EVALUATION OF ATMOSPHERIC CORRECTION METHODS FOR SENTINEL-2 IMAGERY IN THE SPECTRAL IDENTIFICATION OF POPLAR (*POPULUS DELTOIDES* BARTR.) SPECIES

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ABSTRACT: Spectral libraries can be used for the analysis of the spectral properties of tree species, as well as for the detection and mapping of tree species through remotely sensed data. This study aims to statistically analyze the performance of atmospheric correction methods in calibrating ground spectral measurements with the Sentinel-2 imagery. In this context, field spectral measurements of *Populus deltoides* Bartr. species cultivated in Akyazı district of Sakarya province, Turkey obtained with the ASD (Analytical Spectral Devices) FieldSpec-3 high resolution (Hi-Res) spectroradiometer (350nm-2500nm) were used as the main data source. In order to evaluate the effects of atmospheric correction methods in identifying poplar species, ENVI QUAC and Sen2Cor processor were applied to Level-1C product of Sentinel-2 data. Moreover, atmospherically corrected Sentinel-2A imagery was also utilized for the comparison of the reflectance values of poplar trees. Furthermore, five widely used spectral vegetation indices (i.e., NDVI-1, NDVI-2, GRNDVI, CVI, and CLgreen) were estimated for comparison of field measured reflectance spectral data and atmospherically corrected Sentinel-2 data. Linear regression (LR) model and normalized Euclidean distance were utilized to estimate the similarity level between field spectra obtained for poplar trees and the spectral signatures from atmospherically corrected Sentinel-2A products, ENVI QUAC and Sen2Cor processor. The LR results showed that highest R2 values were estimated as 0.996 and 0.997 for Sen2Cor processor and Sentinel-2A image, respectively. Moreover, calculated normalized Euclidean distance results verified the findings that atmospherically corrected imagery better represents the spectral signature of the poplar trees. The results of this study revealed that atmospherically corrected Sentinel-2 image exhibits great potential for integration in spectral resampling of field spectra measurements of poplar species.

1. INTRODUCTION

There are dozens of species, subspecies, and numerous hybrids and clones of the poplar tree genus all over the world (Park et al., 2004; Cseke et al., 2007). Poplar species are one of the most widely distributed cultivated tree species in the world, which have remarkable ecological and economic significance (Myking et al., 2011; Hajek et al., 2014). Turkey has a wide variety of poplar species and the plantation site is about 145,000 hectares according to Populus and Rapidly Growing Forest Trees Research Institute (KAE) official reports. It is important for the national and international forestry sectors to determine the plantation, field border, and wind curtain areas made with registered poplar clones with scientific data.

Remote sensing technologies provide a cost-effective and time-efficient solution for the identification and analysis of poplar cultivated areas in comparison with classical terrestrial techniques. Therefore, the separation of poplar species and clones from other plant and tree species by processing satellite images, as well as the separation of species from each other is an important research topic in remote sensing areas (Tonbul et al., 2020). Existing satellite-based systems, such as Landsat, SPOT, or MODIS data have previously been utilized in cropland monitoring and mapping applications thanks to their worldwide coverages in the literature (Kavzoglu, 2009; Yan and Roy, 2015; Colkesen and Kavzoglu, 2017; Chen et al., 2019). The use of a new generation, freely-available Sentinel-2 multispectral sensor, which includes 13 spectral bands in the visible, near-infrared, and shortwave-infrared range at three different spatial resolutions (i.e., 10, 20, and 60 m) could be beneficial in the assessment of crop types (Colkesen and Kavzoglu, 2017; Tonbul et al., 2020).

The conversion of sensor radiance values into reliable surface reflectance data is a critical issue in the analysis of optical remote sensing data for distinguishing and processing the Earth's surface reflectivity. In particular, atmospheric correction is important in the pre-processing step of the image analysis to eliminate atmospheric impacts and derive physical surface properties (König et al., 2019). Thus, well-calibrated reflectance data provides a higher level of validity and confidence in achieving accurate surface characteristics and reasonable spectral differences for surface materials (Davaadorj, 2007).

