VULNERABILITY OF VEGETATION IN PARTS OF HIMALAYAS AND DYNAMIC GLOBAL VEGETATION MODELLING (DGVM) – STUDY USING VNIR AND THERMAL RESPONSES OF MODIS TIME SERIES DATA

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ABSTRACT:

Vegetation responses to changing climate patterns need to be understood to devise adaptation strategy for a sustainable development, especially in the light of increasing climate related vulnerability. Dynamic Global Vegetation Models(DGVM) have the capacity and scope to develop understanding in this regard, due to their ability in simulating plant-vegetation-climate processes incorporating bioclimatic variables. However, prior to take up modelling using a spatially explicit DGVM, it may be imminent to prioritize the area for vulnerable contexts, so as to calibrate and validate the model optimally. Spatially explicit DGVMs require site level observations at canopy and leaf level/soil strata level for parametrization and implementation. Satellite data in VNIR and thermal regimes provide scope to understand the responses of various vegetation categories and enable to set up baseline addressing the foci of change as regions of vulnerability. Study carried out Western Himalayan transect using MODIS enhanced vegetation index and land surface temperature illustrates potential to differentiate areas that can be vulnerable due to warming trends disturbing cold to warm season energy level transition. Relations of these indices were studied in different vegetation categories and modelled spatially to derive potential vulnerable zones. Many sites showed high vulnerability while some sites showed distinct resilient behaviour by showing increase in EVI during warming periods. Potential zones were studied further using a spatially explicit Dynamic Global Vegetation Model for site level understanding. DGVM results in terms of biomass and carbon were studied to understand the trends in the vulnerable and resilient sites. Detailed characterisation of DGVM based modelling is underway to further diagnose the vulnerability contexts.

1. INTRODUCTION

Global warming is influencing vegetation growth and phenology (Zhang et al, 2004 Parmesan & Yohe, 2003, Myneni et al. 1997, Cleland 2007). Vegetation responses to changing climate patterns need to be understood to devise adaptation strategy for a sustainable development, especially in the light of increasing climate related vulnerability. The responses can vary from cessation of normal phenological processes to increased physiological activity expressed, for instance, as improved vegetation vigour. Trends such as these may need to be confounded using other associated biophysical properties amenable at synoptic scale, which help to discern the levels of relative responses, in turn enabling decision making. Dynamic Global Vegetation Models(DGVM) have the capacity and scope to develop understanding of physiological responses , due to their ability in simulating plant-vegetation-climate processes incorporating bioclimatic variables. However, prior to take up modeling using a spatially explicit DGVM, it may be better to prioritize the area for vulnerable contexts, so as to calibrate and validate the model optimally. Understanding the disturbance in ecological contexts at global scale using combination of MODIS based EVI and LST parameters have provided insights in to collapse of leaf area due to sudden or gradual events (Mildrexler et al 2007, Mildrexler, 2009) and provide scope for applying in determining vulnerability. Regional scale DGVMs might present limitation in terms of attempting site scale calibration, which can be especially true for complex tropical forests, comprising of several plant functional types, yet to be included in to modelling. Downscaling regional DGVM operation to site level involving spatially explicit models may require alternate approach to know the vulnerability prevalent across a region. Such knowledge can help to validate these models more robustly. Satellite data in VNIR and thermal regimes provide scope to understand the responses of various vegetation categories and enable to set up baseline addressing the foci or hotspots of change as regions of vulnerability.

