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Fusion of Landsat 8 OLI and PlanetScope Images for Urban Forest Management in Baton Rouge, Louisiana

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Abstract

In recent years image fusion method has been used widely in different studies to improve spatial resolution of multispectral images. This study aims to fuse high resolution satellite imagery with low multispectral imagery in order to assist policymakers in the effective planning and management of urban forest ecosystem in Baton Rouge. To accomplish these objectives, Landsat 8 and PlanetScope satellite images were acquired from United States Geological Survey (USGS) Earth Explorer and Planet websites with pixel resolution of 30m and 3m respectively. The reference images (observed Landsat 8 and PlanetScope imagery) were acquired on 06/08/2020 and 11/19/2020. The image processing was performed in ArcMap and used 6-5-4 band combination for Landsat 8 to visually inspect healthy vegetation and the green spaces. The near-infrared (NIR) panchromatic band for PlanetScope was merged with Landsat 8 image using the Create Pan-Sharpened raster tool in ArcMap and applied the Intensity-Hue-Saturation (IHS) method. In addition, location of urban forestry parks in the study area was picked using the handheld GPS and recorded in an excel sheet. This sheet was converted into Excel (.csv) file and imported into ESRI ArcMap to identify the spatial distribution of the green spaces in East Baton Rouge parish. Results show fused images have better contrast and improve visualization of spatial features than non-fused images. For example, roads, trees, buildings appear sharper, easily discernible, and less pixelated compared to the Landsat 8 image in the fused image.

The paper concludes by outlining policy recommendations in the form of sequential measurement of urban forest over time to help track changes and allows for better informed policy and decision making with respect to urban forest management.

Keywords

Remote Sensing, Image Fusion, Multispectral Images, Urban Forest, Landsat 8 Operational Land Imager (OLI), PlanetScope, Baton Rouge

1. Introduction

Urban forests provide an array of social, environmental, and economic benefits to people living in the urban areas. According to the Forest Service of the U.S. Department of Agriculture (USDA), urban forests are made up of individual trees, urban parks, river corridors, wetlands, nature preserves, gardens, landscaped boulevards, greenways, river, and coastal promenades [1].

These green spaces have the potential of providing ecosystem benefits to the human population as well. These ecosystem benefits include microclimate regulation, rainwater drainage, sewage treatment, air filtration, noise reduction, recreational and cultural values [2] [3]. In essence, these ecosystem services improve the quality of the air, increase carbon sequestration, and reduce the urban heat island effect.

Increasingly, in the past decade, urban forest ecosystem has come under intense pressure because of the threat posed by multiple factors. Flooding caused by natural disaster and anthropogenic activities have exerted a lot of pressure on urban forest ecosystem. Increased rainfall associated with climate change has altered the flooding experienced in many urban areas of the world including the United States. Recent widespread flooding across Louisiana during the Hurricanes Katrina and Idai has highlighted the significant negative impacts that flooding can have on Urban forest ecosystem. Baton Rouge, Louisiana is not an exception [4] [5].

With all the benefits of urban forests, it is highly essential to monitor the extent and health of these green spaces over time and report on their status and trends as well. This helps to generate information to support decision making in terms of the condition of these trees as well as their extent in Louisiana or the US at large. Irrespective of how small these urban forests such as parks, street trees and landscaped boulevards are, they all have a role to play in the ecosystem such as the regulation of microclimate, filtration of the air and the management of stormwater. Details of these individual trees and green spaces might not be entirely visible in medium and low-resolution satellite imagery and hence might not fully represent what is on ground. This can affect biomass estimates, carbon sequestration and other land cover analysis. Remote sensing has played an important role in monitoring condition of the urban forest ecosystem [6] [7] [8].

Knowing the condition and health of urban forest structure are some of the keys to their sustainability. Information on the physical characteristics of the urban trees such as tree species composition, species diversity, leaf area, biomass, tree density, number of trees and tree health are useful parameters in urban forest monitoring [9]. Thus, this study uses fine resolution image fusion techniques to improve the identification and monitor urban forest in Baton Rouge.

2. Role of Multisensor Image Fusion in Urban Forest Management

Earth observation technology plays a major role in identifying, measuring and monitoring urban forests as well as detailed data on the location. This technology leverages on the power of remote sensing and space systems to capture and store information on the various thematic areas at different energy levels known as bands. Remote sensing also offers a wide range of temporal, spectral, radiometric, and spatial resolution to support analysis of features on the earth surface [10]. Early work of [11] reveals that, the integration of a high-resolution multispectral satellite imagery for urban forest monitoring ensures that more details of such trees are captured to increase the accuracy levels during the image analysis process.

Fonseca *et al.* [10] further explains that image fusion is useful in areas that have complex morphological structure including urban areas, heterogeneous forested areas, landslide scars, and classifying intra-urban land cover. Indeed, several research papers on multi-sensor image fusion have studied 1) the mapping of urban tree cover by fusing multispectral image and LiDAR point cloud data to improve point cloud classification quality, and consequently to produce tree canopy cover maps [12], 2) the fusion of different dataset such as satellite imagery from the same sensor in Turkey's third largest city of Izmir using Principal Component, IHS, and Brovey Transform techniques to improve the spatial resolution of Landsat 7 ETM imagery used in the study. Results indicate, improved spatial resolution of fused Landsat 7 ETM imagery using Principal Component and Brovey Transform techniques [13], 3) the use of Satellite imagery fusion methods such as intensity-hue-saturation (IHS), principal component analysis (PCA) and high pass filter (HPF) to improve urban land cover classes identification [11], and 4) the applications of high-resolution panchromatic and multispectral Quickbird images, and TerraSAR synthetic aperture radar (SAR) data are used for urban land use change studies in the central part of Ulaanbaatar, the capital city of Mongolia. Results of the fused image in Ulaanbaatar city show an increased urbanization leading to land use change [14]. [15] fused airborne LiDAR data with aerial images for a tree-level urban forest inventory. The aboveground points, vegetation points were isolated from non-vegetation points. This was achieved by using the Normalized Difference Vegetation Index (NDVI) derived from the hyperspectral data. Results illustrated that individual trees can be detected from

LiDAR point cloud data using the proposed tree climbing algorithm, and tree crowns can be delineated using the donut expanding and sliding method. [16] fused LiDAR and Landsat Thematic Mapper data to discriminate land covers in the urban areas of Charlotte, North Carolina, USA by using supervised maximum likelihood (ML) and classification tree (CT) methods. The authors found that fusion of higher-resolution structural and intensity surface models from LiDAR with TM data improved total and class-level classification accuracies. Also, in the suburb of Melbourne, Australia, Parmehr *et al.* [17] fused airborne LiDAR and optical remote sensing data to map urban tree cover. Results showed an improved reliability of LiDAR point cloud classification of tree cover.

