DOI 10.4467/21995923GP.17.001.7188 GEOINFORMATICA POLONICA
16: 2017

Ayansina Ayanlade

REMOTE SENSING VEGETATION DYNAMICS ANALYTICAL METHODS: A REVIEW OF VEGETATION INDICES TECHNIQUES

Department of Geography,
Obafemi Awolowo University, Ile-Ife, Nigeria
sinaayanlade@yahoo.co.uk

Keywords: Remote sensing, vegetation assessment, change detections

Abstract

Scientists have made great efforts in developing techniques to assess and monitor the rate of change in vegetation on global, regional and local scales. Vegetation indices are remote sensing measurements used to quantify vegetation cover, vigor or biomass for each pixel in an image. Besides the fact that no single method can be applied to all cases and regions, there are some factors that determine the remote sensing methods to be used in environmental change studies. Such factors include the spatial, temporal, spectral and radiometric resolutions of satellite image and environmental factors. The major question usually comes to mind of environmental researchers in any remote sensing research project is: What remote sensing method should be used to solve the research problem? Therefore, this paper evaluates methods used in the literature to assess, monitor and model environmental change, considering factors that determine the selection of those methods. The review shows over forty vegetation indices, out of which only three (Ratio Vegetation Index, Transformed Vegetation Index and Normalized Difference Vegetation Index) are commonly applied to vegetation assessment. The study show that out of all the vegetation indices, NDVI is the most widely applied to monitor vegetation change on regional and local scales.

PRZEGLĄD ANALITYCZNYCH METOD TELEDETEKCYJNYCH W BADANIU DYNAMIKI ZMIAN WEGETACJI: TECHNIKI OPARTE NA WSKAŹNIKACH WEGETACJI

Słowa kluczowe: Teledetekcja, ocena wegetacji, wykrywanie zmian

Abstrakt

Naukowcy podjęli znaczny wysiłek, mający na celu rozwój technik oceny i monitoringu tempa zmian wegetacji w skali globalnej, regionalnej oraz lokalnej. Wskaźniki wegetacji stanowią pomiary teledetekcyjne, używane do ilościowej oceny pokrycia wegetacją, wigoru wegetacji lub biomasy, dla każdego piksela w zobrazowaniu. Oprócz tego, że nie ma jednej metody, która może być zastosowana we wszystkich przypadkach i regionach, istnieje szereg czynników, które determinują wybór metod teledetekcyjnych do zastosowania w badaniach nad zmianami zachodzącymi w środowisku. Należą do nich uwarunkowania przestrzenne, czasowe, rozdzielczość spektralna i radiometryczna zobrazowań satelitarnych oraz czynniki środowiskowe. Podstawowe pytanie, które przychodzi na myśl badaczom środowiska w dowolnym przedsięwzięciu związanym z teledetekcją to: Która metoda teledetekcyjna powinna zostać użyta do rozwiązania problemu badawczego? Tak więc, artykuł ten stanowi przegląd metod używanych w literaturze do oceny, monitoringu i modelowania zmian środowiskowych, które wyznaczają wybór poszczególnych metod. Przegląd pokazuje ponad czterdzieści wskaźników wegetacji, spośród których tylko trzy (proporcjonalny wskaźnik wegetacji – RVI, transformowany wskaźnik wegetacji – TVI i znormalizowany różnicowy wskaźnik wegetacji – NDVI) są powszechnie używane do oceny wegetacji. Badania pokazują, że spośród wszystkich wskaźników wegetacji, w monitoringu zmian wegetacji w skali regionalnej i lokalnej, najczęściej stosuje się NDVI.

INTRODUCTION

Different methods have been used in the literature to assess vegetation change. Chen (2002) and Ouyang *et al.* (2010) have noted that the fast developing technology of remote sensing offers an efficient and speedy approach for mapping of basic change in vegetation types over large areas. Indeed over the past few decades, remote sensing techniques have been employed by many researchers to investigate change in landuse/landccover (Rao *et al.* 1999; DeFries and Belward 2000; Gonzalez 2001; Shi *et al.* 2002; Ruiz-Luna and Berlanga-Robles 2003; Gao and Liu 2010). It has been shown in these studies that remote sensing is not only good for preparing landuse change maps and observing changes at regular intervals of time, but also cost and time effective. For example, Landsat data have been used to analyse environmental change in different scales since the launch of Landsat MSS in 1972 (NRSA 1978; Salami 1999; Akumu *et al.* 2010). However, it is apparent from literature that remote sensing of environmental change is influenced by a complex set of factors and different studies sometimes arrive at different conclusions about which landuse change detection techniques are most effective (Geist and Lambin 2001; Lu *et al.* 2004).

Lu *et al*. (2004) categorized the remote sensing vegetation change detection methods that have been used in the literature as in Table 1. It is evident from general reviews of other studies, that the remote sensing vegetation change detections methods could be predominantly grouped into two: non-classification and classification methods. This paper therefore, reviews commonly used non-classification methods as related to vegetation change assessment.

Non-classification Based Approaches to Change Detection

This section covers commonly used non-classification based approaches to landuse change detection. Such commonly used methods that will be discussed in this section include image regression; image ratioing; vegetation indices; Markov Chain, and Geographical Information System (GIS) approaches (Table 2). Therefore, the main objective of this section is to assess the relative merits and limitations of each of these approaches, based on an environment related to that of the Niger Delta.

