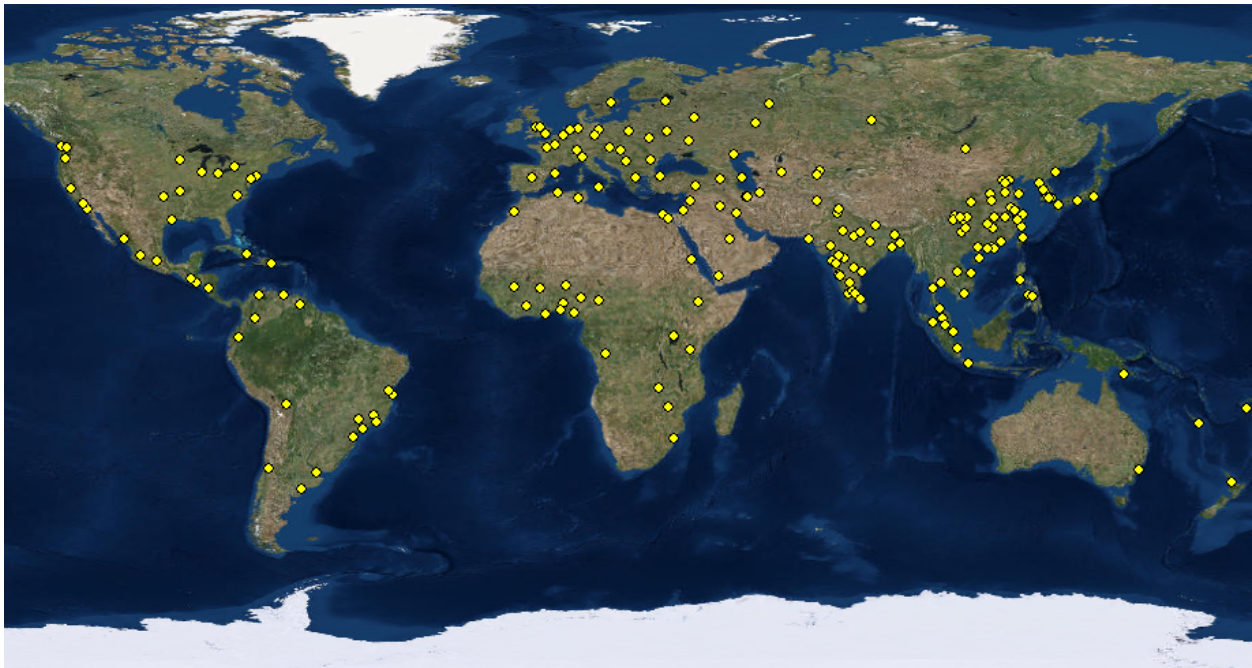


Atlas of Global Expansion

2015 Edition

Cities Classification Procedures Manual

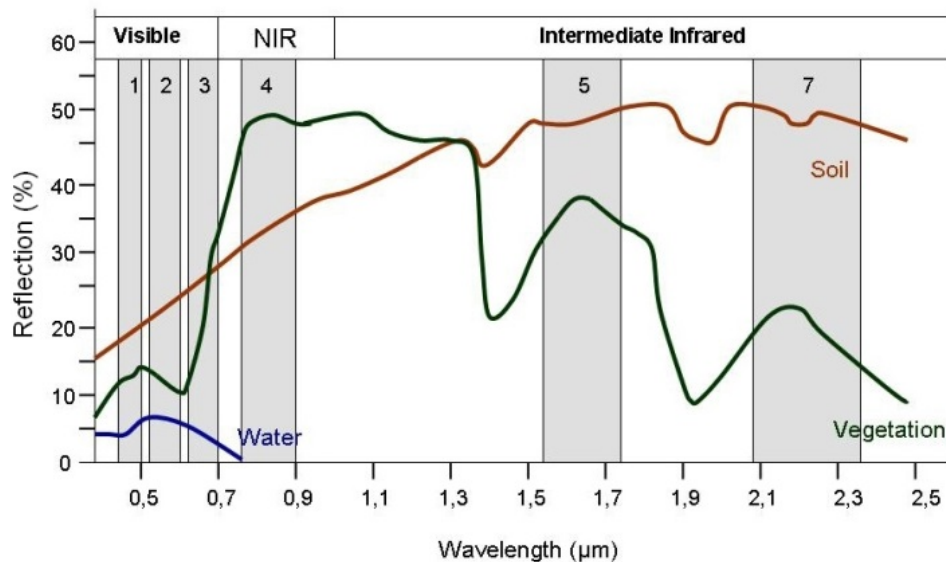


prepared by

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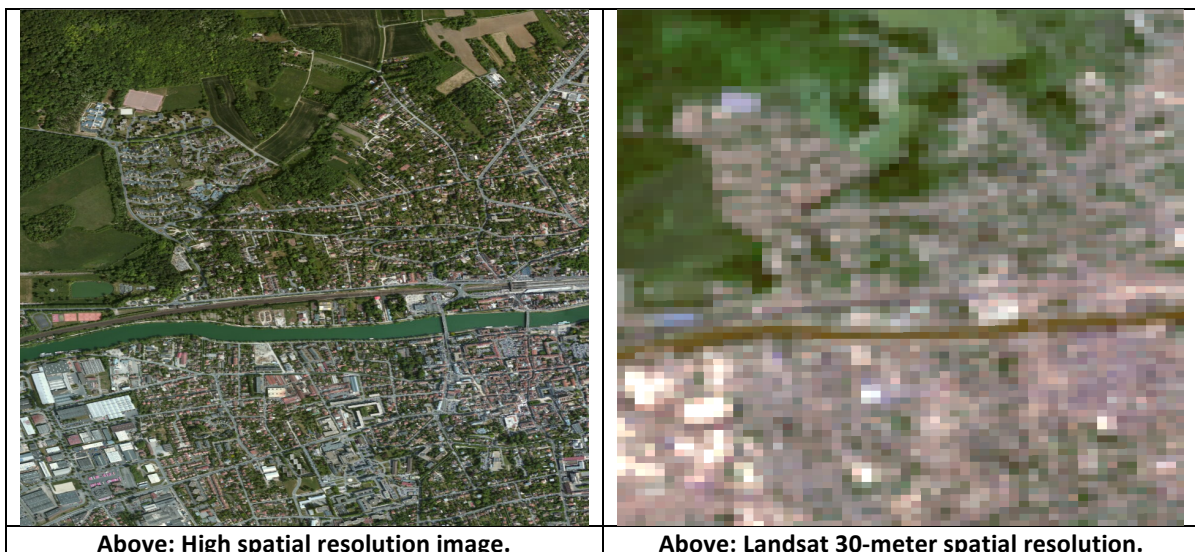
PART 1 Basics of Remote Sensing

The classification of the city areas for the Atlas of Global Expansion: 2015 Edition is using the Landsat series of satellites. The first Landsat satellite (Landsat 1) was launched in 1972. We are using image data from Landsat 4, Landsat 5, Landsat 7, and Landsat 8. The sensor on board the Landsat satellites that we are using collect data in the blue, green, red (visible), near-infrared (NIR), and two intermediate infrared (SWIR) portions of the electromagnetic spectrum (see graphic below). Using these six channels (or bands) allow us to identify various land cover features on the earth's surface.



Reflectance curves for water, vegetation and soil displayed with six reflective bands collected by Landsat.

The spatial resolution of the Landsat image is typically 30-meters, however, some images might be supplied as 28.5-meters. The spatial resolution of the sensor dictates the smallest feature that can be seen in an image. For a land cover feature to be visible in a Landsat image, it will be larger than 30-meters. Below is a comparison of a high spatial resolution image with a 30-meter spatial resolution Landsat image.



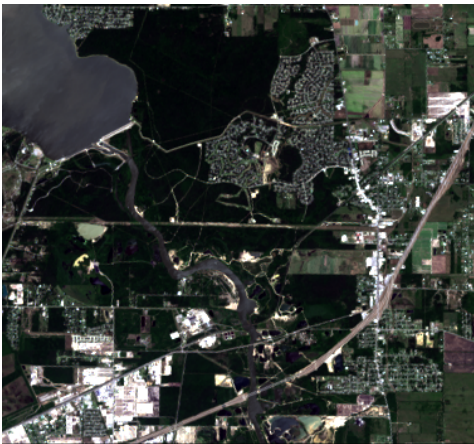
Above: High spatial resolution image.

Above: Landsat 30-meter spatial resolution.

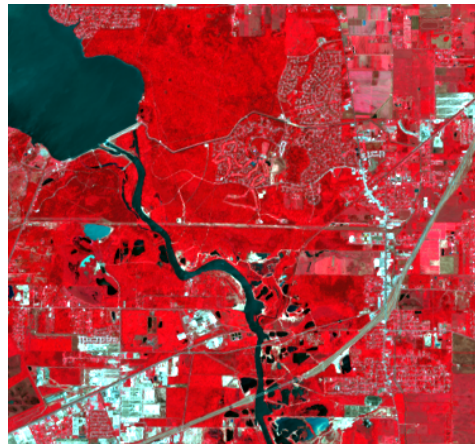
The Landsat bands are typically described as:

Band 1= blue Band 2 = green Band 3 = red Band 4 = NIR Band 5 = SWIR Band 6 = SWIR

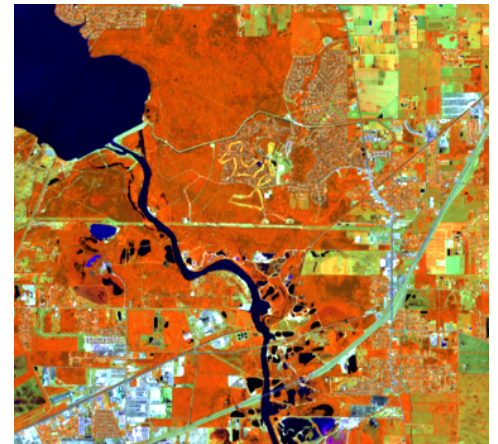
We can alter the way the Landsat image looks on the computer by changing the band combination displayed. When we reference a specific band combination, we will describe it in order of red, green, and blue (R, G, B). A true color image will be displayed as R = Band 3, G = Band 2, B = Band 1. A near-infrared image will be displayed as R = Band 4, G = Band 3, B = Band 2. A popular false color composite band combination is R = Band 4, G = Band 5, B = Band 3. This last band combination tends to highlight the most features in a Landsat image. Examples of these three band composites are provided below.



Above: Landsat image displayed as:
R = Band 3, G = Band 2, B = Band 1.

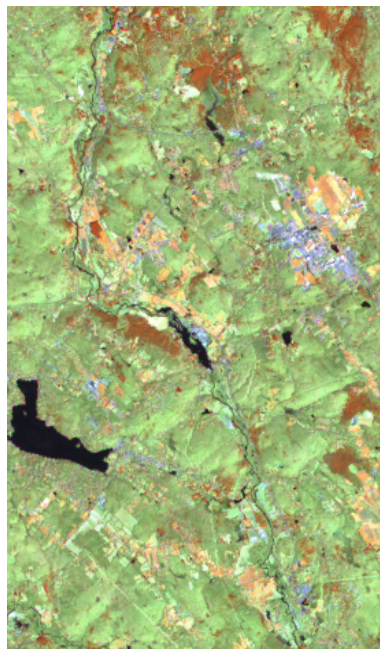


Above: Landsat image displayed as:
R = Band 4, G = Band 3, B = Band 2.

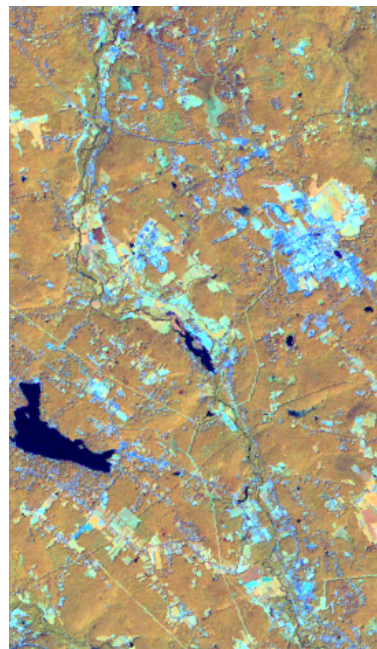


Above: Landsat image displayed as:
R = Band 4, G = Band 5, B = Band 3.

It is also important to understand that images from the same location but taken at different times of the year can look different due to the various stages of vegetation growth and sometimes sun angle.



