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VALLEY MORPHOMETRY AND VALLEY INCISION RATE

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ABSTRACT

Fluvial processes, one of the main actors in the development of the geomorphologic structure, are reflected most saliently by valleys in topographic surfaces. Analyses focusing on valley morphometry that present concrete and accurate data in terms of both existing geometries and formation and development processes play a significant part in explaining geomorphologic properties especially in fluvial morphogenetic regions. Unfavorable aspects such as the insufficiency of existing analysis methods in generating real values and impossibility of conducting process-based analysis have created barriers to achieve the expected success in comprehending valley morphometry. Therefore, in order to eliminate this shortcoming, this study established a methodology by identifying the problems to enlighten which parameters should be placed in what parts of the equation by citing how the parameters should be measured in order to ensure the generation of desired data on both analog and digital data bases. This methodological approach, expressed more clearly and comprehensibly with the help of illustrations and mathematical formulas, was finalized by correlating it with the elements and parameters with counterparts in the concrete field data. As a result, while it was possible to examine concrete quantities in valleys related to length, area and volume based on amount and ratio without limitations on area and section; it was also possible to present a methodological framework that allows process analysis in terms of the operations of the fluvial process and developmental course of the geo-morphological structure.

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STRUCTURED ABSTRACT

Erosional processes are among the most effective factors in shaping the earth and developing geo-morphological units. By concretizing the relief character, especially the external forces that work under the control of atmospheric conditions play an important role both in the maturation of the main geo-morphological units and in the emergence of elementary geographical formations. This fact shows once again that fluvial processes and the valleys which are the most significant geo-morphological products of these processes are the elements that need to be taken into consideration with precision in both theoretical and applied geomorphology studies. Today, many valley characteristics are the subject of morphometric analyses. Geo-morphological analyses with higher accuracy and higher quality are possible by means of identifying new indices and developing the existing ones. However, it is still not possible to claim that morphometric qualities of valleys are entirely presented. It is not completely possible to undertake the analytical assessment of some of the issues related to valley incision and development when learning about the development processes of valleys and paleo-geographic conditions and during the formation of the drainage network.

The formulas used to calculate valley incisions today are based on empirical current and sediment measurements. An accurately designed morphometric model will both make it easier to reach a more distinct outcome by analyzing the output rather than the process elements compared to de-facto conditions and will enable to have a more clear-cut idea prior to the field study. In addition, it will be possible to obtain data more rapidly on wide valleys and/or basins that are much more difficult to investigate via cadastral methods and a significant step will be taken in identifying the change and anomalies in the thalweg lines of valleys and watersheds. In this context, to identify an index including these features; parameters that affect valley formation in a wide spectrum from structural and lithological characteristics to land use were reviewed and it was determined that existence and effects of the variables were significant in evaluating the results of assessment. Then, the parameters related to analysis and measurement on simulated valley and basins were explained along with explanations of the procedures.

On the other hand, lateral positioning and substitution of watershed is shaped under the control of slope-based headwater erosion triggered by the increase in the incline of slope as a result of the decrease in thalweg elevation. This expresses an erosion process which is directly affected by the respective positions of mean thalweg and mean watershed. Identifying thalweg and watershed profiles will help make sense of this relationship. This operation can be done by using digital terrain models as well as identifying points in topographic maps at desired frequencies to transfer them to the profile. At this point, while which parts of the thalweg will be compared with which parts of the watershed when averaging the whole line will not create problems in a wide scale during incline measurements, it will be problematic when the process is considered in small scales. In order to solve the aforementioned problem, the equalization should take the part of the watershed that is closest to the thalweg as the counterpart; and therefore with the highest incline values. The same way can be used in separating watershed that belongs to the right and left slope of the basin by creating the closest line from the start of the main river bed to the watershed. This way, the issue of which point of the thalweg controls which part of the watershed will become clearer to a large extent. In the end, the desired type of incline measurement methods can be selected for the identified lines based on cost to undertake the process. It will be possible to generate more consistent data about the valley geometry after identifying the relation of interaction between thalweg and watershed.

