

Comparison of NDVI Values from Multiple Satellite Sensors to Monitor for Public Health in an Urban Sub-tropical Setting

Julius R. Dewald^{1,*}, Jane Southworth², Scott C. Brown^{1,3}, Jose Szapocznik^{1,3}

¹Department of Public Health Sciences, University of Miami Miller School of Medicine, Miami, FL, USA

²Department of Geography, University of Florida, Gainesville, Florida, USA

³University of Miami School of Architecture, Coral Gables, FL, USA

Abstract Normalized Difference Vegetation Index (NDVI) is commonly used as a measure of greenness in public health research. Changes in NDVI over time in urbanized areas have been linked to improvements to multiple chronic conditions. Studies have been conducted using ASTER or Landsat, but their equivalence has not been established. To determine the equivalence or lack thereof between ASTER and Landsat, and between Landsat 7 and 8, this study compares NDVI values from ASTER, Landsat 7, and Landsat 8 satellite sensors at different times of the year (Fall and Spring) and at different locations in Florida (the City of Miami and Polk County). Although other studies have examined how Landsat and ASTER NDVI values compare, no study has explicitly investigated how NDVI values differ across ASTER and Landsat for urban areas. A comparison of the scatterplots of ASTER with Landsat satellite sensor NDVI scores, produced R^2 values consistently above 0.75 with p-values less than 0.001 across both locations and times of the year, indicating that Landsat and ASTER-derived NDVI values share considerable variance. By repeating these analyses separately by season and location, we demonstrated that the relationship between Landsat and ASTER NDVI varies more by season than location within urban subtropical settings. These findings suggest that studies comparing NDVI values from these different satellite sensors would require calculating separate coefficients for each season.

Keywords NDVI, Vegetation, Landsat 8 OLI, Landsat 7 ETM+, Remote Sensing, ASTER, Comparison

1. Introduction

Understanding how greenness indices, such as Normalized Difference Vegetation Index (NDVI), differ across satellite sensors is critical to understanding the extent to which findings across studies may differ as a function of different satellite sensors. Studies that rely on any measures of greenness, especially temporal ones, must often account for differences across sensors due to different sensors being available across different time periods. An example of such research is found in studies relating greenness to human health. Previous research has shown that higher NDVI predicts lower BMI, lower risk of being overweight or obese [1,2], decreased cardiometabolic conditions [3], and reduced cardiovascular disease [3-5].

For example, our prior research investigated how NDVI relates to chronic medical conditions in urban Miami, Florida, using U.S. National Aeronautics and Space

Administration (NASA) Advanced Spaceborne Thermal Emission and Reflection Radiometer satellite (ASTER) data [3,5,6]. These studies have shown that higher mean NDVI, compared with lower mean NDVI, was associated with reduced risk of diabetes and reduced odds of acute myocardial infarction, ischemic heart disease, heart failure, and atrial fibrillation, as well as Alzheimer's disease and depression [3,5,6]. These cross-sectional studies all used ASTER satellite imagery to calculate and track changes in NDVI through time. However, future longitudinal research linking trajectories of greenness to health outcomes will rely on Landsat 7 and Landsat 8 data (NIH grant R01HL148880 and NIA grant RF1AG0743607). Hence, if different results were obtained using ASTER and Landsat satellites, it would be useful to understand the comparability of NDVI values derived from the ASTER and Landsat satellite sensors.

Although ASTER provides higher resolution imagery than Landsat (15m resolution for ASTER and 30m for Landsat), Landsat has a broader swath width and an extensive historical archive. Furthermore, Landsat imagery has more processing levels than ASTER. Processing refers to the types of calibration and corrections the controlling agency performs upon the satellite imagery before it is made

* Corresponding author:

j.dewald@umiami.edu (Julius R. Dewald)

Received: Sep. 20, 2022; Accepted: Nov. 19, 2022; Published: Nov. 24, 2022

Published online at <http://journal.sapub.org/ajgis>

available to the public. Landsat data can be obtained at a high level of processing where the imagery has been georeferenced using ground control points, elevation data provided by various digital elevation models, and payload correction data collected by the spacecraft and sensor [7,8]. Landsat data also comes with quality reference data that identifies each scene's cloud and shadows [7,8]. This makes it possible to identify clouds and remove them through built in automated processes for each image which makes working with large amounts of Landsat data easier compared to ASTER data— which does not have the same level of processing and does not come with pre-identified clouds and cloud shadows.

