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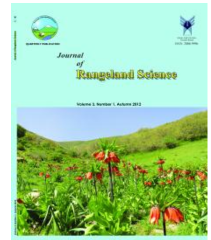

Full Length Article:

Identification of Invasive Species Using Remote Sensing and Vegetation Indices, (Case Study: Vazroud Rangelands, Iran)

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Received on: 08/01/2013
Accepted on: 23/06/2013

Abstract. Biological invasions form a major threat to the provision of ecosystems products and services and can affect ecosystems across a wide spectrum of bioclimatic conditions. Therefore, it is important to systematically monitor the spread of species over broad regions. It has long been recognized that remote sensing and geographical information system could contribute to this capacity. This paper aims to investigate the efficiency of Landsat TM images in identifying and classifying invasive species *Cirsium arvense* and *Stachys byzanthina* in Vazroud rangelands of Iran. For optimizing results, the Cos(t) model was used for atmospheric correction on the image. Then multiple vegetation indices, by extracting the digital mean of pixels related to training samples of the corrected image, were calculated. A supervised algorithm using minimum distance of mean was used as a classification technique for evaluation against ground truth map. The results indicated that NDVI, Ratio, RVI, TVI and NRVI were the most suitable indices for the discrimination of *Cirsium arvense* species. The best indices for the *Stachys byzanthina* species were DVI, NDVI, PVI 1, PVI 2, RVI and WDVI. Of all the indices analyzed, DVI and WDVI were able to discriminate both species but with varying degrees of separation.

Key words: Biological invasion, *Cirsium arvense*, Remote sensing, *Stachys byzanthina*, Vegetation index.

Introduction

Biological invasion is a recognized threat to ecosystems and economies worldwide. Invasive plants have been called non-natives, exotics, aliens, non-indigenous harmful species, and weeds. All of these definitions incorporate a basic concept: invasive plants are plants that have been introduced into an environment in which they did not evolve and thus usually have no natural enemies to limit their production and spread (McQueen and Noemdoe, 2000; Bradley and Mustard, 2006). At international level, there is a growing agreement that invasion by invasive species is one of the greatest threats to biological diversity conservation. Massive habitat destruction by invasion of exotic species into areas where they did not evolve is considered to be one of the causes of diversity loss (Joshi, 2006). Much research into discriminating invasive species from the native vegetation has been undertaken in order to develop a sustainable protection strategy (Parker-Williams and Hunt, 2004). Remote sensing technology has many attributes that would be beneficial to detecting, mapping and monitoring invaders (Joshi, 2006; Huang and Asner, 2009). This technology has been used to assess invasive species attributes such as canopy architecture, vegetation density, leaf pubescence and phenological stage (Everitt *et al.*, 2001). Many studies show remote sensing evolution and satellite imagery processing in discrimination and mapping of invasive vegetation. The resulting maps can be seen as a baseline inventory to assist natural resource or conservation management (Oldeland *et al.*, 2010). For example, Peterson (2005) combined field survey data and multi-seasonal ETM+ images to estimate *Bromus tectorum* in the Great Basin, USA using a specific regression model. His results showed good correspondence between sampled and estimated *Bromus tectorum* ground cover. Kandwal *et al.* (2009) in order to discriminate the invasive species *Lantana camara* using vegetation indices evaluated the utilities of twenty nine common vegetation indices. Their results showed that SAVI is most favorable in discriminating Lantana followed by PVI 3.

This research is an attempt to study and evaluate of some vegetation indices in problem resolvent of composition of *Cirsium arvense* and *Stachys byzanthina* from other species and the preparation of their spatial distribution map.

Materials and Methods

Study area

The study area is located at longitude of 52º 01' 43" to 52º 12' 23" E and latitude of 36º 14' 13" to 36º 18' 49" N in the rangelands of Northern slopes of Alborz Mountains, in the south of Caspian Sea (Fig. 1). The field site includes two ecosystem regions from highland to the forest zone. In highland, the dominant vegetations are related to the rangeland. From 14123 ha of the study area, 5000 ha belonged to the rangelands.

Preprocessing and preparing of official data

Used digital data in this study are part of a frame of TM sensor of Landsat satellite. This image was taken on June 3, 2010. Geometric correction was made using first order polynomial transformation model and nearest neighbor method for resampling. The image was corrected geometrically by choosing 17 ground control points on study area. For atmospheric correction, spectral values for each band converted to radiance and reflectance. Then spectral radiance converted to reflectance (Chavez, 1988).