Another output is related to volume measurement to generally identify the amount of material that is carried by applying a triangular prism whose apex corresponds to thalweg based on width, height and depth that will be determined according to the man of the whole valley. Measurements that will be taken in this context can be diversified by comparing the triangular prisms shaped by respective slopes that will be separated from the projection in the thalweg floor (the plane that combines watersheds) and by interpreting the different segments of the basin independently. Hence, it will be possible to obtain mean valley depth by proportioning the mean elevation of the whole watershed to the mean thalweg elevation; to obtain mean slope incline by proportioning mean thalweg-watershed distance to mean valley depth and to obtain incision coefficient by proportioning mean slope incline to mean valley depth.

On the other hand, proportioning of the mean valley density (the proportion of total valley length to the area of the basin) to mean valley depth (explained above) will provide area based mean incision ratio. Based on the quantity of this ratio, it will be possible to compare incision ratios, to relatively evaluate two neighboring valleys and to observe which valley is more efficient in terms of course of development.

The method addressed in the framework of analyzing valley morphometry aims to define the incision process, for which the existing methodology is insufficient, in terms of amount and ratio. The method presents a methodology, which is both applicable and has the ability to produce consistent and well-directed results due to lack of limitations in using digital or analog data and the ability to obtain data in real scale and to provide opinions as to the course of the erosional process.

One of the most significant outcomes of the study can be summarized as the ability to generate data that will constitute a basis for interpretations related to the paleo-geography and the primary position of the topographic area as a result of explaining the changes to the location of the watershed. It should be apt to emphasize that considered as a whole, this new method that is established will provide the opportunity to undertake an erosional analysis that will shed light to the processes of the geological past.

Keywords: Morphometry, morphometric indexes, valley incision.

VADİ MORFOMETRİSİ VE VADİ KAZILIM ORANI

ÖZ

Jeomorfolojik yapının gelişimindeki başlıca aktörlerden olan flüvyal süreçlerin topografik satıhtaki en belirgin yansımasını vadiler temsil eder. Gerek mevcut geometrilerine gerekse oluşum ve gelişim süreçleri bakımından somut ve doğru verilerin ortaya konacağı vadi morfometrisine odaklanmış analizler, özellikle flüvyal morfojenetik bölgeler için jeomorfolojik özelliklerin açıklanmasında büyük pay sahibidir. Kullanılmakta olan analiz yöntemlerinin özellikle reel veriler üretilmesi konusunda bazı yetersizlikler barındırması ve süreç bazlı tahlillere imkân vermemesi gibi olumsuzluklar vadi morfometrisinin anlaşılmasında istenilen başarının elde edilmesine mani olmaktadır. Bu durumun ortadan kaldırılabilmesi için çalışmanın ana çerçevesinde, eksikliklerin belirlenerek ihtiyaç duyulan verilerin hem analog hem de dijital veri tabanları üzerinden üretilebilmesi için hangi parametrelerin ne şekilde ölçülerek denklemin neresine yerleştirileceği hususlarına ışık tutan bir metodoloji inşa edilmiştir. Bu kapsamda karmaşık bir geometriye sahip olan topografik satıh, daha anlaşılır kılınması için eşdeğeri olacak basit bir üçgen pirizmaya modellenerek uzunluk, alan ve hacim açısından kolayca hesaplanabilecek geometriye indirgenmiştir. İllüstrasyonlar ve matematiksel formüller marifetiyle daha açık ve anlaşılır bir ifadeye kavuşturulan söz konusu metodolojik yaklaşım, somut saha verilerindeki karşılığı olan unsur ve parametrelerle bağdaştırılarak son şekline kavuşturulmuştur. Çalışmanın nihayetinde vadilerde alan ve bölüm kısıtlaması olmaksızın mevcut geometrideki uzunluk, alan ve hacme dair somut niceliklerin miktar ve oran bazlı tetkiki sağlandığı gibi, flüvyal sürecin işleyişi ve jeomorfolojik yapının gelişme seyri bakımından da vetire analizi yapmaya imkân sunacak bir metodolojik çerçeve ortaya konmuştur.

