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TURBULENT FLOW CHARACTERISTICS OF POOL, RUN, AND RIFFLE HYDROMORPHOLOGICAL UNITS IN A MOUNTAIN RIVER

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ABSTRACT

Aim of the study

The study here presented investigates the hydraulic and turbulent characteristics of three fundamental hydromorphological units – pools, runs, and riffles – along a mountain reach of the Skawa River.

Material and methods

Measurements of three velocity components (V_x, V_y, and V_z) were used to determine the flow velocity magnitude, the velocity fluctuations (RMS_{Vmag}), turbulent kinetic energy (*TKE*), and the degree of turbulence (*K*).

Results and conclusions

The absolute variables describing turbulent flow phenomena (V_{mag}, RMS_{Vmag}, and *TKE*) provide a clear distinction between pools, riffles, and runs, whereas the relative turbulence parameter (*K*) primarily differentiates between pools and riffles. The turbulence intensity was the highest in riffles and the lowest in pools. Furthermore, the observed velocity distributions were consistent with the typical velocity profile, showing a decrease in flow velocity and a concurrent increase in turbulence toward the channel bed. Pools exhibited the greatest internal variability in turbulence parameters compared to the other hydromorphological units. These findings highlight that turbulence characteristics display substantial spatial variability both within and among hydromorphological units. Such variability should be considered in the design and implementation of river restoration measures, particularly in mountain rivers where channel morphology strongly influences flow structure.

Key words: turbulent flow, turbulence, hydromorphological units, pools, riffles

INTRODUCTION

River morphology represents one of the fundamental determinants of instream hydraulic conditions. Channel topography, together with the hydrological regime, generates habitat diversity for aquatic organisms inhabiting river ecosystems. To capture this diversity, spatially distinctive morphological units can be delineated. Depending on classification systems, these units have been referred to as: geomorphic units, physical habitats, physical biotopes, hydraulic biotopes, or mesohabitats. Even though the terminology varies, all these concepts converge on the notion of hydromorphological units, applied in this study. A hydromorphological unit is understood here as a spatially distinct instream environment, characterized by relatively uniform hydraulic attributes resulting from interactions between discharge and channel topography. From an ecological perspective, it constitutes the abiotic component of a habitat (Harvey and Clifford,

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2010). Biologists frequently employ the term 'habitat' to describe hydraulic variability within a channel that conditions the existence of aquatic organisms (Kownacki and Soszka, 2004). Ensuring the morphological diversity of river channels is thus critical for restoring species diversity. At the same time, habitat heterogeneity is widely used to assess the ecological status of rivers and evaluate restoration measures (Mouton et al., 2007). The identification and the parameterization of hydromorphological units have therefore become essential components of water management, as they facilitate prediction, evaluation, and design of river habitats (Clifford et al., 2006). The parameters typically used in habitat identification include observations of channel bed morphology, sediment structure, and surface flow patterns. Surface flow characteristics, in turn, reflect hydraulic attributes such as water velocity, depth, and bed material grain size (Jowett, 1993; Harper and Everard, 1998; Clifford et al., 2006). This approach is of interdisciplinary relevance, as it can be applied by biologists, geomorphologists, and hydraulic engineers interested in the ecological quality of river channels.

Research on hydraulic conditions within hydromorphological units has traditionally focused on temporal and spatial averaging of flow velocity and depth. However, some studies highlight the need to analyze turbulent flow processes in respective units (Cardinale et al., 2002; Harvey and Clifford, 2009). Turbulent flow is characterized by velocity fluctuations that directly and indirectly affect ecological processes, including the development of benthic flora (Cardinale et al., 2002), the distribution of food resources, and predator–prey interactions (Roy et al., 2010). Turbulence also plays a crucial role in fish ecology, influencing energy expenditure during movement (Lupandin, 2005; Enders et al., 2009) and habitat selection (Smith et al., 2005). Previous research has demonstrated the importance of characterizing turbulent flow properties within habitats (Cardinale et al., 2002). Harvey and Clifford (2009) suggest that turbulence descriptors may complement existing habitat classifications, while Smith and Brannon (2007) emphasize that turbulence intensity could be an effective discriminator between hydromorphological units that are otherwise similar when described by mean hydraulic parameters.

The spatial distributions of turbulent flow around roughness elements have been investigated (Roy et al., 2004; Tritico and Hotchkiss, 2005), although some studies suggest that these effects are predominantly local. At the scale of morphological units such as pools and riffles, turbulence patterns may be more strongly governed by overall channel morphology than by individual roughness elements (Lamarre and Roy, 2005; Legleiter et al., 2007). These insights notwithstanding, relatively few studies have addressed turbulence distribution at the scale of pools and riffles, and detailed descriptions of turbulence characteristics within basic hydromorphological units remain limited.

Hydraulic environment works provide lots of unit classifications, from relatively wide – 3 units, to more detailed – even 18 units. Jowet (1993) distinguished three units, Hawkins et al. (1993) – eighteen units, Kemp et al. (2000) – fifteen, Parasiewicz (2007) – eleven, and Hauer (2008) distinguished six units. In the project carried out by the University of Agriculture in Krakow (NWMA, 2017), a distinction was made between nine hydromorphological units: riffle, pool, run, rapid, glide, shelf, backwater, side arm, and bar. This division enabled the analysis of units with changing discharge, which is essential, e.g., for analyzing usable areas. Regardless of the division, high-energy units, such as riffles and runs, and low-energy units, such as pools and backwaters, are distinguished. Some research on sub-montane river using turbulent parameters distinguished, in general, three basic units: riffles, runs, and pools (Woś and Książek, 2022).

The present study provides new insights into the hydraulics of mountain rivers through the analysis of three-dimensional velocity structures and turbulence parameters. We hypothesize that significant hydraulic differences (*TKE*, *K*) exist among the three basic hydromorphological units: pools, runs, and riffles. To test this hypothesis, we investigated a natural mountain channel reach of the Skawa River in southern Poland.

MATERIAL AND METHODS

Study site

Velocity measurements were collected in the Skawa River, in southern Poland. The Skawa basin covers the central part of the High Beskids, the Central

Beskids, and the Lanckorona Foothills. The Skawa is a right tributary of the Vistula, measuring 95 km in length with a catchment area of approximately 1,180 km^2.

