

An analysis of vegetation indices in relation to tree species diversity using by satellite data in the northern forests of Iran

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Abstract Vegetation indices have been introduced for analyzing and assessing the status of quantitative and qualitative characteristics of vegetation using satellite images. However, choosing the best indices to be used in forest biodiversity and vegetation is one of the important problems faced by the users. The purpose of this research is to evaluate six vegetation indices in the analysis of tree species diversity in the northern forests of Iran. The present research uses LISS III sensor data from IRS-P6 satellite. Geometric rectification of images was performed using ground control points, and Chavez model was used for atmospheric correction of the data. The six spectral vegetation indices included NDVI, IPVI, Ashburn Vegetation Index (AVI), TVI, TTVI, and RVI. Shannon–Wiener species diversity index was used to analyze diversity, and the value of the index was calculated in each sample plot. Then, the spectral values of each sample plot were extracted from different bands. The best subset regression was used to analyze the relationship between species diversity and the related bands. The results obtained from the regression showed that polynomial equations under scrutiny as independent variables can assess tree and shrub species diversity better than other bands and compounds used ($R^2=0.47$). The obtained results also indicated a higher capacity in the case of the AVI index for estimating tree species diversity in the under study area.

Keywords Vegetation indices · Shannon–Wiener · Northern forests of Iran · Satellite data · Tree species diversity

Introduction

Many spectral vegetation indices have been introduced for analyzing the status of quantitative and qualitative features of vegetation. Among the most well-known spectral vegetation indices are: the Ratio Vegetation Index (RVI), Simple Ratio Vegetation index, Normalized Difference Vegetation Index (NDVI), Modified Soil Adjustment Vegetation Index (MSAVI), Atmospheric Resistance Vegetation Index, as well as Transformed Soil-Adjusted Vegetation Index (TSAVI), Soil Adjusted Vegetation Index (SAVI), DVI, Infrared Percentage Vegetation Index (IPVI), RAI, Enhanced Vegetation Index (EVI), NDWI, Global Environmental Monitoring Index (GEMI), and the Chlorophyll Factor resulting from the Tasseled Cap. Most of studies carried out in order to assess the quantitative features used regression techniques. In these methods, mean square error and root mean square error (RMSE) measures are suggested (Achen 1982). Vegetation indices are mathematical transformations which are defined based on different sensor bands, and which are designed for analyzing and evaluating plants in multispectral satellite observations. The basis for the function of such indices is the difference between the red and the near-infrared bands, the reason behind it being red light absorption by pigments in the chlorophyll, which causes plants to reflect lesser in this band and more intensively in the near-infrared band. Rondeaux et al. (1996), by comparing six vegetation indices, concluded that the MSAVI index has the most sensitivity (98.9 %) toward vegetation. Following MSAVI, SAVI (97.59 %), 0SAVI (95.98 %), TSAVI (94.90 %), GEMI (91.94 %), and NDVI (85.36 %) rank next. Cabacinha and Castro (2009) surveyed the relationship between plant diversity in 22 pieces of forest and five vegetation indices (NDVI, SAVI, EVI, MVI5, and MVI7) of forest structure and of regional geometry using TM images obtained in the

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Cerrado ecoregion, Brazil. The results showed that EVI had the strongest correlation with plant diversity ($r=0.8274$), with Modified Vegetation Index (MVI), NDVI, and SAVI ranking next, whereas the MVI index had no significant correlation with plant diversity. In a research in California, Walker et al. (1992) confirmed a correlation between plant species richness and the NDVI vegetation index. Stoms Estes (1993) published an article titled *A Remote Sensing Research Agenda for Mapping and Monitoring Biodiversity*, which aimed at proposing a research method for using remote sensing data, and at expanding our knowledge of the spatial distribution of species richness and of its ecological determinants, as well as of predicting its response to overall changes, which is discussed in the present article in relation to biodiversity, determining its ecological parameters, and remote sensing capacity in its analysis. Using images from IRS 1C satellite, Bawa et al. (2002) determined