The main goal of this study is to evaluate the effects of atmospheric correction methods on the spectral identification of poplar trees. For this purpose, field spectral measurements of *Populus deltoides* Bartr. species cultivated in the Akyazı district of Sakarya province, Turkey were used as the main data source. In this regard, two atmospheric correction methods, namely, ENVI Quick Atmospheric Correction (ENVI QUAC) and Sen2Cor processor were utilized, and spectral signatures were obtained from corrected images compared with field reflectance spectra through Linear regression (LR) model and Euclidean distance. Furthermore, five spectral vegetation indices were determined in comparison with field spectral data and atmospherically corrected Sentinel-2 data.

2. MATERIALS and METHODS

2.1 Study Area and Dataset

The study area is located in Akyazı district of Sakarya province, Turkey that mainly dominated by poplar species (Figure 1). The other dominant vegetation species in the reference site include corn and hazelnut. Akyazı district is located 170 km southeast of Istanbul with an altitude of approximately 50 m above mean sea level. The climate of the study site is characterized by high summer temperatures and evenly distributed precipitation across the year.

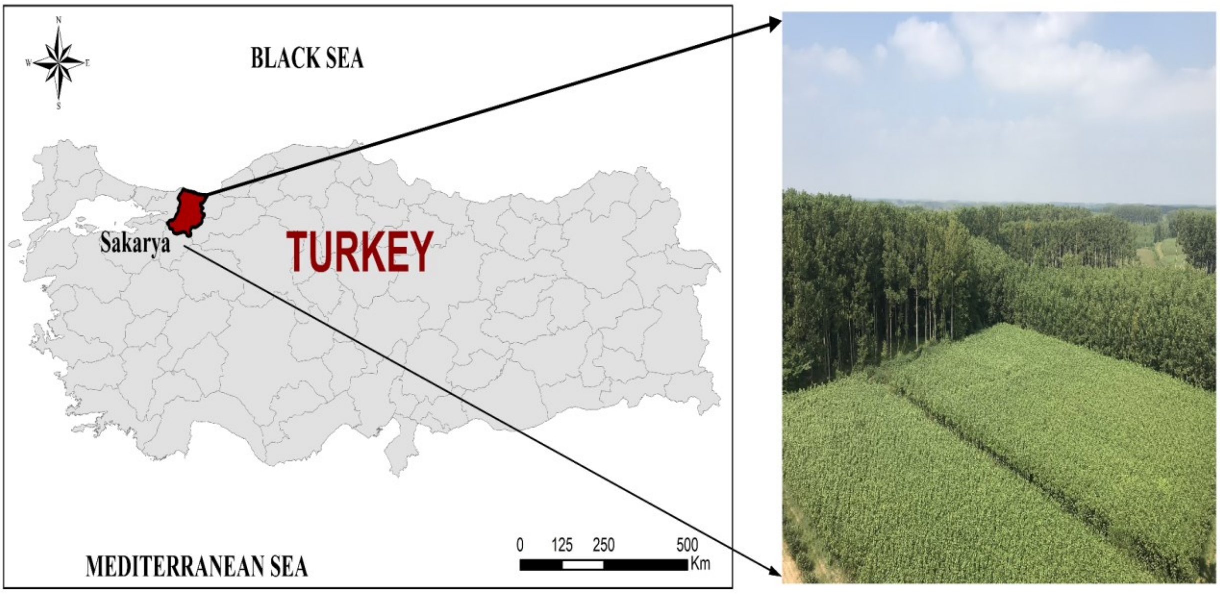

Figure 1. The location of the study site.

The cloud-free Sentinel-2 multispectral imagery, acquired on September 1, 2020, covering the bulk of the study site was utilized in this study. The image was freely retrieved from the ESA Copernicus Hub portal (https://scihub.copernicus.eu). The Sentinel-2 data comprises a multispectral instrument (MSI) with 13 spectral bands, which extends from the visible range to the shortwave infrared (SWIR) range. It also represents three spatial resolutions (10, 20, and 60 m) at a 5-day revisit time. Prior to the analysis, 60 m bands of Sentinel-2 were excluded, and original 10 m and 20 m spatial resolution bands of Sentinel-2 imagery were employed. The 20 m resolution bands and 10 m resolution bands were spatially resampled using the Gram-Schmidt pan-sharpening algorithm as followed by recent studies (Selva et al., 2015; Tonbul et al., 2020).

