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Landsat ETM+ and MODIS EVI/NDVI Data Products for Climatic Variation and Agricultural Measurements in Cholistan Desert

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LANDSAT ETM+ AND MODIS EVINDVI DATA PRODUCTS FOR CLIMATIC VARIATION AND AGRICULTURAL MEASUREMENTS IN CHOLISTAN DESERT

Strictly as per the compliance and regulations of:

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Abstract - The Landsat ETM+ has shown great potential in agricultural mapping and monitoring due to its advantages over traditional receive procedures in terms of cost effectiveness and timeliness in availability of information over larger areas and ingredient the temporal dependence of multi-temporal image data to identify the changing pattern of vegetation cover and consequently enhance the interpretation capabilities. Integration of multi-sensor and multi-temporal satellite data effectively improves the temporal attribute and accuracy of the results. Since 2000, NASA's MODIS sensors (onboard Terra satellite) has provided composite data at 16-days interval to produce estimates of gross primary production (GPP) that compare well with direct measurements. The MODIS Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) which are independent of climatic drivers, also appears as valuable surrogate for estimation of seasonal patterns in GPP. The required data preparation for the integration of MODIS data into GIS is described with focus on the projection from the MODIS/Sinusoidal projection to the national coordinate systems. However, its low spatial resolution has been an impediment to researchers pursuing more accurate classification results. This paper summarizes a set of remote sensing applications of MODIS EVI/NDVI data products in estimation and monitoring of seasonal and inter annual ecosystem dynamics which were designed for studying climatic variation and agricultural measurements and can also be implemented in the drylands (Cholistan Desert) of Pakistan.

Keywords : Cholistan desert, EVI, Landsat ETM+, MODIS, NDVI, vegetation phenology.

I. Introduction

The Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument onboard the Terra and Aqua satellite platforms (Huete et al., 2006; Carrão et al., 2008). Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon (Salomonson and Toll, 1991; GSFC/NASA, 2003; Huete, 2005). The MODIS Terra and MODIS Aqua are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands (Huete, 2005). These data are being used to improve our understanding of land surface global dynamics and processes. The MODIS is playing an important role in the development of validated, global data products useful to interactive Earth system models, able to predict climatic variation or environmental change accurately enough to assist policy makers in making sound decisions concerning the protection of the planet (Riggs et al., 1998; Huete, 2005). There are now over 12 years of MODIS Terra data (first image, February 24, 2000) and 10 years of MODIS Aqua data (first image, June 26, 2002), available producing high quality scientific products with calibration specifications of 2% reflectance and 5% radiance and geolocation of 50 m (Huete, 2005).

II. Study Area

Cholistan Desert (Figure 1) is an extension of the Great Indian Desert, covering an area of 26,330 km^2, lies within the southeast quadrant of Punjab province, placed between 27° 42' and 29° 45' North latitude and 69° 52' and 73° 05' East longitude (Ahmad, 2005; 2008; 2012).

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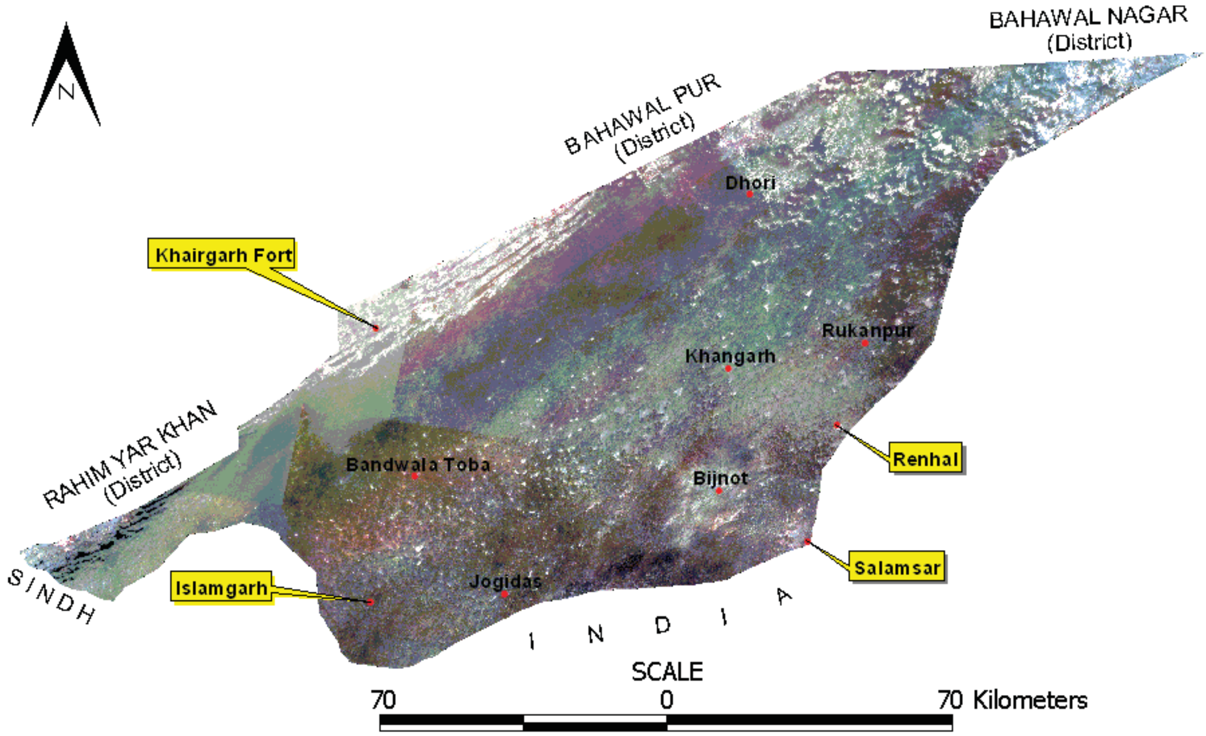

