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RESEARCH PAPER

Application of remote sensing techniques and environmental factors in separating and determining characteristics of vegetation (Case Study: Siahkooh Basin-Yazd)

M. hassanzadeh Nafooti[1], N. Baghestani Meybodi[2], Z. Ebrahimi Khusfi[3], M. chabok[4], M. Ebrahimi Khusfi[5]

[1]*Dept. of watershed management, Maybod Branch, Islamic Azad University, Maybod, Iran*

[2]*Research Institute of Agriculture and Natural Resources, Yazd, Iran*

[3]*College of Natural Resources and Earth Sciences, Kashan University, Iran*

[4]*Watershed management, Islamic Azad University, Maybod, Iran*

[5]*Remote Sensing and Geographic Information System, Dept. of Remote Sensing and GIS, Geography Faculty, University of Tehran, Tehran, Iran*

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Abstract

Considering the capabilities of satellite imagery and Remote Sensing techniques, researchers employ these as a conventional method for exploring deserts and research carried out in arid regions. This study aims to evaluate the application of remote sensing techniques and climatic and geological factors in the separating and determining characteristics of vegetation in arid regions, especially in Siahkooh basin located in the province of Yazd (Iran). At first, in order to detect the vegetation fraction in the study area, 286 plots were sampled in the fieldwork. After applying the necessary preprocessing on the ASTER satellite imagery including the geometric and radiometric corrections, the soil line equation and 13 vegetation indices were calculated. To study the effect of environmental factors on the vegetation fraction, information layers such as geology formations, elevation, slope, aspect, temperature and precipitation were produced and standardized. In order to combine the mentioned layers and investigate the effect of each factor, the backward elimination method was used for training plots. Finally, the accuracy of models was assessed based on the correlation coefficient between measured and estimated values in the test plots. The results of this study showed that MSAVI1 is the most suitable index for estimating vegetation fraction in the case study. Furthermore, the results indicated that climatic and geological factors do not have any significant effect on increasing the accuracy of the models in Siahkooh basin.

***Corresponding Author:** M.Hasanzadeh Nafooti ✉ hasanzadeh.m@gmail.com

Introduction

Iran is located in an arid and semi-arid part of the world with an area of 1.65 million SQKM. Deserts and arid lands comprise a major part of its area. Among these, Yazd province can be named as one of the major arid parts of Iran, a desert, and it is important to obtain information about its vegetation amount and distribution. Satellite data provide possibility for investigating vegetation cover. In order to reduce the effect of undesired factors on vegetation and increase information, vegetation indices were used. Sparse vegetation in most parts of the country has provided special conditions for reflection. Sparse vegetation in these areas leads to soil affecting vegetation reflectance and dominating it (Griffiths.,1985). Furthermore, reflectance from a surface with vegetation is a combination of reflectance from leaves and soil, and therefore differentiating them from one another makes it difficult to use satellite data (Hayez.,1997).

