

Full Length Research Paper

Spectral vegetation indices performance evaluated for Cholistan Desert

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To enhance the vegetation signal in remotely sensed data and provide an approximate measure of live green vegetation, a number of spectral vegetation indices have been developed to estimate biophysical parameters of vegetation. The sensitivity of the normalized difference vegetation index (NDVI) to the soil background and atmospheric effects has generated an increasing interest in the development of new indices. The modified soil-adjusted vegetation index (MSAVI) and its later revision, MSAVI2, are soil-adjusted vegetation indices that seek to address some of the limitations of NDVI when applied to areas with a high degree of exposed soil surface because the reflectance of light in the red and near-infrared (NIR) spectra can influence vegetation index values. The soil-adjusted vegetation index (SAVI) was developed as a modification of the NDVI to correct for the influence of soil brightness when vegetative cover is low. The problem with the SAVI is that it required specifying the soil-brightness correction factor L through trial-and-error based on the amount of vegetation. This article focuses on testing and comparing the sensitivity of vegetation indices to soil background effects. Five vegetation indices; NDVI, transformed normalized difference vegetation index (TNDVI), enhanced vegetation index (EVI), SAVI and MSAVI2 were quantitatively evaluated using Landsat ETM+ dataset over the Cholistan Desert to find the best vegetation index for use in sparsely vegetated semi-arid and arid tracts of Pakistan.

Key words: Atmospheric effects, Cholistan, Landsat ETM+, Remote sensing, Spectral vegetation indices.

INTRODUCTION

The development of long-term data records from multi-satellites/multi-sensors is a key requirement to improve our understanding of natural and human-induced changes on the Earth and their implications (NRC, 2007; Miura et al., 2008). Spectral vegetation indices (VIs) have been and continue to be used for monitoring of Earth's vegetative cover as a precise radiometric measure of green vegetation. Multi-sensor VI continuity/compatibility is, however, a complicated issue due to differences in both sensor characteristics and product generating algorithms (Miura et al., 2008). The analysis of vegetation and the detection of change in vegetative patterns are keys to natural resource assessment and monitoring. One of the major applications for remote sensing data is the detection and quantification of green vegetation. The principle behind this detection is simple. Actively photosynthesizing plants use blue and red light as energy sources. Therefore they reflect relatively small amount of these wavebands back to the sensor (Harris et al., 2004;

Slonecker et al., 2010). Near-infrared energy is highly reflected by the cell wall/air interface that is part of the internal structure of plants. The first vegetative indices were simple ratios of these spectral bands, mainly using the red band and the near-infrared (NIR) band. Over the years, new vegetative index models have been designed to detect sparse green vegetation and simultaneously minimize the effects of soil background brightness, topographical distortion and atmospheric "noise" (Harris et al., 2004).

Accurate evaluation of vegetation response across multiple-year time scales is crucial for analyses of global change (Running and Nemani, 1991; Sellers et al., 1994; Stow, 1995; Justice et al., 1998; Fensholt, 2004; Baugh and Groeneveld, 2006), effects of human activities (Moran et al., 1997; Milich and Weiss 2000; Thiam, 2003; Baugh and Groeneveld, 2006) and ecological relationships (Baret and Guyot, 1991; Asrar et al., 1992; Begue, 1993; Epiphanyo and Huete, 1995; Gillies et al.,

1997; Baugh and Groeneveld, 2006). Such evaluations often require the use of vegetation indices calculated from archived satellite data.

Study area and objectives

Cholistan Desert is an extension of the Great Indian Desert and covering an area of 26,330 km², lies within the southeast quadrant of Punjab province, placed between 27° 42' and 29° 45' North latitude and 69° 52' and 73° 05' East longitude (Ahmad, 2005; 2008).

The objectives of this research paper include:

1. Identification of vegetation cover and the spatial distribution;
2. To analyze the spatio-temporal change of vegetation cover;
3. To perform normalized difference vegetation index (NDVI) calculation, showing vegetation reflectance
4. To develop enhanced vegetation index (EVI) map
5. To produce normalized difference vegetation index (NDVI) map
6. To produce transformed normalized difference vegetation index (TNDVI) map
7. To develop soil-adjusted vegetation index (SAVI) map
8. To develop modified soil-adjusted vegetation index 2 (MSAVI2) map
9. To explore agricultural potential areas using change detection
10. To establish a field check system for comparing ground measurements with the processed remote sensed data.

RESEARCH DESIGN AND METHODS

Vegetation indices among other methods have been reliable in monitoring vegetation change (Glenn et al., 2008). One of the other most widely used indices for vegetation monitoring is the NDVI, because the vegetation differential absorbs visible incident solar radiation and reflects much of the near infra-red (NIR). Data on vegetation biophysical characteristics can be derived from visible and NIR and mid-infrared portions of the electromagnetic spectrum (EMS). The NDVI approach is based on the fact that healthy vegetation has low reflectance in the visible portion of the EMS due to chlorophyll and other pigment absorption and has high reflectance in the NIR because of the internal reflectance by the mesophyll spongy tissue of green leaf. NDVI can be calculated as a ratio of red and the NIR bands of a sensor system (Huete, 2005).

In this research paper, Landsat ETM+ data (USGS, 2008) were used to generate 5 published vegetation indices. The performance of these VIs is then compared for estimation of a known ecological response. The EVI, NDVI, TNDVI, SAVI and MSAVI2 models were applied upon 1999 and 2003 ETM+ images and further change detection technique was used for the EVI, NDVI and TNDVI calculation and SAVI and MSAVI2 classification.

