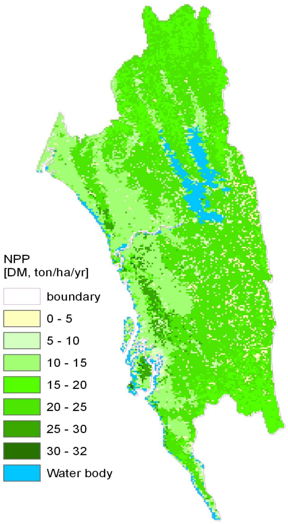
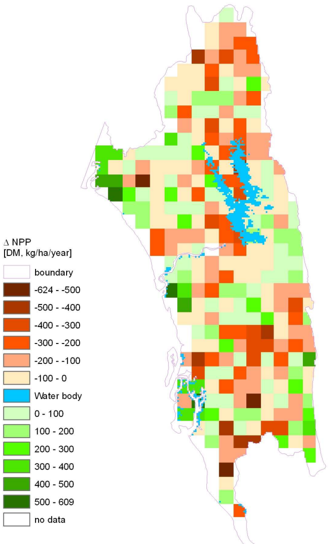
Report 2006/06

Assessing land degradation in the Chittagong Hill Tracts, Bangladesh, using NASA GIMMS

Z G Bai

(December 2006)





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Front cover: net primary productivity and its trend over 1981-2003 in different landscapes of the Chittagong Hill Tracts, Bangladesh

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SUMMARY

Deforestation of Bangladesh is a major cause of environmental degradation in the Chittagong Hill Tracts. The trends of remotely sensed biomass production are used as integrated measure of productivity; their deviance from the norm may indicate land degradation or improvement. Biomass can be assessed using the normalized difference vegetation index (NDVI- the difference between reflected near-infrared and visible wavebands divided by the sum of these two wavebands). Fortnightly, 8-km resolution NDVI measurements from the NASA Global Inventory Modeling and Mapping Studies (GIMMS) 1981-2003 and climate variables were used to analyze biomass trends. Annual NDVI minimum, maximum, maximum-minimum, mean, sum, standard deviation (STD) and coefficient of variation (CoV) were derived for each pixel; their temporal trends were determined by regression and mapped to depict spatial changes. A negative slope of regression indicates a decline of biomass and positive, an increase – except for STD and CoV which indicate trends in variability. Green biomass and net primary productivity were estimated from NDVI data; percentage and absolute changes in net primary productivity were calculated. Urban and irrigated areas were masked.

Rain-use efficiency (the ratio between green biomass (NDVI) and rainfall) was calculated to assess whether this trend reflects biomass degradation or variability in rainfall; combined trends of biomass and rain-use efficiency are considered to be a more robust indicator of land degradation than biomass alone.

In the Chittagong Hill Tracts over the period of 1981-2003, green biomass and net primary productivity decreased over 62 per cent of the land area by an average annual rate of almost 0.2 per cent (162 kg per hectare), and increased over the remaining area at a similar rate; for the CHT as a whole, net primary production was downwards by 44 kg per hectare per year in the 23-year period.

	Positive	Negative	Average
Land area (pixels, %)	38	62	
% NPP change/year	0.78	0.80	-0.21
Δ NPP [DM, kg $ha^{-1}year^{-1}$]	160	161	-44

Over the same period, the trend of annual rainfall was downward.

Potential *black spots* of land degradation were identified as those areas with both declining net primary productivity and declining rain-use efficiency. These areas occupy 20 per cent of the CHT. The combined index reveals three *black spots*: the area around Lake Kaptai; the border between Khgrachhari and Rangamati districts; Naikhongchhari and Alikadam of Bandarban District. The remotely sensed indicators of land degradation are only indicators of complex social, economic and biophysical situation; the areas indicated have been validated by field investigations.

Keywords: land degradation, remote sensing, NDVI, rain-use efficiency, net primary productivity, Chittagong Hill Tracts, Bangladesh.

1 INTRODUCTION

Deforestation is a major cause of environmental degradation and tropical countries under pressure of burgeoning population and widespread poverty are the main frontier of deforestation (FAO 2006). Shifting cultivation is a traditional land use in the Chittagong Hill Tracts (CHT) of Bangladesh. In the past, when population pressure was less, this extensive land-use system was environmentally suitable. Now, steadily increasing population pressure on the land from natural increase of indigenous population and immigration of settlers from the lowland combined with the government restriction on encroachment of reserve forests (Gafur 2001, HARS 2000, Knudsen and Khan 2002), this kind of management is not sustainable. Shifting cultivation and associated burning have destroyed almost all the primary forest (Brammer 1986, Khan and Khisha 1970) and, 37% of the total forest cover has been lost (Farid and Hossain 1988). Farmers have been forced to shorten the fallow period, thereby accelerating soil erosion and nutrient depletion, undermining rural livelihoods (Huq 2000, Ali 2003).

This study uses remote sensing to provide a rapid and consistent measure of land degradation following the procedures detailed by Bai and Dent (2006) who provide an extensive bibliography. Biomass or net primary production is an integrated measure of productivity. Its deviance from the local norm may be taken as a measure of land degradation or improvement. Changes in biomass can be measured by remote sensing of the normalized difference vegetation index (NDVI - the difference between reflected near-infrared and visible wavebands divided by the sum of these two wavebands). NDVI has a strong, linear relationship with the fraction of photo-synthetically active radiation absorbed by the plant (Asrar and others 1984, Sellers 1987, 1994, Sellers and others 1997, Purevdoj and others 1998, Alexandrov and others 1997, Goetz and others 1999, Rasmussen 1998 a, b, Seaquist and others 2003, Turner and others 2002) and above-ground net primary productivity (Running and Nemani 1988, Potter and others 1993, Paruelo 1997). NDVI correlates directly with vegetation productivity (Reed and others 1994, Prince and Goward 1995, Wessels and others 2006) and has been used to detect temporal and spatial trends in vegetation productivity and dynamics (e.g. Woodward 1987, Tucker and others 1991, Bastin and others 1995, Field and others 1995, Myneni and others 1997, Stoms and Hargrove 2000, Los and others 2001, Nemani and others 2003, Wessels and others 2004, 2007, Singh and others 2006, Maselli and Chiesi 2006).

In this study, biomass state and trend over a 23-year period (1981-2003) in the CHT was assessed using corrected historical AVHRR NDVI with information on climate and net primary production.

2 METHODOLOGY

2.1 Study area

The CHT encompasses 13 184 km^2 (10 per cent of Bangladesh) in the south-eastern part of the country (latitude 21.25° - 23.45° N, and longitude 91.45° - 92.50° E), bordering Burma to the southeast, the Indian state of Tripura to the north, Mizoram to the east and Chittagong District to the west (Figure 1).

Ninety per cent is hill country and only 6 per cent is considered suitable for intensive cultivation (Khisa 1997). It comprises steep fold mountains aligned north–northwest to south–southeast, mainly weakly lithified sandstone, shale and some conglomerates. Elevations reach 1000 m, ridges are closely dissected and sharp-edged with steep slopes. About two thirds of the soil is silt, clay loam, acidic, with low nutrient retention capacity and low fertility. *Jhum* (shifting cultivation) is practised on the hill slopes; cotton, rice, tea and oilseeds are raised in the valleys bottoms.

The climate is tropical monsoon: annual temperatures vary according to altitude from 10° to 35° C with mean minimum at sea level of 24° C (December-January) and mean maximum 34°C (March-May). High temperatures are usually accompanied by high humidity during the rainy season. Mean annual rainfall is 2540 mm in the north and east, and 2540 mm to 3810 mm in the south and west. The dry and cool season is from November to March; pre-monsoon season (April-May) is hot and sunny; the monsoon season (June to October) is warm, cloudy and wet. Wind blows from a south-westerly direction during the warm season but from a northerly direction during the cool season. The commencement of the rains in late April is usually accompanied by violent electrical storms.

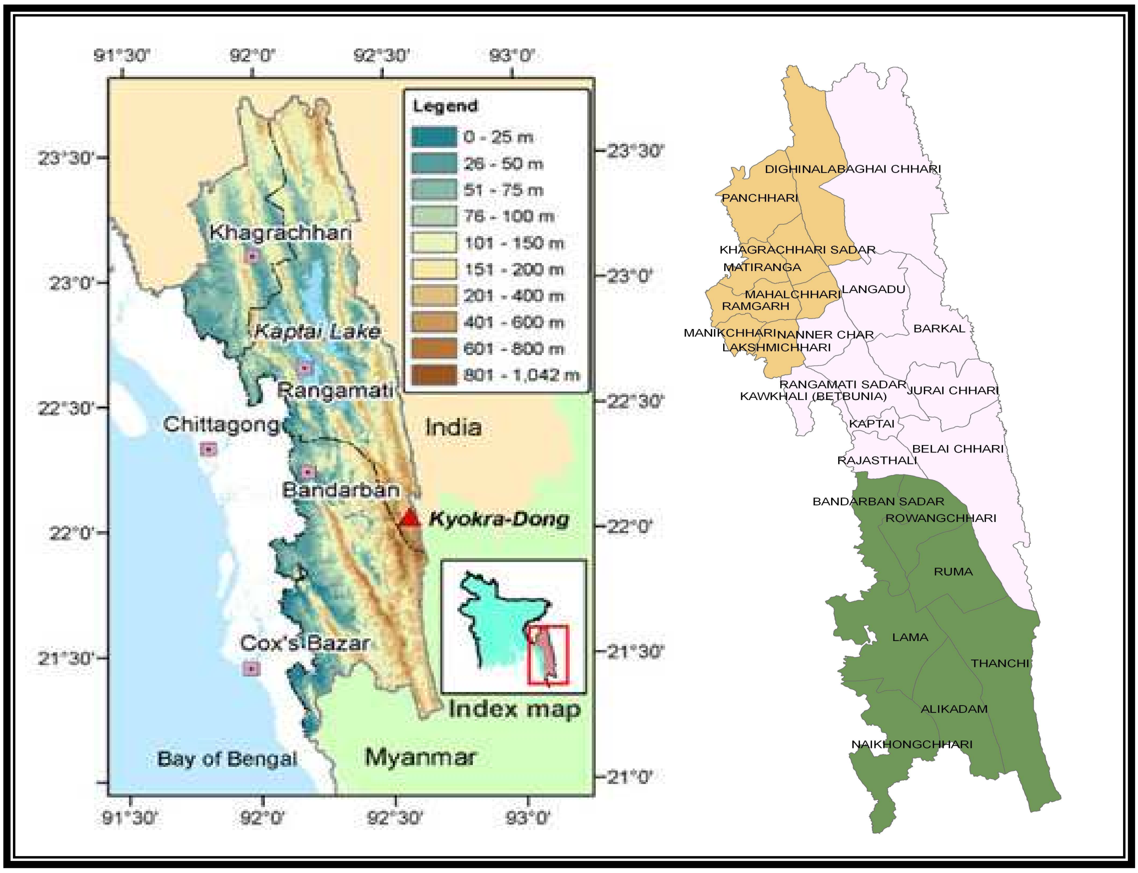


Figure 1. Location of the Chittagong Hill Tracts (http://www.charmbd.com/, modified)

2.2 Data

NDVI: The Global Inventory Modeling and Mapping Studies (GIMMS) data set comprises very high resolution radiometer (AVHRR) data collected by National Oceanic and Atmospheric Administration (NOAA) satellites. The fortnightly images of 8-km spatial resolution are corrected for calibration, view geometry, volcanic aerosols, and other effects not related to actual vegetation change (Tucker and others 2004). GIMMS data from July 1981 to December 2003 were used for this analysis.

Climate: The CRU TS 2.1 dataset comprises 1224 monthly grids of meteorological station-observed data, for the period 1901-2002, covering the global land surface at 0.5 degree resolution. The data are collected from as many stations as possible to develop monthly mean climatology (1961-1990) and time series (1901-2002) of various climate variables, using a thin-spline interpolation with consideration of elevation effects. Data are available for nine climate variables: daily mean, minimum and maximum temperature, diurnal temperature range, precipitation, wet day frequency, frost day frequency, vapour pressure and cloud cover (Mitchell and Jones 2005). Monthly precipitation data from the CRU TS 2.1 dataset from January 1980 to December 2002 were used for this study.

Net primary productivity (NPP): MODIS 8-day NPP data (MOD17A3) are compiled from moderate-resolution imaging spectroradiometer data calibrated in terms of terrestrial gross and net primary production. It is a first regular, near-real-time dataset for repeated monitoring of vegetation primary production at 1-km resolution at an 8-day interval (Heinsch and others 2003). The 8-day NPP was computed from the product of photo-synthetically active radiation (PAR), f_{APAR} (fraction of absorbed photo-synthetically active radiation) and conversion efficiency coefficients obtained from other MODIS product (MOD15A2) and ancillary data (biome properties lookup table – BPLUT). Annual MODIS NPP data from 2000 to 2003 were used to calibrate the GIMMS 23-year NDVI record. Gebremichael and Barros (2006) have validated MODIS for tropical monsoon regions.

Urban/Rural extent: Global Rural-Urban Mapping Project (GRUMP) produced by the Center for International Earth Science Information Network (CIESIN) of the Earth Institute at Columbia University renders human populations in a common geo-referenced framework (CIESIN 2004). The Urban/Rural Extents dataset is used to mask the urban area in this study.

