Determination of relationship between MODIS Vegetation Indices (arithmetic mean), biomass, rainfall, and field measurements of Sandveld Research station in Camel Thorn Savannah of Namibia.

Alois Katiti
University of Tasmania

Namibia is located on the south-west coast of Africa between the latitudes 17.5° and 29° south and 11.5° and 25.5° east. It has a total surface of 824 295 km², with a population of approximately 2.1 million in the most recent population census (2011). Despite these diverse environmental conditions, recurrent drought and desertification have contributed to making Namibia’s natural resources, as well as the rangeland ecosystems, most vulnerable. The country’s natural resource-based economy and limited technical and financial resources further increase the vulnerability. On contrary Namibia’s economic backbone is the agricultural sector where livestock production is the major contributor to the economy. The livestock sector is mainly dependent on the rangeland for forage resources. Therefore Namibia has put more emphasis on vulnerability and adaptation to sustainable use of rangeland resources and its management.

About 70% of the population depends directly or indirectly on these natural rangeland resources for their economic well-being and food security. Yet it is said that the rangeland degradation is taking place at an alarming rate. There are many known causes of rangeland degradation such as overgrazing and, unpredictable rainfall due to climatic changes (Ganzin et al. 2005). The current state of rangeland deterioration in Namibia is a major concern of the government, researchers, grassland scientists as well as land users. The need to balance biodiversity conservation with sustainable development, though widely agreed upon, is elusive in practice, as human societies are increasingly disconnected from ecosystems that support them. The loosening connection and growing scientific acceptance that ecosystems are complex, dynamic, non-linear systems poses new challenges for natural resources monitoring, assessment as well as management. Assessment and measuring of rangeland resources is said to play a vital role in sustainable use of these resources and it is considered to be an important part of conservation programs (Pyke et al. 2002).

The primary cause of rangeland degradation is still unknown, due to lack of knowledge on seasonal variability on the rangeland ecosystem production. On contrary, the study rangeland changes on seasonal or temporal basis have been a very challenging process, but some progress has been made over the years with the aid of technologies such as remote sensing and GIS (Akiyama & Kawamura 2007). Satellite imagery is known to be non-destructive tool that can provide fast, spatially, precise mapping of land surface properties and it provides the best temporal monitoring systems. Recently, numerous earth observation satellites have been used to study variety of natural resources (Bettinger & Hayashi 2006). Land degradation processes are monitored by using satellite remote sensing techniques throughout the world (Geerken & Ilaiwi 2004). Munyati, Shaker and Phasha (2011) used multi-temporal SPOT images to monitor bush encroachment, which is one of the major causes of rangeland degradation in the southern African countries. The use
vegetation indices were found to provide strong foundation as adjunct to field methods for assessing vegetation in the southern Australia (Jafari, Lewis & Ostendorf 2007).

According to Lunetta et al. (2006), MODIS imagery is more attractive than most of multi-spectral imagery due the availability at no-cost and very low cost associated with data processing. However, the utility of MODIS VIs products are limited by availability of high quality (e.g. cloud free data), (Jin & Sader 2005).

The research hypothesis is that seasonal forage biomass productivity can be estimated by using satellite imagery. It has been proven that there is a relatively strong relationship between field biomass data and satellite variables such as the Normalized Difference Vegetation Index (NDVI), Enhance Vegetation Index (EVI), Leaf Area Index (LAI) and the Fraction Photosynthetic Active Radiation (FPAR) estimates (Alleaume et al. 2005; Giri & Shrestha 1996; Omuto et al. 2010). Hayashi (2006), argues that given appropriate assumptions, other variables associated with conventional field measurements such as time, cost and labor can be considerably reduced.

**Aims and objectives**

The main aim of this project is to quantify seasonal biomass (herbage mass) productivity, as well as the seasonal variation of the Camel Thorn Savanna of Namibia from satellite imagery. To address these aim the following objectives are defined.

