REVIEW OF VEGETATION INDICES FOR VEGETATION MONITORING

Dr. Rishiraj Dutta
Asian Disaster Preparedness Center, SM Tower, 24th Floor, 979/69 Paholyothin Road
Samsen Nai, Phayathai, Bangkok-10400, Thailand
Email: rishiraj@adpc.net

KEY WORDS: Vegetation Indices, Remote Sensing, Monitoring, Natural Resources

ABSTRACT: One of the most important applications of remote sensing is monitoring the natural resources through detection and quantitative assessment of green vegetation. Healthy canopies have distinct interactions with the electromagnetic spectrum. Using Remote Sensing technology, collected canopy reflectance data can be used to calculate vegetation indices which in turn are used to estimate vegetation cover for agricultural fields. Vegetation indices has some advantages when it is compared with measured vegetation cover especially in large agricultural fields. Several studies have already been conducted using vegetation indices for vegetation monitoring and assessment. Over the last several decades, vegetation indices have been extensively used in crop monitoring such as growth, phenology, health as well as vegetation and nutrient stress. In this sense, vegetation analyses and detection of changes in vegetation patterns and structure are key to natural resources assessment and monitoring. The aim of this paper, however, is not to evaluate the extensive amount of work carried out on VIs, but rather to provide the reader with a clear understanding of their nature and usefulness. Keeping this in mind, a description of different vegetation indices have been provided in this paper along with some studies conducted around the world.

1. INTRODUCTION

Various vegetation indices have been developed that reduce multiband observations to a single numerical index (Wiegand et al., 1991). This index obtained from two or more wavelength intervals is a sum, difference, ratio, or other linear combinations of reflectance factors or radiance observations. High absorption of incident sunlight in the visible red (RED, 600-700 nm) portion and strong reflectance in the near infrared (NIR, 750-1350 nm) portion of the electromagnetic spectrum by photo-synthetically active tissue in plants is distinctive from that of soil and water, and the other two predominant landscape features. Therefore, vegetation indices developed from spectral observations in these two wavelengths have correlated highly with plant stand parameters, green leaf area index (L), chlorophyll content, fresh and dry above ground phytomass (FM and DM), plant height, percent ground cover by vegetation, plant population and grain or forage yield (Wiegand et al., 1991). According to Wiegand et al., 1973, vegetation indices have been considered a measure of vegetation density or cover, photosynthetically active biomass (Tucker, 1979; Wiegand and Richardson, 1984), leaf area index (Wiegand et al., 1979), green leaf density (Tucker et al., 1985), photosynthesis rate (Sellers, 1985, 1987), amount of photosynthetically active tissue (Wiegand et al., 1986; Wiegand and Richardson 1987) and photosynthetic size of canopies (Wiegand et al., 1989; Wiegand and Richardson, 1990).

Remotely sensed spectral vegetation indices are widely used and have benefitted numerous disciplines interested in the assessment of biomass, water use, plant stress, plant health, and crop production (Jackson and Huete, 1991). The use of vegetation indices requires knowledge of the input variables used to form indices and an understanding of the external environment and architectural aspects of vegetation canopy influence and altered computed index values. The primary goal of remote sensing is to characterize the type, amount and condition of vegetation present in the scene. The amount of light reflected from the surface is determined by the amount and composition of solar irradiance that strikes the surface and the reflectance properties of the surface. A vegetation index can be calculated by ratioing differences and sums and by forming linear combinations of spectral band data (Jackson and Huete, 1991). Vegetation indices (VIs) are intended to enhance the vegetation signal while minimizing solar irradiance and soil background effects. Vegetation index (VI) can be calculated from sensor voltage outputs (V), radiance values (L), reflectance values (ρ) and satellite digital numbers (DN). Soil also influence vegetation index. Vegetation index collected from data obtained from aircraft or space craft based sensors are affected by the intervening atmosphere.

Several vegetation indices have been developed by linear combination or ratios of red, green and near-infrared spectral bands (Basso et al., 2004). Vegetation indices are more sensitive than individual bands to vegetation parameters (Baret and Guyot, 1991). Plant canopy reflectance factors and derived multispectral VIs are receiving increased attention in agricultural research as robust surrogates for traditional agronomic parameters (e.g. leaf area index (LAI), fraction of green cover, fraction of absorbed photosynthetically active radiation (fAPAR) etc. Often viewed simply as measures of plant biomass or green leaf area index, VIs are strongly modulated by interactions of solar radiation with photosynthetically active plant tissues and thus also are indicative of dynamic biophysical properties related to productivity and surface energy balance. Vegetation indices (VIs) have been designed to find a functional relationship between crop characteristics and remote spatial observation. VIs tend to reach a saturation level asymptotically for values of LAI between 3 to 6, based on the type of index used and type of plant (Carlson, et al., 1997).

