EUROPEAN ACADEMIC RESEARCH
Vol. I, Issue 10/ January 2014

ISSN 2286-4822
www.euacademic.org

Impact Factor: 0.485 (GIF)
DRJI Value: 5.9 (B+)

Spatio-Temporal Variations in Vegetation Greenness Using NDVI Data and Hydro-Meteorological Conditions in the Foot-Hill Areas of Arunachal Himalayas

Md. EAHYA AL HUDA
Department of Geography
North-Eastern Hill University
Shillong, Meghalaya
India
SURENDRA SINGH
Department of Geography
North-Eastern Hill University
Shillong, Meghalaya
India

Abstract:

Present paper examines the effect of hydro-meteorological parameters on spatio-temporal variations in vegetation greenness intensity in the foot-hills of Arunachal Himalayas considering Dikrong River catchment as an ideal area. Downloading ten days average data of NDVI for sixteen months of time at three-months interval (January, April, July and October for five years 2003-2006) from SPOT images under Vegetation for Asia Programmme, the greenness intensity maps of each and every point of time were prepared at one-metre spatial resolution in ILWIS platform to analyze the spatial and temporal variations in vegetation greenness cover. Regression analysis was adopted to show the effects of hydro-meteorological parameters of the change in vegetal greenness intensity. The study reveals that, despite of excessive water available in atmosphere during the very wet summers when soil becomes fully saturated with continuous runoff conditions, the poor vegetal cover is seen in more than a half of the study area with its high degree of spatial variability. The vegetation growth is recorded much higher in the post-monsoon period and continues until January when soil moisture provides continuous water supply for plant growth. The growth of poor vegetal cover was faster in this area of foot hills during the post monsoon season. As a result, spatial variation of *vegetation greenness intensity was found minimum varying in its degree from 30% to 50% during the period of ideal vegetal growth. Polynomial regression analysis was found suitable to establish relation between vegetation greenness intensity and hydro-metrological attributes because it gives the maximum values of the degree of determinant, R^2.*

Key words: Vegetation growth, Vegetation Greenness intensity, NDVI, Foot-Hill areas, Arunachal Himalayas, Polynomial regression.

Introduction:

Vegetation cover is an important biological phenomenon which is regulated by natural, man-made and meteorological factors (Dewit et al. 1969, Hunt 1977, Jong et al. 2012). The growth of vegetation is more associated with the physical processes of photosynthesis, transpiration and respiration (McCall and Bishop-Hurley 2003). Remote sensing is the modern technique to identify the vegetation growth in a particular area (Lobo et al. 2004). 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 various techniques of identify the vegetal cover such as image reduction, contrast enhancement, band rationing (Jensen 1996), but NDVI is the most widely used for the purpose of understanding green leaf concentration through calculation of Leaf Area Index (LAI) of area of interest (Pandya et al. 2007).

So, 10 days interval of composite NDVI data was used for vegetation greenness intensity to show spatio-temporal variations and to compare this time-series vegetation greenness intensity with the hydro-meteorological parameters of same points of time.

For this purpose, the present paper focuses (a) to analyze the spatial features of greenness intensity, and (b) to examine the land surface features and hydro-meteorological parameters on greenness intensity in the high humid foot-hills of Arunachal Himalayas considering Dikrong River catchment of about 1,556 sq km area of which more than 80% is under the hill topography with an average annual rainfall of 3,248mm.

Study Area:

Dikrong river catchment is located in the foot-hills of Arunachal Himalayas and lies between 26˚55'N to 27˚22'N latitudes and 93˚13'E to 94˚0'E longitudes (Fig.-1) with its transitional characteristics of its location as it falls under Inter Tropical Convergence Zone (ITCZ) where climate is monsoonal in this part of Asian region. Being its location in the loop of Eastern Himalayas, it is more humid and has different hydrological characteristics than the other parts of North-East Region of the Country. Geologically, the catchment is located in the lower fault line which divides the river catchment into two topographic features: (i) the lower piedmont hills where erosion processes are prevalent and (ii) alluvial plains of depositional processes where frequent floods are experienced (Joshi and Shahid, 2002). However, the flood responses are more related to piedmont hill- topography and land use of its upper part that influence the water flow and discharge of river channels.

