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Izvorni znanstveni članak

# Application of factor analysis in dynamic geomorphology

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**Key words:** landscape, drainage basin, open system, dynamic equilibrium, factor analysis, factor model, horizontal dissection, intensity of erosion, erosional level, slope, driving forces, geological framework

Factor analysis of morphometric data in the area amidst Maceljska Gora, Strahinščica and Ravna Gora allow landscape to be defined in terms of the open system by the use of mathematical criteria. The factor model presented in the form of rotated factor matrix appears as an expression of inner structure of the system in question, where individual factors directly or indirectly indicate certain processes leading to creation of a veriety of landforms. Among the five factors constituting the factor model, the most prominent appear to be the factor of erosional levels F3, and the factor of intensity of erosion F2. The former can be directly referred to neotectonic movements during the period since the beginning of the developement of fourth-order valleys in the investigated area up to the present, while the latter might be thought of reflecting dynamic equilibrium between driving forces and resistant geologic framework in the process of landscape developement.

Ključne riječi: reljef, erozijska površina, otvoreni sistem, dinamski ekvilibrij, faktorska analiza, horizontalna raščlanjenost, intenzitet erozije, erozijski nivo, nagib reljefa, pokretačke sile, geološka građa.

Faktorska analiza morfometrijskih podataka u području između Maceljske gore, Strahinščice i Ravne gore omogućuje da se matematičkim kriterijima definira reljef kao otvoreni sistem. Faktorski model izražen u obliku rotirane faktorske matrice matematički je izraz unutrašnje strukture takvog sistema u kojem pojedini faktori direktno ili indirektno ukazuju na stanovite procese koji vode k stvaranju različitih oblika reljefa. Između pet faktora koji tvore faktorski model naročito se ističu faktor erozijskih nivoa F3 i faktor intenziteta erozije F2. Prvi se može direktno povezati s neotektonskom aktivnošću od vremena kad je u istraživanom području započeo razvoj dolina četvrtog reda do danas, a za drugi se može reći da odražava dinamički ekvilibrij između aktivnih činilaca i rezistentnog geološkog okvira u procesima razvoja reljefa.

#### Introduction

This paper presents the outcomes of factor analysis applied as an exploratory method to morphometric research in the area enclosed by the mountains of Maceljska Gora, Strahinščica and Ravna Gora. The main scope of such an investigation was to find out whether the processes participating in the landscape evolution could be framed in the factor model, with factors disclosing the impact of neotectonics on landscape in the most conspicuous way. Geological interpretation and, identification of individual factors could pave the road to better understading of tectonic problems, primarily in the areas of dissected relief (areas of general uplift), by disclosure of active faults and active tectonic blocks.

In trying to solve this problem, the efforts have been concentrated around the fact that modern land-scape comes into being by the action of many agents, with neotectonics as a dominant case. Some definite patterns exist in the landscape evolution, causing the particular set of correlations among the variety of landforms. If landscape is considered to be an open system (Chorley, 1962), the possibility arises that its inner structure and processes could be inspected by studying the causal and genetic relations among its forms. Here, it must be emphasized that one of the most important features of open systems appears to be the tendency toward permanent adjustment between process and form. Landscape tends to establish the balance between processes that arise

from the flow of matter and energy through resistant geological framework, and diversity of landforms as the eventual outcome (Horton, 1945; Strahler, 1952; Chorley, 1962). That balancing or adjustment may be thought of as continual fluctuating of the system's elements around an average position known as dynamic equilibrium (Hart, 1986).

The open system approach steers exploration toward essentially multivariate character of geomorphic phenomena (Melton, 1957). In other words, tectonic or any other relations in geomorphology should not be looked upon through the prism of individual morphometric parameters, neither should they be regarded as the á priori effect of one and only gemorphic process. The constitution of the open system is distinguished by the interaction of all their parts or components.

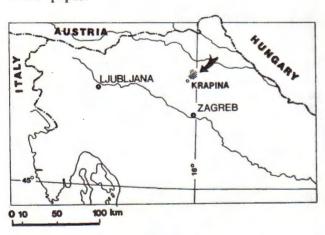
In practice, the method that is most commonly used in recognizing the existence of dynamic equilibrium in a particular system is the identification of significant statistical correlations among the variables within that system (Hart, 1986). Therefore, the multivariate character of geomorphic phenomena throws the emphasis on the application of respective multivariate mathematical methods. These methods enable close inspection into the simultaneous relations among a number of variables, and eventually disclose the causes for their particular behaviour in the investigated system. The most prominent of them is the factor analysis.

## Basic model of factor analysis

A multivariate mathematical method such as factor analysis appears to be quite favourable for investigation of natural systems which complex constitutions have been established as the effect of interactions among various natural processes.

