The Quantification of Landform Characteristics—a Roughness Index

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In much of the geographic literature the surface configuration of an area is described in broad, qualitative terms like "smooth," "gently-rolling," or "rough." It is very difficult, if not impossible, to use these qualitative terms in quantitative research.

Attempts to quantify landform characteristics are not new in geography. Even von Humboldt, almost always considered as one of the fathers of modern geography, recognized the need for some system that would enable different areas of the world to be compared. The various measures and the type of characteristics measured have become very numerous. Investigators have been concerned, among other things, with average elevation, average slope, volume of mountains, density of rivers, and relative relief. A description and critical analysis of many of these measures, especially the European contributions, has been presented by Neunschwander (5). Most of these measures are meant to apply to areas of a few square miles of the earth's surface.

Many geographic problems, on the other hand, require working with larger area units. In the United States these larger units are usually counties, primarily because of the great quantity of census data that is available on a county basis. Some investigations are concerned with relationships between the social and economic data presented in the census and some factor in the physical environment. For studies of this type a quantified measure of suface configuration is sometimes desirable.

To have maximum utility, such a measure should be easy to compute, should be capable of duplication by other investigators, and should present a picture that is in general agreement with other observations concerning the surface configuration of an area. At the same time, it should distinguish between some of the minor variations in the surface configuration.

Probably the measure that is the easiest to compute is the relative relief of a county. This is merely the difference in elevation between the highest and lowest points in the county. This measure fulfills our criterion of ease of computation, and certainly we would be insured of the duplication of results by two or more investigators. The relative relief is also significant in that it will be greater in mountainous counties than in level counties, but in spite of these advantages it is sort of a crude measure.

Other investigators have devised more refined measures based on the average slope of an area. These start with the work of Finsterwalder in 1890, proceed through that of J. L. Rich in 1916 and culminate with the methods of Wentworth, Horton and Hamilton in the 1930's. (2, 4, 6).

All three of the latter utilize a grid system superimposed on a contour map and the counting of the intersections of the contours and the grid system. Wentworth and Horton designed their systems for small areas, but Hamilton used his "Topographic Index" on a county basis. His base maps had a contour interval of 500 feet, however, and this is a rather large interval for many sections of the United States. Also, none of these investigators were very definite on the size of the grid system to be used.

The Roughness Index, developed in this paper, is an extension of the work of these previous investigations. It is a measure designed to be used on a county basis in studies utilizing census data on other variables. It is based on the following assumptions: (1) Maps of a scale of 1:250,000 and contour interval of 100 feet are the most convenient to use for county studies. Maps of a scale larger than this are cumbersome; maps of a scale smaller obscure some important details of the landscape. The major difficulty is that the entire United States is not covered at this scale as yet, but for that matter we do not have complete coverage at any scale of larger than 1:1,000,000. (2) The roughness of a county can be defined in terms of the density of contours. This means that County A in Figure 1 is, by definition, rougher than County B; and County B is rougher than County C. The difficulty here is illustrated in the lower portion of Figure 1; that is, County C might actually be rougher than County B, but because of the contour interval, this rough-

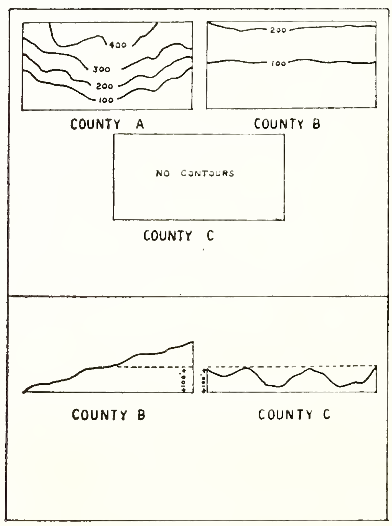

Fig.1

ness is not shown on the base map. It is extremely unlikely that such a situation would be encountered in the real world, however.