During the last decades, using a vegetation index is common in order to determine physical characteristics of vegetative cover. These indices are usually calculated by using a combination of visible and infrared bands and have showed good correlation with vegetation growth, vegetation percentage and biomass amount (Rondeaux *et al.*, 1996). Casanava *et al.*, (1998) used Landsat imagery and PVI, NDVI, RVI and WDVI indices to determine the cover percentage and biomass of rice. They concluded that WDVI and PVI indices can better indicate percent vegetation cover . In arid areas, due to the double effect of soil reflection on NDVI, it cannot indicate vegetation characteristics and decreases the accuracy of estimating vegetation fraction in these regions (Ishiyama et.al.,1997). Vegetation indices which consider soil reflection can better show the vegetation characteristics (Kallel *et al.*, 2007; Darvishzadeh *et al.*, 2008). Ju *et al.*, (2008) concluded that the NDVI index is not an indicator of percent vegetation cover because of heterogeneous topography; therefore, Artificial Neural Networks (ANN) was used as a suitable modelbased on the topography of the study area in order to determine percent vegetation cover. In a study about one of the arid areas located in Colorado, USA, Baugh and Groeneveld (2006) concluded that NDVI is better than vegetation indices for showing percent vegetation cover in arid regions. They used Landsat imagery taken within a 14 year time period and results showed higher accuracy of the NDVI index in comparison to other indices (DVI, IPVI, TSAVI, SAVI). Ghaemi *et al.*, (2009) introduced SAVI, TVI, NDSI, NDVI, SI, BI1, RI, VI1, VI6, VI5, MSR, COSRI, MSAVI in studying the vegetative indices of Nishaboor plain and the first and third components were obtained by principal component analysis and light and chlorophyll bands showed to be the best indices for identifying and differentiation of vegetation. Behbahani *et al.*, (2010) introduced the NDVI and MSAVI indices of ASTER as the best indices for determining the percentage of trees canopy for arid zones. When determining the percent vegetation cover in Samirom rangelands using AWiFS images, Jabbari *et al.*, (2011) showed that rangelands with 20-30 and 30-40 vegetation classes are located at high altitudes and low slopes. Cabasinha and Castro (2009) determined the relationship between vegetation diversity of 22 parcels of forest and 5 vegetation indices (NDVI, SAVI, EVI, MVI5, MVI7), structure and area geometry using TM imagery. Results showed that EVI has a significant correlation with vegetation diversity but MVI5 has no significant correlation with vegetation diversity. Yang *et al.*, (2013) implemented seasonal variation of percent vegetation cover based on analyzing spectral model and remote sensing in mountain regions. Results showed that there is a strong correlation (0.85) and low least error squares (0.08) between percent vegetation measured through field studies and estimated percent of remote sensing data. They showed that vegetation diversity reaches its maximum in May and June in the study area. Koide and Koike (2012) used indices of SPOT images in order to determine areas with high underground water table in warm and humid areas. They've also showed that the new index NDVI is more sensitive to water tension in vegetation and has a strong linear correlation with percent vegetation cover in this area when compared to other indices such as Vis, SAVI and EVI2. Abdollahi *et al.*, (2007) showed that synchronous use of several parameters leads to better conclusion when determining the percentage of vegetation in arid areas. Arkhy *et al.*, (2011) studied monitoring change in vegetation using remote sensing techniques in Ilam dam basin. They showed that the red band differentiation method has the highest accuracy among other methods with a total accuracy of 89 and the Kappa coefficient of 0.82 and the ratio method of near infrared band has least accuracy in monitoring vegetation change with a total accuracy of 64.5 and the Kappa coefficient of 0.24.

The objective of this paper is to evaluate the application of satellite remote sensing technology and environmental factors in order to determine the characteristics of vegetation in arid regions, especially in Siahkooh Basin located in the province of Yazd (Iran).

Materials and methods

Study area

The study area is located in the central arid part of Iran (northern latitude 32°16' 00" to 32°37' 30" and eastern longitude 53°53'30" to 53°32'30"). This region, with the highest and lowest elevation of 2077m and 96m, covers an area of 984 SQKM , in the western part of Ardekan, province of Yazd (Fig.1).

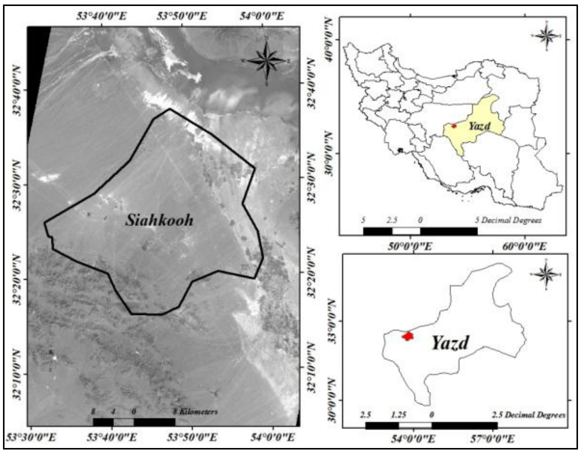

Fig.1. Location of the study area in Yazd Province and Iran.

Data and Sampling

In this study, we used ASTER-1B imagery of TERRA satellite taken on 29-03-2011, percent vegetation cover measured in 286 synchronous plots in the fieldwork, meteorological data obtained from 19 climatology stations, Digital Elevation Method (DEM) and 1: 100,000 geological map.

Random sampling was adopted in this study. A total of 286 points were generated and a GPS was used to locate their position in the fieldwork.