Capability of treating the great amount of numerical data is one of the fundamental characteristics of the method in question. Reduction, transformation and organization of the original set of data by means of intricate mathematical techniques eventually result in a simple form – the form of factor model. Factor model frames the basis on which the processes, responsible for relations among original data, could be interpreted.

The application of factor analysis is feasible in several modes. The way that is convenient in studying the relations among variables is known in a research work as the R-mode factor analysis, and it is used in this paper.



Sl. 1. Karta s lokacijom područja istraživanja

Fig. 1. Map showing location of study area

The method contains elements of matrix algebra, multidimensional geometry and mathematical statistics (Jöreskog, Klovan and Reyment, 1976). It has been designed to express the relations among variables as their correlations with a number of mutually uncorrelated factors (Davis, 1973), and present them in the space of the least possible dimensionality (Raffaelli, 1982). In other words, factor analysis creates the minimal number of new variables that represent the linear combinations of old ones with the same amount of information. In distinction from other multivariate mathematical methods, for instance the principal component analysis, this one tends to explain that particular part of the system's variance which is common among the original variables. Consequently, any variable in the factor model contains two types of variance - common and specific (unique) parts. Common part (communality) is that part of variance which the variable shares with other variables in the factor model, while unique part (uniqueness) means the other part of the variable's variance which is specific to that variable only. If the total variable's variance is expressed as one

 $(\sigma_1=1)$ , then the relationship between communality and uniqueness will be presented as follows:

$$\varepsilon_i = 1 - \sum h_i^2$$

where  $\Sigma h_i^2$ , means communality,  $\varepsilon$  uniqueness (specificity) of variable i, while k represents the number of factors extracted.

Communality holds the information on how much is known about the nature of the factor model. Nevertheless, in the scientific exploration greater importance is attached to the uniqueness of a variable. High values of the specific factor point at a certain source of variability which is not explained by a given factor model (Fulgosi, 1984).

Detachment of the total variance to common and unique parts conveys the meaning of the basic model of factor analysis. It can be put forward as follows:

$$AA' = R - \varphi$$

where A stands for factor matrix (factor model of common factors), A' stands for its transposed value, R stands for the matrix of correlations, and  $\phi$  stands for unique or specific factor.

## Designing the factor-analytical research

The factor analysis does not only comprehend a succesion of mathematical procedures for processing an array of original data. Factor procedures are at heart of the analysis that is, from the mathematical standpoint, exact and unbiased. In effect, the factor analysis begins with designing the factor-analytical study (Fulgosi, 1984). Its first step includes theoretical analysis, that is, setting up the working hypothesis on the basis of previously known data and the outcomes of former investigations. Also, the scope of analysis with the choice of the proper mode must be defined. However, criteria for the selection of original data remain as a crucial element in designing the factor analysis. They comprise: 1) selection of research area, 2) selection of samples (population) and 3) selection of variables.

- 1) Area of investigation is situated amidst the mountains of Maceljska Gora, Strahinščica and Ravna Gora. It reveals the features of very dissected relief. This choice is in accordance with the recognition of the multivariate character of geomorphic phenomena and necessity that their interrelations ought to be studied by respective multivariate methods. The fact that the remarkable dissection of landscape (horizontal and vertical) appears to be the main cause of variability, necessary for successful application of the factor analysis (along with a considerable diversity of geological framework), stands for the above statement. It also refers to the fact that the highly dissected landscape offers a great amount of the available data (variables and samples) required for the respective mathematical and statistical treatment.
- 2) In the R-mode factor analysis, relations among certain attributes or variables in a cluster of samples or objects are subject to study. In that procedure

attention is paid to a specific point in time or to a certain span of time in which relations are observed.

If this is the way to follow in the quantitative landscape analysis, it will be necessary to define the drainage network, as its basic form, in temporal relations. It is achieved by the ordering procedure, whereat the order of valley indicates its relative age or the number of erosional levels, respectively (Filosofov, 1967). However, for relations among the particular attributes of landscape and drainage network to be revealed, it is necessary to take into analysis the whole area gravitating toward the main valley.

Valley system of the main valley is separated from the rest of drainage network by its topographic divide, and could be defined as the local drainage basin (surface of erosion). Chorley (1969) considered drainage basin in terms of the basic, genetically defined unit of landscape, with genesis, form and dimensions as the result of permanent adjustment in balance between the rates of the matter's and energy inputs and outputs. Its age, or the number of erosional levels, keeps with the age of its main

or the oldest valley, respectively.