forest species diversity and richness via vegetation indices and analyzed correlation between NDVI vegetation index and the richness values resulted from the Shannon–Wiener index on the basis of ground data. The results showed that there is a positive correlation between NDVI and tree species diversity. In order to analyze woody plant species diversity of tropical dry forests in Southern California, USA, Gillespie (2005) obtained a modified coefficient of determination equal to 0.50 for the NDVI index using Enhanced Thematic Mapper (ETM)+data. In order to determine tree species richness of tropical forests in Panama, Gillespie et al. (2009) obtained a modified coefficient of determination equal to 0.58 using the NDVI index, ETM+ sensor. The purpose of this research is to analyze six vegetation indices and to select the best vegetation index in the assessment of forest tree species diversity.

Fig. 1 The under study area map

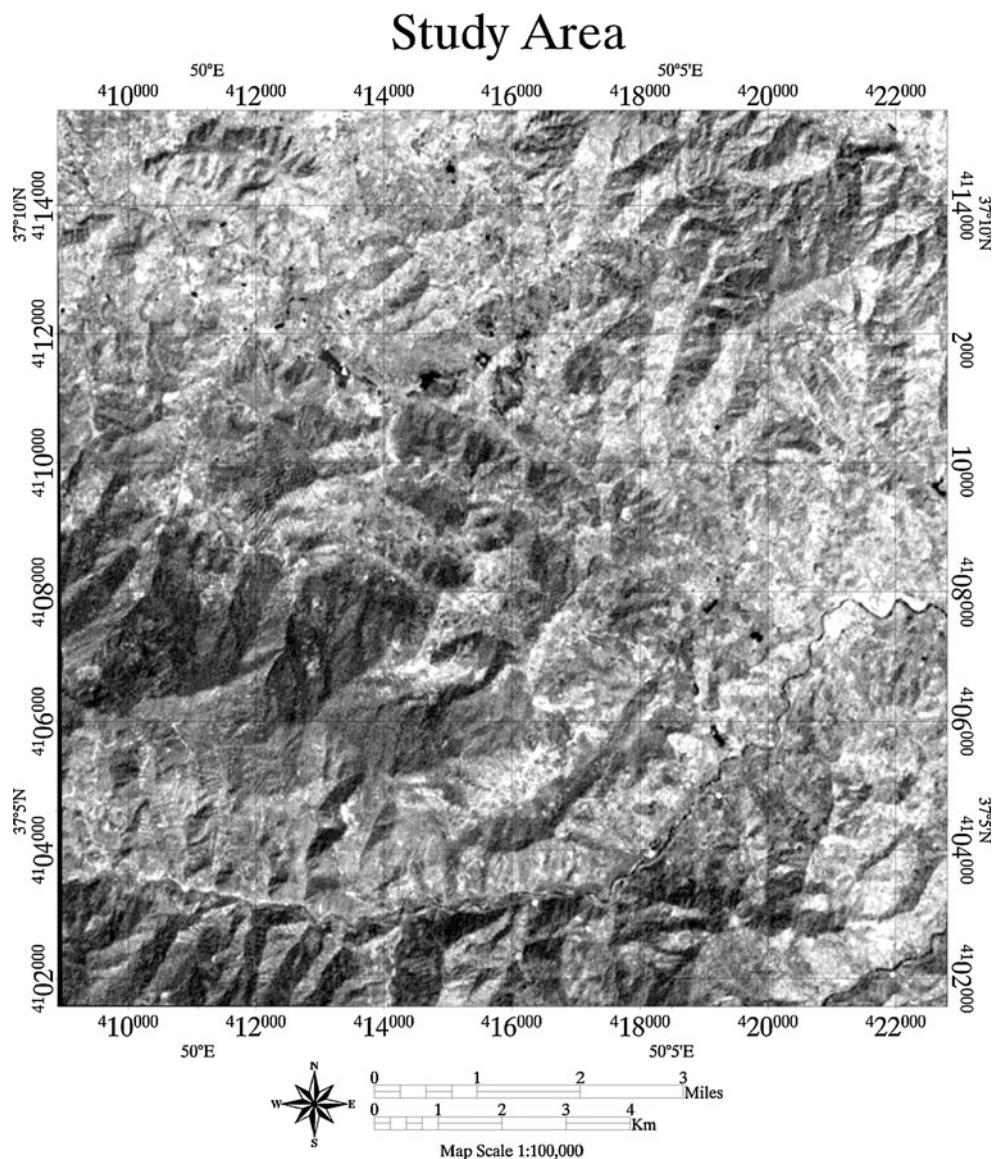


Table 1 Spectral vegetation indices investigated in the study

Row	Index equation type	Latin acronym	Index Latin name
1	$NDVI = \frac{(NIR-RED)}{(NIR+RED)}$	NDVI	Normalized Difference Vegetation Index
2	$NDVI = NIR/(NIR + Red)$	IPVI	Infrared Percentage Vegetation Index
3	$AVI = NIR - Red$	AVI	Ashburn Vegetation Index
4	$TVI : \sqrt{\frac{NIR-RED}{NIR-RED} + 0.5}$	TVI	Transformed Vegetation Index
5	$TTVI = \sqrt{ NDVI + 0.5 }$	TTVI	Thiam's Transformed Vegetation Index
6	$RVI = \frac{RED}{NIR}$	RVI	Ratio Vegetation Index

Material and methods

The area under study

The area under study is in the north of Iran and includes part of Lahijan forest in Guilan province. The area under investigation is located between 49° 59' 0" to 50° 7' 30" east longitude and 37° 5' 0" to 37° 12' 30" north latitude. It features a minimum elevation of 50 m and a maximum of 830 m above sea level, while the general direction runs northward (Fig. 1).