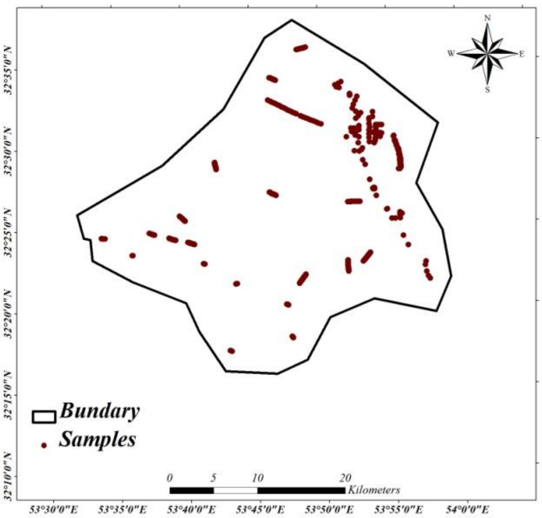

Fig. 2. Location of samples in the study area.

Preprocessing and processing of data

ASTER-L1B data were converted to ground reflectance by using FLAASH atmospheric correction algorithm.

For geometric correction, 17 points were selected in the study area using maps with a scale of 1: 25000 and resampled with quadratic polynomial equations with an accuracy of 0.67 pixels using the nearest neighbor method.

After geometric and radiometric corrections, the study area was extracted from the image .

In order to calculate vegetation indices such as TSAVI, MSAVI and SAVI, it is necessary to obtain the soil line equation. To do so, 860 soil pixels located in the study area were selected, red and near infrared bands were plotted and the soil line parameters were obtained. After that, 13 common vegetation indices, presented in table 1, were calculated.

Table 1. Vegetation indices used in this study.

Index	Equation	Reference
DVI	$DVI = R_{NIR} - R_{RED}$	Tucker, 1979
GEMI	$GEMI = \frac{\mu(1-0.25\mu)-(R_{RED}-0.125)}{1-R_{RED}}$ $\mu = \frac{(R_{NIR}^2 - R_{RED}^2)+1.5R_{NIR}+0.5R_{RED}}{R_{NIR}+R_{RED}+0.5}$	Pinty &Verstraete, 1992
IPVI	$IPVI = \frac{R_{NIR}}{R_{RED}+R_{NIR}}$	Crripen, 1990
MSAVI2	$MSAVI2 = \frac{2R_{NIR}+1-\sqrt{(2R_{NIR}+1)^2-8(R_{NIR}-R_{RED})}}{2}$	Qi *et al.*, 1994
MSAVI1	$MSAVI = \frac{R_{NIR}-R_{RED}(1+L)}{R_{NIR}+R_{RED}+L}$ $L = 1 - 2 \propto NDVI \times WDVI$	Qi *et al.*, 1994
NDVI	$NDVI = \frac{R_{NIR}-R_{RED}}{R_{NIR}+R_{RED}}$	Rouse *et al.*, 1974
PVI	$PVI = \frac{R_{NIR}-\alpha R_{RED}-\beta}{\sqrt{1+\alpha^2}}$	Richardson& Wiegand, 1977
SAVI	$SAVI = \frac{R_{NIR}-R_{RED}(1+L)}{R_{NIR}+R_{RED}+L}$	Huete, 1988
SR(RVI)	$RVI = \frac{R_{NIR}}{R_R}$	Jordan, 1969
TSAVI	$TSAVI = \frac{\alpha(R_{NIR}-\alpha R_{RED}-\beta)}{\alpha R_{NIR}+R_{RED}+\alpha\beta+0.08(1+\alpha^2)}$	Baret & Guyot, 1991
WDVI	$WDVI = R_{NIR} - \alpha R_{RED}$	Clevers, 1989
SAVI2	$SAVI2 = \frac{R_{NIR}}{R_R + \frac{\beta}{\propto}}$	Major *et al.*, 1990
OSAVI	$OSAVI = 1.16\,\frac{R_{NIR}-R_{RED}}{R_{NIR}+R_{RED}+0.16}$	Rondeaux *et al.*, 1996

Other information layers including geological maps, elevation, temperature, rainfall, slope, aspect was prepared by using ArcGIS software. In the next step, the value of each layer was standardized according to their effects on vegetation fraction so that they can be comparable. The standardization method for each layer is presented as follows:

Elevation: by increasing elevation, precipitation and vegetation increases. Therefore, areas with maximum elevation have maximum value and those with minimum elevation have minimum value.