Factor analysis, carryied out in this paper, included fourth-order drainage basins. They number 126 in the investigation area of 180 km<sup>2</sup> in size, sufficing the requirements for the quantitative analysis. Statistical theory holds it as a rule that the number of objects in the analysis must be greater than 100, for the firm correlation coefficients to be established. At that, the number of objects ought to be at least five times as great as the number of variables involved (Fulgosi, 1984). Last but not least, the order of magnitude, constituting the framework of tectonic relations in the landscape under study, has been established by the very choice of respecitve population among the whole array of drainage basins (in the sense of ordering) in the area of investigation. The size of fourth-order drainage basins are ranged from 0,2 to 2 km<sup>2</sup>. Being observed as the single units they indicate locally significant structures appearing in landscape under the strong control of lithology. A number of drainage basins clustered in a specific area can point at the presence of more prominent structures such as horsts and anticlines (10-10<sup>2</sup> km<sup>2</sup>). In that case, the dominant morphogenetic process will be neotectonic activity with subsidiary lithologic affects (Tricart, 1965a). Consequently, fourth-order drainage basins represent the link between local and regional levels in the area of investigation. Meanwhile, according to the postulates of historic geomorphology, they comprise the indicators of landscape development through the period from the appearance of fourth-order valleys in landscape (as first-order valleys) up to the present.

3) One of the basic criteria for introducing a particular variable into the factor analysis is its interpretability. This is of particular importance because the interpretation of factor model depends on the set of selected variables. Therefore, the factor analysis should include the variables that have been known of reflecting some recognized or supposed natural process. Furthermore, it may be desirable

to make use of the variables which are credited with the possibility of better understanding of these processes.

In designing the factor analysis in the research area, the whole variety of morphometric indicators, orherwise commonly used in the morphometry, have been included. In our literature (Prelogović and Hernitz, 1968; Prelogović, Hernitz and Blašković, 1969; Kranjec, Prelogović, Hernitz and Blašković, 1969; Kranjec, Prelogović, Hernitz and Blašković, 1974; Hećimović, 1984) the most representative variables such as valley length of various orders, maximum relief and area of drainage basin had been used independently, or as coefficients, in drawing up particular morphometric maps which outline dominant tectonic relations in the landscape.

Apart from those aforementioned, some other morphometric parameters, thought to be relevant for understanding the evolution of drainage basins, have been introduced into the analysis. Among them, there are measures involving the slope characteristics of drainage basin (mean slope of valley long profile and mean slopes of valley sides), levels of erosion, and finally, valley frequency as the measure of inten-

sity of the landscape dissection.

Most parameters, such as the measures of horizontal and vertical dissection of landscape were derived from direct measuring on topographic maps. That is how the raw data on number and length of the ordered valleys, size of drainage basins and levels of erosion (heights of mouths and origins of fourth-order valleys) were collected. A few variables are composite in character and represent the combination of measured parameters. Although the composite variables would better be less used in the factor analysis, the presence of parameters such as drainage density or total and relative relief, are thought to be essential to the interpretation of tectonic relations in the landscape.

The total of 18 variables were chosen to be factorized, although during the analysis the necessity arose for more, such as the orientation of valleys. But most of all there was the need of appropriate numerical parameter by which the resistant lithologic

framework could be properly represented.

#### Interpretation of factor model

The basis for the interpretation of factor model is offered by the varimax rotated factor matrix (Table 2). The component parts of factor matrix are given in terms of factor loadings which represent the true correlations between variables and factors. The table also contains data on variance, including eigenvalues  $(\lambda)$ , percentile values of explained factor variability  $(\lambda\%)$ , and also the communalities of variables  $(h^2)$ .

Using the Guttman's criterion, five factors with the eigenvalues greater than one were retained in the analysis for further treatment. Factor model obtained by the rotation of extracted factor axes meets the necessary conditions of the \*simple structure\*. Distribution of factor loadings on the respective factor axes is simplified by rotation in the way that each factor is weighted by a few significant and many insignificant values. All factor axes have the unit length. In the table enclosed, variables which contribute to the explanation of respective factors by their high loadings are marked with asterisk. Factor model explains 79,10% of the total variability, which is about the four fifths of all the processes participating in the evolution of fourth-order drainage basins in the area under study. Share of every variable in the explanation of factor model is expressed by its communality (h<sup>2</sup>). High communality indicates that a variable (H2, H1, D1 etc.) is strongly fixed in the frame of the comon factors. On the contrary, low communalities (T2, T1, HG) point at some still unknown source of its variability.

