LANDSAT 8 (OLI) AND LANDSAT 7 (ETM+) FOR ASSESSING POWERFUL STORM EYEWALL INDUCED COASTAL AND VEGETATION CHANGES: HURRICANE MICHAEL OVER FLORIDA PANHANDLE

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ABSTRACT

Hurricane Michael was the second maximum intensity hurricane of the 2018 Atlantic Hurricane Season, landfalling in the Florida Panhandle on October 10, 2018. The Category 5 cyclone produced irreversible geological changes to the coastline from Panama City to Mexico Beach and up to the Cape San Blas area. Satellite imagery for this research were acquired from the Landsat spacecraft-borne sensors, including the Operational Land Imager and Enhanced Thematic Mapper Plus. A before and after images were selected and subjected to several preprocessing techniques using ENVI 5.6 software to analyze and identify the shoreline changes, the impacts on the vegetative layer and its recovery after one year from being ravaged. To complete the research objectives, two remote sensing classification methods were implemented: Unsupervised Classification by IsoData and Supervised Classification by Minimum Distance. Additionally, a Normalized Difference Vegetation Index (NDVI) Estimation was computed for each dated image to quantify the changes on the vegetation density after the passing of the powerful storm. An exceptional amount of sediments and damage to coastal zones were detected after experimenting the hurricane eyewall. Despite the many impacts, it was concluded that the vegetative layer was recovering after a year from the meteorological event.

Keywords: Hurricane Michael, Florida Panhandle, OLI, EMT+, spatial resolution, NDVI

INTRODUCTION

Hurricane Michael was a powerful Category 5 storm with maximum sustained winds of 161 mph and a minimum central pressure of 919 mb. The system had an active period between October 7 to October 11, 2018 since its development in the waters of the Caribbean Sea and its movement through the Gulf of Mexico until landfalling near Panama City area over Florida, USA.[6] Michael was the second maximum intensity hurricane of the 2018 Atlantic Hurricane Season. Its powerful winds and catastrophic storm surge caused extensive damage in the coastal areas of the Florida Panhandle.[6] This was mainly due to the vacuum or suction effect that the eye of this type of cyclone typically has which causes strong disturbances in sea levels combined with torrential rainfall and powerful winds.

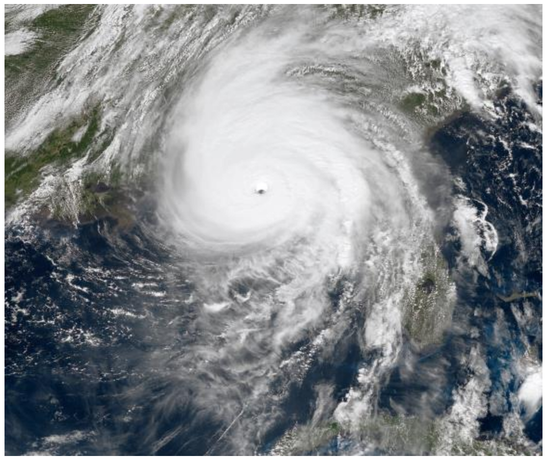

Figure 1. *NOAA GOES True Color Image of Hurricane Michael landfalling near Panama City on October 10, 2018*

As an evidence of climate change, the occurrence of this type of intense tropical cyclone in the Atlantic basin has been more frequent in recent years. The eyewall of Hurricane Michael particularly affected the coast from Panama City Beach to Mexico Beach and up to the Cape San Blas area as reported by NOAA and National Hurricane Center official reports. The incredible force of the hurricane caused severe damage and unprecedent changes in the coastal and natural environments in this region such as sand dunes, beaches, mangroves, but especially to the coast. It even wiped-out coastal roads in the area due to the effects of a 20 feet storm surge combined with catastrophic flooding.[3] **Figure 2** shows a NOAA Visible satellite image of the hurricane landfalling over the area of interest and the angle of movement of the eye.

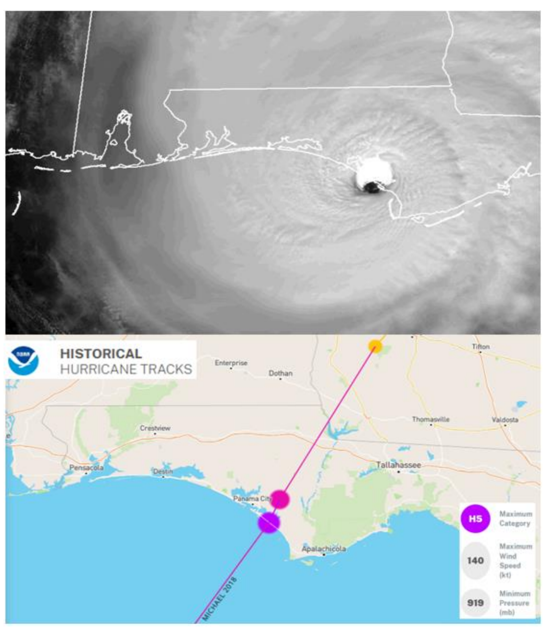

Figure 2. *NOAA Visible Satellite Image of Category 5 Hurricane Michael eyewall landfalling with 160 mph maximum winds and its Historical Track.*

The extent of the damage and changes induced by Hurricane Michael intense eyewall to the coastal environments and vegetation near Panama City can be assessed by many applications of remote sensing and using available satellite imagery. Managed by NASA and the U.S. Geological Survey, the Landsat Satellite Program have contributed to the understanding of Earth in innumerable ways since the first Landsat 1 was launched in July 1972.[4] The current Operational Land Imager (OLI), which is aboard Landsat 8, is a sensitive pushbroom, nine band sensor, which measures in the visible, near infrared, and short wave infrared portions of the electromagnetic spectrum.[5] OLI images have 15m panchromatic and 30m multi-spectral spatial resolutions along a 185 km wide swath, covering wide areas of the Earth's landscape while providing sufficient resolution to distinguish features like urban centers, farms, forests, and others (see **Figure 3**). Several spectral bands from OLI, such as Band 5 (NIR) and Bands 4, 3, 2 (RGB), can be useful in studying vegetation boundaries, landforms, and vegetation peaks or slopes.

Spatial Resolution	30m VNIR/SWIR (15m PAN, 100m Thermal)
Spectral Range	0.43-12.51 μm
Bands	11 (9 and 2)
Temporal Resolution	16 days
Radiometric Resolution	12 bits (4096 DN)
Image Size	185km x 185km
Sensor Type	Pushbroom

Figure 3. *Landsat 8 Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) Sensor General Description*

The previous Enhanced Thematic Mapper Plus (ETM+), which is aboard Landsat 7, is a fixed whiskbroom, eight band, multispectral scanning radiometer capable of providing high-resolution imaging information of the Earth's surface.[4] Landsat ETM+ data is sensed with an IFOV of 30m x 30m in bands 1-5 and 7, 60m x 60m in band 6, and the panchromatic band 8 with 15m of spatial resolution (see **Figure 4**). Multiple spectral bands from ETM+, such as Band 4 (NIR) and Bands 3, 2, 1 (RGB), can be useful in determining green radiation from healthy vegetation to evaluate plant vigor and chlorophyll absorption.

Spatial Resolution	30m VNIR/SWIR (15m PAN, 60m Thermal)
Spectral Range	0.45-12.5 μm
Bands	8
Temporal Resolution	16 days
Radiometric Resolution	8 bits (256 DN)
Image Size	184km x 185.2km
Sensor Type	Whiskbroom

Figure 4. *Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Sensor General Description*

Each sensor has specific characteristic that make them suitable for several remote sensing applications such as multispectral classification and the estimation of vegetation indices. Classification processes are used to categorize pixels in an image into many classes which is the same as assigning pixels to a particular class that are spectrally similar one to another. Two common ways of performing multispectral classification includes supervised and unsupervised classification.[1]

Unsupervised Classification is defined as the identification, labeling, and mapping of natural groups or structures within multispectral data that are uniform internally in respect to brightness in several spectral channels. A typical example of the application of Unsupervised Classification is IsoData, which consists in calculating class means evenly distributed in the data space to iteratively cluster the remaining pixels using minimum distance techniques.[2] According to Campbell and Wynne, Supervised Classification is the process of using samples of known identity to classify pixels of unknown identity, which are pixels located within the training areas that are defined by the analyst. One typical example of the application of Supervised Classification is the Minimum Distance technique, which uses the mean Region of Interest (ROIs) for each class and calculates the Euclidean distance from each unknown pixel to the mean ROI for each class while pixels are classified to the nearest class.[2] Successful classification of digital images will be helpful in the identification of specific features and to identify changes over a geospatial zone.

Changes in ecological zones can be monitored by the estimation of vegetation indices. Vegetation indices are based on digital brightness values and attempt to measure biomass or vegetative vigor.[1] High values of vegetation index identify pixels covered by substantial portions of healthy vegetation. Normalized Difference Vegetation Index or better known as NDVI is one of the most widely used vegetation indices to quantify vegetation greenness. According to USGS, the estimation of NDVI is useful in understanding vegetation density and assessing changes in plant health.[1] Examination of NDVI over long periods of time and large areas will permit the inspection of phenological patterns of varied land cover classes and response to climate and severe meteorological events such as hurricanes, floods, and tornadoes.

OBJECTIVES

The purpose of this research was to apply remote sensing techniques to investigate changes, damages, and erosion caused by the destructive storm surge of Hurricane Michael over Panama City to Cape San Blas coastline in the Florida Panhandle and to determine the extent of the impact caused by the devastating winds and catastrophic flooding of the storm over the vegetation near the landfalling region. Finally, to conclude if the vegetative layer near the zone has recovered after a year from this major event.

METHODOLOGY

Geospatial Region of Study

The selected region of study was the Florida Panhandle in the United States, specifically the coastal zones over Panama City to Mexico Beach and to Cape San Blas. According to the United States Census Bureau, Panama City is situated in Bay County, Florida, United States, near Latitude 30°9’31” N and Longitude -85°39’37” W encompassing an area of 91.8 km^2 from which 75.8 km^2 are land and 16.0 km^2 are water, while Mexico Beach also located in Bay County, Florida, is near Latitude 29°56’29” N and Longitude -85°24’23” W, having a total area of 4.7 km^2 from which 4.6 km^2 are land and 0.1km^2 are water. Cape San Blas is located at the Gulf County in Florida near Latitude 29°39’49” N and Longitude -85°21’20” W from which St. Joseph Peninsula extends northward.

