Maintaining detail and color definition when integrating color and grayscale rasters using No Alteration of Grayscale or Intensity (NAGI) fusion method

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ABSTRACT: Integrating color raster data, such as an elevation tint, with grayscale raster data, such as a hillshade, is an important visualization function in remote sensing (RS) and geographic information systems (GIS). There are a number of methods that have traditionally been used to combine the rasters by transforming the original data, such as Red-Green-Blue (RGB)/Intensity-Hue-Saturation (IHS) transformation. Another method commonly used in RS and GIS is layer transparency, in which one raster is transparently draped over the other. However, all these methods distort the original colors, and transparency suppresses details in the grayscale raster. Cartographers have long struggled with these issues and searched for a way to optimally integrate color and grayscale rasters while retaining the fidelity of the original data.

After reviewing other methods, I introduced a new technique called the No Alteration of Grayscale or Intensity (NAGI) fusion method for integrating color and grayscale rasters. This technique preserves the original colors from the color raster while retaining the details from the grayscale raster thus producing better results over other traditional methods. This paper elaborates on the concept behind this new technique and demonstrates the results with various examples.

The NAGI fusion method does not require any code or programming and can be implemented using raster functions introduced in ArcGIS 10; however, the concepts described can be adapted for any RS/GIS system.

KEYWORDS: Pan sharpening, hillshade, elevation tint, DEM, cartography, gamma stretch, simple mean, linear stretch, image fusion, NAGI

Introduction

There are two primary reasons for integrating color and grayscale rasters, as stated by Viljoen et al. (2006). One is to enhance the visualization of single datasets by combining different characteristics, e.g the elevation tint of digital elevation model (DEM) overlaid on a hillshaded DEM and the other is to visualize the relationship between two different datasets such as slope combined with hillshade.

It is quite common to find maps on which a hillshaded surface is overlaid with a transparently colored thematic layer. The thematic layer could be soils, land use, vegetation, or other types of phenomena, but it is often elevation (figure 1a). Using what is called an elevation tint, ranges of elevation are assigned different colors that mimic what one might see on the ground. Greens in the low-lying valleys transition smoothly to light browns at the lower rocky elevations, which blend into darker browns in the higher treeless areas and finally change to white on the snowcapped peaks.

Traditional methods for integrating color and grayscale rasters

There are various traditional methods available to combine color rasters with grayscale rasters. These methods are discussed and evaluated in the section below.

Layer transparency

Most of the Remote Sensing (RS) and Geographic Information Systems (GIS) software has a layer transparency option that can be used to overlay the color rasters on the grayscale rasters such as a hillshade. This method does not involve any pixel-by-pixel processing, and results are instantaneous. However, there is loss of color saturation, and transparency suppresses details in the grayscale hillshade.

In figure 1, an elevation tint (1a) is overlaid on a grayscale hillshade (1b) using 50 percent layer transparency. The final output (1c) has faded colors, and details in the underlying hillshade are obscured.

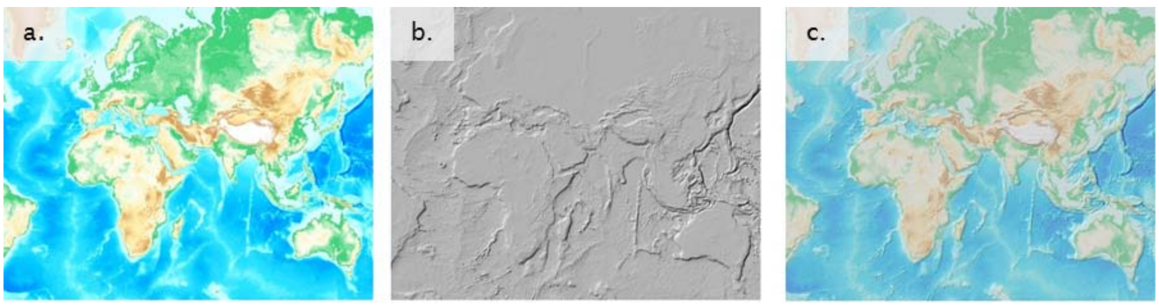

Figure 1: (a) Elevation tint of DEM, (b) hillshade of DEM, (c) elevation tint transparently overlaid on hillshade