Anahtar Kelimeler: Morfometri, morfometrik indisler, vadi kazılımı.

1. Introduction

Erosional processes are among the most effective factors in shaping the earth and developing geo-morphological units. The external forces that especially work under the control of atmospheric conditions play an important role both in the maturation of the main geo-morphological units and in the emergence of elementary geographical formations by concretizing the relief character. The fact that almost all of the settlement areas on earth can be regarded as fluvial morphogenetic regions (Davies, 2014; United Nations, 2016) shows that fluvial processes are the most remarkable factors in terms of geomorphology. This fact shows once again that fluvial processes and the valleys, which are the most significant geo-morphological products of these processes, are the elements that need to be taken into consideration with precision in both theoretical and applied geomorphology studies.

As it is well known; the analytical aspect of geomorphology started to grow stronger in mid 20th century with the contribution of scientists such as R. E. Horton (1932; 1945), A. N. Strahler (1952; 1957), S. A. Schumm (1956), L. B. Leopold and J. P. Miller (1956), M. A. Melton (1957), J. T. Hack (1957) and M. E. Morisawa (1959). Especially in the last quarter of the century, objective and quantitative descriptions became more prominent and made analytical data indispensable components of geomorphology. In this context, many morphometric indices were identified and developed in order to ensure more accurate assessment and evaluation in geomorphology studies (Bull, 1961; 1962; Strahler, 1964; Denny, 1965; 1967; Eagleson, 1970; Doornkamp and Cuchlaine, 1971; Beamont, 1972; Hack,1973; Harvey, 1987). As a result, it was possible to obtain elevation, depth, length, area, volume and ratio information for the relief and accuracy and consistency of geomorphological analyses increased. On the other hand, as in all other geomorphological units, many indices were developed in valley analyses of valleys (Horton, 1945; Strahler, 1957; 1964; Langbein, 1964; Leopold et. al., 1964; Mueller, 1968) and means to undertake detailed investigations were increased. Today, various valley characteristics such as valley length, valley density, valley width-height ratio, valley slope asymmetry and valley sinuosity are the subject matter of morphometric analyses (Karataş and Ekinci, 2014; Topuz and Karabulut, 2016). Geo-morphological analyses with higher accuracy and higher quality are possible by means of identifying new indices and developing the existing ones. However, it is still not possible to claim that morphometric qualities of valleys are entirely presented. It is not completely possible to undertake the analytical assessment of some of the issues related to valley incision and development when learning about the development processes of valleys and paleo-geographic conditions and during the formation of the drainage network.

Process based inferences are as vital as analyzing valley geometry in comprehending fluvial process based geomorphological development. While it is possible to determine existing sediment loss in current geography with below decimeter precision with the help of LIDAR (Laser Imaging Detection and Ranging) technology which can model the topography with acoustic methods and laser pulses (Preti et. al., 2013; Stumpf et. al., 2013; Nadal-Romero et. al., 2015; Raouf et. al., 2017), contributions to understanding paleo-geographic conditions and erosional process are limited. Methods used in this regards are generalizing long-time observations to larger periods and analyzing the sedimentological data obtained from the field (Brocard et. al., 2003; Rixhon et. al., 2011; Fuchs et. al., 2014; Karataş et al., 2016; Ayaz et al., 2018), monitoring the change in the field via satellite images (Shruthi et. al., 2015; Telbisz and Keszler, 2018) or using observation records that spread to many years (Dotterweich et. al., 2012; Frankl et. al., 2012; Korkmaz et al., 2016). Or, possibility to determine sediment volume via direct erosion calculations is assessed (Perroy et. al., 2010; Young et. al., 2010; Moretto et. al., 2012; Kaiser et. al., 2014; McCabe, 2016; McNeils, 2016; Akziz et al., 2018). On the other hand, in addition to methods with several handicaps such as lengthy fieldwork, high cost and high amount of data analysis, the rapid and less cumbersome methods contribute to gaining and understanding about the process by obtaining a general opinion at the very beginning. However, these models used to identify incision rates require modifications since they are unable to provide sufficient explanations (Tomkin et. al., 2003). Hence, new indices and methods are needed to comprehend the previously discussed issues.

