UTILIZING SPECTRAL REFLECTANCE AND VEGETATION INDICES OF *BOUGAINVILLEA SPECTABILIS* FOR MONITORING PARTICULATE AIR POLLUTION IN METRO MANILA

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ABSTRACT: This research aims to examine the potential of high-resolution multispectral remote sensing in assessing particulate air pollution wherein plant responses were utilized as indicators of air quality. Spectral reflectance measurements simultaneous with air particulate matter concentration sampling were conducted daily for a one-month period. Vegetation indices such as Ratio Vegetation Index (RVI), Normalized Difference Vegetation Index (NDVI) and Difference Vegetation Index (DVI) including Red Edge Parameter (REP) were utilized to assess potted bougainvillea plants exposed at different pollution level. Further, a spectral mixture analysis (SMA) was made to simulate the effects of vehicular exhaust soot to the spectral characteristics of a bougainvillea leaf. The generated data was later used in creating a model thru Partial Least Squares (PLS) regression. The SMA-based PLS-ran model was then applied to WorldView-2 imageries in producing an interpolated detailed air quality map showing the spatial extent and concentration of suspended particulate matter. The clearest and least hazed image showed the most reasonable representation of particulate air pollution suggesting a valid scenario. However, portions of vegetated areas present unrealistic estimates due to intrinsic factors like canopy biophysical attributes and external conditions such as soil reflectance, atmospheric and illumination conditions and viewing geometry.

1. INTRODUCTION

Given the detrimental effect of particulate air pollution to environment and health, there is a need to develop air quality management programs that would introduce interventions. For air quality improvement efforts to become comprehensive and effective, an essential requisite of accurate and up-to-date air quality monitoring system must be put in place. Although the Department of Environment and Natural Resources (DENR) has been monitoring air quality in the country by using a high-volume samplers installed in different locations in the metropolis, these stations are sparsely distributed and could only represent a relatively limited area. In addition, many of them are now inoperational due probably to mechanical deterioration and failure as being exposed outdoors.

Given the constraints of the current air quality monitoring system, this research therefore aimed to examine the potential of remote sensing technology in assessing particulate atmospheric pollution wherein plant spectral signatures, specifically of bougainvillea leaves were utilized as indicators of air quality. A crucial component of this research is the integration of ground-based measurements with remotely sensed imagery through the application of a spectral mixture modeling approach.

2. OBJECTIVES

The overall objective of this study is to provide an approximation of the particulate matter concentrations in Metro Manila by utilizing the spectral features of *Bougainvillea spectabilis* as basis for developing air pollution estimation from satellite imagery.

Specifically, it aims to:

1. Measure and interpret the spectral characteristics of plants particularly its leaves exposed to different levels of particulate air pollutants;
2. Utilize vegetation indices as derived from *in situ* measured reflectance in determining the condition of the vegetation with respect to atmospheric condition;
3. Create a model that approximates the concentration of suspended particle matters applied to high resolution satellite imagery; and
4. Validate the result of the particulate air pollution model and application.

3. METHODOLOGY

3.1 Sampling Sites

Sampling was conducted on three air quality monitoring stations of Environmental Management Bureau (EMB) of the Department of Environment and Natural Resources (DENR) which are known to have different levels of TSP based on the latest data released by the agency itself (Fig. 3). These were at the [1] Solid Waste Management Office (SWMO) along East Avenue of Quezon City; [2] Manila Observatory (MO) inside the Ateneo de Manila University campus at Katipunan Avenue also in Quezon City; and at the [3] Marikina Sports Park (MSP) in Marikina City (Fig. 1). SWMO and MSP stations are 3.5 and 2 kilometers away from MO station, respectively.

