Analysis of Surficial Landform Properties: The Regionalization of Indiana into Units of Morphometric Similarity[1]

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Abstract

This study offers a more rigorous alternative to the traditional reliance on qualitative data and the subjective approach in the regionalization of geomorphic units. Using analytical data and techniques, regional geomorphic units are developed for Indiana. The results of a principal componets analysis and a cluster analysis indicate that Indiana can be regionalized using three primary morphometric components: a vertical componet, an areal magnitude factor and a stream network development factor. In addition, a lacustrine factor is found to be of secondary importance within Indiana.

The areal patterns of these morphomeric components indicate that the previous physiographic or regional geomorphic units developed for Indiana fail in delimiting the State into regions of form similarity. The previous investigations, by concentrating on geologic structure and/or process instead of the actual topographic expression, most likely account for this failure.

Introduction

In previous physiographic or regional geomorphic studies, the criteria utilized in delimiting "natural" regions have been highly subjective and somewhat inconsistent. Traditionally, regional geomorphic studies have relied heavily on qualitative descriptions of bedrock structure, general landform characteristics, geologic history and/or climatic characteristics as the basis for forming different regions. Likewise, criteria which are considered crucial for the location of regional boundaries vary from area to area in the regional studies of Fenneman (1), Thornbury (4) and Hunt (3). Hammond has reported on the need to use the identical criteria throughout a single study and has attempted to minimize subjective data by substituting measurable landform characteristics as the standard for delimiting landform regions (2). In his regionalization of the United States, Hammond utilized four variables: slope inclination, vertical dimension, general profile character and some aspects of surface material. While Hammond's work represented a start, it did not satisfactorily eliminate the problem of subjective data or completely meet the needs of geomorphology. First, only two of the variables used could be measured—slope inclination and vertical dimension; the two remaining variables are subjective in nature. Second, the purpose of the study was to develop regions that would indicate areas of similar land-use. From a geomorphic point of view, this is not a particularly useful purpose. Clearly, the need still exists to use analytical criteria in the construction of regions that meet the needs of geomorphology.

A landform assemblage results from the interaction of three basic factors: process, time and geologic structure. Only the result of these

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TABLE 1. *Surficial Geomorphic Variables*

Variable Name	Variable Description
Total Channel Length (TOTALL)	The curvilinear map distance measured along all visible stream channels within the basin's perimeter.
Average Channel Length (AVERL)	The ratio of the total channel length to the number of stream segments.
Basin Area (AREA)	The planimetric area of the basin.
Drainage Density (DRAIND)	The ratio of total stream length to the basin area.
Absolute Relief (RELIEF)	The vertical interval between the highest elevation and lowest elevation within the basin. It is measured in feet.
Mean Slope (MSLOPE)	The ratio of absolute relief to the square root of area.
Gradient of Longest Stream (STRG)	The ratio of the vertical drop of the longest stream to its horizontal length.
Percent of Water (WATER)	The proportion of the area of the sampled quadrangle overlaid with standing water such as lakes, ponds.
Longest Valley-side Slope (SLOPEL)	The linear distance from the farthest point on the basin divide to the channel of the longest stream.
Steepest Valley-side Slope (SLOPEG)	The ratio of the length of the steepest slope to its vertical drop.
Ruggedness Ratio (RUGGED)	The ratio of the absolute relief to the drainage density.
Dissection Ratio (DISS R)	The ratio of total channel length to the basin perimeter.
Circularity Index (CIRCUL)	The ratio of the basin's perimeter to the perimeter of a circle with a diameter equal to the longest axis of the basin's outline.

