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Assessment of the Connectivity and Comfort of Urban Rivers, a Case Study of the Czech Republic

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Abstract: This article investigates public spaces near urban rivers that contribute to the interaction between natural and urbanized areas and between people from different socio-economic backgrounds. The main goal of this study was to evaluate the environment of the largest urbanized areas of the Czech Republic, through which a large watercourse flows and creates a direct interaction with the city center. To evaluate the state of connectivity and comfort of urban rivers in the Czech Republic, a set of tools was applied to three cities: Prague, České Budějovice, and Hradec Králové. The methodology was created to correspond to the territory of Central Europe and was used for the specific assessment of rivers in four dimensions: (a) the spatial and visual accessibility, (b) the condition of the green corridor, (c) the condition of public space, and (d) the condition of the first built line. The dimensions are expressed using thirteen quantitative indicators of the environmental condition. The methodology uses the Urban River Sustainability Index (URSI), which was necessary to adjust the calculations of the indicators and resources for the Central European area. The best results were found in the central part of Prague and the worst in the peripheral part of Hradec Králové. The results call for the use of connectivity and comfort assessments of urban rivers for comparison, motivation, and future improvement in practice.

Keywords: urban rivers; connectivity; comfort; waterfront; Czech Republic; URSI

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1. Introduction

The river comprises a unique ecosystem based on the wide range of functions and services it provides to society and the various flora and fauna species [1]. Anthropogenic interventions into this ecosystem significantly affect its condition and the hydrodynamics of the river. At present, this issue is viewed as a fundamental process of global environmental change, with the impacts manifesting at the regional level [2]. Together with vegetation, watercourses are important habitats for many species of organisms as they help their spread and movement through the landscape [3,4]. Rivers enable the interaction between urbanized areas and the natural environment [5].

Although urban areas occupy only about 4% of the total land surface [6], today, more than half the entire human population live in cities [7]. Rivers flowing through cities provide ecological benefits, including water supply, pollution control, and biological protection [8]. The social benefits include places for leisure, recreation, and education [9]. The economic benefits, including tourism and increased land prices, are also important. As the public prefers riverscapes [10], rivers are the cities' most attractive and active zones [11]. Despite this, urban riverbanks have undergone serious degradation processes caused by factors such as a lack of planning and real estate pressures [12,13].

The river landscape should be understood as an ecosystem, which is strongly influenced by its surroundings at different spatial levels [14,15]. The river system is a carrier of water resources, a component of the ecological environment, and the basis of economic and social development [16]. Among the social benefits are opportunities for the population to be in contact with the natural environment and support its local social life [17]. It is in this respect that the term "watercourse comfort" is introduced. Urban rivers and waterfronts must have characteristics that allow people to have a comfortable presence [18]. Waterfronts should be attractive localities that are sought out by residents for recreation. They are designed as areas that encourage a longer stay and provide a wide range of leisure activities. The character may vary depending on the needs of the inhabitants, although access to and contact with the water is usually allowed. The ideal use of waterfront areas is their transformation into public spaces [19].

Watershed connectivity refers to the movement and availability of water (and everything that water carries) from one part of the landscape to another. The concept of connectivity has long been considered only as a factor in the distribution of species. Therefore, it has mainly been used in the context of biology and landscape ecology concerning landscape corridors and their connections [20]. Vegetation is one of the most important factors in the urban landscape, especially in terms of its connection with all the other factors. It is the primary factor affecting the connectivity of the basin at all scales (spatial and temporal) [21–23] Vegetation, together with water bodies, can moderate warming due to climate change [24,25]. As a linear water body, wider rivers have a remarkable ability to regulate the thermal environment [26].

Changes in connectivity can have a significant effect on all processes in the watershed [27,28]. The connectivity of an urban water system also has economic effects, such as improving the water quality, providing recreational sites, and increasing property values [29,30]. With watershed connectivity, it is important to consider how the system changes through different processes; this means changes in the characteristics of the territory and the distribution of some elements [28]. Two separate parts of connectivity are generally identified—structural and functional connectivity [31]. Ecologists and hydrologists use connectivity to measure natural integrity and ecosystem health in terms of biodiversity, while designers use it for human spatial accessibility to integrate urban life with the river [32]. For urban planners, the primary functions of riverbanks are to allow convenient access for the population while visually and conceptually connecting the river and the city [32].

Hemida et al. [33] bring a methodology for the assessment of the connectivity and comfort of urban rivers. This methodology is primary based on an using the URSI—Urban River Sustainability Index calculations. It is an index that evaluates rivers in four dimensions: (a) spatial and visual accessibility, (b) the state of the green corridor, (c) the state of public space, and (d) the state of the first constructed line. The dimensions are expressed using thirteen quantitative indicators to reveal specific deficiencies in the territory using numerical results or map visualizations. Currently, it is the only available methodology that deals with the evaluation of the unique environment of rivers in the city in terms of connectivity and comfort for residents. The high clarity of the index calculation and its complexity is a positive aspect. The numerical results of the index can be used to evaluate specific positive and negative aspects of the analyzed territory. Among the negatives of the original methodology is the focus of computing resources on the different environment in which it was originally applied. So, an implementation of this index in different territories is limited due to different data sources and local conditions.

The main purpose of this article is to evaluate the connectivity and comfort of urban river areas in the Czech Republic. The method is based on the Urban River Sustainability Index (URSI) [33].

The following goals were formed to evaluate the issue and the contribution of the evaluation methodology in the Czech Republic; their task is to outline the situation around urban rivers in the Czech Republic and to point out specific weak points of the territory.

1. To bring a methodology that corresponds to the territory of the Czech Republic/Central Europe for the specific assessment of the connectivity and comfort of urban rivers.
2. To evaluate the quality of connectivity and comfort of urban rivers in the Czech Republic (according to URSI) and try to determine if the size of the cities according to the number of inhabitants is related to the evaluated aspects.
3. To define a share of areas with an optimal and acceptable value in the selected zones in the Czech Republic.

The main scientifical contribution and novelty of this article is in an expert modification of the URSI to correspond to the territory of Central Europe for the specific assessment of rivers. The modified methodology specifies the local problems in the area and can have a positive effect on improving the quality of the environment. As an alternative, the European ECI TIMUR 2006 set was considered, specifically, the ECI A.4 indicator or the Coefficient of Ecological Stability (KES) method. However, neither of these methods were entirely suitable. ECI TIMUR primarily evaluates the economic and social pillars of the city's development [34]. The KES method is not very objective—the indicator's accuracy depends on the data source, which is derived from the types of land listed in the real estate cadaster, which are often inaccurate and outdated [35,36].

2. Methodology

Study Area

A methodology for the assessment of connectivity and comfort of urban rivers was used for the evaluation of the territory. This evaluation model is based on the concepts of connectivity and comfort in four dimensions: (a) spatial and visual accessibility, (b) condition of the green corridor, (c) condition of public space, and (d) condition of the first built line. Each dimension is composed of quantitative status indicators. This overview of the assessment originates from literary references, e.g., Hermida et al. [33]. The methodology created for this study brings a selection of indicators that are dependent on specific factors that can be applied to the environment of the Czech Republic, respectively, for European countries. The telling ability of numerical values and the appropriateness of setting numerical ranges for the final evaluation were also evaluated. Specific indicators and data sources are intended to assess the complexity of the environment [37].

