Remote sensing technology for mapping and monitoring vegetation cover (Case study: Semirom-Isfahan, Iran)

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ABSTRACT: To determine the suitable indices for vegetation cover and production assessment based on the remote sensing data, simultaneous digital data with field data belonging to the spring rangeland of the Semirom-Isfahan province were analyzed. During two years of monitoring the annual, grass, forb, and shrub vegetation cover and the total production data from 86 were collected. The Global Positioning System (GPS) was used to measure the coordinates of plots and transects. Geometric correction and histogram equalization were applied in image processing, and image digital numbers were converted to reflectance numbers. In the next stage, all vegetation indices were calculated from the Advanced Wide Field Sensor (AWiFS) image data and compared with the vegetation cover estimates, at monitoring points, made during field assessments. A linear regression model was used to select suitable vegetation indices. The results showed that there were significant relationships between the satellite data and the vegetative characteristics. Among the indices, the Normalized Difference Vegetation Index (NDVI) consistently showed significant relationships with the vegetation cover. The estimation of the vegetation cover with the NDVI vegetation index was more accurately predicted within rangeland systems. Using the produced model from the NDVI index vegetation crown cover, percentage maps were produced in three class percentages for each image. Generally introduced indices provided accurate quantitative estimation of the parameters. Therefore, it was possible to estimate cover and production as important factors for range monitoring using the AWiFS data. The Remote sensing data and the Geographic Information System are the most effective tools in natural resource management.

Keywords: AWiFS, remote sensing, vegetation cover, vegetation index.

INTRODUCTION

Remote sensing has been developed as a powerful tool in environmental studies, because it can provide calibrated, objective, repeatable, and cost-effective information for large areas and it can be empirically related to the collected field data (Glenn et al., 2008). One of the most common applications of remote sensing is land/canopy cover monitoring and assessment via remote sensing indices, which combine reflectance measurements from the bands of remote sensing instruments (Khajeddin, 1995; Glenn et al., 2008). Remote sensing indices derived