Another application is the use of VIs as a mapping device. VIs are used in image classification, to separate vegetated from non-vegetated areas, to distinguish between different types and densities of vegetation, to monitor seasonal variations in vegetative vigor, abundance and distribution.

2. TYPES OF VEGETATION INDICES

VIs are influenced by both external and internal factors (Basso et al., 2004). External factors includes sensor calibration, sun and view angle and atmospheric condition while the internal factors are variation in canopy and leaf optical properties and canopy background. In order for us to understand the design of VIs, it is essential to know some concepts related to influence of soil and the use of the soil line and vegetation isoline. It is also useful to introduce the different kind of VIs that have been developed over the years considering all vegetation isoline converge at a single point. These indices are "ratio-based" and measure the slope of the line between the point of convergence and the soil line. The indices are: Normalized Difference Vegetative Index (NDVI), Soil Adjusted Vegetative Index (SAVI) and Ratio Vegetative Index (RVI). When the vegetation isoline are considered parallel to soil line, and the distance is measured perpendicular to the soil line, the indices are called "perpendicular" vegetation indices. These indices are: Perpendicular Vegetative Index (PVI), Weighted Difference Vegetative Index (WDVI), Green Vegetation Index (GVI) and Difference Vegetative Index (DVI). Apart from these there are also other VIs that have been on use for various scientific research such as Enhanced Vegetation Index (EVI), Atmospherically Resistant Vegetation Index (ARVI) and Sum Green Index (SGI).

The objective of this paper is to describe the biophysical principles of vegetation indices and to present a review of the use of these VIs in vegetation monitoring and management.

2.1. Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not. NDVI has found a wide application in vegetative studies as it has been used to estimate crop yields, pasture performance, and rangeland carrying capacities among others. It is often directly related to other ground parameters such as percent of ground cover, photosynthetic activity of the plant, surface water, leaf area index and the amount of biomass.

The NDVI algorithm subtracts the red reflectance values from the near-infrared and divides it by the sum of near-infrared and red bands.

$$NDVI= (NIR-RED) / (NIR+RED)$$

This formulation allows us to cope with the fact that two identical patches of vegetation could have different values if one were, for example in bright sunshine, and another under a cloudy sky. The bright pixels would all have larger values, and therefore a larger absolute difference between the bands. This is avoided by dividing by the sum of the reflectances. This index vary between -1 and +1, however in practice, extreme negative values represent water, values around zero represent bare soil and values over 6 represent dense green vegetation.

2.2. Soil Adjusted Vegetation Index (SAVI)

Huete (1988) proposed the Soil Adjusted Vegetation Index (SAVI) to account for the optical soil properties on the plant canopy reflectance. SAVI involves a constant L to the NDVI equation. The index range is also from -1 to +1.

$$SAVI = \rho NIR - \rho Red / (\rho NIR + \rho Red + L) * (1 + L)$$

The constant 'L' minimizes the soil-brightness influences and produces vegetation isolines independent of the soil background (Baret and Guyot, 1991) 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, then SAVI = NDVI.

2.3. Ratio Vegetative Index (RVI)

The Ratio Vegetation Index (RVI), formed by dividing the NIR radiance by the red radiance, was probably the first index to be defined and is the most commonly used. Tucker (1979) reported that Jordan (1969) used a radiance ratio of 0.800/0.675 μm, measured at the forest floor to derive a leaf area index for forest canopy. The RVI is represented by the equation:

$$RVI = NIR/RED$$

For RVI, soil line has a slope of 1 and passes through the origin which range from 0 to infinity. RVI is quite sensitive to vegetation changes during the time of peak growth. It is not very sensitive when the vegetative cover is sparse.

2.4. Perpendicular Vegetative Index (PVI)

The *Perpendicular Vegetation Index* (PVI) of Richardson and Wiegand (1977), used the red (R) and near infrared (NIR) bands to calculate the perpendicular distance between the vegetation spot on the NIR-Red scatterplot and the soil line. Since vegetation has higher near-infrared and lower red reflectance than the underlying soil, the vegetation spot will be on the top left corner of the scatterplot. As vegetation is increasing in density, the vegetation spot will be moving further towards the top left, away from the soil line. The weakness of the PVI is the assumption that there will be only one type of soil beneath the vegetation. However, this is not always the case, as there are environments where a mixture of soil types (a mixture of soil and rocks for example) can be found within a very small area.