Figure 1: Cholistan Desert - Landsat ETM+ 2003 mosaic image. Source: http://glovis.usgs.gov/

III. Research Design and Methods

The MODIS EVI/NDVI data products for Cholistan Desert were acquired, in this case MOD13Q1 (MODIS Terra_250 m), MOD13A1 (MODIS Terra_500 m), MYD13Q1 (MODIS AQUA_ 250 m), MYD13A1 (MODIS AQUA_500 m) data were downloaded from the Land Processes Distributed Active Archive Center (LPDAAC). Tile number covering this area is h24v06, reprojected from the Integerized Sinusoidal projection to a Geographic Lat/Lon projection (Figure 2), and Datum WGS84 (GSFC/NASA, 2003; Ahmad, 2012a; 2012c).

The MODIS is an optical scanner that measures Earth radiance in 36 bands, ranging from 0.46 μm to 14.39 μm. The MODIS is a key instrument onboard the Terra satellite. The MODIS provides images over a given pixel of land just as often as the Advanced Very High Resolution Radiometer (AVHRR) but in much finer detail and with measurements in a greater number of wavelengths using detectors that were specifically designed for measurements of land surface dynamics (Huete, 2005).

Spectral indices of vegetation, based on satellite observations in the near-infrared (NIR) and visible (usually red) wavebands are widely employed as measures of green vegetation density. The index most commonly used is the Enhanced Vegetation Index (EVI), although a number of alternative indices based on the same two spectral bands have been developed, used mostly with the aim of reducing the sensitivity of the index to extraneous factors such as soil background or the atmosphere (Justice et al., 2002).

Vegetation indices among other methods have been reliable in monitoring vegetation change (Glenn et al., 2008). One of the other most widely used indices for vegetation monitoring is the Normalized Difference Vegetation Index (NDVI), because the vegetation differential absorbs visible incident solar radiation and reflects much of the Near Infra-Red (NIR). Data on vegetation biophysical characteristics can be derived from visible and NIR and mid-infrared portions of the electromagnetic spectrum (EMS). The NDVI approach is based on the fact that healthy vegetation has low reflectance in the visible portion of the EMS (Huete et al., 2002; Huete, 2005) due to chlorophyll and other pigment absorption and has high reflectance in the NIR because of the internal reflectance by the mesophyll spongy tissue of green leaf. The NDVI can be calculated as a ratio of red and the NIR bands of a sensor system (Huete, 2005).

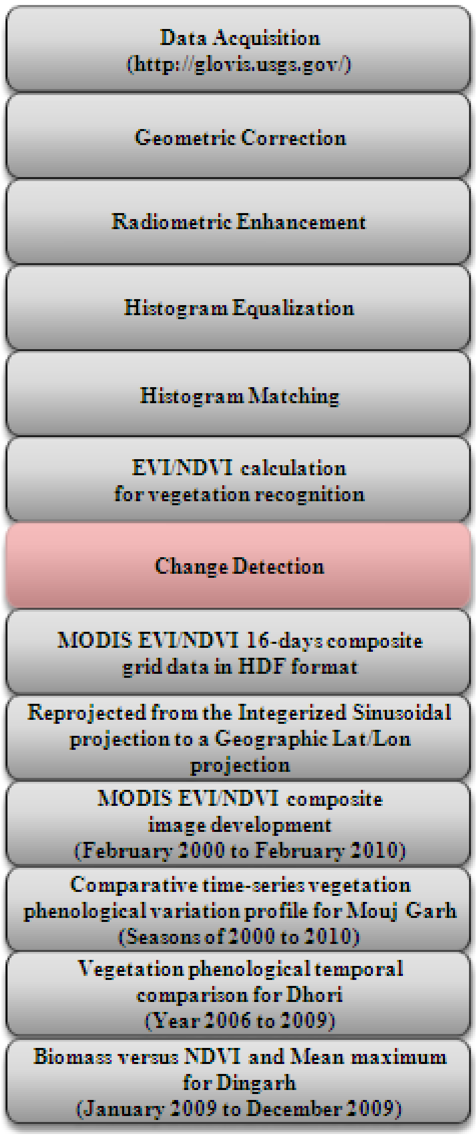

Figure 2 : Scheme for research design and methods.

