Retrieval of Land Surface Parameters for Vegetation Degradation Monitoring in Arid and Semi-arid regions

Yogita Shukla*, Arun Tillu, P S Roy

a Department of Space Sciences, University of Pune, Pune, India
b National Remote Sensing Centre, Balanagar, Hyderabad, India

ABSTRACT

Land surface characterisation is gaining importance due to swift transformations occurring at earth-atmosphere interface. The far-reaching changes brought in the course of the exchange of radiant energy between earth surface and the atmosphere due to rapid urbanisation, deforestation, land degradation and desertification has ultimately resulted in substantial changes in land surface parameters at local, regional and global level. Owing to the significant role arid and semi-arid ecosystems play in determining the intricacies of earth-atmosphere interactions and ultimately affecting the global climatic mechanisms, land surface studies have thus become imperative to assess the potential impact of the environmental changes taking place at the boundary of earth’s surface and the atmosphere.

The vegetation in arid and semi-arid regions experiences a phenomenal change in its growth pattern and is highly dynamic. The change in vegetation canopy density with the change of season has great impact on the land surface properties and their interactions. It is thus very important to assess and monitor the vegetation status and seasonal growth characteristics in association plant diversity in these regions. Vegetation degradation monitoring in arid and semi-arid regions requires long-term observations of vegetation extent and involves the use of a number of parameters (NDVI, Evapotranspiration, PAR, LAI etc.,) to substantiate its impact on these marginal ecosystems. The land surface parameters that have gained recognition for deriving real-time estimates of vegetation condition in these regions are GLAI (green leaf area index), gfc (green fractional cover), albedo, surface temperature, and surface emissivity to name a few. Of these the green leaf area index and green fractional cover have a unique importance owing to their characteristics and their capability to be linked with seasonal changes in vegetation condition.

This paper will present an operational methodology developed through retrieval of land surface parameters for arid and semi-arid regions of Rajasthan using multi temporal and multi-scale satellite data. The satellite data used in this study are S-1 and S-10 data from SPOT Vegetation (4 & 5), IRS-WIFS and IRS-LISS-III data. Satellite data from these sensors gives fairly reasonable estimates of vegetation amount and condition when linked with surface biophysical parameters. The biophysical variables like GLAI and gfc, calculated over a period of time gives real-time spatial description of changes in land use and land cover and can be incorporated into models to make more realistic assessments of linkages between changes in surface properties and biogeochemical processes (Wessman and Asner 1998).

The phenological information coupled with the land surface parameters provide valuable inputs to describe the interactions occurring at the atmosphere-geosphere interface. The seasonality captured through these multitemporal datasets gives an

* Corresponding Author: Yogita Shukla; yogita_s@yahoo.com; phone:+91-9313345486
insight into the various processes of energy exchange phenomenon taking place at land surface. It is of significance to regional climate change studies and large scale monitoring of land use and land cover changes. The surface parameters derived from satellite data for the entire study area will serve as a baseline datum to further the studies related to vegetation degradation monitoring and climate change modelling.

**Key Words:** Land Surface Characterisation, Arid and Semi-arid, Satellite data

### 1. INTRODUCTION

Vegetation degradation at an unprecedented rate has made it obvious to continuously monitor the green cover on a periodic basis. The processes leading to degradation and the extent of problem worldwide are only recently understood. Assessment of the degree to which desertification is increasing is essential to decision-makers and others concerned with land degradation. Therefore, continuous monitoring of vegetation is absolutely indispensable and would certainly add much to our knowledge in understanding our living environment and its interactions with climate, and in predicting the future of our planet. Vegetation monitoring requires reliable and repeatable techniques of accurate and timely information on green cover for spatial and temporal coverage. Multispectral and multitemporal coarse resolution data are therefore useful in describing distribution of different types of land cover at regional level.