Springtime leaf-off



Summertime leaf-on

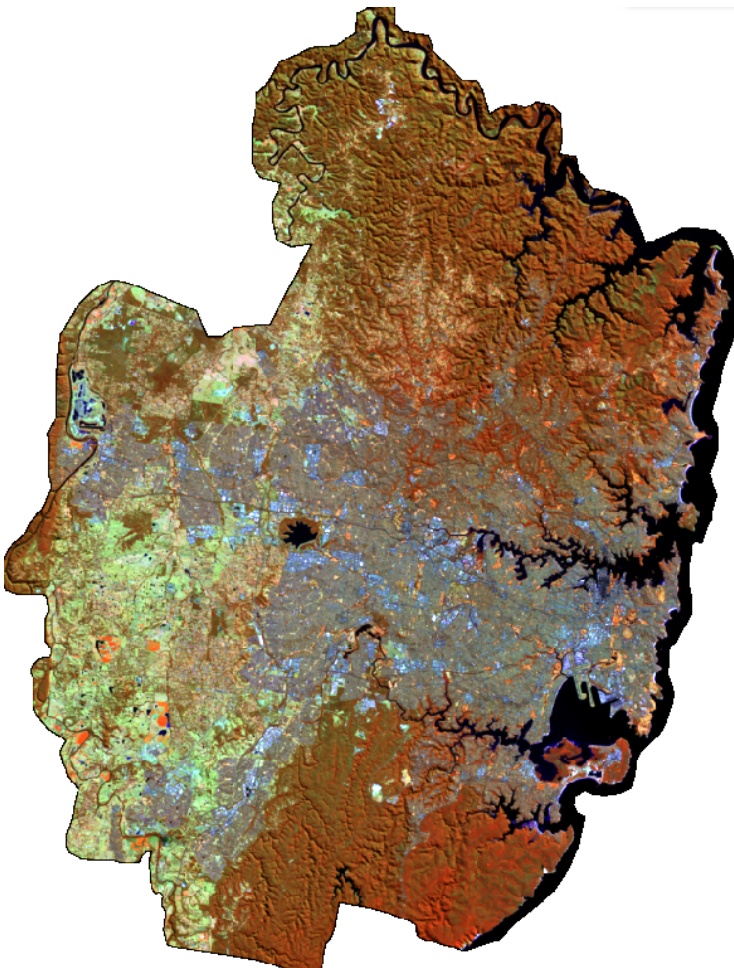
What Land Cover Types Are We Classifying?

Our objective is to use the Landsat images to identify three land cover categories. These are WATER, BUILT-UP and OTHER. These are defined as:

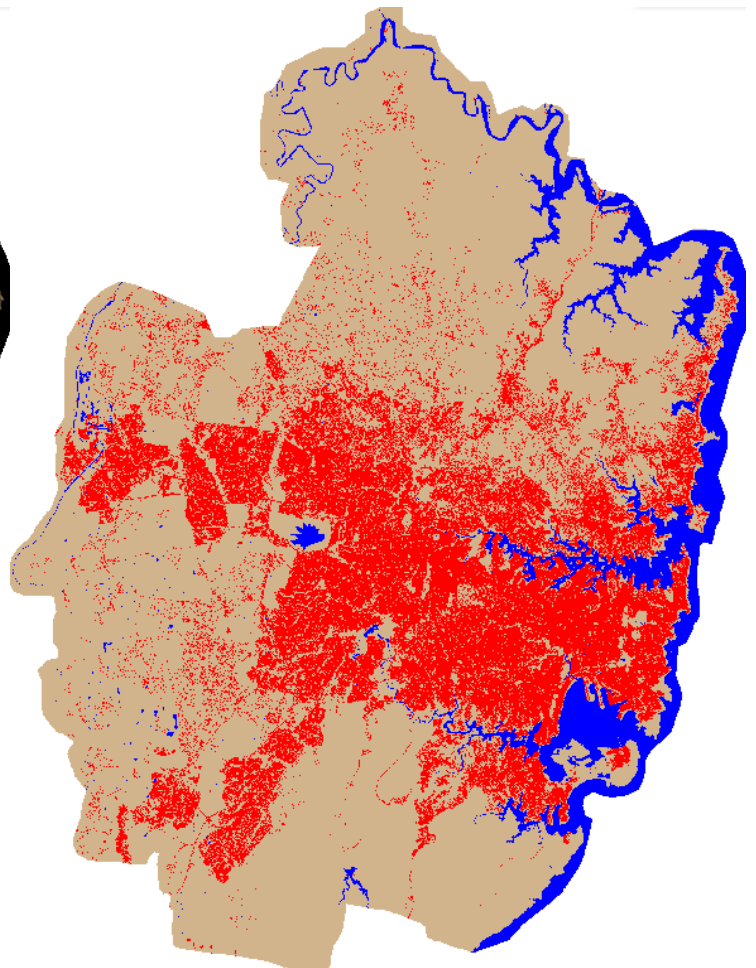
WATER – any Landsat pixel that is comprised of surface water that is readily apparent in the Landsat image. This will include oceans, lakes, ponds, reservoirs, rivers, streams, canals, pools, flooded wetlands.

BUILT-UP – any Landsat pixel that is comprised of structures or surfaces constructed by humans that is readily apparent in the Landsat image. This will include buildings, roads, parking lots, racetracks, railroads, docks

OTHER – any Landsat pixel that is comprised of vegetated surfaces and barren areas. This will include forests, agricultural crops, fallow agricultural fields, wetlands, grass lands, desert lands, beaches, mountain tops, open pit mines and other land cover types that are not water or built-up.

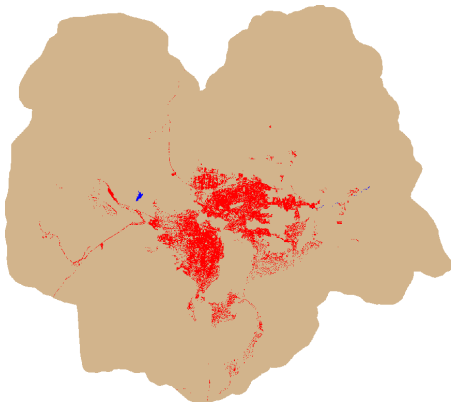


Above: 2014 Landsat image of Sydney, Australia.
(Band Combination R = b4, G = b5, B = b3)

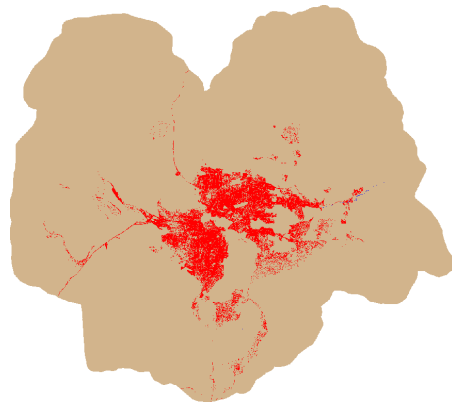


Above: 2014 Land cover classification of Sydney, Australia.
(BLUE = Water TAN = Other RED = Built-up)

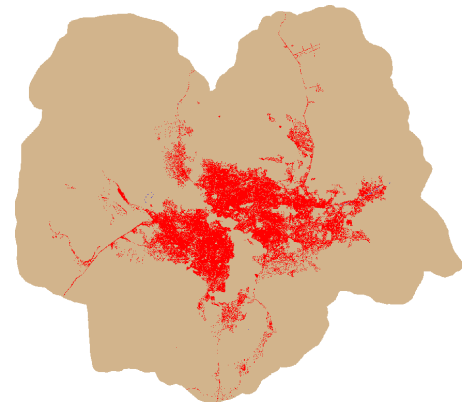
Our goal is to have three dates of land cover for each city that identify **Water**, **Built-up** and **Other** land cover (see examples below). We use these classifications to track the change in built-up land cover over time and identify areas of urban expansion.



Above: Circa 1990 Land cover classification of Kabul, Afghanistan.



Above: Circa 2000 Land cover classification of Kabul, Afghanistan.
BLUE = Water TAN = Other RED = Built-up

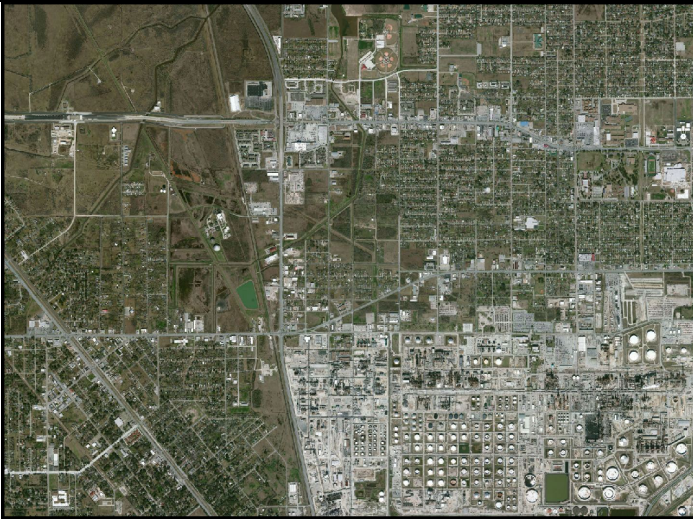


Above: Circa 2014 Land cover classification of Kabul, Afghanistan.

Example Images and Classifications

On the following pages are examples of image data and resulting land cover classifications covering various landscapes. From top to bottom are (1) a high resolution image in true color, (2) Landsat image with a band combination of 4,5,3 and (3) resulting land cover classification from the Landsat image.

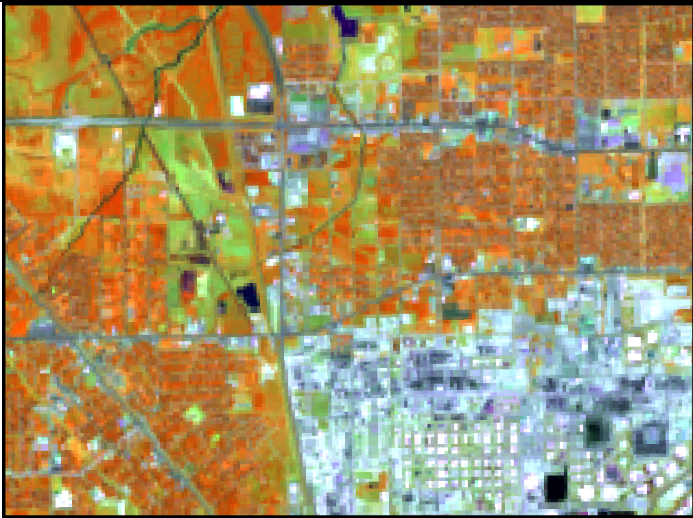
Examine these to get a better understanding of how the Landsat images produce a classified land cover layer.