Field sampling and ground truth map production

To determine training samples, 30 points were sampled by GPS device using stratified-random sampling method. In such a way that by using GPS and recording central point geographical coordinates of a class of *Cirsium arvense* and *Stachys byzanthina* and also their angles coordinate as a circle, first a point map was built in GIS and then ground truth map was prepared by connecting the points of these polygons. Percentage of these species canopy cover was 50-60 in training samples.

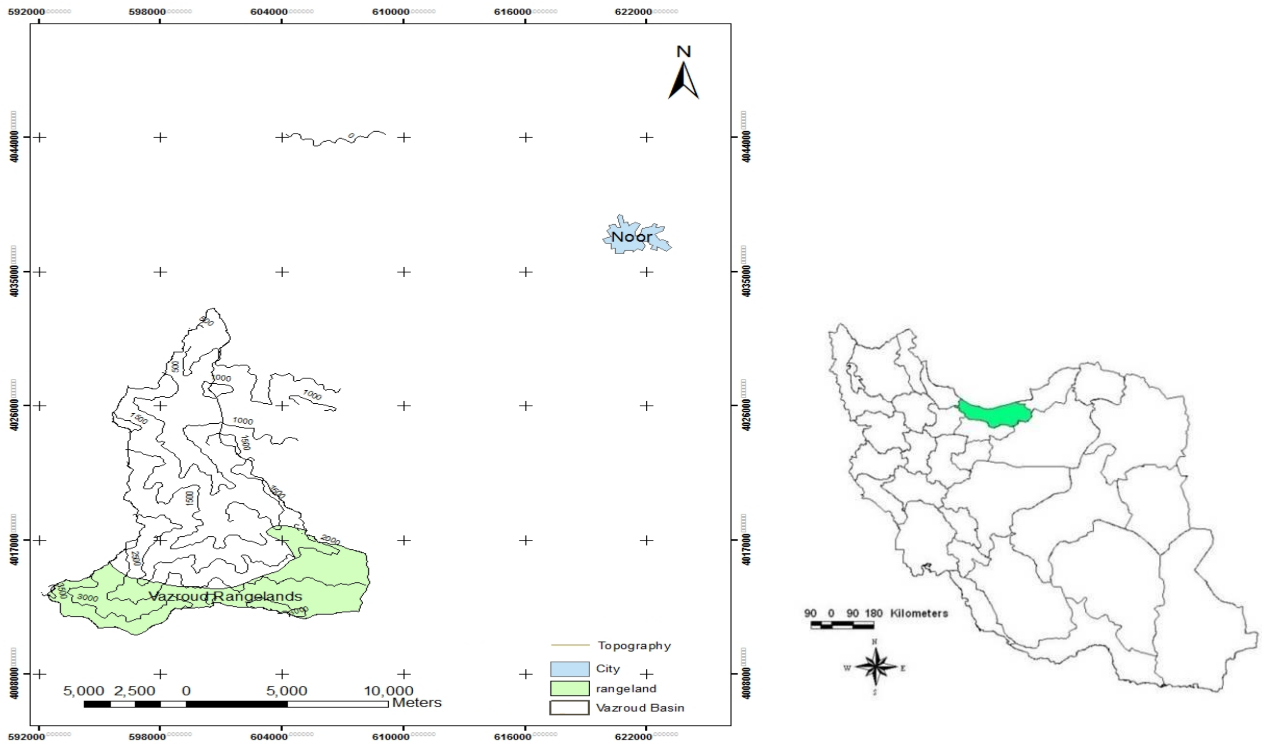

Fig. 1. Location of the study area on Iran and Vazroud basin

Vegetation indices selection and classification

To prevent background soil spectral reflectance's interference in vegetation cover spectral reflectance, NDVI, WDVI, SAVI and TSAVI indices which reduce soil spectral reflectance effects (Alavipanah, 2006) were calculated. To calculate these indices soil line factors were used i.e. the relation between soil line reflectance observed in two different wavelengths. The aim to use this line was to show correct reflectance of vegetation canopy cover from soil's spectral reflectance effects by applying these indices (Baret and Jocquemoud, 1993; Sundison and Henley, 1999). To reveal vegetation and minimize effective variable's impact on reflectance like canopy cover geometry, background soil and atmospheric conditions, some vegetation indices were used. To calculate indices, the mean of digital pixels related to sampling units of the corrected image was extracted. SAVI is intended to minimize the effects of background soil on the vegetation signal by incorporating a constant soil adjustment factor (L) into the denominator of the NDVI formula.