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from satellite data are one of the primary sources of information for operational monitoring of the land's vegetative covers and other land covers. These indices are radiometric measures of the spatial and temporal patterns of land covers, such as, the vegetation photosynthetic activity, which is related to canopy biophysical variables, such as, Leaf Area Index (LAI), fractional vegetation cover, biomass, and the like (Jafari et al., 2007; Glenn et al, 2008). Spectral indices are simple mathematical combinations of two or more spectral values that produce a single value, which describes a photosynthetic organism's quality or condition and quantity (Crippen, 1990; Bannari et al., 1995; Pearson and Miller, 1972; Glenn et al., 2008). The basic idea of a spectral index is to get the multispectral or hyperspectral remote sensing values to collapse to a particular measure, which is related to some characteristics (i.e., vegetation cover and greenness) of an object (Rundquist, 2002). One of the influential tools in studying rangeland, vegetation cover, and vegetation indices in Natural Resources management is the remote sensing technique (Wallace et al., 2006). Their results have proved the efficiency of the vegetation indices for a quantitative estimation of the vegetation parameters. Remote sensing methods are based on brightness and values of the land cover types, which enable characterization of the land cover. As vegetation differentially absorbs the visible incident solar radiant and reflects much of the near infrared (NIR), data on the vegetation biophysical characteristics can be derived from the visible, NIR, and mid-infrared portions of the electromagnetic spectrum. Several vegetation indices have been introduced that use the ratios of these reflections (Goward et al., 1991; Tucker, 1979; Yang et al., 1998). The vegetation indices (VIs) to monitor terrestrial and scapes by satellite sensors were first developed in the 1970s and have been highly successful in assessing the vegetation condition, foliage, cover, and phonology (Pettorelli et al., 2005). Vegetation indices combine reflectance measurements from different portions of the electromagnetic spectrum, to provide information on the vegetation cover on the ground (Campbell, 2011). These VI are radiometric measures of the spatial and temporal patterns of the vegetation photosynthetic activity that are related to the canopy biophysical variables, such as, the leaf area index (LAI) or the fractional vegetation cover and biomass (Asrar et al., 1985; Richardson et al., 1992). Masoud and Koike (2006) used the soil-adjusted vegetation index (SAVI) indicator to prepare a vegetation cover map of the Siwa Region of Egypt, paying attention to the desertification of the area. This was done by reducing the influence of the soil and assuming the value of the soil coefficient to be 0.5. The NDVI has been widely used in many applications including regional and continental-scale monitoring of the vegetation cover (Wessels et al., 2004). Jin and Sader (2005) have reported that the SAVI, NDVI, and Perpendicular Vegetation Index (PVI) indices or even simple band ratios depend on shrub types, and phonological stages are more sensitive than reflectance from green, red, and near infrared bands. These indices have the ability to distinguish various shrub species and separate shrub lands from grass lands. Perry and Lautenschlager (1984) have compared 20 VIs and have found most of them to be functional equivalents. Most VIs are called broadband because they are based on algebraic combinations of reflectance in the red (R) and near infrared (NIR) spectral bands (Bannari et al., 1995; LePrieur et al., 1994). This strong contrast between red and near infrared reflectance has formed the basis of many different vegetation indices. When applied to multispectral remote sensing images, these indices involve numeric combinations of the sensor bands that record land surface reflectance at various wavelengths. Pearson and Miller (1972) first presented the near infrared/red ratio for separating green vegetation from the soil background. Since then, numerous vegetation indices have been proposed, modified, analyzed, compared, and classified (Bannari et al., 1995; Qi et al., 1994). Richardson and Wiegand, (1997) used the Perpendicular Vegetation Index (PVI), Global Vegetation Index (GVI), Soil Brightness Index (SBI), Difference Vegetation Index (DVI), Infrared Percentage Vegetation Index (IPVI), Infiltration Rate (IR)1, IR2, mid-infrared (MIR), RA, Wetness Index (WI), and the visible and near-infrared (VNIR)1 and VNIR2 indices, and found that DVI was the best for density and cover assessment. Thenkabail et al., (1994) proposed six different plant-water sensitive vegetation indices using Aster mid-infrared and shortwave-infrared bands, including the mid-infrared vegetation index (MSVI 1 and 2). They found that these indices were as good or better predictors of yield, leaf area index, wet biomass, dry biomass, and plant height, than the slope-based vegetation indices, in corn and soybean fields. Most of the widely used vegetation indices, such as, the NDVI, Modified Normalized Difference (MND), soil adjusted index (SAI), Ratio Vegetation Index (RATIO) and Transformed Vegetation Index (TVI), use the red and NIR regions in arid and semi-arid rangelands (Pearson and Miller, 1972; Qi et al.,1994; Rouse et al., 1974). In the present study, emphasis was on monitoring the changes in the rangelands, based on field and digital data, to achieve suitable vegetation indices derived from the AWiFS imagery, for estimation of the vegetation parameters.

MATERIALS & METHODS

This study has been conducted in Semirom-Isfahan, Iran, with the latitude between $30^{\circ}42''$ and $31^{\circ}51''$N and longitude between $51^{\circ}17''$ and $52^{\circ}03''$E (Fig. 1). The district has an area of 1541 square kilometers. The area of the rangelands in the Isfahan province of Iran is about 8962 hectares, having 360 mm annual rainfall (Yeganeh et al., 2008).