In all of these studies, improving low spatial resolution multispectral imagery with very fine resolution panchromatic images as well as enhancing and improving visualization of spatial features has been a major goal. In Louisiana, studies focusing on fusing high resolution imagery with low spatial resolution multispectral imagery for urban forestry studies at specific city are very limited. In 2003, Louisiana Department of Environmental Quality (LDEQ) conducted Louisiana-wide study and utilized 2002 Landsat Thematic Mapper Plus (30 m resolution) RGB 7-5-3 fused with higher resolution (15 m) panchromatic band in order to improve visualization of spatial features of the entire Parish [18]. It is important to know that, LDEQ study did not focus on specific city in the state. Also, fusing of the images used only Landsat ETM+ band 8 data with 15 m resolution. To this end, the main objective of this study adopts remote sensing techniques, specifically, using very fine resolution image fusion to improve the identification and monitor urban forest in Baton Rouge. Fusing of high-resolution multispectral images at different resolutions will be performed to assist policymakers in the effective planning and management of urban forest ecosystem in Baton Rouge.

3. Methodology

3.1. The Study Area

Baton Rouge, the capital of the state of Louisiana, is the parish seat of East Baton Rouge parish on the eastern bank of the Mississippi River. According to the United States Census Bureau, the city has a total area of 79.1 square miles (204.9 km^2), of which 76.8 square miles (198.9 km^2) are land and 2.2 square miles (5.7 km^2) (2.81%) are covered by water. It is a low elevation area which lies on an altitude of 56 to slightly over 62 feet above sea level. This city has a longitude and latitude of −91.14 decimal degrees and 30.46 decimal degrees respectively ([19] [20]; **Figure 1**).

According to the United States Census Bureau, Baton Rouge's population census in 2010 recorded a total population of 229,493 but witnessed a decrease by 2020 with a projected total of 227,470. In view of this, the World Population Review reported that, the city is currently declining at a rate of −0.90% annually

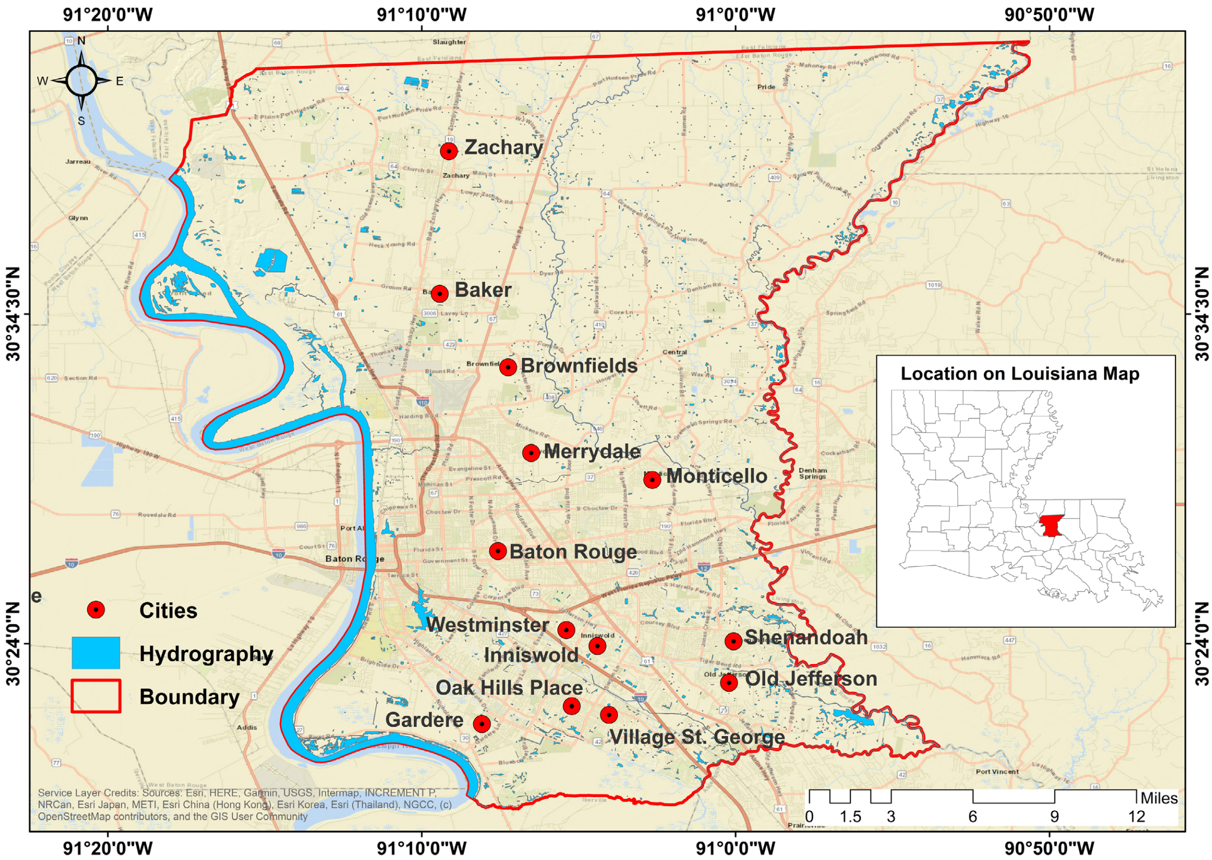

Figure 1. Study Area Map—East Baton Rouge Parish.

and its population has decreased by −5.74% between 2010 and 2020. However, covering over 89 miles, Baton Rouge has a population density of 2502 people per square mile. The city is also noted for being the 18th most-populous state capital, 99th most-populous city in the United States, and the second-largest city in Louisiana after New Orleans [19] [20] [21].

