Biome level characterization (BLC) of western India – a geospatial approach

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Abstract: Environment is constantly changing as a function of climate and more recently due to human activities. Timely and accurate monitoring of these changes is a difficult task for regional planning and management. Up-to-date information on distribution and rate of changes of any ecosystem are required for a wide variety of applications viz., biome status, environmental, climatic etc. Aerospace technology has been found to be a vital tool for assessment and monitoring of these natural resources. The present study focuses on the potential of IRS 1C WiFS data set for the regional level mapping. The temporal resolution along with the recommended spatial and spectral resolution configures for the assessment of the phenological growth of the vegetation in the terrestrial ecosystems. The utilization of the climatic data along with the biogeographic map is proposed to delineate the biomes in the western Indian subcontinent. The product offers the basic input for the eco-physiological processes for studying the land surface interactions and conservation strategies of the arid regions.

Resumen: El ambiente está en constante cambio en función del clima y más recientemente como consecuencia de las actividades humanas. El monitoreo preciso y oportuno de estos cambios es una tarea difícil para la planeación y el manejo de una región. Se requiere información actualizada sobre la distribución y las tasas de cambio de cualquier ecosistema para una amplia variedad de aplicaciones, por ejemplo las referentes a la condición del bioma, las ambientales, las climáticas, etc. La tecnología aeroespacial es una herramienta vital para la evaluación y el seguimiento temporal de estos recursos naturales. El presente estudio se enfoca en el potencial que tienen los datos IRS 1C WiFS para la elaboración de mapas regionales. La resolución temporal, así como las resoluciones espacial y espectral recomendadas, se configuran para evaluar el crecimiento fenológico de la vegetación en los ecosistemas terrestres. Se propone el uso de datos climáticos junto con el mapa biogeográfico para delimitar los biomas de la porción occidental del subcontinente indio. El producto ofrece los insumos básicos sobre procesos ecofisiológicos para el estudio de las interacciones de la superficie terrestre y las estrategias de conservación de las regiones áridas.

Resumo: O ambiente está mudando constantemente em função do clima e, mais recentemente, devido às actividades humanas. A monitorização tempestiva, e exacta, destas mudanças é uma tarefa difícil para o planeamento regional e a gestão. Informação actualizada quanto à distribuição e taxas de mudança de qualquer ecossistema é necessária para um conjunto variado de aplicações como sejam o status do bioma, o ambiente, clima, etc.. A tecnologia aeroespacial tem-se mostrado uma ferramenta vital para a avaliação e monitorização destes recursos naturais. Este estudo foca o potencial do conjunto de dados obtidos pelo IRS 1C WiFS para o mapeamento a nível regional. A resolução temporal, a par com a resolução espacial e espectral recomendadas, mostra-se adequada para a avaliação do crescimento fenológico da vegetação nos ecossistemas terrestres. A utilização dos dados climáticos, juntamente com o mapa biogeográfico, é proposta para o delimitar os biomas na parte ocidental do subcontinente in-
diano. O produto oferece o input básico para o estudo dos processos ecológicos, das interações com a superfície do solo e para as estratégias de conservação das regiões áridas.

**Key words:** Biome level characterization, geospatial approach, green wave, land use/cover, phenology, remote sensing, western India.

### Introduction

In nature, there exists a complex of more than one community. Communities are never stable, but dynamic. Although a typical community maintains itself more or less in equilibrium with the prevailing conditions of the environment, but in nature this is hardly true. They are never found permanently in complete balance with their component species or with the physical environment. Environment always keeps on changing over a period of time due to variations in climate and physiography and the activities of the species of the communities themselves. These influences bring about marked changes in the dominants of the existing community, which is thus sooner or later replaced by another community at the same place. This process continues and successive communities develop one after the other over the same area until the terminal final community again becomes more or less stable for a period of time. This occurrence of relatively definite sequence of communities over a period of time in the same area is known as **Ecological Succession**. Thereafter, a concept of **biome**, defining as 'biotic community of geographical extent characterized by distinctiveness in the life forms of the important climax species' came up (Sharma 1997). The biome is not based on the species of plants and animals present but rather on the life forms of the most important plants (i.e. trees, shrubs, grasses) that give to the landscape its special character. The chief character of a biome is depicted by climax communities with their dominant life forms. Thus a biome is viewed, as a biotic community – a unit larger than a community, constituting the great regions of the world distinguished on an ecological basis, such as tundra biomes, forest biomes, grasslands, deserts etc.

Temperature and precipitation are among the most important determinants in biome distribution along with the topography. If we know the general temperature range and precipitation level, we can predict what kind of biological community is likely to develop on a particular site if that site is free of disturbance for a sufficient time. Biome distribution also is influenced by the prevailing landforms of an area. Mountains, in particular, exert major influences on biological communities.