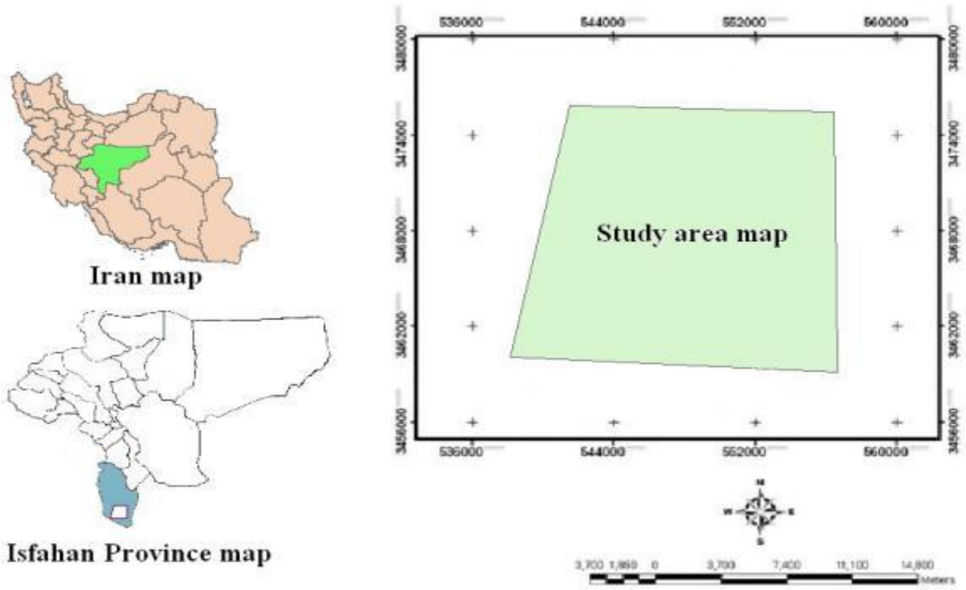

Fig. 1. Study area

IRS_P6 AWiFS image taken on 22 May 2009 and 15 May 2010 were used for the present study. After atmospheric correction and elimination of the offset value of the satellite data, the imagery was geometrically rectified to prepare two or more satellite images for accurate comparison and detection of the change (Mahmodzadeh, 2007). The accuracy of the image registration is usually expressed in terms of Root-Mean-Square (RMS) error. The IRS_P6 AWiFS image was registered to the Semirom digital topographical map using 18 ground control points (GCPs). After the process of image-to-image registration, the AWiFS image 2010 was adopted for the registration of AWiFS image 2009, using 18 GCPs. The registration error (RMS) obtained was 0.23 pixel for AWiFS image 2009 and 0.33 pixel for AWiFS image 2010. Both images were seen to resemble after using the nearest neighbor algorithm. On the different slope aspects of each vegetation type, six 200 m transects on the hypothetical circle circumference, with GPS centering about 60m, were placed (86 sampling site). The distance between the transects was at least 100m. Ten quadrates, $100m^2$ each, were established alongside the transects. The vegetation cover was measured within the quadrates (Fig. 2). In order to analyze the vegetation cover percentages, the data field for each vegetation type was collected by stratified random sampling. In each quadrate the percentage vegetation cover was estimated. Image processing in terms of geometric and atmosphere corrections was done. To reduce the error caused by the sun angle, the digital-number (DN) values were converted to spectral reflectance (Fig. 3). In addition a Digital Elevation Model (DEM), 1:25000 of the site, was used. Several ratios or indices were examined, which have been illustrated in Table 1. Subsequently, the values of the indices relative to ground data, as suggested by Arzani (1994, 1998), were extracted from the image, for two years. Correlations between the vegetation indices and band ratios with cover and yield data were evaluated. For each vegetation community, indices with higher significant correlations ($P < 0.01$ and $P < 0.05$) were selected. Equations of regression between the indices as independent variables and the cover as dependent variables were calculated. Following this, the equations were tested in witness quadrates using the paired analysis of variance (ANOVA) and t-test analysis.