Image Regression

This method establishes the relationships between bi-temporal images. The model performs regression on the selected bands before implementing change detection: using regression function to subtract the previously regressed bands from the first band. In the process,

Table 1. The remote sensing landuse change detection methods categories, adapted from Lu et al. (2004)
Tabela 1. Kategorie metod wykrywania zmian sposobów użytkowania gruntów z wykorzystaniem metod teledetekcyjnych na podstawie Lu i in. (2004)

Categories	Composition
Algebra	Change detection methods that make use of algebra approach include Image Regression; Image Differencing; Image Ratioing; Vegetation Index Differencing; Change Vector Analysis (CVA) and Background Subtraction.
Transformation	The transformation category includes Principal Component Analysis, Tasselled Cap (KT), Gramm–Schmidt (GS), and Chi-Square Transformations.
Classification	This includes supervised, unsupervised and hybrid classification, and Post-Classification Comparison change detection.
Advanced models	In this category are Li–Strahler Reflectance Model, Spectral Mixture Models, and Biophysical Parameter Estimation Models.
Geographical Information System(GIS) approaches	These include overlaying methods and buffering methods.
Visual analysis	This category involves visual interpretation of multi-temporal image composite and on-screen digitizing of changed areas.

Table 2. Commonly used remote sensing methods to assess vegetation degradation and some references
Tabela 2. Często stosowane metody teledetekcji w celu oceny degradacji roślinności

Method	Merits	Limitations	Major References
Image Regression	It accounts for differences in reflectance mean and variance between dates and the image produced can be easily interpreted.	Since it is based on linearity assumption, this technique is not acceptable if a large proportion of the study area has changed between the two image dates.	Singh (1989), Song *et al.*(2001), McGraw (2009), Bhatta (2010).
Image ratioing	It reduces the effects of sun angle, shadow, and topography on the images.	The results are not normally distributed.	Prakash and Gupta (1998), Lu *et al.* (2004), Bhatta (2010).
Vegetation indices	It is simple and easy to apply and is a means of getting vegetation change information for the remote location.	Atmospheric conditions do have a significant influence on the results.	Bannari *et al.* (2003), Matricard *et al.* (2010), Xie *et al.* (2010), Matricardi *et al.* (2010).
Change vector analysis (CVA)	It is flexible and easy to apply when using different types of datasets.	It is difficult to identify vegetation change trajectory using this method.	Chen (2002), Lu *et al.* (2004).
Markov Chain	It is possible to extract information which is not accessible using other change detection techniques.	The complexity of physical environment could affect the result.	Brown *et al*. (2000), Wang *et al* (2010).
GIS-base Change Detection Method	Provides convenient tools for the multi-source data processing and are effective in handling the change detection analysis using multi-source data.	Proper knowledge of GIS is needed before using this method in landuse change analysis.	Coppin *et al* (2004), Ellis and Porter-Bolland (2008), Salamin *et al.* (2010).

this method identifies suitable bands and the thresholds to be used (Lu *et al*, 2004). The regression equation function can be defined as follows:

$$DX_{ij}^{k} = X_{ij}^{k}\left(t_2\right) - X_{ij}^{k}\left(t_1\right) \quad (1)$$

Where pixels from t_1 are assumed to be a linear function of t_2. From this equation, x is the pixel values at line i and column j. According to Singh (1989), it is possible to regress $X_{ij}^{k}(t_1)$ against $X_{ij}^{k}(t_2)$ using a linear regression function. This method accounts for the difference in the mean and variance between the pixel values for different periods of time. The merit of this method is that it reduces the effect of atmospheric, sensor and environmental differences between the two images obtained in a different periods of time.

The major limitation of this approach, however, is that this technique is not acceptable if a large proportion of the study area has changed between the two image dates, since it is based on linearity assumption (Lu *et al*. 2004, Bhatta 2010).

Image Ratioing

The method involves dividing the radiance values from one or more image channels, by the radiance values of data in the same channels from different dates. Studies have shown that image ratioing is a relatively rapid means of identifying areas of change in vegetation coverage (Nelson 1983; Prakash and Gupta 1998; Lu *et al.* 2004). Prakash and Gupta (1998) reported further that the major advantage of this method is that it reduces the effects of sun angle, shadow, and topography on the images. In image ratioing, images are compared pixel by pixel using the equation as follows:

$$RX_{ij}^{k} = \frac{X_{ij}^{k}(t_1)}{X_{ij}^{k}(t_2)} \tag{2}$$

Here, $X_{ij}^{k}(t_1)$ is the pixel value at line i and Column j for band k at a given time t_1, and is divided by the pixel value at line i and Colum j for band k at a given time t_2. Thus, if the reflected radiation is nearly the same in each image then $RX_{ij}^{k} = 1$ and this indicates no change. Whenever $RX_{ij}^{k} > 1$ or $RX_{ij}^{k} < 1$ this indicates the area of change, although, the sign of the value depends upon the nature of the changes between the two dates.

Lu *et al.* (2004) noted the distribution of the results from this method is usually non-normal. They observed that if the distributions are non-normal, and functions of the standard deviations are used to delimit change from non-change, thus making the error rates on either side of the mode not to be equal. As with other change detection methods, another limitation of image ratioing method is the selection of appropriate threshold values in the lower and upper tails of the distribution to represent changed pixel values. According to Bhatta (2010), the best way to achieve this is by selecting arbitrary threshold values and testing them to determine if the change detection was performed accurately. Prakash and Gupta (1998) applied the method in mapping environmental change in a coal mining area of Jharia coal field in India. They performed image ratioing with other methods and were able to map landuse changes along with other methods such as image differencing and differencing of NDVI images. The result from their study showed that image ratioing is sensitive to bad georeferencing, thus their study concluded that the results from image ratioing are not as accurate as results from other change detection methods.