The goal of this research paper is to reveal vegetation change and to explore vegetation potential sites using multi-temporal satellite data in order to assess changes (Singh, 1989). ERDAS Imagine software has been used to generate the false colour composite, by combining the near infrared, red and green bands (4,

3, and 2 respectively) for Landsat ETM+ images 1999 and 2003. This was carried out for vegetation recognition, because chlorophyll in plants reflects very well for the near infrared band compared to the visible band of the electromagnetic spectrum (Hatfield et al., 1984).

SPECTRAL VEGETATION INDICES

To enhance the vegetation signal in remotely sensed data and provide an approximate measure of live green vegetation, a number of spectral vegetation indices have been developed by combining data from multiple spectral bands into single values because they correlate the biophysical characteristics of the vegetation of the land-cover (Campbell, 1987) from the satellite spectral signals (Yang et al., 2008). Jordan in 1969 first presented the ratio vegetation index (RVI). Rouse et al. in 1973 further suggested the most widely used normalized difference vegetation index (NDVI) to improve identifying the vegetated areas and their condition (Rouse et al., 1973; Yang et al., 2008). However, the NDVI index is saturated in high biomass and it is sensitive to a number of perturbing factors, such as atmospheric effects, cloud, soil effects, and anisotropic effects *etc.* Therefore, a number of derivatives and alternatives to NDVI have been proposed in the scientific literature to address these limitations (Yang et al., 2008). Tucker (1979) presented a transformed normalized difference vegetation index (TNDVI) by adding a constant 0.5 to NDVI and taking the square root. It always has positive values and the variance of the ratio is proportional to mean values. The TNDVI indicates a slight better correlation between the amounts of green biomass and is found in a pixel (Senseman et al., 1996a; Sandham and Zietsman, 1997; Yang et al., 2008). To reduce the impact to the NDVI from the soil variations in lower vegetation cover areas, Huete (1988) proposed a soil-adjusted vegetation index (SAVI) by introducing a correction factor *L* (Yang et al., 2008). The SAVI was found to be an important step toward the establishment of simple "global" model that can describe dynamic soil-vegetation systems from remotely sensed data (Huete, 1988). Liu and Huete (1995) proposed the enhanced vegetation index (EVI) to optimize the vegetation signal with improved sensitivity in high biomass regions by incorporating both background adjustment and atmospheric resistance concepts into the NDVI (Justice et al., 1998; Huete et al., 1999).

The MSAVI2 (Qi et al., 1994), is modified soil-adjusted vegetation indices that seek to address some of the limitation of NDVI when applied to areas with a high degree of exposed soil surface. The problem with the original soil-adjusted vegetation index (SAVI) is that it required specifying the soil-brightness correction factor *L* that ranges from 0, for very high vegetation cover, to 1 for very low vegetation cover. Most researchers use 0.5 for *L*, which is for intermediate vegetation cover. *L* to 0 makes SAVI equivalent to NDVI (Huete, 1988).

The NDVI has been widely used in many applications including regional and continental-scale monitoring of vegetation cover (Satterwhite and Henley, 1987; Foran and Pearce, 1990; Myneni et al., 1997; Wang et al., 2004; Wessels et al., 2004; Amiri and Tabatabaie, 2009). The biophysical explanation of the relations between spectral vegetation indices and observable vegetation phenomena is still subject to much discussion (Baret and Guyot, 1991; Sellers et al., 1992; Clevers and Verhoef, 1993; Rondeaux et al., 1996). Although these indices appear to be more reliable and less noisy than the NDVI, they are not widely used except in theoretical studies. The NDVI seems still to be the leading index in remote sensing applications. The reason for this may be either the other indices' more complex formulation or the fact that they have not been convincingly demonstrated to improve on the NDVI in the assessment of vegetation parameters (Rondeaux et al., 1996). Vegetation indices evaluated in this experiment are given in Table 1 and Figure 6.

Table 1. Vegetation indices evaluated in this research paper.

Vegetation Index	Formula	Reference
NDVI	$(NIR-R)/(NIR+R)$; NIR is ETM+ Band 4; R is ETM+ Band 3	Rouse et al., 1973
TNDVI	$\sqrt{((NIR-R)/NIR+R) + 0.5}$	Tucker, 1979
SAVI	$(1 + L) * (NIR - R) / (NIR + R + L)$ with $L = 0.5$	Huete, 1988
MSAVI2	$(0.5) * (2 * (NIR + 1) - \sqrt{(2 * NIR + 1)^2 - 8 * (NIR - R)})$	Qi et al., 1994
EVI	$(NIR-R)/(NIR + (C1 * R) - (C2 * B) + L) * (1 + L)$ C1 = 6.0, C2 = 7.5, L = 1.0	Liu and Huete, 1995; Justice et al., 1998; Huete et al., 1999