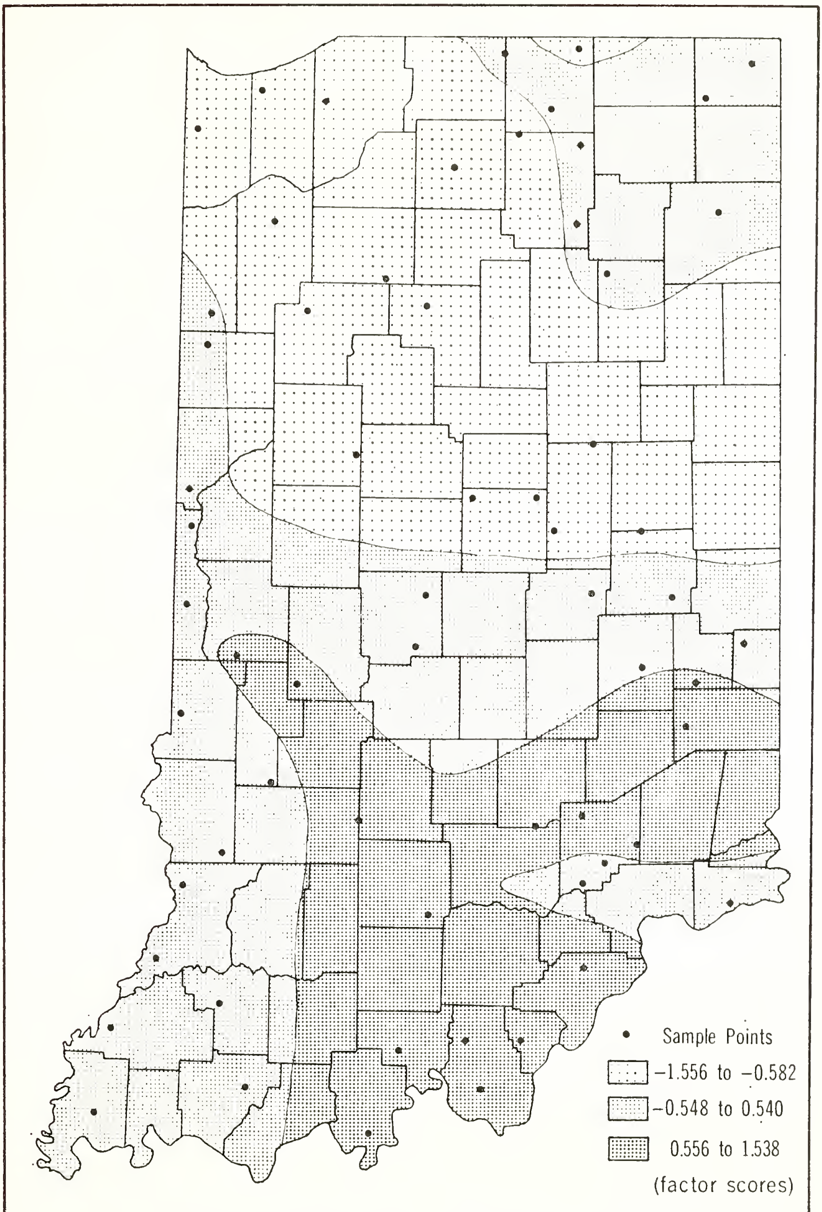

Figure 1: Vertical Component

three factors, namely topographic expression, should be the prime concern when delimiting geomorphic regions. Therefore, the criteria used in the formation of geomorphic regions should be limited to surficial form elements. If one of the primary factors strongly affects a given area, the morphometric properties of the surface will reflect the causal influence.

This study is the initial report of an attempt to delimit geomorphic regions solely using quantitatively measurable data. By limiting the criteria to variables that can be measured, analytical techniques can be used to develop regions that will minimize subjectivity and permit reliable comparisons between features found in different areas. These regions, where the form elements are evaluated numerically, in turn may be used to evaluate the controls of the environment in individual process oriented geomorphic studies. Specifically, this study regionalizes the State of Indiana into areas of morphometric similarity.

Variables

Thirteen variables (Table 1), all of which have been utilized in previous geomorphic studies, form the basis for the regionalization of Indiana into similar morphometric areas. This set of variables measures the major surficial properties of landforms. The data for these variables are obtained from U.S.G.S. topographic maps.

Within a general systems framework, the stream basin can be considered the basic or prevalent geomorphic system; furthermore, within the United States, all land areas are affected by streams and their related processes. For these reasons, stream basins are chosen as the basic unit of measurement in this study. With the exception of one variable (percent of water), all of the variables in this study are calculated from 4th order stream basins.