Vegetation Indices

Vegetation indices are remote sensing approaches used to quantify vegetation cover, vigor or biomass for each pixel in an image (Ouyang *et al.* 2010). Vegetation indices use spectral bands that are sensitive to plants. The red and near-infrared bands are usually used in this method because of their sensitivities in detecting vegetal cover. The spectral bands may be added, divided or multiplied to produce a single value (Lu *et al.* 2004; Matricard *et al.* 2010; Xie *et al.* 2010). Over forty vegetation indices are found in the literature (Table 3), out of which only three (Ratio Vegetation Index, Transformed Vegetation Index and Normalized Difference Vegetation Index) are commonly applied to Landsat images.

Ratio Vegetation Index (RVI) is one of the earliest vegetation indices applied in the remote sensing analysis. The ratio of the near-infrared (NIR) band to a red band can indicate vegetation as below:

$$RVI = \frac{RED}{NIR} \tag{3}$$

RVI has similar limitations and advantages (Bhatta 2010). The main advantage of RVI is that it enhances the contrast between the vegetation and the ground, and it reduces the effects of varying illumination conditions. However, Bannari *et al.* (2003) have reported the limitation of RVI to be its sensitivity to the ground optical properties and its sensitivity to atmospheric effects thus makes its discriminating power weak when the vegetative cover is less than 50%. Out of all the vegetation indices, NDVI is the most widely applied to monitor vegetation change on regional and local scales. NDVI combines two channels (NIR and RED) in a normalized ratio, which makes it possible to differentiate vegetation cover signal from other objects as shown below.

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{4}$$

The lowest value represents the difference between the red and NIR, and especially indicates that the red value is higher than the NIR signal. A higher value signifies a larger difference between the red and near infrared radiation recorded by the sensor (Bannari *et al.* 1995; Lu *et al.* 2004; Xie *et al.* 2010). The value of this index ranges from –1 to +1. It has been shown in the literature that –1 value is generally from ice or cloud on the image, zero values stand for areas with no vegetation, and +1 value signifies the maximum potential density and greenness of leaves. The common range for green vegetation is 0.2 to 0.8. Studies have shown that NDVI values that are less than zero do not have any ecological meaning, therefore, the vegetation index should range from 0.0 to 1.0 (Xie *et al.* 2010; Redowan and Kanan 2012).

However, the major limitation of NDVI method is that it is influenced by environmental factors such as nature of soils; cloud cover and atmospheric effects (Bannari *et al.* 1995; Maxwell and Sylvester 2012; Redowan and Kanan 2012). For instance, Matricard *et al.* (2010)

Table 3. Some Vegetation Indices found in the literature
Tabela 3. Niektóre indeksy roślinności znane z literatury

Index	Initiator	Formula
Atmospherically Resistant Vegetation Index	Kaufman and Tanre (1992)	$ARVI = \frac{(NIR - RB)}{(NIR + RB)}; \quad RB = R - \gamma(B - R)$
Adjusted Green Vegetation Index	Jackson et al. (1983)	$AGVI = GVI - (1 + 0.018GVI)YVI - NSI/2)$
Adjusted Soil Brightness Index	Jackson et al. (1983)	$ASBI = (2.0\ YVI)$
Angular Vegetation Index	Plummer et al. (1994)	$AVI = tan^{-1}\left\{\frac{\lambda_3 - \lambda_2}{\lambda_2}[NIR - R]^{-1}\right\} + tan^{-1}\left\{\frac{\lambda_1 - \lambda_1}{\lambda_2}[G - R]^{-1}\right\}$
Ashburn Vegetation Index	Ashburn (1978)	$AVI = (2.0MSS7 - MSS5)$
Differenced Vegetation Index	Richardson and Wiegand (1977)	$DVI = (NIR - R)$
Enhanced Vegetation Index	Huete et al. (1999)	$EVI = G\frac{(NIR - R)}{(NIR + c_1R - c_2B + L)(1 + L)}$
Global Environment Monitoring Index	Pinty and Verstraete (1992)	$GEMI = \cap(1 - 0.25\cap) - \frac{(R - 0.15)}{(1 - R)}; \quad \cap = \left\{\frac{2(NIR - R^2) + 1.5NIR - 0.5R}{(NIR + R + 0.5)}\right\}$
Greenness Above Bare Soil	Hay et al. (1979)	$GRABS = (GVI - 0.09178BI + 5.58959)$
Green Vegetation Index	Kauth and Thomas (1976)	$GVI = (-0.283MSS4 - 0.660MSS6 + 0.388MSS7)$
Green Vegetation and Soil Brightness	Badhwar (1981)	$GVSB = \frac{GVI}{SBI}$
Misra Green Vegetation Index	Misra et al. (1977)	$MGVI = (-0.386MSS4 - 0.530MSS5 - 0.535MSS6 + 0.243MSS7)$
Misra Non Such Index	Misra et al. (1977)	$MNSI = (0.404MSS4 - 0.039MSS5 - 0.505MSS6 + 0.762MSS7)$
Misra Soil Brightness Index	Misra et al. (1977)	$MSBI = (0.406MSS4 + 0.600MSS5 + 0.645MSS6 + 0.243MSS7)$
Misra Yellow Vegetation Index	Misra et al. (1977)	$MYVI = (0.723MSS4 - 0.597MSS5 + 0.206MSS6 - 0.278MSS7)$
Modified SAVI	Qi et al. (1994)	$MSAVI = \frac{2NIR + 1 - \sqrt{(2NIR + 1)^2 - 8(NIR - R)}}{2}$
Multi-Temporal Vegetation Index	Yazdani et al. (1981)	$MTVI = (NDVI(date2) - (NDVI(date1)$
Normalized difference Greenness Index	Chamard et al. (1991)	$NDGI = \frac{(G - R)}{(G + R)}$

Table 3. Cont.