Global map of irrigated areas: The digital global map of irrigated areas, developed by combining irrigation statistics for 10 825 sub-national statistical units and geo-spatial information on the location and extent of irrigation schemes (Siebert and others 2006) shows the percentage of each 5 arc-minute by 5 arc-minute cells that was equipped for irrigation around the year 2000. The latest version (4.0) was used to mask irrigated land areas. Only those pixels with more than 5 per cent of the irrigated area were considered in this study.

2.3 Analysis

ArcGIS Spatial Analyst and ERDAS IMAGINE were used to calculate various biomass indicators: NDVI minimum, maximum, maximum-minimum, mean, sum or integrated, standard deviation (STD), and coefficient of variation (CoV) as well as climate variables. The fortnightly NDVI data were averaged to monthly; annual NDVI indicators were derived for each pixel; their temporal trends were determined by linear regression (significance level = 0.05) and mapped to depict spatial changes. A negative slope of linear regression indicates a decline of biomass and positive, an increase – except for STD and CoV which indicate trends in variability. Green biomass and net primary productivity were estimated from NDVI data using MODIS 8-day values for the 4 years 2000-2003.

Monthly grids of rainfall for the period 1980-2002 were geo-referenced and re-sampled to the same spatial resolution as the NDVI (8-km) using neighbourhood statistics. Spatial pattern and temporal trend of rainfall for each pixel were determined by regression and statistic analysis. SPSS 12.0.1 for Windows was also used for correlation and confidence analyses.

Black spots of biomass degradation were identified according to their negative trends of biomass and rain-use efficiency.

3 RESULTS

3.1 NDVI indicators of land degradation

Annual NDVI minimum, maximum, maximum-minimum, mean, sum, standard deviation (STD) and coefficient of variation (CoV) were derived:

Minimum NDVI: The lowest value that occurs in any one year (annual) - which is almost invariably at the end of the dry season. Variation in minimum NDVI may serve as a baseline for other parameters.

Maximum NDVI: Represents the maximum or peak biomass. The large spatial variations reflect the diverse landscape and climate.

Maximum-minimum NDVI: The difference between annual maximum and minimum NDVI reflects annual biomass production for areas with just one growing season but may not be appropriate for areas with bimodal rainfall or multi-cropping.

Sum or integrated NDVI: The sum of fortnightly NDVI values for the year most nearly integrates annual biomass production.

Standard deviation (STD): *NDVI* standard deviation is the root mean square (RMS) deviation of the NDVI time series values (annual) from their arithmetic mean. It is a measure of statistical dispersion, measuring spread of the NDVI values.

Coefficient of variation (CoV): CoV can be used to compare the amount of variation in different sets of sample data. CoV images were generated by computing for each pixel the standard deviation (STD) of the set of individual NDVI values and dividing this by the mean (M) of these values.

Temporal trends: The long term trends in the NDVI indicators can be taken as indicators of land degradation, where the trend is declining, or biomass improvement, where the trend is increasing. A positive trend in the value of a pixel-level STD or CoV over time relates to increased dispersion of values, not increasing NDVI; similarly, a negative standard deviation or CoV dispersion, not decreasing NDVI. The trends in STD or CoV may reflect land cover change.

3.2 Spatial patterns and trends in biomass

3.2.1 Spatial-temporal trends in biomass

Biomass varies depending upon climate, phenology, and changes in land use. Using trends in biomass to indicate land degradation is, therefore, not straightforward. The patterns of the NDVI indicators and their temporal trends for each pixel, determined by the slope of the linear regression equation are presented in Figures 2-6; the values of the NDVI indicators are summarised in Table 1.

Table 1. Changes in NDVI indicators from linear regression

NDVI indicators	Pixels (%)		% NDVI change/year			Δ NDVI/year		
	+	-	+	-	mean	+	-	mean
Minimum	72.1	27.9	0.806	0.487	0.450	0.0027	0.0019	0.0015
Maximum	32.2	67.8	0.220	0.202	-0.070	0.0014	0.0015	-0.0006
Max-Min	23.8	76.2	0.544	0.991	0.629	0.0021	0.0034	-0.0021
Mean	38.1	61.9	0.181	0.165	-0.036	0.0009	0.0010	-0.0003
Sum	38.1	61.9	0.181	0.165	-0.036	0.0109	0.0116	-0.0033
STD	32.8	67.2	0.519	0.802	-0.385	0.0006	0.0008	-0.0004
CoV	35.6	64.4	0.608	0.863	-0.365	0.0012	0.0016	-0.0007

In the Chittagong Hill Tracts over the period of 1981-2003, patterns and trends in the mean and sum NDVI are similar: some 38 per cent of the land area increased and 62 per cent decreased (Table 1, Figures 2 and 6b & c).

Individual NDVI indicators (annual minimum, maximum, max-min, mean and sum) were spatially integrated for the whole CHT; their temporal trends are shown in Figure 7: the trends in the all indicators were downwards, except for NDVI minimum - upwards over more than 70 per cent of the area (Figure 3b & c, Table 1), which could result from an intensification of land use practices, in particular, shortening the fallow. Trend in spatially integrated monthly NDVI for the CHT as a whole over 270 months indicated that the biomass overall decreased over the 23 years (Figure 8).

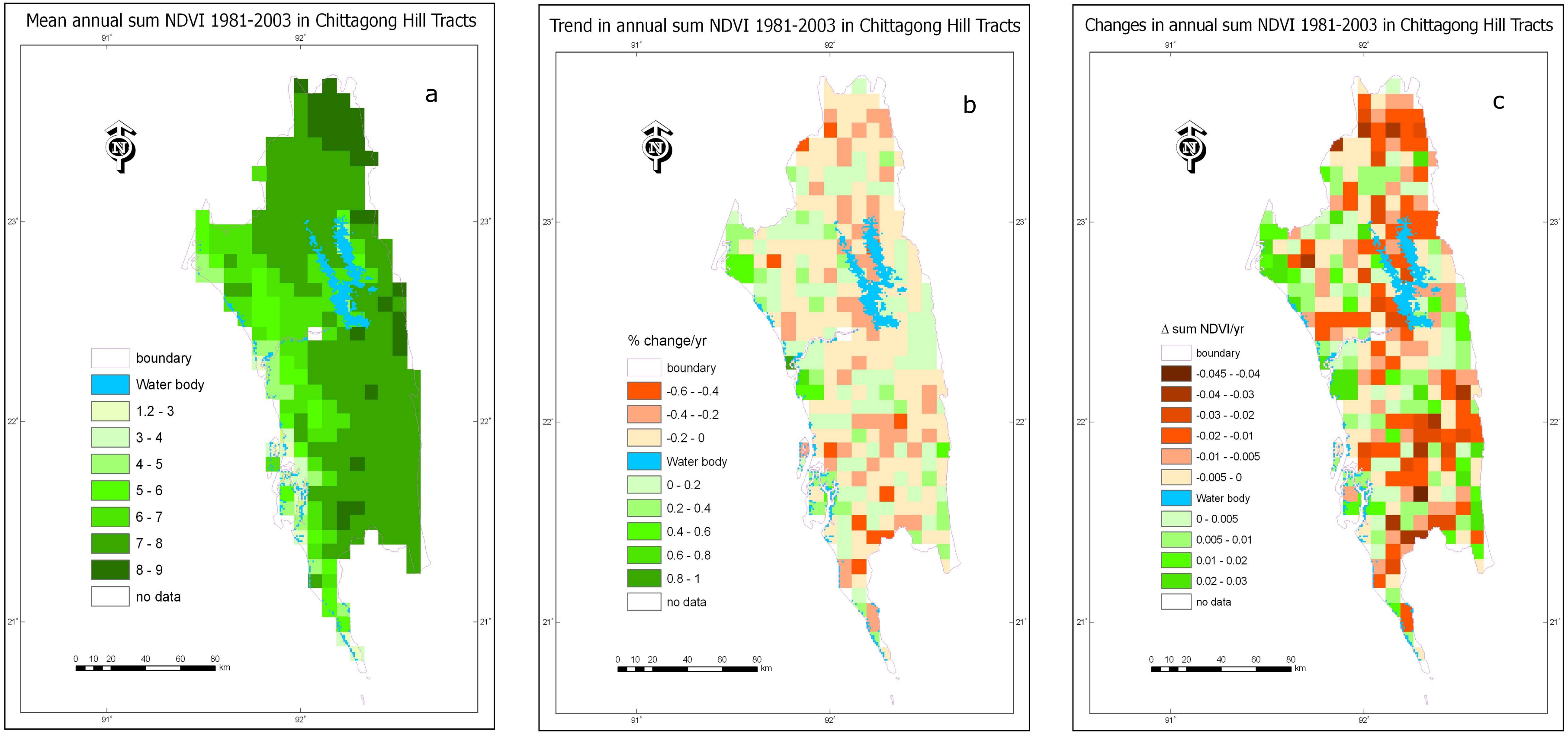
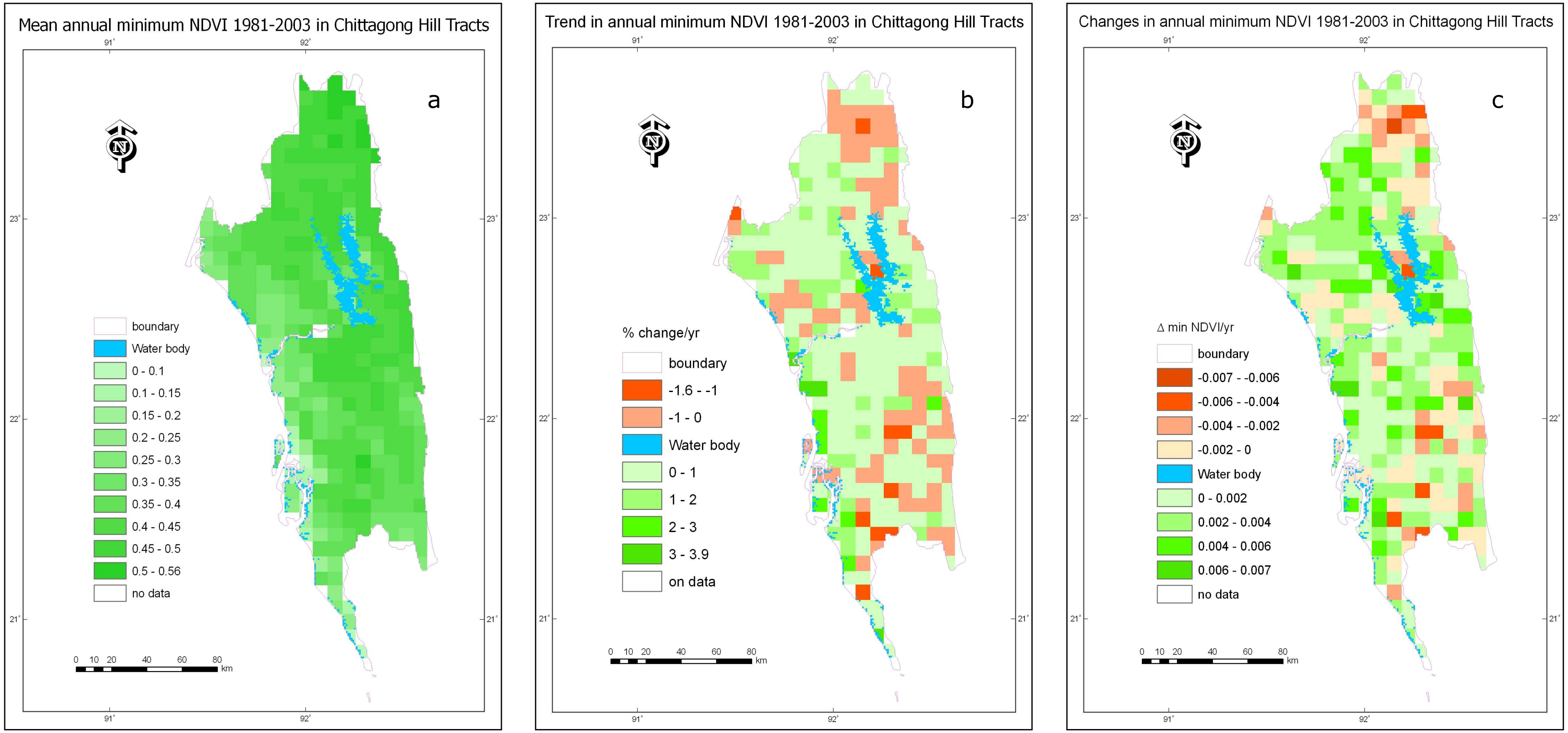


Figure 2. Spatial pattern (a) and temporal trends (b & c) in sum NDVI 1981-2003


Mean annual minimum NDVI 1981-2003 in Chittagong Hill Tracts

Trend in annual minimum NDVI 1981-2003 in Chittagong Hill Tracts

Changes in annual minimum NDVI 1981-2003 in Chittagong Hill Tracts

Figure 3. Spatial pattern (a) and temporal trends (b & c) in minimum NDVI 1981-2003