Slope: slope causes water to advance out of reach of vegetation quickly. Therefore, in this research high-sloped areas were given lower weight.

Aspect: in the analytic vegetation map based on direction, highest weights were allocated to north, west, east and south, respectively.

Geological formations: there are four formations in this research: QT1, Qt2, Qcf and Qal for which a value from 0 to 1 was assigned to for the percent vegetation cover of each formation, such that Qcf has the highest and Qal has the lowest value.

Precipitation: increased precipitation increases vegetation; therefore, areas with higher rain have higher weight value.

Temperature: increased temperature increases sensitivity to drought and decreases vegetation. Based on this, maximum weight was assigned to areas with minimum temperature and minimum weight was assigned to areas with maximum temperature.

Vegetation fraction: In order to determine percent vegetation cover, vegetation indices were used based on satellite imagery. Areas with dense vegetation gained higher weight.

Finally, the value of each sample point in all mentioned layers was then extracted by overlaying the sample point on these information layers.

Vegetation indices were calculated in MATLAB software. . The evaluation of obtained results was carried out by using cross validation methods.

Statistical analysis

One approach to simplifying multiple regression equations is the stepwise procedures. These include forward selection, backwards elimination, and stepwise regression. In this research, we use backwards elimination method, because this method has an advantage over forward selection and stepwise regression because it is possible for a set of variables to have considerable predictive capability even though any subset of them does not. Forward selection and stepwise regression will fail to identify them. Because the variables don't predict well individually, they will never get to enter the model to have their joint behavior noticed. Backwards elimination starts with everything in the model, so their joint predictive capability will be seen (http://www.jerrydallal.com). It is necessary to mention that in this stage one-third of samples were used as test samples and two-thirds were used as training data. Validity of models was measured using correlation values and estimated values were evaluated in the location related to test samples.

Results

Equation 2 shows the soil line equation for the study area.

Equation 2. $R_{NIR} = 1.6R_{RED}$

The evaluation results of vegetation indices have shown in Table 2.

Table 2. R^2 and RMSE between observed values and estimated values using vegetation indices by Cross Validation.

Index	R^2	RMSE (%)
DVI	0.17	10.60
GEMI	0.14	10.75
IPVI	0.18	10.52
MSAVI1	**0.69**	0.078
MSAVI2	0.009	11.65
MSR	0.18	10.54
NDVI	0.18	10.52
PVI	0.11	10.95
SAVI	0.17	10.56
SAVI2	0.18	10.54
SR(RVI)	0.18	10.54
TSAVI	0.17	10.59
WDVI	0.11	10.95
OSAVI	0.18	10.52

DVI: Difference vegetation Index
GEMI: Global Environmental Monitoring Index
IPVI: Infrared percentage vegetation Index
MSAVI: Modified soil Adjusted Vegetation Index
MSR: Modified Simple Ratio
NDVI: Normalized Difference Vegetation Index
PVI: Perpendicular Vegetation Index
SAVI: Soil Adjusted Vegetation Index
RVI: Ratio Vegetation Index
TSAVI: Transformed Soil Adjusted Vegetation Index
WDVI: Weighted Difference Vegetation Index
OSAVI: Optimized Soil Adjusted Vegetation Index

The results of cross validation confirm the fact that MSAVI1 index, which considers soil line coefficients, can better estimate percent vegetation cover in comparison to other vegetation indices. Regarding obtained results, those indices which consider soil line coefficients can better indicate percent vegetation cover than other indices. Regarding results related to the t-test, there is no significant difference between estimated values obtained by these indices (P-value>0.05). Among them, MSAVI1 index has higher accuracy than other indices and therefore, it is selected as the most suitable index. In the next step, layers related to effective parameters on vegetation were prepared.

The geologic formations map of the study area is shown in fig. (3).

