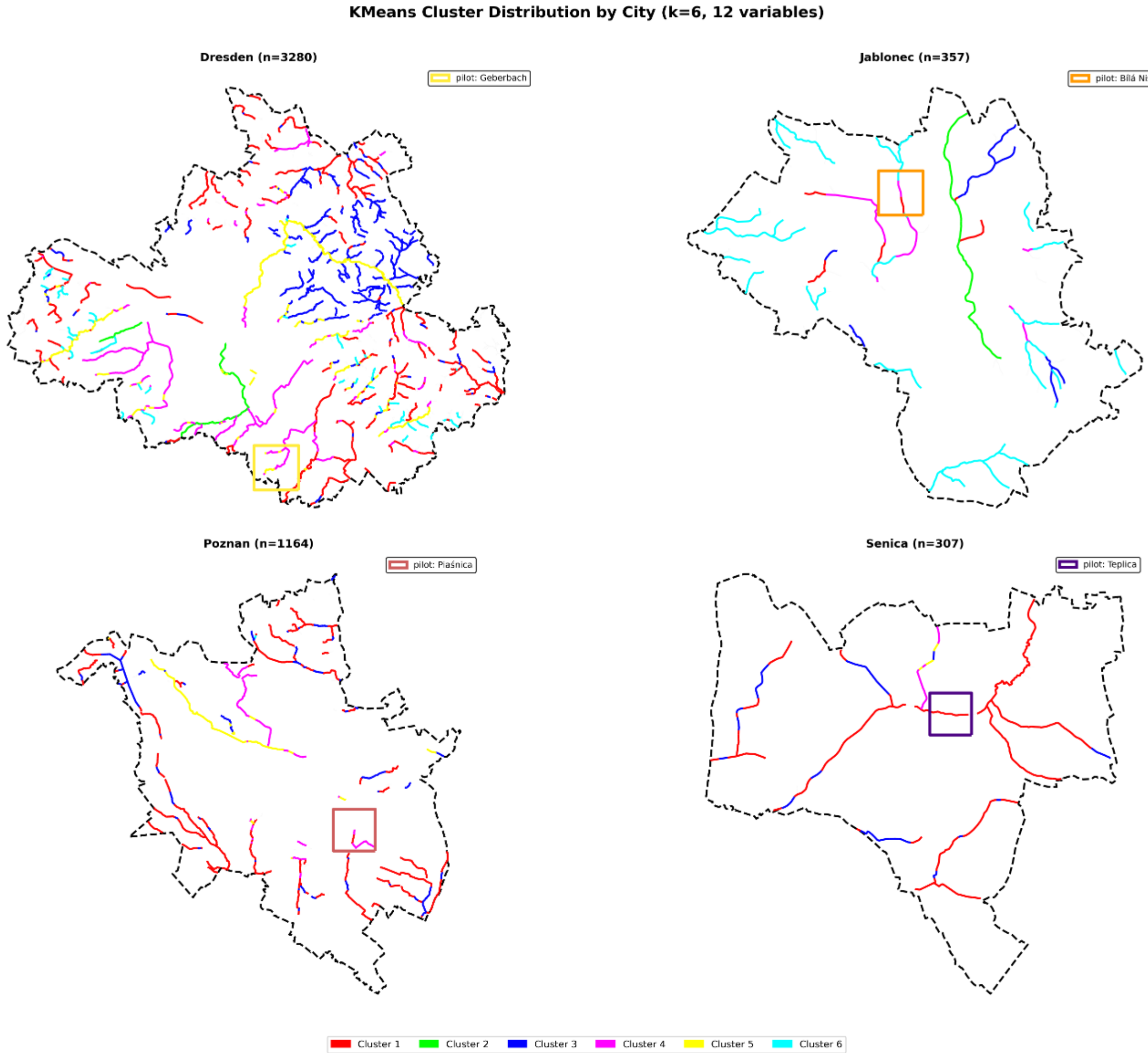
Visibility ratios are generally high across all cities, with mean values ranging from 0.75 in Jablonec to 0.92 in Senica. This indicates that most stream segments have good visibility, with relatively open viewsheds. Senica shows the highest visibility, likely due to its more open landscape. The quantile distribution shows that most segments fall into the higher visibility ranges across all cities.





4.2.2. Cluster analysis

K-means clustering was performed to classify stream segments based on their environmental characteristics. Evaluation of cluster solutions using silhouette score analysis indicated that 6 clusters provided the good performance under the total number of 8 clusters. Given the balance between model performance and interpretability, we selected the 6-cluster solution for further analysis. The spatial distribution of these clusters is shown below, revealing distinct patterns across the four study cities. We note that in three cases, namely Dresden, Jablonec nad Nisou and Poznań, the pilot sites are dominated by Cluster 4 segments, whereas the stream segments of Senica fall under Cluster 1.

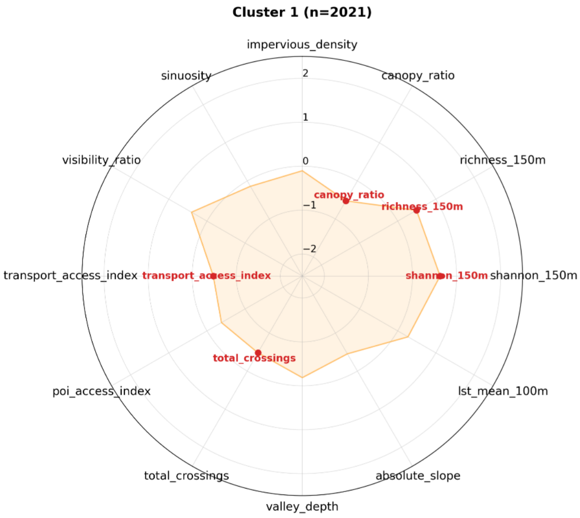


CLUSTER 1

Cluster 1 (n = 2,021) is characterised by high diversity in green land cover, combined with low canopy cover and high green richness. This cluster represents the largest proportion of all clusters. In Dresden, it accounts for a greater share (54.2%) than in the other three cities, and within Dresden itself this cluster contains more segments than any of the other clusters (33.4%). For Senica, it takes the biggest portion (73.9%) of the city's streams. The underlying causes may include the heterogeneous composition of green cover in suburban Dresden, as well as in both the city centre and suburban areas of Poznan and Senica.

Cluster 1, #1, id3146, stream_id: 223, Dresden

Cluster 1: High Shannon, Low Canopy, High Richness

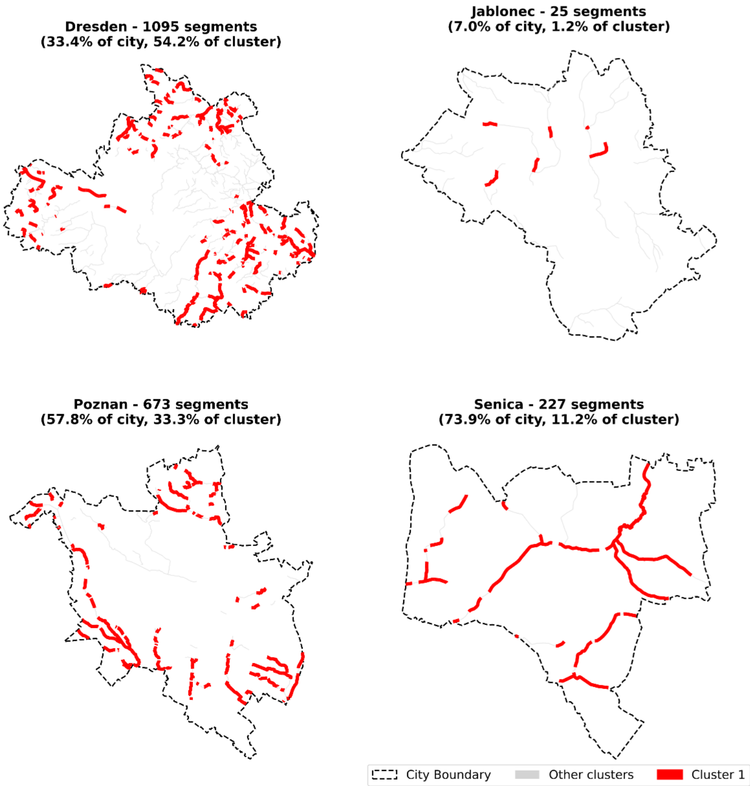


Cluster 1, #2, id3819, stream_id: 302, Dresden

Cluster 1, #3, id295, stream_id: 12, Senica

Cluster 1, #4, id3976, stream_id: 320, Dresden

Cluster 1, #5, id2158, stream_id: 129, Dresden



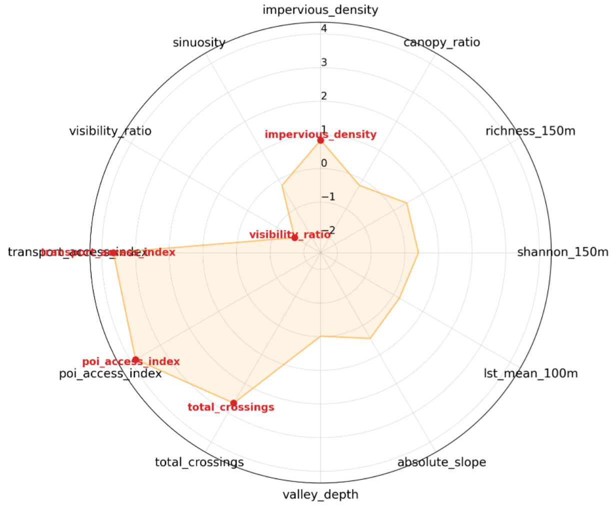
CLUSTER 2

Cluster 2 (n = 173) combines several urban characteristics: high POI accessibility, high transport accessibility, a high number of crossings, and a high density of impervious cover. In Jablonec nad Nisou, 14.6% of the city's streams fall into this category, making it the second-largest cluster type in the city. These elevated values can be attributed to the dense concentration of points of interest around the Mšenský potok stream, supported by a well-developed transport network.