We conducted the survey on a 1.5 km-long reach located in the montane part of the river, where the catchment (area 607 km²) has a mountainous character, the mean watercourse slope is 0.69%, and the width of the water-filled channel is 20–30 m. The measurements were carried out under low-flow conditions (discharge 2.9–3.8 $m^3 \cdot s^{-1}$), while the mean annual flow was 7.5 $m^3 \cdot s^{-1}$ and the mean low flow was 1.4 $m^3 \cdot s^{-1}$.

Field methods

Hydromorphological units within the study reach were identified based on hydraulic and morphological characteristics, specifically local variations in lateral and longitudinal channel topography. Units were distinguished through field observations of water depth, flow velocity, and surface flow patterns, following the classification criteria presented in Table 1. Since detailed measurements of three-dimensional velocity components are highly time-consuming, surveys were conducted under various discharges within the range of low and mean flows for this section of the river, as recorded at the gauging station in Sucha Beskidzka. Given that hydromorphological units are defined by both hydraulic and morphological properties, their extent and boundaries shift with changes in discharge.

The research design aimed to include at least eight replicates of each hydromorphological unit type: pools, runs, and riffles. However, difficulties in measurement in highly turbulent, low-depth conditions after post-processing led to a reduction in the number of riffles to 5 units.

Velocity measurements

Velocity components and flow depth were measured at eight locations within each hydromorphological unit in accordance with the assumptions outlined by Parasiewicz (2007). Measurements were performed using a Sontek MicroADV at three relative depths: z/h = 0.2, 0.4, and 0.6, where z denotes the distance from the bed and h denotes the local flow depth. The level z/h = 0.2 was selected to represent near-bed hydraulics, as the boundary layer extends up to 30% of the water column (Sukhodolov et al., 1998). The intermediate level, z/h = 0.4, was chosen in accordance with the Six-Tenths Method commonly applied in fluvial morphology, where velocity at this height approximates the depth-averaged velocity (Kinzel et al., 2007). Given the challenges of capturing full velocity profiles in highly turbulent flows, many ecohydraulic studies employ measurements at this level to estimate average flow conditions in gravel-bed rivers (Wilcox and Wohl, 2007; David et al., 2013). The level z/h = 0.6 was adopted as a proxy for maximum velocity within the water column. In turbulent flows, upper-profile measurements are challenging to obtain with acoustic probes due to aeration; during our field campaign, we confirmed that z/h = 0.6 was the highest level at which reliable data could be collected in riffle units.

Instantaneous velocity components in the streamwise (x), transverse (y), and vertical (z) directions were recorded at each point for 60 s at a sampling frequency

Table 1. Hydromorphological units description modified from Bisson et al. (1996) and Parasiewicz (2007)

Hydromorphological unit	Description
Pool	a channel segment with concave longitudinal profile, high depth, slow water flow, and smooth water surface; hydraulics, in short: deep and slow flow
Run	a monotone channel segment with well-determined thalweg, moderate velocity, and depth, ripples or traveling waves on the water surface; hydraulics, in short: medial depth and medial flow velocity
Riffle	a shallow area with fast current velocity and strong turbulence on the surface, visible as standing unbroken or broken waves; hydraulics in short: shallow and fast flow

of 20 Hz (Buffin-Bélanger and Roy, 2005). The stationarity of the velocity time series was determined in the laboratory before measurements began, and the established measurement duration was used in this study (Wyrębek, 2012). The MicroADV probe was mounted on an adjustable tripod, allowing for stable positioning at predetermined locations within the channel.

Data processing

Data quality was controlled by applying a minimum signal-to-noise ratio (SNR > 5) and correlation coefficient (COR > 40%), which are acceptable thresholds for highly turbulent flows (Martin et al., 2002). Outliers were removed using the phase-space threshold despiking method (Goring and Nikora, 2002; Wahl, 2002). Following post-processing, fewer than 1000 individual values were automatically excluded. The final dataset comprised 493 high-quality time series for analysis, including 192 time series collected in eight pools (64 files at $z/h = 0.2$, 64 at $z/h = 0.4$, and 64 at $z/h = 0.6$), 192 in eight runs (64 files at $z/h = 0.2$, 64 at $z/h = 0.4$, and 64 at $z/h = 0.6$), and 109 in five riffles (36 files at $z/h = 0.2$, 37 at $z/h = 0.4$, and 36 at $z/h = 0.6$).

Turbulence characteristics

Each velocity time series was decomposed into mean and fluctuating components:

$$v_x = V_x + v_x'$$

where v_x is the instantaneous streamwise velocity, V_x is the mean streamwise velocity, and v_x' represents the fluctuating component. Transverse and vertical velocities were decomposed analogously as $v_y = V_y + v_y'$ and $v_z = V_z + v_z'$.

The mean velocity components (V_x, V_y, V_z) were subsequently used to calculate the magnitude of the three-dimensional velocity vector (mean flow):

$$V_{\mathrm{mag}} = (V_x^2 + V_y^2 + V_z^2)^{0.5}$$

Turbulence intensity, representing the magnitude of velocity fluctuations, was determined as the root mean square (RMS_{Vmag}) values of three-dimensional velocity, which is the root-mean-square value of the time series of individual velocity magnitude values.

A commonly used characteristic of overall turbulent energy, the turbulent kinetic energy (*TKE*) was calculated for each time series according to:

$$TKE = 0.5\,(RMS_x^2 + RMS_y^2 + RMS_z^2)$$

Another key turbulence characteristic is the degree of turbulence (*K*), often referred to as turbulence intensity, which represents the relative magnitude of velocity fluctuations. *K* is defined as the ratio of the root mean square of the velocity magnitude fluctuations to the mean flow velocity:

$$K = RMS_{\mathrm{Vmag}} \,/\, V_{\mathrm{mag}}$$

Statistic calculation

The distribution of variables was tested for normality using the Kolmogorov–Smirnov test, and the homogeneity of variances was examined with Levene's test. Since the assumption of variance homogeneity was not satisfied, differences among unit types were assessed using the nonparametric Kruskal–Wallis test, with the level of statistical significance set at $p < 0.05$. Letters a, b, and c were used to denote statistically significant differences among the groups: pools, runs, and riffles. All analyses were conducted in R version 4.3.2 (R Core Team, 2023) using the ggstatsplot package (Patil, 2021).