- To determine the relationships between MODIS vegetation indices and field biomass measurements of seasonal biomass productivity and rainfall;
- To determine the best fit linear regression model, for the study area;
- To determine significant seasonal variations in biomass production;
- To compare the findings with similar studies and possibly identify overall shortcomings.

**Literature Review**

Tueller (1989), argue that the future of rangeland resources assessment, monitoring and management is dependent upon an increase in scientific capability. Rangeland scientists admit that lack of good quality research on rangeland ecosystems, especially monitoring and tracking of changes that occur within these ecosystems, is mainly due to lack of application of different techniques and skills in using available techniques (Tueller 1989). There is no universal or overall best method for studying rangeland processes, but good results can be obtained by the integration of a range of methods. Techniques need to be critically selected, taking into consideration factors such as suitability, applicability and adaptability to the specific area of concern.

**Role of Rangelands**

Native rangelands are a valuable natural resource with diverse ecological and environmental aspects that have a significant impact on the functioning and biodiversity of any natural ecosystem. Various authors, (Akiyama & Kawamura 2007; Ganzin et al. 2005) highlighted
that rangeland vegetation communities are the fundamental variable that impacts on and links many parts of the human and physical environment.

According to Barbour, Burk and Pitts (1987); (Cilliers, Müller & Drewes 2004) that even though rangeland ecosystems are considered one of the most important variables, knowledge and understanding about their dynamics is relatively poor. Study of different rangeland ecosystems’ functional integrity and biodiversity has become increasingly specialized and fragmented (Denis 2010). Production yield and sustainability are definitely the most important measures in assessing rangelands over a certain period of time. Rangeland resources plays a key role as a source of livelihood for communities living in rural areas (Omuto et al. 2010). They almost depend entirely on rangeland resources for food, fuel wood, and pasture for their livestock.

Rangelands are said to have a history of biological decline with desertification, erosion, loss of native grasses as well as incursion of invader woody vegetation (Noble 1998). Sub-Sahara African countries have suffered severely from the effects of rangeland degradation, mainly due to overgrazing and over exploitation of natural resources. But rangeland degradation has never enjoyed the status, attention and emotive appeal of other environmental issues. This is because through the 1960s rangeland degradation has slipped from political view as the mechanism of agriculture obscured degradation behind spectacular gain (Ganzin et al. 2005).

Relationships between different variables and rangeland production

Vegetation Indices and biomass production
Remote sensing provides an efficient means of studying the relationships between ground data and satellite data across wide regions. Shoshany and Karnibad (2012) confirm that by using high or medium resolution imagery it is possible to compare and estimate various field measures such as biomass and rainfall with vegetation indices and produce models to establish quantitative relationships between these parameters.

Rainfall and biomass productivity
Precipitation is a primary determinant of rangeland biomass productivity, but according to Shoshany and Karnibad (2012) there is lack of real data on its spatial distribution for validation. Vegetation greenness is regarded as an indicator of the actual distribution of rainfall, and earlier studies had shown that shrub patterns indicate the influence of rainfall and its efficiency. A study by Maposa et al. (2012) showed poor linear relationship between these two variables. On contrary de Leeuw and Nyambaka (1988) produce promising results of $r^2 = 0.62$ to $r^2 = 0.99$ in Kenya and Northern Tanzania. Disparity exists because of the bimodal annual rainfall and high soil fertility of the East African countries. They further argue that some plants perform better with little rainfall, whereas some yield less with excess rainfall.

Rainfall and Vegetation Indices
NDVI’s relationships with rainfall were tested for mixed-effect modelling in low mixed vegetation types of Somalia. De Leeuw & Nyambaka (1988); Omuto et al. (2010) on the other hand suggests that the most common application of remote sensing in detecting
human-induced loss of vegetation cover is by eliminating rainfall dynamics from time-series NDVI images. They latter spatially interpolated the monthly rainfall with the aid of NDVI-rainfall relationship on pixel-basis.

