UTILIZING NORMALIZED DIFFERENCE VEGETATION INDEX TO ASSESS THE ACTIVITY OF THE MAVERICK BADLANDS, BIG BEND NATIONAL PARK, TEXAS: 1999-2018

by

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A directed research report submitted to the Geography Department of

Texas State University in partial fulfillment

of the requirements for the degree of

Master of Applied Geography

with a specialization in Geographic Information Science

May 2019

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Introduction

In recent years, remote sensing has seen an increase in the availability of high spatial resolution imagery. The various bands of imagery can be manipulated to reveal information that is useful in various studies, such as vegetation change. Normalized Difference Vegetation Index (NDVI) uses the red and near-infrared bands and has been implemented in many studies to identify healthy and unhealthy vegetation in an area, as well as help with understanding the ecology of areas that change over time. Other studies have used NDVI to link vegetation patterns to climate change and anthropogenic processes.

Big Bend National Park (BIBE) has a diverse ecological and climatic past. The arid environment is highly susceptible to invasive species, high erosion rates, and climatic variability (Maxwell 1968). Using NDVI, the variability and change of vegetation can be seen throughout the various ecoregions of the park. This study focuses on a portion of the Maverick Badlands within the lowland regions of BIBE. Using satellite imagery, a time-scale analysis was performed in the study area. Comparing the vegetation cover output of historic imagery to present imagery can assess the state of the Maverick Badlands. Having more vegetation present in the badlands will indicate the activity of the formations (Battaglia et al. 2011). Erosion wears down badland materials and then allows the encroachment of vegetation to occur (Battaglia et al. 2011). Badlands experience a natural change between active to inactive slopes. Vegetation cover is an indicator that a slope has become dormant and the activity of the badlands has changed (Thomas 2011). The purpose of this study is to utilize NDVI to evaluate the activity (active or inactive) of the Maverick Badlands by determining if there has been a change in vegetation cover, an increase in vegetation will signify that the badlands have been or are becoming more inactive.

Background

Badland activity (active or inactive) is altered based on many variables, one of which can be climate change. A clear sign of an inactive badland is the increase in vegetation cover (Thomas 2011). Based on previous visual assessments, both types of badland environments occur within the Maverick Badlands of BIBE. The changing of various climate variables, such as precipitation and temperature, will have a direct impact on vegetation cover (IPCC 2013). NDVI has proven to be a valuable tool to assess the changing of vegetation and ground cover (Olisegun and Adeyewa 2013). Studies using NDVI have also shown the success in evaluating vegetation response to climate changes at various small and large scales (Xu, Yang, and Chen 2015).

Increased levels of CO_2 and other greenhouse gases from climate change have been predicted to impact terrestrial ecosystems (Patrick et al. 2006). Vegetation in arid environments are highly vulnerable to climate change and it can alter the natural ecosystems of these regions (Xu, Yang, and Chen 2015). General circulation models (GCMs) have predicted a world-wide precipitation increase of up to 7 percent (Patrick et al. 2016). Arid and semi-arid ecosystems will experience greater impact of worldwide climate change because water availability increases will directly influence vegetation (Weltzin et al. 2003). There have been no known studies performed on vegetation analysis in the Maverick Badlands. Knowledge of the possible landscape changes can help create an understanding of any larger scale changes in the ecosystem.

Literature Review

Previous studies have focused on badlands or the use of NDVI to indicate the effects of climate change on vegetation. However, there have been no previous studies to link the two variables. The knowledge of badlands, the use of NDVI, vegetation within the study area, and climate trends will be a fundamental background for the planned research.

Early French trappers in North America coined the term badlands when they encountered lands that were difficult to cross due to the maze-like resemblance of channels and hills (Abrahams and Parsons 1994). Badlands are composed of impervious clays and shales varying with soft sandstones that have sparse vegetation due to the high erodibility (Maxwell 1968). Badlands are dissected, gullied landscapes with extensive rilling, piping, and mass movement (Thomas 2011). The combination of slopes and drainage networks are essential in the definition of badlands (Laity 2008). Typical badland bedrock is unconsolidated or weakly consolidated rock (Thomas 2011). The majority of badland materials include swelling clays, silts, and sands, which have low permeability (Laity 2008). Quirk and Blackmore (1955) found that 70% of rainfall is infiltrated within 10 minutes. The Maverick Badlands of BIBE include the Penn, Aguja, and Javelina Formations and only one study has been conducted in these badlands (Maxwell 1968; Melancon 2009).

