APPRAISAL OF THE DAMAGES CAUSED BY THE 12TH JANUARY 2010 HAITI EARTHQUAKE BY ASTER MULTITEMPORAL IMAGERY ANALYSIS

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ABSTRACT

A strong earthquake of 7.0 Mw magnitude struck on January 12th 2010 Haiti, causing serious damages to most of its capital, Port-au-Prince, and neighbouring areas.

Enriquillo-Plantain Garden fault is the main fault system that contributed to the 12th January earthquake. It is a prominent strike-slip fault being the result of the relative movement between Caribbean and North-American crustal plates.

This paper studies the impacts of Haiti earthquake on natural and human environments, using satellite imagery acquired before and after the earthquake. In particular, ASTER multispectral data sets were employed, aiming at pinpointing the damages caused by the strong seismic event.

The analyzed scenes, acquired before and after the earthquake, cover two different areas, the Haiti capital, Port-au-Prince, and the Miragoane lake region, located west of the capital. The analyzed ASTER bands are the visible and near-infrared (VNIR), as well as the thermal bands (TIR), including the backward looking NIR ones.

The application of various remote sensing techniques to the ASTER multitemporal imagery pointed out severe damages across the capital, consisting mostly of destroyed buildings, and nearby coastline regions, while, as regards the Miragoane region, severe alterations of lake coastline were identified. However, extended cloud coverage in both study areas was present, preventing sometimes suitable results.

INTRODUCTION

On January 12th 2010, 4.53 p.m. local time, a really strong earthquake of a 7.0 Mw magnitude hit the Haiti island causing major material damages and much human loss. Haiti is a Caribbean country that shares the Ispaniola island with Dominican Republic on the western side of the island, covering one third of it.

The Enriquillo-Plantain Garden (EPG) fault is the main fault system that contributed to the catastrophic earthquake. It is a prominent strike-slip fault being the result of the relative movement between Caribbean and North-American crustal plates. The quake epicentre was about 25 km (USGS) west of the country capital centre, Port-au-Prince, causing serious damages to all surrounding areas such as Carrefour, Petit and Grand Goâve.

The state apparatus was unable to respond to this event and face it promptly; thus, many foreign forces rushed to help in many ways. There were many dead, seriously injured and homeless people, while major drugs and food shortages occurred.

Different studies were carried to apply Remote Sensing methods for detecting areas

damaged by the 2010 earthquake (1,2). Satellite data offer a direct and quick way to extract useful information about the earthquake impacts. There are plenty of satellite data that can be used like the optical and the radar systems. Optical data of a high spatial resolution can give satisfying information about areas like the residential ones that faced more serious damages.

This case study used various relevant methods in order to examine the Haiti earthquake impacts on natural and human environment, using as input high resolution optical satellite data and comparing techniques and results with one another in terms of damage assessment. The analyzed satellite data are ASTER multispectral bands which do not exhibit a very high spatial resolution (about 15 m), meaning that they don't reach the 1 m or less spatial resolution of VHR sensors, such as Quickbird, Ikonos, Wordview and others do, but are quite good for attempting a first serious damage evaluation.

DATA

The analyzed imagery consists of ASTER (*Advanced Spaceborne Thermal Emission and Reflection Radiometer*) "*L1B Registered Radiance at the Sensor V003*" data set covering two different areas, the Haiti capital, Port-au-Prince, and the Miragoane lake region, located west of the capital, on the south side of the island. The analyzed ASTER bands are the visible and near-infrared (VNIR) with 15 meters ground resolution, as well as the thermal bands (TIR) with 90 m ground resolution: on the whole nine spectral bands, including the backward looking NIR ones.

More specifically, five ASTER scenes were used. Three, acquired before the earthquake, cover the Northern and Southern parts of Port-au-Prince as well as the Miragoane lake area, on the south-western side of the island, while other two, recorded after the earthquake, show the capital center and the Miragoane lake area (Figure 1, left).

The two pre-earthquake images, showing the Northern and Southern parts of Port-au-Prince, were acquired on January 11th 2009, with a cloud cover of 1% and 12% respectively. The pre-earthquake imagery covering the Miragoane lake area was gathered on January 18th 2009 at (2% cloud cover). On the other hand, the two post-earthquake images, showing the capital centre and Miragoane lake area, were acquired respectively on January 21st 2010 at with a 0% cloud cover and on January 8th 2011 (4% cloud cover).

PREPROCESSING

Before applying any image processing method to the acquired scenes, first of all, it was necessary to carry out suitable pre-processing procedures for correcting and preparing the original data.

