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COMPLEXITY AS AN INDICATOR OF AESTHETIC QUALITY OF LANDSCAPE

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A b s t r a c t

The purpose of the article is to describe the *complexity* index as a quantitative parameter and indicate the position in the hierarchy of factors affecting urban riverside landscape on the example of the Odra River in Wroclaw.

Keywords: *landscape complexity*, *aesthetic quality of landscape*, *landscape indicators*, *rough sets theory*

S t r e s z c z e n i e

Celem niniejszego artykułu jest opisanie wskaźnika *złożoność* jako parametru ilościowego oraz wskazanie miejsca w hierarchii czynników oddziałujących na wartość krajobrazu nadrzecznego miast na przykładzie Odry we Wrocławiu.

Słowa kluczowe: *złożoność krajobrazu*, *jakość estetyczna krajobrazu*, *wskaźniki krajobrazu*, *teoria zbiorów przybliżonych*

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1. Introduction

In recent years the visual qualities have become an important element of landscape planning and management strategies [8, 30]. R.B. Litton (1979) underlines the gaps in knowledge and the need for research on the links between landscape structure and perception [19].

Ecological qualities of landscape and the indicators describing them are the subject of many scientific studies conducted worldwide; due to the Rio Declaration they were included in the environmental policies of states. Until recently the topic of visual quality of landscape received less attention in Europe. The situation was changed by the European Landscape Convention (2001), promoting an integrated approach to landscape combining social, cultural and visual aspects with ecological functions. The result of this is the fact that in recent years the landscape indicators have become one of the priorities of landscape research and are increasingly used in the assessment of landscape quality. The significance and need to include ecological aspects in addition to aesthetic ones in the research were emphasized by numerous researchers throughout the world [13, 22, 35, 36, 39].

Visual complexity of landscape refers to the diversity and wealth of elements in landscape and landscape patterns [21]. R. Kaplan and S. Kaplan (1989) stress the fact that complexity is the source of content and exploration opportunities [18]. The abundance of landscape elements and the diversity of land cover are, according to M. Tveit et al. (2006) the two most important indicators of visual landscape character [37]. Some studies emphasize the role of vegetation in landscape preferences [2], as well as spatial diversity and complexity [7], water forms [3], the lay of the land, topography, the scope of visibility [15, 27].

In the literature of the subject *complexity* is expressed as the diversity of elements in the form of the number and types of objects, land cover and pattern variability – the variety of forms of land use, as well as size and shape diversity. The description and approach to *complexity* depends to a large extent on the manner in which output information is obtained (Tab. 1); in most cases these factors are qualitative in nature. A. Ode et al. (2008) indicates the need to develop quantitative parameters permitting measurement and comparison [21].

According to [6] one of the only and at the same time most difficult steps in developing landscape valuation is measuring the impact power of the individual landscape elements on its general value.

Therefore the purpose of the article is to describe the *complexity* indicator as the qualitative parameter and to indicate its impact power as compared to other indicators on the value of urban riverside landscape on the example of the Odra River in Wroclaw.

2. Methods

Field studies were carried out on the Odra River in Wroclaw between the 248th kilometer of the Upper Odra in Wroclaw and the 252nd kilometer on the Central Wroclaw Water System.

The purpose of the field experiment was to obtain a linear film footage of the riverside landscape of Wroclaw seen from the river level, which was assumed as level zero. To accomplish that a motor boat was hired from the Water Rescue Service (WOPR).

The image was recorded using a professional camcorder Sony DCR-VX2000E, between 10 am and 2 pm at stabilized lighting conditions. The camera was attached in the front part of the boat in such a manner as to ensure a fixed viewing angle in relation to the level of the river. Moreover a photographic documentation was prepared of the Wroclaw riverside landscape from the level of waterfronts.