RESULTS

The pools ranged in depth from 40 to 100 cm, and exhibited noticeable variability in their hydraulic characteristics. In two pools, the streamwise velocity (V_x) was approximately 25 cm · s^{-1}; in another two, it reached up to 50 cm · s^{-1}; whereas in three pools, the velocities attained values of up to 70 cm · s^{-1}. Across all pools, the streamwise component (V_x) clearly dominates, with values increasing from near-bed measurements (0.2*h*) towards the water surface (0.6 *h*). The transverse velocity component (V_y) exhibits relatively small magnitudes, oscillating around zero, which reflects alternating motions in the lateral (left–right) direction relative to the streamwise axis. The vertical component (V_z) exhibits the smallest values, close to zero, with both upward- and downward-directed values. Overall, velocity distributions indicate that pools exhibit relatively low mean streamwise velocities (Fig. 1).

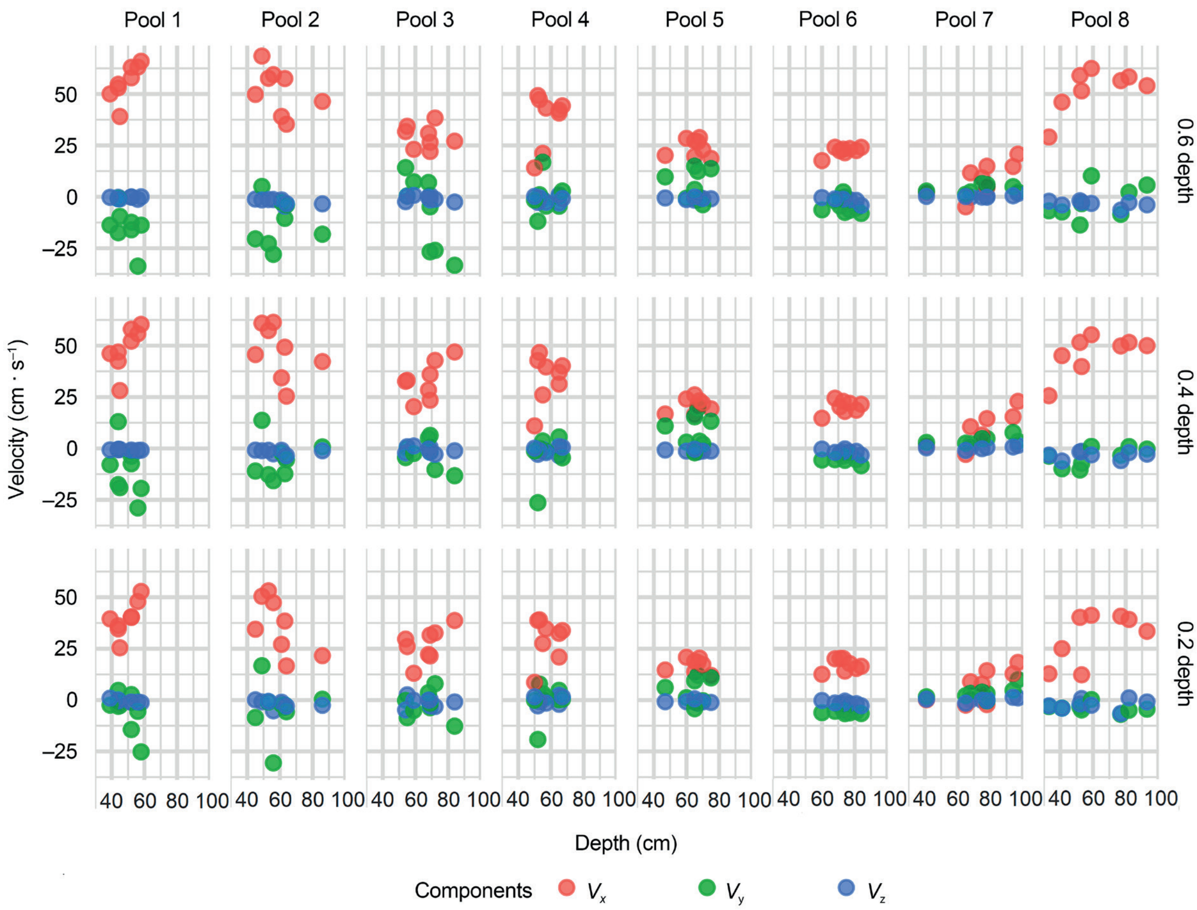

Fig. 1. Distribution of flow velocity components in eight investigated pool units (Pool 1 – Pool 8). Streamwise (V_x), transverse (V_y), and vertical (V_z) velocities are shown for three relative depths (z/h = 0.2, 0.4, 0.6; h – local flow depth) (Source: Authors' own elaboration)

The runs exhibited greater similarity to each other than the pools did in their streamwise velocity component (V_x), which ranged approximately between 40 and 100 cm · s^{-1}. As in pools, V_x generally increases from near-bed measurements (0.2 *h*) toward mid- and upper-depth positions (0.4 *h* and 0.6 *h*). Under the investigated flow conditions, the water depth ranged from 30 to 70 cm. Compared to pools, however, runs exhibit consistently higher streamwise velocities across all depths. The transverse component (V_y) oscillates around 10 m/s, but the values are greater than in pools. The vertical component (V_z) oscillates around zero. Overall, runs exhibit higher mean streamwise velocities than pools, combined with moderate transverse and vertical variability (Fig. 2).

Riffles (25–50 cm depth) are characterized by the highest velocities among all unit types, with streamwise component (V_x) frequently exceeding 120 cm · s^{-1} and reaching up to 160–170 cm · s^{-1} in some profiles. Values of V_x systematically increase with depth in the water column, from 0.2 *h* toward 0.6 *h*. The transverse component (V_y) fluctuates around zero but exhibits greater variability than in pools and runs up to 50 cm · s^{-1}. Overall, riffles exhibit the most energetic hydraulic conditions, characterized by higher mean streamwise velocities and greater variability in both the transverse and vertical components than in pools and runs (Fig. 3).

