

## Hydromorphological Index for Rivers (HIR): A New Method for Hydromorphological Assessment and Classification for Flowing Waters in Poland

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### ABSTRACT

The method based on original metric called Hydromorphological Index for Rivers (HIR) was developed in 2017 for the purpose of the monitoring of the hydromorphological status of flowing waters in Poland. It fulfils the requirements of the EU Water Framework Directive (WFD). It allows the assessment of both lowland rivers as well as mid-altitude and highland streams. The proposed system can be used to assess the natural and heavily modified rivers as well as artificial channels. The basis of the proposed system is a field survey, which is supplemented by the analysis of Geographic Information Systems (GIS) data and remote sensing materials. The analysis of the GIS data and remote sensing materials already enable to estimate preliminary classification of the hydromorphological status of the non-surveyed water bodies. On the basis of the field survey, the principal HIR value can be estimated for the considered river site and comparing with the reference conditions, the hydromorphological quality status in the five-class system can be calculated. The properly selected, representative survey sites (one or more depending on the heterogeneity of the environment), enable the classification and evaluation of entire surface water bodies in the framework of the national environmental monitoring. The GIS component of the HIR proved to be useful in verifying the determination of heavily modified water bodies and in assessing the needs of river restoration. It was also applied in the development of the National river restoration program for predicting the impact of the proposed restoration measure on the state of hydromorphology.

**Keywords:** hydromorphology, rivers, streams, monitoring, surface water classification, flowing water

### INTRODUCTION

The method presented in this paper is based on the original metric called Hydromorphological Index for Rivers (HIR). It was prepared in 2017

for the purpose of river monitoring in Poland (Szoszkiewicz et al. 2017). It can be used for various river types (lowland, mid-altitude and highland), including natural rivers as well as modified and even artificial channels.

The proposed method constitutes an original system of hydromorphological assessment, which was developed based on various Polish and European methods. Many elements of the HIR method are based on the River Habitat Survey (RHS) system, which was developed in the UK (Raven et al. 1998, Boon et al. 2002, Environmental Agency 2003, Szoszkiewicz et al. 2006, Jusik et al. 2014). Moreover, significant elements of the two Polish methods were also used (Adynkiewicz-Piragas 2009, Radecki-Pawlik 2014).

The major purpose of the HIR method development was national monitoring meeting criteria of the Water Framework Directive (WFD) (European Commission, 2000) and European and Polish standard for assessing the hydromorphological features of rivers (EN 14614, 2004). The proposed method can also be utilized to predict the engineering modifications (environmental impact assessment) as well as the results of river restoration measures. Moreover, the HIR system can be used for various scientific ecological investigations of various groups of aquatic organisms.

The HIR is a field survey based method but it is supported by an analysis of the GIS data which deliver preliminary classification of hydromorphological status. Nevertheless, in the result of the field survey, the basic HIR index can be calculated for the stretch of watercourse. Comparing the HIR value with the reference conditions, the hydromorphological quality status in the five-class system can be calculated for this stretch. Representative survey sites enable for the classification of entire rivers or whole water bodies recognized by the national environmental monitoring. The final evaluation of a water body combines an average HIR value from several stretches surveyed in the field and preliminary evaluation based on the GIS data.

The process of the HIR method development is based on the original database consisting of hydromorphological survey records of 1,107 sites, carried out in the field by the authors of this paper in the period 2003–2016 (Fig. 1). This database represents full hydromorphological gradient, from the reference conditions to extreme degradation. The analysis of these data was the basis for developing a river classification method meeting the criteria of the WFD.