Previous research has already compared Landsat 7 to ASTER-derived NDVI and found that the values differ between the two sensors. The difference was due to ASTER's higher reflectance in the red band and lower reflectance in the near-infrared band than the Landsat 7 ETM+ sensor [9]. Comparing the NDVI values between the two sensors revealed that the ASTER sensor had NDVI values 8.1% lower on average than the NDVI values obtained from the Landsat 7 ETM+ sensor [10]. Most previous studies have examined how these sensors detect NDVI across various landcovers [11,12]. Despite these results, there has been a lack of studies comparing how the NDVI values from these two sensors compare in urban settings [13]. Further, no study has yet compared how ASTER and Landsat 8 NDVI values correlate when measuring vegetation greenness [12].

The primary focus of this study is to examine how NDVI values between ASTER, Landsat 7, and Landsat 8 satellite sensors compare in urbanized human environments found within Miami, Florida. Miami was chosen due to the usage of ASTER in previous cross-sectional studies that examined the relationship between changes in greenness and public health [3,6], and the importance of using Landsat in currently ongoing longitudinal studies. In addition to its processing capabilities, Landsat is useful for longitudinal studies because there are more frequent images, which makes it easier to match the same time of the year across multiple years. Furthermore, due to the subtropical setting of Florida, there was a more extensive selection of imagery when

compared with more temperate urban locations such as New York City which is in a temperate ecological zone and only has a limited window of greenness before the senescence of vegetation during the winter. This is important to increase the pool of useable imagery to find nearly cloudless imagery across all three satellite sensors. Lastly, in addition to the direct comparison between Landsat and ASTER NDVI values, this study will also provide equations allowing for the conversion of ASTER NDVI to Landsat NDVI (both Landsat 7 and Landsat 8, respectively) to allow for direct comparisons across satellite sensors.

Urban area was defined consistent with the United States Census Bureau classification that classifies separately Urbanized Areas (UAs) and Urban Places Outside of UAs (UPs). UAs are continuously built-up areas with a population of 50,000 or more, such as Miami, FL. UPs are built-up areas with at least 2,500 inhabitants that are not part of a larger UA. Accordingly, to evaluate transferability of these approaches, a second study location was also selected to represent a UP also in Florida. For this reason, the Northeastern corner of Polk County FL, was included in this study. This section of Polk County can be defined as a UP comprised of multiple small townships (Haines City, Davenport, and various unincorporated communities). This area also has similar environmental and climatic conditions to Miami, FL. Furthermore, both of these locations were chosen because prior research has examined the relationship between changes in greenness and public health [6]. Using these study areas this research compares ASTER and Landsat satellite imagery using generalized linear models to determine the compatibility of ASTER and Landsat in an UA and a UP area. Examining how Landsat and ASTER NDVI values compare in urban settings is useful to better understand differences between findings across these satellite sensors and to determine how to increase the comparability of such findings.

2. Materials and Methods

2.1. Data

Table 1. Image sets used for the ASTER and Landsat NDVI comparisons

Location	Imagery	Sensor	Acquisition Date and Time	Resolution	Study Area Size (km ²)
Miami	ASTER	-	10/18/2014 3:01pm	15m	72.09
	Landsat 8	OLI_TIRS	10/17/2014 3:50pm	30m	
	Landsat 7	ETM+	10/25/2014 3:47pm	30m	
Miami	ASTER	-	3/8/2014 3:01pm	15m	75.76
	Landsat 8	OLI_TIRS	3/23/2014 3:50pm	30m	
	Landsat 7	ETM+	3/15/2014 3:46pm	30m	
Polk County	ASTER	-	11/17/2020 3:12pm	15m	67.51
	Landsat 8	OLI_TIRS	11/25/2020 3:55pm	30m	
	Landsat 7	ETM+	11/17/2020 3:17pm	30m	
Polk County	ASTER	-	2/18/2014 3:13pm	15m	60.75
	Landsat 8	OLI_TIRS	2/10/2014 3:56pm	30m	
	Landsat 7	ETM+	2/18/2014 3:52pm	30m	

Table 2. Monthly average precipitation and standard deviation across years 2009-2020; and precipitation for the month in which images from all three satellites were available – all in inches

