



Assessment of the naturalness and anthropogenic transformation of the habitats of small mountain streams in different climate zones

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Abstract

The study compares the quality of the habitats of mountain streams in sections without visible human integration and those permanently transformed by human activity between mountain areas in different climate zones. Three mountain streams with small catchments (10–20 km²) characterized by different natural conditions were selected for the research. The selected streams are Bystrzanka (Beskid Niski, Polish Carpathians), Peshok (Darjeeling Himalaya in India), and Fanshen (Hengduan Shan in China). Field studies were carried out using the British River Habitat Survey (RHS) method. Habitat quality was analyzed based on the following indicators: Habitat Quality Assessment (HQA) and Habitat Modification Score (HMS). The obtained results indicated that sections of mountain streams located in upper catchment areas show greater habitat naturalness in relation to stream sections in lower areas. This results from the greater variety and number of natural hydromorphological elements in streams and the close vicinity of channels. In both upper and lower stream sections, regardless of the degree of naturalness and anthropopressure, the same RHS attributes have the greatest impact on the HQA and HMS values. Similar regularities in the degree of naturalness and anthropogenic modifications of the habitat between the upper and lower reaches of streams can be also expected in other mountain areas, apart from areas not affected by human activities.

Keywords Stream habitat quality · Human impact · Mountains · River Habitat Quality method

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Introduction

Streams are important habitats that provide shelter and feeding opportunities for a wide range of organisms, such as fish, insects, plants, mollusks, birds and mammals (Gebrekiros 2016). The habitat quality of streams depends on the diversity and abundance of natural and anthropogenic elements as well as on their mutual proportions within channels, riparian zones and watersheds. The greater the predominance of natural elements, the better the stream habitat quality. The dominance of anthropogenic components, on the other hand, shows a clear transformation of the habitat by humans (Raven et al. 1998). Proper quantification of physical habitat characteristics in rivers is necessary to understand the physical processes that affect the physical composition and structure of habitats (Fernández et al. 2011). Habitat assessment is critical in determining the limiting natural and human factors that affect water chemistry and aquatic biological communities. These limiting factors exist at many different spatial scales, from drainage-basin characteristics to streambed conditions (Fitzpatrick et al. 1998).

Johnson and others (2001) note that habitat assessments are the basis of most impact-assessment and resource inventories, species-management plans, mitigation planning and compliance monitoring. Within the past few decades, the number of systems that can be used for habitat assessment and classification has increased substantially, and new ones are continually being published. Each assessment or classification scheme differs in terms of goals, spatial scale, quantitiveness, the effort and time required, and applicability to streams of different sizes (Fitzpatrick et al. 1998). A brief review of this literature shows that methods of evaluating river habitats can generally be classified into two groups. The first group involves partial to macro-scale evaluation and mapping, often by means of remote sensing techniques. This approach is based on geographic information system (GIS) spatial analysis and remote sensing image data. The second approach relies on field surveys and is based on field data collection. The indicators surveyed often include channel attributes, riparian characteristics, and land use adjacent to a river, all of which are easily observed and measured at the site (Ding et al. 2015). This group includes the River Habitat Survey (RHS) method, which is one of the most commonly used methods of quantifying channel modifications and the habitat quality of rivers and streams. It was developed in the early 1990s by the British Environmental Agency (Raven et al. 2000).

Among the issues that are considered in the scientific literature regarding stream habitats, relatively little attention is paid to the hierarchy of factors/elements that

determine the degree of naturalness and transformation of a given habitat. This problem was analyzed in relation to European rivers by Szoszkiewicz et al. (2006), who showed similarities and differences in river habitats between lowlands and mountains. There is high correlation between channel attributes and bank attributes and geographical regions. Moreover, mountain areas are characterized by a higher number of channel attributes (high-energy flow type, exposed boulders) and bank attributes (e.g., rip-rap, reinforced bank, side bar) than lowland areas (Szoszkiewicz et al. 2006).

High anthropopressure in mountainous areas is manifested in the intensive development of residential and road infrastructure (Falcucci et al. 2007; Kijowska-Strugała 2019). The construction of buildings and the development of hydrotechnical infrastructure affects the hydromorphological state of streams and thus influences the deterioration of their habitat quality (Wiejaczka et al. 2014; Bucala and Wiejaczka 2015). According to Wohl (2006, 2017), human effects on mountain streams may result from activities within the stream channel that directly alter channel geometry, the dynamics of water and sediment movement, contaminants in the stream, or aquatic and riparian communities. Human impact can also result from activities within the watershed that indirectly affect streams by altering the movement of water, sediment, and contaminants into the channel. Elozegi et al. (2010) reports that human activity leads to the transformation of the natural environment into a more homogeneous one with less diversity.

In the scientific literature there is a lack of studies comparing the quality of the stream and river habitats using the same method in different mountain areas. The importance of such studies results from the fact that the increase of anthropogenic infrastructure elements (buildings, road network, riverbed reinforcements) in the mountain areas (Starkele and Basu 2000; Kijowska-Strugała 2019) consequently may cause changes in the quality of the habitat in the sections currently not changed. There is a need for research documenting the current state of habitat quality of mountain streams, which could be a reference base for further research.

The main aim of the study is to compare the quality of the mountain streams habitat in their lower sections with a visible human activity and the upper sections without noticeable human interference. We focused on small catchments (10–20 km²), where the human activity on the functioning of a mountain environment is more visible than in large basins (Gregory 2006; Wohl 2006, 2017; Krocak et al. 2016; Zhang et al. 2019). Three mountain streams with different climatic and natural conditions were selected for this comparative research: Bystrzanka (Beskid Niski, Polish Carpathians), Peshok (Darjeeling Himalaya in India), Fanshen (Hengduan Shan in China). Each of the selected

catchments reflect the environment that is typical for a given mountain area.

