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Assessment of vegetation indices for estimating plant coverage and plant density in the Northern Sarawat Mountains, Saudi Arabia

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Abstract

Vegetation indices from remote sensing data have been widely used for more than three decades for the quantitative assessment of the biophysical characteristics of plants. Because the Sarawat Mountains are dry and semi-dry, many vegetation indices are less sensitive to plants but highly sensitive to the soil in this region. This study evaluated various vegetation indices (22) that estimate plant coverage and plant density and compared the indices to the method of hybrid classification in order to identify the best vegetation indices for estimating plant coverage in the region. The study found exaggerated values in the vegetation indices MNDVI, TSAVI2, WDRVI, PVI1, IPVI, NDVI, NRVI, and TNDVI in the dry period and in the vegetation indices TSAVI2, MNDVI, MGNDVI, TNDVI, PVI2, and WDRVI in the wet period. The indices gave poor estimates of plant coverage in the study area and were unable to separate the spectral reflectance of soil from that of plants. We used two SPOT satellite images from two dates, one in 2010 and the other in 2011. Image analysis was performed using various programs including ERDAS IMAGINE9.1, IDRISI TAIGA16 and ARCGIS10. This study indicated that vegetation indices are not very capable of separating categories of plant density and that vegetation indices are better than the hybrid classification method. To validate the results of different classes of plant coverage and plant density, an accuracy assessment technique was used. According to the assessment, the vegetation indices MSAVI1, MSAVI2, WDVI, GESAVI are best in the dry period, and GESAVI, MSAVI1, SAVI, PVI1, OSAVI, and WDVI are best in the wet period for the study area, while MNDVI and MGNDVI never performed well in the study area.

Keywords: Remote sensing, vegetation indices, plant coverage, plant density, hybrid classification, Satellite data.

INTRODUCTION

Spectral vegetation indices are effective methods to detect and quantify green plants from remote sensing data (Eastman, 2001). The data vary according to substrate and habitat; thus, the same index cannot work well in dense forests, pastures, dry land and wetlands. The challenges of applying the vegetation indices in those environments has led to the emergence and development of approximately 150 vegetation indices

(Verrelst et al., 2006). These indices have attempted to improve sensitivity and increase the effectiveness of assessing or monitoring vegetation while taking into account the external and internal conditions that affect the application of a given vegetation index in the study area. Natural conditions have received great attention from the researchers, such as soil in arid and semi-arid areas, the abundance of evergreens in areas of dense vegetation, and shade, as well as other components of the atmosphere. The problem of soil noise is most acute when vegetation coverage is low (Ramachandra, 2007). Remote sensing studies show that when the dispersed plant coverage is less than 30%–40%, satellite sensors are not capable of detecting vegetation, and the signal received shows mostly the soil background (Colwell, 1974; Huete et al., 1984; Elvidge and Lyon, 1985; Smith et al., 1990). Vegetation indices can thus be adversely influenced by variations in the spectral characteristics of rocks and soils. When rocks and soils influence vegetation index values, these data are misinterpreted as changes in green biomass. To some extent, this spectral influence is present in all vegetation indices (Elvidge and Lyon, 1985). The perpendicular vegetation index is considered the best available index for multispectral imagery of arid and semiarid regions where there is wide variation in the spectral characteristics of rock and soil. A suite of vegetation indices that attempt to address these problems have emerged (NDVI, TNDVI, PVI, SAVI, OSAVI, MSAVI, GESAVI, etc.), which often try to reduce the impact of brightness on the plant (Gilabert et al., 2002). However, the capacity of the modified vegetation indices to exclude the effect of the soil and vegetation varies widely, and some indices still need to be further adjusted to be more sensitive to the soil. As a result of the varying abilities of the vegetation indices to overcome the effects of external and internal conditions, there is an urgent need to evaluate and identify their efficiency in the assessment and monitoring of vegetation in many regions of the world. In environments with a heterogeneous climate, topography and vegetation, an ideal vegetation index would theoretically normalise all of these differences. The ideal vegetation index should be sensitive to vegetation coverage, insensitive to soil background (colour, brightness, moisture and roughness), and independent of the spatial and spectral resolutions of the sensors (Bannari and Asalhi, 2004). The vegetation indices generally attempt to enhance the spectral contribution of green vegetation by minimising spectra related to the soil background, solar irradiance, sun angle, senescent vegetation and atmosphere. These indices have been found to be well correlated with various vegetation parameters including green leaf area, percentage of biomass in green cover, productivity and photosynthetic activity (Lantenschlager and Perry 1981; Asrar et al., 1984; Sellars, 1985; Anderson and Hanson 1992; Leprieur et al., 1994; Huete et al., 1997; Lawrence and Ripple 1998; Baugh and Groeneveld, 2006; Yuhong et al., 2006; Amiri and Tabatabaie, 2009).

Vegetation indices of the northern Sarawat Mountains, whether arid or semi-arid, are susceptible to the problems of low sensitivity for vegetation and high sensitivity to the soil. This often leads to difficulty separating soil and vegetation because the brightness of soil often exceeds the vegetation reflection, making it difficult to determine the plant coverage, plant density, green biomass, and the plant chlorophyll content in the region. Additionally, vegetation indices in this region are affected by rocks, which reduce the ability to distinguish characteristics of the natural vegetation in the area. Therefore, the performance of a set of vegetation indices developed in other environments may be impeded in Sarawat. To test the effectiveness of various indices there, we used multispectral remote sensing data from 2010 to represent the dryness of soil and plants, and data from 2011 to represent wetter conditions. We evaluated the ability of the indices to minimise the impact of the brightness of soil and rock and to accurately distinguish evergreen plants without saturation. We attempted to identify appropriate vegetation indices to assess the properties of the natural vegetation and address the challenges posed by the conditions of the region, which reduce the accuracy of natural vegetation estimates in the northern Sarawat Mountains.

The objectives of this study are as follows: identify the effectiveness of vegetation indices in plant coverage estimates in northern Sarawat Mountains, compare the styles of vegetation indices and methods of hybrid classification, find suitable vegetation indices to estimate plant coverage in northern Sarawat Mountains, and determine the best and the worst vegetation indices to distinguish the natural vegetation from soil reflection.