The NDVI values range from -1 to +1; because of high reflectance in the NIR portion of the EMS, healthy vegetation is represented by high NDVI values between 0.1 and 1 (Liu and Huete, 1995; USGS, 2008; 2010). Conversely, non-vegetated surfaces such as water bodies yield negative values of NDVI because of the electromagnetic absorption property of water. Bare soil areas represent NDVI values which are closest to 0 due to high reflectance in both the visible and NIR portions of the EMS (Townshend, 1992). The NDVI is related to the absorption of photosynthetically active radiation and basically measures the photosynthetic capability of leaves, related to vegetative canopy resistance and water vapour transfer (Wan, 2003; Rahman et al., 2004).

Present research aims to reveal vegetation change using multi-temporal satellite data (Singh, 1989). ERDAS Imagine software has been used to generate the false colour composite, by combining the near infrared, red and green bands (4, 3, 2 respectively) for Landsat ETM+ images of 1999 and 2003 (path 149, row 40; path 150, row 40 and 41; path 151, row 40 and 41). This was carried out for vegetation recognition, because chlorophyll in plants reflects very well for the near infrared band compared to the visible band of the electromagnetic spectrum (Hatfield et al., 1984). Ground control points obtained using Global Positioning System (GPS) from locations (Steven, 1987; Shaw and Turner, 2000; Brook and Kenkel, 2002) in relation to the classes of the research area has been plotted on Landsat image.

IV. Vegetation Indices

The Global MODIS vegetation indices, produced at 16-days and 250, 500, 1000 m and Climate Modeling Grid spatial resolutions (Huete, 2005), provide consistent spatial and temporal comparisons of terrestrial vegetation canopy greenness, a composite property of leaf area, chlorophyll and canopy structure (Gallo et al., 1985; Chen et al., 2007).

Two vegetation index products are derived from atmosphere corrected, bidirectional red, near-infrared, and blue surface reflectances that are masked for water, clouds and cloud shadow; the MODIS NDVI which provides continuity with NOAA's AVHRR (Holben, 1986; Cihlar and Huang, 1994; DeFries et al., 1995; Verhoef et al., 1996; Ramesh et al., 2003; Potter et al., 2005; 2007) time series record for historical and climate applications, and the enhanced vegetation index (EVI), which minimizes canopy-soil and aerosol variations and improves sensitivity over dense vegetation conditions (Qi et al., 1994). The two products more effectively characterize a global range of vegetation states and processes, and improve upon the extraction of canopy biophysical parameters (Jiang et al., 2008).

V. Modis Vegetation Index Algorithm

In order to generate the proper Vegetation Index quality data, the algorithm will make a last run and reanalyze the input quality information (GSFC/NASA, 2003). Because the VI quality data structure is different than that of the input, the algorithm will, both pass input QA fields untouched to the VI quality, and generate new QA fields that are specific to the Vegetation Index. The MODIS VI quality data is 16 bit long, and contains 10 different QA fields. Although MODIS quality data is hard to deal with as it is, it is in the user's benefit to realize how valuable this data could be (Huete, 2005). VI's are most useful as (GSFC/NASA, 2003):

- Radiometric measures of the amount, structure, and condition of vegetation
- Indicators of seasonal and inter-annual variations in vegetation useful in change detection studies, phenology observations, and vegetation mapping, and

- Intermediaries in the assessment of various biophysical vegetation parameters, including:
  - o Green cover fraction
  - o Biomass
  - o Leaf area index
  - o Fraction of absorbed photosynthetically active radiation.