We hypothesized that the habitat quality in sections clearly changed by man and without visible (direct) anthropopressure is similar in relation to various mountain areas and is conditioned by the same natural and anthropogenic factors.

Study area

The analyzed catchments are located in mountain areas in a different climatic zones (Table 1). The basic climatic factors differentiating the environment of mountain areas are temperature and rainfall (e.g., Collados-Lara et al. 2018, 2020).

The Bystrzanka stream (Figs. 1, 2; Table 1) is located in the Western Polish Carpathians (the Low Beskid) and has a catchment area of 13 km²; it is 7.1 km long, with a mean gradient of 26‰. Due to the lithological conditions (Carpathian flysch with sandstones and slates), the relief within the catchment, and the erosive activity of the streams and precipitation, the study area is susceptible to landslides, which cover 27% of the catchment. The Bystrzanka catchment has a warm, humid continental climate (Cfb) (Köppen 1931), with a mean annual temperature of 8.1 °C and annual precipitation of 840 mm (535–1164 mm). The average multiannual flow in the Bystrzanka stream is 0.17 m³ s⁻¹. The catchment land structure is mostly forests (38%), but also grassland (36%) and arable land (9%).

The Peshok stream (Figs. 1, 2; Table 1) is the right-bank tributary of the Teesta River in the Darjeeling Himalayas. The catchment area is 10 km² and is formed of metamorphic rocks intensely folded Darjeeling gneisses with intercalations of quartzites and mica schists. The stream is 7 km long and the mean gradient of the channel is over 200‰. Frequent landslides play an important role in delivering material to the channel (Patel and Soja 2000).

According to Köppen (1931), the catchment climate can be classified as subtropical monsoonal (Cwb) and the local climatic conditions do not differ from the regional pattern (Prokop and Walanus 2017). The mean annual temperature range from 23.0 °C in lower part of the catchment to 14.8 °C at the high 1900 m a.s.l. The sum of annual rainfall within the Peshok catchment fluctuates between 2300 mm (lower part) and 2700 mm (upper part). The average multiannual flow is 0.34 m³ s⁻¹. In the land-use structure of the catchment area, 49% is agricultural lands (tea gardens, rice, vegetables and fruit plantations), 47% forests, and 4% built-up lands.

The Fanshen catchment (Figs. 1, 2; Table 1) on the right bank of the middle reaches of the Dadu River is located in Shimian county, Sichuan province, China. This catchment is an elongated shape in the east of the Hengduan mountains on the Qinghai-Tibet Plateau. The main channel of this catchment is about 6.6 km long. The average gradient of the channel is 114‰, and the area is 19.9 km². The highest point of the catchment is 2285 m.s.l. and is located at the highest point of Jidu mountain near Haiyang village; the lowest point is 823 m.s.l. and is located at the mouth of the catchment. Due to the uplift of the Qinghai-Tibet Plateau, the natural environmental conditions in the study site are complicated. There are frequent strong earthquakes adjacent to the Shimian-Yuexi-Haojue fault zone. The exposed strata are stratigraphic Triassic. The lithology of the catchment, which has strong geological tectonic action due to an active fault, is slate and phyllite. In terms of climate conditions, Fanshen Gully is located within a mid-latitude subtropical monsoon climate. Most of the rainfall is in the summer season. Due to the geological and geomorphological conditions, slope failure, bank collapse and soil slip frequently occur on both sides of the Fanshen Gully, especially in the upper reaches. Moreover, loose materials can easily form a debris flow hazard after heavy rainfall.

Table 1 Environmental characteristic of studied catchments

Parameters	Bystrzanka	Peshok	Fanshen
Geographical coordinates (outlet)	49° 37' 49.40" N, 21° 03' 21.07" E	27° 04' 00.81" N, 88° 25' 36.27" E	29° 13' 34" N, 102° 19' 38" E
Catchment area (km ²)	13	10	20
Denivelation (m a.s.l.)	300–753	230–1930	823–2285
Stream length (km)	7.2	7.1	6.6
Annual temperature (°C)	5.7– 8.1	14.8–23.0	3.6–12.0
Annual rainfall (mm)	535–1164	2300–2700	1000–1400
Climatic type (according to Köppen, 1931)	Cfb	Cwb	Cfa
Forest area (%)	45	47	48
Agricultural land area (%)	47	49	51
Built-up area (%)	8	4	1

