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Prediction of Landscape Function and Soil Surface Condition in the Libyan Rangelands Using Selected Spectral Vegetation Indices

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Abstract: Spectral Vegetation Indices (SVIs) have been used to examine variations in vegetation formation and phenology. Lately, researchers and agricultural practitioners have utilized SVIs to examine various soil properties for instance moisture and nutrients. From our review of the literature, there were few comprehensive studies conducted to know whether it is possible or not to predict landscape function indices by using remote sensing technology, and which spectral vegetation index is the best predictor. It has been shown that landscape function indices can be accurately predicted by Normalized Different Vegetation Index (NDVI). Therefore, we attempted to test the ability of selected SVIs to predict landscape function indices (LFA-SSA) in the Mediterranean steppes of Al-Jabal Al-Akhdar, northeast Libya. We used data collected between May and October of 2006 and 2014. A total of 28 sites were chosen to collect the data for both SVIs and LFA-SSA. Simple linear regression was applied between LFA-SSA and SVIs. The results demonstrated that there is a positive linear relationship between LFA-SSC and the selected SVIs. The findings revealed that the Normalized Different Vegetation Index (NDVI) and Modified Soil Adjusted Vegetation Index (MSAVI) acquired from the Landsat Enhanced Thematic Mapper Plus (ETM+) could be utilized in predicting the variability of significant structural and functional qualities of soil and vegetation in the Mediterranean climate.

Keywords:SSCI, MSAVI, WII, LFA-SSA

INTRODUCTION

In arid and semi-arid areas, vegetation cover has been identified as being linked to various ecosystem indicators, for instance, microbial processes(Mazzarino, Bertiller, Sain, Laos, & Coronato, 1996), nutrient cycling and storage (Maestre & Escudero, 2009), and soil-water infiltration and overflow(Vásquez-Méndez et al., 2010). Studies have examined the ability of the Normalized Different Vegetation Index (NDVI) to determine variations in vegetation formation, phenology, and general health (Holm, Burnside, & Mitchell, 1987; Yeganeh, jamale Khajedein, Amiri, & Shariff, 2014; Zhao et al., 2009 Jiang et al., 2006). Lately, researchers and agricultural practitioners have employed the NDVI to examine some worthy properties of soil such as moisture (Han, Wang, & Zhao, 2010) and nutrients(Rivero, Grunwald, Binford, & Osborne, 2009). A study conducted by (Paredes, 2011)examined the connection between plant cover and biomass while testing several SVIs. It seems that there were few comprehensive studies that have directly examined the relationship between landscape function and soil surface condition indices (LFA-SSA) and the SVIs. These studies were conducted to determine whether it is possible to predict LFA indices by using remote sensing technology, and which SVIs is the best predictor of landscape function indices. It has shown that LFA parameters could accurately be predicted by the NDVI as seen in restored

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Australian mines(Lau, Hewson, Ong, & Tongway, 2008; Ong, Tongway, Caccetta, & Hindley, 2009), at two gold and uranium mining operations in the Highveld grassland biome and the Eastern Cape Province in South Africa(Furniss, 2010; Kakembo, Ndlela, & Cammeraat, 2012), semi-dry grass-lands in Spain(García-Gómez & Maestre, 2011), and in the Patagonian rangeland steppes(Gaitán et al., 2013).LFA indices could be mapped using remote sensing tech-nology(Lau et al., 2008). Some results showed a significant positive linear relation-ship between SVIs and both vegetation cover and plant biodiversity(Gaitán et al., 2013).

In another study, there was a positive and lin-ear relationship between the NDVI and soil surface condition indices except in the stabil-ity index where the relationship was weak(Furniss, 2010). The NDVI could repli-cate the ecosystems existing in semi-arid Mediterranean steppesand might be a useful index to regulate the status of the larger re-gions in these ecosystems functions, and the potential encroachment of desertification (Gaitán et al., 2013; García-Gómez & Maestre, 2011; Mahmoud, Hasmadi, Alias, & Azani, 2016).