So far, three publications summarizing the results of the HIR method have been published – two from the Greater Poland voivodship

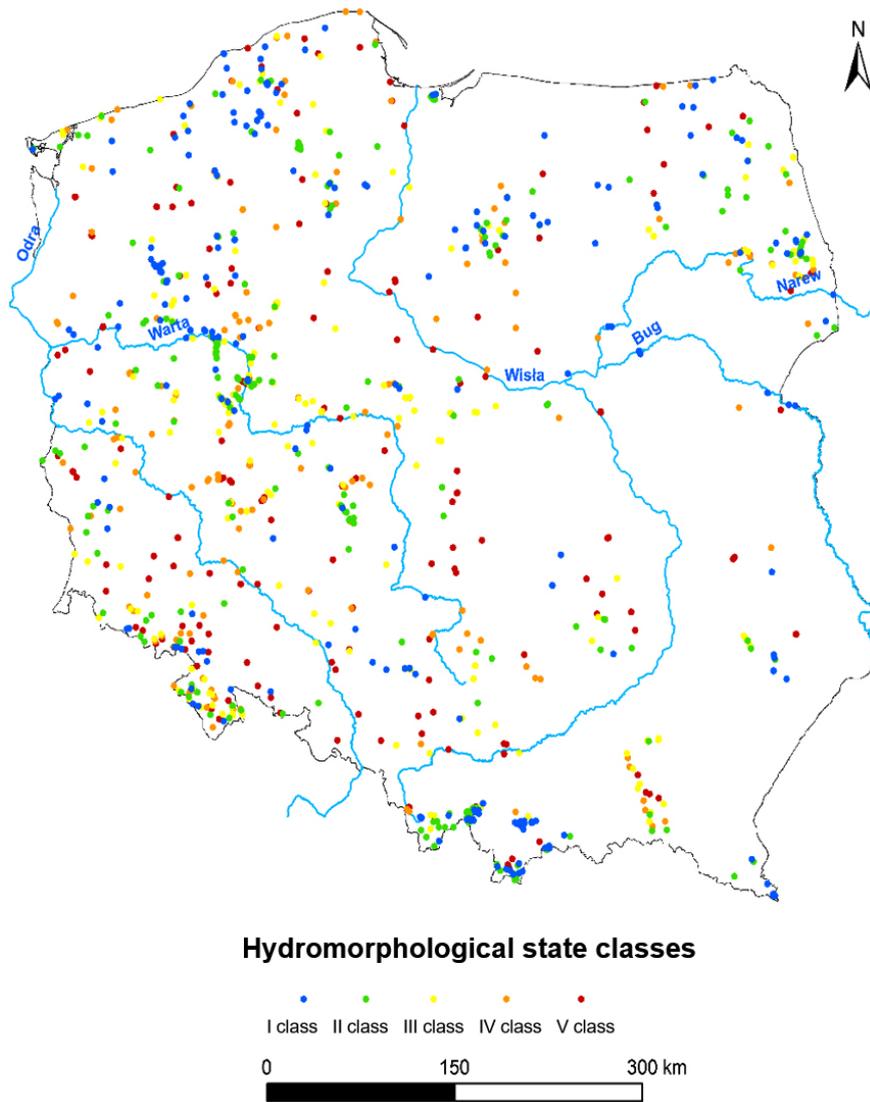
(Pietruczuk et al. 2019, 2020) and one from the Lower Silesian voivodship (Przesmycki et al. 2019). The GIS component of the HIR proved to be useful in verifying the determination of heavily modified water bodies and in assessing the needs of river restoration (Grela et al. 2019). It was also applied in the development of the National river restoration program, for predicting the impact of the proposed restoration measures on the state of hydromorphology (Biedroń et al. 2020).

### Preliminary analysis based on the GIS data

The preliminary assessment of the hydromorphological quality of rivers is based on the commonly accessible, generally public spatial data as satellite images (e.g. Geoportals WMS service or Google Earth platform). In this way, the information supportive to field the survey was provided. Moreover, this preliminary assessment can be already utilized by the national monitoring program for the water bodies that are not considered under the field survey scheme.

Preliminary protocol considers the abundance of hydromorphological elements along the river reach or by estimation the frequency of various attributes. The analysis includes the information on hydrological regime, channel sinuosity calculated in 5 class-scale, engineering structures as water management facilities, spillways and flow regulation structures, dams, as well as bridges. Among non-engineering hydromorphological attributes the tree presence in the valley along the surveyed river reach can be recorded based on remote sensing materials.