A random sample of sixty quadrangles was drawn from all the U.S.G.S. topographic maps (scale 1:24,000) that cover Indiana. The sample size insured ample areal coverage of the whole State (Figure 1). On each quadrangle drawn from the sample, the center of the map served as the base from which the nearest fourth order basin was located. As an indication of basin size, a fourth order basin might extend over six quadrangles. For the variable, percentage of water, only the original quadrangle drawn in the sample was utilized.

Analysis

The multiplicity of variables used in this study requires simplification in order to remove redundancy among the variables and to discover the contrasting morphometric elements. This can be achieved by utilizing the technique of principal components analysis. The purpose of using this technique is to investigate how much of the total variance within the sixty stream basins, exhibited in the thirteen variables, can be accounted for by a smaller number of new "principal components." These

TABLE 2. *Principal Components Analysis of the Surficial Geomorphic Variables*

	F_1	F_2	F_3	F_4	F_5
Factor Interpretation	Vertical Expression	Areal Magnitude	Stream Network Development	Basin Shape	Lacustrine
Sum of squares over variables attributable to factor	3.039	3.258	2.134	1.134	1.241
Varimax Solution					
TOTALL (log)	—0.187	0.367	0.879	0.136	0.042
AVARL (log)	0.051	0.815	—0.024	—0.078	—0.161
AREA (log)	—0.329	0.786	0.414	0.099	0.181
DRAIND (log)	0.271	0.771	0.371	0.024	—0.233
RELIEF (log)	0.952	—0.055	0.024	0.101	0.118
MSLOPE (log)	0.846	—0.436	—0.190	0.022	—0.002
STRG (log)	0.725	0.346	0.093	0.212	0.164
WATER	0.051	—0.034	—0.071	—0.020	0.935
SLOPEL (log)	—0.392	0.744	0.151	0.114	—0.041
SLOPEG (log	—0.362	0.369	0.233	—0.179	0.253
RUGGED	0.616	0.449	—0.270	0.257	0.357
DISS R	—0.064	—0.205	0.923	—0.111	—0.134
CIRCUL (log)	0.032	—0.012	0.004	0.959	0.022

principal components will form the basis for regionalizing Indiana into morphometric areas.

Transformation of ten of the variables into their logarithmic equivalent was required to satisfy the assumptions of normality and linearity for the data (Table 2). After the transformations, the correlation matrix was subjected to a principal axis solution in which five of the eigenvectors (those having values greater than 1.00) were rotated to a normal varimax position. These five orthogonal factors account for approximately eighty-three percent of the total variance in the original data matrix (Table 3). From examination of the varimax solution, these five factors designated the vertical or "steepness" factor, the horizontal or areal magnitude factor, level of stream network development, basin shape and the lacustrine factor respectively.

With the isolation of the five principal components, the next step in the regionalization is to aggregate the sixty individual factor scores into groups of similarity. The degree of similarity among the factor scores is determined by the distance between each observation in factor space. Close points are considered similar to each other; distant points or aggregates of points distant from each other are considered dissimilar.

The Vertical Component. The vertical component, which accounts for 36.3 percent of the total variance (Table 3), is identified primarily with relief, the slope of the land, and stream gradient (Table 2). Since this component accounts for the largest proportion of the total variance, it appears to be the most important surficial element of variation within

TABLE 3. *Percent of Communality Over the Factors and Eigenvalues*

Factor Number	Eigenvalue	Percent of Communality Over: All 13 Factors		5 Rotated Factors	
1	4.720	36.3	36.3	43.7	43.7
2	2.408	18.5	54.8	22.3	66.0
3	1.601	12.3	67.1	14.8	80.8
4	1.056	8.1	75.3	9.8	90.5
5	1.021	7.9	83.1	9.5	100.0
6	0.721	5.5	88.7		
7	0.526	4.0	92.7		
8	0.359	2.8	95.5		
9	0.303	2.3	97.8		
10	0.143	1.1	98.9		
11	0.112	0.9	99.8		
12	0.030	0.2	100.0		
13	0.001	0.0	100.0		