Due to the proximity of the state of Louisiana to the Gulf of Mexico, its low-lying environs including the east Baton Rouge Parish and New Orleans are particularly more prone to certain natural disasters especially, flooding, and other hurricane effects. The city's climate conditions, include a humid subtropical climate with mild winters, hot and humid summers, moderate to heavy rainfall, and the possibility of damaging winds and tornadoes all year. Averagely, Baton Rouge records an annual high temperature of 79˚F, an annual low temperature of 58˚F accompanied by an annual precipitation of 60.65 inches of rain [22]. Even though the area has experienced snow consecutively in 2008, 2009 and 2010, it is a rare phenomenon and is usually limited to some cold winter fronts.

In terms of the vegetation and tree characteristic of the urban forest in Baton Rouge, [3] report that, the City of Baton Rouge has an estimated 1,036,175 trees with a standard error (SE) of 60224. The tree cover in city of Baton Rouge is estimated at 44.6 percent (45%) with its five most common species in the urban forest being Live oak (9.5 percent), Sweet gum (8.8 percent), Loblolly pine (7 percent), Pecan (6.5 percent), Bald cypress (5.9 percent), and Water oak (5.6 percent). Sample of urban forest species in Baton Rouge is shown in **Figure 2**.

The city also has a shrub cover occupying approximately 15 percent with other ground cover types that include impervious (20 percent), bare soil (5 percent), and herbaceous (11 percent). The soils formed are usually sediment deposited by the Mississippi and Atchafalaya Rivers and their distributaries. Loamy soils are known to be the dominant type of soil in this city, on the natural levees, whereby clayey soils are dominant in the backswamps. More so, most of the soils that are subject to flooding are in woodland and almost all the soils that are protected from flooding are used for cultivated crops and pasture [23].

This city is particularly large research, medical, technology and industrial center of the South with its largest industry being petrochemical production and manufacturing. For instance, ExxonMobil's Baton Rouge Refinery complex is the fourth-largest oil refinery in the country and the world's 10th largest. Its transportation structure is made up of highways, pipelines, and deep-water access which enhances economic activities.

Since Baton Rouge is the furthest inland port on the Mississippi River that can accommodate ocean-going tankers and cargo carriers, the ships are able to transfer their cargo (grain, oil, cars, containers) at Baton Rouge onto rails and pipelines (to travel east-west) or barges (to travel north). Generally, Baton Rouge acts as the cultural and economic hub which is located at the center of the Greater Baton Rouge area, the second-largest metropolitan area in Louisiana.

3.2. Data Acquisition

The location of urban forestry parks was picked using the handheld GPS and extracted into an excel sheet. This sheet was converted into a.csv file and imported

Figure 2. Sample of the urban forest species at Southern University campus in Baton Rouge, Louisiana. Photo courtesy of Dr. Yaw A. Twumasi.

into ArcMap for a visual representation of the distribution of these green spaces in East Baton Rouge. Landsat 8 and PlanetScope satellite images were acquired from two different sources. The Landsat 8 level 2 surface reflectance image was obtained from the United States Geological Survey (USGS) website, specifically the Earth Explorer platform [24]. The Landsat 8 image was acquired on June 08, 2020, with a spatial resolution of 30 m. Table 1 shows characteristics of Landsat 8 OLI image including information on projection and datum. The PlanetScope satellite data was obtained from the Planet website [25] and the image was captured on November 19, 2020, with a pixel resolution of 3 m. Tables 2-7 show

Table 1. Characteristics of Landsat 8 data for East Baton Rouge.

Image ID	LC08_L2SP_023039_20200806_20210330_02_T1
Acquisition Date	2020-08-06T 16:38:14.8440570Z
Cloud Cover	6.77
Agency	United States Geological Survey
Platform	LANDSAT 8
Product Format	GEOTIFF
Processing Level	L2SP
Data Type	UINT16
Datum	WGS84
Map Projection	UTM
UTM Zone	15N
Resolution	30
Units	METER

Table 2. Characteristics of PlanetScope scene 1 for East Baton Rouge.

Image ID	20201119_165303_42_225b
Acquisition Date	2020-11-20T11:16:09Z
Cloud Cover	0
Platform	PlanetExplorer
Product Format	GEOTIFF
Processing Level	Level 3B
Provider	PlanetScope
Data Type	12 bits
Datum	WGS 1984
Map Projection	UTM
UTM Zone	15N
Resolution	3
Units	METERS

Table 3. Characteristics of PlanetScope scene 2 for East Baton Rouge.

Image ID	20201119_165305_80_225b
Acquisition Date	2020-11-19T16:53:05.80725Z
Cloud Cover	0
Platform	PlanetExplorer
Product Format	GEOTIFF
Processing Level	Level 3B
Provider	PlanetScope
Data Type	12 bits
Datum	WGS 1984
Map Projection	UTM
UTM Zone	15N
Resolution	3
Units	METERS

Table 4. Characteristics of PlanetScope scene 3 for East Baton Rouge.

Image ID	20201119_165308_18_225b
Acquisition Date	2020-11-19T16:53:08.184965Z
Cloud Cover	0
Platform	PlanetExplorer
Product Format	GEOTIFF
Processing Level	Level 3B
Provider	PlanetScope
Data Type	12 bits
Datum	WGS 1984
Map Projection	UTM
UTM Zone	15N
Resolution	3
Units	METERS

Table 5. Characteristics of PlanetScope scene 4 for East Baton Rouge.

Image ID	20201119_165142_29_227b
Acquisition Date	2020-11-19T16:51:42.290318Z
Cloud Cover	0
Platform	PlanetExplorer
Product Format	GEOTIFF

Continued

Processing Level	Level 3B
Provider	PlanetScope
Data Type	12 bits
Datum	WGS 1984
Map Projection	UTM
UTM Zone	15N
Resolution	3
Units	METERS

Table 6. Characteristics of PlanetScope scene 5 for East Baton Rouge.