Index	Initiator	Formula
Normalized difference Index	McNairn and Protz (1993)	$NDI = \frac{(NIR - MIR)}{(NIR + MIR)}$
Normalized difference Vegetation Index	Rouse (1973) Rouse et al. (1974)	$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$
Perpendicular vegetation Index	Richardson and Wiegand (1977)	$PVI = \frac{(NIR - aR - b)}{\sqrt{A^2 + 1}}$
Ratio Vegetation Index	Birth and McVey (1968)	$RVI = \frac{R}{NIR}$
Redness Index	Escadafal and Huete (1991)	$RI = \frac{(R - G)}{(R + G)}$
Soil Adjusted Vegetation Index	Huete (1988)	$SAVI = \frac{(NIR - R)}{(NIR + R + L)(1 + L)}$
Soil Background Line	Richardson and Wiegand (1977)	$SBL = (MSS7 - 2.4MSS5)$
Soil Brightness Index	Kauth and Thomas (1976)	$SBI = (0.332MSS4 + 0.660MSS5 + 0.675MSS6 + 0.262MSS7)$
Transformed Soil Atmospherically Resistant Vegetation Index	Huete and Liu (1994)	$TSARVI = \frac{[a_{rb}(NIR - a_{rb}RB - b_{rb})]}{[RB + a_{rb}NIR - a_{rb}b_{rb} + X(1 + a^2{}_{rb})]}$
Transformed SAVI	Baret et al. (1989)	$TSAI = \frac{[a(NIR - aR - b)]}{[R + aNIR - ab + X(1 + a^2)]}$
Transformed Vegetation Index	Deering et al. (1975)	$TVI = \frac{\left(\frac{RED - NIR}{RED + NIR} + 0.5\right)1}{2}$
Vegetation Index Number	Pearson and Miller (1972)	$VIN = \frac{NIR}{R}$
Yellow Vegetation Index	Kauth and Thomas (1976)	$YVI = (\_0.899MSS4 + 0.428MSS5 + 0.076MSS6 - 0.041MSS7)$

Source: Modified from Bannari et al. (1995), Silleos et al.(2006), Redowan and Kanan (2012) noted that NDVI values tend to change as a result of soils moisture changes. Soil reflectance is a direct function of water content; therefore, they tend to darken when wet. Since the spectral response to moistening is not exactly the same in the two spectral bands, the NDVI is affected. Cakir *et al.* (2006) further argued that NDVI differencing is not effective in a region where vegetation cover is low because of the predominance of background effects. Likewise, cloud and other atmospheric conditions also have a significant influence on NDVI. For example, Van Leeuwen *et al*. (2006) and Ji and Peters (2007) noted that slight changes in NDVI differencing values between two dates occur as a result of differences in atmospheric conditions, with increased haze leading to a reduction in NDVI. Thus, the method needs to be applied to images acquired under clear sky conditions and atmospheric correction is essential.

The Transformed Vegetation Index (TVI) was derived from NDVI. This index is usually used principally to eliminate negative values and to normalize the NDVI histogram. The commonly used TVI derived from Landsat MSS data is given as:

$$\boldsymbol{TVI} = \left(\frac{\boldsymbol{RED - NIR}}{\boldsymbol{RED + NIR}} + 0.5 \right) \tag{5}$$

Where 0.5 is a bias term that automatically prevents negative values under the square root for most images. TVI was developed in order to avoid operating with negative NDVI values, correct NDVI values that estimated the Poisson distribution; and to create a normal distribution. However, studies have shown that there are no differences between NDVI and TVI in terms of image output or active vegetation detection (Silleos *et al.* 2006; Maxwell and Sylvester 2012; Redowan and Kanan 2012). The majority of these studies have shown that the TVI should be used with great caution because this index could turn out to be more sensitive to a number of factors such as cloud condition, atmospheric and soil characteristics of the study area.

Mostly to assess vegetation change, vegetation index differencing is commonly applied usually by subtracting the vegetation index images of one date from another. The left and right ends of the tails of the vegetation index difference image histogram detect a change in the vegetation. Several studies have used vegetation index differencing to assess vegetation change and it has often been found to be better than other methods (Bannari *et al.* 1995; Lu *et al.* 2004; Xie *et al.* 2010; Matricard *et al.* 2010; Ouyang *et al.* 2010). For instance, Matricard *et al.* (2010) employed this method to assess tropical forest degradation caused by logging and fire, using Landsat imagery and found it a reliable method to assess change in vegetation.

CONCLUSION

The question at hand is "which of these methods will be appropriate for a given change detection research project?" Or the best and overall suitable method for LUCC study of interest is not fully understood? Maybe that is why some scholars proposed and applied two or more methods in LUCC analysis (Petit *et al*., 2001; Rogan and Yool, 2001; Yang and Lo, 2002, Wang *et al*, 2009, Wang *et al*, 2010). Many of these studies have compared the effectiveness and benefits of using different change detection methods in remote sensing research. The results from these studies showed that application of two or more change detection methods leads to a better accuracy of results and a better comparison of the methods. For example, Fung (1990) applied three of these methods: Image Differencing, PCA, and KT transformation for land-cover change detection. The conclusion from this literature review study is that images associated with changes in the near-infrared reflectance could detect a change in land use patterns, even changes between vegetative and non- vegetative features could also be detected.

Above all, it is very clear from the reviewed studies above that there are a variety of change detection methods that have been used. However, it is still practically difficult to select a suitable method to apply in LUCC detection for a specific research project (Lu *et al*, 2004). Selection of a suitable change detection method requires careful consideration of major factors such as peculiarity of the study area and the desired outcome of the research. Generally, it is practically impossible to apply all of the possible change detection methods in a LUCC research for the same data, the same study area and at the same time. What is revealing from this review is that reliability and accuracy of these methods depend on the nature of the research in terms of the environmental condition of the study area and the desired information to be derived from the analysis. Meanwhile, all methods are not totally right but some are useful, therefore, the methods should be viewed as complementary to each other.