There are two major types of badlands, active and inactive. Both have been visually assessed in BIBE. Badlands are inactive once significant erosion has taken place and vegetation becomes more abundant. Climate is a significant limiting factor in the ability for the occurrence of vegetation to occur within badland environments (Thomas 2011). Lack of vegetation, erosion and infiltration are directly related to rainfall and the badland materials (Laity 2008).

Battaglia et al. (2011) conducted a study on the evolution of badlands within the Roglio basin in Tuscany, Italy. The study focused on the physicochemical properties of an active versus an inactive badland. Results indicated that there were no physicochemical differences between the two badland formations. Inactive badlands lack ongoing erosion and contain high levels of vegetation within the Roglio basin. Vegetation is a strong indicator of an inactive badland feature (Battaglia et al. 2011). Battaglia et al. (2011) indicated that if climate change and the alteration of land use in the Roglio basin continues to occur, the active badland formations will increasingly become inactive.

Climate change in BIBE has been studied on a few occasions. A study was performed that encompassed the entirety of BIBE to predict climate change for the next hundred years within the park based on 1971-2000 climate normals (Herbert 2004). The study used two models to evaluate climate trends (ECHAM4/OPYC3, Max-Planck-Institut für Meteorologie; and CCSR/NIES, Japanese Center for Climate Research Studies/National Institute for Environmental Studies). The study analyzed twelve weather stations for climate trends: Alpine, Boquillas Ranger Station, Candelaria, Castolon, Chisos Basin, Lajitas, Marathon, Marfa, Panther Junction, Persimmon Gap, Presidio, and Sanderson (Herbert 2004). Results indicated that regional climate change projections for the BIBE region predict annual average precipitation and annual average temperature to increase by 333mm and 11.1° C respectively, by the end of the 21st century (Herbert 2004). Results for Panther Junction, the closest weather station to the Maverick Badlands, climate change projections predict annual average precipitation and annual average temperature model averages to increase by 321mm and 10.6° C respectively, by the end of the 21st century (Herbert 2004, Melancon 2009). An increase of summer precipitation in BIBE has been directly linked to an increase in vegetation (Patrick et al. 2006). This may result in in change in the activity of the Maverick Badlands.

NDVI is the reflectance variance between the near infrared bands (NIR) and visible red bands that represents the photosynthetic capability of vegetation (Gu et al. 2016). Figure 1 provides the equation that is used to calculate NDVI values. The NDVI calculation ratio reduces many forms of multiplicative noise that are present within the bands of multi-date imagery (Jensen 2007). The output values for NDVI range from -1 to 1, where values closer to -1 are generated by clouds, water, or snow, values closer to 0 represent bare soils, and values closer to 1 represent healthy vegetation (Jensen 2007).

$$\mathrm{NDVI} = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}$$

Figure 1: NDVI equation (Jensen 2007).

Xu, Yang, and Chen (2015) examined vegetation responses to climate change in an arid area of China by assessing the NDVI variation over time compared to climate variables. The study looked over yearly and monthly changes in an arid region consisting of grasslands and croplands. Results indicated a significant increase of vegetation cover in both land covers. Additionally, precipitation and temperature alteration were both significant over time and there were lagged effects between monthly precipitation and NDVI.

Climate change has been directly linked to vegetation change. NDVI can assess the variability of vegetation cover over different periods of time, indicating the activity of badland features. Previous studies have provided information to adequately organize the research within this study.

Site Description

BIBE resides in the northern portion of the Chihuahuan desert in Brewster County, Texas. BIBE spans over 3,240 km^2 and is bordered by the Rio Grande River along the southern portions of the park (Maxwell 1968). BIBE was established in 1944 and is managed by the National Park Service. The Chisos Mountains are contained within the park boundaries (Maxwell 1968). Topography extends from river lowlands to rugged mountains to desert environments (Maxwell 1968). The Maverick Badlands are in the western portions of BIBE (Melancon 2009). The Köppen climate classification for the study site is subtropical desert (BWh). The closest weather station to the study site is at Panther Junction, located at an elevation of 1,140 meters (Melancon 2009). The Panther Junction weather station is about 24 km from portions of the Maverick Badlands. Annual temperatures range between 9.4 ºC and 27.3º C at the Panther Junction weather station (NCDC 2004).