Tablica 1 Mofrometrijske varijable
Table 1 Morphometric variables

D1	broj dolina I reda	
20	number of I-order valleys	_
D2	broj dolina II reda	
D3	number of II-order valleys	_
L1	broj dolina III reda number of III-order valleys	
		_
	ukupna duljina dolina I reda	km
	total length of I-order valleys	KIII
L2	ukupna duljina dolina II reda	km
	total length od II-order valleys	KILL
L3	ukupna duljina dolina III reda	km
	total length of III-order valleys	KIII
L4	duljina doline IV reda	1
	length of IV-order valley	km
PB	veličina erozijske površine	km <sup>2</sup>
	area of basin	Km-
H2	nadmorska visina ušća doline IV reda	
	height of basin mouth	m
H1	nadmorska visina izvora doline IV reda	
	height of origin of IV-order valley	m
НО	najviša kota na razvodnici	
	height of heighest point on watershed	m
UR	ukupni reljef	
	total relief	m
RR	relativni reljef	
	relative relief of valley side	m
HG	gradijent doline IV reda	-
	slope of IV-order valley	m/km
T1	srednji nagib lijeve padine doline IV reda	
	mean left valley side slope of IV-order valley	0
T2	srednji nagib desne padine doline IV reda	
	mean right valley side slope of IV-order valley	0
FD	frekvencija dolina	
	valley frequency	m/km <sup>2</sup>
DG	gustoća erozijske mreže	
	drainage density	km/km <sup>2</sup>

Factor matrix can be put in a form of diagram. Geometric illustration or the plot of factor loadings represents projection of factor space on the plain of two factor axes. The position of variable among the factor axes is determined by the magnitude of its factor loading and could be expressed in the best way by the vector. Figures enclosed (Fig 2, 3 and 4) show the clusters of variables with the highest factor loadings as single vectors. With the same reason, variables with insignificant factor loadings are not represented in the form of vector. Since the plot of factor loadings is just a geometric expression of factor matrix (Table 2), the full interpretation of factor axes is possible to get to by means of the figures enclosed.

Tablica 2 Rotirana faktorska matrica

Table 2 Varimax rotated factor matrix

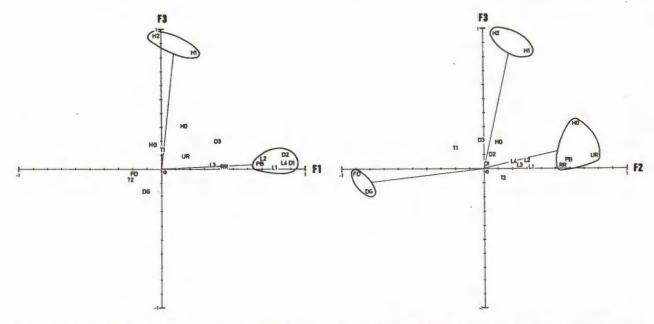
	F1	F2	F3	F4	F5	h <sup>2</sup>
D1	0.8868*	0.0194	0.0382	-0.1110	0.3528	0.9250
D2	0.8586*	0.0556	0.0981	-0.0067	0.2116	0.7948
D3	0.3916	-0.0158	0.2006	-0.0751	0.7642*	0.7835
L1	0.7924*	0.3289	0.0108	-0.1728	0.3307	0.8754
L2	0.7115*	0.3037	0.0559	0.1242	0.3193	0.7189
L3	0.3585	0.2534	0.0241	-0.1462	0.7390*	0.7608
L4	0.8643*	0.2077	0.0472	-0.0962	-0.1849	0.8357
PB	0.7022*	0.5940*	0.0600	-0.0947	0.3133	0.9566
H2	-0.0318	0.0866	0.9593*	-0.0060	0.0750	0.9344
H1	0.2365	0.3124	0.8340*	0.2742	0.0554	0.9274
H0	0.1569	0.6379*	0.3075	0.2743	0.2166	0.6482
UR	0.1652	0.7719*	0.0882	0.3400	0.2068	0.7892
RR	0.4292	0.5495*	0.0242	0.4868	0.3118	0.8210
HG	-0.0597	0.0982	0.1775	0.7822*	0.0694	0.6624
<b>T</b> 1	0.0102	-0.2046	0.1354	0.6089*	-0.4322	0.6178
T2	-0.2157	0.1363	-0.0748	0.7006*	-0.1757	0.5923
FD	-0.2016	-0.8969*	-0.0289	0.0523	-0.1122	0.8612
DG ·	-0.1154	-0.8119*	-0.1578	0.1062	0.1605	0.7344
λ	4.5767	3.6077	1.8608	2.0932	2.0995	
λ%	25.43	20.04	10.34	11.63	11.66	
λ% cum 25.43 45.		45.47	55.81	67.44	79.10	

#### First factor F1

Explains 25,43% of the total variability. Predominantly is loaded with variables representing the component parts of drainage network. The highest loadings characterize the variables D1, D2, L1, L2 and PB, or the total number and the total length of first-order and second-order valleys belonging to fourth-order drainage basins PB. It is evident that third-order valleys (D3, L3) are not significantly bound to the first factor, meaning that they are not familiar with the rest of the component parts in drainage network. Group of variables D1, D2, L1, L2, L4 and PB is positively corelated with the first factor. It provides evidence that changes in drainage network reflect themselves in accordance to all their component parts. Since F1 is composed of variables representing the elements of horizontal dissection, simultaneously reflecting the size of fourth-order drainage basins, it may be readily identified like the factor of horizontal dissection (size factor) (Figure 2).