ACKNOWLEDGEMENT

This study is part of a research funded and supported by PTDF (Petroleum Technology Development Fund) through Nigerian government.

BIBLIOGRAPHY

Ahmad, F. (2012) A review of remote sensing data change detection: Comparison of Faisalabad and Multan Districts, Punjab Province, Pakistan. *Journal of Geography and Regional Planning*, 5(9), 236–251.

Akgn A., Eronat A. H., and Trk N. (2004) Comparing Different Satellite Image Classification Methods: An Application in Ayvalik District, Western Turkey. *In ISPRS Congress Istanbul 2004, Proceedings of Commission IV.* 1091–1097.

Almutairi, A. and Warner, T.A. (2010) Change Detection Accuracy and Image Properties: A Study Using Simulated Data. *Remote Sensing.* 2010, *2*, 1508–1529.

Aplin, P (2005) Using remote sensing data. *In Clifford and valentine (edu): Key methods in geography.* Reprint edition, Sage publication, London. 230–308.

Avitabile, V., Baccini, A., Friedl, M.A and Schmullius, C. (2012) Capabilities and limitations of Landsat and land cover data for above ground woody biomass estimation of Uganda. *Remote Sensing of Environment,* 117, 366–380.

Bannari, A., Morin, D., Bonn, F. and Huete, A. R. (1995) A review of vegetation indices. *Remote Sensing Reviews,* 13: 1, 95–120.

Balzter, H. (2000) Markov chain models for vegetation dynamics. *Ecological Modelling, 126*, 139–154.

Bhatta, B. (2010) *Analysis of Urban Growth and Sprawl from Remote Sensing Data*, 65 Advances in Geographic Information Science, 65–83.

Boakye, E. Odai, S. N. Adjei, K. A. and Annor, F. O. (2008) Landsat Images for Assessment of the Impact of Land Use and Land Cover Changes on the Barekese Catchment in Ghana. *European Journal of Scientific Research*, 22 (2) 269–278.

Brown, D. G., Pijanowski, B. C. and Duh, J. D. (2000). Modelling the relationships between land use and land cover on private lands in the Upper Midwest, USA. *Journal of Environmental Management,* 59, 247–263. Briassoulis, H. (2000) Analysis of Land Use Change: Theoretical and Modelling

Approaches. *Regional Research Institute*. [Online]. Available from: http://www.rri.wvu.edu/WebBook/Briassoulis/contents.htm [Accessed 08 March, 2010].

Camplbell, J. B. (2002) *Introduction to remote sensing*. Third edition, Taylor and Francis, London and New York.

Carvalho, L. M. T., Fonseca, L. M. G., Murtagh, F. and Cleves, J. G. P. W., (2001) Digital change detection with the aid of multiresolution wavelet analysis. International Journal of Remote Sensing, 22, 3871–3876.

Chavez,P.S.JR, and Mackinnon, D. J. (1994) Automatic detection of vegetation changes in the south-western United States using remotely sensed images. *Photogrammetric Engineering and Remote Sensing*, 60, 571–583.

Chen, X.W. (2002) Using remote sensing and GIS to analyze land cover change and its impacts on regional sustainable development. *International Journal of Remote Sensing,* 23, 107–124.

Chen, S., Chen, L., Liu, Q., Li, X. and Tan Q. (2005) Remote sensing and GIS-based integrated analysis of coastal changes and their environmental impacts in Ling ding Bay, Pearl River Estuary, South China. *Ocean and Coastal Management* 48 (2005), 65–83.

Chen, N.W., Li, H.C. and Wang, L.H., (2009). A GIS-based approach for mapping direct use value of ecosystem services at a county scale: management implications. *Ecological Economics 68 (11)*, 2768–2776.

Collins, J. B. and Woodcock, C. E. (1996) An assessment of several linear change detection techniques for mapping forest mortality using multi-temporal Landsat TM data. *Remote Sensing of Environment*, 56, 66–77.

Coppin, P. R. and Bauer, M. E. (1996) Digital change detection in forest ecosystems with remote sensing imagery. *Remote Sensing Reviews*, 13, 207–234.

Coppin, P.R., Jonckheere, I., Nackaerts, K., Muys, B. and Lambin, E. (2004) Review ArticleDigital change detection methods in ecosystem monitoring: a review. *International Journal of Remote Sensing*, 25 (9) 1565–1596.

DeFries, R. and Belward, A. S. (2000) Global and regional land cover characterization from satellite data; an introduction to the Special Issue. *International Journal of Remote Sensing*, 21, (6and 7), 1083–1092.

Ellis, E.A and Porter-Bolland, L. (2008) Is community-based forest management more effective than protected areas? A comparison of land use/land cover change in two neighbouring study areas of the Central Yucatan Peninsula, Mexico. *Forest Ecology and Management* 256, 1971–1983.

Estes, A.B., Kuemmerle, T., Kushnir, H., Radeloff V.C., and Shugart, H.H (2012) Land-cover change and human population trends in the greater Serengeti ecosystem from 1984––2003. *Biological Conservation* 147, 255–263.

Foody, G. M. (2003): Remote sensing of tropical forest environments: towards the monitoring of environmental resources for sustainable development. International Journal of Remote Sensing, **24**(23):4035–4046.

Foody, G.M. and Mathur, A., (2004), A relative evaluation of multiclass image classification by support vector machines. *IEEE Transactions on Geoscience and Remote Sensing*, 42, pp. 1336–1343.

Fung, T. (1990) An assessment of TM imagery for land-cover change detection. IEEE Transactions on *Geosciences and Remote Sensing*, 28, 681–684.

