Trans. Inst. Indian
Geographers

Vegetation Greenness Parameterisation Using Temporal VGT- NDVI Data and Meteorological Conditions in Upper Dikhu River Catchment of Patkai Hills, Nagaland

Bendanginla, Surendra Singh and Hiambok Jones Syiemlieh Shillong, Meghalaya

Abstract

This paper analyses the effect of forest-meteorological factors on vegetation cover considering spatio-temporal variations in vegetation greenness intensity in the particular environmental conditions of Upper Dikhu River catchment which is located in the Patkai Hills of Nagaland Himalaya. The greenness intensity maps of each and every point of time were prepared at one-metre spatial resolution to analyse the spatial and temporal variations in vegetation greenness cover in the study area. Regression analysis was pursued to prioritize the effects of meteorological factors of the change in vegetal greenness intensity.

The distributional patterns of greenness intensity spatially vary because of the variation in topo-features (elevation and slope), while its temporal variations found significant owing to noticeable variability in the meteorological attributes.

Polynomial regression was the best-fit mathematical form which captured the maximum degree of temporal variability of mean greenness intensity up to 54.0 percent. It showed a decreasing trend when Heat index, Precipitation and PET increased. However, there was a positive impact of soil moisture which optimized greenness intensity as 117.5 mm moisture was available in the soil. Such conditions of meteorological phenomena are prevalent in the post-monsoon seasons (October to December) in the study area.

Keywords: *Greenness intensity, topo-features, heat index, polynomial form, soil moisture storage, mean-NDVI, spatio-temporal variation*

Introduction

Vegetation phenology is an important dimension of biological studies. While reviewing the literature, plant growth characterisation was more concerned with the simulation of physiological processes such as the analysis of photosynthesis, transpiration, respiration, distribution of dry matter among plant organs and water absorption by roots and carbohydrate assimilation in early literature (Dewit et al. 1969, Hunt 1977). Later on, vegetation growth models were developed in order to examine the physiological processes and phenological events, their stages and environmental stress using Potential Evapotranspiration based plant growth index, photosynthetic efficiency index for measurement of reproduction the green leaf biomass (McCall and Bishop-Hurley, 2003) and Thornthwaite-based thermal efficiency index (Singh et al. 2006). Recently, biophysical environment of vegetation and its growth have widely been parameterised by using remotely sensed data with various techniques of predicting green leaf biomass (Asshbindu 1989), ground water potentials (Gupta 1991, Mukherjee and Banerjee 2005), rate of Potential Evapotranspiration (PET), Net Primary Productivity (NPP) and vegetation index (Ricotta 1999). Time series data of Normalised Difference Vegetation Index (NDVI) are being widely used for spatio-temporal analysis of vegetation cover and greenness intensity.

There are numerous Digital Image Processing techniques such as slicing, image reduction and magnification, transects, contrast enhancement, band ratioing and so on (Jensen 1996); out of which NDVI happens to be the most widely used for the purpose of understanding green leaf concentration through calculation of Leaf Area Index (LAI) (Pandya et al. 2007). It is helpful in predicting chlorophyll status in the vegetation for the analysis of phenological as well as bio-technological processes of different types of tree species (Su 2002, Mukherjee and Banerjee 2005). This technique has been widely used for accurate description of vegetation cover and land cover classification for various purposes such as preparation of vegetation index (De Fries et al. 1995), detection of land cover changes using Landsat TM images of different dates (Jomma and Kheir 2005), analysis of phenology of cropping system and also prediction of spatio-temporal variation of runoff generation using SPOT-VEGETATION 10-day composite NDVI data (Panigrahy et al. 2003, Upadhyay et al. 2008, Gupta and Panigrahy 2008). No doubt, multi temporal Remote Sensing data are being widely used for the study of dynamic phenomena (Upadhyay et al. 2008) and gaining importance as an appropriate tool for International Geosphere Biosphere Programme- Data Information System (IGBP-DIS) which runs in cooperation with many worldwide agencies. Under this program, a time series of AVRR-NDVI monthly maximum value at spatial resolution of 1*1 sq km data have been provided for the earth surface (Eidenshink and Faundeen 1994). It is used for preparation of vegetation index (Ricotta et al. 1999).

An effort is, therefore, made here (a) to use 10-day time-series composite NDVI data for parameterisaton of vegetation greenness intensity to show spatial features of vegetation type based on its leaf shade density and (b) to compare this time-series vegetation greenness intensity with the meteorological data of same points of time to examine the causes of changes in vegetal cover. The main features of the present research are the analysis of spatio-temporal patterning of vegetation greenness intensity and prioritisation of its impact of forest-meteorology factors (Temperature, Rainfall, Potential Evapotranspiration and Soil Moisture) in the humid Patkai hills of Nagaland Himalaya considering Upper Dikhu River catchment as a meso- areal domain of the present study.