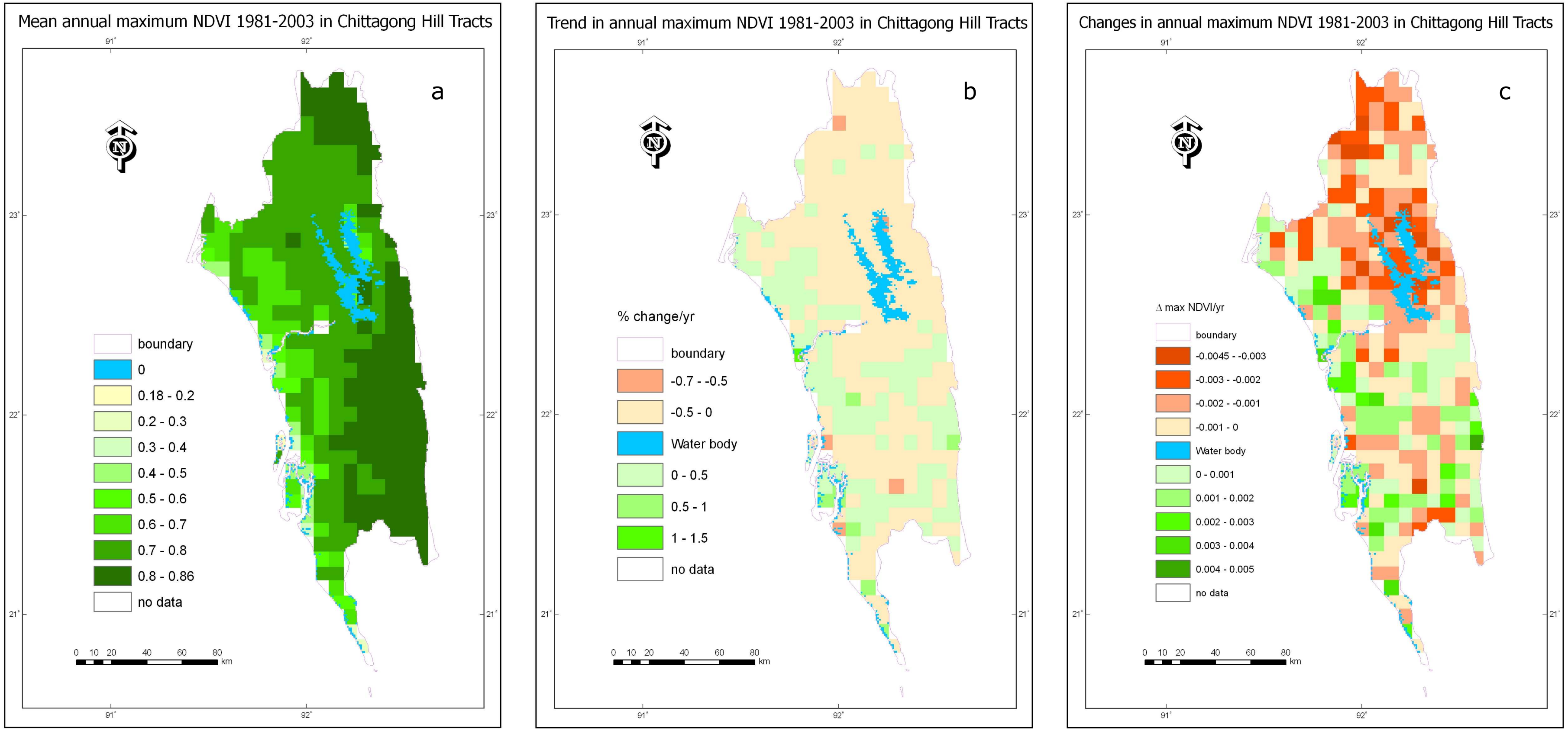


Figure 4. Spatial pattern (a) and temporal trends (b & c) in maximum NDVI 1981-2003

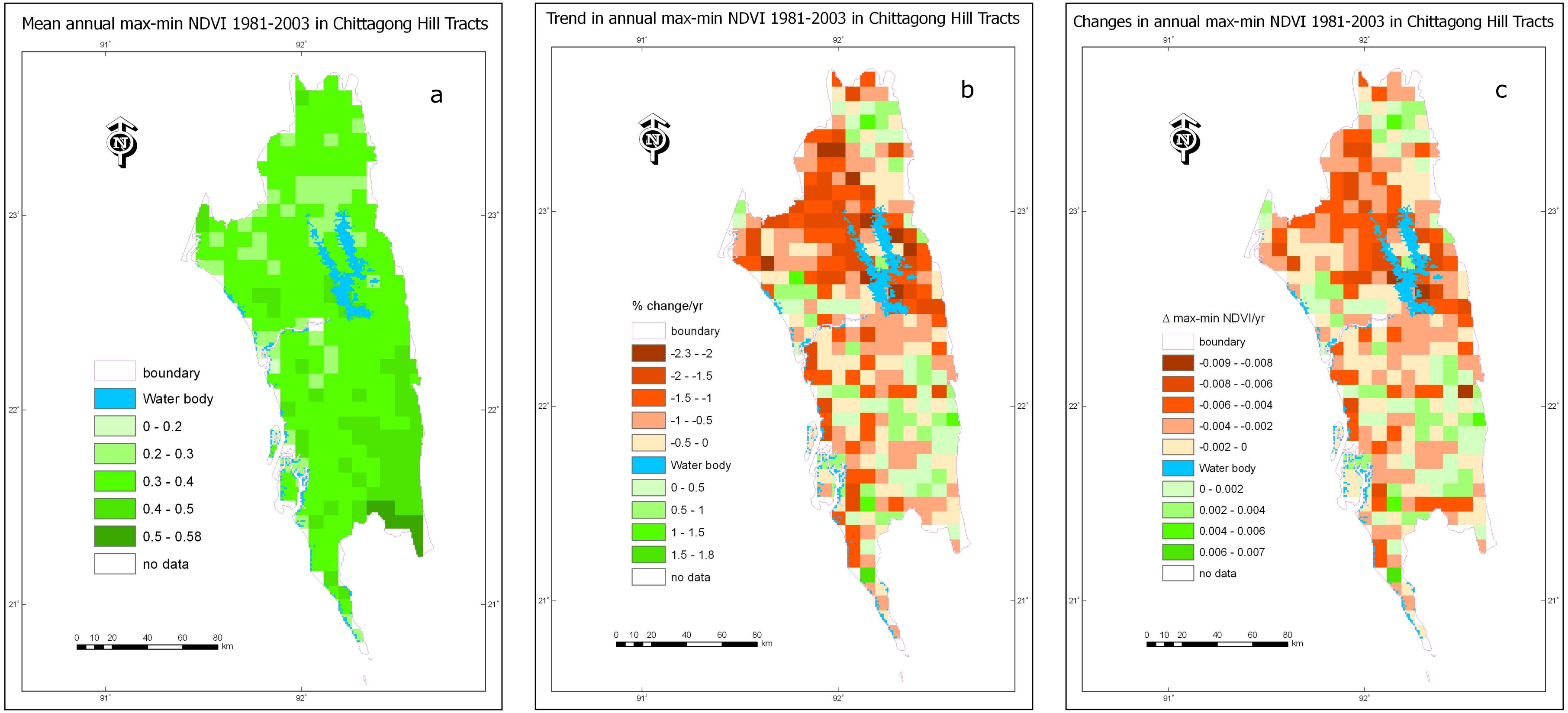


Figure 5. Spatial pattern (a) and temporal trends (b & c) in maximum-minimum NDVI 1981-2003

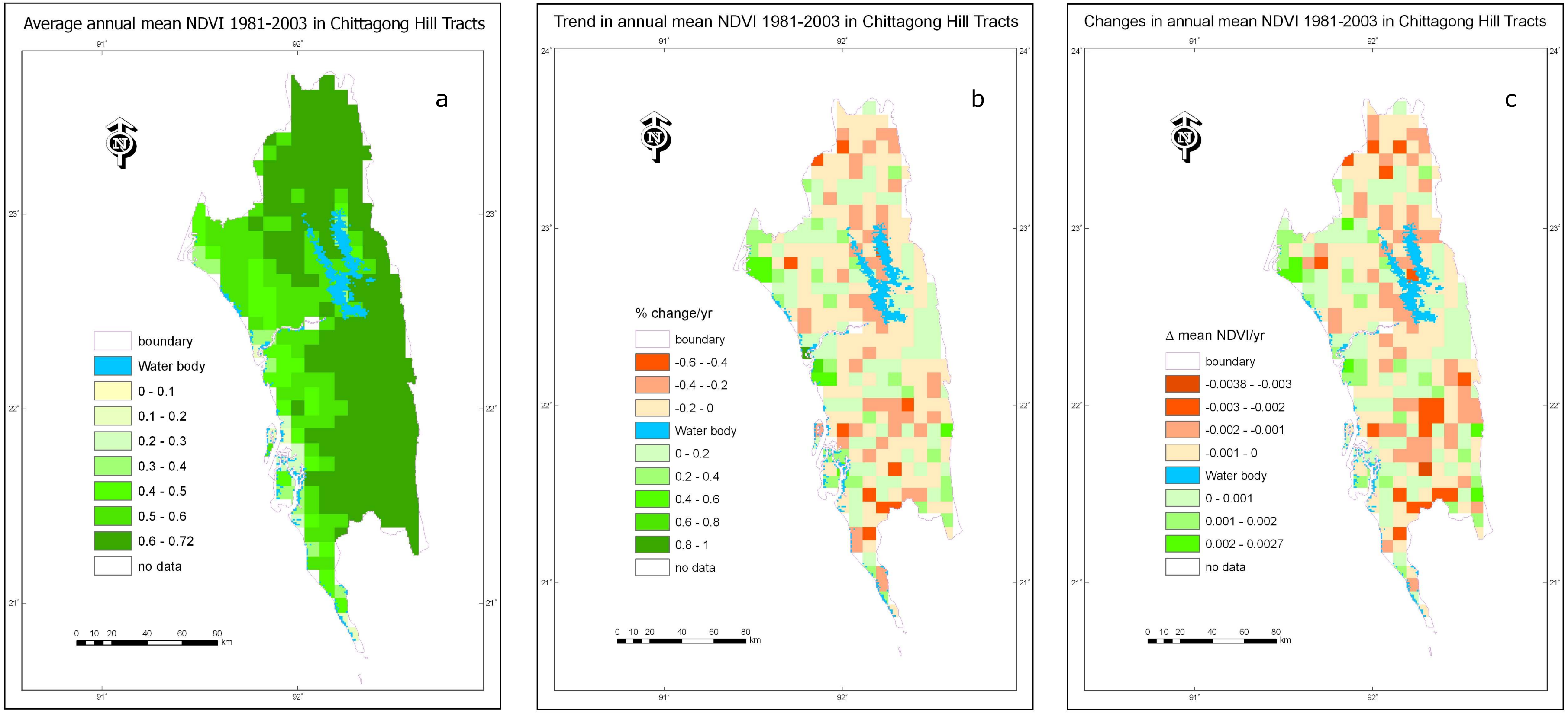


Figure 6. Spatial pattern (a) and temporal trends (b & c) in mean NDVI 1981-2003

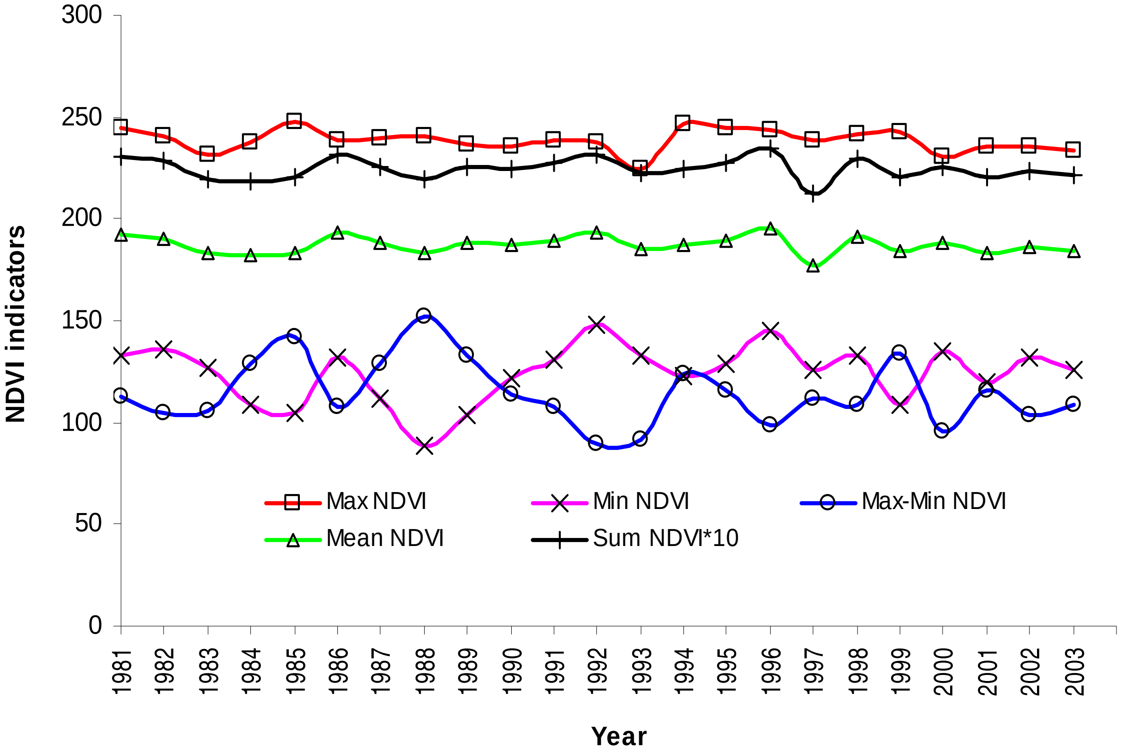


Figure 7. Trends in spatially integrated NDVI indicators in the Chittagong Hill Tracts