The length of the main river is recorded 145 km with an average slope of 5-15% with the perimeter of 264 km. Topographically, hill slopes are steep covering a area of about 61.54% with its narrow flat valleys located in the upper parts of the river catchment (Fig.-2 and 3). Such topography helps in accelerating the saturation processes and fast flow while the lower part is gentle plain accommodating about a quarter part of the catchment (27.01%) with sediment deposition. Average temperature is recorded 15.15°C in January (moderately cold) and 26.96°C in July (Hot). Sometimes rainfall is high during pre-monsoon period (April) but July is the peak of monsoon when it precipitates up to 602 mm to 986 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). Land use / land cover pattern of Dikrong river catchment is dominated by forest (75% areas are under dense and open forests) in the upper parts and agricultural and abandoned land (12% of total area) in the lower parts of the catchment. Soils are fine loamy and coarse silty which have high faction of sand helping in retaining more water to regulate runoff. As a result, runoff has also been recorded in the dry weather of winter seasons in spite of less rainfall and moderate PET conditions (Al Huda and Singh, 2012).

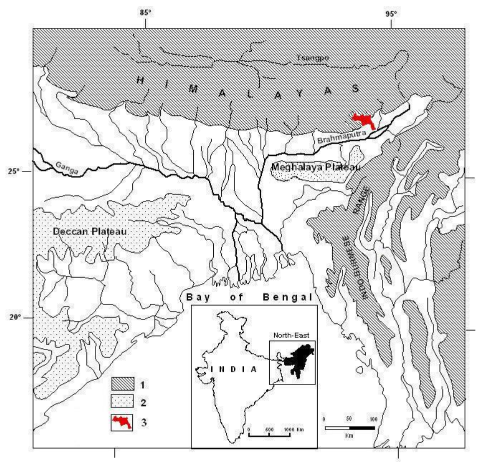


Fig.-1: Location of Dikrong River Catchment
1=Areas above 1600 m a.s.l., 2= Areas of 900 to 1600 m a.s.l., 3= Study Area

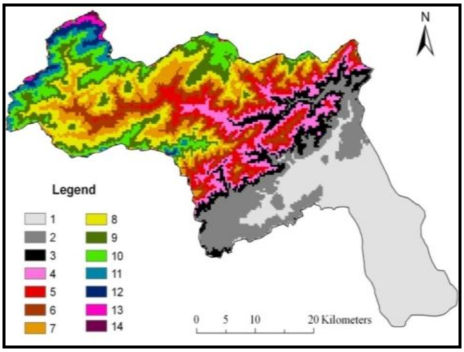


Fig.-2: Digital Elevation Model (DEM) of Dikrong River Catchment
Abbreviations: Elevation in meters **1**. 0 – 200, **2**. 200 – 400, **3**. 400 – 600, **4**. 600 – 800, **5**. 800 – 1,000, **6**. 1,000 – 1,200, **7**. 1,200 – 1,400, **8**. 1,400 – 1,600 ,**9**. 1,600 – 1,800, **10**. 1,800 – 2,000, **11**. 2,000 – 2,200, **12**. 2,200 – 2,400, **13**. 2,400 – 2,600, and **14**. Above 2,600

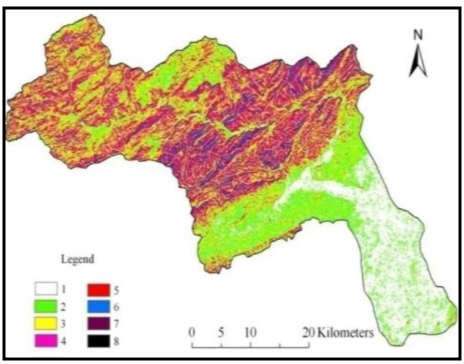


Fig.-3: Slope Variations in the Dikrong River Catchment
Abbreviations: Slope in percent; **1**= Very Gentle (2- 4), **2**= Gentle (4-10), **3**= Moderate (10-20), **4**= Moderately Steep (20-35), **5**= Steep (35-60), **6**= Very Steep (60-100), **7**= Most Steep (100-175), **8**= Extremely Steep (above 175)

Methods and Materials Used:

There are two main salient features of the present study to analyze the spatio-temporal vegetation cover which is based on NDVI greenness intensity and hydro-meteorological factors. The topographic factors such as elevation slope, drainage as well as soils are fixed in its nature over a period of time; the temporal changes in vegetation cover might be the result of meteorological phenomena. Spatio-temporal vegetation cover was analyzed by using the 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 Asia Program. The data of vegetation cover for an interval of three months were downloaded from the website (http://free.vgt.vito.be/) to analyze the seasonality effects of changes in vegetation cover taking into account of four years (January 2003 to December 2006). January (moderately cold and dry), April (moderately cold and moderately dry), July (hot and wet) and October (moderately cold and moderately wet) months were taking into account to analyze the spatio-temporal variation of greenness. The first 10 days mean data of each month were used for spatio-temporal variations. The DN values of each pixel were converted to obtain NDVI value by applying the following formula (Bartholome, 2006)

$$PV = (Scale*DN) + Offset$$

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 analyzed considering its spatial resolution of 10*10 sq meters size. In fact, the algorithm produces output NDVI values in the range of -1.0 to +1.0. Increasing the positive NDVI values indicates increasing amounts of healthy and strong green vegetation. The values closer to zero and decreasing negative NDVI values indicate non vegetated features such as barren land surfaces, water, snow, ice and clouds etc. the analysis id based on vegetation greenness intensity to show the variability for a given classification in which five classes vegetation greenness types was categorized (Bartholome 2006). They are: Non-Vegetation cover (NDVI value below 0.0), Poor Vegetation

(0.0-0.4), Normal Vegetation (0.4-0.7), High Vegetation (0.7-0.9), Very High Vegetation Cover (0.9-1.0). These classifications must provide the salient features of the spatio-temporal distribution of greenness intensity for the Dikrong river catchment. The statistical analysis of greenness intensity was pursued on the basis of its main parameters like maximum, minimum, mean, variance and growth rate values that vary over time.

On the other hand, there are various methods of assessing the reference evapotranspiration (ET_0) mainly classical method forwarded by Blaney-Criddle (1962) establishing relation of day time duration with temperature, Hamon (1961) method that is based on water vapor density in the environment, Hargreaves and Samani (1985) on radiation balance and temperature variation, and Papadakis (1975) method which is saturation deficit based (Xu, and Singh, 2001; Loukas et. al 2003; Bautistaet et. al 2009). Such methods are largely dependent on field observations used for different environmental conditions. The PET calculation by T-M procedure which is first introduced by Thornthwaite (Thornthwaite 1948) and, later on, Thornthwaite and Mather (Thornthwaite and Mather, 1957) with its notebook procedure has been used by many geographers (Soja et. al 2010), meteorologists and climatologists (Subrahmanyam 1983), and found its suitability especially for the monsoon based hydrologic regime. In this method, temperature- based heat index, i.e., $i = (T^0C/5)^{1.514}$ with a location specific correction factor of unadjusted PET is used for the assessment of soil moisture and runoff variability over time. In order to compare daily runoff with other parameters of water balance equation ($P = RO + PET + \Delta ST$, where RO= Runoff, P= Precipitation, PET= Potential Evapotranspiration and ΔST= Changes in soil moisture), the T-M procedure is used. In order to make data standard, daily average statistics of temperature and rainfall for five consecutive years (2003-2006), were used for Itanagar station (that is centrally located in the study area). The concerned statistics were collected from the Rural Works Department, Government of Arunachal Pradesh, Itanagar. While daily discharge statistics of the same period of time were collected from the Water Resource Department, Government of Assam, Guwahati for Sisapather gauge station (that is at the mouth of river catchment). Calculations of daily soil moisture availability and runoff were made to set the water holding capacity of 200 mm as specified by NBSS & LUP, Jorhat (NBSS and LUP, 2004) with adopting standard procedure of water retention capacity analysis.

Mean NDVI for each point of time is considered as dependent variable and these attributes of hydro-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.

Results and Discussion

(A) Statistical Analysis:

The mean NDVI values in the temporal distribution of 16 time series (January 2003 to October 2006) were recorded moderate (0.402 to 0.522). It is interesting to note that the greenness intensity and its growth rate are higher in moderately cold (20^0 C to 25^0 C) weather conditions. Moderate to high growth rate was observed in the month of October (maximum growth rate 31.14% in October, 2004). However, the hydro-meteorological factors like rainfall, soil moisture and PET were recorded high during the monsoon period (Table-1). There are some general inferences of such high humid conditions suitable for vegetal growth. In the present study, the vegetation growth increases with increasing vegetation greenness intensity from post-monsoon period of October. It is to be mentioned here that the vegetation at foot-hills of Arunachal Himalayas may continue until the post-monsoon period in November-December because of availability of soil moisture and moderate temperature. Besides this, the negative vegetation growth rates were recorded mostly in the pre-monsoon period of April due to dry soil, low rate of runoff and evaporative demand is not filled by the precipitation. The variability of soil moisture storage recorded maximum of 200 mm in the month of April and July, 2002, July and October, 2003, April to October, 2004, July and October, 2005 and July in 2006. The maximum runoff was recorded in the month of July (varying from 319.891 mm in 2003 to 378.955 mm in 2004). The lowest soil storage was recorded in the year of October, 2006 with a storage capacity of only 112 mm (Table-1).