PVI (Crippen, 1990), stated that it is sensitive to atmospheric variation. The vegetation isolines are parallel to soil line. Soil line has arbitrary slope, passes through origin and the index range from -1 to +1.

$$PVI = 1 / \sqrt{}a2 + 1 (\rho NIR - a\rho Red - b)$$

Where ‘a’ and ‘b’ are the coefficient derived from the soil line: $NIR_{soil} = a\ RED_{soil} + b$.

2.5. Weighted Difference Vegetative Index (WDVI)

Weighted Difference Vegetative Index (WDVI) is a mathematically simpler version of PVI, but it has an unrestricted range. Like PVI, WDVI is very sensitive to atmospheric variations (Qi et al., 1994). Vegetation isolines are parallel to soil line. Soil line has arbitrary slope and passes through origin, vegetation index range is infinite.

$$WDVI = \rho NIR - a\rho Red$$

Where ‘*a*’ is the slope of the soil line.

2.6. Green Vegetation Index (GVI)

GVI stands for Green Vegetation Index. There are several GVIs. The basic way these are devised is by using two or more soil points to define a soil line. Then a Gram-Schmidt orthogonalization is performed to find the "greenness" line which passes through the point of 100% (or very high) vegetation cover and is perpendicular to the soil line. The distance of the pixel spectrum in band space from the soil line along the “greenness” axis is the value of the vegetation index. GVI provides a complete picture of vegetation amount and variability caused by soil and moisture. It is a repeatable measure that can be applied consistently across various scenes, sample locations and time intervals. Growers, consultants and scientists can easily correlate the Green Vegetation Index to industry-standard vegetation measures, such as Green Leaf Area Index, plant height, biomass or percent canopy cover. The end result is quantifiable vegetative status.

2.7. Difference Vegetative Index (DVI)

Another simple vegetation index is the Difference Vegetation Index (DVI), which is also sensitive to the amount of the vegetation. Mathematically, it is in the form of:

$$(NIR\ Band) – (RED\ Band)$$

DVI has the ability to distinguish the soil and vegetation but not in shady areas. Hence, DVI doesn’t give proper information when the reflected wavelengths are being affected due to topography, atmosphere or shadows.

2.8. Enhanced Vegetation Index (EVI)

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. EVI is computed following this equation:

$$EVI = G * (NIR - RED) / (NIR + C1 * RED - C2 * BLUE + L)$$

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.

2.9. Atmospherically Resistant Vegetation Index (ARVI)

The main feature of the Atmospherically Resistant Vegetation Index (ARVI) is its capacity to reduce the influence from the atmosphere by employing the blue band in conducting atmospheric corrections on the red band. It's a self-correcting process in image-based consideration (Kaufman and Tanre, 1992). Compared to the red band, the blue band is much more easily scattered by the atmospheric particles. This explains why the sky is usually perceived as being blue. Thus, the ARVI takes the advantage of the different scattering responses from the blue and red band to retrieve information regarding the atmosphere opacity, and can be written as follows:

$$ARVI = (\rho_{NIR} - \rho_{rb}) / (\rho_{NIR} + \rho_{rb})$$

Where ρ_{NIR} is the reflectance of the near infrared, ρ_{rb} equals $\rho_r - \gamma\ (\rho_b - \rho_r)$, γ (gamma value) is like a weighting function that depends on the aerosol type, and ρ_r and ρ_b refer to the reflectance of the red and blue bands, respectively.

2.10. Sum Green Index (SGI)

This SGI is generally used to detect changes in vegetation greenness. This is useful in detecting forest disturbance because it is highly sensitive to small changes in vegetation canopy opening. The sum greenness (SG) is the mean of reflectance across the 500 nm to 600 nm portion of the spectrum. This sum is then normalized by the number of bands to convert it back to units of reflectance. The value of this index ranges from 0 to more than 50 (in units of % reflectance). The common range for green vegetation is 10 to 25 percent reflectance.

3. APPLICATION OF VEGETATION INDICES (SOME RESEARCH EXAMPLES)

Several researches have been published which gives an evidence of the extensive use of VIs in the last decades. Some of the VIs, are explored in this section.