Image ID	20201119_165258_67_225b
Acquisition Date	2020-11-19T16:52:58.674101Z
Cloud Cover	0
Platform	PlanetExplorer
Product Format	GEOTIFF
Processing Level	Level 3B
Provider	PlanetScope
Data Type	12 bits
Datum	WGS 1984
Map Projection	UTM
UTM Zone	15N
Resolution	3
Units	METERS

Table 7. Characteristics of PlanetScope scene 6 for East Baton Rouge.

Image ID	20201119_165301_05_225b
Acquisition Date	2020-11-19T16:53:01.051818Z
Cloud Cover	0
Platform	PlanetExplorer
Product Format	GEOTIFF
Processing Level	Level 3B
Provider	PlanetScope
Data Type	12 bits
Datum	WGS 1984
Map Projection	UTM
UTM Zone	15N
Resolution	3
Units	METERS

characteristics of PlanetScope image scenes from 1 to 6 including date of acquisition, projection, datum and cloud cover.

3.3. Image Processing and Data Fusion

Landsat 8 was downloaded and imported into ArcMap as single bands with a.tif file format. These bands were combined into a multi-spectral band using the composite band in ArcMap. Also, the Near-Infrared (NIR) band of PlanetScope was imported into ArcMap to aid in the image fusion process. The clip tool was used to create a subset of the satellite images for the study area. Since the Landsat 8 and PlanetScope images have the same projection and datum, we did not perform co-registration of the images. In fusing remote sensing data, there three major techniques are used. These are Multiplicative, Principal Components, and Brovey Transform. Principal components are normally used in an application that entails an original color of the input multispectral image. This allows the output image to resemble the input file [26] [27]. The radiometric accuracy of the of the output file of Principal Components is excellent. However, this method requires a lot of computation. Hence, tends to slow the system [26] [27]. The Multiplicative method uses a simple multiplicative algorithm which integrates the two raster images, one with lower and higher resolution. In all the three bands, the digital number of the merged image can be computed by using the following simple arithmetic integration of the two raster sets [26]:

$$DN_{Bi} \times DN_{\text{high res}_{\text{Image}}} = DN_{\text{Bi}_{\text{new}}} \quad (1)$$

where DN is the digital number, Bi is band number, with i ranging from 1 to 3, $DN_{\text{high res}_{\text{Image}}}$ is the digital number of high-resolution image and $DN_{\text{Bi}_{\text{new}}}$ is the digital number of the band i of the merged image.

Computationally, it is very simple, fastest method and requires the least system resources [26] [27]. The weakness of this method is that the output merged image (lower and higher resolution) does not retain the radiometry of the input multispectral image. In the Brovey Transform method, three bands are used according to the following formula [27]:

[DNB1/DNB1 + DNB2 + DNB3] × [DNhigh res. image] = DNB1_new

[DNB2/DNB1 + DNB2 + DNB3] × [DNhigh res. image] = DNB2_new

[DNB3/DNB1 + DNB2 + DNB3] × [DNhigh res. image] = DNB3_new

where:

$$B(n) = \text{band (number)}$$

Brovey Transform visually increase contrast in the low and high ends of an image histogram. It produces an RGB with the higher degree of contrast [26] [27]. It provides contrast in shadows, water and high reflectance areas such as urban features. The weaknesses of using Brovey Transform are that it does not preserve the original scene radiometry. Giving the weaknesses of using the above methods, this paper uses Intensity-Hue-Saturation (IHS) method to fuse the low-and high-resolution imagery to improve the urban forest areas. Although the IHS method uses only three bands in the fusion process, this simple method produces a very high-quality image that can facilitate further image analysis [26] [28] [29].

In this study, the 6-5-4 band combination for Landsat 8 was used to visually inspect healthy vegetation and the green spaces in the landscape. Also, the NIR panchromatic band of PlanetScope was used in the fusion process. In ArcMap, the image fusion or pan-sharpening process required four inputs. We selected the lower resolution image (Landsat 8), set the R-G-B channels, added the high-resolution image (PlanetScope), and finally selected the pan-sharpening type. Specifically, the "Create Pan-Sharpened raster dataset" tool in the ArcToolbox was used to merge the images together.

4. Results

Figure 3 and Figure 4 show band combination of Landsat 8 satellite image and PlanetScope image. Figure 5: NIR band of the PlanetScope image.

Figure 6 shows the GPS location and distribution of urban forestry parks in East Baton Rouge Parish. The road network indicates that these parks are situated close to the various cities and are easily accessible to the community members.

Figure 7 shows a comparison of the fused Landsat 8 and PlanetScope image on the left and the 30 m Landsat 8 image on the right.