The preliminary protocol includes several attributes of the river valley, which are analyzed in the 100 m wide buffer for rivers with channel width  $\leq 30$  m and whereas in the case of rivers wider than 30 m, the buffer is 1000 m wide. In this way, the information on the abundance of various forms of land use is delivered, distinguishing the urban, agricultural and semi-natural form of management. Moreover, the information on the lateral connectivity of river with its valley is recorded, including the presence of embankments, inter-embankment zones, ox-bow lakes and wetlands. In the case of large rivers (channels  $>30$  m), the information on the channel dimensions variability, number of bars (side bars and mid channel bars) and islands is recorded.



**Fig. 1.** The distribution of the survey sites utilized for the development of HIR method (N = 1107 river sites). Colors indicate the classes of hydromorphology

### Preliminary evaluation based on the GIS data

The preliminary assessment is based on the remote sensing materials and spatial databases. In order to assess the presence and abundance of natural elements the GIS Hydromorphological Diversity Score (GIS-HDS) was developed, whereas the GIS Hydromorphological Modification Score (GIS-HMS) informs on the degree of morphological degradation. The range of attributes considered for the GIS-HDS and GIS-HMS estimation is presented in Tables 1 and 2. The number of attributes included depends on the size of the rivers (number of attributes is greater in large rivers).

The preliminary evaluation of the whole river body considers GIS-HDS as well as GIS-WPH which are calculated on the basis of

various hydromorphological attributes HDSA and HMSA:

$$GIS-HDS = \sum HDSA_i \quad (1)$$

where: *GIS-HDS* – GIS-Hydromorphological Diversity Score;  
*HDSA<sub>i</sub>* – Hydromorphological Diversity Score Attributes;  
*i* – attributes 1–7;

and

$$GIS-HMS = \sum HMSA_i \quad (2)$$

where: *GIS-HMS* – GIS Hydromorphological Modification Score;  
*HMSA<sub>i</sub>* – Hydromorphological Modification Score Attributes;  
*i* – attributes 1–6.

**Table 1.** Attributes included in the GIS Hydromorphological Diversity Score

Attribute symbol	Attribute name	Scale	Attribute range	Score
HDSA1	Natural river route (unaligned, meandering on lowlands)	% of the river body length	none	0
			≤25	1
			25–50	3
			50–75	5
			>75	7
HDSA2*	Mid-channel bars and islands	% of the river body length	none	0
			≤10	1
			10–30	2
			30–50	3
			>50	5
HDSA3*	Side bars	% of the river body length	none	0
			≤10	1
			10–30	2
			30–50	3
			>50	5
HDSA4**	Floodplain land use	Mean value based on three land use categories	urban areas	1
			agricultural areas	5
			seminatural areas	10
HDSA5	Woodland on bank	% of the river body length	none	0
			≤25	1
			25–50	2
			50–75	3
			>75	5
HDSA6	Oz-bow lakes	% of the river body length	none	0
			≤10	1
			10–30	2
			30–50	3
			>50	5
HDSA7	Wetlands	% of the river body length	none	0
			≤10	1
			10–30	2
			30–50	3
			>50	5

\* not applicable for small and medium rivers (channel ≤30 m)

\*\* buffer width: ≤30 m – 100m, >30 m – 1000m

The result of evaluation based on the analysis of the GIS data enable to estimate GIS-Factor which come out from the GIS-HDS and the GIS-HMS:

$$GIS\ Factor = \frac{\left(\frac{GIS\ HDS - GIS\ HMS}{10}\right) + 1.2}{3} \quad (3)$$

The GIS-Factor based on the remote sensing data and available spatial databases provides preliminary hydromorphological assessment of the water body, which might be a large section of a river. Moreover GIS-Factor is applied for final hydromorphological classification as a ratio influencing HIR estimated in the result of the field survey.

### Field survey approach

Field survey is carried out on a standard stretch of the river with a length of 500 m (streams and brooks with channel width ≤30 m) or 1000 m (watercourses with a channel wider than 30 m).