Cluster 2, #1, id2142, stream_id: 126, Dresden

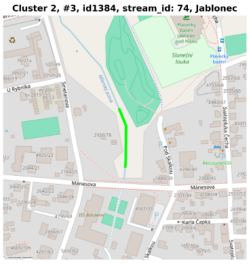
Cluster 2: High POI Access, High Transport Access, High Crossings

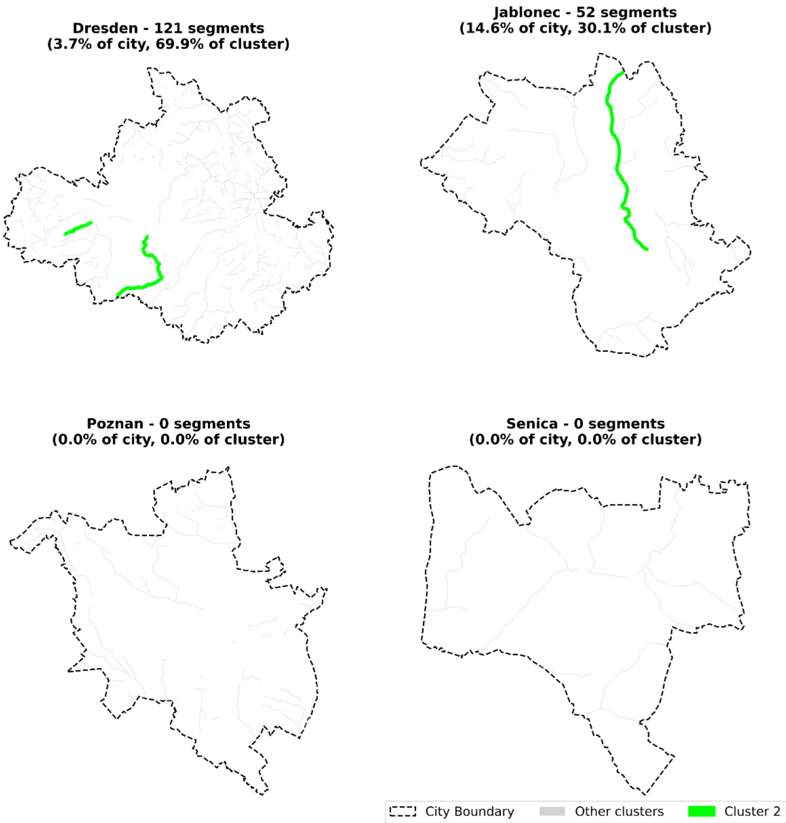
Cluster 2 (n=173)



Cluster 2, #2, id4286, stream_id: 349, Dresden

Cluster 2, #3, id1384, stream_id: 74, Jablonec



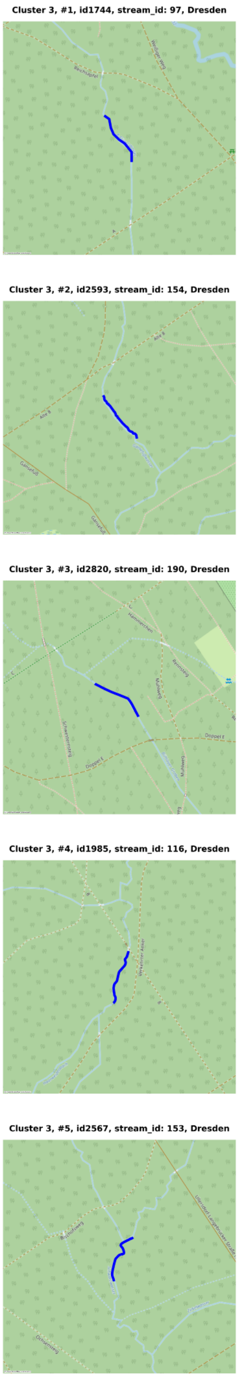


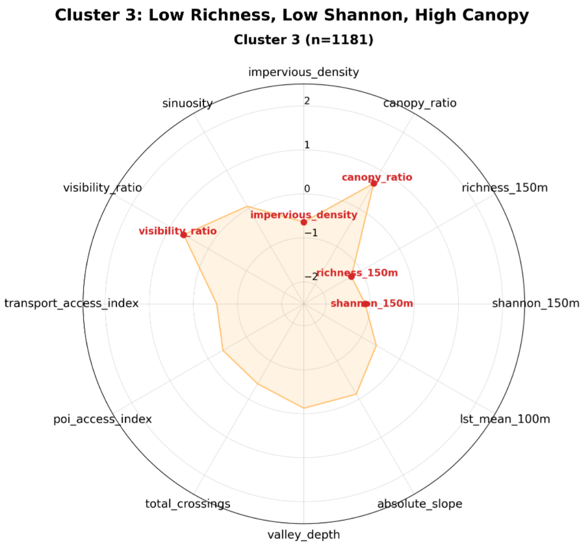
Cluster 2, #4, id5230, stream_id: 579, Dresden

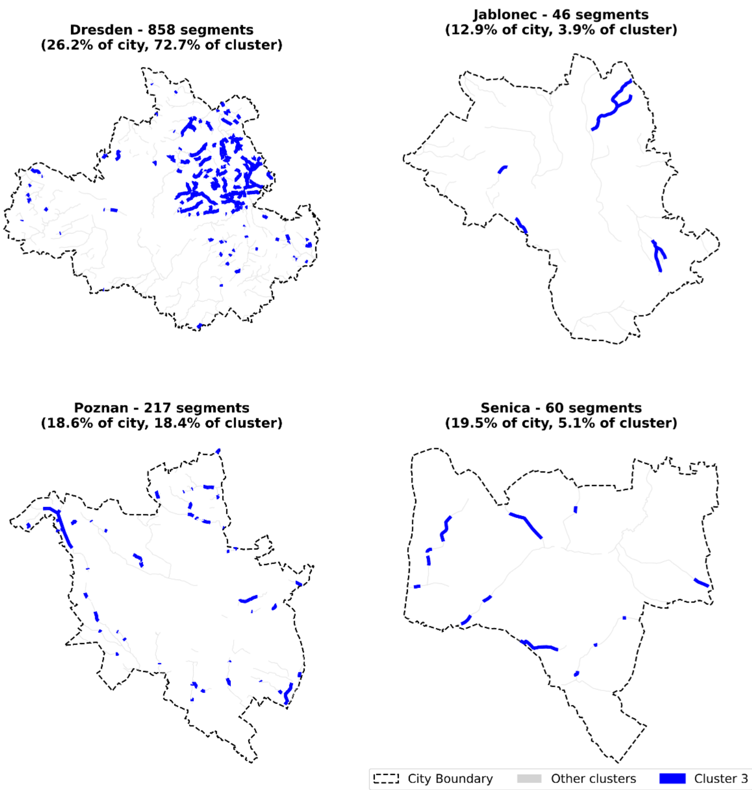
Cluster 2, #5, id5676, stream_id: 699, Jablonec

CLUSTER 3

Cluster 3 (n = 1181) is characterised by low green cover diversity, low green richness, along with high canopy cover and high visibility, and low land surface temperatures. The largest share of segments in this cluster occurs in Dresden (23.7%), followed by Jablonec (12.9%). These patterns reflect stream corridors with dense and uniform tree cover type and open viewsheds that provide good visibility. In Dresden, these segments are primarily located in the northeastern part of the city, associated with smaller tributary streams.



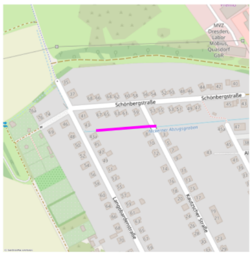




CLUSTER 4

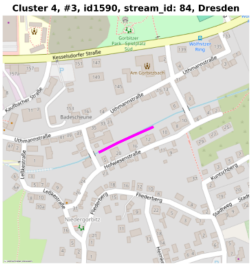
Cluster 4 (n=716) has high impervious cover, and low visibility, combined with high total crossings, high transport access, and high land surface temperature. 72.9% of this cluster's segments are located in Dresden, while Poznan accounts for 19.7%. This pattern can be attributed to high built-up area density, frequent road and railway intersections with streams, well-developed transportation networks, and limited viewsheds due to surrounding built environment.

Cluster 4, #1, id3764, stream_id: 293, Dresden



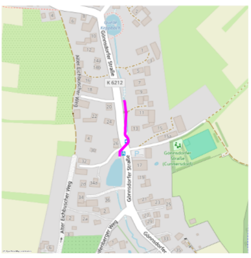
Cluster 4, #2, id1817, stream_id: 103, Dresden

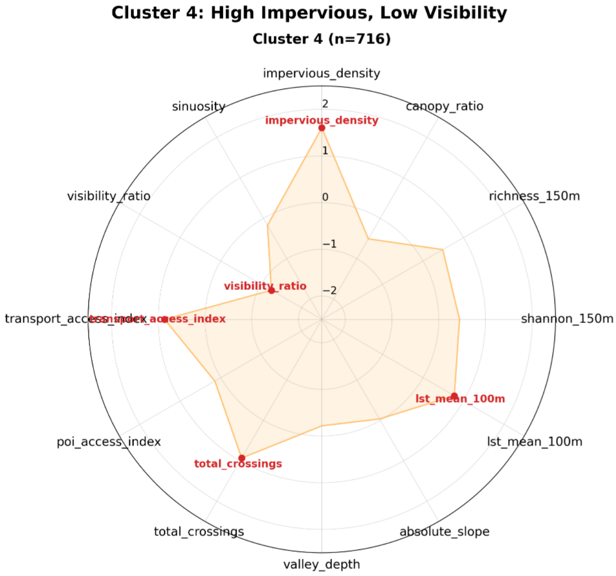
Cluster 4, #3, id1590, stream_id: 84, Dresden

