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APPLICATIONS

DEVELOPMENT OF COLOUR MAP SHADING WITH DIGITAL ELEVATION MODEL

by

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ABSTRACT

Most of the existing maps have insufficient information for the users to understand the terrain characteristics. Obtaining understandable maps is an important task in contemporary computer-assisted cartography. Relief shading is a technique for portraying hypsography on a three dimensional map using graded shadow effects.

In our study, a colour map shading algorithm using a digital elevation model has been proposed and implemented. We consider physical, physiological and psychological factors and combine them to develop an algorithm for colourful relief shading. The colours were assigned together with contour lines for better understanding for users. In addition to hill shading, an enhancement technique accompanied by colour pattern recognition has been also developed to beautify other cartographic features such as roads, built up areas, rivers, forest areas and text.

1.0 Introduction

Nowadays, computers can increase the value of a map as a decision-making tool. Maps provide important information for significant decisions at many levels. The computer is fast and precise, and has a useful role to play in the production of maps. The marriage of mapping and the computer does raise a legitimate suspicion about the validity of maps produced at low cost and in great numbers by well-meaning computer users with little knowledge of the fundamental principles of cartography.

Since numerous instruments and techniques have been developed for relief shading, there still remains a problem to balance cost-benefit and esthetical qualities. As digital image processing systems have been utilized for the extraction of terrain height from stereoscopic images to build digital elevation models, commercially available hardware and software are beyond the increasing need for generation of relief shading with colours and have not yet reached a stage of maturity. Hence this leads us to think that the previous relief shading technique is to be improved for high quality of colour mapping.

2.0 Previous works

The highest quality hill shading may be manual, but such quality can only be produced by a skillful artist. Since hill shading has been considered very desirable for centuries, it is not surprising that there have been numerous attempts to make the process more mechanical and thus minimize the need for the talents of the artist.

A century ago, scientists worked out the equations for determining the intensity of light reaching an observer from a point on a three-dimensional surface under illumination by parallel rays. Their work was largely of theoretical interest, because of the immense amount of calculation needed to make use of the equations, as well as the practical problem of producing any graphic result. Now, however, the computer makes quick and easy computation possible and, as a consequence, hill shading now can be produced by automated methods.

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Over the last decades, a number of hill shading techniques have been developed. These techniques were developed within various disciplines so that each technique has its own theory, methods and limitations. Unfortunately, there is no unifying theory behind all these techniques. Some of them are simple ad hoc techniques with a weak theoretical background. The differences in all these techniques are due to input data, experimental configuration, way of processing, theoretical assumption and way of solving problems. But all hill shading techniques are used to assign only monotone but not colours.

2.1 The shading effects equation

The most common technique of shading effect $\mathbf{I_s}$ is based on the assumption that the terrain surface is given as Lambertian surface, as shown in Figure 1.

$$I_s = \cos \theta$$

where θ : angle between light source (illumination) S and normal vector **N** of the surface.

Hill shading can be generated according to the sun's and the observer's positions as follows:

$$\cos \theta = n_x s_x + n_y s_y + n_z s_z$$

where: cos θ — the shading value.

n_x, n_y, n_z — X, Y, Z components of the normal vector respectively.

s_x, s_y, s_z — X, Y, Z components of the direction of a ray of the sun respectively.

and the normal vector *N* of the terrain surface can be expressed by directional cosines:

$$N\ (n_x,\ n_y,\ n_z)$$

If the terrain surface $Z_{x,y}$ is given, the normal vector is given as follows:

$$n_x = \frac{a}{S},\ n_y = \frac{b}{S} \text{ and } n_z = -\frac{1}{S}$$

where S, a = $\delta Z/\delta X$ and b = $\delta Z/\delta Y$ are given approximately as follows:

$$S = \sqrt{a^2 + b^2 + 1},$$

$$a = \frac{Z_i + 1,_j - Z_i - 1,_j}{2d},$$

$$\text{and } b = \frac{Z_{i,j} + 1 - Z_{i,j} - 1}{2d}$$

where, d = interval of the grid.

