DESERTIFICATION PROCESS INVESTIGATION ON LORDSBURG PLAYA

ArcGIS Pro Toolbox Documentation

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SOUTHERN PLAINS
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List of Abbreviations and Acronyms

HSIP .... Highway Safety Improvement Program
NDVI .... Normalized Difference Vegetation Index
NDMI .... Normalized Difference Moisture Index
NDDSI .... Normalized Difference Dry Soil Index
NMDOT .... New Mexico Department of Transportation
NWS .... National Weather Service

Background

The Lordsburg Playa in New Mexico is a recognized global hotspot for dust storms, contributing to 17 crash fatalities on I-10 in the area since 2014. In recent years, climate change has contributed to alterations in vegetation and weather dynamics, further influencing the frequency and intensity of dust events in the region. In response to the pressing need for improved traffic safety, the New Mexico Department of Transportation (NMDOT) has implemented static and electronic message boards, a quicker warning system (i.e., the National Weather Service alerts, social media notifications, and website updates), rapid highway closures, and mitigation programs under the Highway Safety Improvement Program (HSIP) to revegetate the Lordsburg Playa area. While these initiatives have been very successful to date, NMDOT remains interested in exploring the relationships between desertification (caused by factors such as drought, cattle grazing, and moisture loss) and the frequency of dust storms.

This ArcGIS Pro geoprocessing toolbox provides an automated workflow for detecting and characterizing significant landscape change, with an emphasis on desertification dynamics. The tools utilize multi-temporal Landsat imagery to derive key spectral indices, including the Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture Index (NDMI), and Normalized Difference Dry Soil Index (NDDSI). These indices function as indicators of vegetation condition, moisture availability, and soil exposure, respectively. The indices are subsequently evaluated using Mann–Kendall trend tests and hotspot analyses to identify statistically significant spatial and temporal patterns of change. The toolbox is designed to be flexible: users may apply it to other geographic contexts or incorporate alternative temporal frameworks beyond those employed in the accompanying report.

Data Preparation

This toolbox is designed to work exclusively with Landsat 8-9 Collection 2 Level 2 imagery downloaded from https://earthexplorer.usgs.gov. Level 2 imagery has been atmospherically corrected and shows surface reflectance values. In the “Search Criteria” section, users should identify a study area by either using the map pane to draw a polygon, or by uploading a shapefile. In the “Date Range” settings, select dates that cover the full study period, then use the “Search Months” parameter to narrow the search to only return imagery from a desired season. Our analysis used early summer months (targeting June) to capture more vegetation than non-growing season months. Users should aim to download one image per year, with each image captured at roughly the same time of year. When the search area and date range have been configured, select “Data Sets” to move on to the next pane. Within “Data Sets”, expand “Landsat”, then expand “Landsat 8-9 Collection 2 Level-2, and finally select “Landsat 8-9 OLI/TIRS C2 L2”. Click on “Results” at the bottom-right corner of the pane to view all imagery returned for the query. Use the thumbnail imagery to quickly assess if there is cloud cover over the study area for that date, then click the “Show Footprint” icon to view the imagery footprint (Figure 1).