Fig. 1 Study area. Localization of studied streams

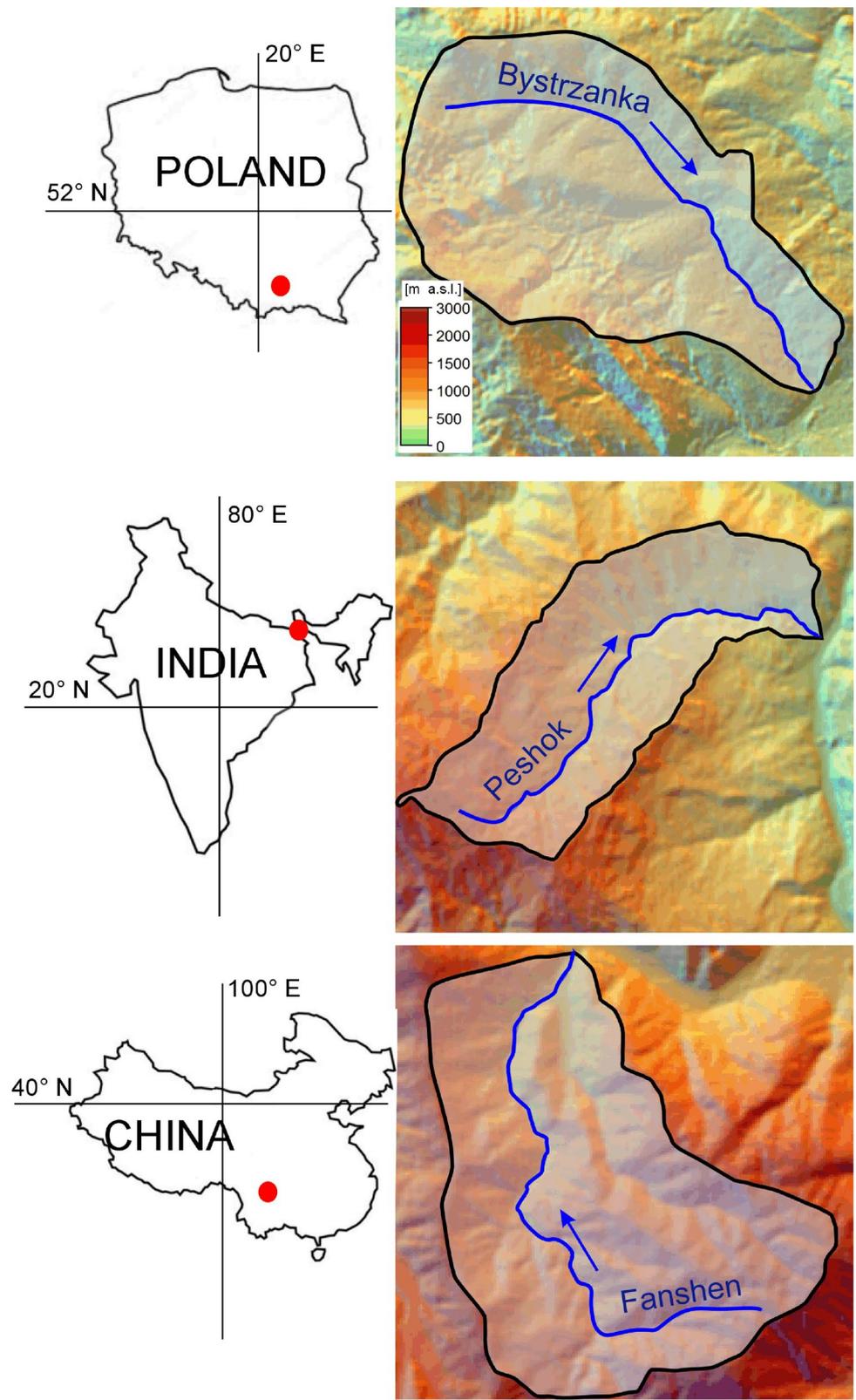


Fig. 2 Upper and lower sections of the analyzed streams



Methods

The research in Peshok, Fanshen and Bystrzanka catchments was conducted between 2016 and 2018. Field studies were conducted using the British River Habitat Survey (RHS) method on sections without visible anthropopressure and on sections marked by noticeable human interference. Two research sections were selected in each of the analyzed streams (Fig. 3, step 1). The first was located in the upper reaches and the second was in the lower reaches of the streams.

Studies using the RHS method were carried out in two stages for the 500 m section of the stream (Fig. 3, step 2). The first stage of this method characterizes the basic morphological features of the streambed and banks at ten control profiles that are set every 50 m. Assessment was conducted of the following: the material which forms the

banks and the bottom of the stream channel, natural elements and modifications of the banks and the bottom of the stream channel, flow type, vegetation structure on the channel banks as well as in the close vicinity of the channel. The second stage includes a synthetic description that is carried out for the entire research section, taking into account various morphological forms and transformations that were not registered in the previous stage (e.g., valley description, streambed parameters, number of water structures). Guidelines for research with the RHS method include the publications of Raven et al. (1998) and the Environment Agency (2003). The collected information was used to compare the quality of the stream habitat in sections clearly changed by humans and without noticeable human intervention using two synthetic indicators: Habitat Quality Assessment (HQA) and Habitat Modification Score (HMS), (Fig. 3, step 3).