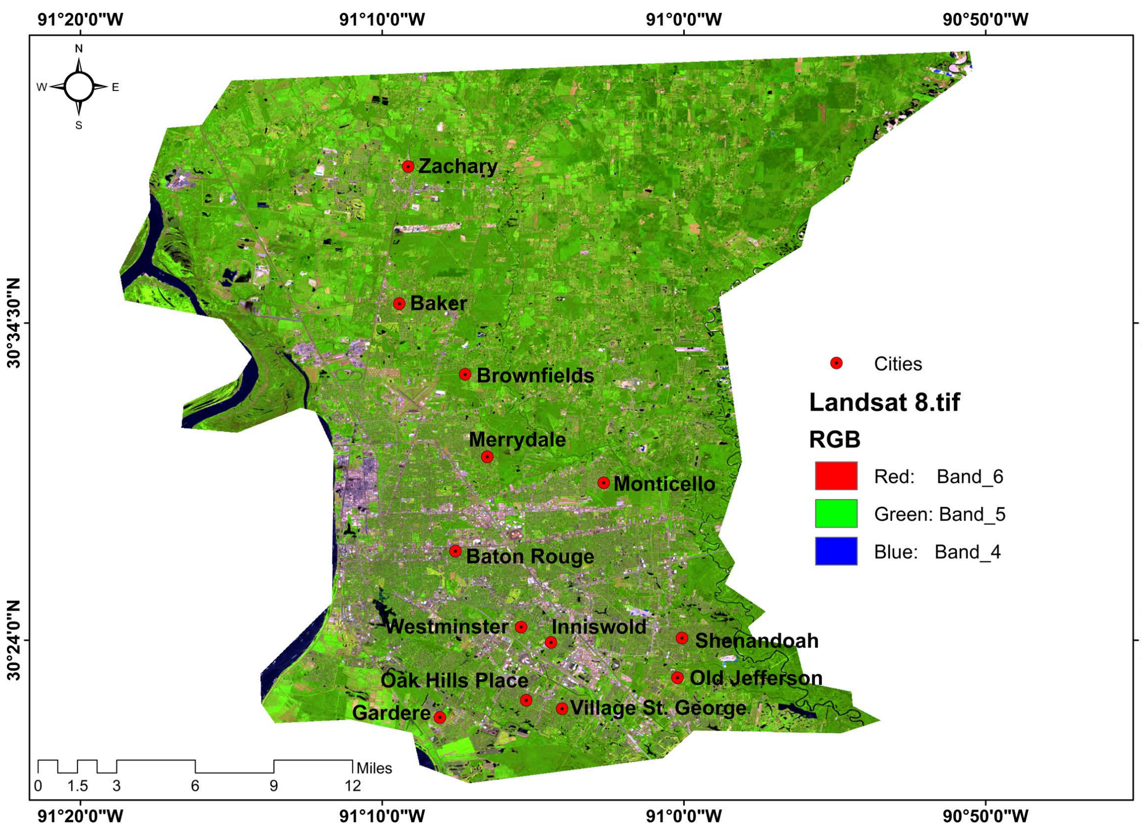

Figure 3. 6-5-4 band combination of Landsat 8 image in ArcMap.

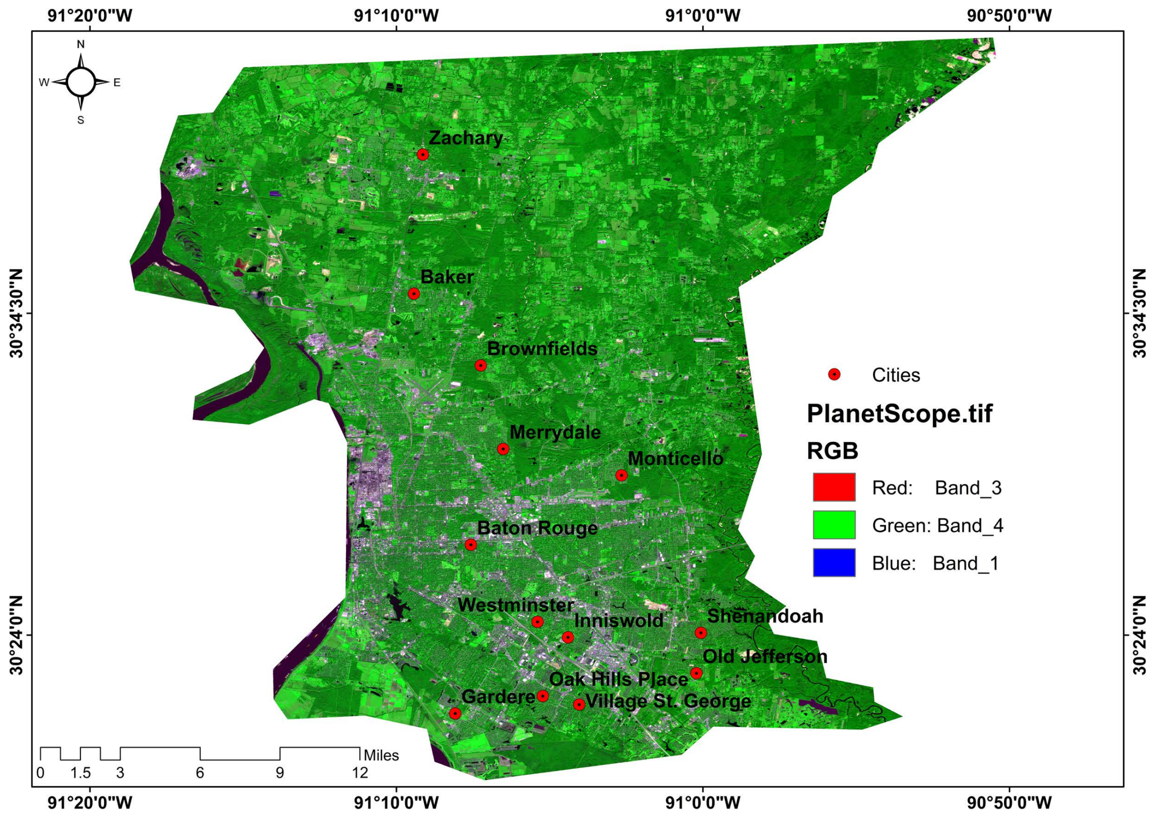

Figure 4. 3-4-1 band combination of the PlanetScope image in ArcMap.