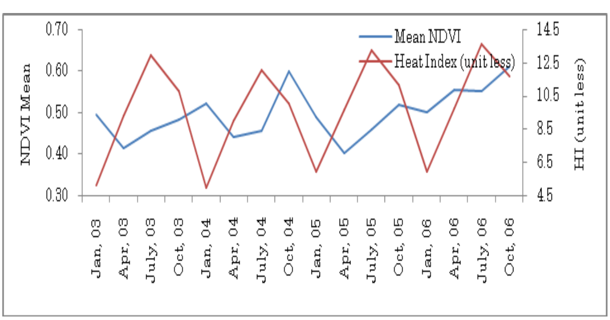
	NDVI Characteristics						Meteorological Parameters			
Period	Min NDVI	Max NDVI	Mean NDVI	3-months growth Rate (%)	Standard Deviation	CV (%)	HI (unit less)	Rainfall (mm)	PET (mm)	ST (mm)
Jan, 03	0.128	0.864	0.496	-12.68	0.21	43.19	5.14	0.60	27.60	174
Apr, 03	0.024	0.808	0.416	-16.13	0.23	54.83	9.29	209.20	86.67	129
July, 03	0.040	0.872	0.456	9.62	0.24	53.05	12.97	986.60	159.30	200
Oct, 03	0.072	0.892	0.482	5.7	0.24	49.46	10.78	232.20	103.95	200
Jan, 04	0.164	0.880	0.522	8.3	0.21	39.92	5.01	64.40	27.60	174
Apr, 04	0.092	0.792	0.442	-15.33	0.2	46.11	9.00	315.60	86.67	200
July, 04	0.036	0.876	0.456	3.17	0.24	53.55	12.06	894.20	148.68	200
Oct, 04	0.280	0.916	0.598	31.14	0.19	30.99	10.04	394.40	95.04	200
Jan, 05	0.116	0.864	0.490	-18.06	0.22	44.43	5.93	26.00	33.12	169
Apr, 05	0.028	0.784	0.402	-17.94	0.22	54.17	9.69	175.40	93.09	125
July, 05	0.056	0.860	0.458	13.9	0.23	51.05	13.22	602.40	159.30	200
Oct, 05	0.108	0.928	0.518	13.1	0.24	46.02	11.15	126.40	112.86	200
Jan, 06	0.132	0.872	0.502	-3.09	0.22	42.91	5.94	38.40	30.36	172
Apr, 06	0.332	0.776	0.554	10.36	0.13	23.45	9.72	167.80	86.67	129
July, 06	0.244	0.860	0.552	-0.36	0.18	32.54	13.63	365.00	159.30	200
Oct, 06	0.296	0.924	0.610	10.51	0.18	30.00	11.67	105.40	115.83	112

Table- 1: Distributional Characteristics of Vegetal Cover and Meteorological Parameters (January 2002- October 2006)

The coefficients of spatial variation of mean NDVI are ranges between 23.45 to 54.83%. The maximum variation (54.83%) was calculated in April, 2003 when the meteorological conditions were found very wet with high precipitation of 209 mm. The coefficient of variation was also recorded high in April 2005 (54.17%), July 2004 (53.55%), and July 2003 (53.05%). During these periods of time the hydro-meteorological conditions were found more wet with high rainfall of 175.40 mm, 894.20 mm, and 986.60 mm respectively that might have fully saturated the soils. As a result, some areas of steep slopes might have released more sub-surface water to the lower parts of the Dikrong River Catchment. On the other hand, the high variability of mean NDVI has experience of negative vegetal growth, i. e. high variability of 54.83% have negative growth rate of -16.13% in April 2003. The maximum negative growth rate during three months of pre-monsoon seasons (January to April, 2005) was calculated -36.00%.