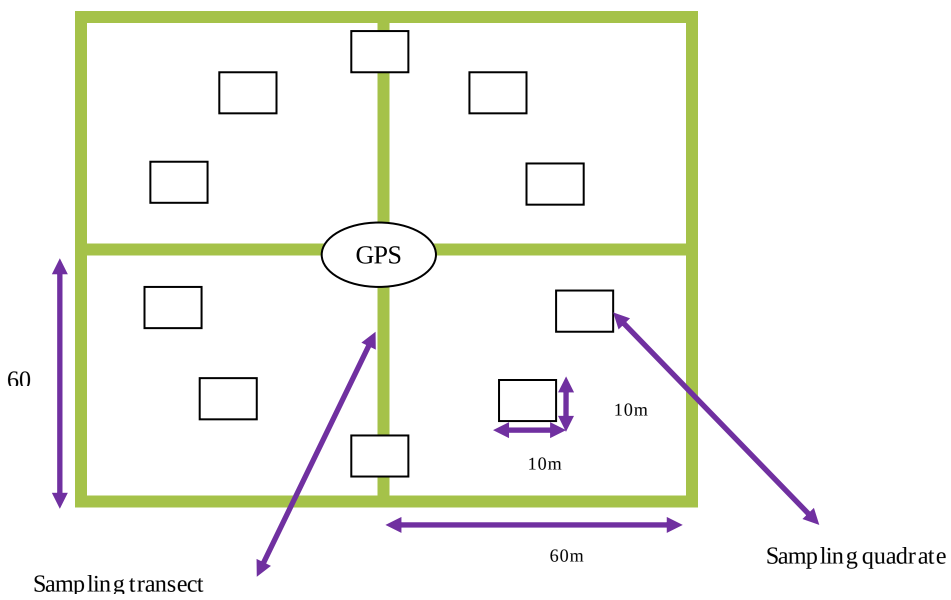

Fig. 2. Sampling method in each site

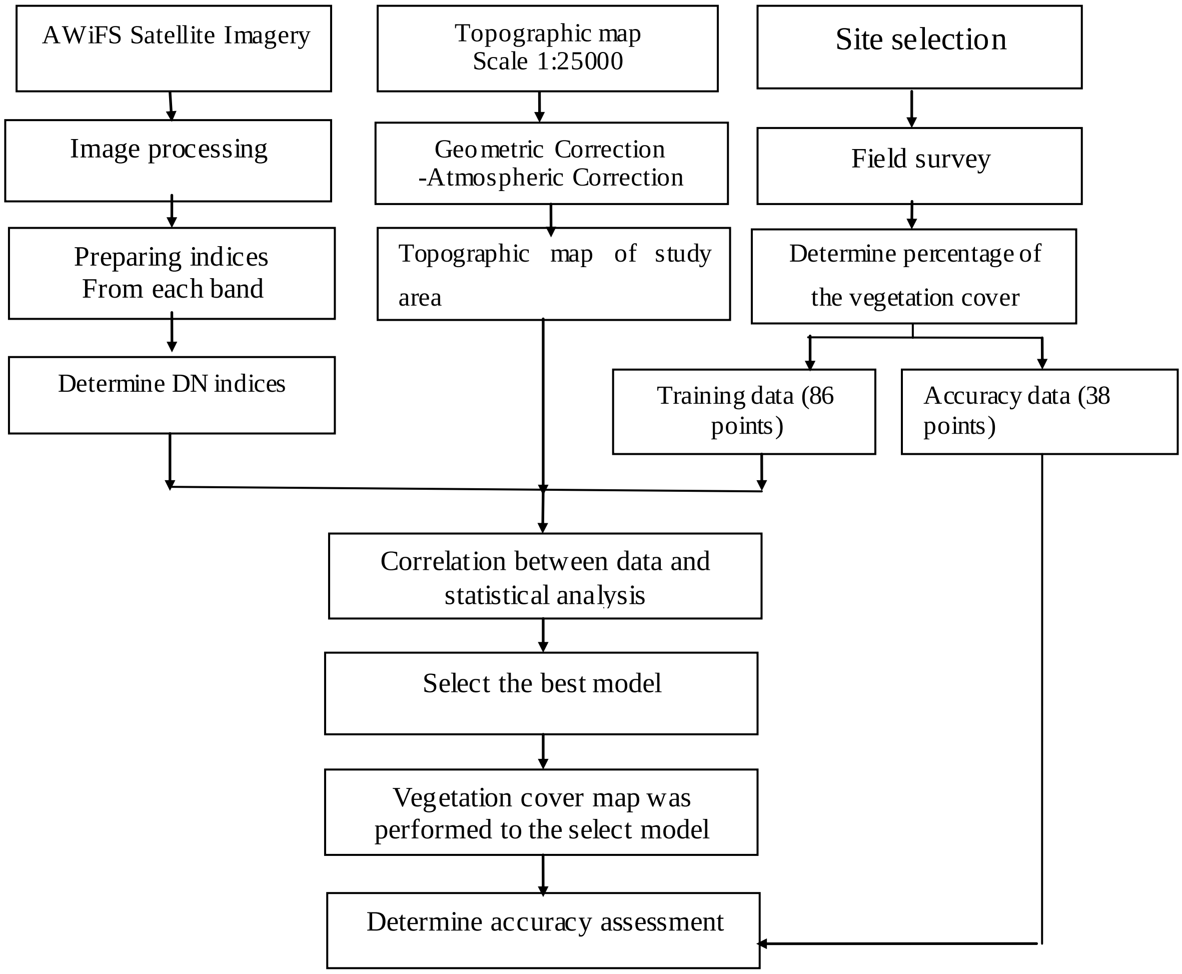

Fig. 3. Model for image processing and integrating ground data with satellite data