Miami monthly precipitation averages (inches) 2009-2020				Polk County monthly precipitation averages (inches) 2009-2020			
Month	Average monthly across years 2009-2020	Standard Deviation	Precipitation in month when images from all three satellites are available	Month	Average	Standard Deviation	Precipitation in month when all images from all three satellites are available
January	1.22	1.24	-	January	2.47	1.77	-
February	1.62	1.67	-	February	1.87	1.22	0.93 (2014)
March	1.23	0.92	1.46 (2014)	March	3.13	3.54	-
April	2.43	2.3	-	April	2.6	1.83	-
May	3.76	2.83	-	May	5.74	3.86	-
June	2.66	1.49	-	June	8.59	2.28	-
July	3.57	2.46	-	July	8.18	3.19	-
August	3.9	2.48	-	August	6.81	1.75	-
September	2.96	3.04	-	September	6.29	3.22	-
October	2.46	1.89	5.15 (2014)	October	2.89	2.91	-
November	1.08	0.84	-	November	1.8	1.49	3.55 (2020)
December	1.68	2.35	-	December	1.94	1.98	-

This study relies on ASTER, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Instrument, and Landsat 8 Operational Land Imager (OLI) imagery. The ASTER data was downloaded from the EarthData website at Level 1B, and the Landsat data was acquired from the Earth Explorer website at Level 1. Images for these two locations were taken from two different times of the year (October-November and February-March) to replicate the study of the relationships between the NDVI values of the different satellite sensors across two seasons (Fall and Spring). Therefore, this study utilizes four images from each satellite seen in **Table 1**. Image sets and the seasons of Fall and Spring were chosen primarily based on the availability of cloud-free images across all three satellite sensors used in this study. The ASTER images were geometrically corrected to the Landsat imagery of each image set using first-order polynomials generated from various control points placed across the different image sets. This was done to perfectly match the ASTER to the Landsat pixels. Further, the ASTER images were resampled using bilinear interpolation to match the spatial resolution of the Landsat images.

Precipitation data from NOAA (<https://www.ncei.noaa.gov/access/past-weather>) was used to determine if any of the imagery occurred during an abnormal rainfall period that could impact the overall NDVI value by plants growing greener with the additional water [14-17]. Although this relationship between precipitation and greenness is more pronounced in arid regions with more herbaceous vegetation, we included an analysis of precipitation to be aware of any anomalous rainfall events that occurred during the study times. Anomalous rainfall events could also affect NDVI through the occurrence of standing water, which was shown to mask vegetation and thereby lower NDVI values [18]. This knowledge will aid in interpreting major differences in the NDVI values. Average monthly precipitation levels in

inches were calculated for Miami and Polk County using precipitation data spanning from 2009 to 2020. Average monthly rainfall and total rainfall for each month of imagery used can be seen in **Table 2**. Except for October 2014 in Miami, all image dates were within one standard deviation of the average monthly rainfall. The abnormally high rainfall during October 2014 in Miami occurred throughout the month. Landsat 7 and the ASTER imagery for this set were captured on the 17th and 18th of October, respectively, and ~50% of the total monthly rainfall was captured by this point. Furthermore, by the date when the Landsat 8 image was captured occurred on October 25th, all the monthly rainfall had occurred. Despite this abnormal increase in rainfall, this image set will still be included in this study.

2.2. Study Areas

All areas of cloud cover, Landsat 7 scan-line error, or open water were removed from the study areas as needed for each image set. The areas used to test the similarity between ASTER and Landsat 7 and 8 can be seen in **Figure 1**, these areas represent the study area before the removal of cloud cover or scan line error. For Miami, the constraining features rely on two main components. First is the boundary for the city of Miami, as provided by the City of Miami GIS Open Data Portal (<https://datahub-miamigis.opendata.arcgis.com/>). The second is areas classified as 'developed' by the 2013 National Land Cover Database (NLCD) (<https://www.mrlc.gov/>). The 2013 version of the land cover dataset was used to closely match temporally to the date of the imagery used for this analysis. For Polk County, the criteria for inclusion in this study are slightly altered. The individual cities within Polk County are substantially smaller than the city of Miami. Therefore, instead of a city boundary, all developed areas in the ASTER image footprint were used as defined by the NLCD dataset within Polk County. In reference to the

November Polk County imagery set, the 2019 NLCD dataset was used for imagery for 2020. For Polk County, there was no cloud cover or scan line error within the study areas. The exact area of Polk County being used for this study is limited by the extent of the ASTER imagery within the boundary of Polk County itself. This intersection of boundaries results in only the northeastern corner of the county being used. We ran the analysis only after the final image sets were chosen for the study.