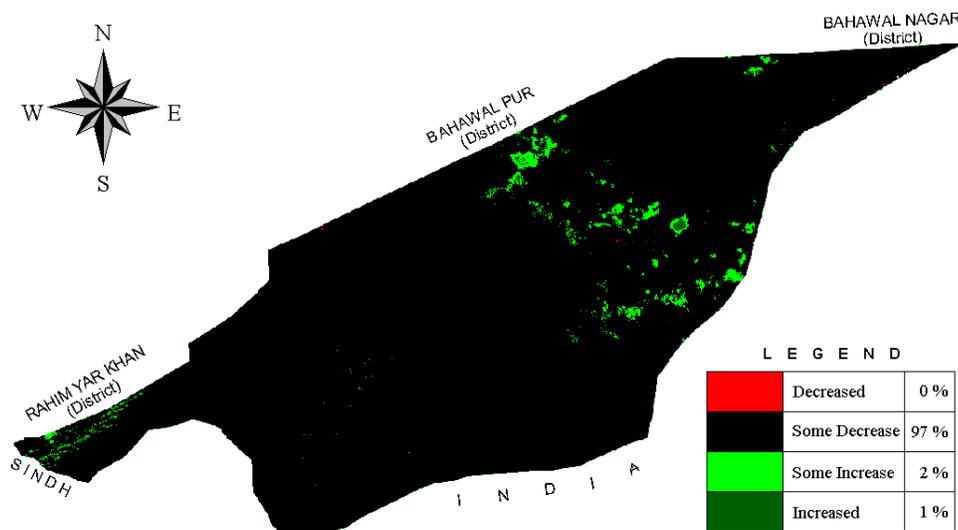


Figure 1. Map showing change detection using EVI model.

RESULTS

The enhanced vegetation index (EVI) is an 'optimized index' designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences (Liu and Huete, 1995; Justice et al., 1998; Huete et al., 1999). The EVI is computed following the equation:

$$EVI = G \times \frac{(NIR - RED)}{(NIR + C1 \times RED - C2 \times Blue + L)}$$

Where NIR/red/blue are atmospherically-corrected or partially atmosphere corrected (Rayleigh and ozone absorption) surface reflectances, *L* is the canopy background adjustment that addresses non-linear, differential NIR and red radiant transfer through a canopy, and C1, C2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band. The coefficients adopted in the EVI (Figure 1) algorithm are; *L* = 1, C1 = 6, C2 = 7.5, and G

(gain factor) = 2.5 (Liu and Huete, 1995; Justice et al., 1998; Huete et al., 1999, 2002; Karnieli and Dall'Olmo, 2003; Huete, 2005; Gao and Mas, 2008).

The normalized difference vegetation index (NDVI) is a normalized ratio of the NIR and red bands. The NDVI is computed following the equation:

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$$

Where, ρ_{NIR} and ρ_{red} are the surface bidirectional reflectance factors for their respective MODIS bands. The NDVI is referred to as the 'continuity index' to the existing 20+ year NOAA-AVHRR derived NDVI (Rouse et al., 1973) time series (Moran et al., 1992; Verhoef et al., 1996; Jakubauskas et al., 2001; Huete et al., 2002; Zoran and Stefan, 2006; USGS, 2010), which could be extended by MODIS data to provide a longer term data record for use in operational monitoring studies (Chen et al., 2003).

The theoretical basis for the NDVI lies with the red-NIR contrast of vegetation spectral reflectance signatures (Rahman et al., 2004). As the amount of live, green

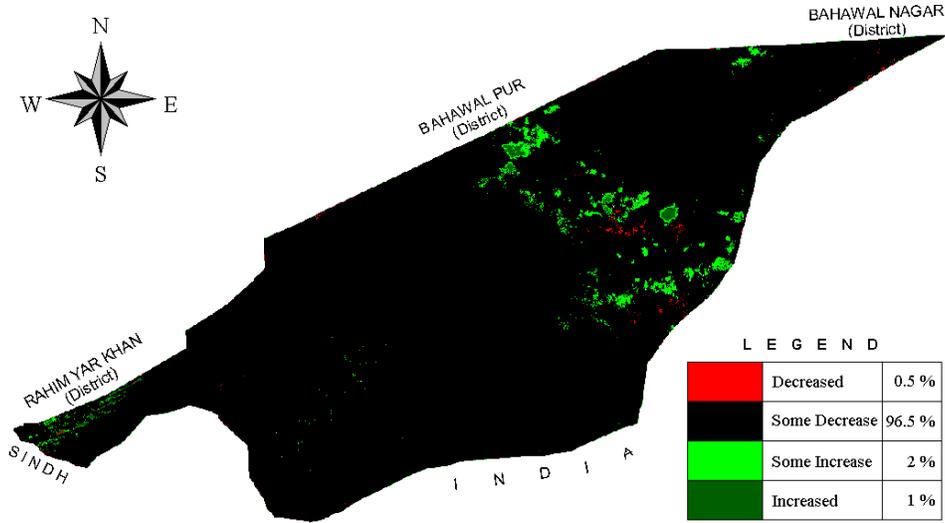


Figure 2. Map showing change detection using NDVI model.

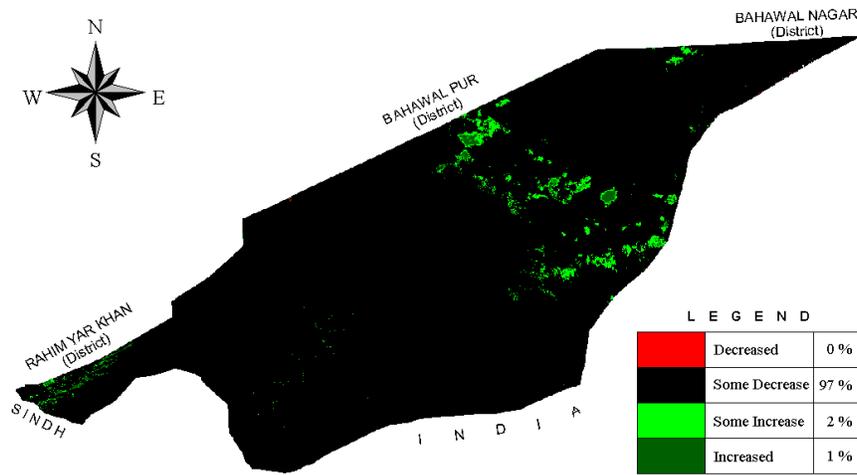


Figure 3. Map showing change detection using TNDVI model.

vegetation increases within a pixel, the red reflectance will decrease due to chlorophyll absorption while the non-absorbing NIR spectral region will generally increase especially leaf structure and amount (Baret and Guyot, 1991).

