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NDVI Variability in North East India

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ABSTRACT *The variability of the Normalized Difference Vegetation Index (NDVI) in north east India in response to rainfall and temperature was analysed using twice-monthly NOAA/AVHRR satellite imagery acquired during 1982–2002 from the GIMMS (Global Inventory Modeling and Mapping Studies) data-set. Corresponding rainfall and temperature estimates were extracted from the Climate Research Unit's CR TS 2.1 data-set for 34 study sites, chosen using the GLC 2000 land use categories. The selected sites represent nine land use categories under differing institutional frameworks. Results showed a weak linear relationship between the growing season rainfall and NDVI range when plotted in a scatter diagram. The negative correlation between NDVI and rainfall and temperature and NDVI in the study area was accentuated during the growing season and a one- and two-month lag for rainfall and temperature respectively was operating. A gain coefficient image to determine the temporal change in NDVI during the 21-year period indicated a consistent decline for much of the study area. Among the study sites those under state protection fared better than sites under other institutional frameworks. Along with rainfall and temperature, land use and institutional frameworks emerged as causative factors in the dynamics of vegetation greenness in north east India.*

KEY WORDS: Normalized Difference Vegetation Index, gain coefficient, north east India

Introduction

Water availability for vegetation growth is a prime consideration in the tropics (Camberlin *et al.*, 2007) and tropical areas where abundant water in the form of high precipitation is available are rare. In tropical north east India, the potential benefits of high precipitation are offset, by poor water storage systems on the one hand and on the other by a consistent decline in its forested landscape over the years. Although the north east is India's green belt and one of India's two global biodiversity hotspots, it is also an area under threat of deforestation as an intricate mix of numerous factors combine to take a toll on its forest cover. Recent State of Forest Reports point to continued forest losses in north east India, including its protected landscapes (FSI, 1995; FSI, 2005; FSI, 2008) and in such a context it seems desirable to assess the vegetation health of this region.

Among the various vegetation indices the Normalized Difference Vegetation Index (NDVI) is the most widely used remotely-sensed vegetation index (Wang *et al.*, 2003; Herrmann *et al.*, 2005; Chamaille-Jammes *et al.*, 2006), in spite of certain

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shortcomings such as sensitivity to soil colour, atmospheric effects, illumination and observation geometry (Herrmann *et al*., 2005) and cloud contamination issues (Chen *et al*., 2003; Camberlin *et al*., 2007). Although attempts to explore alternative vegetation indices such as the Modified Soil-Adjusted Vegetation Index (MSAVI) (Qi *et al*., 1994), the Soil-Adjusted Vegetation Index (SAVI) (Huete, 1988), the Enhanced Vegetation Index (EVI) (Huete *et al*., 2002) and the Wide Dynamic Range Vegetation Index (WDRVI) (Gitelson, 2004) have been made, none of these have gained as much acceptance as NDVI (Herrmann *et al*., 2005) which has been widely used across diverse biomes as a proxy for rainfall (Barbosa *et al*., 2006), as a surrogate for vegetation growth (Schmidt & Karnieli, 2000; Al-Bakri & Taylor, 2003; Anyamba & Tucker, 2005), in ecological studies (Pettorelli *et al*., 2005), to assess above ground biomass (Runnstrom, 2000), photosynthesis (Piao *et al*., 2006) and in assessing vegetation health.

While it has been established that NDVI correlates well with precipitation and/or temperature in arid and semi-arid contexts, this relationship has been less intensively explored in areas with high precipitation, although NDVI-based studies pertaining to India (Jeyaseelan *et al*., 2007; Krishna-Prasad *et al*., 2008) do exist. Among the various vegetation indices, it is NDVI that serves as the 'continuity' index and is more suitable to highly absorbing red reflectances over forested sites (sites with high or tending towards closed canopies). As Huete *et al*. (1997) observe, the soil and atmosphere resistant vegetation index (SARVI) is more sensitive to measuring near infrared reflectance (NIR) in incomplete vegetation canopies (that is, canopy covers that are not fully closed). NDVI is less useful in landscapes with negligible forested canopies (such as semi-arid/arid environments that have poor vegetation cover in terms of canopy). Thus while Huete *et al*. (1997) point out that NVDI values increased significantly as spectral signatures became darker, they also implied that weak spectral signatures associated with arid vegetation would not be depicted properly by NDVI in desert, savannah and grassland areas.

While problems with the use of NDVI could arise from the effects of plant senescence and soil background reflectance when vegetation amounts were low (Purevdorj *et al*., 1998), this was not problematic in the context of north east India which accounts for over a quarter of India's area under forest; 7.7% of the country's total geographical area.

The objectives of this research were to: i) examine the spatial patterns of vegetation vigour (NDVI) as they relate to different meteorological and land cover elements in north east India; ii) determine the temporal change in growing season NDVI during the period 1982–2002 and visualize these changes; and iii) assess whether differences in NDVI between areas under differing institutional frameworks existed.

While the relationship between vegetation and rainfall in arid and semi-arid environments has received much attention relatively few studies have focused on such links in high precipitation belts. Thus north east India which receives the highest rainfall in the world provides an ideal setting in which vegetation-rainfall links can be explored.

The Study Area

Spread over an area of 255,000 kilometres^2 north east India comprises the 7 states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura (see Figure 1). Tenuously linked with the Indian mainland by a narrow stretch of land 21 kilometres in width, the region remained – as a result of British colonial policy – relatively isolated, physically and culturally until 1950, a trend that allowed an internal homogeneity of sorts to develop (Saikia, 2004). The region is a combination of lowlands and plateaux, hills and mountains in a 3 : 7 ratio. Elevation varies from 30 to 130 metres in the former and between 800 and 3,000 metres in most parts of the latter. Topography varies sharply along the northern reaches of Arunachal Pradesh where elevation ranges from 4,000 to 7,950 metres. In the Meghalaya-Karbi plateau elevation ranges from 1,200 to 1,700 metres, except for the Shillong peak that reaches 1961 metres; similar differences in relative relief along the eastern hills are far lower than the northern parts of Arunachal.