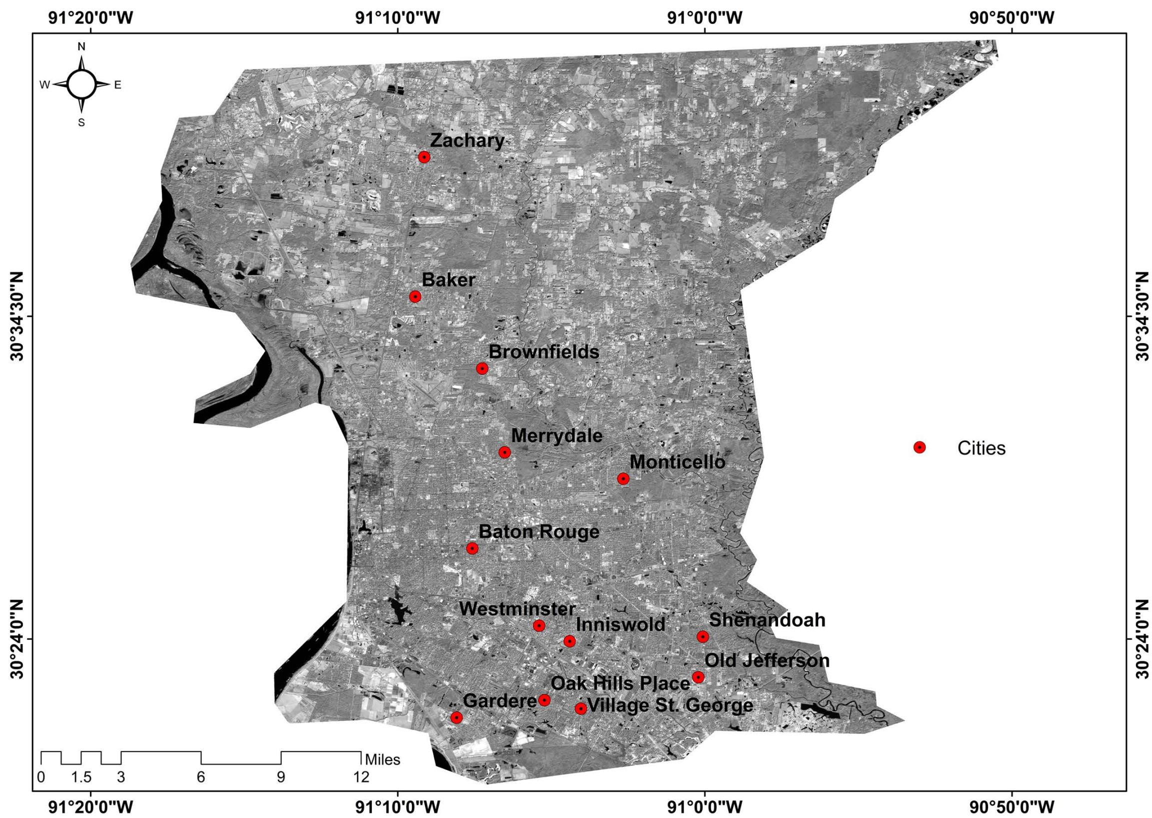

Figure 5. NIR band of the PlanetScope image in ArcMap.

Figure 6. Distribution of BREC parks in East Baton Rouge Parish.

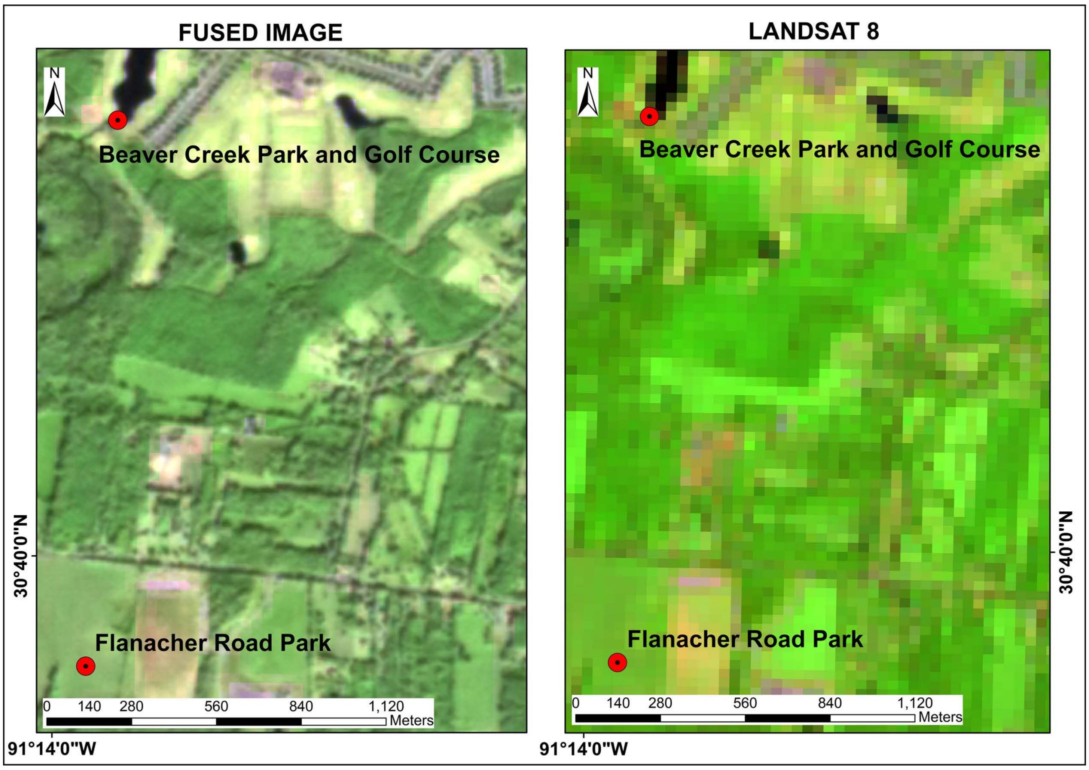

Figure 7. Northwest section of East Baton Rouge showing the 3 m fused image to the left and the 30 m Landsat 8 image to the right.

The image captured highlights the Northwestern part of East Baton Rouge. The fused image reveals more details of the landscape compared to the image on the right. Moreover, features in the right image are more pixelated compared to the left image. The parks, trees and greenspaces are difficult to identify in the Landsat 8 image on the right. This is same for Figures 8-11.