As shown in figure 2, with the increase in layer transparency, the colors are further compromised; however, augmented details can be seen in the underlying grayscale hillshade. Thus, using the layer transparency method, the colors and details are compromised depending on the percentage of transparency. To overcome the loss of colors, thematic content can be designed with more saturated colors in the first place, and to preserve details, more vertical exaggeration can be used for hillshade. However, this solution does not provide optimal results, and mapmakers still have a result that compromises the input to some extent.

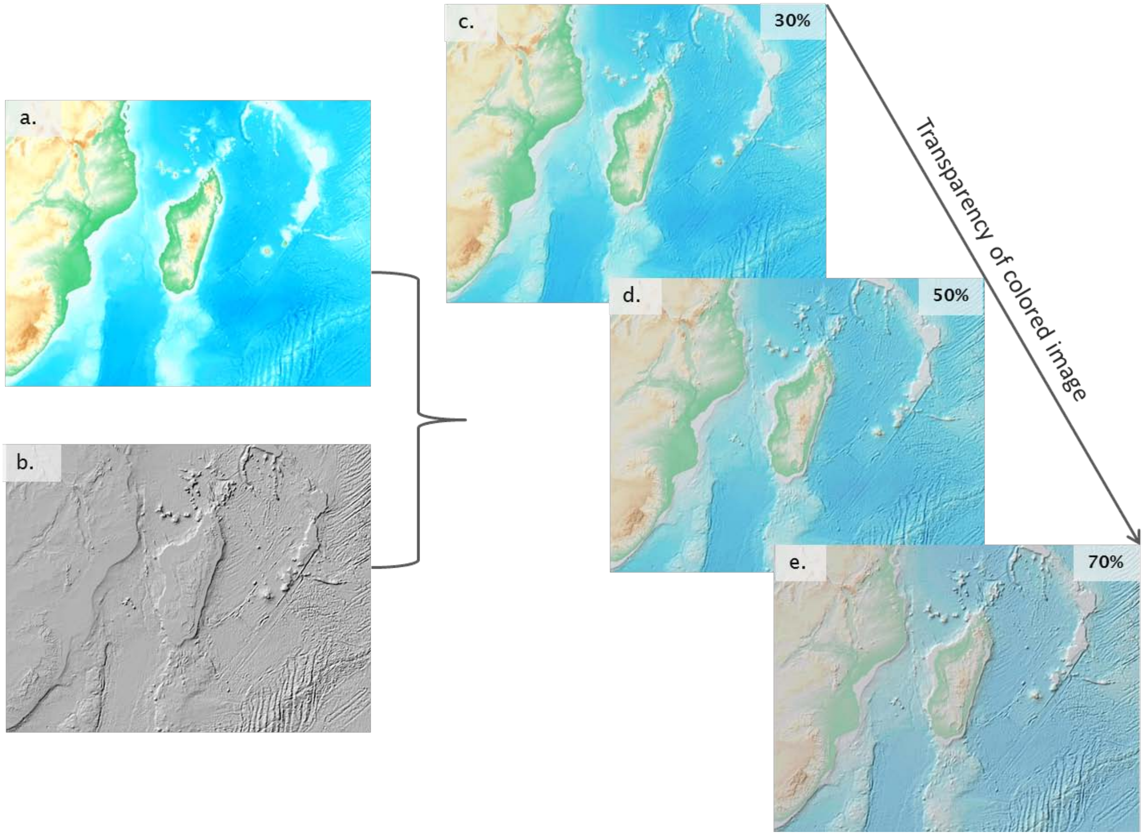

Figure 2: (a) Elevation tint of DEM, (b) hillshade of DEM, (c) elevation tint overlaid on hillshade using 30 percent transparency, (d) 50 percent transparency, and (e) 70 percent transparency