2.2 Atmospheric Correction Methods

In this study, Level- 1C product of Sentinel-2 and atmospherically corrected Sentinel-2 (Level-2A) imageries were utilized to evaluate the performances of ENVI QUAC and Sen2Cor processor, which are widely-used atmospheric correction. The Level-1C product, provides Top-Of-Atmosphere (TOA) reflectance together with geometric and radiometric corrections. The Level-2A image provides Bottom-Of-Atmosphere (BOA) reflectance with the same tiling, encoding, and filing structure as Level-1C. The ENVI QUAC method generates reflectance spectra within the range of about 10 percent of the ground truth (Bernstein et al., 2012). It is characterized by the observation that the average reflectance of various material spectra (except for highly structured materials such as vegetation, mud, and shallow water) is not scene-dependent (https://www.l3harrisgeospatial.com/docs/quac.html). The Sen2Cor is the Sentinel-2 Level-2A Prototype processor, which performs terrain, atmospheric, and cirrus correction for Level -1C input data. This processor was generated by Sentinel-2 Mission Performance Center (http://step.esa.int/main/third-party-plugins-2/sen2cor/), which is based on two key auxiliary datasets: the radiative transfer look-up tables (LUTs) and the DEM (Li et al., 2018).

2.3 Field Spectral Data Collection

The reflectance spectral data obtained from field observation were used in this study. The spectra of the poplar trees were collected using ASD FieldSpec3 spectroradiometer with a spectral range of 350 to 2500 nm. Several canopy spectral measurements were collected from the same locations and the obtained spectral reflection curves of poplar are shown in Figure 2.