2. Purpose and method

The formulas used to calculate valley incisions today are based on empirical flow and sediment measurements. An accurately designed morphometric model will both make it easier to reach a more distinct outcome by analyzing the output rather than the process elements compared to de-facto conditions and will enable to have a more clear-cut idea prior to the field study. In addition, it will be possible to obtain data more rapidly on wide valleys and/or basins that are much more difficult to investigate via cadastral methods and a significant step will be taken in identifying the change and anomalies in the thalweg lines of valleys and watersheds.

To identify an index including these features, existing indices that focused on valley morphometry were examined first in order to identify an index with the specified features and shortages that prevent obtaining the desired results were determined. Later, parameters that affect valley formation in a wide spectrum from structural and lithological characteristics to land use were reviewed to identify an index including these features and it was determined that existence and effects of the variables were significant in evaluating the results of assessment. Then, the parameters related to analysis and measurement on simulated valley and basins were explained along with explanations of the procedures.

This method is preferred for making the narrative clear and understandable by moving away from the intricate structure of a true topographic surface to a much simpler schematic drawing. In an actual basin which will be encountered during the application phase, it would be appropriate to use scaling in line with the size of the research area, the topographic maps and digital terrain models that the researchers possess. Also, the geographic information system software that is used may provide opportunities for the application to be diversified and additions to be made. Moreover, mathematical expressions of the methodological application steps in addition to schematic description allowed arranging the operations that carried out in a certain form and ensured ease of applicability.

3. Findings

The fact that the geomorphological structure, in general, is shaped under the control of tectonic and climatic factors (Beaumont et. al., 1992; Whipple and Tucker, 1992) is consistent and forms an integrity with the river beds on earth incised by rivers, the flow dynamics that direct this incision and the ground characteristics (Sklar and Dietrich, 2004; Lague et. al., 2005; Lamb et. al., 2008; Chatanantavet and Parker, 2009). Therefore, many researchers naturally have focused on the correlation between the speed increase based on bed incline and sediment load in the framework of valley incision calculations (Ries, 1998; Oskin et. al., 2014). However, since sediment transportation does not follow a standard process due to variable bed dynamics and the nature of the bedrock, the studies in this regard do not obtain satisfactory results (Tomkin et. al., 2003; Demoulin, 2011). The extent of increase in margin of error in studies based on parameter-result analysis is better observed with the addition of the isostatic ascent that follows the valley incision (Montgomery, 1994) and the hydraulic power under the influence of antecedents (Cowie et. al., 2006; Whittaker et. al., 2007). In this case, it would be much easier to protect against the misleading influence of the change observed in the dynamic elements when the existing valley geometry is assessed in correlation with the valleys that are the parts of the same tectonic and fluvial system (Ekinci and Karataş, 2013; Karataş, 2017). Interpreting the valleys together, especially the neighboring ones, will ensure that well directed decisions can be taken in regards to changes in watersheds and in inter-fluvial areas. Hence, it is important to take changes in watershed and headward erosion process into consideration as well as thalweg line. In this regard, it is seen that data related to the distance between thalweg and watershed and elevation difference are highly significant in a valley incision model.

Thalweg line corresponds to the curve accepted to represent the deepest parts of the riverbed (Erinç, 2000; Hoşgören, 2004; 2011). In this sense, it can be regarded as the equivalent of rivers' incision activity. Watersheds follow the areas that are the highest in elevation between two basins in the route where basins, which point to the catchment areas of different rivers, are separated. Among these areas, there is the interfluve zone where the flow is limited to sheetflow and there is no deep incisions due to indistinctive surface slope with variable width based on flatness or sharpness of the relative ridges. Hence, lateral positioning and substitution of watershed is shaped under the control of slope-based headwater erosion triggered by the increase in the incline of slope as a result of the decrease in thalweg elevation. This expresses an erosion process, which is directly affected by the respective positions of mean thalweg and mean watershed. Identifying thalweg and watershed profiles will help make sense of this relationship. This operation can be done by using digital terrain models as well as identifying points in topographic maps at desired frequencies to transfer them to the profile (Figure 1).