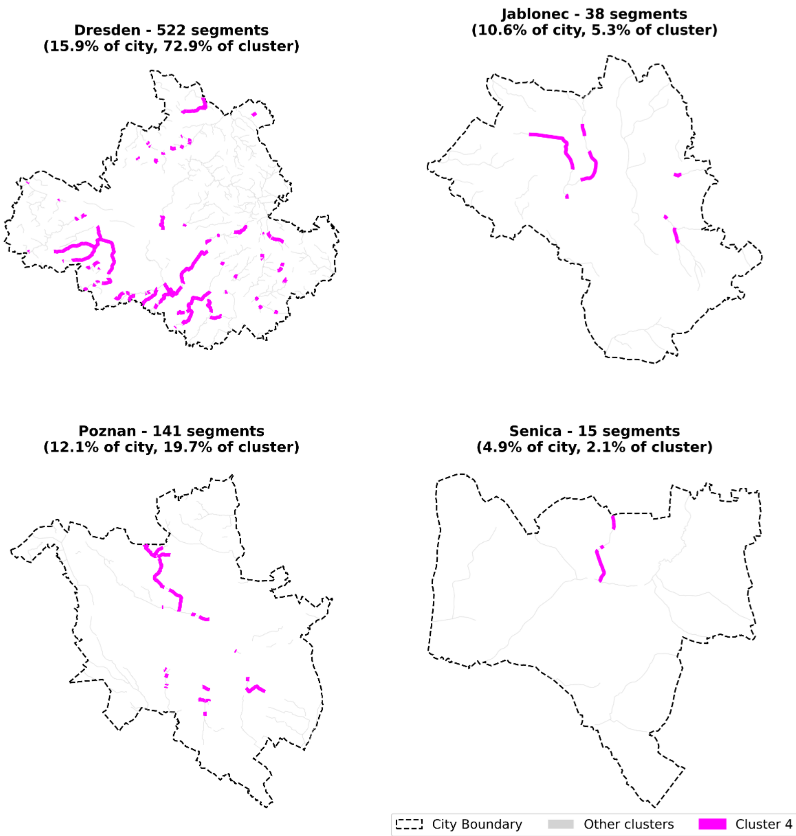


Cluster 4, #4, id1878, stream_id: 105, Dresden

Cluster 4, #5, id2432, stream_id: 142, Dresden

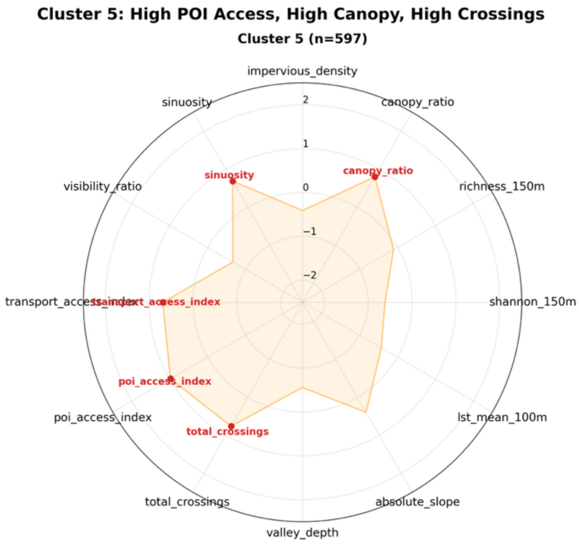


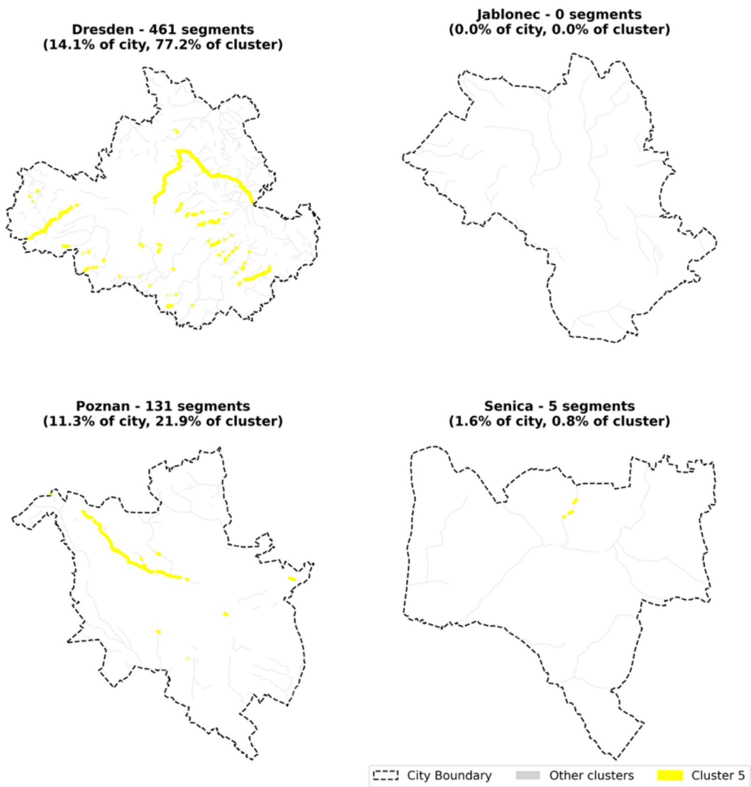




CLUSTER 5

Cluster 5 (n = 302) is characterised by a combination of high POI accessibility, high sinuosity, high canopy cover, and a large number of total crossings. This cluster is found mainly in Dresden (77.2%), and Poznan (21.9%). The streams in this cluster (e.g. Prießnitz stream in Dresden) provides good access to points of interest and is intersected by multiple transportation corridors. The largely natural channel, surrounded by minimally disturbed open areas, contributes to the high canopy cover and strongly meandering channel morphology observed in this cluster.





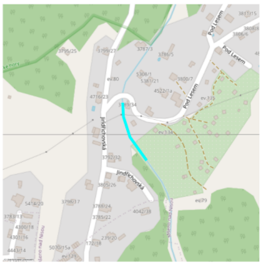
CLUSTER 6

Cluster 6 (n=421) stands out with its high valley depth and steep slope, along with high canopy cover, narrow valley width. Jablonec has most streams belonging to this cluster inside the city (54.9%). It can be explained by the deep valley morphology, steep terrain that are mostly seen in the urban fringe of Jablonec.

Cluster 6, #1, id5753, stream_id: 715, Jablonec

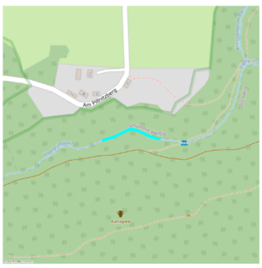
Cluster 6, #2, id2037, stream_id: 122, Dresden

Cluster 6, #3, id5762, stream_id: 716, Jablonec

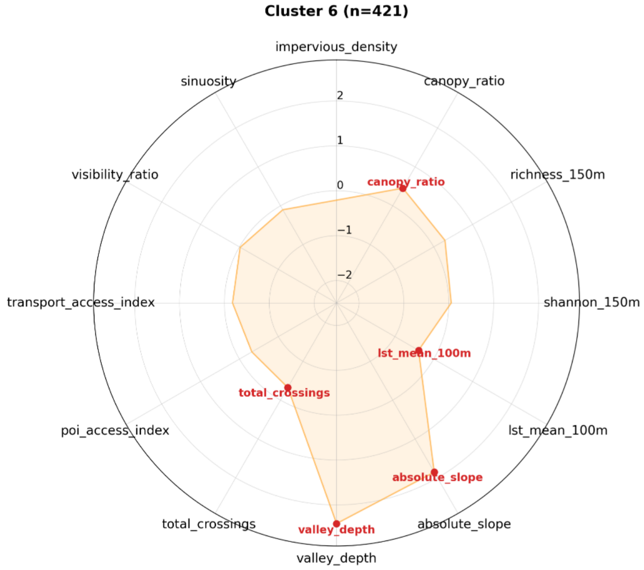


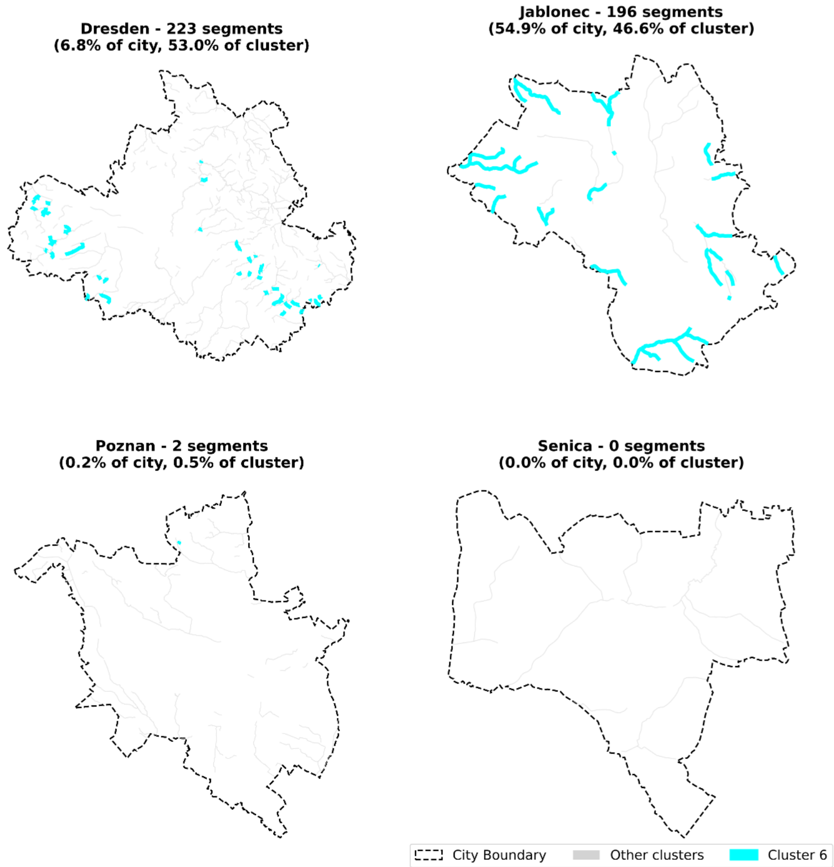
Cluster 6, #4, id5860, stream_id: 734, Jablonec