The three most populated cities in the Czech Republic, which have watercourses near their historic centers, were chosen for the research (Figure 1). Prague, through which two rivers flow—the Vltava and Berounka—and a network of smaller watercourses. Prague is the capital of the Czech Republic with a population of 1,335,084 inhabitants, an area of 496.2 km^2, and a population density of 2537 inhabitants/km^2 [38]. The evaluation of this study deals with the Vltava, which is the longest river in the Czech Republic. It flows through Prague for a length of 31 km and it is 330 m at its widest point. The Vltava has nine islands on the territory of Prague [39].

České Budějovice, with 94,229 inhabitants, is the seventh most populous city in the Czech Republic. The area of the city is 55.6 km^2 and it has a population density of 1680 inhabitants/km^2. Two rivers flow through the territory—the Vltava and the Malše. The city is located in the South Bohemia region and its average altitude is 381 m.a.s.l. Since the beginning of history, the region has been famous for its rich network of ponds, which, despite various transformations, have been largely preserved to this day [40].

Hradec Králové is the eighth most populous city in the Czech Republic, with a reported population of 92,683 and a city area of 105.7 km^2. The population density is 877 inhabitants/km^2. The Elbe and Orlice rivers flow through the territory. The city is located in the Hradec Králové region in northeastern Bohemia and its average altitude is 235 m.a.s.l.

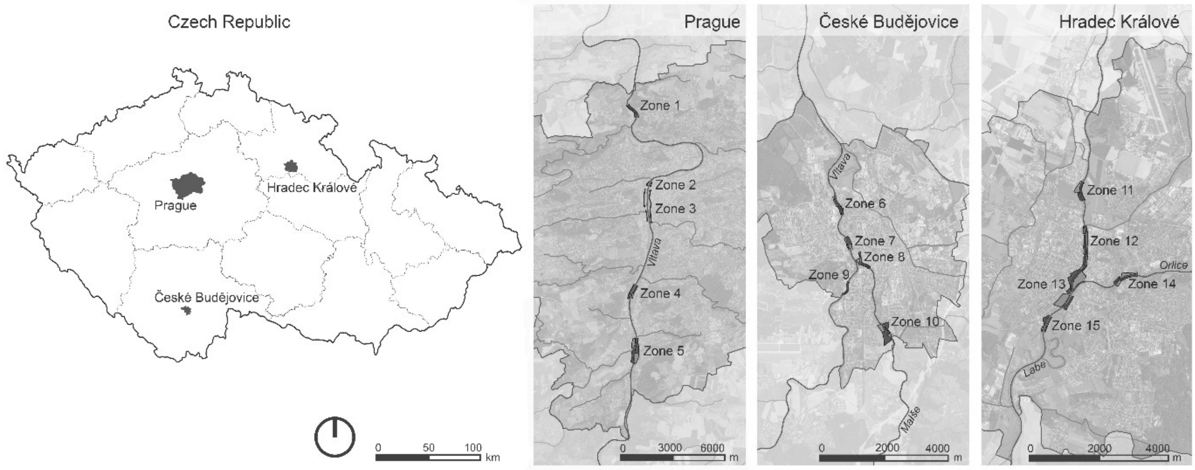

Figure 1. The designation of three studied cities and designation of fifteen analyzed zones in the individual cities in the Czech Republic.

The assessment could not be carried out in all areas near the rivers of the selected cities due to the high levels of difficulty in collecting and evaluating the monitored indicators. For this reason, it was necessary to select model locations in the monitored areas. For site selection, a statistical cluster analysis was performed so that homogeneous zones along the rivers in individual cities could be defined. Three data sets were used for the delineation: population density, land use, and percentage of vegetation. Data from the population and housing censuses [41,42], Census Hub [43], and population density map layer of the Inspire Geoportal [44] were used to calculate the population density. Corine Land Cover data [45], degree of urbanization data (DEGURBA) [46], and the Land Cover map layer of the Inspire Geoportal [44] were used to calculate land use. The results of the percentage of vegetation were obtained from the Green System document, which was processed in each city within the valid spatial plan and also from Copernicus High Resolutions Layers [47] and Natura 2000 [48] data. After processing the cluster analysis of the watercourse environment, five zones with specific representative characteristics were selected in each of the three investigated cities (Figure 1 and Table 1).

Table 1. Overview of quantitative description of zones by types for comparison.

Zone	City	Type of Territory	Number of Units
Z1	Prague	The northern border of the urban area—a quiet, recreational part of the city, built-up on one side of the bank of the watercourse.	3
Z6	Č. Budějovice		4
Z11	H. Králové		4
Z2	Prague	A representative part of the city.	4
Z7	Č. Budějovice		4
Z13	H. Králové		4
Z3	Prague	The historic center with waterfronts.	11
Z8	Č. Budějovice		9
Z12	H. Králové		10
Z4	Prague	Waterfront with linear greenery and a central cycle path.	4
Z9	Č. Budějovice		5
Z14	H. Králové		4
Z5	Prague	The southern border of the urban area—only partially built-up, and close to industrial areas and cottage areas.	4
Z10	Č. Budějovice		4
Z15	H. Králové		4

After delineating five zones in each city, points of discontinuity were identified, allowing these zones to be further divided into twenty-six analytical units. These rupture points are specific places where the continuity of movement has been interrupted due to different ownership regimes, bridging, the location of informal settlements, or elevated road infrastructures (Figure A1).

For a precise orientation in the methodology, the individual steps are shown in the diagram of research methodology (Figure 2). A design of the connectivity and comfort evaluation method/model for individual indicators requires a clear summary of the description of their purpose and the calculation process (Table 2). To be able to evaluate or compare the situation of a given city, a modified Urban River Sustainability Index (URSI) is used for this study. The URSI is an index that is calculated using the weight assigned to each indicator (Table 3). The indicators were measured for the final assessment in a total of 78 analytical units, 26 in each city. Each analytical unit was numerically evaluated on a scale from −2 to 2 as follows: 2 = optimum value, 1 = acceptable value, 0 = average value, −1 = deficient value, and −2 = detrimental value. Individual factors are defined by equations based on the measurement of species diversity using Fisher's alpha index [49], the conceptual basis of Shannon's formula [50], or partial calculations. Each indicator has its own numerical evaluation table, and the numerical result expresses the status of the indicator in the given analyzed unit. Along with the numerical results, the value can be expressed by map visualizations.

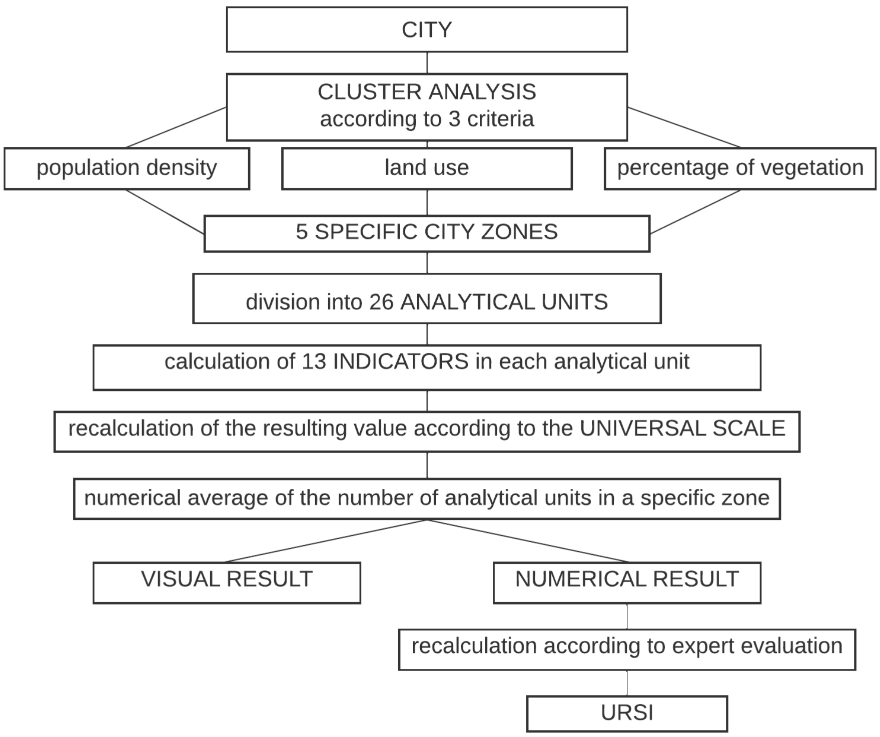

Figure 2. Diagram of research methodology (counted for one city).