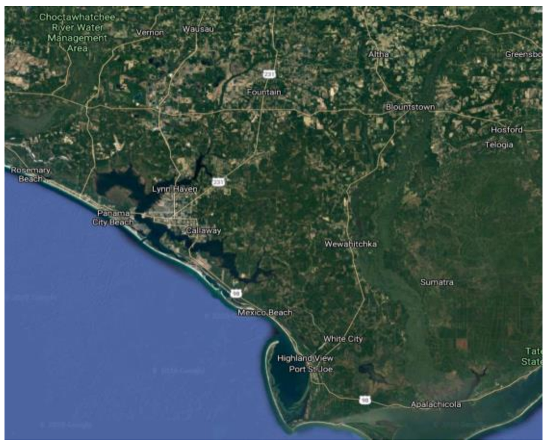

Figure 5. *Google Earth Map for the Geospatial Region of Study from Panama City to Cape San Blas in Florida, USA*

Remote Sensing Software Tool

ENVI 5.6 Software was used to perform all image processing, analysis, and visualization for this research. This software is an ideal tool for processing and analyzing geospatial imagery having the capacity of handling remotely sensed spectral, multispectral, and hyperspectral data.

Satellite Imagery Acquisition

Landsat 8 - OLI (Operational Land Imager) and Landsat 7 - ETM+ (Enhanced Thematic Mapper Plus) images from the study region were acquired from USGS EarthExplorer Data Base (https://earthexplorer.usgs.gov/). The Level 1 images obtained from the two satellite sensors were from dates before and after Hurricane Michael landfall, and a year after the catastrophic event. Images from OLI included September 22, 2018, October 24, 2018, and September 25, 2019. Images from ETM+ included September 30, 2018, October 16, 2018, and October 3, 2019.

Landsat 8 (OLI) and Landsat 7 (ETM+) Image Preprocessing

Different Preprocessing Techniques were applied to the different acquired images. Images were subjected to Radiometric Correction including Radiometric Calibration and Dark Subtraction (DOS) Method to Band Minimum for atmospheric correction. Spatial (approx. 4500 x 4500) and Spectral subsets of the images were obtained during this process. NNDiffuse Pan Sharpening tool was applied to improve spatial resolution of the images based on the 15 meters Panchromatic Band.

Image Analysis from Different Spectral Bands

True Color images (RGB) were obtained using Bands 4, 3, and 2 from OLI and using Bands 3, 2, and 1 from ETM+. Grayscale images of the Red Band were obtained using Band 4 from OLI and Band 3 from ETM+. False Color images were obtained using Bands 5 (NIR), 3 (Green), and 2 (Blue) from OLI and using Bands 4 (NIR), 2 (Green), and 1 (Blue) from ETM+.

Supervised and Unsupervised Multispectral Classification

The atmospherically corrected images were subjected to both Supervised and Unsupervised Multispectral Classification. For the Unsupervised Classification, the IsoData Classification Technique was applied with 5 to 10 Number of Classes and with 5 Maximum Iterations. For the Supervised Classification, a total of 5 Regions of Interest (ROI) were defined including Vegetation, Ocean, Sediments
City, and Clouds. The Minimum Distance Classification (MDC) Technique was applied by selecting the 5 training classes from the defined ROI.

Normalized Difference Vegetation Index Estimation

The Normalized Difference Vegetation Index (NDVI) was computed using the NDVI Tool and applying the corresponding Raster Mask from the Raster Management Tool. The Red and Near IR bands from both OLI and ETM+ images were selected for this purpose.

Remote Sensing Analysis

Coastline and vegetation changes were assessed based on the different band images, the multispectral classification and NDVI results from before, after, and after one year from the cyclone landfalling. Similarities and differences among the obtained images were analyzed and evaluated by selecting 10 random pixels from different multispectral classes and vegetation values.

RESULTS AND DISCUSSION

Landsat 8 – OLI

An analysis of the geospatial region affected by the catastrophic event of Category 5 Hurricane Michael was performed by using ENVI 5.6 Software. From the ENVI 5.6 Data Manager several images were generated using the multispectral bands of interest from OLI. The focus was on the Visible and Near-Infrared bands that are helpful for detecting changes in vegetation cover and landforms. **Figure 6** shows the results for True Color Images using Bands 4, 3, 2 (RGB) from OLI sensor for the three different dates of interest. The first image, **a)** 22-sep-2018, is prior the catastrophic event, the second image, **b)** 24-oct-2018, was taken 14 days after the atmospheric event, and the third one, **c)** 25-sep-2019, is from almost a year after the meteorological event.

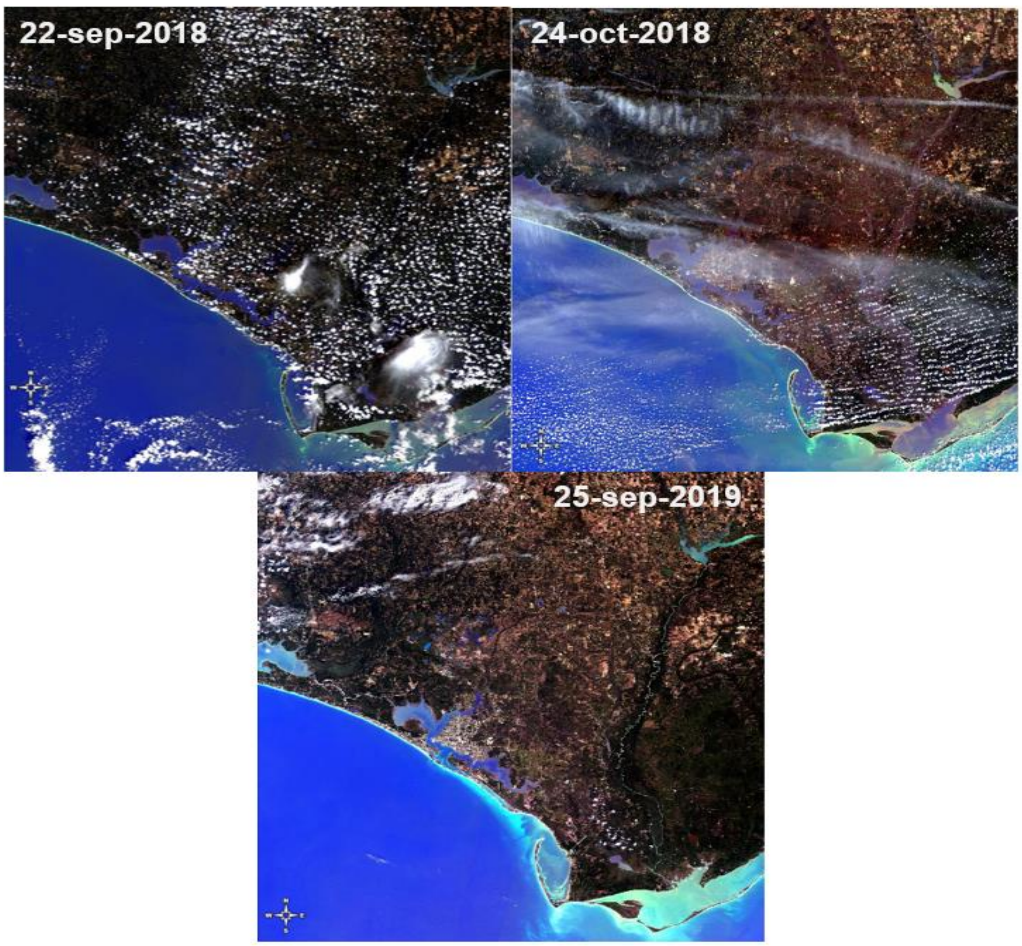

Figure 6. *True Color (RBG) Images for Hurricane Michael landfalling region over Florida Panhandle from Landsat OLI on a) 22-sep-2018, b) 24-oct-2018, and c) 25-sep-2019.*

The biggest challenge when working with the first two images was the presence of cloud cover near the populated zones and over some areas of interest throughout the images. However, when analyzing these images at large scale, it can be noticed the changes that have occurred in the green vegetative layer as its reflectance changed due to the damage caused by the powerful cyclone through the area of the hurricane eyewall track. Taking a closer look at these images by zooming to Panama City zone, as shown in **Figure 7**, the changes in both vegetation and urbanized areas become more evident. In the image at 14 days after the hurricane it is possible to detect the extend of the destruction that occurred in both vegetation and the buildings of this city although the images became more pixelated when taking an even closer zoom. Structures near the coastal regions were swept by the storm surge and the powerful winds.