**Methods/techniques of Rangeland assessment/monitoring**
Lu (2006), highlighted that there are three overall main approaches for rangeland biomass estimation/assessment, which include field measurements, remote sensing and GIS approach. Of the three approaches field measurements are considered to be accurate but prove to be costly and time consuming (Mitchard et al. 2009).

**Traditional ground-based (field measurement) methods**
According to Gibbons and Freudenberger (2006), traditionally information about vegetation condition has been collected using ground truthing methods and was considered to be more site specific. Currently various traditional methods/techniques of field assessment/evaluation are well known to scientists and researchers.

Contrary to new techniques (GIS and remote sensing) used in environmental monitoring and assessment, traditional methods are known to be very laborious and expensive. For instance, most field-based used traditional method to determine biomass production which is known as the plot-based or quadrat technique (Figure 1). As the name suggests the technique is more useful for smaller areas, but it can also be applied on a farm scale. All the standing plant material within the quadrat is harvested to determine the biomass in kg/m$^2$. Usually only a few quadrats are harvested and estimations made by extrapolating over the larger area. Once the material has been clipped it is weighed wet and air dried, and then samples analyzed. Clipping of quadrates offers the most direct and accurate results, which show the actual yield biomass production. Quadrats are also used to successfully estimate several other vegetation attributes such as plant density, cover and species distribution.

*Source: University of Idaho*  
*Figure 1: Example of quadrat for harvesting grass material.*
A Remote Sensing Approach

Tueller (1989), state that the future of rangeland resources development and management is dependent upon increased scientific capability. He further stressed that remote sensing can provide significant information on the rangeland conditions. For over 30 years and as early as the 1980’s remote sensing has been recommended to assist rangeland managers and researchers with resources development and management (Tueller 1989). He highlighted the two most common uses of remote sensing in range management as 1) vegetation assessment (change detection), and 2) evaluation of different utilizations. It is widely believed that with the strong commitment to the US space program, i.e. National Aeronautics and Space Administration (NASA), the study and understanding of land cover and its dynamics of the past and present, research in the science of range management and environmental monitoring will be pushed to new heights (Justice et al. 2002).

The issue of taking environmental monitoring or observation of the global changes to the next level was emphasised as early as 1972 when Landsat 1 was launched. However, it goes as far back to 1930’s when aerial photos were used. With its fast pace of development these advanced technologies were highly welcomed by a wide range of scientists and researchers. According to Tueller (1989), the high expectations of technology were only realised when various professionals could understand and apply the techniques in their respective fields.

Although there are many types of satellite imagery available the main focus here is on Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery, which was used for the study. MODIS is seen as a potential replacement for most traditional methods on regional-scales, although little work has been done and published regarding its applications on seasonal assessment or monitoring of rangeland. Pioneering work by Alleaume et al. (2005) and Hüttich et al. (2011), proves that there is a great potential in using MODIS, although these studies were employed on a local scale, in the Etosha and Kalahari districts respectively. Current knowledge on the use of MODIS is fragmented, as contemporary research has focused on rangelands, vegetation and land cover, and various other environmental monitoring and assessment processes. Moderate-to-fine spatial resolution systems data combined with field survey data can be used to verify coarse-resolution forest maps and discern causes of Landcover changes (Fuller 2006).

The MODIS Product

The MODIS website (http://modis.gsfc.nasa.gov 2011) provides a search engine that permits the user to search the MODIS catalogue for particular areas of interest and select the resolution of data and specific dates. This means that MODIS data can be obtained free of charge through the Level 1 and Atmosphere Archive Distribution Systems (LAADS). By utilizing the Search & Order Tool on the LAADS website, one can search and subset data by collection, date and time, geographic area, science products and selected metadata (http://modis.gsfc.nasa.gov, 2011). By using the FTP page to find the directorates that starts with “MOD” (for MODIS Terra HDF data or “MYD” (for MODIS Aqua HDF data) MODIS satellite imagery can be downloaded.
Vegetation Indices (VI), which mostly a combination of surface reflectance bands at two or more wavelengths, designed to highlight certain properties of the vegetation (ENVI Guide, 2010). MODIS vegetation products of LAI, FPAR and Net Primary Production have been designed to address questions of ecosystem productivity contributing to carbon cycle research (Myneni et al. 2003). A lot if VIs have been developed to make use of the difference between the red and the infrared reflectance values, highlighting the chlorophyll (for overviews see (Fuller 2006) (Schröter et al. 2009), (O’Farrell et al. 2010). VIs has been designed to provide consistent comparisons of temporal and spatial changes in vegetation and have been widely used in land cover studies, land use and vegetation change detection studies.