The (L) factor chosen depends on the density of the vegetation and its determination depends on prior knowledge about vegetation density (Huete, 1988). NDVI is based on this fact that chlorophyll existing in plant structure is able to absorb red light and leaf mesophyll reflects NIR light. NDVI ranges from -1 to 1 which its negative values represent non-vegetation surfaces (Rouse *et al.*, 1974).

Supervised method in minimum distance of mean classifier was used as classification technique. After featuring the pixel that assigns the selective samples spectral value mean of every class to itself, the distance of every unclassified pixel with mean pixels is calculated and the intended pixel assigns to a class which has the closest distance to the mean (Zobeiry and Majd, 2005).

Accuracy and precision assessment of indices

In each confusion matrix, an overall accuracy, producer and user accuracies, kappa coefficient, commission and omission errors are reported. The coefficient is calculated by multiplying the total number of pixels in all the ground truth classes (N) by the sum of the confusion matrix diagonals (X_{kk}), subtracting the sum of the ground truth pixels in a class times the sum of the classified pixels in that class summed over all classes ($X_{k\Sigma}X_{\Sigma}k$), and dividing by the total number of pixels squared minus the sum of the ground truth pixels in that class times the sum of the classified pixels in that class summed over all classes:

$$k = \frac{N\sum_k X_{kk} - \sum_k X_{k\Sigma}X_{\Sigma k}}{N^2 - \sum_k X_{k\Sigma}X_{\Sigma k}} \quad \text{……… (Equation 1)}$$

k varies from 0 (full disagreement) to 1 (full agreement) and if k<0.4, 0.4<k<0.75 and k>0.75, it will be classified as poor, fair and power, respectively. The best classification happen when overall accuracy and kappa coefficient are both high (>0.6) (Foody, 1992). The steps of this study are shown in (Fig. 2).

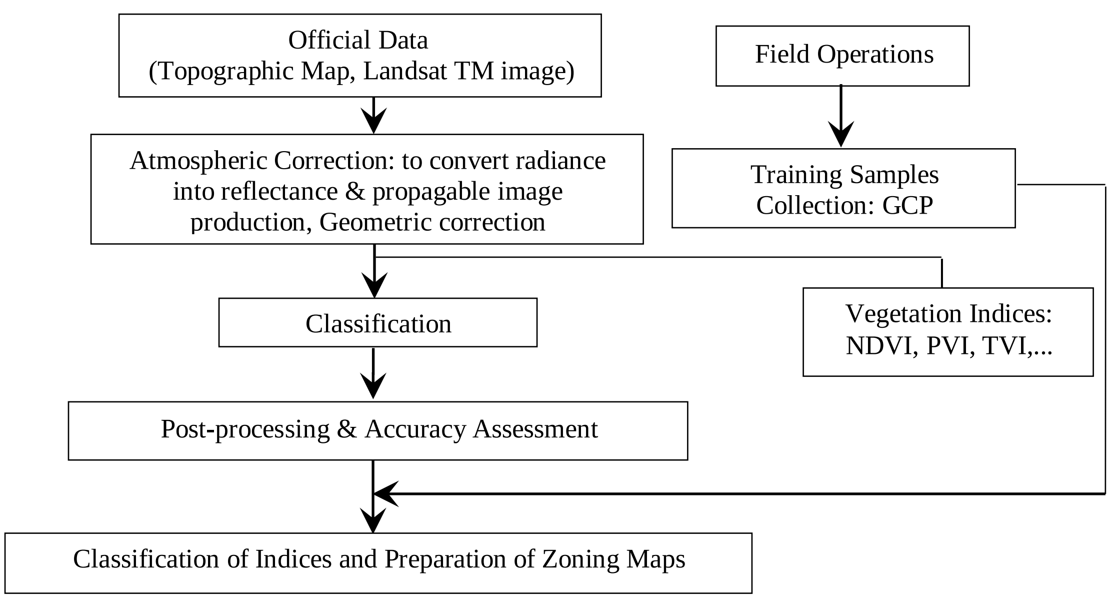

Fig. 2. Steps of the study

Results

Using corrected bands were obtained vegetation map for each index. Determinate coefficient and regression coefficient of red and near infrared bands are 98.49% and 99.24% respectively. High determinate coefficient implies high relationship of spectral value levels in both bands. Regression coefficient shows the correlation level observed for dependent variable and its predicated level from regression model (Figs. 3 and 4).