VI. Results

The EVI and NDVI models were applied upon 1999 and 2003 ETM+ images (Figure 3a, b; Table 1) and further change detection technique was used for EVI and NDVI calculation. The findings showed that the sand dunes have undulating to steep topography, with the dunes lying parallel to each other and connected by small streamers. They are very well drained and have coarse textured, structure less soils derived from aeolian material (Khan, 1993). The near level to gently sloping areas have deep to very deep sandy soils which are very well drained, calcareous and coarse textured. Loamy soils occur on the level to near level areas with hummocks of fine sand on the surface. These soils are moderately deep, relatively well drained, calcareous and with a moderately coarse to medium texture (FAO/ADB, 1993). Clayey soils occur on level areas and are moderately deep, poorly drained, calcareous, saline-sodic, moderately fine textured to fine textured with a pH range from 8.6 to 10.0 (Baig et al., 1980; Ahmad, 2008). The soil of Cholistan Desert is productive for dryland agriculture. Groundwater is saline, it can be used for irrigation to grow salt tolerant trees, vegetables, crops and fodder grasses in non-saline, non-sodic coarse textured soils. This can occur with minimum adverse effects due to the rapid leaching of salts beyond the root zone (Ahmad, 2008).

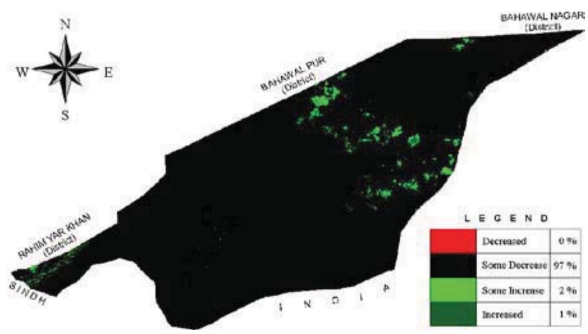

Figure 3a : Map showing change detection using EVI model. Source: After Ahmad F 2012.

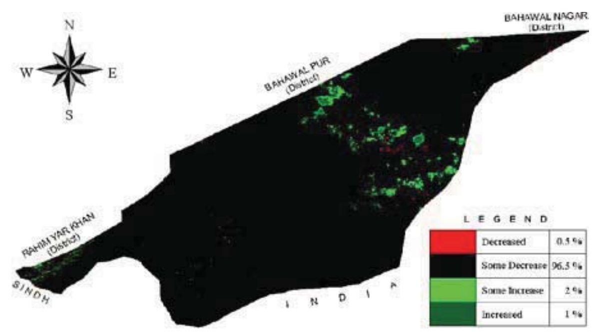

Figure 3b : Map showing change detection using NDVI model. Source: After Ahmad F 2012.

Table 1 : Vegetation matrix percentage for individual change classification.

Vegetation Indices	Decreased %	Some Decrease %	Some Increase %	Increased %
EVI	0	97	2	1
NDVI	0.5	96.5	2	1

Figure 4 shows comparative vegetation phenological variation profile for Khangarh, Cholistan Desert. MODIS EVI Terra 250 m, MODIS EVI Terra 500 m, MODIS NDVI Terra 250 m and MODIS NDVI Terra 500 m data for the year 2009 was used to evaluate green cover fraction and biomass at the same location. The result showed that EVI differs from NDVI by attempting to correct for atmospheric and background effects. EVI appears to be superior in discriminating subtle differences in areas of high vegetation density, situations in which NDVI tends to saturate. The NDVI has been used for several decades, which is advantageous for studying historical changes (Trishchenko et al., 2002). The EVI is a good indicator of the phenology of the land cover types, the research tested the contribution of EVI data to the land cover classification (Gao and Mas, 2008). Further, MODIS EVI Terra 500 m provides better result as compared to MODIS EVI Terra 250 m data. The finer the resolution of a satellite product, in time and space, results in 'higher frequency' noise. Aggregating a product to a coarser resolution generally "smooths" things out.

Figure 5 shows comparative time-series vegetation phenology metrics for Renhal, seasons of 2000 to 2010. MODIS EVI Terra 500 m and MODIS EVI Aqua 500 m data was used to evaluate green cover fraction and biomass at the same location. Differences in Terra's and Aqua's orbits result in different viewing and cloud-cover conditions for a given location. Terra satellite, the local equatorial crossing time is approximately 10:30 am in a descending node with a sun-synchronous, near-polar, circular orbit. Aqua satellite, the local equatorial crossing time is approximately 1:30 pm in an ascending node with a sun-synchronous, near-polar, circular orbit (Salomonson and Toll, 1991; GSFC/NASA, 2003; Huete, 2005).

The result showed that MODIS EVI Terra 500 m data provides better result as compared to MODIS EVI Aqua because around noon on a sunny, dry day with no clouds and no pollution is the best atmospheric conditions for remote sensing in the visible portion of the spectrum. Comparative time-series vegetation phenology metrics showed that climate was stable (start/end) and land degradation or desertification can't be seen during the seasons of 2000 to 2010. Variation in biomass and soil productivity can be seen due to summer monsoon especially in the years 2000, 2001, 2003 and 2007; indicates that the soil at Renhal is productive and small scale dryland agriculture can be practiced using rainwater or ground saline water for irrigation.