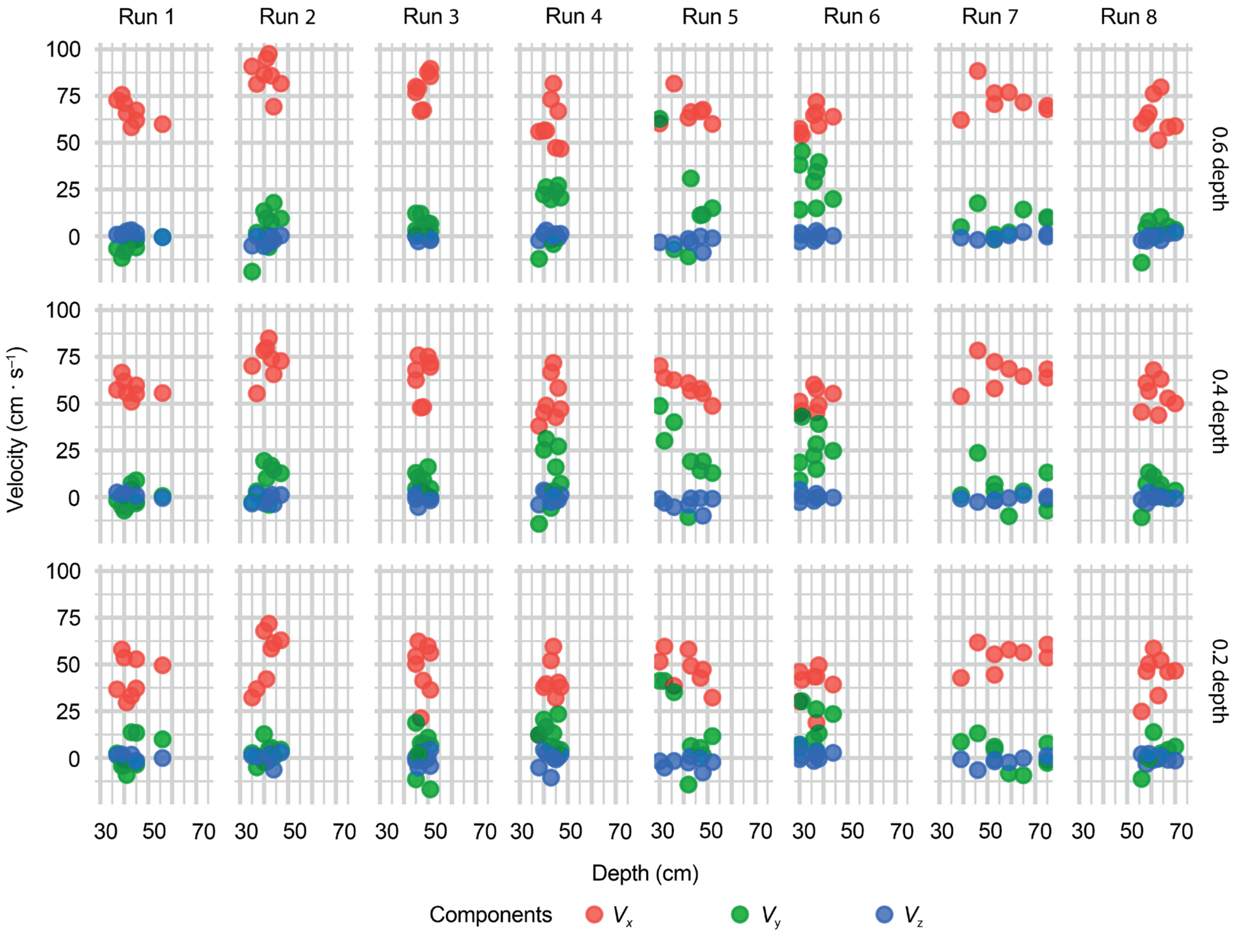

Fig. 2. Distribution of flow velocity components in eight investigated run units (Run 1 – Run 8). Streamwise (V_x), transverse (V_y), and vertical (V_z) velocities are presented for three relative depths (z/h = 0.2, 0.4, 0.6; h – local flow depth) (Source: Authors' own elaboration)