Furthermore, with the human population rising by almost a billion a decade, over the next three decades at least sustained increases in food production is required. According to the projections from the Integrated Model for Assessment of the Greenhouse Effect (IMAGE model: Alcamo 1994) and from other analysis, this will result both in further conversion of natural ecosystems to agriculture. Both of these processes always accelerate the release of carbon in the atmosphere. In addition, as more land is converted to agriculture, there is less area of natural ecosystems available to act as carbon-sink; thereby, reducing the potential sink strength of the terrestrial biosphere. Changes in the composition and structure of ecosystems are driven by a combination of management practices and changes in climate and atmospheric composition. Hence it makes the assessment of natural resources, changes in the ecosystem so important to incorporate that new arriving policies and strategies would not hinder the biospheric activities rather would allow it to flow on sustainable basis.

**Present knowledge on biomes**

The emergence of biome or ecoregional level studies is an important step in dealing with difficult natural resource issues. Ecoregional studies have distinctive emphasis on interaction between development and conservation, including biological and physical resources. The study requires both greater depth of understanding of interactions of humans and ecosystems and more focus on immediate social needs. Nevertheless this has grown in
part by efforts to fill a critical gap in dealing such problems by scaling our understanding from local to global and how human activities interact with the atmosphere.

Last decade has been a uniquely productive era for mapping and modeling of earth’s surface with roots in bioregional sciences, such as biogeography, regional economics of natural resources etc. and contemporarily having substantial improvements in computing technologies and also in our understanding of global and regional systems and the availability of improved earth science data sets. This is clearly articulated by the International Geosphere Biosphere Program (IGBP) core projects on Biospheric Aspects of the Hydrological Cycle (BAHC), Global Change and Terrestrial Ecosystems (GCTE), International Global Atmospheric Chemistry (IGAC), Land-Use and Land Cover Change (LUC), Global Analysis, Interpretation and Modeling (GAIM), Land-Ocean Interactions in the Coastal Zone (LOICZ), Past Global Changes (PAGES) etc. which have all identified the need for improved baseline landcover datasets for the studies of global change. Landcover is a case in point. These have typically used the correlation between major biome patterns and climate for the description of landcover. Such models tend to be based on simplified set of climatic parameters to delineate potential landcover patterns. This is because of existing global landcover databases, although valuable, have coarse resolution. IGBP determined that 1.1 km AVHRR data were the appropriate choice for generating landcover datasets at global level.

Review on NOAA-AVHRR

The potential of the data provided by the Advanced Very High Resolution Radiometer (AVHRR) for vegetation monitoring at the regional scale was first demonstrated (Tucker et al. 1985) in Africa and the research involved the application of Normalized Difference Vegetation Index (NDVI). In the five years since 1986 three factors have contributed to this interest: first, the unique multi-layer archive derived from the sensor; second, its large spatial coverage, which has made possible certain new types of investigations at a very broad scales of regional, continental; and global; and third, the high temporal frequency (Prince & Justice 1991).

The wide field of view of the AVHRR provides large-area coverage but involves considerable difficulty in the collection of ground data for validation. Results of measurement of primary production using a harvest technique are described by Diallo et al. (1991), as the results from the application of slightly different methods in Niger that were suitable for the more extensive and uniform terrain in the study region (Wylie et al. 1991). These field methods rely maximum on the above-ground standing annual vegetation as the estimate of seasonal production and, therefore, are subject to some well-known sources of error (Beadle et al. 1985). However, they are capable of estimating net production in large areas (in excess of 10 km2) as is necessary for analysis of the AVHRR data. The use of AVHRR NDVI data to model regional primary production is discussed by Prince (1991), in which the subject of scale is addressed and relevant variables are identified at the regional scale. Factors that obscure the relationship between the satellite measurement of NDVI and various measurements of the vegetation were identified. Atmospheric water vapor, in particular, the seasonal change associated with the movement of the intertropical convergence zone has an important effect owing to the presence of a water vapor absorption band in channel 2 of the AVHRR. The extent of this problem for remote sensing of vegetation and some possible solutions were assessed by Justice et al. (1991).

Since then, the emphasis has been on refining the data interpretation techniques, including studies of the necessary corrections for attenuation of radiation in the atmosphere, improvements in cloud masking, and addressing some problems associated with the NDVI in general and the calculation of surface NDVI from satellite data in particular. Specifying and modeling the relationship between primary production and AVHRR NDVI data and developing operational methods for application of the data have been important issues.

Research using AVHRR data has provided us with important experiences relevant to the design of the new generation of instruments for vegetation monitoring (Potdar 1990). The spectral channels should avoid as much as possible atmospheric absorption bands. Spatial pre-processing of multitemporal datasets, including navigation, rectification and registration, is a cumbersome task and is recommended that these be regarded
largely as operational responsibilities to be undertaken prior to the distribution of the data.