Specific limitations were found in using the original URSI (Hermida et al. [33]) and so this study brings and works with a modified version of the original methodology of URSI. This is primarily a modification of the calculation formulas for 4 out of 13 indicators, which did not correspond to their specifications in the original version. These are the formulas of the 6th, 10th, 12th, and 13th indicators, which needed to be redefined mathematically by adding or changing the calculation formulas. Another major limitation was the original introduction of different initial data sources for the calculations of individual indicators. These could not be used for our conditions due to the original focus of the study on another continent. In this case, we introduced new sources that correspond to Central Europe's environment. In this case, the data and the derived indicators are defined and processed for the urban environment of the Czech Republic, respectively, for Europe (Table 2). Data source overview with a detailed description is documented in Table A1. Each evaluation indicator can be expressed as a spatial dimension through schematic maps (we present an example of indicator 1 in Figure 3) or as a numerical result.

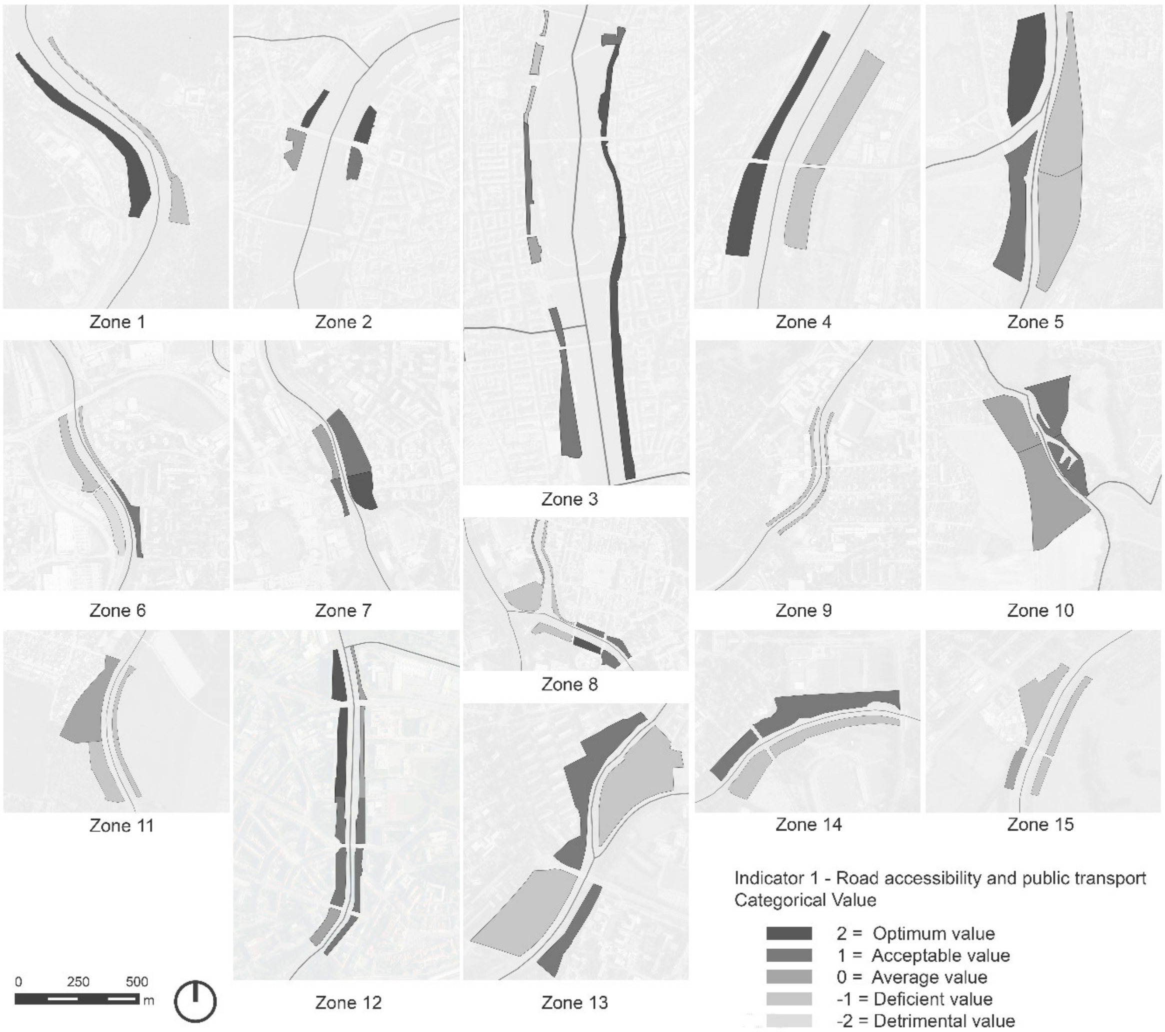

Figure 3. Data visualization: map of the result of indicator 1—road accessibility and public transport.

Table 2. Overview of evaluated factors.

Indicators	Weighing	Required Information; Sources
Connectivity		
a. Spatial and visual accessibility		
1. Road accessibility and public transport		
Evaluates the connection of the road network and different modes of transport to the given public space [51].		
AV = A + B **A: road accessibility** Has vehicular, pedestrian, and cycle path = 3 Has vehicular and pedestrian path = 2 Has pedestrian path = 1	Optimum: = > 3.5 Acceptable: = > 2.5 < 3.5 Medium: = > 1.5 < 2.5 Deficient: = > 0.5 < 1.5 Detrimental: = > 0 < 0.5	Required information: Type of road: pedestrian, bike path, and vehicular Public transport: network and bus stops