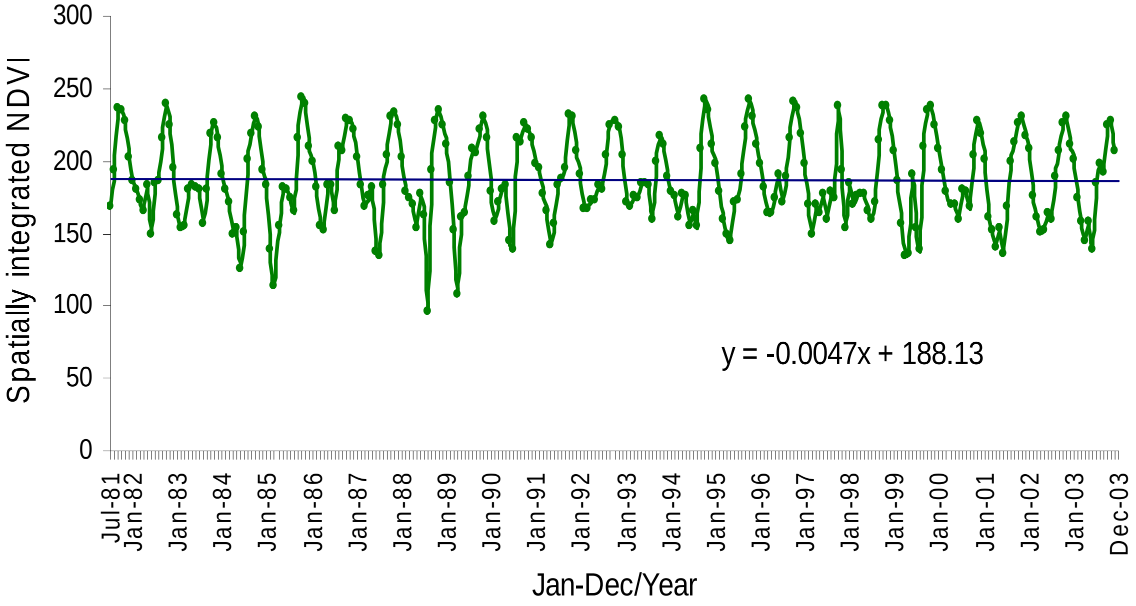


Figure 8. Trend in total biomass production 1981-2003 in the CHT

3.2.2 Variability in biomass production

Multi-year average standard deviation and coefficient of variation (CoV) of NDVI in the CHT for each pixel are shown in Figure 9a and Figure 10a, respectively; their temporal trends in both relative and absolute changes over the period of 1981 and 2003 are depicted in Figure 9b & c and Figure 10b & c, respectively.

The biomass production fluctuated drastically in Thanchi and Alikadam of Bandarban district and Belaichhari of Rangamati district (Figures 9-10a), these variations increased with time over the period. In contrast, variations in biomass productivity in Khagrachhari and northern Rangamati district were low and diminished (Figure 9b, c and Figure 10b, c). Three wavelets of the biomass fluctuation were distinguished: 1984-1985, 1987-1988 and 1998-1999, which could related to three intensive and persistent El Niño events (1982-1983, 1987-1988, and 1997-1998); the overall trends in the variations went down (Figure 11).

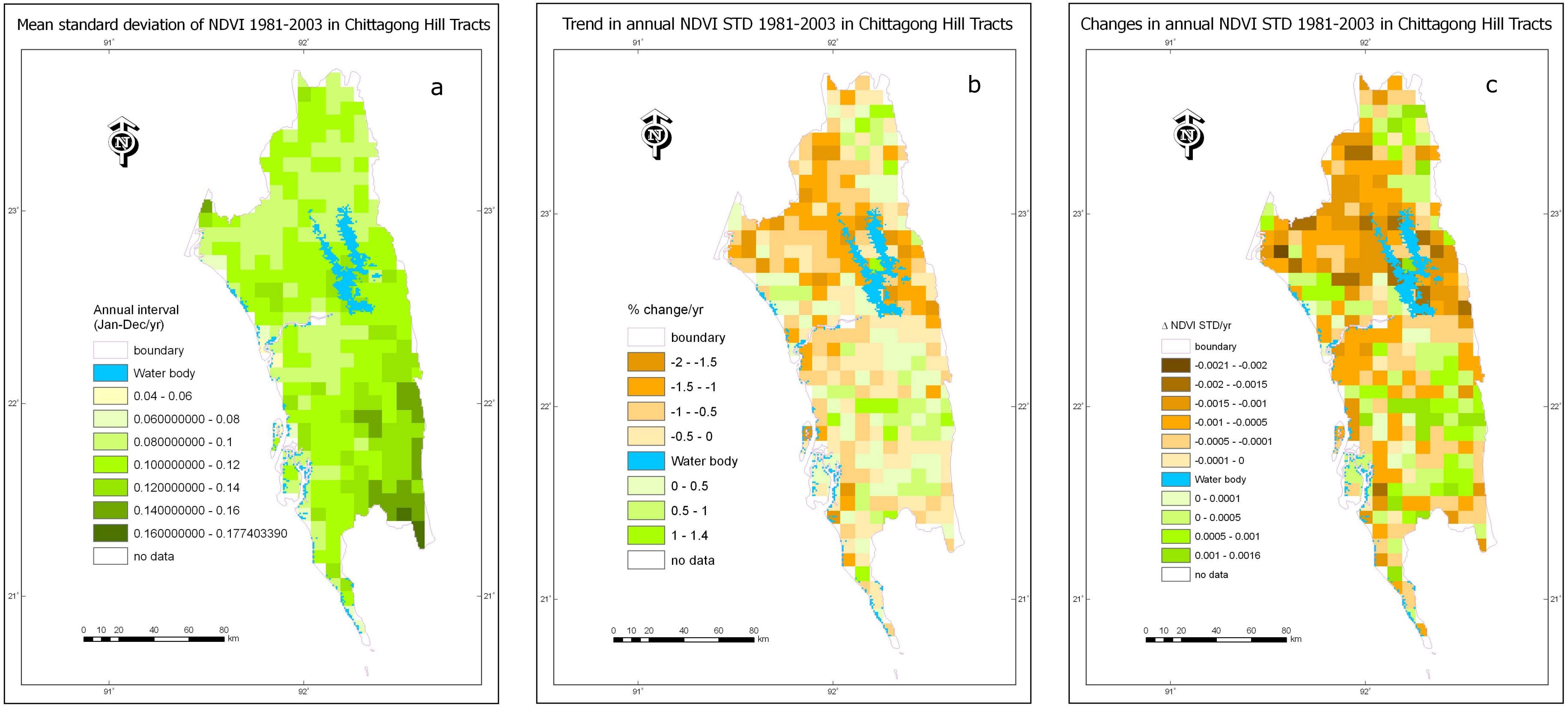
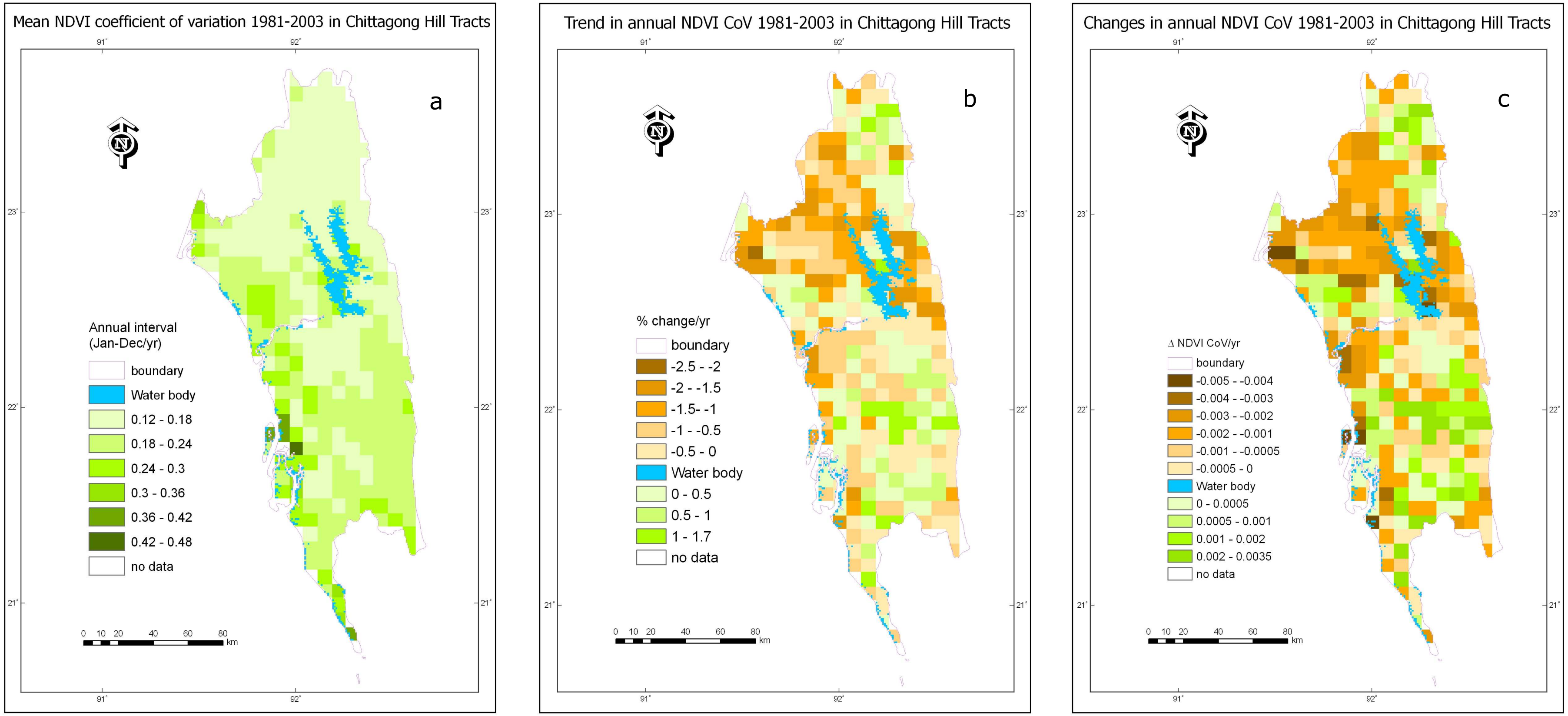


Figure 9. Spatial pattern (a) and temporal trends (b, c) in NDVI standard deviation 1981-2003


Mean NDVI coefficient of variation 1981-2003 in Chittagong Hill Tracts

Trend in annual NDVI CoV 1981-2003 in Chittagong Hill Tracts

Changes in annual NDVI CoV 1981-2003 in Chittagong Hill Tracts

Figure 10. Spatial pattern (a) and temporal trends (b, c) in NDVI coefficient of variation 1981-2003

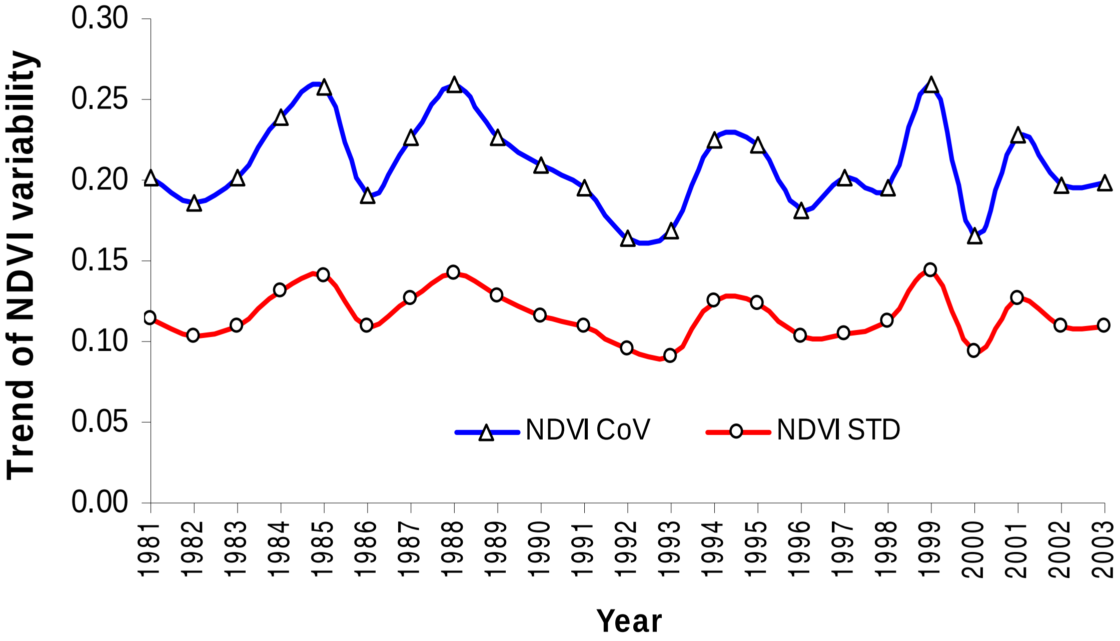


Figure 11. Trends in variability in biomass production in the CHT

3.3 Spatial patterns and trends in rainfall

Figure 12 shows spatial pattern and temporal trend in annual precipitation in the CHT over 1980-2002: rainfall decreases from south to north (Figure 12a), their negative trend exhibited over 90 per cent of the land area with a distinctive area between Bandarban and Rangamati districts (Figure 12b, c). Spatially integrated monthly rainfall for the entire CHT shows an overall declining trend (Figure 15).

The higher the annual rainfall, the greater its variation it is (comparing Figure 12a and Figures 13-14a). Fluctuation in annual rainfall is greatest in Bandarban district, in particular, in the Lama and Alikadam (Figure 13a), the trends of the rainfall standard deviation and coefficient of variation in the areas were downward (Figure 13-14b, c). For the CHT as a whole, the rainfall variation decreased over the period (Figure 16).