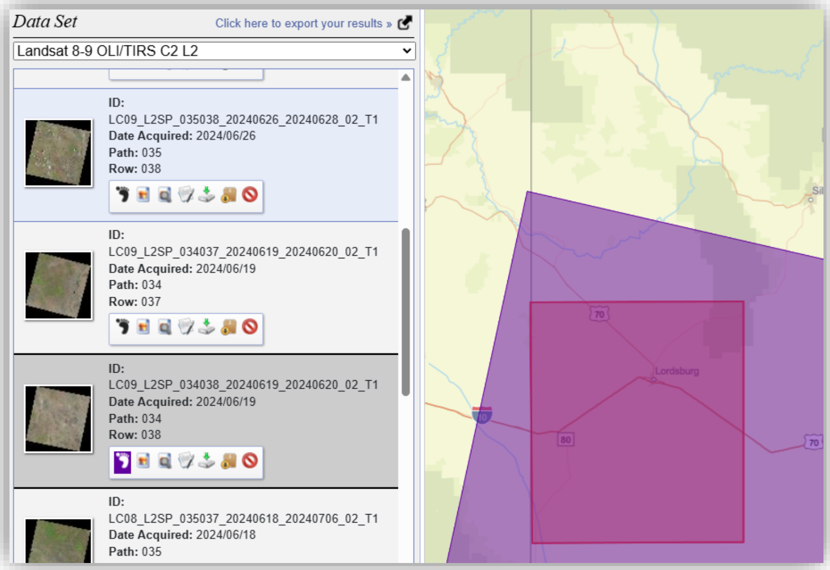

Figure 1. USGS Earth Explorer search results pane.

Once an image has been selected, click the “Download Options” icon for the image. After the download options have loaded, select “Product Options” from the pop-up. A secondary pop-up will appear. Select the uppermost centered button to the left of “Landsat Collection 2 Level-2 Product Bundle” to download all bands and reference files for the Landsat Scene (Figure 2). The product bundle of the scene will download as a compressed .tar file. Repeat this process, downloading one cloud-free scene for each year of interest. After downloading all bundles, extract each .tar to a separate directory for each scene. The imagery is now ready to analyze!

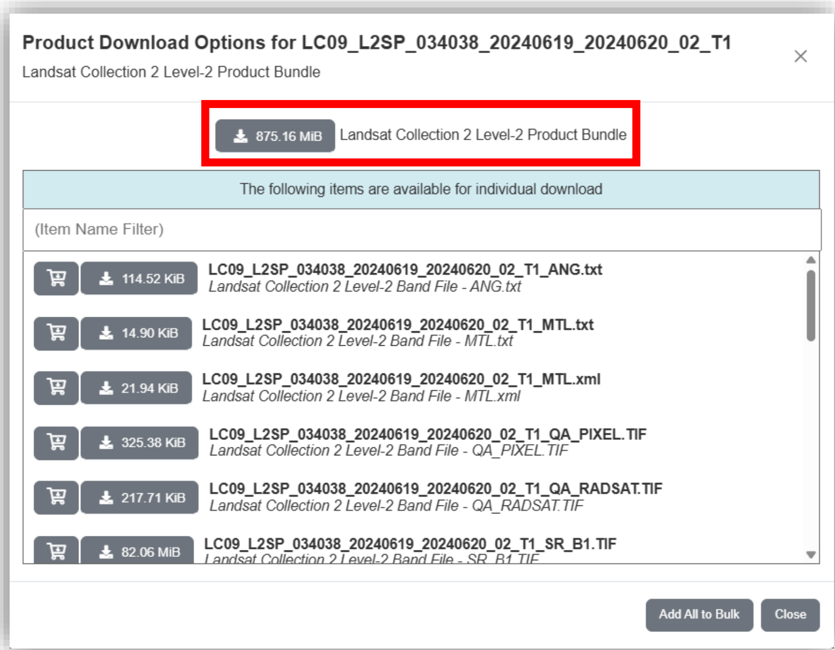

Figure 2. Landsat Product Download Options, with download button highlighted in red.

User Guide

This section outlines the input parameters and output datasets created from each tool. To begin using the tool, create an ArcGIS Pro Project or open an existing project. In the Catalog Pane (right side by default, but can also be opened under the “View” tab in the top ribbon), right-click on the “Toolboxes” section, then select “Add Toolbox”. Navigate to the toolbox location and select the “Lordsburg-Playa-Trend-Analysis-Tools.pyt” file to add it to the project.

The following tools should be executed in order 1-4, as outputs from previous tools are necessary for the following tool.