There were two pre-earthquake scenes, covering the capital area on the northern and southern sides. So, it was created a mosaic consisting of the pairs of the VNIR (green, red and near-infrared) bands which later became a stacked three bands file.

It was then applied a mask to the pre-quake mosaic scenes according to the post-quake scene to create the final stacked image that covers exactly the same area as the post-quake image. Next, the two images were co-registered (3) using a number of tie points that were inserted manually on pixels that the user evaluates covering the same area.

15 Ground Control Points (GCPs) with a RMS of 0.004 were used for the capital

images and, as regard the Miragoane lake images, 11 GCPs were employed with a RMS of about 0.589.

As far as the data Radiometric Correction is concerned, the VNIR bands radiance values were converted to relative reflectance by applying the IAR Reflectance Calibration which normalizes the pixel values of original bands to the average spectrum calculated from the entire scene (3).

On the other hand, the TIR bands were radiometrically calibrated by applying, more specifically, the Thermal Atmospheric Correction for approximating and removing the atmospheric contributions from thermal infrared radiance data. The algorithm first determines the wavelength that most often exhibits the maximum brightness temperature. This wavelength is then used as the reference wavelength. Only spectra that have their brightest temperature at this wavelength are used to calculate the atmospheric compensation. The surface temperature of every pixel is estimated from the data and used to approximate the brightness temperature using the Planck function (3).

ANALYSIS METHODS

As it was mentioned before, first of all, it was necessary, for applying the next image processing procedures, to create stacked files of VNIR bands and other ones of the TIR bands as regards the imagery acquired before and after the earthquake.

Principal Component Analysis

The Principal Component Analysis (PCA) was applied to a stacked file including the 3 VNIR bands of the pre- and post-earthquake scenes, covering the Haiti capital, obtaining on the whole six Principal Components (PC). As such, important statistical information can be taken analyzing the resulting eigenvectors and eigenvalues matrixes.

It appears that all the eigenvector values of the first PC are positive while the second PC exhibits positive values for the pre-quake bands and negative ones for the post-quake bands. This means that the second principal component is possibly somehow highlighting the differences between imagery acquired before and after the earthquake (Figure 1, right). In dark tones are showed areas appearing brighter after the earthquake than previously. These areas exhibit high 2nd PC negative values. It is possible also to pinpoint changes along the coastline of the capital. On the other hand, the eigenvalues matrix shows that the first band collects the 67.24% of the whole components information, while the second one gets the 24.55%. The PC3 up to the PC6 bands get 5.99%, 1.47%, 0.47% and 0.27% respectively and collect the total noise as well.

Next, the PCA was applied to the thermal bands of pre- and post-earthquake imagery covering the Miragoane lake obtaining ten Principal Components in total. Unfortunately, the corresponding results were hindered by the high cloud coverage of the thermal imagery acquired after the earthquake over Miragoane lake area.

Normalized Difference Vegetation Index (NDVI)

Another image analysis method that was applied to the Haiti ASTER bands was the calculation of the *Normalized Difference Vegetation Index* (NDVI) whose values indicate the amount of green vegetation present in a given pixel. Higher NDVI values indicate greener vegetation. First of all, NDVI was calculated separately from the stacked files of Red and NIR (Nadir looking) bands of ASTER scenes covering the Port-au-Prince area and acquired before and after the earthquake. NDVI images taken after the earthquake showed that there are some parts of the capital coastline and some other regions in the capital centre where the pixels had got big negative values, what does mean strong shortage of vegetation on these areas. Conversely, the pre-earthquake NDVI images exhibited more extensive positive values; this can be an indicator of changes that appeared in the area and would represent vegetation or land use alterations that possibly have a relation with the 2010 earthquake.

Moreover, the NDVI was calculated from the stacked Red and NIR bands of the pre- and post-earthquake imagery covering the Miragoane lake region: the resulting images show clearly enough the extensive cloud coverage of the scene. Clouds appear very dark because of the cloud high capability of absorbing the sun radiation. Just due to this extensive cloud coverage over most of the image, only the lake was selected as study area since it appears quite clear on both date images. Moreover, north and south of the Miragoane Lake passes a segment of EPG fault that makes the area more interesting to be studied. Comparing the NVDI images obtained from the two dates, alterations show up along the lake coastline and not only there.