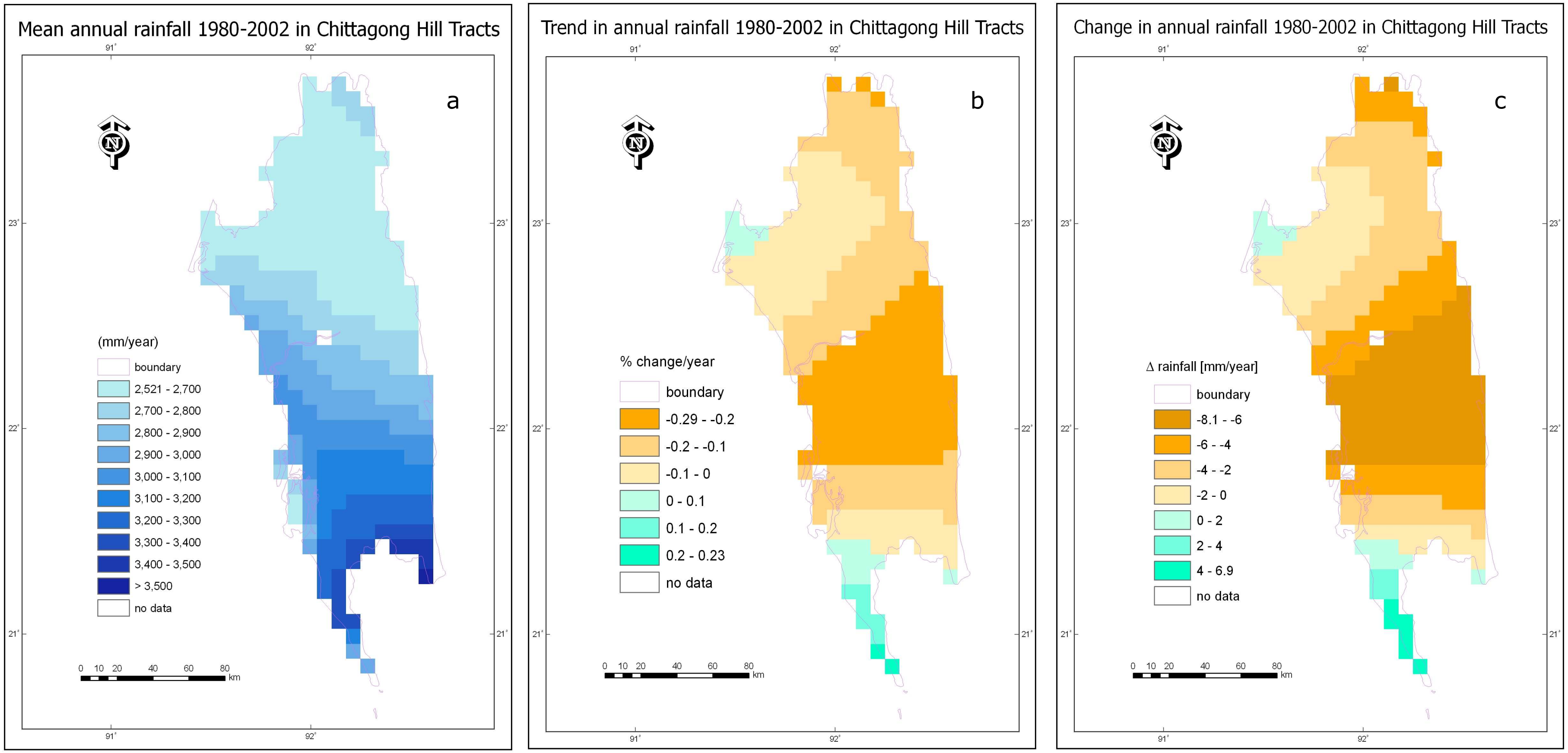


Figure 12. Spatial pattern (a) and temporal trend (b, c) in annual rainfall 1980-2002

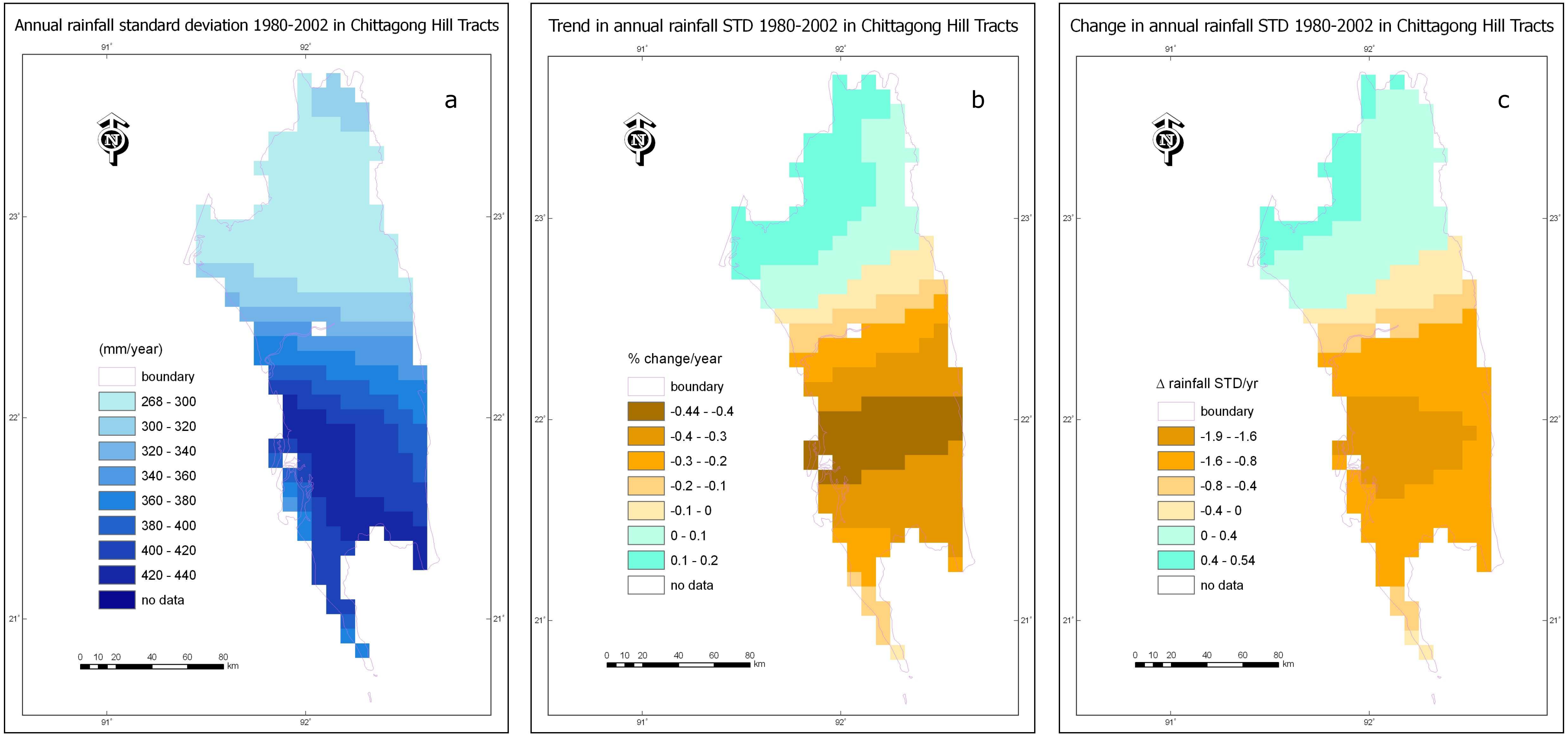
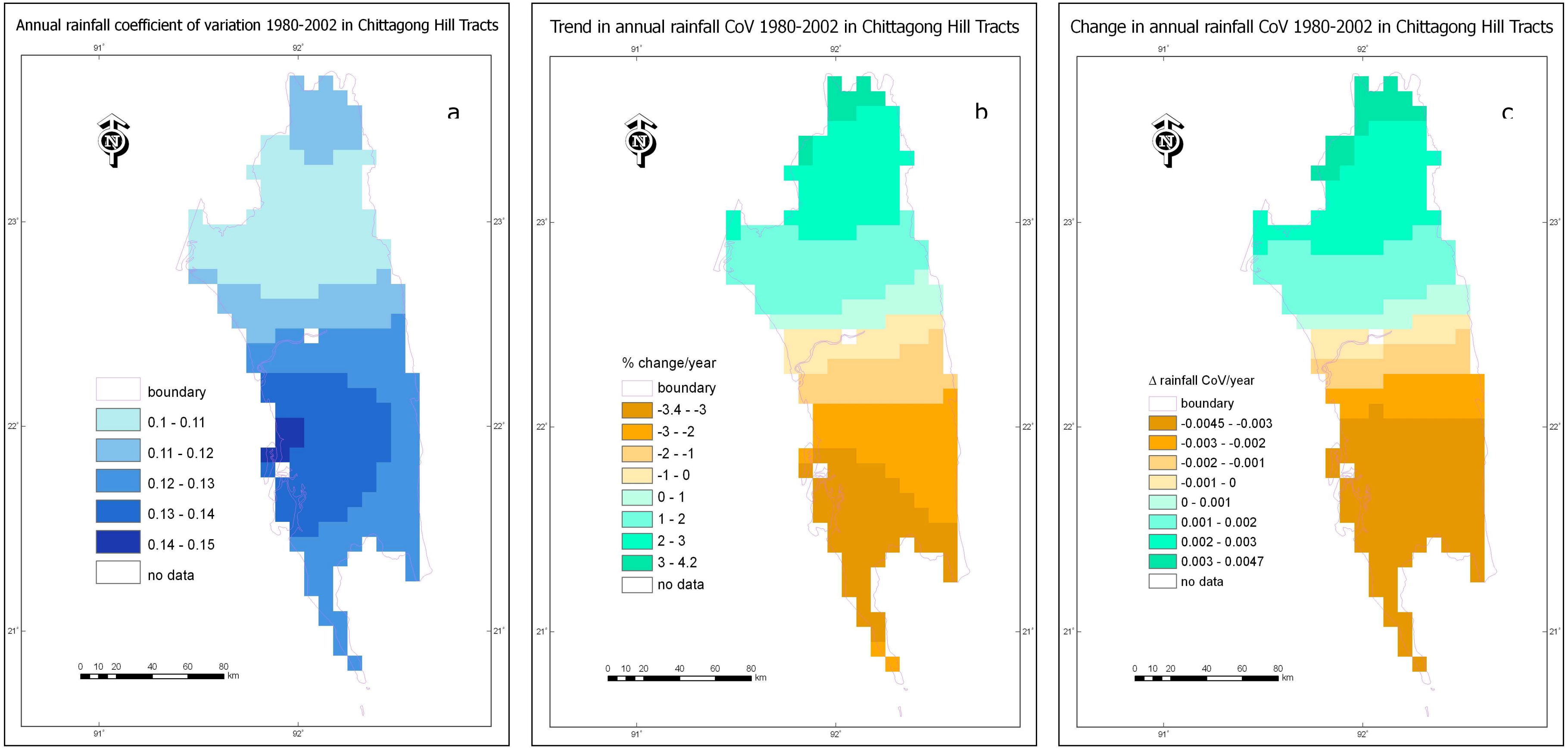


Figure 13. Spatial pattern (a) and temporal trends (b, c) in annual rainfall standard deviation 1980-2002



Annual rainfall coefficient of variation 1980-2002 in Chittagong Hill Tracts

Trend in annual rainfall CoV 1980-2002 in Chittagong Hill Tracts

Change in annual rainfall CoV 1980-2002 in Chittagong Hill Tracts

Figure 14. Spatial pattern (a) and temporal trends (b, c) in annual rainfall coefficient of variation 1980-2002