Study Area

Study area includes the Upper Dikhu River catchment that lies between 26° 0′ N to 26°52′ N latitudes and 94°30′ E to 95°16′ E longitudes with an areal extent of about 3,047 sq. km. It is situated on the western slopes of Patkai hills in Nagaland (Fig.1) (see page 59 for the fig. 1). The upper ridges of the catchments are elevated about 2,200 m a.s.l. while its mouth, i.e., the foothill part of river catchment ends at 150 m a.s.l. (Fig.-2A). It is important to note that more than 50 percent of the cultivated area of the entire state of Nagaland is concentrated only within and around the Upper Dikhu River catchment (Jha 1976). As such, the lower part of the river valleys and gentle slopes are under some kind of cultivation, whether settled or *jhum,* while remaining areas are dominated by forests. The river Dikhu is one of the major tributaries of river Brahmaputra and receives water through numerous small tributaries from the hills through which it flows. It originates near Surmi at an elevation of 1,897 m. After traversing a tortuous northerly course of 107.5 km through dense forests in hilly terrain of Nagaland, it enters the plains of Assam and thereafter traverses an approximate distance of 80 km to join the river Brahmaputra. The banks of the Dikhu River vary in width from 40 m to 100 m associated with slopes varying from moderate to strong (8-16%). However, most of the areas of the upper reaches of the catchment have strongly steep to cliff- like slopes (more than 32% gradient) (Fig.-2B) (see page 59 for the fig. 2A and 2B).

Average temperature is recorded 17°C in January (moderately cold) and 28°C in July (Hot). Rainfall is sometimes sufficiently high in pre-monsoon period (April) but July is the peak of monsoon when it precipitates up to 600 mm. Post-monsoon showers which occur from October onwards are helpful for soil recharge and vegetation growth. Due to thick fertile soils (1.2 m to 1.8 m) having 200 mm of water retention capacity and high nutrient contents promote vegetal growth (NBSS & LUP 2004). Moderate slopes along the river valleys and balanced topographic features (almost equal areas under valley slopes and high hills) and good drainage conditions of the river catchment create congenial ecological conditions for dense vegetal cover and greenness intensity. As a result, more than 54.50 % of land is under dense forests which includes other forest areas like reserved forests (0.77%), protected forests (0.1%), proposed forests (4.17%) and the village forests (48.90%) (Statistical Hand book of Nagaland 2004).

Material and Methods

There are two main dimensions of the present analysis to characterise the spatio-temporal pattern of vegetal cover based on its greenness intensity and to describe the main causes of change in these patterns. As land attributes of the area (elevation, slope, drainage as well as soils) are static in its nature over a period of time, the temporal changes in vegetal cover might be the result of variable meteorological phenomena. However, many studies conclude that spatial patterns of vegetation cover are controlled implicitly by two elements of topography: the elevation and the slope

(Thapa 2004). Spatio-temporal analysis of vegetal cover was pursued by using Multi Spectral 10-day time series composite NDVI data which are being provided at 1*1 sq km spatial resolution using SPOT images under Vegetation for Africa Program (VGT Extract, see http://www.vgt4africa.org/VEGTExtract.do). The data of vegetation cover for an interval of three months were downloaded from the website of above cited program (http://free.vgt.vito.be/) to characterize the seasonality effects of changes in vegetal cover taking into account five years downloaded data (January 2004 to December 2008). The months of January (moderately cold but dry), April (moderately cold and moderately dry), July (warm and wet) and October (moderately cold and moderately wet) for each year were considered to analyse the regular features of spatial distribution of vegetation greenness intensity. The variations in these four seasons are with the attributes concerned to forest meteorology to show their effects. It is to note that this website provides 10-days average raw data sets. First 10-days average data of each required month were used to make the spatio-temporal analysis in order. After downloading the concerned data from website, a standard procedure was adopted to make data of NDVI through the use of software downloaded from the given website**.** Raw physical DN values of each pixel were converted to obtain NDVI by applying the following formula as given in the Manual of the Program (Bartholome 2006: 100) see also website http://www.devococast.eu/VGTExtract.do.

$$PV = (Scale*DN) + Offset, \quad \ldots \quad \ldots \qquad (1)$$

where PV= Physical Value as output for NDVI value, DN= the Digital Number stored in the input data file, scale (constant) = 0.004 and offset (constant) = -0.1 for NDVI. Pixel-wise statistics of NDVI were generated by using ILWIS (Integrated Land and Water Information System) and its distributional patterns were analysed considering its spatial resolution of 1*1 sq meter size.

In fact, NDVI values vary ranging from +1 to -1. In order to analyse the intensity of greenness of vegetal cover to show its spatial variability for which a given classification in which five classes of vegetation greenness types was followed (Bartholome 2006). They are: Non-Vegetation cover (NDVI value below 0.0), Stressed Vegetation (0.0-0.4), Normal Vegetation (0.4-0.7), Dense Vegetation (0.7-0.9), Very Dense Vegetation Cover (0.9-1.0). This classification must provide the main features of the distribution of each point of time in order to highlight the greenness- based spatio-temporal characteristics of vegetal cover. Statistical analysis of greenness intensity distribution was pursued on the basis of its main parameters like maximum, minimum, mean, variance and growth rate values that vary over time.

After collecting monthly statistics of Temperature (T) and Precipitation (P) for all defined periods of time (January 2004 to December 2008) from centrally located meteorological station of the study area - Mokokchung (Nagaland), the statistics of four main attributes of forest-meteorology, namely, Heat Index (HI), Potential-Evapotranspiration (PET), Precipitation

(P) and Soil Moisture Storage (ST) were generated using T-M procedure that is based on 'thermal efficiency' criteria of vegetation growth and is dependent on general water budget equation {P- (PET+ ΔST+ RO)= 0} (Thornthwaite and Mather 1957). HI is directly converted from Temperature as it establishes the relationship following 'base variable and power constant' equation:

$$HI= (Tm/5)^{1.514} , \quad \ldots \quad \ldots \qquad (2)$$

where Tm = mean monthly temperature (°C); Tm= $\{(T_{max} - T_{mini})/2\}$. The attribute Precipitation is directly used from given raw data, while other attributes like PET and ST were calculated with a specific given T-M procedure (Singh et al. 2010). Mean-NDVI for each point of time is considered as dependent variable and these attributes of forest-meteorology as independent variables to establish the 'best- fit line' in each distribution for which five mathematical functions, namely, linear, polynomial, logarithmic, power and exponential, were used. The main analysis of the distribution and discussions are mainly based on the 'best- fit statistics' for prioritizing the vegetation factors