For a given azimuth **A** measured clockwise from the south and sun elevation **h** measured from the horizon, the sunlight vector $S\ (s_x,\ s_y,\ s_z)$ is *given as follows:*

$$s_x = Sin\ A*Cos\ h$$
$$s_y = Cos\ A*Cos\ h$$
$$s_z = -Sin\ h$$

3.0 Colour map shading algorithm

The overall system is mainly focused on producing colours in RGB mode, the selection of optimal shading map and typographic features for successful colourful shading map making. Since most of the theoretical background has already been described in a previous section, this section deals with the algorithms that have been developed for various modules.

The technique discussed in the previous section represents the basic methodology for relief shading without any colour. Our target is to combine shade and colour into a map. To do this we applied the fundamental concepts of colour production, that is, RGB-IHS colour conversion using a cylindrical model, and relief shading. At first, the DEM map is coloured in three colour bands (RGB) which are manually assigned according to contour height. This requires a somewhat artistic sense to design the colour codes for the terrain height. What we have learned from the basicidea of relief shading, is that the *shading intensity* on any elevation point corresponds to the amount of sun energy and that both of them are related to the cosine values of normal and sun light vectors. Therefore, before applying cosine values to a coloured DEM map, we need to convert the colour from RGB to IHS mode, then substitute the intensity *I* with the cosine value and re-convert colour to the RGB mode, as explained in Figure 2.

Conversion — *Substitution* — *Conversion*

R, G, B ⟶ *(I, H, S)* ⟶ (cos θ, H, S) ⟶ *(R' G' B')*

Painting DEM — *Colour shading*

Algorithm:

Step 1: Input A (sun azimuth) and h (sun elevation)

Step 2: Read the elevation at point x, y

Step 3: Calculate normal vector N and sun light vectors S

Step 4: Compute cos θ
If cos θ < 0 Then cos θ = 0
Convert cos θ to gray scale value.

Step 5: ***Painting and shading part:***
Apply the colour conversion to convert RGB to IHS.

From the theory of colour conversion from RGB-IHS using cylindrical model, we have:

$$\begin{vmatrix} I \\ V_1 \\ V_2 \end{vmatrix} = \begin{vmatrix} \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \\ \frac{-1}{\sqrt{6}} & \frac{-1}{\sqrt{6}} & \frac{2}{\sqrt{6}} \\ \frac{1}{\sqrt{6}} & \frac{-2}{\sqrt{6}} & 0 \end{vmatrix} * \begin{vmatrix} R \\ G \\ B \end{vmatrix} \quad (1)$$

$$\begin{vmatrix} R \\ G \\ B \end{vmatrix} = \begin{vmatrix} \frac{4}{3} & \frac{-2\sqrt{6}}{9} & \frac{\sqrt{6}}{3} \\ \frac{2}{3} & -\frac{\sqrt{6}}{9} & -\frac{\sqrt{6}}{3} \\ 1 & \frac{\sqrt{6}}{3} & 0 \end{vmatrix} * \begin{vmatrix} I \\ V_1 \\ V_2 \end{vmatrix} \quad (2)$$

Since we are interested only in the conversion from RGB to $R'\ G'\ B'$, we can express $R'\ G'\ B'$ as functions of R, G, B and I (intensity):

$$R' = f(I, R, G, B)$$
$$G' = f(I, R, G, B)$$
$$B' = f(I, R, G, B)$$

where I = cos θ

consequently:

$$R' = \frac{1}{9}(12I + 5R - 4G - 4B)$$

$$G' = \frac{1}{9}(6I + 4R + 7G - 2B)$$

$$B' = \frac{1}{9}(I - 3R - 3G + 6B)$$

Applying the formula above, the DEM map will be coloured with R'G'B' combination.

4.0 Symbolization and lettering for coloured shading map

The symbols and letters on a map are important, since they can provide users with more meaningful information. Only a person thoroughly familiar with a given area would not need symbols and names to identify the mapped items. Moreover, after the colour map shading is completed by the proposed technique, symbolization and lettering should be redesigned to harmonize the coloured shade. So, we have developed a colour pattern recognition to identify each map layer and enhance the image in raster mode to overlay on the colour-shaded map.