Normalized Difference Vegetation Index (NDVI)
The Normalized Difference Vegetation Index (NDVI) is one of the most widely used VI (Asner et al. 2004). The NDVI ranges from -1 to +1, where values at 0.1 and below correspond to barren soil, values from about 0.2 to 0.3 represent grass and shrubland, and high values (0.6-0.8) can be found in tropical rain forests (Alleaume et al. 2005). The higher the NDVI the higher the amount of photosynthetically active vegetation is (de Lange 2006). NDVI is defined as;

\[ NDVI = \frac{\rho_{NIR}-\rho_{RED}}{\rho_{NIR}+\rho_{RED}} \]

where \( \rho_{NIR} \) is reflectance in the NIR band, and \( \rho_{RED} \) is reflectance in the RED band.

Enhanced Vegetation Index (EVI)
The Enhanced Vegetation Index (EVI) was developed to improve the NDVI by optimizing the vegetation signal by using the blue reflectance (blue band) to correct for soil background signals to reduce atmospheric influences, including aerosol scattering.

It tends to be very useful in the regions where NDVI may saturate the EVI, and this is defined by (Huete et al. 2002; Matsushita et al. 2007).

\[ EVI = 5.2 \times \frac{\rho_{NIR}-\rho_{RED}}{\rho_{NIR}+\rho_{RED} - 7.5\rho_{BLUE} + 1} \]

Leaf Area Index (LAI)
The Leaf Area Index represents the aggregate photosynthetic surface area of plant canopies or canopy components per unit land area. It is usually estimated or expressed in terms of the aggregate single-sided surface area of foliage per unit area of ground surface, and represented by the equation below.

\[ LAI = \frac{Total \ Leaf \ Area \ (one \ surface)}{Unit \ ground \ area (horizontal)} \]

The LAI ratio calculated from the above equation can be greater than 1.0 in for densely overlapping and highly productive or lush vegetation types.

Fraction of Photosynthetically Active Radiation (FPAR)

FPAR is mainly associated with measuring proportions of available radiation in the photosynthetically active wavelength of 0.4 to 0.7 \( \mu \text{m} \) that a canopy can absorb. Very similar to LAI, it is considered a biophysical variable which describes canopy structure and is related to functional process rates of energy exchange and mass exchange. Both LAI and FPAR have
been used extensively as satellite-derived parameters and can be considered proxies of surface photosynthesis, evapotranspiration, and most importantly annual NPP (Myneni et al. 2003).

**Geographic Information System (GIS)**
GIS is defined by many users as a computer-based system which consists of hardware and software to aid collection, facilitation, manipulation, analysis, storage, output and distribution of spatial data and information (Bolstad 2008). Technologies such as GIS have been advocated as mediums through which many of the objectives of the new development mechanisms could be achieved.

Although GIS is in a fairly diverse field, it has been used in combination with remote sensing to present a powerful tool, especially in assessing and monitoring of environments on both a regional and global level (de Leeuw & Nyambaka 1988). GIS is widely adopted as part of the innovative but cost-effective and sustainable approach to multifarious problems facing the resource planner.

**Methods**
The ultimate goal of the study is to investigate the extent to which MODIS satellite imagery can be useful to study biomass seasonal changes.