Results and Discussion

(A) Statistical Analysis

The mean-NDVI values in the temporal distribution of 20 points of time (January 2004 to October 2008) appear to be very high (0.62 to 0.68) in the month of January; in the case of January 2004, it was 0.6826. It implies interestingly that greenness intensity and its growth rate are higher in moderately cold (15°C to 20°C) weather conditions. Moderate growth rate (10-12 %) is observed during the post Monsoon season (October to January) especially when it is associated with moderate monthly rainfall of 50-100 mm even in the month of January at the time of less soil moisture storage (Table-1). There are general inferences drawn from numerous studies that warm humid conditions are suitable for optimal intensity and growth of vegetal cover (Champion and Seth 1968). In the present study, the evidences of NDVI based greenness intensity of vegetation and its growth as found in Table -1, are deviating from the general findings but they are interesting. Vegetal growth starts increasing with increasing greenness intensity from post-monsoon time of October. It is argued that the growth of the vegetation at foothills in Assam Valley may continue until a secondary peak of growth is realized in post-monsoon season sometime in November due to abundance of soil moisture and high temperature (Uma Shankar 1991, Uma Shankar et al. 1993). Similar results are also drawn from the present analysis that post-monsoon season is ideal for maximum growth of vegetation intensity. On the other hand, the growth is recorded negative, for instance in April 2004, up to -44.36 percent during the spring season (January to April) when soil is dry and evaporative demand is not filled by the precipitation. The causes of such variability may be the most variable phenomenon of soil moisture storage as it was recorded to the maximum of 200 mm in the month of April and July 2004, October 2005, July and October 2006, April, July and October 2007 and July 2008. The lowest soil storage was recorded in the year of April 2008 with a storage capacity of only 42 mm.

Table- 1: Distributional Characteristics of Vegetal Cover and Meteorological Parameters (January 2004- October 2008)

Period	NDVI Characteristics								Meteorological Parameters			
	Max NDVI	Min NDVI	Mean NDVI	3-months growth Rate (%)	Standard Deviation	Coefficient of Variation (C.V %)	Kurtosis	Skewness	Heat Index	Precipitation (mm)	PET (mm)	ST (mm)
January 2004	0.88	0.37	0.68	0.00	0.12	24.23	-0.64	-0.39	6.32	52.00	36.14	104.00
April 2004	0.68	0.07	0.38	-44.64	0.79	127.60	-1.19	0.00	9.22	385.60	83.46	200.00
July2004	0.84	0.04	0.44	16.43	0.24	29.08	-1.20	0.00	11.56	215.60	136.89	200.00
October 2004	0.90	0.07	0.49	12.00	0.24	28.47	-1.18	-0.02	10.47	57.60	100.98	161.00
January 2005	0.86	0.34	0.63	27.13	0.14	27.25	-1.02	-0.14	5.05	7.60	27.80	88.00
April 2005	0.78	0.31	0.57	-8.27	0.12	25.27	-1.02	-0.09	10.51	66.50	109.14	88.00
July2005	0.87	0.07	0.48	-16.91	0.22	28.07	-1.18	-0.01	11.60	327.30	136.89	49.00
October 2005	0.92	0.14	0.53	11.66	0.22	28.58	-1.17	-0.04	10.65	63.80	103.95	200.00
January 2006	0.90	0.36	0.66	24.42	0.14	25.75	-0.95	-0.18	4.52	0.00	19.46	131.00
April 2006	0.78	0.22	0.50	-24.87	0.15	27.17	-1.14	0.01	9.49	177.40	83.46	104.00
July2006	0.88	0.09	0.52	4.31	0.22	27.27	-1.11	-0.11	13.17	579.80	157.95	200.00
October 2006	0.90	0.14	0.57	9.16	0.20	25.93	-1.04	-0.12	11.55	69.90	112.86	200.00
January 2007	0.88	0.33	0.62	9.66	0.14	25.54	-1.04	-0.07	7.14	0.00	41.70	80.00
April 2007	0.73	0.04	0.38	-39.23	0.20	28.51	-1.19	0.01	10.92	187.80	109.14	200.00
July2007	0.86	0.08	0.49	30.46	0.21	27.30	-1.17	-0.02	13.50	338.00	157.95	200.00
October 2007	0.91	0.04	0.50	1.03	0.24	27.78	-1.15	-0.04	12.50	184.00	133.65	200.00
January 2008	0.89	0.37	0.66	32.88	0.13	23.99	-0.83	-0.19	7.91	27.90	47.26	73.00
April 2008	0.77	0.36	0.58	-12.58	0.11	26.68	-1.09	-0.06	12.85	84.00	144.45	42.00
July2008	0.87	0.08	0.47	-19.51	0.23	28.67	-1.19	0.00	13.94	602.20	157.95	200.00
October 2008	0.90	0.04	0.51	10.41	0.23	26.60	-1.05	-0.12	12.21	116.90	127.71	190.00

Secondly, the coefficients of spatial variation of mean-NDVI are moderate (24.23 to 28.58%) in almost all points of time considered for present study except for April 2004 when it was recorded very high. During this time the meteorological conditions were found more wet with exceptionally high precipitation (385 mm) that might have fully saturated the field capacity of soils. As a result, some areas with steep slopes might have released much more sub-surface water and created flood conditions in valley floors in the lower parts of Dikhu River catchment. Consequently, this made spatial variability of mean-NDVI very high (127.60%) and the negative vegetal growth (-44.64%) during three-month of dry season (January to April 2004) was experienced.