Therefore, we attempted to test the ability of selected SVIs to predict LFA-SSA. We used data collected in May and October of 2006 and 2014 in the Mediterranean steppes of Al-Jabal Al-Akhdar known as (The Green Mountain), northeast Libya.

MATERIALS AND METHODS

The Study Area: The study area is located on the southern slope of Al-Jabal Al-Akhdar, northeast Libya, approximately 32°N, and 21°E, occupying an area of about 3000 km² (Figure 1). The rainfall range in the region is between 50 to 250 mm per year and tempera-ture reach below 0^{o}C in January and up to 35^{o}C in July and August. 2008).

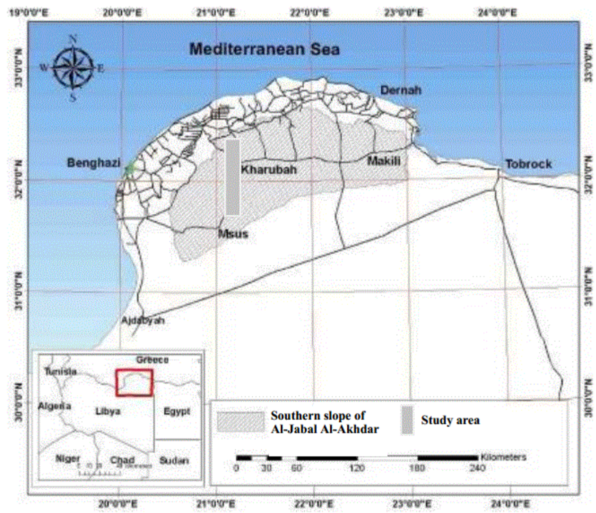

Figure:(1). Southern Al-Jabal Al-Akhdar map, shows the location of study area(Hamad, 2012)

At lower elevations and reduced rainfall, a belt of dwarf shrub steppe consisting of *Artemisia herba-alba* and *Haloxylonscoparium* occupies the low hills and the undulating and narrower alluvial plains. Further south, a steppe of stem and leaf-succulent plants occupy the board flat alluvial plains and drier undulating plains. Spe-cies in this formation include *Haloxylonsco-parium, Anabasis articulata, Suaedapruinosa,* and *Salsolatetrandra*(Mahmoud et al., 2008).

Landscape Function Analysis, Soil Surface Condition Methodology: To achieve the ob-jective of this research we used LFA method-ology. LFA data was collected on line transects oriented in the direction of resource flow. The soil surface data are combined in different combinations to reflect major soil habitat quali-ty indices.(Tongway & Hindley, 2004). Five LFA-SSA indices were used (Table 1).

Table: (1). Landscape Function and Soil Surface As-sessment Indices (LFA, SSA)

Index Name	Code	Scale / Unit
Soil Stability Index	SSI	0 - 100
Water Infiltration Index	WII	0 - 100
Nutrient Cycling Index	NCI	0 - 100
Soil Surface Condition Index	SCCI	0 - 100
Landscape Organization Index.	LOI	0 - 1

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SVIs Data Sources and Analysis: We attempted to test satellite images of the Landsat Enhanced Thematic Mapper Plus (ETM+) which would cover a vast area and save time and money. We used two Landsat satellite images captured from Landsat-7 (ETM+) in September (2006 and 2014) with eight bands and resolution of 30m (Table 2). Typically, Landsat 7 ETM+ images include many types of errors which affect the results. ERDAS Imagine software V.9 was employed to correct the satellite image's radiometric, atmospheric and geometric errors, and calculate SVIs. It should be noted that these errors have been minimized in the sensors of newer devices. The Universal Transverse Mercator coordinator system (UTM) was used to correct the images geometrically. The Geographic Information System (GIS) data of 28 sites (ground control points) were used to correct and validate the geometric errors.