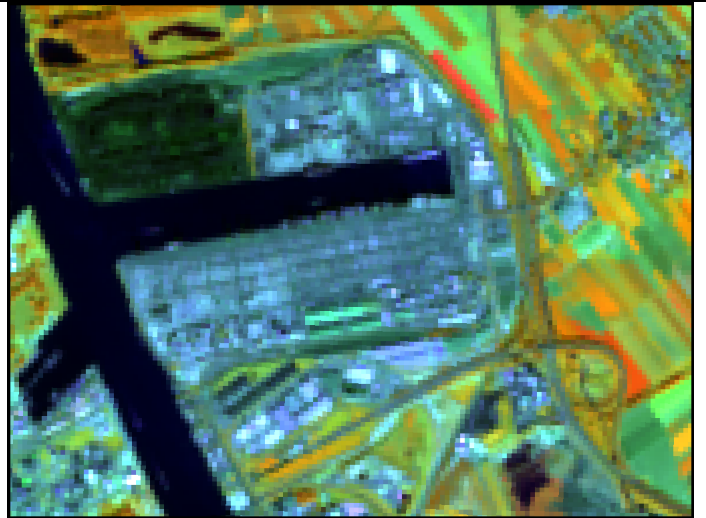
High Spatial Resolution Image



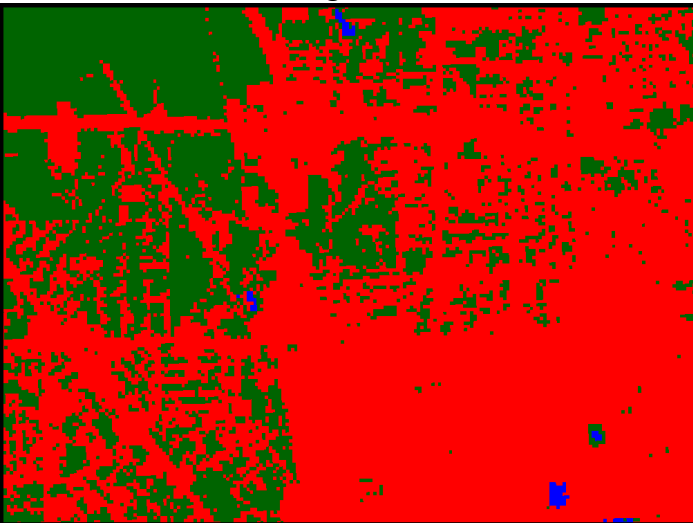
High Spatial Resolution Image



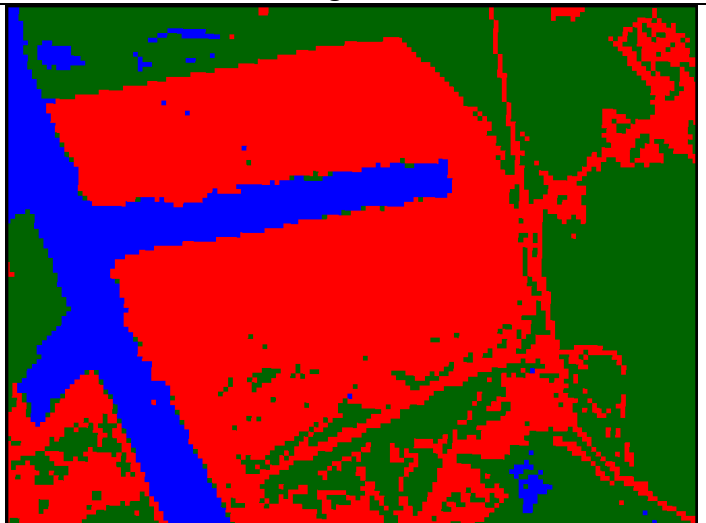
Landsat Image Bands 4, 5, 3



Landsat Image Bands 4, 5, 3



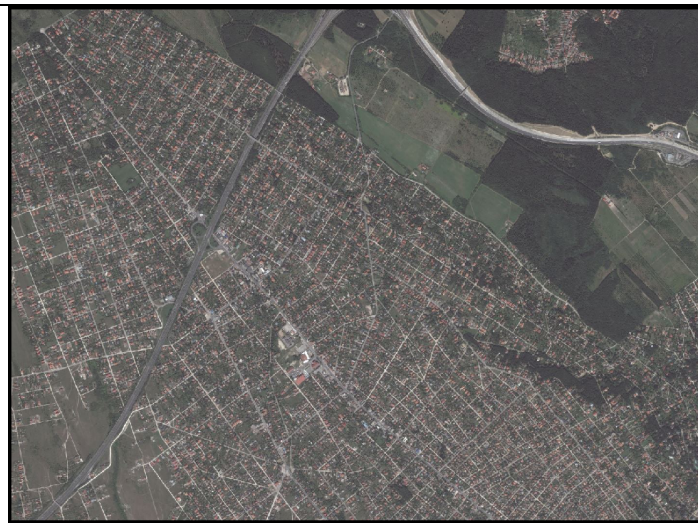
Classified Land Cover



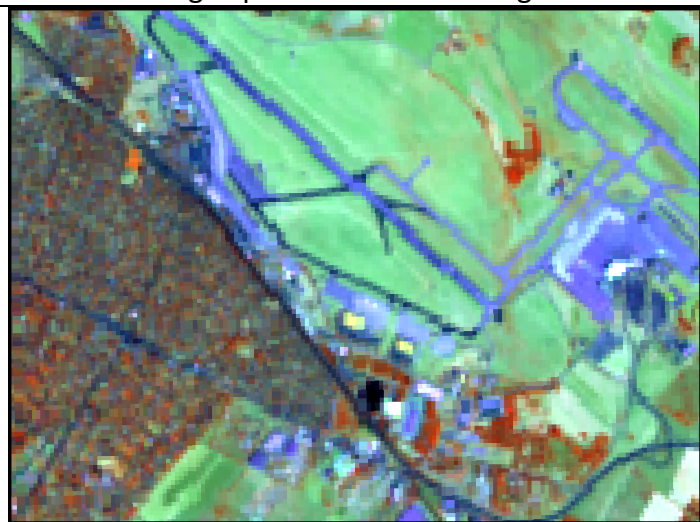
Classified Land Cover



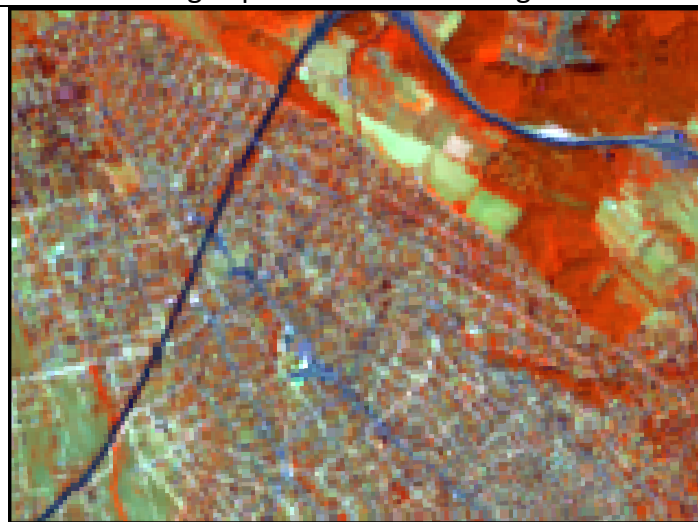
High Spatial Resolution Image



High Spatial Resolution Image



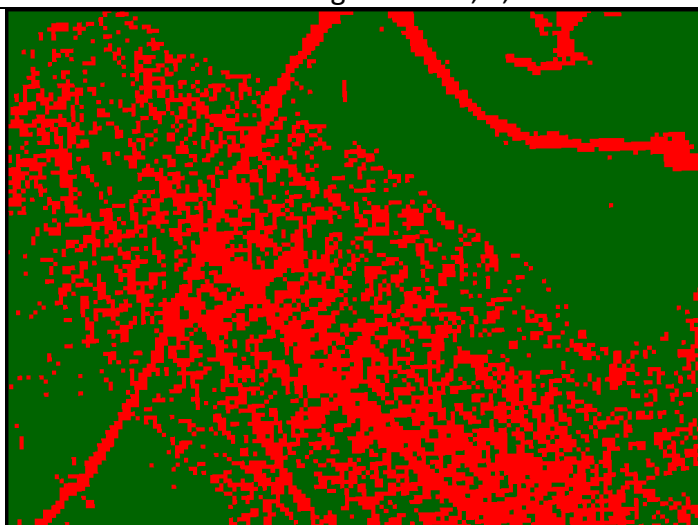
Landsat Image Bands 4, 5, 3



Landsat Image Bands 4, 5, 3



Classified Land Cover



Classified Land Cover



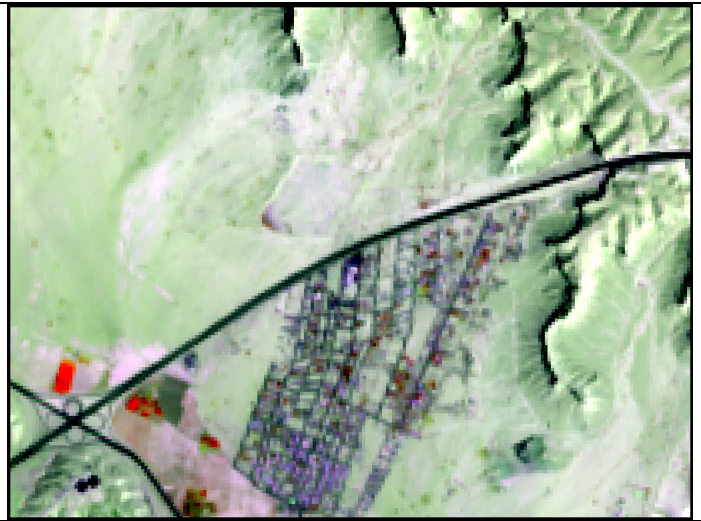
High Spatial Resolution Image



High Spatial Resolution Image



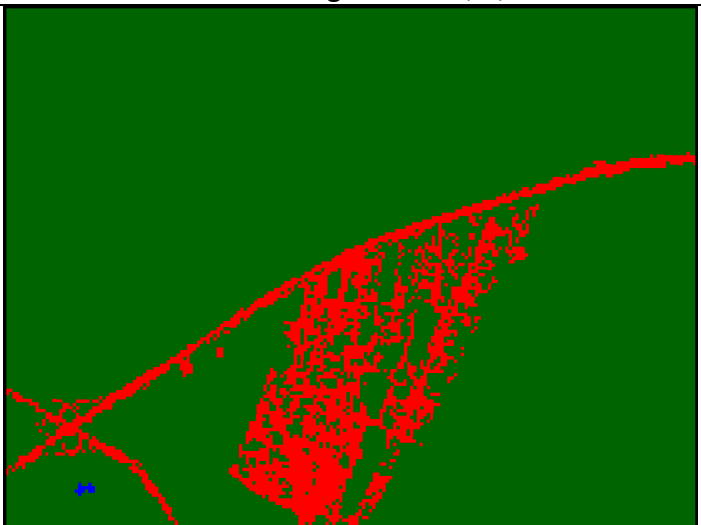
Landsat Image Bands 4, 5, 3



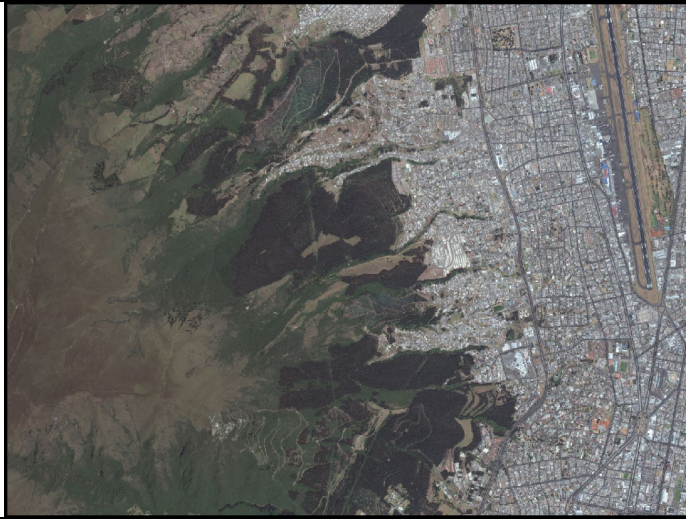
Landsat Image Bands 4, 5, 3



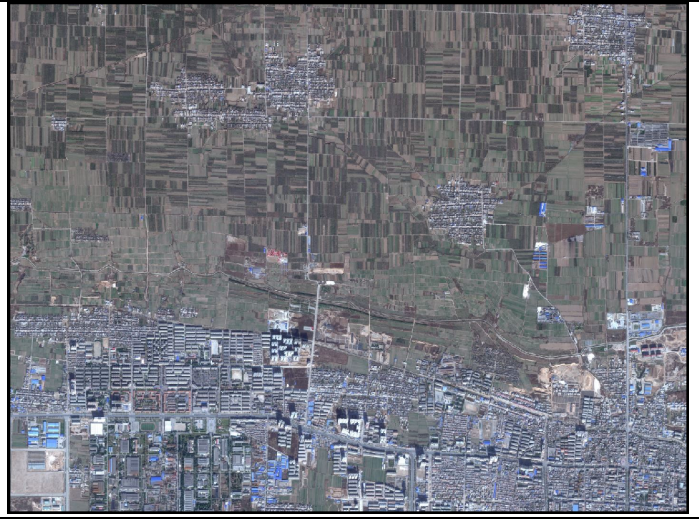
Classified Land Cover



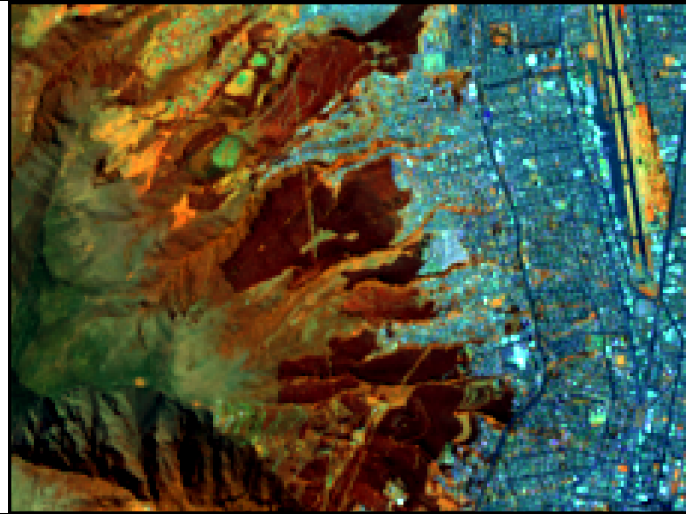
Classified Land Cover



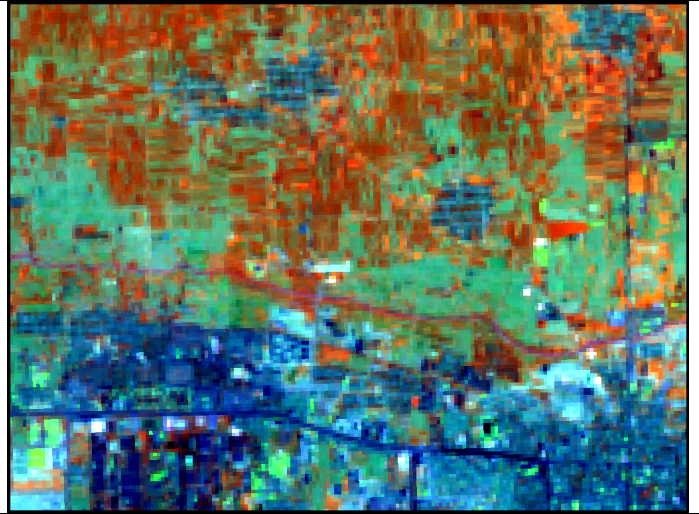
High Spatial Resolution Image



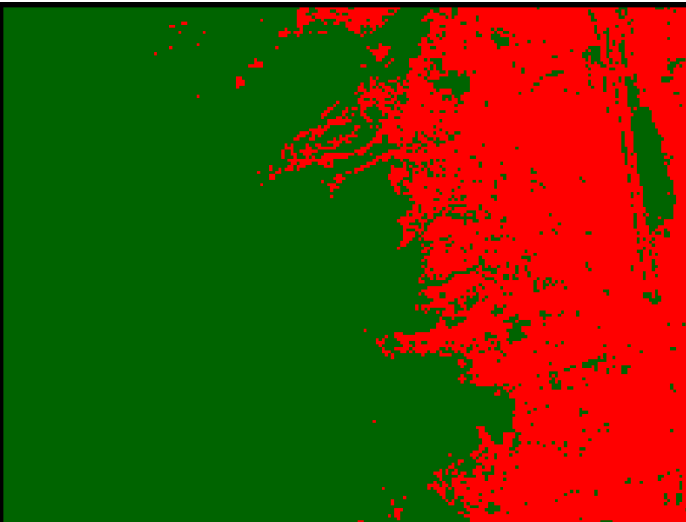
High Spatial Resolution Image



Landsat Image Bands 4, 5, 3



Landsat Image Bands 4, 5, 3



Classified Land Cover



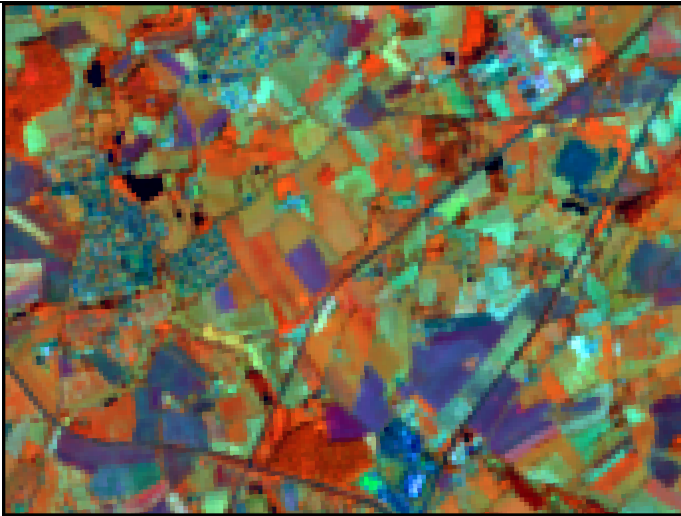
Classified Land Cover



High Spatial Resolution Image



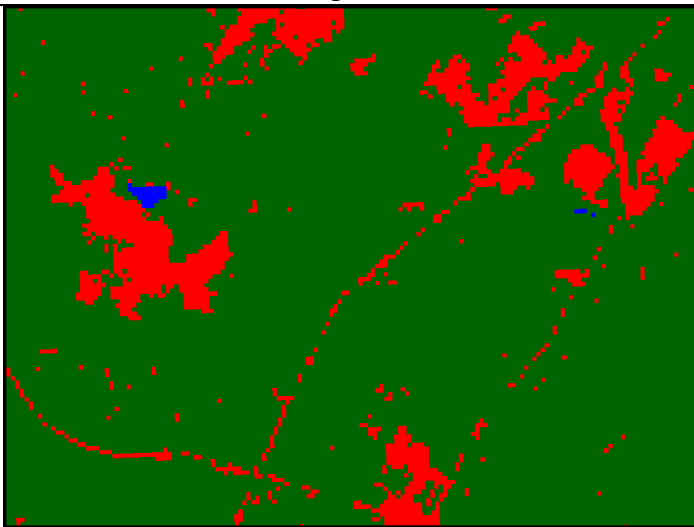
High Spatial Resolution Image



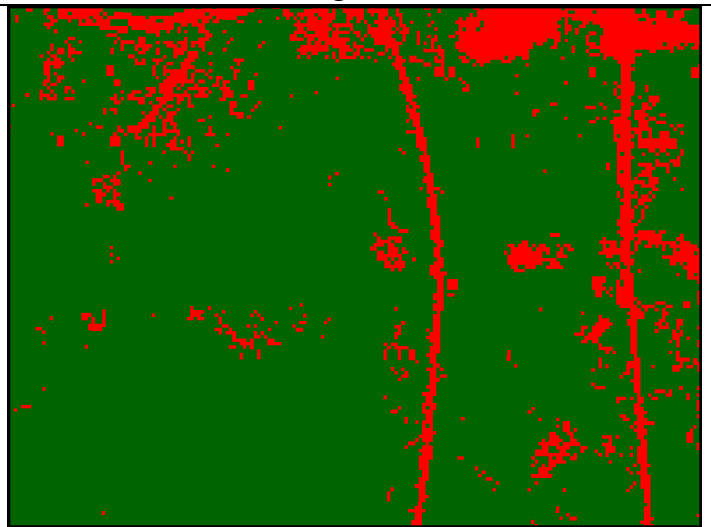
Landsat Image Bands 4, 5, 3



Landsat Image Bands 4, 5, 3



Classified Land Cover



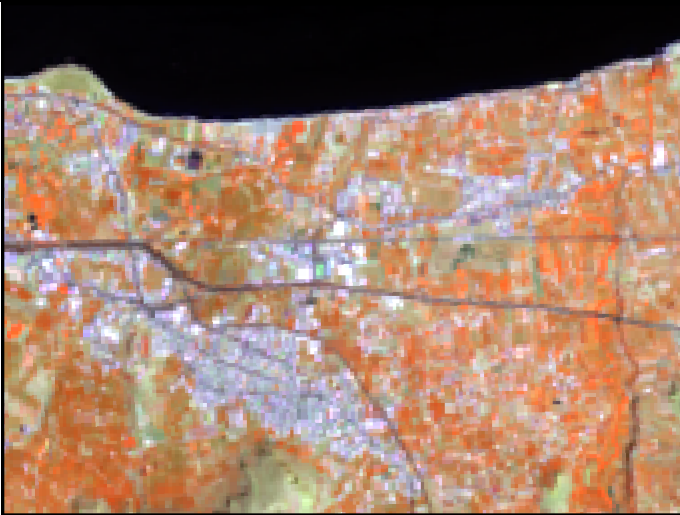
Classified Land Cover



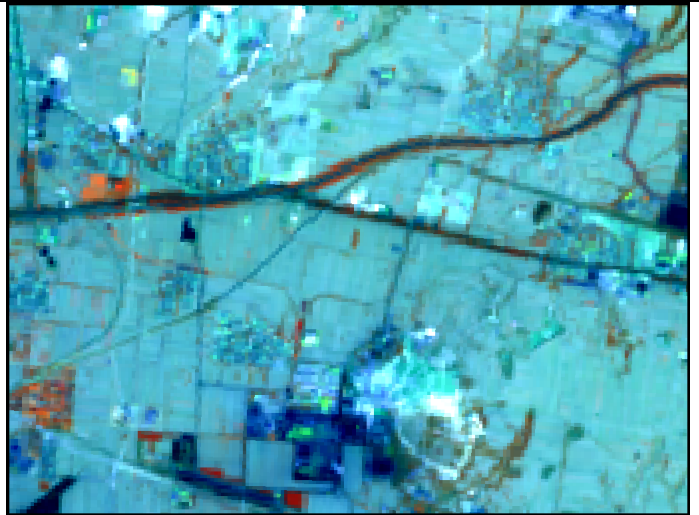
High Spatial Resolution Image



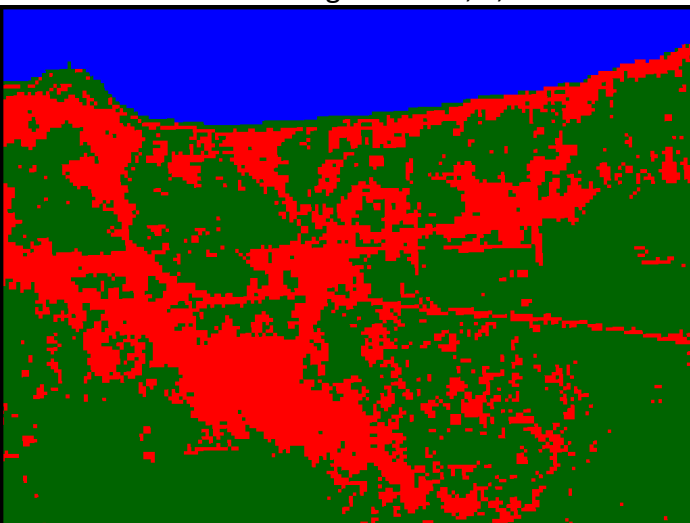
High Spatial Resolution Image



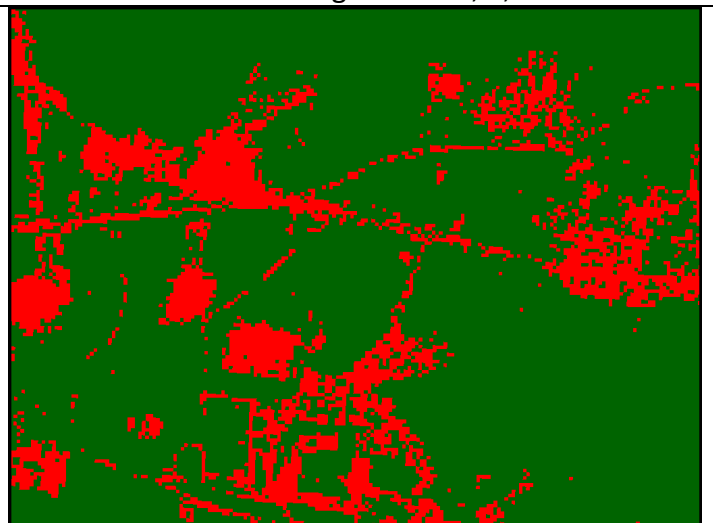
Landsat Image Bands 4, 5, 3



Landsat Image Bands 4, 5, 3



Classified Land Cover