Has no path = 0 **B: accessibility to public transport** Has public transport (on the riverbank) = 1 Does not have public transport = 0	Universal scale (same for all calculations) Optimum value = 2 Acceptable value = 1 Average value = 0 Deficient value = −1 Detrimental value = −2	Sources: Map applications [52–56] and field survey
2. Access to the pedestrian network Quantifies the representation of suitable walking trails, and therefore, the possibility of safe movement of people with reduced mobility [57].		
$AP = \Sigma (P + L)/2$ **P: slopes < 5%** P = (slopes areas < 5%)/(analysis unit areas) × 100 **L: walking trails ≥ 90 cm** L = (walking trails ≥ 90 cm)/(analysis unit areas) × 100	Optimum = > 80% Acceptable = > 60% < 80% Average = > 40% < 60% Deficient = > 20% < 40% Detrimental = > 0% < 20%	Required information: Slope of walking paths, width of walking paths, and length of walking paths Sources: Map applications [52–55,58], and field survey and measurement
3. Height of the surrounding buildings Evaluates the height of the surrounding buildings, which determines the pedestrian's field of vision. Lower buildings allow users to enjoy a larger field of vision [59].		
$HB = \Sigma (h)/P$ h: height factor Without building or ≤ 4 floors = 3 Building > 4 ≤ 10 floors = 2 Building > 10 floors = 1 **P: total number of plots in the analysis unit**	Optimum = > 2.40 Acceptable = > 1.80 < 2.40 Average = > 1.20 < 1.80 Deficient = > 0.60 < 1.20 Detrimental = > 0 < 0.60	Required information: Number of floors on the first built line and number of buildings in the first built line Sources: Map applications [58,60] and field survey
b. Conditionof the green corridor		
4. Soil permeability Evaluates the representation of permeable and impervious surfaces. Soil permeability is key to supporting the ecosystem properties of urban environments [61].		
SP = (permeable soil + emipermeable soil)/(analysis unit area) × 100 Types of soil surface: Permeable soil = vegetation and bare ground Semipermeable soil = aggregates and textures that allow the passage of water Impermeable = concrete, asphalt, and construction	Optimum = > 1.6 Acceptable = > 1.2 < 1.6 Average = > 0.8 < 1.2 Deficient = > 0.4 < 0.8 Detrimental = > 0 < 0.4	Required information: Orthophoto of the evaluated area with a resolution of surfaces Sources: WMS data for QGIS, orthophoto [62], map applications [63], and field survey
5. Vegetation diversity Evaluates the richness of plant species—the relationship between the number of individuals and the number of species. This uses Fisher's alpha index, which is based on the assumption that species' abundance follows a logarithmic distribution and does not have fixed thresholds. A higher number on this index corresponds to higher species diversity [64].		
$VD = \alpha fis \times \ln(1 + n/\alpha fis)$ n = number of individuals for each species	Optimum = > 16 Acceptable = > 12 < 16 Average = > 8 < 12 Deficient = > 4 < 8 Detrimental = > 0 < 4	Required information: Number of species and number of individuals for each species Sources:

		WMS data for QGIS, orthophoto [62], map applications [47], field survey, and secondary information obtained from the municipality
COMFORT		
c. Condition of public space		
6. Facilities mixture		
Quantifies the existence and diversity of facilities in a given area. The Shannon diversity index is used as a conceptual basis, the value of which is usually influenced not only by the data distribution but also by the number of species categories in a given ecosystem [50].		
FM = −Σ [(pi) × ln(pi)] Pi: share of units in individual species Ni: types of facilities Rest: benches, seats Playful: playground and equipment Sports: exercise machines and sports fields Food consumption: tables and barbeque	Optimum = > 1.6 Acceptable = > 1.2 < 1.6 Average = > 0.8 < 1.2 Deficient = > 0.4 < 0.8 Detrimental = > 0 < 0.4	Required information: Number of facilities classified by type of activity Sources: Field survey and map applications [53]
7. Surface with shadow		
Quantifies the representation of paved areas in the territory that are protected by temperature-regulating shade. The most effective source of shade is vegetation [65].		
SS = (shadow projected from the trees)/(area of the stay areas and trails) × 100	Optimum = > 80% Acceptable = > 60% < 80% Average = > 40% < 60% Deficient = > 20% < 40% Detrimental = > 0% < 20%	Required information: Orthophoto of the study area: wood surface Sources: WMS data for QGIS, orthophoto [62,66], and field survey
8. Night lighting		
Evaluates the level of surface illumination during night hours.		
NL = (illuminated area)/(analysis unit area) × 100	Optimum = > 80% Acceptable = > 60% < 80% Average = > 40% < 60% Deficient = > 20% < 40% Detrimental = > 0% < 20%	Required information: Number of luminaires and illuminated surface Sources: Secondary information obtained from the municipality and field survey
9. Maintenance and management of public space		
Evaluates the level of care for public spaces.		
MM = (Σ F/FA)/(Na) × 100 **F: frequency in days each activity must be carried out per week** F = 7/E E = frequency in days when each activity must be carried out **Fa: frequency in days each activity is carried out per week** Fa = 7/Ea Ea = frequency in days when each activity is carried out Na = total number of activities	Optimum = > 80% Acceptable = > 60% < 80% Average = > 40% < 60% Deficient = > 20% < 40% Detrimental = > 0% < 20%	Required information: Quantity and type of activities managed in an area Sources: Secondary information obtained from the municipality Field survey
d. Condition of the first built line		
10. Diversity of uses		

Evaluates the variety and frequency of individual types of establishments in the first built line.		
DU = −Σ [(pi) × ln(pi)] Pi: share of units in individual species	Optimum = > 4 Acceptable = > 3 < 4 Average = > 2 < 3 Deficient = > 1 < 2 Detrimental = > 0 < 1	Required information: List of uses on the ground floor by property of the first built line Sources: Map applications [53,57], secondary information obtained from the municipality, and field survey
11. Socio-spatial integration Evaluates the degree of representation of the population with lower incomes (quartile one) in the waterfront area compared to the general representation in the entire city district. The index of spatial segregation (ISEA index) is applied to the evaluation [67].		
ISEA = a1 + b1 **a1: percentage of people in Q1 in the blocks surrounding the analysis unit** a1 = (number of people in Q1 in the analysis unit)/(total number of people in the analysis unit) **b1: percentage of people in Q1 in the city**	Optimum = > 0.76 = < 1.25 Acceptable = > 0.57 < 0.76 or > 1.25 = < 1.41 Average = > 0.38 < 0.57 or > 1.41 = < 1.58 Deficient = > 0.19 < 0.38 or > 1.58 = < 1.75 Detrimental = > 0 < 0,19 or > 1.75	Required information: Information about the population in each specific city district Sources: Secondary information obtained from the municipality, databases [41–43], and field survey
12. Porosity of the first built line Evaluates the height of the fence and the percentage of free space of the first built line.		
AP = Σ [l × (ae + re)]/L **l: the length of a particular plot of land** **L: the sum of the lengths of all plots in the analyzed unit** ae = height of the first built line Height of the enclosure of the building = > 1.65 m = 0 Height of the enclosure of the building = > 1 m < 1.65 m = 0.5 Height of the enclosure of the building = > 0 m < 1 m = 1 re = full-empty relation of the first built line = < 33% of empty = 0 33–66% of empty = 0.5 = > 66% of empty = 1	Optimum = > 1.6 Acceptable = > 1.2 < 1.6 Average = > 0.8 < 1.2 Deficient = > 0.4 < 0.8 Detrimental = > 0 < 0.4	Required information: Lengths of individual plots, the sums of the lengths of all plots, the fence heights, and filling the land with construction Sources: Map applications [52,53,60,68] and field survey
13. Accessibility to the first built line Evaluates the car or pedestrian accessibility of buildings in the first built line.		
AF = Σ (l × c)/L **l: length of each plot** **L: sum of the front length of plots in the analysis unit** c = presence or absence of access to each plot Plot has direct access = 1 Plot does not have access = 0	Optimum = > 0.8 Acceptable = > 0.6 < 0.8 Average = > 0.4 < 0.6 Deficient = > 0.2 < 0.4 Detrimental = > 0 < 0.2	Required information: Lengths of individual plots, the sums of the lengths of all plots, and information about the accessibility of the plot Sources: Map applications [53,60] and field survey

Table according to methodology for the assessment of connectivity and comfort of urban rivers [33] with our additions and modifications.