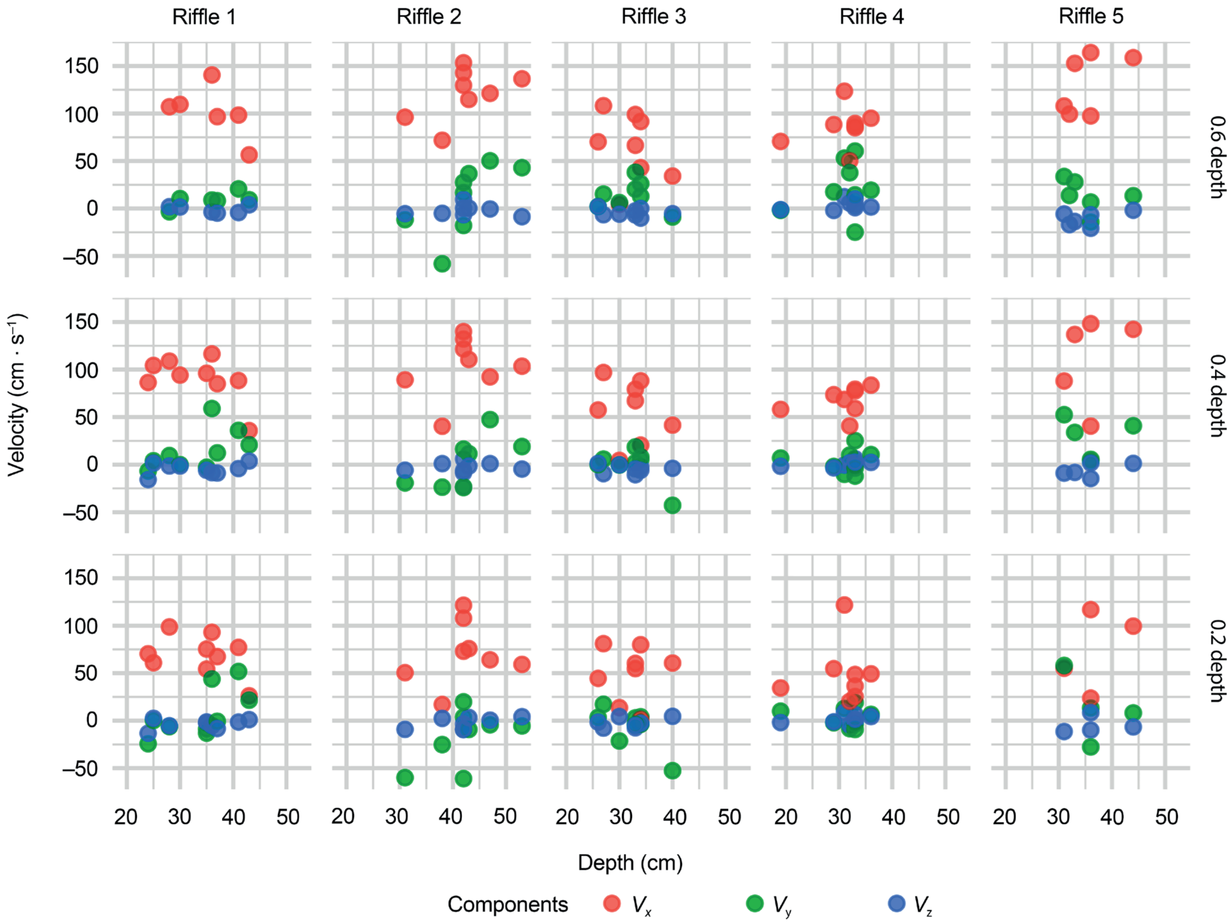

Fig. 3. Distribution of flow velocity components in five investigated riffle units (Riffle 1 – Riffle 5). Streamwise (V_x), transverse (V_y), and vertical (V_z) velocities are shown for three relative depths (z/h = 0.2, 0.4, 0.6; h – local flow depth) (Source: Authors' own elaboration)

The velocity magnitude density distribution suggests that, across all three sampling locations, flow velocities vary among the morphological units. In pools, the majority of values are below 25 cm · s^{-1}; in runs, they concentrate around 50 cm · s^{-1}; while riffles display the highest variability, with a moderate predominance of velocities between 70 and 100 cm · s^{-1} (Fig. 4).

The root mean square of velocity magnitude ($RMS_{V\mathrm{mag}}$) further demonstrates that absolute turbulence differs among the morphological units across all three sampling sites. In pools, most *RMS* values are below 5 cm · s^{-1}; in runs, they are concentrated around 10 cm · s^{-1}; while in riffles, the distribution is the most uniform, with a slight predominance of values between 10–15 cm · s^{-1} at 0.2 h and 15–20 cm · s^{-1} at higher elevations within the flow profile (Fig. 5).

Turbulent kinetic energy varied markedly across hydromorphological units and depths. At 0.2 *h*, riffles displayed the highest mean *TKE* (332.66 cm^2 · s^{-2}), substantially exceeding values in runs (131.80 cm^2 · s^{-2}) and in pools (36.65 cm^2 · s^{-2}). At mid-depth (0.4 *h*), the pattern persisted, with riffles again showing the greatest mean turbulence (352.20 cm^2 · s^{-2}), followed by runs (117.23 cm^2 · s^{-2}) and pools (28.83 cm^2 · s^{-2}). At the upper position (z/h = 0.6), mean *TKE* decreased in all unit types; riffles maintained the highest values (306.94 cm^2 · s^{-2}), compared with runs (86.58 cm^2 · s^{-2}) and pools (21.57 cm^2 · s^{-2}) (Fig. 6).

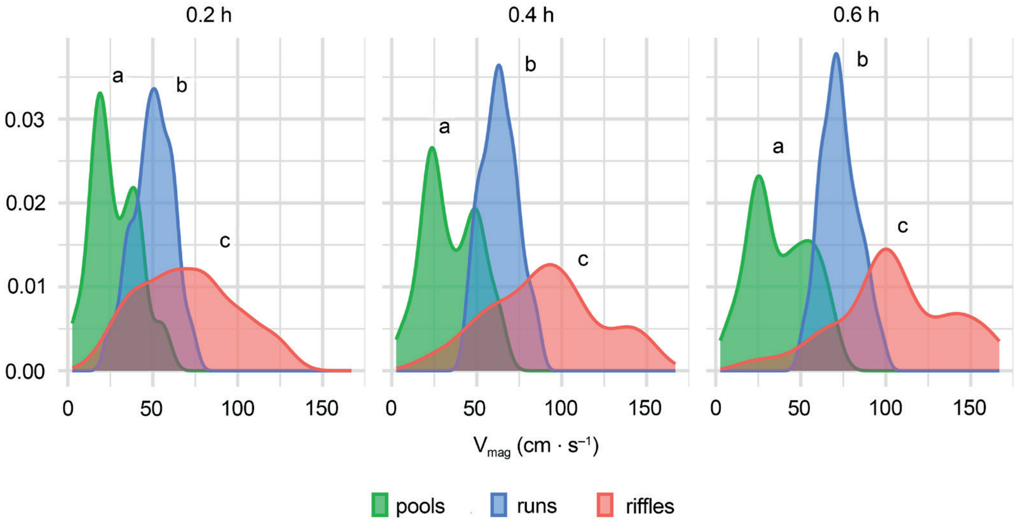

Fig. 4. Probability density distributions of velocity magnitude (V_{mag}) in pools (green), runs (blue), and riffles (red) at three relative depths (z/h = 0.2, 0.4, 0.6). Different letters (a, b, c) above the plots denote statistically significant differences among hydromorphological unit types (Source: Authors' own elaboration)