Satellite data

The present research uses LISS III sensor data captured in August 2008 from IRS-P6 satellite. The spatial resolution equals 5.23 m in multispectral bands and 6.5 m in the panchromatic band.

Providing ground data

Selective sampling method was used in this study, with 30 square-shaped sample plots of 2,500 m². The center of each sample plot was determined using GPS, and data like species type, height, and *breast* height diameter (more than 7.5 cm) were collected.

Pre-processing and processing satellite data

In order to ensure the degree of image accordance, forest roads were land surveyed using GPS to analyze geometric correctness of the data; then using the PCI Geomatica software, geometric correction was applied. An ETM+georeferenced image was set as the base for the georeferencing operation. Images were georeferenced using 45 ground control points and an RMSE of less than 0.5 pixels.

Atmospheric correction of the image was performed using the ENVI 4.7 software and Chavez method (1996). Using Eq. (1), the spectral values of each band (DN) were converted to radiation, and using Eq. (2), radiation values were converted to emission capacity for each band.

$$L_{\lambda} = (LMAX - LMIN/255)DN + LMIN \tag{1}$$

$$P_{\lambda} = \pi L\pi/ESUN_{\lambda}\cos \theta d_r \tag{2}$$

L_{λ} =spectral band of radiation, LMIN and LMAX =minimum and maximum spectral radiation in each band, DN= the numerical value of each band, π =3.14, d_r =the inverse square of the Earth–Sun distance, θ =the sun angle, and $ESUN_{\lambda}$ =the average solar radiation above the atmosphere