Figure 6 shows comparative time-series vegetation phenological variation profile for Mouj Garh, seasons of February 2000 to February 2010 at 16-days interval. MODIS EVI Terra 500 m and MODIS NDVI Terra 500 m data was examined for evaluation of climatic variation in the desert environment. The finding showed that climate at Mouj Garh was stable (start/end) and land degradation can't be seen thoughout the decade 2000 to 2010. The soil at Mouj Garh is productive and irrigated through perennial canal system.

Figure 7 shows biomass versus NDVI and mean maximum from January 2009 to December 2009 at Dingarh, Cholistan Desert. The biomass and NDVI demonstrated clear inter-seasonal consistency indicated by the larger amount of biomass and the corresponding higher NDVI values in January, February, March, April, August, September, October, November and December 2009 and the smaller amount of biomass in May, June and July 2009. The variation in biomass are fairly well represented by the changes of NDVI. The inter-seasonal (Gazdar, 1987) consistency of NDVI and biomass support the common use of NDVI to study vegetation response to climate variation (Anyamba and Eastman, 1996; Kogan, 1997; Li and Guo, 2012).

Figure 8 shows comparative time-series vegetation phenological profile for Bandwala Toba, Cholistan Desert, year 2002 to 2009. The profile showed that climate was stable (start/end) and land degradation can't be seen. The year 2003 showed the maximum NDVI values during June to September. The profile also indicates that green cover fraction, biomass productively and soil moisure increased due to summer monsoon at Bandwala Toba. The year 2009 showed minimum NDVI values during June and July due to extreme temperature. The NDVI is successful as a vegetation measure (Choudhury, 1987; Jakubauskas et al., 2002; Chen et al., 2006; Zoran and Stefan, 2006). The strength of the NDVI is in its ratioing concept (Moran et al., 1992), which reduces many forms of multiplicative noise (illumination differences, cloud shadows, atmospheric attenuation, and certain topographic variations) present in multiple bands (Liu and Huete, 1995; Chen et al., 2002). The NDVI is referred to as the 'continuity index' to the existing 20+ year NOAA-AVHRR derived NDVI (Rouse et al., 1973) time series (Moran et al., 1992; Verhoef et al., 1996; Jakubauskas et al., 2001; Huete et al., 2002; Zoran and Stefan, 2006; USGS, 2010; Ahmad 2012b), which could be extended by MODIS data to provide a longer term data record for use in operational monitoring studies (Chen et al., 2003).

Figure 9 shows vegetation phenological temporal comparison for Dhori, period 2006 to 2009. The temporal curves indicate that the other vegetation phenology metrics, climate was stable, green cover fraction, and biomass productively increased due to summer monsoon. The profile showed maximum biomass in 2008 and minimum in 2009. Dhori is located at the northern part of the desert and small scale agriculture is practiced in summer season. Year-to-year fluctuations of rainfall in the desert provide an opportunity to characterize and assess the temporal dynamics of desertification or land degradation processes and phenology. Such information was retrieved and analyzed by combined use of satellite imageries in the reflectivity and thermal spectral bands (Karnieli and Dall'Olmo, 2003).