1) Make Multidimensional Raster from Local Files

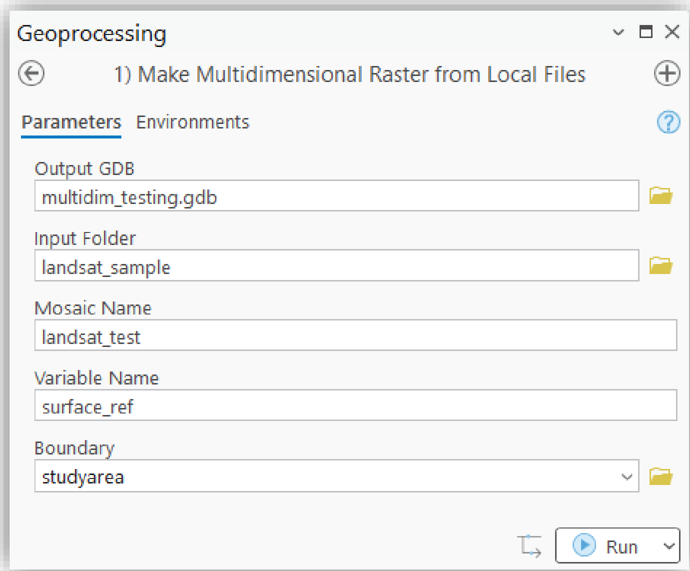

Figure 3. Parameters for Make Multidimensional Raster from Local Files.

The “Make Multidimensional Raster from Local Files” tool uses the previously downloaded Landsat scenes to create a multidimensional mosaic dataset stored in a geodatabase. This dataset consists of many parts, including a catalog to describe pixel sources and imagery footprints, a boundary feature class, and a multidimensional table to store variables and dimensions such as time. This dataset will be the foundation for the rest of the analysis.

The parameters are:

1. **Output GDB**
    a. The geodatabase to create and store the new multidimensional mosaic. You must have write access to this geodatabase.
2. **Input Folder**
    a. The directory which contains the extracted Landsat scenes, each in their own subfolder.

3. **Mosaic Name**
    a. The name of the output dataset, stored in the geodatabase selected in the first parameter.
4. **Variable Name**
    a. In this case we are using surface reflectance imagery, so the example parameter is set to "surface_ref". Can be any string.
5. **Boundary**
    a. The study area boundary. At this stage, the boundary will only be used to set the coordinate system of the mosaic dataset. The entire Landsat scene will be ingested into the mosaic.

The output multidimensional mosaic dataset can be found in the output geodatabase. Each Landsat scene is also composited into a multiband raster and added to the geodatabase. You may choose to add the mosaic to your Map, but it is not required for the following tools.

Now, the surface reflectance values can be converted to spectral indices to analyze landscape patterns of vegetation, moisture, and dry soil exposure.

2) Calculate Spectral Index

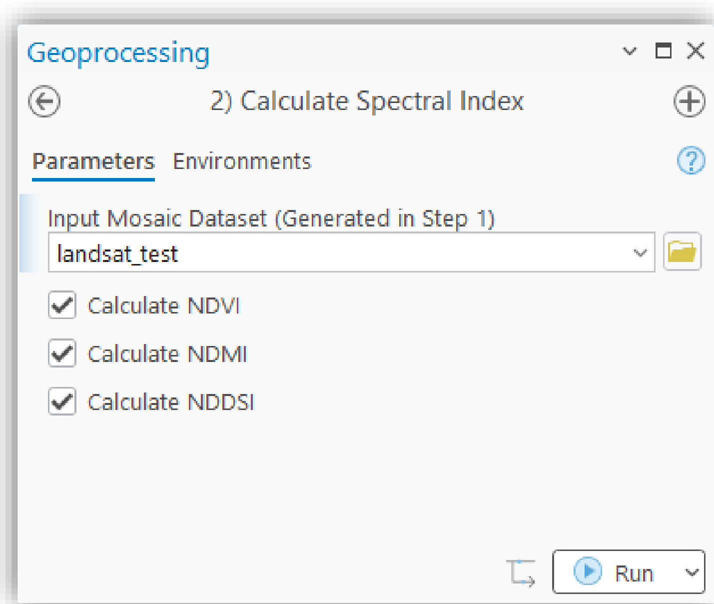

Figure 4. Parameters for Calculate Spectral Index.