Classified Land Cover

PART 2 Classification Process

The classification algorithm we are using is known as ISODATA (Iterative Self-Organizing Data Analysis Technique). It is iterative in that it repeatedly performs an entire classification (outputting a thematic raster layer) and recalculates statistics. Self-Organizing refers to the way in which it locates the clusters that are inherent in the data. The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with arbitrary cluster means, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration.

On the first iteration of the ISODATA algorithm, the means of N clusters will be arbitrarily determined. Following each iteration, a new mean for each cluster is calculated, based on the actual spectral locations of the pixels in the cluster, instead of the initial arbitrary calculation. These new means are used for defining clusters for the next iteration. The process continues until there is little change between iterations.

The initial cluster means are distributed in feature space along a vector that runs between the point at spectral coordinates

$$(\mu_1 - \sigma_1, \mu_2 - \sigma_2, \mu_3 - \sigma_3, \dots, \mu_n - \sigma_n)$$

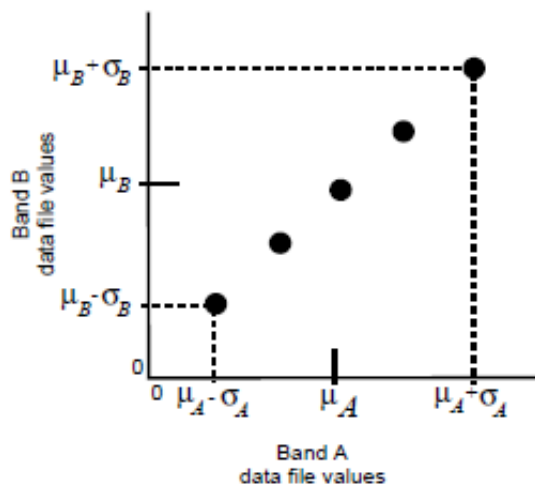
and the coordinates

$$(\mu_1 + \sigma_1, \mu_2 + \sigma_2, \mu_3 + \sigma_3, \dots, \mu_n + \sigma_n)$$

Such a vector in two dimensions is illustrated in the figure below. The initial cluster means are evenly distributed between

$$(\mu_A - \sigma_A, \mu_B - \sigma_B) \text{ and } (\mu_A + \sigma_A, \mu_B + \sigma_B)$$

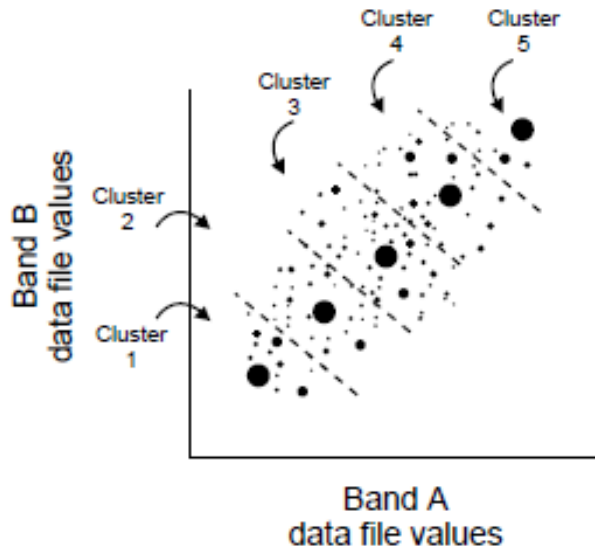
The figure below shows five arbitrary cluster means in two-dimensional (2 band) spectral space.



Above: ISODATA arbitrary clusters distribution

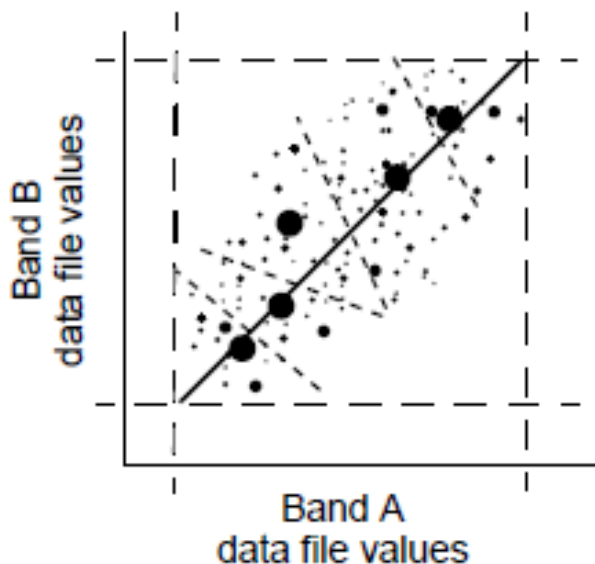
Pixels are analyzed beginning with the upper left corner of the image and going left to right, block by block.