Panchromatic sharpening

Another commonly used technique for combining color (multispectral) rasters with grayscale (panchromatic) rasters in RS and GIS is panchromatic sharpening, more commonly known as pan-sharpening. Pan-sharpening is also known as multi-sensor data fusion, image fusion, image integration, and resolution merge (Yuhendra et al., 2011). Pan-sharpening combines the spatial properties of higher-resolution panchromatic imagery with spectral information of lower-resolution multispectral imagery to produce a high-resolution multispectral image (Klonus et al., 2008). Though the main application of pan-sharpening is to combine multispectral imagery with panchromatic imagery, this technique can also be effectively used to integrate thematic data with grayscale hillshades. There are various pan-sharpening methods available; one of the most commonly used is Intensity-Hue-Saturation (IHS) (Chikr El-Mezouar et al., 2011). In this method, Red-Green-Blue (RGB) values are transformed to IHS color space, and then intensity is replaced by values from the grayscale image. The resultant image is then transferred back to the RGB color model (figure 3d).

Esri’s ArcGIS software also provides Brovey and Esri fusion methods. The Brovey method multiplies each resampled multispectral pixel by the ratio of the corresponding panchromatic pixel intensity to the sum of all the multispectral intensities (URL 1). The Brovey transformation equation for the red band is given below:

$$Red_{out} = \frac{Red_{in}}{(Red_{in} + Green_{in} + Blue_{in}) * Pan}$$

The Esri pan-sharpening transformation uses a weighted average and the additional near-infrared band (optional) to create its pan-sharpened output bands. The result of the weighted average is used to create an adjustment value that is then used in calculating the output values (URL 1).

Though color loss in the IHS fusion method (figure 3d) is less when compared to Esri (figure 3e) and Brovey (figure 3f) fusion methods, all these traditional pan-sharpening methods compromise the colors in one way or another, as shown in figure 3.

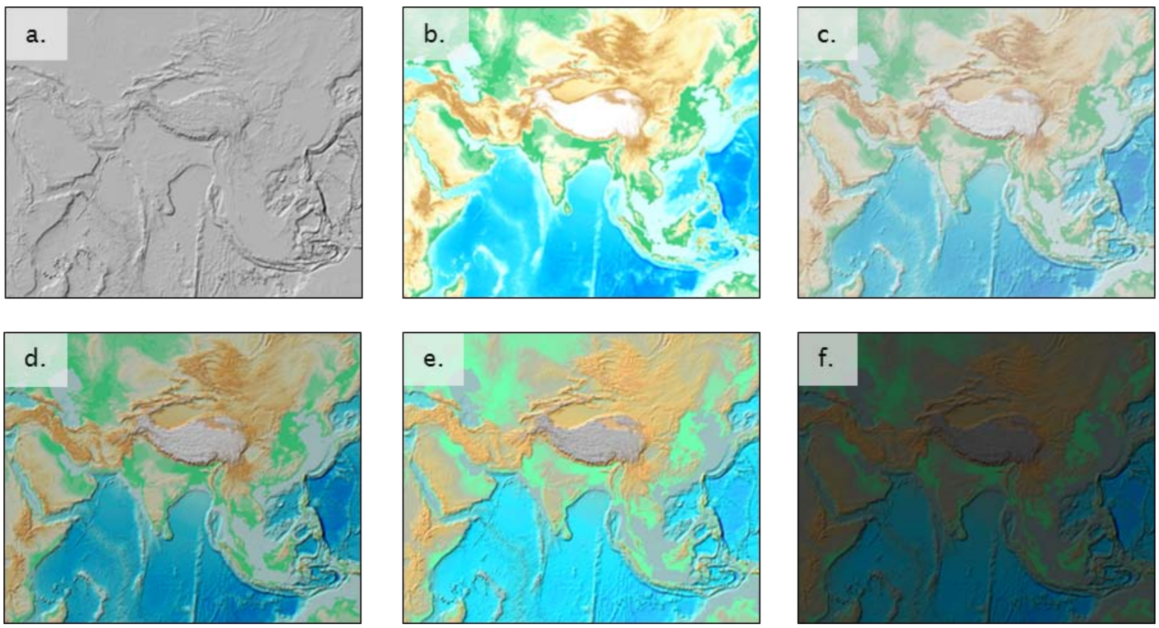

Figure 3: (a) Hillshade of DEM, (b) elevation tint of DEM, (c) elevation tint overlaid on hillshade using 50 percent transparency, (d) IHS fusion method output, (e) Esri fusion method output, and (f) Brovey fusion method output.