#### Second factor F2

Explains 20,04% of the total variability and together with the first factor accounts for 45,47% of the total variance. It is a bipolar factor involving two groups of variables with significant loadings, but of opposite signs. The components of vertical dissection UR, HO and RR are clustered on the positive pole of the factor, while the variables reflecting drainage density, FD and DG, take place on the oposite side (Figure 3). Antagonism of these groups points at a different behaviour of respective variables in the geomorphic processes. In the landscape with low relief, there will be highly dissected drainage network and vice versa. Since the variables FD and DG



- Geometrijski prikaz faktorskog modela projekcija prve i treće faktorske osi rotirane faktorske matrice
- Fig. 2. Geometric illustration of factor model plot of first and third factor axes of rotated factor matrix

 Geometrijski prikaz faktorskog modela – projekcija druge i treće faktorske osi rotirane faktorske matrice

Fig. 3. Geometric illustration of factor model - plot of second and third factor axes of rotated factor matrix

actually comprise the elements of horizontal dissection, it is evident that the second factor puts together horizontal and vertical disections of landscape. The first and the second factors evince the high degree of mutual relationship. The main reason for their mutual dependence becomes evident by the closer inspection into Table 2. Factors F1 and F2 are loaded with the variable significantly (0,70F1+0,59F2) and partly with the variable RR (0,43F1+0,55F2). Next important indicator is the position of all groups of variables explaining the first and the second factors. All three of them lie almost in the plane of the F1 and F2 factor axes. Besides, this relationship is indicated by already mentioned strong correlation between FD-DG cluster and F2, since the two variables synthetize the component parts of horizontal dissection.

If the first factor shows up the horizontal dissection of drainage network by its segments, the second factor obviously reflects the aspects of present-day landscape in the horizontal and vertical dissection of relief and drainage network. In other words, F2 reflects the processes of erosion and denudation that take part in the moulding of fourth-order drainage basins in the investigated area. Therefore, it could be properly called as the *factor of erosion* or the factor of intensity of erosion.

#### Third factor F3

Explains further 10,34%, and together with the first and the second factors accounts for 55,81% of the total variability. It is positively correlated with the group of two variables, namely H2 and H1 (Table 2, Figure 2 and 3), while relations with the other variables are of no importance. Variables H2 and H1 represent the local levels of erosion in the

area of fourth-order drainage basins, where H1 means the altitude of their origins, and H2 the altitude of their mouths or the basic level of erosion for a particular fourth-order drainage basin. Consequently, the third factor F3 can be referred to as the factor of erosional levels.

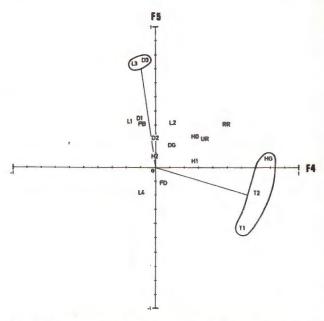
# Fourth factor F4

Takes part with 11,63% in the total variability, and together with the former three factors it accounts for 67,44% of the whole variance. It is predominantly bound to the variables HG, T2 and T1 (Figure 4), that is to the slope elements in the area of the main valley - slope of fourth-order valley (mean slope of the long profile) and slopes of its sides (slopes of the cross-profile). A brief insight into the factor matrix (Table 2) reveals the close relationship to the second factor, which is showed up by the modefactor loadings of the variable rate (0,56F2+0,49F4). This kinship is logical, since the relative relief refers to the depth of erosive cut of fourth-order valleys into surrounding landscape, which reflects itself on the slope elements.

The fourth factor F4 is easily explained as the factor of slope.

#### Fifth factor F5

Explains further 11,66% of the variance, and with the rest shares in explanation of 79,10% of the total variability among the original data. Being considered in genetical terms, it is similar to the first factor because of significant factor loadings of the variables D3 and L3 (Table 2, Figure 4). Correlations with the other components of horizontal dissection are weak. This factor confirms the special status of



 Geometrijski prikaz faktorskog modela – projekcija četvrte i pete faktorske osi rotirane faktorske matrice

Fig. 4. Geometric illustration of factor model – plot of fourth and fifth factor axes of rotated factor matrix

third-order valleys in the drainage network. Since it accounts for a particular erosional level in the drainage developement, it may be defined as the factor of partial horizontal dissection or the factor of third-order valleys.