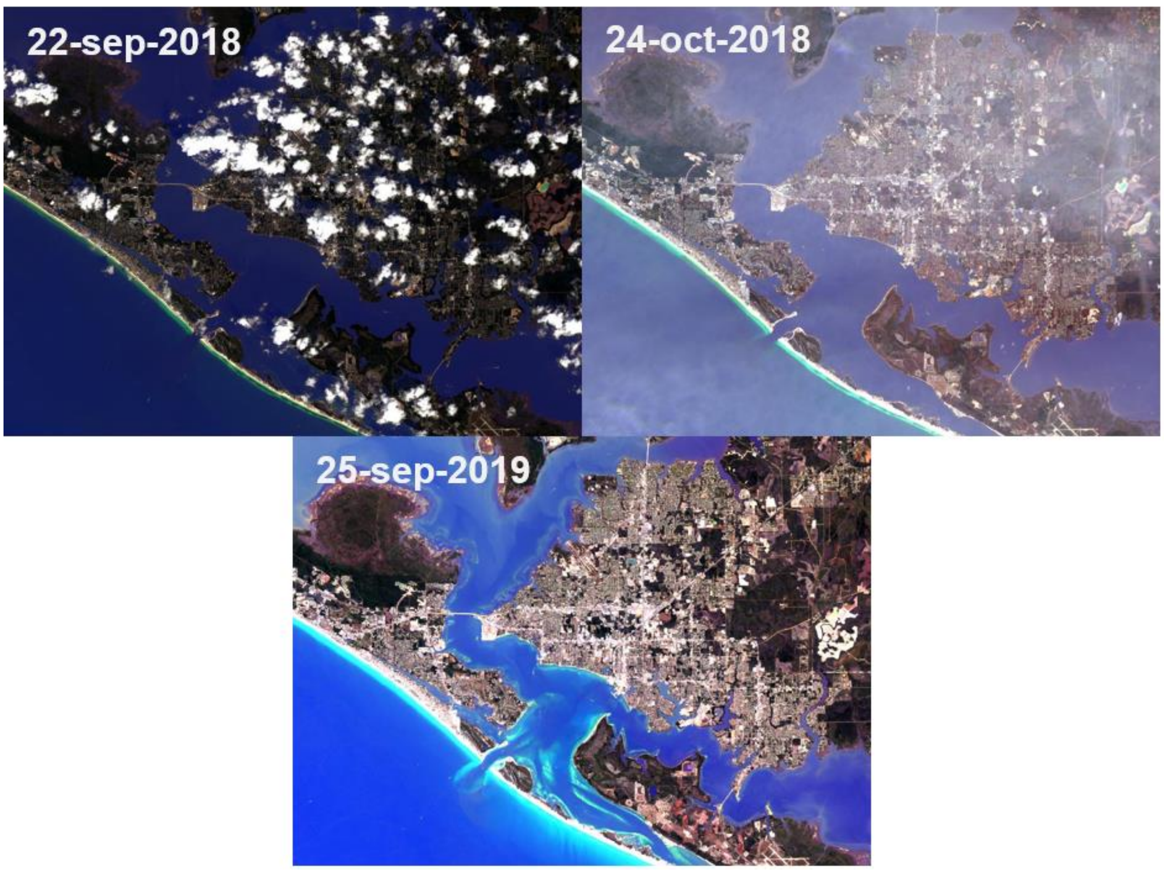

Figure 7. *RGB Image Zoom to Panama City, Florida, USA on a) 22-sep-2018, b) 24-oct-2018, and c) 25-sep-2019.*

A closer look toward Mexico Beach zone allows to detect changes in the coastline area. In **Figure 8b** from 24-oct-2018, it is evident how the sand was dragged by the storm surge into the terrain giving the perception of having a wider coastal area when actually erosion is affecting the shoreline as a consequence of the effects of the tropical cyclone. Some changes are also perceived when looking at the burned like vegetation that surrounds Mexico Beach City and with some swampy areas that still flooded after 14 days from the event. **Figure 8c** from 25-sep-2019 demonstrate that coastline changes caused by Hurricane Michael were permanent and no recovery was observed for the Mexico Beach coastline.

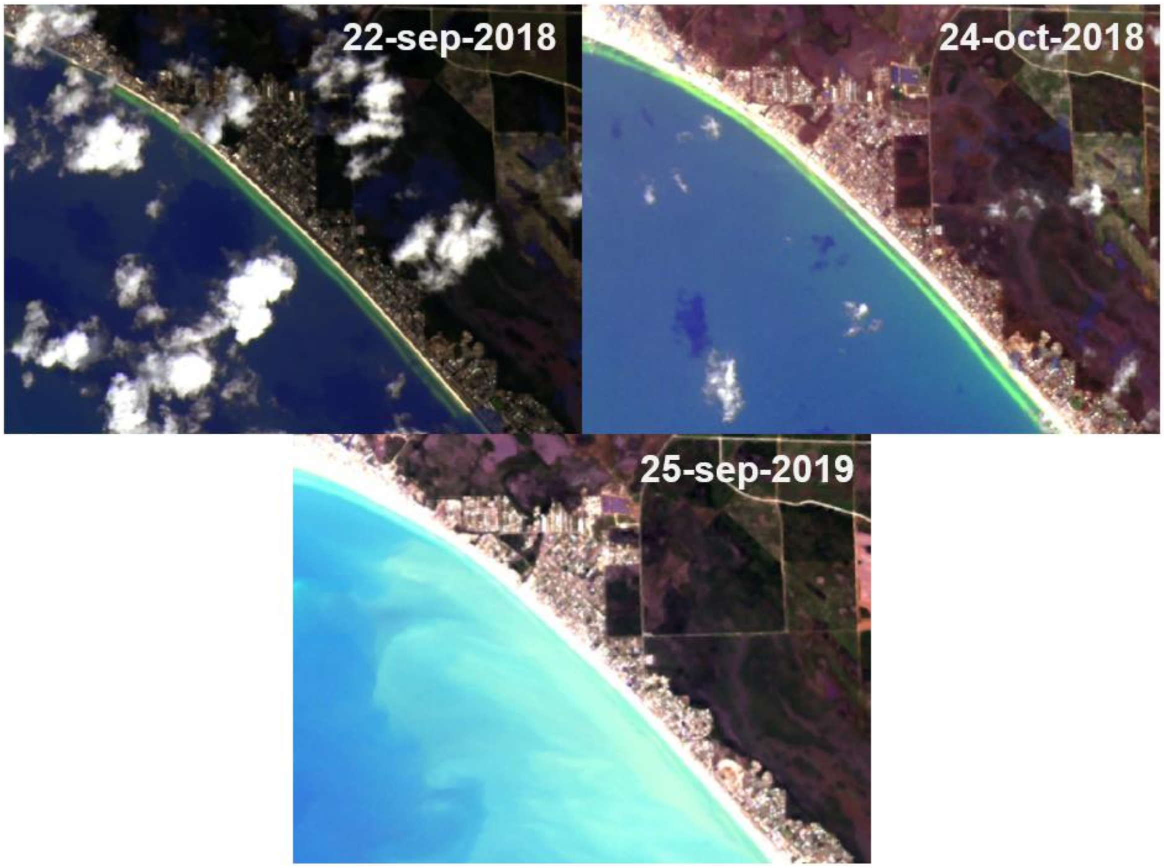

Figure 8. *RGB Image Zoom to Mexico Beach, Florida, USA on a) 22-sep-2018, b) 24-oct-2018, and c) 25-sep-2019.*

One of the most evident changes cause by the combined effects of the Category 5 storm was observed over the St. Joseph Peninsula, as seen in **Figure 9**. Comparing the image from 22-sep-2018 with the one from 24-oct-2018 it can be seen how the storm surge effects caused a major geological change by dividing the peninsula into two separated areas as marked with the line arrow. Originally through that zone there was a street that obviously was completely destroyed by Hurricane Michael. **Figure 9c** from 25-sep-2019 confirms that the changes caused by the storm surge over this area were irreversible. A similar effect was observed farther south in the Cape San Blas area where a characteristic formation in the sandy terrain was completely erased from the view corresponding now to the ocean (see **Figure 10**).

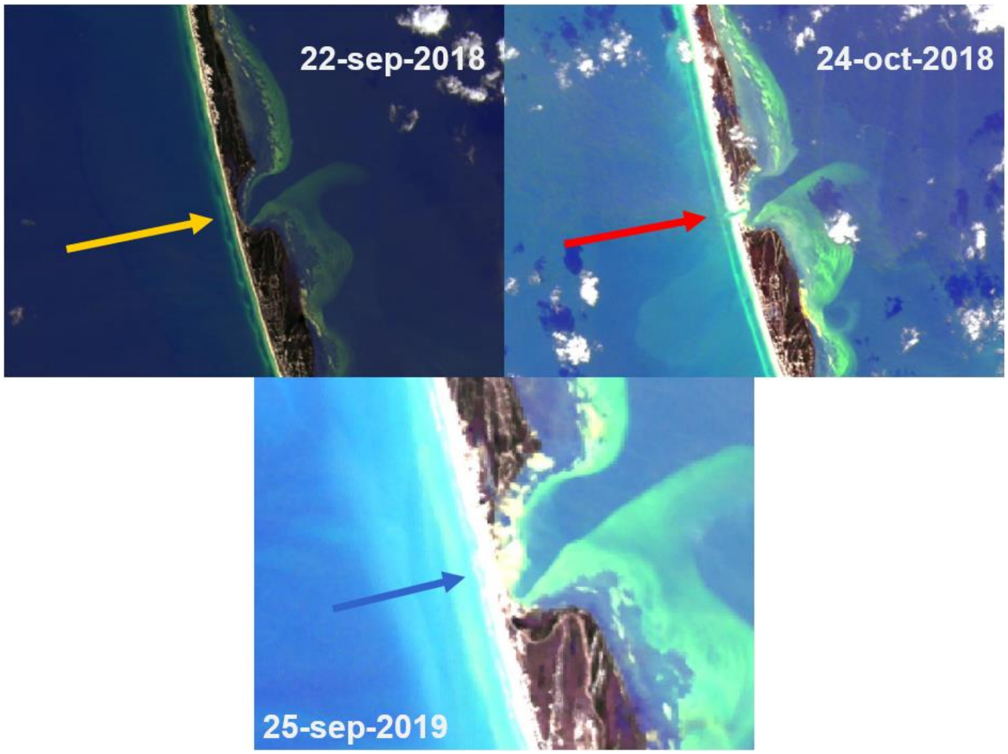

Figure 9. *RGB Image Zoom to St. Joseph Peninsula, Florida, USA on a) 22-sep-2018, b) 24-oct-2018, and c) 25-sep-2019.*

Figure 10. *RGB Image Zoom to Cape San Blas, Florida, USA on a) 22-sep-2018, b) 24-oct-2018, and c) 25-sep-2019.*

Grayscale Images from the Red Band of OLI (**Figure 11**) allows to identify change patterns in the vegetative areas. These changes become more evident when observing the False Color images obtained by using Bands 5 (NIR), 3 (Green), and 2 (Blue) from OLI. False Color images highlight the vegetation over the study region as seen in **Figure 12**.