The NDVI (Figure 2) is successful as a vegetation measure in that it is sufficiently stable to permit meaningful comparisons of seasonal and inter-annual changes in vegetation growth and activity (Choudhury, 1987; Jakubauskas et al., 2002; Chen et al., 2006; Zoran and Stefan, 2006). The strength of the NDVI is in its ratioing concept (Moran et al., 1992), which reduces many forms of multiplicative noise (illumination differences, cloud shadows, atmospheric attenuation, and certain topographic variations) present in multiple bands (Chen et al., 2002).

The transformed normalized difference vegetation index (TNDVI) represents the vegetation biomass (Figure 3) and is expressed as the ratio of near-IR reflection to red reflection (Tucker, 1979). The TNDVI is computed following the equation:

$$TNDVI = \sqrt{\frac{(Infrared - Red)}{(Infrared + Red)}} + 0.5$$

Greenland (1994) expresses TNDVI as “an integrated function of photosynthesis, leaf area and evapo-transpiration”. The amount of biomass is directly and inversely related to surface temperature as a function of a number of interrelated effects, including evapo-transpirational cooling, sunlight interception, moisture

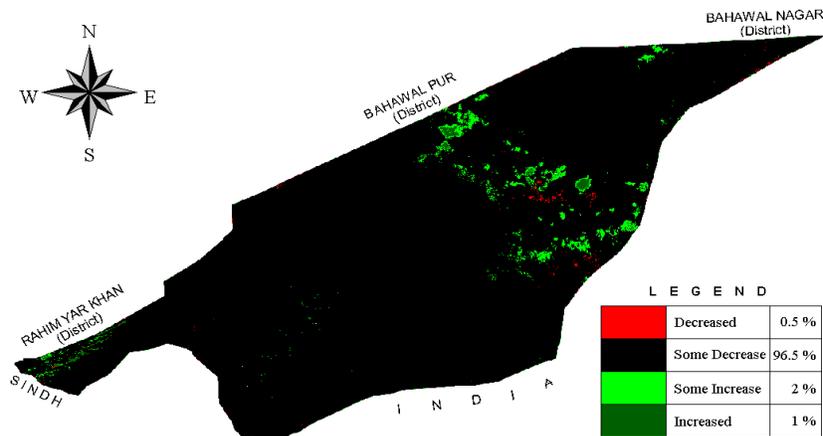


Figure 4. Map showing change detection using SAVI model.

retention, land cover, the surface energy balance and partial canopy cover (Friedl and Davis, 1994; Sandham and Zietsman, 1997; Yang et al., 2008).

In areas where vegetative cover is low and the soil surface is exposed, the reflectance of light in the red and near-infrared spectra can influence vegetation index values (Huete, 1988). This is especially problematic when comparisons are being made across different soil types that may reflect different amounts of light in the red and near infrared wavelengths (Huete et al., 2002). The soil-adjusted vegetation index (SAVI) was developed as a modification of the normalized difference vegetation index (NDVI) to correct for the influence of soil brightness when vegetative cover is low (Huete, 1988; Richardson and Everitt, 1992; Rondeaux et al., 1996; Senseman et al., 1996; Lyon et al., 1998). The SAVI (Figure 4) is structured similar to the NDVI but with the addition of a “soil brightness correction factor” (Huete, 1988).

$$SAVI = \frac{NIR - RED}{(NIR + RED + L)} * (1 + L)$$

Where NIR is the reflectance value of the near-infrared band, RED is reflectance of the red band, and *L* is the soil brightness correction factor. The value of *L* varies by the amount or cover of green vegetation: in very high vegetation regions, *L*=0; and in areas with no green vegetation, *L*=1. Generally, an *L*=0.5 works well in most situations and is the default value used. When *L*=0 makes SAVI equivalent to NDVI (Huete, 1988; Rondeaux et al., 1996), then SAVI = NDVI (Huete, 1988).