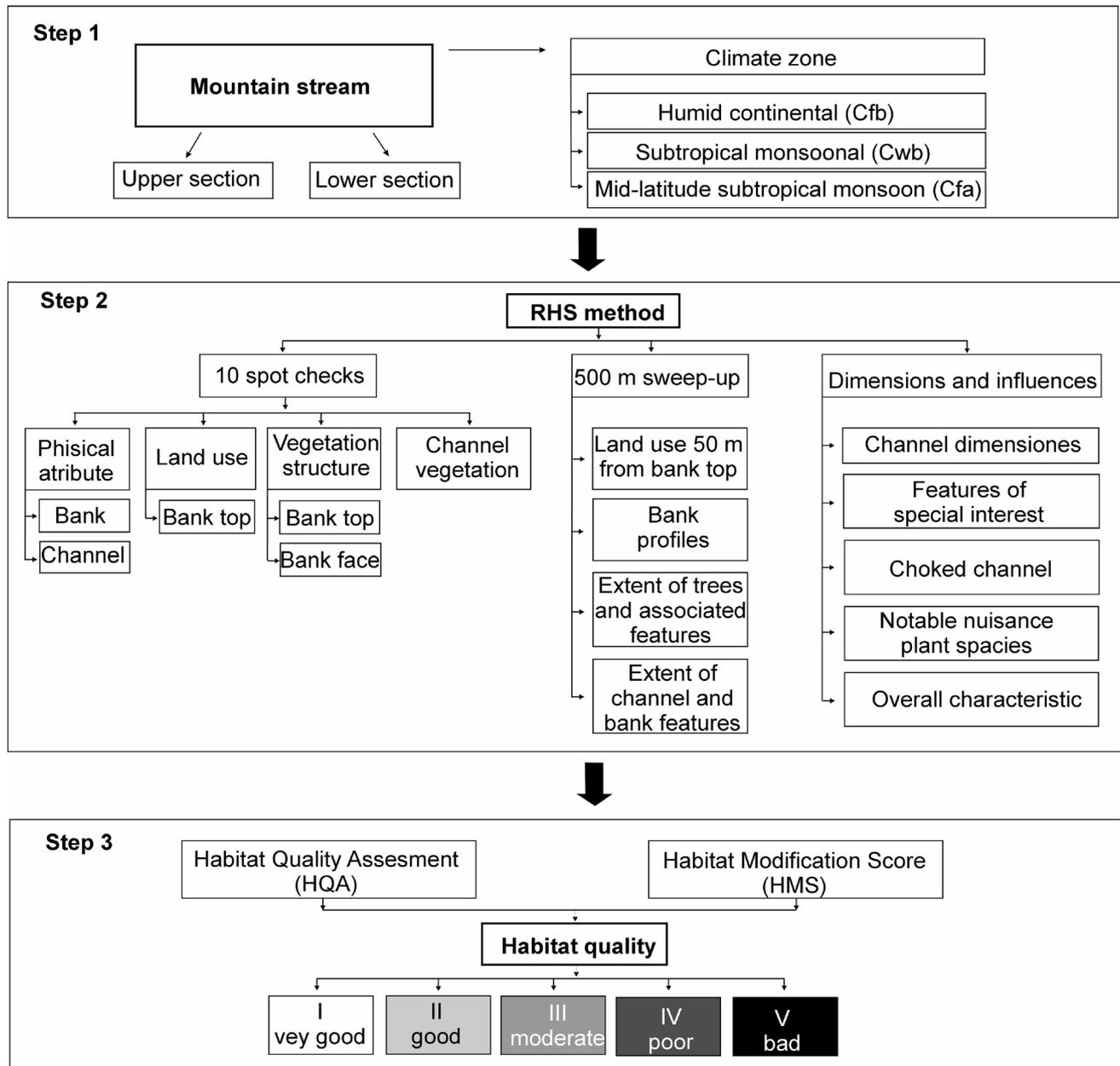


Fig. 3 Flowchart of methodological approach in the study

Generally, due to the HQA naturalness indicator, it is possible to assess the diversity of the natural elements of stream channels and riparian zones. The assessment components are the physical parameters of the streambed, features of the banks, types of streambed vegetation, structure of vegetation on the slopes, tree structure (distribution of trees along the channel) and land use at a distance up to 50 m from the channel. These elements are prescribed points, the sum of which allows classification of the studied section of the stream into a specific category. The HMS habitat transformation index is calculated on the basis of information on

the type and number of water constructions, bank reinforcements, changes in the streambed profile, and disturbances in the valley's water resources. High HQA values and low HMS values mean a stream has the best habitat quality. Table 2 presents the scores and descriptive categories of HQA and HMS, based on Raven and others (1998), Walker et al. (2002) and Jusik et al. (2014).

In this research, the quantitative characteristics of the hydromorphological state of the selected streams are presented in the form of percentages of particular cross sections located at 50 m intervals (ten profiles along the whole 500 m

Table 2 Scores and descriptive categories of Habitat Quality Assessment (HQA) and Habitat Modification Score (HMS)

Classes	HQA		HMS	
	Score	Descriptive category	Score	Descriptive category
I	> 57	Very high quality	0–2	Semi-natural
II	50–56	High quality	3–8	Predominantly unmodified
III	37–49	Sufficent quality	9–0	Obviously modified
IV	30–36	Low quality	21–44	Significantly modified
V	< 30	very Low quality	> 45	Severely modified

RHS section) in which the occurrence of the given natural and anthropogenic elements was found. The characteristics of the channel bed were related to ten transverse profiles, whereas in the case of the banks the total number of observation points was 20 (10 for the left and right banks in each of the particular transverse profiles).

Multivariate statistical techniques (Hierarchical Cluster Analysis—HCA) were used for group analyses of stream sections with similar habitat quality. HCA analysis uses the attributes taken into account when calculating the HQA and HMS indicators. This analysis is based on the average distance between connections using the Manhattan city block index of similarity.

Furthermore, the variation of attributes within each analyzed channel section was examined. The number of attributes and the Shannon–Wiener diversity index were calculated within each RHS category (bank material, bank modification, natural bank features, channel substrate, channel modification, channel features, flow type, land use within 5 m of the banktop, banktop vegetation structure, bankface vegetation structure, channel vegetation type). The Shannon–Wiener diversity index was calculated in relation to the entire research section as well as the individual attributes tested.

The Wilcoxon test was used to show statistically significant differences between the analyzed channel sections. In this study, the number of attributes within each RHS category presented in Table 2 (the same as in the Shannon–Wiener diversity index) were used.

Results

The hydromorphological state of the upper reaches of streams

The dominant material that forms the banks of the Peshok channel is rock outcrops and boulders (≥ 256 mm), whereas Fanshen is sand (< 2 mm) and Bystrzanka is

loamy-sandy with coarse rocky debris (loose, fine-grained material that covers the top layer of soil) (Table 3). The natural morphological elements of the streambeds of these streams are most often erosive undercutting of the banks (Bystrzanka), and vegetated point bars (Fanshen). At Peshok stream, no natural elements of the bank were found. In the case of Bystrzanka and Peshok, no anthropogenic modifications of the banks and bottom were found, but in Fanshen there were 15% of the profiles with bank modifications in the form of concrete reinforcements (Table 3).