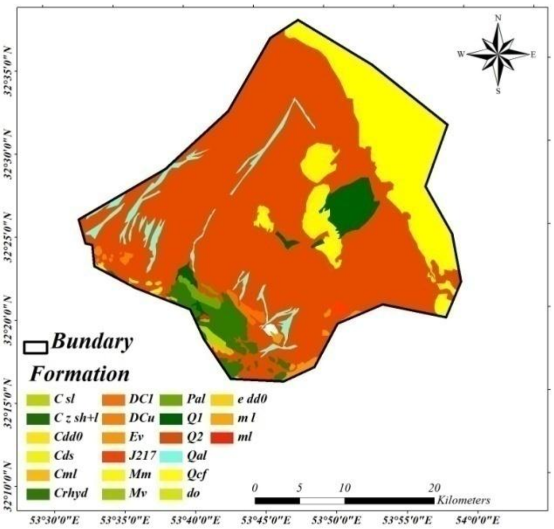

Fig.3. Geological map of Siahkooh basin.

Upon investigating sample plots within the study area, it was shown that these plots are placed in 4 formations Q1, Q2, Qcf and Qal. The percent vegetation cover of each formation is shown in fig. (4).

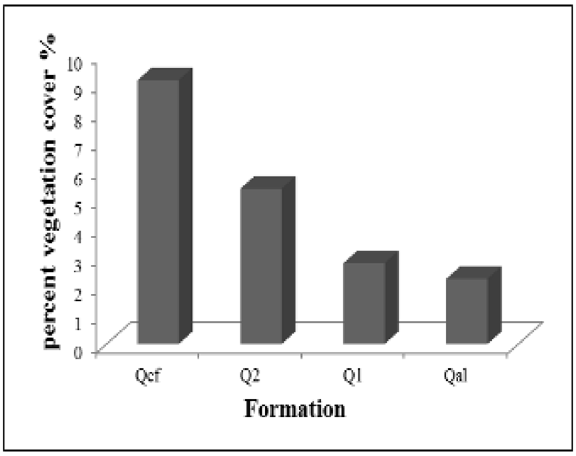

Fig. 4. Percentage of vegetation in different formations in Siahkooh basin.

Fig. (5) shows elevation classes in Siahkooh basin. The maximum and minimum elevation within this area is 2077m and 956m respectively.

Fig. (6) indicates slope classes and fig. (7) shows main aspect maps of Siahkooh basin.

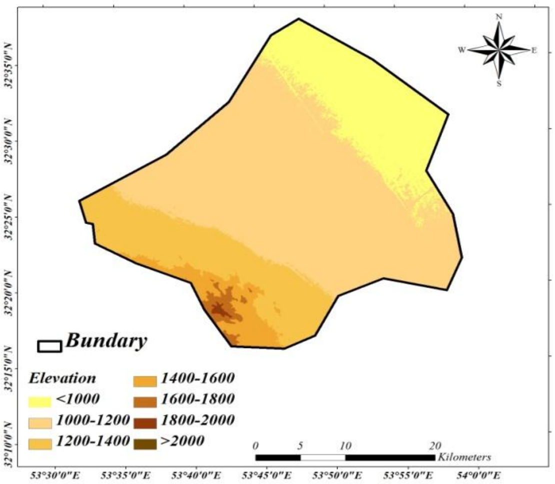

Fig. 5. Elevation classes of Siahkooh basin.

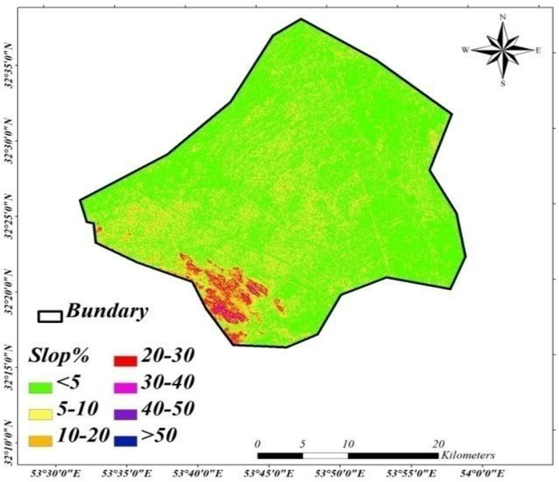

Fig.6. Slope classes of Siahkooh basin.