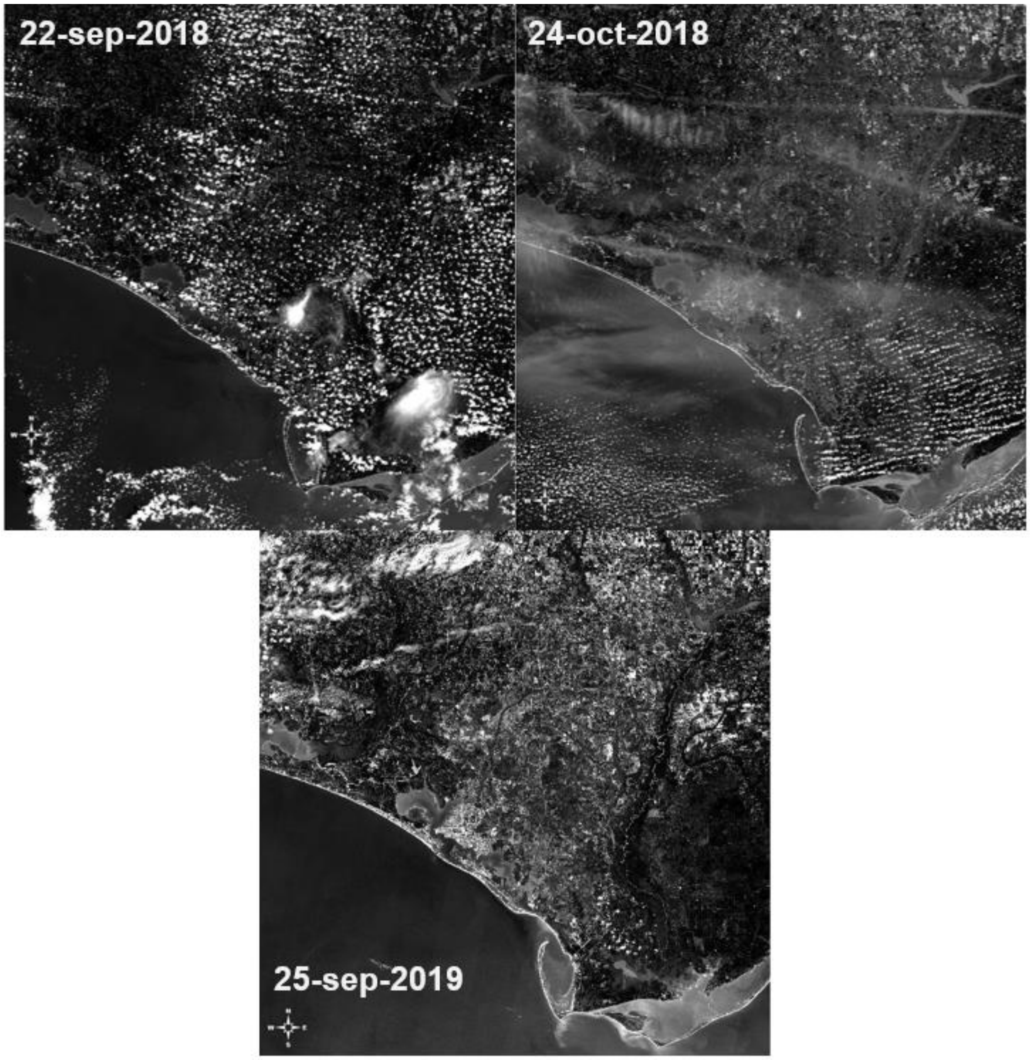

Figure 11. *Gray Scale Images of the Red Band for Hurricane Michael landfalling region over Florida Panhandle from Landsat OLI on a) 22-sep-2018, b) 24-oct-2018, and c) 25-sep-2019.*

A change in brightness is seen when looking at the three images, where red color looks denser on 22-sep-2018 image, evidently as a response of the healthy vegetation before hurricane event. In **Figure 12b** from 24-oct-2018, it is evident how the loss of vegetation makes the landforms within the ground affected area more noticeable, as the delimitations of the river mouths, their meanders, and bay areas that surround Panama City become more highlighted.

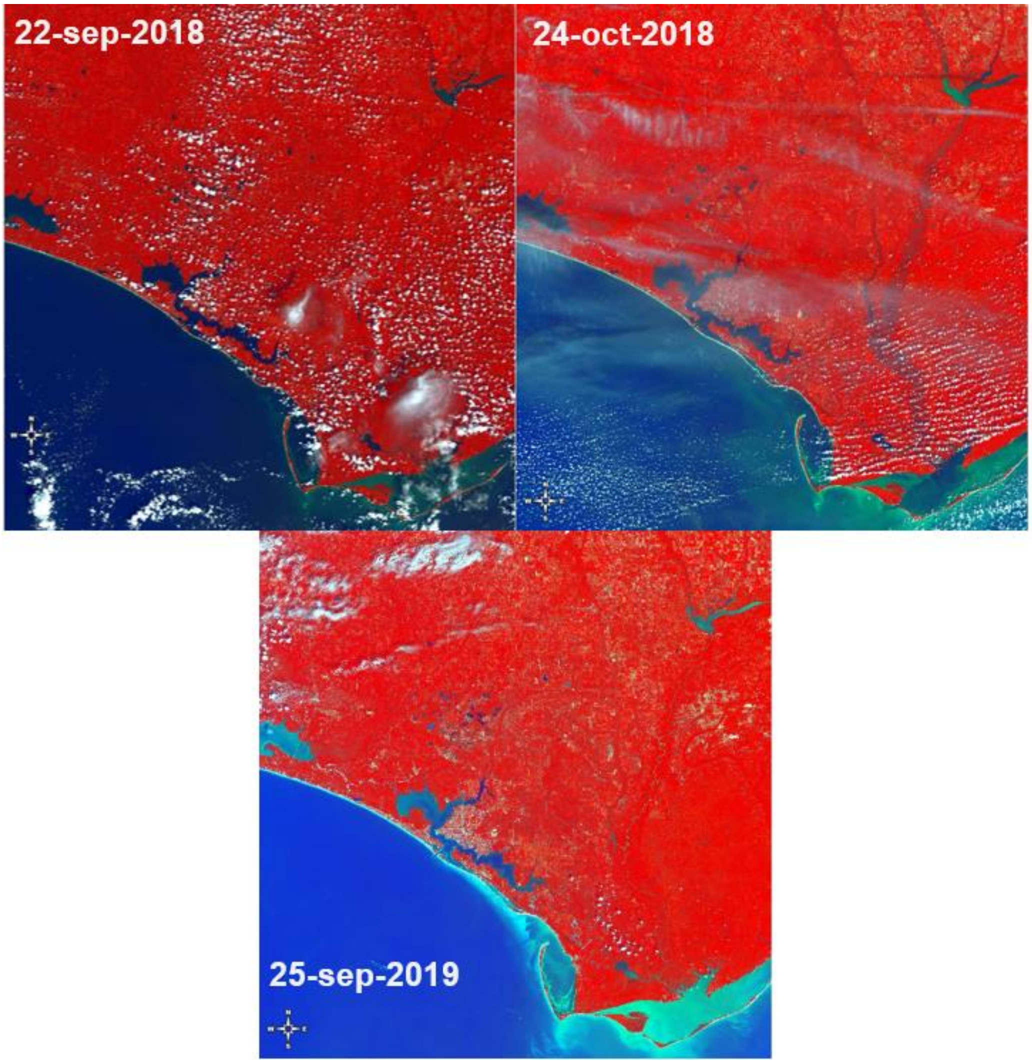

Figure 12. *False Color Images for Hurricane Michael landfalling region over Florida Panhandle from Landsat OLI on a) 22-sep-2018, b) 24-oct-2018, and c) 25-sep-2019.*

Results for the Unsupervised Multispectral Classification using IsoData technique applied with ENVI 5.6 to the OLI images are shown in **Figure 13**. The advantage of IsoData is that it does not require extensive knowledge and helps in minimizing the possibility of human error since the software program manages the classification according to the integrated algorithm. IsoData showed a variable number of classes in the different images obtained having 10 classes for 22-sep-2018, 9 classes for 24-oct-2018 and 7 classes for 25-sep-2019. Especially, a great disturbance is observed among the pixels or classes identified with this program algorithm for the 24-oct-2018 image, compared to the other two unsupervised classification image results, which was probably caused by the inconsistent values of the pixels because of the recent devastation caused by the hurricane over the area of study.

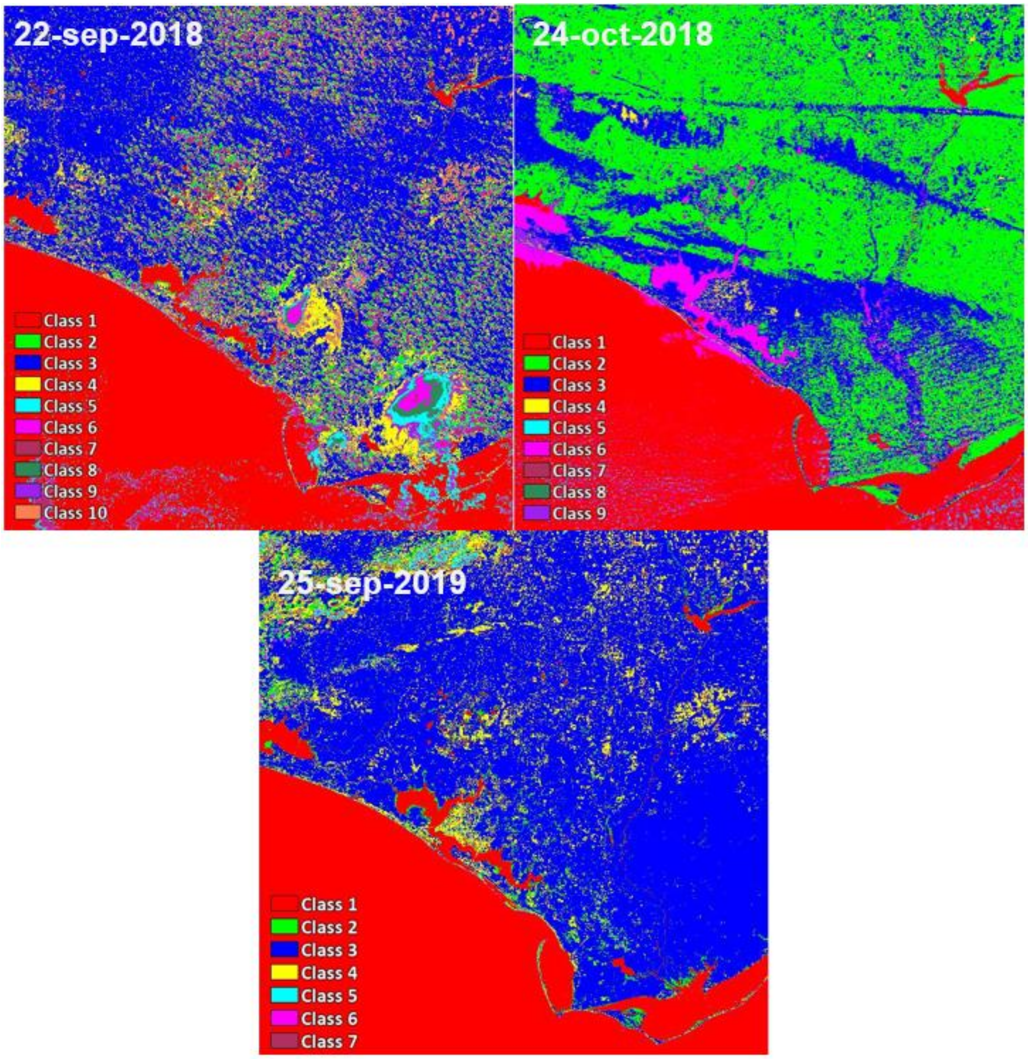

Figure 13. *IsoData Unsupervised Classification for the region over Florida Panhandle affected by Hurricane Michael, Landsat OLI on a) 22-sep-2018, b) 24-oct-2018, and c) 25-sep-2019.*

Supervised Multispectral Classification applying the Minimum Distance technique was possible through the identification of 5 different ROIs or training areas to the software program. Depiction of vegetation, ocean, suspended sediments, city, and clouds was possible within the area of study as seen in **Figure 14**. On **Figure 14b** from 24-oct-2018, is impressive the large amount of suspended sediments that were still discharging from the rivers to the ocean at 14 days from the devastating event. This indicates how water bodies at the zone still disturbed after two weeks from the torrential rainfalls of Hurricane Michael over the zone. In the same figure, it is also observed how the urban area of Panama City is highlighted in the supervised classification probably due to the loss of vegetation cover in the area.