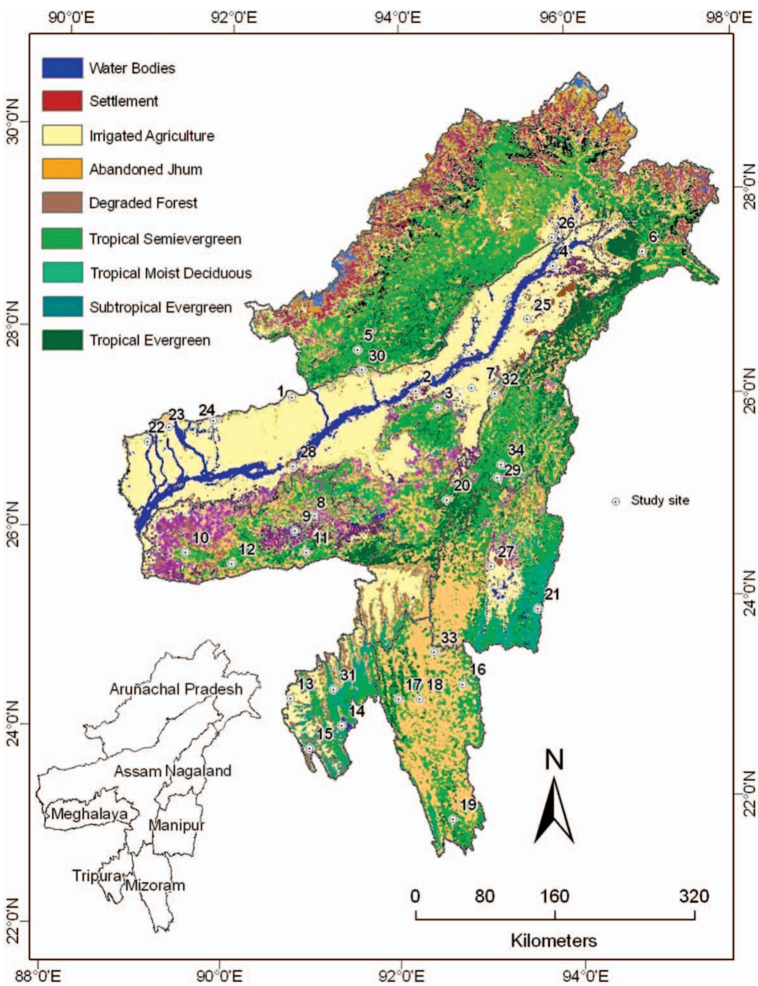

Figure 1. Spatial distribution of the 34 study sites based on the GLC 2000 land use categories. The site numbers relate to Table 1 (column 1). The inset (lower left) show the boundaries of the 7 states in north east India

The climate is a blend of cold humid monsoon in areas above the 2,000 metres contour line, wet subtropical in southern stretches of Arunachal, western Nagaland, Mizoram and Manipur to humid mesothermal monsoonal in the valley and plateau areas (Barthakur, 2004). Rainfall, copious throughout the region, is torrential especially across the Cherrapunji-Mawsynram-Pnursula belt of southern Meghalaya bordering Bangladesh (Saikia, 2004); and in Cherrapunji rainfall in excess of 6,300 mm annually is a routine occurrence (Soja & Starkel, 2007). In the rest of the region, average annual precipitation ranges from 1,000 to over 4,000 mm with about 60% being concentrated during the months of June to October. Z-scores indicate that rainfall commonly fluctuated by 0.5 to 1.5 standard deviations from the mean during the 1982–2002 period, although during certain years, fluctuations of 2 standard deviations from the mean also occurred.

Against such a backdrop luxuriant tropical vegetation ranging from alpine, subtropical pine and montane to tropical wet evergreen, semi-evergreen, and moist deciduous thrives making the territory a global biodiversity hotspot. While much of the area has been brought under the plough in the lowlands, in the hills, shifting cultivation locally known as *jhum*, is practised. Generally, the proportion of irrigated land is lower in the region as a whole than in other parts of India.

Forests are central to the region in terms of its economy. The timber trade, tourism and wildlife resorts, and shifting cultivation in the hill areas are closely woven with the region's forest wealth. Forest cover stood at 54% of the total area in 1993 (FSI, 1995) and increased to 66% in 2005 (FSI, 2008) although doubts have been expressed over official data (Bose, 2005). Official reports (FSI, 2008) state that forest cover varies between 80.9% (of the total geographical area) in Arunachal Pradesh, to 35% in Assam, with the other states placed between 76% (Manipur) to 88.6 % (Mizoram).

Only 6.8% of forests in the region belong to the very dense category (FSI, 2008) and many protected areas are largely bereft of forest cover. Forest areas under state control are of three types: National Parks (NP), Wildlife Sanctuaries (WLS) and Reserved Forests (RF) in order of declining levels of protective enforcement and increasing levels of encroachment, settlement and illegal logging. During 1993, 33.7% of the forest area was under RF, 14% under NPs and WLSs but the majority was 'unclassified' category (FSI, 1995), the latter being almost entirely being under community control in the hill areas in which autonomous councils administer the forest. In such community owned areas, tribal communities decide matters such as the area to be brought under *jhum* or the quantity of bamboo to be extracted for sale at paper mills and so on; in some instances communities revere certain forests as sacred groves (SG) that are often quite well preserved. Among the numerous community protected SGs the Mawphlang grove near Shillong has been particularly well preserved for several generations.

Data-sets

Normalized Difference Vegetation Index

The NDVI used in this study is derived from the GIMMS (Global Inventory Modeling and Mapping Studies) National Oceanographic and Atmospheric

Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR) data-set maintained by the University of Maryland Global Land Cover Facility (GLCF) (see http://www.landcover.org). The GIMMS data has been corrected for residual sensor degradation and sensor inter-calibration differences, effects of changing solar zenith and viewing angles, volcanic aerosols, atmospheric water vapour, cloud cover and other effects not related to actual vegetation change (Gutman *et al*., 1996; Slayback *et al*., 2003; Tucker *et al*., 2004) using non-linear decomposition methods (Herrmann *et al*., 2005) and maximum value compositing to minimize cloud contamination (Holben, 1986). This new GIMMS data-set is of superior quality than other NDVI data-sets such as the Pathfinder Land (PAL), Global Vegetation Index (GVI) and previous versions produced by the GIMMS group (Tucker *et al*., 2004; Herrmann *et al*., 2005).

