Lesson 6: Spectral Indices

Lesson Description
In this lesson, we cover the basics of creating spectral indices, which are used to highlight specific features on the landscape, such as vegetation, water, geological features, and so on. We use the perhaps the most common spectral index, the normalized difference vegetation index (NDVI) and the modified normalized difference water index (MNDWI), to assess vegetation density and surface water in imagery covering the area surrounding Hawassa, Ethiopia. Finally, we reclassify these data to segment features of interest.

Objectives:
The student will:
1) Learn how to spectrally enhance satellite imagery using spectral indices
2) Classify spectral index data to extract features

Keywords:
Normalized difference vegetation index (NDVI), modified normalized difference water index (MNDWI), reclassification

Resources Required:
ArcMap

Data Used:

LC08_L1TP_168055_20170110_20170311_01_T1: Landsat 8 imagery near Hawassa, Ethiopia

Background:
Spectral indices are used to emphasize specific features or phenomena within remotely sensed imagery. We create spectral indices by transforming spectral data using ratios between bands to reduce the data into meaningful information. Features that can be extracted using spectral indices range from vegetation, geologic and hydrologic features, burned areas, and snow, among many others. These indices enhance data interpretation and are used in many scientific applications such as monitoring plant/crop health, delineating water bodies, calculating burn extents, spatial modeling, and so on.
While there are numerous spectral indices available that emphasize a number of different landscape features, perhaps the most common spectral index is the normalized vegetation difference index (NDVI). This index is primarily used to detect vegetation density and health. NDVI is derived as follows:

\[
NDVI = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}
\]

where NIR is the near infrared band and red is the red band.

\section*{Equation 1}

Resultant values scale from -1 to 1, where positive values typically represent vegetation and (with denser vegetation closer to 1) and negative values represent no vegetation (bare soil, snow, water, etc.), as shown in Figure 1.

Examine how this equation works using Figure 2. Vegetation reflectance is low in the red (band 3), but reflects highly in the NIR (band 4). In dense vegetation, where there is higher NIR reflectance (and low red reflectance), the numerator (NIR – Red) will be a positive value, and the denominator (NIR + Red) will be a similar positive value, giving us a resultant value close to 1. On bare soil, where red reflects about equally to NIR, the numerator will have a value close to 0 and a similar value on the denominator, giving us a resultant value closer to 0. Finally, water reflects higher in the red than NIR, giving us a value close to -1.
Lesson:
Step 1. Creating Spectral Indices

We will create an NDVI layer to assess vegetation density using the imagery in the data folder.

1.1 Copy the data folder into your local directory, then drag the metadata file, *LC08_L1TP_168055_20170110_20170311_01_T1_MTL.txt*, to the ArcMap Table of Contents window.

1.2 We will also add the individual bands needed to calculate NDVI, the red and NIR bands. From the Catalog window, add the layers:

   *LC08_L1TP_168055_20170110_20170311_01_T1_B4.tif* (red)
   *LC08_L1TP_168055_20170110_20170311_01_T1_B5.tif* (NIR)

1.3 Feel free to examine these layers in areas of dense vegetation and no vegetation. Use the Identify tool to determine values at these locations, in dense vegetation, you should see high reflectance values in NIR band and lower values in the red band.

1.4 Find the Raster Calculator (Spatial Analyst) tool using the Search window or use ArcToolbox and navigate to:

   Spatial Analyst Tools > Map Algebra > Raster Calculator

1.5 The Raster Calculator tool allows us to perform calculations on raster datasets. These calculations can range from single layer addition/scaling, differencing between multiple layers, conditional statements, and much more.

1.6 We will use the Raster Calculator to calculate NDVI using Equation 1 from the previous page. In the Raster Calculator window, the box in the upper left lists the layers currently in your map viewer. Double-click the NIR band, *LC08_L1TP_168055_20170110_20170311_01_T1_B5.tif*, to add it into the equation box. Click the ‘-’ symbol, then double click the red band, *LC08_L1TP_168055_20170110_20170311_01_T1_B4.tif*. This makes up the numerator portion of the equation (NIR – Red), place this portion of the equation in parentheses, then click the ‘/’ symbol, and repeat these steps to create the denominator using the ‘+’ symbol. Our equation will appear as follows:

![Figure 3. NDVI output](image-url)
1.7 Save the Output Raster as \texttt{LC8_Hawassa\_NDVI.tif} and click OK to run the calculation.

1.8 On the output layer, change the symbology to a color gradient with a neutral color as the midpoint (which represents 0 values in the NDVI layer, e.g. \(\text{\ding{51}}\text{\ding{51}}\text{\ding{51}}\)). Examine the NDVI raster and compare it to the original imagery. Your image should look similar to Figure 3, where values are closer to 1 in areas of dense vegetation or values closer to -1 in areas of no vegetation.

1.9 We can now roughly classify the data into three categories: No Vegetation, Sparse Vegetation, Dense Vegetation

1.10 Find the \textit{Reclassify (Spatial Analyst)} tool using the \textit{Search} window or use \textit{ArcToolbox} and navigate to:

\textbf{Spatial Analyst Tools > Reclass > Reclassify}

1.11 In this window, select the NDVI layer, \texttt{LC8\_Hawassa\_NDVI.tif}, as the \textit{Input Raster}, the \textit{Reclass Field} will remain as VALUE. Now, we want to set new values for specific value ranges. Click \textit{Classify...} and set the \textit{Classes} drop-down menu to 3, then click \textit{OK}. In the \textit{Reclassification} table, input the values from Table 1 exactly as shown, with a space before and after each “-” (Figure 4).