Cluster 6, #5, id1961, stream_id: 114, Dresden



Cluster 6: Deep Valley, Steep Slope

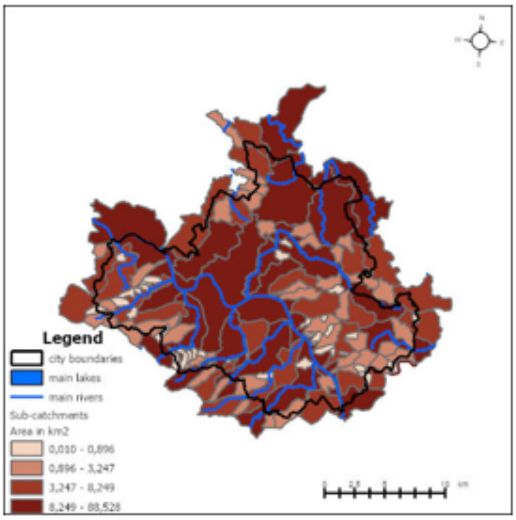




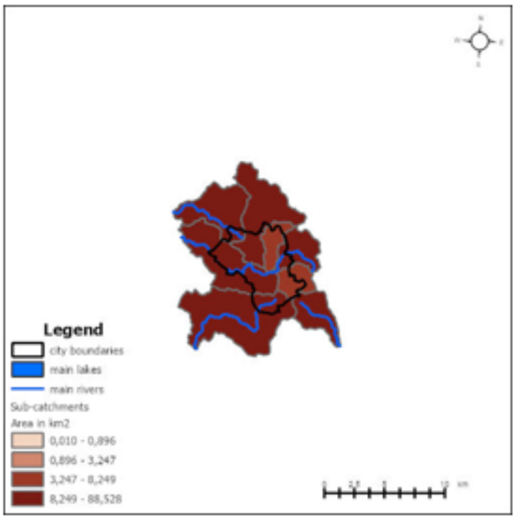
4.3. Sub-catchment-level analysis

4.3.1. Mapping variables in four cities

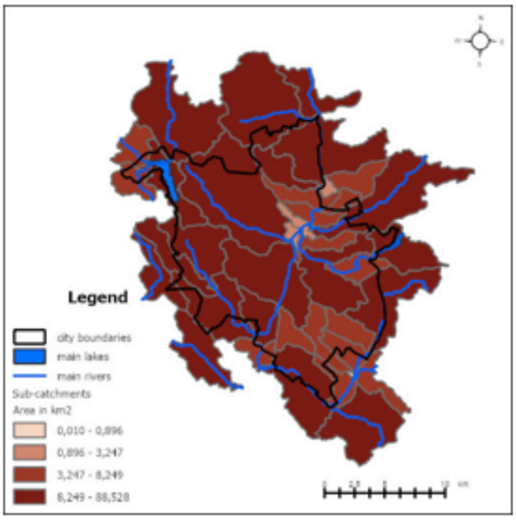
AREA OF THE CATCHMENT IN KM2



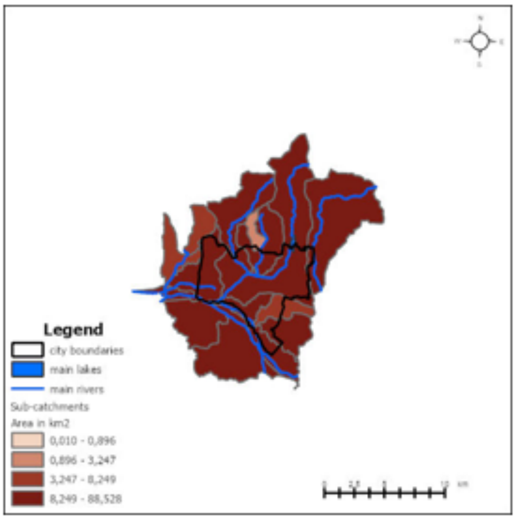
Dresden



Jablonec nad Nisou



Poznań



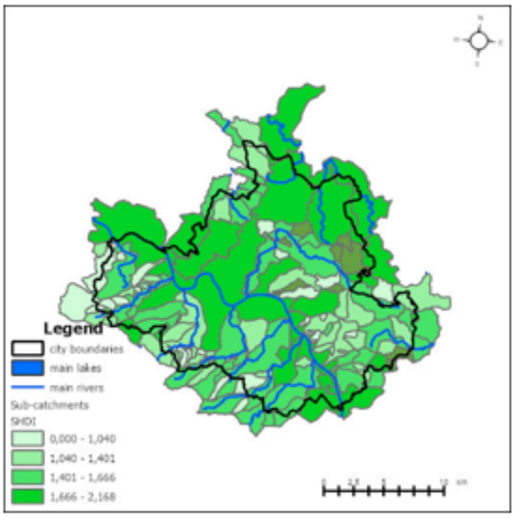
Senica

Descriptive statistics for cities

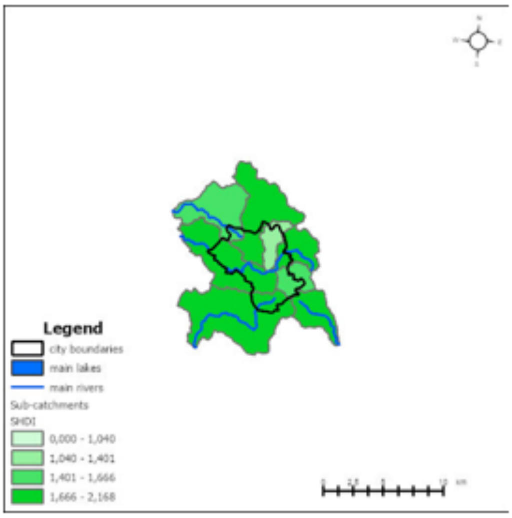
City	N significant	Mean	Minimum	Maximum	Standard deviation
Dresden	119	3,91	0,0110	88	9,0
Senica	12	17,83	2,93235	51,2	15,73
Jablonec	7	18,690	5,759	35,326	12,216
Poznań	40	13,976	0,00972	52,69	12,200

Summary: The smallest sub-catchments occur in Dresden, which is due to the dense network of small streams in the city. Similar values are typical for the Czech Republic and Slovakia. Similar sub-catchment divisions may be due to historical and cultural factors.

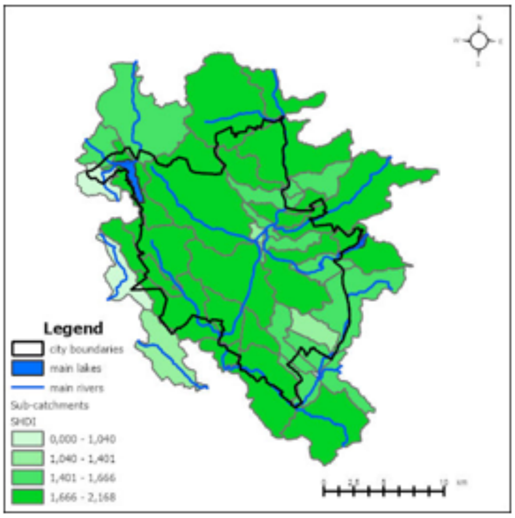
SHDI



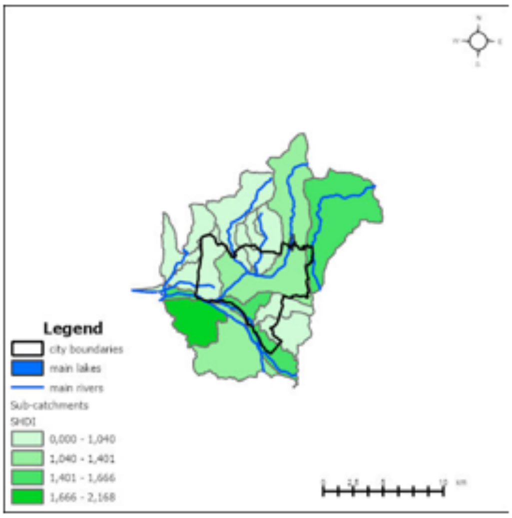
Dresden



Jablonec nad Nisou



Poznań



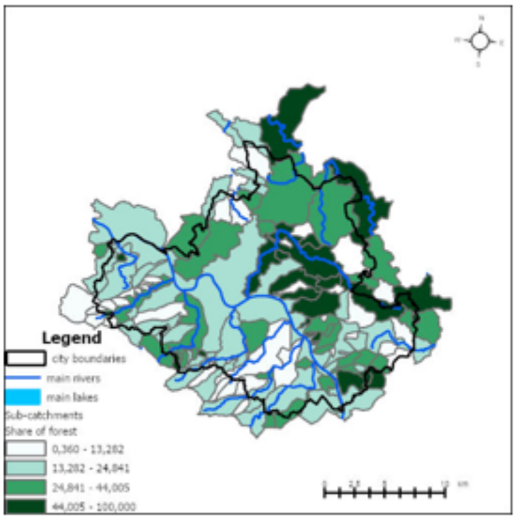
Senica

Descriptive statistics for cities

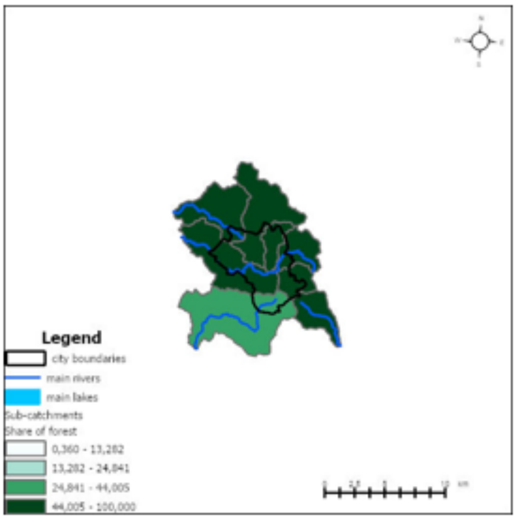
City	N significant	Mean	Minimum	Maximum	Standard deviation
Dresden	119	1,20	0,0000	2	0,4
Senica	12	0,92	0,09484	1,9	0,50
Jablonec	7	1,625	1,310	1,895	0,199
Poznań	40	1,611	0,46019	2,17	0,368

Summary: The highest SHDI values were recorded in Poznań and Jablonec nad Nisou. Jablonec also has the lowest standard deviation. The highest value for Czech sub-catchments was calculated for Mohelka (1.89).

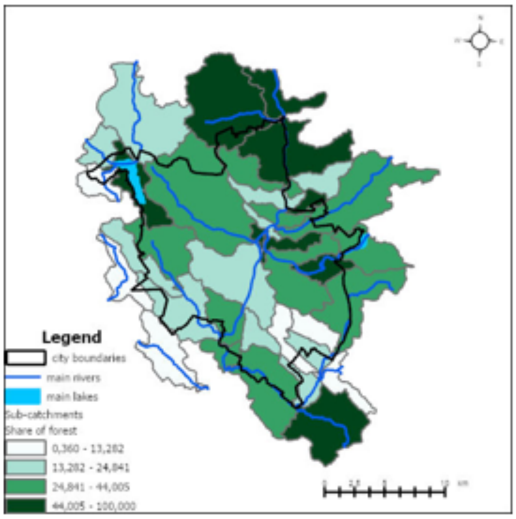
SHARE OF FOREST IN %



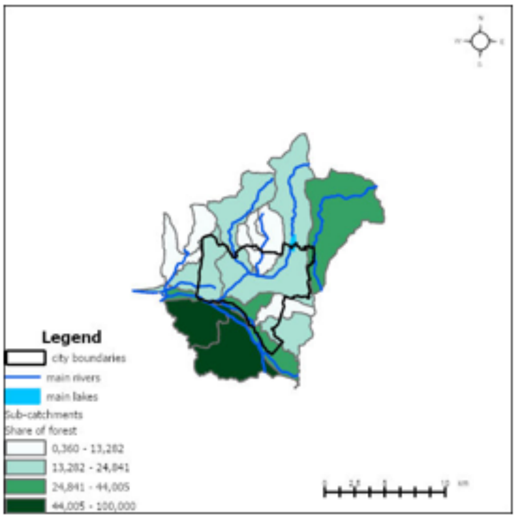
Dresden



Jablonec nad Nisou



Poznań



Senica

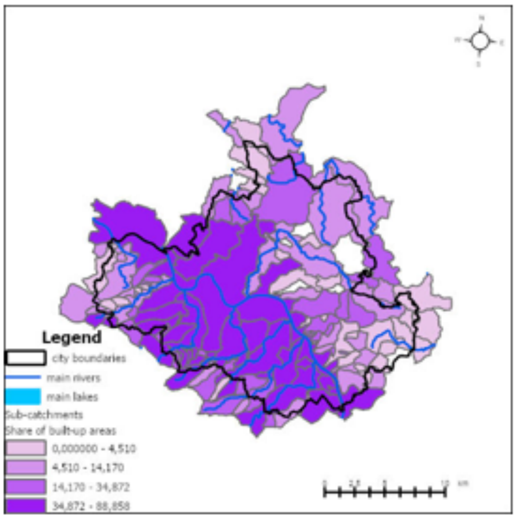
Descriptive statistics for cities

City	N significant	Mean	Minimum	Maximum	Standard deviation
Dresden	119	36,31	0,4313	100	30,3
Senica	12	21,57	0,35987	76,2	23,87
Jablonec	7	61,839	41,259	76,810	11,666
Poznań	40	31,377	2,03197	100,00	20,973

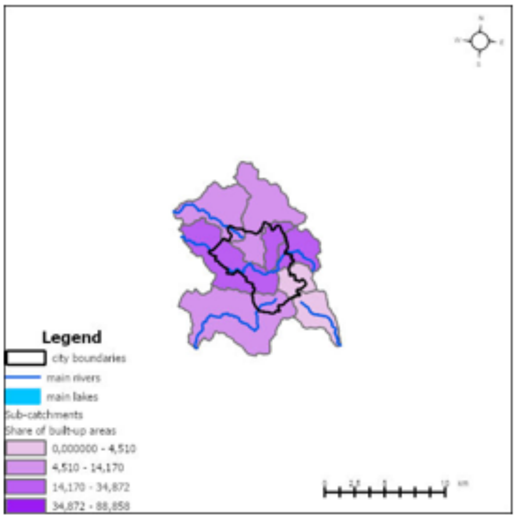
Summary: Sub-catchments in Jablonec nad Nisou have the highest percentage of forests (average 62%), which is due to physiographic conditions and relief. Jablonec also has the lowest standard deviation. The

Dresden and Poznań catchment group is also noteworthy, with almost 100% forest cover, which is crucial for the quality of life of residents of these large cities Senica has the lowest percentage of forests in the analyzed group (22%).