Every composite NDVI image was manually checked for navigation accuracy by comparing the mapped data to a reference coastline and processed for inter-channel calibration; then decomposed and reconstructed using empirical mode decomposition to correct for solar zenith angle effects (Tucker *et al*., 2004). Atmospheric corrections were made for the volcanic stratospheric aerosols released from El Chichon and Mt Pinatubo (Tucker *et al*., 2005), of which the latter is relevant to tropical areas (Tucker *et al*., 2004).

Calibration to AVHRR data is performed in two steps, first a pre-flight calibration is applied and a second calibration offset is estimated from measurements that the AVHRR takes from outer space (Los *et al*., 2002). Further relative and absolute calibrations detailed elsewhere (Los *et al*., 2002) can also be applied.

The GIMMS NDVI data prompted new research on the spatial distribution and seasonal dynamics of vegetation over large areas (Los *et al*., 2002) and was selected for this study because of its temporal span, easy availability, quality and widespread applicability.

Although a recent study of India using the GIMMS NDVI data-set (Jeyaseelan *et al*., 2007) was made, it dealt with north east India very briefly. Moreover this study used coarse resolution meteorological division data in that only 3 such divisions covered the 255,000 km^2 of north east India. This study follows Krishna-Prasad *et al*. (2008) and used the same GIMMS dataset for another high precipitation (up to 5,000 mm annually) subset of India.

The NDVI data was derived from the following NOAA satellites:

NOAA-7	1 January 1982 to 8 February 1985
NOAA-9	11 February 1985 to 7 November 1988
NOAA-11	11 November 1988 to 19 September 1994
NOAA-9 (descending)	20 September 1994 to 18 January 1995
NOAA-14	19 January 1995 to 31 October 2000
NOAA-16	1 November 2000 to 31 December 2002

Although the 8 kilometres twice-monthly maximum value composite data-set is available during the period 1981–2004, to maintain temporal consistency with the climate parameters, NDVI data during 1982–2002 has been used in this study.

CRU Gridded Precipitation and Temperature Estimates

When a sufficiently dense network of rain gauges exists, rainfall measurements from rain gauge stations are considered the most accurate and reliable source of rainfall data (Herrmann *et al.*, 2005). In north east India, time series data maintained by the India Meteorological Department's Regional Meteorological Centre at Guwahati from rain gauge stations across the 255,000 km^2 area is incomplete for the *c*.25 rain gauge stations. Rather than just using complete records from only eight of these climate stations, that were not spatially well distributed across the area, interpolated rain gauge data was preferred. Monthly rainfall from the CRU TS 2.1 Climate Dataset produced by the Climatic Research Unit (CRU) of the University of East Anglia (Mitchell & Jones, 2005), and reformatted for use in a geographical information system (GIS) by Antonio Trabucco of the International Water Management Institute (IWMI) was used. Previous studies have utilised the CRU TS 2.1 data-set (Camberlin *et al.*, 2007; Dent & Bai, 2008), in conjunction with the NDVI. The CRU TS 2.1 data-set refines previous methods (Mitchell & Jones, 2005) and has climate grids that are constructed for nine climate variables for the period 1901–2002. In the present study monthly precipitation and temperature values during 1982–2002 were used.

GLC 2000

The Global Land Cover's (GLC2000) Regional Land Cover data-set was used to select NDVI pixels related to specific land use categories (LUC), following previous studies (Camberlin *et al.*, 2007; Balaghi *et al.*, 2008).

Leaf Area Index Values

Since NDVI has been found to be less suitable in forest areas with high Leaf Area Index (LAI), MODIS LAI data was examined to assess whether LAI values were high enough to negate the utility of using NDVI in estimating vegetation health. In the absence of existing studies on LAI across different land use types in north east India, level-4 MODIS global LAI 8 day composites at 1 km resolution were acquired from the Land Processes Distributed Active Archive Center (see https://lpdaac.usgs.gov/lpdaac/get_data) to assess LAI values.

Methodology

The NDVI time series data comprised 504 twice-monthly images spanning 21 years from 1982–2002. The bi-monthly composites were averaged into monthly images in a GIS. Using point locations based on the major land use categories identified by the regional GLC 2000 data-set that was imported into the GIS, the monthly pixel values of NDVI were extracted. The GIS also enabled monthly precipitation and temperature values of the same locations to be derived from the CRU TS 2.1 grid data-sets over the period 1982–2002. Although the regional GLC 2000 data-set for India enabled 26 LUCs to be distinguished, this study used only nine categories that accounted for 86% of the total study area. Thus tropical semi-evergreen and irrigated agriculture (each covering 23% of the area), abandoned *jhum* (19%), tropical evergreen (6%), tropical moist deciduous (5%), degraded forest (4%), sub-tropical evergreen (2%), savannah (1%) and settlement (0.23%) LUC pixels were selected (see Figure 1). These were representative of the varying institutional controls prevalent in the area and included 9 NPs, 7 WLSs, 3 RFs, 6 sites under community control (of these Mawphlang represented a SG), 2 under private land ownership and 7 of settlements, taking an important urban centre from each state (see Table 1).

Multi-seasonal MODIS LAI values were explored to assess whether they were within the normally accepted range of LAI values within which NDVI values did not saturate. These varied spatially and seasonally between 0.178 to 0.306 in the agricultural areas to 1.50 to 1.73 in forested areas and were well within acceptable limits (Baret & Guyot, 1991; Reich *et al.*, 1999; Turner *et al.*, 1999; Smith *et al.*, 2002).