Cartographers have long struggled with these issues and searched for a way to optimally integrate color and grayscale rasters while retaining the fidelity of the original data. Viljoen et al. (2006) show promising results with SatValMod, which is a Visual Basic for Applications (VBA) extension to ArcGIS 9.3; however, the tool could not be run on any other dataset besides the sample data provided with it.

After briefly reviewing the other methods, I introduced a new technique for integrating color and grayscale raster data called No Alteration of Grayscale or Intensity (NAGI) fusion method. This technique retains the original colors while maintaining the details from the grayscale hillshade. The next section elaborates on the concept behind the technique and compares the results with other methods.

No Alteration of Grayscale or Intensity (NAGI) fusion method

As discussed in the previous section, layer transparency and most of the other traditional image fusion methods introduce color distortion when color rasters are integrated with grayscale hillshade rasters. To solve this problem, I developed the NAGI fusion method which is divided into three steps. In the first step, a simple mean is calculated using input rasters. In the second step, a gamma stretch is applied to the output from the first step, and in the third step, a minimum-maximum linear stretch is applied to the output from the second step.

Gamma stretch

Gamma stretch is a non-linear curve stretch that affects the degree of contrast between the midlevel gray values of a raster. A gamma stretch does not affect the black or white values in a raster dataset. By applying a gamma stretch, the overall brightness of a raster dataset is altered. Gamma values lower than 1 decrease the contrast in the darker areas and increase the contrast in the lighter areas. This darkens the image without saturating the dark or light areas. Conversely, a gamma value greater than 1 increases the contrast in darker areas. Gamma value lower than 1 is used in the NAGI fusion method to decrease the gray from middle values.

Minimum-maximum linear stretch

A linear stretch linearly expands the original range of image values to fill the total range of the output device (Lillesand et al., 1994). It can be applied in a number of ways, one of which is a minimum-maximum stretch. A minimum-maximum linear stretch (figure 4) is the simplest method to enhance the contrast in an image in which a pixel value in the low end (4) of the original histogram is assigned to extreme black (0) and a value at the high end (104) is assigned to extreme white (255). The remaining pixel values are distributed linearly between these extremes (URL 2).

A linear stretch is used to distribute the values across 256 values, from 0 to 255. Features in the image are easier to distinguish as the pixel values are distributed across the entire histogram range, brightening and increasing the contrast of the image. Linear stretch can be defined by the equation below:

$$BV_{out} = \left(\frac{BV_{in} - \min_k}{\max_k - \min_k} \right) quant_k$$

where

- BV_{in} is the original input brightness value
- $quant_k$ is the maximum range of display levels (i.e., 255),
- min_k is the minimum value in the image,
- max_k is the maximum value in the image, and
- BV_{out} is the output brightness value

Figure 4 shows the histogram of the stretched image after applying the minimum-maximum linear stretch with values of 4 and 104.