- Dutta (2013) explored the use of NDVI for determining green leaf tea quality. The study observed that NDVI can be used as a tool for monitoring tea quality.
- Payero et al. (2004) compared 11 vegetation indices in order to estimate plant height and develop its quantitative relationship with VIs. Among the VIs used were NDVI, IPVI (Infrared Percentage Vegetation Index), TVI and RATIO.
- Ferreira and Huete (2004) used MQUALS (light aircraft-based Modland Quick Airborne Looks package, consisting of a spectroradiometer and digital camera), MODIS, AVHRR and Landsat ETM+ in order to investigate VI's ability to differentiate the physiognomies in the Brazilian Cerrado and monitor their seasonal dynamics.
- Fensholt (2004) identified and validated net primary production (NPP) model variables from the MODIS sensor, focusing on the semi-arid ecosystem. Two MODIS VIs were evaluated against the NOAA AVHRR NDVI to exploit the improvement of the MODIS sensor quality and also to examine the possibility of establishing an empirical relation in order to reap the full benefit of 20 years' availability of NOAA AVHRR data.
- Steven et al. (2003) used NDVI and SAVI from a range of earth observation satellites currently in operation, such as AVHRR, ATSR-2, Landsat MSS, TM and ETM+, SPOT-2 and SPOT-4 HRV, IRS, IKONOS, SeaWiFS, MISR, MODIS, POLDER, QuickBird, and MERIS. Spectroradiometric measurements were made over a range of crop canopy densities, soil backgrounds and foliage colour. The reflected spectral radiances were convoluted with the spectral response functions of the satellite instruments to simulate their responses. The results indicated that vegetation indices could be interconverted to a precision of 1-2%.
- Price et al. (2002) evaluated the use of raw Thematic Mapper (TM) band combinations and several derived

VIs to determine optimal vegetation indices and band combinations for discriminating among six grassland management practices in eastern Kansas. Tasselled Cap Brightness Index, GVI, Wetness Index, the first three components from Principle Component Analysis (PCA1, 2, 3), NDVI, GR (Green Ratio) and MR (MIR Ratio) were used as VIs.

- Huete et al. (2002) performed an initial analysis of the MODIS NDVI and EVI performances from both radiometric and biophysical perspectives, using MODIS, airborne radiometric measurements, Landsat ETM+ and in situ field biophysical data collected over four validation test sites. The results showed good correspondence between airborne-measured, top-of-canopy reflectances and VI values with those from the MODIS sensor at four intensively measured test sites.
- Gilabert et al. (2002) introduced a generalized soil-adjusted vegetation index (GESAVI), theoretically based on a simple vegetation canopy model.
- Silleos et al. (2002) carried out the first operational work to assessing crop damage using space remote sensing techniques. A linear regression model was used to compare remote sensing estimations with field observations. The results of the model application for all the studied fields showed an agreement in 60% of cases, with a deviation of about 10%.

REFERENCES

Baret, F. and Guyot, G. (1991). Potentials and Limits of Vegetation Indices for LAI and APAR Assessment. *Remote Sensing of Environment*, 35: 161-173.

Basso, B., Cammarano, D. and Vita, P.D. (2004). Remotely Sensed Vegetation Indices: Theory and Applications for Crop Management. *Rivista Italiana di Agrometeorologia*, 1: 36-53.

Carlson, Toby N. and Ripley, David A. (1997). On the Relation between NDVI, Fractional Vegetation Cover, and Leaf Area Index. *Remote Sensing Environment*, 62: 241-252.

Crippen, R.E. (1990). Calculating the Vegetation Index Faster. *Remote Sensing of Environment*, 34: 71-73.

Dutta, R. (2013). Monitoring Green Leaf Tea Quality Parameters of Different TV Clones Grown in Northeast India using Satellite Data. *Food Chemistry*, 139: 689-694.

Fensholt, R. (2004). Earth Observation of Vegetation Status in the Sahelian and Sudanian West Africa: Comparison of Terra MODIS and NOAA AVHRR Satellite Data. *International Journal of Remote Sensing*, 25(9): 1641-1659.

Ferreira, L.G., and Huete, A.R. (2004). Assessing the Seasonal Dynamics of the Brazilian Cerrado Vegetation Through the Use of Spectral Vegetation Indices. *International Journal of Remote Sensing*, 25(10): 1837-1860.

Gilabert, M.A., Gonzalez-Piqueras, J., Garcia-Haro, F.J. and Melia, J. (2002). A Generalized Soil-Adjusted Vegetation Index. *Remote Sensing of Environment*, 82(2-3): 303-310.

Huete, A., Didan, K., Miura, T., Rodriguez, E.P., Gao, X. and Ferreira, L.G. (2002). Overview of the Radiometric and Biophysical Performance of the MODIS Vegetation Indices. *Remote Sensing of Environment*, 80(1-2): 195-213.