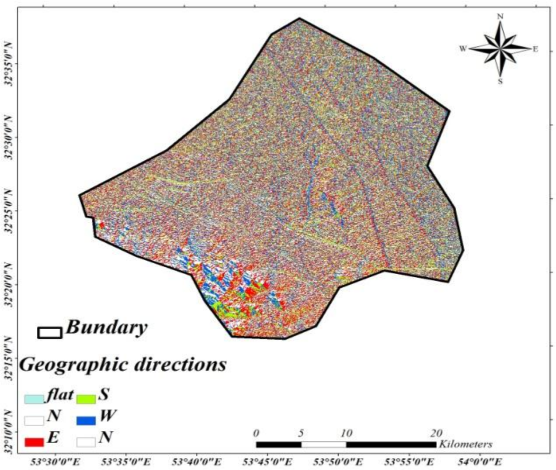

Fig. 7. Geographic directions of Siahkooh basin.

By correlating the annual precipitation and annual temperature gradients of the study area and the digital elevation model, the precipitation and mean annual temperature layers were prepared for Siahkooh basin (fig. 8, 9).

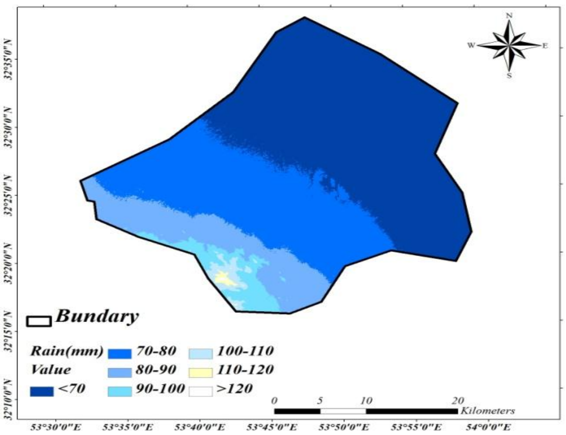

Fig. 8. Annual rainfall classes of Siahkooh basin.

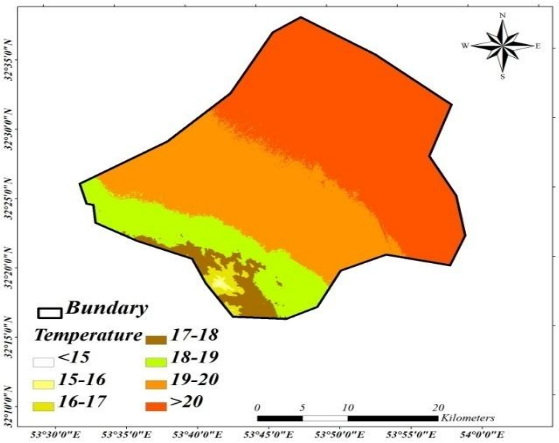

Fig. 9. Annual average temperature of Siahkooh basin.

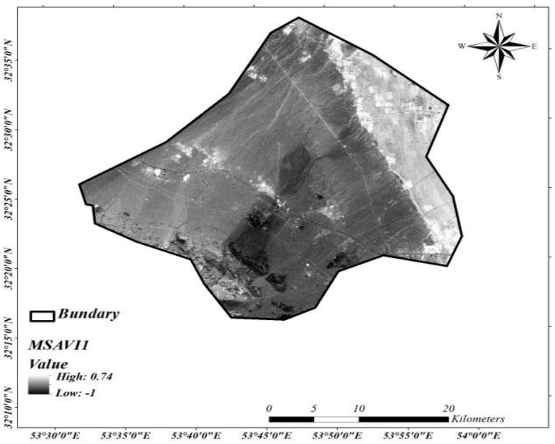

Fig.10. MSAVI index map of Siahkooh basin.