The survey according to the HIR method includes an evaluation of three zones (Fig. 2):

- river channel – includes riverbed (permanently or partially located under water) and bank face (situated between water line and bank top);
- coastal zone – river valley adjacent to the bank top (5 m wide in river width ≤30 m and 10 m wide in river width >30 m);
- river valley – includes buffer 50 m (river width ≤30 m) or 100 m (river width >30 m) wide adjacent to the bank top.

**Table 2.** Attributes included in the GIS Hydromorphological Modification Score

Attribute symbol	Attribute name	Scale	Attribute range	Score	
HMSA1	Watercourse realignment	% of the river body length	none	0	
			≤25	1	
			25–50	3	
			50–75	5	
			>75	7	
HMSA2	Damming structures	% of the river body length	none	0	
			≤0,2	3	
			0,2–0,5	5	
			>0,5	7	
HMSA3	Water management structures	% of the river body length	none	0	
			≤5	2	
			5–33	4	
			>33	6	
HMSA4	Groynes and river hydraulic structures	% of the river body length	none	0	
			≤5	1	
			5–33	2	
			>33	3	
HMSA5	Bridges, fords, ferries	number/km of the river body length	≤0.2	0	
			0.2–0.5	1	
			0.5–1.0	2	
			>1.0	3	
HMSA6	Embankments of small and medium rivers (channel ≤30 m)	embankments (% of the river body length)	none	0	
			≤25	0,5	
			25–50	1	
			50–75	1,5	
	summarising scores for each bank	embanked floodplain size	>2 channel width	0,5	
			≤2 channel width	1	
			no floodplain	1,5	
HMSA6	Embankments of large rivers (channel >30 m)	% of river body	No floodplain between embankments	none	0
				≤25	2
				25–50	2,5
				50–75	3
			floodplain between embankments ≤2 of channel width	>75	3,5
				none	0
				≤25	1
				25–50	1,5
	sum for highest value of each bank	floodplain between embankments >2 of channel width	50–75	2	
			>75	2,5	
			none	0	
			≤25	0,5	
				25–50	1
				50–75	1,5
				>75	2

Field observations are conducted in **two stages**:

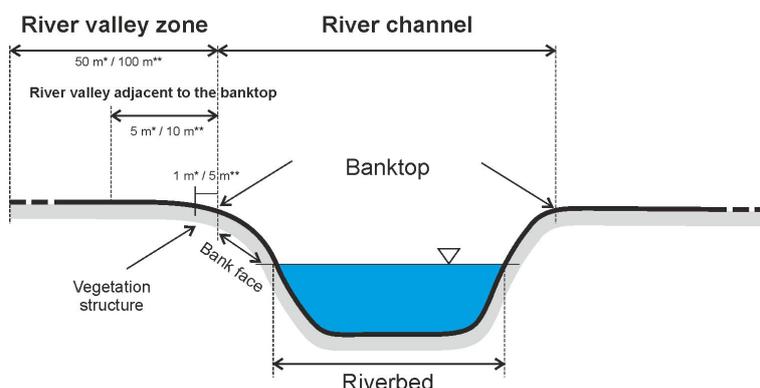
- **The first stage** is carried out on ten spot-checks (profiles), spaced equally every 50 m (narrower channels ≤30 m) or 100 m (wider rivers >30 m). The attributes recorded in each spot-check include: river bed and bank material, dominant flow type, natural habitat

features as well as types of modifications. The attributes are recorded across the channel in a 1 m wide transect in narrower rivers (≤30 m) or 10 m in case of wider watercourses (>30 m) (Fig. 2, 3). Moreover, the structure of aquatic and bank vegetation as well as land use of a bank zone is recorded in 10 m wide transects.