Gao, J. and Liu, Y. (2010) Determination of land degradation causes in Tongyu County, Northeast China via land cover change detection. *International Journal of Applied Earth Observation and Geoinformation* 12, 9–16.

Geist, H.J and Lambin, E.F (2001) What Drives Tropical Deforestation?: A meta-analysis of proximate and underlying causes of deforestation based on sub national case study evidence. *LUCC Report Series* No. 4.

Gong, P., (1993) Change detection using principal component analysis and fuzzy set theory. *Canadian Journal of Remote Sensing*, 19, 22–29.

Gordon,H.R.(1978),Removal of atmospheric effects from satellite imagery of the ocean. *Appl. Opt*. 17, 1631–1636.

Guo, Q., Kelly, M., Gong, P. and Liu, D. (2007) An object-based classification approach in mapping tree mortality using high spatial resolution imagery. *GIScience and RemoteSensing*, 44, pp. 24–47.

Hall, F. G., Strebel, D. E., Nickeson, J. E., and Goets, S. J. (1991a) Radiometric rectification: toward a common radiometric response among multidate, multisensory images. *Remote Sensing of Environment*, 35, 11–27.

Hall, F. G., Botin, D. B., Strebel, D. E., Woods, K. D., and Goets, S. J. (1991b) Large-scale patterns of forest succession as determined by remote sensing. *Ecology*, 72, 628–640.

Healey, S.P., Yang, Z., Cohen, W.B. and Pierce, D.J. (2006) Application of two regression-based methods to estimate the effects of partial harvest on forest structure using Land sat data. *Remote Sensing of Environment, 101,* 115–126.

Heo, J., and Fitzhugh, T. W. (2000) A standardized radiometric normalization method for change detection using remotely sensed imagery. *Photogrammetric Engineering and Remote Sensing*, 66, 173–182.

Huber, W. (2001). Estimating Markov transitions. *Journal of Environmental Managements,* 61, 381–385.

Hay, G.J. and Castilla, G. (2008) Geographic object-based image analysis (GEOBIA): a new name for a new discipline. *In Object-Based Image Analysis-Spatial Concepts forKnowledge-Driven Remote Sensing Applications*, T. Blaschke, S. Lang and G. Hay (Eds.), 75–89.

Ji, L., and A.J. Peters, 2007, Performance evaluation of spectral vegetation indices using a statistical sensitivity function. *Remote Sensing of Environment*, vol. 106,(1), 59–65.

Jeyanthi1, P. and Kumar, V.J.S. (2010) Image Classification by K-means Clustering. Advances in Computational Sciences and Technology, 3(1), 1–8.

Jensen, J. R. (1996) *Introductory Digital Image Processing: a Remote Sensing Perspective.* Englewood Cliffs, NJ: Prentice-Hall, 56–78.

Kaufman, Y. J., and Sendra, C. (1988), Algorithm for automatic atmospheric corrections to visible and near-IR satellite imagery. *International Journal of Remote Sensing* 9, 1357–1381.

Kovalskyy, V. and Roy D.P. (2013) The global availability of Landsat 5 TM and Landsat 7 ETM+ land surface observations and implications for global 30 m Landsat data product generation *Remote Sensing of Environment* 130, 280–293.

Lambin, E.F (1996) Change detection at multiple temporal scales: seasonal and annual variations in landscape variables. *Photogrammetric Engineering and Remote Sensing.* 62, 931–938.

Lambin E.F. and Ehrlich, D (1995) Combining vegetation indices and surface temperature for land-cover mapping at broad spatial scales. *International Journal of Remote Sensing.* 16, 573–579.

Lambin E.F and Ehrlich, D (1996) The surface temperature-vegetation index space for land cover and land-cover change analysis. *International Journal of Remote Sensing.* 17, 463–487.

Lambin E.F. and Ehrlich D. (1997) Land-cover changes in sub-Saharan Africa (1982–1991): Application of a change index based on remotely-sensed surface temperature and vegetation indices at a continental scale, *Remote Sensing of Environment*, 61, (2) 181–200.

Lambin E.F., Geist H. and Lepers E. (2003) Dynamics of land use and cover change in tropical regions. *Annual Review of Environment and Resources*, (28) 205–241.

Lambin E.F and Strahler, A.H (1994a) Indicators of landcover change for change-vector analvsis in multi-temporal space at coarse spatial scales. *International Journal of Remote Sensing* 15, 2099–2119.

Lambin E.F and Strahler, A.H (1994b) Change-vector analysis: a tool to detect and categorize land-cover change processes using high temporal-resolution satellite data. *Remote Sensing of Environment.* 48, 231–244.

Lambin E.F., Turner II B.L., Geist H., Agbola S., Angelsen A., Bruce J.W., Coomes O., Dirzo R., Fischer G., Folke C., George P.S., Homewood K., Imbernon J., Leemans R., Li X., Moran E.F. Mortimore M., Ramakrishnan P.S., Richards J.F., Skånes H., Steffen W., Stone G.D., Svedin U., Veldkamp T., Vogel C., Xu J. (2001) The Causes of Land-Use and – Cover Change: Moving beyond the Myths. *Global Environmental Change*. 11, 261–269.

Li, X., and Yeh, A. G. O., (1998) Principal component analysis of stacked multitemporal images for the monitoring of rapid urban expansion in the Pearl River Delta. *International Journal of Remote Sensing*, 19, 1501–1518.

Lillesand, T.M and Kiefer, R.W. (2000) Remote sensing and image interpretation. Fourth edition, John Wiley and Son, Inc. 470–605.

Liu, D. and Xia, F. (2010) Assessing object-based classification: advantages and limitations. Remote Sensing Letters Vol. 1, (4), 187–194.