The "Calculate Spectral Index" tool uses the previously created multidimensional mosaic dataset to calculate multiple spectral indices on each slice of the mosaic. The indices enabled by this tool are the Normalized Difference Vegetation Index (NDVI), the Normalized Difference Moisture Index (NDMI), and the Normalized Difference Dry Soil Index (NDDSI). Each index reveals different patterns about the landscape, namely vegetation health, soil and vegetation moisture content, and dry soil exposure.

The parameters are:

1. Input Mosaic Dataset (Generated in Step 1)
    a. The path to the mosaic dataset, stored in a geodatabase.
2. Calculate NDVI
    a. A toggle to calculate NDVI – enabled by default.
3. Calculate NDMI
    a. A toggle to calculate NDMI – enabled by default
4. Calculate NDDSI
    a. A toggle to calculate NDDSI – enabled by default

Outputs will be stored in the ArcGIS Pro project directory under a new folder named "output_indices". The full path will be printed as a message in the geoprocessing tool. Each index is stored as an Esri Cloud-Reference-Format (.crf) file, with the calculated index as the last portion of the filename (ex: imagery_ndvi.crf).

Each output index is multidimensional. To view data from different time slices, add the .crf file to the Map. Highlight the layer in the "Contents" pane, then see the "Multidimensional" options appear on the top ribbon. Under the "Multidimensional" options, "StdTime" will be available in the "Current Display Slice" section. Use the drop-down menu to select a slice (Figure 5).