**Wide field sensor (IRS 1C – WiFS) for ecorregional studies**

India launched IRS-1C remote sensing satellite in December 1995 with WiFS sensor having potential to provide inputs for vegetation studies because of its spectral bands B1 (0.62-0.68 µm) and B2 (0.77-0.86 µm). Its high temporal resolution, i.e. 5 days and large area coverage (810 × 810 km²) is helpful in developing improved yield models and assessing crop condition (Ray et al. 1994). The details available in this data are best suited for land cover characterization at regional scale.

WiFS data provide advantage of covering a very large area in single instantaneous field of view (IFOV) avoiding any illumination difference. Suitability of such moderate resolution data for regional vegetation as compared to AVHRR data should make a better choice for monitoring and research. The pixel size of 188 m suits regional scale mapping. Probability of obtaining cloud free data has increased with WiFS data with five days revisit capability. Besides for certain episodic events like, forest fire, drought etc. frequent data of WiFS enable crop monitoring and forecasting (Oza et al. 1996).

To assess the potential of WiFS sensor and its use at regional level, Indian Institute of Remote Sensing (NRSA) has taken a project entitled ‘Biome Level Characterization of Indian Vegetation using IRS-1C/1D WiFS data’. Various zones viz. Gujarat (Singh et al. 1999a; 1999b), Northeast (Roy & Joshi 2000b; 2001) and Western Himalayas (Joshi et al. 2001a; 2001b) have been mapped. The paper here presents the recent study in the state Rajasthan, India using WiFS. The study highlights the characterization of desert biome in India.

**Anthropological impacts on biome**

Humans have become the dominant organisms over most of the earth, having disturbed more than half of the world’s terrestrial ecosystems to some extent. It has been observed elsewhere that human preempt about 40 percent of the net terrestrial primary productivity of the biosphere either by consuming it directly, by interfering with its production / use, or by altering the composition of human-dominated ecosystems to organisms different from those in corresponding natural ecosystems.

The past one hundred years technological revolution has given human beings the capability to modify the biosphere substantially and in particular to exterminate all life not only directly with weapons but, more permanently, indirectly, through disrupting life support systems. In the evolution of culture, human beings also lost the sense of evolutionary justice, which stems from the conviction that it is our responsibility to share the biosphere with all other biota. Widespread and accelerating species extinction and irreparable disruptions of life processes by human agency during recent times are reversing the trend of biological evolution and diversification that had taken place during the last 3.5 billion years. Even the rich cultural diversity of human species, which reflected the diversity of lifestyles adapted to drastically differing habitats evolved during the last 20 or 30 thousand years, has been greatly reduced and diluted. Almost universally a single cultural precept has come to dominate human endeavor, that of material short-term gain. All the current socioeconomic, political and cultural compulsions globally are the destruction of the diverse value systems and visions of life retained during human history. We all end up merely aping a single dominant style or trend.

What we most often hear from the authorities is the accusation that the common people are destroying the forests by collecting fuelwood. They are also accused of committing the crime of keeping vast numbers of ‘unproductive’ cattle, sheep and goats, and by grazing them in the forests, degrading them. The forest fires regularly sweeping across practically forests are supposedly started by the people. The common people who are directly dependent on the forest resources for income and are considered as exploiting the so-called Minor Forest Produce (M.F.P) and wiping out the forest biodiversity. The landless and the tribal people are depicted as regularly encroaching into governmental forests and clearing them for cultivation. The tribal people everywhere are specially accused of practicing shifting cultivation that is pointed out as being a most destructive practice for forests.

Destruction of biotic potential of land leads to desertification. Such problem arises due to overgrazing, indiscriminate felling of trees and over-exploitation of land resources. The devastating effects of deforestation in India include soil, water
and wind erosions. This may result either due to a natural phenomenon linked to climatic change or due to abusive land use. Removal of vegetal cover brings about marked changes in the local climate of the area. Thus, deforestation, overgrazing etc. bring about changes in rainfall, temperature, wind velocity etc. and soil erosion. Desertification often starts as patchy destruction of productive land. Increased dust particles in the atmosphere lead to desertification and drought in margins of the zones that are not humid. Even the humid zones are in danger of getting progressively drier if drought continues to occur over a series of years. Indications are that the temporary phenomenon of meteorological drought in India is tending to become permanent one. This trend is not restricted to the fringes of existing deserts only. The threat of desertification is thus real because as the forest diminishes, there is steady rise in the atmospheric temperature.

**Climate change vis-a-vis biome**

An important aspect of the effects of environment on the life of an organism is the interaction of ecological factors. All the factors are interrelated. Variations in any one may affect the other. For instance, if weather is a description of physical conditions of the atmosphere (humidity, temperature, pressure, wind and precipitation) then climate is the pattern of weather in a region over long time periods. The interactions of atmospheric systems are so complex that climatic conditions are never exactly the same at any given location from one time to the next. While it is possible to discern patterns of average conditions over a season, year, decade, or century, complex fluctuations and cycles within cycles make generalizations difficult and forecasting hazardous.