To determine temporal change in NDVI during the 20-year period the gain coefficient was determined. From the regression equation of Y on X , we have

$$y = a + b\,x,$$

Table 1. Land use categories and prevailing institutional frameworks in the study sites

Site no.	Station	Land use	Institutional set-up	State
1	Barnadi WLS	Degraded forest	State protected	Assam
2	Kaziranga NP	Savannah	State protected	Assam
3	Saibol	Tropical semi-evergreen	Community ownership	Assam
4	Dibru Saikhowa NP	Tropical evergreen	State protected	Assam
5	Pakhui WLS	Tropical semi-evergreen	State protected	Arunachal Pradesh
6	Namdapha NP	Tropical evergreen	State protected	Arunachal Pradesh
7	Kumarband Ali	Irrigated agriculture	Private ownership	Assam
8	Shillong	Settlement	Urban settlement	Meghalaya
9	Mawphlang	Degraded forest	Community ownership	Meghalaya
10	NokrekNP	Subtropical evergreen	State protected	Meghalaya
11	Cherrapunji	Tropical semi-evergreen	Community ownership	Meghalaya
12	Balpakram NP	Tropical semi-evergreen	State protected	Meghalaya
13	Agartata	Settlement	Urban settlement	Tripura
14	Gumti WLS	Tropical moist deciduous	State protected	Tripura
15	Trishna WLS	Tropical moist deciduous	State protected	Tripura
16	MurlenNP	Tropical semi-evergreen	State protected	Mizoram
17	Dampa WLS	Tropical evergreen	State protected	Mizoram
18	Aizawl	Settlement	Urban settlement	Mizoram
19	Ngengpui WLS	Tropical semi-evergreen	State protected	Mizoram
20	Intanki NP	Tropical evergreen	State protected	Nagaland
21	Yangoupokpi Lokchao WLS	Tropical moist deciduous	State protected	Manipur
22	Ripu RF	Tropical moist deciduous	Reserved forest	Assam
23	Chirang RF	Degraded forest	Reserved forest	Assam
24	Manas NP	Temperate broadleaved	State protected	Assam
25	Moran-Dinjan	Irrigated agriculture	Private ownership	Assam
26	Pasighat	Settlement	Urban settlement	Arunachal Pradesh
27	Imphal	Settlement	Urban settlement	Manipur
28	Guwahati	Settlement	Urban settlement	Assam
29	Kohima	Settlement	Urban settlement	Nagaland
30	Nameri NP	Tropical moist deciduous	State protected	Assam
31	Kulai RF	Tropical moist deciduous	Reserved forest	Tripura
32	Satsukba	Tropical moist deciduous	Community ownership	Nagaland
33	Vanbawng	*Jhum* abandoned	Community ownership	Mizoram
34	Khuzomi	Tropical semi-evergreen	Community ownership	Nagaland

and

$$\mathrm{b} = \frac{\mathrm{sxy}}{\mathrm{sxx}}$$

where

$$\mathrm{Sxy} = \sum (xi - \bar{x})^*(yi - \bar{y})$$

and

$$\mathrm{Sxx} = \sum (xi - \bar{x})^2$$

To calculate the gain coefficient an average growing season (June to October) image was produced by aggregating 10 twice-monthly growing season images per year for the 20-year period to derive the $\bar{y}$ component and this was subtracted from each yi^{th} observation. The xi and $\bar{x}$ components were derived using a spreadsheet and thereafter the gain coefficient was calculated using a GIS. The resultant gain coefficient image was re-classed into suitable classes.

Results and Discussion

Rainfall and NDVI were incorporated in linear regression analysis with rainfall as independent and NDVI as dependent variable. Following earlier studies (Al Bakri & Suleiman, 2004; Herrmann *et al.*, 2005) the following relationships were examined:

- Mean growing season rainfall vs. NDVI range.
- Average monthly rainfall vs. average monthly NDVI.
- Cumulative rainfall vs. NDVI.
- Cumulative rainfall vs. average monthly NDVI.
- Average monthly temperature vs. average monthly NDVI.
- Average growing season temperature vs. average monthly NDVI.

Analysis of the growing season rainfall during 1982–2002 showed a wide variation from 237 mm in Pasighat to 787 mm in Cherrapunji (see Table 2). Likewise NDVI values varied substantially among the study sites with minimum values (NDVI *min*) ranging between 0.049 in Imphal and 0.414 in Intanki, and maximum values (NDVI *max*) ranging from 0.624 in Pasighat to 0.901 in Vanbawng. While the NDVI range approximates the weather driven component of NDVI (Schmidt & Gitelson, 2000), NDVI *min* indicates the ecosystem resource and NDVI *max* reflects the ecosystem resource as well as the weather component (Al Bakri & Suleiman, 2004). The lowest NDVI *min* occurred in the sites of Imphal and Shillong, both being urban centres with dwindling vegetation. Conversely the highest NDVI *min* occurred in the Intanki NP, a state protected forest site with tropical evergreen vegetation. Likewise, most of the higher NDVI *min* values occurred in other state protected sites, conforming to NDVI *min* representing the ecosystem resource component. Similarly irrigated agriculture or settlement sites accounted for 6 of the 10 lowest NDVI *max*