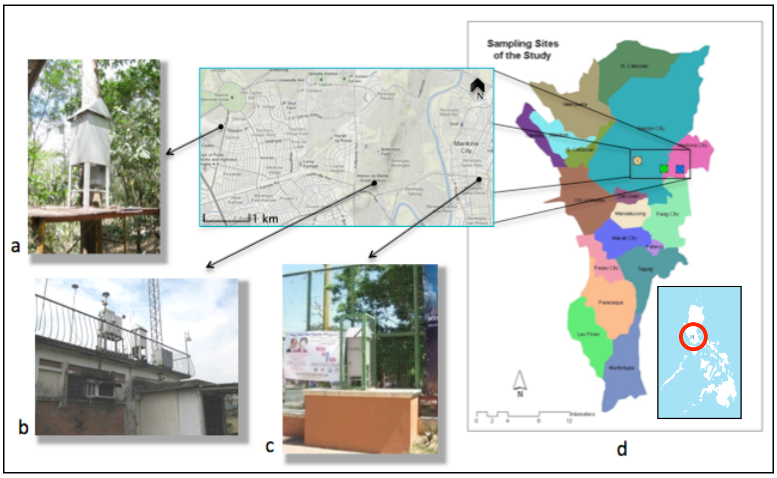

Figure 1. The three sampling sites of the study: (a) SWMO station, (b) MO station and (c) MSP station as shown from (d) Metro Manila map

The high-volume sampler of SWMO is about 12 m away from the road with moderate to heavy traffic and is inside a densely vegetated mini-park. MO station on the other hand is situated inside a relatively "cleaner" environment. The sampler was placed on a rooftop and is away from tress or tall buildings making it obstruction-free. Among the three sampling stations, the one nearest to a main road (about 5m) is in MSP and is quite visible to the passing public.

3.2 The Specimen

The bougainvillea saplings were taken from the Manila Seedling Bank at Quezon Avenue in Quezon City. The specimen were of uniform age at approximately one year old and were regularly pruned. They were deployed on respective stations on 12 January 2010 with an average height of 0.7 meter. Prior to the actual measurement, the saplings were transferred and acclimatized for three weeks to adjust to the environment. During the period of exposure, these plants were watered every morning and late afternoon with distilled water being used. A complete fertilizer was also applied twice during the whole duration of exposure. The water and the fertilizer were directly poured into the soil.

3.3 Simultaneous Measurements of Environmental Variables

In situ measurements at three stations were done daily from February 1 to March 2, 2010. Leaf spectra of potted bougainvilleas placed on each station were obtained at three levels – top, middle and bottom leaves using a field spectroradiometer (Ocean Optics USB4000) connected to a laptop computer. The spectral range of the instrument is from visible to near infrared region ranging from 345-1047 nm with interval of 0.22 nm. The device was calibrated using a white reference panel (Spectralon™) before the actual measurement was made. To level off the differences in leaf angle, five sample measurements were taken from each level to compute for the average value. Reflectance was acquired at about 1-2 cm above sunlit sides of the leaf using a fiber optic cable with 22^{o} field of view. This was done on clear sunny days between 10:00 am and 1:00 pm. Simultaneously, ambient air quality were also determined by a handheld Particle Mass Monitor instrument (Sibata Model GT-331). This portable battery-operated device can gauge in standard mass concentrations at PM10, PM7, PM2.5, PM1 and TSP. The instrument operates on a four-minute cycle before it displays the result on its embedded Liquid Crystal Display (LCD), just enough time to do the spectra measurement.

3.4 Vegetation Indices

Three vegetation indices namely the Ratio Vegetation Index (RVI), Normalized Difference Vegetation Index (NDVI) and Difference Vegetation Index (DVI) were computed from the measurements taken on field. Additionally, Red Edge Position (REP) was also calculated for vegetative status analysis. Table 1 shows the details of VIs used in this study.

Table 1. Summary of the vegetation indices used in the study

Index	Formula	Range	References
RVI	NIR/RED (1)	0 to ∞	Jordan, 1969
NDVI	(NIR-RED)/(NIR+RED) (2)	-1 to +1	Rouse, 1974
DVI	NIR - RED (3)	∞	Tucker, 1979
REP	$R_{re} = \frac{(R_{670} + R_{780})}{2}$ where: R = reflectance, R_{re} = reflectance at inflection point $REP = 700 + 40\left(\frac{R_{re} - R_{700}}{R_{740} - R_{700}}\right)$ (4)	680 to 780	Guyot and Baret, 1991

3.5 Spectral Mixture Analysis (SMA)

In order to determine the effects of soot on the optical properties of the leaves, a controlled experiment was performed. Minute amount of vehicle exhaust pipe soot was applied above the surface of a bougainvillea leaf. The soot was pulverized and air-dried before it was gently and evenly applied over the entire surface of the leaf four times with reflectance measurement at every interval. A minimum of five spectral measurements per sample were taken before averaging. Leaf was weighed before and every after the soot was spread. The leaf was placed inside a light plastic container to consider those mislaid soot outside the leaf. To complete the parameters needed for the model, grid method was used to obtain the area of the leaf.