A high-pressure ridge influences precipitation within this region in the winter and a low-pressure thermal system in the summer. The summer often experiences a maritime tropical air mass and convection precipitation (Herbert 2004). Annual mean precipitation is 362 mm at the Panther Junction weather station. However, due to the aridity of the region droughts are common (Herbert 2004).

Vegetation within the park primarily consists of desert shrub, cacti, and grasslands in the lowland desert areas. In the mountainous regions, pines, oaks, and juniper are abundant. The riparian lowlands consist primarily of giant cane and tamarisk (Holbrook et al. 2012).The vegetation found in the region of the Maverick Badlands consists of lechuguilla (*Agave lechuguilla),* creosote bush (*Larrea tridentat),* ocotillo (*Fouquireia splendens*), silver leaf

(*Leucophyllum fruesens*), honey mesquite (*Prosopid glandulosa*), and cholla and prickly pear cacti species (*Opuntia family*) (Wauer and Fleming 2002).

The study site is located off of Panther Junction Road near the western entrance of the park. A portion of the Maverick Badlands was selected for this study based on collected GPS locations, field observations, and satellite imagery assessment. Figure 2 illustrates the location of the study area within the park boundary.

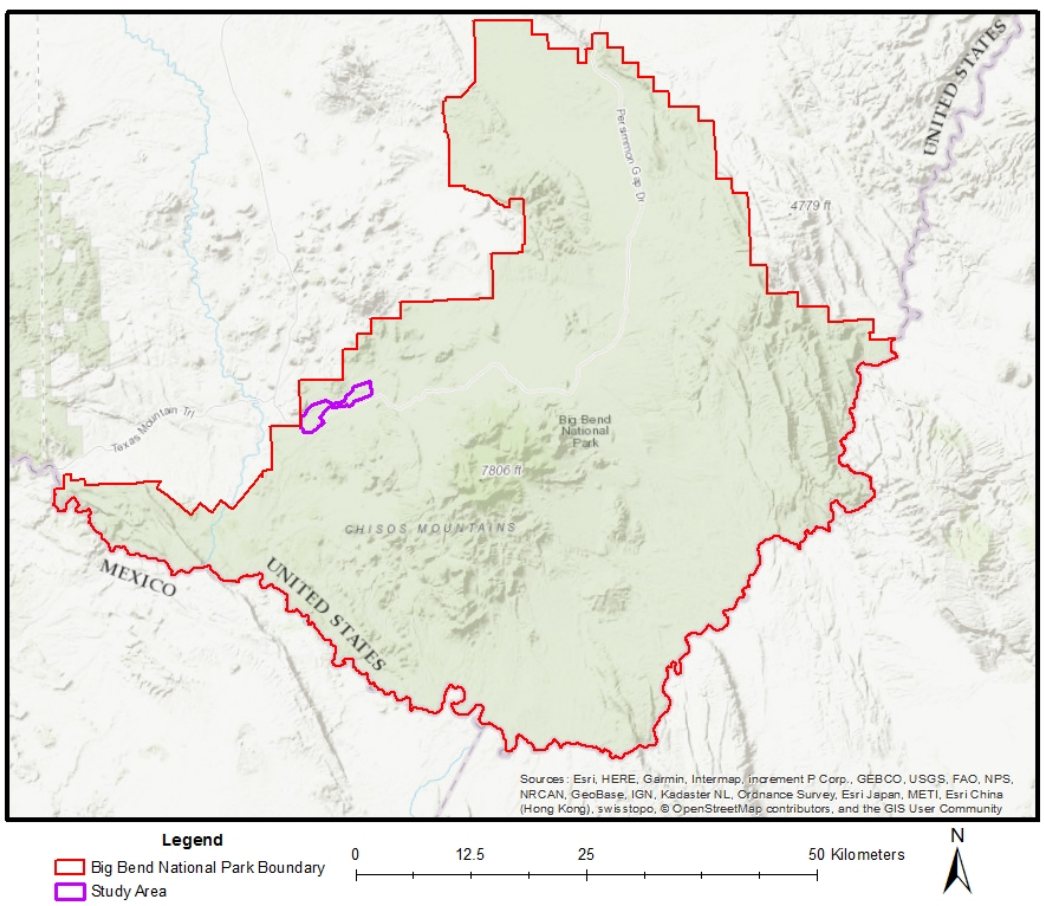

Figure 2: Study Area within BIBE Boundary Map.