Fig. 2 Regression between Shannon–Wiener and TVI

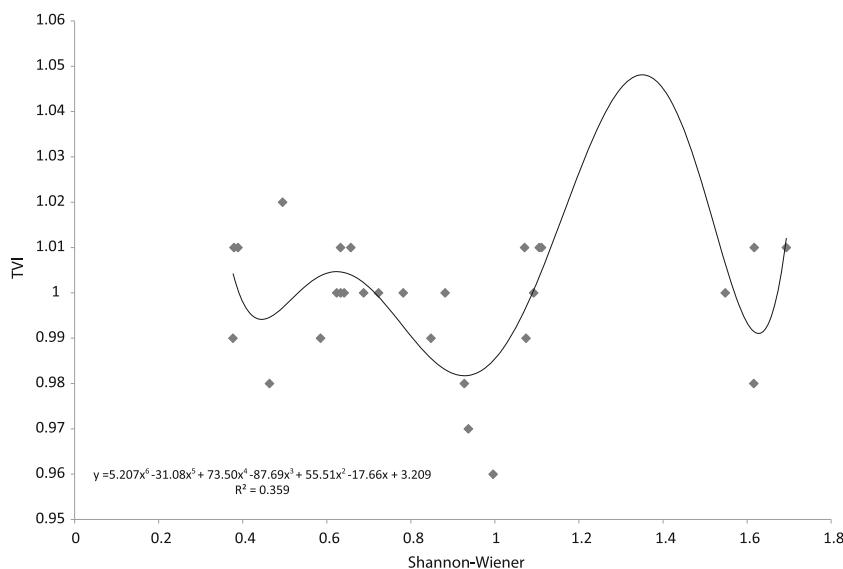
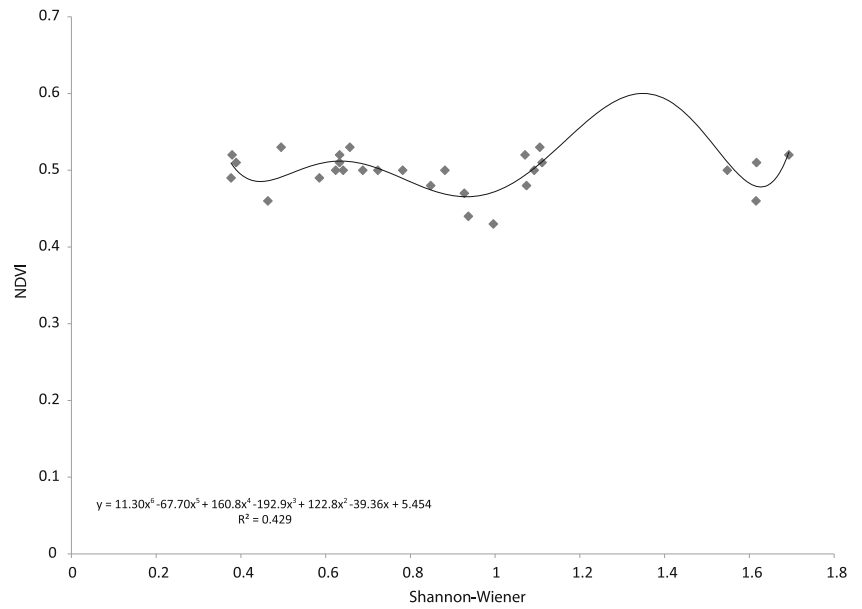


Fig. 3 Regression between Shannon–Wiener and NDVI



for each band (watts per meter squared per steradian per micrometer).

Extracting vegetation indices from satellite images

The following indices have been extracted using the PCI Geomatica software:

1. The Normalized Difference Vegetation Index:

NDVI is one of the most practical indices in the world and is vastly used in various cases. This index is ascribed to Rouse et al. (1973); however, its concept was first proposed. The spectral vegetation indices investigated in the study show in Table 1. The NDVI index reacts to any change in the amount of biomass

and chlorophyll, and to levels of canopy water stress. The NDVI index is essentially based on the different behaviors shown by the difference in wavelength of electromagnetic emissions from plants: The chlorophyll in plants absorbs energy from the red (long) wavelength, whereas the mesophile reflects infrared radiation. This index is obtained from Eq. (3).