Theory involving thermal energy, its effect on ecological development as well as role of energy in functioning of self-organising systems and their organising ability are perceived to follow second law of thermodynamics (Kay 2000).Opportunity available with MODIS based Land Surface Temperature parameter provides scope for studying response of vegetation systems in terms of energy behaviour in comparison to vegetation condition as expressed by EVI. Land Surface Temperature has been derived using various fractions of electromagnetic spectrum (emissivity in bands 31 and 32 are estimated from land cover types, atmospheric column water vapor and lower boundary air surface temperature) as well as ground based relations. Surface temperature (which is the common product available from MODIS free online source from TIR remote sensing), Ts is addition of Air temperature and a ratio (ratio of aerodynamic resistance at boundary layer to specific heat of air weighted by a factor). Factor is difference between net all wave radiation at the surface and Latent heat flux i.e evapo-transpiration . Though it is a relatively complex set of equations to arrive at T_s it is worth understanding keeping in view of its ability to understand how vegetation responses are deviating from the normal in tune with warming trends. The equation form of the concept above is

$$T_s = T_a + [R_b / C\rho * (R_n - LE)]$$

Where R_n - Net all wave radiation at the surface, R_b - Boundary layer aerodynamic resistance, $C\rho$ –Emissivity and LE - Latent Heat Flux (Evapotranspiration) . Latent Heat Flux is affected by plant, air and radiation properties like a) resistance at canopy by stomata and LAI, b) resistance offered by dynamics of air movement, c) vapour density deficit of the air (packing of water molecules), d) specific heat of the air (how much energy air can retain), e) density of the air, f) slope of saturation vapour-pressure relationship, g) flux of energy in to or out of the surface (soil, leaf, water etc) and h) net all wave radiation at surface.

Enhanced Vegetation Index employed in the study is an optimized version standardized in MODIS sensor, and is sensitive to high biomass regions. EVI helps to monitor vegetation better through de-coupling of canopy background signal and reduced atmospheric influences .

$$EVI = NIR - RED/(NIR+C1*RED-C2*BLUE+L)$$

where NIR, RED, and BLUE are atmospherically-corrected (or partially atmospherically-corrected) surface reflectances, and C1, C2, and L are coefficients to correct for atmospheric condition (i.e., aerosol resistance). For the standard MODIS EVI product, L=1, C1=6, and C2=7.5.

Potential vulnerability as a satellite derived understanding attempted here, derives rationale from the fact that any increase in land surface temperature with concomitant increase in foliage manifestation retains scope for eco-physiological resilience, while otherwise, situation may push vegetation in to sub-productive situation due to linked eco-physiological limitations causing disturbed phenology.

2. MATERIALS AND METHODS

2.1 Study Area

A study window covering sufficient biogeographic variation corresponding to diverse phenological categories of vegetation in Western Himalayas was chosen between geographic extent of 30 20 55.68 N, 75 17 51.09 E (Lower left), 33 21 04.23 N, 79 18 19.64 E (Upper right) covering 482 columns and 362 lines of MODIS data. Such an extent enables wide range of responses possible across terrain and climate range. Window covered entire Himachal Pradesh as well as parts of Jammu and major parts of Southern Ladakh, corresponding to Hanle and Puga valleys (Fig 4). Study area covered following vegetation types, which are characteristic of most of the Himalyan vegetation transects. – Tropical (Dry and Moist Deciduous), Sub-tropical (Mixed Chir pines), Temperate (Conifer, Broadleaf), Deodar gregarious as well as tropical and Alpine grasslands . Region experiences a temperature range of -25 Deg C (Hanle) to 45 Deg C (Baddi, Himachal) and an average annual rainfall range of 200 – 2000 mm.

2.2 Satellite Data Used

Datasets from MODIS EVI (Enhanced Vegetation Index) and LST (Land Surface Temperature) composites (16 and 8 day respectively) for area covering vegetation categories from subtropical to cold arid alpine in Himachal Prdesh, India were analysed. EVI and LST have ability to represent plant performance/growth and potential stress respectively. While EVI compensates better for saturation issues of LAI, LST integrates extrinsic/intrinsic factors of land cover warming. Selection of the data was done to represent distinct seasons each in a normal and anomalous year, after studying temporal responses in 2000-2009 time series data. Data set for 2009 was known thermally anomalous year and 2006 a normal year, as defined by IMD.