The study area

The study area is in the northern part of the Sarawat Mountains in Saudi Arabia. The study area extends between latitudes 21° 00' 33" and 33° 23' 21" N and longitudes 40° 12' 17" and 40° 28' 3" E, and includes Shifa and Hada (Figure 1). Shifa is located to the southwest of the city of Taif, at an elevation ranging between 1800-2000 m above sea level, and up to a maximum height of 2600 m. It enjoys a mild climate during the summer months, which contributes to the abundance of vegetation (MAKSA 2007). Shifa is located on the shelf of Jal, or Alcosta from above, overlooking the Tohamah Valley of the Hejaz Mountains (Ghoneim, 2005). The Hada area is located to the west of the city of Taif. It is a mountainous region which reaches a height of more than 2100 m and also enjoys an abundance of vegetative cover (MAKSA 2007). To determine the boundary of the study area accurately, the natural

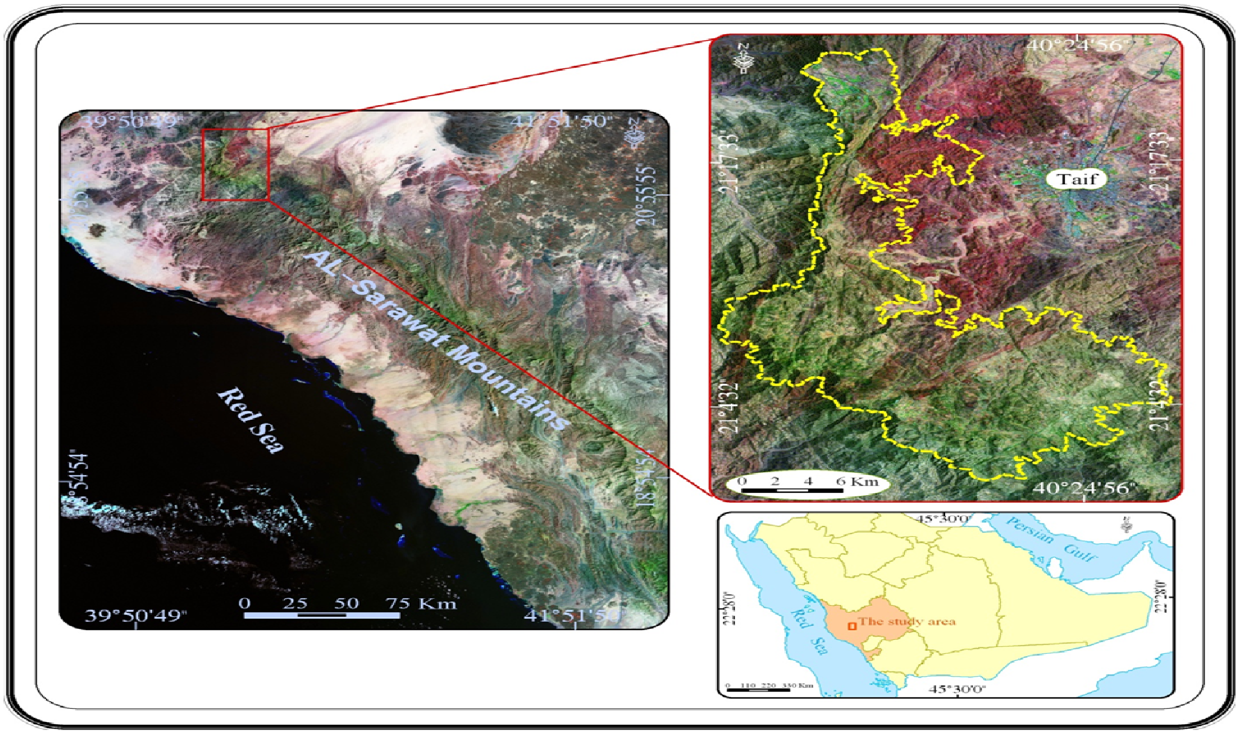

Figure 1. Location of the study area.

Table 1. Equations used to build the vegetation indices in the study area.

Number	Vegetation Index	Formula	Source and reference
1	Advanced vegetation index (AVI).	AVI= √ ([NIR × (255 - Red) × (NIR - Red)])	Azizia et al., 2008.
2	Enhanced vegetation index (EVI2).	EVI2= G × [(NIR - Red) / (NIR+ β × Red + L)] G= 2.5, β=2.4, L=1	Jiang et al., 2008.
3	Global environment monitoring index (GEMI).	GEMI= η(1-0.25η)–[(Red-0.125)/(1- Red)] $\eta = \frac{2\ (\mathrm{NIR}^2 - \mathrm{Red}^2) +\ 0.5\ \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red} + 0.5}$	Pinty and Verstraete, 1992.
4	Green normalized difference vegetation index (GNDVI).	GNDVI=NIR– Green/ NIR + Green	Gitelson et al., 1996.
5	Infrared Percentage Vegetation Index (IPVI).	IPVI=[(NIR-Red)/(NIR +Red)]+1/2	Crippen, 1990.
6	Modified green normalized difference vegetation index (MGNDVI).	MGNDVI=SWIR– Green/ SWIR +Green	Gitelson et al., 1996.
7	Modified normalized difference vegetation index (MNDVI).	MNDVI =(SWIR –Red)/(SWIR + Red)	Rouse et al., 1973.
8	Modified soil-adjusted vegetation index (MSAVI2)	MSAVI2= [2 × NIR +1 -√(2 × NIR +1)^2 -8 × (NIR - Red)] / 2	Qi, et al., 1994.
9	Normalized difference vegetation index (NDVI).	NDVI =NIR– Red/ NIR +Red	Rouse et al., 1973.
10	Normalized ratio vegetation index (NRVI).	NRVI=RVI – 1 /RVI + 1 RVI= NIR / Red	Baret and Guyot, 1991.
11	Optimized soil-adjusted vegetation index (OSAVI).	OSAVI=(NIR - Red)/(NIR + Red + 0.16)	Rondeaux et al., 1996.