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \tag{3}$$

The value of this index ranges from -1 to +1: the value represents vegetation if $0 < NDVI \leq 1$, the value represents

Fig. 4 Regression between Shannon–Wiener and AVI

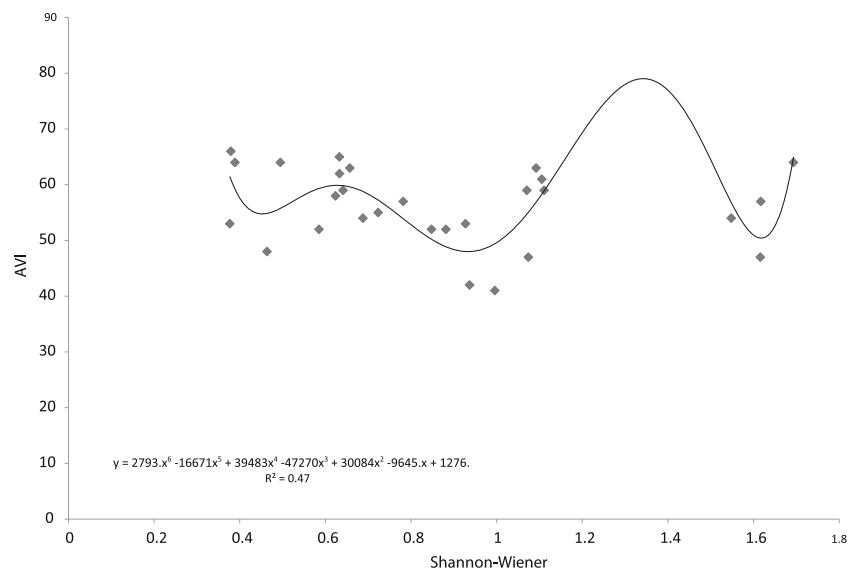
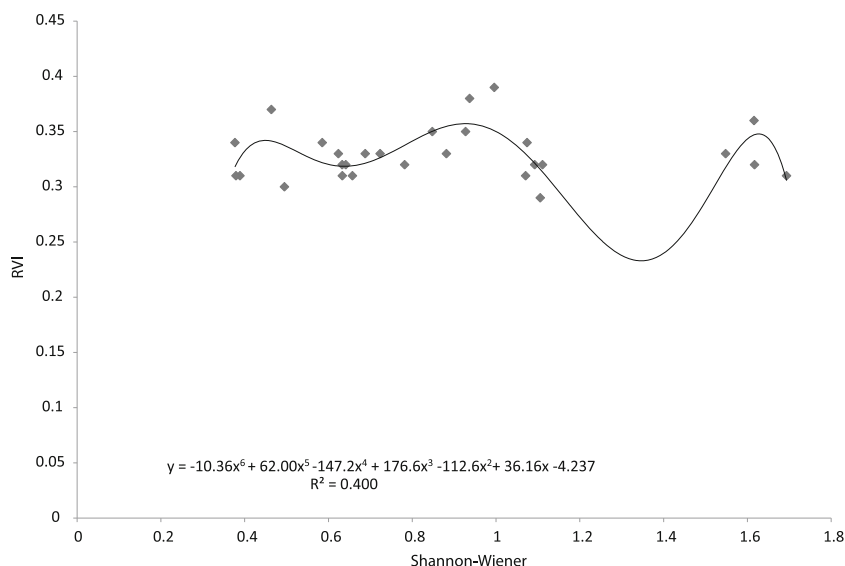


Fig. 5 Regression between Shannon–Wiener and RVI



soil if $0 \leq NDVI \leq 1$, and if $-1 \leq NDVI \leq 1$, it represents the existence of soil. Normal variation for vegetation ranges between 0.2 and 0.8 at most.