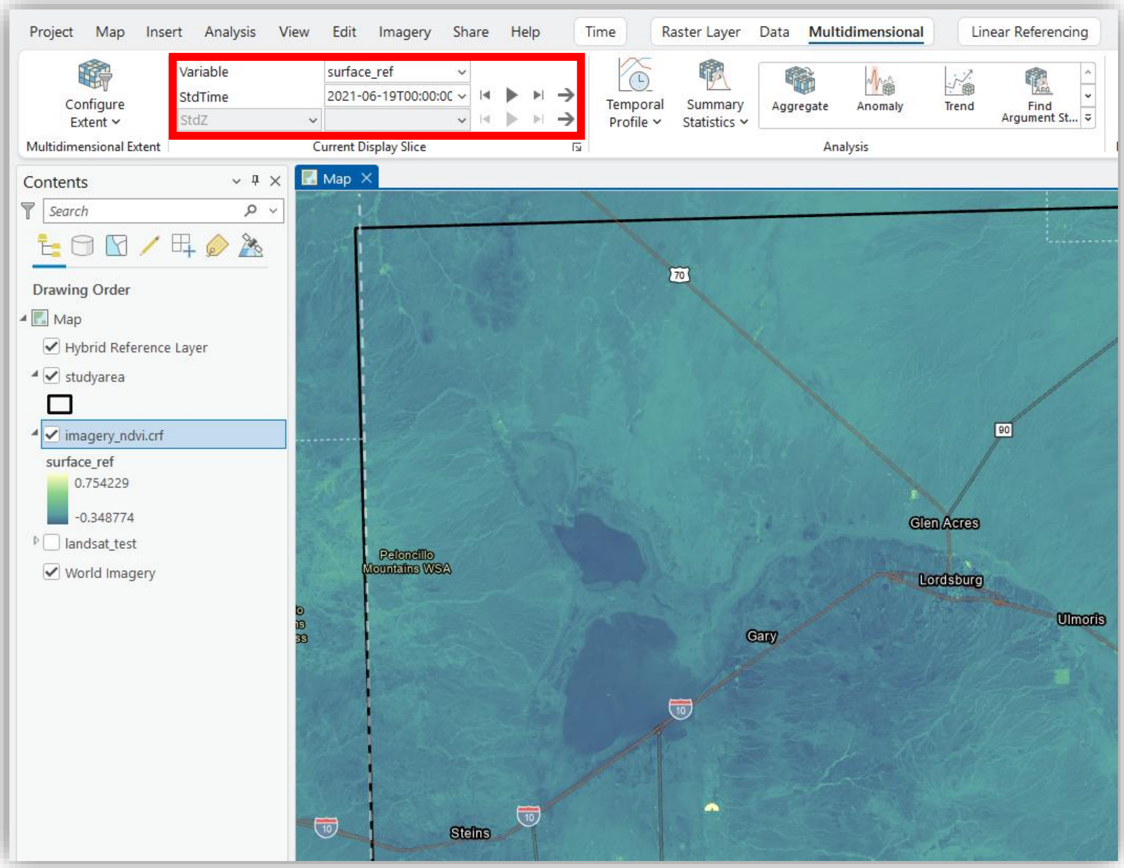

Figure 5. Viewing NDVI data from 2021. Time slice options highlighted in red.

3) Calculate Mann-Kendall Trend

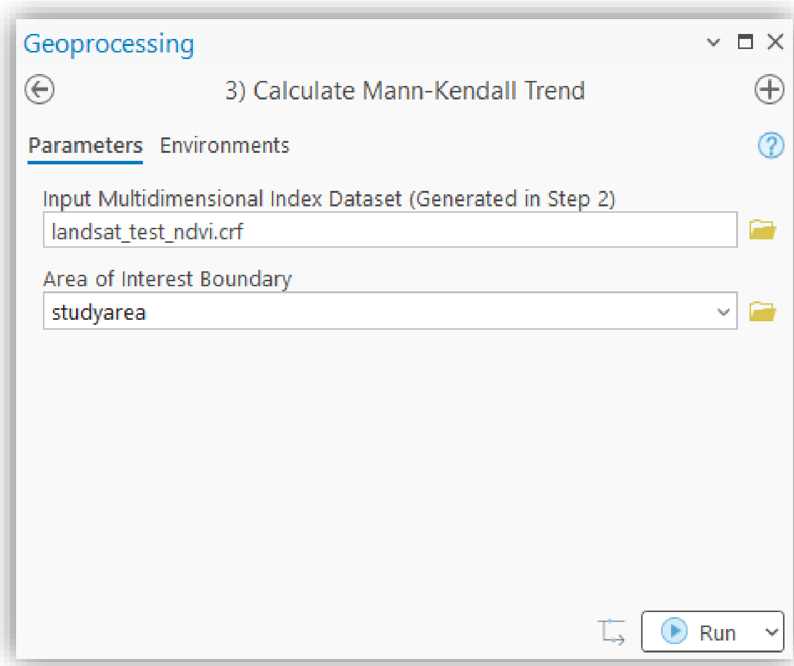

Figure 6. Parameters for Calculate Mann-Kendall Trend.

The Mann-Kendall test determines if there is a significant positive or negative trend in the value of a given pixel over time. In this case, the tool can evaluate whether an area has experienced a statistically significant increase or decrease in the values of a given index such as NDVI. The output of this tool is a 5-band raster where each band provides additional context to the results of the test. In this case, the tool uses the p-value band of the raster as a mask to remove any pixels where change was not statistically significant in either a positive or negative direction. The magnitude of this change is described by the Sen's slope band of this output raster.

The parameters are:

1. Input Multidimensional Index Dataset (Generated in Step 2)
    a. A single index's multidimensional dataset. These will be located in the "output_indices" subfolder within your ArcGIS Project directory.
2. Area of Interest Boundary
    a. The study area feature class. Only pixels within the study area will be evaluated.