## Meaning of factor model in geomorphic process

Factor model represents a totality of processes participating in the landscape development. Drainage basin shape and dimensions occur to be the outcome of delicate balancing between dynamic and static participants in the geomorphic process. Landform evolution during the geological history has been considered by many authors as being the consequence of interaction between endogenetic forces and resistant geological framework. In its utter simplicity, that evolution may be pondered upon in terms of relation between the recent tectonic activity (particulary its vertical component) as the prime active participant, and lithology as the most significant passive component. However, when performing a detailed research work in the domain of dynamic geomorphology, it is necessary to take into account not only the factor of climate which is an important driving force, but also the structural elements (fissures, bedding), and even the anthropomorphic factor (for instance, deforestation enhances the processes

Factor model involves the factors of horizontal dissection, intensity of erosion, erosional levels, slope, and partial horizontal dissection as an outside coating of the simple structure, with the passive and active components hidden deeper within the constitution of individual factors.

Relationship among dynamic and static elements is mirrored in a certain degree of mutual dependance

among individual factors because of significant correlation with the same variables. The most prominent variables are RR, wich binds together all the factors aforementioned, and PB which puts together the first and the second factors. The high value of uniqueness, distinguishing the crucial variables of the fourth factor, indicates their participation in some process that is not involved in the factor model.

The factor of erosional levels F3 comes into prominence by its simplicity among the five factors that frame the factor model in the study area. Except from erosional levels, there are no additional morphometric parameters significantly correlated with the third factor. Since the erosional leveles depend primarily on the growth of landforms with the superimposed drainage network, this factor might be directly referred to the neotectonic activity spanned from the beginning of evolution of fourth-order valleys in landscape up to the present. The problem of the explicit definition of individual components in geomorphic process is more or less inherent to the structure of remaining factors. Although endogenetic forces strongly effect the intensity of erosive processes, there is no doubt that overall steepnes of slope, steepnes of the valley sides, total and relative relief, and other morphometric parameters likewise hold an information on geology (lithology and structure) in the study area.

Urgency for detachment of the lithologic component from the remaining participants in the landscape development is especially accentuated in the factors of horizontal dissection F1 and slope F4. Increased horizontal dissection, as well as increased steepness of valley slopes may outcome from the stronger uplift during the landscape evolution, but may likewise be influenced by the existing geological framework. Lithology and structure directly effect infiltration of sufrace waters (especially of atmospheric origin). Generally, it holds true that the sparsely distributed drainage network will develop on the rocks resistant to erosion and with the high infiltration capacity. In the area of investigation the Maceli Sandstones (Lower Miocene) exhibit the features of that kind. Resistant and highly permiable rocks also tend to enhance steep long and cross valley profiles. Just the opposite tendency in the developement of drainage network appears in the sediments with low permeability and bad consistency, such as clays and marly clays of the Lower Miocene. Relationship between lithological composition and erosion has not yet been fully understood in quantitative terms, and may remain hidden behind some other rock features such as fracturing, which sometimes effect different lithological units to behave similarly in respect to erosion (Ritter, 1978). Therefore, the search for structural landforms in the present-day landscape, solely dealing with the factors of horizontal dissection and slope, may be an arduous task.

Relations among the individual component parts of landscape and drainage network have been studied by many authors. The first who endeavored to put them forth in the quantitative form was Horton (1945). He proved the basic relation among morphometric parameters, getting into touch the angle of

valley side slope  $\Theta$ , relative relief H and drainage density D in the equation:

# $tg\Theta = 2HD$

This is a theoretical connection among the basic parameters of landscape, that leads to the setting of characteristic slope angles in a particular area (Young, 1961). Provided that the slope angle is theoretically a constant value  $tg \Theta = k$ , relative relief and drainage density refer to each other like inversed proportions:

$$HD = k;$$
  $H = k/D$ 

This relation is best represented in the second factor F2, where the components of vertical dissection (HO, UR, RR) and summary horizontal dissection (FD, DG) are placed at the opposite poles of the factor, while factor loadings of variables T1 and T2 appear to be insignificant.

The same relation is revealed in L. Miljajeva's coefficient (1966) which serves as a mean for designing the one of the most important morphometric maps – the map showing the intensity of erosion:

$$k_m = (h \Sigma 1)/p$$

where  $\Sigma l/p$  can be replaced by drainage density DG, h by total relief UR, while p represents the surface element of quadrangular grid (1 km²). However, while the Miljajeva's coefficient represents the »casual« value with regard to deliberate location of quadrangular grid on a topographic map, the second factor reflects in the equation  $k_{F2}=UR\times DG$  the clear genetic features of landscape, because it shows how the process of erosion effects the particular place on the earth's surface during the particular span of time.