Changes in the composition and structure of ecosystems are driven by a combination of management practices and changes in climate and atmospheric composition. For example, the biomass increase currently observed in many forested areas largely reflects successional changes due to past changes in forest management. Future global change effects will be superimposed on these present trends. In particular, the current trend of biomass increases may be reversed in some areas, as the effects of global change become increasingly important. Under global change, present vegetation assemblages will likely change through increased mortality of some of their components, followed by establishment and growth of new assemblages, rather shift as intact biomes. Mortality of the present vegetation, which releases carbon to the atmosphere, is a fast process, while the growth of new assemblage of vegetation, which absorbs the carbon from the atmosphere, is slower. Thus, the processes by which ecosystem structure and composition will change, will probably release a transient pulse of carbon to the atmosphere on a timescale of decades to centuries, irrespective of whether the new theoretical equilibrium biome distribution eventually stores more or less carbon than the present distribution.

**Satellite remote sensing for mapping and monitoring**

Understanding the interaction between the atmosphere and biosphere is a crucial part of efforts to improve models of Earth’s physical systems. Song (1999) illustrates a specific example of one component of this, examining the effect of phenological changes on land surface albedo. Furthermore, the advent of satellite measures created opportunities to use empirical data for improved understanding of bioclimatic processes. The most widely used measure is the NDVI (Normalized Difference Vegetation Index) which is being calculated to take advantage of active vegetation high reflectance in the near infrared and low reflectance in the red visible light band to discriminate it from dormant and non vegetated areas and on the basis of phenological variations among vegetation cover itself.

Phenology, the traditional study of seasonal plant and animal activity driven by environmental factors has found new relevance in research into global climate change. The satellite view is synoptic and integrating, therefore observes ‘broad brush’ changes in the ecosystem dynamics. What satellites cannot observe are the details driving the events, therefore, unless biospheric changes are quite profound, they are likely to be missed by satellite observations and this is the area where phenology can contribute. Generalized NDVI images show the gross progression of vegetative seasons around the world. Several studies in mid 1980s used these data to lay the foundation of satellite phenological analysis. While a few other papers subsequently incorporated derived phenological parameters in satellite based vegetation dy-
namic and land cover analysis, refined phenological measures have only began to develop (Roy & Joshi 2000b, 2001).

The concept of ‘Green Wave’ or ‘Green Up’ states an integration of conventional and satellite derived measures is to understand the mid latitude spring onset of photosynthesis. Satellite NDVI data and surface observations show that the mid-latitude onset of greenness often occurs abruptly in early spring and then greenness gradually increases to a maximum in mid summer. The approach identifies sharp increases in the NDVI that can be related to the onset of ‘significant photosynthetic activity’. The onset and offset of the ‘green period’ are the key derived measures, with all others easily computed. These ‘features’ are extracted by comparing smoothened data with a moving average of the time series so that departures from an established trend are identified. Thus, indices that measure the onset of the green wave are ideal biological measures of the climatic variability.

**Green wave**

Recently the scientific community has become concerned with the prospects of global change. Currently, a broad definition is emerging which emphasize changes within the hydrosphere and biosphere as well as the atmosphere. Perhaps more importantly, it is also generally recognized that a number of feedback mechanisms are at work between the ‘spheres’ and even subtle changes in one may have long lasting effects of the entire system. The advent of satellite measures created opportunities to use empirical data for improved understanding of bioclimatic processes. In order to realize this potential, these data must be calibrated with surface information. The paper is a first part of an on-going project aimed at connecting these NDVI data with the first appearance of mid-latitude deciduous foliage in spring, commonly called the ‘green wave’ or ‘green-up’. The appearance of foliage causes rapid increases in near-infrared reflectance and transpiration (Kaufmann 1984; Rosenberg 1983). An Earth Resource Observation Satellite research team has a functional methodology to determine the onset time of these NDVI reflectance changes, allowing calculation of satellite green-up dates for specific sites (Reed et al. 1994).

The green wave is of particular interest as a dynamic feature resulting from close atmosphere-biosphere interaction. Increasing solar radiation receipts allow vegetation to resume growth, but these biospheric events may in turn feed back upon the lower atmosphere, through modification of the surface energy and moisture balances, resulting in detectable changes in surface temperature and moisture (Schwartz & Karl 1990; Schwartz 1992, 1996).