Note: Depending on how the "Input Multidimensional Index Dataset" is added as a parameter, a "Use the filtered records" toggle may appear. The toggle does not affect the output for this tool and can be ignored.

Outputs will be stored in the ArcGIS Pro project directory under a new folder named "output_trends". The full path will be printed as a message in the geoprocessing tool. Two outputs will be created for each index. The first is the full 5-band test result raster with no masking applied (*datasetname*_mk_trend.crf). The second (ending with _sig.crf), contains the Sen's slope raster, masked by significance (p value < 0.05). The second raster contains pixels that have had significant change in both positive and negative directions. If no pixels have a p value <0.05, a warning will be generated in the geoprocessing dialog. In the final tool, the changes will be split into binary positive/negative bins, and hotspots of change will be identified.

4) Map Hotspots of Significant Change

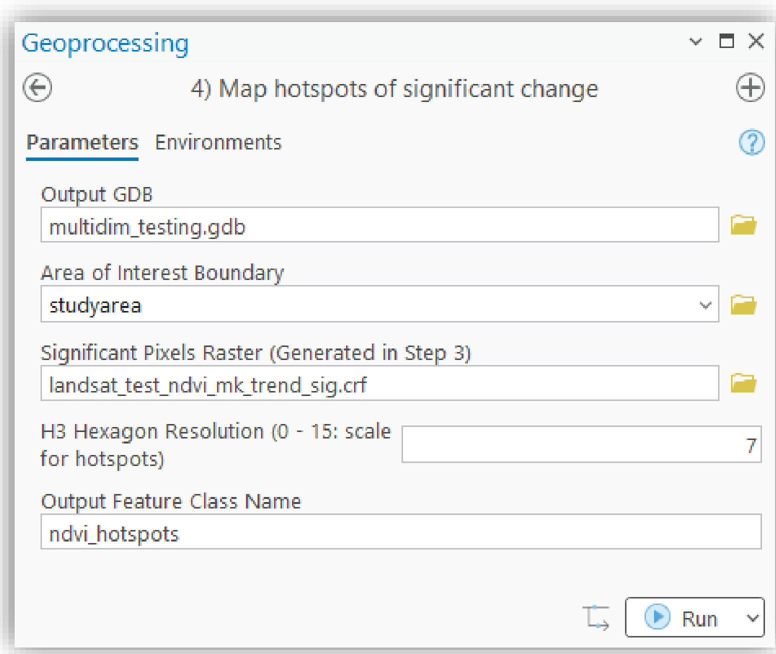

Figure 7. Parameters for Map Hotspots of Significant Change.

Note: If no statistically significant pixels were identified in tool “3) Calculate Mann-Kendall Trend”, this tool will fail to run.

The final tool uses the Getis-Ord Gi* statistical test to determine statistically significant clusters among the trend results. More information on how this test functions in a GIS can be found in Esri’s documentation covering how hot spot analysis works. Outputs inform users about where the greatest amount of change is occurring across spatial and temporal dimensions, facilitating data-driven decisions for mitigation and recovery efforts. Firstly, a H3 hexagon tessellation is created at a user defined resolution level, 7 by default. A resolution level of 7 corresponds to about 5.2km^2 per hexagon. Increasing the H3 resolution (up to 15) reduces the output hexagon size. More information about H3 tessellations can be found on the H3 website. After creating a tessellation, significant pixels are converted to points and joined to the hexagon they are within. The Getis-Ord Gi* test is performed on the count of significant pixels within each H3 hexagon.

The parameters are:

1. Output GDB
    a. The output geodatabase. Hotspot feature classes will be stored here.
2. Area of Interest Boundary
    a. The study area feature layer. Hotspots and hexagons will be generated within this boundary.
3. Significant Pixels Raster (Generated in Step 3)

a. An index of significant pixels, generated in step 3. This dataset should end in "_sig".