Table 1. Vegetation indices compared in this study

Acronym	Author	Formula	AWiFS bands
NDVI	(Rouse *et al*., 1974)	(NIR-R)/(NIR+R)	(b3 – b2) / (b3+b2)
IPVI	(Boyd *et al*., 1996)	[(NIR-R)/(NIR+R)]+1/2	(NDVI+1)/2
SVI	(Pearson and Miller 1972)	NIR/ R	b3/b2
RATIO	(Boyd *et al*., 1996)	NIR/R	b3/b2
SAVI-1	(Pearson and Miller 1972)	(MIR×R)/NIR	(b4×b2) / b3
SAVI-3	(Pearson and Miller 1972)	NIR/(R+MIR)	b3 / (b2+b4)
SAVI-4	(Pearson and Miller 1972)	MIR/(NIR+MIR)	b4 / (b3+b4)
TVI	(Boyd *et al*., 1996)	(NIR-R)/(NIR+R)+0.5	(b3-b2) / (b3+b2)+0.5

Study of the Validity of the Produced Map

The map was validated against the field data from the ground. This was done by visiting the regions corresponding to the remotely sensed satellite data and matching the data from 38 control points in each vegetation type, with the interim map of the vegetation data, so that the reliability of the map and its Capa coefficient could be determined.

RESULTS

Significant correlations between the digital data and quantitative measurements of cover were observed in all vegetation types. The rate of correlations and equations obtained between the vegetation indices and vegetation cover parameters have been illustrated in Table 2. At this scale, in a study area, only NDVI vegetation indices were significantly correlated with the field cover data ($P < 0.05$), the strongest relationships explaining 78% of the variance in the field measurements (R^2 = 0.38). The other vegetation indices were not significantly related to the vegetation cover percentage of the field data. The results of using stepwise regression to establish a relationship between field cover and different vegetation indices are shown in Table 3. Each of the indices were first entered into the model, but they were subsequently removed in the subsequent stages of running the final model. The equation for this model is Equation (1):

$$Y = 10.08 + 86.55\ NDVI \quad (1)$$

Given the goodness of fit between the NDVI index and vegetation cover (Table 3), the null hypothesis was rejected at the probability level of 1%.

Table 2. Relationships between field cover and vegetation indices in the study area

Vegetation index	Correlation coefficient with cover (%)
NDVI	0.62**
IPVI	0.07
SVI	0.08
RATIO	-0.05
SAVI-1	0.22
SAVI-3	0.06
SAVI-4	0.05
TVI	-0.08

* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

Table 3. ANOVA analysis between NDVI index and vegetation cover (%)

Index entered into the model		Sum of Squares	Df	Mean Square	Sig.
NDVI		3559.263	20	177.963	0.05
		10801.492	44	245.488	
Mean along transect	Actual value	8.81±21.07	-	-	
	Estimated value	2±22.61	-	-	

As a significant linear relationship existed between the crown cover percentage and the above spectral bands, the validity of the model was established. In the resultant map, depicted in Figure 4, the region was subdivided into five separate levels, based on the percentage of the crown cover. The total validity and the Capa coefficient for this map were 68.5 and 72.4%, respectively. Moleele et al. (2001) obtained the validity of the vegetation cover at about 63.5% (Moleele et al., 2001), which conformed to the results obtained in this research. This model could also be used to estimate the vegetation cover from the satellite data (Fig. 5).