The density of contour lines was found in the following manner. A grid of north-south and east-west lines was superimposed on a county. The intersections of the grid lines with the contour lines were counted. (A contour line tangent to a grid line was counted as one crossing). The grid was then rotated 45 degrees to a northwest-southeast, northeast-southwest orientation, and the intersections were counted again. The total number of cossings was then divided by 4. This gave the average number of crossings in any one direction. This number was then divided by the land area of the county in square miles, and the quotient was then multiplied by 10 to move the decimal place. The resulting number is called the "Roughness Index." The formula may be written as:

$$RI = \frac{(N \times M)/4}{A} \times 10$$

where N is the total number of intersections (in all four directions)

M is the distance in miles between the grid lines.

A is the land area of the county in square miles.

It has been pointed out that measures of landform characteristics should be capable of being duplicated by other investigators. One method of insuring duplication of the roughness index would be to compute it a great number of times for each county and then take the arithmetic mean of these computations as the "true" value. On the other hand, if all of the indices were grouped closely around the mean value, such a procedure would not be necessary.

Another question arises at this point. That is, what size grid should be used? The smaller the grid, the smaller should be the variations around the mean index number. The larger the grid, however, the less work entailed in obtaining the index number for a county.

To answer these questions some simple statistical techniques can be used. Even though the grid is placed over a county in a specific direction, there is still an infinite number of possible placings. The first grid line may be placed exactly on the border of a county, or 0.1 mile from the border, or 0.15 mile, etc. The statistical universe for each county is, therefore, infinite. The problem is to compare the mean and standard deviation of the roughness index of this infinite universe with the mean and standard deviation computed from a sample from the universe.

Three counties in Ohio were chosen for the analysis. The particular counties varied from relatively smooth (Fayette, RI = 4.1) to relatively rough (Vinton, RI = 34.1). Two, four, six, eight, and ten mile grids were used. The roughness index was computed five times for each grid size in each county. Because of this, the so-called "small sample theory" was used in this analysis.

The results of these computations are shown in Table 1. As the grid size increases, the standard deviation of the universe also increases. The standard deviation of the universe also increases as the roughness increases. However, if the grid size is kept small, the first roughness index computed is close to the mean of several computations; and the standard deviation of the universe is low. Therefore, the process of taking the mean of several roughness indices is unnecessary because the first one will be near the mean anyway. Also, a low standard deviation in the universe indicates that another investigation will arrive at a roughness index of comparable magnitude. As an example, with a two-mile grid, the roughness indices of Vinton County would have a standard deviation of 0.8 roughness index points. Now, in a normal distribution, 95 per cent of all cases will fall within 2 standard deviations above or

TABLE 1

Comparison of the Standard Deviation of the Roughness Index of the Infinite Universe with the Standard Deviation of the Roughness Index of a sample of 5.

County	Size of Grid	1st RI	Mean RI of Sample	σ of Sample	Universe σ of (σ adj.)	2xσ adj
Fayette	2 mi.	4.1	4.0	0.1	0.2	0.4
Fairfield	2 mi.	13.9	13.6	0.2	0.4	0.8
Vinton	2 mi.	34.1	33.9	0.4	0.8	1.6
Fayette	4 mi.	3.8	4.0	0.3	0.6	1.2
Fairfield	4 mi.	14.3	13.9	0.3	0.6	1.2
Vinton	4 mi.	34.1	33.8	0.6	1.2	2.4
Fayette	6 mi.	4.5	4.4	0.3	0.6	1.2
Fairfield	6 mi.	13.7	13.2	0.4	0.8	1.6
Vinton	6 mi.	33.6	34.6	1.0	2.0	4.0
Fayette	8 mi.	4.4	4.6	0.6	1.2	2.4
Fairfield	8 mi.	14.0	13.4	1.3	2.6	5.2
Vinton	8 mi.	34.5	35.4	1.1	2.2	4.4
Fayette	10 mi.	5.4	4.2	0.9	1.8	3.6
Fairfield	10 mi.	13.8	14.7	1.2	2.4	4.8
Vinton	10 mi.	38.6	37.8	2.3	4.5	9.0

below the mean; for Vinton County 95 per cent of the roughness indices will fall within 1.6 index points of the mean. As the grid size is increased, this range increases. For this reason it was decided to use a grid size of two miles.