The material that forms the bottom of the channels in Fanshen and Bystrzanka is mainly stones (according to the RHS method, this is loose material with a diameter of 64–256 mm); in Peshok it is bedrock. Among the natural elements of the channel bottoms, bedrock (sections in the Peshok and Bystrzanka streams), exposed boulders (all analyzed streams), vegetated boulders (Bystrzanka), vegetated (Fanshen) and unvegetated (Peshok) midchannel bars were distinguished (Table 3). In Bystrzanka and Fanshen, unbroken standing waves were most common (50% of profiles), while in Peshok there was rippled flow (turbulent flow with short waves with glassy ridges) (50% of profiles).

In terms of land use within a 5 m strip from the top of the banks (defined as the land adjacent to the bank top, changing into floodplain), deciduous or mixed woodland dominated in the upper research sections of the streams, constituting 60% in Peshok and 85% in Bystrzanka and Fanshen. In close proximity (< 100 m) to the stream channels, no compact buildings were noted.

The differentiation of the bank vegetation structure types in the RHS method is based on four categories (complex, simple, uniform structure and lack of vegetation). The components correspond to types of vegetation that contribute to the formation of a vertical bank profile. In the RHS method, the vegetation structure is determined separately for the top of the bank and the bank face (the area between the top of the bank and the water level in the channel). At the top of the banks of the studied stream sections there is mainly a complex structure (Peshok 75%, Fanshen 90%) or a simple structure (Bystrzanka 60%). On the Bystrzanka bank face, no vegetation was recorded in most profiles (due to the numerous eroding cliffs of the banks), whereas in Peshok and Fanshengou a complex vegetation structure dominated.

An important element that also directly affects the hydromorphological state of streams is aquatic vegetation, whose diversity ensures good habitat conditions for invertebrates and other organisms. Mosses were recorded on all sections of Peshok and Bystrzanka, but at Fanshen there was no vegetation in the streambed.

Table 3 Physical attributes of stream habitat in the upper and lower reaches of the analyzed streams (the values are expressed in percentage share in the total number of profiles)

Elements (physical attributes)	Streams					
	Bystrzanka—upper	Bystrzanka—lower	Peshok—upper	Peshok—lower	Fanshen—upper	Fanshen—lower
Bank material						
Soil	100	45	0	10	0	0
Gravel/sand	0	0	0	0	50	5
Cobbles	0	0	0	0	0	30
Boulders	0	0	25	45	15	10
Bedrocks	0	5	75	15	20	0
Gabions	0	50	0	5	0	0
Concrete	0	0	0	25	15	50
Invisible	0	0	0	0	0	5
Bank modifications						
None	100	45	100	50	85	40
Reinforced/resectioned	0	55	0	50	15	60
Natural bank features						
None	15	60	100	95	0	55
Eroding cliff	50	10	0	5	20	5
Unvegetated point bar	10	5	0	0	10	10
Vegetated point bar	20	25	0	0	50	20
Stable cliff	10	0	0	0	0	10
Channel substrate						
Bedrocks	10	0	60	0	10	0
Boulders	20	0	30	60	30	50
Cobbles	70	40	0	10	60	50
Gravel	0	60	10	20	0	0
Concrete	0	0	0	10	0	0
Channel modifications						
None	100	100	100	50	100	100
Reinforced	0	0	0	20	0	0
Resectioned	0	0	0	15	0	0
Channel features						
None	0	10	0	10	10	0
Bedrock	10	15	45	0	0	5
Exposed boulders	40	35	40	40	40	45
Vegetated boulders	40	0	0	0	0	0
Unvegetated midchannel bar	0	0	5	0	0	0
Vegetated midchannel bar	0	0	0	0	5	0
Natural impediments	0	0	0	0	0	5
Flow type						
Smooth	40	70	0	0	0	0
Rippled	50	0	10	30	50	0
Unbroken standing waves	10	30	50	40	40	40
Broken standing waves	0	0	10	30	10	60
Waterfall	0	0	30	0	0	0
Land-use within 5 m of banktop						
Deciduous/mixed woodland	85	35	60	65	85	5
Suburban development	0	55	0	35	0	35
Scrub and shrubs	5	0	40	0	15	20

Table 3 (continued)

Elements (physical attributes)	Streams					
	Bystrzanka—upper	Bystrzanka—lower	Peshok—upper	Peshok—lower	Fanshen—upper	Fanshen—lower
Grassland	10	5	0	0	0	0
Arable land	0	0	0	0	0	15
Orchard	0	0	0	0	0	25
Banktop vegetation structure						
Uniform	15	10	0	5	0	55
Simple	60	40	25	5	10	10
Complex	20	50	75	70	90	10
None	5	0	0	20	0	25
Bankface vegetation structure						
Uniform	20	5	0	30	10	50
Simple	30	25	25	25	25	15
Complex	0	10	75	35	50	5
None	50	60	0	10	15	30
Channel vegetation types						
Mosses	100	100	100	0	0	0

The hydromorphological state of the lower reaches of the streams

The dominant material of the banks of the streams was gabions in Bystrzanka, boulders in Peshok, and concrete in Fanshen (Table 3). Modifications in the form of reinforcements/resections were noted in all channels (50–60% of the profiles). Eroding cliffs (5–10%), unvegetated and vegetated bars (0–25%) and stable cliffs (0–10%) sporadically appeared on the examined sections of the streams.

