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Hydro-morphological classification of urban river sections based on LIDAR data

Hydromorfologiczna klasyfikacja odcinków rzek miejskich na podstawie danych LIDAR

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Abstract

The assessment of hydro-morphological conditions is a part of ecological evaluation of water bodies. Many methods have been developed, but only a few of them are dedicated to urban rivers. Hydro-morphological classification would be a basis for river valley management, including restoration issue. One of the main problems in this assessment is the rate of change in urban catchment and urban river valley. Traditional methods, which are based on field study, are expensive and prolonged. The paper is focussed on using Light Detection and Ranging (LIDAR) data for classification of urban river sections. Although the assessment based on this data has some limitations, it is a good alternative to field study and may provide preliminary screen of the river valley. This material will make possible observation of river valley evolution in the future.

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Streszczenie

Ocena warunków hydromorfologicznych stała się elementem oceny stanu ekologicznego wód. Dotychczas powstało wiele metod oceny tych warunków, ale niewiele z nich nadaje się do oceny rzek miejskich. Klasyfikacja hydromorfologiczna powinna być podstawą do zarządzania doliną rzeczną, w tym planowaniem działań rewitalizacyjnych. Jednym z głównych problemów w prowadzeniu tej oceny jest dynamizm zmian w zlewni miejskiej i dolinach rzek. Tradycyjne metody, które są oparte na badaniach terenowych są kosztowne i czasochłonne. Artykuł koncentruje się na wykorzystaniu danych LIDAR do klasyfikacji odcinków rzek miejskich. Pomimo, że ocena na podstawie tych danych ma pewne ograniczenia, jest to dobra alternatywa dla badań terenowych i może dostarczyć wyników będących podstawą do klasyfikacji odcinków. Użyta metoda umożliwi również obserwację i ocenę zmian w obrębie dolin rzecznych w przyszłości.

1. INTRODUCTION

The investigations on the assessment of hydro-morphological conditions of the river valley date back to the beginning of geographical research, while their intensification, chiefly in Europe, took place after the year 2000, in parallel with entering the European Union Directive 2000/60/EC into force. The directive has been called the Framework Water Directive (FWD). The EU member states have been obliged to perform the evaluation of the degree of urban impact to surface waters, and then to take actions to restore at least good ecological status of waters by 2015. In accordance with the FWD, the assessment of hydro-morphological conditions became a basis for determination of the ecological condition of waters [Directive 2000/60/EC]. The first method was developed in Austria, around 1980, Germany 1985 - LÖFL-LWA method, worked out in North Rhine Westphalia, Netherlands [Tolkamp 1981]. The subsequent ones had appeared in Switzerland [Bundi *et al.* 2002], France [Agences de l'eau & Ministère de l'environnement, 1998], and UK - River Habitat Survey [Raven *et al.* 1997]. After the year 2000, the next were developed in such EU countries, as Denmark [Laubel *et al.* 2003], Czech Republic [Matouskova, Bacanova 2006], Poland -

MHR method [Ilnicki *et al.* 2009]. From among all the methods applicable for assessment of hydro-morphological conditions, only few have been developed specifically for urban rivers, or those greatly modified, where the engineering actions could have stopped or changed naturally occurring processes. Such methods are required taking into consideration the necessity of assessing conditions before elaboration of management plans and restoration actions. At the same time, one should remember that the existing research methods limit themselves to investigate physical conditions of river valleys, while the aim of conducting effective actions should be in relation to the situation in the entire drainage basin [Davenport *et al.* 2001].

The accurate assessment of hydro-morphological conditions needs to be carried out with regard to study and site work, which entails high time and financial outlays. Performing only the study work impoverishes the assessment with selected elements, while it enables to make general characteristics, observe the trends of changes in the valley and perform preliminary classification of river valley sections.

In this case, the quality of performed assessment depends considerably on the analytical material. Recently, airborne laser scanning has been performed in many countries, providing new material for environmental analyses. The LIDAR technology enables to perform investigations not only for large and inaccessible areas, for instance, mountainous, but also urban with extensive building development [Thomaa *et al.* 2005]. The former research had been focussed generally either on individual elements of the river valleys or the assessment of selected products coming from processing of the point cloud. The LIDAR data have been widely used in determining the flooding hazard zones. To compare, one of the most important sources used in analysing the morphology of the river valley as well as in other hydrographical projects is the high-resolution Digital Model Terrain. The construction of the model can be made in photogrammetry laboratories, using various techniques. In turn, the laser scanning technology provides high accuracy of the final product, obtained in a relatively short time [Rumsby 2008].