All the distribution of greenness intensity follows the flat curve indicating the general trends toward the uniform distribution pattern of greenness intensity in the Dikrong river catchment. The temporal variations of greenness intensity (mean NDVI values) and seasonal growth of greenness intensity do not vary much temporally. If the coefficient of variation of 23.45% is contributed by topographic factors, then it is minimum in the temporal distribution pattern because the fluctuation varying from 23.45 to 54.83%.

The greenness intensity does not correspond much more to the hydro-meteorological factors in the temporal pattern of distribution because the mean NDVI value has inverse trends with almost all the factors to the greenness intensity. So the relationship of mean NDVI value with hydro-meteorological factors becomes negative (Fig.-4).



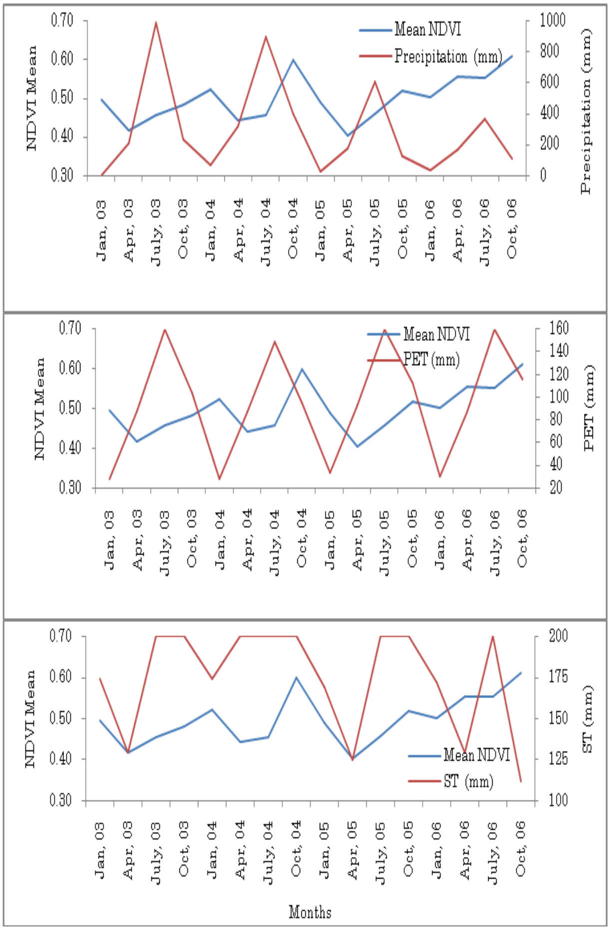


Fig.-4: Temporal Variation in Mean NDVI with its Hydro-Meteorological Attributes

(B) Analysis of Spatial Variation:

It is mentioned earlier that the spatial variation in greenness intensity was minimum (CV=23.45%) in the month of April, 2006 when the hydro-meteorological factors were also recorded very low. Comparing topo-features (elevation and slope) with areal extent of the variations in greenness intensity, it is found that the areas of steep to most steep slopes (35-175%) have high 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 occupy normal vegetal greenness cover (0.4 - 0.7). The upper reaches of Dikrong river catchment and its tributaries which are topographically classed as high-elevated relief features show normal greenness intensity (Fig- 5).

Period	Poor Vegetation (0-0.4)		Normal Vegetation (0.4-0.7)		High Vegetation (0.7-0.9)		Very High Vegetation (0.9-1.0)	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Jan, 03	25216	16.20	39486	25.37	90927	**58.43**		
Apr, 03	12207	7.84	78780	**50.62**	64642	41.54		
July, 03	21401	13.75	46501	29.88	87726	**56.37**		
Oct, 03	11838	7.61	47738	30.67	96054	**61.72**		
Jan, 04	21637	13.90	22301	14.33	111692	**71.77**		
Apr, 04	5875	3.77	97941	**62.93**	51814	33.29		
July, 04	82146	**52.78**	53962	34.67	19521	12.54		
Oct, 04	898	0.58	11302	7.26	143364	**92.12**	64	0.04
Jan, 05	22967	14.76	22984	14.77	109677	**70.47**		
Apr, 05	9589	6.16	134472	**86.41**	11568	7.43		
July, 05	10085	6.48	49818	32.01	95727	**61.51**		
Oct, 05	3313	2.13	24067	15.46	127634	**82.01**	615	0.40
Jan, 06	22739	14.61	19193	12.33	113697	**73.06**		
Apr, 06	424	0.27	75396	48.45	79809	**51.28**		
July, 06	1233	0.79	30779	19.78	123616	**79.43**		
Oct, 06	668	0.43	15297	9.83	139586	**89.69**	79	0.05