Data and Methodology

An initial field assessment was performed in November of 2018. During this assessment, GPS points were taken using the Trimble Geo 7X unit around the border of a portion of the badlands. Pictures were also taken for visual aid in the assessment of vegetation encroachment.

Three Landsat images were acquired from the United States Geological Survey Earth Explorer site. The first image is a Landsat 5 TM image acquired on November 18, 1999. The second image is a Landsat 5 TM image acquired on November 10, 2008. The third image is a Landsat 8 OLI TIRS image acquired on November 13, 2018. The projection used is UTM, Zone 13, WGS 84. Radiometric corrections were performed to account for the differences in the satellites, sun angle, radiance, and reflectance differences by converting the digital numbers to top-of-atmosphere reflectance values. With the corrected imagery, they can be compared between multi-dates.

Each image was clipped to the study area and then the ERDAS Imagine NDVI tool was implemented on each subset image's pixels. In Model Builder, the NDVI values of the images were differenced. Each image has new pixel values ranging from -1 to 1 due to the implementation of the NDVI formula. Additionally, there are three NDVI difference outputs between the years (1999:2018, 1999:2008, and 2008:1999). Each output has a corresponding statistic that shows the correlation of the change in vegetation cover within the metadata in ERDAS Imagine. Finally, the difference outputs were reclassified into three groups: the lower 2.5%, the middle 95%, and the upper 2.5%. These were calculated from the mean by adding and subtracting two standard deviation values to find the middle 95% of the histogram. The lower

2.5% indicate areas of vegetation loss and the higher 2.5% indicate areas of vegetation growth (Jensen 2007).

Results

The visual assessment provided many examples of vegetation that had been encroaching onto the badland slopes. Figures 3 through 5 provide photographic examples of what was found in November 2018. Figure 3 shows a badland slope with (1) stabilization of the top of the slope and (2) encroachment of vegetation on the side of the slope. Figure 4 is a close-up of the vegetation that is growing on the slope with a pen for scale. Figure 5 illustrates the base of a badlands slope that has rilling to separate the active and dormant portion of the slope. For future studies, these sites could be revisited and compared for vegetation cover and placement.

Figure 3: Badland slope with vegetation encroachment (11/2018).

Figure 4: Vegetation close-up for Image 2 (11/2018).

Figure 5: Base of badland slope separated by a gully/rill (11/2018).

From the metadata of the NDVI and NDVI Differences outputs the following statistical information was found in the ERDAS Imagine. These data are found in Tables 1 through 6.

Table 1: Statistics for NDVI calculation for the year 1999.

NDVI Output 1999					
Minimum	Maximum	Mean	Median	Mode	Standard Deviation
-0.0868	0.28539	0.093	0.09123	0.08622	0.022

Table 2: Statistics for NDVI calculation for the year 2008.

NDVI Output 2008					
Minimum	Maximum	Mean	Median	Mode	Standard Deviation
-0.0427	0.33143	0.119	0.11714	0.11819	0.031

Table 3: Statistics for NDVI calculation for the year 2018.

NDVI Output 2018					
Minimum	Maximum	Mean	Median	Mode	Standard Deviation
-0.0323	0.36872	0.165	0.15965	0.1651	0.037

Table 4: Statistics for NDVI difference calculation between 1999 and 2018.

NDVI Difference 1999 to 2018					
Minimum	Maximum	Mean	Median	Mode	Standard Deviation
-0.08654	0.24265	0.072	-0.0865	-0.0865	0.03

Table 5: Statistics for NDVI difference calculation between 1999 and 2008.

NDVI Difference 1999 to 2008					
Minimum	Maximum	Mean	Median	Mode	Standard Deviation
-0.07502	0.14247	0.026	-0.075	-0.075	0.022

Table 6: Statistics for NDVI difference calculation between 2008 and 2018.