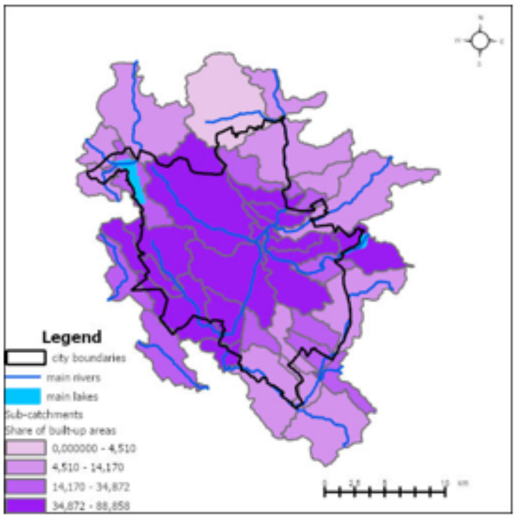
SHARE OF BUILT-UP AREA IN %



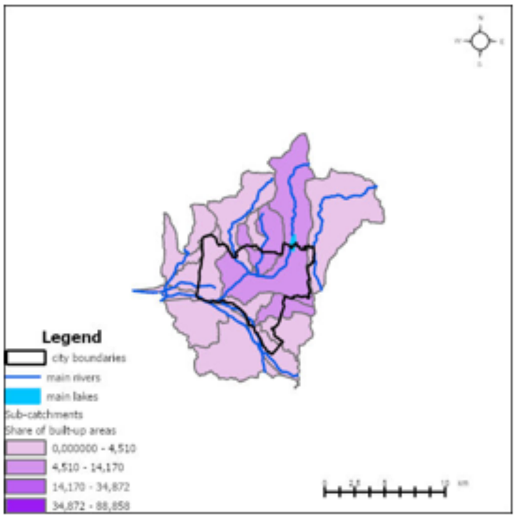
Dresden



Jablonec nad Nisou



Poznań



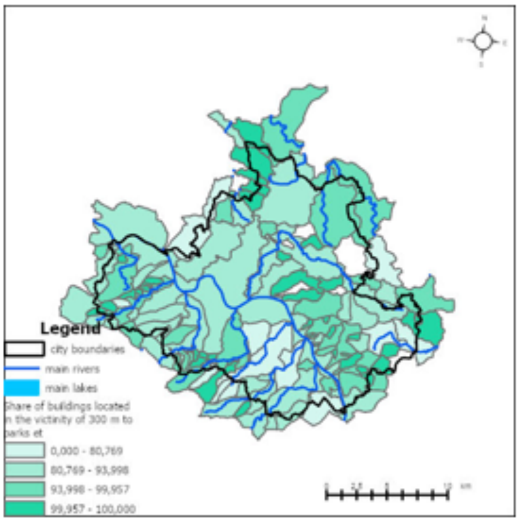
Senica

Descriptive statistics for cities

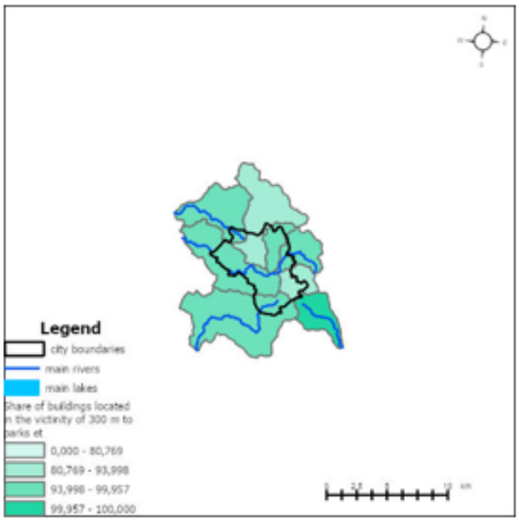
City	N significant	Mean	Minimum	Maximum	Standard deviation
Dresden	119	19,59	0,0000	89	20,8
Senica	12	3,58	0,69757	8,8	2,58
Jablonec	7	9,556	1,839	17,070	5,911
Poznań	40	26,985	0,00000	62,79	17,619

Summary: The highest percentage of built-up areas is characteristic of the largest cities in this group, Poznań (27%) and Dresden (20%). The densest development occurs in the centers of these cities, which are located on the largest rivers, the Warta in Poznań and Elbe in Dresden, which is typical of the historical development of cities along rivers.

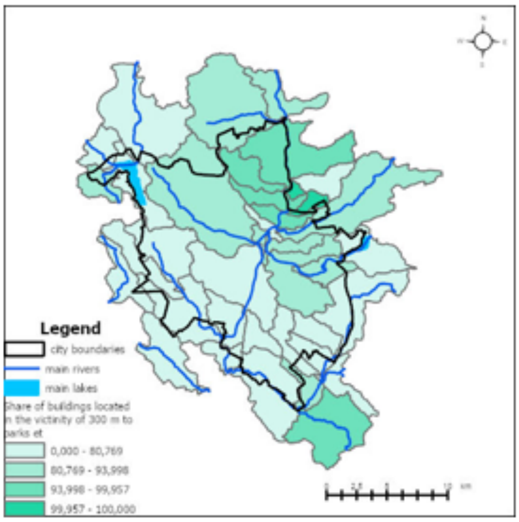
SHARE OF BUILDINGS LOCATED IN THE VICTINITY OF 300 M TO PARKS AND FOREST IN %



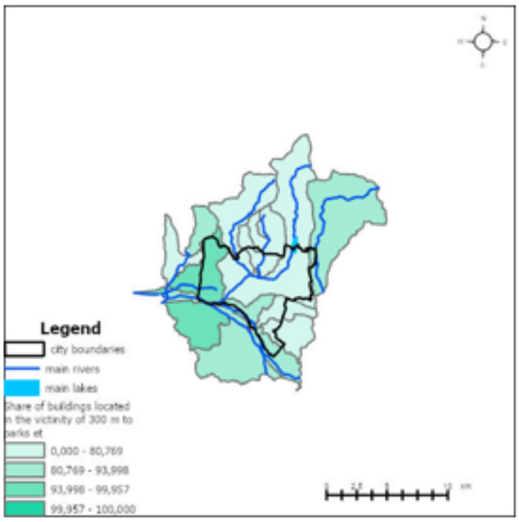
Dresden



Jablonec nad Nisou



Poznań



Senica

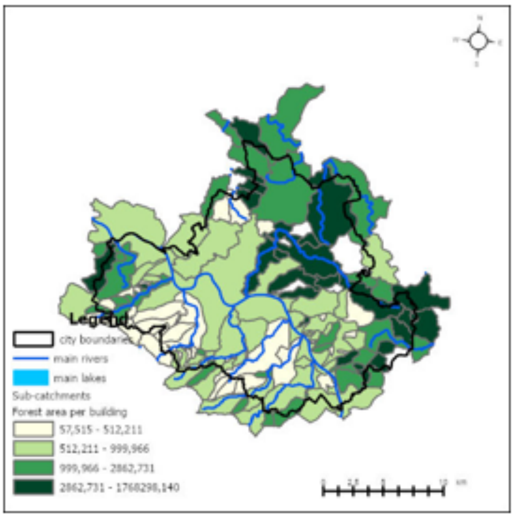
Descriptive statistics for cities

City	N significant	Mean	Minimum	Maximum	Standard deviation
Dresden	109	92,19	0,0000	100	15,6
Senica	12	58,47	0,00000	95,5	32,66
Jablonec	7	94,120	82,501	100,000	5,864

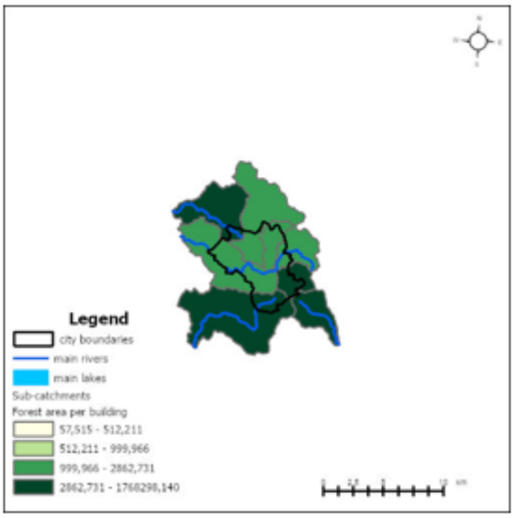
Poznań	39	72,885	28,40549	100,00	20,797

Summary: Dresden (92%) and Jabłoniec (94%) have the highest access to green spaces, which is an indicator of quality of life. Senica (58 %) fares the least in this regard, with a high standard deviation. In Poznań, poorer access to green spaces can be noted in peripheral catchment areas, where intense suburbanization is occurring.

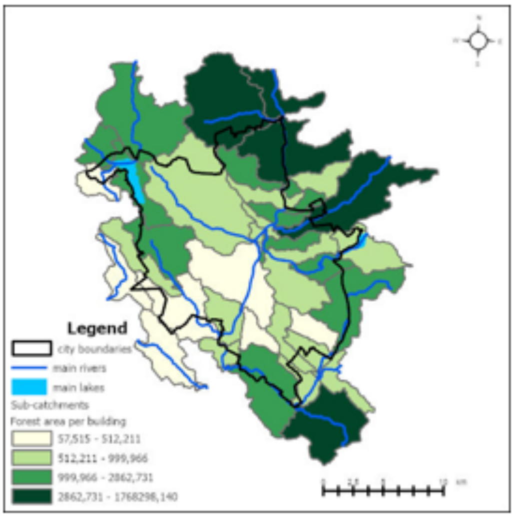
FOREST AREA PER BUILDING IN M^2



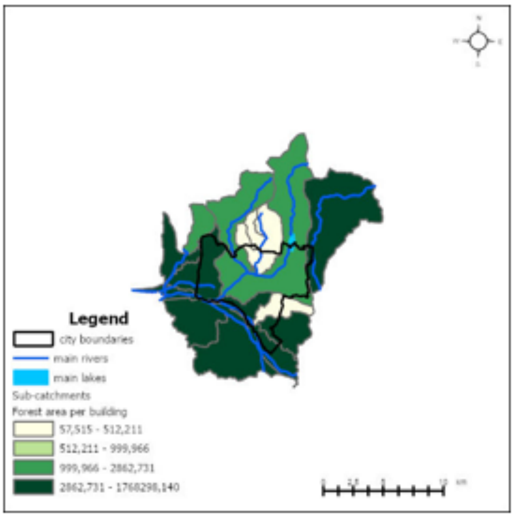
Dresden



Jablonec nad Nisou



Poznań



Senica

Descriptive statistics for cities

City	N significant	Mean	Minimum	Maximum	Standard deviation
Dresden	109	30527,63	144,1579	1768298	176146,9

Senica	12	17672,78	66,83699	160070,5	45095,67
Jablonec	7	3240,022	1676,839	5919,127	1424,220
Poznań	39	2517,218	57,51483	51614,66	8142,733

Summary: In this case, the Dresden sub-catchment area fares best, while the Senica catchment area fares worst. In Jablonec nad Nisou, on the other hand, the low standard deviation is significant, indicating little variation in this indicator across catchments.

4.3.2. Cluster analysis

The results of the cluster analysis based on the dendrogram (see below), assuming that the increasing level of dissimilarity is noticeable from the agglomeration distance above 22, indicate the existence of five basic groups of units (clusters) similar in terms of the examined features important from the point of view of planning restoration activities, taking into account the need to improve biodiversity, quality of life and adaptation of cities to climate change.