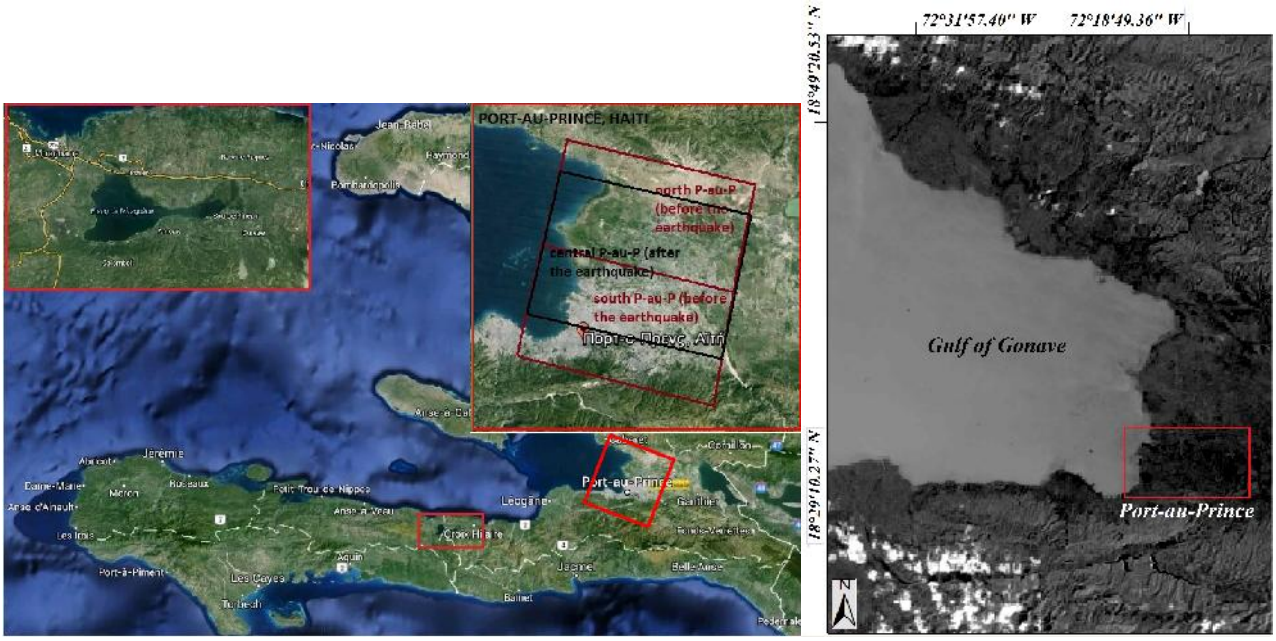

Figure 1: (Left) Location map of the study areas shown within red squares. (Right) 2nd Principal Component obtained by processing the VNIR bands of the images covering the Port-au-Prince and the broader area, acquired before and after the earthquake

False Colour Composite (FCC) Images

Another image processing method applied to the ASTER imagery was the False Colour Composite (FCC) of peculiar by-products. In particular, the combined bands were the aforementioned NDVI images gathered from different dates. As such, the pre-earthquake dates were indicated as NDVI 2009 for both study areas whereas the post-earthquake dates as NDVI 2010 for the capital area and NDVI 2011 for the lake area respectively. The FCCs were set adopting as Red band NDVI 2009, as Green band NDVI 2009 and as Blue one NDVI 2010 or NDVI 2011. Thus, FCC (Figure 2) were obtained that appear in grey, yellow and blue colours. Areas depicted in grey colours show up where no temporal changes have occurred, while yellow colour areas stand for regions that during 2009 were reflecting more than after the earthquake (as yellow sets the red and green colours contribution). This probably means that yellow shades have to do with vegetated regions that after the earthquake do not exist anymore or changed their use (like sedimentary areas). The opposite may occur also for the blue colour areas. Blue regions represent vegetated areas that were reflecting more after than before earthquake. Serious alterations can be easily observed along the whole lake coastline and the characteristic islet on the eastern side of the lake (Figure 2, right). A significant observation about the two NDVI images is that for the capital image on the south the clouds that existed before the earthquake look blue while for the lake NDVI image the clouds look yellow because existed after the earthquake.

RESULTS

The outcomes of the whole image analysis process evidenced that the original data, gathered for this study, were carrying various problems like extended cloud coverage especially in regions of interest in both study area scenes. More specifically, the pre-earthquake capital images had cloud coverage over a specific area on the south that didn't cause such a serious problem to the study, while the post-quake lake images exhibited extended cloud coverage on the whole scene, so hindering the analysis.