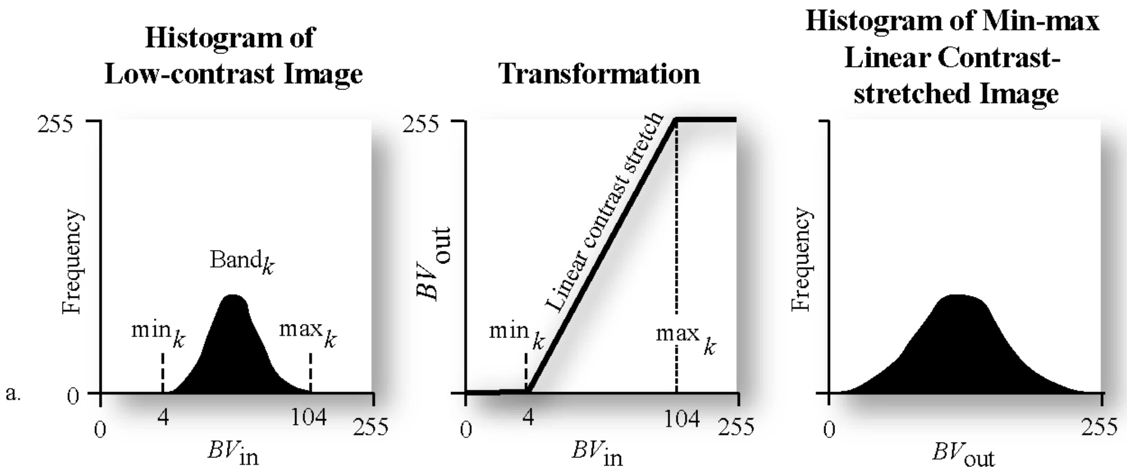

Figure 4: Minimum-maximum linear contrast stretch

Source: URL 3

NAGI fusion method

In the first step of the NAGI fusion method, a panchromatic image (i.e., the hillshade) is added to each of the three bands of the multispectral (RGB) image, and then the mean is calculated. The multispectral raster could be any thematic layer, such as land cover/land use; soils; geology; or, in this example, an elevation tint. The equation for the simple mean is given below, where Red_{in}, $Green_{in}$, and $Blue_{in}$ are the RGB bands of the input multispectral image and Pan_{in} is the panchromatic image:

$$Red_{out} = 0.5 * (Red_{in} + Pan_{in})$$

$$Green_{out} = 0.5 * (Green_{in} + Pan_{in})$$

$$Blue_{out} = 0.5 * (Blue_{in} + Pan_{in})$$

This combined output produces a result that is less saturated (lightened) in color. The reason is that gray values from the hillshade, which are usually concentrated around a mean of about 180 (figure 5a); shift the histogram for the combined output toward the higher values (figure 5c). Histograms of the grayscale hillshade, elevation tint (red band out of RGB bands is shown in the example), and combined output of simple mean calculation are shown in figure 5.

In the second step of the NAGI method, a gamma stretch of lower than 1 is applied. Testing with various datasets showed that a gamma value around 0.5 works well for this method. As mentioned earlier, any gamma value below 1 decreases the contrast in darker areas and increases the contrast of middle ranges, thus shifting the histogram toward the darker values. With the gamma stretch, the gray in the middle values of the raster are reduced. This shifts the histogram toward the lower values and also stretches the middle ranges, as shown in figure 5d.

The last step of the NAGI method is to increase the saturation of the raster. A minimum-maximum linear stretch is applied to the tails of the histogram so that the pixel values are distributed across the entire range, thus brightening the whole image (figure 5e).