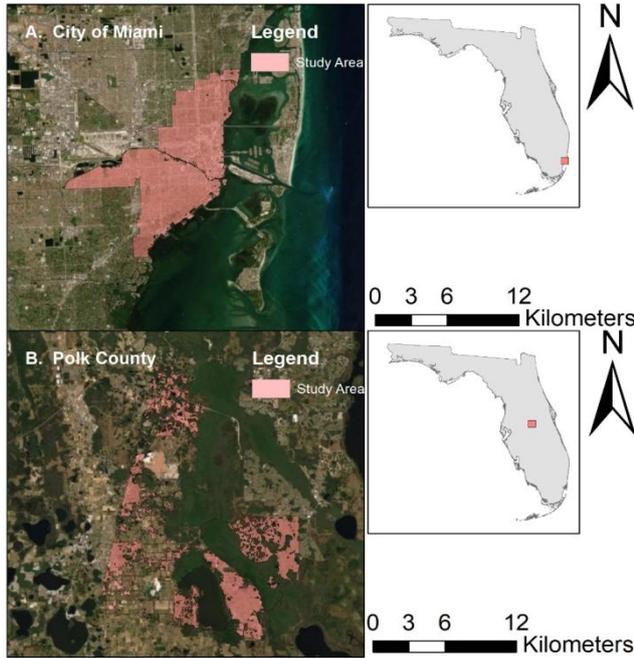


Figure 1. Total study areas for the (A) City of Miami and (B) Polk County before cloud cover and scan line errors were removed per image set

2.3. Radiometric Correction

All imagery used in this study was first converted from the simple digital number (DN) to Top-of-Atmosphere reflectance. This is necessary as NDVI has to be calculated with reflectance values. The handbooks of ASTER, Landsat 7, and Landsat 8 provide models that have been commonly used in previous satellite comparison studies [7-10,12,13,19]. These models are used for this study as well. Landsat 7 and Landsat 8 have the following equation that can directly convert DN to reflectance values:

$$\rho_{\lambda}' = M_{\lambda} * Q_{cal} + A_{\rho}$$

Where ρ_{λ}' is top of Atmosphere planetary reflectance, M_{λ} =Band-specific multiplicative rescaling factor from the metadata, Q_{cal} is the cell value DN, and A_{ρ} is the band-specific additive rescaling factor from the metadata [7,8]. Whereas the ASTER satellite data first needs to have the DN converted to radiance units using the following equation:

$$L_{\lambda} = (Q_{\lambda} - 1) * UCC_{\lambda}$$

UCC_{λ} is the unit conversion coefficient for band λ to convert DN to radiance, obtained from the ASTER User Handbook [19]. The UCC_{λ} is in $W/(m^2*ster*\mu m)/DN$. This

spectral radiance was then converted to Top-of-Atmosphere planetary reflectance using the following formula:

$$p_{\lambda} = \frac{\pi * L_{\lambda} * d^2}{ESUN_{\lambda} * \cos\theta_s}$$

Referring to the above equation, p_{λ} is Top-of-Atmosphere planetary reflectance (%); L_{λ} is spectral radiance at sensor's aperture in $W/(m^2*ster*\mu m)$; $ESUN_{\lambda}$ is band dependent mean solar exoatmospheric irradiance in $W/(m^2*\mu m)$; θ_s is solar zenith angle in degrees; d is Earth-Sun distance in astronomical units [19]. These also can be found in the ASTER header files or the user handbooks mentioned earlier [19].

2.4. Vegetation Index

As stated earlier, NDVI is the vegetation index that is commonly used in human health-related research due to its known relationship with higher NDVI predicting better health outcomes. NDVI is the ratio of the difference between the near-infrared (NIR) and red bands divided by the sum of NIR and red. The formula is expressed as:

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

2.5. Comparison and Equations for Conversion

Comparisons using generalized linear models of the NDVI values between every satellite image were performed on a pixel-to-pixel basis within each image set. The number of pixels varies for each image set but is in the range of 75 to 85 thousand. Generalized linear models were performed for each combination of satellite imagery for every image set (i.e. Landsat 8 and ASTER, Landsat 7 and ASTER, Landsat 7 to Landsat 8). Any correlation with a p-value of 0.001 or less was considered significant. The coefficients of each generalized linear model were averaged for each study area to create conversion equations that can convert ASTER-derived NDVI into near equivalencies of Landsat NDVI values at each season. The final coefficients for the conversion equations were developed based on the average values of multiple correlation coefficients, for the same season. For example, the Fall conversion coefficients were developed by taking the average values of the coefficients from the Fall image sets for Miami and Polk County, separately.