Table 1. Continue

12	Soil- adjusted vegetation index (SAVI).	SAVI=[(NIR-Red)/(NIR +Red +L)](1+L) L= 0.5	Huete, 1988.
13	Transformed normalized difference vegetation index (TNDVI).	TNDVI =√([(NIR-Red)/(NIR +Red)+0.5])	Tucker, 1979.
14	Difference Vegetation Index (DVI).	DVI= a × NIR - Red a= slope	Richardson and Wiegand, 1977.
15	Generalized soil-adjusted vegetation index (GESAVI).	GESAVI=(NIR-b Red-a)/(Red +z) a= slope, b= intercept, z=0.35	Gilabert et al., 2002.
16	Modified soil-adjusted vegetation index (MSAVI1).	MSAVI1=[(NIR-Red)/(NIR+ Red +L)] (1+L) L =1-2y NDVI × WDVI	Qi et al., 1994.
17	Perpendicular vegetation index (PVI1).	PVI1 = (b NIR – Red + a) /√(1 + b^2) a= slope, b= intercept.	Perry and Lautenschlager, 1984.
18	Perpendicular vegetation index (PVI2).	PVI2 = (NIR - a) (Red + b) /√(1 + a^2) a= slope, b= intercept.	Walther and Shabaani, 1991.
19	Transformed soil-adjusted vegetation index (TSAVI1).	TSAVI1= a× [(NIR-a) × (Red- b)] / [(Red + a) (NIR -a × b)] a= slope, b= intercept.	Baret, et al., 1989.
20	Transformed soil-adjusted vegetation index (TSAVI2).	TSAVI2=a (NIR –a × Red - b) / (Red + a × NIR –a × b+0.08 (1+a^2)) a= slope, b= intercept.	Baret and Guyot, 1991.
21	Wide dynamic range vegetation index (WDRVI).	WDRVI =(a × NIR–Red)/(a ×NIR +Red) a= slope.	Gitelson, 2004.
22	Weighted difference vegetation index (WDVI).	WDVI=NIR - Y Red y= slope.	Clevers, 1989.

boundary of the 1900 m contour line was used to separate Shifa, Hada and the other regions. This line was used as a threshold value, which is the boundary between the cliffs and the flat regions. The study area covered an area of roughly 419.401 km^2, with variable topography, flora and solar intensity from one side to the other (Figure 1).

MATERIAL AND METHODS

To compare the effectiveness of vegetation indices in estimating plant coverage in the northern Sarawat Mountains, we used the following steps.

Selection of vegetation indices

Spectral vegetation indices were selected based on previous studies of effectiveness that included the conditions expected to be the most influential in the study area. These conditions were plant density, plant coverage, common species, the ability to avoid the effects of soil reflection, atmospheric constituents, and terrain (shadows). This study excluded spectral vegetation indices that rely on the blue band range because the blue band range was not included in the Satellite data used (SPOT-5). Additionally, the study excluded the corrected chlorophyll index because it cannot estimate the effect of vegetation indices on plant leaf area and biomass in the study area. The spectral vegetation indices included ones that depend on the soil line coefficients to remove the effect of the soil, others that depend on the coefficient of static, and still others that do not remove the effect of the soil (Table 1).

Criteria for the selection of suitable vegetation indices to estimate plant coverage in the study area

The criteria for the selection of suitable vegetation indices to estimate plant coverage in the study area were the following: 1) ability to discriminate plant coverage and plant density without exaggeration in their appreciation, i.e., the index represents plant density as it exists in the study area; 2) low sensitivity to the soil such that the index can exclude the effect of soil reflection from estimates of plant reflection; 3) ability to show the spatial and temporal variations in the structure of the plant and their density in the study area; and 4) highly accurate classification as determined by field observations or by high resolution spatial images (60 cm) for inaccessible places.

Data sources

To assess the effectiveness of the vegetation indices in estimating the properties of vegetation in the study area, we relied heavily on metadata and spatial data, which most importantly included books and scientific research on vegetation indices in the study area, in addition to government statistics obtained from the Ministry of Agriculture in KSA. Spatial data included remote sensing data acquired from the SPOT-5 Satellite. Two dates were selected to test the ability of the indices to separate the spectral reflectance of plants from that of soil and to determine plant coverage in the study area. The first was in the summer (06/6/2010), to represent the dry season for soil and plants, and the other was in the spring (4/25/2011) to represent the wet season. Another image was acquired on 05/01/2011 from the GeoEye-1 satellite, which is characterised by spatial resolution up to approximately 60 cm, and it was used to check the classification techniques. These data are not available for the entire study area, so only small parts of Shifa and Hada were checked with the high resolution image. All of the satellite data and the 30 m digital elevation model data (DEM) was taken from the King Abdul Aziz City for Science and Technology in Saudi Arabia.

Field work is important to evaluate the effectiveness of spectral vegetation indices, both to validate the results and to make sure that the index can distinguish among the plants, soil and rocks in the study area. The field work was conducted in several phases. The reconnaissance survey lasted for two consecutive days, 6/18-19/2010. After data processing, the sampling sites were selected using the hard-copy of the images and classified maps. A global positioning device produced by GARMIN Etrex Summit was used to locate the sampling sites easily in the field. Samples were taken by using the judgment sample method. Sixty samples from across the study area were collected from the field. Fifteen samples were collected from the Hada area because of its small extent and the number of buildings. Similarly, 11 samples were collected from Shifa because of the small extent of tourist facilities nearby. Twenty samples were collected from the Valley of Khammas, where dense vegetation covers the sides of the valley, which is more than 10 km long. At the top of Dakka Mountain the vegetation is very dense, and there are more agricultural lands in the middle of the Gawa Valley. Valley of Ghazal is situated on the eastern side of Valley of Khammas. Fourteen samples were collected there because the valley is narrow and inaccessible, and the plants are spread over cliffs and steep mountain slopes. To further verify the ability of the indices to estimate the properties of the natural vegetation in the study area, 356 sites were evaluated using images from GeoEye-1, which covered part of Hada and Shifa. Additionally, Google Earth was used to validate the development of vegetation in the study area, especially in upland areas and on the steep slopes that comprise a wide region in the central and eastern parts of the study area. In total 416 sites, dispersed across the area, were checked during this study. The sampling sites included in the areas of vegetation were very dense, dense, medium, poor, and very poor as well as barren areas that were completely free of vegetation. The second trip, initiated on 1/1/2012, lasted for 5 days.

Data processing and analysis

In this study, atmospheric corrections were made to remove the effect of aerosols and obtain more accurate data from the satellite image. These particles, including smoke, dust, and water vapour, strongly affect all spectral vegetation indices. They affect the contrast between the infrared (IR) and near infrared (NIR) values and lead to lower index values, whether they are based on the difference between the two ranges of NIR-Red or the ratio between the two.

The two Spot-5 images were radiometrically calibrated and converted to reflectance values. The reflectance values for each date were atmospherically corrected using the 6S model (Vermote et al. 1997). We assumed a continental type aerosol and used a locally measured visibility value for each date (Table 2). The atmospheric corrected data were evaluated against the standard spectral reflectance curves of sand, mud, vegetation and water (Lillesand et al. 2008).