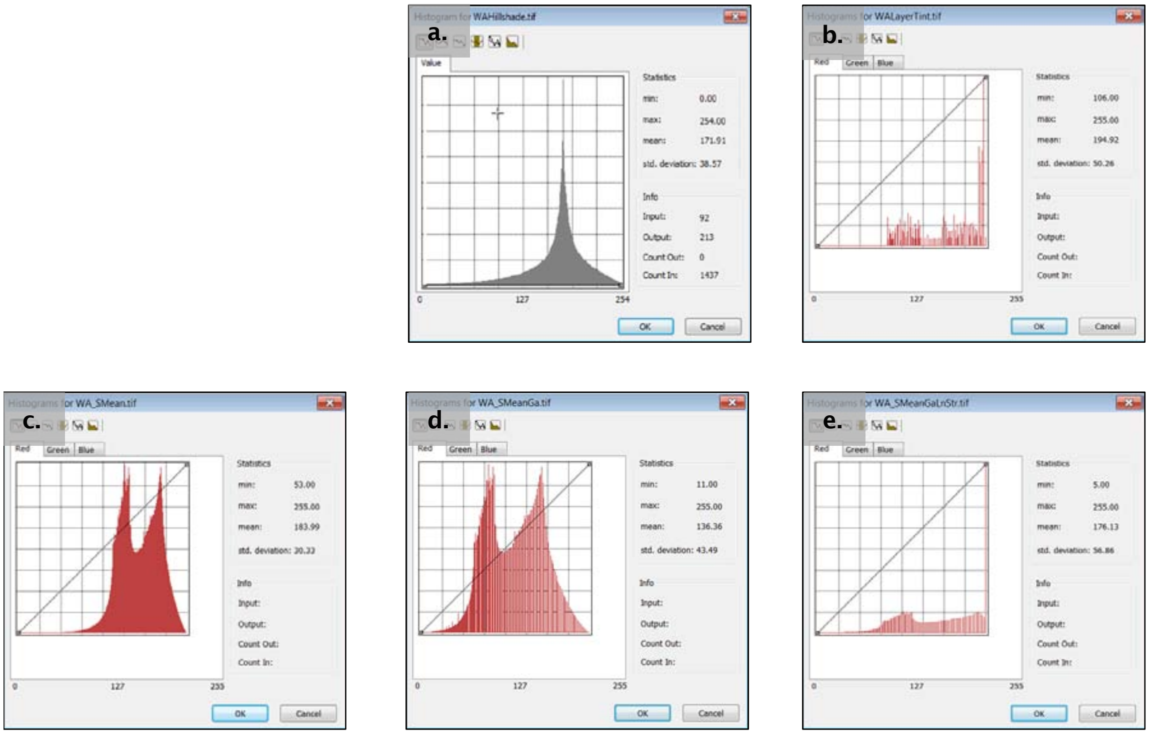

Figure 5: Histogram of (a) hillshade, (b) red band of multispectral (RGB) image, (c) simple mean, (d) gamma stretch of 0.5, (e) min-max stretch

After following these steps, final output has nearly the same colors as the input color, and the details in the pan-chromatic raster are retained. The results are discussed in the next section.

Results

The NAGI fusion method was tested on various datasets, and the results are discussed below. The first example (figure 6) used ETOPO1 global elevation/bathymetry data; figure 6a shows the hillshade of the ETOPO1 DEM, and figure 6b shows the elevation tint of the ETOPO1 DEM. Elevation tint was generated by applying a color map file to the DEM.

Color maps contain a set of values that are associated with colors and are used to display the colors of a raster. Each pixel value is associated with a color, defined as a set of RGB values. Below is an example of the contents of a color map file, where the first column is pixel value, and second, third, and fourth columns define the red, green, and blue colors, respectively.

1 255 0 0
2 100 0 100
3 50 200 10
4 45 60 100

Figures 6c and 6d show the results of using layer transparency and IHS methods, respectively, where colors are compromised. Figure 6e shows the output from the NAGI fusion method, which retained the colors from the color raster very well, and details in the input hillshade remain discernible. In this example, a gamma value of 0.5 was applied and minimum-maximum values of 10, 220 (tails of histogram) were lineally stretched to 0 to 255.This method gives the flexibility to modify the gamma and contrast stretch values based on the results.