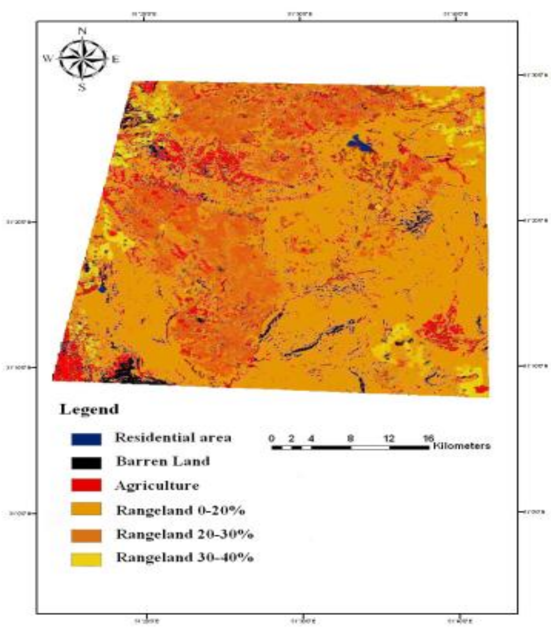

Fig. 4. Vegetation cover (%) map of study area

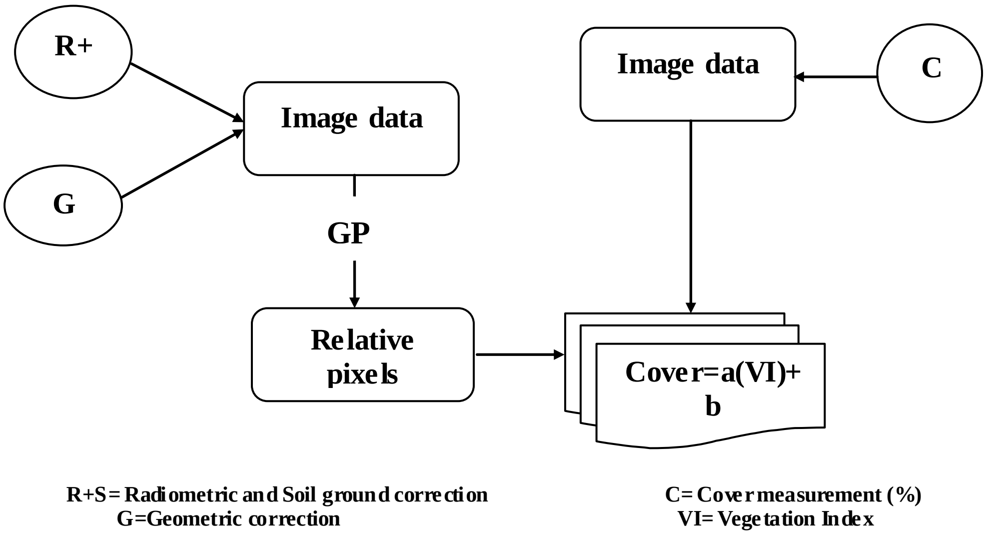

Fig. 5. Model for estimating vegetation cover from satellite data

For better estimation of the cover, single band ratios or vegetation indices (combination of bands) were used. The vegetation indices and ratios that had a positive correlation with the relative vegetation parameters and which had negative correlations with the relative vegetation parameters showed higher and lower values for image of good conditions, respectively, at all sites.

So far, many plant spectral indices have been introduced for studying the quality and quantity specifications of the vegetation cover. Selecting the best index for quantitative analysis of the vegetation cover is one of the most significant problems that users have to address (O'Neill, 1996). In most similar research studies only one index has been used as an independent variable. It is successful when the vegetation cover is associated with highly vigorous growth, turgid plant leaves, and the deleterious effects of soil reflection are minimal. Therefore, in regions of drought and semi-drought, even in years with sufficient rain for plant growth, one index by itself cannot describe the vegetation cover of the region. The use of various vegetation indices is, therefore, more suitable for studying the vegetation cover in such regions, due to the variety of information that is produced by using the existing data from different spectral bands. Out of the eight vegetation indices used in this research, seven vegetation indices were not significantly related to the percentage of the vegetation cover of the region due to the high variance in the cover data. The NDVI index was the only index that was closely related to the percentage of the vegetation cover of the region. This index was correlated with the vegetation cover (r=0.28) in a study performed by Arzani (1998). Khajedeen (1995) in his study of the semi-arid rangelands found that the NDVI index was the only suitable index for studying the vegetation cover in that region. The results of a study by Sepehri (2003), in regions with a high vegetation cover percentage, also found this index to be correlated with the vegetation cover. Apan et al. (1997) in their study believed that the reason for the reduction of NDVI correlation with the crown cover percentage was the effect of the background soil on the vegetation cover. However, Zahedifard's (2002) study NDVI had a meaningful correlation with the vegetation cover percentage (R^2= 0.83%) even though the vegetation cover rate was low. Farzad Mehr et al. (2004) in a study performed in the Semirom region estimated that the correlation between the NDVI index and vegetation cover data was significant at the $P < 0.5\%$ error. For the preparation of the vegetation cover map of Kalahurd, Sadeghi (2009) employed the Aster Satellite data. The results of his studies showed that there was a meaningful correlation between the numerical data resulting from the AWiFS image and the crown cover percentage. The results of this research also showed that only the NDVI index had a meaningful relation with the crown cover percentage. The significance of the crown cover percentage among the spectral gauge can be attributed to the high reflection of the vegetation cover in the Red and NIR spectral regions, which is considered an acceptable result.