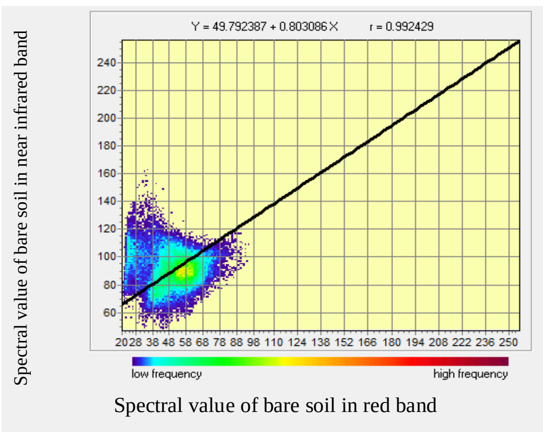

Fig. 3. Distribution of spectral values of bare soil pixels in space of red and NIR bands

Relation between soil line and red and near infrared bands is:

$Y = 0.803\,X + 49.79$ ………….. (Equation 2)

X and Y are spectral value of bare soil in red and NIR bands. Equation 2 is used to create PVI 2 ,PVI 3, TSAVI and TSAVI1 (Schmidit and Karnieli, 2001).

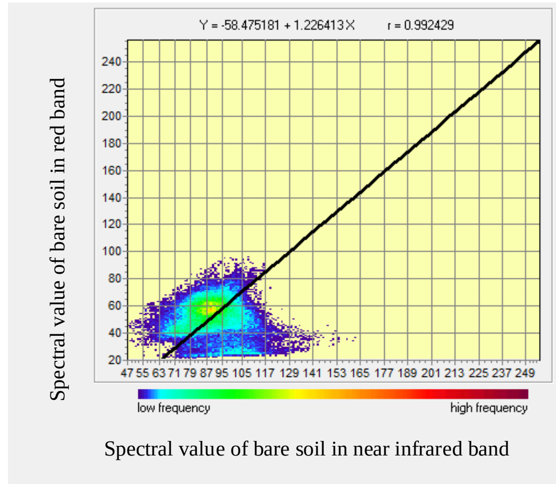

Fig. 4. Distribution of spectral values of bare soils pixels in space of NIR and red bands

Relation between soil line and near infrared and red bands is:

$Y = 1.266\,X - 58.47$ ………..….. (Equation 3)

Where X: Spectral value of bare soil in NIR band and Y: Spectral value of bare soil in red band. The obtained coefficients are used to create PVI, PVI 1, DVI and WDVI indices (Schmidit and Karnieli, 2001).

The best response for separation of *Cirsium arvense* from other classes is relevant when using NDVI, Ratio, RVI, TVI and NRVI. For separation of *Stachys byzanthina* best responses were obtained by using DVI, NDVI, PVI 1, PVI 2, RVI and WDVI (Table 1).

Table 1. Overall Accuracy (O. A.) and Kappa coefficient for vegetation indices (see nomenclature in last page)

Veg. Index	Formulae	O. A. (%) *C. arvense*	*S. byzanthina*	Kappa *C. arvense*	Coefficient *S. byzanthina*
AVI	$NIR - RED$	71.42	57.14	0.42	0.08
CTVI	$\frac{NDVI + 0.5}{\lvert NDVI + 0.5\rvert} \times \sqrt{\lvert NDVI + 0.5\rvert}$	75	62.5	0.5	0.25
DVI	$(b \times NIR) - RED$	71.42	87.5	0.46	0.72
NDVI	$NIR - RED/NIR + RED$	87.5	87.5	0.75	0.75
NRVI	$RVI - 1/RVI + 1$	75	75	0.75	0.5
PVI	$(\sin(a) \times NIR) - (\cos(a) \times RED)$	71.42	71.42	0.46	0.46
PVI 1	$\frac{(bNIR - RED + a)}{\sqrt{b^2 + 1}}$	62.5	87.5	0.25	0.75
PVI 2	$\frac{(NIR - a).(RED + b)}{\sqrt{1 + a^2}}$	62.5	87.5	0.25	0.75
PVI 3	$(a.NIR) - (b.RED)$	75	75	0.5	0.5
Ratio	NIR/RED	87.5	62.5	0.75	0.25
RVI	RED/NIR	87.5	87.5	0.75	0.75
SAVI L0.25	$\frac{NIR - RED}{NIR + RED + 0.25} \times 1.25$	55	71.42	0.35	0.36
SAVI L0.5	$\frac{NIR - RED}{NIR + RED + 0.5} \times 1.5$	50	75	0.3	0.5
TSAVI	$\frac{a(NIR - (a \times RED) - b)}{RED + (a \times NIR) - ab + X(1 - a^2)}$	64.28	57.14	0.31	0.22
TSAVI 1	$\frac{a\big((NIR - a)(RED - b)\big)}{RED + a.NIR - ab}$	75	65	0.5	0.45
TVI	$\sqrt{\left(\frac{NIR - RED}{NIR + RED}\right) + 0.5}$	87.5	75	0.75	0.5
WDVI	$(NIR - (a \times RED)$	64.28	87.5	0.31	0.75

