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Analyzing of Surface Relations in an Experimental Drainage Basin

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ABSTRACT

In recent decades, modeling perspectives in geomorphology have been developed. Utilizing these new opportunities, geomorphologists have analyzed numerous existing concepts and introduced new ones as well. Allometry, as a concept derived from biology, is a method to describe interrelations between variables. In biology, allometry is defined as the study of the rate of relative changes between two parts of a system .This rate is always a constant fraction of the relative growth rate of that system and its amount is defined by a power function. This research, attempts to analyze allometric relations in surfaces of a drainage basin in various stages of development using data extracted from analyzing of an experimental basin model. In fact the aim of this paper is to evaluate the growth of surfaces with different slopes in an experimental basin to show how surfaces change through basin development and to find growth laws of basin surfaces. Results show that during developmental stages of the basin, elevation surfaces with different slopes changed based on positive or negative allometric relations and eventually the extent of the surfaces and their relations tended to a constant value reaching which is an index indicating tendency of the basin towards steadiness. Results of the present paper could help to predict the future condition of basins and provides guidelines for environmental management.
KEYWORDS: drainage basin, allometric relations, scale, log-log plots, evolution.

INTRODUCTION

Proportion is a mathematical concept which can reflect various concepts in geomorphology including stability. In a sense, in geomorphology, stability and instability result from variability in relations between components and equilibrium is achieved when there will be certain relations between these components. The proportion and relations between the landforms' components play the key role in determining landscape scales. Furthermore changes in environment lead to change in form and formation of new equations by affecting equilibrium ratios between components. Due to change in geomorphic forms over time, different kinds of geomorphologic concepts can be analyzed by mathematical equations. Allometry is one of such components which is the study of the proportion of parts of a system describing some key geomorphologic concepts such as equilibrium and stability. In fact, this research can be called the geomorphic analogue of allometry in biology. Allometry, as a newly developed subject, is important in epistemology and knowledge production. Results of this research can lead to invention of new methods in analyzing drainage basins and their function and therefore formation of modern strategies for environmental management.

The term allometry in the sense of rational growth was first defined by Huxley and Teissier [1]. They also agreed on conventional terminology for discussing concepts and relations. Gould (1972), defined allometry as "a general term for all relationships, dynamic or static, fit by power functions and involving change of shape correlated with size increase [2]. Bull [3] described allometric relations arisen from changes in landforms' dimensions during developmental stages. Woldenberg's [4] attempts showed that Horton's [5] main law of drainage arrangement, in fact, reflected allometric relations. Comparing Horton's laws with allometric growth and equilibrium concept in open systems and also studying river discharge relation with surface and bifurcation ratio as well as discharge in comparison with stream orders, Woldenberg concluded that river geomorphic laws defined by Horton and Strahler are double logarithmic expression of the relation between the components of a basin. Evans [6] in concern with allometric development of glacial cirques concluded that large glacier cirques have different gradient from small glacier cirques and that their vertical dimensions grow more slowly than their horizontal dimensions. Bull [7] showed that sedimentary structures such as alluvial fans are growing landforms allometrically related to sediment production of their origin. Different analysis has been used with considerable success to describe growth laws in geomorphology and in all researches mentioned above, geomorphic features and drainage basins seem to exhibit similar scaling behavior. These scaling laws show that growth in geomorphology is not in the form of simple

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isometric relations. Growth laws are nonlinear and this nonlinearity may cause different properties in geomorphic systems.

The present research, extracted from a research project in University of Isfahan, attempts to analyze the relations between different erosional surfaces in an experimental drainage basin during its developmental stages.

Allometry:

In biology, allometry is the study of size-related changes in organic processes and structures [8]. Allometric law in a living organism, for instance, states that relative growth of an organ is a constant fraction of the growth of the whole organism. That is to say if two parts of a system are allometrically related to the whole system, they are related to each other, as well, in a power equation. Scaling with size typically follows a simple power law behavior of the form: $y = ax^b$ [2, 9, 10].

The mentioned concepts and models can be benefited from in geomorphology through measuring components and their changes during time and therefore defining growth stages or certain concepts such as equilibrium in geomorphic systems. In ergodicity as well, allometry can be used to state changes in geomorphic landscapes and to define a relation representing each stage in a way that a particular relation between the components of landscape introduces the related stage. Furthermore, allometry can be used both for landforms and processes.