The calculation of the weight of individual indicators for the final URSI value is based on the evaluation of eleven experts in the original methodology [33]. These experts (persons with postgraduate education in the field of urban planning) evaluated the priority and the degree of influence of each indicator on the overall result using a Likert scale, which was chosen as a suitable psychometric tool for determining the values from 0 to 5 [69]. The maximum sum of expert evaluations permitted was 55. Based on the participation of all eleven experts, the average value of the indicator was calculated. Values were classified in four ranges: (a) 3.0–3.5 (1 indicator), (b) 3.51–4 (5 indicators), (c) 4.01–4.5 (4 indicators), and (d) 4.51–5.0 (3 indicators). The criterion for solving the measured range is always twice the previous one: b = 2a, c = 4a, and d = 8a. So, 1a + 5b + 4c + 3d = 1. After substituting the values, the result is a = 1/51. The values for conversion are thus defined as: (a) 1/51, (b) 2/51, (c) 4/51, and (d) 8/51 (Table 3).

Table 3. Weight of each indicator for the final URSI calculation.

	Dimensions and Indicators	Sum of the Experts Evaluation	Average Sum/Number of Experts	Weighting Values
CONNECTIVITY				
a. Spatial and visual accessibility				
1	Road accessibility and public transport	52	4.73	8/51
2	Access to the pedestrian network	50	4.55	8/51
3	Height of the surrounding buildings	37	3.36	1/51
b. Condition of the green corridor				
4	Soil permeability	43	3.91	2/51
5	Vegetation diversity	46	4.18	4/51
COMFORT				
c. Condition of public space				
6	Facilities mixture	46	4.18	4/51
7	Surface with shadow	44	4.00	2/51
8	Night lighting	53	4.82	8/51
9	Maintenance and management of public space	49	4.45	4/51
d. Condition of the first built line				
10	Diversity of uses	47	4.27	4/51
11	Socio-spatial integration	43	3.91	2/51
12	Porosity of the first built line	39	3.55	2/51
13	Accessibility to the first built line	40	3.64	2/51

3. Results

This section presents the results of the numerical evaluation of thirteen indicators in fifteen zones in three cities of the Czech Republic, as shown in Table 4.

Table 4. Indicator values in individual zones and cities (České Budějovice—ČB; Hradec Králové—HK).

	Ind. 1.	Ind. 2.	Ind. 3.	Ind. 4.	Ind. 5.	Ind. 6.	Ind. 7.	Ind. 8.	Ind. 9.	Ind. 10.	Ind. 11.	Ind. 12.	Ind. 13.
Prague	**0.62**	**1.51**	**1.81**	**0.31**	**0.45**	**−1.11**	**0.02**	**0.09**	**1.67**	**−1.38**	**2**	**−0.31**	**1.14**
Zone 1	0.17	2	2	1.33	1.67	−1	0.67	−0.67	1.33	−1.67	2	0.67	2
Zone 2	1.25	1.75	1.5	−0.5	−0.75	−1.75	−0.25	1.75	2	−1.5	2	−1.5	0.5
Zone 3	0.64	1.82	1.55	−1	−0.91	−1.55	−0.82	1.36	2	0	2	−1.63	1.45
Zone 4	0.5	1.5	2	0.5	0.75	−0.75	0.25	−0.75	2	−1.75	2	0.67	0
Zone 5	0.5	0.5	2	1.25	1.5	−0.5	0.25	−1.25	1	−2	2	0.25	1.75
ČB	**−0.01**	**1.38**	**1.93**	**0.95**	**0.1**	**−1.55**	**−0.12**	**−0.17**	**0.72**	**−1.74**	**2**	**0.18**	**1**
Zone 6	−0.68	1	2	1.5	0.5	−1.5	0.67	−0.75	0.5	−1.75	2	−0.33	1.33
Zone 7	1	1.25	1.75	0.25	0	−1	−0.25	0.25	0.5	−1.5	2	0	1.5
Zone 8	0.14	1.67	1.89	−0.22	−0.67	−1.67	−0.56	1.67	1	−1.44	2	−0.89	0.89
Zone 9	−1	2	2	1.2	−0.6	−1.6	−0.2	0	0.6	−2	2	0.8	−0.4
Zone 10	0.5	1	2	2	1.25	−2	−0.25	−2	1	−2	2	1.33	1.67
HK	**1.14**	**−0.43**	**1.15**	**1.98**	**−0.17**	**−1.56**	**0.57**	**−0.43**	**0.26**	**−1.79**	**2**	**0.41**	**0.67**
Zone 11	−0.75	0.25	2	1.75	−0.5	−1.75	1	−1.5	0	−2	2	1.5	1
Zone 12	0.87	1.5	1.9	−0.3	−1.1	−1.8	−0.4	1.6	0.8	−1.2	2	−1.2	1.7
Zone 13	0	1.5	2	1	0.75	−0.75	0.25	0.5	0.5	−1.75	2	−0.25	0
Zone 14	0.08	1.5	2	1.5	0.5	−1.5	0.5	−1	0	−2	2	1	0.67
Zone 15	−0.63	1	2	1.75	−0.5	−2	1.5	−1.75	0	−2	2	1	0

Indicator 1 (road accessibility and public transport) indicates a problem in the peripheral area of Hradec Králové zone 11 with a value of 0.75. The highest value of 1.25 is reported in zone 2 in Prague. Indicator 2 (access to the pedestrian network) shows above-average values in the urban environment of the Czech Republic. On the contrary, zone 11 of Hradec Králové shows the worst access to the pedestrian network, with a value of 0.25. All three analyzed cities have high values in the area of indicator 3 (height of surrounding buildings).

The data for indicator 4 (soil permeability) show ecologically ideal values of 2 for soil permeability in the peripheral part of České Budějovice zone 10 and a value of 1.75 in Hradec Králové, specifically zones 11 and 15. Indicator 5 (vegetation diversity) shows high values in the peripheral zones of Prague 1 and 5. Low values were found in the same city, in central area 3 or zone 12 of Hradec Králové. The values of indicator 6 (facilities mixture) show the comprehensively bad situation of smaller cities and their peripheral parts, where zones 10 and 15 show the lowest possible value of −2.

Indicator 7 (surface with shadow) draws attention to the problem of the absence of shaded surfaces in the central areas of cities. The lowest value, −0.82, is shown in central zone 3 in the capital city of Prague. Due to the high representation of natural vegetation, the highest value was measured in marginal zone 15 of Hradec Králové, namely 1.5. Indicator 8 (night lighting) refers to the partially desirable differences between the lighting of the central and peripheral parts of cities. This difference is most noticeable in České Budějovice, where the highest difference was demonstrated in the measured value of 1.67 in zone 8 and the lowest value in zone 10, where, according to the −2 value, lighting was entirely absent. The highest efficiency of the waterfront lighting of the analyzed cities is demonstrated by a value of 1.75 in the central part of Prague, zone 2. Indicator 9 (maintenance and management of public space) shows large differences between the capital and smaller cities. In Prague, the maximum possible value was found in three zones. A potential problem in this area could arise in the future in Hradec Králové, where the total value for the city is documented as 0.26.

Indicator 10 (diversity of uses) around watercourses shows alarming values in all the analyzed cities. The worst situation was found in smaller towns. Hradec Králové has a total of three areas with the lowest possible value of −2 and the overall worst average result of −1.79. The central area of Prague, zone 3, shows the highest measured value of 0. Indicator 11 (socio-spatial integration) consistently shows the highest values. The maximum values prove that there is no problem with exclusion or segregation in the urban river environment in the Czech Republic. Indicator 12 (porosity of the first built line) shows the worst situation in the central area of Prague zone 3 with a value of −1.63. A relatively high value of 1 was found in the peripheral parts of Hradec Králové zones 14 and 15, with the highest value of 1.33 in zone 10 in České Budějovice. It should be added that the developments in the peripheral parts have a lower number of historical buildings, which in the central parts often determine the aesthetic appearance of the location. Indicator 13 (accessibility of the first built line) shows the overall satisfactory situation of Czech cities in terms of land accessibility. The highest values were measured in the peripheral parts of Prague. These were specifically, a value of 2 in zone 1 and a value of 1.75 in zone 5. The worst accessibility with a value of −0.4 was shown by zone 9 in České Budějovice, where an absence of access from public space was found.