The modified soil-adjusted vegetation index 2 (MSAVI2) is modified soil-adjusted vegetation indices (Figure 5) that seek to address some of the limitation of NDVI when applied to areas with a high degree of exposed soil surface (Qi et al., 1994). The problem with the original SAVI is that it required specifying the soil-brightness correction factor *L* through trial-and-error based on the amount of vegetation in the study area. Not

only did this lead to the majority of researchers just using the default *L* value of 0.5, but it also created a circular logic problem of needing to know what the vegetation amount or cover was before one could apply SAVI which was supposed to give the information on how much vegetation there was. Qi et al. (1994) developed the MSAVI2 to more reliably and simply calculate a soil brightness correction factor (Jiang et al., 2007; Qi et al., 1994; Qi et al., 1994a; Ray, 2011). The MSAVI2 is computed following the equation:

$$MSAVI2 = \frac{(2 * NIR + 1 - \sqrt{(2 * NIR + 1)^2 - 8 * (NIR - RED)})}{2}$$

DISCUSSION AND CONCLUSIONS

As the use of space and computer technology developed, humankind has a great advantage of produce this much important research projects with the help of technology in an easier, more accurate way within less time than other ways. As a result all these can have a very effective role in helping the country to increase the amount and the quality of agricultural products. With different vegetation indexes applied, the changes in biomass were assessed for the years between 1999 and 2003. It was shown that the multitemporal and multisensor satellite data have a great success in biomass analysis (Akkartala et al., 2004). Ground cover as estimated did not take into account the physiological status of the vegetation in the sense that we did consider as cover all vegetation whatever its status. The use of vegetation indices, in general, takes into account mostly the green living vegetation (Cyr et al., 1995). Landsat ETM+ different bands have been used in order to estimate the vegetation quantities parameter based on vegetation indices.

Figure 6 shows comparative analysis of five vegetation indices quantitatively evaluated in this research paper.

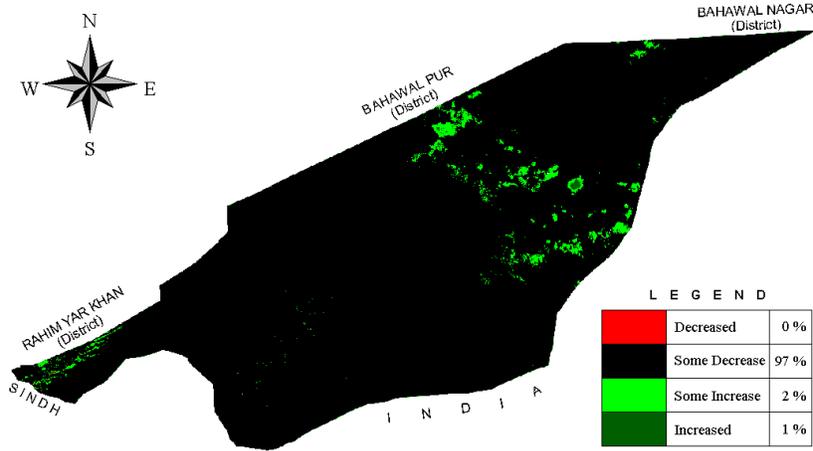


Figure 5. Map showing change detection using MSAVI2 model.

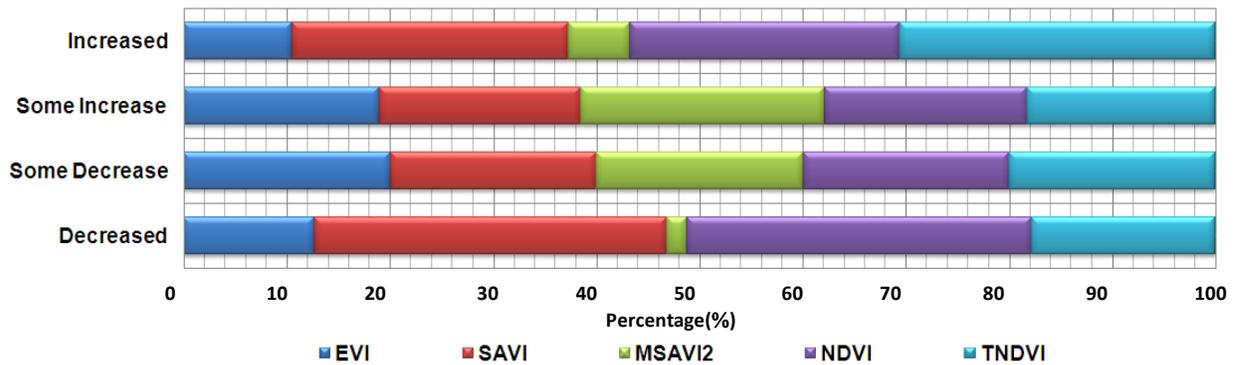


Figure 6. Comparative analysis of vegetation indices.

According to the findings, the MSAVI2 vegetation index showed minimum decrease while the result of the SAVI and the NDVI was same (Huete, 1988) expressed in Figure 2 and 4. All the vegetation indices showed the same percentage in 'some decrease' class. The MSAVI2 showed slightly raise in 'some increase' class while the result of the other indices; the EVI, SAVI, NDVI and TNDVI showed the same result. In 'increase' category, the MSAVI2 showed minimum increase, the EVI showed increase and the result of the SAVI, the NDVI and TNDVI was same. The modeling process is effective to estimate land cover from satellite images, even using a limited number of data (Bocco et al., 2007). The EVI is the best to optimize the vegetation signal with improved sensitivity in high biomass regions by incorporating both background adjustment and atmospheric resistance concepts.

The gained result showed significant correlations between ETM+ bands and vegetation groups such as grasses, forbs, shrubs, and bushy trees (Solaimani et al., 2011). The NDVI is the most commonly used of all the VIs tested and its performance, due to non-systematic

variation as described by Huete and Liu (1994) and Liu and Huete (1995). The soil background is a major surface component controlling the spectral behavior of vegetation canopies and on which the retrieval of biophysical characteristics of the canopy depends. Although vegetation indices, such as the soil-adjusted vegetation indices, considerably reduce these soils effects, estimation of the vegetation characteristics from the indices still suffers from some imprecision, especially at relatively low cover, if no information about the target is known (Rondeaux et al., 1996). The results of this research are encouraging and the techniques described provide an improved method for estimating the quantity of vegetative cover across large and complex desert environment with satellite imagery. This study also identified several data acquisition and processing issues that warrant further investigation. Studies are under way to assess the importance of coordinating and timing field data collection and image acquisition dates as a means of improving the strength of the relationships between image and land condition trend analysis (Senseman et al., 1996) ground-truth data.