Logofet, D. O., and Lesnaya, E. V. (2000). The mathematics of Markov models: What Markov chains can really predict in forest successions. *Ecological Modelling, 126*, 285–298.

Lu, D. S., Mausel, P., Brondizio, E. S., and Moran, E. (2002a) Change detection of successional and mature forests based on forest stand characteristics using multitemporal TM data in the Altamira, Brazil. XXII FIG International Congress, *ACSM–ASPRS Annual Conference Proceedings*, Washington, DC, USA, 19–26.

Lu, D., Mausel, P., Brondízio, E. and Moran, E (2002b) Assessment of atmospheric correction methods for Landsat TM data applicable to Amazon basin LBA research. *International Journal of Remote Sensing*, vol. 23 (13) 2651–2671.

Lu, D., Mausel, P., Brondízio, E. and Moran, E.(2004) Change detection techniques. *International Journal of Remote Sensing*, 25 (12), 2365–2407.

Lu, D., Mausel, P., Brondízio, E. and Moran, E.(2005) Land-cover binary change detection methods for use in the moist tropical region of the Amazon: a comparative study. *International Journal of Remote Sensing*, 26 (1), 101–114.

Lu, D. and Weng Q. (2007) A survey of image classification methods and techniques for improving classification performance. *International Journal of Remote Sensing*, 28 (5), 823–870.

Mantero, P., Moser, G. and Serpico, S.B. (2005) Partially supervised classification of remote sensing images through SVM-based probability density estimation. IEEE Transactions on Geoscience and Remote Sensing 43 (3), 559–570.

Matricardi, E.A.T, Skole, D.L., Pedlowski, M.A., Chomentowski, W. and Fernandes, L.C (2010) Assessment of tropical forest degradation by selective logging and fire using Land sat imagery. *Remote Sensing of Environment, 114,* 1117–1129.

McGraw H. (2009) *Digital analysis of remote sensing image*. The Mcgraw Hill Companies, Inc. USA. 645–649.

Mertens B. and Lambin E.F. (2000) Land-cover change trajectories in southern Cameroon. *Annals of the Association of American Geographers*, September issue, 90 (3), 467–494.

Meyfroidt P. and Lambin E.F., (2008) Causes of the reforestation in Vietnam *Land Use Policy*, (25), 182–197.

Mountrakis, G., Im, J. and Ogole, C. (2011) Support vector machines in remote sensing: A review. ISPRS Journal of Photogrammetric and Remote Sensing 66, 247–259.

NASA, (1979) *Landsat data user handbook*, 1979, 7–8.

NASA, (2000) Instructor's Guide for computer resources: global land vegetation module. Online]. Available from: http://www.ccpo.odu.edu/~lizsmith/SEES/pdf_files/vg_ig.pdf [Accessed 2 July 2010].

NASA, (2010) sTechnical detail about the Thematic Mapper. [Online]. Available from: http://landsat.gsfc.nasa.gov/about/tm.html [Accessed 12 June 2010].

NRC (national Resource Centre) (2005), *Glossary of remote sensing terms*. Canada Centre for Remote Sensing. [Online]. Available from: http://www.ccrs.nrcan.gc.ca/glossary/index_e.php?id=2965 [Accessed 28 March, 2010].

Ouyang, W., Hao, F.H., Zhao, C. and Lin, C., (2010) Vegetation response to 30 years hydropower cascade exploitation in upper stream of Yellow River. Commun Nonlinear Sci Numer Simulat 15, 1928–194.

Otukei, J. R. and Blaschke T. (2010) Land cover change assessment using decision trees, support vector machines and maximum likelihood classification algorithms. *International Journal of Applied Earth Observation and Geoinformation* 12S, S27–S31.

Pandy, A.C and M. S. Nathawat, M.S. (2006) *Land Use Land Cover Mapping Through Digital Image Processing of Satellite: A case study from Panchkula, Ambala and Yamunanaga Districts*, Haryana State, India.

Patarasuk, R. and Binford, M.W. (2012) Longitudinal analysis of the road network development and land-cover change in Lop Buri province, Thailand, 1989–2006. *Applied Geography* 32, 228–239.

Pax-Lenney, M., Woodcock, C. E., Collins, J. B., and Hamdi, H. (1996), The status of agricultural lands in Egypt: the use of multitemporal NDVI features derived from Landsat TM. *Remote Sensing of Environment*, 56, 8–20.

Perumal, K. and Bhaskaran, R. (2010) Supervised classification performance of multispectral images. *Journal of computing*, vol. 2(2), 124–129.

Petit, C., Scudder, T., and Lambin, E. (2001) Quantifying processes of land-cover change by remote sensing: resettlement and rapid land-cover change in south eastern Zambia. International Journal of Remote Sensing, 22, 3435–3456.

Powell, C.B. (1995) *Wildlife Study 1*. Report submitted to the Environmental Affairs Department, Shell Petroleum Development Company of Nigeria, Ltd.

Prakash, A., and Gupta, R. P. (1998) Land-use mapping and change detection in a coal mining area – a case study in the Jharia coalfield, India. *International Journal of Remote Sensing*, 19, 391–410.

Reddy, C.S., Rao, K. R. M., Pattanaik, C. And Joshi. P. K. (2009) Assessment of large-scale deforestation of Nawarangpur district, Orissa, India: a remote sensing based study. *Environ Monit Assess*. 154. 325–335.

Ringrose, S, Vanderpost, C., and Matbeson, W. (1996) The use of integrated remotely sensed and GIS data to determine causes of vegetation cover change in southern Botswana. *Applied Geography,* 16 (3), 225–242.

Rogan, J., and Yool, S. R. (2001) Mapping fire-induced vegetation depletion in the Peloncillo Mountains, Arizona and New Mexico. *International Journal of Remote Sensing*, 22, 3101–3121.