The spectral distance between the candidate pixel and each cluster mean is calculated. The pixel is assigned to the cluster whose mean is the closest (minimum spectral distance formula). Considering the regular, arbitrary assignment of the initial cluster means, the first iteration of the ISODATA algorithm always gives results similar to those in the figure below (the separation between cluster means is evenly distributed).



Above: ISODATA first pass distribution

For the second iteration, the means of all clusters are recalculated, causing them to shift in feature space. The entire process is repeated—each candidate pixel is compared to the new cluster means and assigned to the closest cluster mean.



Above: ISODATA second pass distribution

The ISODATA method repeats the clustering of the image until either:

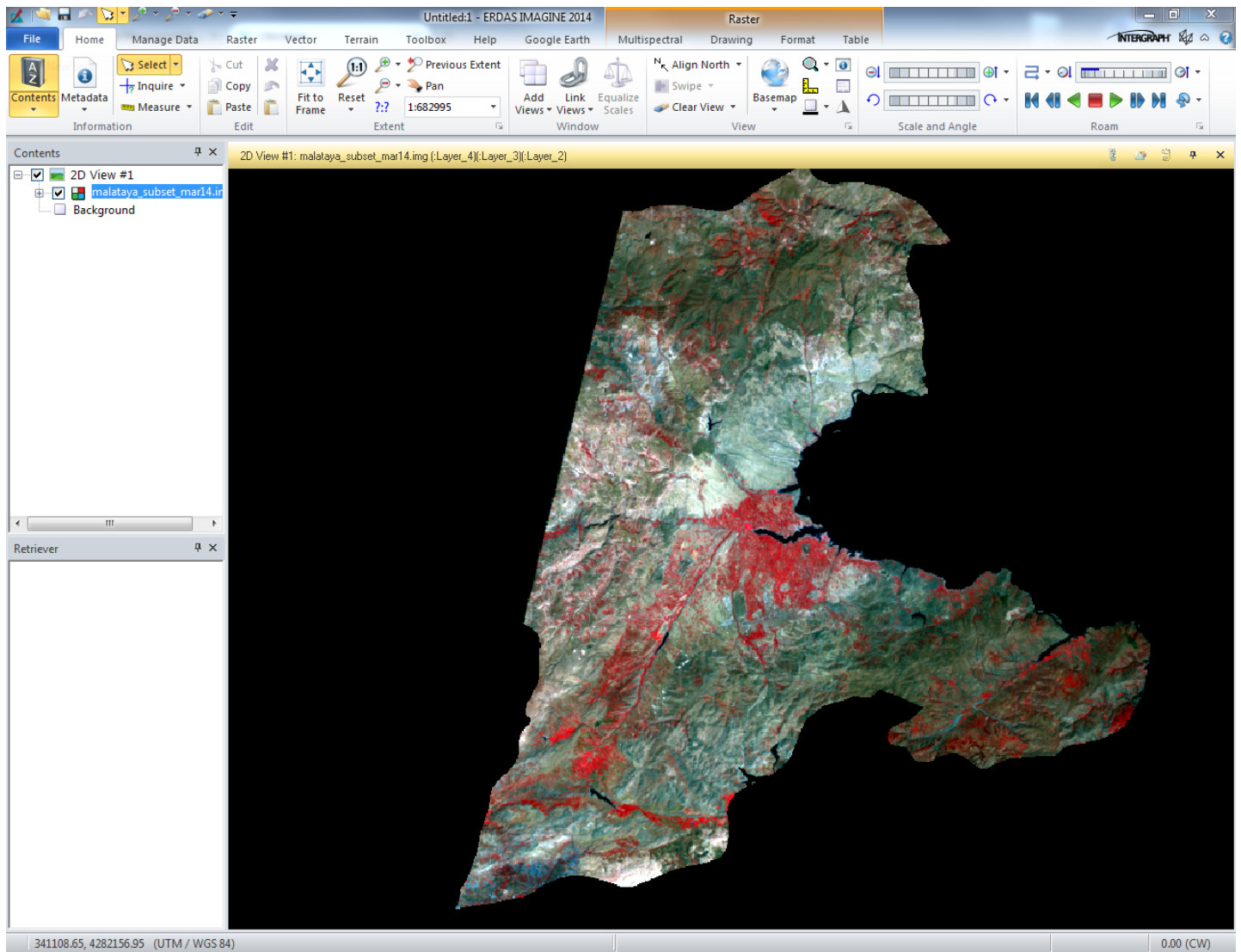
- a maximum number of iterations has been performed (Maximum Iterations), or
- a maximum percentage of unchanged pixels has been reached between two iterations (Convergence Threshold).

The resulting ISODATA clusters are labeled starting with Class 1 to Class N (depending on the number of classes specified). Class 1 will be comprised of darker pixels while the higher clusters will be comprised of brighter pixels.

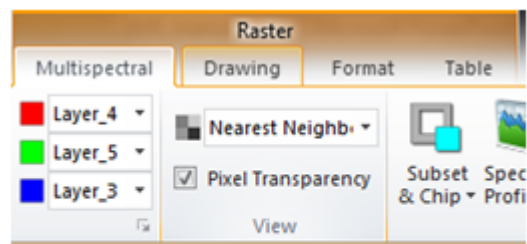
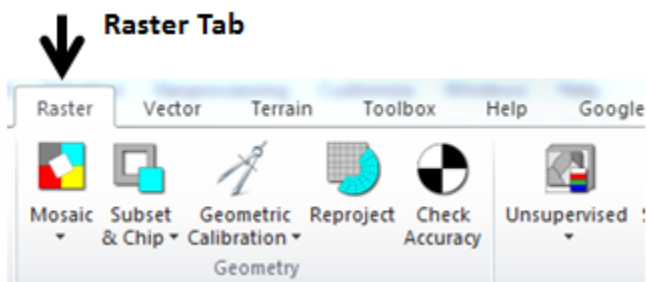
The advantages of using ISODATA are: you don't need to have a lot of knowledge about the image beforehand, little user effort is required, and it is very effective at identifying spectral clusters in data.

Overview ERDAS IMAGINE

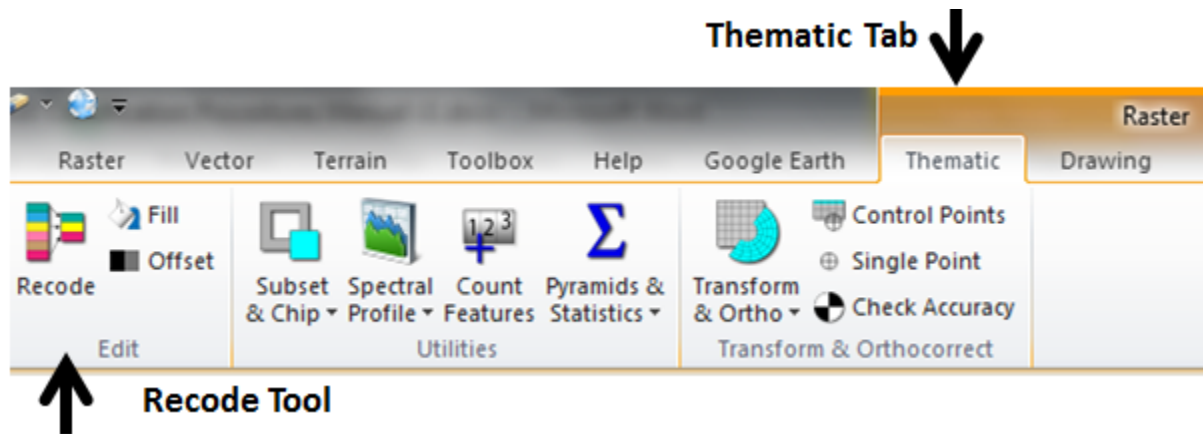
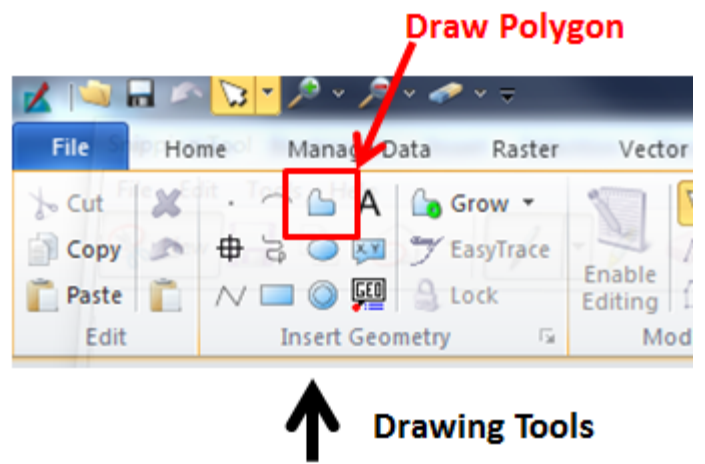
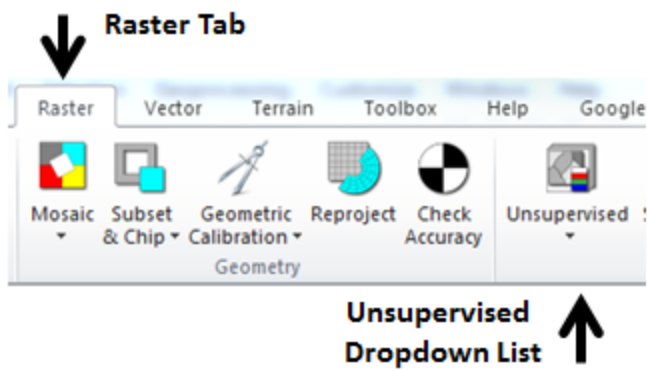
Below is the basic ERDAS IMAGINE window as it appears when a raster image has been loaded.



Some basic tools you will need:



↑ Change Bands in Landsat Image



During training you will become more familiar with the location and function of these tools.

Classification Steps

STEP 1:

Load the Landsat image in the ERDAS IMAGINE View window.

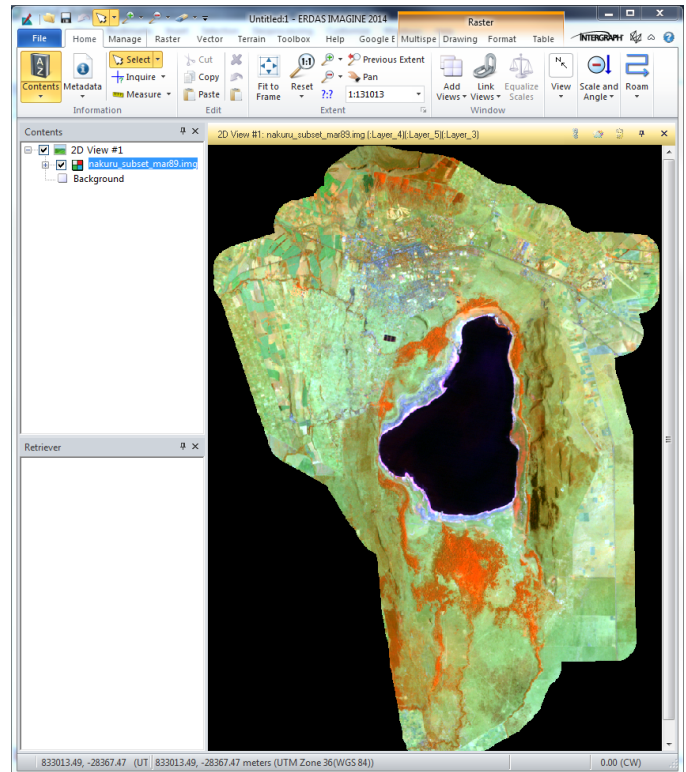
NOTE: The Landsat image provided has a specific naming nomenclature. It includes the city name, subset (specifies it is a subset of a larger scene clipped to administrative boundaries), and the month and year the image was collected.

CITY NAME_subset_MONTHYEAR.img

EXAMPLE: Nakuru_subset_mar89.img

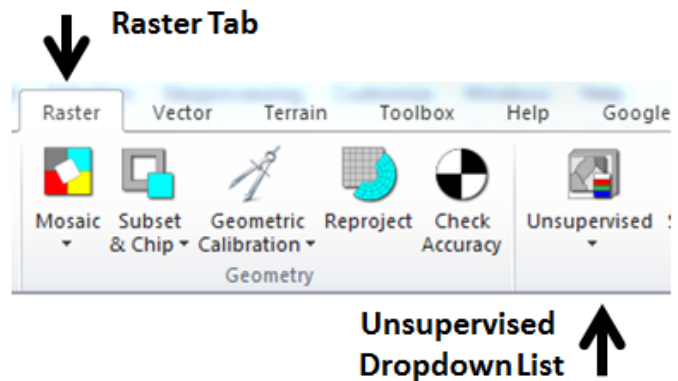
NOTE: The Landsat image supplied might also have a “masked” label meaning the built-up pixels from a previous date have been masked out.

EXAMPLE: Nakuru_subset_mar89_masked.img



STEP 2:

Under the Raster tab, click on the Unsupervised dropdown list and click on Unsupervised Classification.