Table 1

Complexity – suggested indicators and application using different data sources [21]

Concept	**Data source**			
Complexity	**Landscape photos**	**Orthophotos**	**Land cover data**	**Field observations**
1. *Distribution of landscape attributes*				
Richness of landscape elements	Number of landscape elements per view	Number of landscape elements per area	Number of landscape elements per area	Number of landscape elements per area
Diversity of land cover	Number of different land covers per view	Diversity and evenness indices[a)]	Diversity and evenness indices[a)]	Number of different land covers per area
2. *Spatial organization of landscape attributes*				
Edge density		Edge density[a)]	Edge density[a)]	
Heterogeneity		Heterogeneity Index[b)]	Heterogeneity Index[b)]	
Aggregation of land		Aggregation indices[a)]	Aggregation indices[a)]	
3. *Variation and contrast*				
Contrast	Degree of contrast between land covers in view			Degree of contrast between land covers
Shape variation	Degree of variation between shapes in view	Shape indices[a)]	Shape indices[a)]	Degree of variation between shapes
Size variation	Degree of variation between size in view	Size distribution indices[a)]	Size distribution indices[a)]	Degree of variation between size

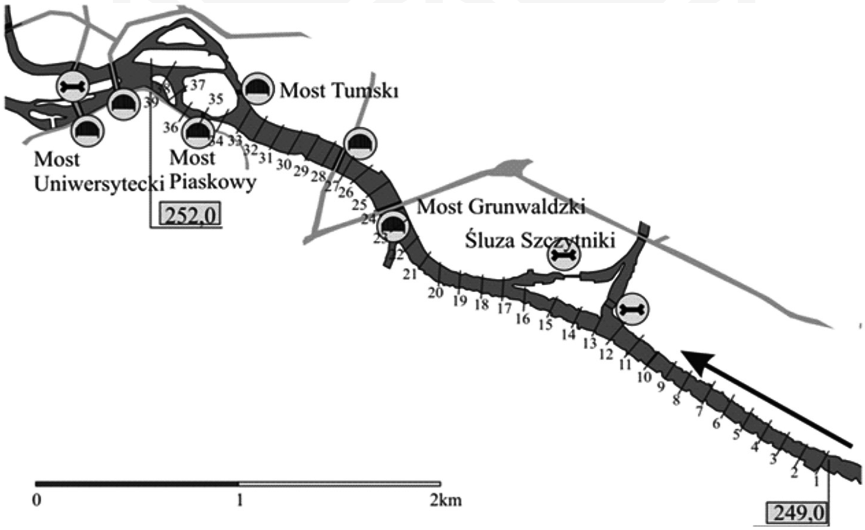
a) A range of diversity, evenness, edge density, aggregation, shape and size distribution indices are found within landscape metric software such as FRAGSTAT [20] and IAN [10] developed within landscape ecology.

b) The heterogeneity index is the proportion of points on different land types and is calculated using a grid of points for which land types are recorded [11].

As shown in Tab. 1 the indicators describing the *complexity* of landscape in the studies based on photographic images are qualitative indicators. In the studies the aspect of spatial distribution of individual landscape attributes is completely overlooked. As a consequence an attempt at was made to describe the landscape as the contact point of various types and forms of use and land cover as well as a quantitative depiction *of landscape complexity* through two proprietary parameters: *the Vertical complexity coefficient* [*Vcc*] (Tab. 2) and *the Horizontal complexity coefficient* [*Hcc*] (Tab. 2).

The studies also covered inventory, analysis and assessment of the three groups of parameters related to riverside landscape of the town (after: [29]): the following aspects were included in the first of these: *the width of the river bed* [*wrb*], *flora – number of species* [*f-ns*], *flora – green coverage* [*f-gc*], *nature value* [*nv*] [23]; the second group encompasses town-related factors, such as *landscape dominants* [*ld*], *destructive elements* [*de*], *historical value* [*hv*] [23] and the third group of perception-related parameters – *Horizontal complexity coefficient* [*Hcc*], *the Vertical complexity coefficient* [*Vcc*], *colour – number of colors* [*c-nc*], *colour – harmony* [*c-h*] [23].

The distance between the valuation points was established at 100 m, thus outlining 40 valuation points (Ill. 1) on a 4-kilometer section of the river.