Training samples of *Cirsium arvense* and *Stachys byzanthina* introduced to software in order to classify the indices which had more efficiency than other indices. Thus were created vegetation maps for both species and by minimum distance algorithm (Figs. 5 and 6). Maximum occupied area by *Cirsium arvense* is relevant to RVI and TVI (10.5 km^2) and by *Stachys byzanthina* is relevant to DVI and WDVI (5.84 and 5.46 km^2 respectively).

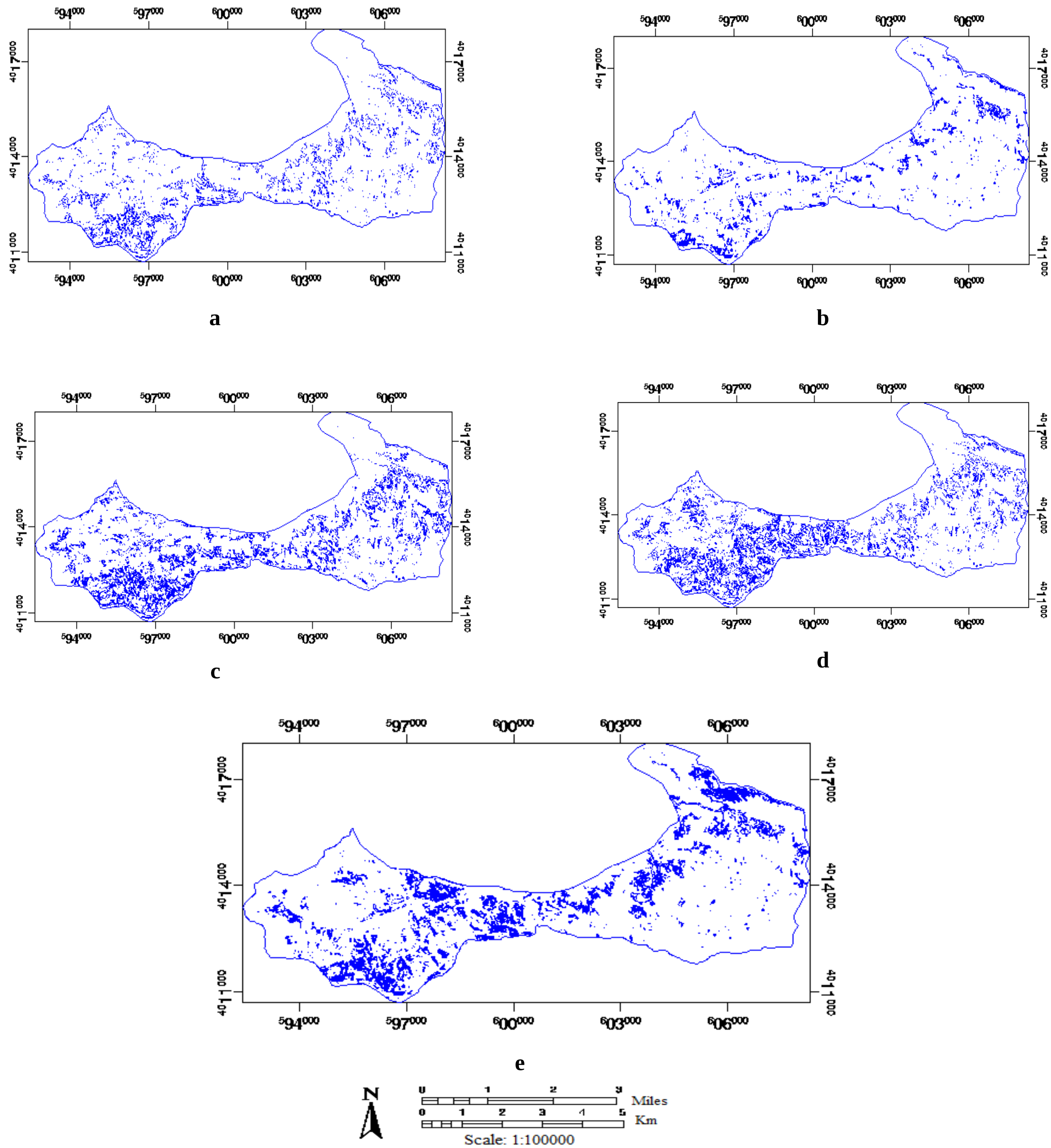

Fig. 5. *Cirsium arvense* mapping of the study area by classification of: a) NDVI, b) Ratio c) RVI, d) TVI and e) NRVI