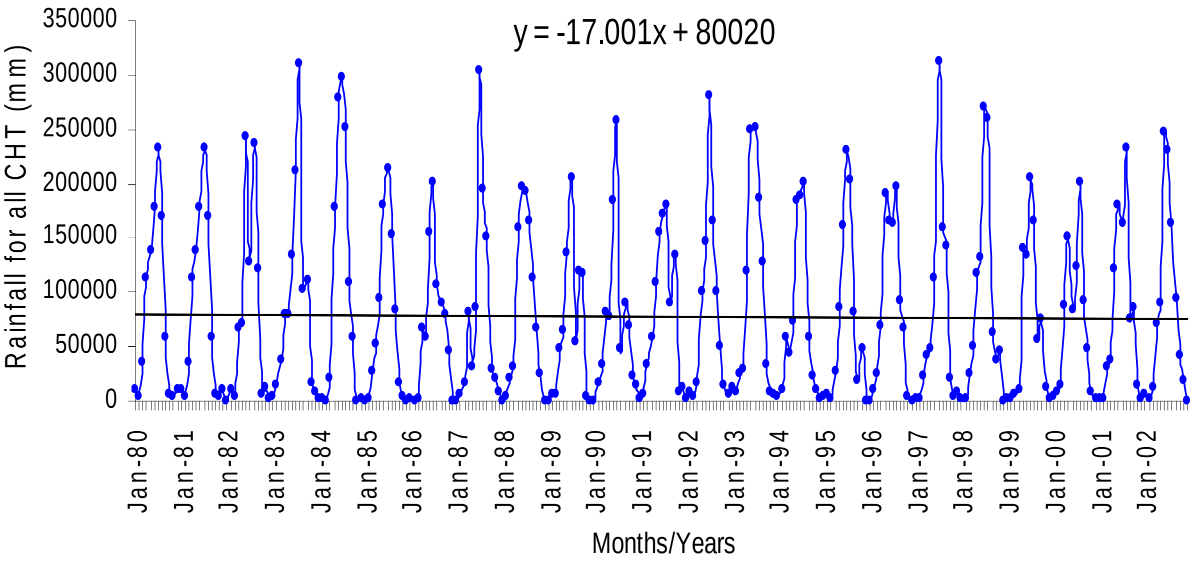


Figure 15. Spatially integrated monthly rainfall 1980-2002 in the CHT

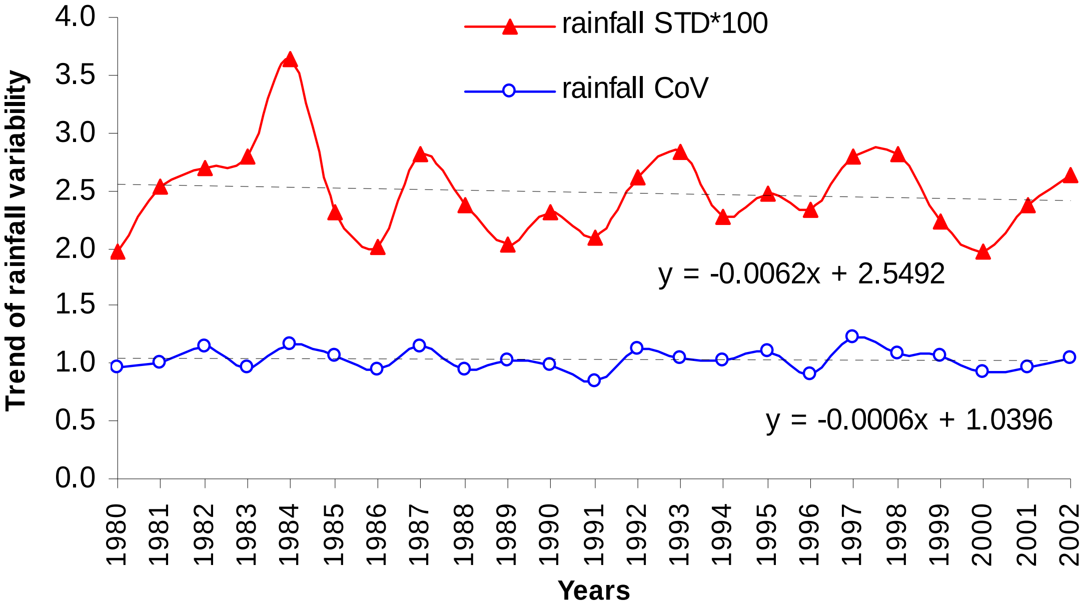


Figure 16. Trend in variability of annual rainfall in the CHT

3.4 Correlations: biomass, rainfall and temperature

Annual biomass (Figure 2a) does not essentially reflect the annual rainfall (Figure 12a) which has fluctuated significantly, both spatially (Figure 12b, c) and cyclically over the period (Figures 13-15). The overall trends in annual rainfall and biomass was downwards. Figure 17 shows relationship between spatially integrated (the entire CHT) monthly biomass (NDVI) and monthly rainfall: the biomass peak growth lagged behind antecedent precipitation by ca. 3-4 months with correlation coefficient of 0.74 (Correlation is significant at the 0.01 level) (Figure 18). At a site close to Rangamati city (22.65° N, 92.18 ° E), biomass peak productivity lagged ca. 3-4 months behind both rainfall and temperature with correlation coefficient of 0.57 and 0.49, respectively (significant level = 0.01) (Figure 19).

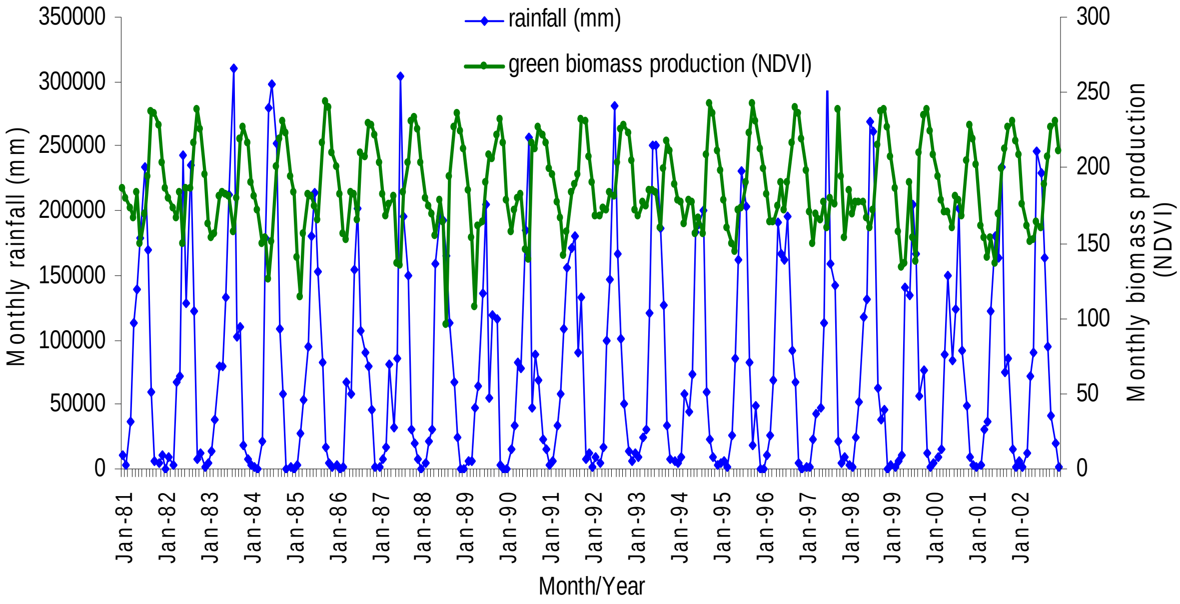


Figure 17. Covariability between monthly biomass and rainfall in the CHT

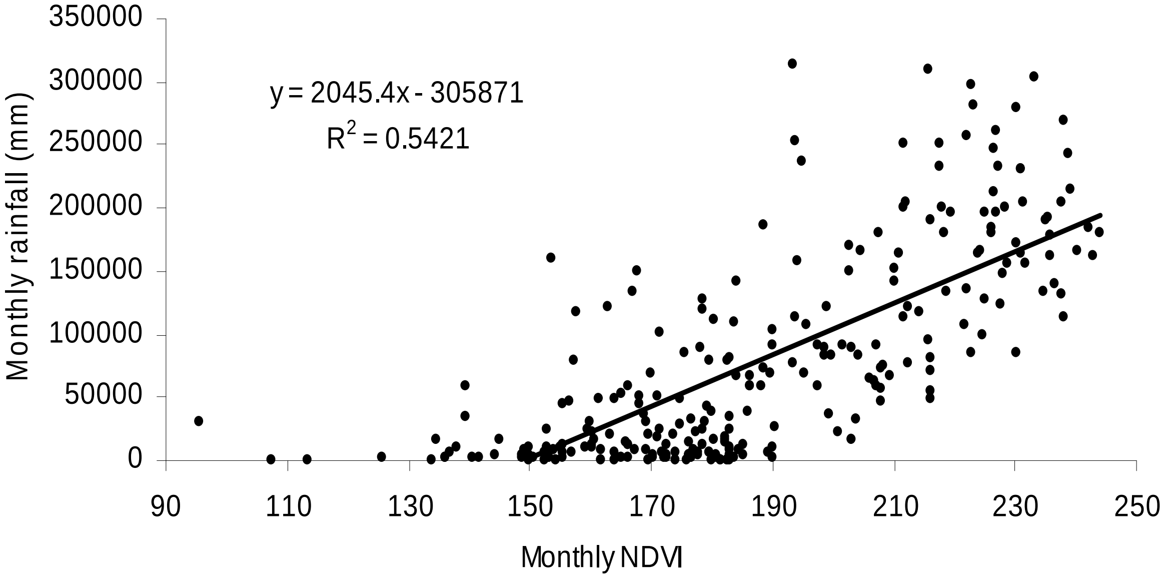
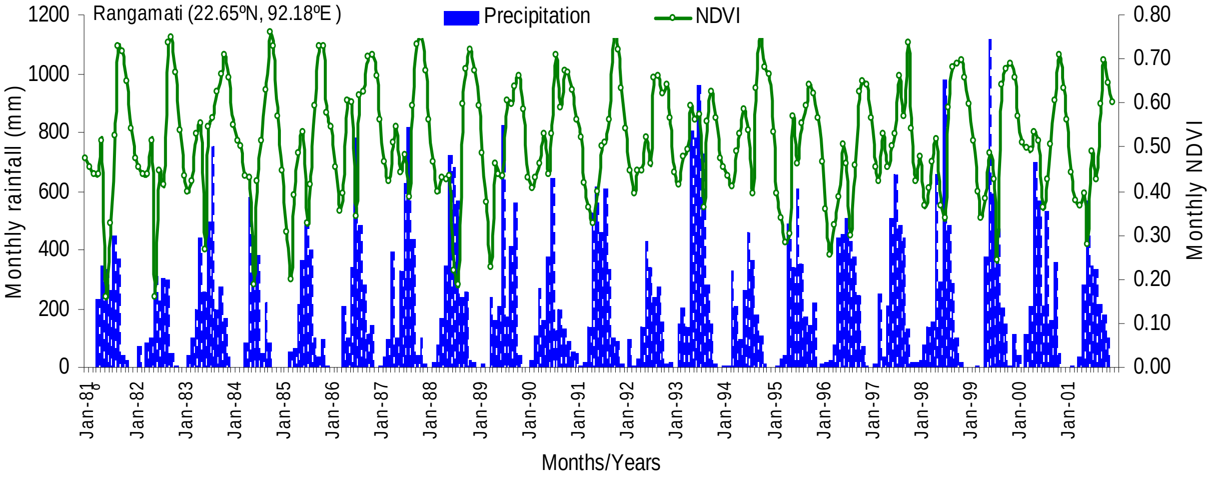


Figure 18. Correlation relationship between NDVI (all pixels) and rainfall (all pixels) in the CHT. Each dot represents one month



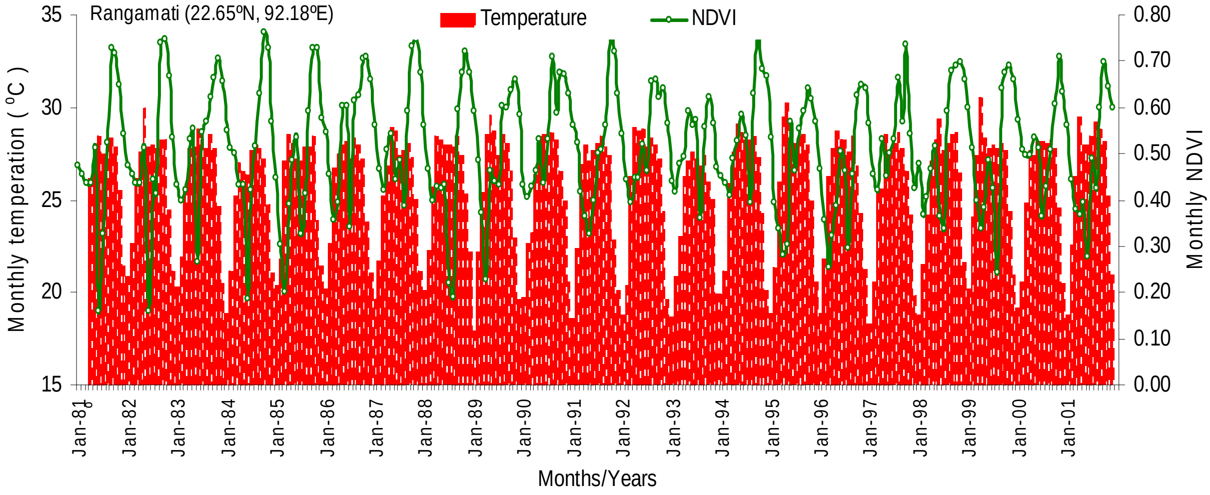


Figure 19. Rainfall, temperature and biomass at Rangamati, the CHT

3.5 Rain-use efficiency

Biomass fluctuates according to variation in rainfall, stage of growth, and changes in land use. Rain-use efficiency (RUE), the ratio of net primary production (NPP) to precipitation combines information on biomass production and rainfall. Negative deviations from normal range of RUE values are shown to be a robust indicator of land degradation where production is constrained by rainfall.

Arguably, production of biomass in CHT is not always constrained by rainfall; sometimes the rain is in large excess. Further local development of the index is required to assess its value as an indicator of land degradation.

Figure 20 shows the spatial pattern and temporal trend in rain-use efficiency over 1981-2002: over 78 per cent of the land area exhibited an upward trend; in the remaining area in the decreased RUE, three areas stand out as *black spots* of both declining biomass production and declining rain-use efficiency: the area around Lake kaptai, Baghai Chhari of Raangamati and Dighinala and Sadr of Khgrachhari, and South areas of Naikhongchhari and Alikadam, Bandarban District (Figure 20b, c).

In the CHT, the higher the rain-use efficiency, the larger variation (standard deviation) it is (comparing Figure 20a and Figure 21a).