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REFERENCES

- Ahmad F (2005). Historical and archaeological perspectives of soil degradation in Cholistan, *J. Geographic*, 10: 31-35.
- Ahmad F (2008). Runoff farming in reducing rural poverty in Cholistan desert, *Revista Sociedade & Natureza*, Instituto de Geografia, Universidade Federal de Uberlândia, Brazil, 20(1): 177-188.
- Akkartala A, Türüdüa O, Erbekb FS (2004). Analysis of changes in vegetation biomass using multitemporal and multisensor satellite data, *Proceedings of XXth ISPRS Congress, Istanbul, Turkey*. URL: <http://www.isprs.org/proceedings/XXXV/congress/yf/papers/946.pdf>.
- Amiri F, Tabatabaie T (2009). Operational Monitoring of Vegetative Cover by Remote Sensing in Semi-arid Lands of Iran, *Proceedings of the 7th FIG Regional Conference, Spatial Data Serving People: Land Governance and the Environment - Building the Capacity, Hanoi, Vietnam*. URL: http://www.fig.net/pub/vietnam/papers/ts05c/ts05c_amiri_tabatabaie_3706.pdf.
- Asrar G, Myneni RB, Choudhury BJ (1992). Spatial heterogeneity in vegetation canopies and remote sensing of absorbed photosynthetically active radiation: A modeling study, *Remote Sensing Environ.*, 41: 85-103.
- Baret F, Guyot G (1991). Potentials and limits of vegetation indices for LAI and APAR assessment, *Remote Sensing of Environ.*, 35: 161-173.
- Baugh WM, Groeneveld DP (2006). Broadband vegetation index performance evaluated for a low-cover environment, *Int. J. Remote Sensing*, 27(21-22): 4715-4730.
- Begue A (1993). Leaf area index, intercepted photosynthetically active radiation, and spectral vegetation indices: A sensitivity analysis for regular-clumped canopies, *Remote Sensing Environ.*, 46: 45-59.
- Bocco M, Ovando G, Sayago S, Willington E (2007). Neural network model for land cover classification from satellite images, *Agric. Technol.*, 67(4): 414-421.
- Campbell JB (1987). *Introduction to remote sensing*, The Guilford Press, New York. p. 281.
- Chen PY, Fedosejevs G, Tiscareño-López M, Arnold JG (2006). Assessment of MODIS-EVI, MODIS-NDVI and VEGETATION-NDVI Composite Data Using Agricultural Measurements: An Example at Corn Fields in Western Mexico, *Environmental Monitoring and Assessment*, Springer, Netherlands. 119(1-3): 69-82.
- Chen PY, Srinivasan R, Fedosejevs G, Kiniry JR (2003). Evaluating different NDVI composite techniques using NOAA-14 AVHRR data, *Int. J. Remote Sensing*, 24: 3403-3412.
- Chen PY, Srinivasan R, Fedosejevs G, Báez-González AD, Gong P (2002). Assessment of NDVI composite using merged NOAA-14 and NOAA-15 AVHRR data, *Geographic Inform. Sci.*, 8(1): 31-38.
- Choudhury BJ (1987). Relationship between vegetation indices, radiation absorption, and net photosynthesis evaluated by sensitivity analysis, *Remote Sensing Environ.*, 22: 209-233.
- Clevers JGPW, Verhoef W (1993). LAI estimation by means of the WDVl: A sensitivity analysis with a combined PROSPECT-SAIL model, *Remote Sensing Environ.*, 7: 43-64.
- Cyr L, Bonn F, Pesant A (1995). Vegetation indices derived from remote sensing for an estimation of soil protection against water erosion, *Ecological Modelling*, 79(1-3): 277-285.
- Epiphany JCN, Huete AR (1995). Dependence of NDVI and SAVI on sun/sensor geometry and its effect on fPAR relationships in Alfalfa, *Remote Sensing Environ.*, 51: 351-360.
- Fensholt R (2004). Earth observation of vegetation status in the Sahelian and Sudanian West Africa: Comparison of Terra MODIS and NOAA AVHRR satellite data, *Int. J. Remote Sensing*, 10: 1641-1659.
- Foran B, Pearce G (1990). The use of NOAA AVHRR and the green vegetation index to assess the 1988/1989 summer growing season in central Australia, *Proceedings of the 5th Australasian Remote Sensing Conference*, Perth. pp. 198-207.
- Friedl MA, Davis FW (1994). Source of variation in radiometric surface temperature over a tallgrass prairie, *Remote Sensing Environ.*, 48: 1-17.