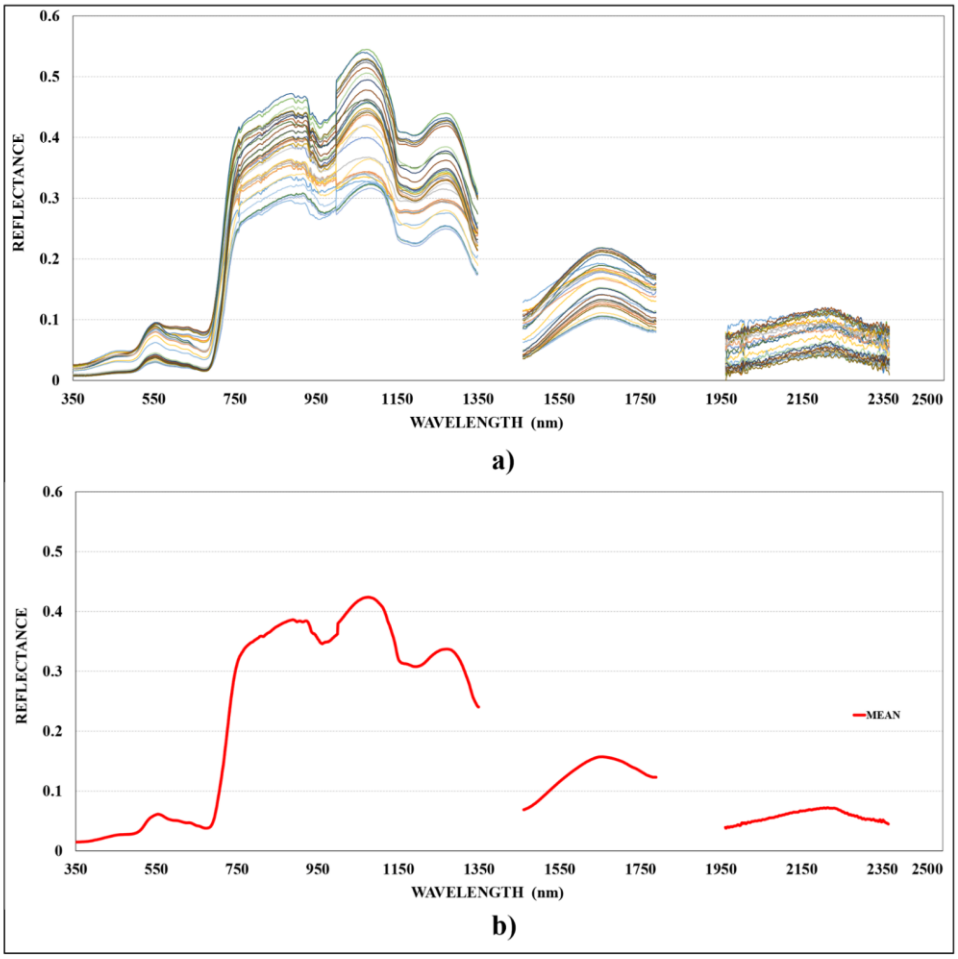

Figure 2: Reflectance spectra of poplar (*Populus deltoides* Bartr.) for (a) all spectral measurements and (b) mean spectral measurement which obtained using field spectrometer.

As shown in Figure 2, the spectral curves of poplar show a high reflectance in the red-edge and NIR range of the electromagnetic spectrum. On the other hand, the reflectance values decreased in the SWIR region and were strongly affected by the moisture content. It should be pointed out that the spectral regions (1350-1460 nm, 1790-1960 nm, and 2365-2500 nm) which are blocked by the atmospheric water absorption were excluded before processing. In all field measurements, the fiber optic pistol was held at a constant 1.5 m above the sampling points. The measurements were conducted between 11:00 a.m. and 3:00 p.m. on a cloud-free sunny day to maximize illumination and minimize cloud effects (Abdel-Rahman et al., 2013; Ramoelo et al., 2013). A white reference panel (Spectralon) was utilized to calibrate the sensor and transform the spectral radiance to reflectance (Ramoelo et al., 2013; 2015).

2.4 Spectral Indices

Spectral vegetation indices have been widely used as important ancillary data for forest and crop-related studies. In this study, five spectral indices namely, NDVI-1, NDVI-2, GRNDVI, CVI, and CLgreen were calculated from the atmospherically corrected images. The results were compared with field reflectance data to investigate the representative level of the atmospherically corrected image. The formulas of the indices and the references were given in Table 1.

Table 1: Summary of vegetation indices used in this study.

Indices	Abbreviation	Formula	Reference
Normalized Difference Vegetation Index-1	NDVI-1	$\frac{NIR1-Red}{NIR1+Red}$	Tucker, 1979
Normalized Difference Vegetation Index-2	NDVI-2	$\frac{NIR2-Red}{NIR2+Red}$	Tucker, 1979
Green-Red Normalized Difference Vegetation Index	GRNDVI	$\frac{NIR2-(Green+Red)}{NIR2+(Green+Red)}$	Wang et al., 2007
Chlorophyll Vegetation index	CVI	$NIR2*\frac{Red}{Green^2}$	Vincini et al., 2008
Chlorophyll Green	Clgreen	$(\frac{NIR}{Green})^{-1}$	Gitelson et al., 2006

3. RESULTS

In order to analyze the effects of the two atmospheric correction methods (ENVI QUAC and Sen2Cor processor) on the spectral identification of poplar trees, reflectance spectra measurements of ASD were resampled to Sentinel-2 spectral wavelength configuration using the built-in resampling functions in the ENVI software (v. 5.0). The ENVI resampling procedure fits a Gaussian model with a full-width-half-maximum (FWHM) equal to the band spacing for resampling the data (Adjorlolo et al., 2013; Chemura et al., 2017). Spectral response curves of Sentinel-2 data were customized for the central wavelengths of ten extracted spectral bands. Table 2 shows the comparison results of the atmospheric correction methods with ASD field spectra data for Sentinel-2 bands.