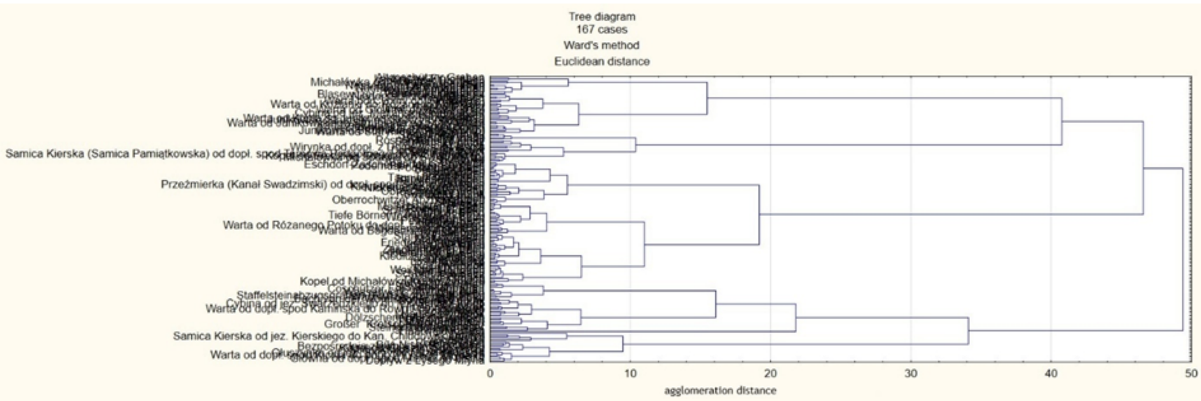


Figure: Dendrogram of sub-catchment clustering

The most numerous cluster is **cluster 4** (71 sub-catchments, including as many as 61 in Dresden). It is distinguished by very good accessibility to forests and parks. 95% of buildings are located in the zone with very good accessibility. This indicator is high despite the relatively low share of forests (20%). It includes numerous smaller catchments located mainly south of the Elbe river, including the upper section of the analyzed Geberbach stream (case study in Dresen).

Cluster 3 is only found in the two largest cities and is distinguished by a very high share of built-up areas (52.8%). It also has a low forest density combined with a high SHDI index. It is most abundant in southern Dresden and southwestern and central Poznań. It includes sub-catchment, were Piaśnica is located (case study stream in Poznań), as well as the lower reaches of the Geberbach stream.

All cities have sub-catchment areas belonging to clusters 1 and 5. **Cluster 5** is distinguished by a very high share of forests (75%) and the high availability of green spaces (parks and forests) near buildings. 98% of buildings are located within 300 meters of such facilities. The area of forest per building is also the highest here. On the other hand, it has the lowest share of built-up areas (9%).

Cluster 1, on the other hand, includes the largest catchments (average 35 km^2), including the Elbe River in Dresden. This cluster also has the highest average SHDI (1.77). This cluster is most numerous in Jablonec nad Nisou. It includes the Bila Nysa and Teplica sub-catchments, which are being analyzed in detail in the project. In Jablonec nad Nisou there are only catchments belonging to the two mentioned clusters 1 and 5.

Cluster 2 is most numerous in Poznań (8) and Senica (5). 42% of the sub-catchment in Senica falls into this group. It is distinguished by the lowest share of forests (9%) and the poorest access to green spaces (forests and parks). In Poznań, these catchments are located peripherally and are under significant pressure from suburbanization processes.

Table: Summary of indicators describing the obtained clusters - mean value

Cluster	SHDI	Sub-catchment area in km2	Share of forest in %	Share of built-up areas in %	Share of buildings located in the victinity of 300 m to parks etc. in %	Forest area per building in m^2
1	1,77	35,23	41,03	14,35	82,39	5571,31
2	1,06	7,82	9,43	10,80	34,67	1486,44
3	1,47	7,85	24,57	52,80	82,38	618,28
4	1,29	2,90	20,54	15,22	94,60	7884,41
5	1,12	5,46	74,86	9,28	97,46	102077,88
Total	1,32	8,12	31,72	21,08	85,34	21918,78

Table: Summary of indicators describing the obtained clusters - standarised mean value

Cluster	SHDI	Sub-catchment area in km2	Share of forest in %	Share of built-up areas in %	Share of buildings located in the victinity of 300 m to parks etc. in %	Forest area per building in m2
1	1,03	2,35	0,21	-0,27	-0,14	-0,11

2	-0,49	0,01	-0,91	-0,45	-2,38	-0,14
3	0,39	0,01	-0,38	1,67	-0,14	-0,15
4	0,00	-0,41	-0,52	-0,23	0,44	-0,10
5	-0,37	-0,19	1,41	-0,53	0,57	0,56
Total	0,06	0,04	-0,12	0,07	0,00	0,00

Table: Summary of clusters according to cities.

Cluster	City	Number of sub-catchments	Share
1	Dresden	3	1,80%
	Jablonec	3	1,80%
	Poznań	9	5,39%
	Senica	2	1,20%
	Sum	17	10,18%
2	Dresden	4	2,40%
	Poznań	8	4,79%
	Senica	5	2,99%
	Sum	17	10,18%
3	Dresden	20	11,98%
	Poznań	13	7,78%
	Total	33	19,76%
4	Dresden	61	36,53%
	Poznań	7	4,19%
	Senica	3	1,80%
	Sum	71	42,51%
5	Dresden	21	12,57%
	Jablonec	4	2,40%
	Poznań	2	1,20%
	Senica	2	1,20%
	Sum	29	17,37%
Total		167	100%

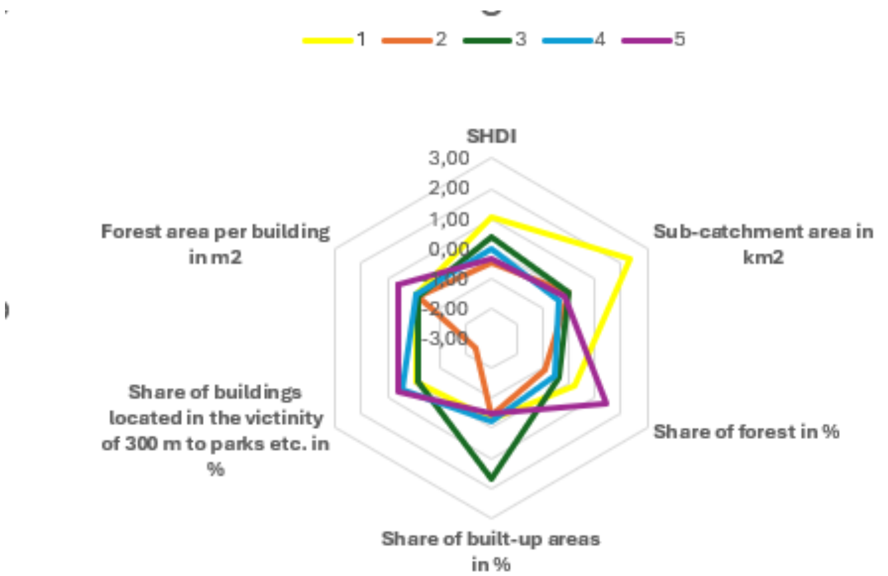
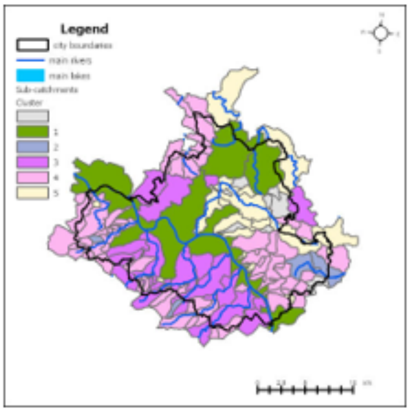
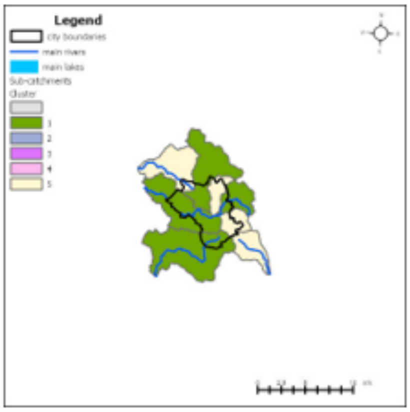


Figure: Radar plot for the designated clusters.

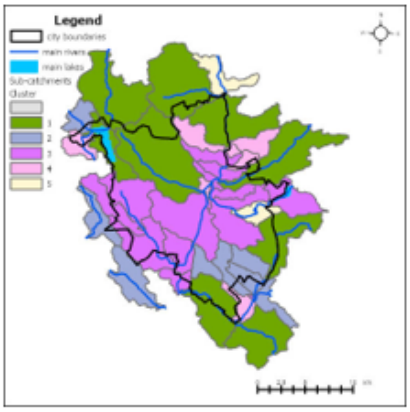
Cluster analysis results for catchments in individual cities



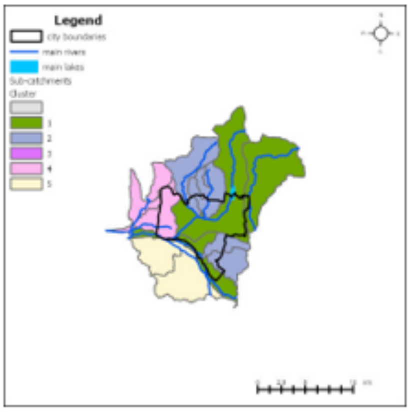
Dresden



Jablonec nad Nisou



Poznań



Senica

5. Conclusions

The assessments of ecosystem services at the pilot level are done in a way that they can provide an evidence base for decisions about what and how measures can be applied to enhance the ecosystem services with only small inputs but maximum effectiveness to enhance the benefits for the population. Measures will be identified by a before-after comparison; that is, the flexible ecosystem services assessment methodical framework should be applied to the recent situation as well as to suggested alterations. Alterations with the best improvement of values would be selected, also in view of different services and other factors to avoid trade-offs. The way is to identify these sections, where a slight change of single parameter will be enhancing the service by a maximum.

The city-level stream segment analysis examines all streams in the four cities using variables related to biodiversity, climate adaptation, and quality of life, all of which can be measured through open spatial data. Using the in-stream biodiversity measurements obtained from the pilot cases, the spatial variables were further validated to confirm their suitability as proxies for representing in-stream biodiversity. Through clustering analysis, the resulting typology provides cross-case information on patterns which allow for identifying context-specific and transferrable stream restoration potentials. Six distinct cluster types were identified. The pilot sites in Senica fall into Cluster 1 (characterized by high biodiversity and low canopy cover), while the pilot sites in the other three cities fall into Cluster 4 (characterised by high imperviousness and low visibility). Each cluster highlights both strengths and limitations in the associated variables, which should be taken into account when planning future restoration strategies.

Sub-catchment-level analysis is useful, on the one hand, to contextualise the findings from stream segment analysis with other local variables and, on the other hand, to draw higher sub-catchment level decisions for targeted stream restoration. Seen in the context of sub-catchment-level analysis, the pilot sites were classified into different clusters. Teplica (Senica) and Bila Nysa (Jablonec nad Nisou) are part of Cluster 2, which is characterized by a high biodiversity index associated with the Shannon Index (SHDI). This cluster also includes the largest sub-catchments. Cluster 3, in turn, includes Piaśnica (as part of a larger catchment - of Maltańskie Lake) in Poznań and the lower reaches of the Geberbach stream. Cluster 3 occurs exclusively in the largest analyzed cities, i.e., Poznań and Dresden, and is characterized by a very high share of heavily urbanized and built-up areas (53%), a relatively low share of forests, and a relatively high biodiversity index.