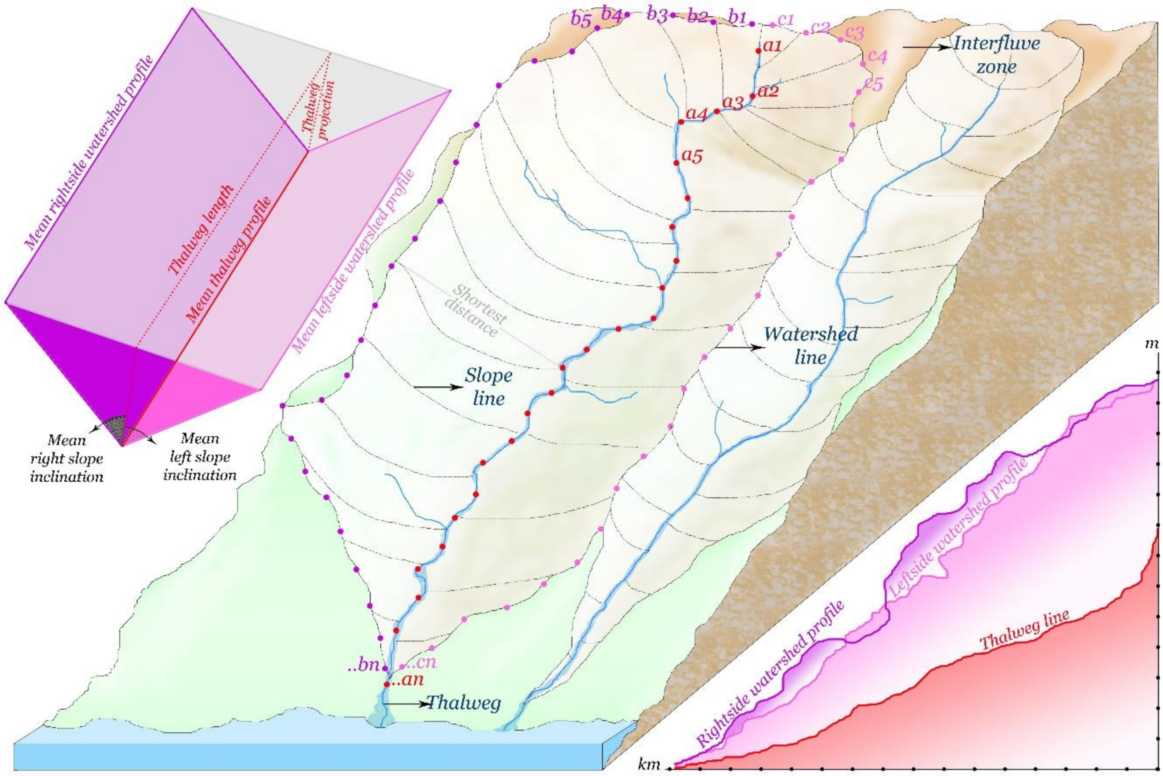

Figure 1. Valley incision rate parameters, simulated profile parsing and model triangular prism.

Following the assignment of the mean thalweg and watershed lines, it is necessary to determine the slope between these two lines. Demoulin (2011) made a calculation by taking the area between thalweg and hypsometric slope profiles as the basis and roughly found an average integral value. However, this method, which aims to estimate an average weight load for the basin, does not intend to provide concrete results on directly valley or segment based calculations and valley incision. As a matter of fact, while which parts of the thalweg will be compared with which parts of the watershed when averaging the whole line will not create problems in a wide scale during incline measurements, it will be problematic when the process is considered in small scales. In order to solve the aforementioned problem, the equalization should take the part of the watershed that is closest to the thalweg as the counterpart; and therefore with the highest incline values (Figure 1). The same way can be used in separating watershed that belongs to the right and left slope of the basin by creating the closest line from the start of the main river bed to the watershed. This way, the issue of which point of the thalweg controls which part of the watershed will become clearer to a large extent (Figure 1). In the end, the desired type of incline measurement methods can be selected for the identified lines based on cost to undertake the process (Karataş and Ekinci, 2014). Sub basins should also be evaluated among themselves when practicing this method in basins with developed branches. It will be possible to generate more consistent data about the valley geometry after identifying the relation of interaction between thalweg and watershed.