**Study site**
The Sandveld Research Station is approximately 8,336 ha in size, it lies about 1,300 m above sea level at 19° 7’ S latitude and 22° 2’ E longitudes Figure 3, eastern Namibia in the central Kalahari. The research station is situated in the *Camel Thorn savanna vegetation* according to Gies, (1971) vegetation map *Figure: 2* where *Acacia erioloba* is the most prominent tree species.

![Map of Vegetation types of Namibia, and location of Sandveld research station.](source: Gies (1971))

*Figure: 2* Map of Vegetation types of Namibia, and location of Sandveld research station.
Field-based sampling

Forty quadrates per camp were clipped, in a particular group (i.e. A, B or C) to determine the grazing capacity (dry matter production i.e. biomass/ha) of the specific camp. Dates on which quadrates are clipped and botanical composition determined are fixed and set for December/January, May/June and September of every year.

Spatial data Acquisition and Processing

The NASA MODIS biophysical data products, of which the FPAR, LAI 8-day and NDVI/EVI come in a set of two respectively, are all archived in the NASA HDF-EOS data format. HDF-EOS is a derivative data format built upon the Hierarchical Data Format (HDF) pioneered by the National Center for Supercomputer Applications (NCSA), there are also number of NASA web sites offering new tools, and NASA HDF-EOS group is well known for offering a wide range of software tools for processing almost all types of satellite imagery acquired by its satellites (Geophysical & Data 1998).

The LAI/FPAR product at 1 km spatial resolution daily (MOD15A2), 8-day period composite was acquired from EOS Data Centre Distribution Active Archive Center (EDC DAAC). For NDVI/EVI a 16-day 250m resolution composite (MOD13Q1), level-2 products from MODIS Terra sensor was acquired for 2005 May to 2010 December period. Most literature on MODIS, more specifically by Ballantine et al (2005) concludes that MODIS provides large spatial scale data necessary for land cover mapping on national and regional levels, and it is also used as a tool for understanding the influence of human activities and how the natural environment responds to those activities.

There are two MODIS instruments on-board the Terra and Aqua space crafts. The sensors have a viewing swath width of 2,330 km, covering the whole globe on a daily basis (http://modis.gsfc.nasa.gov/index.php). MODIS data is used for continental to global scale mapping of the earth’s surface and most importantly it has moderate to coarse resolution which is sufficient for geomorphic and ecological studies (Ballantine et al. 2005). All MODIS land products are acquired in Integerized Sinusoidal (IS) projection with 10-degree grid, where the globe is tiled for production and distribution purposes into 36 tiles along the east-west axis and 18 tiles along the north-south axis each 1200x1200 km (FPAR, LAI User’s Guide, 2003). The NASA MODIS biophysical data products, of which both sets of FPAR/LAI 8-day and NDVI/EVI 16-day come in one image bundle, which is archived in NASA HDF-EOS format.

Google Earth, ArcGIS and ENVI

The farm map of the area was generated by manual digitizing on an Image©2012 Digital CNES/SPOT image of Google Earth (Figure 3a). The digitized Google KMZ file was imported into ArcGIS. In ArcGIS different camps were digitized to produce polygons separating the farm into different units. The first step before working with the imagery was to reproject MODIS land products from default SI projection to WGS84 world projection.
Figure 3: (a) Sandveld Research station Google Earth image, (b) Shape file in ArcGIS.

Figure 4 (a) Shape file imported in ENVI (b) Standard vector loaded onto the MODIS image.

Figure 5 (a) Regions of Interest (ROIs) of farm management sections (b) Camps (ROIs) under investigation.
Extraction of Statistics
The ROIs that were defined with ENVI are typically used to extract statistics; image-separate statistics consisting of basic statistics (i.e. minimum value, maximum value, standard deviation as well as the mean values of the VIs). The spectral information of each of each ROI is determined on pixel level to identify spectral class associated with land cover. Only mean statistical values of six of the ROIs in Error! Reference source not found. (b) were used for comparison or determination of relationships with field biomass measurements.