Gravel (Bystrzanka, 60%), boulders (Peshok, 60%) as well as boulders and cobbles (Fanshen, 50% each) are the dominant materials that form the bottom of the studied channels. In the analyzed streams, exposed boulders dominate among the natural morphological features of the bottoms (35–45% of the profiles). Modifications of the stream bottom (fortifications and profiling) were noted only in Peshok.

The Bystrzanka stream bed is dominated (70% of profiles) by smooth flow (slow laminar flow, not disturbing the water surface); Peshok is dominated by unbroken standing waves (40% of profiles); in Fanshen is dominated by broken standing waves (60% of profiles), (turbulent flow with foamed water and breaking wave crests).

In terms of land use 5 m from the bank tops, suburban buildings dominated in Bystrzanka and Fanshen, (35–55%) and deciduous woodland dominated in Peshok (65%). Complex vegetation structure dominated on the top of the Bystrzanka and Peshok banks, and at Fanshen the uniform structure type dominated. Due to the reinforcements in Bystrzanka and Fanshen, no vegetation was found on the

bank face in 60% and 30% of the profiles, respectively. Despite the high level of anthropopressure in the Bystrzanka streambed, aquatic plants in the form of mosses were found in all measurement profiles (Table 3).

Assessment of the habitat quality of streams

HQA values reflect the degree of diversity of the natural hydromorphological features of a habitat; those calculated for the upper sections of the research streams ranged from 55 (Fanshen) to 64 (Bystrzanka), as shown in Table 4. In terms of the diversity of natural elements, the analyzed watercourse sections are in the range of very high (Bystrzanka, Peshok) and high quality (Fanshen). The high value of the HQA indicator in the studied sections was decisively influenced by the large diversity of bank vegetation structure, as well as the diversity and abundance of natural bank features and the arrangement of trees and associated features (Tables 3, 4).

On the lower sections of the studied streams, the HQA values were much lower and ranged from 37 (Fanshen) to 49 (Bystrzanka), as shown in Table 4. In terms of the diversity of natural elements, the HQA values are in the sufficient quality class (Table 2). Similarly to the upper sections, these values were affected by the number and diversity of bank vegetation structures and natural bank features.

HMS values determine the degree of anthropogenic changes in stream hydromorphology; those calculated for the upper sections of the analyzed streams ranged from 0 (Bystrzanka, Peshok) to 6 (Fanshen), as shown in Table 4;

Table 4 Components and values of HQA and HMS indicators (highest values are in bold type)

Indicator	Bystrzanka— upper	Bystrzanka— lower	Peshok—upper	Peshok—lower	Fanshen—upper	Fanshen—lower
HQA	64	49	58	47	55	37
HMS	0	28	0	25	6	39
Indicator components	% Share of indicators					
HQA arising from flow type	10.9	10.2	12.1	14.9	12.7	16.2
HQA arising from channel substrate	9.4	12.2	10.3	14.9	10.9	16.2
HQA arising from channel features	12.5	14.3	12.1	10.6	10.9	13.5
HQA arising from bank features	15.6	12.2	0.0	2.1	14.5	21.6
HQA arising from bank vegetation structure	20.3	30.6	32.8	34.0	32.7	18.9
HQA arising from channel vegetation in stream	3.1	4.1	3.4	0.0	0.0	0.0
HQA arising from land use in 50 m from banks	6.3	4.1	13.8	8.5	7.3	2.7
HQA arising from trees and associated features	14.1	12.2	15.5	14.9	10.9	10.8
HQA arising from special features (e.g., waterfall, boulder > 100 cm)	7.8	0.0	0.0	0.0	0.0	0.0
HMS arising from modifications at cross sections	0.0	78.6	0.0	80.0	66.7	61.5
HMS arising from modifications not at cross sections	0.0	7.1	0.0	4.0	33.3	28.2
HMS arising from synthetic assessment of whole section	0.0	14.3	0.0	16.0	0.0	10.3

this indicates a semi-natural and predominantly unmodified habitat quality, respectively. Low HMS values signify a lack of or only minor anthropogenic modifications of stream channels. The lower sections had higher HMS values (from 25 in Peshok to 39 in Fanshen). All analyzed lower sections can be classified as significantly modified (IV class, Table 2). High HMS values were mostly a result of the presence of reinforcements (concrete walls, gabions), artificial profiling of the banks of streams (Table 3), and the presence of bridges and stream culverts.

Discussion

Studies of the quality of river habitats with the RHS method were conducted in various mountain areas (Carpathians, Darjeeling Himalayas, Hengduan Mountains), which enabled assessment and comparison of habitat quality. The degree of naturalness of the studied streams in individual mountain areas is similar and is conditioned by the diversity and abundance of natural elements and their relation to anthropogenic elements, whose presence in turn causes deterioration of habitat quality. The degree of naturalness of the studied streams (both upper and lower sections) in mountain areas is mainly influenced by the same hydromorphological attributes, i.e., bank vegetation structure (on the bank

top and bank face), and the system of trees and associated features along the channel. The average share of the bank vegetation structure is 28% of the total value of HQA; the average share of the system of trees and associated features along the channel is 13%.

Table 5 presents the Shannon–Wiener diversity index for the attribute types within the categories analyzed with the RHS method. The attributes were most diverse in the lower part of Bystrzanka and Fanshen streams (1.41). The lowest value was found in the upper part of Peshok stream (1.27), as shown in Table 5. Generally, the highest diversity index figures were noted in the lower sections of the streams. This indicates a greater diversity of natural and anthropogenic elements of the hydromorphological state, which determines the quality of stream habitats. The coefficient of variation (CV) of the Shannon–Wiener diversity index ranged from 24% (Peshok—upper) to 47% (Fanshengou—lower).