STEP 3:

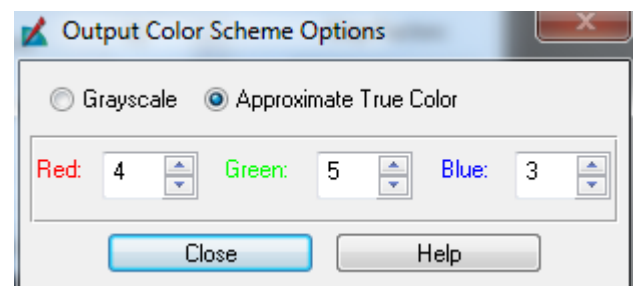
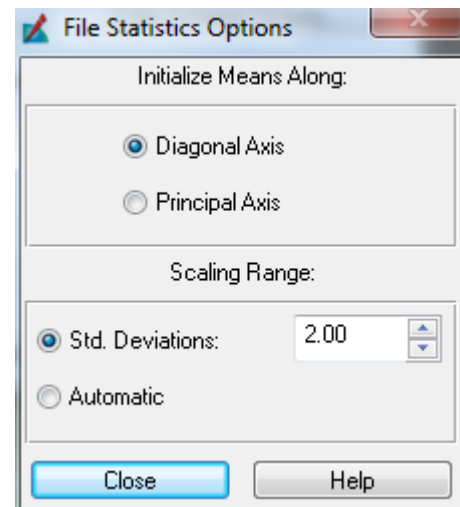
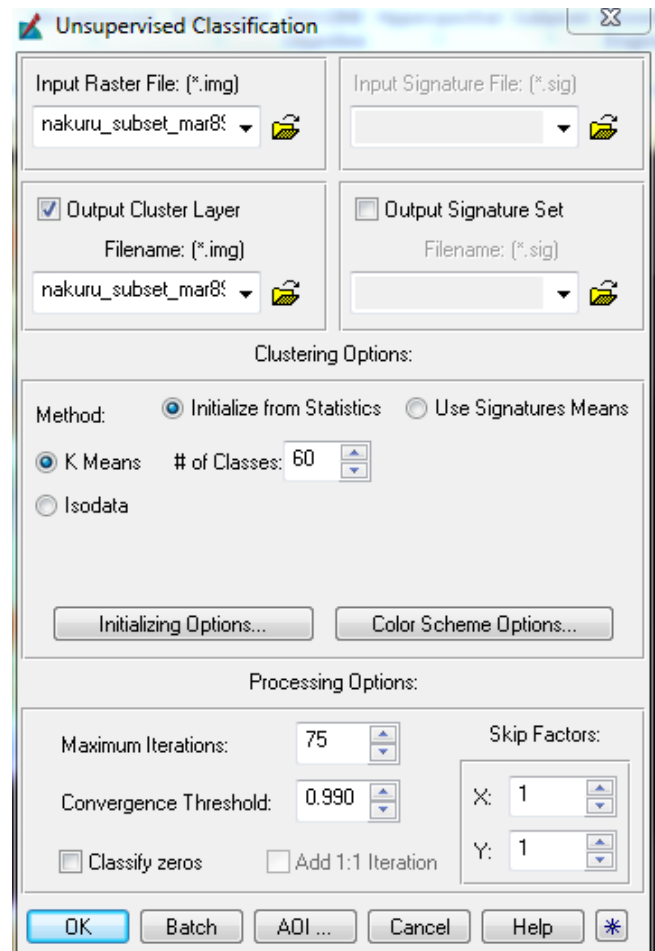
Set parameters in the Unsupervised Classification window.

- **Input Raster File:** Enter the name of the image on which to perform clustering.
EXAMPLE: Nakuru_subset_mar89.img
- **Output Cluster Layer:** Enter the name of the output classified thematic raster image
EXAMPLE: Nakuru_subset_mar89_60cl.img

NOTE: Following the naming nomenclature we add **60cl** which identifies 60 classes are being created for this classified image (see # of Classes below).

- **Clustering Options:** Define how the initial cluster means are generated. The clusters are generated from the input file.
 - o Check **Initialize from Statistics**
 - o Check **K Means** (Pixels are iteratively classified into this number of clusters without any deleting, splitting, or merging during the process.)
 - o **# of Classes = 60**
 - o Initializing Options Button
 - Diagonal Axis
 - Std. Deviations = 2.00
 - o Color Schemes Options Button
 - Approximate True Color
 - Red 4, Green 5, Blue 3
- **Processing Options:**
 - o Maximum Iteration = **75**
 - o Convergence Threshold = **0.990**

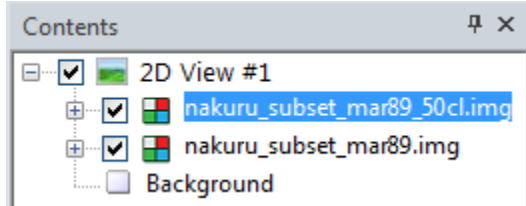
Click OK to run Unsupervised Classification.



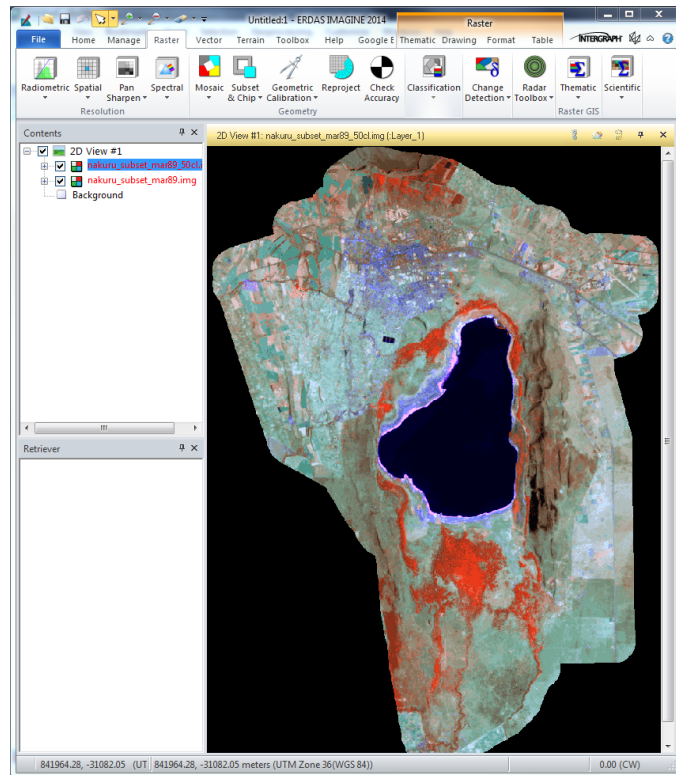
STEP 4:

Load the output cluster layer from the Unsupervised Classification process in the ERDAS IMAGINE View window over the Landsat image.

- Right click on output Cluster Layer in Table of Contents on the left of the View window.



- Click on Display Attribute Table (window appears at the bottom of the screen)
- Identify and label clusters.

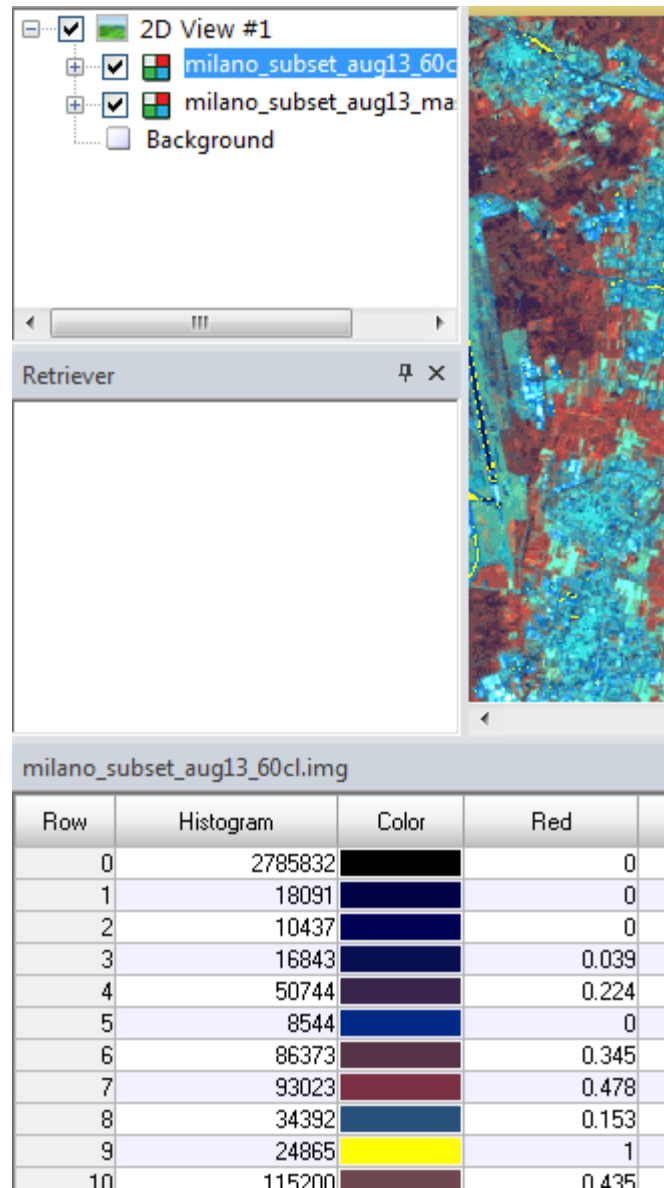


Row	Histogram	Color	Red	Green	Blue	Opacity	Class_Names
0	2785832		0	0	0	0	Unclassified
1	18091		0	0	0.267	1	Class 1
2	10437		0	0	0.337	1	Class 2
3	16843		0.039	0.059	0.306	1	Class 3
4	50744		0.224	0.145	0.298	1	Class 4
5	8544		0	0.161	0.525	1	Class 5
6	86373		0.345	0.2	0.286	1	Class 6
7	93023		0.478	0.192	0.259	1	Class 7
8	34392		0.153	0.318	0.482	1	Class 8
9	24865		0	0.345	0.667	1	Class 9
10	115200		0.435	0.286	0.31	1	Class 10
11	116526		0.608	0.22	0.263	1	Class 11
12	69944		0.333	0.361	0.404	1	Class 12
13	178106		0.541	0.298	0.302	1	Class 13
14	61670		0.122	0.442	0.620	1	Class 14

To identify and label clusters, change the color of each cluster to yellow to identify it in the image. Turn off and on the cluster image over the Landsat image to help you identify the clusters.

Notice in the image to the right that cluster 9 has been colored yellow. Pixels belonging to cluster 9 appear yellow in the image.

NOTE: Since we are most interested in Built-up land cover, when labeling the clusters and you are not sure if it is Built-up or Other, error on the side of calling the cluster Built-up.



Once you determine which class it represents, change the Color to – Blue for **Water**, Green for **Other** Red for **Built-up** –

AND

change the Class Name to 1 for **Water**, 2 for **Other** 3 for **Built-up**.

Continue this process for each of the clusters until all the clusters have been colored and labeled similar to the image to the right.

Right click on the cluster image in the Table of Contents and Save Layer As

CITY NAME_Tx_TEMP.img

EXAMPLE: Budapest_T3_temp.img

This is the classification file you will use for editing. This will prevent the loss of data from the original classification.

Row	Color	Class_Names
0	Black	Unclassified
1	Blue	1
2	Blue	1
3	Green	2
4	Green	2
5	Green	2
6	Green	2
7	Red	3
8	Green	2
9	Green	2
10	Green	2
11	Green	2
12	Green	2
13	Red	3
14	Green	?

STEP 5:

Recode the 60 clusters into the 3 classes of Water, Other, Built-up based on your identification and labeling.

Make sure the cluster layer is highlighted in the Table of Contents.

Click on the Recode Tool under the Thematic Tab.

In the Recode Window Copy the Class Name values (1, 2, 3) into the New Values column.

Click Apply.

Right click on the previously saved TEMP file and Save.

Remove the TEMP file from the Table of Contents and then Open it again.

Right click on the TEMP file and open the Display Attribute Table. Change the colors so Class 1 is Blue, Class 2 is Green, Class 3 is Red.

Row	Old Value	New Value	Histogram	Red	Green	Blue	Class Names
0	0	0	1.03136e+006	0	0	0	Unclassified
1	1	1	32382	0	0	0	11
2	2	2	4749	0	0	0	11
3	3	3	7176	0	0.392157	0	02
4	4	4	2855	0	0.392157	0	02
5	5	5	16132	0	0.392157	0	02
6	6	6	20673	0	0.392157	0	02
7	7	7	6678	1	0	0	03
8	8	8	51808	0	0.392157	0	02
9	9	9	23667	0	0.392157	0	02
10	10	10	22365	0	0.392157	0	02
11	11	11	72374	0	0.392157	0	02
12	12	12	37472	0	0.392157	0	02

Row	Color	Red
0	Black	0
1	Blue	0
2	Green	0
3	Red	1

SUGGESTIONS:

- Remember that clusters containing dark pixels will be the lower numbered clusters (*i.e.* Class 1). These will typically represent water and shadowed areas. Higher numbered cluster will contain brighter pixels. These typically include barren and built-up (bright rooftops), and clouds if there are any in the image.
- Some clusters will be easy to identify as belonging to one of the three land cover categories. Other clusters will be comprised of a mix of land cover categories. IMPORTANT, if a clusters looks to contain pixels that are comprised of both Built-up and Other, label that cluster as Built-up.
- Clouds and cloud shadows may exist in some Landsat images. Since we cannot see through the clouds, we do not know what land cover is beneath them. Label clouds as Other. Cloud shadow will likely be labeled as Water.