A triangular prism will be defined in which the thalweg based on width, height and depths determined according to the mean of all reference points in a valley $(\sum a / na)$ is the apex point; the mean distance between watershed lines is the leg; difference between watershed lines and thalweg is height; and air distance main river bed length is the depth. This triangular prism will allow measurement of the volume and in general will identify the amount t of the material that is transported (Şekil 1).

Measurements that will be taken in this context can be diversified by comparing the triangular prisms shaped by respective slopes that will be separated from the projection in the thalweg floor (the plane that combines watersheds) and by interpreting the different segments of the basin independently. (Figure 1). This method, which will significantly contribute to the identification of valley asymmetry (Karataş, 2015) can be mathematically expressed based on the elements provided in Figure 1;

$$\Rightarrow \quad \sim e_a = \frac{\sum a}{\mathrm{na}} \quad , \quad \sim e_b = \frac{\sum b}{\mathrm{nb}} \quad \text{and} \quad \sim e_c = \frac{\sum c}{\mathrm{nc}}$$

$$\Rightarrow \quad \sim e_{watershed} = \frac{\sim b + \sim c}{\mathrm{nb+nc}} \quad , \quad \sim k_{right\ slope} = \sim b - \sim a \quad \text{and} \quad \sim k_{leftt\ slope} = \sim c - \sim a$$

$$\Rightarrow \quad \sim k = \sim e_{watershed} - \sim a \quad \text{or} \quad \bar{\mathrm{e}}_i = \lim_{n\to\infty} \frac{\sum_{i=1}^{n} e_i}{n}$$

$$\Rightarrow \quad \sim k_r = \frac{\sim v}{\sim k}$$

e: elevation, n: number of points, a: thalweg point, b: right watershed point, c: left watershed point, k: amount of incision, k_r: incision rate, v: valley density.

Hence, it will be possible to obtain mean valley depth by proportioning the mean elevation of the whole watershed to the mean thalweg elevation; to obtain mean slope incline by proportioning mean thalweg-watershed distance to mean valley depth and to obtain incision coefficient by proportioning mean slope incline to mean valley depth. On the other hand, proportioning of the mean valley density (the proportion of total valley length to the area of the basin) to mean valley depth (explained above) will provide area based mean incision ratio. Based on the quantity of this ratio, it will be possible to compare incision ratios, to relatively evaluate two neighboring valleys and to observe which valley is more efficient in terms of course of development. By reversing the process at this point, process-based conclusions can be made to provide a wide range of possibilities for understanding and making sense of the paleo-geographic conditions, which include the primary appearance of the surface and the positions of watershed lines during the establishment of the drainage network in the field.

4. Result and discussion

The method addressed in the framework of analyzing valley morphometry aims to define the incision process, for which the existing methodology is insufficient, in terms of amount and ratio. The method presents a methodology, which is both applicable and has the ability to produce consistent and well-directed results due to lack of limitations in using digital or analog data and the ability to obtain data in real scale and to provide opinions as to the course of the erosional process.

The topographic area with a complex geometry is modeled with a simple triangular prism to simplify measurement in terms of length, area and volume. In addition, the dynamic of watershed lines and its relationship to thalweg are open for assessment to allow process analysis. Calculations undertaken directly on the data obtained from the field allow examination of any parts (in desired dimensions) or the whole area without any problems. Also, an clarification is provided about which parts of the watershed line are related to which parts of thalweg and probable errors are prevented in regards to the exchange between the dynamics on the valley floor and watershed line and inter-fluvial zone. Another point that needs to be addressed because of the study is the ability of the method to generate data that will constitute a basis for interpretations related to the paleo-geography and the primary position of the topographic area as a result of explaining the changes to the location of the watershed. When regarded as a whole, this new method will provide opportunities to conduct erosion analyses that will shed light on the fluvial process in the geological past.

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