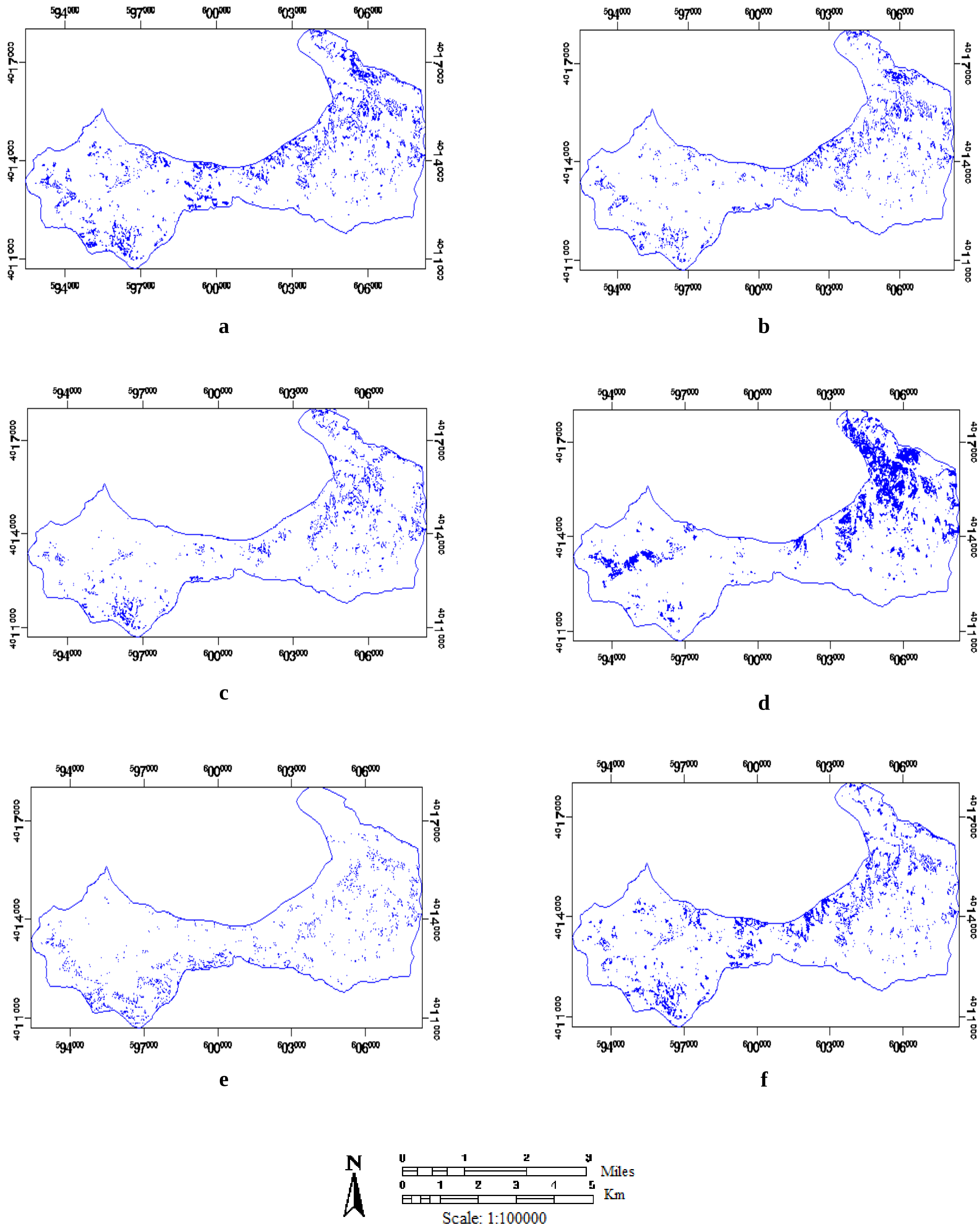

Fig. 6. *Stachys byzanthina* mapping of the study area by classification of: a) DVI, b) NDVI, c) PVI1, d) PVI2, e) RVI and f) WDVI

Since each class is scattered about its mean with some deviation, so initially to incorporate the deviation, μ±SD were taken as criterion for the spectral plots (Kandwal *et al.*, 2009; Fig. 7).