The image data were geometrically rectified to the Universal Transverse Mercator (UTM) map projection system in zone 38 north, using 86 ground control points that were evenly distributed within the Spot-5 satellite image from 2011. A 1:50000 topographic map was used in the rectification process. The image rectification accuracy was <0.5 pixel. The 2010 image was registered to the rectified image from 2011. The image registration accuracy was approximately 0.455 pixels.

We extracted the study area from the images using the Subset function in ERDAS IMAGINE 9.1. To extract the study area, a binary image or image mask (with a value of “1” for study area and “0” for other areas) were formed for each date. Binary images were used as input layers in the unsupervised classification ISODATA algorithm to obtain complete separation between the study area and the other areas.

The soil lines were calculated after the zone free of vegetation cover was extracted from the SPOT-5 images

Table 2. The input data required for the 6S model (Green band of Spot satellite images).

DATA		6/06/2010	25/04/2011
Geometric conditions	solar zenith angle	18.18 deg	22.87 deg
	view zenith angle	0.0 deg	0.00 deg
	scattering angle	161.82 deg	175.13 deg
Atmospheric conditions		Midlatitude summer (uh2o=2.93g/cm2,uo3=.319cm-atm)	Midlatitude winter (uh2o=.853g/cm2,uo3=.395cm-atm)
Aerosols Model Type		Continental aerosols model	Continental aerosols model
Visibility		10 km *	10 km
Target at Sea Level		-0.0	-0.0
Sensor aboard a Satellite		-1000	-1000
User's band		0	0
XS1		0.500-0.590	0.500-0.590
Ground type, Homogeneous surface		0	0
Directional effects		0	0
vegetation		1	1
Atmospheric correction of RAPP= 0.126		-0.128	-0.145

*- Visibility values were taken for study area from this web site (http://www.wunderground.com/history/).

Table 3. Soil line coefficients for Spot satellite images.

Type of soil	Description	Soil line coefficients	6/06/2010	25/04/2011
Dry sandy soil	Red as an independent variable	*intercept-a*	0,032385	0,019187
		slope-b	1,090057	1,118554
		R	0,957	0,973
		R^2	0,916	0,948
	Infrared as an independent variable	*intercept-a*	-0,006217	-0,000609
		slope-b	0,840554	0,847717
		R	0,957	0,973
		R^2	0,916	0,948

for 2010 and 2011. The soil line equation was applied to the region specified by using the program IDRISI TAIGA16. The equation used in the soil line was as follows:

$NIR_{soil}= a\ R_{soil} + b$

The red band (R) serves as an independent variable and the near infrared band (NIR) as a dependent variable in the equation, as in all equations of spectral vegetation indices except the PVI1 index, which uses the NIR as the independent variable and red as the dependent. Table 3 shows the coefficients of soil line values that were calculated from the 2010 and 2011 images. These calculations show that the differences between the images produced a slope value greater than 1%. Additionally, the calculations have revealed a high coefficient of regression (R^2) between the Red and NIR bands in 2010, which suggests homogeneous soil in the selected area.

Vegetation indices were constructed in the spatial model of ERDAS IMAGINE version 9.1. Twenty-two vegetation indices were constructed for the 2010 and 2011 images, each with a change in the soil line coefficients. In this study, the threshold value has been chosen based on the standard deviation method, which is fully capable of detecting low-density plant cells and vegetation when incorporated into vegetation indices. The method is based on taking the minimum values of representative areas free of vegetation (bare soil) and using the average value minus a standard deviation to represent very poor and poor plant coverage. The mean value plus a standard deviation represents areas with medium plant density, and the maximum value is used to delineate dense and very dense vegetation and agricultural areas. This method has been used in ARCGIS 9.2 and is a classification method in which the study area is classified into two categories to calculate plant coverage and then into six categories to calculate plant density in order to test the effectiveness of the

Table 4. Evaluation of the effectiveness of Vegetarian Indices for assessing plant coverage in the northern Sarawat Mountains.

Vegetation indices	Dry period 2010		Wet period 2011	
	Area of vegetation (%)	Area of bare soil (%)	Area of vegetation (%)	Area of bare soil (%)
AVI	79.9	20.1	86.02	13.98
DVI	84.5	15.5	85.61	14.39
EVI2	84.46	15.54	85.08	14.92
GEMI	83.99	16.01	86.68	13.32
GESAVI	84.33	15.67	87.34	12.5
GNDVI	80.98	19.02	85.86	14.14
IPVI	85.27	14.73	87.45	12.55
MGNDVI	84.85	15.15	88.82	11.18
MNDVI	85.91	14.09	90.12	9.88
MSAVI1	84.42	15.58	86.78	13.22
MSAVI2	84.49	15.51	86.66	13.34
NDVI	85.27	14.73	87.16	12.84
NRVI	85.27	14.73	87.16	12.84
OSAVI	83.96	16.04	86.89	13.11
PVI1	85.31	14.69	86.83	13.17
PVI2	84.48	15.52	86.12	13.88
SAVI	84.16	15.84	86.61	13.39
TNDVI	85.27	14.73	87.69	12.31
TSAVI1	85.67	14.33	88.31	11.69
TSAVI2	84.86	15.14	90.16	9.84
WDRVI	85.52	14.48	87.4	12.6
WDVI	84.12	15.88	86.48	13.52
Overall	84.31	15.69	86.91	13.09

vegetation indices.

We also employed a hybrid classification method for plant coverage in ERDAS IMAGINE 9.1. To verify the appropriate vegetation indices to assess the plant coverage and plant density, we used an accuracy assessment that calculates the accuracy of the vegetation index classification through the kappa coefficient and accuracy percentage. Of the visited points, 416 were used in the validation of the classification.

RESULTS AND DISCUSSION

Twenty-two spectral vegetation indices were used in the study area, and all indices produced different values for the area of plant coverage. As shown in Table 4 and Figure 2, the proportion of plant coverage for all vegetation indices ranged from 79.90% to 85.91% in the dry period, and the percentage increased to 85.08% to 90.16% in the wet period. The difference between the high and low index values for plant coverage was not large. In addition, the highest values for plant coverage presented in Table 4 may not result from the abundance of vegetation as much as from the exaggerated values for some vegetation indices and their inability to separate the reflection of the soil from that of plants.