Table 2. Mean growing season rainfall and NDVI in the 34 study sites

	NDVI *min*	NDVI *max*	NDVI *range*	Mean GSR (mm)
Nokrek	0.120	0.845	0.725	451.8
Balpakram	0.215	0.881	0.666	509.8
Manas	0.259	0.683	0.425	393.5
Kaziranga	0.283	0.742	0.459	300.7
Intanki	0.414	0.805	0.391	279.6
Dibru Saikhowa	0.228	0.776	0.549	281.7
Namdapha	0.151	0.724	0.573	251.3
Ripu	0.372	0.823	0.452	404.4
Cherra	0.082	0.882	0.800	800.0
Mawphlang	0.092	0.816	0.724	615.8
Nameri	0.210	0.865	0.655	296.0
Chirang	0.248	0.836	0.588	404.4
Pakhui	0.155	0.888	0.733	296.0
Barnadi	0.348	0.771	0.423	368.5
Gumti	0.206	0.753	0.547	382.7
Dampa	0.348	0.887	0.539	399.0
Ngengpui	0.318	0.875	0.558	470.9
Murlen	0.135	0.876	0.741	412.6
Yangoupokpi Lokchao	0.152	0.808	0.656	256.1
Trishna	0.336	0.795	0.459	382.7
Agartata	0.218	0.663	0.445	363.0
Shillong	0.069	0.778	0.709	382.5
Guwahati	0.316	0.665	0.349	415
Aizawl	0.265	0.884	0.619	371.8
Imphal	0.049	0.681	0.632	273.9
Kohima	0.133	0.797	0.664	273.9
Pasighat	0.306	0.624	0.318	237
Kulai	0.3465	0.8335	0.487	365.7
Satsukba	0.3955	0.816	0.4205	287.4
Vanbawng	0.3465	0.901	0.5545	360.6
Khuzomi	0.2765	0.8825	0.606	284.8
Saibol	0.139	0.803	0.664	296.2
Moran-Dinjan	0.175	0.713	0.538	302.1
Kumarband Ali	0.188	0.681	0.493	303.7

Note: GSR: growing season rainfall.

values; while protected or community owned sites accounted for most of the highest NDVI *max* values. Thus in both instances the importance of the ecosystem resource component is apparent.

The NDVI range (NDVI range = NDVI *max* minus NDVI *min*) was least in Guwahati at 0.349 and the highest in Cherrapunji at 0.80.The mean growing season rainfall (GSR) and NDVI range when plotted in a scatter diagram showed a weak linear relationship. When non-linear relationships were explored, they showed a decline in R^2 values from 0.15 to 0.13 and 0.10 for logarithmic and power relationships respectively (see Figure 2). Based on an assumption that NDVI response to rainfall might be reaching a threshold when either the NDVI range or the GSR were high, further analysis was carried out excluding the very high precipitation site of Cherrapunji. However, this exclusion did not change the results appreciably, apparently nullifying the assumption. By excluding the site of Guwahati, R^2 increased marginally. This seemed to suggest that when sites with lower NDVI range values were excluded the linear relationship improved marginally, although it continued to be weakly linear. This is not inconsistent with previous

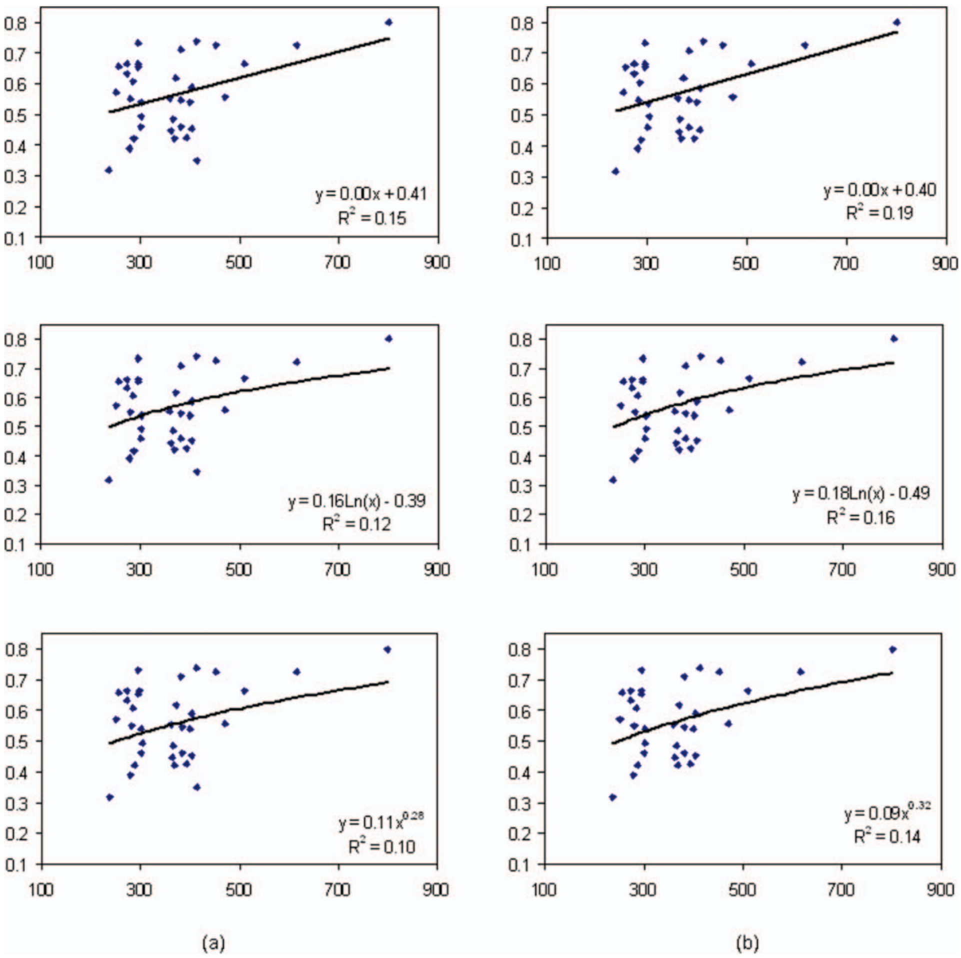

Figure 2. Linear, logarithmic and power relationships between mean growing season rainfall and NDVI range for (a) all sites and (b) all sites excluding Guwahati. The vertical axes show NDVI range while the horizontal axes show mean growing season rainfall in Millimetres

research in semi-arid contexts (Al Bakri & Suleiman, 2004) where non-linear relationships between seasonal rainfall and NDVI range were found.

Correlation between NDVI and Rainfall

To understand the spatial pattern of NDVI as they relate to certain meteorological elements, maps of mean NDVI and growing season NDVI were compared with interpolated rainfall and temperature maps (see Figure 3). The inverse relationship between NDVI and rainfall was noticeable in Meghalaya, Tripura and Mizoram, though for certain other areas these relationships were fuzzier. For example, along the northern rim of the study area where rainfall was distinctly lower, a positive relationship existed with areas which had low mean and growing season NDVI values. This could be due to the relatively lower NDVI values occurring in these areas, on account of the temperate vegetation. Due to the higher elevation, alpine meadows and temperate coniferous vegetation predominated (GLC, 2003).