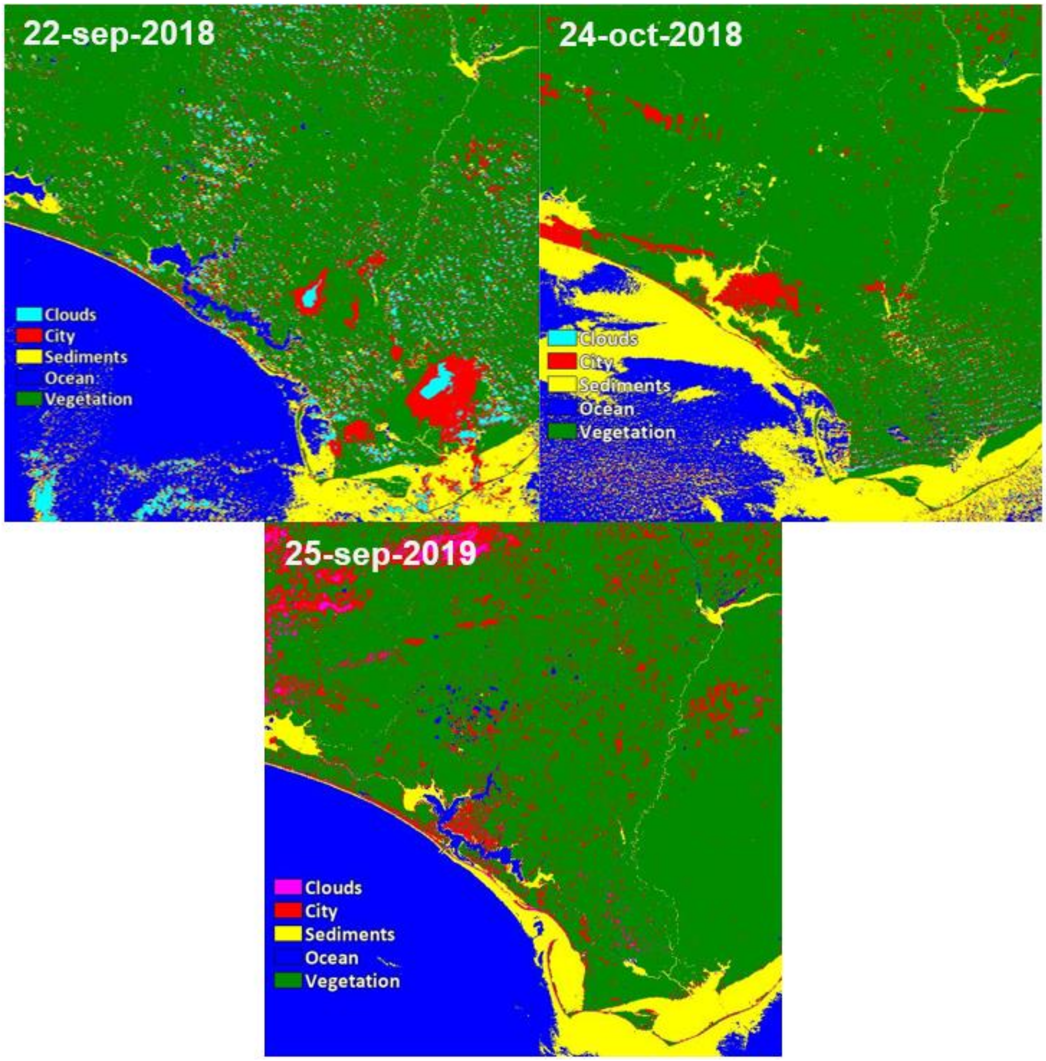

Figure 14. *Minimum Distance Supervised Classification for the region over Florida Panhandle affected by Hurricane Michael, Landsat OLI on a) 22-sep-2018, b) 24-oct-2018, and c) 25-sep-2019.*

In terms of the Normalized Difference Vegetation Index (NDVI), Red and NIR bands are the ones of interest. According to the literature, calculations of NDVI for a given pixel always result in a number that ranges from -1 to 1, however, no green leaves should have a value close to 0 and using the corresponding Raster Mask is possible to cover the values from the ocean or water bodies. Results obtained for the NDVI confirmed that the devastating winds of Hurricane Michael caused a significant loss in the vegetative cover through the study area being more evident just near the eyewall landfalling zone at Panama City (see **Figure 15**). A decrease in the NDVI values is evident for the results for 24-oct-2018, ranging from 0.34 to 0.83, compared to the results for 22-sep-2018, ranging from 0.29 to 0.86, however, after one year from the meteorological event, NDVI values were recovered to high values as 0.89. This is the evidence that the vegetative layer was recovering after one year. It is important to denote that the NDVI values in the image from

22-sep-2018, before hurricane landfall, were probably affected by the cloud cover in the area of interest.

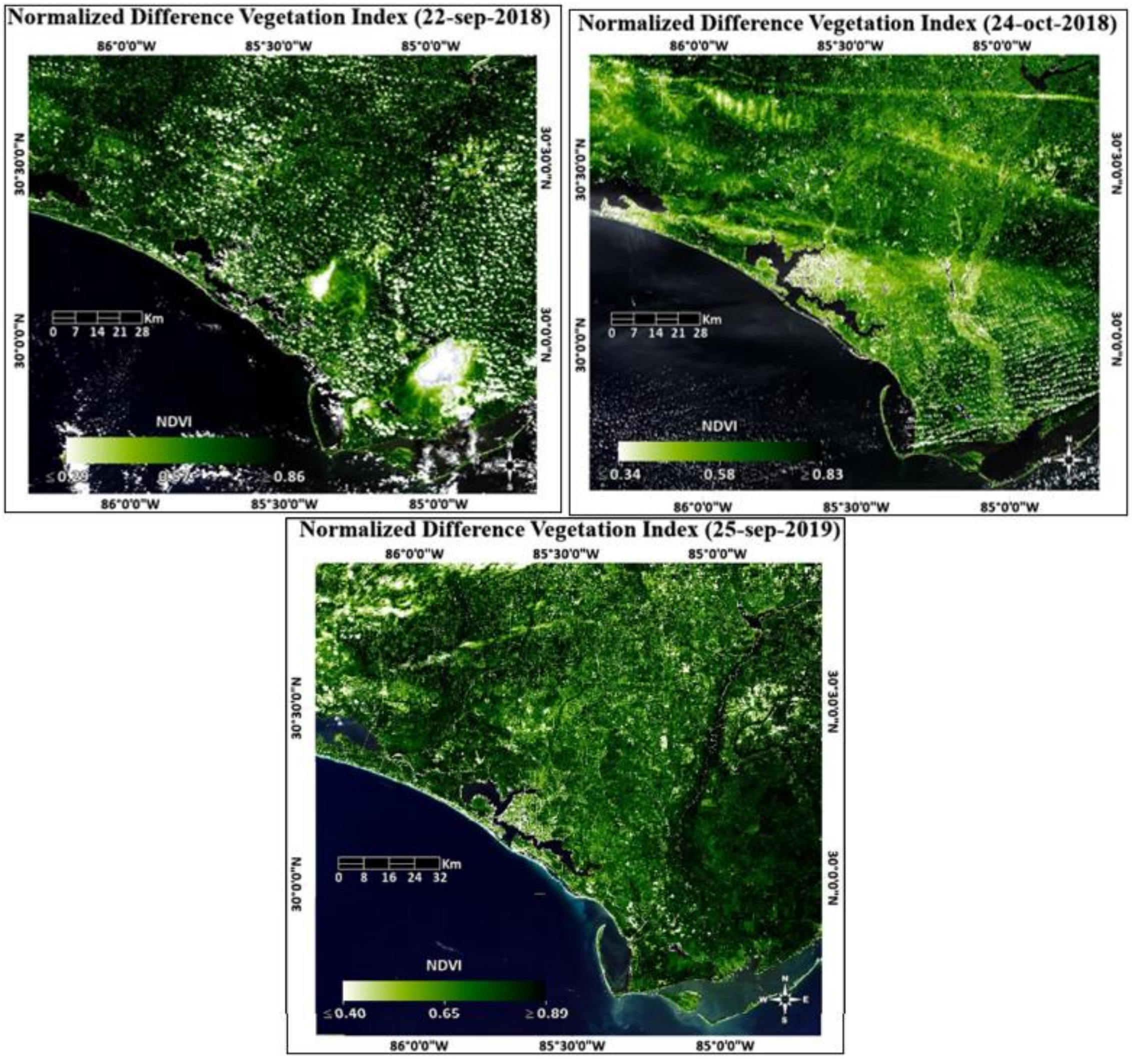

Figure 15. *Normalized Difference Vegetation Index (NDVI) for the region over Florida Panhandle affected by Hurricane Michael, Landsat OLI on a) 22-sep-2018, b) 24-oct-2018, and c) 25-sep-2019.*

Table 1 shows the comparison results for ten randomly selected pixels in the area affected by Hurricane Michael. Mathematical results show how NDVI values were as high as 0.82 before hurricane landfall, which is indicative of a very healthy vegetation and were diminished to 0.46 after the area experienced the powerful winds of the tropical cyclone. Then, after almost a year from the major weather event, the vegetative cover was recovering as the NDVI values are again returning to their original values or have passed over them. Also when comparing the pixel classification for IsoData and Minimum Distance classification, it can be inferred that Class 2 and

Class 3 from IsoData correspond to Vegetation class from Minimum Distance Classification, while Class 4 appears to correspond to the pixels classified as City.