If relief (UR, RR) and absolute height of watersheds (HO) are considered to be the direct reflection of neotectonic activity, and drainage basin to be the straight outcome of interaction between climate and lithology (Ritter, 1978), the second factor fully merits its name – the factor of intensity of erosion. Coefficient  $k_{F2}$  points out the complex relationship between neotectonic activity on the one hand, and lithology and climate on the other. This is not a static realtionship, as shown in Miljajeva's coeficient, but the one that reflects the tendency of drainage basins to establish and retain, by adjustment of their shapes (in the set of morphometric parameters), the state of equilibrium which ensures the most efficient and the most stable transfer of matter

Geologic interpretation of the fifth factor is not easy to deduce, for it is not clear why third-order valleys appear as a particular segment of drainage network. It is important to stress a good correlation between the valley side slopes of fourth-order valleys and the fifth factor (T1=-0,43F5). That correlation is negative, and it means that third-order valleys seldom appear to figure as the side tributaries of the main valley, which in turn has the steep sides of its own (and vice versa). The author adheres to the opinion that the fifth factor possibly discloses

and energy.

the break of equilibrium during the evolution of fourth-order drainage basins, being provoked by the change in tectonic regime in the area of investigation. Third-order valleys possibly arose during the period when, due to the weak tectonic activity, erosional downcutting ran slowly. Later, by acceleration of tectonic movements, the growth of individual tectonic blocks had been intensified, causing deeper valley- cutting into the surrounding geologic background and increase in horizontal dissection in the first- and second-order basins.

#### Conclusion

Systems approach in the field of dynamic geomorphology offers the possibility that landscape (in its entirety or through individual drainage basis) is considered to be an open system which keeps the balance between input and output of matter and energy by adjustment of its forms. This approach offers the following advantages:

 it puts the emphasis on the close relationship between process and form

it points out the multivariate nature of geomorphic processes.

Understanding the landscape in terms of the open system theory, with dynamic equilibrium as the central point of interest, paves the way to the broad application of factor analysis as one of the most prominent multivariate mathematical method. This method is able to quantify the complexity of relations among the components of drainage basin, and above all, to point at the processes which participate in the landscape evolution.

Fourth-order drainage basins in the area amidst the mountains of Maceljska Gora, Strahinščica and Ravna Gora were subjected to factor analysis. The choice of population defined both the temporal framework for present relations to be explored (from the beginning of developement of fourth-order valleys up to the present), and the order of magnitude regarding the morphostructures that were expected to be disclosed in landscape (morphostructures of either local or regional appearance) by the further treatment of factor model.

Variables involved in the analysis represent morphometric parameters, being used in the field of dynamic geomorphology in our and foreign literature by many authors. Four groups of variables have been applied in the analysis:

- morphometric parameters of drainage network (D1, D2, D3, L1, L2, L3 and L4)
- geometric elements of drainage basin (PB)
   variables reflecting magnitude of drainage network dissection (FD, DG)
- parameters of slope (T1, T2 and HG)

By factorizing the original data matrix, the factor model is obtained which consists of five factor axes. They are interpreted as follows:

factor of horizontal dissection F1 (25,43%)
 (0,89D1+0,86D2+0,79L1+0,71L2+0,86L4+0,70PB)

- factor of intensity of erosion F2 (20,04%)
   (0,64HO+0,77UR+0,55RR+0,59PB-0,90FD-0,81DG)
- factor of erosional levels F3 (10,34%) (0,96H2+0,83H1)
- factor of slope F4 (11,63%)
   (0,78HG+0,61T1+0,70T2)
- factor of third-order valleys F5 (11,66%) (0,76D3+0,74L3)

All five factors explain 79,10% of the total variability and account for about 4/5 of all the processes participating in the landscape evolution of the inve-

stigated area. Factor of erosional levels is distinguished by the simplest constitution, indicating the trend and intensity of vertical neotectonic movements. The rest of factors represent the complex combination of diversified constituents in the process of landscape creation. They express interaction of neotectonic activity and climate as the main dynamical agents on the one hand, with lithology and structure, forming the resistant geologic framework, on the other. The second factor reflects the basic laws of geomorphic relations. They are illustrated by the negative correlation among drainage density DG (FD) and relief UR (RR) on the one hand, and the highest elevations on watershed HO on the other. At the same time, slope is proportional to these parameters.