Taken together, the average value for plant coverage was 84.31% in the dry period and 86.91% in the wet period, indicating few bare soil areas, and a medium density of plants in the study area. These values may be due to the dense plant growth in hard to reach areas and above 1900 m, which are not as affected by human intervention as the lower lands. The MNDVI index reports the highest area of vegetation in both the dry and wet seasons because this index depends on short wave infrared (SWIR). This range cannot separate the soil from plant reflectance very accurately, and the values likely

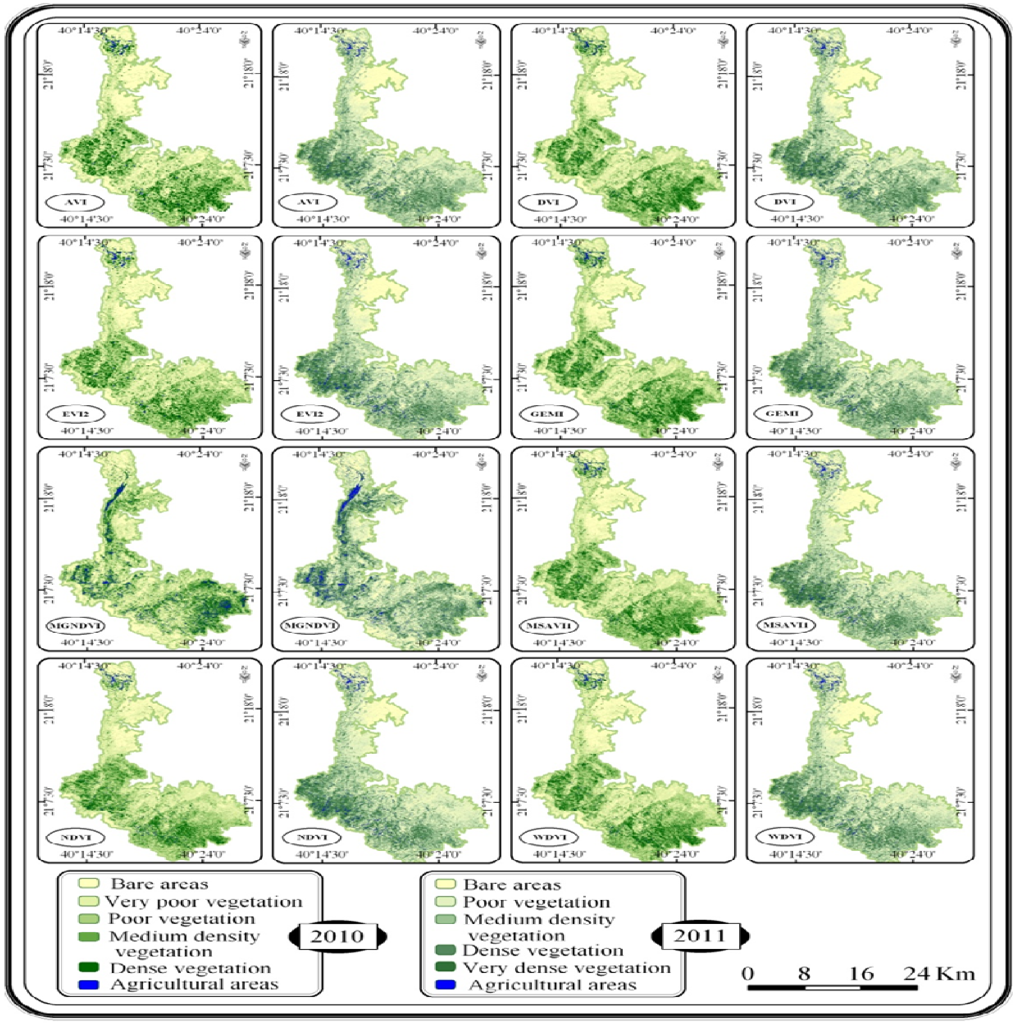

Figure 2. Samples to assess the effectiveness of vegetation indices to estimate density in the northern Sarawat Mountains.

reflect sensitivity to soil and the inability to distinguish it from bare soil with plant cover. The advanced vegetation index (AVI) showed less vegetation (79.90% cover) than the other indices in the dry period. The primary reason may be AVI's lack of sensitivity to soil reflection and its inability to distinguish between plant types. The EVI2 index calculated the least vegetated area (85.08%) for the wet period. Our research showed the highest values for vegetated area in IPVI, MGNDVI, NDVI, NRVI, TNDVI, PVI1, TSAVI2 and WDRVI in the dry and wet periods. These values ranged between 84.85% and 85.52% in the dry period and between 87.40% and 88.82% in the wet period (Table 4). The rest of the indices, EVI2, GEMI, MSAVI2, OSAVI, SAVI, DVI, GESAVI, MSAVI1, and PVI2, are characterised by their efficiency in detecting the area of vegetation in the dry period. These indices produced values for vegetation area that were nearly equal to the overall average for all vegetation indices. Therefore, these vegetation indices are good indicators of the plant coverage in the northern Sarawat Mountains. Other vegetation indices (EVI2, DVI, PVI2, GESAVI and MSAVI1) had the ability to discriminate the areas of vegetation in the study area in the wet period. The GNDVI was not able to detect vegetation well during either the dry or wet period. The WDVI and PVI2 were characterised by a decline in their ability to detect the area of vegetation during the wet period.

The ability of the vegetation indices to estimate plant density in the northern Sarawat Mountains (considering bare areas, very poor vegetation and dense vegetation) is shown in Table 5. The percentage of bare areas ranged between 14.09% to 20.10% in the dry period but the range declined to 9.84% to 14.92% in the wet period. This difference between the two periods indicates that the vegetation indices varied in their ability to separate soil

Table 5. The effectiveness of spectral vegetation indices to estimate plant density in the northern Sarawat Mountains.