group one	—1.556 to —0.582
group two	—0.548 to 0.540
group three	0.556 to 1.538

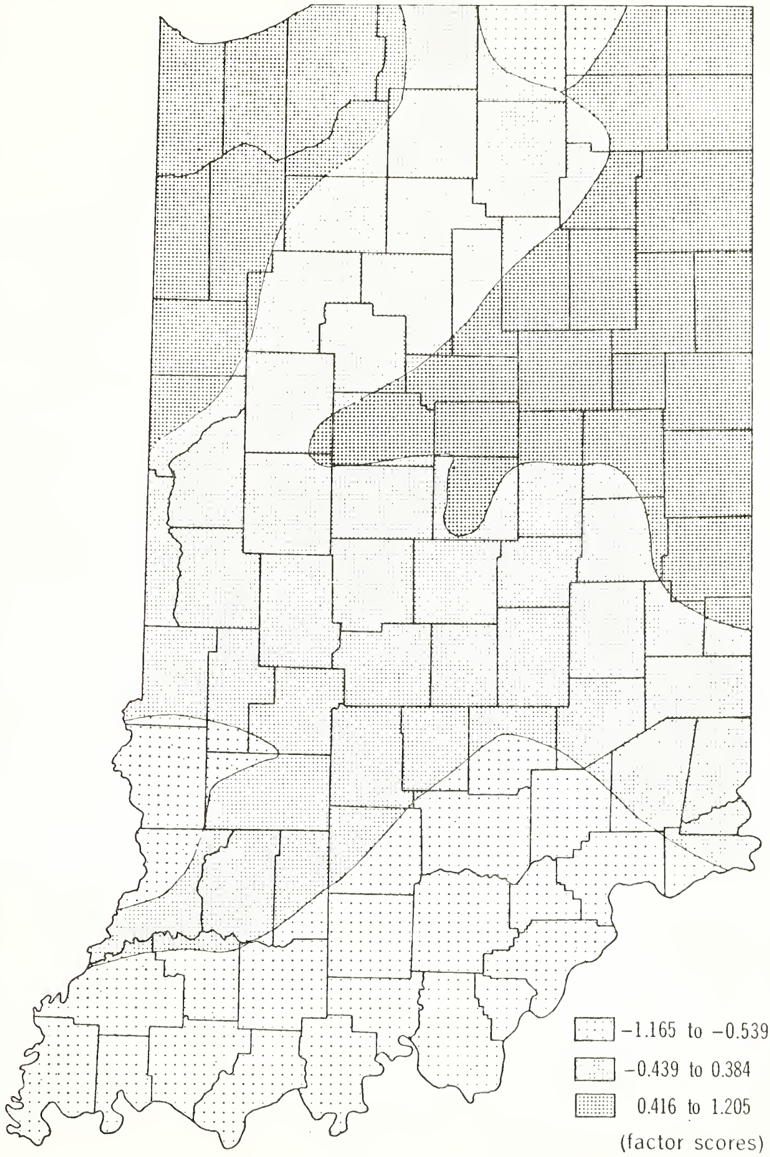

Figure 2: Areal Magnitude

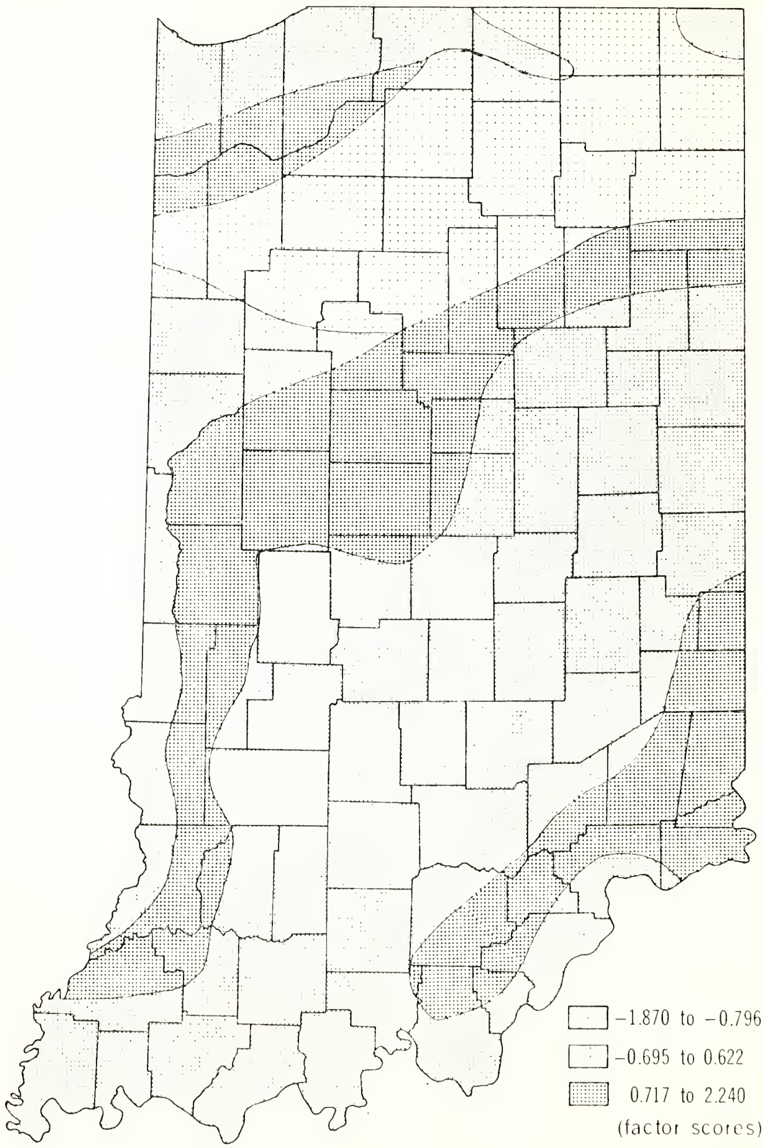

Figure 3: Stream Network Development

Indiana. Inspection of the plot of the factor scores for the first component indicated that the vertical factor aggregates into three basic groups:

Figure 1 illustrates the areal expression of the vertical component for the three factor groupings.

The general pattern of vertical land expression increases toward the south. The three regions, as delimited on the map, show no simple correlation to the previous more genetic oriented regions. While it is true that the area of maximum vertical expression is primarily located in areas not glaciated during the Wisconsin Period, it is not limited to the non-glaciated portion of the State. Likewise, physiographic regions such as the Crawford upland and Mitchell plain appear not to be valid divisions in regard to morphometric elements. This is substantiated further by the second and third components.

Areal Magnitude Factor. The highest factor loadings on the second component are essentially measures of stream basin extensiveness. Similar to the first component, the plot of the factor scores for the magnitude factor indicate three grouping:

group one	—1.165 to —0.439
group two	—0.539 to 0.384
group three	0.416 to 1.205

The areal expression of these three factor groupings are delimited on Figure 2. As with the first component, no strong correlations between the previous physiographic units of glaciated and non-glaciated areas and various glacial phenomena are reflected by this component.

Stream Network Development Factor. This component represents the last major dimension contributing to morphometric variation within the State (Table 3). The remaining two components account for only 16 percent of the total variability. The plot of the factor scores for this component indicates the following groupings:

group one	—1.870 to —0.796
group two	—0.695 to 0.622
group three	0.717 to 2.240

The areal expression of these groupings is given on Figure 3. The areas of maximum development follow the major stream systems within the State regardless of the underlying materials. This would seem to indicate that if physiographic units use genetic criteria as the basis for division, more emphasis should be placed on current-day processes than past phenomena.

The Shape Factor. It is suggested that the shape component, which is heavily weighted only by one variable (Table 2), be disregarded as a criterion for regionalization. First, inspection of the factor score plot showed no apparent groupings. The values appeared as a continuum. Second, inspection of the areal expression of the absolute values of the factor scores indicated a random pattern throughout the State. The behavior of this component could be interpreted as indicating that stream