Assam did not conform to the general inverse relation between rainfall and NDVI. This may be due to a combination of low proportion of forested landscape and dominance of irrigated agriculture. However, within Assam the densely forested area around Saibol and to its immediate south exhibits, like the other forested areas in the region, an inverse rainfall-NDVI relation. Therefore well forested tropical and

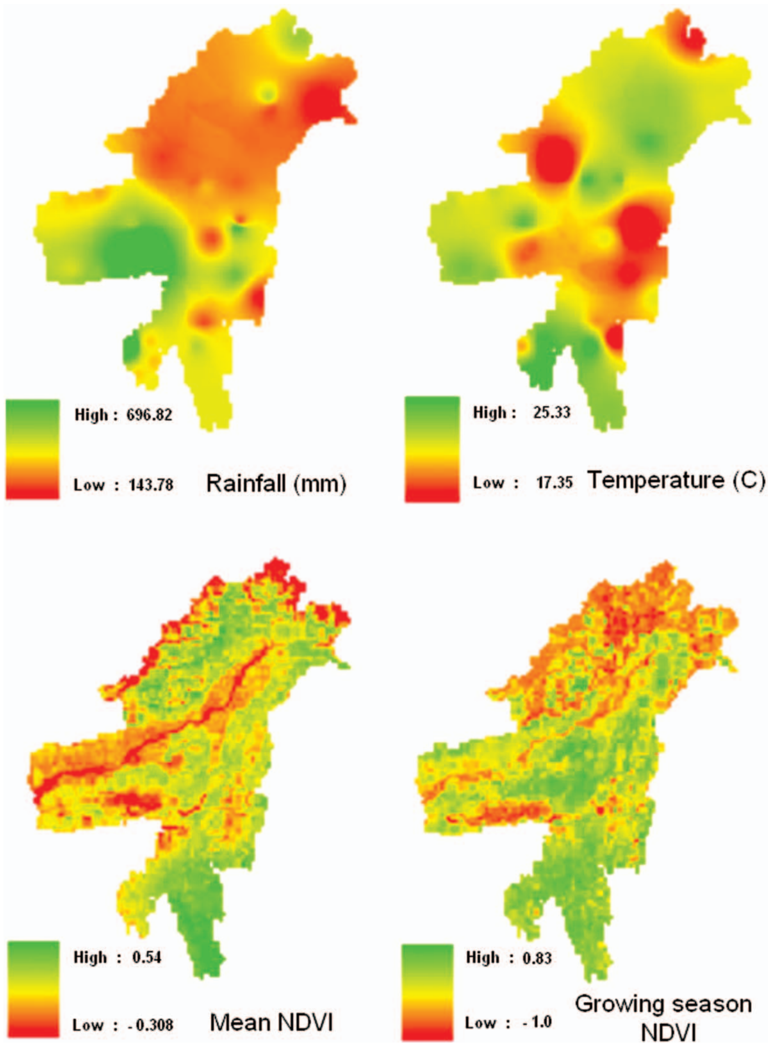

Figure 3. Temperature, growing season NDVI, mean NDVI rainfall are shown clockwise. Temperature and rainfall show growing season values, which were interpolated using kriging, based on values of the 34 sites

subtropical landscapes appear to adhere to an inverse rainfall-NDVI relationship while less well forested, agricultural or temperate areas remain an exception to such a trend.

Although higher values exist for the growing season NDVI map, a reasonably good correspondence between the former and the mean NDVI map is visible, suggesting low inter-annual variability. This is in agreement with previous research in another high precipitation and densely forested zone of India (Krishna Prasad *et al*., 2008).

Correlation coefficients computed for NDVI and rainfall using monthly values during 1982–2002 exhibited a negative correlation in 19 of the 34 sites, of which 14 showed significant ($P < 0.05$) results. These 14 sites comprised moist deciduous, tropical evergreen and tropical semi-evergreen land uses, two settlement sites and 1 with degraded forest (see Table 3) and remained consistent when 1 and 2 month rainfall lags and growing season values were considered. The sites with settlements had the lowest significance levels, probably since most such sites had relatively lower maximum NDVI levels.

When a 1 month rainfall lag was explored, 4 more sites (2 each of settlement and irrigated agriculture LUCs) showed significant correlations adding to the previous list of 14. On using a 2 month rainfall lag the negative relationship became more pronounced and 26 sites showed such a relationship, of which 21 coefficients were significant. Further, the coefficient values increased perceptibly across all but one of the sites compared to those with a 1 month lag. These included all 11 tropical evergreen and tropical semi-evergreen sites, half the moist deciduous sites and 3 settlement and 2 degraded forest sites. Previous studies in comparatively lower rainfall regimes found good correlation between NDVI and rainfall lags (Wang *et al*., 2003; Chamaille-Jammes *et al*., 2006; Piao *et al*., 2006), and such a lag was evident in north east India, although the relationship was negative on account of the high precipitation.

Similarly when growing season correlations were sought, 30 sites reflected the negative effect of high precipitation on NDVI with significant negative coefficients. The only exceptions were those of Vanbawng and Satsukba (both with very low values) and the two irrigated agriculture sites, which showed positive correlations. The irrigated agriculture sites would benefit from higher precipitation, since wetland paddy cultivation thrives in waterlogged conditions during the growing season, and irrigation is provided in addition to the rainfall effect.

Thus it appears that the negative correlation between NDVI and rainfall gets accentuated during the growing season and can be attributed to the short rainfall regime during the monsoon from June to October when the bulk of the rainfall is received by the study area. In contrast to arid areas where too little rainfall is a constraint to vegetation growth, in the high precipitation belt of north east India, too much precipitation seems to play a similar constricting effect. This is in agreement with previous studies which show that above certain rainfall thresholds the relationships between rainfall and NDVI were insignificant (Nicholson & Farrar, 1994; Fuller & Prince, 1996; Piao *et al*., 2006).