Table 1. *Comparison of Normalized Difference Vegetation Index (NDVI), IsoData Unsupervised Classification, and Minimum Distance Supervised Classification for ten randomly distributed pixels over vegetation and city zones in Landsat OLI Images in the region affected by Hurricane Michael eyewall.*

Pixel	Georeference	22-sep-2018			24-oct-2018			25-sep-2019		
		NDVI	IsoData	Minimum Distance	NDVI	IsoData	Minimum Distance	NDVI	IsoData	Minimum Distance
1	30°7’20” N -85°40’40” W	0.81	Class 3	Vegetation	0.55	Class 3	Vegetation	0.82	Class 3	Vegetation
2	30°18’14” N -85°40’54” W	0.68	Class 2	Vegetation	0.57	Class 3	Vegetation	0.78	Class 3	Vegetation
3	-30°10’34” N -85°26’33” W	0.82	Class 3	Vegetation	0.46	Class 3	Vegetation	0.72	Class 3	Vegetation
4	30°15’45” N -85°18’48” W	0.84	Class 3	Vegetation	0.72	Class 2	Vegetation	0.78	Class 3	Vegetation
5	29°54’43” N -85°20’40” W	0.82	Class 3	Vegetation	0.64	Class 3	Vegetation	0.76	Class 3	Vegetation
6	29°44’52” N -85°16’1” W	0.78	Class 3	Vegetation	0.60	Class 3	Vegetation	0.83	Class 3	Vegetation
7	30°32’52” N -85°19’5” W	0.85	Class 3	Vegetation	0.57	Class 3	Vegetation	0.77	Class 3	Vegetation
8	30°10’19” N -85°39’36” W	0.23	Class 8	City	0.16	Class 9	City	0.17	Class 4	City
9	29°56’12” N -85°23’47” W	0.64	Class 4	City	0.36	Class 3	City	0.42	Class 4	City
10	29°48’25” N -85°18’7” W	0.60	Class 9	City	0.32	Class 4	City	0.48	Class 4	City

Landsat 7 – ETM+

For the Enhanced Thematic Mapper Plus sensor, three images were equally pre-processed for the comparison of the impact the Florida Panhandle had after the Hurricane’s landfall. Preprocessing techniques included Radiometric Calibration, Dark Subtraction Method and Diffuse Pan Sharpening for atmospheric correction and detail enhancement. Primary image analysis was performed with band combinations.

True Color images (RGB), were generated using the bands 3 (Red), 2(Green) and 1 (Blue). A differentiation of tones in the vegetative layer can be observed along the region of interest. **Figure 16a** displays the darkest tone of green compared to the image after the event, as seen on **Figure 16b.** This means that the regions that were once vegetated before the event **(Figure 16 a)**, show a noticeable lack of vegetation days after the hurricane’s landfall **(Figure 16 b)**. **Figure 16c** represents a year after the event, appearing to be a darker green tone than **Figure 16b**, hinting a possible recovery of vegetation.

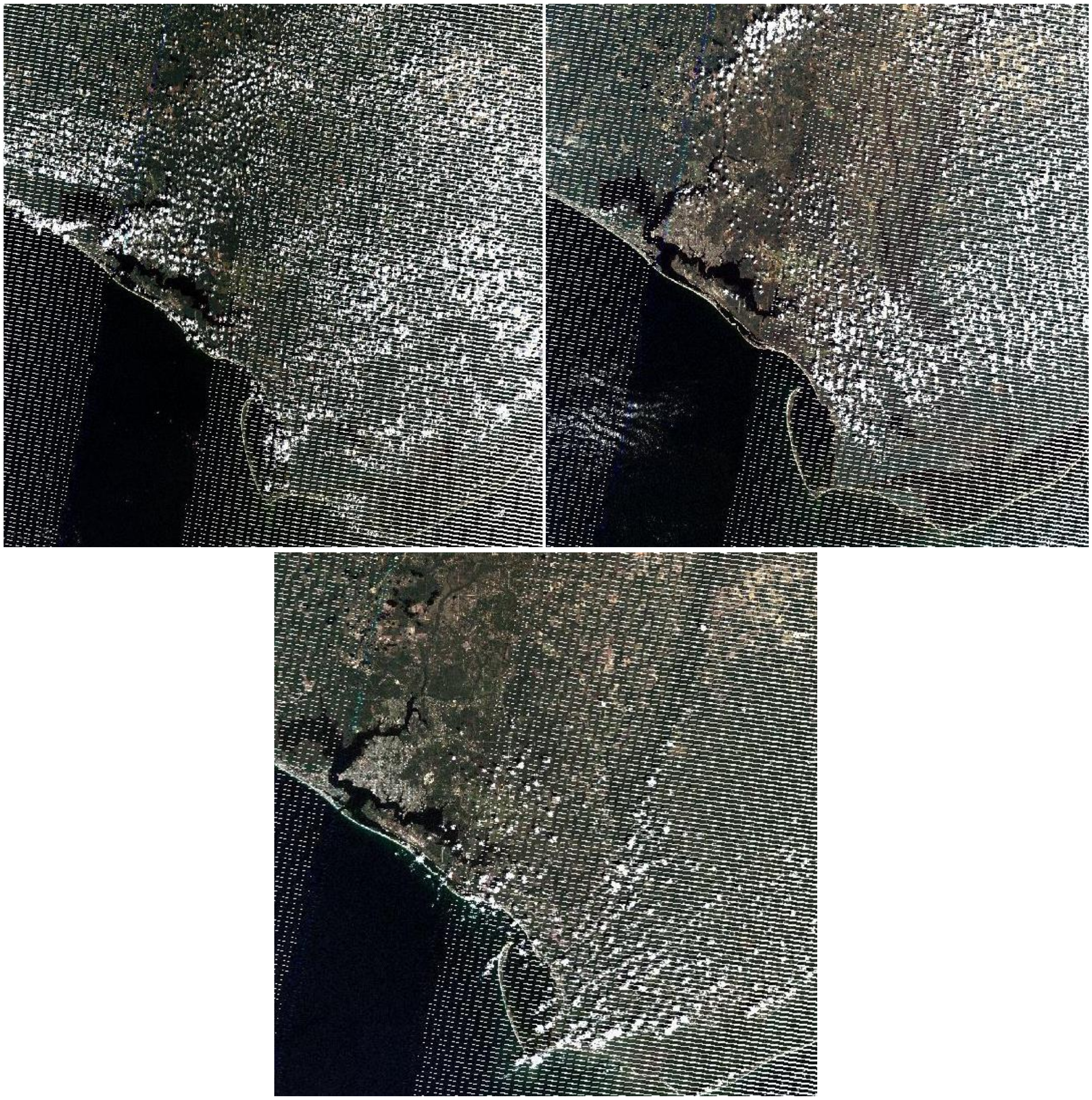

Figure 16: *True Color images using bands 1, 2, 3 and 4 for Hurricane Michael landfalling region over Florida Panhandle from Landsat ETM on a) 30-sep-2018, b) 16-sept-2018, and c) 03-oct-2019.*

False Color images **(Figure 17)** were obtained using the bands 4 (NIR), 2 (Green), and 1 (Blue). As a result of the stripings on the images, a linear stretch of 2% was applied to Figures 17a and 17b for a better distinction of the overall vegetation's health. Although, **Figure 17b** shows a lighter red tone than figure a indicating less reflection, thus, less vegetation. A linear stretch of 5% was applied to the image after the event (**Figure 17c**), and the tone seems discernibly different than Figure 17a and 17b, displaying a brighter tone.