In the present framework of global vegetation dynamic studies, seasonality is a topic of prime relevance in the assessment of the potential climatic impacts; these impacts are theoretically identified as anomalies or unexpected trends in a seasonal signal produced by vegetation canopy. Furthermore, radiometric changes in the canopy associated with the succession of the season are a typological characteristic of vegetation itself (Anon., 1998). Thus the availability of well-calibrated long-term time series of canopy measurements is of much value for classifying vegetation. The seasonal and long-term variations of factors such as albedo, surface roughness, resistances to heat exchanges (sensible and latent), are also related to vegetation dynamics (Anon., 1998). The capability to identify these variations, the physical characteristics of land cover is a key for accurate prescriptions of these variables. Quantitative estimates of vegetation especially heterogeneous surfaces need to be established in order to fully understand and predict the future trend of our changing environment.

A key parameter in the functioning of the energy exchange processes occurring within the earth-atmosphere interface, vegetation is a sensitive indicator of land surface characteristics. Remote sensing techniques provide powerful tool to obtain such information and as a result, a number of satellites (LANDSAT, SPOT, NOAA AVHRR & METEOSAT) have been launched to measure the earth reflected solar radiation in the spectral wavebands that contain vegetation information. The data acquired by these satellite systems have the advantage of frequent repetitivity to capture the vegetation seasonal evolution, which is the basic requirement especially for climate and meteorological studies where boundary conditions have to be prescribed as in the case of general circulation models or forecasting models (Anon, 1998).

The VEGETATION instrument onboard the SPOT-4 satellite and IRS-WiFS dataset provide a unique set of remote sensing measurements suitable for vegetation monitoring because of its unique spectral (Blue, Red, NIR and SWIR bands for SPOT and Red and NIR for WiFS) and spatial (1*1km resolution for SPOT and 188*188m for WiFS) configurations. The high temporal frequency (daily for SPOT and weekly for WIFS), timely update the vegetation status for short-term change detection and the long term estimates from the satellite instrument enables long term degradation monitoring. Analysis of the satellite data has revealed the possibility of using remote sensing techniques to characterize surface properties, and much knowledge has been gained about the functioning of vegetation and its role on environmental and climate changes. Several studies have been done for estimation of land surface albedo, biophysical properties (Barnsley *et al*., 2000, Lihong Su *et al*.,
2000) using SPOT-4 VGT data. Results of such studies suggest that the above dataset used in conjunction with appropriate BRDF models yield good estimates of land surface albedo and those biophysical properties useful in vegetation information extraction.

Radiometric measurements in the spectral domain contain useful information about vegetation. Analysis of remotely sensed data has revealed the possibility of using remote sensing techniques to characterize vegetation properties. However, the information contained in a single spectral band is usually not enough to fully characterize vegetation properties and its dynamics (Qi, et al., 2000). Computation of vegetation indices like normalized difference vegetation index (NDVI) was the only practical way to maximize the information content from the spectral radiometric measurements so far. Although this index could be quantitatively related to several vegetation parameters such as leaf area index (LAI), percentage vegetation cover, interceptive photosynthetically active radiation (IPAR), and green biomass (Asrar et al., 1985), it had been found to be very sensitive to other external factors such as soil background, view and sun angle geometry, as well as atmospheric conditions (Bradley et al., 2007).

Effort has been made in the past years to minimize these external effects. Huete (1988) modified the NDVI to account for the soil effect and developed the SAVI, and Qi et al., (1994) further improved this index and obtained MSAVI to only further reduce soil effect, but also increase the vegetation sensitivity. Kaufman and Tanre (1992) incorporated the blue band into the NDVI and developed an atmospherically resistant vegetation index (ARVI), which was found to be 4 times less sensitive to the atmosphere than NDVI. However the use of blue band makes the ARVI much more sensitive to bi-directional as well as soil effects than NDVI (Qi, et al., 2000). Nevertheless, there is yet no perfect vegetation index and additional work is needed to use remote sensing data in visible-near infrared spectral region for quantitative purposes in arid and semi-arid regions (Jiang et al., 2006).

Qi et al., 2000, have characterized physical and biophysical properties of terrestrial surfaces of the arid and semi-arid regions so that surface conditions can be monitored with multitemporal and large-scale data. The various surface parameters such as green leaf area index (GLAI), fractional cover of green vegetation, senescent vegetation, land-surface albedo etc., gives quantitative estimates of vegetation of especially heterogeneous surfaces. To obtain meaningful information from remotely sensed data specially the VEGETATION (VGT) and WiFS, a quantitative relationship between the data product and surface physical or biophysical parameters must be established.