Time-series trend and regression analysis
First of all, the time series trend relationship between field biomass data, rainfall and VI's indices (i.e. NDVI, EVI, LAI and FPAR) was determined by using a simple line graph. The line graph was very important to observe the pattern and the behavior of these variables together. The second part involved using linear regression to develop a regression model with the best fit line between biomass and different vegetation indices.

Results

Visual interpretation

This part shows the visual pattern of the changes over time series of different seasons, and the data of both VI’s and and biomass is graphed to demonstrate the similarities and differences over time series patterns. Visual analysis of graphed data is based on interpretation of the changes in pattern between the above mentioned parameters. With this strategy it is very easy to highlight the similarities and the dissimilarities that occur over time and it can greatly help to indicate the relationships that exist. Visual comparison of the relationships between field measure data and MODIS satellite estimates of biomass production over three seasons is demonstrated in the figures below. Although both VIs and biomass are charted on the same diagram the measurements units are different. Seasonal changes for the month of December over 2005 – 2009 three month dormant period of October to December (Figure 6).

Figure 6  (a) NDVI vs. biomass and (b) EVI vs. biomass.
Figure 7 shows 5-months of active growing (raining) season January to May.

Figure 7: (a) NDVI and biomass and (b) EVI and biomass.

Four months dormant season which extends from June to September is depicted in Figure 8.

Figure 8 (a) NDVI and biomass and (b) EVI and biomass.

LAI/FPAR and its relationships with biomass are shown in the figures below, May season is highlighted in Figure 9.

Figure 9 (a) LAI v/s biomass and (b) FPAR v/s biomass
September season variation relationship is demonstrated in Figure 10.

Figure 10: (a) LAI v/s biomass and (b) FPAR v/s biomass.

Figure 11 (a) LAI v/s biomass and (b) FPAR v/s biomass
Trend Estimation using linear regression

The second part uses basic statistical analysis of linear regression application to determine the relationships between VIs and biomass. Table 1 is a regression calculation for estimated seasonal trends of the VIs and the biomass relationship.

Table 1: The linear relationship of field biomass (kg) and VIs for period 2005 December to 2010 May.

<table>
<thead>
<tr>
<th>Month/ Season</th>
<th>VIs v/s Biomass</th>
<th>Regression Equation</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>NDVI/Biomass</td>
<td>Y= -1E - 05x + 0.3138</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>EVI/Biomass</td>
<td>Y= 1E - 05x + 0.1491</td>
<td>0.62</td>
</tr>
<tr>
<td>September</td>
<td>EVI/Biomass</td>
<td>Y= -3E - 05x + 0.2082</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>NDVI/Biomass</td>
<td>Y= -3E - 05x + 0.2893</td>
<td>0.40</td>
</tr>
<tr>
<td>December</td>
<td>EVI/Biomass</td>
<td>Y= 2E - 05x + 0.1954</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>NDVI/Biomass</td>
<td>Y= 5E - 05x + 0.3247</td>
<td>0.11</td>
</tr>
<tr>
<td>May</td>
<td>LAI/FPAR/ Biomass</td>
<td>Y = 0.4465x- 16462</td>
<td>0.73</td>
</tr>
<tr>
<td>September</td>
<td>LAI/FPAR/ Biomass</td>
<td>Y= 0.8334x-31046</td>
<td>0.75</td>
</tr>
<tr>
<td>December</td>
<td>LAI/FPAR/ Biomass</td>
<td>Y= 0.0977x-2377.6</td>
<td>0.0059</td>
</tr>
</tbody>
</table>

3.3 Rainfall Data
In addition to the above-mentioned parameters, rainfall data was deliberately integrated to indicate possible links between the abnormal behavior within the trend of the biomass productivity as well as the VIs.
Discussion

In the previous chapter, biomass and VI results were compared visually and by using linear regression to determine the relationships that might exist between these variables. The results clearly indicated that there is a very poor relationship between VI’s and field data over some seasons, but fairly acceptable relationships exist during certain seasons of the year. The method of data collection and analysis are said to play a significant role in the final result for interpretation. In this case, where the relationships are illustrated with the graphs, the relationship is more clearly visible and can be more readily investigated, than it is with the results produced statistically. The trends and patterns visible in graphed data are also more easily seen than in statistical simple linear regression.