Correlation between NDVI and Temperature

Maps comparing mean and growing season NDVI with temperature (see Figure 3) show certain similarities in southern Meghalaya, western Arunachal Pradesh,

Table 3. Coefficient of determination (R^2) for the correlations between NDVI and rainfall in the 34 sites. The numbers in the column header indicate the investigated relationships listed below the table

Station	1	2	3	4
Barnadi	0.180	0.081^{ns}	−0.051	−0.274
Kaziranga	0.210^{ns}	0.362	0.034^{ns}	−0.282
Saibol	-0.064^{ns}	-0.108^{ns}	−0.146	−0.032
Dibru Saikhowa	−0.207	-0.068^{ns}	−0.346	−0.427
Pakhui	−0.461	−0.353	−0.594	−0.485
Namdapha	−0.544	−0.421	−0.662	−0.510
Kumarband Ali	0.173	−0.127	0.053^{ns}	0.041
Shillong	−0.191	−0.187	−0.192	−0.226
Mawphlang	−0.168	−0.067	−0.258	−0.405
Nokrek	−0.278	−0.222	0.298	−0.253
Cherra	−0.484	−0.410	−0.517	−0.458
Balpakram	-0.056^{ns}	-0.015^{ns}	−0.143	−0.213
Agartata	0.013^{ns}	0.012^{ns}	0.001	−0.449
Gumti	−0.155	−0.271	−0.387	−0.551
Trishna	0.126	0.012^{ns}	-0.123^{ns}	−0.498
Murlen NP	−0.652	−0.692	−0.672	−0.537
Dampa	−0.473	−0.586	−0.630	−0.476
Aizawl	−0.144	−0.185	−0.216	−0.363
Ngengpui	−0.683	−0.735	−0.729	−0.548
Intanki	0.085^{ns}	0.262	−0.240	−0.307
Yangoupokpi Lokchao	−0.448	−0.578	−0.650	−0.456
Ripu	0.375	0.488	0.099^{ns}	−0.209
Chirang	0.189	0.311	-0.055^{ns}	−0.364
Manas	0.241	0.352	0.47^{ns}	−0.288
Moran-Dinjan	0.359	−0.312	−0.222	0.165
Pasighat	0.141	0.082^{ns}	0.010^{ns}	−0.419
Imphal	0.006^{ns}	−0.061	-0.120^{ns}	−0.442
Guwahati	0.156	0.099^{ns}	0.023^{ns}	−0.229
Kohima	0.116^{ns}	−0.166	−0.212	−0.317
Nameri	−0.428	−0.324	−0.524	−0.542
Kulai	-0.114^{ns}	−0.166	−0.215	−0.058
Satsukba	-0.059^{ns}	-0.075^{ns}	-0.082^{ns}	0.092
Vanbawng	0.039^{ns}	-0.024^{ns}	-0.003^{ns}	0.062
Khuzomi	-0.028^{ns}	-0.108^{ns}	−0.177	−0.088

1 = monthly rainfall versus monthly NDVI.
2 = monthly rainfall with 1 month lag versus monthly NDVI.
3 = monthly rainfall with 2 month lag versus monthly NDVI.
4 = Growing season rainfall versus growing season NDVI.
^{ns} = not significant at 0.05 *P*-level; other values significant at 0.05 *P*-level.

Tripura and Mizoram although exceptions occur in middle Assam, Manipur and Nagaland, where negative relationships seem to operate. NDVI and temperature correlation in stations across 8 of the 9 LUCs showed a negative but insignificant relationship when explored using year round values during 1982–2002 (see Table 4). Kaziranga was the only site that did not exhibit a negative relationship between NDVI and temperature, showing a significant positive relationship instead, perhaps due to the nature of the savannah grassland vegetation found here, more akin to warmer arid regions. However a significant ($P < 0.05$) relationship existed when growing season correlations were explored and in 6 LUCs significant negative relationships were found. Further analysis using a temperature lag of 1 month,

Table 4. Coefficient of determination (R^2) for the correlations between NDVI and temperature in a few sites

Land use category		All year	GS no lag	GS 1 month lag
Moist deciduous	Kulai	-0.057^{ns}	-0.169^{ns}	-0.380
Moist deciduous	Satsukba	-0.079^{ns}	-0.188^{ns}	-0.407
Jhum abandoned	Vanbawng	-0.100^{ns}	-0.218	-0.447
Tropical semi-evergreen	Khuzomi	-0.098^{ns}	-0.244	-0.478
Tropical semi-evergreen	Saibol	-0.087^{ns}	-0.231	-0.455
Irrigated agriculture	Moran-Dinjan	-0.092^{ns}	-0.235	-0.363
Irrigated agriculture	Kumarband Ali	-0.082^{ns}	-0.215	-0.364
Subtropical evergreen	Balpakram	-0.050^{ns}	-0.235	-0.294

Note: GS: growing season.