- Gao Y, Mas JF (2008). MODIS EVI as an ancillary data for an object-based image analysis with multi-spectral MODIS data. URL: http://www.isprs.org/proceedings/XXXVIII/4-C1/Sessions/Session5/6590_YGao_Proc_poster.pdf.
- Gillies RR, Carlson TN, Cui J, Kustas WO, Humes KS (1997). A verification of the 'triangle' method for obtaining surface soil water content and energy fluxes from remote measurements of the Normalized Difference Vegetation Index (NDVI) and surface radiant temperature, *Int. J. Remote Sensing*, 18: 3145-3166.
- Glenn EP, Huete AR, Nagler PL, Nelson SG (2008). Relationship between remotely-sensed vegetation indices, canopy attributes and plant physiological processes: What vegetation indices can and cannot tell us about the landscape, *Sensors*, 8: 2136-2160.
- Greenland D (1994). Use of satellite-based sensing in land surface climatology, *Progress in Physical Geography*, 18(1): 1-15.
- Harris NR, Louhaichi M, Johnson DE (2004). *Laboratory Manual for Landscape Ecology, Spatial Analysis of Landscape Data, Lab 9, Landscape Ecology and Analysis*. URL: <http://www.oregonstate.edu/dept/range/labmanual/Laboratory9.pdf>.
- Hatfield JL, Asrar G, Kanemasu ET (1984). Intercepted photosynthetically active radiation estimated by spectral reflectance, *Remote Sensing Environ.*, 14: 65-75.
- Huete AR (1988). A soil-adjusted vegetation index (SAVI), *Remote Sensing Environ.*, 25(3): 295-309.
- Huete AR (2005). Global Variability of Terrestrial Surface Properties Derived from MODIS Visible to Thermal-Infrared Measurements. URL: <http://ieeexplore.ieee.org/iel5/10226/32601/01526782.pdf>.
- Huete AR, Liu HQ (1994). An error and sensitivity analysis of the atmospheric- and soil-correcting variants of the NDVI for the MODIS-EOS. *IEEE Trans. Geosci. Remote Sensing*, 32: 897-905.
- Huete AR, Justice C, Leeuwen W (1999). MODIS vegetation index (MOD 13) algorithm theoretical basis document version 3. URL: http://modis.gsfc.nasa.gov/data/atbd/atbd_mod13.pdf.
- Huete AR, Didan K, Miura T, Rodriguez EP, Gao X, Ferreira LG (2002). Overview of the radiometric and biophysical performance of the MODIS vegetation indices, *Remote Sensing Environ.*, 83: 195-213.
- Jakubauskas ME, David R, Kastens JH (2002). Crop identification using harmonic analysis of time-series AVHRR NDVI data, *Computers Electronics Agric.*, 37(1-3): 127-139.
- Jakubauskas ME, Legates DR, Kastens JH (2001). Harmonic analysis of time-series AVHRR NDVI data, *Photogrammetric Eng. Remote Sensing*, 67(4): 461-470.
- Jiang Z, Huete AR, Li J, Qi J (2007). Interpretation of the modified soil-adjusted vegetation index isolines in red-NIR reflectance space, *J. Appl. Remote Sensing*. doi:10.1117/1.2709702
- Jordan CF (1969). Derivation of leaf-area index from quality of light on the forest floor, *Ecology*, 50: 663-666.
- Justice C, Vermote E, Townshend JRG, Defries R, Roy DP, Hall DK, Salomonson VV, Privette J, Riggs G, Strahler A, Lucht W, Myneni R, Knjazihhin Y, Running S, Nemani R, Wan Z, Huete AR, Vanleeuwen W, Wolfe R, Giglio L, Muller JP, Lewis P, Barnsley M (1998). The Moderate Resolution Imaging Spectroradiometer (MODIS): Land remote sensing for global change research, *IEEE Trans. Geosci. Remote Sensing*, 36: 1228-1249.
- Karnieli A, Dall'Olmo G (2003). Remote-sensing monitoring of desertification, phenology, and droughts, *Management of Environmental Quality: An Int. Journal*, 14(1): 22-38.
- Liu HQ, Huete AR (1995). A feedback based modification of the NDVI to minimize canopy background and atmospheric noise, *IEEE Trans. Geosci. Remote Sensing*, 33: 457-465.
- Lyon JG, Yuan D, Lunetta RS, Elvidge CD (1998). A change detection experiment using vegetation indices, *Photogrammetric Eng. Remote Sensing*, 64(2): 143-150.
- Milich L, Weiss E (2000). GAC NDVI interannual coefficient of variation