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

The lower parts of Dikrong river catchment which has poor greenness intensity of vegetation in January to April, become normal and high vegetal patches in October. It is observed that overall greenness intensity increases in the very gentle to gentle slopes during post-monsoon season and it is decreases in the pre-monsoon season (Fig.-5). The months of October and January have the maximum area under the class of high vegetation (mean NDVI 0.7 to 0.9) which shrinks to one-third or even much lesser sometimes during the of pre-monsoon (till April) season (Table-2). In this time soil recharge and the level of moisture storage becomes lower than 200 mm. Greenness intensity becomes very low as mean- NDVI below 0.4 resulting to poor vegetation (Fig-5).

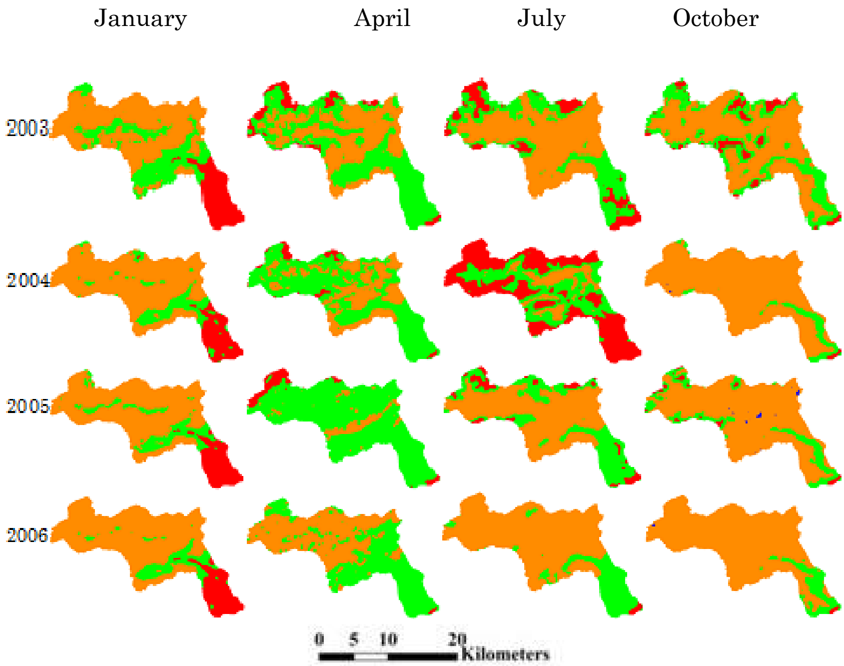
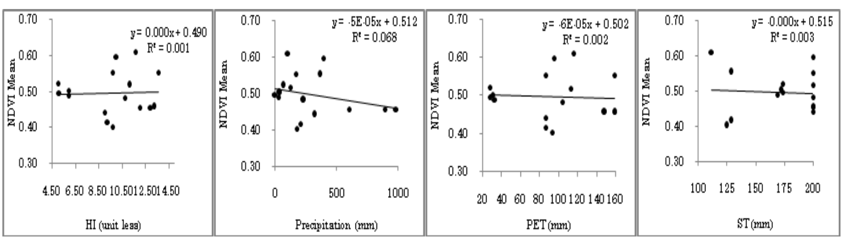


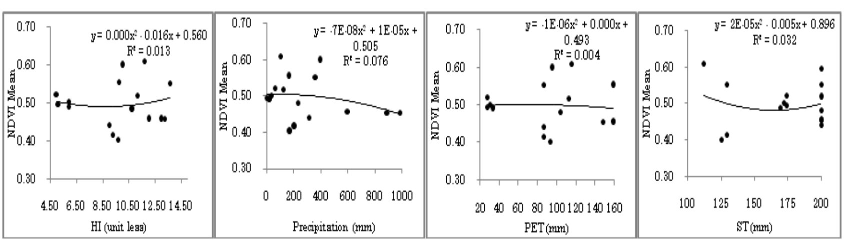
Fig.-5: Greeness Cover distribution: Poor Vegetation (0.0-0.40), Normal Vegetation greeness Cover (0.40-0.70), High vegetation (0.70-0.90), Very High Vegetative Cover (0.9-1.0)