Table (2). Landsat Satellite Imagery Characteristics

Instrument	Acquisition date	Path /row	Spectral bands	
			bands	Wave-length (µm)
ETM+	Dec.2006		1	0.45 - 0.52
	Dec.2014	183/38	2	0.525 - 0.60
			3	0.63 - 0.69
			4	0.77 - 0.90
			5	1.55 - 1.75
			6	10.40 - 12.5
			7	2.09 - 2.35
			Pan.	0.52 - 0.90

The Selected Vegetation Indices: Vegetation Indices have been widely used in remote sensing applications of rangeland management, they are also used in available software in markets(Mróz & Sobieraj, 2004). Through a review of the most common Vegetation Indices that were used in the arid and semi-arid rangelands studies included the advantages and disadvantages of each index, we concluded that the Normalized Difference Vegetation Index (NDVI) and Modified Soil Adjusted Vegetation Index (MSAVI) are the most useful indices to achieve the objective of this study.(Rouse Jr, Haas, Schell, & Deering, 1974)was the first to describe the NDVI (Equation 1). Several Near Infra-Red (NIR) wavelengths across the 750 to 900 nm band, as he found, had no important differences. Higher NDVI values are led by darker soil substrates under incomplete canopies. Fortunately, in our study area there is no dark soil, so NDVI may be useful in predicting LFA indices to produce a model that could monitor the status of rangelands in a large area. MSAVI is a modification of the Soil Adjusted Vegetation Index (SAVI) to account for areas which have a low (i.e. <40%) vegetation cover. MSAVI is particularly important for the study areas which have different soil brightness coefficients (Gaitán et al., 2013). As a result of the abovementioned advantage, MSAVI is considered to be a suitable index for rangeland studies in arid areas. Moreover, it usually has a strong correlation relationship with field data related to vegetation cover. It is also very useful for degradation classification in monitoring desertification (Mahmoud et al., 2016), as well as the estimation of biomass. Due to the reasons above, MSAVI may be suitable for the research objective (Equation 2).

$$\text{NDVI} = NIR - \text{R} \,/\, NIR + R \ldots\ldots \text{ Equation 1}$$

$$\text{MSAVI} = \frac{[2 * \text{NIR} + 1 - \sqrt{(2 * \text{NIR} + 1)2 - 8 * (\text{NIR} - \text{R})}]}{2} \ldots\ldots \text{Equation 2}$$

Where R is the Red band, and NIR is the Near Infra-Red.

Sampling Design and Statistical Analysis:A total of 56 values for each index were calculated from 28 sites in 2006 and 2014. The site layout was based on the Western Australia Rangeland Monitoring System(Russell, 2007; Watson, Thomas, & Fletcher, 2007). There were five line-transects per site. There was an analysis of NDVI and MSAVI variations between the years 2006 and 2014 and their links

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to landscape function and soil surface condition in the study area. SPSS software, version 20,was employed for all statistical analysis (SPSS Inc., Chicago, IL, USA). In all statistical testing, significant differences were regarded as probability values less than 5 %. Our hypothesis was posed as follows: There is a linear relationship between LFA-SSA indices and the selected SVIs. In other words, LFA-SSA indices can be predicted using NDVI and MSAVI. Simple linear regression was applied with LFA-SSA indices as dependent variables and SVIs as independent variables (the predictors). 39 samples (70%) were randomly selected for the prediction model, while the rest (17 samples) were used for the cross-validation model. This process was repeated 100 times in order to estimate the means of coefficient of determination (R^2) for both prediction and validation models, as presented in Equation 3.

$$R^2 = [(1 / N) * \Sigma [(xi - x) * (yi - y)] / (\sigma x * \sigma y)]^2$$ ……………Equation 3

Where N is the number of observations used to fit the model, Σ is the summation symbol, xi is the x value for observation i, x is the mean x value, yi is the y value for observation i, y is the mean y value, σx is the standard deviation of x, and σy is the standard deviation of y.