2.3 Methodology

2.3.1 Homogenous Vegetation Strata: Homogeneity of vegetation is a percept linked to scale of observation. However, for a current inquiry, satellite based pixels accounting for the continuity of land cover within 3X3 pixels dimension is construed so, to facilitate coarse resolution (1X1km) correspondence of 24 m vegetation type map. Hence vegetation type map was resampled to 120 m resolution (5 X 5 pixels) and visually best possible square window was marked as to correspond to HVS, assuming any discontinuity as part of the pixel only. Vegetation categories principally corresponded to forest and natural vegetation as defined under national database prepared for Biodiversity Characterisation Project (Sponsored by Department of Space and Biotechnology jointly). Under this national project more than one season satellite data was used to prepare forest and other natural cover maps in entire India. Database for the study area selected was prepared during Phase I of the study using IRS LISS III datasets of 1999-2000 period. Coarse grid database consisting of 120 m pixel was used to draw 'homogenous vegetation strata' transects across entire Country. The HVS transects had to adopt to the varying patch shape and sizes of 37 categories considered. Transects varied from 4 x 4 km to 1 X 1 km in size so as to sample at least one EVI/LST pixel (of 1000 m pixel size) and they corresponded to at least 1% of the cover.

2.3.2 Response of vegetation categories in EVI and LST Euclidean space: Responses selected over each representative vegetation category were plotted as type-wise means across EVI-LST space for cold (January) and warm (April) months of normal (2006) and anomalous (2009) year. Major categories depicted differentiation and demonstrated the inherent potential of thermal and vegetation index combination to differentiate intended forest vegetation phenological categories. Comparison of normal and warm year distribution in terms of the displacement (highlighted by direction and magnitude of arrows empirically) within the Euclidean space (as depicted in Fig.3) pointed out the potential of Euclidean distance that can be employed for discriminating responses. In order to track the significantly deviating pixels, values showing magnitude beyond the average magnitude (beyond two sigma) were selected, so that extrema of the movement is represented as anomaly. It was assumed that values performing within two-sigma Euclidean distance of EVI-LST space were not depicting any abnormal behavior hence were not candidates of being vulnerable/responsive to warming trends prevalent. Method was assessed in a spreadsheet for calibrating the representation of distinction and implemented in ERDAS Imagine 2010 suite using modeler functionality.

Euclidean distance between respective indices between each year was used for measuring the departures from normal quantum and direction of variation. Direct ratios between and within year responses provided only limited picture of the pattern, while euclidean distance could sum up the between-year departures very well. The extreme deviations occurring (Fig 1-C.a & b) were categorized in to four levels viz., Non responsive (not showing extreme change) Adaptive (better performing in warmed conditions), Highly vulnerable and Very highly vulnerable (drastic decrease in vegetation foliage activity in warmed conditions).

2.3.3 Dynamic Global Vegetation Modelling: Intent to model the transient behaviour of the vegetation especially in the light of rapidly changing climatic conditions have led to development of dynamic vegetation models with a backdrop of initial static models. Inability of two dimensional dynamic models to account better for the competition for light has led to development of models which provides better appreciation of 3-D structure as well as light distribution among stands over the earlier dynamic representation of plant processes like photosynthesis, evapotranspiration, respiration, mortality (Sato, et al , 2007) .

3. RESULTS AND DISCUSSIONS

Study attempted to select vulnerable zones using relations between EVI and LST. Responses in these indices during anomalous year compared against that of normal year were tested for major departures in terms of reduced EVI and increased LST. Initial tests included direct ratios of each parameter and their normalization using their differences. As a preparatory analysis, comparison of overall LST trends between years showed consistent warmed surfaces in April from January of 2009 as compared to that during 2006 (Fig.1), which lends added credence to the anomaly observed as global phenomenon. Following this scatter of different vegetation categories in Himalayan region across EVI-LST space showed characteristic spread.