As for contour lines, we developed a so-called *elevation classification principle* as a primary technique, which will be discussed at the end of this chapter.

4.1 Colour classification principle

Colour classification plays an important role in distinguishing map layers with respect to the colour code. Each symbol can be represented as a group of colour-pixels which have the same colour pattern. *A colour pattern* can be *visually* defined as a group of colours related to their RGB combination.

In our study, we selected five map symbols from a topographic map; contour lines, built up areas/roads, rivers, forest areas and letters.

Colour classification can be implemented in three steps:

(1) **Colour identification:** five map symbol characteristics were defined with colour attributes or codes.

(2) **Symbol colour group:** using selected image processing procedures such as *brightness-contrast adjustment* and *colour difference, painting, erasing* and so on (in our study Photoshop Adobe 2.5 for Macintosh was used) to collect all colour pixels of the same pattern to a pixel group of the same RGB combination.

(3) **Symbol extraction:** when a pixel group of RGB combination has been defined and recognized, the corresponding symbols were extracted for the subsequent enhancement procedure.

(4) **Enhancement:** recognized symbols and letters were re-designed in size, thickness, pattern, direction etc. to produce more esthetical and easy to understand map elements.

Table 1 shows the procedures of enhancement of map symbols and letters.

4.2 Estimation for automated and manual utilization in symbolization

In the implementation, the number of automated operations should be maximized while the number of manual operations should be minimized. The estimated number of automated and manual operations that were used in our study is shown in Table 2.

5.0 Products of coloured shading map with enhanced symbols and letters

Figure 3 shows a comparison between an example of an original map and a complete colour map with coloured shading effects and enhanced layers.

6.0 Conclusions

A technique to produce a painted topographic map with shading effects as well as enhanced symbols and letters in richer colours and easily understood patterns, sizes and thicknesses has been developed by the authors. The test example shown in this paper was better understood by many monitors with little geomorphological or cartographic knowledge. The manual work was reduced to about a quarter in the "computer art" work.

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Table 1. Enhancement of Map Symbols and Letters

Step	Procedure to perform	Methods	Facilities
1.	Colour identification	Colour visualization	Photoshop Adobe 2.5
2.	Symbol colour group	– Brightness/Contrast adjustment – Colours difference – Painting, Erasing...	Photoshop Adobe 2.5
3.	Symbol extraction	Check/Read/Write image files	Programme written in C by the authors
4.	Enhancement (size, thickness, pattern etc.)	– Thickening – Rotating – Pattern Generation	Programme written in C by the authors and Photoshop Adobe 2.5

Table 2. Estimation of utilization for automated and manual works

Operations	Shading map	Forest area	Contour lines	City/Roads	Rivers	Lettering	Total	Percentage (per cent)
Automated	2	6	6	5	4	2	25	74
Manual	1	1	3	1	1	2	9	26
Total	3	7	9	6	5	4	34	100

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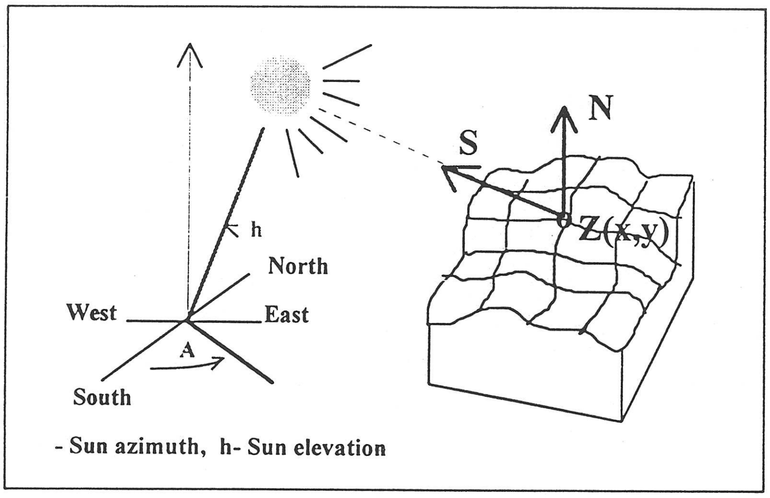