RESULTS AND DISCUSSION

As portrayed in tables 3 and 4, the findings demonstrated that there exists a good linear relationship between LFA-SSA indices and the selected SVIs. The applied regressions showed a positive and linear correlation between both NDVI and MSAVI, and SSCI (R^2 = 0.62 and 0.51 respectively, and $P < 0.05$ in 89% of the cases). Increments in variability were equally computed for the five LFA-SSA indices, while the indices for landscape organization, soil stability, water infiltration, nutrient cycling, and overall soil health ranged from 0 to 0.3, 33% to 61%, 26% to 38%, 14% to 33%, and 23% to 44% in that order. In this study, a linear relation between MSAVI and LFA indices was realized in -nutrient cycling and infiltration that had $R^2$of 0.44 and 0.36 in that order, while their correlation with the NDVI was relatively weak (Table 3).In their research(García-Gómez & Maestre, 2011) calibrated vegetation cover and LFA indices with NDVI calculated from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), in Steppes semi-arid area. During the process of model's validation, the two researchers obtained R^2 values varying from 0.49 to 0.75, while MSAVIshowed a weak linear relationship with SSI, WII and NCI (R^2 = 0.10, 0.22 and 0.33 respectively). In our results, MSAVI has a strong positive correlation with WII and NCI, R^2 = 0.46 and 0.55 in that order, while in the case of stability index the results were the same as Gaitán et al (2013)(R^2 = 0.1). There was a positive and linear relationship between NDVI and MSAVI, and landscape function and soil surface condition indices except for stability index where the relationship was weak. Our results were supported by similar results in the Mediterranean climate of South Africa (Furniss, 2010). Discrepancies in the stability index are not operated by variations in vegetation cover; hence this role cannot be suitably determined from SVIs (Furniss, 2010).

On the other hand, the frail connection amid the stability index and SVIs obtained here implies that other factors in addition to vegetation cover have an impact on the stability of soil. From the results, we realized that about 35% of Landscape Organization Index is predicted by NDVI, a finding probably operated by the constructive linear correlation amid Total Patch Area (TPA) in our data. However, the linear relationship between NDVI and LOI in 2006 was weaker than 2014, this may be attributed to the precipitation which has a very strong positive relationship with NDVI (Nicholson, Davenport, & Malo, 1990). This could explain why the linear relationship between NDVI and LFA-SSA indices especially LOI was positively very strong in both prediction and validation models (R^2 = 0.65 and 0.75 respectively) in the

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Mediterranean Spanish steppes which receives more precipitation compared to the study area (400mm) (García-Gómez & Maestre, 2011). Referring to a research conducted by (Yeganeh et al., 2014), there was a very high linear relationship between NDVI and SAVI, and changes in the vegetation cover where R^2 was 0.85 in about 90% of the cases. Despite the approaches primarily employed in achieving the correlations found, of which could not be expounded with measurements considered in the current study, the obtained results prove that SVIs could be employed in predicting deviations in the dry areas of rangeland ecosystems. The findings of the current research demonstrate the potential of Landsat ETM+ in evaluating the changeability of functional and structural qualities over extensive areas, but it entails a few limitations that ought to be considered. For instance, the models generated entailed R^2 values being less than 0.68. Also, the average of R^2 values were less than 0.71 in all validation models as indicated in Table 3, implying that developments on the extrapolative remote sensing information ability to envisage such indicators are likely. Our results illustrate that the LFA-SSA indices may be determined remotely with the help of Vegetation Indices set from satellite imagery that is directly related to the amount of minerals in the soil, vegetation and litter cover. The findings also support similar results in the Mediterranean climate (Furniss, 2010; Gaitán et al., 2013; García-Gómez & Maestre, 2011).

Table (3). Summary of 100 Models Used to Predict and Validate LFA-SSA Indices by Using NDVI

Model	Variables	Mean R^2		General Mean R^2	% of significant ($p<0.05$)	
		2006	2014		2006	2014
Prediction ᵃ	NDVI - SSI	0.26	0.37	0.32	89	89
	NDVI - WII	0.25	0.32	0.29	90	100
	NDVI - NCI	0.39	0.16	0.28	90	87
	NDVI - SSCI	0.56	0.68	0.62	100	100
	NDVI - LOI	0.26	0.45	0.35	67	100
Validation ᵇ	SSI	0.33	0.31	0.32	67	68
	WII	0.36	0.35	0.36	46	60
	NCI	0.46	0.32	0.39	86	73
	SSCI	0.66	0.71	0.69	75	90
	LOI	0.25	0.46	0.36	42	41

a: in all cases n = 39 b: in all cases n = 17

Table (4). Summary of 100 Models Used to Predict and Validate LFA-SSA Indices by Using MSAVI