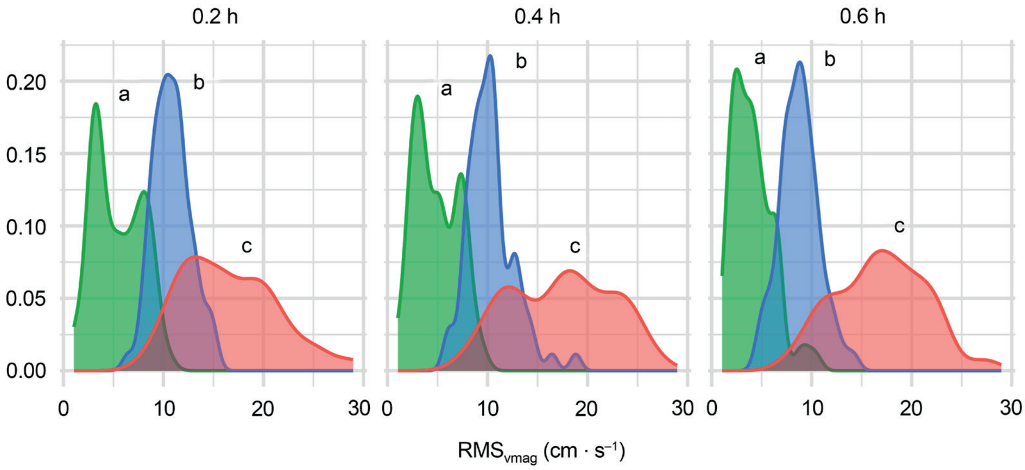

Fig. 5. Probability density distributions of velocity fluctuations (*RMS* velocity magnitude) in pools (green), runs (blue), and riffles (red) at three relative depths (z/h = 0.2, 0.4, 0.6). Different letters (a, b, c) above the plots denote statistically significant differences among hydromorphological unit types (Source: Authors' own elaboration)

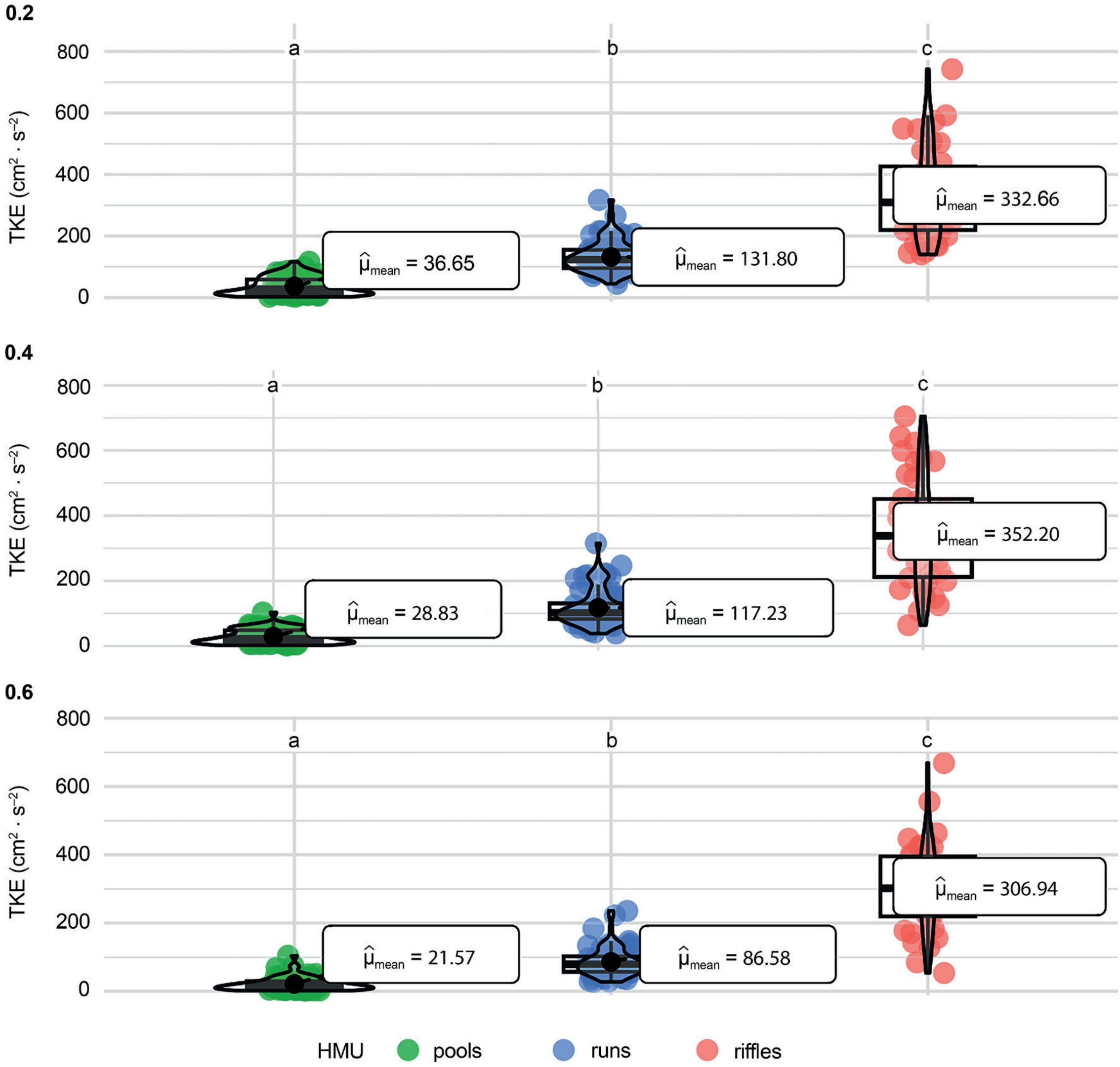

Fig. 6. Turbulent kinetic energy (*TKE*) [$cm^2 \cdot s^{-2}$] in pools (green), runs (blue), and riffles (red) at three relative depths (z/h = 0.2, 0.4, 0.6). Mean values are shown within each distribution. Different letters (a, b, c) above the plots denote statistically significant differences among hydromorphological unit types (Source: Authors' own elaboration)

Overall, riffles consistently sustained the most energetic flow conditions at all depths, runs represented an intermediate hydraulic environment, and pools exhibited the lowest turbulence levels. In all units, *TKE* increased upward in the water column, reflecting a systematic reduction of turbulence intensity with distance from the channel bed. The turbulence degree (*K*) exhibited systematic differences among hydromorphological units and decreased with height in the water column. At 0.2 *h*, riffles reached the highest mean turbulence (0.26), followed by runs (0.23) and pools (0.21). At mid-depth (0.4 *h*), riffles remained dominant (0.22), whereas runs (0.17) and pools (0.15) were significantly lower. At 0.6 *h*, turbulence values decreased across all unit types, with riffles sustaining the highest mean (0.18) compared to pools and runs (both 0.12). Overall, riffles consistently maintained the greatest turbulence intensity, pools the lowest, and runs occupied an intermediate position, whereas turbulence intensity decreased upward from the bed (Fig. 7).