Table 3. NDVI averages and standard deviations for the four different image sets of this study

	Landsat 8		Landsat 7		ASTER	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
M. Fall	0.34	0.16	0.30	0.14	0.26	0.14
M. Spring	0.30	0.13	0.24	0.12	0.24	0.11
P. Fall	0.49	0.13	0.47	0.12	0.42	0.12
P. Spring	0.42	0.12	0.37	0.11	0.35	0.11

M.= Miami, P.= Polk County, Std Dev.= Standard Deviations

3. Results

As seen in **Table 3**, the ASTER NDVI values were generally lower than the associated Landsat 7 and Landsat 8 NDVI values. This disparity is consistent with prior research that has documented that the difference in red band detection and NIR wavelengths in a reduced NDVI score compared to Landsat 7 [9,10,12,13].

Direct linear regressions between the ASTER and Landsat 7 and 8 imagery resulted in strong correlations ($R^2 > 0.75$) across all locations, dates, and satellite sensors, as seen in **Figure 2** and **Table 4**. Miami's Spring image set had R^2 values of 0.83 and above for all comparisons, with the highest R^2 being 0.935 for the Landsat 7 and Landsat 8 comparisons. The R^2 of the Landsat 8 and ASTER imagery within the Spring image set of Miami was lower, with a value of 0.83, than the corresponding R^2 of the Fall image set (R^2 of 0.85). However, the Landsat 7 and Landsat 8 comparison for the Spring image set of Miami had a higher R^2 of 0.935 than the Fall Miami image set, which was 0.929. Overall, values were relatively similar.

The Fall image set, and the Spring image set across all comparisons for the Polk County location had nearly identical R^2 values. What is of note about the Polk County

generalized linear model results is how they compare to the Miami results. Despite the images from the different satellite sensors for each image set of Polk County being closer in time than the images in the Miami image sets (see Table 1), the R^2 for each comparison was still lower (see Table 4). For example, for both image sets of Polk County, the ASTER imagery and Landsat 8 imagery were taken on the same day. However, the R^2 between the ASTER and Landsat 8 NDVI values in Polk County resulted in a lower value than their Miami counterparts.

The root mean square estimate (RMSE) seen in Table 4 found the highest values between the ASTER and Landsat 8 NDVI values, ranging from 0.086 to 0.101 with an average of 0.095. In contrast, the RMSE of the ASTER NDVI to Landsat 7 NDVI models demonstrated RMSE values ranging from 0.052 to 0.073, with an average of 0.064. The lowest RMSE values were found among the Landsat 7 and Landsat 8 NDVI comparisons, where the range of RMSE values was between 0.051 to 0.068, with an average of 0.061. Overall, the low RMSE of the various generalized linear models demonstrate tell us that, at worst, a model that converts ASTER NDVI to Landsat 8 NDVI will have an error of 0.101 out of an NDVI range of -1 to +1. Moreover, Landsat 7 and 8 were highly comparable.

Table 4. Generalized linear model results for the four different image sets of this study

	Landsat 8 vs ASTER				Landsat 7 vs ASTER				Landsat 7 vs Landsat 8			
	R ²	Slope	Intercept	RMSE	R ²	Slope	Intercept	RMSE	R ²	Slope	Intercept	RMSE
Miami Fall	0.855	0.851	-0.025	0.101	0.855	0.905	-0.009	0.073	0.929	1.024	0.031	0.059
Miami Spring	0.833	0.787	0.005	0.086	0.857	0.856	0.03	0.052	0.935	0.901	-0.023	0.066
Polk County Fall	0.765	0.843	0.006	0.095	0.794	0.906	-0.001	0.073	0.879	0.889	0.028	0.051
Polk County Spring	0.769	0.796	0.009	0.097	0.809	0.912	0.005	0.057	0.856	0.828	0.023	0.068

All linear regression models presented here had a p value of less than 0.001.