Thirdly, each and every distribution of greenness intensity follows 'platykurtic' curve (more flat than normal) indicating a trend towards uniform pattern of greenness intensity in the study area. It means that, in spite of significant temporal variations in greenness intensity (mean-NDVI values) and seasonal growth, the spatial features of growth do not vary much temporally. If 24.23 percent coefficient of spatial variability is contributed by topographic

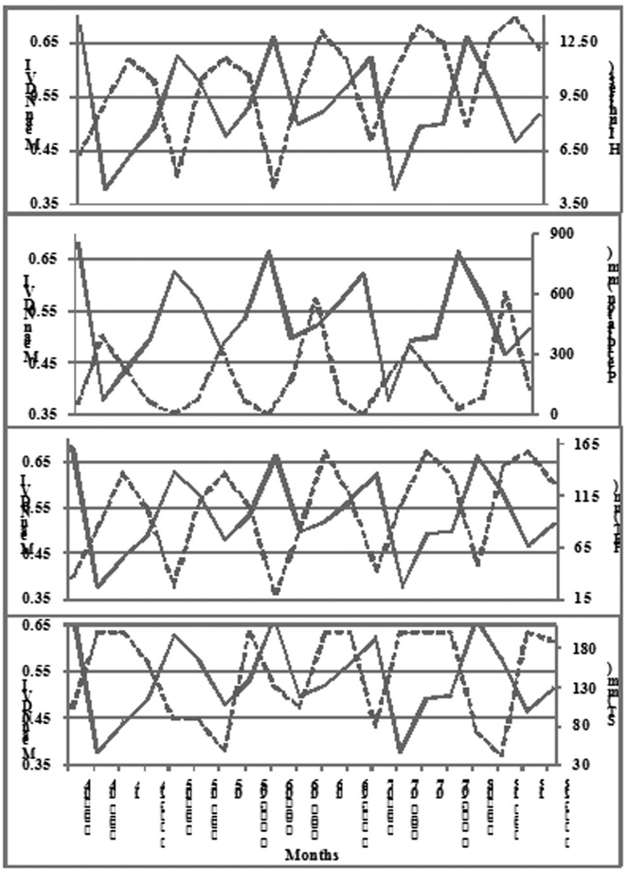


Fig. 3 : Temporal Variation in Mean NDVI with its Forest- Meteorological Attributes

factors in the study area as it is minimum in the temporal distribution, then its temporal fluctuation of about 4 to 6 percent (varying from 24.23 to 30.0 %) may be the result of variable meteorological factors contributing to the vegetal growth processes.

Fourthly, greenness intensity does not correspond to forest-meteorological attributes in its temporal trend. Mean-NDVI value has inverse trends with almost all factors attributing to greenness intensity. So the relationship of mean-NDVI with its contributing factors becomes negative (Fig.3), which may be elaborated in detail in the coming discussion.

(B) Analysis of Spatial Variation

It is described earlier that spatial variation in greenness intensity (mean-NDVI value) was minimum (CV=24.23%) in the month of January 2004 when the value of meteorological attributes were recorded very low. If this time period (January 2004) is considered as base point of time and spatial constant to analyse its temporal trends that occurred due to changes in meteorological attributes of greenness intensity, then two dimensions of this analysis may provide clues to justify the impact assessment of meteorological attributes. First, the need to understand the causes of spatial variations at base point of time, assuming spatial features of greenness intensity as constant (January 2004 conditions) which can be compared with topo-features for causality description and secondly to interpret the changes in spatial variation of greenness intensity over time in respect to changes in the meteorological parameters that can be used for soil salanity management (Aldakheel 2011).

Comparing topo-features (elevation and slope) with areal extent of the variations in greenness intensity at base point of time, it is evident that the areas of moderate to strong and gentle slopes (0-8%) of open valley floors have dense intensity of greenness of vegetation cover (mean-NDVI varies from 0.7 to 0.9), while the remaining areas of high elevation except few patches of *jhum* occupy normal vegetal greenness cover (0.4 -0.7 mean-NDVI). The upper reaches of Dikhu River and its tributaries which are topographically classed as high-elevated relief features show normal greenness intensity (see page 60 for the fig. 4).

Table-2: Area and Percentage coverage of Various Vegetation classes for Different Periods

	Non-Vegetation Cover		Stressed Vegetation Cover		Normal Vegetation Cover		Dense Vegetation Cover		Very Dense Vegetation Cover	
Period	Area (sq km)	%	Area (sq km)	%	Area (sq km)	%	Area (sq km)	%	Area (sq km)	%
January 2004	Neg	Neg	1.00	0.03	705.60	23.16	2340.47	**76.81**	Neg	Neg
April 2004	Neg	Neg	984.55	32.31	2062.52	**67.69**	0.00	0.00	Neg	Neg
July2004	Neg	Neg	2347.35	**77.04**	358.93	11.78	340.80	11.18	Neg	Neg
October 2004	Neg	Neg	264.68	8.69	725.10	23.80	2056.40	**67.49**	Neg	Neg
January 2005	Neg	Neg	5.49	0.18	1489.33	48.88	1552.25	**50.94**	Neg	Neg
April 2005	Neg	Neg	9.65	0.32	2844.94	**93.37**	192.48	6.32	Neg	Neg