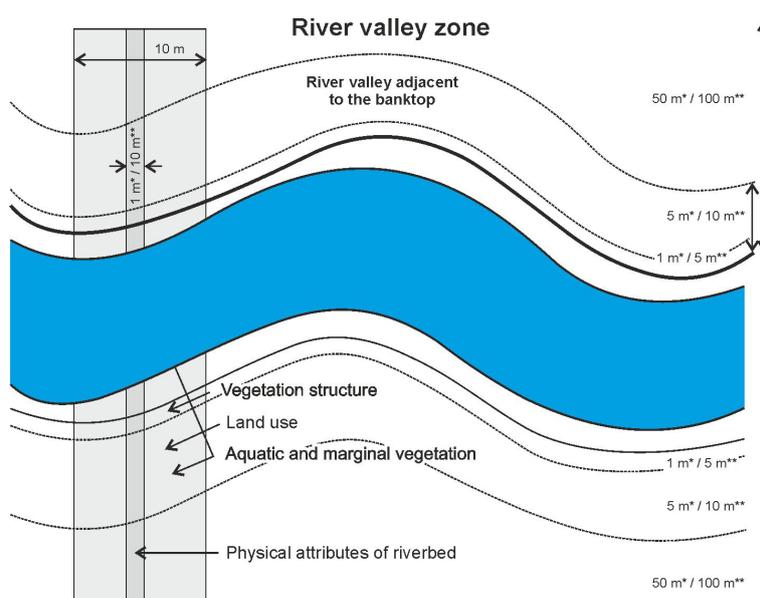
- **The second stage is synthetic assessment** of the entire river section and it delivers an overview of the entire survey site, where the natural features and modifications, which were not recorded in the previous stage (e.g. occurred between spot checks) are recorded. Moreover, a predominant valley form is described, as well as the channel dimensions and presence of hydroengineering facilities are included.

The field approach of the assessment was taken from a widely used and tested British method of hydromorphological status assessment, the River Habitat Survey, which has been tested under the Polish rivers conditions for over a decade. (Environmental Agency 2003, Szoszkiewicz et al. 2007). The hydromorphological classification of watercourses is based on Hydromorphological Index for Rivers (HIR). Multimetric HIR index

combines two indices: Hydromorphological Diversity Score (HDS) and for the Habitat Modification Score (HMS). HDS informs on the presence of natural attributes of the channel, coastal zone and the river valley. Each of the HDS attributes delivers a range of points enabling to calculate HDS of the river stretch (Table 3). The detailed procedure of scoring is presented in the HIR method manual (Szoszkiewicz et al. 2017). HMS provides the information on the hydromorphological modifications. It includes various forms of fluvial ecosystem transformations, such as profile modifications and reinforcements and presence and abundance of engineering facilities. The HMS value is calculated by summing up the categories presented below (Table 4) although the detailed approach of scoring is provided in the original HIR manual (Szoszkiewicz et al. 2017).



**Fig. 2.** Three zones in rivers evaluated in the HIR method \*River width  $\leq 30\text{m}$ ; \*\* River width  $>30\text{m}$  (Szoszkiewicz et al. 2017, modified)



**Fig. 3.** Scheme of field research on single spot check \*River width  $\leq 30\text{m}$ ; \*\* River width  $>30\text{m}$  (Szoszkiewicz et al. 2017, modified)

**Table 3.** Attributes included in the Hydromorphological Diversity Score

Attribute name	Maximum score (percentage in HDS)	
	rivers width ≤30m	rivers width >30m
The river channel zone – riverbed		
Variation of the river line	10 (7.4%)	not rated
Variation of the riverbed slope	3 (2.2%)	3 (2.8%)
Heterogeneity of water flow	12 (8.9%)	10 (9.2%)
Heterogeneity of riverbed material	12 (8.9%)	7 (6.6%)
Natural morphological features of riverbed	14 (10.4%)	10 (9.2%)
Natural morphological elements of banks	18 (13.3%)	18 (16.7%)
Variation of vegetation types in the river channel	16 (11.8%)	14 (13.0%)
The river channel zone – bank face		
Structure of bank vegetation	5 (3.7%)	5 (4.6%)
Variation in elements accompanying trees	14 (10.4%)	10 (9.2%)
The river valley adjacent to the banktop zone		
Structure of bank-top vegetation	5 (3.7%)	5 (4.6%)
Not-managed bank-top zone	4 (3.0%)	4 (3.7%)
The river valley zone		
Natural land use of the valley	14 (10.4%)	14 (13.0%)
Connection between the river and the valley	8 (5.9%)	8 (7.4%)
<b>TOTAL</b>	<b>135 (100%)</b>	<b>108 (100%)</b>