Ill. 1. Valuation points in the study area

The statistical analysis aimed at examining the impact power of the selected parameters on the riverside landscape value of towns utilizes rough sets theory [25, 31, 4, 5]. In this theory the information system is understood as:

$$S = (U, Q, V, \rho)$$

where:

U – finite set of objects,

Q – finite set of attributes: $V = UV\rho$, $q \in Q$, where Vq is the domain of attribute q, $\rho: U \times Q \rightarrow V$, whereas the informative function is the one that $\rho(x, q) \in Vq$ for each $q \in Q$ and $x \in U$ [4, 14].

Table 2

Scoring and method for determining the parameters associated with the complexity of the landscape (author study)

<table>
<tr><td rowspan="3">1.</td><td colspan="2">HORIZONTAL COMPLEXITY COEFFICIENT [Hcc]</td></tr>
<tr><td>description of factor</td><td>the ratio of horizontal line length to sectional view length</td></tr>
<tr><td>method of parameter determining</td><td>

$Hcc = hl/s$

where:

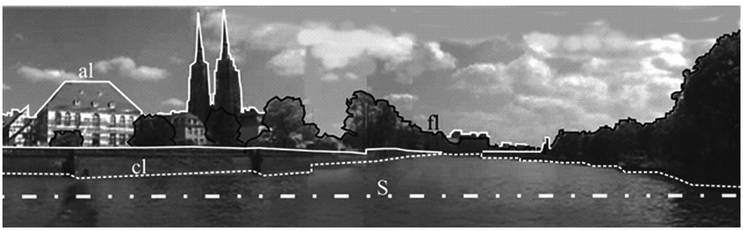
Hcc – horizontal complexity coefficient,
hl – horizon line length,
s – sectional view length.

</td></tr>
<tr><td rowspan="3">2.</td><td colspan="2">VERTICAL COMPLEXITY COEFFICIENT [Vcc]</td></tr>
<tr><td>description of factor</td><td>the ratio of the sum of the length of flora line, the length of architectural line and the length of coastal line to the length of sectional view</td></tr>
<tr><td>method of parameter determining</td><td>

$Vcc = (al + cl + fl)/s$

where:

Vcc – vertical complexity coefficient,
al – length of architectural line,
cl – length of coast line,
fl – length of flora line,
s – length of sectional view.



</td></tr>
</table>

Table 3

Decision table – fragment of the chart (author study)

CONDITIONAL ATTRIBUTES												DECISION ATTRIBUTE
	associated with the river				related to the city			related to the perception				
1	2	3	4	5	6	7	8	9	10	11	12	13
observation point	width of the river bed [*wrb*]	flora – number of species [*f-ns*]	flora – green coverage [*f-gc*]	nature value [*nv*]	landscape dominants [*ld*]	destructive elements [*de*]	historical value [*hv*]	Vertical complexity coefficient [*Vcc*]	Horizontal complexity coefficient [*Hcc*]	colour – number of colors [*c-nc*]	colour – harmony [*c-h*]	VALUE OF LANDSCAPE
1.	4	3	4	4	1	1	1	1	1	1	2	2
2.	4	3	4	4	1	1	1	3	2	1	2	2
3.	4	3	4	4	1	1	1	2	2	1	2	2
4.	4	3	4	4	1	1	1	2	2	2	2	3
5.	4	3	4	4	1	1	1	3	3	2	2	3
6.	4	3	4	4	2	1	1	5	5	2	2	3
7.	4	3	4	4	2	1	1	5	5	2	2	4
8.	4	3	4	4	1	1	1	3	3	2	2	3
9.	4	3	4	4	2	1	1	2	1	2	2	4
10.	4	3	4	4	1	1	1	2	2	1	2	2
…												
36.	3	3	2	1	1	1	5	3	1	2	2	6
37.	5	3	2	1	1	1	2	3	2	3	2	9
38.	3	3	2	1	2	3	2	5	3	3	2	7
39.	3	3	2	1	2	3	1	5	4	2	1	5
40.	4	3	2	1	1	1	1	3	2	3	2	7