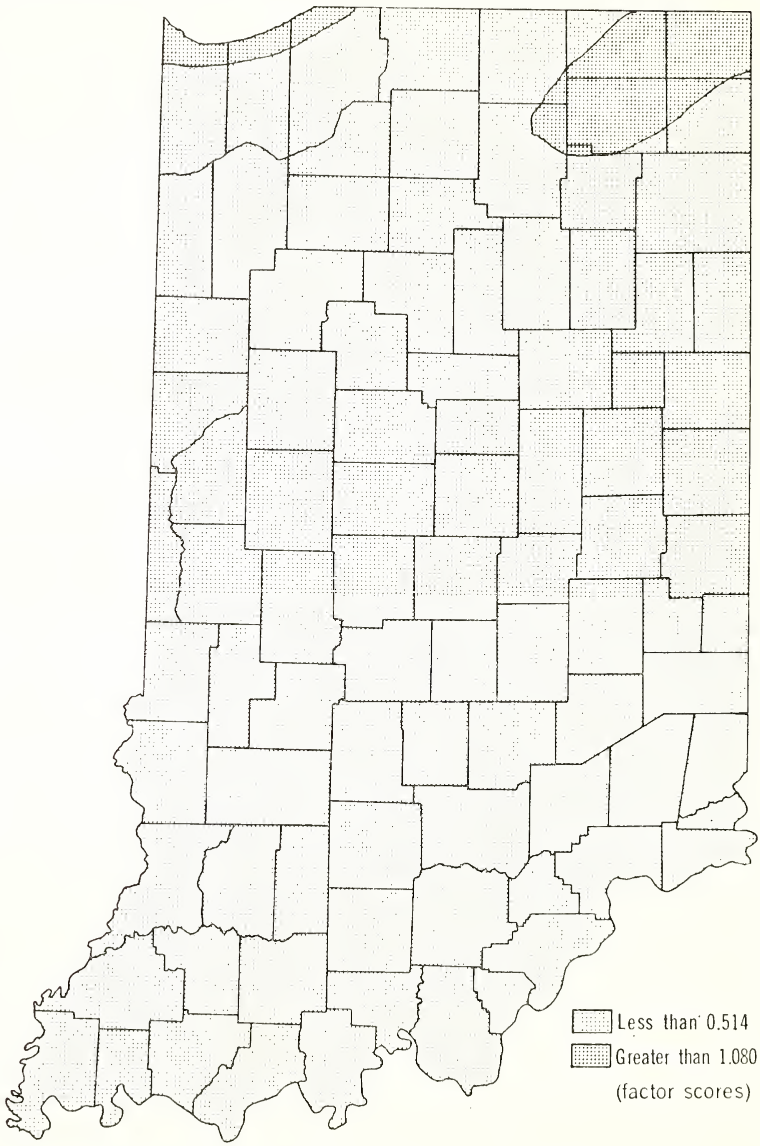

Figure 4: Lacustrine Factor

basin shape is purely a result of random processes. However, it probably reflects the difficulty of developing any quantitative measure of shape without the use of vectors.

The Lacustrine Factor. With the fifth component accounting for only 7.9 percent of the total variability, it is considered to be of secondary importance when delimiting regions within Indiana. The plot of the factor scores indicated a dichotomous arrangement:

group one	less than 0.514
group two	greater than 1.080

Figure 4 shows that the land areas in the immediate vicinity of Lake Michigan and the northeastern portion of Indiana are different from the remaining portion with regard to this component.

Conclusions

This study offers a more rigorous alternative to the traditional reliance on qualitative data and the subjective approach in the regionalization of geomorphic units. Using analytical data and techniques, regional geomorphic units are developed for Indiana. Since the individual form elements within the regions can be evaluated numerically, reliable comparisons between different areas are possible in contrast to the subjective regional comparisons that must result when using the traditional approach.

This study establishes that three basic factors determine the variance of morphometric properties throughout Indiana; namely, the vertical expression of the land, the horizontal expression of the land and the development of stream networks. While this study successfully isolates areas having similar morphometric properties, no attempt is made to combine the three primary components into a composite regionalization. The need still exists to investigate other areas in order to develop a better understanding of the exact values of the factor scores and to determine if the limits of the factor scores used in this study can be applied universally before a composite classification is developed.

From the inspection of the areal pattern of the three components, it appears that previous physiographic studies do not delimit Indiana into regions of form similarity. Most likely, this results from their over emphasis on geologic structure and geologic history as the basic criteria for regionalization. By concentrating on the actual topographic expression and using analytical techniques offered in this study, the undue influence of a single contributing factor, such as geologic structure, is prevented. If a purpose of regional geomorphic studies is to complement process-oriented geomorphic studies, regionalization using analytical procedures will be more fruitful than the traditional approach.

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