5. Implication for Policy Development and Conclusions

Overall, the fused images using Intensity-Hue-Saturation (IHS) method have better contrast and improve visualization of spatial features than non-fused images. An understanding and the use of image fusion can facilitate better decisions and policymaking. Image fusion generates a high-resolution output that highlights lots of details within the landscape. This technique can identify all manner of changes and is more effective than existing land-use land cover change detection [30]. Image fusion provides city planners and land-use experts with relevant information on the location of facilities and resources in the cities. This technique helps decision-makers understand and appreciate the complexities of urban development through the lens of remote sensing and GIS and guides them to propose strategies that ensure that urban areas remain resilient in a changing climate. In other words, researchers and various stakeholders can extract more reliable detail to assess land use land cover changes for better governmental

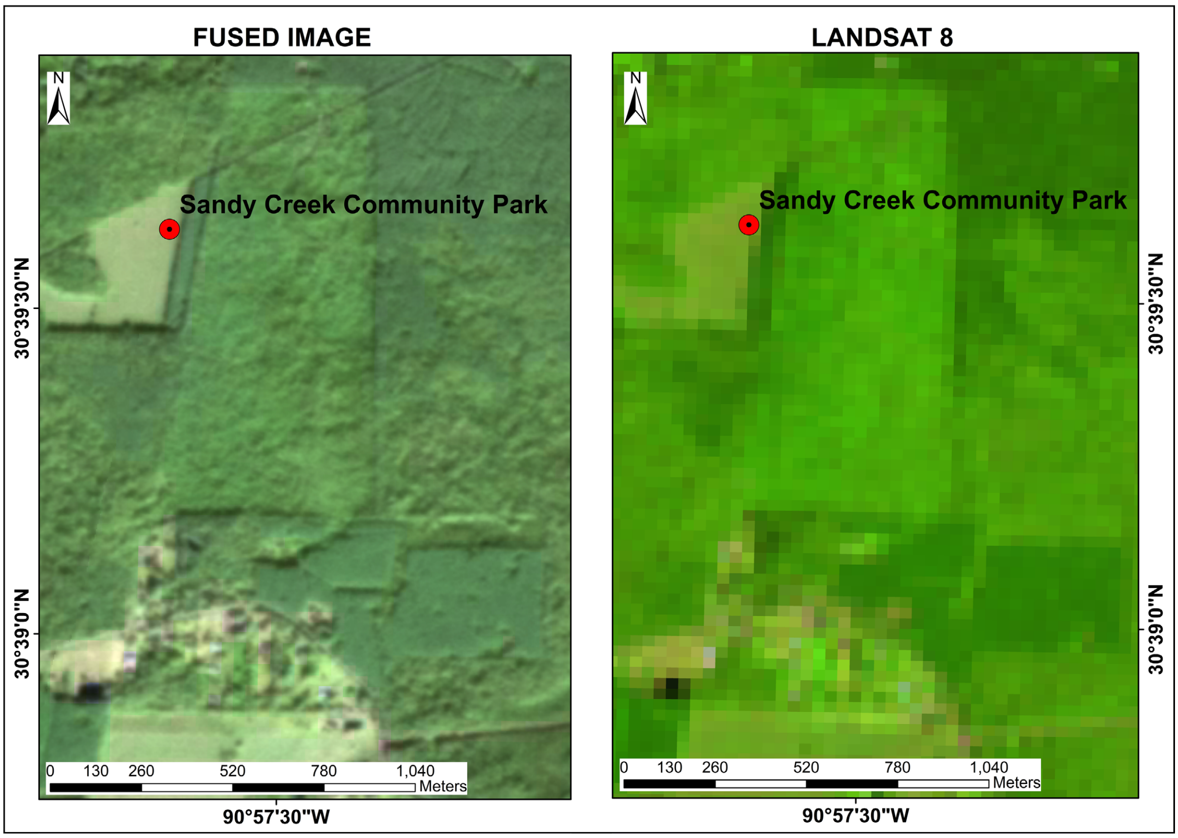

Figure 8. Northeast section of study area showing Sandy Creek community park as a pan-sharpened image to the left and the 30 Landsat 8 image to the right.

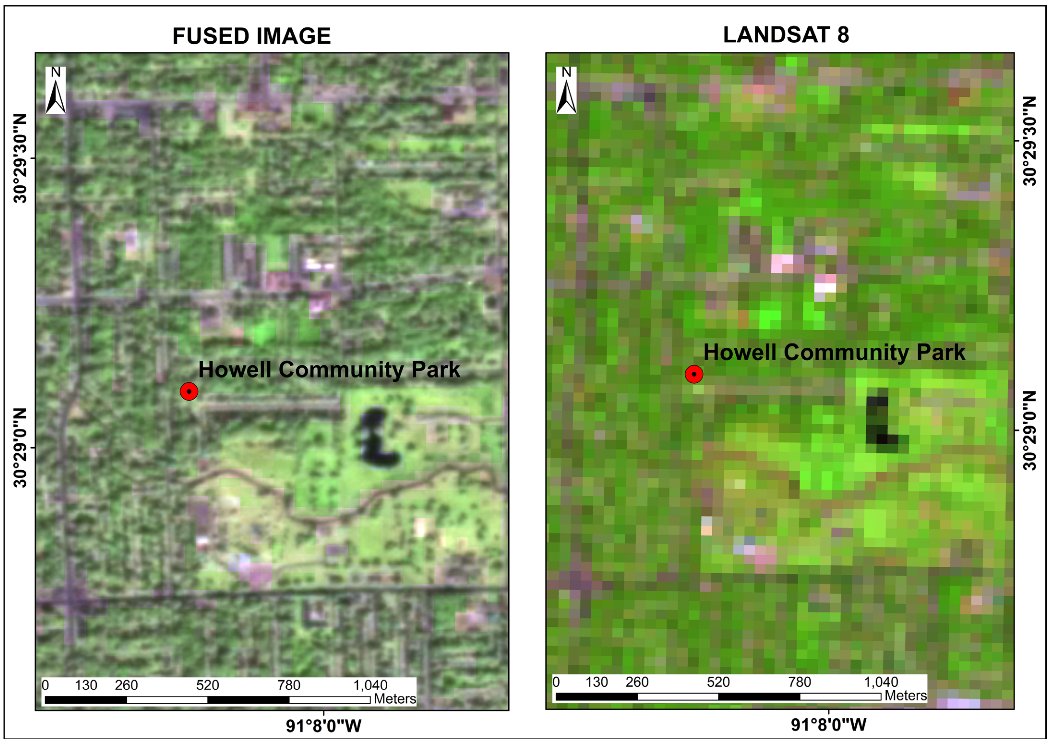

Figure 9. Southeast section of East Baton Rouge showing Howell Community Park with the roads, trees, buildings appearing sharper and less pixelated compared to the Landsat 8 image on the right. At a zoom scale of 1:8000, the patterns are clearly defined, and shape of the features is easily discernible in the fused image.