May season (5-month active growing season)

Relationship between NDVI/EVI and field biomass measurements

Typically this season is known as the 5-month active growing season with peak precipitation of more than 80 per cent of the total annual rainfall. During this season the grassy layer is usually in good stable condition with healthy canopy and basal cover. It is clearly noticeable from (Figure 7) that the rainfall patterns shown of the area were not different from the above-described pattern. With favorable rainfall during this season NDVI and EVI displayed a very similar pattern with field biomass measurements over the three-year period (i.e. 2006, 2007 and 2008). There was a sudden change in 2009 and 2010, whereby NDVI showed a sharp decrease between these two years. This was totally opposite to what was observed with EVI, which showed a gradual sharp increase, whereas field biomass production also indicated a steady increase throughout. On the other hand minimum precipitation was recorded in 2009 which could be the major reason for the abnormal pattern observed in NDVI.
The correlation between field biomass and NDVI was negative with low correlation ($R^2 = 0.17$), whereas relatively high negative correlation ($R^2 = 0.62$) was observed between EVI and field biomass.

**Relationship between LAI/FPAR and field biomass measurements**

Figure 9, shows that both LAI and FPAR decreased during the first period of 2006 to 2007, and FPAR continued to decrease steadily until 2009, contrary the LAI which increased from 2007 to 2008, reaching its maximum in 2009 from where a very slight constant was observed. When looking at the pattern of LAI and biomass the dissimilarity was only observed during the 2006 to 2007 period, with an increase in field biomass data and in LAI, which continued to decrease until 2008. From 2007 to 2010 both the LAI and field biomass data followed a very similar irregular pattern.

**September season (4-month dormant season)**

**Relationship between NDVI/EVI and field biomass measurements**

During this season both the NDVI and EVI showed a different pattern from that of field biomass measurements. The seasonal fluctuation of biomass and the VIs were in the opposite direction during most of the season, for instance, when a steady increase was observed in field biomass measurements a sharp decrease in both EVI and NDVI was recorded during the 2006 to 2007 period. While there was still an increase in field biomass measurements during the following period (i.e. 2007-2008), very little or no significant changes were observed with the VIs.

From VIs (i.e. EVI and NDVI) it can be seen that there was not much plant activity occurring during this season, as these indices depend on the reflection caused by green plant material (photosynthesis processes). In contrast there was always dry material to be harvested as the specific area of study was not grazed during or after the growing season until field measurements were taken (carried over biomass). An early rainfall of about 53 mm received around September 2009 might have boosted the new growth of green material, which could be observed in the increase of both NDVI and EVI, while there was a slight decrease in field biomass during the same period of 2008 to 2009. Overall lack of enough green material could be the main contributing factor leading to the dissimilarity of VIs and field biomass throughout the season.

**Relationship between LAI/FPAR and field biomass measurements**

FPAR and LAI also showed a decrease during the 2006 and 2007 seasons, a very similar pattern followed by NDVI, EVI and field biomass during the same period of the season. As stated in the previous section this behavior might be caused by the rainfall as there was no rainfall prior to or during this period. From 2007 to 2009 the fluctuation in seasonal field biomass as well as FPAR and LAI had a similar flow pattern with an increase followed by a decrease. From the visual observations Figure 10, the changes that occurred between these variables are almost constant; this shows that there is a reasonable relationship. Even though positive relationships were observed by visual interpretation between the field biomass, NDVI and EVI, the rainfall seems not to play an important role in the overall fluctuations that were indicated.
Statistical results tend to be more supportive of the fact that a positive relationship exists between field biomass and LAI and FPAR with the highest correlation of $R^2 = 0.75$. During a similar period NDVI and EVI yielded a negative relationship with field biomass ($R^2 = 0.40$) and ($R^2 = 0.62$) respectively, which could be proof that LAI and FPAR provides more robust statistical results. One could possibly suggest that the robustness of the later two VIs were because of their high sensitivity to woody plants, which tend to be green throughout the seasons.