2. OBJECTIVE AND METHODOLOGY OF THE RESEARCH CONDUCTED

The scope of the investigations presented in the paper was the hydro-morphological classification of the river valley parts in the urbanised river drainage area, on the basis of data resulting from the laser scanning. As the research object, there were selected 500-m sections of the river valleys on the area of the Silesian Upland, south Poland, being a highly urbanised, and transformed with centuries-old industrial activities, in particular, coal mining. The results of the analysis carried out on the assessment of individual elements of individual hydro-morphological elements, were verified through site investigations using the Urban River Survey (URS) and River Habitat Survey (RHS) methods.

The investigations were based on the data from the laser scanning that had been performed in 2013 for more than 60% territory of Poland, including all the towns. The point cloud utilised in the research has a density of at least 12 points/m², with colour coding attributes (RGB), and reflective intensity. As the LIDAR data supplied were initially classified, the renewed classification process was not carried out. The data analysis was conducted using the FUGRO - Fugro Viewer software. The software allows:

- Scrolling of data:
 - Displaying altitude models,
 - 3D-perspective data scrolling,
 - Displaying cross-sections,
 - Visualisation of area morphology in colour scale,
 - Presentation of reflectance intensity values,
 - Overlapping vector and bitmap data on the set of measurement data.
- Data analysis:
 - According to classification of point cloud, reflectance, source ID and flight lines,
 - Generation of levels,
 - Distance measurements.
- Presentation of data.

The Fugro Viewer is a simple-serviced free tool, not requiring high computation power and consequently, being widely used. The URS method, used in verification, originates from the British RHS method, most-widespread in Europe. The RHS method had been developed in 1997 by the British Environmental Agency, as a simple and, at the same time, effective method of data collection. The base investigation section for the RHS method is a 500-m-long sections of a quasi-natural river valley. The summary indexes for the URS method are: quantified Habitat Modification Scores (HMS), being an index to evaluate habitat modification), and Habitat Quality Assessment (HQA), that is an index to evaluate water course neutrality). However, the RHS method does not reflect a total description of urban rivers, which are characterised by high transformation levels, and problems related to water quality condition. To meet the needs of the URS method, the investigated river section is defined as the one having a normal length of 500 m and at minimum 300 m, related to one engineering type. The URS correspondingly as the RHS is based on identification of the elements of the morphological structure of the stream, utilising it in assessment of its quality and character of the habitat. The investigations, presented here, are based on the description of a specified river section. The description here is a two-stage process as follows. First stage is the characteristics of principal morphological features of the river valley and its banks, being described in 10 control profiles, spaced in every 50 m. These being related to: type of flow, substrate of bottom and banks, structure of water and bank vegetation, utilisation of banks, amount of bank erosion, type of transformation and technical enforcement on the banks and bottom of the stream.

The second stage contains a synthetic description for the entire section, and includes all the characteristics and transformations not recorded in the previous stage, and additionally, description of the valley, dimension of the trough, rapids, sedimenting material and others [Szozzkiewicz 2009]. The elements that differ the URS from RHS are among others, assessment of pollutant size, uniformity of the section or stream function. The codification and abbreviations used in filling the form were adapted to the conditions of the urban river [Gurnell 2011]. The URS method classifies the urban sections and the number of elements evaluated allows to its wide use. Systematically conducted investigations enable to monitor the changes that occur in the valley and evaluate the effects of planned engineering and recovery actions. At the same time, the URS results must be in relation to the drainage basin of a specified river with the aim of ensuring an integrated approach to assessment of the urban rivers and their potential [Davenport 2001].

Taking into account the list of indexes applied, the authors of the URS method have worked out four types of classification based on the set of the indexes, and realised using the decision tree method. The classifications include the following aspects:

- Material clusters,
- Physical Habitat clusters,
- Vegetation clusters,
- Joint classification - Stretch Habitat Quality Index (SHQI).

The scope of assessment is presented in Table 1 below.

Table 1. Scope of assessment included in the classification.

<i>Material clusters</i>	<i>Physical habitat clusters</i>	<i>Vegetation clusters</i>
Semi-natural (coarse)	Semi-natural (active)	Un-vegetated channel, high bank tree cover connected to channel,
Semi-natural (mixed) -	Semi-natural (stable) -	Low channel vegetation cover in channel, high bank tree cover connected to channel,
Semi-natural (fine) -	Recovering	Medium channel vegetation cover, medium bank tree cover,
Lightly engineered	Uniform active	High channel vegetation cover, low bank tree cover,
Engineered	Uniform moderately active	High vegetation, medium trees,
Heavily engineered	Uniform stable	Low channel vegetation cover, low bank tree cover,
Very heavily engineered		Low vegetation, high trees, but disconnected from channel,
		Un-vegetated, high trees, but disconnected from channel.