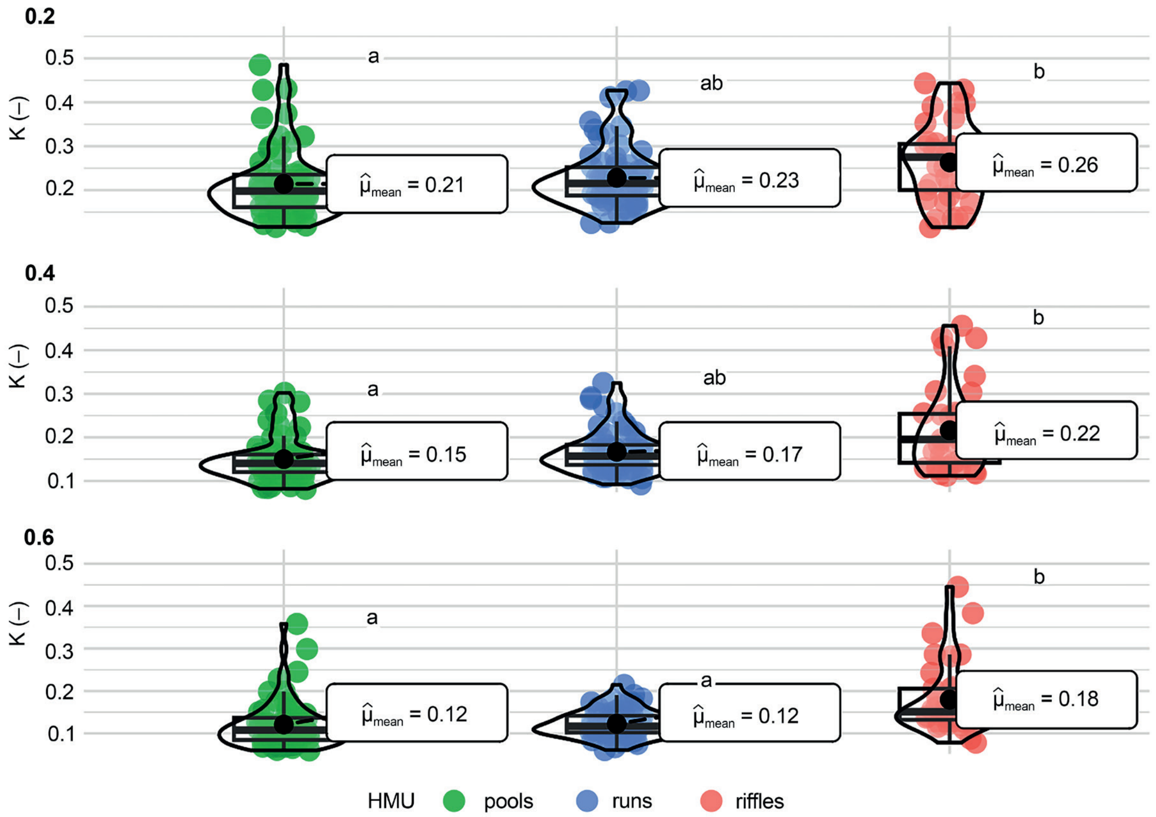

Fig. 7. Turbulence degree (K) in pools (green), runs (blue), and riffles (red) at three relative depths (z/h = 0.2, 0.4, 0.6). Mean values are indicated within each distribution. Different letters (a, b, c) above the plots denote statistically significant differences among hydromorphological unit types (Source: Authors' own elaboration)

DISCUSSION

Our results suggest that most turbulence parameters can be used to differentiate hydraulic environments within the three fundamental hydromorphological units: pools, runs, and riffles. Similar results were obtained for another, sub-montane reach of the Skawa River (Woś and Książek, 2022). In that study, an additional hydromorphological unit – rapid – was also analyzed; however, no differences in turbulence parameters were found between riffles and rapids, despite their morphological distinctions observed in the field (Woś and Książek, 2022).

The velocity magnitude and velocity fluctuations within the investigated hydromorphological units were, as expected, the lowest in the pools and the highest in the riffles. Velocity fluctuations are more intense in riffles than in pools and runs, where flow velocities are generally more stable and uniform. Riffles are characterized by higher turbulence, driven by shear layers and horizontal vortices that induce greater flow variability. In contrast, pools exhibit higher flow stability, relatively lower velocities, and reduced turbulence (Robert, 1997).

The velocity distribution within each investigated hydromorphological unit followed a typical profile, with flow velocity decreasing toward the channel bed. Near-bed velocity profiles are essential for understanding the formation and persistence of individual hydromorphological units, as well as for studying sediment transport processes (Robert, 1997). The difference in mean velocity between the identified units decreases with increasing depth. During high-flow conditions, velocity differences between pools and riffles may diminish or even reverse, with higher velocities occurring near the channel bed in riffles (Keller 1971; Robert 1997). However, this is not a universal rule for all river systems, and may occur when riffles have greater channel width than pools (Heritage and Milan 2004; Caamaño et al. 2009).

The turbulence tended to increase toward the channel bed. Therefore, it can be stated that lower mean velocities and higher pulsations characterize near-bed flow, whereas in the zone of maximum velocities, the absolute fluctuations are minimal. Such hydraulic conditions are commonly reported in mountain river habitats, primarily due to the influence of bed roughness (Tritico and Hotchkiss, 2005). A similar trend was observed in studies of turbulent flow structure in a gravel-bed river with velocities ranging from 30 to 70 $cm \cdot s^{-1}$, where turbulence intensity varied between 5 and 10 $cm \cdot s^{-1}$ (Roy et al., 2004). The described pattern of turbulence intensity distribution was also reported in a sand-bed river with flow velocities of approximately 10 $cm \cdot s^{-1}$ and a water depth of around 1 m (Nikora et al., 2003). Having said that, it has also been noted that turbulence magnitude may decrease in the near-bed zone of streams, within the layer below 0.2 *h* (Buffin-Bélanger et al., 2005; Książek et al. 2011). An increase in turbulence intensity was also observed in general with rising local velocity.