In principle, plants are special, highly sensitive weather instruments that integrate the combined effect of weather factors such as temperature, rainfall, humidity, wind and sunshine in their growth response. These can be observed year after year and dates recorded when certain growth stages such as opening of leaf buds or appearance of first flower occurs. Ideally this would mean collecting phenological events from a small set of plant species whose ranges cover the major portion of mid-latitude continental areas. Next, biome diversity should be represented, an objective that is somewhat at odds with the previous one. The best compromise might be to use a few wide-ranging plant species as ‘indicators’ and then describe their relationship to the representative species within their each major biome. Lastly, physical mechanisms responsible for the phenological events must be well understood, if the information gathered is to be put in to the best use.

Long-term phenological records frequently provide a useful measure of the species level biological response to climate variation at specific sites. The challenge in interpreting these measures lies typically in developing a method that can both transform species data in meaningful information at the biome level and generalize the results to broader geographic areas. Schwartz (1994) outlined a conceptual approach to this problem, which incorporates satellite, native species and indicator plant data. The integrated approach of phenological data analysis (satellite-indicator-native) can help in bridging gap between local and larger scale measurements. However, connection between conventional phenology and remotely sensed greenness measures at the ecosystem level are being confirmed and further studies are underway. For example, Inouye & McGuire (1991) found that decreased snow cover adversely affects production in an early-blooming herbaceous perennial of montane Western north America; Kramer (1997) concludes that differences in tree species’ phenological responses to temperature changes can have long term consequences on their geographic distribu-
tion; and so on. Thus, phenology-climate relationships can also reveal the potential impacts of future climate changes as well.

**Approach for biome level classification of India**

**Study area**

**Location**

Rajasthan lies between 23° 30’ and 30° 11’ N latitude and 69° 29’ and 78° 17’ E longitude, in the track of the Arabian sea branch of the southwest monsoon. The Aravalli, and in the southeast, the plateau of Hadauiti being the only highland channel the SW monsoon coming from Kathiawar and stop the drier eastern flow, creating the desert in the west. While the western boundary of the state is part of Indo-Pak international boundary. Punjab and Haryana surround the state in the north, Uttar Pradesh in the east, Madhya Pradesh in the southeast and Gujarat in the southwest (Anon. 1994).

**Physiography**

Physiography of the state is the product of long years of erosion and depositional processes. The present landforms and drainage systems have been greatly influenced and determined by the geological formation and structures. Four major physiographic regions can be identified within the state, namely,

1. The Western desert (Thar)
2. The Aravalli hills
3. The Eastern plains and
4. The Southeastern plateau.

The Aravalli hill ranges, running from northeast to southwest divides the state approximately into the western arid and eastern semi-arid regions. It is also a major water divide. The area, to its east, is well drained by integrated drainage systems, while the area, to the west, has a single integrated drainage system, i.e., the Luni drainage system in the southeastern part of the desert.

**Climate**

The climate of Rajasthan varies from arid to sub-humid. To the west of the Aravalli range, low humidity and high wind velocity characterize the climate. The climate is semi-arid to sub-humid in the east of the Aravalli range and characterized by more or less the same extremes in temperature but relatively lower wind velocity and high humidity with better rainfall.

A marked variation in diurnal and seasonal range of temperatures occurs throughout the state that is the most characteristic phenomenon of warm-dry continental climate. The summer begins with the month of March with temperature rising progressively through April, May, June and reaches up to 49° C at some places. The winter season remains from December through February with marked decline in minimum temperature in December and January. A sharp decline in night temperatures is experienced throughout the arid and semi-arid zone of western Rajasthan on account of quick release of the thermal radiation from sandy soil soon after the dusk.

The climate is marked by low rainfall with erratic distribution. The general trend of Isoheights is from NW to SE. There is a very rapid and marked decrease in rainfall west of Aravalli range making western Rajasthan the most arid part. However, on the eastern side, the rainfall is much higher during the rainy season than the potential evaporation demands during that time, thus, providing water surplus during the rainy season resulting in more vegetation and cultivation.

Apart from the above prominent climatic factors, the humidity, wind velocity and duration of sunshine, etc. affect the cropping pattern in significant way which in turn affect agricultural practices and also life style of the people.

**Satellite data**

IRS-1C WiFS data is being used to do the mapping of regional biome types. To capture the phenological variability, data set comprising of different seasons is used. Cloud cover data have been discarded and the analysis is performed using monthly data sets (dated 13-1-98 & 17-1-98; 4-4-98 & 23-4-98; 18-10-98 & 21-10-98 and 7-12-98 & 10-12-98).

**Ancillary data**

Survey of India (SOI) toposheets on 1:1,000,000 scale; Biogeographical maps of climatic factors like, temperature, rainfall and humidity of different zones have been used.

**Hardware/software**

Silicon Graphics, Octane Machine (Workstation)/IRIX Operating System with ERDAS IMAGINE 8.3 for the Digital Image Processing
(DIP) and ARC/INFO for Geographical Information System (GIS) have been used.