The joint classification (SHQI), which is to perform the task of demonstrating the general quality of the research section, is made through adding the marks from partial classifications, in accordance with the values itemised in Table 2.

3. RESULTS AND DISCUSSION

The investigations carried out on the basis of analyses of the material obtained from the airborne-generated laser scanning data have revealed the possibility of identification of selected elements of morphological condition assessment. Comparing results obtained during research carried out within the assessment of urban rivers with Italians' observations in evaluation of hydro-morphological conditions for a mountain river [Cavalli 2008], the biggest obstacle was that the issue connected with the material clusters are problematical. The quality of the results obtained in current research depended on the local conditions, in particular, the density of vegetation in the banks. The interpretation of the laser scanning data was identical to the results of assessment conducted using the evaluation performed by means of the URS and RHS methods aimed at assessing the engineering character of the trough, its dimensions (without depth of water), banks use, structure of banks and slopes. Besides, 100% identification was possible for engineering structures, shaded spots and continuity of trees. A part of the elements subjected to hydro-morphological investigation was either identified only in the case

Table 2. Values of individual indexes to quote the SHQI.

<i>Material</i>		<i>Physical conditions</i>		<i>Vegetation</i>	
<i>Index</i>	<i>Mark</i>	<i>Index</i>	<i>Mark</i>	<i>Index</i>	<i>Mark</i>
Semi-natural (coarse)	1	Semi-natural (active)	1	Un-vegetated channel, high bank tree cover conn	1
Semi-natural (mixed)	1	Semi-natural (stable)	2	Low channel vegetation cover in channel, high bank tree cover conn	1
Semi-natural (fine)	2	Recovering	3	Medium channel vegetation cover, medium bank tree cover	1
Lightly engineered	2	Uniform active	4	High channel vegetation cover, low bank tree cover	3
Engineered	4	Uniform moderately active	5	High vegetation, medium trees	4
Heavily engineered	4	Uniform stable	6	Low channel vegetation cover, low bank tree cover	4
Very heavily engineered	5			Low vegetation, high trees disconn	6
				Un-vegetated, high trees disconn	7

SHQI: Stretch Habitat Quality Index.

The SHQI classification is the six-stage one:

- 3–4: very good,
- 5–6: good,
- 7–9: average,
- 10–12: below average,
- 13–15: poor,
- 16–18: very poor.

Table 3. Scope of compatibility of investigation results obtained from LIDAR data and URS method.

<i>Evaluation of 100% compatibility URS method</i>	<i>Element evaluated compatible to a limited degree</i>	
<i>Element</i>	<i>Element</i>	<i>Limitation degree</i>
Engineering type - stretch	Protection level	Only for bank protection (without bottom)
Engineering type - profile	Channel substrate	Difficulty in distinguishing from material of similar fraction
Measurements (without depth)	Type of protection	Identifiable only protections located sufficiently above water level
Bank top land use	Natural elements	Within investigations conducted, all such elements recorded (very small sample)
Vegetation structure	Flow type	Recorded only the changes in flow type, and not flow type itself
Hydrotechnical components	Pollution indicators	Found only oily fractions and slimes floating on the surface
Tree features	Pollution sources	Identified only the largest outlets

URS: Urban River Survey

of selected sections, or provided approximate results, that is level of reinforcement, material of bank, protections, natural elements, flow rate, contamination indexes and its sources. The elements of hydro-morphological assessment that failed to be assessed on the basis of airborne laser scanning were those to be found below the water level that is material of bottom, and its reinforcement, vegetation in the trough. Also, none of the materials analysed contained the information relating to its structure and vegetation. Definitely greater expectation to obtain the data mentioned above would be in the case of using either a bathymetric scanner or the devices for mapping the trough and bottom of the reservoir.

Table 3 presents the parameters for which their interpretation was identical to the result of assessment performed using the URS method, or the elements were identified only in the case of selected sections or gave approximate results.

In accordance with the above, a list has been prepared of indexes to be possibly computed and proposed in the URS method:

- dominant channel substrate type,
- bank sediment calibre index,
- proportion biodegradable bank protection,
- count of vegetated side bars,
- count of unvegetated side bars,
- count of unvegetated and vegetated mid-channel bar,
- count of unvegetated and vegetated point bar,
- dominant natural bank profile type,
- number of natural bank profile types,
- dominant, artificial bank profile type,
- number of artificial bank profile types,
- proportion natural bank profiles,
- proportion no bank protection - above the water level, only,
- proportion artificial bank profiles,
- complexity bank face structure,
- complexity bank top structure,
- complexity tree cover,
- dominant bank material protection type - above the water level, only,
- dominant bank protection class - above the water level, only,

- proportion immobile bank materials,
- proportion open matrix bank protection,
- proportion solid bank protection,
- number of flow types - estimated, based on intensity.