In trying to explain the factor model thoroughly, it is desirable to include some additional variables into the factor analysis. Variables of particular importance are those taking into account the existing geological framework, more or less resistant to the activity of endodynamic and exodynamic forces. The necessity of variables that may express the lithology of the area under study in terms of quantitative relations is particularly emphasized. Investigation founded solely on the morphometric variables does not represent the basis strong enough for complete understanding of processes running in the present-day landscape.

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# Primjena faktorske analize u dinamskoj geomorfologiji

Z. Peh

Sistemski pristup proučavanju strukturno-geomorfoloških odnosa omogućuje da se reljef (u cjelini ili kao pojedinačne erozijske površine različitih redova) razmatra kao otvoreni sistem koji neprestano održava ravnotežu između inputa i outputa materije i energije prilagodbom svojih oblika. Takav pristup ima slijedeće prednosti:

- postavlja naglasak na tijesnu vezu između procesa i forme
   naglašava multivarijantnu prirodu geomorfoloških procesa.
- Shvaćanjem reljefa kao otvorenog sistema koji se nalazi u stanju dinamičke ravnoteže između forme i procesa ističe se u prvi plan faktorska analiza kao multivarijantna metoda koja je u stanju kvantificirati odnose između svih elemenata erozijskih površina i na taj način ukazati na procese koji sudjeluju u njihovom formiranju. Faktorskoj analizi podvrgnute su erozijske površine četvrtog reda u području između Maceljske gore, Strahinščice i Ravne gore. Izborom populacije definiran je i vremenski raspon u kojem se proučavaju strukturno-geomofološki odnosi (od početka formiranja dolina četvrtog reda u reljefu do danas), a ujedno i red veličine morfostruktura koje je moguće otkriti u reljefu (morfostrukture lokalnog i regionalnog karaktera).

Varijable korištene u analizi predstavljaju morfometrijske parametre koji se koriste u strukturno-geomorfološkim istraživanjima u našoj i inozemnoj literaturi. Korištene su četiri grupe varijabli:

 morfometrijski parametri erozijske mreže ((D1, D2, D3, L1, L2, L3, L4)

- geometrijski elementi erozijskih površina (PB)

- varijable koje održavaju intenzitet disekcije erozijske mreže (FD, DG)
- morfometrijski parametri vertikalne raščlanjenosti reljefa (HO, H1, H2, UR, RR)

- elementi nagiba reljefa (T1, T2, HG)

Faktorskom analizom dobiven je faktorski model s pet rotiranih faktora koji su interpretirani na slijedeći način:

- faktor horizontalne raščlanjenosti F1 (25,43%)
   (0,89D1+0,86D2+0,79L1+0,71L2+0,86L4+0,70PB)
- faktor intenziteta erozije F2 (20,04%)
   (0,64HO+0,77UR+0,59PB-0,90FD-0,81DG)
- faktor erozijskih nivoa F3 (10,34%) (0,96H2+0,83H1)
- faktor nagiba reljefa F4 (11,63%) (0,78HG+0,61T1+0,70T2)
- faktor dolina trećeg reda F5 (11,66%) (0,76D3+0,74L3)

Svih pet faktora objašnjavaju 79,10% ukupne varijabilnosti sistema, odnosno odgovaraju za oko 4/5 svih procesa koji sudjeluju u formiranju erozijskih površina četvrtog reda u istraživanom području.

Faktor erozijskih nivoa F3 ima najjednostavniju građu i izravno ukazuje na smjer i intenzitet vertikalnih neotektonskih pokreta. Preostali faktori predstavljaju složenu kombinaciju različitih čimbenika u procesu formiranja suvremenog reljefa. Oni izražavaju interakciju neotektonskih pokreta i klime kao glavnih dinamičkih čimbenika te litologije i strukturnih elemenata koji čine rezistentni geološki okvir. Drugi faktor F2 odražava osnovne zakonitosti među elementima reljefa i erozijske mreže. Te zakonitosti izražene su u obratno proprocionalnom odnosu između gustoće erozijske mreže DG(FD) te dubine erozijskog ureza UR(RR) i maksimalnih visina reljefa HO. Istovremeno nagib reljefa je proporcionalan ovim veličinama.

Potpuna eksplikacija faktorskog modela nalaže uvođenje novih varijabli u faktorsku analizu. Posebno su važne varijable koje prikazuju geološku građu, odnosno elemente koji pružaju manji ili veći otpor djelovanju endogenetskih i egzogenetskih sila. Naročito se ističe potreba za varijablama kojima se može kvantitativno izraziti litološka građa istraživanog područja. Oslonac isključivo na morfometrijske varijable ne predstavlja dovoljno čvrstu podlogu na kojoj se može upoznati sva ukupnost procesa u suvremenom reljefu. To je problem kojem treba usmjeriti buduća istraživanja.