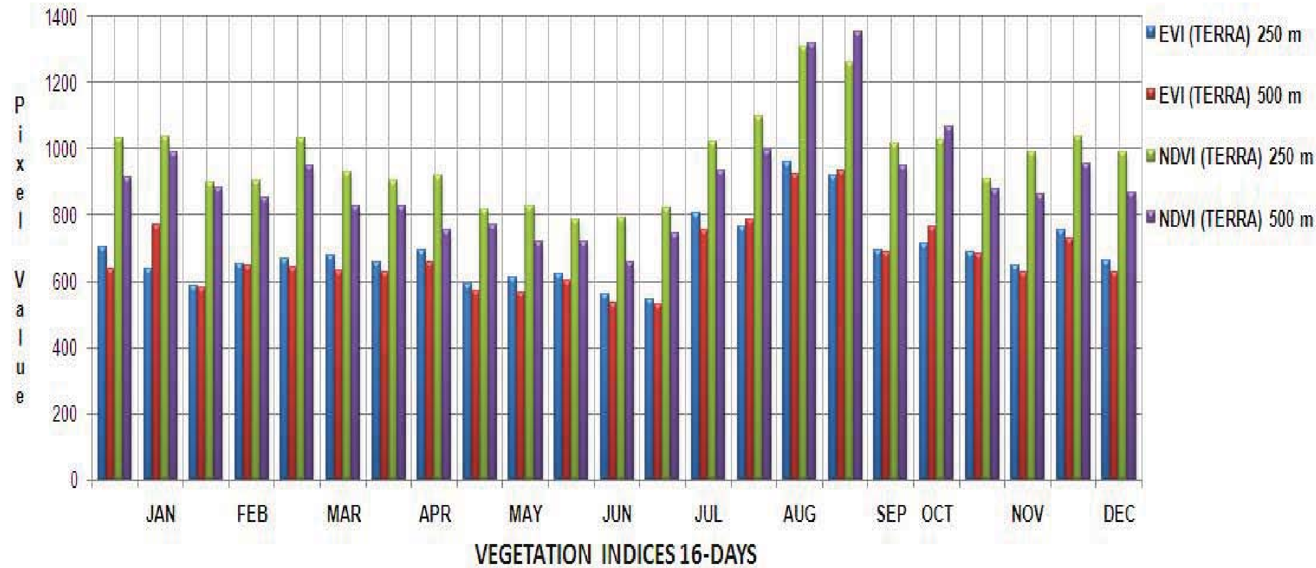

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Figure 4 : Comparative vegetation phenological variation profile for Khangarh, Cholistan Desert, Year 2009.

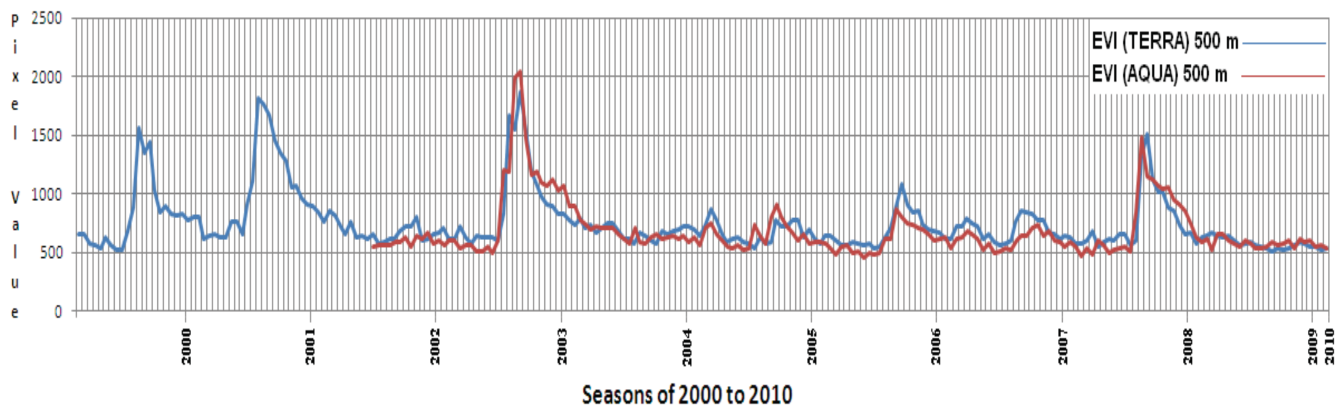

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Figure 5 : Comparative time-series vegetation phenology metrics for Renhal, Cholistan Desert.

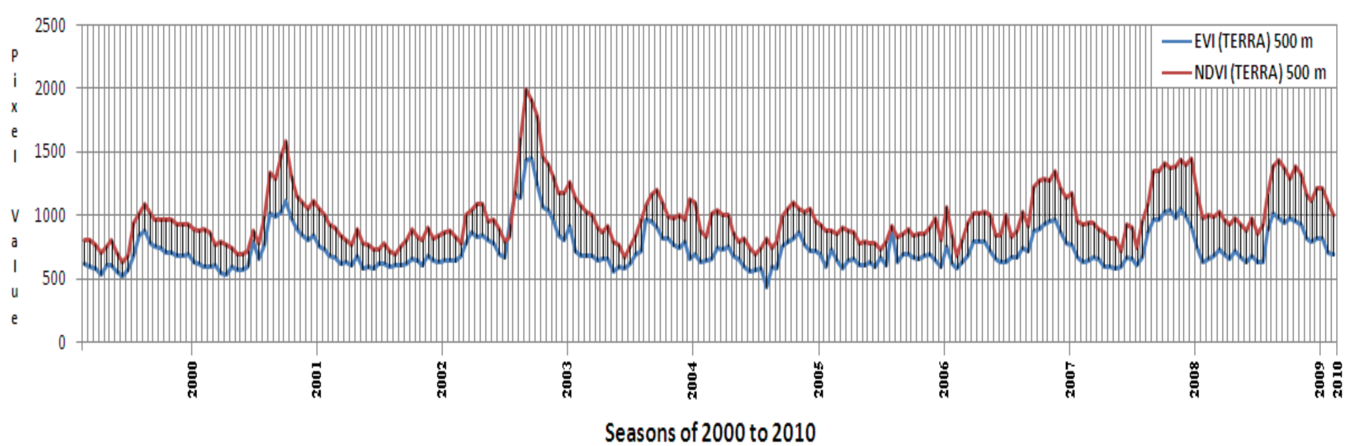

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Figure 6 : Comparative time-series vegetation phenological variation profile for Mouj Garh, Cholistan Desert.