Editing Steps

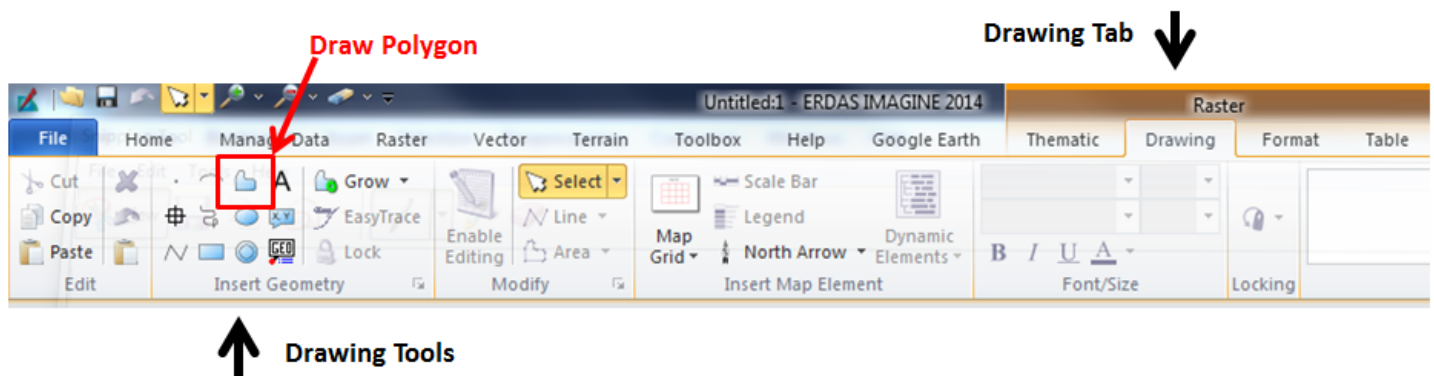
At this stage you should have a Landsat scene that has been classified into three land cover categories of Water, Other and Built-up.

To edit the resulting land cover classification in ERDAS IMAGINE, we will be creating AOI (Area Of Interest) files. These are essentially just polygon or line features that focus any processes on just those areas outlined by the AOI (hence the name Area Of Interest). The goal of editing is to outline those areas in the classification that we want to change. This will consist of changing those pixels that were incorrectly classified as Built-up into Other. In addition, we will likely need to do some edits to Water pixels because many of the mountainous areas contain shadows that have spectral characteristics that are very similar to water and thus need to be changed to Other.

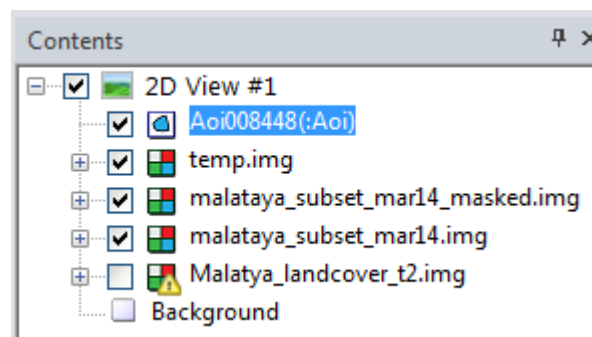
NOTE: Most of your time will be spent in the editing process. It is an easy process, but relies on your image interpretation skills. Do the best you can and rely on your co-workers to help you if you have difficulties identifying land cover features.

NOTE: When editing a T3 classification, you will likely encounter errors from the previous T2 classification. You do not need to concern yourself with what was incorrectly classified in T2. Just do not add to the errors.

STEP 1:

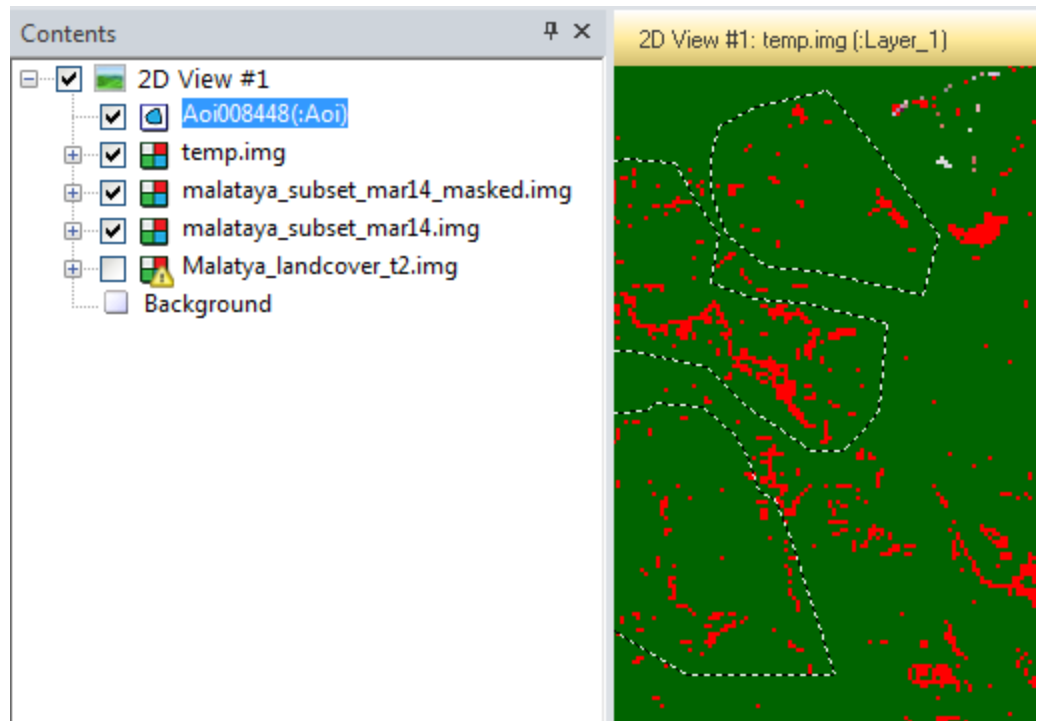


To begin drawing an AOI, In the raster tab select drawing. This will open the drawing tools as shown above. The drawing tool you will use almost exclusively is the polygon tool (outlined in red above). When you click on the polygon tool, an AOI file will be automatically generated and listed in the table of contents.



STEP 2:

Select the polygon tool and start drawing AOI polygons around the pixels you want to edit.

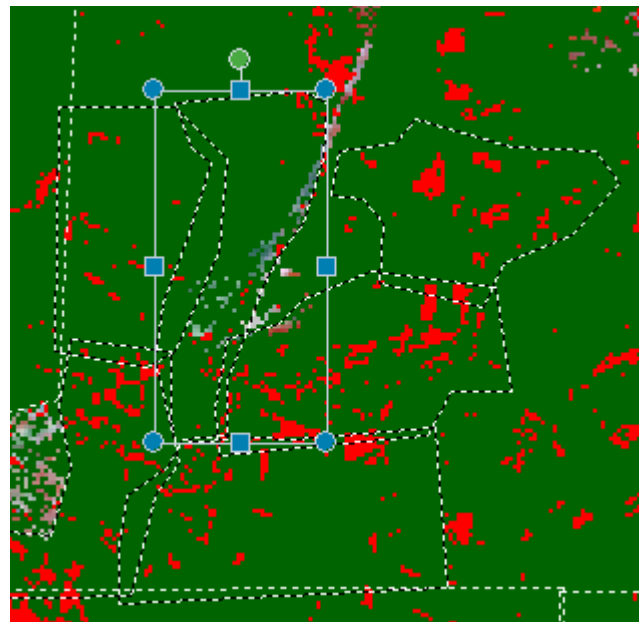


As you edit, you will want to save your AOI files so that you can come back later and continue with the editing process and also it provides us with a record of what was changed. This is one of the quirky things about ERDAS IMAGINE. *You can only have one AOI file opened at a time.* This AOI file can contain as many polygons and lines as you want. To save the AOI file, right click on it in the Table of Contents and give it a name. The naming nomenclature is as follows:

CITY NAME_TIME PERIOD_PURPOSE.img

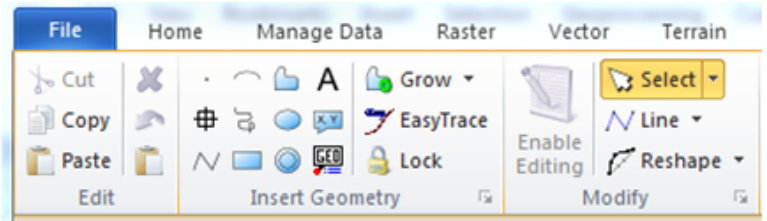
EXAMPLE: Nakuru_T3_builtup_clean.AOI

NOTE: AOI polygons can overlap. There is no need to keep polygon boundaries aligned with neighbor polygons (see image to right).

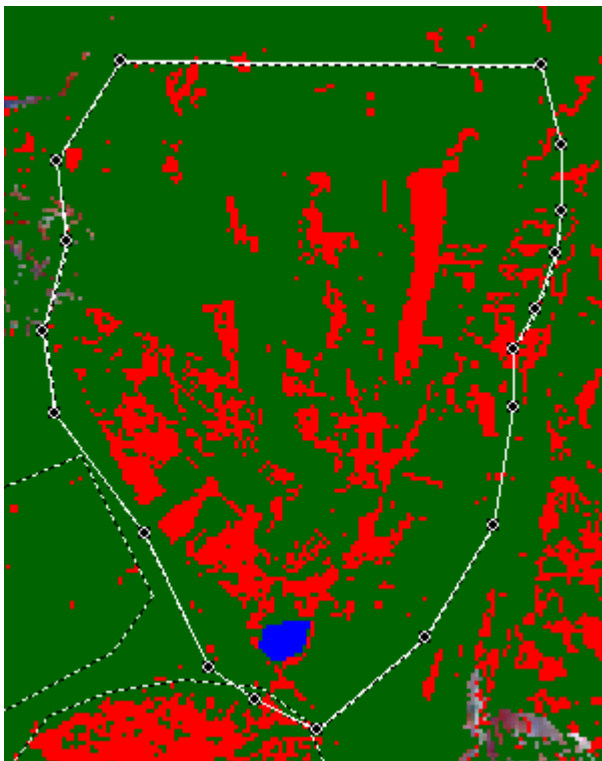


Additional Editing Tools

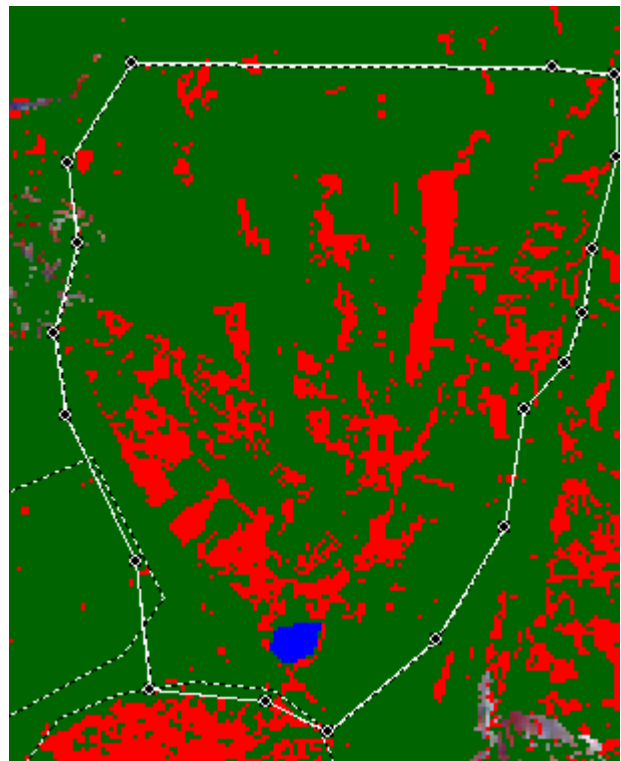
After you have drawn an AOI polygon or line and you want to make a change to its extent, you can use the Reshape Tool to drag vertices or lines to new locations. Select the AOI polygon you want to change then click on Reshape. The polygon will display with vertices shown in the view window. Click and drag these vertices to a new location, or click and drag the line segment between two vertices to a new location.



Reshape Tool



Original polygon extent

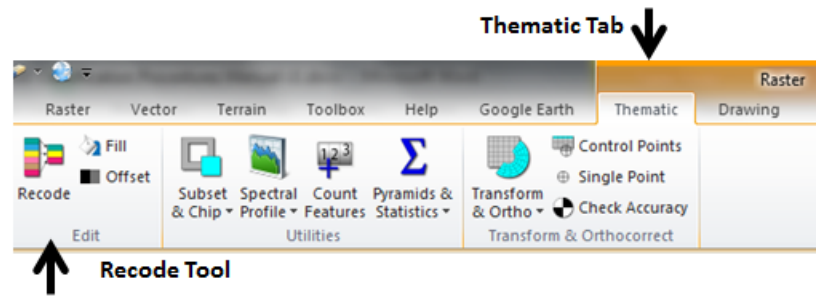


Reshaped polygon extent

When you have completed the creation of AOIs to edit the classification, you will use the Recode Process to change the pixels within the AOIs from one land cover category to another. In the example below, land cover pixels classified as class 3 (Built-up) are being recoded to class 2 (Other).

STEP 3:

Once you are satisfied with your polygons, it is time to recode the misclassified pixels from one category to another, in this instance Built-up to Other.