In order to evaluate the accuracy of spectral separability between ASD data and atmospheric correction methods, normalized Euclidean distance and Linear regression (LR) model were estimated. Firstly, the normalized Euclidean distance was used to measure the difference among ASD data and atmospheric correction methods. Its value of 0 indicates the absolute identity between two variables. The normalized Euclidean distances were estimated as 0.286, 0.277, 0.122, and 0.117 for Level-1C, ENVI QUAC, Sen2Cor processor, and Level-2A, respectively. The results showed that the highest similarity values (i.e., 0.117 and 0.122) were acquired for the Level-2A and Sen2Cor processor compared to the Level-1C product and ENVI QUAC method. On the other hand, the lowest similarity value (0.286) was estimated for the Level-1C product.

Table 2: Reflectance values of Sentinel-2 products and ASD field spectra data.

Sentinel-2 Bands	ASD Data	Level-1C	Level-2A	ENVI QUAC	Sen2Cor processor
Blue	286.03	943	263	402	246
Green	604.12	851	481	719	464
Red	389.06	617	326	470	315
Veg. red edge	914.07	813	609	585	588
Veg. red edge	2822.69	2249	2555	2676	2489
Veg. red edge	3471.76	2856	3109	3614	3029
NIR	3666.37	2847	3322	3530	3260
Narrow NIR	3807.52	3339	3569	3931	3498
SWIR	1471.44	1441	1243	877	1190
SWIR	711.46	602	511	388	480

Secondly, the LR model was used to compare and validate the performances of spectral separability within ASD data and atmospheric correction methods (Figure 3).The LR model calculated R^2 values of 0.964, 0.997, 0.972, and 0.996, respectively, for Level-1C, Level-2A, ENVI QUAC, and Sen2Cor processor. As shown in Figure 3, there is a strong linear relationship (i.e., high coefficients of determination) between the ASD data and atmospheric correction methods. Results also indicate that normalized Euclidean distance and LR model give parallel results for the identification of spectral identification between ASD data and atmospheric correction methods.