Among the key results, the low values of indicator 10 (diversity of uses), which are at an unacceptable value of −1.79 in Hradec Králové, should be mentioned. The area of indicator 6 (facilities mixture), where the average value for České Budějovice reaches −1.55, and for Hradec Králové −1.56, can also be identified as a potential problem in the surveyed cities. On the contrary, overall higher values were found using the index of spatial segregation for indicator 11 (socio-spatial integration). Indicator 3 (height of the surrounding buildings), where the highest result was measured in Hradec Králové, is also close to the optimal values with its results. It can be stated that positive results are also demonstrated for indicator 2 (access to the pedestrian network) and indicator 9 (maintenance and management of public space). A trend is already emerging in these sectors, where the value is proportional to the size of the analyzed cities—Prague has the highest value, and Hradec Králové the lowest.

By comparing the individual zones (distribution according to Table 1), we found that the worst situation of indicator 1 (road accessibility and public transport) is in the zones of the northern borders of the inner city (Z1, Z6, and Z11), where the average value of these zones reaches −0.42. Regarding indicator 2 (access to the pedestrian network), it can be stated that there is a good situation for the waterfront zones with green lines (Z4, Z9, and Z14) and the historic center zones with floodplains (Z3, Z8, and Z12). Both groups reach a value of 1.66. The results indicate the poor condition of the historic center zones with waterfronts (Z3, Z8, and Z12) in the area of indicator 4 (soil permeability), where an average value of −0.51 was measured. This group of zones shows a worse condition for indicator 5 (vegetation diversity), where the value is −0.89. The problem is according to the value −0.59 and also with indicator 7 (surface shading). The lowest average values, i.e., −2, were found in the zones of the southern borders of the inner city (Z5, Z10, and Z15) in the area of indicator 10 (diversity of uses). Indicator 12 (porosity of the first built line) indicates a problem in the historical center zones with alluvium (Z3, Z8, and Z12), where the values reach −1.24.

It is evident from the map diagram (Figure 3) of indicator 1 (road accessibility and public transport), that the capital city of Prague has the highest values, where a total of eight analytical units with a maximum value of 2 can be observed. This value can be seen sporadically in smaller cities. The lack of transport accessibility in zone 9 of České Budějovice is particularly surprising. Map schemes also visualize the problem in zones 11 and 15 of Hradec Králové.

The processing of the final URSI value for the individual city zones is presented in graphs so that the visually observable values of each indicator can be displayed. These graphs are supplemented by a summary of the numerical results (Figure 4).

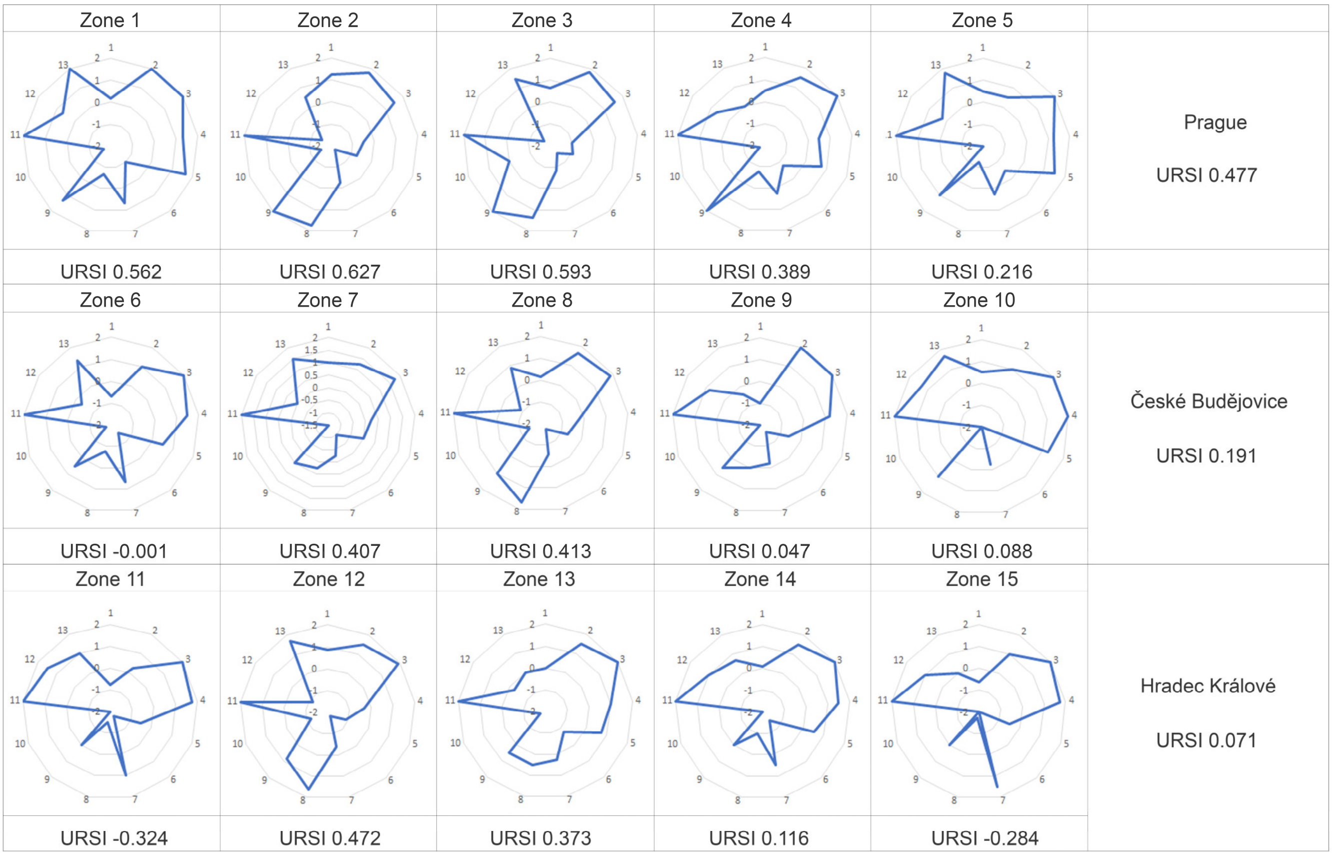

Figure 4. Urban River Sustainability Index (URSI) in individual zones and cities.

The resulting URSI values (Figure 4) show the best situation for connectivity and comfort in the capital city of Prague. The worst situation is demonstrated in Hradec Králové. The URSI values reach higher numbers in zones that are characterized as central zones with a higher population density and land use and a lower percentage of vegetation (Z2, Z7, Z13, Z3, Z8, and Z12). Except for České Budějovice, medium values were found in the waterfront zones with linear greenery and a central cycle path (Z4 and Z14). The lowest values are shown in marginal zones with a lower population density and a higher percentage of original vegetation (Z1, Z6, Z11, Z5, Z10, and Z15).

Of the percentage indicators of the area with acceptable and optimal values (Table 5), Prague has the best values, with three indicators at 100% and two below 20%. These results confirm the findings from the graphs presented in Figure 4. The results are slightly worse for the other two cities (the worst being in Hradec Králové).