Partial Least Squares or Projection to Latent Structures (PLS) was utilized as the statistical modeling technique for the generated data from the experiment describe above where the spectral bands of satellite images are the predictors (the x variables) while the soot content as the response (the y variable). PLS was preferred instead of the ordinary least squares method since PLS is particularly appropriate when the number of predictors exceeds the number of cases or when the predictor variables are highly correlated (Unscrambler, 2010). The regression equation is given as:

$$Y = B + B_1x_1 + B_2x_2 + \ldots + B_nx_n \qquad (5)$$

Where Y is the soot; B_i (i =1…n) are the coefficients; x_i are the spectral reflectance at specific wavelength; and n is the number of bands.

3.6 Satellite Imagery Utilized

High-resolution multispectral WorldView-2 (WV-2) images were used in the analysis of the study. Launched in October 2009, it has a 0.46m (panchromatic) and 1.84m (multispectral) spatial resolution at nadir but resampled commercially at 0.5m and 2.0m, respectively. WV-2 offers four additional bands – coastal blue, yellow, red edge and NIR2, aside from the traditional blue, green, red and NIR channels with each band having a dynamic range of 11-bit radiometric resolution.

Four WV-2 image datasets were obtained taken concurrent within the sampling period dated February 2, 5 and 24 of 2010. Mosaicking was done on February 5 imageries since it is composed of two separate datasets (Fig 2). It is relatively the clearest as far as cloud cover is concerned. Images taken on February 2 and 24 contain approximately 10 and 20% cloud cover, respectively.

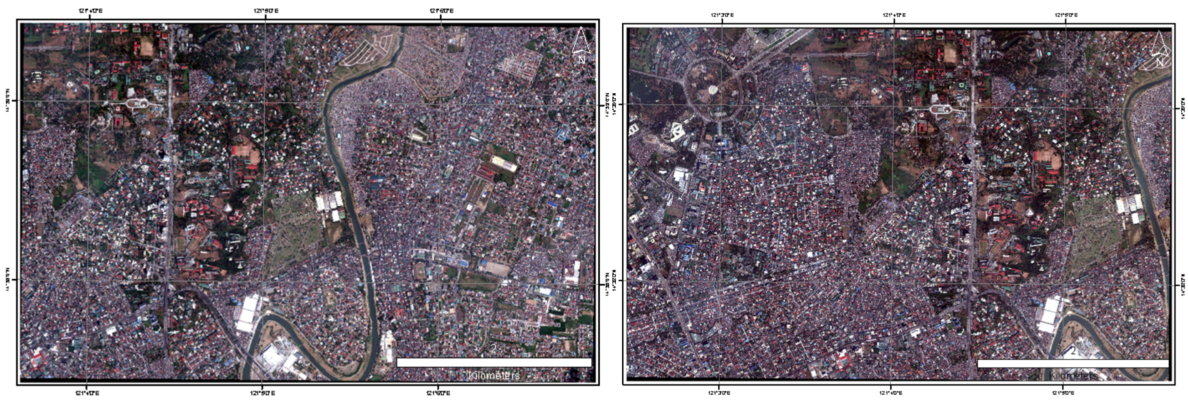

Figure 2. Feb. 5 image in true colors taken at 10:39:20AM (left) and 10:39:57AM (right)

3.7 Radiance and Reflectance Calibration

According to the product documentation catalogue by Updike and Comp (2010), all of WV-2 images distributed to the client are already geometrically and radiometrically corrected. Nonetheless, as added by the same authors, as its image pixel data are unique to the hardware specifications of WV-2 satellite, it must be converted to spectral radiance at a minimum before radiometric/spectral analysis or comparison with imagery from other sensors in a radiometric/spectral manner. The equation for radiance calibration as well as the metadata file which includes the needed parameters are provided by Digital Globe.

Since the data required for the model is in percent reflectance R, there is a need to convert the calibrated radiance. This was done by employing regression to the 8-band value reflectance of a common feature to its equivalent radiance in the image. A similar method was conducted by Maas and Rajan (2010) who took advantage of pseudo-invariant materials to normalize one image to another or convert pixel values to surface reflectance. First, five invariant materials were chosen for spectra measurement which are present and visible in all images. These were GI sheet rooftop, concrete rooftop, asphalt road, concrete road, and a pond. Measurement was done all on the same day at 10:00 – 11:00 AM with clear skies. The location for each feature was noted so as to identify it easily in the imagery. This simple technique neglects the atmospheric, viewing geometry and topographic effects.