Restoration should be carried out along the entire length of the stream and ensuring good water quality is an important aspect, which is directly related to the development and use of the entire catchment. From the perspective of the urban issues addressed in the project, Cluster 3 seems more representative and poses the greatest challenge. Additionally, the upper Geberbach stream has been included in Cluster 4. It is distinguished by very good accessibility to forests and parks. 95% of buildings are located in the zone with very good accessibility. This indicator is high despite the relatively low share of forests (20%). It includes numerous smaller catchments located mainly south of the Elbe river,

The results of the urban spatial analysis will be combined with the results of the other parts of the multi-perspective analysis to inform the analysis of synergies and conflicts.

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Appendix

Appendix A: Mapping sheet for urban stream structure recording

Renner et. al (2018) Anleitung für die Strukturkartierung kleiner urbaner Fließgewässer

Protokol structural analyses urban streams

River name: ______________ editor: __________ Date: ______________
Section: ______________ Section from: __________ to: ______________

River type
- strongly changed ☐
- atificial stream ☐

Documentation
foto No: __________

Direction of flow: ________

Special stream characteristics

special features:
- None ☐
- Section > 50% in pipe ☐
- Temporarily waterfilled ☐
- Stream permanently dry ☐
- Standing water body ☐

Measures of profile

Upsite width	m
Water width	m
Profile depth	m
Water depth	cm

Remarks:

Shade:
- 0-20% shadow ☐
- 21-40% shadow ☐
- 41-60% shadow ☐
- 61-80% shadow ☐
- 81-100% shadow ☐

Water body maintenance:
- Almost no maintenance ☐
- Cut of ☐
- Grass cut ☐
- Partly plantreed removal ☐
- Complete reed removal ☐
- Basic water plant removal ☐

Leaves (within channel)
- no ☐
- 1-2 different sorts ☐
- 3-5 different sorts ☐

Transverse facilities:
- Barrage ☐
- Bottom slide/ramp ☐
- Bottom drop ☐
- Bridge ☐
- Underpass ☐
- Other ☐
- No transverse ☐

Odour
- almost odourless, fresh ☐
- Odour present, not unpleasant ☐
- Unpleasant musty odour ☐

Color
- colourless, clear ☐
- slightly cloudy ☐
- more clouded ☐

Profile/ Stream Course

Dominant profile type
- (Near-) natural profile [1]
- Changing development [2]
- Decayed technical profile [3]
- trapezoid profile [4]
- Fully constructed profile [5]

Course of stream (bonus)
- meandering [1]
- stretched [2]

Continuousness (for fish/mzb)
- yes [1]
- no [5]
- limited [3]

Stream diversity (bonus)
- moderate-good [1]
  > 3 different structures & shapes
- small [2]
  < 2 differentstructures& shapes

Stream bed

Bed substrate / diversity

	Main	2nd
Mud, slush		
Clay, loam, silt		
Sand		
Gravel		
Stones, rocks		
Turf/peat		
Organic material		

Rating: 4-5 x = Ind. 1, 3 x = Ind. 2

technical bed (> 50%)
- Partly technical bed [4]
- Massive technical bed [5]

Bed pollutions

	High	Medium	Low
Organic waste	5	4	3
Digested sludge	5	4	3
Littering	5	4	3
Substrate erosion	5	4	3
Iron clogging	5	4	3
Algae growth	5	4	3

Special bed structures
- many [1]
- few / slight [2]

such as: stagnant or rushing water zones, potholes, eddies, dead wood, shallowsroots, islands,

Bed construction (>10-50%) [4]
- Stone or gravel placement [4]
- unjointed stone setting/paving [4]
- Concrete with sediment [4]
- Concrete without sediment

Base of embankment

embankment

	L	R
continous	1	1
Almost half of the section	2	2
Several parts exist	3	3
Single parts exist	4	4
Not existing	5	5

technical embankment > 30%
- Biological/fascine [3]
- Bank lawn [3]
- Stone embankment [4]
- Wooden construction [4]
- Pavement [4]
- Raw construction [4]
- Concrete Wall [5]

Page 1

Stream bank characteristics

Vegetation

	L	R	L	R
	>50%		>20%	
Autochtonous forest	1	1		
Reed	1	1		
Autochtonous tree galery	1	1		
Autocht. single shrubs	2	2		
Tiered treeline/hedgerow	2	2		
Herbaceous vegetation	2	2		
Allochthonous trees/shrubs	3	3		
Meadow, lawn	3	3		
Allochthonous tree galery	4	4		
Allochthonous forest	4	4		
Massive constructions	5	5		
Digholes, stairs	5	5		

Special bank structures

many	1
few / slight	2

such as: nesting wall, clash tree, dugout, root wall, fallen tree, bank nose, breakout, overhanging plants

Visible bank pollutions

	Much	Less	Few
Organic waste	5	4	3
Littering	5	4	3
Step damages	5	4	3
Iron clogging	5	4	3
Sewage pass	5	4	3
Rainwater pass	5	4	3
Drainage	5	4	3

3x "few"= Index 5, 2x"Less"= Index 5

Bank constructions (beyond embankment)

	>30%
Biological/fascine	3
Bank lawn	3
Stone embankment	4
Wooden construction	4
Pavement	4
Raw construction	4
Concrete, wall	5

Stream environmental characteristics

Land use and vegetation (within 50 m on both stream sides from the top edge of embankment)

	L	R	L	R
	>50%		>20%	
Autochtonous forest	1	1		
Near-natural e.g. reed	1	1		
Succession, fallow	2	2		
Hedge, shrubs, grove	2	2		
Meadow, lawn	2	2		
Agricultural grassland	3	3		
Park, urban greenery	3	3		
Forest	3	3		
Garden, orchard, nursery	3	3		
Biodiverse cemetry	3	3		
Solar plant, rainwater pool	3	3		
Recreation / sports	4	4		
Acre field	4	4		
Cemetry poor structured	4	4		
Housing with greenery	4	4		
Housing dense built-up	5	5		
Industrial, commercial	5	5		
Public place, transport	5	5		

pollution of the water's edge areas (within 10 m on both stream sides from the top edge of embankment)

Water-critical facilities	5
Paved transportation area	5
Mining, dighole, dump	5
Dike, wall	5
Rubble, littering,	5
organic waste	5

River buffer strip (within 3 m on both stream sides from the top edge of embankment)

	L	R
Forest, Treeline	1	1
Near-natural e.g. reed	1	1
Succession	2	2
Species rich meadow	2	2
Park, grassland	3	3
Garden, forest, acre	4	4
Non-paved pathway	4	4
Partly paved area	4	4
Completely paved	5	5

Socio-cultural characteristics

Visibility of the stream

very well	1
well	2
medium	3
hardly	4
not visible	5

Passability of the area

very well	1
well	2
medium	3
hardly	4
not possible	5

Peculiarity of the river

very well	1
well	2
medium	3
small	4
not to mention	5

Livability of the streamside area

very high	1
high	2
medium	3
small	4
not valuabel	5

Accessibility to the water

very well	1
well	2
medium	3
hardly	4
not possible	5

Page 2

Evaluation matrix		Index	mean
Profile	Dominant profile type		
	Course of stream (bonus)		
	Continuousness (for fish and mzb)		
	Stream diversity (bonus)		
stream bed	Bed substrate / diversity		
	technical bed		
	Bed pollutions		
	Bed construction (>10-50%)		
	Special bed structures		
Base of Embankment	embankment		
	technical embankment		
Stream bank charactersitics	Vegetation		
	Special bank structures		
	Visible bank pollutions		
	Bank constructions		
stream environmental characteristics	Land use and vegetation (10-50m)		
	pollution of the water's edge areas (3-10 m)		
	River buffer strip (until 3 m)		
Socio-cultural characteristics	Visibility of the stream		
	Livability of the streamside area		
	Passability of the area		
	Accessibility to the water		
	Peculiarity of the stream		
Overall mean			

Appendix B: Overview of the methodical framework and data need for the assessment of regulating and cultural ecosystem services (Table by Henriette John)

	simple Approach		Enhanced Approach			
Ecosystem Service	Indicators/ parameters	Parameters/Block from Structural Mapping	Sub-Service	Indicators/ parameters	Parameters/Block from Structural Mapping	Additional (mostly external) Data
Flood regulation	Retention of surface water	River buffer strip Bank constructions Vegetation			Block River bed Block Stream bank characteristics Block River environmental characteristics	DGM 10 Map with HQ 100 Maps with dikes and longitudinal
Low water regulation		Block River bed Block Stream Bank characteristics Transverse facilities				
Sediment regulation		Block River bed Transverse facilities				
Cooling effect		Shade Land use and vegetation			Shade Land use and vegetation	On-site mapping photos aerial images
Retention of		Land use and vegetation				
Habitat provision / biotope type assessment	Bank characteristics	Bank constructions Vegetation Visible bank pollutions			Transverse facilities	Map of biotope types FFH - maps & - conservation status Red List - Biotopes Satelite images
	Environmental characteristics	River buffer strip Land use and vegetation				
Habitat provision / river	Stream characteristics	Stream diversity Continuouness			Block River bed Stream diversity Block Stream bank characteristics Accessibility to the water Shade	WFD-Data on biological condition (Fish, Phytoplankton, Makrozoobenthos, Makrophyten/Phytobenthos) WFD-Data on chemical condition
	Bed characteristics	Bed substrate / diversity Bed pollutions				
	Bank	Technical embankment Pollution of water's edge areas				
Habitat provision (Habitat quality)	Structural diversity of waterbody and	Land use and vegetation Vegetation River buffer strip				
	Bed, bank, and profile conditions	Bed substrate/diversity Special bed structures, Bed Profile/Stream Course				
	Environmental impacts	socio-cultural characteristics Visible bank pollutions Pollutions of the water's edge areas				
Aesthetic ecperiences	bed and bank characteristics	aggregated value		Perceived naturalness of land use/land cover classes	Vegetation Land use and vegetation	Copernicus Riparian Zones, Survey-results on popularity of design elements of the stream
	environmental characteristics	Visibility of the river Land use and vegetation		Naturalness - absence of unnatural elements	all parameters that contain constructions/pollutions	OpenStreetMaps (OSM), Digital landscape model (DLM)
				Peculiarity/rarity - rare land use types	Peculiarity of the river	
Nature experience & tranquillity promoting health, recuperation or enjoyment through passive or observational interactions with the river landscape				Accessible/viewable type-specific special habitats (gravel & banks, riverbank breaks, deadwood structures, wet & marshy meadows, semi-dry meadows, hot lands)	Partial: Vegetation, Land use and Vegetation, Special bed structures, Special bank structures	On-site mapping photos, aerial images
				Naturalness - absence of unnatural elements (e.g. bridges, paved roads, railway lines, power lines, wind	Partial: Transverse facilities, Land use and vegetation, Vegetation, Bank constructions	OSM, DLM
				Naturalness - morphological condition	Overall rating of watercourse structure mapping	In Germany: Karten zum 3. WRRL-Bewirtschaftungsplan (BfG)
				Naturalness - land use/land cover	Block River environmental characteristics Vegetation	Copernicus Riparian Zones
				Accessibility of the riverbank	Accessibility	
				Silence: Noise-reduced areas	Partial: livability	Environmental Agency of the city, noise maps, OSM, photos
health, recuperation or enjoyment through active or immersive interactions with the river landscape			Hiking, running	Presence of paths (including unofficial paths and trails)	Indirectly in: Passability	OSM, DLM, on-site mapping photos
			cycling	Presence of cycle paths (including unofficial paths that can be used by bicycles)	Indirectly in: Passability	OSM, DLM, city map, on-site mapping photos
			swimming,	Bathing prohibition	-	information via water agencies and/or public authorities
			splashing	Typical water hazards	Indirectly in: transverse facilities, special bed structures	On-site mapping photos
				Morphological condition of the water body	Indirectly in first four blocks + transverse facilities	National WFD publications, In Germany: Karten zum 3. WRRL-Bewirtschaftungsplan (BfG)
				Biochemical status of the water body	Partial: Odour, Colour, Bed pollution, Visible bank pollution, Pollution of the water's edge areas	Maps/data sets of WFD, In Germany: Karten zum 3. WRRL-Bewirtschaftungsplan (BfG)
				Bathing areas (shallow banks)	Indirectly in: Special bed structures, Accessibility	On-site mapping photos
				Water depth	Water depth	
			non-motorised boating	Water body width	Water body width	
				Water depth	Water depth	
				Transverse structures	Transverse facilities	On-site mapping photos, In Germany: Karten zum 3. WRRL-Bewirtschaftungsplan (BfG)
				Boat landing site (including natural spots like sand banks)	partially and indirectly in: Special bed structures, Accessibility	On-site mapping photos, aerial images, city map, OSM, waterway map
			fishing	Sections without fishing ban	-	information via State fishing associations, environmental agencies
				Accessibility of the riverbank: No obstacles on the banks and paths	Accessibility, Passability	
				Sole dynamics	Dominant profile type, river bed	
				Special habitats typical of the water	Special bed structures, Special bank	On-site mapping photos, aerial images
Education				Areas where education is supported by infrastructure (e.g. viewing platforms, information boards, information centres, themed trails, etc.)	Partial: livability	field mapping, web search
Quality of life in stream		River environmental characteristics socio-cultural characteristics				