**Table 4.** Attributes included in the Hydromorphological Modification Score

Attribute name	Maximum score (percentage in HMS)	
	rivers width ≤30m	rivers width >30m
Transformed transverse section of the river channel	8 (6.3%)	8 (8.7%)
Hydroengineering structures	30 (23.8%)	18 (19.6%)
Transformations observed in spot-checks	60 (47.6%)	40 (43.5%)
Disturbance of the connectivity with the river valley	12 (9.5%)	12 (13.0%)
Other types of human degradation	16 (12.8%)	14 (15.2%)
<b>TOTAL</b>	<b>126 (100%)</b>	<b>92 (100%)</b>

In practice, HDS and HMS values usually does not exceed 100.

$$HIR = \frac{\left(\frac{HDS - HMS}{100}\right) + 0.85}{1.8} \quad (4)$$

### Rivers evaluation based on field survey

The evaluation of a river section takes into consideration both the HDS and HMS indices. The HIR score ranges from 1 (reference conditions) to 0 (extreme degradation):

The process of reference conditions determination was carried out on the rivers that have not been subjected to significant anthropogenic pressure with apparent natural fluvial processes taking place. The principal reference criteria were as follows:

- absence or very small scale of hydromorphological modifications confirmed by low values

of Hydromorphological Modification Score ( $HMS \leq 4$ ),

- domination of natural forms of land use (forests, woodlands and bushes, tall herbs, wetlands and unvegetated open natural areas), within 50 m buffer from the bank top.

Both criteria were detected on 217 river sites (19.6% of all analyzed), which were considered as reference ones. This group was used to analyze the HIR diversification among various groups of rivers in Poland and to identify the hydromorphological types of watercourses. In this way, the hydromorphological classification of the river was proposed in the five river type system (Table 5).

The HIR components form two negatively correlated gradients: HDS forms a gradient of diversity of natural morphological elements of the watercourse and river valley, while HMS is related to the gradient of anthropogenic changes in hydromorphology. The hydromorphological

**Table 5.** Classification system of Polish rivers based on HIR index

River type	Status water body	Channel width	Altitude	Valley peat-bog	HIR multimatrix				
					I	II	III	IV	V
R1	natural	≤30 m	>200 m a.s.l.	-	≥0.824	≥0.715	≥0.600	≥0.485	<0.485
R2			≤200 m a.s.l.	no	≥0.761	≥0.639	≥0.500	≥0.375	<0.375
R3			≤200 m a.s.l.	yes	≥0.725	≥0.592	≥0.459	≥0.326	<0.326
R4		>30 m	-	-	≥0.728	≥0.613	≥0.486	≥0.359	<0.359
R5	artificial	-	-	-	≥0.513	≥0.420	≥0.342	≥0.253	<0.253

transformations of rivers usually lead to a decrease in the heterogeneity of the river habitat (Fig. 4).

The method of calculating the HIR components is similar to the synthetic hydromorphological indicators calculated on the basis of the RHS method (Szozkiewicz et al. 2012). The RHS equivalent of HDS is Habitat Quality Assessment – HQA, while the RHS equivalent of HMS is also the Habitat Modification Score (Fig. 5).