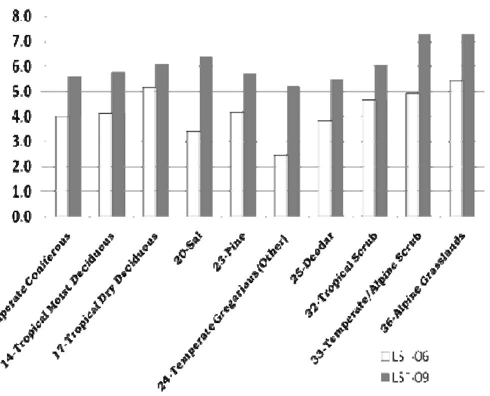

Fig.1. Land Surface Temperature difference (Warm to Cold month) of different vegetation categories in Western Himalayas based on MODIS-LST. 2009 skin temperatures have warmed up more.

Clusters observed in temperature and greenness gradients were termed Green-warm, Brown-warm or brown-cold with respected to their foliage features as well as their habitat nature (Fig 2). This scatter supported further visualization of varied movement of energy in the ecological system considered. Different magnitudes (of Euclidean distances) observed in various vegetation categories revealed overall higher magnitude in 2009 as compared to 2006 meaning more energy in former. Alpine systems were highly variable (7.86 and 9.84) followed by temperate coniferous (12.32 and 2.46)(Table 1). Higher magnitudes were also recorded in Alpine vegetation followed Tropical forests. Sal forests have showed contrasting magnitude in Euclidean space which may indicate that warmer years might propel increased foliage output. Tropical dry deciduous and scrub formations showed relatively lesser magnitudes indicating invariant systems. Analysis illustrated the way to discern variability inherent in the vegetation and demonstrated scope of differentiating responses across vegetation types. Based on this understanding entire vegetation was analysed for degrees of potential vulnerability/resilience as a continuum.

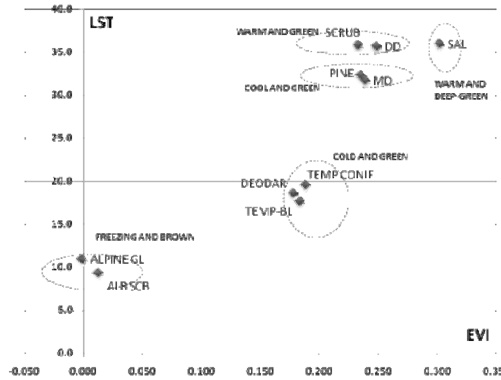

Fig.2. Distribution of Vegetation types across EVI-LST space in Western Himalayas

Alpine systems in open high altitude plateaus (Hanle, Ladakh) as well as valleys of Kaza in HP showed very high and high departures indicating potential vulnerability. Interestingly, valleys Sangla (Keylong) fared better than normal movement, possibly pointing towards adaptation to changing climate. Results depicted as Geographic representation of the database showed that out of 1,25,350 sq km studied it was observed that 1,230 sq km actually benefitted from warming where as 2,442 and 5,042 sq km area was showing very high and high vulnerability. About 24,320 sq km was observed to be showing slight deviation from normal, which may indicate potential vulnerability.

Sl no.	Vegetation Types	2006 Mean	2006 SD	2009 Mean	2009 SD
1	Tropical Dry Deciduous	14.97	2.90	17.80	2.70
2	Tropical Moist Deciduous	11.93	5.13	16.73	2.46
3	Sal	9.86	0.56	18.62	0.65
4	Tropical Scrub	13.60	2.59	17.64	2.29
5	Pine	11.97	3.41	16.45	2.09
6	Temperate Coniferous	10.30	12.32	15.50	2.46
7	Temperate Gregarious (Other)	6.75	0.58	14.49	1.28
7	Deodar	10.57	3.92	15.16	2.58
8	Temperate/Alpine Scrub	13.01	4.03	19.13	4.35
9	Alpine Grasslands	13.88	9.84	19.09	7.86

Table 1. Euclidean Distances in EVI-LST Space between January and April, 2006 & 2009 for different Vegetation Types in Parts of Western Himalaya