Table 5. Indicators and percentages of the area with acceptable and optimal values in five zones of individual cities.

	Indicators	Prague	České Budějovice	Hradec Králové	Average of Czech Cities
1	Road accessibility and public transport	57.7%	38.5%	42.3%	46.2%
2	Access to the pedestrian network	92.3%	84.6%	80.8%	85.9%
3	Height of the surrounding buildings	100%	100%	100%	100%
4	Soil permeability	42.3%	69.2%	69.2%	60.2%
5	Vegetation diversity	46.2%	34.6%	19.2%	33.3%

6	Facilities mixture	7.7%	0%	0%	2.6%
7	Surface with shadow	26.9%	34.6%	42.3%	34.6%
8	Night lighting	65.4%	53.8%	42.3%	53.8%
9	Maintenance and manag. of publ. space	100%	76.9%	38.5%	71.8%
10	Diversity of uses	15.4%	0%	0%	5.1%
11	Socio-spatial integration	100%	100%	100%	100%
12	Porosity of the first built line	23.1%	37.5%	42.1%	34.2%
13	Accessibility to the first built line	76.9%	62.5%	66.7%	68.7%
	Average	**57.9%**	**53.2%**	**49.5%**	**53.5%**

After analyzing the individually defined dimensions (Table 2), it can be concluded that this study locates the biggest problem in the cities of the Czech Republic in the dimension of the condition of public space. The average value of all analyzed cities for indicators 6, 7, 8, and 9, as for a single dimension, falls below the average value of 0 to −0.13. The largest share of this result is the value −1.4 found for indicator 6—facilities mixture. The highest result within the defined dimensions is the average value of 1.01 in the dimension of spatial and visual accessibility, where the height of the surrounding buildings along the waterways mainly achieves positive values.

4. Discussion

The main goal of this study was to research the connectivity and comfort of selected urban river areas of the Czech Republic based on the Urban River Sustainability Index (URSI). From a methodological point of view, the main task was to expertly modify the URSI to correspond to the territory of Central Europe for the specific assessment of rivers. The results of the study confirmed that the connectivity and comfort of urban rivers in the Czech Republic are related to the city's identity [70]. It is thus possible to support Stedman's [71] claim that the physical environment and its characteristics contribute to building a good feeling about a given place, and in this specific case, the urban river corridors.

It can be stated that the river environment in all three analyzed cities achieves average to above-average results in most indicators. The identity of larger rivers has been significantly transformed over the past centuries. From the 19th century, the water flow was the driving force driving the mills, where it served rowers or sand mining. The second half of the 19th century brought about a fundamental change when architecturally valuable bridges and embankments were built in the centers of larger cities. The embankment, with its avenues, became the main traffic road and a popular promenade. These lucrative locations opened up original views of the river and the city panorama [72]. With the advent of the 20th century, society and the use of watercourses changed. There was an increase in industrial functions. Rafting was replaced by steamships [73]. The shores also had to be adapted to the new arrangement. The river was both a driving force and a threat in the form of floods. These caused the construction of high embankment walls in some cities. The rivers in the cities did not even avoid the questionable straightening and strengthening of the banks. Toward the end of the 20th century, the river ceased to be a barrier and became a place that offered experiences and the possibility to meet different social groups. The level of connectivity and comfort thus became very important in the 21st century.

The most important result values were found for indicators of insufficient equipment in the territory and a low variety of uses in areas around watercourses. This is where urban planning should be improved. The problems are numerically more pronounced in the outskirts of cities and smaller towns. Therefore, this deficiency can be called the problem of marginal parts. The problems of the central parts can be characterized above all by the lack of environmentally oriented solutions to the urban space in the vicinity of the rivers. These are primarily the results of indicators showing a low diversity of vegetation and impaired soil permeability with a high level of buildup in the vicinity of watercourses. A low level of shading of the paved surface by natural vegetation is also a potential problem. The values demonstrate that while in the peripheral parts of cities it is appropriate to address the addition of equipment and the support for diversity, in the central parts of urbanized environments, it is necessary to give space to the active solution for supporting ecosystem-oriented solutions. These resulting solutions are essential for maintaining a high level of usability in urban river areas and for using urban waterways as a key element for future climate change mitigation.

Concerning an evaluation of the set objectives of this work, it is possible to state that the main goals were achieved. Using the methodology, specific shortcomings of the analyzed territories were identified within the study, and specific solutions were proposed. The problem of the cities of the Czech Republic is highlighted by the values related to the diversity of use (indicator 10), which can be solved by supporting a diverse mix of commercial equipment and supporting establishments near watercourses for the greater public interest [74]. Another problematic area is the facilities mixture (indicator 6), which could be supported by supplementing the various equipment in public places, especially in the peripheral parts of cities. It is mainly in smaller cities, where the low representation of night lighting (indicator 8) is often inefficient, where it can be characterized as a problem. In this case, it is possible to support the numerical value by gradually modernizing lighting fixtures with a suitable design and introducing technologies and sensors that would minimize the impact on the environment and the cost of energy [75]. In some parts of the cities, these steps are already taking place. Another problematic area is the low shading of the surface by natural vegetation (indicator 7), which can be solved by supplementing it so that there is no overheating of paved surfaces [76]. The results in České Budějovice and Prague reveal the largest number of paved areas that are not protected by shade in the vicinity of rivers.

The summary results of the URSI values showed a higher value for cities with higher populations. Individual sub-indicators confirmed this trend by 61.5% in the case of eight indicators (1, 2, 5, 6, 8, 9, 10, and 13). All the mentioned indicators were evaluated as pivotal by experts and received the two highest values for the final recalculation. Indicators 3, 4, and 12 show an opposite trend, which logically points to a better state of smaller cities. We can state that 53.5% of the evaluated territories reached acceptable or optimal values. Positive values were manifested in seven out of the thirteen indicators (Table 5).

If we were to compare the results achieved in the Czech Republic with similarly oriented studies abroad, Hermida [33] investigated a comparable topic in Ecuador. It can be stated that, as expected, Czechia shows higher values and, thus, a better level of urban planning than Latin America Ecuador, where the previous version of the methodology has already been applied [33]. The advantage of this study of the river environment in the Czech Republic is that it is processed according to a modified methodology that works with modified calculations of individual indicators to ensure that the results obtained are more accurate and verifiable. The methodology also refers to supplemented resources for calculations. The average of Czech cities for areas with acceptable and optimal values is 53.5%, and in Ecuador it is 41.1%. The results of this study are consistent with the conclusions of Jiang [77]. The latter states that expanded connectivity of ecological networks can improve urban ventilation and help optimize the spatial pattern of riparian green space systems in cities with intensive river networks to mitigate the urban heat island (UHI). Using a modified methodology, the study identified specific problems for which real solutions could be found. In our assessment, the higher values of the marginal parts of indicators 4 and 12—soil permeability and porosity of the first built line—call for improving the connectivity of ecological networks [78]. Additionally, on the contrary, lower values of indicator 7 surface with a shadow in the central areas of cities. These factual data refer to the importance of supporting the ecosystem functions of waterfronts in their planning [79].

5. Conclusions

The spaces of urban rivers in the Czech Republic can be evaluated as valuable public spaces that offer the possibility of quality mental and physical rest. The main goal of this study was to research selected urban rivers in the Czech Republic and their surrounding areas based on the Urban River Sustainability Index (URSI), which was modified to correspond to the territory of Central Europe. Through the selected thirteen indicators, this index comprehensively evaluated the researched topic using numerical results or map visualizations. The key contribution of the methodology was the possibility of defining specific problems in the given territories based on the results. The defined problems can be localized to the precision of analytical units.