It has been recognized that radiometric measurements of sparsely vegetated regions such as arid and semi-arid areas or farming areas of different types of crops, is strongly anisotropic (Qi et al., 1994). The spectral reflectance (brightness) of the surface is heavily dependent upon the position of the observer relative to illumination source and the target (e.g., Pinty and Verstraete, 1991). In such regions, no one single component (soil or vegetation or single type of crop) totally dominates the pixel responses. The relative contribution to the signal observed from space varies depending on the surface heterogeneity and variables of interest. Consequently, it is necessary to investigate how each individual component contributes to the satellite observations, and how to effectively interpret the data in terms of surface physical parameters. Developing a relationship between the normalized difference vegetation index (NDVI) and the green leaf area index (GLAI) is essential to describe the pattern of spatial or temporal variation in GLAI that controls carbon, water, and energy exchange in arid ecosystem process models (Shukla et al., 2004, Steltzer & Welker, 2006). In this rationale the present study is to explore the quantitative relationship and multitemporal satellite observations for continuous monitoring of vegetation degradation in arid and semi-arid regions of Rajasthan.

**STUDY AREA**

The study area is entire state of Rajasthan – perceived as the Desert State of India it has widely contrasting topography from sand dunes to Aravali hills. It is immensely rich in natural beauty and it's beautiful forests and valleys are as famous as its desert. Geographically, no other region can claim greater diversity than Rajasthan - a region of lofty hills and rolling sand
dunes, of scorching heat and freezing cold, of fertile plains in the east and sparsely populated areas of Jaisalmer in the west it is the largest state in the country presenting a kaleidoscope of ecosystems.

The forest area in Thar Desert is scanty with poor growth of vegetation. While the productivity is extremely low, the demand for fuel and fodder is very high. Consequently there is over-exploitation of vegetation cover accentuating the pace of desertification. Vegetation degradation in Rajasthan is thus not limited to the desert areas only and has extended towards the east as well. The semi-arid lands have become degraded to the point where their original biotic functions have been damaged, with subsequent reclamation being costly or in some cases impossible. The plants and animals of this state find refuge in protected areas that cover almost one-fifth of the ecoregion (Anon., 2001).

Although the Thar Desert may seem inhospitable to humans, it is actually the most densely populated desert in the world. The continually increasing population intensifies pressure on marginal lands and subverts efforts to introduce sustainable agricultural practices, leading to environmental problems such as soil erosion and deforestation. And as farmers move to the area now that irrigation water is available, conservationists are looking for ways to protect the desert and help people have a better quality of life. Quantitative relationship between the data products and effective surface parameters at varying scales helps in understanding and monitoring vegetation degradation at regional to global scales.

**MATERIALS AND METHODS**

The Data set used in this study are SPOT VGT-S1 (daily synthesis), SPOT VGT-S10 (ten day synthesis) product and IRS1D-WIFS data.

**SPOT-VGT data**

The VGT-S1 products are complied by merging segments (data strips) acquired in a single day while the S-10 datasets are compiled by maximum value composite (MVC) synthesis processing of 10-day datasets. These products provide data from all spectral bands, the NDVI and auxiliary data on image acquisition parameters. These images are composed of the 'best' ground reflectance measurements of all segments received during one day (S1) and ten-day (S10) for the entire surface of the Earth. Vegetation instrument onboard SPOT satellite with four spectral bands blue (0.43-0.47\(\mu\)m), red (0.61-0.68\(\mu\)m), infrared (0.78-0.89\(\mu\)m) and short wave infrared (1.58-1.75\(\mu\)m) at a spatial resolution of 1 km and temporal resolution of 1 day meets the requirement of vegetation mapping at a continental scale.

**IRS1D-WIFS data**

The WiFS sensor provides reflectance data in red (0.62 - 0.68 microns) and near-infrared (0.77 - 0.86 microns) bands at 188 m spatial resolution and at 5 days re-visit, covering a swath of about 812 km, and is useful in deriving regional level vegetation information. High frequency of the availability of the WiFS data due to the short re-visit period also facilitates the monitoring of vegetation at regional scale.