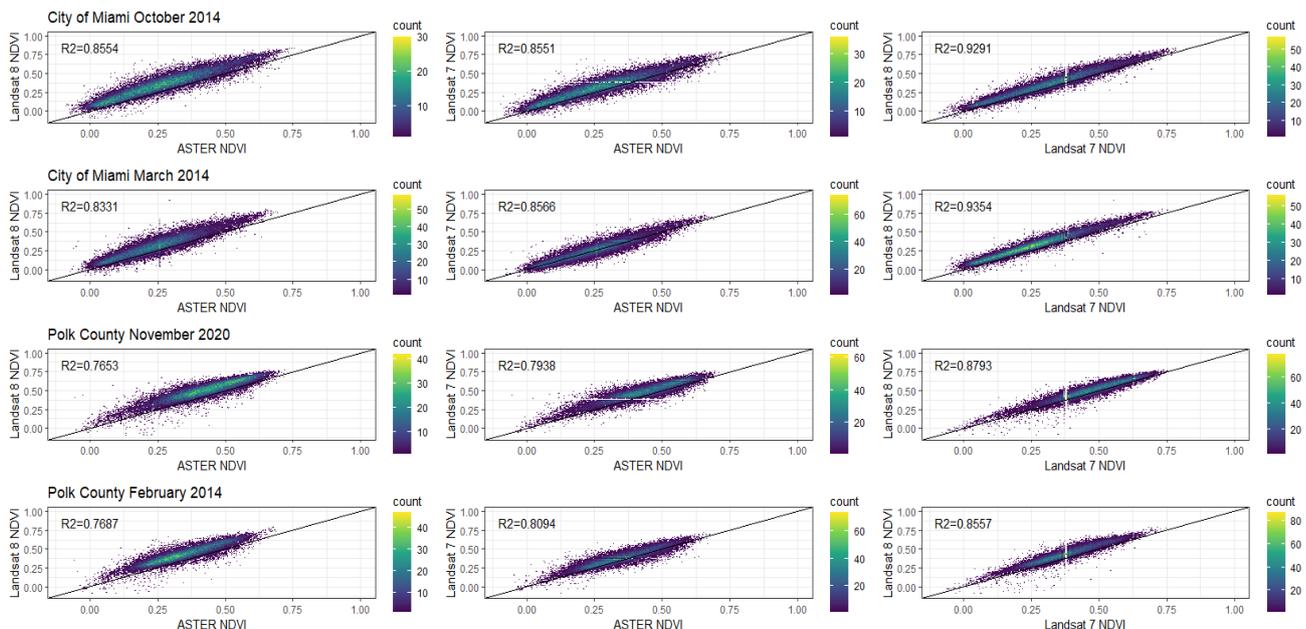


Figure 2. Scatterplots relating NDVI values between the ASTER and Landsat satellite sensors across the four different image sets. Each scatterplot includes the associated R^2 value for that specific comparison

Overall, the average NDVI score in Miami was lower than that of the Polk County region, as shown in Table 3. This difference is to be expected because the City of Miami as an Urban Area has more population/building density whereas Polk County as an Urban Place with lower density, has more area available for trees. This is because within the USA, urban areas typically have less vegetation in the form of lawns, parks, and trees when compared to suburban landscapes; however, this relationship may not be valid in more arid locations [20]. Furthermore, despite the higher-than-average precipitation levels in October 2014 for Miami, the mean NDVI values across all the satellite sensors did not differ from the NDVI values of March 2014 for Miami. This is reflected in the R^2 values seen between Landsat 7 and Landsat 8 for October 2014 in Miami, which did not differ from the R^2 of the March imagery for Miami. As such, precipitation differences either had no impact or had not yet been realized in terms of resultant vegetation and NDVI changes.

3.1. Converting ASTER and Landsat 7 NDVIs to Landsat 8 NDVI

The differences between the satellites appears to be sufficiently systematic and predictable, that it is possible to convert ASTER-derived NDVI to Landsat 8 or 7 derived NDVI using the averaged intercepts and coefficients found in Table 5. These coefficients represent near-perfect linear relationships. Although these intercepts and coefficients would only apply to the specific geographical areas included in the current study, they are similar to values seen in previous ASTER-Landsat comparison studies [10,13]. Lastly, intercepts and coefficients necessary to convert Landsat 7 NDVI values to Landsat 8 NDVI values are provided per season in Table 6.

Table 5. Coefficients to convert ASTER NDVI to Landsat NDVI stratified across season and Landsat satellite

	ASTER to Landsat 8		ASTER to Landsat 7	
	Slope	Intercept	Slope	Intercept
Fall	0.8472524	-0.0096417	0.9050592	-0.0051516
Spring	0.7913629	0.0068464	0.8840475	0.0170924

Table 6. Coefficients to convert Landsat 7 NDVI to Landsat 8 NDVI stratified across season

	Landsat 7 NDVI to Landsat 8 NDVI	
	Slope	Intercept
Fall	0.9568511	0.0296827
Spring	0.8648640	0.0000000

4. Discussion

A comparison of the scatterplots of ASTER with Landsat satellite sensor NDVI scores, produced R^2 values consistently above 0.75 with p-values less than 0.001 across both locations and times of the year, indicating that Landsat and ASTER-derived NDVI values share considerable

variance. By repeating these analyses separately by season and location, we demonstrated that the relationship between Landsat and ASTER NDVI varies more by season than location within urban subtropical settings. These findings suggest that studies comparing NDVI values from these different satellite sensors would require calculating separate intercepts and coefficients for each season.