The Wilcoxon test of the Shannon–Wiener diversity index for dependent samples (Table 6) showed significant differences in attribute abundance in five comparisons (Table 6). In the lower sections of all analyzed streams, the differences between the diversity indexes were statistically significant.

The degree of habitat transformation in the streams under consideration results from the modification of the banks (and/or bottoms) of the channels in the form of artificial fortifications and profiling. Stream channel modifications

Table 5 Shannon–Wiener diversity index of attribute types within the studied reaches of streams: the highest value (bold italic), the lowest value (italic)

Category	Stream					
	Bystrzanka		Peshok		Fanshen	
	Upper	Lower	Upper	Lower	Upper	Lower
Bank material	0.11	0.16	0.14	0.19	0.18	0.18
Bank modifications	0.11	0.15	0.11	0.15	0.14	0.15
Natural bank features	0.18	0.17	0.11	0.12	0.14	0.18
Channel substrate	0.09	0.09	0.10	0.10	0.10	0.09
Channel modifications	<i>0.07</i>	<i>0.07</i>	<i>0.07</i>	0.10	0.08	0.07
Channel features	0.14	0.12	0.14	0.09	0.10	0.10
Flow type	0.09	0.09	0.10	0.10	0.10	0.09
Land use within 5 m of the banktop	0.13	0.15	0.14	0.15	0.14	0.19
Banktop vegetation structure	0.16	0.16	0.14	0.16	0.13	0.17
Bankface vegetation structure	0.16	0.17	0.14	0.18	0.18	0.17
Channel vegetation type	<i>0.07</i>	<i>0.07</i>	<i>0.07</i>	<i>0.00</i>	<i>0.00</i>	<i>0.00</i>
Sum	1.30	1.41	1.27	1.36	1.29	1.41
Coefficient of variation (%)	31.6	30.1	23.8	42.9	43.3	47.3

Table 6 Comparison of individual attributes in the analyzed channel sections using the Wilcoxon test (significant statistics shown in bold, $p < 0.05$)

Section combinations	<i>p</i> value
Upper vs. upper	
Bystrzanka—upper vs. Peshok—upper	0.15
Bystrzanka—upper vs. Fanshen—upper	0.76
Peshok—upper vs. Fanshen—upper	0.28
Lower vs. lower	
Bystrzanka—lower vs. Peshok—lower	0.03
Bystrzanka—lower vs. Fanshen—lower	0.01
Peshok—lower vs. Fanshen—lower	0.03
Upper vs. lower—the same stream	
Bystrzanka—upper vs. Bystrzanka—lower	0.81
Peshok—upper vs. Peshok—lower	0.15
Fanshen—upper vs. Fanshen—lower	0.02
Upper vs. lower—different streams	
Bystrzanka—upper vs. Peshok—lower	0.26
Bystrzanka—upper vs. Fanshen—lower	0.09
Peshok—upper vs. Fanshen—lower	0.03
Lower vs. upper—different streams	
Bystrzanka—lower vs. Peshok—upper	0.12
Bystrzanka—lower vs. Fanshen—upper	0.84
Peshok—lower vs. Fanshen—upper	0.05

make up an average of 50% of the total HMS value. In addition to gravel mining and dams, reinforcing and profiling represent typical human interference in the habitats of rivers in all regions of the world, regardless of natural conditions (e.g., Wiejaczka et al. 2014; Bucala and Wiejaczka 2015; Wiejaczka and Kijowska-Strugała 2015; Stoffel et al. 2016).

The conducted research showed that the upper sections of the streams have habitats that are more natural than those of the sections located in the lower sections. The upper sections are characterized by a habitat naturalness that is 25% higher than in the lower sections (based on average HQA value). In turn, the lower sections show a 93% greater transformation of the habitat than the upper sections (based on average HMS value). Based on the combined HQA and HMS indicators, it was shown that the upper sections have very good (Bystrzanka and Peshok) and good habitat quality (Fanshen), while the lower sections have poor habitat quality (Table 7). The obtained results confirm the regularities observed by Bucala and Wiejaczka (2015): in mountain areas the lower parts of the basin are subjected to more anthropopressure than the upper parts (more buildings, denser road networks and hydrotechnical buildings in streams), which affects the quality of the river habitat. High anthropopressure in the bottom of the valleys or at the foot of slopes in mountain areas is a result of the accessibility of the terrain, e.g., lower relative heights and a dense road network (Eiter and Potthoff 2016; Kijowska-Strugała 2019).

Based on the HCA analysis (number of individual attributes) three groups of sections with similar stream habitat quality were identified (Fig. 4). The first group contained the upper section of Fanshen and lower and upper Peshok, both of which have relatively high HQA values (55 and 47, respectively) and similar diversity index values. The second group contained the lower sections of Fanshen and Bystrzanka, which are characterized by the most modified stream habitats (HMS values of 39 and 29, respectively) and equal diversity indexes. A third group is formed by the upper section of Bystrzanka due to the fact that it has the highest

Table 7 Location of the upper and lower studied stream sections in relation to classification of the habitat quality of streams based on the HQA and HMS indicators (I—very good, II—good, III—moderate, IV—poor, V—bad) (Raven et al. 1998; Walker et al. 2002; Jusik et al. 2014)