**IRS1D-LISS-III data**

The LISS-III sensor provides reflectance data in 0.52 - 0.59 microns (B2) 0.62 - 0.68 microns (B3) 0.77 - 0.86 microns (B4) 1.55 - 1.70 microns (B5) at 23.5 m spatial resolution and at 25 days re-visit, covering a swath of about 141 km, and is useful
in deriving vegetation information at higher resolution. These datasets were used for validation of GLAI and $gfc$ equations derived from SPOT and WiFS data.

**Ground data**

The ground data was collected for entire state of Rajasthan. The preliminary information on landuse/landcover in the state was obtained through a reconnaissance survey and the major landuse/landcover are: Dry deciduous forest of *Anogeissus pendula*, Dry deciduous Forest of *Tectona grandis*, Mixed dry deciduous forest, Desert rangelands, Desert scrub, Thorn Forest, *Acacia* scrub, *Anogeissus* scrub, Intensive agriculture, Irrigated agriculture and rain fed agriculture.

After the preliminary survey the vegetation cover map was produced using the field information and satellite data. This map served as a potential stratum to compute the surface parameters GLAI and $gfc$. For obtaining surface parameter values from ground, sampling sites were decided using Normalised Difference Vegetation Index (NDVI). The NDVI for the entire Rajasthan were scaled to eight levels and different sampling sites were identified in each level. A total of 66 sampling sites were considered (it is 0.02% of the total number of pixels covering the study area).

**Plan of Study**

1. **Data processing**

The SPOT-VGT (S-1 & S-10) datasets procured were MVC synthesis products already processed for geometric and radiometric corrections. However, SPOT-VGT S-1 data has stripes of missing data at regular intervals in the equatorial regions due to inherent MVC synthesis characteristics. These stripes shift daily by a constant factor. Basic processing of the data has been carried out to overcome this error by generating five-day composite image. Threshold values are used for a preliminary level correction for thick clouds. The MVC synthesis products are though free from most of the geometric and radiometric corrections, still some corrections are required on these products also due to difference in reflectance for different viewing angles.

The IRS-1D WiFS datasets procured were raw and therefore were processed for geometric and radiometric corrections. Remote sensing data are originally stored as digital numbers which were calibrated to represent geophysical units of radiance, or W·m$^{-2}$·sr$^{-1}$. However satellite instruments measure radiance at the top of the atmosphere (TOA) and thus require atmospheric corrections to get the reflectance values from the earth surface.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Output Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Calibration</td>
<td>DN to radiance (W·m$^{-2}$·sr$^{-1}$)</td>
</tr>
<tr>
<td>2. Atmospheric corrections</td>
<td>Radiance to reflectance</td>
</tr>
</tbody>
</table>

The reflectance values obtained after atmospheric corrections were then used to calculate normalized difference vegetation index (NDVI).

2. **NDVI calculation**
The Normalized Difference Vegetation Index (NDVI) is one of the ratios (Rouse et al., 1973), which is highly correlated with vegetation parameters such as green leaf biomass and green leaf areas and hence is of considerable value for vegetation discrimination (Curran 1980; Hatfield, 1983; Justice, et al., 1985; Roy, 1993; and Jeyaseelan et al., 2007).

$$\text{NDVI} = \frac{(IR-R)}{(IR+R)}.$$  

Moreover, it reduces variation due to surface topography, and in compensation for variation in radiance as a function of sun elevation for different parts of scene, which is highly valuable in continental studies. The maximum NDVI is calculated to determine the index of greenness of the vegetation at the time of peak growth season. It simply provides the maximum greenness of the vegetation in the study period (Roy et al., 2000).

$$\text{NDVI}_{\text{max}} = \text{MAX} (\text{NDVI}_1, \text{NDVI}_2, ..., \text{NDVI}_n)$$

The NDVI derived through satellite data was qualitatively linked with the surface parameters.

2. Derivation of effective surface parameters

The multiscale data set was analyzed using geostatistics techniques to define the surface heterogeneity at local and regional scales and to derive effective surface parameters meaningful at large scales. The derived parameters were then used in the development of procedures to quantitatively relate the data products with surface properties at large scales.