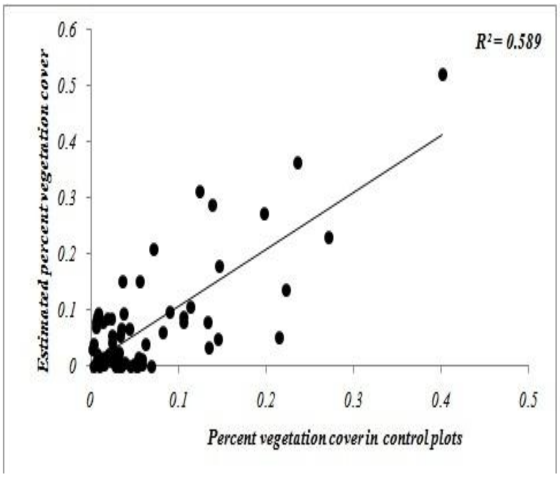

Fig. 11. Diagram of accuracy of the proposed model for the study area.

To calculate percent vegetation cover (fig. 10), the MSAVI1 index was used due to its high correlation with measured values and lower RMSE.

As explained previously in the methodology, in order to study the effect of different environmental factors on percent vegetation cover in the study area, two-thirds of samples were used by applying the backward method in the modeling process. The results obtained from multivariate regression on dependent and independent variables are presented in table 3.

Table 3. Extracted models using backward elimination in 152 training points.

$Fv1= -0.019X1-0.014X2-0.011X3-0.028X4+0.65X6+0.018$

$Fv2=-0.011X1-0.012X3-0.027X4+0.652X5+0.009$

$Fv3= -0.013X3-0.027X4+0.65X5+0.001$

$Fv4=-0.029X4+0.647X5-0.005$

$Fv5=-0.641X5-0.026$

X1:geology, X2=topography, X3=aspect, X4:Slop, X5=MSAVI1.

Owing to the fact that the high R^2 in multivariate regression does not imply its inefficiency and the efficiency of a model is confirmed when it can give a good description of the dependent variable (Rezaie and Soltani, 1998); therefore, extracted models were validated based on higher R^2, F and lower standard errors (S.E). The results of this validation have presented in table (4). Also, the results of the variance analysis with linear multivariate regression have presented in table (5).

Table 4. Results of the extracted model evaluation.

Model	R	R²	R² adjusted	RMSE
1	0.83	0.689	0.678	0.07906
2	0.83	0.688	0.680	0.07882
3	0.829	0.688	0.682	0.07858
4	0.829	0.687	0.683	0.0784
5	0.829	0.686	0.684	0.07827

Table 5. Results of variance analysis using the multiple linear regression method.

Model	Variation reference	Sum-squares	df	Mean-square	F
1	Regression	2.017	5	0.403	64.557
	Residuals	0.912	146	0.006	
	Total	2.93	151		
2	Regression	2.016	4	0.504	81.141
	Residuals	0.913	147	0.006	
	Total	2.93	151		
3	Regression	2.016	3	0.672	108.82
	Residuals	0.914	148	0.006	
	Total	2.93	151		
4	Regression	2.014	2	1.007	163.85
	Residuals	0.916	149	0.006	
	Total	2.93	151		
5	Regression	2.011	1	2.011	328.28
	Residuals	0.919	150	0.006	
	Total	2.93	151		

Finally, a graph was plotted in order to determine model accuracy based on observed and estimated values (fig. 11). The fitness of numbers in this graph has an R² of (0.59) which shows strong correlation between observed and estimated values. By applying this model on bands contributing in the model, the percent vegetation cover map of the study area was produced (fig. 12).

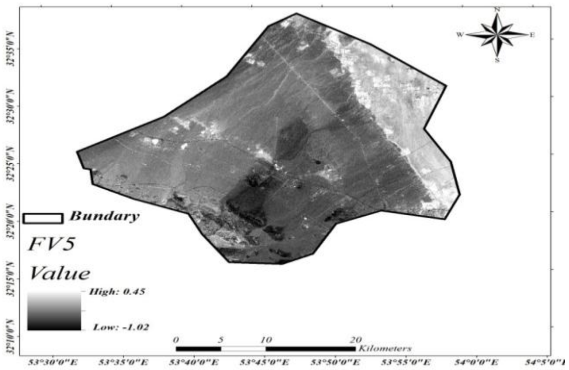

Fig. 12. Vegetation map of Siahkooh basin based on the best model.