The NDVI index had a strong correlation with the total cover. The image belonged to the vegetative growth stage when those plants were green and active. In combination with this band, a band of middle infrared was also used, was found to be suitable for cover estimation (Arzani, 1994). Band red was also sensitive to the brightness of the soil surface and was able to make an accurate estimation of the cover (Jianwen et al., 2005). Arzani (1994, 1998) investigated the ability of some vegetation indices and proved the real ability indices that had been created based on the middle infrared band. On account of the low percentage of crown cover in the region under study (25%) and the prevailing effect of the background reflection, as well as the nonlinear nature of relations between the spectral reflection and plant specifications, the correlation relations have practically lower justification coefficients. This was supported by Schmidt and Karnelli (2001) as well as Sellers et al. (1992). The results obtained by Sepehri (2003) also showed that because of the prevalence of spectral reflection of the soil, the estimation of the vegetation cover (< 40%) was difficult and there had to be other data such as the type of the soil, color, and leaf surface indices included in the model for the estimation of a vegetation cover less than 40% (Seperhi, 2003). The results obtained by Pickup et al. (1993) also showed that in the arid and semi-arid range, except for rainy seasons, most of the time the vegetation cover was not green and its reflection specifications were close to the soil specifications. Therefore, a vegetation index should have the capability of being used both in drought and green conditions of the cover.

Therefore, it can be concluded that by applying tested vegetation indices, the estimation of the vegetation cover and the conditions in the region had no desirable result. Finally, the field measurements were made by several different field workers, adding another source of variation to the data. For example, it has been shown that there may be up to a 20% difference in the measurements of the vegetation cover made by experienced field workers, using objective methods, similar to those made at the pastoral lease (Wilson et al., 1987).

CONCLUSION

One of the main objectives of this study was to identify the vegetation indices that were the best available predictors of a vegetation cover, which could then be used to construct a vegetation cover map, in the semi-arid rangelands in the center of Iran. Generally, based on the results of this research, there were significant correlations between the quantitative vegetation characteristics and AWiFS data in the sites of Semirom-Isfahan (Grassland and Shrub land). Suitable indices for each vegetation community differed based on the vegetation composition. Therefore, it is possible to evaluate rangeland vegetation using the AWiFS data for sustainable utilization. On account of the complexity of the range ecosystem it is very difficult to show all the changes with the quantitative model. However, suitable indices and ratios obtained from different vegetation communities in this study can provide accurate estimations from the vegetation parameters. The criteria that make an image-based vegetation index suitable for regional monitoring are strongly related to the vegetation cover and the vegetation types in the district and have the ability to predict this cover within the semi-arid regions. Simple red-infrared contrast indices, in particular NDVI, have been widely used with success in arid land studies throughout the world. Our results confirm that they are the best indices for recording the vegetation cover in semi-arid regions. This suggests that NDVI and simple red–infrared indices are useful for general cover monitoring, regardless of more localized soil and vegetation variation. The procedures described in this article can be considered as a simple rangeland remote sensing analysis models and can be used elsewhere to frequently provide efficient monitoring of the quantity of the cover, which is a prerequisite for an effective management and planning decision and for safe utilization of rangelands (Fig. 5). Therefore, remote sensing methods for vegetation cover assessment should be formulated in a manner that takes advantage of their strengths and minimizes their weaknesses. Remote sensing applications are perhaps the strongest when they are used as scaling tools for observational ground data, rather than as detailed physical models of the landscape.

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