NDVI Difference 2008 to 2018					
Minimum	Maximum	Mean	Median	Mode	Standard Deviation
-0.12582	0.18078	0.046	-0.1258	-0.1258	0.024

Figures 6 and 7 illustrate the outlying 5% of the histograms for vegetation differences between 1999-2008 and 2008-2018. The green pixels indicate areas of higher vegetation growth and the red pixels are areas of vegetation loss. These images show the spatial distribution of the changing vegetation.

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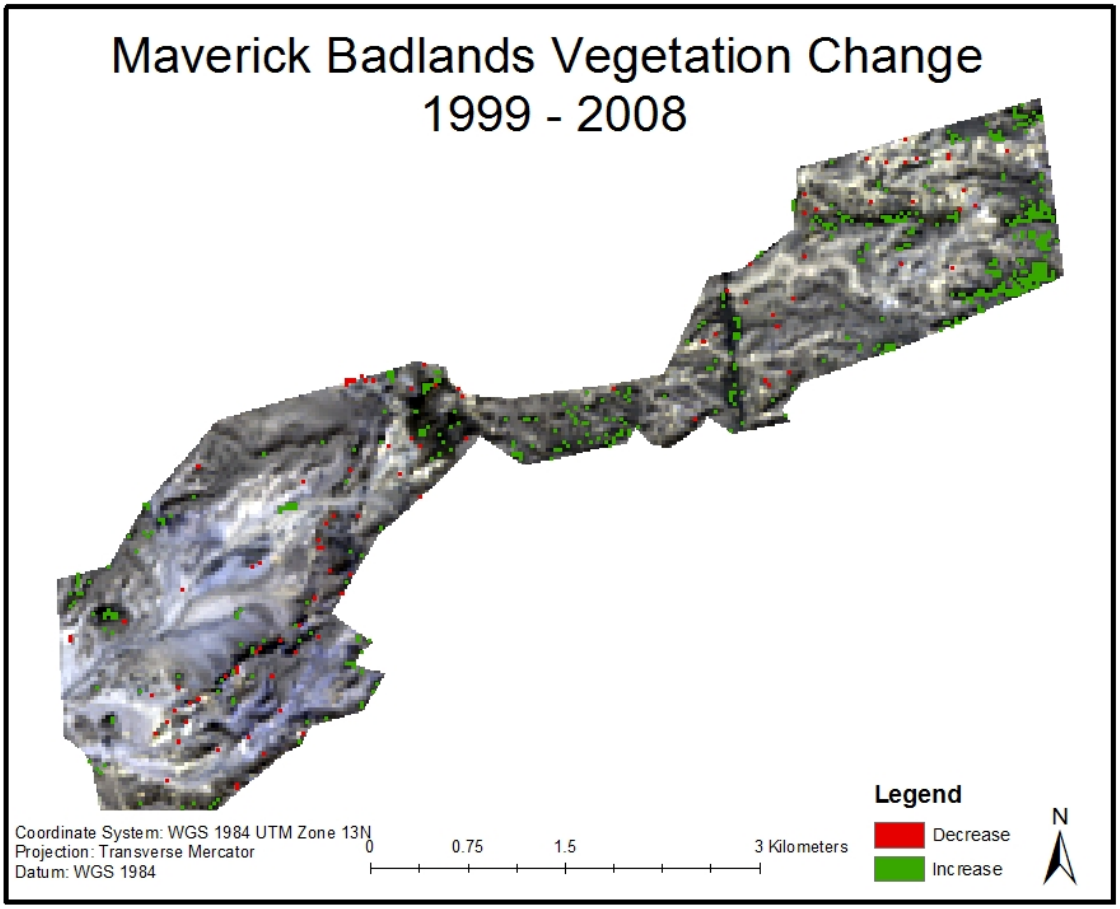

Figure 6: Outlying 5% of vegetation change within the study area from 1999 to 2008.