**Methodology**

**Radiometric correction**

Unwanted artifacts like additive effects due to atmospheric scattering removed through a set of preprocessing or cleaning up routines. First order corrections were done by dark pixel subtraction technique. This technique assumes that there is a high probability of at least a few pixels within an image, which should be black, i.e. with zero reflectance. However, because of atmospheric scattering, the image system records a non-zero DN value at the supposedly dark-shadowed pixel location. This represents the DN value that must be subtracted from the supposedly dark shadowed pixel location. This represents the DN value that must be subtracted from the particular spectral band to remove the first order scattering component (Roy & Joshi 2001).

**Geometric correction**

Images are registered geometrically using toposheets of Survey of India (SOI) on 1:1,000,000 scale. The common uniformly distributed Ground Control Points (GCPs) are marked and imagery was resampled by nearest neighborhood method. The monthly data are then co-registered for further analysis. The state/regional boundaries are extracted by overlaying the digital boundary provided by SOI (Roy & Joshi 2001).

**Vegetation indices**

Most remote sensing techniques for vegetation monitoring use data recorded through those parts of the electromagnetic spectrum which provide a strong signal from vegetation while contrasting with background material. Hype (1988) critically examined the role and importance of canopy background signals in the global assessment and monitoring of vegetation from satellites. The coupling of soils and vegetation occurs in both in a ‘biome’ as well as in a radiometric sense.

The NDVI is the vegetation index most frequently used for regional scale vegetation monitoring. This can be in part explained by its effectiveness as a surrogate measure of biophysical parameters, partly by the fact that calculation of the NDVI requires no *a priori* information concerning the imaged scene and partly by the fact that the calculation of the NDVI is such that there is some normalization for variations in viewing conditions (Curran 1980; Holben & Fresher 1980; Justice et al. 1985). Townshend et al. (1985) have discussed in detail about the utility of NDVIs while doing biome level classification of African and South American continents using NOAA-AVHRR data of different seasons. Matrices derived from the NDVI temporal profiles included many of those suggested by Lloyd (1990) and Reed et al. (1994).

**Vegetation and land use mapping**

Analysis of the satellite data is being carried out using various digital analytical procedures. For the classification of the satellite data, stacking of maximum NDVI and WiFS data set is taken. The mapping step involves using a clustering based on the ISODATA clustering run on maximum value of NDVI, NIR and Red band. Each cluster is assigned a preliminary cover type label taking care of the spatial pattern and spectral or multi-temporal statistics of each class and on comparison with ancillary data and extensive ground truth.

Ancillary data includes descriptive land cover information, NDVI profiles and class relationships to the other landcover legends. Related ‘single category’ classes are then grouped using a convergence of evidence approach. The cloud were masked out. The unsupervised classification is followed by post classification refinement for the coherent set of classes (Joshi et al 2001a,b).

**Results**

**Analysis of NDVI images**

Accurate quantitative information on the distribution and phenology of vegetation formations is limited, yet is fundamental for the effective management of forest resources. Four different time period NDVI images are the representative for seasonal changes. The NDVI images show the foliage cover in the respective time period. The bounded values of NDVI range from −0.16 to 0.32 (January), -0.12 to 0.11 (April), -0.15 to 0.51 (October) and −0.13 to 0.42 (December). The values vary relatively for every class, the graph of which shows the respective phenological changes in the dif-
different communities residing together (Fig. 1a & b). The large range of NDVI values is observed in the month of October and December. The ageing or senescence in April is well discriminated by the spatial distribution of NDVI values.

The comparative analysis revealed the influ-

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Fig. 1. (a) NDVI profiles of forest classes (b) NDVI profiles of non-forest classes.
ence of seasonal variation on the vegetation. During January, the vegetation is showing a growing trend; in April, there is decline in NDVI values. Further, the influence of monsoon is very much clear in October. Again the cyclic reduction in NDVI values has been analyzed and decline in foliage cover has been observed. The maximum NDVI image has been computed to represent the maximum foliage cover for all the classes.

Spectral and temporal discrimination of vegetation cover types

The area-averaged temporal plots were selected and analyzed. NDVI values obtained for different cover types (forest and non-forest) are plotted in Fig. 1a & b. The representative sites selected were having variation in the NDVI response in the individual cover types. For each location area-averaged NDVI value was plotted for the composite time period. The maximum values are true indicators of foliage cover irrespective of the area. The dry deciduous forest of teak and kardhai showed high values in the month of December while the dry deciduous dominated by Kardhai & Salai and Kardhai & Babool have shown a highest value in October. The non-forest classes have shown a phenological trend, having high values in October and December. The difference in NDVI values within agriculture and sand dune classes has helped to differentiate them, in spite of topographical similarities. After critical evaluation it is apparent that different cover types exhibit characteristic NDVI curves. The trend of the temporal variation, i.e. phenology has not been affected by the climatic variations. Intensive data sets may help in tracing the seasonality and to establish the timing of ‘green-up’ and ‘senescence’ and estimate the length of growing period year by year.