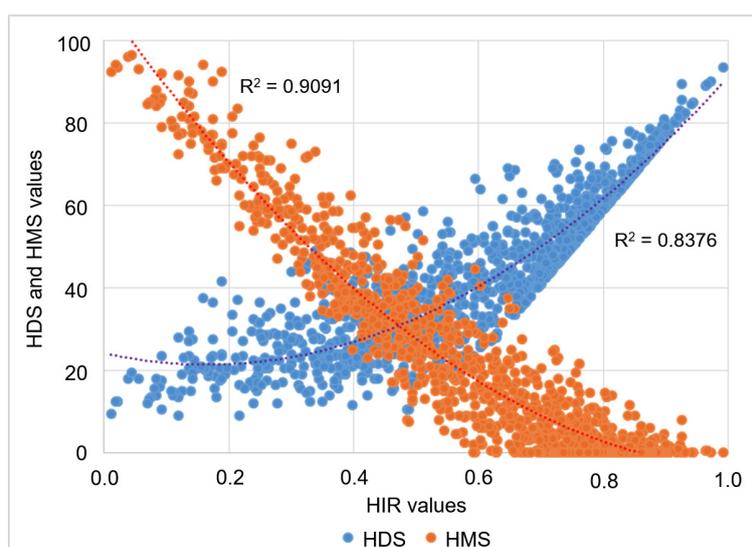
### Water body assessment

River assessment based on a survey of a single site delivers the information limited to the local conditions. Such information is not efficient to characterize the entire river over a distance of tens of kilometers but surveying a single site its hydromorphological quality can be estimated classification for the purpose of local monitoring. Moreover, local assessment is principal for Environmental Impact Assessment (EIA) of the planned channel modifications and various water engineering projects. The local hydromorphological data can be also used for the ecological

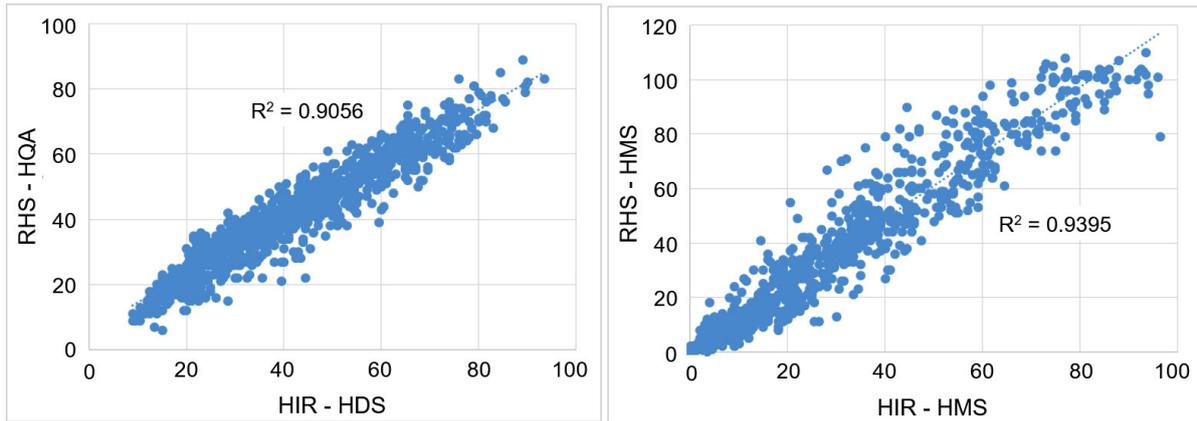
studies of various aquatic organisms (fish, macro-invertebrates, macrophytes et al.).

The hydromorphological assessment of rivers with a length of several kilometers or tens of kilometers (e.g. entire surface water bodies) requires the field data gathered from 1–3 stretches and analysis of the GIS data. The number of recommends survey sites depends on river heterogeneity of the land use in the river valley zone and varies between one (homogenous land use) to three (large diversity of land use). Three land use categories are distinguished in this process: (1) natural/semi-natural areas, (2) agricultural land, and (3) urban localities. The considered buffer width is 100 m from river both banks (river width ≤30 m) or 1000 m (river width >30 m). The land use category is considered when it covers at least 25% of the buffer zone area (Fig. 6).