2. The IPVI index:

The IPVI index was first introduced by Crippen (1990). Considering the subtraction of the red in the numerator as irrelevant, Crippen attributed to the IPVI index the following features:

- Ratio-based index
- Isovegetation lines converge at origin
- Range 0 to +1
- Soil line has a slope of 1 and passes through origin

$$IPVI = (NDVI)/2 \quad \text{or} \quad IPVI = NIR/NIR + RED \quad (4)$$

3. The Ashburn Vegetation Index (AVI) Index:

This index was introduced by Ashburn in 1978 and is based on the difference between the red and the infrared bands. The equation is as follows:

$$AVI = NIR - red \quad (5)$$

4. The Transformed Vegetation Index (TVI):

Deering et al. (1975), to modify NDVI, proposed the following equation:

$$TVI = \sqrt{\frac{(NIR - RED)}{(NIR + RED)}} + 0.5 \quad (6)$$

Fig. 6 Regression between Shannon–Wiener and IPVI

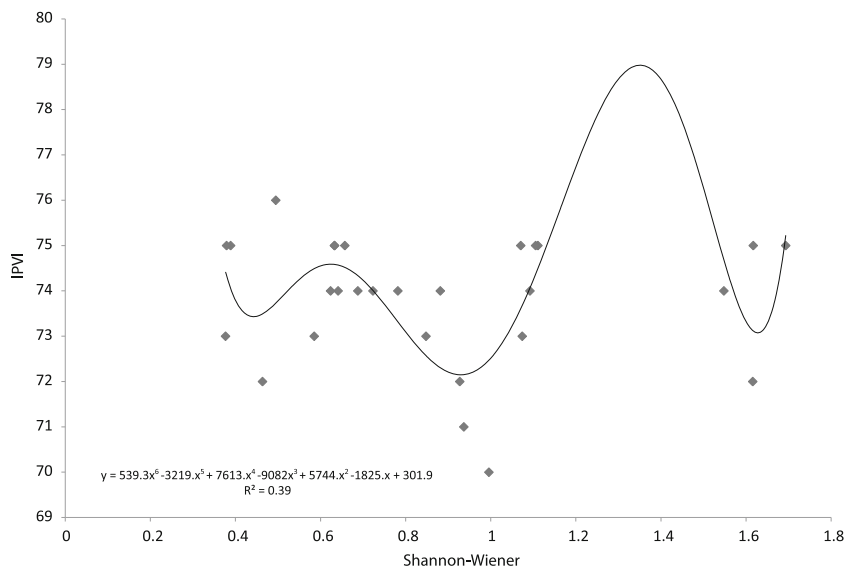
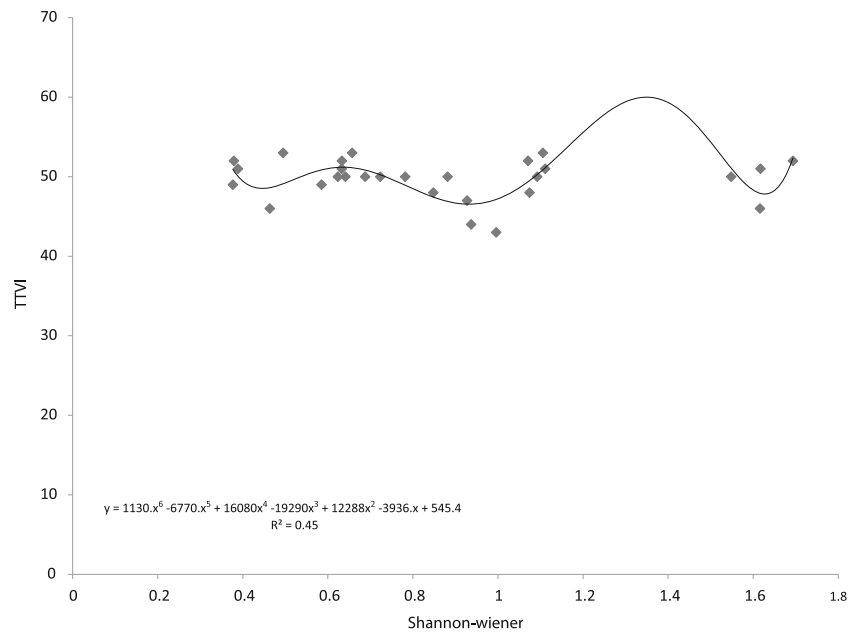