Furthermore, the VNIR bands spatial resolution was not enough for a more detailed research of destroyed buildings on the capital centre; however, it provided a satisfying overview of the situation after the earthquake. In this framework, figure 3, showing the 2nd PC of stacked VNIR bands of pre- and post-quake images, exhibits areas and important buildings in the capital that suffered

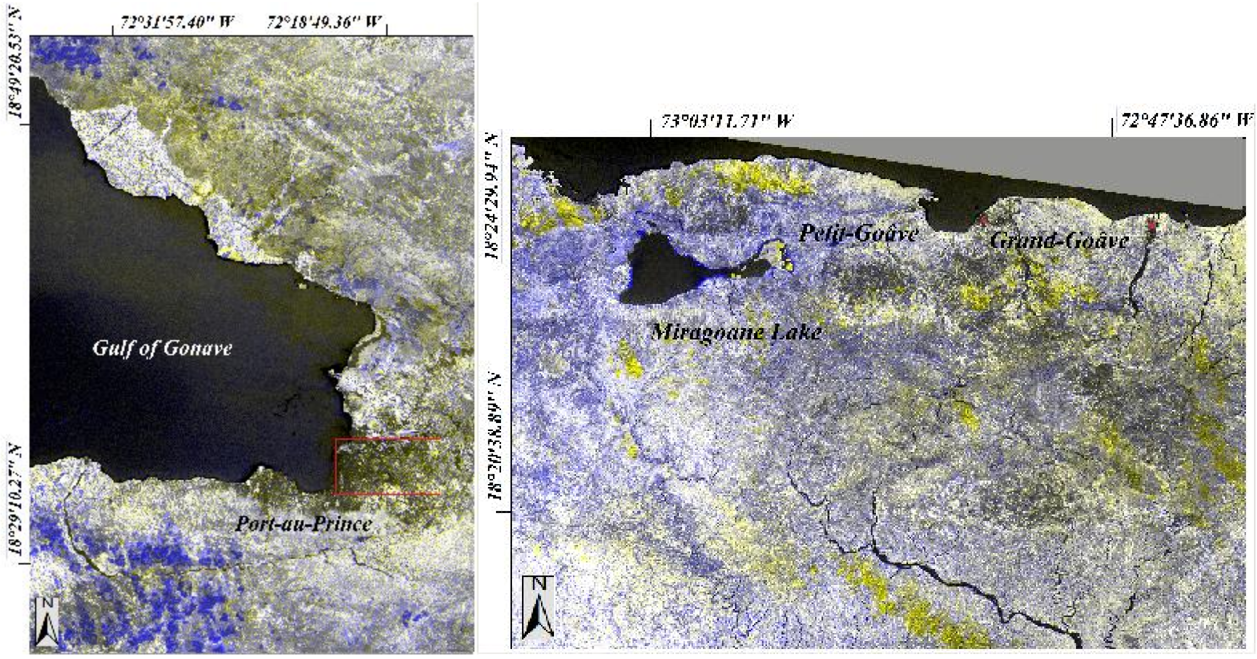

Figure 2: (Left) FCC image of NDVI '09 and NDVI '10, Port-au-Prince. (Right) FCC image of NDVI '09 and NDVI '11, Miragoane lake

severe damages like the National Palace of Port-au-Prince and the building of the National Bank of the Republic of Haiti. Moreover, there are regions shown in black that represent the buildings that collapsed completely or partially. They are: the National Palace, the Haitian Parliament, the Haitian Foreign Ministry, the Bank of the Republic of Haiti, the *Sainte Anne* church, the Country Supreme Court, the *École des Casernes Dessalines* facilities, the *Congrégation des Sœurs de Notre-Dame* building, the Turgeau hospital, the *Saint Louis roi de France* cathedral, the Saint John evangelist school and an area of debris. These results were checked with the International Chapter and SERTIT damage maps. It seems that some areas that are shown in these maps have been detected. Of course, it was impossible to identify these buildings with ASTER imagery because of its relatively low spatial resolution, but it could be stressed that the 2nd PC is showing in dark colours whole areas around these buildings that are seemingly destroyed areas.

On the other hand, as far as Miraogane lake area is concerned, figure 4, where a *FCC* of multitemporal NDVIs is portrayed, shows specific areas along the lake coastline where many alterations and changes can be observed. Most of these occur on the eastern side of the lake coastline.

CONCLUSIONS

Current results of this research were related with other similar studies (4) and, as aforementioned, with study maps from USGS and other geo-portals for pinpointing the damaged areas and comparing the obtained results.

Many buildings where is known that have collapsed were difficult to be pinpointed by means of the results of the present study because of the not extremely high spatial resolution, while areas of collapse were detected on some analysis by-products.

Useful recommendations for future research should be the acquisition of imagery with better spatial resolution, preferably with the same viewing geometry, for obtaining more valuable results and managing to contribute to the study of the effects of the Haiti strong earthquake.