The information in a system based upon the rough set theory is stored in a tabulated form requiring the development of decision tables (Tab. 3) containing conditional attributes, that is elements whose impact is assessed and the decision attribute – an element that is subject to their influences. Conditional attributes – 11 parameters associated with a town's riverside landscape – require a division into classes, which are assigned corresponding point values. The division was made proportionately to the observed instances. Landscape value (decision attribute) was estimated at the point range between 0–10. The points are awarded after classifying the individual observed fragments to classes: degraded landscape, numerous destructive elements – 0,1; monotonous landscape, no or isolated eye-catching elements – 2, 3; landscape of moderate variety, with a small number of eye-catching elements – 4, 5, 6; diverse landscape with eye-catching elements – 7, 8; landscape unique on a town, country scale – 9, 10.

In the rough sets theory the parameter describing the impact power of conditional attributes on the decision attribute is the quality of approximation (approximation coefficient) γp, where: γ_p where:

$$\gamma_p = \frac{\sum_{i=1}^{n} card(\underline{P}X_i)}{card(U)} \quad \text{dla} \quad F = \{X_1, X_2, \ldots, X_n\}.$$

Approximation coefficient adopts the value from the range (0.1), where the value 0 defines the lack of any relationships between the examined attributes, whereas the value 1 signifies very strong relationships. In order to determine the impact power of the studied conditional attributes on the decision attribute, subsequent individual conditional attributes were removed, observing how the value of the approximation coefficient obtained for the whole set of attributes changes. The analysis included all the examined elements combined into groups of two, three and four. All the possible combinations of the evaluated elements were considered. The element or group of elements, whose removal results in the approximation coefficient γp taking the lowest value, has the greatest impact on the estimated landscape value.

3. Results

The application of the rough sets theory for the analysis of field study results allowed to determine that the connection between the specified parameters related to the town's riverside landscape and its visual value is similar in each case. The values of approximation coefficients calculated for individual attributes that were shown in Tab. 4 do not allow any of them to be distinguished.

In view of the above, the effects of the elements combined sets of two, three and four ones on the value of municipal riverside landscape were analyzed. The obtained results are demonstrated in Tab. 5, where the groups of factors characterized by the strongest effects are listed. Among all the groups of conditional attributes with the highest impact on the decision attribute in each case there are factors present that are related to the complexity of landscape structure. The sequence of groups presented in Tab. 5 comprising two elements indicated three groups with an equivalent impact power, among which the parameters are present of *Horizontal complexity coefficient* [*Hcc*] and *colour – number of colors* [*c-nc*]. The analysis concerning the effects of groups of four attributes demonstrated that of greatest significance were *Vertical complexity coefficient* [*Vcc*], *the Horizontal complexity coefficient* [*Hcc*] and *colour – number of colors* [*c-nc*] the three parameters describing landscape complexity. Similar results were obtained in the analysis of a three-element system – the lowest value of the approximation coefficient was obtained for two equivalent groups comprising the *Vertical complexity coefficient* [*Vcc*], *the Horizontal complexity coefficient* [*Hcc*] and *colour – number of colors* [*c-nc*] parameters in combination with *landscape dominants* [*ld*] and *historical value* [*hv*], respectively.

Table 4

γ*p* – values calculated for simple attributes (author study)

Condition attributes		γ*p* – values
Associated with the river	width of the river bed [*wrb*]	0.9487
	flora – number of species [*f-ns*]	0.9487
	flora – green coverage [*f-gc*]	0.8718
	nature value [*nv*]	0.9487
Related to the city	landscape dominants [*ld*]	0.8974
	destructive elements [*de*]	0.9487
	historical value [*hv*]	0.9487
Related to the perception	Vertical complexity coefficient [*Vcc*]	0.9487
	Horizontal complexity coefficient [*Hcc*]	0.8974
	colour – number of colors [*c-nc*]	0.8205
	colour – harmony [*c-h*]	0.9487

Table 5

Groups of factor s with the greatest response of approximation coefficient value (author study)