3.8 Image Masking and Feature Discrimination

After preprocessing, there was a need to detect candidate pixels representing bougainvillea plants over the entire acquired image. In order to have a basis for classification, a total of forty bougainvillea shrubs were first identified and located. The statistics were generated out from the identified bougainvillea and an appropriate criterion was chosen based on its statistical accuracy. To narrow down the filtering, non-vegetative covers were masked out using NDVI values. Additionally, a band ratio of green/yellow was also utilized to filter out newly cut grasses and lawns. Wolf (2010) introduced its normalized form but used it originally to discern soil.

4. RESULTS AND DISCUSSION

4.1 Total Suspended Particles (TSP)

Daily Total Suspended Particles or TSP was measured in three stations which started from February 1 and ended last March 2, 2010. The actual reading was done between 10:00 AM – 1:00 PM to synchronize with that of spectral reflectance measurement. Figure 3 illustrates the data observed.

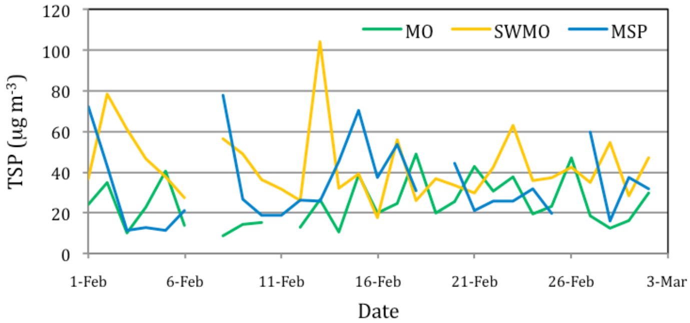

Figure 3. TSP readings over one month observation at three stations

Based on the graph, SWMO recorded the highest TSP among all stations. Station MO on the other hand got the lowest values in general.

4.2 Vegetation Indices

The three VIs mentioned above were calculated at all stations for the whole extent of the sampling period. These were the average values of the measurements taken from the bottom, middle and top leaf levels of each specimen. In Figure 4 (a) and (b), it is expected that RVI and NDVI would display similar trend since NDVI only normalizes the values from RVI. Noticeable are the DVI values where all stations are relatively close with each other. Among the DVI values in three stations, MO and SWMO show a closer link as compared to MSP. Also, their values are somehow uniform during the last week of exposure. During the last day of sampling, MO recorded the highest values at all indices including NDVI at almost 0.80 while the other two sites had below 0.70.