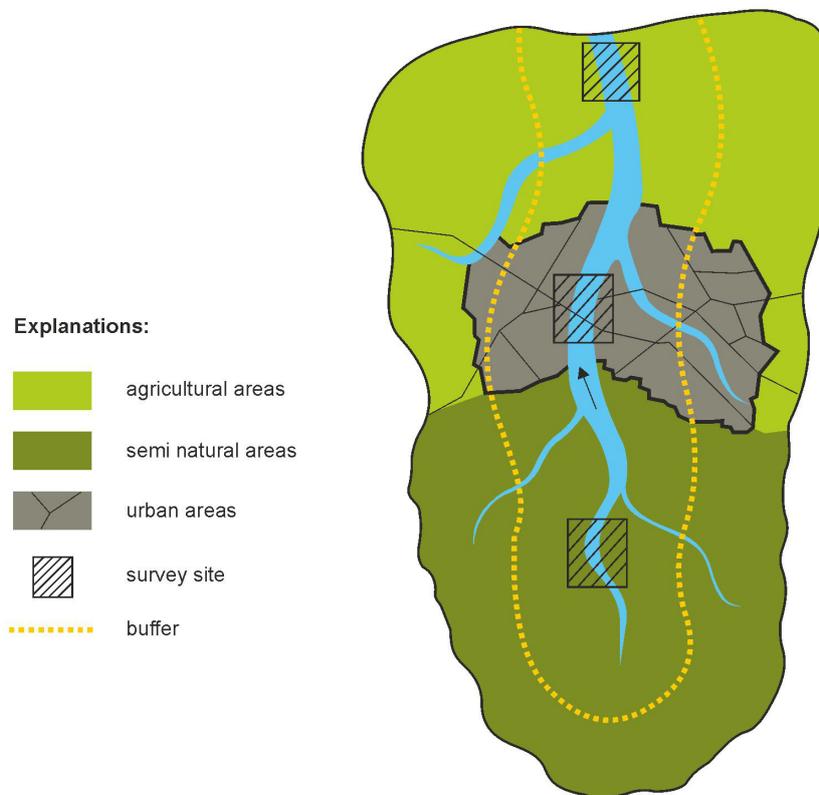
The assessment of the hydromorphological state of the entire Water Body consists in calculating the weighted average of the HIR values, taking into account the weighting factor for three forms of land development (calculated on the



**Fig. 4.** Polynomial regression curves between HIR and its components – HDS and HMS (N = 1107 river sites)



**Fig. 5.** Linear regression curves between indices calculated on the basis of the HIR (HDS, HMS) and RHS (HQA, HMS) methods



**Fig. 6.** Scheme of the water body survey (Szoszkievicz et al. 2017, modified)

basis of their percentage share in the buffer), according to the following formula:

$$HIR_{mean} = \frac{(HIR_U \cdot wU) + (HIR_A \cdot wA) + (HIR_S \cdot wS)}{100} \quad (5)$$

where:  $HIR_{mean}$  – average HIR value for the whole water body;

$HIR_U$  – HIR calculated for the survey sites located in an urbanized area;

$wU$  – weighting factor for urbanized areas calculated on the basis of their percentage share in the buffer;

$HIR_A$  – HIR calculated for the survey sites located in an agricultural area;

$wA$  – weighting factor for agricultural areas calculated on the basis of their percentage share in the buffer;

**Table 6.** Impact of GIS-Factor on the final classification of the river body (HIR of the waterbody)

HIR <sub>mean</sub> based on the surveyed stretches	HIR <sub>mean</sub> class	GIS-Factor		
		≤0.4	0.4–0.6	>0.6
1	1	2	1	1
2	2	3	2	1
3	3	4	3	2
4	4	5	4	3
5	5	5	5	4

HIR<sub>s</sub> – HIR calculated for the survey sites located in a semi-natural area;

wS – weighting factor for semi-natural areas calculated on the basis of their percentage share in the buffer.

The hydromorphological status of entire water body base on average HIR value (HIR<sub>mean</sub>) out of each surveyed stretch (HIR of each field surveyed site) modified by GIS-Factor (based on the preliminary assessment of remote sensing data). Average HIR is a weighted mean value based on HIR of 1–3 stretches representing proportionally various types of land use in the bank buffer along the entire surface water body. Moreover, the final classification of the water body is modified by GIS-Factor derived from on the remote sensing and spatial databases (Table 6).

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