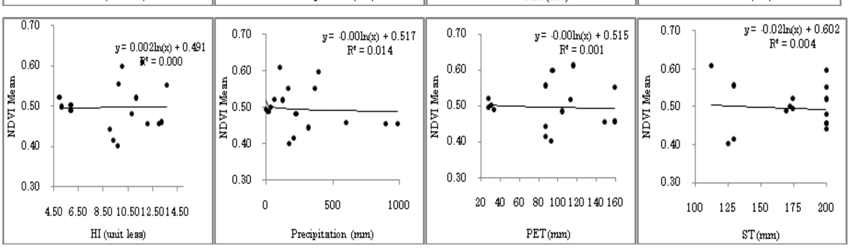
It is mentioned earlier that the temporal trend of vegetation greenness intensity does not much more corresponds with hydro-meteorological factors. The greenness intensity is higher during moderate Heat Index, moderate amount of monthly rainfall and moderate level of soil moisture storage as appeared in Table-1. It is important to highlight that intensive greenness of vegetation cover especially during post-monsoon season, all the factors of hydro-meteorology have negative relationship, it is to be stated that intensity of greenness decreases as temperature, precipitation, and PET increases. Moreover the determinant variable of the present analysis may be extended to make the exercise of best-fit regression for each and every distribution.

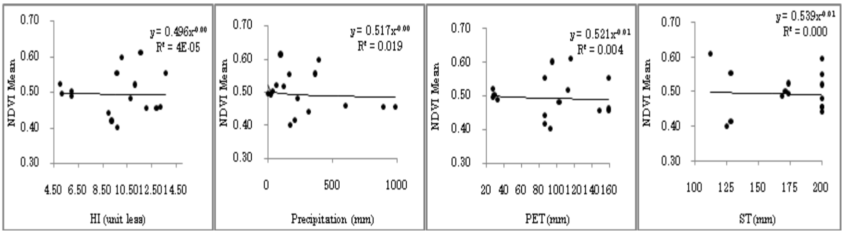
(C) Regression Results:

After applying five mathematical functions for distribution of mean NDVI to each hydro-meteorological factors, it is found that coefficient of correlation is negative and weak in many cases, that is why the degree of determinant is very low (Fig.-6). From the five mathematical functions of linear, polynomial, Logarithmic, Power and Exponential; polynomial is found the best-fit because of the maximum degree of determinant in the distribution of mean NDVI with all considered hydro-meteorological factors. In polynomial distribution the degree of determinant of heat index was calculated (R^2= 0.013), precipitation (R^2=0.076), PET (R^2=0.004) and soil moisture storage (R^2=0.032) (Fig.-6).

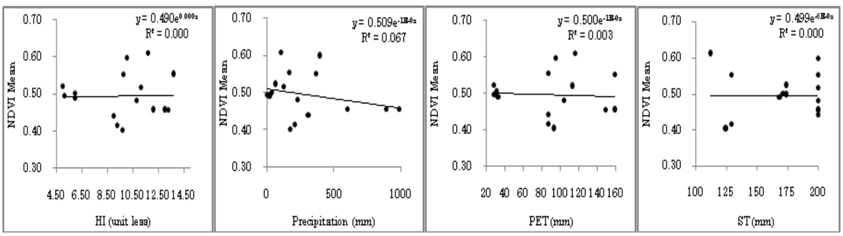
1.


2.


3.




4.



5.

Fig.-6: Best-Fit of Mean NDVI with its Hydro-Meteorological Attributes for different mathematical functions: 1=Linear, 2= Polynomial, 3=Logarithmic, 4= Power and 5= Exponential

Conclusions:

The greenness intensity of vegetal cover was found normal (0.304 to 0.610 mean NDVI value) with its low coefficient of spatial variation (CV varies from 23.45 to 54.83%) during the winters of moderate meteorological conditions. Because of the elevation, slope and land surface attributes such variations in the vegetal cover were observed in the foot-hills of Arunachal Himalayas. Moreover, the inter-relationships between the mean NDVI value and hydro-meteorological factors are calculated negative in almost all the cases. However, the following inferences are drawn from the present study:

(a) It is important to note that the greenness intensity does not correspond much more to the hydro-meteorological factors significantly. Consequently, spatial pattern of greenness intensity are not much diversified as coefficient of spatial variation ranges from 23.45 to 54.83 percent. The distribution pattern is more flat - that is indicative of less spatial variation in vegetation greenness.