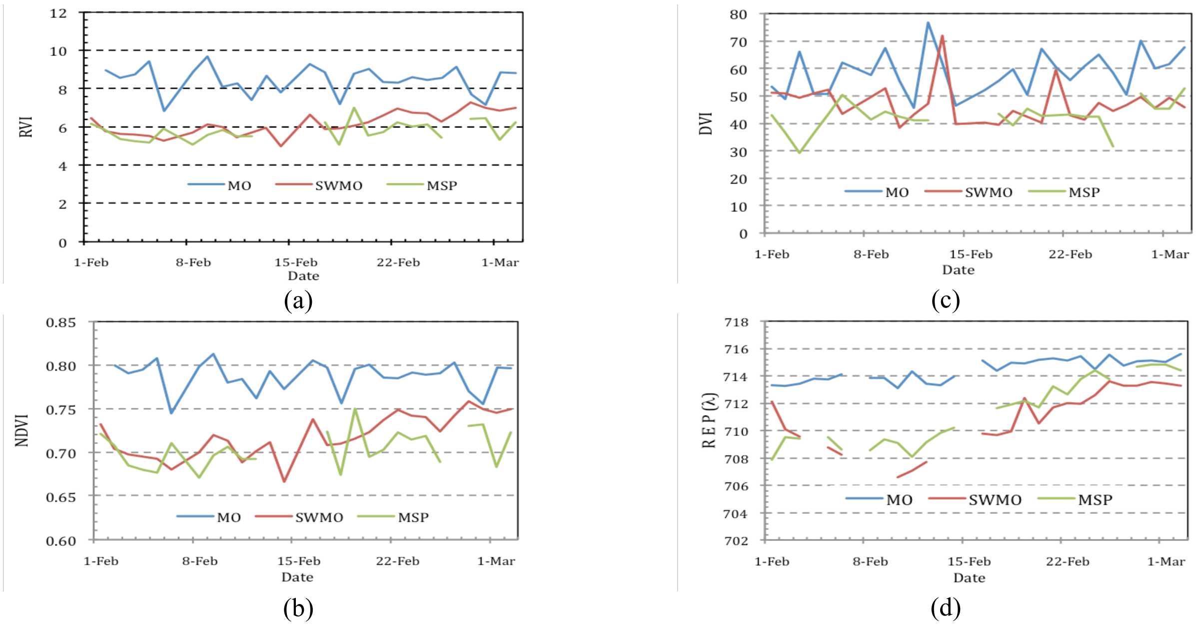

Figure 4. Daily RVI (a), NDVI (b), DVI (c) and REP (d) at all stations for one-month observation

4.3 SMA-Based Soot Estimation Model

Figure 5 illustrates the effects of the accumulated soot to spectral features of bougainvillea leaf in the simulation conducted. Each of the five lines in the graph corresponds to the average of five scans of the subjected leaf per scenario. The "clean" refers to the scanning of the leaf prior to the first soot application. The "1st-4th" refers to the successive soot treatments. The average amount of soot per application was 0.783 mg cm^{-2} and the total accumulated soot was 1.182 mg cm^{-2}.

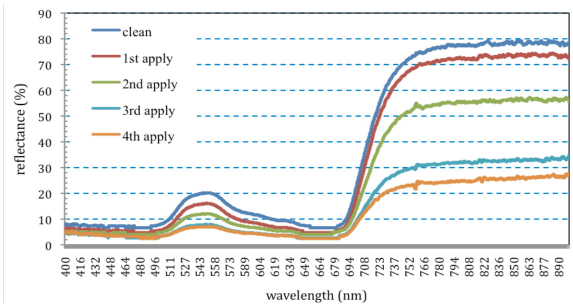

Figure 5. Leaf reflectance as applied with soot in mg cm^{-2}

The spectra generated from the spectral mixing experiment became an input to the PLS regression method. The resulting soot estimation model had a coefficient of determination of 0.91.

4.4 Digital Image Processing

4.4.1 Identification of the Specimen

A total of 40 identified bougainvillea shrubs were selected on field prior to feature detection. These points were divided into two sets: the training dataset (25 pixels) which were chosen randomly and the check dataset (15 pixels) for accuracy assessment. The standard deviation from the mean of the identified bougainvillea plants was chosen as the selection criterion since it yielded the highest accuracy of 60.87% to Image 1 which is the clearest and has the least haze. It also is consistently high in the other two images.

4.4.2 Application of Model to Image Datasets

Finally, after converting radiance to reflectance, the estimation soot model was applied to the masked image on Feb. 5. After running the SMA-based estimation model, the discriminated pixel values correspond to the soot content and these were interpolated using kriging technique. Zooming in to selected sites of the map shows more spatial details for clearer understanding (Fig. 6). In the top left corner, a closer view of Quezon City Circle can be seen wherein shades of blue is dominant (the area is vegetated with contiguous parks) but a distinct of yellow and spots of red can be trace encircling the busy circumferential road. On its opposite side is a river system – the Marikina River, which is generally “cleaner” as it is away from major streets. Its condition of being low in pollution actually stretches down to the lowest portion of the river. The bottom two depicts high and low level of TSP on heavily traffic junction (Katipunan-Aurora) and cemetery (Loyola Memorial Park), respectively. However, a portion of vegetated areas seem to be unrealistic and does not represent TSP levels as anticipated due probably to numerous factors such as atmospheric effects, soil background, the presence of twigs and flowers on canopies, illumination conditions, sensor geometry and misclassification of pixels.