3.6 Net primary productivity

Net primary productivity (NPP) is the rate at which vegetation in an ecosystem fixes CO_2 from the atmosphere (gross primary productivity, GPP) minus the rate at which the vegetation returns CO_2 to the atmosphere through plant respiration (Jiang and others 1999). NPP is vital to human society, both converting sunlight and CO_2 into essential materials (food, fibre and wood) and because it creates environments suitable for human inhabitation.

There are no field measurements of NPP for the CHT. Remote sensing of NPP fills this gap and is available at the regional scale.

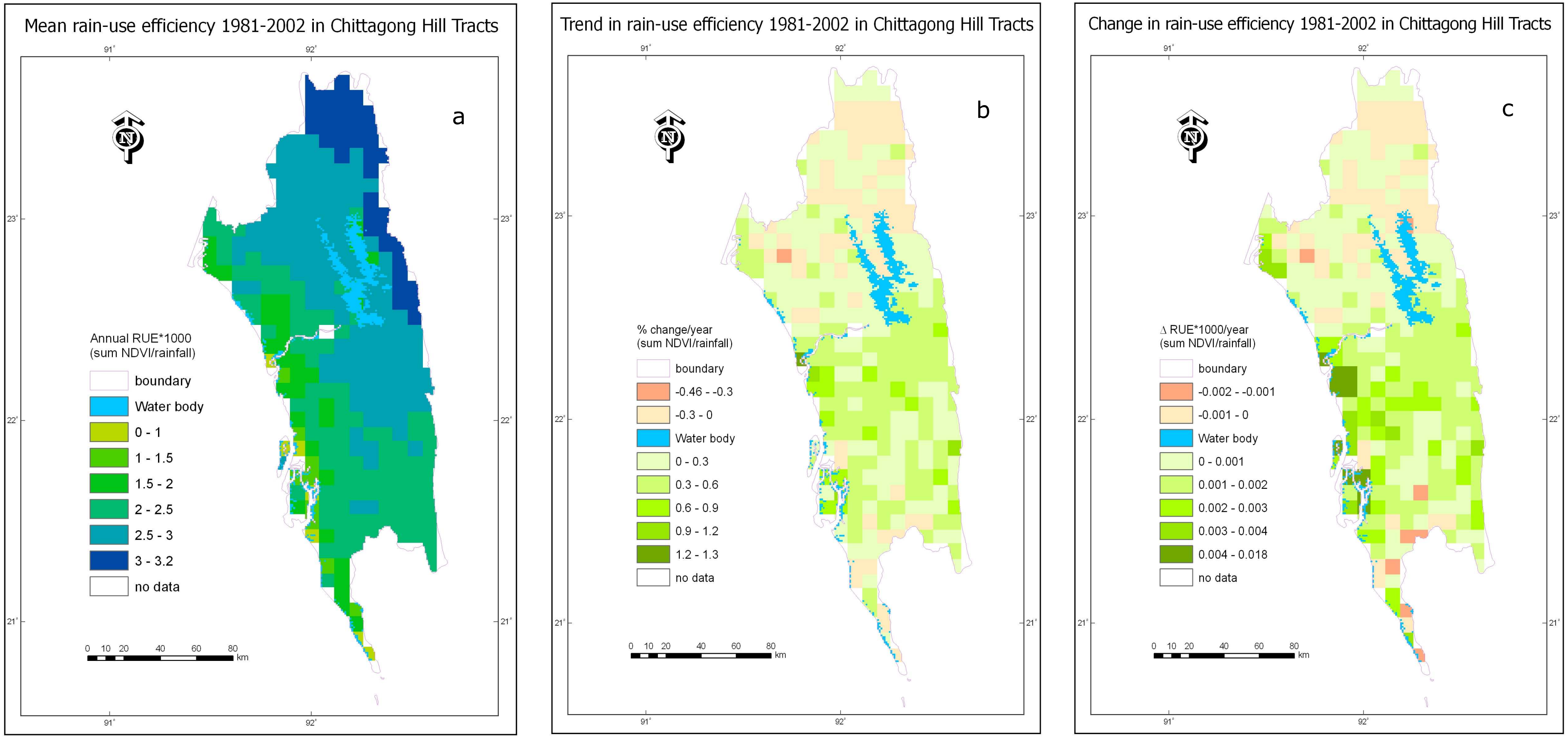


Figure 20. Spatial pattern (a) and temporal trends (b, c) in rain-use efficiency

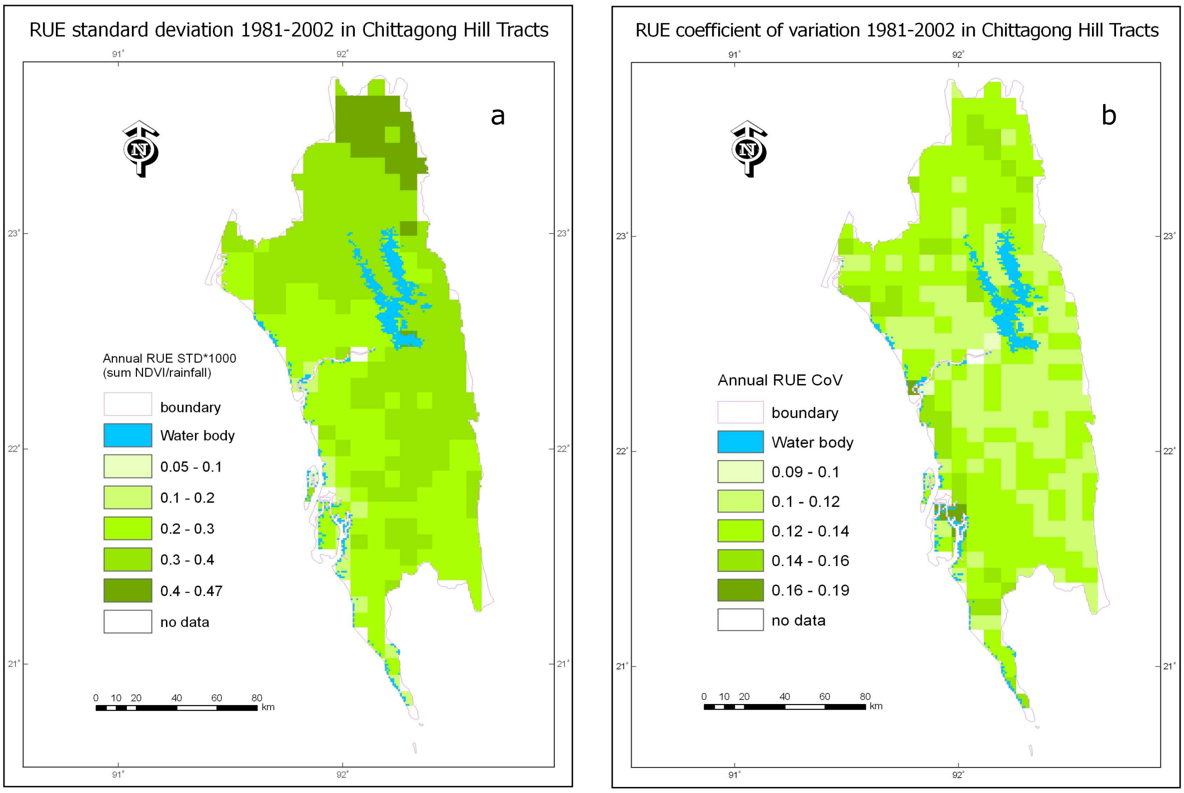


Figure 21. Spatial variability in RUE standard deviation and coefficient of variation

The MODIS NPP data (g C m^{-2} $year^{-1}$) were converted into dry organic matter or DM (ton ha^{-1} $year^{-1}$), taking 1.0 gram carbon being equivalent to 2.2 grams oven dry organic matter (organic matter = 45% carbon by weight) (ORNL NAAC, http://www-eosdis.ornl.gov/NPP/html_docs_grass_dict.html). Four-year (2000-2003) mean annual NPP for the CHT derived from the MOD17A3 NPP dataset at 1-km resolution were calculated and shown in Figure 22a. The 4-year mean annual NPP was re-sampled into 8-km resolution by neighbourhood statistics; four-year mean annual sum NDVI over the same period (2000-2003) was calculated. Correlation between the two raster data for the CHT was analyzed:

$$NPP_{MOD17}\ [DM,\ ton\ ha^{-1}\ year^{-1}] = 1.35 * NDVI_{sum} + 11.69 \qquad [1]$$
$(r = 0.66, n = 323, P<0.005)$

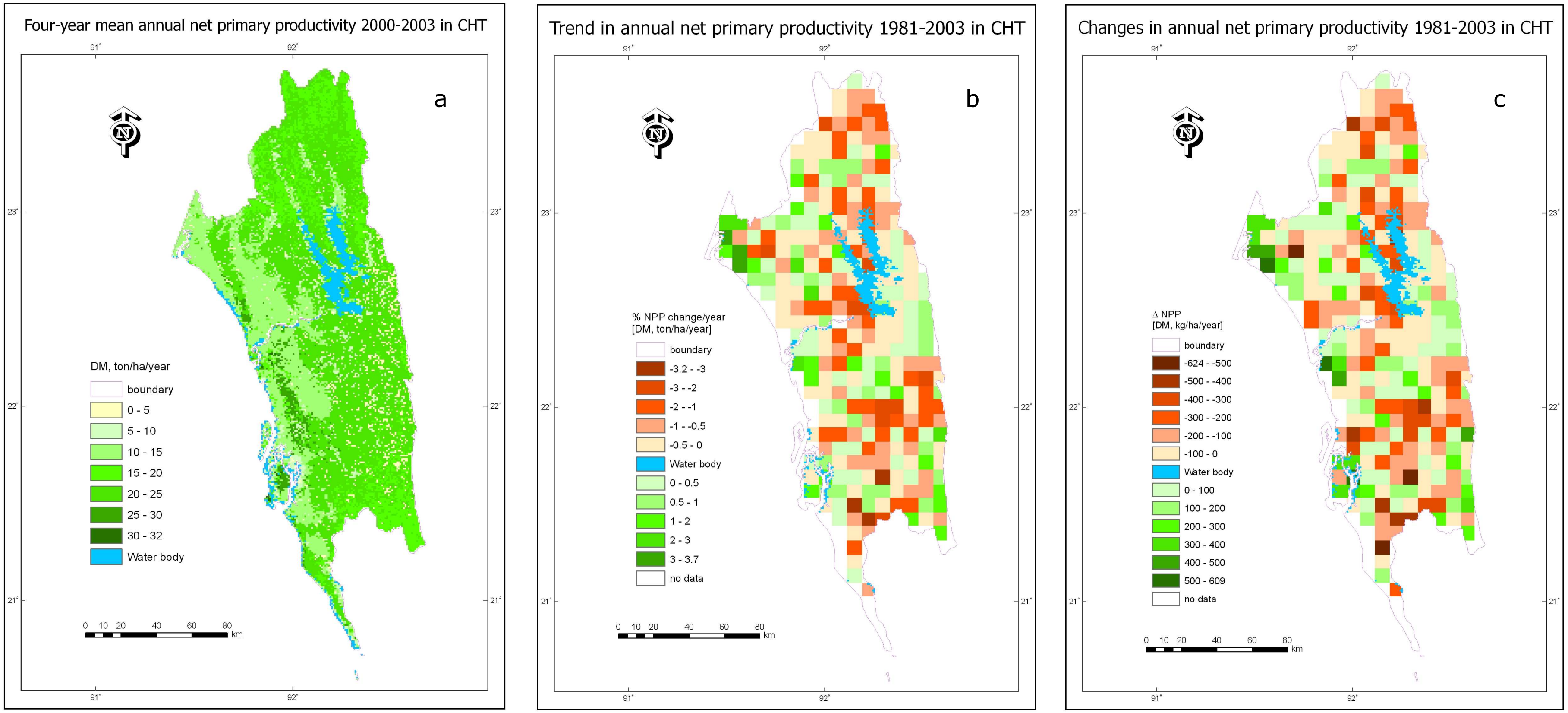
Where NPP_{MOD17} is annual net primary production derived from the MOD17A3, $NDVI_{sum}$ is 4-year (2000-2003) mean annual sum NDVI derived from the GIMMS. DM is dry organic matter.

Taking the four-year mean annual NPP as a default yearly biomass productivity for the CHT, and the regression trend in the annual sum NDVI over the 23-year period as deviation (Figure 2b, c), the percentage and absolute changes in net primary production were calculated and depicted in Figure 22b and c, respectively, and listed in Table 2.

Table 2. Changes in net primary production 1981-2003 in the CHT

	Positive	Negative	Average
Land area (pixels, %)	38	62	
% NPP change/year	0.78	0.80	-0.21
Δ NPP [DM, kg $ha^{-1}year^{-1}$]	160	161	-44

Statistics indicate that over the period 1981-2003, NPP decreased over about 62 per cent of land area with an average rate of 162 kg per hectare per year; 38 per cent increased with an annual mean rate of 160 kg per hectare; for the CHT as a whole, net primary production overall decreased by 44 kg per hectare per year (Table 2).


Four-year mean annual net primary productivity 2000-2003 in CHT

Trend in annual net primary productivity 1981-2003 in CHT

Changes in annual net primary productivity 1981-2003 in CHT

Figure 22. Pattern (a) and trends (b, c) in annual net primary production: b – percentage change; c – absolute change

3.7 *Black spots* of land degradation

In the CHT, over about 20 per cent of the land area has suffered both declining net primary productivity and declining rain-use efficiency over 1981-2003. These areas are the most likely *black spots* of land degradation: the area around Lake kaptai; border area between Khgrachhari and Rangamati districts; Naikhongchhari and Alikadam of Bandarban District (Figure 23).