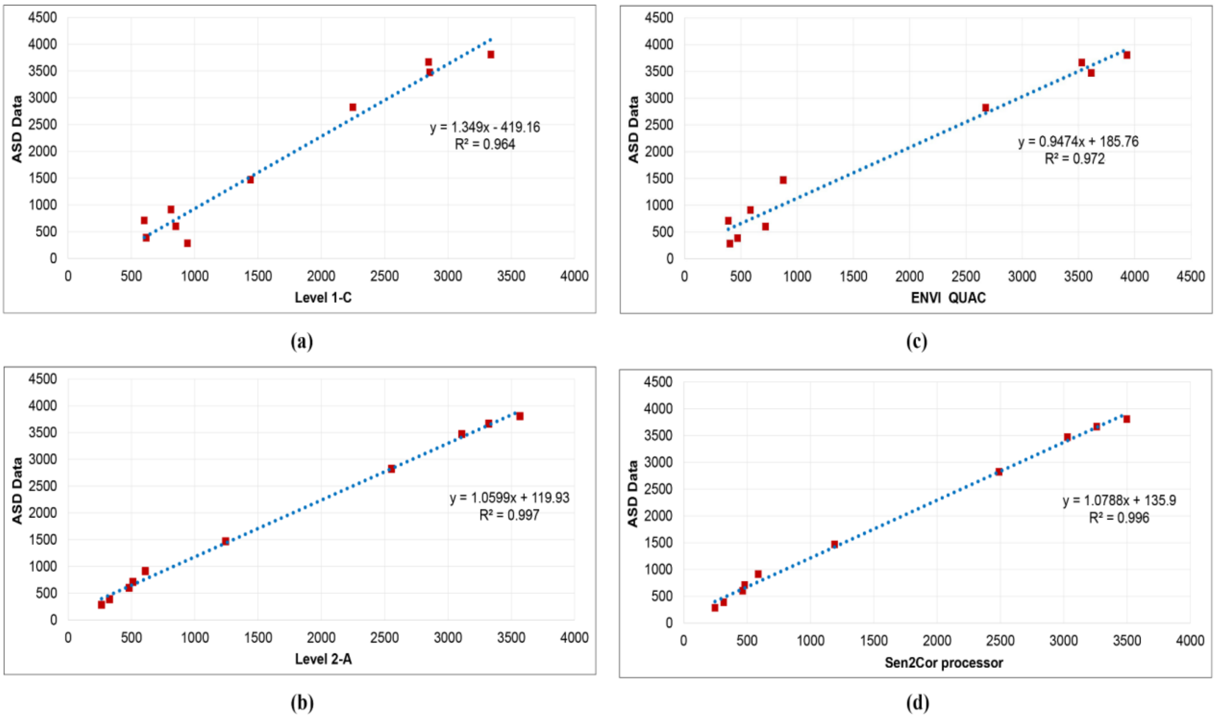

Figure 3: Linear regression plots with ASD data for (a) Level 1-C, (b) Level-2A, (c) ENVI QUAC, (d) Sen2Cor processor.

The five spectral indices (i.e., NDVI-1, NDVI-2, GRNDVI, CVI, and CLgreen) were computed for comparison of field measured reflectance spectral data with Sentinel-2 product and atmospheric correction methods (Table 3). In general, spectral indices exhibit good adherence for Level-2A and Sen2Cor processor in comparison with ASD data.

Table 3: Spectral comparison between ASD data and atmospheric correction methods for spectral indices.

Indices	ASD Data	Level-1C	Level-2A	ENVI QUAC	Sen2Cor processor
NDVI-1	0.808	0.644	0.821	0.765	0.824
NDVI-2	0.815	0.688	0.833	0.787	0.835
GRNDVI	0.586	0.389	0.631	0.536	0.636
CVI	4.059	2.845	5.029	3.572	5.118
Clgreen	0.174	0.298	0.155	0.199	0.153

In order to statistically compare the differences between ASD reflectance spectra measurements and atmospheric correction methods, Euclidean distance method was utilized to compute the accuracy of spectral separability. The results obtained from the spectral separability analysis are presented in Table 4. It should be pointed out that the lower distance indicates the highest similarity. As can be seen from the table, the better spectral similarities were estimated for the Sen2Cor processor and Level-2A for all indices except for CVI. For instance, the NDVI-1 Euclidean distance was estimated as 0.164 for Level-1C, whereas NDVI-1 Euclidean distances were computed as 0.016 for Sen2Cor processor and 0.013 for Level-2A.

Table 4: Euclidean distance results between ASD Data and atmospheric correction methods.

Indices	ASD & Level-1C	ASD & Level-2A	ASD & ENVI QUAC	ASD&Sen2Cor processor
NDVI-1	0.164	0.013	0.043	0.016
NDVI-2	0.127	0.018	0.028	0.022
GRNDVI	0.197	0.045	0.051	0.050
CVI	1.214	0.970	0.487	1.059
Clgreen	0.124	0.019	0.025	0.021

4. CONCLUSIONS

The utilization of remotely sensed data is a crucial research subject for distinguishing poplar species from other plants and tree species. In this manner, spectral libraries can be used as a reference to identify and map poplar species with remotely sensed data by investigating the spectral properties of tree species. The purpose of this study is to conduct statistical analysis for evaluating the performance of two atmospheric correction methods (ENVI QUAC and Sen2Cor processor) by calibrating ASD field spectral measurements with Sentinel-2 image. In order to evaluate the accuracy of spectral separability between ASD field spectra and Sentinel-2 atmospheric correction methods, Linear regression (LR) model and normalized Euclidean distance measurement were employed. The findings of this study showed that Sen2Cor processor and Level-2A product resembled the characteristics of spectrally resampled field spectra of poplar species (*Populus deltoides* Bartr.) more accurately, compared to ENVI QUAC and Level-1C product. The results of the linear regression indicated high prediction accuracies varied from 0.964 to 0.997 and normalized Euclidean distances ranging from 0.117 to 0.286. Furthermore, statistical analysis of spectral vegetation indices confirmed that Level-2A product of Sentinel-2 had the highest correlation between the resampled ASD field spectrum data. The analysis of this study also indicated that Sentinel-2 bands offer a great opportunity for combination with spectral resampling of field spectra collection of poplar species.

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