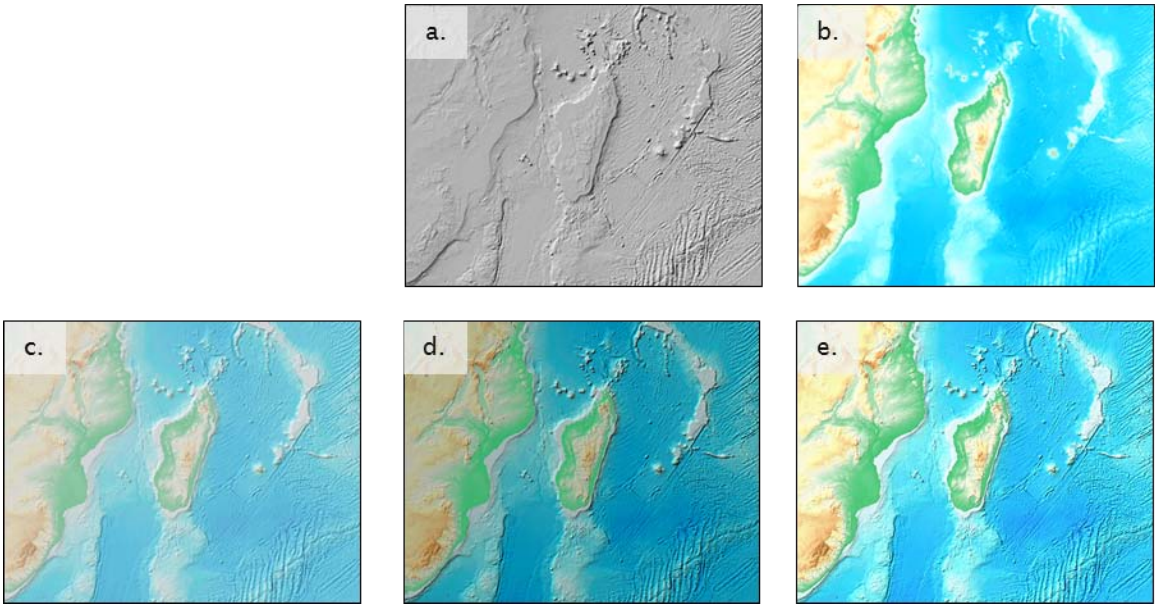

Figure 6: (a) Hillshade of DEM, (b) elevation tint of DEM, (c) elevation tint overlaid on hillshade using 50 percent transparency, (d) IHS fusion method output, and (e) NAGI fusion method output

In a second example (figure 7), GTOPO30 data was used to create a hillshade (figure 7a) and an elevation tint (figure 7b) for the state of Washington. In this case, the elevation tint was generated using a color ramp rather than the color map file used in the previous example. Figure 7e shows the output from the NAGI fusion method, which retained the colors much better when compared to the layer transparency (figure 7c) and IHS fusion (figure 7d) methods.