Figure 1. Relief shading at elevation point $Z_{x,y}$

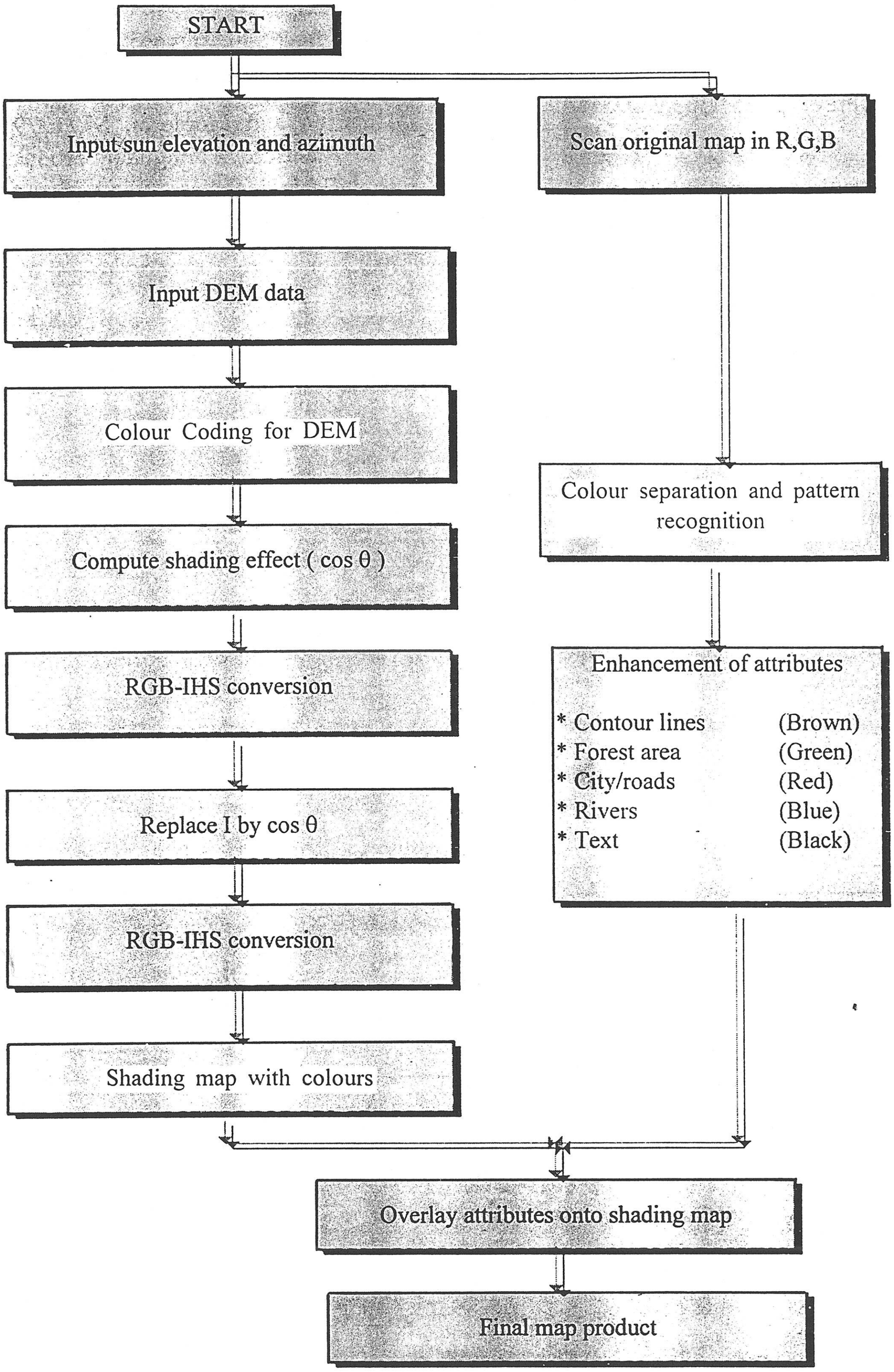