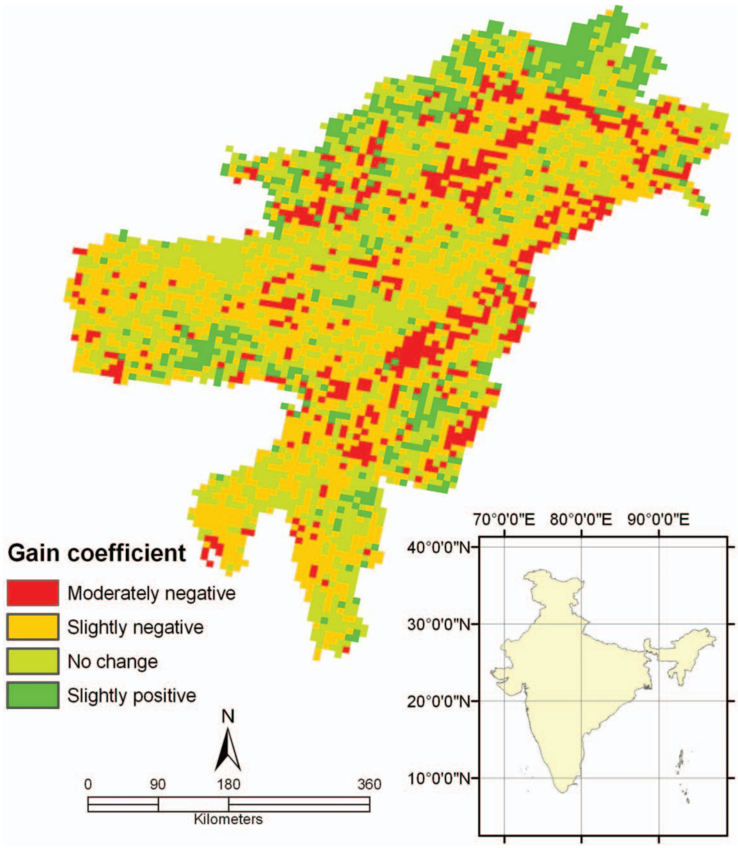

Figure 4. While the four gain coefficient categories are well distributed across north east India, some degree of concentration of the slightly positive gain category is apparent in the northern and eastern margins which incidentally are areas with higher elevation, lower population densities and relatively lower accessibility

showed that the correlation coefficients were markedly higher relative to the correlation for growing season without a lag for all the LUCs except for the savannah and the settlement sites.

Temporal Change in NDVI

To determine temporal change in NDVI during 1982–2002 the gain coefficient was calculated in ArcGIS 9.2 and a spreadsheet program. The growing season gain coefficient image was re-classed into the categories moderately negative, slightly negative, no change and slightly positive (see Figure 4). While nearly one-third of the pixels indicate no change, only 11.3% show an improvement in greenness or NDVI gain coefficient values (see Table 5). This gain is far outweighed by the slightly negative gain coefficient pixels category in 41.2% of the pixels. Further losses in the moderately negative category skews the overall scenario even further as the negative to positive gain coefficient amounts to a ratio 5 : 1, when the losses in two negative gain categories are compared to the positive gain category. Thus overall loss in NDVI values over a time series of 21 years shows a consistent decline for much of north east India and losses far outweigh the gains that accrued.

Among the study sites the state protected sites fared better vis-à-vis the other institutional frameworks (see Table 6). A third of the state protected sites showed a slightly positive gain coefficient compared to less than a fifth of those under community ownership. In general, the state protected sites showed a 5 : 3 ratio of negative to positive gain respectively, better than the comparative 5 : 1 ratio for the

Table 5. The gain coefficient pixels based on categories

Category	No. of pixels	% area
Moderately negative	589	14.78
Slightly negative	1,642	41.20
No change	1,303	32.69
Slightly positive	451	11.32

Table 6. The study sites based on gain coefficient categories and institutional frameworks. Figures in parenthesis indicate respective percentages

Category	State protected	Community ownership	Private	Settlement
Moderately negative	2 (10.53)	3 (50.00)	–	–
Slightly negative	8 (42.11)	1 (16.67)	1 (50.00)	3 (42.85)
No change	3 (15.79)	1 (16.67)	1 (50.00)	3 (42.85)
Slightly positive	6 (31.58)	1 (16.67)	–	1 (14.28)
Total	19	6	2	7

Table 7. Sites under state protection based on gain coefficient categories. Figures in parenthesis indicate respective percentages

Category	NP	WLS	RF
Moderately negative	1 (11.11)	1 (14.29)	–
Slightly negative	2 (22.22)	3 (42.86)	3 (100.00)
No change	1 (11.11)	2 (28.56)	–
Slightly positive	5 (55.55)	1 (14.29)	–
Total	9	7	3

entire study area. Within the state protected sites the NPs were better placed during the 1982–2002 growing seasons than WLSs and RFs, a trend attributable to higher levels of protection accorded to these sites (see Table 7). Among community owned sites, the SG of Mawphlang fared best. Likewise, forested sites fared better than non-forested sites (agriculture and settlement) and this is understandable given the nominal vegetation cover in the non-forest sites.

Conclusions

The study adds to the scanty literature on the relationships between NDVI and environmental characteristics in high precipitation areas. Results from the study showed that rainfall and temperature explained the behaviour of NDVI among different LUCs in north east India under differing institutional frameworks. Differing correlations were obtained, governed by the investigated relationships between NDVI, temperature and rainfall and the period of lag involved.

While mean growing season rainfall and NDVI range showed a weak linear relationship, the negative correlation between rainfall and NDVI (across 252 months during 1982–2002) found to exist in the high precipitation study area was more pronounced. The inverse relationship between NDVI and rainfall that was visualised using interpolated values of the 34 sites was confirmed by negative correlation in a majority of the sites. This correlation intensified when 1 and 2 month rainfall lags were explored, and, all the tropical evergreen and tropical semi-evergreen sites and half the tropical moist deciduous sites conformed to this relationship. However, when only growing season rainfall and NDVI correlations were run, the significance values were relatively much higher, except for the irrigated agriculture sites. The growing season coinciding with the rainfall regime was probably the underlying factor behind the higher inverse correlation.

Similarly, a weak correlation existed between temperature and NDVI across all but the savannah LUC site. Growing season temperature-NDVI correlations showed more significant negative correlations in 6 of the 9 LUCs used in the analysis. As with rainfall, a temperature lag of a month occurred in all the LUCs barring the savannah and the settlement sites. The study showed that interpolated rain gauge data could be used in data scarce contexts.

In assessing temporal change over the growing season during 1982–2002 negative gains outweighed positive trends by a 5 : 1 ratio. The gain coefficient thus indicated a consistent decline over much of north east India. When the 34 study sites were assessed in terms of the gain coefficient, those under state protection fared better relative to those under other institutional frameworks. Among the state protected sites the NPs fared the best followed by WLSs and RFs reflecting the results of protective measures. While rainfall and temperature emerge as negative causative factors in the dynamics of vegetation greenness in north east India, land use and institutional frameworks are also causative factors. In study sites where protective measures by state institutional agencies were in place small spatio-temporal gains accrued amidst an overall decline in gain coefficient over much of north east India, ostensibly India's fading green belt.

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