The only group of indexes for which no index value was obtained is the group 'waste and invasion species'. On the basis of indexes to be possibly determined, the possibility was analysed of making classification of individual sections. The classification, according to the building material, characterises the building material of the bottom and protections installed in the trough. Since the assessment of a part of these elements based on laser scanning data proved to be impossible, the classification of the section in this view could not be made. The classification of physical conditions is based on indexes that characterise the number and character of flows, deposition of sediments and other physical attributes of the trough. The original classification includes six types of the sections. Based on analyses of the results obtained from the laser scanning data, it is possible to determine four classes:

- Semi-Natural (Coarse) - Semi-Natural (Mixed) - only one class,
- Recovering,
- Uniform Active,
- Heavily Engineered - Very Heavily Engineered - only one class.

The classification in the domain of vegetation has been, in the first stage, based on the existence of plants on the banks and then on the existence of them in the trough. Owing to this, one can make a preliminary classification that includes the following allocations:

- Low channel Vegetation cover, Low bank Tree cover/High channel Vegetation cover, Low bank Tree cover - only one class,
- Un-Vegetated channel, High bank Tree cover-connected to channel/Low channel Vegetation cover in channel, High bank Tree cover connected to channel - only one class,

- Medium channel Vegetation cover, Medium bank Tree cover/High Vegetation, Medium Trees/Low Vegetation, High Trees-but disconnected from channel/Un-Vegetated, High Trees-but disconnected from channel - only one class.

As the full classifications related to individual elements of assessment proved to be impossible, as a consequence of this, the joint classification of the sections, following the rules proposed in the URS manual also could not be made.

With the aim of comparing, the investigation using the RHS method, designed for off-town areas, was also performed. Using this method, the synthetic indexes HMS and HQA can be determined.

A trial to determine the HQA index (characteristics of stream neutrality) based on the LIDAR data was biased with possible (several dozen percent) error to be made due to a high effect of vegetation and natural elements of river bottom on the final assessment result. In turn, a very low risk of making a substantial error in the final assessment is assigned to determination, this way, of the HMS index (characteristics of habitat transformation). The assessment is generally conditioned by anthropogenic effects, easily interpretable on the basis of LIDAR data.

4. CONCLUSIONS

Apart from the above-mentioned impossibility of performing evaluation of selected hydro-morphological elements based on the available LIDAR data in the investigations conducted, the legitimacy has been justified relative to their use for making such an assessment. On the basis of the data obtained from airborne laser scanning, one can characterise most elements to be evaluated using the URS and RHS methods. When comparing the list of the elements possible to be assessed based on such a material, available from airborne laser scanning, analytical one with the scope of elements evaluated by means of other methods, one can draw an important conclusion on wide capabilities of the LIDAR data. From among 10 parameter categories necessary for assessment of hydro-morphological conditions as specified in the EN 14614:2005 standard, only for one of them, there would

be a problem with performing such an evaluation. Moreover, an analysis of the results of investigations performed together with relating them to the current state of knowledge has confirmed the fact that based on the airborne laser scanning data, one can make a preliminary hydro-morphological classification of river valley sections and the investigation can provide the grounds for identification of changes within the river valley being analysed and consequently, constitute an important element of hydro-morphological monitoring of the rivers.

The utilisation of the laser scanning technology for assessment of hydro-morphological conditions can be applied in valorisation of the valley sections, and in preliminary planning of revitalisation actions.

Airborne laser scanning proves to be the best method to investigate the interrelation of hydro-morphological conditions in the valley and in the drainage basin. The use of this kind of data can also provide a basis for assessment of continuity of a river valley, and identification of barriers for migration of the fish.

An important hindrance in the investigations was the use of data from a topographic scanner, while in the investigation of the trough morphology and vegetation structure below the water level, the Rother method should be used. Apart from the site investigation, the application of bathymetric scanner should be an alternative.

Dynamic development of tele-detection techniques over the last decades allows to presume that in the next years, the airborne scanning data will be updated similarly as aerial photographs in present times. Further development will, undoubtedly, be connected with lowering of the cost of data acquisition and a wider access to the analytical software, both commercial and open-source type.

Such a sequence of events, together with the capabilities offered by the laser scanning technology, will allow to perform more and more accurate investigations on the interrelationship between the changes in the drainage basin and consequences in the river valleys and quality of the surface water. A proposal of applying such a technology is particularly attractive in the urban areas where the dynamics of changes is the highest, and impact on the natural environment most important.

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