From the achieved results of the URSI values and the percentage of area with acceptable and optimal values of all three analyzed cities (Prague, České Budějovice, and Hradec Králové), it can be stated that the most favorable location of the river area is in the central areas of Prague. The worst situation was found in the peripheral zones of Hradec Králové. As for the monitored indicators, this study revealed problems with insufficient equipment in the territory, a low variety of uses of areas around watercourses, and low-quality night lighting. The analyzed central areas show deficiencies in the low diversity of vegetation, impaired soil permeability, and low level of shading of the paved surface by natural vegetation. These shortcomings can be solved primarily by supporting ecosystem-oriented solutions. These include, for example, support for the diversity of vegetation, the implementation of at least semipermeable surfaces instead of impermeable ones, and the addition of natural greenery for the targeted shading of areas. The solution is possible through the implementation of specific support measures, such as supporting the diversity of the mix of commercial equipment, complementing public space equipment, and incorporating new public lighting technologies and additions.

Currently, the Czech Republic lacks a methodology for evaluating the visual, aesthetic, and functional aspects of the waterfronts. The approach proved to be utterly unique in the environment of the whole of Central Europe, as no similar studies were found. The methodology used and the results achieved should evoke strong motivation in both the public and private spheres. The effort to achieve the prestige of the given place according to the URSI values would motivate the public to participate more. The results could be applied by specific cities within spatial plans or by landowners. The methodology for assessing the connectivity and comfort of urban rivers proves to be suitable for possible use in future concepts. For defining editing priorities, both thematically and locally, a suitable type of document that would solve this issue is the concept of urban shores. This document would make it possible to plan the development of the river area in a city-wide context and improve the individual deficiencies in the area. The greater visual appeal of urban rivers would be achieved. This work appeals to a more conceptual use of the environment of watercourses in city-wide planning and the support of their ecosystem properties. Urban river corridors and their environment are key elements in the fight against climate change and the prevention of UHI. This research highlights the key role of waterways in cities and the need to work with these unique spaces, for example, through the detection of territorial deficiencies using URSI.

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Appendix A

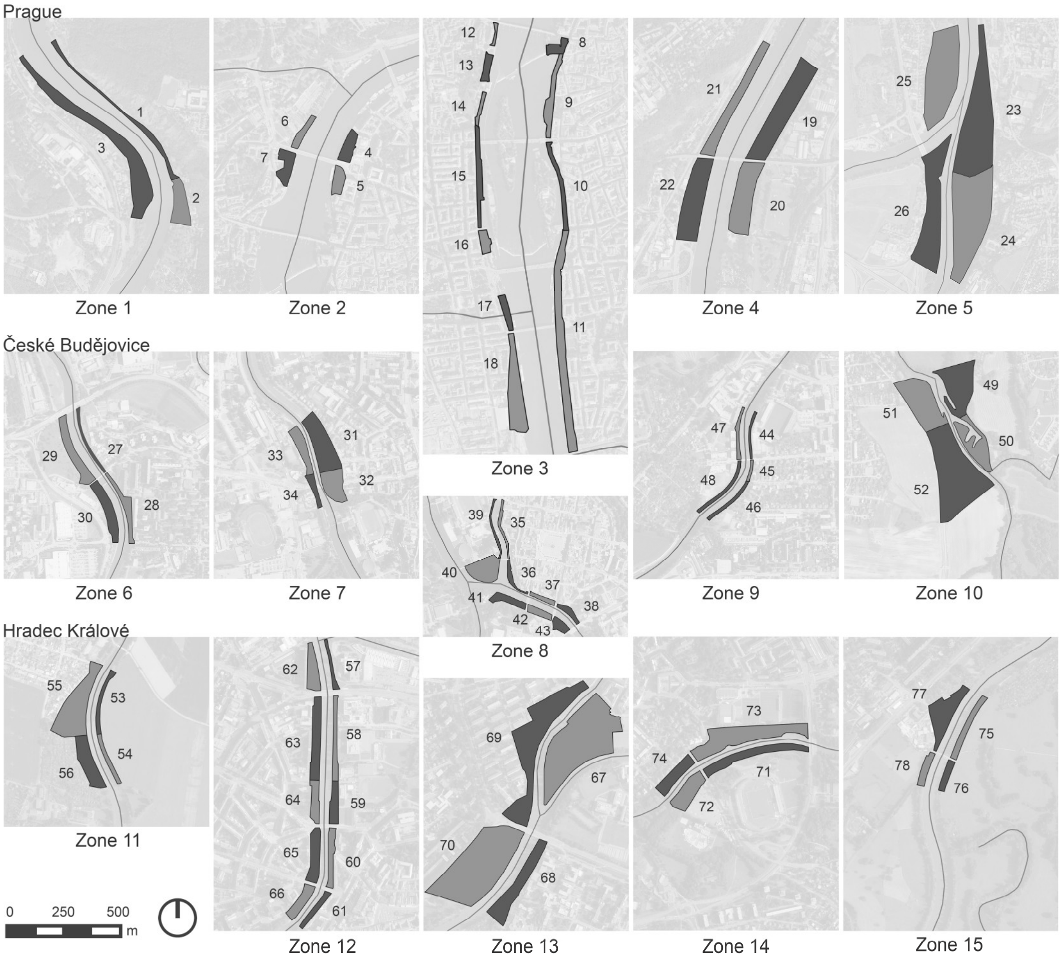

Figure A1. Designation of 78 analysed units in 15 studied zones in three cities.

Table A1. Data source overview.

Data File	Used in a Parameter	Source	Spatial Coverage	Link
Census hub	statistical cluster analysis—population density, Indicator 11	Eurostat	Europe	[43]
Population and housing censuses	statistical cluster analysis—population density, Indicator 11	Eurostat	European Union	[41]
Population and housing censuses	statistical cluster analysis—population density, Indicator 11	Czech statistical office	Czech Republic	[63]
Population density map	statistical cluster analysis—population density	Czech National Geoportal	Czech Republic	[64]
Corine land cover	statistical cluster analysis—land use	Copernicus	Europe	[45]
Degree of urbanisation (DEGURBA)	statistical cluster analysis—land use	Eurostat	European Union	[46]
High resolutions layers	statistical cluster analysis—percentage of vegetation, Indicator 5	Copernicus	Europe	[47]

Natura 2000 Network viewer	statistical cluster analysis—percentage of vegetation	European Environment Agency	European Union	[48]
Google maps	Indicators 1, 2, 6, 10, 12, 13	Google	Whole world	[53]
Seznam maps	Indicators 1, 2, 12	Seznam	Whole world	[52]
Geoportal Praha	Indicator 1, 2	Geoportal Praha	Prague	[54]
Eurogeographics Maps for Europe	Indicators 1, 2	Eurogeographics	Europe	[55]
TENtec Interactive Map Viewer	Indicator 1	European Comission	European Union	[56]
Open Cadastral Map	Indicators 2, 3	Eurogeographics	Czech Republic, Denmark, Netherlands, Poland, Slovenia, Spain	[58]
Google Earth	Indicators 3, 10, 12, 13	Google	Whole world	[57]
Geoportal ČÚZK	Indicators 4, 5, 7	ČÚZK	Czech Republic	[59]
Imperviousness	Indicator 4	Copernicus	Europe	[63]
Datasets—Ortophoto	Indicator 7	European Comission	European Union	[66]
Building Height	Indicator 12	Copernicus	Europe	[68]

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