4. H3 Hexagon Resolution (0 – 15: scale for hotspots)
    a. The size of the H3 hexagons. Higher resolutions have smaller sizes.
5. Output Feature Class Name
    a. The name of the output feature class. This string will be split into two feature classes, one ending in "_positive" and the other in "_negative", indicating which direction the hotspot is trending towards.

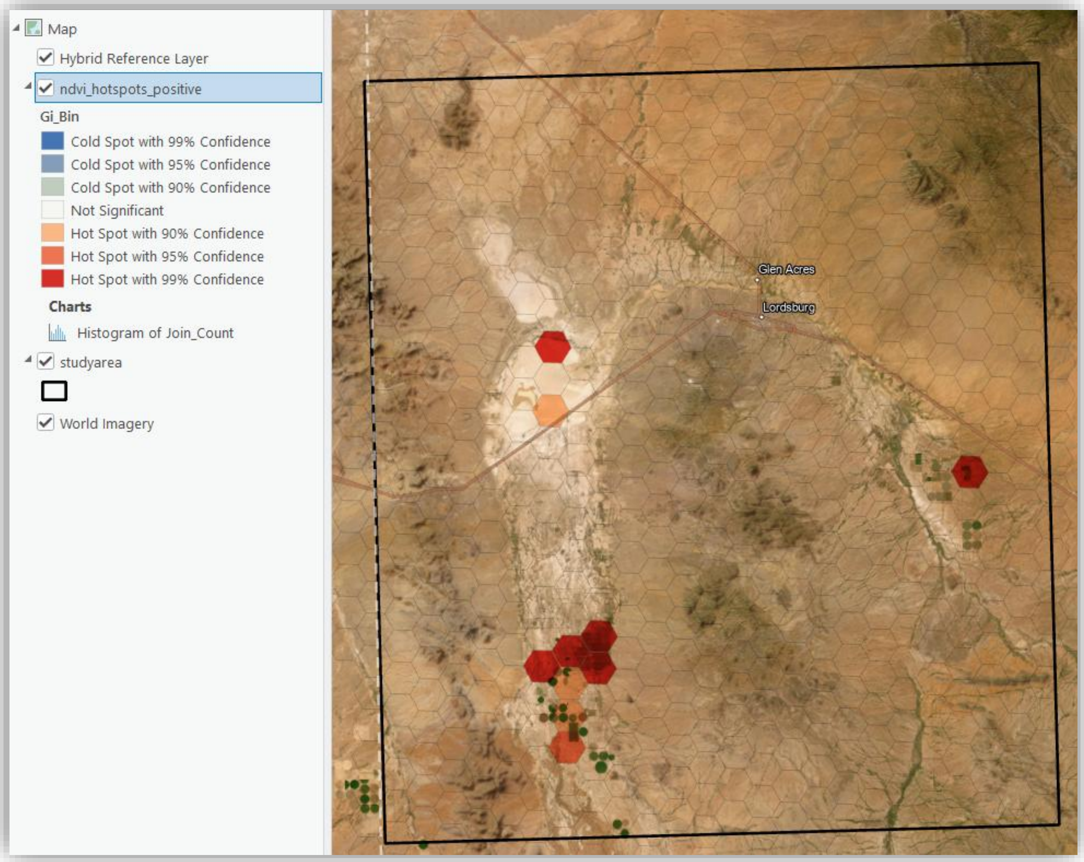

Figure 8. Negative-trending NDMI hotspots. Darker reds indicate higher confidence.

These datasets can be used to inform management decisions about where mitigation or restoration funds could be best applied to slow or enhance these trends. The tools in this toolbox can also be applied to different study areas and different time spans.

References

Kendall, M. G. (1948). Rank correlation methods.

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the econometric society*, 245-259.

Ord, J. K., & Getis, A. (1995). Local spatial autocorrelation statistics: distributional issues and an application. *Geographical analysis*, *27*(4), 286-306.