Figure 2. Colour map shading processing steps

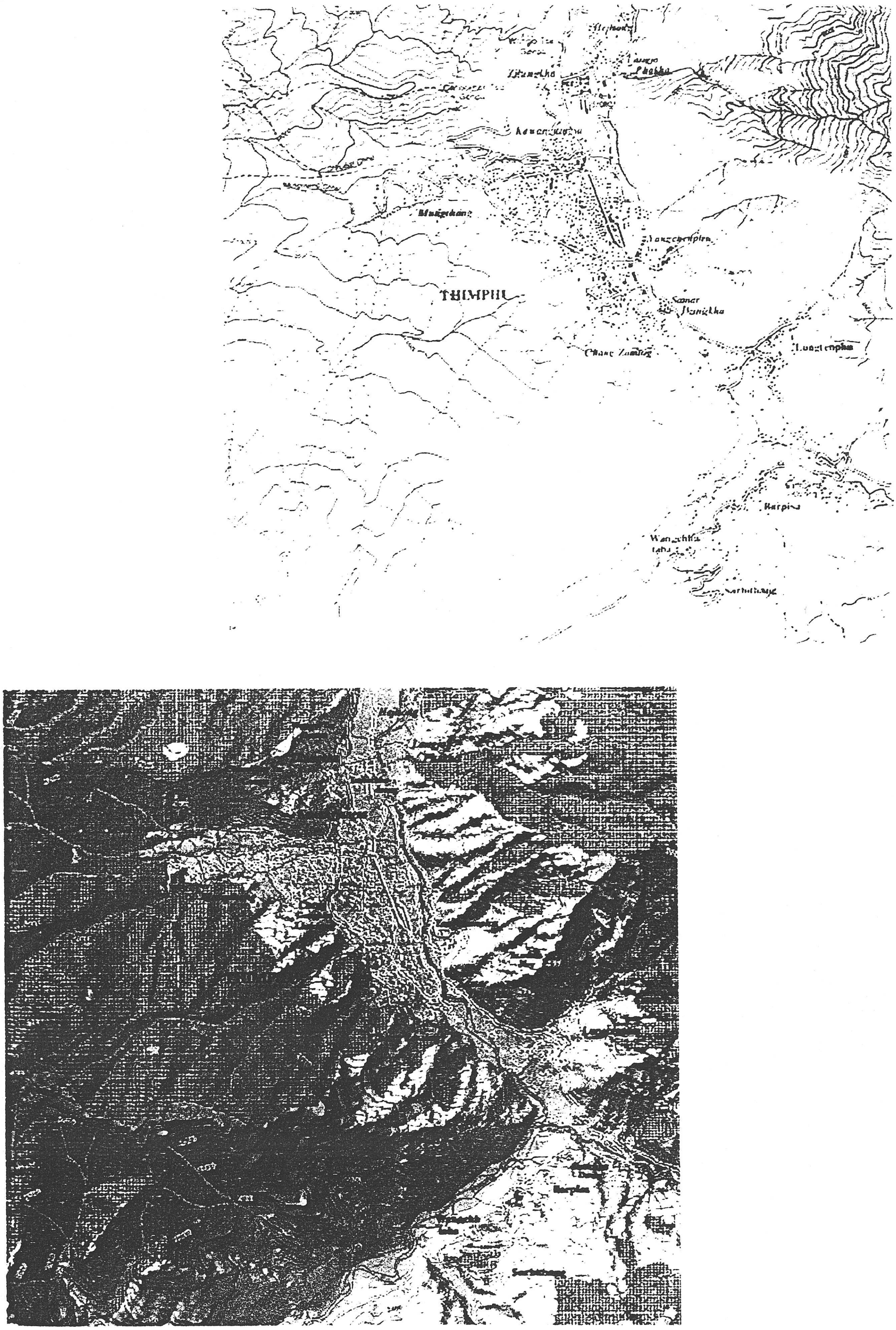

Figure 3. Original map and final product