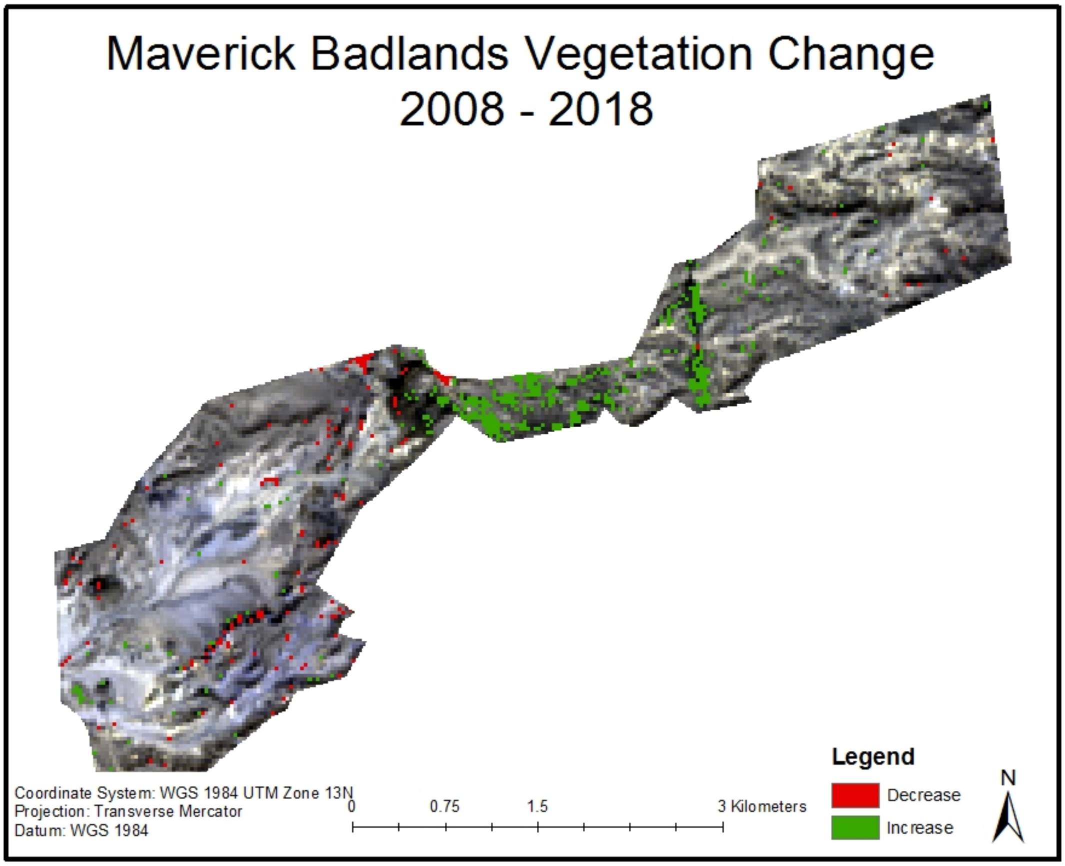

Figure 7: Outlying 5% of vegetation change within the study area from 2008 to 2018.

Discussion and Conclusion

For the NDVI calculation output over the three images the maximum, mean, median, mode, and standard deviation have all steadily increased from 1999 to 2018. Additionally, the minimum has decreased over the years. Having higher values for NDVI cover indicate the encroachment of vegetation. These results imply that the badlands could be becoming more inactive.

Based on the mean difference between 1999 and 2018, vegetation cover has slightly increased. Additionally, there was a greater amount of vegetation growth between 2008 and 2018 than between 1999 and 2008. However, the rate of increase for the differences between the years is relatively consistent. Therefore, the rate of stabilization is steady between the years. Visual representation helps understand the spatial distribution of the stabilization.

The areas of vegetation growth between 1999 and 2008 occurred mostly within the eastern portion of the study area. Some pixels of vegetation growth occurred within the middle portion of the study area. Few areas of growth occurred within the western portion. For the vegetation change between 2008 and 2018 a strong increase in vegetation occurred within the middle portion of the study area. However, there was more vegetation loss in the western portion. Based on these images, it appears that the middle portion is experiencing more stabilization than the rest of the study area. Further studies could be conducted to focus on this area to determine the rate and cause of stabilization within Maverick Badlands.

Certain limitations occurred in the data due to the imagery resolution of 30 meters. Having access to higher resolution imagery would provide more conclusive results. Additionally, due to the remote location, the nearest weather station resides in a different sub-ecoregion.

Having a localized weather station with historic data could provide useful data for comparison to the NDVI difference outputs. Multivariate statistical analysis could be performed to compare the temperature, precipitation, and vegetation cover if a weather station was able to provide accurate, local data. Furthermore, this study was only performed during November. A more extensive study looking at different periods of the year would be beneficial in supporting the hypothesis of the changing activity of the Maverick Badlands.

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