Appendix C: Methodical framework for assessing the cultural ecosystem services (Table by H. Kamps, basing on Hayes et al. 2022)

CES class according to CICES V 5.2a	CES	Indicators/parameters	Included in watercourse structure mapping	Other data source	Calculation and limit valuesb
Elements of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	Hiking, running	Presence of paths (including unofficial paths and trails)	Indirectly in "Passability"	OpenStreetMaps (OSM), Digital landscape model, on-site mapping	[1] if passability < 3 otherwise [0] (cf. Hayes et al. 2022: 488; cf. Scheikl et al. 2021: 131)
	Cycling	Presence of cycle paths (including unofficial paths that can be used by bicycles)	Indirectly in "Passability"	OpenStreetMaps (OSM), Digital landscape model, city map, on-site mapping	[1] if passability 1 or 2, otherwise [0] (cf. Hayes et al. 2022: 488; cf. Scheikl et al. 2021: 132)
	Swimming, splashing	Bathing prohibition	No	On-site mapping	Swimming ban is only marked on the map, no basis for evaluation (cf. Scheikl et al. 2021: 134)
		Typical water hazardsc	Indirectly in "transverse facilities", "special bed structures"	On-site mapping	Must be set to [1] or [0, K.O.-criterion] based on on-site-observations or pictures
		Morphological condition of the water body	Indirectly in first four blocks plus transverse facilities	National EU-WFD publications In Germany: Bundesanstalt für Gewässerkunde: Karten zum 3. WRRL-Bewirtschaftungsplan	Still in development, must be adapted to bathing
		Biochemical status of the water bodyc	Partial ("Odour", "Colour", "Bed	Maps/data sets of the EU Water Framework Directive	If EU-WFD data is available:

			pollution", "Visible bank pollution", "Pollution of the water's edge areas")	In Germany: Bundesanstalt für Gewässerkunde: Karten zum 3. WRRL-Bewirtschaftungsplan	[1] if overall status according to WFD < 3 Otherwise [0] If WRR data not available: [1] if saprobic index class < 3 Otherwise [0] Saprobic index class according to Rolauffs et al. 2003 or comparable
		Bathing areas (shallow banks)	Indirectly in parameters "Special bed structures" and "Acces-sibility"	On-site mapping, image interpretation	[1] if shallow banks are present Otherwise [0] (Hayes et al. 2022: 488; Scheikl et al. 2021: 133)
		Water depth	Yes		Not included in the assessment but can be used to distinguish between swimming and splashing (Scheikl et al. 2021: 134). Either textual distinction or different cartographic representation
	Non-motorised boating	Water body width	Yes		[0, K.O.-criterion] if water width <5 m [1] if water width ≥ 5 m (Hayes et al. 2022: 488; Scheikl et al. 2021: 135)
		Water depth	Yes		[0, K.O.-criterion] if water depth < 60 cm [1] if water depth ≥ 60 cm (Hayes et al. 2022: 488; Scheikl et al. 2021 135)

		Transverse structures	Yes ("Transverse facilities")	On-site mapping, In Germany: Bundesanstalt für Gewässerkunde: Karten zum 3. WRRL-Bewirtschaftungsplan	[0, K.O.-criterion] if stream crossed by transverse facility except bridge Otherwise [1] (Hayes et al. 2022: 488; Scheikl et al. 2021: 135)
		Boat landing site (including natural landing spots like sand banks)	No, only partially and indirectly in "Special bed structures" and "Accessibility"	On-site mapping, aerial image interpretation, city map, OSM, waterway map	If shallow banks or boat landing sites available [1] Otherwise [0] (Hayes et al. 2022: 488; Scheikl et al. 2021: 135)
	Fishing	Sections without fishing ban	No	State fishing associations, environmental agencies	Sections with fishing ban are only described (e.g. as map layers) (Scheikl et al. 2021: 138)
		Accessibility of the riverbank: No obstacles on the banks and paths	Yes ("Accessibility" and "Passability")		[1] if accessibility AND passability < 3 Otherwise [0] (cf. Hayes et al. 2022; cf. Scheikl et al. 2021)
		Sole dynamics	Yes ("Dominant profile type", "riverbed")		[0] if profile type = 5 OR riverbed has technical bed or bed construction Otherwise [1] (cf. Mühlmann 2013:22, 40-44; cf. Scheikl et al. 2021: 137)
		Special habitats typical of the water body	Yes ("Special bed structures", "Special bank structures")	On-site mapping, aerial image interpretation	[1] if special bed structures = 1 OR special bank structures = 1 Otherwise [0]
Elements of living systems that	Nature experience	Accessible/viewable type-specific special habitats (gravel and	Partial ("Vegetation", "Land use and	On-site mapping, aerial image interpretation	[1] if (special bed structures = 1) OR (special bank structures

enable activities promoting health, recuperation or enjoyment through passive or observational interactions	& tranquillity	sand banks, riverbank breaks, deadwood structures, wet and marshy meadows, semi-dry meadows, hot lands)	Vegetation", "Special bed structures", "Special bank structures")		= 1) OR (Land use and vegetation = meadows) OR (vegetation = meadows) Otherwise [0] (cf. Scheikl et al. 2021: 146f)
		Naturalness - absence of unnatural elements (e.g. bridges, paved roads, railway lines, power lines, wind turbines)	Partial ("Transverse facilities", "Land use and vegetation", "Vegetation", "Bank constructions")	OSM, Digital Landscape Model	[0] if transverse facilities are present OR dominant profile type = {Decayed technical profile; trapezoid profile; fully constructed profile} OR vegetation = {Massive constructions, Digholes, stairs} OR bank constructions = {Stone embankment; Wooden construction; Pavement; Raw construction; Concrete, wall} OR land use and vegetation = {Solar plant, rainwater pool; Recreation / sports; Acre field; Cemetery poor structured; Housing with greenery; Housing dense built-up; Industrial, commercial; Public place, transport } OR pollution of the water's edge areas = 5 OR river buffer strip = {Partly paved area; Completely paved} Otherwise [1]
		Naturalness - morphological condition	Overall rating of watercourse structure mapping	In Germany: Bundesanstalt für Gewässerkunde: Karten zum 3. WRRL-Bewirtschaftungsplan	[1] if overall mean < 2.5 [0] if overall mean ≥ 2.5
		Naturalness - land use/land cover	River environmental characteristics (5th block) plus vegetation	Copernicus Riparian Zones	[1] if river environmental characteristics < 3 AND vegetation = {Autochtonous forest;

					Reed; Autochtonous tree galery; Autocht. single shrubs; Tiered treeline/hedgerow; Herbaceous vegetation} Otherwise [0]
		Accessibility of the riverbank	Yes ("Accessibility")		[1] if accessibility < 3 Otherwise [0]
		Silence: Noise-reduced areas	Partially in livability	Environmental Agency of the city, OSM, photos	[1] if livability < 3 Otherwise [0]
Elements of living systems that enable education and training, including the importance of between and within species genetic diversity	Education	Areas where education is supported by infrastructure (e.g. viewing platforms, display and information boards, information centres, adventure and themed trails, etc.)	Partially in livability	Local Agencies	Only described and marked on map (Scheikl et al. 2021: 144)
Elements of living systems that enable aesthetic experiences	Beauty and landscape	Perceived naturalness of land use and land cover classes	Yes ("Vegetation", "Land use and Vegetation")	Copernicus Riparian Zones, Survey-results on popularity of design elements of the stream	[0] if vegetation = {Massive constructions; Digholes, stairs} OR land use and vegetation = {Garden, orchard, nursery; Biodiverse cemetry; Solar plant, rainwater pool; Recreation / sports; Acre field; Cemetry poor structured; Housing with greenery; Housing dense built-up; Industrial, commercial; Public place, transport} Otherwise [1]

					(cf. Scheikl et al. 2021: 146) Should be updated to survey results (popularity of the design elements)
		Naturalness - absence of unnatural elements	Yes, blocks 1-3 plus "land use and vegetation"	OSM, DLM	[0] if transverse facilities are present OR dominant profile type = {Decayed technical profile; trapezoid profile; fully constructed profile} OR vegetation = {Massive constructions, Digholes, stairs} OR bank constructions = {Stone embankment; Wooden construction; Pavement; Raw construction; Concrete, wall} OR land use and vegetation = {Solar plant, rainwater pool; Recreation / sports; Acre field; Cemetery poor structured; Housing with greenery; Housing dense built-up; Industrial, commercial; Public place, transport } OR pollution of the water's edge areas = 5 OR river buffer strip = {Partly paved area; Completely paved} Otherwise [1]
		Peculiarity/rarity - rare land use types	Yes "Peculiarity of the river"		[1] if peculiarity < 3 Otherwise [0]

a Scheikl et al. (2021) used CICES V5.1, we updated classes to CICES V5.2 (CICES 2023)

b Values in square brackets represent the value assigned to each parameter (cf. Hayes et al. 2022: 489)

c These parameters are not part of Scheikl's original method but were added by us to better fit our data