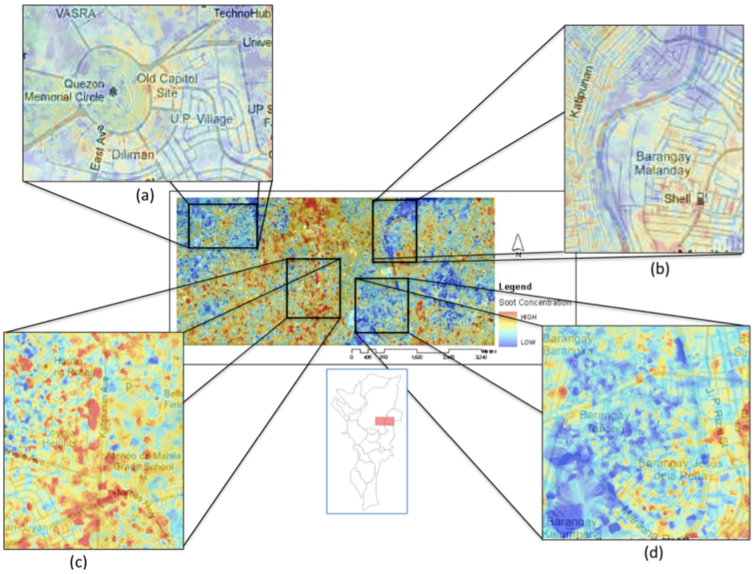

Figure 6. Interpolated Feb. 5 image showing closer views of (a) Quezon City Circle; (b) Marikina River; (c) Aurora-Katipunan Junction; and (d) a cemetery and subdivision.

4.7 Validation of the Model Results

The results of the PLS-ran model integrated with remotely sensed images was validated by a combination of field measured data and image-processed datasets. The locations of the exposed specimen were pinpointed from each of the three images and extracted its corresponding pixels. The values from these pixels were used as an input for the model and correlated it to the TSP recorded on that same date. Furthermore, particles less than or equal to 10 µm were excluded in the TSP concentration following the principle that coarser particles settle immediately than finer ones. The resulting graph is in Figure # with a coefficient of determination of 0.61.

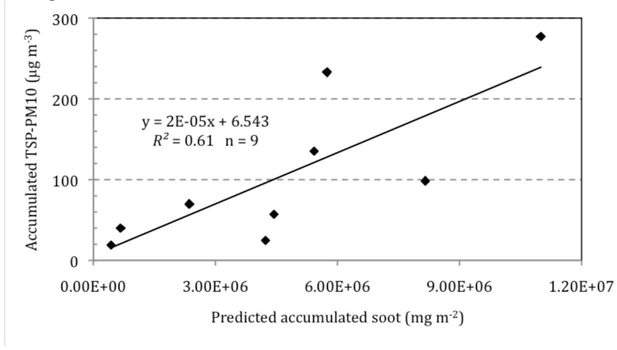

Figure #. Regression of field and image datasets for validation

5. CONCLUSION AND RECOMMENDATION

Vegetation indices used in this study (RVI, NDVI, DVI and REP) aided the analysis by comparing the specimen exposed at different levels of pollution. The specimen in MO station which is generally the least polluted consistently maintained the highest average values for all indices throughout the sampling period. On the other hand, SWMO which recorded the highest TSP data had the lowest values of the indices quantified.

The estimation model that was applied to remotely sensed images produced maps that illustrates detailed and justifiable scenarios such as low particulate air pollution levels on residential, parks and along rivers while high concentration can be seen on major thoroughfares. For areas that were not reasonably represented, various factors were considered such as atmospheric conditions, biophysical attributes of the trees like presence of twigs and flowers, soil reflectance, illumination conditions and viewing geometry. Not to mention the misclassification of pixels which is apparent mostly on trees.

Validation of the estimation model was made by integrating the on-field TSP recorded data to the soot-estimated pixels of the specimen at three sampling stations at three different dates (images) which yielded a 0.61 coefficient of determination.

It is strongly suggested that further advance image processing is needed to account at least for the atmospheric effects which played a crucial role in the resulting map. Furthermore, although radiance to reflectance conversion performed in this study resulted in a high coefficient of determination, it still needs improvement. Current atmospheric correction algorithms such as MODTRAN, FLAASH, etc. used by remote sensing community may increase the accuracy.

In relation to the first recommendation, a longer sampling period would also give a better chance to acquire more image datasets as a function of sensors' temporal revisit. A higher accuracy of validation could have been attained in this study if more image datasets were available at different dates within the sampling period.

Lastly, it is recommended to explore and use an extensive algorithm to discriminate trees from other vegetation habit so as to accurately filter out only the shrubs which are the subject of this research. Usage of WV-2 panchromatic image may be useful in doing so considering its half meter resolution.

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