Land use/land cover pattern in Rajasthan

The geographical area of the state is 342,239 km². According to Forest Survey of India (FSI), the actual forest area in the state occupies only 13,871 km², i.e. 4.05% of the geographical area while the recorded forest cover is 31,700 km² which is 9.26% of the geographical area (Anon. 1999).

Forest

According to Champion & Seth (1968), major part of Rajasthan falls under subgroup 6B, i.e.

| Table 1. Forest classes mapped using WiFS vis-à-vis Champion & Seth (1968). |
|------------------|------------------|
| Classes Mapped   | Champion & Seth  |
| Dry Deciduous    | Desert Thorn Forest |
| Thorn Forest     | Ravine Thorn Forest |
| Desert Forest    | Rann Thorn Forest |
| Sand Dune Scrub  | Zizyphus Scrub |
| Northern Tropical Thorn Forest with following types (Table 1): |
| C1 Desert Thorn Forest |
| C2 Ravine Thorn Forest |
| C3 Rann Thorn Forest |
| DS1 Zizyphus scrub |
| DS2 Tropical Euphorbia scrub |

1. Desert Thorn Forest: The region is flat to undulating, with low hillocks or hills. The soils are partly in situ but usually fluvial or aeolian deposits in various stages of consolidation. On riverain strips and shifting sand different types are developed. Locally, consociations of certain species are prominent, notably Acacia senegal and Prosopis spicigera. Calligonum polygonoides, Leptadenia pyrotechnica, Crotolaria burhia etc. are typical of dune vegetation.

2. Ravine Thorn Forest: Acacia is conspicuous, standing fairly close together where not subjected to maltreatment, with more or less complete grass cover between. This type occurs typically with about 600 to 750 mm annual rainfall on intensively drained ground and dry porous soils generally; it gives way to the semi-desert type where the rainfall decreases.

3. Rann Thorn Forest: Where the soil is reddish and gravelly the awned grasses such as Aristida, Heteropogon and Chrysopogon take an upper hand. Salvadora and Rhus mysoensis predominate on waste lands and Sweda, Salsola, Ginus, Sporobolus on saline soils. Nearby the habitat is favourable enough for dry deciduous forest (Boswellia and Anogeissus pendula types).

4. Zizyphus Scrub: Common throughout the thorn belt, intermingled with the Euphorbia type which is slightly more conspicuous in rocky areas and owing its origin to intense biotic pressure.
Fig. 2. (a) Forest cover map of Rajasthan (b) Forest type map of Rajasthan.
Zizyphus may have colonised old cultivation or old cutting.

5. Tropical Euphorbia Scrub: Like the Zizyphus scrub, this also owes its present form to excessive grazing and felling of tree growth but edaphic factors also possibly involved. It occupies stony sites in general.

Non-Forest

Wastelands are lands, which are degraded and at present lying unutilized or which are not being
used to its optimum potential due to different constraints. Broadly these lands can be grouped as cultivable or non-cultivable. As per estimates, Rajasthan has about 92.56 lakh hectares of wastelands of different types. The cultivable wastelands are capable of or have the potential for development for agricultural or pasture purposes or even can be afforested. The non-cultivable wastelands on the other hand are barren lands that can not be put to any productive use either for agriculture or to develop forest cover.

Various land use patterns are in practice in the state, depending on the type of the soil and water resources and the human endeavors to tackle them. Mainly six groups of land use classes are predominant in the state namely, forest, land put to non-agricultural uses, permanent pastures, gullied or ravinous land, net sown area and fallow land.

**Biome level characterization**

The geospatial analysis has delineated two biome zones in the western India, Rajasthan viz. Tropical thorn/savanna forest and Tropical arid zone (Fig. 3a). Thorn forests or thorn scrub comprised of low grazing trees, shrubs and frequently stem-succulents. It is distributed in the entire eastern Rajasthan bordering dry humid climatic region in the east and dry arid climate in the west. This region is comprised in the areas where annual precipitation averages 800 mm and dry season extends for 6 to 8 months. The woody species are deciduous and small leafed; many have thorns or spines. The high anthropogenic factor has resulted in the desertification of the area. The tropical arid zone is the representative of the desert ecosystem, with scattered adapted bushes and xerophytic plants. This area is rarely devoid of life. Shrubs are the dominant growthform, with typically small leaves and frequently spines and thorns. They form an open canopy and except after rains when annuals may cover the desert floor, the ground between shrubs in bare of vegetation growth.