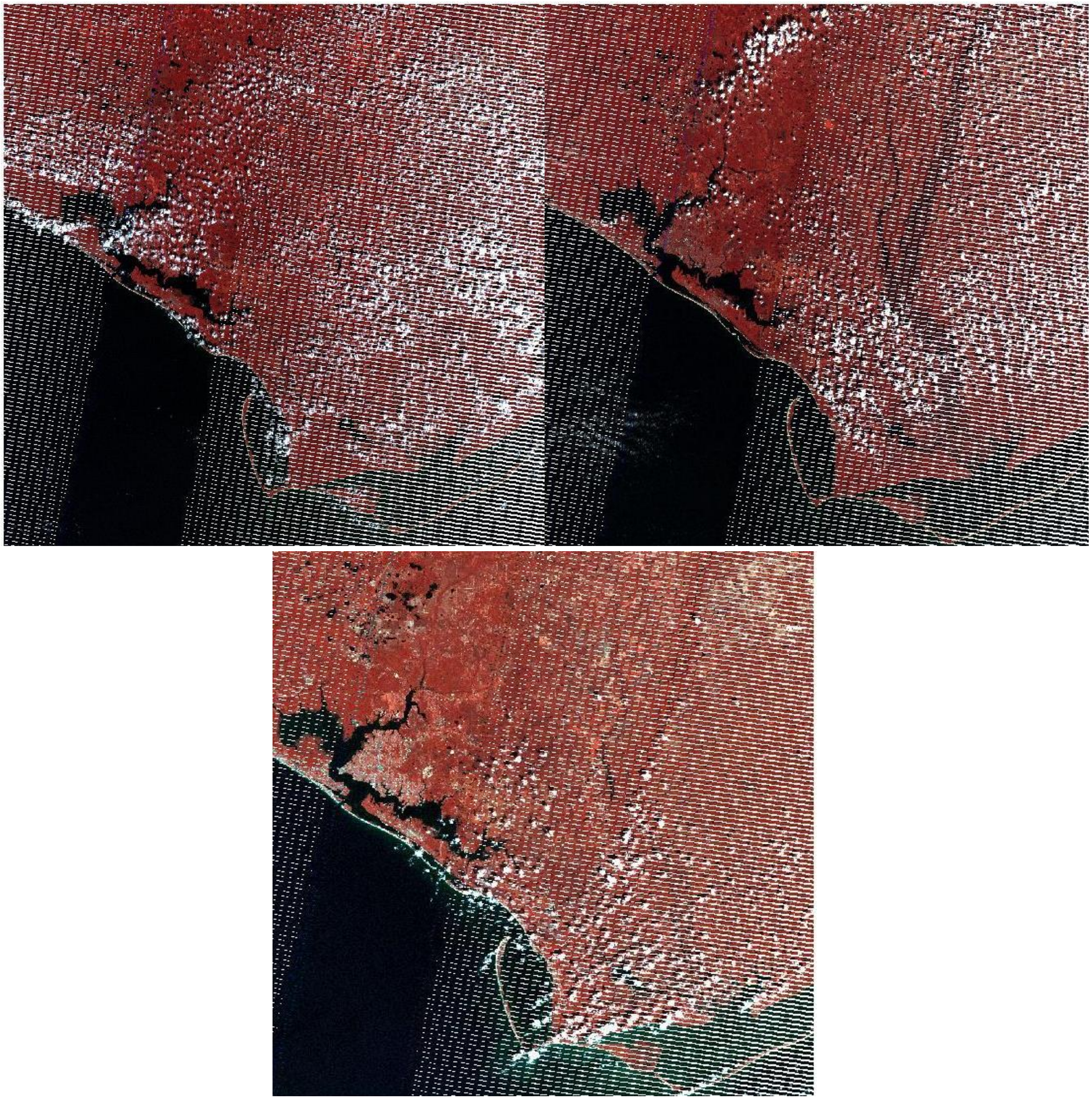

Figure 17: *False Color images using the NIR band for Hurricane Michael landfalling region over Florida Panhandle from Landsat ETM on a) 30-sep-2018, b) 16-sept-2018, and c) 03-oct-2019.*

An Unsupervised and Supervised Multispectral Classification was performed for each image. This provided a general perspective of the distribution of the different classes. The first technique applied was the IsoData Classification, with 10 different classes and a maximum of 5 iterations. Isodata Classification provided a slight approximation to the overall changes caused by the passing event. Regardless of the different classes varying in each image, there is a pattern on the "after" images of the event (**Figure 18b**: Class 3 and 5, and **Figure 18c:** Class 4 and 5) and can be inferred as suspended or displaced sediments due to the heavy rainstorms.

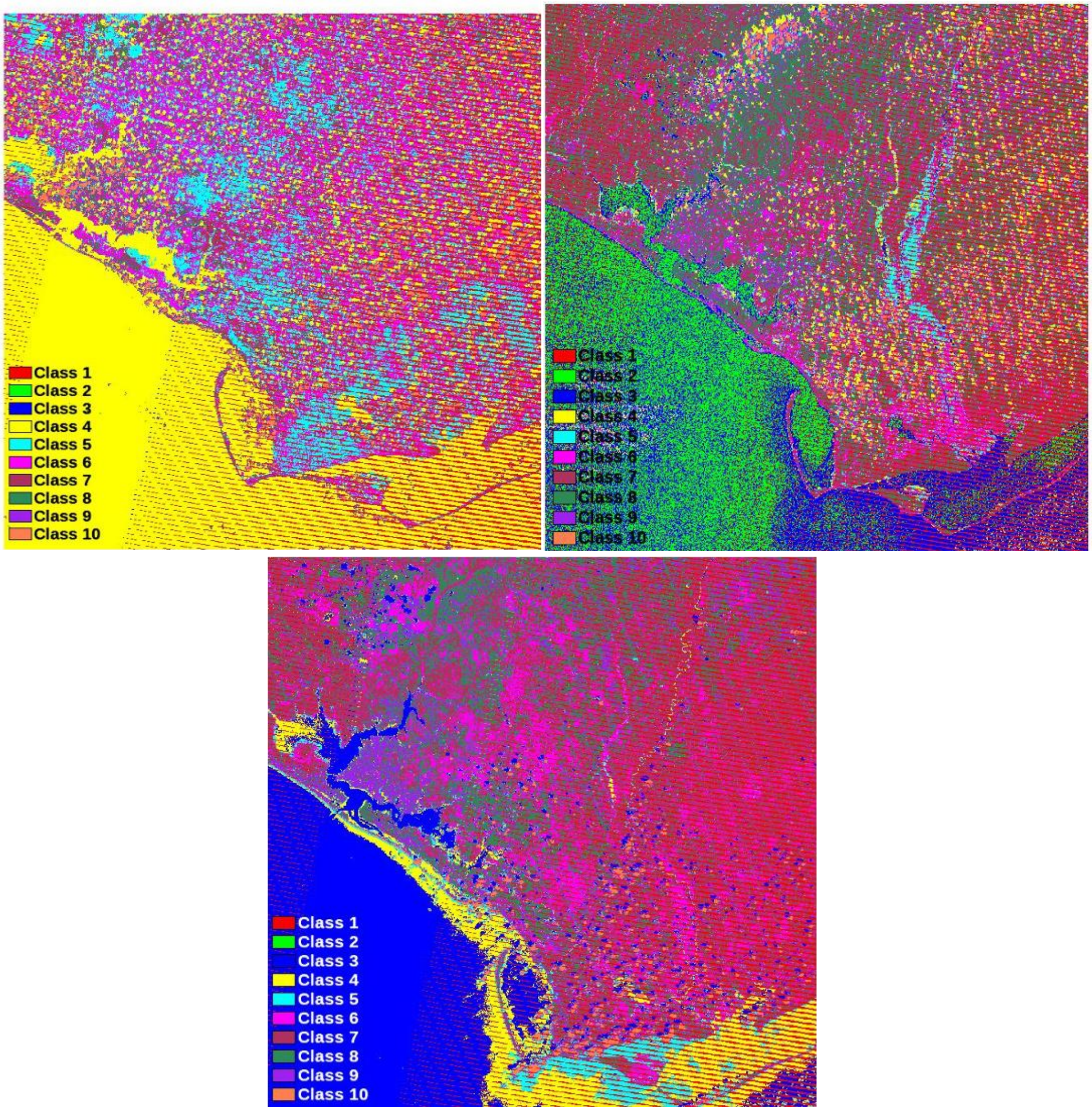

Figure 18: *IsoData Unsupervised Classification for the region over Florida Panhandle affected by Hurricane Michael, Landsat ETM on a) 30-sep-2018, b) 16-sept-2018, and c) 03-oct-2019.*

For the Supervised Classification, 5 Regions of Interest (ROI) were defined: Vegetation, Ocean, Sediments, City and Clouds. They were selected for the application of the Minimum Distance Classification, just like the previous OLI images. **Figure 19a** presents the Florida Panhandle before the event, displaying a majority of vegetation and an accurate classification of the City and Clouds clases. Though the cloud's dark shadow was classified as part of the Ocean class due to its high absorption, it did not interfere with the analysis.

A high disruption of suspended sediments can be observed on **Figure 19b**, five days after hurricane Michael's landfall. One considerable observation is the presence of suspended sediments along the river, near tributaries, and around the water bodies on the interior of the Panhandle. A year after the event (**Figure 19c**), exposes an overall vegetative ground with low to none amount of sediments, contrary to the image after the event. However,with the passing of a year, there is a large amount of sediment deposition along the coastline of Cape San Blas, and this could be presumed as a long term result of the event.

When comparing the Minimum Distance Classification with the IsoData technique, the latter allowed less for interpretation. Although Isodata showed a higher inaccuracy of the representations, it still provided supporting data for the study. The Minimum Distance Classification exhibited a clear distribution of the classes within the region of study, which evidenced the changes of sediment suspension due to the rain activity from the Hurricane Michael.

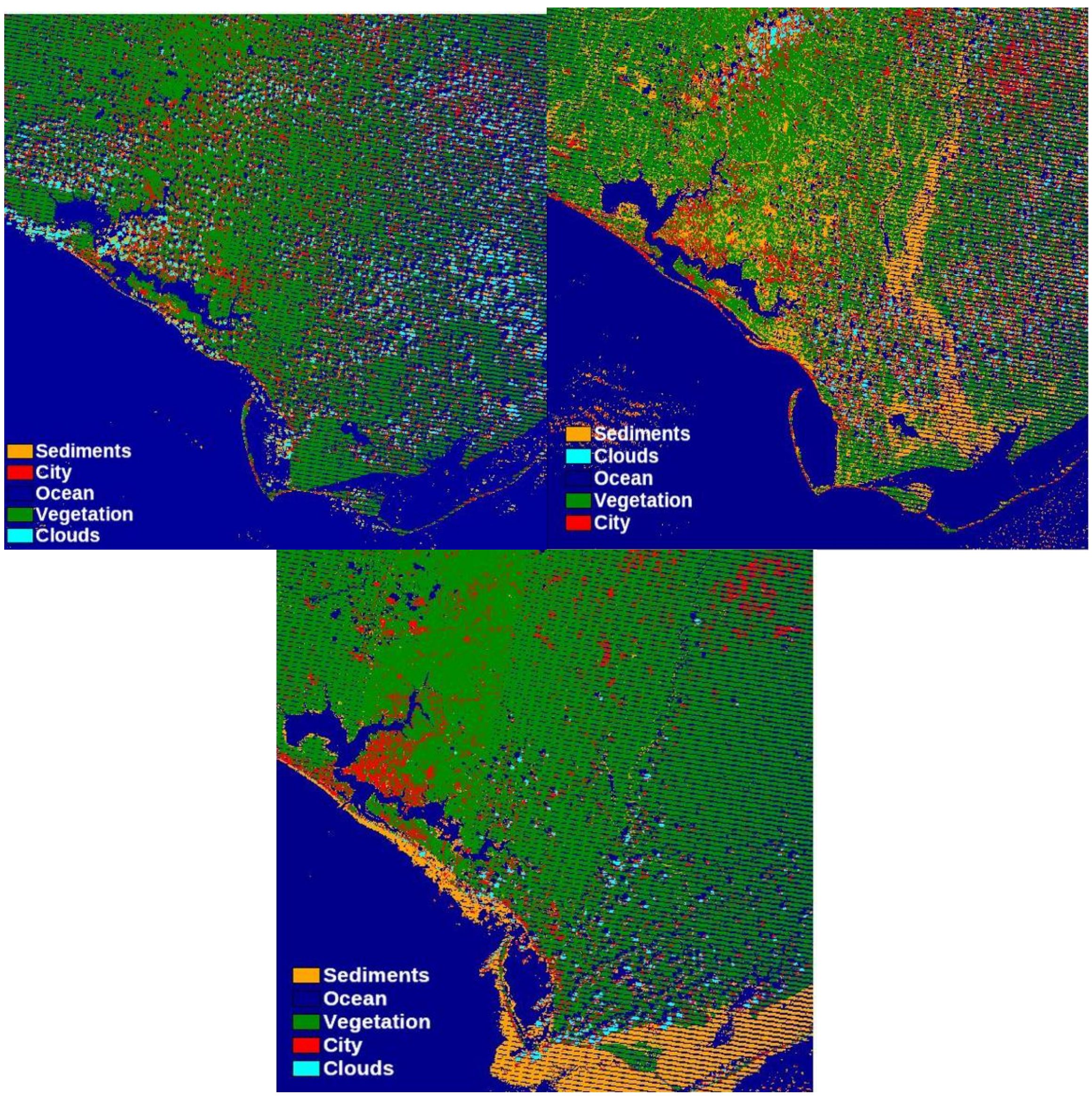

Figure 19: *Minimum Distance Supervised Classification for the region over Florida Panhandle affected by Hurricane Michael, Landsat ETM on a) 30-sep-2018, b) 16-sept-2018, and c) 03-oct-2019.*