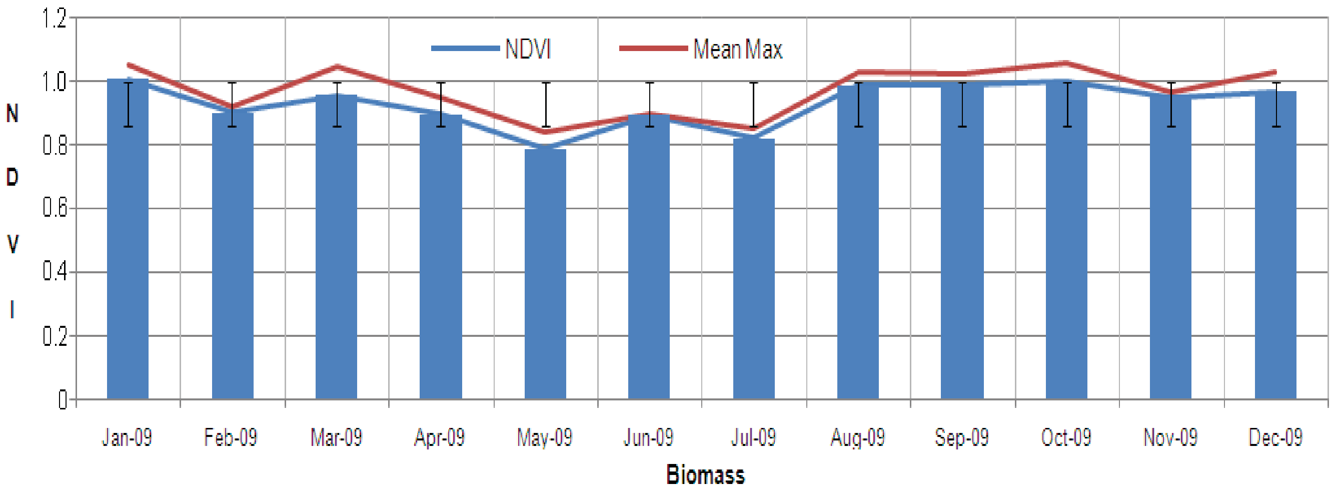

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Figure 7 : Biomass versus NDVI and mean maximum from January 2009 to December 2009 at Dingarh, Cholistan Desert.

(The error bars of biomass are shown with 1 standard deviation).

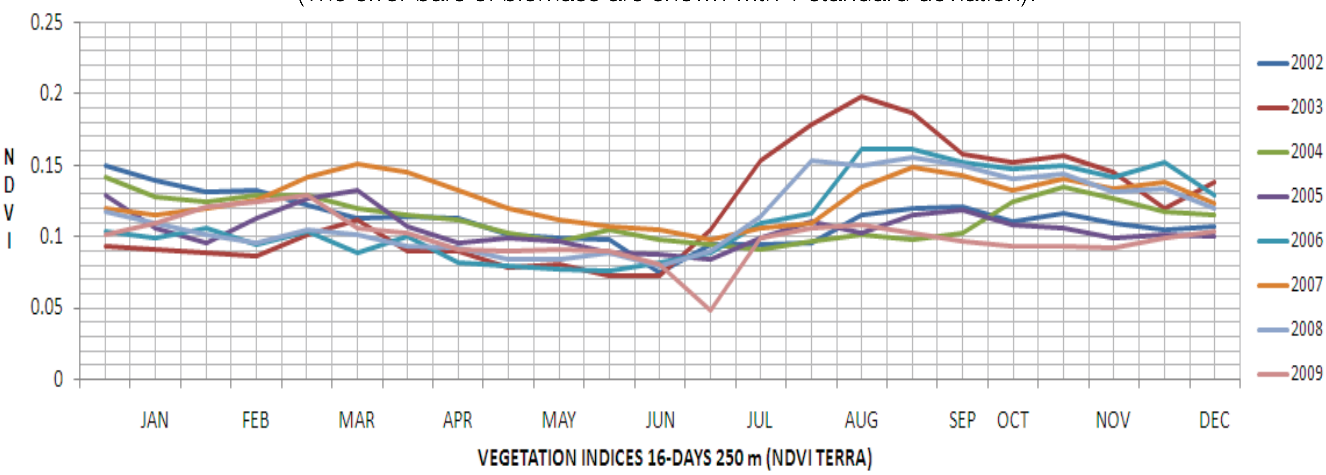

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Figure 8 : Comparative time-series vegetation phenological profile for Bandwala Toba, Cholistan Desert, Year 2002 to 2009.