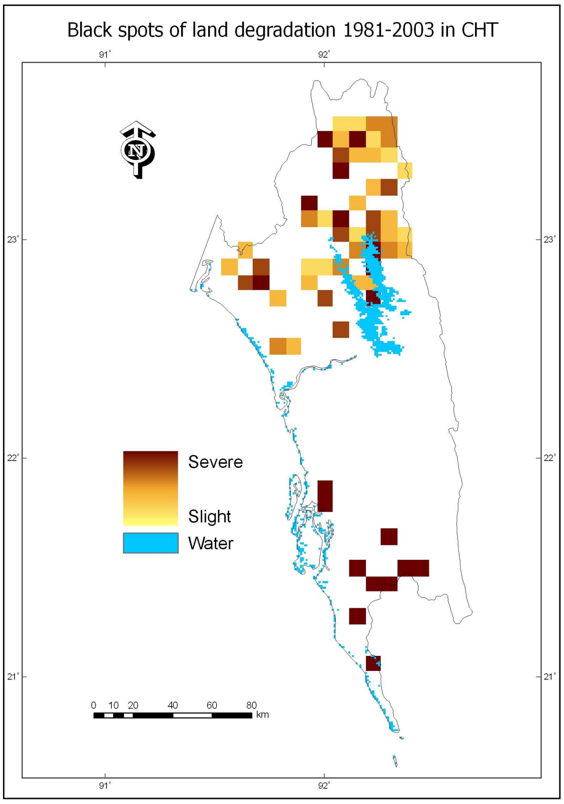


Figure 23. Pixels with both declining NPP and declining RUE over 1981-2003

The combined trends of biomass and rain-use efficiency may be a more robust indicator of land degradation or improvement than crude biomass but this requires much more local validation. Preliminary studies are reported below (3.8).

3.8 Field validation

Several *black spots* (A, B, C & D) and *bright spots* (E & F) in Figure 24, derived from Figure 22c, were selected for validation. Independent field surveys: ground truth for the five points (A, B, C, D & E) were carried out by Md. Abdul Alim, Bangladesh Centre for Advanced Studies (BCAS). Findings of the ground truth activities are presented bellow:

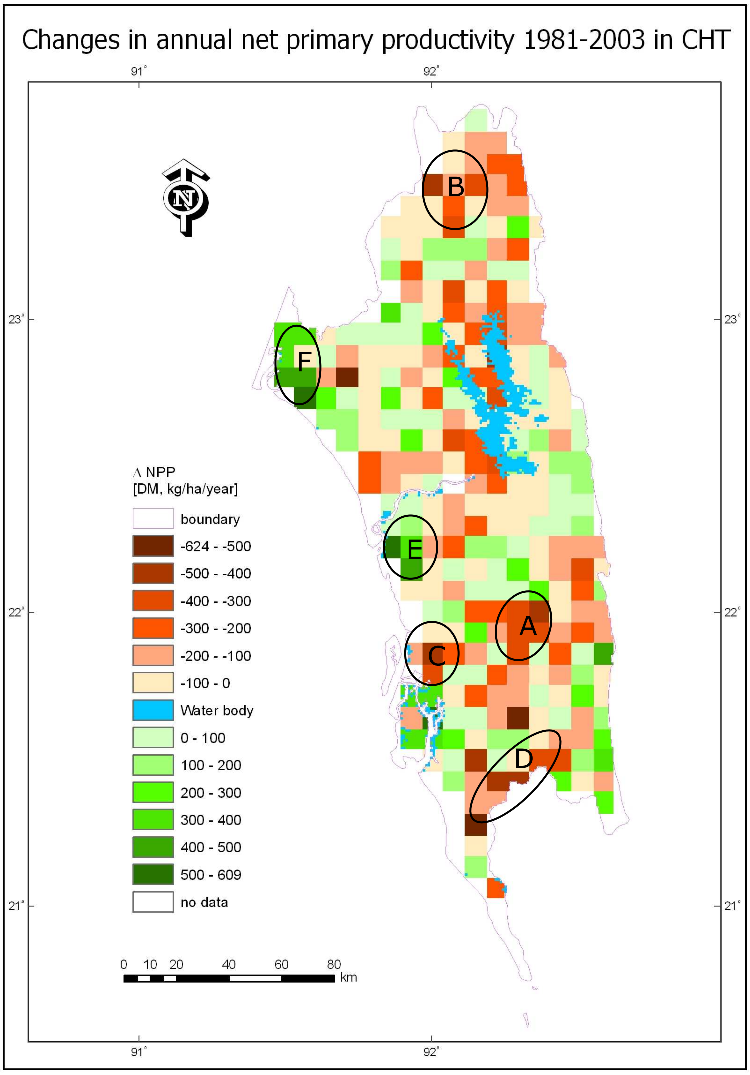
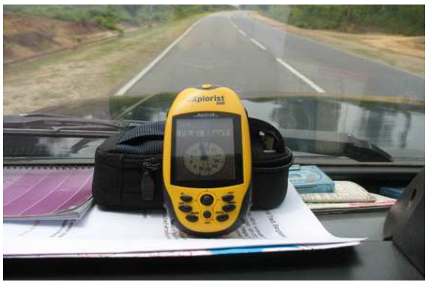


Figure 24. Sites chosen for field survey and validation

Site A: represents the hill country in the Ghalangya Union of Ruma Upazila of Bandarban District which shows a severe decline in biomass production.



Ground truth point navigation with GPS

People spoken with: Elders in Korang/Pali Karbari Para of Ghalangya Union of Ruma Upazila under Bandarban District.

Observation: The area comprises low and high hills, used for *Jhum* cultivation with a three-year fallow period. During the fallow and across the area not used for cultivation, vegetation is with jungle especially bamboo, herbs, and small trees.

Climate change: Local people report that over the last five to seven years, temperatures have increased while rainfall is decreasing, and the onset of the rainy season is delayed. This year it is delayed by a month.

Land-use change: Local people report that, before signing the Peace Accord with the Government, the area was covered by big *Gorjon* and *Champa* trees. After the Peace Accord in 1997, people from other parts of the country got access to the forest area and started to log these trees for profit. During that time, the river was only way to transport the timber.

A view of site 'A'

Accessibility became easier after the construction of Bandarban-Thanchi road in 1999/2000, which resulted in increase logging. As a result, the rate of deforestation increased and now there are no *Gorjon* and *Champ* trees left in the area. The area is now being used for *Jhum* cultivation with three-year fallow period. The rest of the land area is covered only with scrub so biomass production decreased considerably.

Site B: Hill country close to international border in the north. Remote sensing indicates of *black spots* of land degradation with decreasing biomass and decreasing RUE. The area is within Babu Chara Union of Dighinala Upazila of Khagrachari District. The Myani River passes through the area in a narrow valley.

People spoken with:
Nandalad Karbari, Vill: Jarul Chari, Union: Babu Chara, Upazila: Dighinala, District: Khagrachari

A view of area 'B'

Discussion with local people at area 'B'

Observation: The area consists of hills and a narrow valley. Hills are covered with degraded planted forest, mainly a teak; some areas are used for *Jhum* cultivation. North and west part, along the international border, is reserved forest (Naraichari) area. Valley areas are mainly used for rice cultivation.

Climate change: Local people report that temperature is increasing and rainfall is decreasing.

Land-use change: During 1960s and 70s, the area was covered with dense forest, even in the valley, and there are very few indigenous settlements. *Jhum* cultivation was practised with five-year fallow period. From 1980 onwards, the bottom lands were converted from forest to paddy to meet the demand of increased population. In 1985, 10-15 thousand households migrated to the neighbouring country due to political unrest. After signing Peace Accord, the refugees returned home during 1997-98 but did not get their land back because people from the plains occupied those areas. The homeless returned people entered into the forested land to build homes and clear land for cultivation.

Naraichari reserve forest area was very famous for its teak. After the Peace Accord in 1997, illegal logging stated and within 2/3 years it became degraded. There is no reforestation activity in the area.

Area 'C' was covered with this type of Gorjon tree

Site C: Area exhibiting declining trend of biomass. Area 'C' is within Harvang Union of Chakoria Upazila of Cox's Bazaar District. The area consists of *Tilas* (low altitude hills) and *Baid* (narrow valley).

People spoken with: Local elders and learned people.

Observation: *Tilas* belong to the Forest Department. Mostly covered with weeds; some area are newly afforested. *Baid* areas are used for rice cultivation.

Land-use change: Before 1980, the area was a dense forest area with big trees like *Gorjon*, *Chapalish* and *Jam* trees. After 1980, the forest was degraded by illegal logging. In 1983, Government initiated re-forestation under a wood-lot gardening program. During this program, the Forest Department cleared the degraded forest and replanted with exotic Acacia, Eucalyptus and Minzium but local people destroyed the planted forest and by 1990 and the area became almost barren.

Site D: Low hill country close to Burmese border in Dochhari Union of the Nikhongchori Upazila of Bandarban District.

People spoken with: Elders of Dochhari Union of Nikhongchari Upazila of Bandarban District.

Observation: Same as point 'A'.

Climate change: Same as point 'A'

Land use history of the site: Situation is the same as the area 'A'.

A view of area 'D'

Site E: A coastal plain of Anwara Upazila of Chittagong Distrist close to the Bay of Bengal, drained by many small canals. Remote sensing shows a significant increase in biomass.

People spoken with: 1. Chairman and members of Anwara Union Parishad; 2. Area manager, BRAC, Anwara Union; 3. Local elders

Observation: Agricultural land and settlement. Agricultural land grows various crops throughout the year. Homestead forest is very dense and appears forested from a distance.

Climate change: According to the local people, temperature is increasing, rainfall is decreasing, and frequency of storms and cyclones is increasing.

Land-use change: The cyclone of 1991 destroyed many houses and trees. After this disaster, government and private sectors started various programs including 'Coastal Green Belt Project' and awareness-building on the importance of plantations for reducing the impacts of cyclones. Huge plantation activities have been carried out under the Coastal Green Belt Project.

As a result, local people started homestead plantations. Except for the agricultural land, all other areas are now under planted trees and still increasing.

In 1974, *Boro* (dry season January - April) rice cultivation was introduced with irrigation from the canal. Dams keep out the saline water in the dry season, preserving fresh water from the upstream area. All cultivable land is now under Boro cultivation in the dry season which contributes to increased biomass production.

Follow-up:
Field investigation at sites B and E by José Ramón Olarieta, Universitat de Lleida, interviewed local people to try to better understand the land use changes occurring in the past 20 years.

Site B, north of the town of Khagrachari, showed a decrease in biomass because rice cultivation in the valleys was started in the 1980s, due also to settlers pushing locals to the hills, and to extraction of trees in the Forest Reserve after the 1997 peace agreement.

Site E, (south of the city of Chittagong) showed an increase in biomass since 1980s due to the availability of irrigation for a second rice crop, to plantation of trees along the roads after the 1990s cyclone, and to a government programme of tree plantation along the coast.

Further research would focus on the spatial relation between biomass and land use/cover change so as to identify *black spots* of biomass degradation to be addressed by policy and improved management.

4 SUMMARY AND CONCLUSIONS

Remote sensing of biomass can indicate land degradation and improvement. Combination of the biomass trend with rain-use efficiency trend may be a more robust indicator of land degradation than crude biomass but interpretation is not straightforward. The various NDVI patterns must be followed up by fieldwork to establish the actual conditions on the ground.

Green biomass and net primary productivity decreased over 62 per cent of the land area, the correlation coefficients of biomass to precipitation and temperature were moderate (0.74 and 0.49, respectively). Biomass growth lagged behind antecedent precipitation and temperature by some 3-4 months. Total annual rainfall decreased over the period.

Twenty per cent of the land area suffered a decrease in both declining net primary productivity and declining rain-use efficiency. These areas may be recognized as *black spots* of land degradation: the area around Lake Kaptai; border area between Khgrachhari and Rangamati districts; Naikhongchhari and Alikadam of Bandarban District.

Field investigation of 5 areas confirmed the evidence of remote sensing. Therefore, it may be concluded that analysis of NDVI/biomass data identifies *black spots* that should be addressed by policy and improved management.

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ABBREVIATIONS

APAR	Absorbed Photosynthetically Active Radiation
AVHRR	Advanced Very High Resolution Radiometer
BPLUT	Biome Properties Lookup Table
CHT	The Chittagong Hill Tracts
CoV	Coefficient of Variation
CRU TS	Climate Research Unit, Time Series
DM	Dry Organic Matter
EMDI	The Ecosystem Model–Data Intercomparison
ENSO	El Niño/Southern Oscillation Phenomenon
F_{APAR}	Fraction of Absorbed Photosynthetically Active Radiation
GIMMS	Global Inventory Modeling and Mapping Studies
GLASOD	Global Assessment of Human-Induced Soil Degradation
GPP	Gross Primary Productivity
LandSAT ETM+	Landsat Enhanced Thematic Mapper Plus
MEI	Multivariate ENSO Index
MOD15A2	MODIS 8-Day Net Photosynthesis
MOD17A3	MODIS 8-Day Net Primary Productivity
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity
ORNL	Oak Ridge National Laboratory
PAR	Photosynthetically Active Radiation
RUE	Rain-Use Efficiency
SeaWIFS	Sea-Viewing Wide Field-of-View Sensor
SPOT	Systėme Pour l’Observation de la Terra
SPSS	Statistical Package for the Social Sciences software
STD	Standard Deviation

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