Fig. 7 Regression between Shannon–Wiener and TTVI



5. The Thiam’s Transformed Vegetation Index (TTVI):

$$TTVI = \sqrt{NDVI + 0.5} \quad (7)$$

6. The Ratio Vegetation Index (RVI)

The Ratio Vegetation Index is the simplest vegetation index which was first proposed by Jordan in 1969. Rouse et al. (1973) suggested using RVI for separating green vegetation from background soil using Landsat MSS sensor imagery.

$$RVI = \frac{RED}{NIR} \quad (8)$$

RED and NIR denote respectively the number of pixels in the red and near infrared bands. The value of this index ranges between zero and infinity. Normal variation for vegetation ranges between 0.2 and 0.8 at most.

Tree and shrub diversity analysis

In this stage, the extracted bands from satellite images were imported into the GIS software, and the average DN of corresponding pixels in each sample plot was extracted. Ground data were also investigated using the Ecological Methodology software, and the Shannon–Wiener index of richness was calculated for each sample plot.

Shannon–Wiener function

$$H' = \sum_{i=1}^3 P_i \log_2 P_i \quad (9)$$

H' = Shannon – Wiener Species Diversity Index

P_i = The number of the *i*th species in proportion to the total number of species

Statistical analyses

Regarding that most studies used regression techniques in order to assess quantitative and qualitative features (Gong et al. 2003; Haboudane et al. 2004) and usually used the coefficient of determination measure to evaluate the results of parameters’ assessment using regression models, the present study also analyzed the best subset relationship between the Shannon–Wiener diversity index and spectral values using regression models, resulting in the detection of the best model. The coefficient of determination ranges between 0 and 1 and is a standardized measure. Therefore, most researchers prefer the coefficient of determination to other parameters (Achen 1982).

Results

After the geometric correction of images, and then matching them with road and waterway land survey, the geometric accuracy of images was achieved. Using the best subset regression, the relationship between the Shannon–Wiener Index, as the dependent variable, and spectral values, as the dependent variables, was determined after the digitization of images from the location of sample plots. The results obtained from the regression showed that polynomial equations under scrutiny as independent variables can assess tree

and shrub species diversity better than other bands and compounds used ($R^2=0.47$). The obtained results indicative also of a higher capacity in the case of AVI and NDVI for the assessment of tree and shrub species diversity in the area are under investigation (Figs. 2, 3, 4, 5, 6, and 7).

Discussion

Each vegetation index, according to the formula, presents specific characteristics of vegetation. By analyzing the relationship of vegetation to studied properties, many ecologists and researchers in the study of plant communities have assessed the capacity of such indices for evaluating plant communities. It is not possible to use only one vegetation index in order to closely scrutinize, or even to determine the type of, vegetation, while using several indices side by side, as well as using complementary information about the area under study, can be much useful and effective. This research studied six indices which were most frequently used by researchers. Atmospheric disturbances are also among the other issues that affect the values of vegetation indices. Since wavelength of the red band is shorter than that of the infrared band, it features a more intense transmission than by infrared, hence the values of such vegetation indices as NDVI less than their real ones. Chavez method, consistent with the 1996 version, was used in order to remove unwanted effects of atmosphere on the images; then, each index was applied to them. Among the indices under study, the AVI index, with a coefficient of determination (R^2) equal to 0.47, showed the best performance and can best assess tree species diversity. With a coefficient of determination (R^2) equal to 0.39, the IPVI index showed the weakest performance. Following AVI, the NDVI and TTVI indices can best assess tree species diversity in the area under study. It is suggested that further research be done in different habitat conditions and more spectral vegetation indices be compared.

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