July2005	Neg	Neg	376.53	12.36	1426.03	**46.80**	1244.51	40.84	Neg	Neg
October 2005	Neg	Neg	131.12	4.30	354.50	11.63	2552.64	**83.77**	8.81	0.29
January 2006	Neg	Neg	2.25	0.07	941.07	30.88	2103.74	**69.04**	Neg	Neg
April 2006	Neg	Neg	847.76	27.82	2184.01	71.68	15.30	0.50	Neg	Neg
July2006	Neg	Neg	103.94	3.41	398.88	13.09	2544.25	**83.50**	Neg	Neg
October 2006	Neg	Neg	69.51	2.28	499.71	16.40	2477.84	**81.32**	Neg	Neg
January 2007	Neg	Neg	4.51	0.15	1982.47	**65.06**	1060.09	34.79	Neg	Neg
April 2007	Neg	Neg	1751.58	**57.48**	1289.77	42.33	5.72	0.19	Neg	Neg
July2007	Neg	Neg	245.57	8.06	741.00	24.32	2060.49	**67.62**	Neg	Neg
October 2007	Neg	Neg	370.14	12.15	933.45	30.63	1741.72	**57.16**	1.76	0.06
January 2008	Neg	Neg	1.00	0.03	959.22	31.48	2086.84	**68.49**	Neg	Neg
April 2008	Neg	Neg	3.11	0.10	2900.80	**95.20**	143.16	4.70	Neg	Neg
July2008	Neg	Neg	661.23	21.70	713.44	23.41	1672.40	**54.89**	Neg	Neg
October 2008	Neg	Neg	225.86	7.41	1087.24	35.68	1733.97	**56.91**	Neg	Neg

N.B,.: Bold figures show very high percentage shares, neg= negligible

Secondly, most of the areas of valley of Dikhu River system which have normal greenness intensity of vegetation in winters become stressed patches (mean NDVI 0.0-0.40) and the areas of dense vegetation become normal. It can be said that in general, overall greenness intensity increases in valley slopes and valley flats of gentle slopes during post-monsoon season and it diminishes during pre-monsoon season (Fig-4). For example, the months of October and January have the maximum area (more than two-third) under the class of dense vegetation (mean-NDVI 0.7 to 0.9) which shrinks to one-third or even much lesser sometimes during the dry season of pre-monsoon (till April) (Table-2). In this time soil recharge and the level of moisture storage becomes lower than 100 mm. Greenness intensity becomes very low as mean- NDVI below 0.4 resulting to stressed vegetation (Fig-4).

As stated earlier, the temporal trend of vegetation greenness intensity does not match with forest-meteorological attributes. It appears that greenness intensity is higher during low Heat Index (below 9.50), low amount of monthly rainfall (150 mm) and moderate level of soil moisture storage (about100 mm) as appeared in Table-1. In such situations of intensive greenness of vegetal cover especially during post-monsoon season, all parameters of meteorology have negative relationship, it is to be stated that intensity of greenness diminishes as temperature, precipitation and PET increases. However, these variables determine the priority of factorial impact; the concerned analysis may be extended to make the exercise of best-fit regression for each and every distribution.

(C) Regression Results

Applying five mathematical functions for distribution of mean-NDVI subject to each forest-meteorological attribute, it is found that coefficient of correlation is negative and weak in many cases, that is why degree of determinant is very low (Fig-5). However, there are a few important inferences form regression analysis.

Polynomial is found the best-fit form because it captures the maximum degree of variability in the distribution of mean-NDVI with all considered meteorological attributes like heat index (R^2= 45.1%), precipitation (R^2=53.5%), PET (R^2=53.5%) and soil moisture storage (R^2=48.5%), (Table-3). It implies that variability in greenness intensity follow a curvilinear pattern of polynomial type rather than linear ones. Undoubtedly, in case of mean-NDVI with soil moisture storage, the degree of curve linearity is seen to be convex. It shows that increasing soil moisture storage increases greenness intensity up to a certain extent, after that greenness intensity diminishes sharply (Fig-5, see inset 2D). However, the polynomial coefficient X^2 of greenness intensity with soil moisture storage is calculated in minus terms (though its value is extremely low as 0.00002) and another coefficient X is positive (as 0.0047) that have combined positive effects during the initial stage of leaf development especially after few showers of rain. But when X reached to its (soil moisture storage) optimal level of 117.5 mm during rainy season, a negative condition appears