Salami, A.T., Akinyede, J., and de Gier, A., (2010) A preliminary assessment of NigeriaSat-1 for sustainable mangrove forest monitoring. *International Journal of Applied Earth Observation and Geoinformation 12.* S18–S22.

Schowengerdt, R.A. (2007) *Remote sensing models and methods for image processing*. US Academic press.

Serneels S. and Lambin E.F. (2001) Proximate causes of land-use changes in Narok District, Kenya. *Agriculture, Ecosystems and Environment*, 85, (1–3), 65–82.

Seto, K. C., Woodcock, C. E, Song, C. Huang, X., L U, J and Kaufmann, R.K (2002) Monitoring g land-use change in the Pear l River Delta usin g Landsat TM. *International Journal of Remote Sensing* 23, (10), 1985–2004.

Singh,A.(1989) Digital change detection techniques using remotely-sensed data. *International Journal of Remote Sensing*,10, 989–1003.

Silapaswan, C. S., Verbyla, D. L., and Mcguire, A. D. (2001) Land cover change on the Seward Peninsula: the use of remote sensing to evaluate the potential influences of climate warming on historical vegetation dynamics. *Canadian Journal of Remote Sensing,* 27, 542–554.

Song, C. Woodcock, C.E., Seto, K.C., Lenney, M.P. and Macomber, S.A. (2001) Classification and change detection using Landsat TM data: when and how to correct atmospheric effects? *Remote Sensing of Environment*, **75**, 230–244.

Soudani, K., Francxois C, and Maire G. (2006) Comparative analysis of IKONOS, SPOT, and ETM+ data for leaf area index estimation in temperate coniferous and deciduous forest stands. *Remote Sensing of Environment* 102: 161–75.

Stow, D. A., and Chen, D. M. (2002) Sensitivity of multitemporal NOAA AVHRR data of an urbanizing region to land-use/land-cover change and misregistration. *Remote Sensing of Environment*, 80, 297–307.

Stehman, S.V. (2012) Impact of sample size allocation when using stratified random sampling to estimate accuracy and area of land-cover change. *Remote Sensing Letters* 3(2), 111–120.

Sunar, F. (1998) An analysis of changes in a multi-date data set: a case study in the Ikitelli area, Istanbul, Turkey. *International Journal of Remote Sensing*, 19, 225–235.

Tuia, D., Pacifici, F., Kanevski, M. and Emery, W.J. (2009) Classification of very high spatial resolution imagery using mathematical morphology and support vector machines. IEEE Transactions on Geoscience and Remote Sensing 47 (11), 3866–3879.

Tuia, D., Muñoz-Marí, J., Kanevski, M and Camps-Valls, G. (2011) Structured Output SVM for Remote Sensing Image Classification Journal of Signal Processing Systems, 65(3), 301–310.

Van Leeuwen, W., B. Orr, S. Marsh, and S. Herrmann (2006), Multi-sensor NDVI data continuity: Uncertainties and implications for vegetation monitoring applications, *Remote sensing of environment*, *100*(1), 67–81.

Verbyla, D. L. and Boles, S. H. (2000) Bias in land cover change estimates due to misregistration. *International Journal of Remote Sensing*, 21, 3553–3560.

Yang, X. and Liu, Z. (2005) Using satellite and GIS for land-use and land-cover change mapping in an estuarine watershed. *International Journal of Remote Sensing* 26(23): 5275–5296.

Yang, X., and Lo, C. P. (2000) Relative radiometric normalization performance for change detection from multi-date satellite images. Photogrammetric Engineering and Remote Sensing, 66, 967–980.

Yang, X., and LO, C. P., (2002) Using a time series of satellite imagery to detect land use and land cover changes in the Atlanta, Georgia metropolitan area. International *Journal of Remote Sensing*, 23, 1775–1798.

Yu, Q., Gong, P., Clinton, N., Biging, G., Kelly, M. and Schirokauer, D. (2006) Object-based detailed vegetation classification with airborne high spatial resolution remote sensing imagery. *Photogrammetric Engineering and Remote Sensing*, 72, 799–811.

Wang, S.Y., Liu, J.S. and Ma, T.B (2010) Dynamics and changes in spatial patterns of land use in Yellow River Basin, China. *Land Use Policy 27,* 313–323.

Wang, Y., Mitchell, B.R., Nugranad-Marzilli, J., Bonynge, G., Zhou, Y., and Shriver, G. (2009) Remote sensing of land-cover change and landscape context of the National Parks: A case study of the Northeast Temperate Network. *Remote Sensing of Environment, 113,* 1453–1461.

Weber, K. T. (2001) A method to incorporate phenology into land cover change analysis. *Journal of Range Management*, 54, 1–7.

Wen, G., Tsay, S., Cahalan, R. F., and Oreopoulos, L. (1999),Path radiance technique for retrieving aerosol optical thick- ness over land. *J. Geophys. Res.* 104(24), 321–332.

Weng, Q. (2002) Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling. *Journal of Environmental Management*, 64, 273–284.

Xie, Z., Xu, X. and Yan, L. (2010) Analyzing qualitative and quantitative changes in coastal wetland associated to the effects of natural and anthropogenic factors in a part of Tianjin, China. *Estuarine, Coastal and Shelf Science* 86, 379–386.

Xiang, M., Hung, C. Pham, M.. Kuo, B. and Coleman, T. (2005) A Parallelepiped Multispectral Image Classifier Using Genetic Algorithms. *Geoscience and Remote Sensing Syposium, 2005 proceeding, IEEE International.* 482–485.

Xiang, S., Nie, F. And Zhang, C. (2008) Learning a Mahalanobis distance metric for data clustering and classification. *Pattern Recognition* Vol. 41, 3600–3612.