The mean turbulence intensity at all investigated depths was significantly higher in riffles compared to pools. Similar results were obtained for the Skawa River using a different methodological approach (Hawryło et al., 2013). Conversely, studies conducted on a lowland river in the United Kingdom found no significant differences in turbulence intensity between pools and riffles, concluding that pools represent the most heterogeneous habitats in terms of turbulence magnitude (Harvey and Clifford, 2009). Our investigation also confirms that pools differ the most between one another. The form of the V_{mag} and $RMS_{V\mathrm{mag}}$ distributions observed in pools indicates potential difficulties in unambiguously distinguishing pools from runs. Similarly, the degree of turbulence did not reveal statistically significant differences between these hydromorphological units. A similar issue in the field was also noted by Jowett (1993). Conversely, the origin of pools differs: some develop as a result of transverse obstructions within the channel, whereas others are formed through water impoundment induced by the concave configuration of the channel bed. The turbulence may also vary within different parts of a single habitat. For instance, laboratory studies have shown that turbulent shear stresses in the head of a pool exceed those occurring elsewhere in the channel, including in the riffles (Dashtpeyma and MacVicar, 2023).

Wilcox and Wohl (2007) reported higher *TKE* values in pool units than in runs; however, other studies have reported higher *TKE* in riffles than in pools (Smith et al. 2005; Roy et al. 2010). *TKE* increased toward the channel bed, as the roughness of the bed material enhances velocity fluctuations by several hundred percent compared to a smooth bed (Nikora et al., 2002). This trend was also observed in studies of a sand-bed river with a depth comparable to that of the Skawa River (Nikora et al., 2003).

Fish avoid areas with high turbulence, therefore, it is essential that *TKE* values are not exceeded in rest pools in fish passes. A TKE_{crit} value of 500 $cm^2 \cdot s^{-2}$ is considered the threshold between high turbulence ($TKE > 500\ cm^2 \cdot s^{-2}$) and low turbulence ($TKE \leq 500\ cm^2 \cdot s^{-2}$) (Daneshfaraz et al., 2025 after Santos et al., 2012, and Marriner et al. 2016). The average *TKE* values in riffles under natural conditions are lower than the critical estimated value for fish ladders at pools, TKE_{crit}. Only locally it is exceeded, reaching 700 $cm^2 \cdot s^{-2}$ throughout the water column. There is also a difference between the pool unit in the river and the pool in the fish pass, indicating a different flow nature. According to Pena et al. (2018), *TKE* in fish lader pools can reach up to 1500 $cm^2 \cdot s^{-2}$.

CONCLUSION

Our results suggest that the absolute variables describing turbulent flow phenomena – V_{mag}, $RMS_{V\mathrm{mag}}$, and *TKE* – provide a clear distinction between pools, riffles, and runs, whereas the relative turbulence parameter (*K*) differentiates primarily between the two basic units: pools and riffles. The turbulence is the highest in riffles, and the lowest in pools. Furthermore, compliance with the typical velocity profile was observed, characterized by a decrease in flow velocity and a concurrent increase in turbulence toward the channel bed. It was noted that pools exhibit the greatest internal variability compared to the other studied hydromorphological units. It should be noted that the examined hydraulic and turbulence parameters show substantial variability among hydromorphological units, which should be considered in the planning and design of river rehabilitation and restoration measures.

It would be interesting to use the results of the study (specifically, velocity and turbulence) for the calibration and verification of two- or three-dimensional models. Knowledge of hydraulic parameters in natural conditions is crucial when designing fish passes and restoring habitats based on the nature-based solution concept. A challenge would be to expand the research in order to verify the fishway design criteria based on *TKE*.

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CHARAKTERYSTYKA PRZEPŁYWU TURBULENTNEGO JEDNOSTEK HYDROMORFOLOGICZNYCH TYPU PLOSO, BYSTRZE I RYNNA W RZECE GÓRSKIEJ

ABSTRAKT

Cel pracy

Badanie dotyczy charakterystyki ruchu turbulentnego trzech podstawowych jednostek hydromorfologicznych rzeki górskiej: plosa, rynny i bystrza, na przykładzie górskiego odcinka Skawy.

Materiał i metody

Na podstawie pomiarów trzech składowych prędkości przepływu (V_x, V_y i V_z) określono wartość prędkości przepływu (V_{mag}), fluktuacje prędkości ($RMS_{V\mathrm{mag}}$), energię kinetyczną turbulencji (*TKE*) oraz stopień turbulencji (*K*). Badaniami objęto 8 plos, 8 rynien i 5 bystrzy, wykonując pomiary prędkości w ośmiu pionach każdej jednostki na trzech wysokościach względnych profilu hydrometrycznego 0,2 *h*, 0,4 *h*, i 0,6 *h*.

Wyniki i wnioski

Bezwzględne parametry opisujące zjawiska przepływu turbulentnego wyraźnie różnicują jednostki hydromorfologiczne: plosa, bystrza i rynny, natomiast względny parametr turbulencji (*K*) tylko odróżnia plosa od bystrzy. Intensywność turbulencji była najwyższa w bystrzach, a najniższa w plosach. Zaobserwowane rozkłady prędkości były zgodne z typowym profilem prędkości – wykazywały spadek prędkości przepływu oraz jednoczesny wzrost turbulencji w kierunku dna koryta. Spośród analizowanych jednostek plosa charakteryzowały się największym zróżnicowaniem wewnętrznym parametrów turbulencji. Uzyskane wyniki potwierdzają, że parametry turbulencji wykazują znaczną zmienność przestrzenną zarówno w obrębie, jak i pomiędzy jednostkami hydromorfologicznymi. Zmienność tę należy uwzględniać przy projektowaniu i realizacji działań renaturyzacyjnych rzek, zwłaszcza w rzekach górskich, gdzie morfologia koryta mocno wpływa na strukturę przepływu.

Słowa kluczowe: przepływ turbulentny, turbulencja, jednostki hydromorfologiczne, bystrza, plosa