**Discussion**

The temporal data provides a wider view to find out the qualitative status as well as quantitative status of the vegetation. NOAA-AVHRR has been widely used over the world for vegetation mapping at global and continental level studies. The introduction of WiFS offered an advantage with its spatial temporal resolutions for vegetation studies. Earlier studies have established the application of WiFS for regional studies (Joshi et al. 2001a,b; Roy & Joshi 2000b, 2001; Singh et al. 1999a,b). Besides, multiday WiFS data has been used for assessing crop growth within the season and comparison across the season. It has been used to provide pre-harvest multiple forecasts of wheat production over large region (Bhagia et al. 1997; Oza et al. 1996) and for other crops as well (Sehgal & Dubey 1997).

The concept of NDVI images is quite significant in case of regional level mapping for the reason that the bioclimatic phenomenon are understood with the help of phenology which in itself is an effective subject. Understanding the dynamics of global change and modeling the Earth’s physical systems will require concentrated interdisciplinary effort (Kramer 1997; Myking 1997; Regniere & Sharov 1999; Song 1999; Spano 1999). Phenological analyses can play an important role in the ongoing studies. Development of systematic observation networks on the national and global scale will be critical in realizing such potential contributions.

The terrestrial biosphere is an active component of the Earth system. Vegetation has a strong control over the flows of water, carbon and energy between land and atmosphere and between land and oceans. Vegetation develops in response to climate and hydrology and it feeds back to the Earth’s climate system. We need to develop management strategies that allow sustainable use of natural resources and that help us to adapt and mitigate changes in the Earth’s functioning that may already have been set in motion. This requires a multidisciplinary understanding of the interactions between the land surfaces, the climate system and water resources. To analyze temporal variations in biosphere-atmosphere-hydrology interactions, long observational records are required. Issues such as long-term carbon uptake by a particular ecosystem, soil moisture ‘memory effects’ carried from one season to the next or the interannual climate variability caused by cyclic patterns in ocean temperatures require sustained monitoring of vegetation-atmosphere fluxes over multiple years. By switching on or off certain land surface processes, or by perturbing the geographical distribution of certain biome types, we ‘tickle’ the system. The reaction of other parts of the sys-
tem can then be analyzed to elucidate the mechanisms behind, for example, desertification or to assess the consequences of tropical deforestation. In another category of coupled models, vegetation development and distribution interactively respond to the simulated climate. Such studies show that in the past in some regions a specific climate-vegetation combination may have been stable that differs from the combination actually found at that time. Here also phenology has got an important place to hold in terms of showing variability among the vegetation structure. Bolstered by global surface data collection, phenological research will be poised to improve the understanding of atmosphere-biosphere interactions that have implications for global change – such as the onset of Spring plant growth in temperate climates (Schwartz 1999).

In the case of Rajasthan, the WiFS data has proved significant for the discrimination of different land cover/use classes. There is an intermixing among the classes of Desert forest and Sand dune classes but the NDVI variability in these classes led to the proper discrimination of the land cover/use classes. The vegetation in Rajasthan is mostly dry deciduous type and scrub.

In spite of the characteristic features of WiFS to characterize the vegetation, it also has some limitations. The wider pixel may create complexity in interpretation, overestimation or underestimation of the vegetation cover leading to inaccuracy in nomenclature/classes. This paper has emphasized exclusively the role of medium resolution sensor for vegetation monitoring. The regional phytophenological classified map provides details on vegetation stratum. This can be further exploited in conjunction with high-resolution sensors and extensive ground truth to provide for quantitative forest resource information.

**Conclusion**

Proper assessment and evaluation of the resource potential of a country is an essential prerequisite for national development. For these reasons most developing countries are now seeking new technologies to improve their resource evaluation programs. This is true in the tropics where forest resources are depleting both quantitatively and qualitatively at an ever-increasing rate. Up-to-date information on the current status with possible monitoring of their status is currently very pressing issues in such countries. At a finest resolution, WiFS data is best suited to monitor vegetation dynamics even in a very small interval of time period at a regional scale (1:1 million) comparable with that available with LISS or Landsat or NOAA-AVHRR (Roy & Joshi 2001; Joshi et al. 2001a,b). The present study emphasizes the use of WiFS data for land cover and land use mapping at mesoscale for regional level assessment and monitoring. The NDVI has been found related to green leaf activity and as such provides a useful means to monitor the vegetation cover/phenology. The advantage of the sensor lies in suitable spatial and spectral resolutions for regional level, competitive band combination for vegetation studies and temporal resolution for vegetation dynamics. It offers wider coverage for comparison of regional or continental level studies. Its effectiveness is in discrimination of forest types and major crops and other land cover and uses. The accuracy of medium resolution data in regions dominate with uniform features. Hybrid approach of classification proved to be more useful than other approaches. WiFS data have been found to be satisfactory (accuracy~80 to 87%) to perform forest assessment, mapping and delineation.

**References**