Groups of	*γp* – values	**Condition attributes (Parameters)**										
		associated with the river				**related to the city**			related to the perception			
		width of the river bed [*wrb*]	flora – number of species [*f-ns*]	flora – green coverage [*f-gc*]	nature value [*nv*]	landscape dominants [*ld*]	destructive elements [*de*]	historical value [*hv*]	Vertical complexity coefficient [*Vcc*]	Horizontal complexity coefficient [*Hcc*]	colour – number of colors [*c-nc*]	colour – harmony [*c-h*]
1	2	3	4	5	6	7	8	9	10	11	12	13
2 attributess	0,6923									X	X	
				X						X		
								X			X	
	0,7436			X							X	
						X					X	
	0,7949					X				X		
										X	X	
3 attributess	0,5128								X	X	X	
	0,5641			X					X	X		
								X	X		X	
	0,5897					X				X	X	
		X						X			X	
	0,6154			X						X	X	
				X				X			X	
4 attributess	0.4103					X			X	X	X	
								X	X	X	X	
	0,4615	X							X	X	X	
		X						X	X		X	
	0.4872						X		X	X	X	
						X		X	X	X		
				X				X		X	X	
						X		X	X		X	
	0.5128								X	X	X	X
			X						X	X	X	
				X					X	X	X	
					X				X	X	X	
				X		X			X	X		
				X			X		X	X		
								X		X	X	X
						X		X		X	X	
		X		X				X			X	

4. Discussion

The objective of the experiment was to examine the power of impact of the *complexity* factor and to indicate the position in the hierarchy of factors influencing the visual quality of urban riverside landscape. The results indicate that the relationships in the spatial structure of landscape play an important role for its aesthetics.

The results obtained in the study indicate that the parameters describing the complexity of the structure, and thereby the landscape view belong to the parameters that have the greatest impact on aesthetic quality. The abovementioned findings are substantiated in the studies conducted by inter alia G. De la Fuente de Val and others [9], K. Hanyu [16], N. Schutte i J. Mallouff [28]. In numerous studies conducted worldwide the notions such as landscape complexity or diversity are similarly interpreted and evaluated attributes, and the high value of coefficient assessment is strongly correlated with landscape structure [12, 17, 33]. The indicators describing diversity and complexity of landscape in fact have been considered by many researchers as the most important prognostic factors in the process of investigating aesthetic preferences of landscape [9, 12, 40].

The fact that diversity of spatial structure of landscape has significant correlations with aesthetic value is also underlined by J.F. Palmer (2004), simultaneously indicating spatial aspects that have the most powerful effect on the understanding of landscape aesthetics research [24]. In his studies, the diversity of land surface is indicated as the most important spatial attribute affecting the quality of landscape – the aspect was expressed as the *Vertical complexity coefficient* [*vcc*] in this study.

The presented results of the paper show that analogically to the studies carried out by G. De la Fuente de Val and others [9], N. Schutte and J. Mallouff [28], A. Scott [30], that landscape diversity affects aesthetic qualities of landscape. However, as indicated by the latter, the relationship is not simple – crossing a certain level of complexity may have a negative impact on the clarity and understanding of the landscape by an observer, thus a crucial aspect is also spatial order and harmony [32] and a limited number of elements and colors introduced into the landscape [26, 34].

The rough sets theory, although not used for landscape research to date, is a methodology for solving numerous problems that require intelligent data analysis, seeking hidden interrelationships between data and making appropriate decisions in a situation of incomplete or partially contradictory data being present. Moreover, one of the advantages of the applied method – a substantial one in the case of estimating landscape value, is the possibility to obtain credible results even for small databases [4].

5. Conclusions

The results obtained in the paper show that spatial indicators describing landscape complexity are one of the essential ones and may be used for assessing its aesthetic quality.

Landscape diversity plays an important role in the visual perception of aesthetic characteristics and provides numerous psychological advantages. Homogenization of landscape may not only lower its value but also adversely affect psychological well-being.

Some authors suggest that higher uniformity of agricultural landscapes contributes to a less favorable perception of its visual qualities, mainly due to the lack of color contrast caused by reduced diversity of plants, monoculture plantations [38, 1].

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