Vegetation indices	Dry period 2010						Wet period 2011					
	Bare areas (%)	**Very poor vegetation** (%)	**Poor vegetation** (%)	**Medium density vegetation (%)**	**Dense vegetation (%)**	**Agricultural areas (%)**	**Bare areas (%)**	**Poor vegetation** (%)	**Medium density vegetation** (%)	**Dense vegetation (%)**	**Very dense vegetation (%)**	**Agricultural areas (%)**
AVI	20.1	27.45	25.48	14.31	12.24	0.42	13.98	33.61	28.72	10.96	11.76	0.97
DVI	15.5	30.1	26.37	15.12	12.54	0.37	14.39	31.55	29.88	11.72	11.49	0.97
EVI2	15.54	30.37	27.98	16.43	9.22	0.46	14.92	34.18	27.48	9.77	12	1.65
GEMI	16.01	27.48	25.42	15.11	15.48	0.5	13.32	30.05	31.41	13.45	10.82	0.95
GESAVI	15.67	30.1	29.01	12.61	12.07	0.54	12.66	38.25	26.48	9.77	11.94	0.9
GNDVI	19.02	22.77	24.84	18.39	14.52	0.46	14.14	27.54	30.9	13.7	12.76	0.96
IPVI	14.73	33.9	27.18	10.88	12.51	0.8	12.55	39.54	24.11	9.37	13.03	1.4
MGNDVI	15.15	28.63	25.81	13.7	13.59	3.12	11.18	32.24	27.83	13.54	12.34	2.87
MNDVI	14.09	31.22	27.18	12.16	12.83	2.52	9.88	37.26	26.73	10.64	13.12	2.37
MSAVI1	15.58	30.18	28.13	12.86	12.74	0.51	13.22	36.98	26.03	9.84	12.79	1.14
MSAVI2	15.51	30.26	28.12	13.01	12.62	0.48	13.34	36.05	27.23	10.24	12.13	1.01
NDVI	14.73	33.9	27.18	10.88	12.51	0.8	12.55	39.54	24.11	9.37	13.03	1.4
NRVI	14.73	33.9	27.18	10.88	12.51	0.8	12.55	39.54	24.11	9.37	13.03	1.4
OSAVI	16.04	31.24	27.95	11.27	12.57	0.93	13.11	37.92	25.06	9.82	12.87	1.22
PVI1	14.69	34.5	26.69	11.11	12.4	0.61	13.17	37.32	26.01	10.11	12.39	1
PVI2	15.52	30.7	26.8	14.32	12.25	0.41	13.88	33.72	28.65	11.09	11.69	0.97
SAVI	15.84	30.41	28.04	12.48	12.59	0.64	13.39	36.4	26.49	10.17	12.45	1.1
TNDVI	14.73	33.7	26.66	11.59	12.6	0.72	12.31	38.83	24.36	10.09	13.15	1.26
TSAVI1	14.33	29.34	29.72	14.53	11.58	0.5	11.69	39.55	27.45	9.08	11.18	1.05
TSAVI2	15.14	29.41	29.21	14.41	11.44	0.39	9.84	40.66	30.43	8.79	9.57	0.71
WDRVI	14.48	34.65	27.07	10.84	12.21	0.75	12.6	39.88	24.06	9.23	12.92	1.31
WDVI	15.88	31.09	27.33	12.56	12.55	0.59	13.52	36.17	26.86	10.32	12.14	0.99
Overall	15.69	30.77	27.32	13.18	12.46	0.58	13.09	36.33	26.99	10.31	12.16	1.12

from vegetation. The AVI index had the highest value for bare areas in the dry period, while the EVI2 index had the highest value for bare areas in the wet period. The MNDVI index was better able to separate soil reflection from vegetation as indicated by its higher value for bare areas in

Table 6. Comparison between vegetation indices and the hybrid classification method to estimate the plant coverage and plant density in the northern Sarawat Mountains.

Period	Method	Vegetation coverage (%)	Bare areas (%)	Very poor vegetation (%)	Poor vegetation (%)	Medium density vegetation (%)	Dense vegetation (%)	Very dense vegetation (%)	Agricultural areas (%)
Dry 2010	Vegetation indices	84.31	15.69	30.77	27.32	13.18	12.46	-	0.58
	Hybrid classification	80.87	19.13	27.41	25.59	13.41	13.94	-	0.52
Wet 2011	Vegetation indices	86.91	13.09	-	36.33	26.99	10.31	12.16	1.12
	Hybrid classification	85.37	14.63	-	38.91	25.31	8.56	11.23	1.36

the dry than the wet period. The GNDVI, GEMI, SAVI and OSAVI indices were unable to distinguish bare areas in the dry season, and GNDVI, AVI, PVI2 and WDVI were unable to do so in the wet season, even though these indices contain a constant coefficient to remove the effect of solar brightness. In contrast, EVI2, MSAVI2, SAVI, DVI, GESAVI, MSAVI1, PVI2 and WDVI were able to distinguish bare areas in the dry season and MSAVI1, MSAVI2 and SAVI were able to in the wet season (Table 5). The WDRVI index had the greatest cover of very poor vegetation in the dry period, while the TSAVI2 index had the greatest cover of very poor vegetation in the wet period. The GNDVI index had a low value for plant cover that was very poor vegetation in both the wet and dry periods. The WDRVI index had the lowest value for cover of medium density vegetation (10.84%) in the dry period and NDVI had the lowest value (24.11%) in the wet period. Additionally, GNDVI and GEMI had high values for plant cover of medium density vegetation in the dry and wet periods, 18.9% and 31.41%, respectively (Table 5). This difference in percentage of plant cover is likely due to the lack of sensitivity of some indices for plants that are less green. This study showed great disparity among the indices in the estimates of dense vegetation. The percentage of plant cover ranged from 9.22% to 15.48% in the dry period and between 8.79% to 13.70% in the wet period. The GEMI and MGNDVI indices had the highest values of plant coverage for dense vegetation in the dry and wet period, respectively, whereas the EVI2 and TSAVI1 indices had the lowest values of plant coverage for dense vegetation in the dry and wet periods, respectively (Table 5).

Effective vegetation indices can distinguish between dense and very dense vegetation in the wet period. The percentage of dense plant cover ranged from 9.57% (TSAVI2) to 13.12% (MNDVI) in the wet period. The percentage of very dense plant cover ranged between 0.37% to 3.12% in the dry period and between 0.71% to 2.87% in the wet period. The highest values for agricultural areas were obtained by the MGNDVI in both the dry and wet periods. The TSAVI2 had the lowest plant coverage value for agricultural areas in the dry period, whereas the GESAVI showed the lowest value for agricultural areas in the wet period.