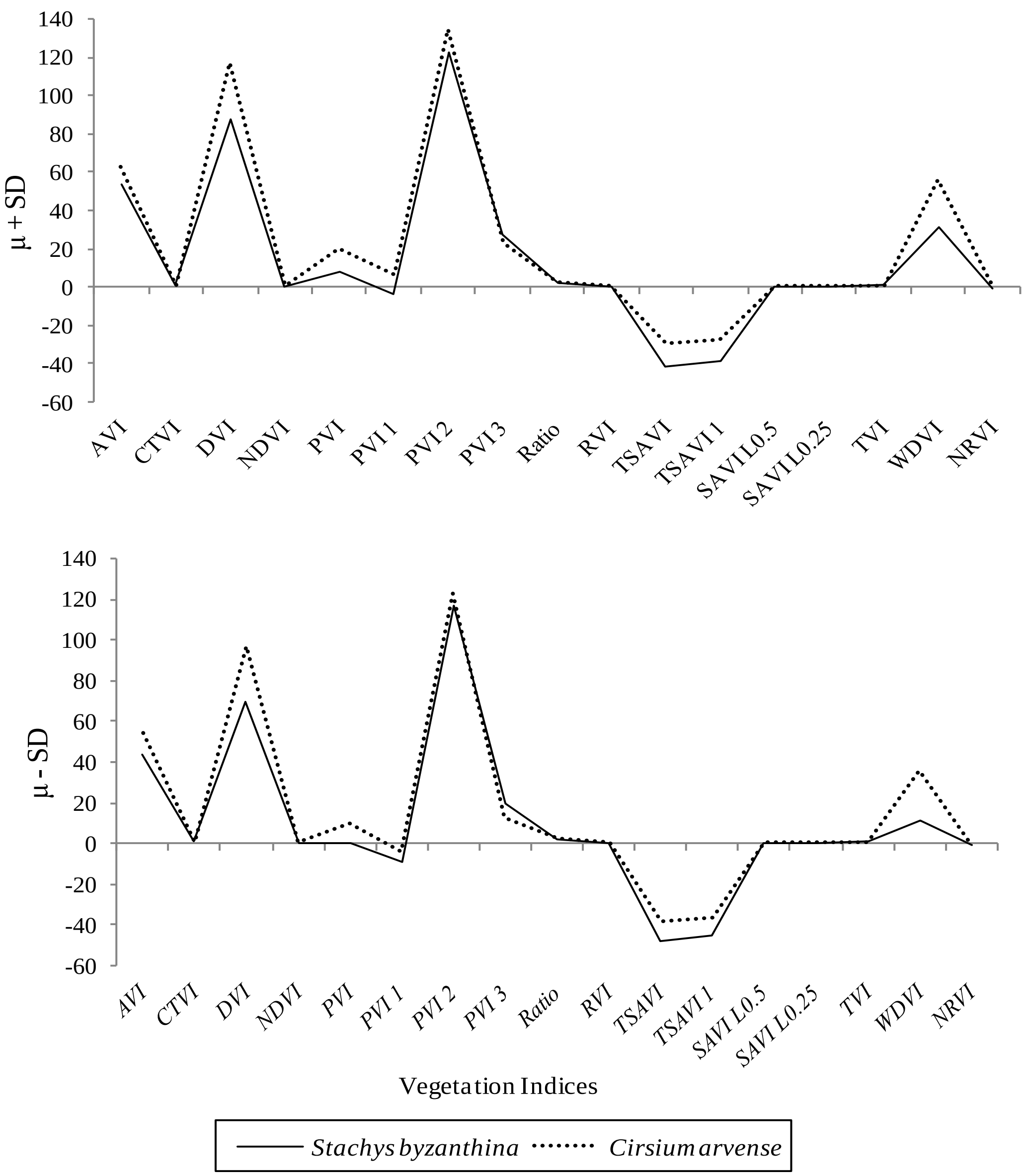

Fig. 7. Spectral analysis of vegetation indices developed using Landsat TM bands

The graph helped in selecting the best performing indices for separating *Stachys* from *Cirsium* and its visual interpretation shows that of all the indices analyzed, DVI and WDVI are most adequate to distinguish *Stachys byzanthina* and *Cirsium arvense* but with varying degrees of separation. Therefore, these indices can produce good results as a measure separation in future studies.