\textbf{Table 1: NDVI ranges for classification}

<table>
<thead>
<tr>
<th>Old values</th>
<th>New values</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1 - 0.2</td>
<td>1</td>
</tr>
<tr>
<td>0.20001 - 0.35</td>
<td>2</td>
</tr>
<tr>
<td>0.35001 - 1</td>
<td>3</td>
</tr>
<tr>
<td>NoData</td>
<td>NoData</td>
</tr>
</tbody>
</table>

![Figure 4. Parameters for the ArcGIS Reclassify tool](image)

1.12 The new layer will have 4 new classes:

0 – Unclassified Data
1 – No Vegetation
2 – Sparse Vegetation
3 – Dense Vegetation
In the **Properties** on the **Symbology** tab, select a new color gradient that better represents a range from sparse to dense vegetation.

**1.13** Now, compare the classified layer and the original true color image. **Answer Question 1** on the final page of this lesson.

![Figure 5: Original natural color imagery (left) compared with reclassified NDVI data (right)](image)

**Step 2. The Modified Normalized Difference Water Index (MNDWI)**

The Modified Normalized Difference Water Index (MNDWI) is a common spectral index for extracting surface water modified from the traditional Normalized Difference Water Index (NDWI). Again, values range from -1 to 1, and values greater than 0 typically represent bodies of water (oceans, lakes, rivers, etc.). The MNDWI is calculated similar to NDVI, as follows:

\[
MNDWI = \frac{Green - SWIR}{Green + SWIR}
\]

where Green is the green band and SWIR is the shortwave infrared band.

**Equation 2**

**2.1** Add the individual bands needed to calculate MNDWI, the green and SWIR1 bands:

- `LC08_L1TP_168055_20170110_20170311_01_T1_B3.tif` (green)
- `LC08_L1TP_168055_20170110_20170311_01_T1_B6.tif` (SWIR1)
2.2 Again, open the **Raster Calculator** to calculate MNDWI using Equation 2. Refer to step 1.6 if necessary. Our equation will appear as follows:

\[
\text{float("LC08_L1TP_168055_20170110_20170311_01_T1_B3.TIF" - \\
LC08_L1TP_168055_20170110_20170311_01_T1_B6.TIF")/float("LC08_L1TP_168055_20170110_20170311_01_T1_B3.TIF" + \\
LC08_L1TP_168055_20170110_20170311_01_T1_B6.TIF")}
\]

2.3 Save the **Output Raster** as *LC8_Hawassa_MNDWI.tif* and click **OK** to run the calculation.

2.4 Again, we can reclassify the values to segment the water pixels. However, instead of reclassifying the data into a new layer, we will simply classify the symbology to extract water. Open the **Properties of LC8_Hawassa_MNDWI.tif**, on the **Symbology** tab, click **Classified** in the **Show**: box on the left-hand side. Now, change the number of classes to 2 using the dropdown menu near **Classes**. Click the **Classify…** button, in the **Break Values** box on the right side of the window, change the top value to 0.1 and ensure the second value is 1 (Figure 6). Click **OK**.

2.5 Now, double-click the top color symbol in the **Symbol** column (for -1 – 0.1), click **No Color**. Double-click the second color symbol and select a blue color to represent water (Figure 7).

2.6 The MNDWI layer should now show only water pixels. Overlay this layer over the original imagery to examine its accuracy. **Answer Question 2**.

Indices can be used for much more than vegetation and water. The following is a list of indices developed to emphasize specific features (list from [https://github.com/rander38/Remote-Sensing-Indices-Derivation-Tool](https://github.com/rander38/Remote-Sensing-Indices-Derivation-Tool)):
Vegetation Related Indices

- NDVI (Normalized Difference Vegetation Index)
  http://www.indexdatabase.de/db/i-single.php?id=58

- SAVI (Soil Adjusted Vegetation Index)
  http://www.indexdatabase.de/db/i-single.php?id=87

- EVI (Enhanced Vegetation Index)
  http://www.indexdatabase.de/db/i-single.php?id=16

- EVI2 (Enhanced Vegetation Index 2)
  http://www.indexdatabase.de/db/i-single.php?id=237

- NDMI (Normalized Difference Moisture Index)
  http://www.indexdatabase.de/db/i-single.php?id=56

- NMDI (Normalized Multi-band Drought Index)

Hydrologic Indices

- NDWI (Normalized Difference Water Index)
  http://www.indexdatabase.de/db/i-single.php?id=60

- MNDWI (Modified Normalized Difference Water Index)
  http://www.tandfonline.com/doi/abs/10.1080/01431160600589179

Geologic/Soil Indices

- Clay Minerals Ratio
  https://www.indexdatabase.de/db/i-single.php?id=204

- Ferrous Minerals Ratio
  https://www.indexdatabase.de/db/i-single.php?id=205

Burn Indices

- NBR (Normalized Burn Ratio)
  http://www.indexdatabase.de/db/i-single.php?id=53

- BAI (Burn Area Index)
  http://www.tandfonline.com/doi/abs/10.1080/01431160210153129
Miscellaneous Indices

NDBI (Normalized Difference Built-Up Index)
http://www.tandfonline.com/doi/abs/10.1080/01431160304987

NHFD (Non-Homogenous Feature Difference (NHFD))

NDSI (Normalized Difference Snow Index)
http://ieeexplore.ieee.org/document/399618/?arnumber=399618&tag=1

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Exercise Questions

1. Do you think the NDVI calculation and classification accurately represent vegetation across the landscape? Why or why not?

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2. Do you think the MNDWI calculation and classification accurately represent water across the landscape? Why or why not? What about within lakes versus rivers?

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3. Examine Figure 2, why do you think green (band 2) and SWIR (band 5) are used in the MNDWI calculation to emphasize water?

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4. Examine the list of indices at the end of the lesson, do any of these indices relate to your current projects or interests? What are some applications you could imagine these being used for?

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