The roughness index of the northeastern United States is shown in Figure 2. The White Mountains, Adirondacks and parts of the Appa-

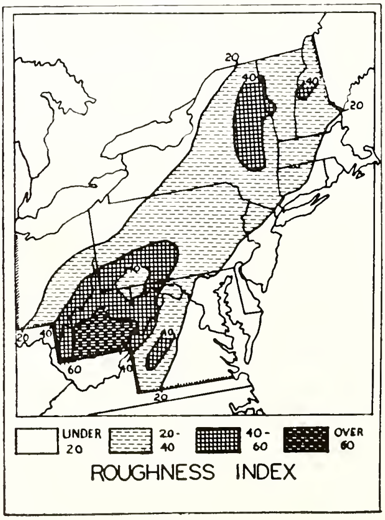

Fig.2

lachians have a roughness over 40. The roughest area is in West Virginia in the Appalachian Plateau and adjacent Appalachian Mountains. Figure 3 is a map of the relative relief. In general pattern the maps are similar (the coefficient of correlation (r) between these two variables is +.62), but they differ in detail. The area of maximum relative relief does not

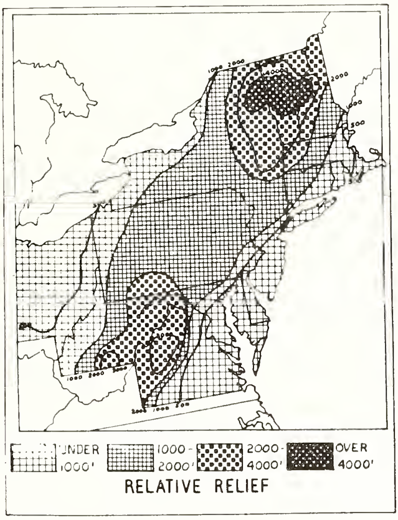

Fig.3

coincide with the area of maximum roughness. This does not necessarily indicate a weakness in the roughness index; these are two different landform characteristics. As an example, Grafton, New Hampshire (RI 49.1, RR 4900 feet) can be compared with Tyler, West Virginia (RI 50.3, RR 700 feet). The roughness indices of these two counties are very similar, but the relative relief in Grafton County indicates the presence of mountains. Grafton is in the White Mountain region; Tyler is in the maturely dissected Appalachian Plateau.

Figure 4 shows Hammond's classification of landforms for this area (3). Again, in general outline, the map is similar to the map of roughness. Similarity would also be found between Fenneman's physiographic regions and the roughness (1).

The roughness index, therefore, meets the requirements set forth earlier. It is easy to compute, it is capable of duplication, it presents a picture that is in general agreement with what others think of the area, and it brings out details that the other measures do not.

When the roughness index is compared with some of the economic and social variables in the northeast, some interesting results are obtained. As might be expected, we find that as the roughness increases, the percentage of farmland in pasture increases (r = +.73), the percentage of cropland decreases (r = —.51), the average size of farm increases (r = +.41), and the amount spent on petroleum products (a measure of intensity of land use) decreases (r = —.57). On the other hand, some expected relationships do not materialize. There is only a

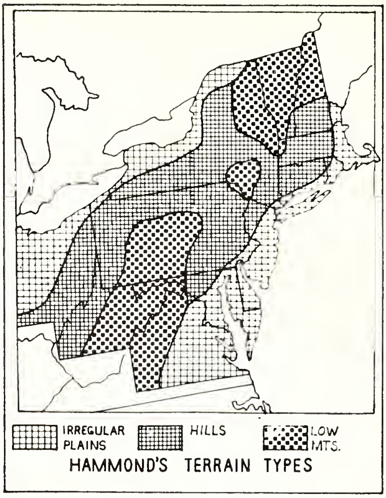

Fig.4

very slight correlation between the density of the rural farm population and the roughness (r = —.20), but the rural level of living decreases as the roughness increases (r = —.48).

Other relationships could be pointed out, but the ones presented are sufficient to show that the roughness index is capable of being used with the economic and social variables available on a county basis in the United States Census.

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