Analysis reveals distinct areas showing potential vulnerability especially in high altitude grasslands, which have strong tendency of experiencing acute temperature fluctuation. Large patches in Hanle and Puga valleys are known sub-zero sites with extremely desiccating winds that may take toll on foliage cycles, while the warming dries up the moisture. On the contrary , similar alpine systems but with different terrain feature of narrower valleys in Lahul of Himachal Pradesh have actually shown rather resilient behavior, with more EVI in warmed contexts. Analysis of the phenomenon as size of geographical extent in terms of patch size indicated quite a notable dimension of the process prevalent. Large patches can only result from process occurring over large space and time domain, while very small patches may be even at noise due to image features or process errors. (Fig.4)

Possible resilience observed can also be due to a relatively higher woody fraction of vegetation prevalent in Lahul region as compared to Ladakh. While woody vegetation may achieve exploitation of moisture and temperature, cold grasslands may tend to show low growth. It is also interesting to note that not many highly or very highly vulnerable patches could be seen around adaptive region, which may possibly point to the biogeographic characteristic of the region.

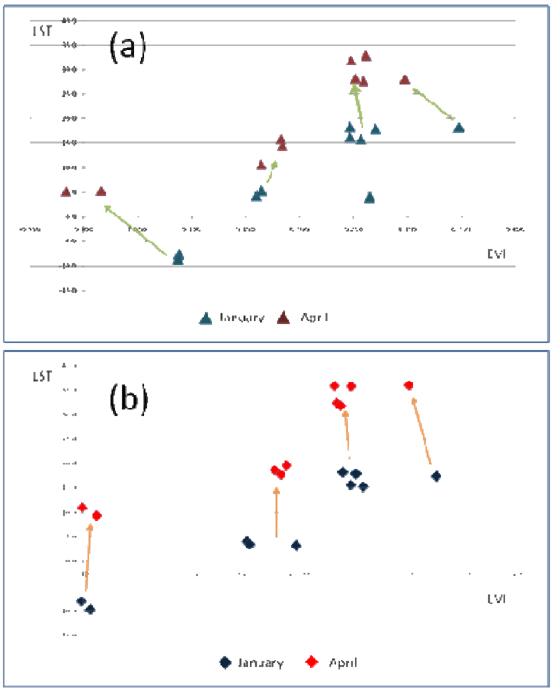

Fig.3. Comparative magnitudes of Euclidean distance shown by different vegetation types in Western Himalayan system during (a) normal (2006) and (b) warm (2009) year.

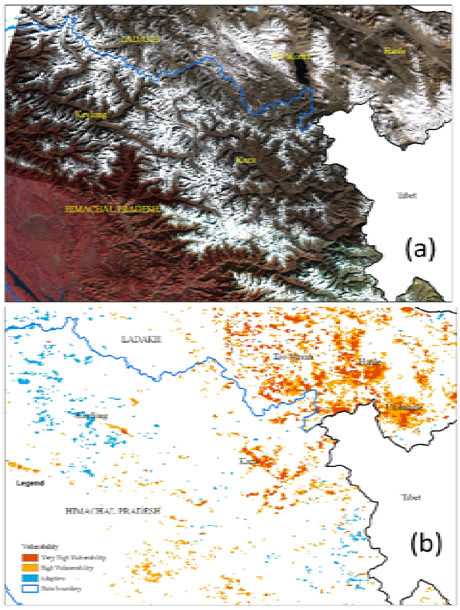

Fig.4. False color composite (a) of Study region using IRS AWIFS data showing Temperate/Alpine region with spatially modelled potentially vulnerable patches based on LST-EVI relations derived from the study. Notable are the large vulnerable patches in Central east where as western sector has more resilient zones (sky blue patches)