- (CoV) images: Ground truth sampling of the Sahel along north-south transects, *Int. J. Remote Sensing*, 21: 235-260.
- Miura T, Yoshioka H, Suzuki T (2008). Evaluation of spectral vegetation index translation equations for the development of long-term data records, *Proceedings of IEEE Int. Geosci. Remote Sensing Symposium*, Boston, Massachusetts, U.S.A. doi: 10.1109/IGARSS.2008.4779447
- Moran MS, Inoue Y, Barnes EM (1997). Opportunities and limitations for image based remote sensing in precision crop management, *Remote Sensing Environ.*, 61: 319-346.
- Moran MS, Jackson RD, Slater PN, Teillet PM (1992). Evaluation of simplified procedures for retrieval of land surface reflectance factors from satellite sensor output, *Remote Sensing Environ.*, 41: 169-184.
- Myneni RB, Keeling CD, Tanser CJ, Asrar G, Nemani RR (1997). Increased plant growth in the northern high latitudes from 1981 to 1991, *Nature*, 386: 698-702.
- NRC (2007). *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, National Research Council of the National Academies, The National Academies Press, Washington, D.C., p.428. URL: http://www.nap.edu/openbook.php?record_id=11820&page=428.
- Qi J, Chehbouni A, Huete AR, Kerr YH (1994a). Modified Soil Adjusted Vegetation Index (MSAVI), *Remote Sensing Environ.*, 48: 119-126.
- Qi J, Kerr Y, Chehbouni A (1994). External factor consideration in vegetation index development, *Proceedings of Physical Measurements and Signatures in Remote Sensing*, ISPRS, pp.723-730.
- Rahman MdR, Islam AHMH, Rahman MdA (2004). NDVI Derived Sugar cane area Identification and crop condition Assessment, *Planplus: 2, Urban and Rural Planning Discipline*, Khula University, Bangladesh.
- Ray TW (2011). A FAQ on vegetation in remote sensing. URL: <http://www.yale.edu/ceo/Documentation/rsvegfaq.html>.
- Richardson AJ, Everitt JH (1992). Using spectral vegetation indices to estimate rangeland productivity, *Geocarto International*, 7(1): 63-69.
- Rondeaux G, Steven M, Baret F (1996). Optimization of soil-adjusted vegetation indices, *Remote Sensing Environ.*, 55: 95-107.
- Rouse JW, Haas RH, Schell JA, Deering DW (1973). Monitoring vegetation systems in the Great Plains with ERTS, *Third ERTS Symposium*, NASA SP-351 I, pp. 309-317.
- Running SW, Nemani RR (1991). Regional hydrologic and carbon balance responses of forests resulting from potential climate change, *Climatic Change*, 19: 349-368.
- Sandham LA, Zietsman HL (1997). Surface temperature measurement from space: A case study in the South Western Cape of South Africa, *South Afr. J. Enol. Viticulture*, 18(2): 25-30.
- Satterwhite MB, Henley JP (1987). Spectral characteristics of selected soils and vegetation in northern Nevada and their discrimination using band ratio techniques, *Remote Sensing Environ.*, 23: 155-175.
- Sellers PJ, Berry JA, Collatz GJ, Field CB, Hall FG (1992). Canopy reflectance, photosynthesis and transpiration III. A reanalysis using improved leaf models and a new canopy integration scheme, *Remote Sensing Environ.*, 42: 187-216.
- Sellers PJ, Tucker CJ, Collatz GJ, Los S, Justice CO, Dazlich DA, Randall DA (1994). A global 1u by 1u NDVI data set for climate studies, Part 2: The adjustment of the NDVI and generation of global fields of terrestrial biophysical parameters, *Int. J. Remote Sensing*, 15: 3519-3545.
- Senseman GM, Bagley CF, Tweddle SA (1996). Correlation of rangeland cover measures to satellite-imagery-derived vegetation indices, *Geocarto International*, 11(3): 29-38.
- Senseman GM, Tweddle SA, Anderson AB, Bagley CF (1996a). Correlation of land condition trend analysis (LCTA) rangeland cover measures to satellite-imagery-derived vegetation indices. URL:http://www.cecer.army.mil/techreports/and_vegi/AND_VEGI.LLN_post.PDF.
- Singh A (1989). Review Article: Digital Change Detection Techniques using Remotely Sensed Data, *Int. J. Remote Sensing*, 10: 989-1003.
- Slonecker T, Fisher GB, Aiello DP, Haack B (2010). Visible and Infrared Remote Imaging of Hazardous Waste: A Review, *Remote Sensing*, 2: 2474-2508.
- Solaimani K, Shokrian F, Tamartash R, Banihashemi M (2011). Landsat ETM+ Based Assessment of Vegetation Indices in Highland Environment, *J. Advances in Developmental Research*, 2(1): 5-13.
- Stow D (1995). Monitoring ecosystem response to global change: Multitemporal remote sensing analyses. In J. Moreno and W. Oechel (Eds). *Anticipated Effects of a Changing Global Environment in Mediterranean Type Ecosystems*, Springer-Verlag, New York. pp. 254-286.
- Thiam A (2003). The causes and spatial pattern of land degradation risk in southern Mauritania using multitemporal AVHRR-NDVI imagery and field data, *Land Degradation & Development*, 14: 133-142.
- Tucker CJ (1979). Red and photographic infrared linear combinations for monitoring vegetation, *Remote Sensing Environ.*, 8: 127-150.
- USGS (2008). Earth Resources Observation and Science Center. URL: <http://glovis.usgs.gov/>
- USGS (2010). What is NDVI? United States Geological Survey: Science for Changing World. URL: <http://ivm.cr.usgs.gov/>
- Verhoef W, Meneti M, Azzali S (1996). A colour composite of NOAA-AVHRR NDVI based on time series analysis (1981-1992), *Int. J. Remote Sensing*, 17(2): 231-235.
- Wang J, Rich PM, Price KP, Kettle WD (2004). Relationships between NDVI and tree productivity in the central great plains, *Int. J. Remote Sensing*, 25: 3127-3138.
- Wessels KJ, Prince SD, Frost PE, Zyl DV (2004). Assessing the effects of human-induced land degradation in the former homelands of northern South Africa, *Remote Sensing Environ.*, 91: 47-67.
- Yang Z, Willis P, Mueller R (2008). Impact of band-ratio enhanced AWIFS image to crop classification accuracy, *The Future of Land Imaging, Going Operational*, The 17th William T. Pecora Memorial Remote Sensing Symposium, Denver, Colorado.
- Zoran M, Stefan S (2006). Climatic changes effects on spectral vegetation indices for forested areas analysis from satellite data, *Proceedings of the 2nd Environmental Physics Conference*, Alexandria, Egypt, pp. 73-83.