Although the extensive application of allometry in geomorphology has not been yet accepted widely, it has had significant results in several conducted researches [11-13]. For instance, in allometric geomorphologic analyses, drainage basin is considered as the whole system and its components include drainage networks, slope, basin length, and width and other variables. Thus researchers have tended to define certain relations between these components and the system as a whole. One result of such studies is Hack's law. This law states that there is a relation in the form of $l \equiv a^h$ between basin area (a) and main channel length (l). Typically, one performs linear regression analysis on log (l) against log (a) to obtain the exponent h [14].

MATERIAL AND METHODS

As to analyze allometry in developmental stages of a drainage network, an experimental basin was selected with approximate dimensions of 4×2.5 m and a surface of 6.26 square meters (fig.1).

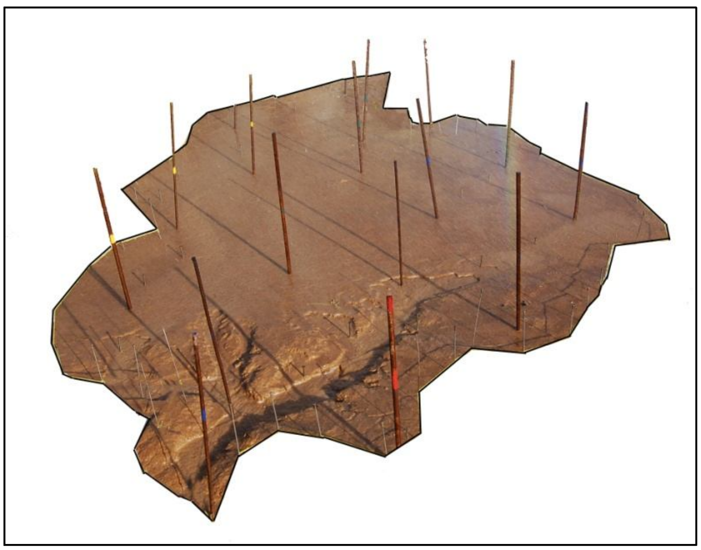

Figure 1: Experimental drainage basin in first stage of erosion

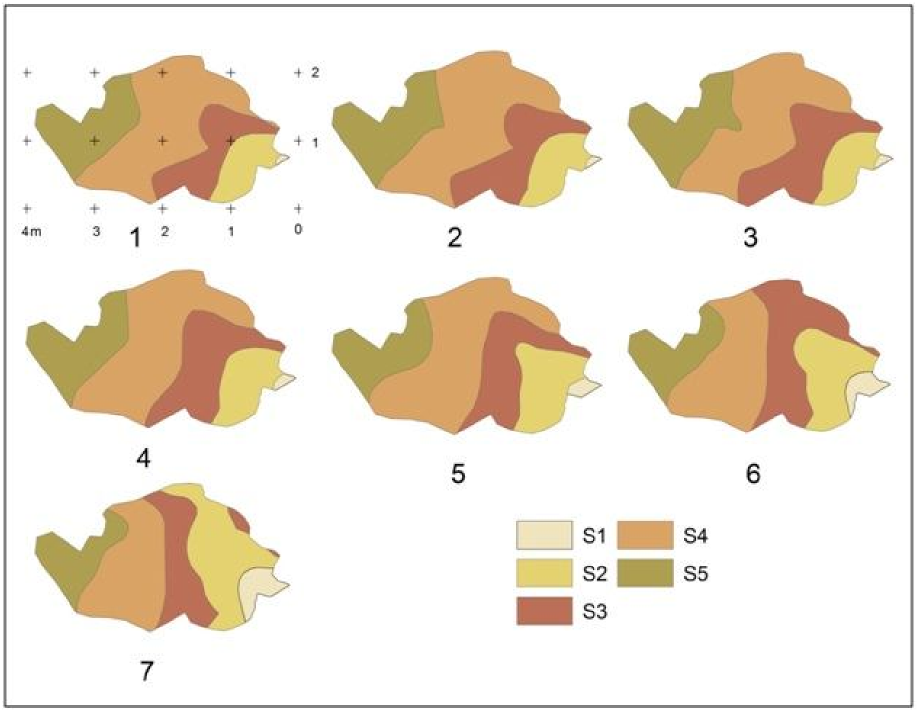

Figure 2: 7 stages of basin evolution

Table 1: regression results for 7 stages of basin evolution

Variable 1	Variable 2	Exponent	Constant	R	P- value
S1	S2	0.333	2.246	0.978	0.000
	S3	0.032	1.485	0.244	0.598
	S4	-0.137	1.776	0.904	0.005
	S5	-0.160	0.778	0.973	0.000
S2	S3	0.045	1.369	0.119	0.800
	S4	-0.396	2.484	0.886	0.008
	S5	-0.464	1.148	0.962	0.001
S3	S4	-0.497	2.993	0.425	0.342
	S5	-0.333	1.322	0.264	0.568
S4	S5	0.895	0.513	0.829	0.021