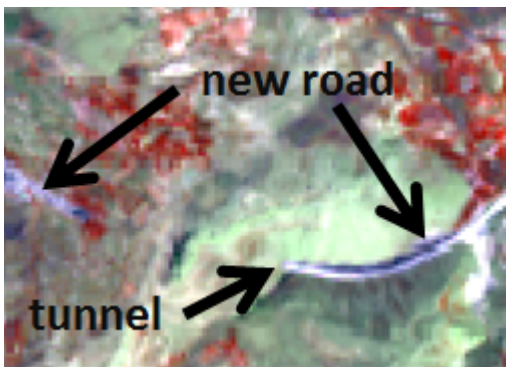
Make sure the cluster layer is highlighted in the Table of Contents.

Use the Recode Tool to change Built-up class value 3 to the Other class value of 2 in the New Value column.

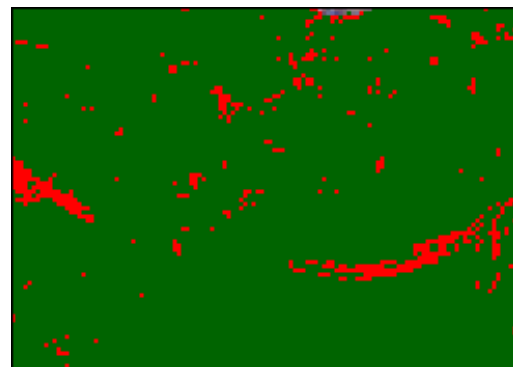
Row	Old Value	New Value
0	0	0
1	1	1
2	2	2
3	3	2

Click Apply

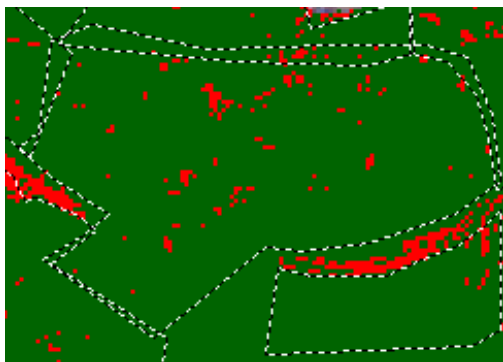
The recode should be applied only to the pixels within the AOI polygons as shown in the examples below.



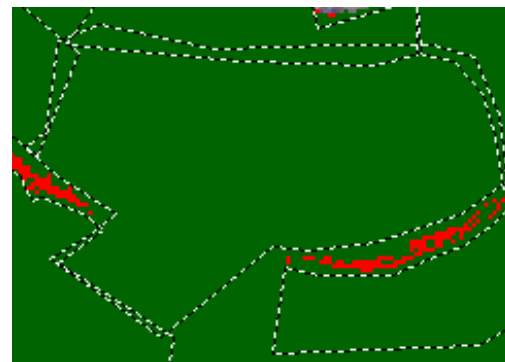
(1) Landsat image showing new road and tunnel.



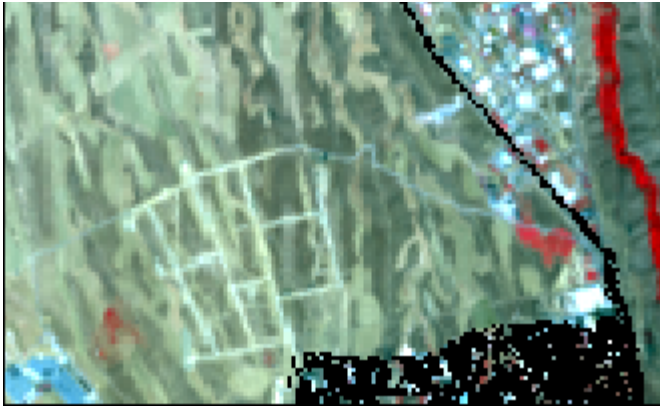
(2) Resulting classification after labeling of clusters.



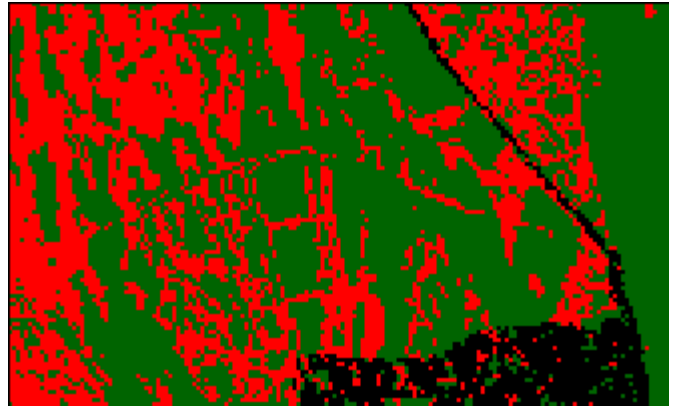
(3) AOIs drawn to eliminate misclassified Built-up pixels.



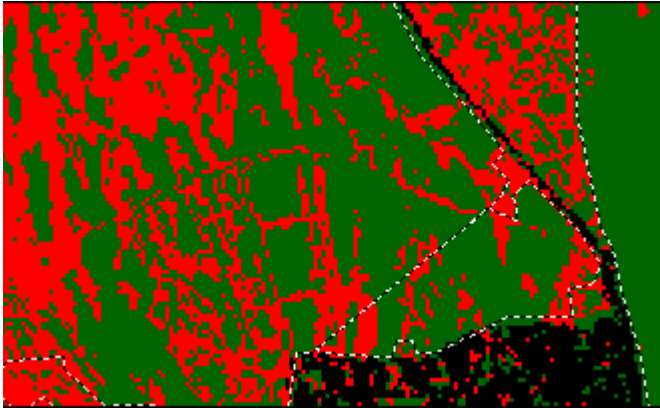
(4) Classification following edits.



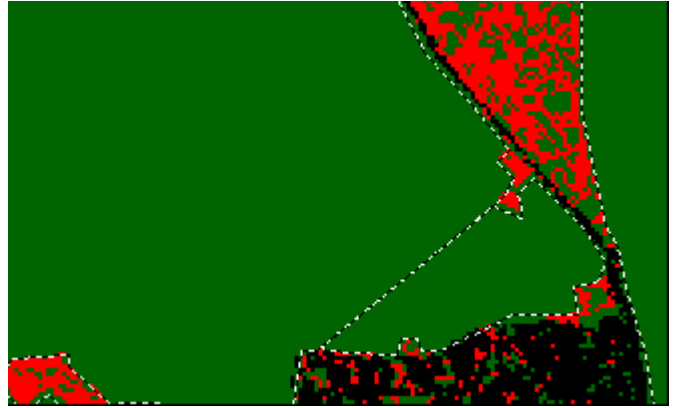
(1) Landsat image showing new road and tunnel.



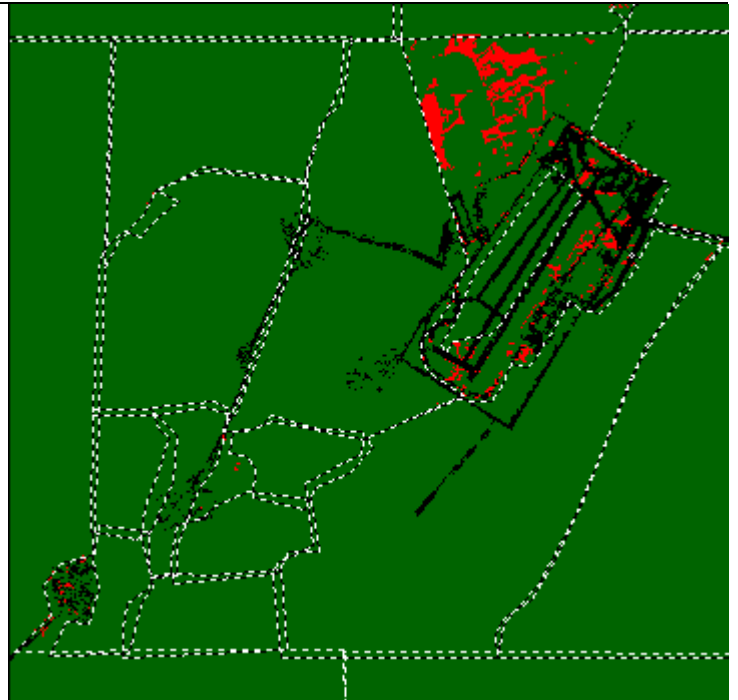
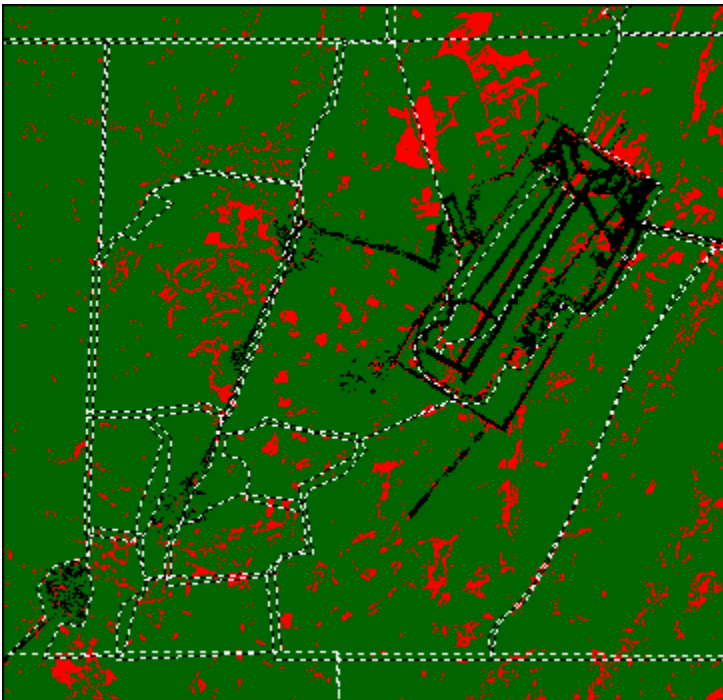
(2) Resulting classification after labeling of clusters.



(3) AOIs drawn to eliminate misclassified Built-up pixels.



(4) Classification following edits.



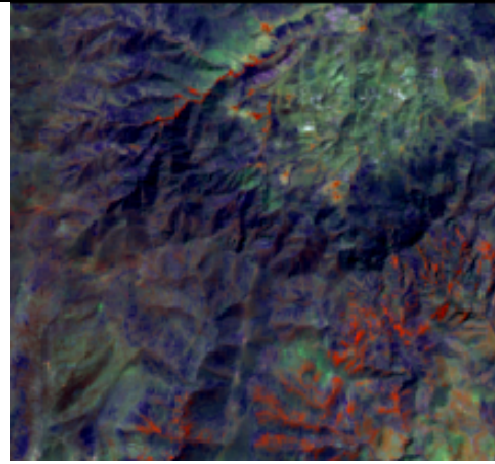
NOTE: Make sure to save both the AOI file and the edited land cover layer. Remove the AOI file from the Table of Contents.

STEP 4:

In some cases Water will also need to be cleaned. This will follow the same procedure used as for editing the Built-up pixels.

Open a new AOI file by clicking on the Polygon drawing tool. Give the new AOI file a new name:

EXAMPLE: Nakuru_T3_water_clean.AOI



Mountain shadows identified as water.

Once you are satisfied with your polygons, recode the misclassified pixels from one category to another, in this instance Water to Other.

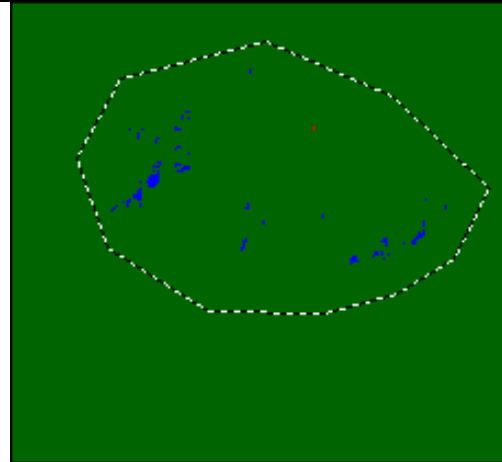
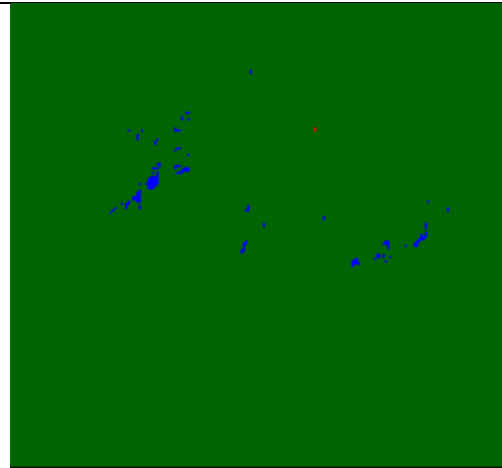
Make sure the cluster layer is highlighted in the Table of Contents.

Use the Recode Tool to change Water class value 1 to the Other class value of 2 in the New Value column.

Row	Old Value	New Value
0	0	0
1	1	2
2	2	2
3	3	3

Click Apply

The recode should be applied only to the pixels within the AOI polygons.



NOTE: Make sure to save both the AOI file and the edited land cover layer. Remove the AOI file from the Table of Contents.

CONGRATULATIONS! The classification process is now complete. The classification layer should now be saved in the dropbox for review.