HMS classes	HQA classes				
	I	II	III	IV	V
I	I Bystrzanka—upper; Peshok—upper	II	II	III	III
II	II	II Fanshen— upper	III	III	IV
III	III	III	III	IV	IV
IV	III	IV	IV Bystrzanka—lower; Peshok—lower; Fanshen— lower	IV	V
V	IV	IV	IV	V	V

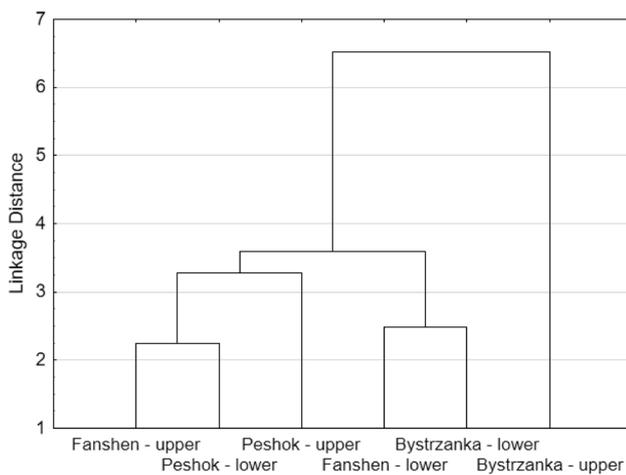


Fig. 4 Hierarchical cluster analysis (HCA) dendrogram for upper and lower sections of the analyzed streams, obtained using city block (Manhattan) distances

HQA values (64) and no anthropogenic transformation of the habitat.

Taking into account the obtained result, it can be assumed that the research hypothesis was confirmed. The habitat quality in sections clearly changed by man or without visible anthropopressure is similar in relation to various mountain areas and is conditioned by the same natural and anthropogenic factors. In mountainous areas, regardless of the climatic zone, affected by human activity, the changes in the habitat quality are similar.

The analysis carried out in this study indicated that the quality of the stream habitats changes along their courses. On one hand, this is due to a decrease in the number and diversity of natural elements (RHS attribute, Tables 2, 3) and an increase in the number and diversity of anthropogenic attributes that affect the quality of the habitat. This is confirmed by the observations of Bucała and Wiejaczka (2015), who showed a deterioration in the quality of the habitat of small Carpathian streams (Jaszczce and Jamne streams) along with their course from upper to lower sections. Studies by

Wiejaczka and Kijowska-Strugała (2015) also indicated differences in the habitat quality of the same river between downstream and upstream sections from the Carpathian reservoirs. In turn, a study conducted by Wiejaczka et al. (2014) in Darjeeling Himalayas (Teesta river) indicate that the diversity of natural hydromorphological elements of this large mountain river with noticeable human interference (bridges) is not significantly different from that in the sections without noticeable anthropogenic pressure. However, the habitat quality in the man changed sections was worse.

Given the results of our research as well as the results of previous analysis, it is important to consider the dynamics of the hydromorphological state of streams and rivers along their course (from upper to lower sections) when testing the habitat quality of streams in mountain areas.

Considering the diversity of natural and anthropogenic hydromorphological elements determining the habitat quality of the streams in its longitudinal course and the observed increase of the anthropogenic infrastructure (buildings, road network, riverbed reinforcements) in mountain areas (Starkeł and Basu 2000; Bucała and Wiejaczka 2015; Kijowska-Strugała 2019), attention should be paid to the possible scenario of changes in the quality of mountain streams habitat. Progressive anthropoppression up the streams in mountain areas can lead to transformation, deterioration and unification of the habitat quality of streams comparing to the current state. This may have further consequences for the environment biodiversity especially development of its biotic elements. In this context, the worldwide restoration process of stream habitats may be of great importance (Roni et al 2008).

Conclusions

Studies of mountain stream habitats carried out with the RHS method allow the following conclusions to be drawn:

1. Sections of mountain streams located in the upper catchment areas show greater habitat naturalness in relation

to sections located in lower parts; this is the result of the greater variety and number of natural hydromorphological elements of channels and the close vicinity of streams.

2. Both in upper and lower stream sections, regardless of the degree of naturalness and anthropopressure, the same attributes (bank vegetation structure, modifications at cross sections) have the greatest impact on HQA and HMS values.
3. The upper sections of mountain streams present a similar degree of naturalness (similar HQA values between 55 and 64), which allows the habitat quality in these sections to be classified as very high (Carpathians, Darjaling Himalaya) and high (Hengduan Shan). In terms of the degree of modification (HMS values between 0 and 6), the upper sections of the streams were classified mainly as semi-natural (Carpathians, Darjeeling Himalayas) and predominantly unmodified (Hengduan Shan).
4. The lower sections of the studied streams in the studied mountain regions showed the same class of habitat naturalness, i.e. sufficient quality (HQA values between 37 and 49), and similar class of habitat modifications, i.e., significantly modified (HMS values between 25 and 39).
5. The comparison of HQA and HMS values showed that the habitat quality in the upper sections is characterized as very good (Bystrzanka and Peshok streams) and good (Fanshen stream), while the lower sections have poor habitat quality.

The obtained results confirm the hypothesis that the difference between the habitat qualities of sections of stream clearly changed by human activity and without visible human interference is similar in relation to different mountain areas and is conditioned by the same natural and anthropogenic features. Similar regularities between the upper and lower reaches of streams in terms of the degree of naturalness and anthropogenic modification of the habitat can be also expected in other mountain areas not affected by human activities.

The analysis showed that the RHS method is sensitive enough to detect differences in habitat quality between natural and anthropogenic stream sections. In addition, it has been shown that the RHS method, which so far has been used mainly in Europe, is suitable for use in mountain areas in various climate zones.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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