This completely natural miniature drainage basin located in Yazd-Ardakan plain and a natural gap altered its base level which facilitated water flow. The erosion effects were visible in stairwell shape with different dimensions after artificial rainfall performed on its surface. The operation was performed two days and the basin changes were recorded. After simulating the basin developmental stages according to gauging method of measuring, height of applied bars were measured and evaluation and measurement of basin changes were conducted. Surface changes were measured during artificial rainfall. After two days of artificial rainfall, surface ratios became almost stable and no change in ratios was detected following further rainfalls. Then the elevation map of the basin was designed in five surfaces with different slopes during seven stages of development (fig. 2).

RESULTS AND DISCUSSION

During rainfall, selected surfaces gradually suffered erosion and reformed to terrace shape, basin surface reformed to stairwell shape in a way that different surfaces were separately visible and formed independent levels. Surfaces changed continuously in a manner that in most cases surfaces close to the basin outlet developed towards basin upstream. Instead, the extent of upstream reduced due to less erosional rates. The surfaces were measured in each stage. Each terrace's surface relates to the rest of the basin in a particular equation (a power function) which proves allometry in this miniature basin according to Bull's definition (1975).

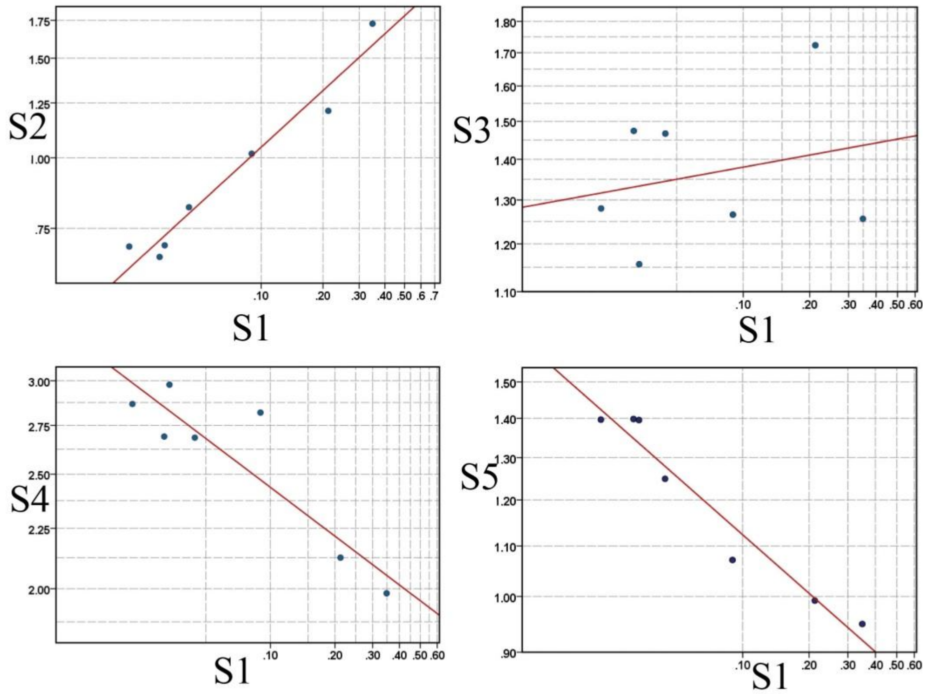

Figure 3: relationship between surface 1 and other surfaces in log-log plots

In this basin surfaces are categorized in two groups; surfaces that reduce in extent during time and surfaces that increase in extent. In this equation surfaces 1 and 2 increase in extent gradually after rainfall commencement which is clearly visible especially in the last stages. On the contrary the surface area of surfaces 4 and 5 decrease gradually after rainfall commencement and surface 3 as an intermediate surface shows no particular trend and has no meaningful relation with other surfaces.