Model	Variables	Mean R^2		General Mean R^2	% of significant ($p<0.05$)	
		2006	2014		2006	2014
Prediction ᵃ	MSAVI - SSI	0.10	0.50	0.25	20	83
	MSAVI - WII	0.46	0.36	0.41	100	91
	MSAVI - NCI	0.55	0.44	0.49	93	83
	MSAVI- SSCI	0.54	0.49	0.51	87	100
	MSAVI - LOI	0.16	0.48	0.32	100	100
Validation ᵇ	SSI	0.19	0.53	0.36	30	100
	WII	0.30	0.38	0.34	73	47
	NCI	0.50	0.29	0.39	81	54
	SSCI	0.45	0.38	0.41	63	74
	LOI	0.07	0.38	0.22	30	69

a: in all cases n = 39 b: in all cases n = 17

CONCLUSION

NDVI and MSAVI were able to determine the changes in the function of the ecosystem that appeared to have a correlation with LFA parameters. Notably, the stability, nutrient cycling, as well as infiltration indices have emerged to be reliable from a multitude of ground-oriented and spectral data. Something is very intricate and expensive to attain when employing only field-based assessment. Therefore, SVIs can be employed as a consistent and comparatively simple to use a tool in monitoring and assessing rangeland degradation processes. Furthermore, additional case studies from different environments should be conducted.

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التنبؤ بوظائف المنظر الطبيعي وحالة سطح التربة في المراعي الليبية باستخدام مؤشرات غطاء نباتي طيفية مختارة

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المستخلص: استخدمت أدلة الغطاء النباتي الطيفية (SVIs) لدراسة الاختلاف في تركيب الغطاء النباتي والفينولوجيا. حديثاً وظَّف بحاث ومهنيين زراعيين أدلة الغطاء النباتي الطيفية في دراسة خصائص مختلفة للتربة مثل الرطوبة والمغذيات. من خلال استعراض الباحث للدراسات السابقة يبدو أنه أجريت القليل من الدراسات لمعرفة ما إذا كان من الممكن التنبؤ بمؤشرات وظائف المنظر الطبيعي باستخدام تكنولوجيا الاستشعار عن بعد، وأي دليل غطاء نباتي طيفي هو الأفضل. بينت هذه الدراسات أن مؤشرات وظائف المنظر الطبيعي يمكن التنبؤ بها بدقة باستخدام دليل التباين الخضري للغطاء النباتي (NDVI). لذلك قام الباحث بمحاولة اختبار قدرة أدلة غطاء نباتي طيفية مختارة على التنبؤ بمؤشرات وظائف المنظر الطبيعي (LFA−SSA) في سهوب مناخ البحر الأبيض المتوسط بالجبل الأخضر شمال شرق ليبيا. استخدم الباحث بيانات جمعت بين مايو وأكتوبر لسنتي 2006 و2014. تم استخدام 28 موقعاً لجمع بيانات أدلة الغطاء النباتي الطيفية ومؤشرات وظائف المنظر الطبيعي. تم تطبيق الانحدار الخطي البسيط بين SVIsو LFA−SSA. بينت النتائج وجود علاقة خطية إيجابية بين مؤشرات وظائف المنظر الطبيعي والأدلة الطيفية المختارة. أظهرت النتائج أنه يمكن استخدام دليل التباين الخضري للغطاء النباتي (NDVI) ودليل الغطاء النباتي المعدل للتربة (MSAVI) المتحصل عليهما من صور الأقمار الصناعية لاند سات (+ETM) Landsat في التنبؤ بتغير خصائص صفات التربة والغطاء النباتي التركيبية والوظيفية المهمة في المناخ المتوسطي.

الكلمات المفتاحية:SSCI, MSAVI, WII, LFA-SSA.

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