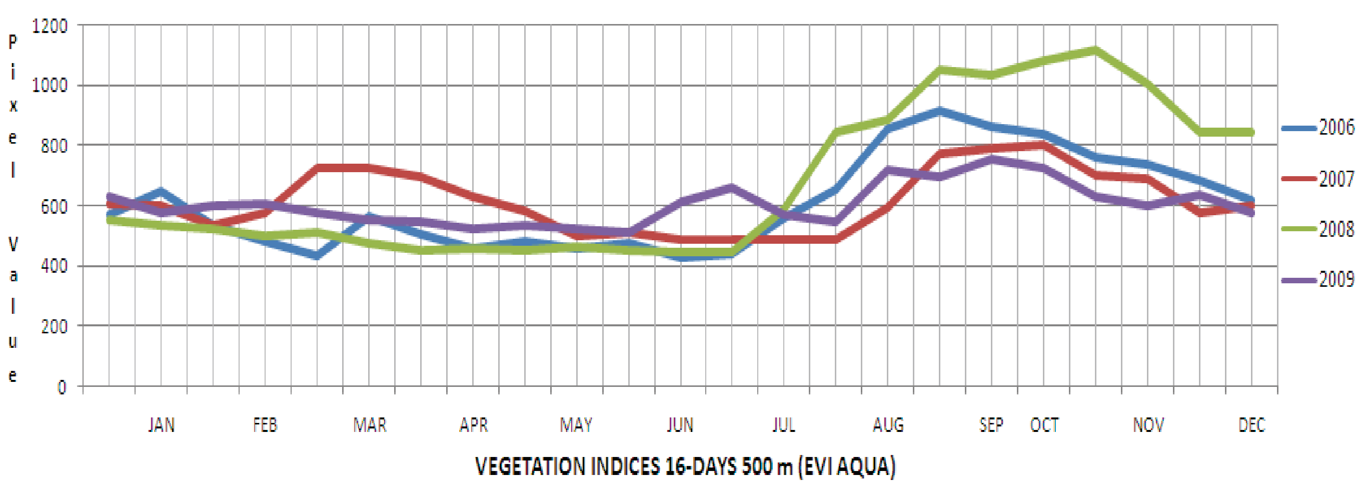

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Figure 9 : Vegetation phenological temporal comparison for Dhori, Cholistan Desert, Year 2006 to 2009.

VII. Discussion and Conclusions

This communication presents a new methodology for studying vegetation phenology using remote sensing (Charbonneau and Kondolf, 1993). The methodology provides a flexible means to monitor vegetation dynamics over large area using remote sensing. Initial results using MODIS data for the Cholistan Desert demonstrate that the method provides realistic results that are geographically and ecologically consistent with the known behaviour of vegetation in the desert. In particular, the MODIS-based estimates of green up onset, maturity onset, and dormancy onset show strong spatio-temporal patterns that also depend on land cover type (Baret and Guyot, 1991; Charbonneau and Kondolf, 1993; Justice et al., 1998).

The methodology presented in this research paper has several desirable properties. Since it treats each pixel individually without setting thresholds or empirical constants, the method is globally applicable (Vermote and Vermeulen, 1999; Vermote et al., 2002). Further, it is capable of identifying phenologic behaviour characterized by multiple growth and senescence periods within a single year, which is common in semiarid regions. Finally, because the method is tied to a specific calendar period, it provides the potential to monitor vegetation phenology in near real time (Campbell, 1987; Lillesand and Kiefer, 1994; Lillesand et al., 2004).

Phenology is the study of the times of recurring natural phenomena. One of the most successful of the approach is based on tracking the temporal change of a vegetation index such as EVI or NDVI. The evolution of vegetation index exhibits a strong correlation with the typical green vegetation growth stages (Zhao et al., 2005). The results (temporal curves) can be analyzed to obtain useful information such as the start/end of vegetation growing season. However, remote sensing based phenological analysis results are only an approximation of the true biological growth stages. This is mainly due to the limitation of current space based remote sensing, especially the spatial resolution, and the nature of vegetation index. A pixel in an image does not contain a pure target but a mixture of whatever intersected the sensor's field of view (Gao and Mas, 2008).

Validation is a key issue in remote sensing-based studies of phenology over large areas (Huete, 1999; Schwartz and Reed, 1999; Zhang et al., 2003; 2004). While a variety of field programs for monitoring phenology have been initiated (Schwartz,1999; Zhang et al., 2003; 2004), these programs provide data that are typically specie-specific and which are collected at scales that are not compatible with coarse resolution remote sensing observations.

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