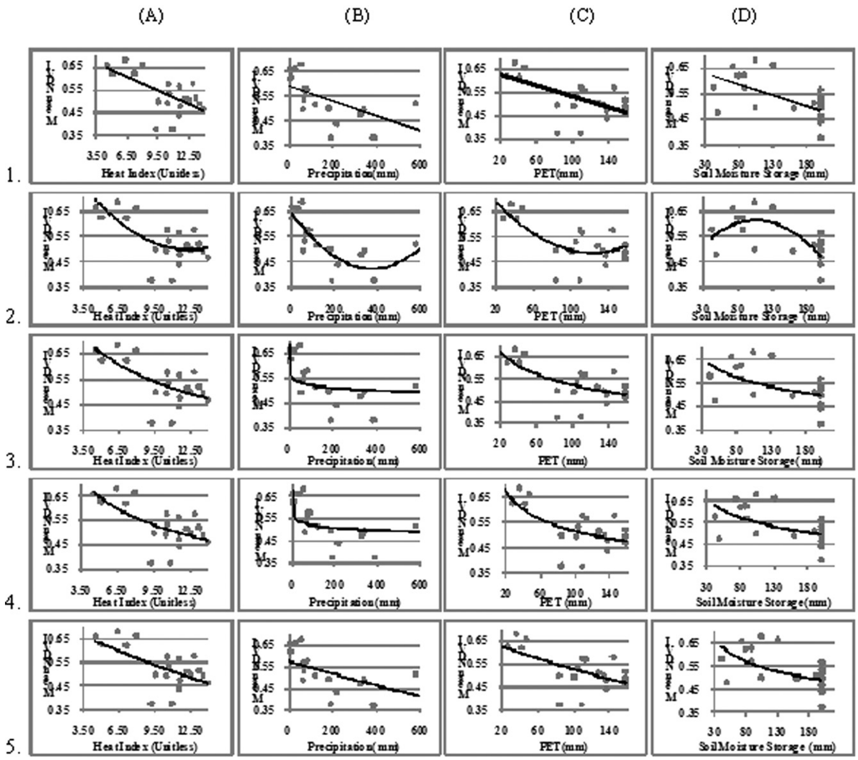


Fig.-5: Best-Fit of Mean NDVI with its Forest-Meteorological Attributes for different mathematical functions: 1=Linear, 2= Polynomial, 3=Logarithmic, 4= Power and 5= Exponential and consequently, diminishes greenness intensity. On the other hand, the concave nature of greenness intensity (decreasing with decreasing rate) has been found with heat index. This is indicative of thermal efficiency and precipitation as priority factors of normal vegetal growth. The above factors also control soil moisture which plays an important role in plant growth.

Optimization of such polynomial functions with the help of their first order differentials to make it zero $dY/dX= 0$ (the first order differential of any polynomial is $dY/dX = 2aX + b= 0$ if equation is written as $Y= aX^2 + bX + c$) must provide the solution as X= (b/2a) (see Table-3 for optimal levels of greenness intensity as well as its factors). It is found that Heat Index at 13.0 (that is indicative of 24°C temperature), 250 mm of rainfall, 100 mm of PET and 117.5 mm of soil moisture storage are ideal conditions for optimal greenness intensity for vegetal cover (Table-3). Such conditions are prevalent in the post- monsoon seasons in the study area. It implies that soil moisture storage has a direct impact on greenness intensity of vegetation in the Upper Dikhu River catchment.

Table-3: Best Fit Mathematical Functions of Mean NDVI (Dependent) with respect to Meteorological Parameters (independent Variables)

Mathematical Function	Form of NDVI w. r. t.	Degree of Determinant (R^2)	Optimal Level of Attributes	Optimal Level of Greenness Intensity (mean-NDVI)
Heat Index (HI, Unitless)				
Linear	$Y= -0.019X +0.735$	0.38		
Polynomial	$Y= 0.003X^2 -0.078X +0.983$	0.45	13.0	0.476 (Normal)
Logarithm	$Y= -0.17\ln(X) +0.935$	0.42		
Power	$Y= 1.067X^{-0.31}$	0.35		
Exponential	$Y= 0.748e^{-0.03X}$	0.32		
Precipitation (P, mm)				
Linear	$Y= -0.000X+0.585$	0.37		
Polynomial	$Y= 2E\text{-}06X^2 -0.01X +0.643$	0.69	250.0	.4325 (Normal)
Logarithm	$Y= -0.0112 \ln(X) +0.591$	0.36		
Power	$Y= 0.585X^{-0.02}$	0.34		
Exponential	$Y= 0.580e^{-0.000006X}$	0.35		
Potential Evapotranspiration (PET, mm)				
Linear	$Y= -0.001X+0.657$	0.40		
Polynomial	$Y= 2E\text{-}04X^2 -0.004X +0.772$	0.54	100.0	0.5722 (Normal)
Logarithm	$Y= -0.09\ln(X) +0.967$	0.48		
Power	$Y= 1.134X^{-0.17}$	0.41		
Exponential	$Y= 0.654e^{-0.00x}$	0.33		

Soil Moisture Storage (ST, mm)				
Linear	Y= -0.000X+0.658	0.34		
Polynomial	Y= -2E-05X^2 +0.0047X +0.429	0.49	117.5	0.705 (Dense)
Logarithm	Y= -0.08ln(X) +0.951	0.25		
Power	Y= 1.169X$^{-0.16}$	0.25		
Exponential	Y= 0.666 e$^{-0.00X}$	0.33		

N.B.: N= 20 for present case as 20 occurrences are considered for temporal analysis

Conclusions

The greenness intensity of vegetal cover found normal (0.62 to 0.68 mean-NDVI value) with its low coefficient of spatial variation (CV varies from 24 to 28%) during the winters of moderate meteorological conditions. Such variations in the vegetal cover are due to the elevation and slope gradient of land surface features in the Patkai Hills. However, relationships of greenness intensity with the meteorological factors are calculated negative in all the cases except available soil moisture storage which is most influential factor for the growth of greenness of vegetal cover especially during the post-monsoon season when there is occurrence of soil moisture recharge with its fairly high storage to feed water during winter growth of vegetation greenness. In particular, the following inferences are drawn from the present study:

(a) In spite of variable topo-features of land surface, the spatial variability of greenness intensity does not vary significantly. Consequently, spatial pattern of greenness intensity are not much diversified as coefficient of spatial variation ranges from 24.6 to 29.0 percent. Its distribution follows 'platykurtic' nature (more flat) that is indicative of less spatial variation in vegetation greenness.

(b) Temporal variations of mean-NDVI do not match significantly with the forest-meteorological attributes. However, these attributes have variable effects on greenness intensity.