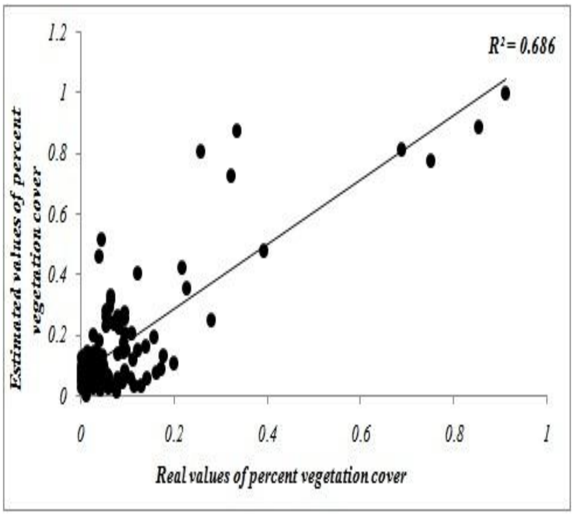

Fig. 13. Real values of percent vegetation cover against estimated values using MSAVI1.

Discussion and conclusion

As the study area is considered an arid area, it is expected that indices which consider soil reflectance can estimate vegetation fraction more accurately than other indices. Results showed that only MSAVI1 has acceptable results (fig. 13). Indices like OSAVI, MSAVI2 and SAVI show results with lower accuracy because in their calculations, empirical coefficients are used and these coefficients are not suitable for the considered study area.

An important point shown in fig. (13) is that there are several data which have significant differences with other indices. Regarding field observations, this data is not considered sampling error as it is obtained in pistachio farms located in the study area and water accessibility has lead to a vegetation cover of over 50%.

Regarding studies of other researchers, NDVI is not a good indicator for percent vegetation cover in arid areas (Ishyama et.al, 1997) and indices which consider soil reflection can estimate vegetation more accurately (Darvishzadeh et.al, 2008). In this study results showed that this index has lower accuracy than MSAVI1 which considers soil line factors and has higher accuracy than other indices such as DVI, GEMI, MSAVI2, PVI, SAVI, TSAVI and WDVI. This is due to allocating empirical factors to indices such as SAVI and MSAVI2 which reduces accuracy.

GEMI is an index which is presented to reduce atmospheric effects. This index showed to have low accuracy in this research. This is because of excessive soil reflectance in the study area (Liang, 2003). Also, in calculating this index, various constants are used which may not be suitable for the study area and create this error. Results in table (5) showed that among extracted models, model number 5 is the most suitable model for estimating percent vegetation cover in Siahkooh, due to high R^2, F and low standard error. On the other hand, results of fitness for determining the accuracy of the model in the study area showed strong correlation ($R^2= 0.684$) between observed and estimated values. Therefore, model 5 is the most appropriate model for estimating percent vegetation cover in the study area. In order to justify this, one must refer to the variables that have constructed this model. As the model shows, the MSAVI1 index has the highest effect in determining vegetation in the study area. In arid and semi-arid areas, because of sparse and dispersed vegetation, soil reflection has a considerable effect on recorded values, and this is one of the most important points which should be considered when studying vegetation of arid areas. There have been many attempts for minimizing the effects of the environment on the numerical value of spectral reflection caused by vegetation in arid areas. For example, Qi et.al (2002) developed an index named MSAVI which has significantly reduced the effects of soil reflection. In this research, by calculating soil coefficients, we tried to reduce soil reflectance effect and as results showed, the most suitable model for determining percent vegetation cover in the study area was MSAVI1. As the equation related to this index shows, additionally red and mid-infrared bands which are sensitive to vegetation, also the coefficients related to the soil line equation are used and this decreases or eliminates soil reflectance and increases accuracy. As table (3) shows, although environmental parameters were entered into other models but they had no effect in increasing accuracy and at the last model (5) was selected as the most suitable model for the study area. The reason for environmental factors having no effect in increasing modeling accuracy is low variance of parameters such as temperature, precipitation, slope and uniform formations in most sampled plots. Therefore, it seems that the most significant factor in showing vegetation in Siahkooh is spectral reflection of vegetation canopy in sample plots which was shown with high accuracy using ASTER. This shows the high capability of ASTER imagery in indicating the most important characteristic of vegetation in the study area. It also presents an accurate estimation of vegetation as well as reducing required time and costs.

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