Estimation of green leaf area index

Green leaf area index (GLAI) is an important variable describing the density of green vegetation. It is defined here as the total single-side area of green leaves per unit ground area. Theoretically, its values can range from 0 to infinity. Approaches to deriving GLAI exist using either empirical relationships with spectral vegetation indices (Asrar et al., 1985, Baret, 1995, Chen and Cihlar, 1996) or model inversion techniques (Goel and Deering, 1985, Jacquemoud, 1993, Qi et al., 1995). In this study we have combined both the empirical relationships and model inversion techniques to develop suitable algorithms.

Estimation of fractional cover

An operational algorithm to estimate the total amount of green vegetation cover over large scales was used which was further validated from LISS-III data. This parameter, the Green Fractional Cover, $gfc$ is an important surface physical property (Foody et al., 1997; Skole and Qi, 2000). It is not only an indicator of biomass production, but also an important variable controlling hydrological processes in the arid and semi-arid regions (e.g., Shuttleworth, 1995; Goodrich et al., 2000).

3. Development of quantitative relationships

Although many vegetation indices, simplistic in composition, have been qualitatively related to amount of vegetation present, the physical link between these VIs and surface parameters needs to be considered. BRDF models provide a physical link between vegetation properties and reflected radiation, but are difficult to use in operational mode because most models...
require prior information about the vegetation. The above approaches were merged with vegetation indices to establish a quantitative relationship between remote sensing data and vegetation properties.
Sample plots of 30x30 m laid for sampling
66 Sample plots selected for sampling
Sample plots of 30x30 m laid for sampling
Obtain GLAI values from ground measurements

Remotely Sensed Images from WiFs and SPOT4-VGT
Data Processing
NDVI Approximation using Arithmetic functions
Vegetation Type Map

Vegetation Type Map
Potential Stratum
Empirical relationships developed through model inversion techniques
OVV’s calibration of green cover product (GLAI and gfc)

Obtain fractional cover from LISS-III
GLAI and gfc maps

Figure 1: Methodology Adopted for Land Surface parameterisation
RESULTS

The derived results would contribute to fill the lacunae in the knowledge about the degrading factors behind the vegetation of a highly fragile ecosystem i.e., arid and semi-arid areas, besides revealing important parameters for subsequent biodiversity characterization, inventorization, strategic planning and developing action plans. Following results were derived from the present study.

Major Observations

The NDVI values from the satellite data showed a strong correlation with the green vegetation parameters calculated from ground (Fig. 4 a & b; Fig. 5 a & b), the GLAI values obtained from the ground showed that in these regions information on land cover and land surface characteristics purely on the basis of NDVI values may not be accurate and precise. The effect of soil backscatter on NDVI may give misleading information, which on the other hand does not affect GLAI and $gfc$. 

![Figure 4 a: SPOT NDVI & GLAI 2002](image1)

![Figure 4 b: SPOT NDVI & GLAI 2003](image2)

![Figure 5 a: WiFS NDVI & GLAI 2002](image3)

![Figure 5 b: WiFS NDVI & GLAI 2003](image4)
Empirical relationship was established between ground based GLAI observations and satellite based NDVI values and GLAI algorithms keeping in view of aridity were developed using model inversion techniques.

**Derived surface parameter algorithms:**

1) **Green leaf area index (GLAI)**

Green vegetation cover in arid regions is highly dynamic and seasonal. Unlike the fractional green vegetation cover, which is a two-dimensional horizontal variable, the \( GLAI \) is a variable describing the density of green vegetation. It is defined here as the total single-side area of green leaves per unit ground area. GLAI calculations obtained from ground values showed a strong correlation with NDVI obtained from satellite data, however a time independent equation for GLAI estimation for the study area could not be approximated because of highly dynamic and seasonal nature of the vegetation amount as a result following GLAI equations based on an aridity index had been developed during this study:

<table>
<thead>
<tr>
<th>GLAI equations for SPOT data</th>
<th>GLAI equations for WiFS data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dry year</strong></td>
<td></td>
</tr>
<tr>
<td>GLAI = 0.281 + 7.53 NDVI</td>
<td>GLAI = 0.242 + 4.78 NDVI</td>
</tr>
<tr>
<td><strong>Below average wet year</strong></td>
<td></td>
</tr>
<tr>
<td>GLAI = 0.2413 + 6.7154 NDVI</td>
<td>GLAI = 0.306 + 4.5112 NDVI</td>
</tr>
<tr>
<td><strong>Average wet year</strong></td>
<td></td>
</tr>
<tr>
<td>GLAI = 0.2093 + 6.059 NDVI</td>
<td>GLAI = 0.3632 + 4.271 NDVI</td>
</tr>
<tr>
<td><strong>Above average wet year</strong></td>
<td></td>
</tr>
<tr>
<td>GLAI = 0.183 + 5.5209 NDVI</td>
<td>GLAI = 0.4146 + 4.0551 NDVI</td>
</tr>
<tr>
<td><strong>Wet year</strong></td>
<td></td>
</tr>
<tr>
<td>GLAI = 0.161 + 5.07 NDVI</td>
<td>GLAI = 0.461 + 3.86 NDVI</td>
</tr>
</tbody>
</table>

2) **Green fractional cover**
Estimation of fractional green vegetation cover, \( g_{fc} \), from remotely sensed data is often associated with computation of spectral vegetation indices and their empirical relationships with fractional green vegetation cover. In this study it had been assumed that a pixel signal consists of the contribution from two components: soil and vegetation. Let the fractional green vegetation cover be \( g_{fc} \) and, therefore, the fractional soil cover would be \( 1 - g_{fc} \). The resulting signal, \( S \), as observed by a remote sensor can be expressed as

\[
S = g_{fc} S_v + (1 - g_{fc}) S_s
\]  

where \( S_v \) is the signal contribution from the green vegetation component and \( S_s \) from the soil component. For pixels consisting of more than two components, equation (1) needs to be modified. This analysis assumed that a pixel consisted of only vegetation and soils. Equation (1) can be applied to remotely sensed data in the reflectance domain (Maas, 1998) and in the spectral vegetation index domain (Zeng et al., 1999 and Qi et al., 2000). When applied with a spectral vegetation index such as the normalized difference vegetation index (NDVI), equation (1) may be approximated as

\[
NDVI \approx g_{fc} \frac{NDVI_{veg}}{NDVI_{soil}} (1 - g_{fc}) \frac{NDVI_{soil}}{NDVI_{soil}} 
\]

& can be re-written as

\[
g_{fc} = \frac{NDVI_{soil}}{NDVI_{veg}} \frac{NDVI_{veg}}{NDVI_{soil}} 
\]

Where \( NDVI_{soil} \) is the NDVI value of an area of bare soil or objects void of vegetation, and \( NDVI_{veg} \) is the NDVI value of a pure vegetation pixel. Validation was made with fine spatial resolution LISS-III data acquired over the same region.

**CONCLUSIONS**

SPOT-4 Vegetation and IRS-WiFS data has great potential for assessment of phenological status of different vegetation types. In arid and semi-arid regions however, land cover characterization purely on the basis of vegetation indices from satellite data does may not give precise information of land surface characteristics. This study demonstrates that estimation of surface parameters of green vegetation like green leaf area index (GLAI) and green fractional cover (\( g_{fc} \)) from the satellite data gives better quantitative approximates of the land surface characteristics and useful for monitoring vegetation status in arid and semi-arid regions. However, the presence of persistent cloud cover in WiFS and LISS-III datasets placed some major constraints during the study and green fractional cover and GLAI maps for the year 2003 from WiFS data could not be generated for the entire study area.
WORK PLAN

The entire research work was carried out at three places:

1) Department of Space Sciences, University of Pune, Pune.
2) Forestry and Ecology Division, Indian Institute of Remote Sensing (IIRS), Dehradun.
3) In the Field (Rajasthan).

The required satellite were acquired data through the GLC-2000 project on which the institute was already working. The required software/hardware platform is available at IIRS where the data was processed. The research project was completed in the period of three years six months of which six months were spent in the field for collection of primary data/ground truthing. About eighteen months were required for processing of data and data interpretation at IIRS and eight months at Department of Space Sciences, University of Pune for interpretation of results obtained including the development of quantitative relationship between remote sensing data and the vegetation properties. Ten months were required for validating the algorithms derived from the study, preparing maps of ancillary information and writing the thesis.

REFERENCES

Anon., 1998, VEGETATION OVERVIEW