Discussion

Regarding that accessing basic and up to date data about rangelands requires successive measurements in a period of several years, and since every component of rangeland has different reflectance, it's suggested to use vegetation indices to study rangeland cover. However, to analyze cover precisely and even to determine cover types, it's impossible to use only one index and it's more useful and fruitful to use several indices along with each other and to apply previous information about the region under study. Because red band wavelength is shorter than infrared band wavelength, they have higher distribution than infrared band. As a result, some vegetation indices levels like NDVI are less than their real level. Therefore, accurate geometric and radiometric corrections of images are the preprocess requirements in zoning invasive species. In this study, before applying indices and classification in order to remove undesirable atmospheric effects on the image and consequently to offer better relations with vegetation cover quantitative parameters and accurate process of field with canopy cover at different times, Cos (t) method was used.

As were mentioned in results section, NDVI and RVI show fine performance in *Cirsium arvense* and *Stachys byzanthina* zoning discrimination. From this view our study agrees with findings of other researchers like Peterson (2005), Bradley and Mustard (2006), Hestir *et al.* (2008), Kandwal *et al.* (2009) and Evangelista *et al.* (2009). TVI and DVI efficiency for the discrimination the invasive species were observed in Kandwal *et al.* (2009) study. TSAVI1 had almost the same accuracy of the NDVI and RVI that this similar function can be due to very low effect of background soil in measured samples, because field sampling was done while this species was in its proper vegetation growth and background soil had trivial effects on reflection.

Since TVI benefits from NDVI in its structure and both are standard of slope line between red and near infrared space, it has almost the same accuracy (Deering *et al.*, 1975). To map accurately the result of this type of biological invasions, there is a clear need of combined use of remote sensing, GIS and expert knowledge. Management dealing with invasive species requires accurate mapping and modeling techniques and development of those will be a valuable step toward conservation of native biodiversity.

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Nomenclature of Vegetation Indices

AVI: Ashburn Vegetation Index
CTVI: Corrected Transformed Vegetation Index
DVI: Difference Vegetation Index
NDVI: Normalized Difference Vegetation Index
NRVI: Normalized Ratio Vegetation Index
PVI: Perpendicular Vegetation Index
RVI: Ratio Vegetation Index
SAVI: Soil Adjusted Vegetation Index
TSAVI: Transformed Soil-Adjusted Vegetation Index
TVI: Transformed Vegetation Index
WDVI: Weighted Difference Vegetation Index

شناسایی گونه‌های مهاجم با استفاده از سنجش از دور و شاخص‌های گیاهی، مطالعه موردی: مراتع وازرود (ایران)

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چکیده

هجوم‌های زیستی از یک خطر عمده در تأمین محصولات و خدمات اکوسیستم‌ها ناشی می‌شوند و می‌توانند در طیف وسیعی از وضعیت‌های زیست اقلیمی بر روی اکوسیستم‌ها تأثیر بگذارند. بنابراین اغلب پایش سیستماتیک گسترش گونه‌ها در یک ناحیه وسیع اهمیت دارد. مشخص شده که تکنیک‌های سنجش از دور و سامانه اطلاعات جغرافیایی می‌توانند در شناسایی گونه‌های مهاجم سودمند باشند. این مقاله نیز به بررسی کارآیی تصویر لندست TM در شناسایی و طبقه‌بندی گونه‌های مهاجم کنگر صحرایی و سنبله نقره‌ای در مراتع وازرود می‌پردازد. جهت حصول نتایج بهتر، تصحیح اتمسفری تصویر با مدل Cos (t) انجام و سپس تعدادی از شاخص‌های گیاهی با استخراج میانگین رقومی پیکسل‌های مربوط به نمونه‌های تعلیمی بر روی تصویر تصحیح شده اعمال گردیدند. طبقه‌بندی با الگوریتم حداقل فاصله از میانگین انجام و با نقشه واقعیت زمینی مورد ارزیابی صحت و دقت قرار گرفت. نتایج نشان داد که شاخص‌های NDVI، Ratio، RVI، TVI و NRVI برای تشخیص گونه کنگر صحرایی و شاخص‌های DVI و WDVI برای سنبله نقره‌ای مناسب‌ترین شاخص‌ها بودند. همچنین از میان کلیه شاخص‌های آنالیز شده، شاخص‌های DVI و WDVI با درجات متفاوتی از تفکیک قادر به تفکیک این دو گونه از هم بوده‌اند.

کلمات کلیدی: هجوم زیستی، ***Cirsium arvense***، سنجش از دور، ***Stachys byzanthina***، شاخص گیاهی