(c) Polynomial regression is the best fit form of the distribution of mean greenness intensity of vegetal cover. Soil moisture storage is the most influential factor of meteorology which optimizes vegetal greenness growth at its ideal availability of 117.5 mm which is available in the post-monsoon seasons of high growth and dense-vegetal cover.

Acknowledgement

We are thankful to Professor Uma Shankar, Department of Botany, North-Eastern Hill University, Shillong for his fruitful suggestions at the final draft of the manuscript and also to the University Grant Commission, New Delhi for providing financial assistance under Rajiv Gandhi National Scholarship for pursuing Ph.D. Program to the first author.

References

Aldakheel Y. Y. (2011): Assessing NDVI spatial pattern as related to irrigation and soil salinity management in Al-Hassa Oasis, Saudi Arabia, *The Journal of Indian Society of Remote Sensing*, 39(2): 171-180; DOI 10.1007/s 12524-010-0057-z

Ashbindhu S. (1989): Digital change detection techniques using remotely sensed data. *International Journal of Remote Sensing*, 10(6):989-1003

Bartholome E. (2006, Ed): *VGT4Africa User Manual* (I Edn), No. EUR 22344 EN. Prepared by Joint Research Centre and Institute for Environment and Sustainability, European Commission, Italy: 98-101 (for ready reference, see http:// europa.eu.int)

Champion H. G. and Seth S. K. (1968): *A Revised Survey of Forest Types of India*. Manager of Publications, Government of India, Nasik

De Fries R., Hansen M. and Townshend J. (1995): Global Discrimination of land cover types from matrices derived from AVHRR pathfinder data. *Remote Sensing Environment,* 54: 209-222

Dewit C. T., Browner R. and Vries F. W. T. P. (1969): the simulation of Photosynthesis systems:I-models and methods, *Proceedings,* IPB/PP technical Meeting, Pudoc, Wageningen

Eidenshink J. C. and Faundeen J. L. (1994): the 1-Km AVHRR global land data set- first stage in implementation. *International Journal of Remote Sensing*, 15 (17): 3443-3462

Gupta P. K. and Panigrahy S. (2008): Predicting the spatio-temporal variation of runoff generation in India using remotely sensed input and soil conservation service-curve number model. *Current Science*, 95 (11): 1580-1587

Gupta R. P. (1991): *Remote Sensing Geology*, I Edn, Springer-Verlag, Newyork

Hunt, W. F. (1977): A Simulation model for decomposition in grassland. *Ecology*, 58:469-484

Jensen J. R. (1996): *Introductory Digital Image Processing: A Remote Sensing Perspective*. Prentice Hall, New Jersey: 179 and 316

Jomaa I. and Kheir R. B. C. (2005): Multi-temporal unsupervised classification and NDVI to monitor land cover change in Lebannon, *Options Mediterraneennes*-series B(No 46), Environment Monitoring in the South-East Mediterranean Region Using RS/GIS techniques. Downloaded from http://ressources.ciheam.org/om/pdf/b46/00800525.pdf, on 12. 06. 2011

Mc Call D. G. and Bishop-Hurley G. J. (2003): A pasture growth model for use in a whole farming dairy production model. *Agriculture Systems*, 76(3):1183-1205

Mukherjee A. P. and Banerjee D. M. (2005): *Normalised Difference Vegetation Index (NDVI) Analysis-Use of vegetation Health as Ground water Indicator*, the Vision RI Viewpoint website, http://www.visionriviewpoint.com/article.asp?articlied=53downloaded on 3.3.2011.

NBSS & LUP (2004): *Soil Series of Nagaland*, Technical Bulletin, NBSS Publication-109, National Bureau of Soil Survey and Land Use Planning, Nagpur. 79-82

Pandya M.M., Singh R. P., Chaudhari K.N., Murali K. R. and Kirankumar A. S. (2007):

Spectral Characteristics of sensors onboard IRS-1D and P6 satellites: Estimation and their influence on surface reflectance and NDVI, *The Journal of Indian Society of Remote Sensing*, 35(4): 333- 350

Panigrahy S. Ray S.S., Sood A. P., Sharma P. K. and Parihar J. S.(2003): *Cropping System Analysis of Punjab State Using Remote Sensing and GIS- Scientific Note*. RSAM/ SAC/CS/SN04/2003, Space Application Centre, Ahmedabad

Ricotta C. Avena G. and Palma A. De (1999): Mapping and monitoring net primary productivity with AVHRR- NDVI time series: Statistical equivalence of cumulative vegetation Indices. ISPRS, *Journal of Photogrammetry and Remote Sensing*, 54: 325-331

Singh S. Sharma B. and Dey P. P. (2006): Predicting simmer rice yield based on biological and technological parameters of monsoon lands of Brahmaputra valley, India, *International Agricultural Engineering Journal*, 15 (2-3): 91-107

Singh. S., Starkel L. and Syiemlieh H.J. (2010): *Land Degradation and Ecorestoration in the Extremely Wet Monsoon Environment of Cherrapunji Area, India,* Bookwell Publications, New Delhi: 48-50

Statistical Handbook of Nagaland (2004): Directorate of Economics and Statistics, Government of Nagaland, Kohima

Su Z. (2000): Remote Sensing of Land Use and Vegetation for Meso-scale Hydrological studies, *International Journal of Remote Sensing*, 21(2): 213-233