As shown in Table 6 and Figure 3, we see that the vegetation indices are better than the hybrid classification techniques for detecting the percentage of plant cover in the dry period. The hybrid values for percentage of vegetative cover are approximately 3.33% less than those for the same class derived from the vegetation indices. The percentage of plant cover in the wet period is 85.37%, which is less than the values from the vegetation indices by approximately 1.54%. Additionally, the vegetation indices are better able to separate bare areas than to estimate vegetation coverage in the dry period, as shown in Table 6, and they identify vegetation coverage with higher efficiency than the hybrid classification method. The increased plant density during the wet period increased the ability of the indices to clearly discriminate soil reflection from plant coverage. Therefore, the percentage of bare areas increased to 14.63%. The hybrid classification had a poor ability to distinguish the very poor vegetation class in the dry period. Because of the similarity between the spectral signature of soil and the class of very poor vegetation in the wet period, the vegetation indices and hybrid classification were not able to detect the very poor vegetation class under improved weather conditions and increased humidity in the study area. The ability of the hybrid classification and the vegetation indices to distinguish poor vegetation increased by 36.33% - 38.91% in the wet period (Table 6). The efficiency of the hybrid classification and the vegetation indices did not differ greatly for the classes of medium and dense vegetation. For very dense vegetation, the effectiveness of both methods was greatly improved. The agriculture

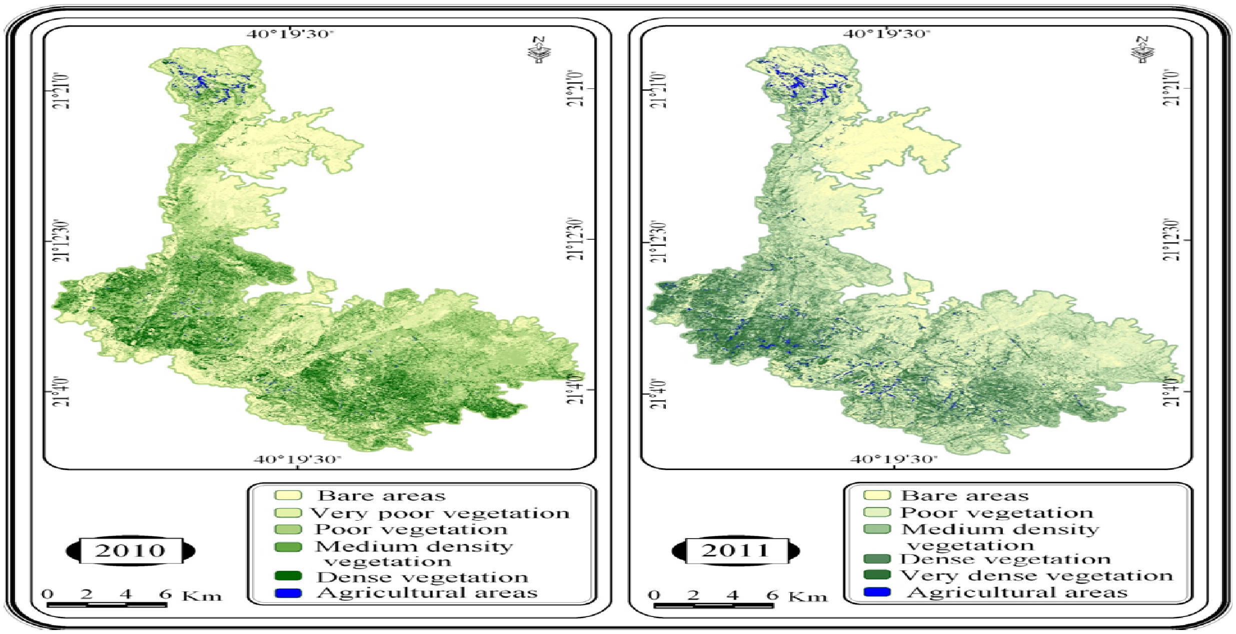

Figure 3. Plant density as derived from hybrid classification and vegetation indices in the northern Sarawat Mountains.

Table 7. The accuracy of suitable vegetation indices to estimate plant coverage and plant density in the northern Sarawat Mountains.

Ranked	Vegetation indices	Dry period 2010		Ranked	Vegetation indices	Wet period 2011	
		Percentage (%)	Kappa			Percentage (%)	Kappa
First	MSAVI1	91.11	0.8885	First	GESAVI	93.75	0.9172
	MSAVI2	90.63	0.8825		MSAVI1	93.03	0.9078
	WDVI	90.14	0.8763		SAVI	92.55	0.9018
	GESAVI	89.90	0.8732		PVI1	92.31	0.8985
Second	EVI2	89.42	0.8677		OSAVI	91.59	0.8879
	SAVI	88.46	0.8549		WDVI	90.14	0.8711
	TSAVI1	86.78	0.8346	Second	MSAVI2	89.66	0.8647
	PVI2	86.06	0.8271		TSAVI1	89.42	0.8583
	AVI	85.82	0.8237		NDVI	86.06	0.8138
Third	OSAVI	80.53	0.7545		NRVI	86.06	0.8138
	DVI	79.09	0.7423		IPVI	85.58	0.8072
	GNDVI	78.13	0.7282		WDRVI	85.58	0.807
	TSAVI2	77.64	0.7246	Third	TNDVI	84.62%	0.795
Fourth	PVI1	74.76	0.6823		EVI2	84.13	0.7942
	IPVI	73.56	0.667		TSAVI2	81.97	0.7597
	NDVI	73.56	0.667	Fourth	AVI	77.40	0.7077
	NRVI	73.56	0.667		PVI2	77.16	0.7042
	TNDVI	73.56	0.667		GNDVI	70.19	0.6325
	WDRVI	73.32	0.6638	Fifth	GEMI	69.95	0.6314
Fifth	GEMI	61.54	0.5104		DVI	68.75	0.6017
Sixth	MNDVI	36.54	0.2085	Sixth	MNDVI	40.14	0.2059
	MGNDVI	33.65	0.1658		MGNDVI	38.70	0.1964