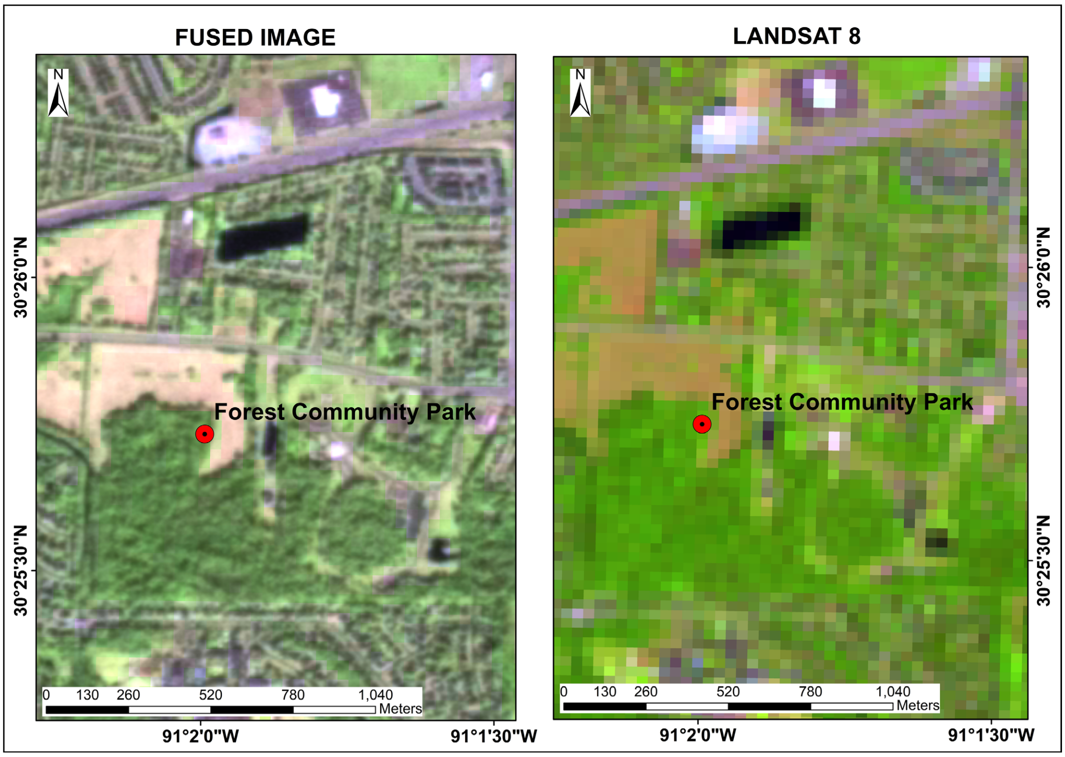

Figure 10. Southwest section of East Baton Rouge showing Forest Community Park with the fused image (3 m) to the left and original Landsat 8 image to the right. The open space, water body, buildings and roads can be clearly seen in the pan-sharpened image.

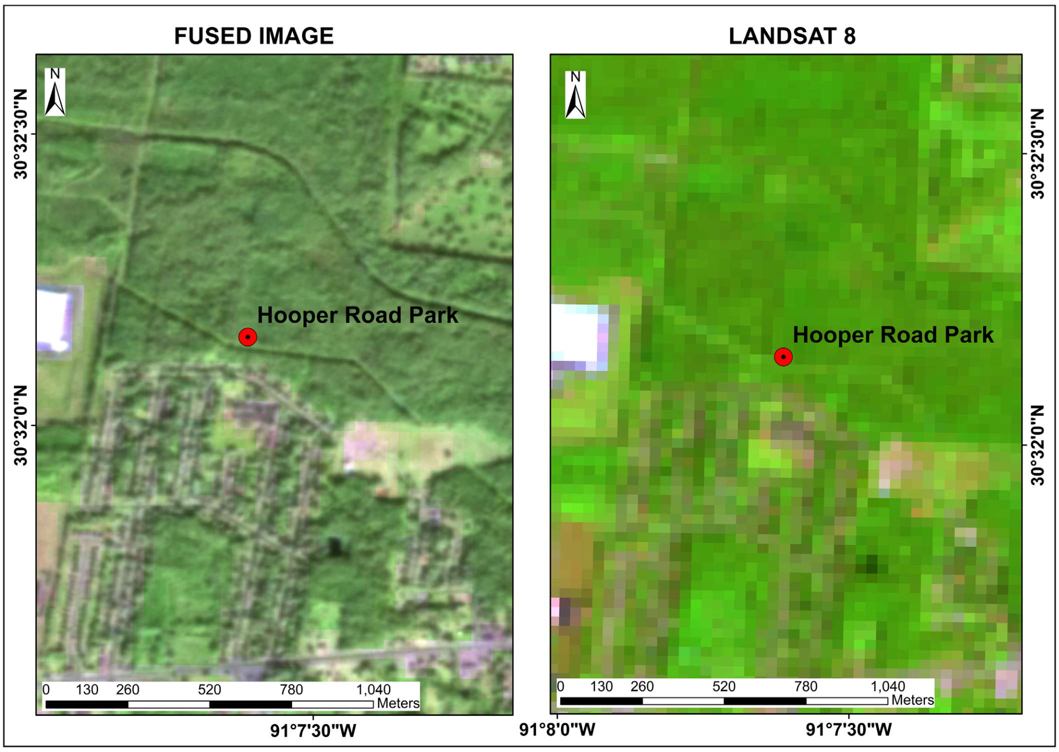

Figure 11. Central section of study area showing Hooper Road Park at a resolution of 3 m. The right image shows the 30 m Landsat 8 image.

decision-making eliminating redundancy.

Louisiana is known for various natural disasters including hurricanes and flooding. The precision of these fused images can accurately support emergency response and urban forest management such as tree debris removal after a major hurricane incidence. While such information can be used as decision support tool for urban forest managers and those charged with policy making in the years ahead, it can also serve as educational tool to guide stakeholders in the sustainable management of urban trees. Policy recommendation in form sequential measurement of urban forest over time can help to track changes and allows for better informed policy and decision making with respect to urban forest management.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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