REFERENCES

1 A A V V, 2011. Special Issue: Haiti 2010 Earthquake. PS&RS, 9: 883-952

2 A A V V, 2011. Special Issue: Haiti 2010 Earthquake. PS&RS, 10: 995-1066

3 ENVI Version 4.7, 2009. Getting Started with ENVI, ITT Visual Information Solutions

4 de las Doblas Lavigne M, 2010. Geological Deformations & Potential Hazards triggered by the 01-12-2010 Haiti Earthquake (Google Earth Imagery), In: GEO Haiti Event Supersite Website, 03-11-2010.

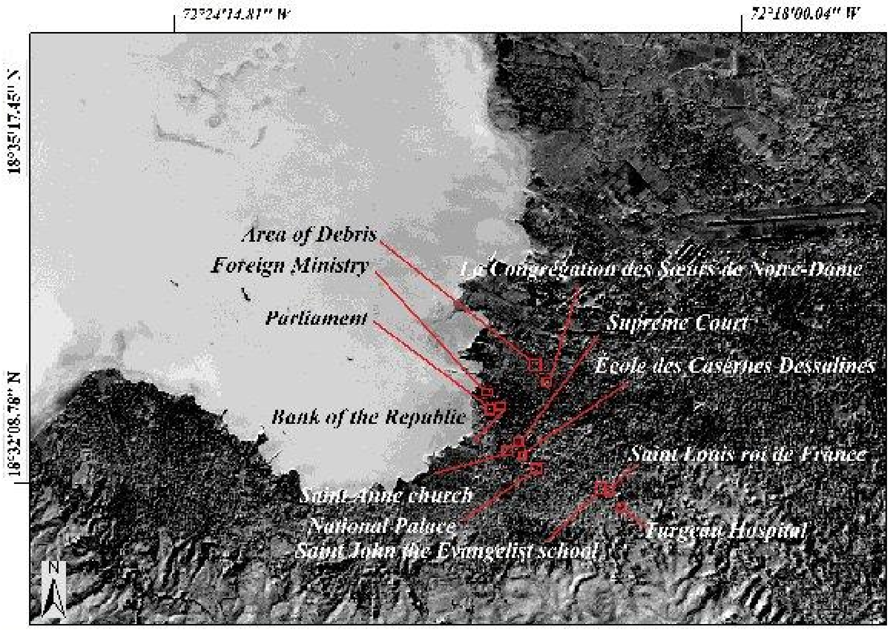

Figure 3: Damaged areas and collapsed buildings in central Port-au-Prince (2nd PC)

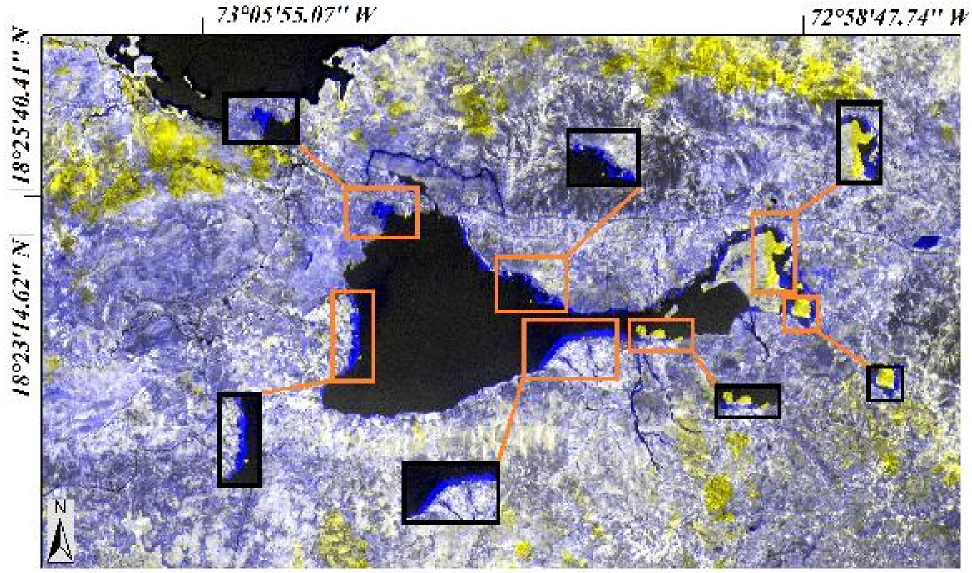

Figure 4: Changes along the Miragoane lake coastline (FCC of multitemporal NDVIs)