Jackson, R.D. and Huete, A.R. (1991). Interpreting Vegetation Indices. *Preventive Veterinary Medicine*, 11: 185-200.

Jordan, C.F. (1969). Derivation of Leaf Area Index from Quality of Light on the Forest Floor. *Ecology*, 50: 663-666.

Kaufman, Y. J. and Tanre, D. (1992). Atmospherically Resistant Vegetation Index (ARVI) for EOS-MODIS. *IEEEE Transactions on Geosciences and Remote Sensing*, 30(2): 261-270.

Payero, J.O., Neale, C.M.U. and Wright, J.L. (2004). Comparison of Eleven Vegetation Indices for Estimating Plant Height of Alfalfa and Grass. *Applied Engineering in Agriculture*, 20(3): 385-393.

Price, K.P., Guo, X.L. and Stiles, J.M. (2002). Optimal Landsat TM Band Combinations and Vegetation Indices for Discrimination of Six Grassland Types in Eastern Kansas. *International Journal of Remote Sensing*, 23(23): 5031-5042.

Qi, J., Chehbouni, A., Huete, A.R., Kerr, Y.H. and Sorooshian, A. (1994). A Modified Soil Adjusted Vegetation Index, *Remote Sensing of Environment*, 48(2): 119-126.

Richardson, A.J. and Wiegand, C.L. (1977). Distinguishing Vegetation from Soil Background Information. *Photogrammetry, Engineering and Remote Sensing*, 43: 1541-1552.

Sellers, P.J. (1987). Canopy Reflectance, Photosynthesis and Transpiration. II. The Role of Biophysics in the Linearity of their Interdependence. *Remote Sensing of Environment*, 21: 143-183.

Sellers, P.J. (1985). Canopy Reflectance, Photosynthesis and Transpiration. *International Journal of Remote Sensing*, 6: 1335-1372.

Silleos N., Perakis, K. and Petsanis, G. (2002). Assessment of Crop Damages using Space Remote Sensing and GIS. *International Journal of Remote Sensing*, 23(3): 417-427.

Steven, M.D., Malthus, T.J., Baret, F., Xu, H. and Chopping, M.J. (2003). Inter-calibration of Vegetation Indices from Different Sensor Systems. *Remote Sensing of Environment*, 88(4): 412-422.

Tucker, C.J., Townshend, J.R.G. and Goff, T.E. (1985). African Land Cover Classification using Satellite Data. *Science*, 227: 369-375.

Tucker, C.J. (1979). Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. *Remote Sensing of Environment*, 8: 127-150.

Wiegand, C.L., Richardson, A.J., Escobar, D.E. and Gerbermann, A.H. (1991). Vegetation Indices in crop Assessments. *Remote Sensing of Environment*, 35: 105-119.

Wiegand, C.L. and Richardson, A.J. (1990). Use of Spectral Vegetation Indices to Infer Leaf Area, Evapotranspiration and Yield: I. Rationale. *Agronomy Journal*, 82: 623-629.

Wiegand, C.L., Shibayama, M., Yamagata, Y. and Akiyama, T. (1989). Spectral Observation for Estimating the Growth and Yield of Rice. *Japanese Journal of Crop Science*, 58: 673-683.

Wiegand, C.L., Richardson, A.J. (1987). Spectral Component Analysis. Rationale and Results of Three Crops. *International Journal of Remote Sensing*, 8: 1011-1032.

Wiegand, C.L., Richardson, A.J., Jackson, R.D., Pinter, P.J., Jr., Aase, J.K., Smika, D.E., Lautenschlager, L.F. and McMurtrey, J.E. (1986). Development of Agro-meteorological Crop Model Inputs from Remotely Sensed Information. *IEEE Transactions on Geoscience and Remote Sensing*, GE-24: 90-98.

Wiegand, C.L. and Richardson, A.J. (1984). Leaf Area, Light Interception and Yield Estimates from Spectral Components Analysis. *Agronomy Journal*, 76: 543-548.

Wiegand, C.L., Richardson, A.J. and Kanemasu, E.T. (1979). Leaf Area Index Estimates for Wheat from LANDSAT and their Implications for Evapotranspiration and Crop Modelling. *Agronomy Journal*, 71: 336-342.

Wiegand, C.L., Gausman, H.W., Cuellar, A.J., Gerbermann, A.H. and Richardson, A.J. (1973). Vegetation Density as Deduced from ERTS-1 MSS Response. Third ERTS Symposium, NASA Sp-351, US Government Printing Office, Washington DC; Vol.-I, pp. 93-116.