4.1. Comparability Across Satellite Sensors

Overall, the comparison between ASTER and the Landsat NDVI values within urban settings revealed that these different satellite sensors can be corrected to make their values comparable. ASTER NDVI values were generally lower than both Landsat satellite sensors across both study areas. These differences have been noted in previous studies and has been attributed to the differences in red band wavelengths in ASTER compared to the Landsat satellite sensors. Also, the Landsat 8 and ASTER NDVI comparison R^2 values were lower than the Landsat 7 and ASTER comparisons. This difference is likely because Landsat 8 has narrower spectral bands, improved calibration, higher 12-bit radiometric resolution, and more precise geometry than Landsat 7 [21]. These differences affect NDVI values as the narrowed spectral bands result in higher NIR values. Previous research that compared the NDVI values of these satellite sensors found that Landsat 8 NDVI values are generally higher than the associated Landsat 7 NDVI values in areas of lower vegetation cover [22]. This was found to be true within this study as well, as the average NDVI values of Landsat 8 were higher than those of Landsat 7, see Table 3.

This study demonstrated that NDVI values in urban areas across ASTER, Landsat 7, and Landsat 8 satellite sensors are closely correlated and have relatively low intercept differences. The inclusion of Polk County revealed that differences in population density and thus availability of land for trees within built-up areas appear to have a similar magnitude of shared variance between NDVI values derived from ASTER and Landsat imagery. Although other research has also observed similar NDVI values between the satellite sensors in studies that included a range of population densities [12], this study is the first to focus specifically on urban areas. Finally, according to these results, direct comparisons of NDVI values from ASTER to Landsat 7 or Landsat 8 should include corrections for slope and intercept to ensure comparability across satellite sensors. Thus, future health/greenness studies that use Landsat based NDVI results can increase the comparability with ASTER-based NDVI results by deriving slope and intercept corrections to ensure comparability across ASTER and Landsat using the methods presented here.

4.2. Climatic Environments

The coefficients used for conversion from ASTER to Landsat NDVI may not generalize for all locations in the subtropics. However, at least within subtropical urban areas, seasonality is likely more important than location, with different seasons requiring different correction coefficients.

For each season, general linear models would need to be developed to establish the slope and intercept to compare across satellite sensors.

As stated earlier, this study focused on subtropical urban settings. Examination of how these satellite sensors compare in other settings, such as temperate environments which rely on previous ASTER-Landsat NDVI comparisons, have been conducted in temperate locations in China. However, these studies did not specifically look at how NDVI across these satellite sensors compare in urban environments. Nevertheless, these studies also found that the NDVI values between the different satellite sensors were also strongly correlated [10,12,13,23].

Despite a lack of an ASTER and Landsat comparison for urban areas in a temperate environment, the results of this study indicate that Landsat-derived NDVI is an adequate replacement for ASTER-derived NDVI, so long as the appropriate conversion equation is used. Landsat imagery has the advantage of a more extensive library of more frequent imagery to rely on, a greater degree of processing and extra informational layers that delineate areas of cloud cover and cloud shadows for each image. Studies that examine changes in greenness over longer stretches of time (20 years or more) will benefit from the extra level of processing that Landsat's more frequent imagery provides.

4.3. Method for Conversion

Lastly, this research outlines the methods required for potential future research that would need to compare NDVI values across ASTER and Landsat satellite sensors. Given the different corrective equations for Fall and Spring image sets, the coefficients are clearly season-specific. However, the method developed here is transferable across sites and therefore useful to other research comparing different geographic areas. This in of itself is an important finding and a significant caution to others who are utilizing multiple satellite sensor data sources within a single study.

4.4. Future Research

Future research will investigate if the differences across satellite sensors by seasonality can be replicated in temperate urban environments, although it is reasonable to suspect that urban NDVI values between ASTER and Landsat satellite sensors are likely to remain strongly correlated in these locations. Future work will also expand the current research for other subtropical locations in different countries and continents, particularly in the Global South.

Funding: This work was funded in part by grants R01HL148880 and RF1AG0743607 to Scott C. Brown and José Szapocznik at the University of Miami.

Data Availability Statement: NDVI data created for this study will be uploaded on to Dryad Digital Repository upon publication of the manuscript.