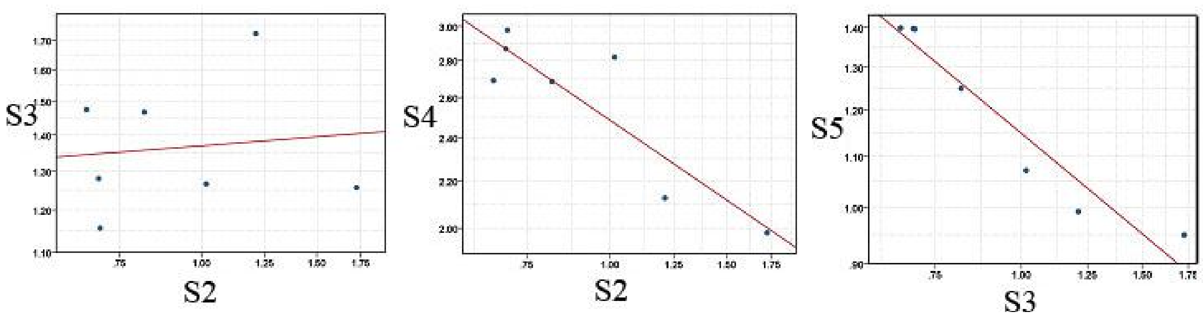

Figure 4: relationship between surface 2 and other surfaces in log-log plots

As in table 1, in the simulation of 7 developmental stages of this drainage basin surface, areas 1 and 2 increase in an allometric relation with great correlation (R=0.978). This equation is of positive power which indicates positive allometry and this relation is meaningful at $P<0.05$. Surfaces 1 and 3 show no allometric or meaningful relation due to intermediate function of surface 3. Surfaces 1 and 4 with moderate correlation show a meaningful allometry and as seen in table 1 this relation is negative allometry i.e. an increase in surface 1, results in a decrease in surface 4 (fig.3). Surface 1 and 5 changes in these 7 stages are the same as the relation between surfaces 1 and 4, i.e. a meaningful negative allometric relation (R=0.973). Surfaces 2 and 3 again have no meaningful relation as for the intermediate function of surface 3 (fig. 4). Surfaces 2 and 4 show a negative allometric relation with moderate correlation (R=0.886). Surfaces 2 and 5 show a meaningful negative allometric relation as well except that their correlation is high (R=0.962). Surfaces 4 and 5 have also moderate and meaningful correlation (R=0.829). This relation is also a positive one, i.e. as area in surface 5 decreases; surface 4 area decreases too and vice versa (fig. 5).

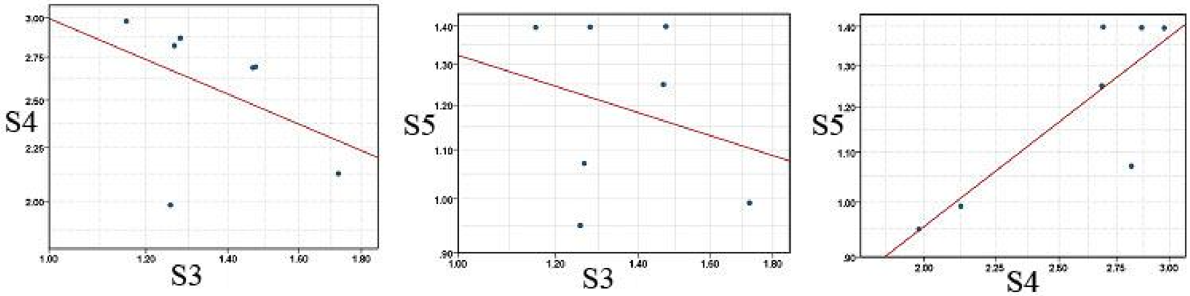

Figure 5: relationship between surface 3 and 4 with other surfaces in log-log plots

Results show that during developmental stages of a basin, surfaces change during time with an allometric relation and in a particular mode changes tend towards zero which indicates a constant concept in geomorphology. In other words, erosive changes continue to a certain limit and remain constant from then on. This border determines a limit as a threshold. In this stage no more changes occur and basin reaches a steady stage. It is obvious that coefficients and equations in this stage show the characteristics of the basin steadiness. This steadiness in the basin does not mean dynamic equilibrium because in dynamic equilibrium the proportions are constant while the process is still in progress whereas here erosion rate has become constant and stability of shape is due to process halt and not due to equilibrium of erosion rate with base level change.

In this basin when the ratio of the surfaces with decreasing extent reaches 40 percent of the total basin surface and the increasing surfaces reach 33 percent of the total basin surface, surface proportions remain almost constant and the basin reaches steadiness. Thus allometric relations in this basin are provable as a basin that tends towards steady state.

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