(b) The growth rate of greenness intensity increases gradually from hot and wet weather conditions of monsoon period (in the month of July) and it continues to moderate hot and moderate wet weather conditions of post-monsoon period (in the month of October).

(c) Polynomial regression is found the best fit of distribution of mean greenness intensity of vegetation cover with almost all the factors of hydro-meteorology.

BIBLIOGRAPHY:

Al Huda, Md. E. and Singh, S. 2012. "Assessment of Runoff in the High Humid Foot-hill Areas of Arunachal Himalayas Using Thornthwaite Equation." *International Journal of GEOMATE* 3(2): 397-401.

Bartholome E. 2006. *VGT4Africa User Manual* (1st Ed), No. EUR 22344 EN, 98-101. Prepared by Joint Research Centre and Institute for Environment and Sustainability, European Commission, Italy.

Bautista, F., Bautista, D. and Carranza, C. D. 2009. "Calibration of the equations of Hargreaves and Thornthwaite to estimate the potential evapotranspiration in semi-arid and subhumid tropical climates for regional applications" *Atmósfera* 22(4): 331-348.

Blaney, H. F. and Criddle, W. D. 1962. "Evaporation from free water surface at high altitudes." *Trans. ASCE*. 123: 243-265.

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.

Hamon, W. R. 1961. "Estimating potential evapotranspiration." *Journal of Hydraulics Division, Proceedings of the*

American Society of Civil Engineers 871: 107–120.

Hargreaves, G. H. and Samani, Z. A. 1985. "Reference crop evapotranspiration from temperature." *Trans. ASAE* 1 (2): 96-99

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.* New Jersey: Prentice Hall. 179-316

Jong, R. D., Verbesselt, J., Schaepman, M, E. and Bruin, S. D. 2012. "Trend changes in global greening and browing:contribution of short-term trends to longer term change." *Global Change Biology* 18: 642-655.

Joshi, R. C. and Shahid, H. M. A. 2002. "A Study of Channel Runoff and Ground Water Level Fluctuation of Ranga River Basin, Eastern Himalaya, India." *Indian Journal of Geomorphology* 7(1-2): 49-56.

Lobo, A., Lengendre, P., Robollar, J. L. G., Carreras, J. and Ninot, J. M. 2004. "Land cover classification at a regional scale in Iberia: separability in a multi-temporal and multi spectral data set of satellite images." *International Journal of Remote Sensing* 25(1): 205-213.

Loukas A, Vasiliades L. and Mpastrogiannis, N. 2003. "Water balance model for the evaluation of surface water resources." In *Proc. 8th Int. Conf. on Environmental and Technology*. 492-499.

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.

NBSS and LUP. 2004. "The Soils of Arunachal Pradesh." at R.F. 1: 250,000, prepared for Government of Arunachal Pradesh, Itanagar by the National Bureau of Soil Survey and Land Use Mapping, Regional Centre, Jorhat.

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.

Papadakis, J. 1975. "Climate of the World and their Potentialities" A. V. Cordoba 4564, Buenos Aires, Argentina. 5-6.

Soja, R., Starkel, L. and Singh, S. 2010. "Water Circulation and Availability of Water." In *Land Degradation and Ecorestoration in the Extremely Wet Monsoon Environment of Cherrapunji Area, India*. 1st ed. edited by Singh, S., Starkel, L. and Syiemlieh, H. J., 30-50. New Delhi: Bookwell.

Subrahmanyam, V. P. 1983. "Water balance approach to the study of aridity and droughts with special reference to India." In *Proceeding of the Hamburg Workshop*, pub. No. 148. 125-135.

Thornthwaite, C. W. and Mather, J. R. 1957. "Instructions and Tables for Computing Potential Evapotranspiration and Water Balance." *Publications in Climatology* 10(3): 185-204. Drexel Institute of Technology, Centertown, New Jersey.

Thornthwaite, C. W. 1948. "An approach towards a rational classification of Climate." *Geogr. Rev.* 38(1): 55-94.

Xu, C. Y. and Singh, V. P. 2001. "Evaluation and generalization of temperature-based methods for calculating evaporation." *Hydrological Processes* 15: 305–319.