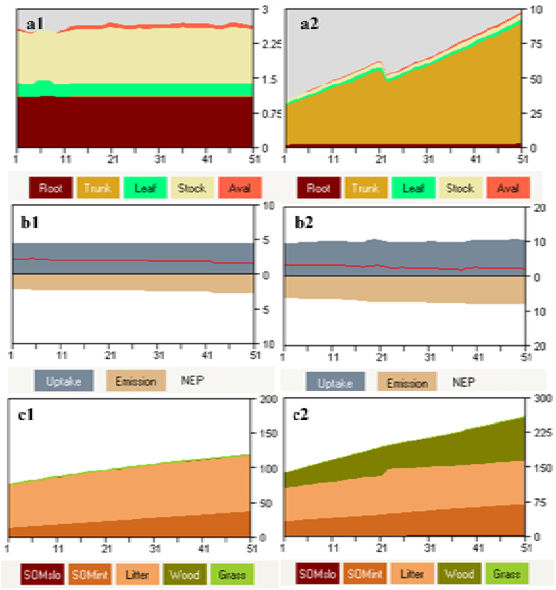

Fig.5. Biomass (a1,a2), Carbon flux (b1,b2) and Carbon Storage (c1,c2) of Cold area Tall Grass (Hanle '1s) and Boreal Woodland Vegetation (south of Sangla, '2s) in potentially vulnerable and potentially resilient patches of Western Himalayas using SEIB-DGVM (Ver 2.54) . (Units : Mg C/ha on Y-axes, X-axes indicate time in years). Soil Organic Matter (slow and Internal), Litter, Wood and Grass Pools produced asCarbon Storage. Biomass : Shown in different fractions. Carbon flux shown as uptake and emission and NEP shown as line .

Consequent to the delineation of vulnerable zones in the study region, attempt has been made to apply a dynamic vegetation growth model at specific instances of varied resilience. Realization by climatic researchers of the need to address the complexities of vegetation surface at finer scale, as well as influence of vegetation on climate trends, has greatly influenced the integration of different biophysical models towards coupling. Spatially Explict Individual Based Simulator (SEIB) –DGVM (Sato et al, 2007) (Ver. 2.54 downloaded : Jul 2011, seib-dgvm.com), complied using g95-MinGW was employed for developing understanding in sites showing vulnerability. Initial attempts were focused on ability of the model to synthesize extant vegetation at the site and develop further upon the same. Though we proposed the use of LPJ-GUESS Education module , its specific intent of being only education version made us to use this open source software. SEIB relies on a three dimensional interpretation of the real world vegetation with improved light interception and allocation routine. Its disturbance module also covers occurrence of fire at a critical biomass spill over. With 2.54 vegetation suited to field compatibility were found to be modeled. Model run was executed for 50 years at site showing vulnerability (Hanle) as well as at site showing resilient behavior (Sangla). SEIB model synthesized (Fig.5) tall grass and boreal woodland PFTs in these two sites respectively which matches the expected vegetation on ground. The model results show a trend characteristic of grassland and woodland accumulating biomass over half century and without any loss of substantial carbon over any point of time, possibly due to cessation of growth. Emissions seem to go up in later part, possibly due to the quantum of carbon available at pool. Woodland seems to show dip in the growth in first half of 50 years and to catch up later for a continuous growth. However , since the climate pattern for 50 years is assumed to be as that of calibrated year sequence (NCEP reanalysis available for modelling through SEIB link), results can be considered as inputs for calibrating model performance in test site. A collaboration is underway with institute involved in this region for calibrating the model performance. Detailed behaviour of the site would be studied using climate data adapted to SEIB from ongoing efforts using models like WRF.

4. CONCLUSION

Developing upon the approach of disturbance index using MODIS data, this study illustrates the potential of EVI in conjunction with LST to delineate pockets of vulnerability in the context of global scale vegetation responses. Such hot spots picked can serve as sites for applying dynamic vegetation models to understand vegetation behaviour and devise strategies of adaptation if required. Such trends especially in highly ecologically fragile set up of alpine and temperate bioclimatic setup are critical from the view point of loss of habitats and species vulnerability also. Spatially explicit vegetation models can precisely help to understand functional aspects of such pattern deviations and strengthen adaptation programmes.

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