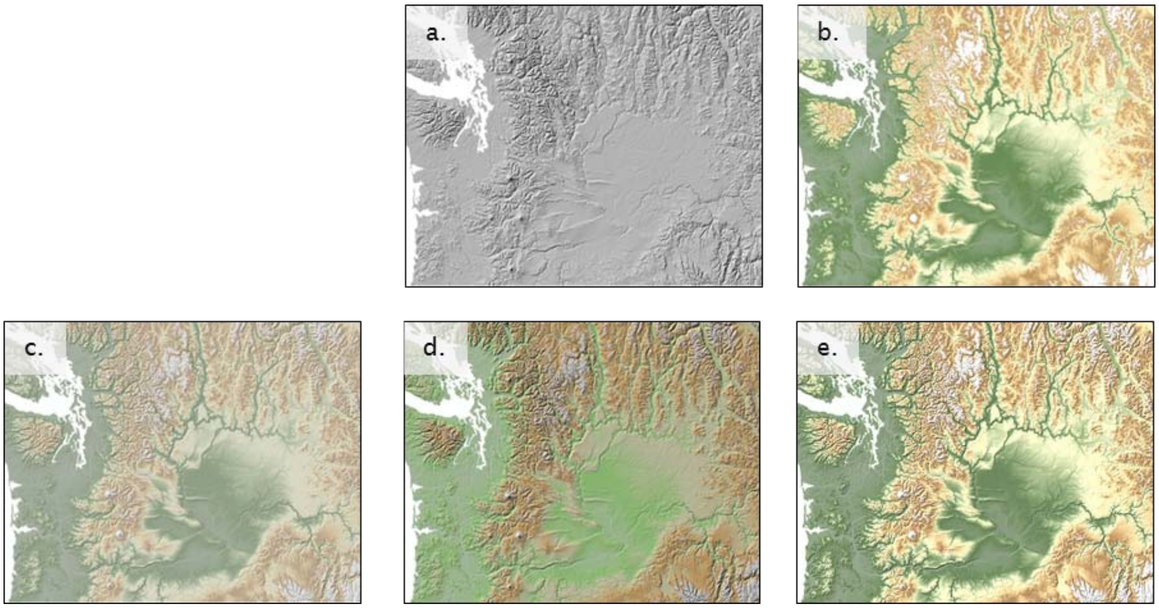

Figure 7: (a) Hillshade of DEM, (b) elevation tint of DEM, (c) elevation tint overlaid on hillshade using 50 percent transparency, (d) IHS fusion method output, and (e) NAGI fusion method output

In a third example (figure 8), a rasterized geology map (figure 8b) was combined with a hillshade of the same area (figure 8a) using the NAGI fusion method (figure 8e), which retained the colors much better than other methods (figures 8c and 8d).

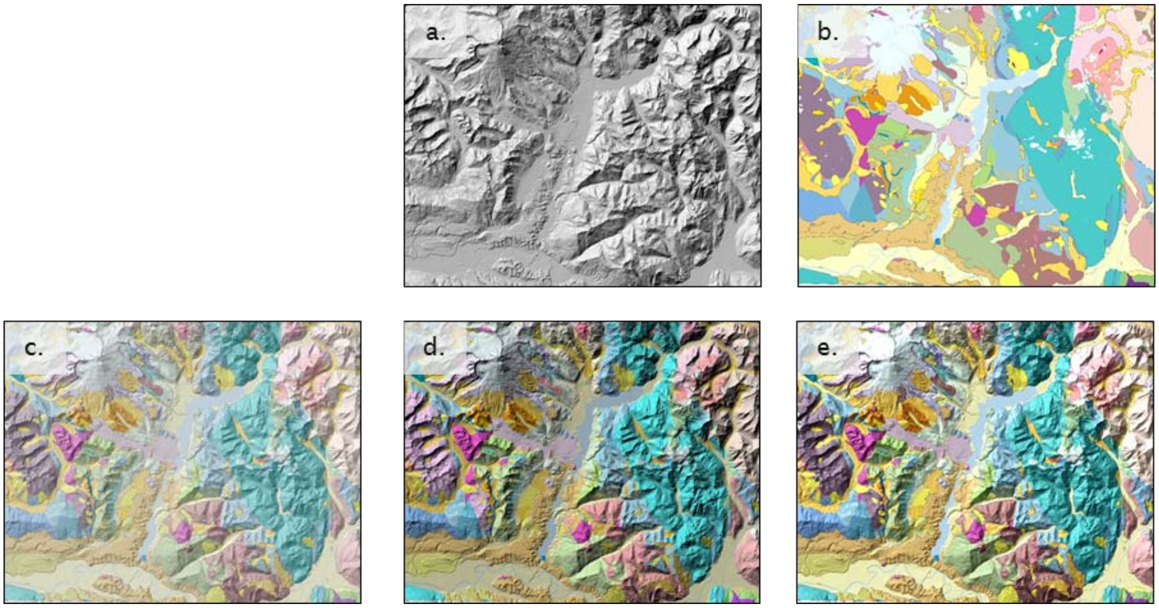

Figure 8: (a) Hillshade of Mt. Baker DEM, (b) rasterized geology map of Mt. Baker, (c) geology map overlaid on hillshade using 50 percent transparency, (d) IHS fusion method output, and (e) NAGI fusion method output

Conclusion

The NAGI fusion method produces better results when compared to traditional fusion methods, as there is no compromise in color and detail. The NAGI fusion method does not require any code or programming and can be easily implemented using raster functions introduced in ArcGIS 10. However, the method can be adapted for any RS/GIS system. It also provides control over the parameters such as gamma and contrast stretch values. The examples produced show that the method works well with a variety of datasets and thematic content, demonstrating the versatility of the method. Step-by-step instructions for applying the NAGI fusion method using raster functions in ArcGIS 10 are available in Esri's *ArcWatch* newsletter (Nagi 2012a, 2012b).

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