December season (3-month dormant season)

Relationship between NDVI/EVI and field biomass measurements

A similar seasonal fluctuation pattern seen in field biomass has also been spotted in both the NDVI and EVI. This pattern was suddenly disrupted during the season of 2008 to 2009 when there was a sudden sharp increase in field biomass, whereas both the NDVI and EVI remain constant with little or no increase over this period. By carefully analyzing the results shown in Table 1, one can unambiguously conclude that the overall relationships between VIs and biomass are very poor for the available data of the area. It can easily be stated that there is no simple linear relationship between these variables, although such relationships have been reported in various literature. During this season the correlation between field biomass and NDVI and EVI was the lowest with correlation coefficient of $R^2 = 0.11$ and $R^2 = 0.12$ respectively.

Relationship between LAI/ FPAR and field biomass measurements

During the first two phases of that 2006 and 2007 period, a very close pattern of chart flow was observed with LAI, FPAR and field biomass in which all these variables decreased. Field biomass showed a continued decrease reaching its lowest during 2008, contrary to LAI and FPAR which showed a sudden sharp increase reaching its highest point during 2008. The last period demonstrated an increase in field biomass, while the LAI and FPAR tend to decrease steadily over this period. Statistical results of the relationship of LAI and FPAR during this season were very low with correlation coefficient ($R^2 = 0.0059$). Statistically the relationships were insignificant; these could be possibly due the lack of woody part contribution as this season followed another four-month dormant period.

Conclusion

The study’s main focus was to determine whether VI’s statistical mean can provide substantially similar trends or patterns when compared with seasonal field biomass measurements. The results illustrated a range of differences between both field biomass and VIs, however variation in interpretations of the two techniques in analysis of the outcome creates challenges. Contrary to this, the study takes the position that visual analysis of the graphs and statistical linear regression ($R^2$) of the data can serve as judgment aids, showing that changes have occurred and that both negative and positive relationships exist. The graphical part portrays a reasonable time-series relationship throughout most of the seasons, but there are some exceptional cases, such as during the September season, when both EVI and NDVI showed no common pattern with field biomass. Very similar observation could have been made with FPAR and LAI during the last three phases (i.e.
2007, 2008 and 2009), when there was no direct connection with field biomass. This season also had the lowest correlation results of the study.

Although some conclusion could be drawn from the study, the results did not show convincing strong relationships that could be used to predict one variable from other variable. Considering the environmental and climatic factors as well as the functionality of the VIs conclusive comments can however be made. For instance, the high correlation observed with LAI and FPAR could be due their robust functionality in a woody/shrubland savanna. Integration of these results obtained from these two methods can make a significant contribution towards understanding the seasonal biomass productivity and the biophysical processes of the study area.

The results also demonstrated that methods or techniques in analyzing and comparing MODIS data and field biomass measurements data can be used to determine the seasonal variability to a certain extent. However, the study could not confirm the hypothesis of the possibility to determine the biomass productivity using a most suitable model. On the other hand, there is potential to establish convincing positive relationships between VIs and field biomass of the study area provided enough data is made available. Therefore the study recommends that whole farm data (full data set) of field biomass must be made available to make sound judgment on the relationships, as ground data shortage might have the main influence on the final outcome of the study.

Reference


Hayashi, R 2006, 'Above ground biomass estimation in a 285-hectare site of mixed pine-hardwood using landsat thematic mapper imagery and regression analysis'.


Matsushita, B, Yang, W, Chen, J, Onda, Y & Qiu, G 2007, 'Sensitivity of the Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) to topographic effects: A case study in high-density cypress forest', Sensors, vol. 7, no. 11, pp. 2636-2651.