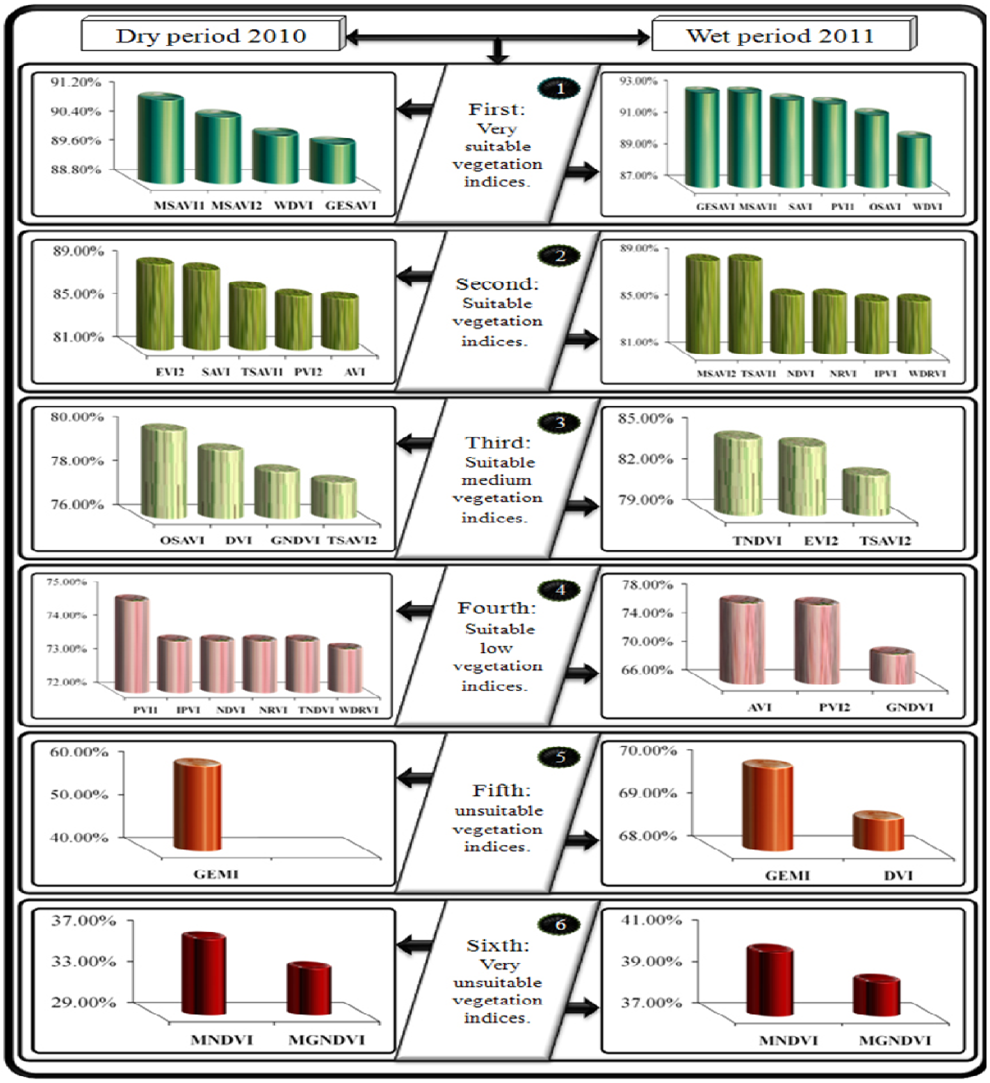

Figure 4. Rank of vegetation indices to estimate plant coverage and plant density in the northern Sarawat Mountains.

areas could be distinguished in both the dry and wet conditions due to the spectral reflectance of high concentrations of chlorophyll (Figure 3). This study indicates that the accuracy of vegetation indices differs: some have the ability to distinguish plant coverage and plant density with accuracy assessment values greater than 90% in both the dry and wet periods (Table 7). These indices are the best tool for detecting plant coverage and plant density in the northern Sarawat Mountains. In contrast, there are other vegetation indices with low accuracy for detecting plant coverage and plant density, with assessment values less than 40%. Based on the accuracy assessment and the Kappa coefficients, the vegetation indices are classified in six groups for the dry and wet periods (Figure 4). Notably, the vegetation indices that ranked first in the wet period, including SAVI and OSAVI, do not depend on the coefficients of soil line as do the others, but instead depend on a hypothetical fixed coefficient of the soil line in the study area whenever there is plant coverage and plant density.

Finally, vegetation indices are suitable when they depend on the coefficients of the soil line where plant coverage decreases as does plant density and bare soil increases. We also found that MSAVI1 and WDVI have the most accurate assessment percentages in the dry and wet periods, which indicates that these indices are not affected by the climatic conditions of the study area. Therefore, these indices are the best of the first group and are appropriate to estimate plant coverage and plant density in the northern Sarawat Mountains. Additionally, the MSAVI2 and TSAVI1 vegetation indices are the best in the second group and appropriate to estimate plant coverage and plant density in this region in both dry and wet periods. As noted in Table 7, the vegetation index (GEMI) is not suitable in dry or wet seasons, making it one of the worst vegetation indices for estimating plant coverage and plant density in the study area. Lastly, the MNDVI and MGNDVI are the worst vegetation indices for estimating plant coverage and plant density in the northern Sarawat Mountains in the dry and wet periods (Figure 4).

CONCLUSIONS

In this study, we used 22 vegetation indices to estimate plant coverage and plant density from Spot satellite data from 2010 and 2011 in a complex topographic mountainous area located in the northern Sarawat Mountains. The effectiveness of the vegetation indices differed greatly for estimating vegetation properties. This study indicated that the difference in vegetation indices in determining the area of plant coverage ranged between 79.90% and 85.91% in the dry period and increased to 85.08% to 90.16% in the wet period. The IPVI, MGNDVI, NDVI, NRVI, TNDVI, PVI1, TSAVI2 and WDRVI showed the highest values for the percentage area of vegetation in the dry and wet periods. These values range between 84.85% to 85.52% in the dry period and between 87.40% to 88.82% in the wet period. The rest of vegetation indices (EVI2, GEMI, MSAVI2, OSAVI, SAVI, DVI, GESAVI, MSAVI1, PVI2) are characterised by their efficiency at detecting the areas of vegetation in the dry period. These indices calculated values for percentage vegetated area that were nearly equal to the overall average for all vegetation indices. Therefore, these vegetation indices show the nature of plant coverage well in the northern Sarawat Mountains.

This study indicated that the vegetation indices method is better than the hybrid classification technique in detecting the percentage of vegetation coverage in the dry period. The hybrid technique's percentage vegetation cover was approximately 3.33% less than the same class derived from vegetation indices. The percentage of vegetation coverage in the wet period was 85.37%, which is less than the index estimates by approximately 1.54%. Additionally, the vegetation indices are better able to separate bare areas from vegetation coverage in the dry period and to efficiently identify vegetation cover than the hybrid classification method. With the improvement of plant density during the wet period, the vegetation indices can better discriminate the soil reflection from plant coverage. Based on the accuracy assessment percentage and the coefficients of Kappa, the vegetation indices are classified into six groups for the dry and wet period. The vegetation indices ranked first in the wet period, including the SAVI and OSAVI indices, do not depend on the coefficients of soil line as do the other indices in the same group. Instead they depend on a hypothetical fixed coefficient of the soil line where plant cover and plant density increase. Therefore, the vegetation indices are suitable when they depend on the coefficients of soil line. The MSAVI1 and WDVI indices are highly accurate in the dry and wet periods, which indicates that these indices are not affected by the climatic conditions of the study area. These two indices are the best in the first group for estimating plant coverage and plant density. The MSAVI2 and TSAVI1 vegetation indices are the best in the second group and are appropriate for estimating plant coverage and plant density in both the dry and wet periods in the northern Sarawat Mountains.

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