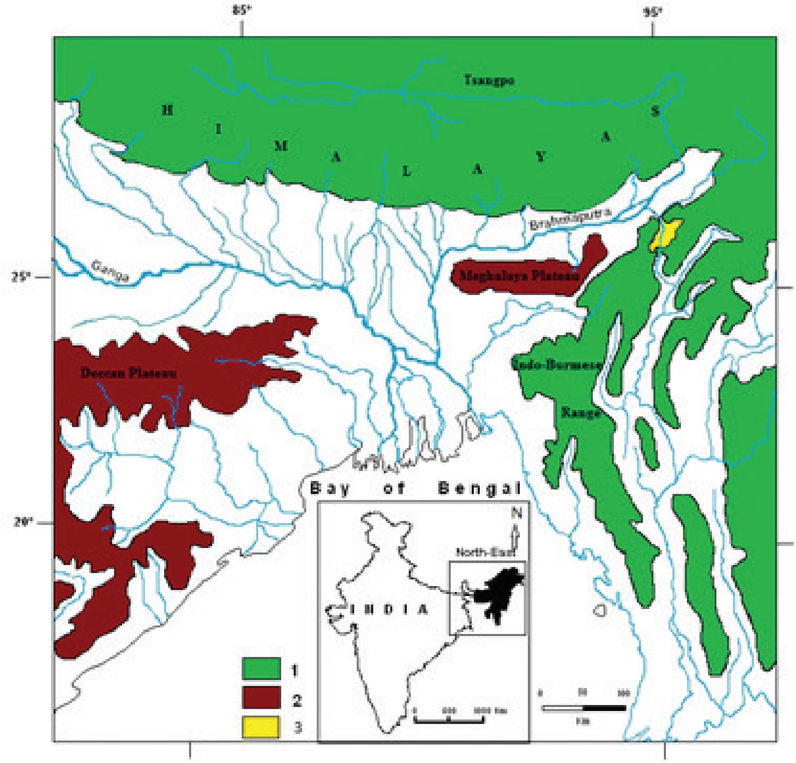
Thapa P. (2004): *Land Resource Evaluation for Land Use Planning of Mawkynrew C. &R.D. Block, East Khasi Hills Meghalaya*. Unpublished Ph. D. Thesis, Department of Geography, North Eastern Hill University, Shillong: 120-149

Upadhyay G. Ray S. S. And Panigrahy S. (2008): Derivation of crop phonological parameters using multi-Date SPOT-VGT-NDVI data a case study for Punjab, *The Journal of Indian Society of Remote Sensing*, 36(1): 37-50

Uma Shankar (1991). *Nutrient cycling in degraded ecosystems (grasslands) of Meghalaya*. Unpublished Ph.D. Thesis, North-Eastern Hill University, Shillong.

Uma Shankar, Pandey, H. N. and Tripathi, R. S. (1993). Phytomass dynamics and primary productivity in humid grasslands along altitudinal and rainfall gradients. *Acta Oecologica* 14(2): 197-209.

Bendanginla,
Surendra Singh*
Hiambok Jones Syiemlieh
Department of Geography
North- Eastern Hill University
Shillong
Corresponding Author

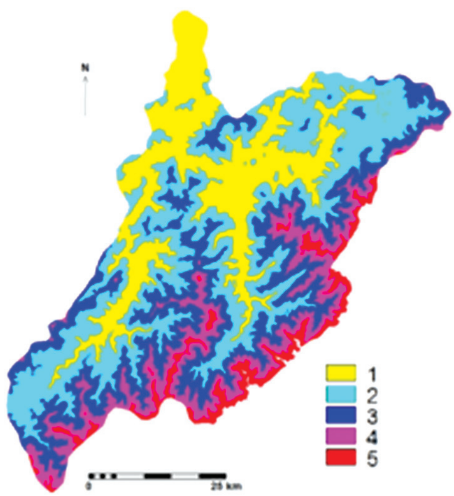


1=Areas above 1600 m a.s.l., 2= Areas of 900 to 1600 m a.s.l. , 3= Study Area

Fig.-1: Dikhu River Catchment in its Regional Surroundings

(See page 47 for text)

A



B

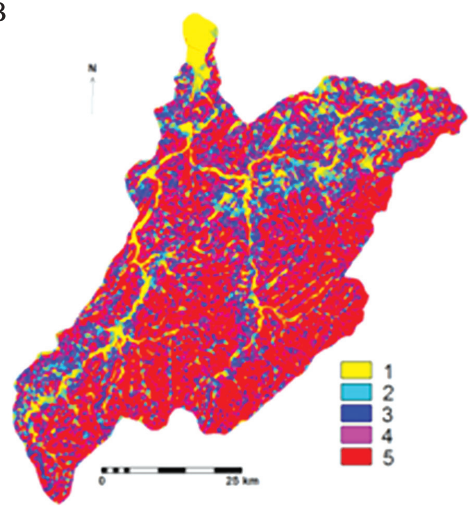


Fig-2A: Elevation Map: 1= 150-600m, 2= 600-1000m, 3= 1000-1400m, 4= 1400-1800m, and 5= 1800-2200 m

Fig-2B: Slope Map: 1- Very gentle and gentle slope (0-8%), 2- Moderate and Moderately Strong (8-16%), 3- Strong and Very Strong (16-24%), 4- Highly Strong (24-32%) and 5- Steep Slopes and Cliffs (above 32%) (See page 47 for text)

Fig.4: Greeness Cover distribution:

Non-Vegetation Cover (<0), Stressed Vegetation (0.0-0.40),

Normal Vegetation greeness Cover (0.40-0.70), Dense vegetation (0.70-0.90),

Very Dense Vegetative Cover of high intensity of its greeness (0.9-1.0)

(See page 52 for text)