A Normalized Difference Vegetation Index Estimation was computed to compare the impact and changes in the vegetation before and after the event. The bands used for this technique were the Red and Near Infrared bands. Additionally, a “Band Mask” to cover the water bodies was generated for the three different images, along with the Green/White Linear color application. The color bar in **Figure 20** represents the vegetation measurement tool, ranging from a light Green (low vegetation index) to a darker green (high vegetation index). The image before the meteorological event, has the highest NDVI value of 0.59 and an average of 0.30. **Figure 20b** exhibits a decrease of almost half the value from before the event, this being a máximum of 0.30 NDVI value and an average of 0.15. Interpretation of this data suggests a diminish of the vegetative layer after the passing of Hurricane Michael, presuming it to be caused by the effects of this event. The NDVI for the Florida Panhandle a year after the event, has a maximum value of 0.31 and an average value of 0.16. With just a 0.1 increase in the values versus **Figure 20b**, this suggests a slow recovery of vegetation.

To determine whether the recovery of the vegetational layer of the affected area has been possible, ten pixels were randomly selected and were subjected to comparison among the three dated images (**Table 2**). The highest NDVI value is 0.319 can be found before the event as part of the Vegetation class, to later decrease to a 0.009 relating it to a Sediment class value. After a year of the catastrophe, the same pixel increased in value to 0.250 returning to the Vegetation class, implying a recovery of Vegetative density. Comparing the IsoData results with the Minimum Distance Classification, it is inferred that Class 1 corresponds to Sediments Class, Class 4 corresponds to Vegetation and Class 2 corresponds to City Class.

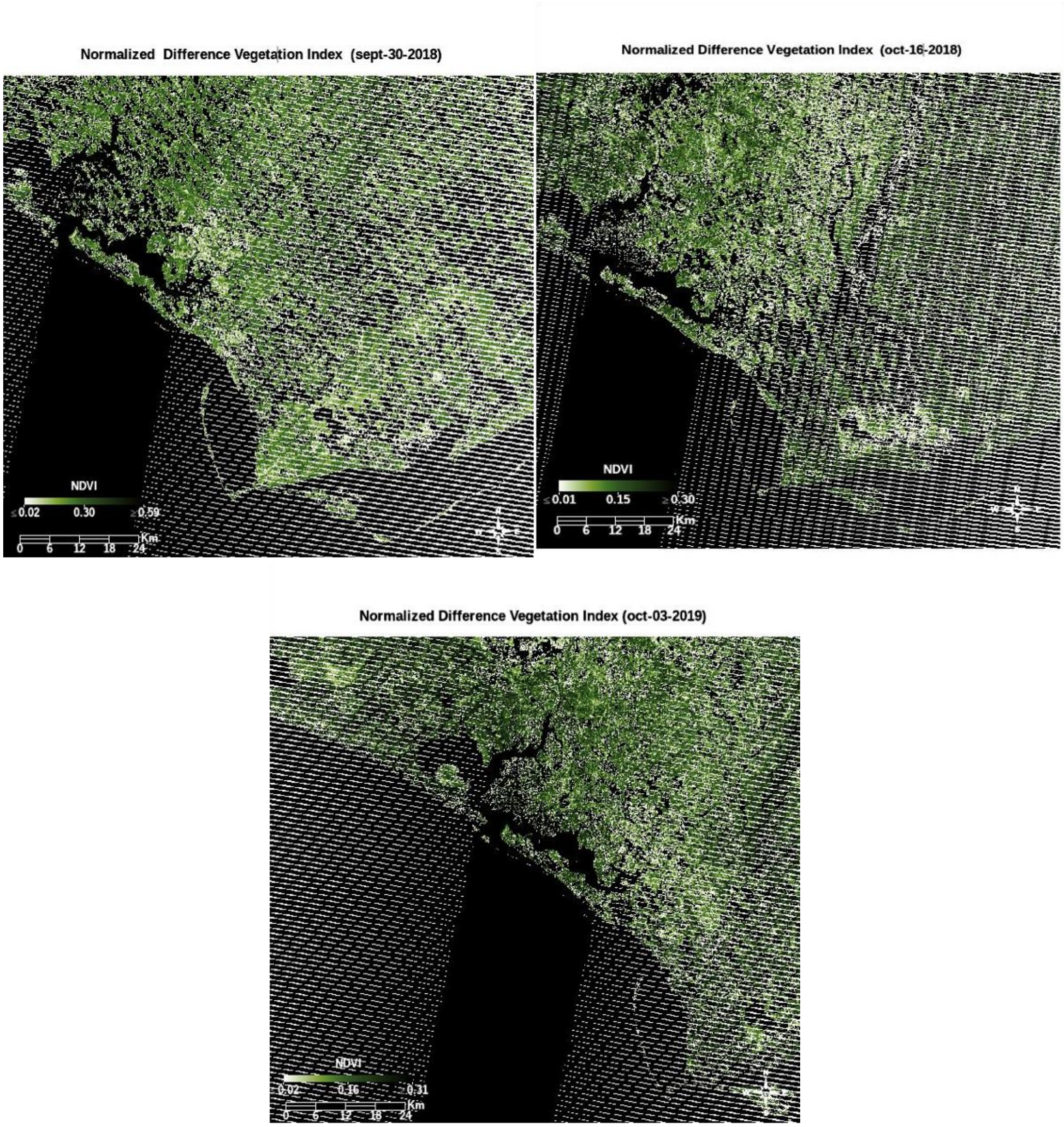

Figure 20*: Normalized Difference Vegetation Index (NDVI) for the region over Florida Panhandle affected by Hurricane Michael, Landsat ETM on a) 30-sep-2018, b) 16-sept-2018, and c) 03-oct-2019.*

Table 2. *Comparison of Normalized Difference Vegetation Index (NDVI), IsoData Unsupervised Classification, and Minimum Distance Supervised Classification for ten randomly distributed pixels over vegetation and city zones in Landsat ETM+ Images in the region affected by Hurricane Michael eyewall.*

Pixel	30-sep-2018			16-oct-2018			03-oct-2019		
	NDVI	IsoData	MDC	NDVI	IsoData	MDC	NDVI	IsoData	MDC
1	0.190	Class 4	Veg	0.120	Class 4	Veg	No data	Class 2	City
2	0.109	Class 4	Veg	0.052	Class 1	Seds	0.0526	Class 1	Seds
3	0.0337	Class 4	Veg	0.0927	Class 1	Seds	No data	Class 2	City
4	0.186	Class 4	Veg	0.111	Class 4	Veg	0.1923	Class 4	Veg
5	No data	Class 2	City	0.0217	Class 1	Seds	0.056	Class 4	Veg
6	0.0405	Class 4	Veg	0.036	Class 4	Veg	0.008	Class 1	Seds
7	0.188	Class 4	Veg	No data	Class 1	Seds	0.148	Class 4	Veg
8	0.154	Class 2	City	No data	Class 1	Seds	0.0468	Class 4	Veg
9	0.285	Class 4	Veg	0.1965	Class 4	Veg	0.109	Class 4	Veg
10	0.319	Class 4	Veg	0.0099	Class 1	Seds	0.2500	Class 4	Veg

Processing Errors

The images acquired from the ETM+ posed a great challenge to process and to train the ROI's because of the striping present in the images that were caused by the system's failure back in 2003. The images were processed using ENVI56 software for MacOS Mojave (Version 10.15.6), and unfortunately, some correcting features such as "Destriping" were limited for this version and could not be applied. Another system error occurred in the assignment of coordinates for the NDVI images.

CONCLUSIONS

ENVI 5.6 Software is a powerful tool for processing digital images to investigate and/or detect coastal and vegetation changes caused by a catastrophic meteorological event such as the powerful Hurricane Michael. Remote Sensing is very helpful in determining the extent of the impact caused by the devastating winds and catastrophic flooding of a storm over the vegetation near the eyewall landfalling region. The spatial resolution enhanced by the panchromatic band in OLI sensor image permit the detection of damage to coastal zones after this type of major weather event. Supervised Multispectral Classification has the capacity of detecting the great amount of sediment suspensions in the rivers, lakes, and river mouths after torrential rainfall and major flooding events. Through NDVI estimation, it was possible to conclude that the vegetative layer in this region of the Florida Panhandle suffered important damage after the category 5 storm passed but was recovering after a year from the event.

RECOMMENDATIONS

This study can be expanded by searching on other databases for available images without cloud interference. The Landsat Gap Fill Tool by Triangulation Method or a two-file gap-fill can be used to correct or fill the scene data loss or wedge-shaped gaps on the images caused by the failure of the Scan Line Corrector of ETM+ sensor. For the Supervised Classification it is recommended to use more classes or Regions of Interest (ROI) to obtain a more accurate description of the changes that occurred in the affected zone. Finally, this research can be improved by searching for images from satellite sensors with an improved 1 meter of spatial resolution, such as IKONOS sensor, to better assess the impacts caused by this catastrophic event from Panama City, Mexico Beach, St. Joseph Peninsula and Cape San Blas in the Florida Panhandle.

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