Acknowledgments: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

- [1] Pereira, G., et al., The association between neighborhood greenness and weight status: an observational study in Perth Western Australia. *Environmental Health*, 2013. 12(1): p. 1-9.
- [2] Dadvand, P., et al., Risks and benefits of green spaces for children: a cross-sectional study of associations with sedentary behavior, obesity, asthma, and allergy. *Environ Health Perspect*, 2014. 122(12): p. 1329-35.
- [3] Brown, S.C., et al., Neighborhood greenness and chronic health conditions in Medicare beneficiaries. *American journal of preventive medicine*, 2016. 51(1): p. 78-89.
- [4] Pereira, G., et al., The association between neighborhood greenness and cardiovascular disease: an observational study. *BMC public health*, 2012. 12(1): p. 1-9.
- [5] Wang, K., et al., Relationship of neighborhood greenness to heart disease in 249 405 US Medicare beneficiaries. *Journal of the American Heart Association*, 2019. 8(6): p. e010258.
- [6] Brown, S.C., et al., Health disparities in the relationship of neighborhood greenness to mental health outcomes in 249, 405 US Medicare beneficiaries. *International journal of environmental research and public health*, 2018. 15(3): p. 430.
- [7] Landsat 7 science data users handbook, in General Interest Publication. 1998.
- [8] USGS, L., Data Users Handbook, 2 (2016) <https://landsat.usgs.gov/sites/default/files/documents/Landsat8DataUsersHandbook.pdf>.
- [9] Xu, H.-q. and T.-j. Zhang, Cross comparison of ASTER and Landsat ETM+ multispectral measurements for NDVI and SAVI vegetation indices. *Spectroscopy and Spectral Analysis*, 2011. 31(7): p. 1902-1907.
- [10] Hanqiu, X. and Z. Tiejun. Comparison of Landsat-7 ETM+ and ASTER NDVI measurements. in *Proc. SPIE*. 2011.
- [11] Peijun, D., et al. Comparison of Vegetation Index from ASTER, CBERS and Landsat ETM+. in 2007 IEEE International Geoscience and Remote Sensing Symposium. 2007.
- [12] Xu, H., S. Huang, and T. Zhang, Built-up land mapping capabilities of the ASTER and Landsat ETM+ sensors in coastal areas of southeastern China. *Advances in Space Research*, 2013. 52(8): p. 1437-1449.
- [13] Xu, H. and T. Zhang, Assessment of consistency in forest-dominated vegetation observations between ASTER and Landsat ETM+ images in subtropical coastal areas of southeastern China. *Agricultural and Forest Meteorology*, 2013. 168: p. 1-9.
- [14] Hao, F., et al., Vegetation NDVI Linked to Temperature and Precipitation in the Upper Catchments of Yellow River. *Environmental Modeling & Assessment*, 2012. 17(4): p. 389-398.
- [15] Mallick, J., et al., Evaluating the NDVI-Rainfall Relationship

- in Bisha Watershed, Saudi Arabia Using Non-Stationary Modeling Technique. *Atmosphere*, 2021. 12(5): p. 593.
- [16] Fayeche, D. and J. Tarhouni, Climate variability and its effect on normalized difference vegetation index (NDVI) using remote sensing in semi-arid area. *Modeling Earth Systems and Environment*, 2021. 7(3): p. 1667-1682.
- [17] Méndez-Barroso, L.A., et al., Seasonal and interannual relations between precipitation, surface soil moisture and vegetation dynamics in the North American monsoon region. *Journal of hydrology*, 2009. 377(1-2): p. 59-70.
- [18] Reynolds, M.K. and D.A. Walker, Increased wetness confounds Landsat-derived NDVI trends in the central Alaska North Slope region, 1985–2011. *Environmental Research Letters*, 2016. 11(8): p. 085004.
- [19] Abrams, M., S. Hook, and B. Ramachandran, ASTER user handbook, v2: Advanced spaceborne thermal emission and reflection radiometer. USA: NASA/Jet Propulsion Laboratory California Institute of Technology, 2002. 2 (2002.135).
- [20] Pozzi, F. and C. Small. Vegetation and population density in urban and suburban areas in the USA. in *Third International Symposium of Remote Sensing of Urban Areas*. 2002.
- [21] Irons, J.R., J.L. Dwyer, and J.A. Barsi, The next Landsat satellite: The Landsat data continuity mission. *Remote Sensing of Environment*, 2012. 122: p. 11-21.
- [22] Xu, D. and X. Guo, Compare NDVI extracted from Landsat 8 imagery with that from Landsat 7 imagery. *American Journal of Remote Sensing*, 2014. 2(2): p. 10-14.
- [23] Du, P.J., et al., Comparison of vegetation index from ASTER, CBERS and landsat ETM, in *IGARSS: 2007 IEEE International Geoscience and Remote Sensing Symposium, Vols 1–12: Sensing and Understanding our Planet*. 2007. p. 3341-3344.