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Land Degradation and Improvement in Cuba

1. Identification by remote sensing

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LADA

Land Degradation Assessment in Drylands

ISRIC World Soil Information

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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MAIN POINTS

1. **Land degradation is a global environment and development issue.** Up-to-date, quantitative information is needed to support policy and action for food and water security, economic development, environmental integrity and resource conservation. To meet this need, the Global Assessment of Land Degradation and Improvement uses remote sensing to identify degraded areas and areas where degradation has been arrested or reversed. This screening will be followed up in the LADA partner countries by field investigations to establish the situation on the ground.

2. **Land degradation and improvement is inferred from long-term trends of productivity when other factors that may be responsible (climate, soil, terrain and land use) are accounted for.** The remotely-sensed normalized difference vegetation index (NDVI) or greenness index is used as a proxy indicator of productivity; it may be translated to net primary productivity (NPP). Spatial patterns and temporal trends of NDVI combined with climatic indices are analysed for the period 1981-2003 at 8km resolution; land degradation is indicated by a declining trend of climate-adjusted NDVI and land improvement by an increasing trend.

3. **In Cuba, over the period of 1981-2003, net primary productivity increased overall.** Areas of decreasing climate-adjusted NPP occupy 29 per cent of the country, notably in the south-east. Over the 23 years, degrading areas, so defined, suffered an average loss of net primary production of 10 kgC/ha^{-1} year^{-1}.

4. **69 per cent of the degrading area is cropland – almost 30 per cent of the cultivated area** – mostly in the drier south east of the country.

5. **About 3.2 million people - 28 per cent of the population - depend directly on these degrading areas.** The correlation between land degradation and $\log_e$ population density is positive: the higher the population density, the more severe the degradation.

6. **Land improvement, defined by an increase in climate-adjusted net primary productivity, is identified across just over one per cent of the country.** Sixty per cent of the improving area is cropland – about 1 per cent of the cultivated area.

Key words: land degradation/improvement, remote sensing, NDVI, rain-use efficiency, net primary productivity, land use/cover, Cuba

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Abbreviations

CIESIN	Center for International Earth Science Information Network, Colombia University, Palisades, NY
CoV	Coefficient of Variation
CRU TS	Climate Research Unit, University of East Anglia, Time Series
ENSO	El Niño/Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations, Rome
GIMMS	The Global Inventory Modelling and Mapping Studies, University of Maryland
GLADA	Global Assessment of Land Degradation and Improvement
JRC	Joint Research Centre, European Commission, Ispra, Italy
LADA	Land Degradation Assessment in Drylands
Landsat ETM+	Land Resources Satellite, Enhanced Thematic Mapper
LUS	Land Use Systems, FAO
MOD17A3	MODIS 8-Day Net Primary Productivity dataset
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Productivity
RESTREND	Residual Trend of sum NDVI
RUE	Rain-Use Efficiency
SOTER	Soil and Terrain database
SPOT	Système Pour l'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme, Nairobi, Kenya
VASClimO	Variability Analyses of Surface Climate Observations

1 Introduction

Economic development, burgeoning cities and growing rural populations are driving unprecedented land-use change. In turn, unsustainable land use is driving land degradation: a long-term loss in ecosystem function and productivity that requires progressively greater inputs to repair the situation. Its symptoms include soil erosion, nutrient depletion, salinity, water scarcity, pollution, disruption of biological cycles, and loss of biodiversity. This is a global development and environment issue - recognised by the UN Convention to Combat Desertification, the Conventions on Biodiversity and Climatic Change, and Millennium Goals (UNCED 1992, UNEP 2007).

Quantitative, up-to-date information is needed to support policies for food and water security, economic development and the environment. The only harmonized assessment, the *Global assessment of human-induced soil degradation* (Oldeman and others 1991), is a map of perceptions - the kinds and degree of degradation, not a measure of degradation - and is now out of date. Within the FAO program *Land Degradation Assessment in Drylands* (LADA), the new *Global Assessment of Land Degradation and Improvement* (GLADA) maps degradation and improvement according to change in net primary productivity (NPP, the rate of removal of carbon dioxide from the atmosphere and its conversion to biomass).

Satellite measurements of the normalised difference vegetation index (NDVI or greenness index) for the period 1981-2003 are used as a proxy for NPP. NDVI data have been widely used in studies of land degradation from the field scale to the global scale (e.g. Tucker and others 1991, Bastin and others 1995, Stoms and Hargrove 2000, Wessels and others 2004, 2007, Singh and others 2006). However, remote sensing can provide only indicators of land degradation and improvement: a negative trend in greenness does not necessarily mean land degradation, nor does a positive trend necessarily mean land improvement. Greenness depends on several factors including climate (especially fluctuations in rainfall, temperature, sunshine and the length of the growing season), land use and management; changes may be interpreted as land degradation or improvement only when these other factors are accounted for.

Where productivity is limited by rainfall, rain-use efficiency (RUE, the ratio of NPP to rainfall) accounts for variability of rainfall and, to some extent, local soil and terrain characteristics. RUE is strongly correlated with rainfall; in the short term, it says more about rainfall fluctuation than land degradation but we judge that its long-term trends distinguish between rainfall variability and land degradation. To get around the correlation of RUE with rainfall, Wessels and others (2007) have suggested the alternative use of residual trends of NDVI (RESTREND) – the difference between the observed NDVI and that modelled from the local rainfall-NDVI relationship. In this report, land degradation is identified by a declining trend in *both* NDVI and RUE; in addition the comparable RESTREND values are presented.

The pattern of land degradation is further explored by comparisons with soil and terrain, land cover, and socio-economic data. In the LADA program, areas identified by this first screening will be validated and characterized in the field by national teams.

2 Context and methods

2.1 LADA partner country: Cuba

Land degradation is widespread in Cuba. It threatens food and water security, economic development, natural resources and the environment; its symptoms are soil erosion, nutrient depletion including depletion of soil organic matter, soil compaction, salinity and sodicity. According to Herrera and others (1986), some 70 per cent of the country has suffered from soil erosion, a quarter of which is rated as serious. The immediate causes are deforestation, shifting cultivation without adequate fallows, overgrazing, and poor uptake of soil conservation practices. Apart from loss of topsoil by erosion, soil organic is lost under cropping without incorporation of crop residues, manure or compost, particularly under mono-cropping. Nutrient depletion and acidification are related symptoms of land degradation. Soil salinity is attributed to overexploitation of groundwater and inadequate drainage.

2.2 Data

2.2.1 NDVI and net primary productivity

The NDVI data from July 1981 to December 2003 used in this study are produced by the Global Inventory Modelling and Mapping Studies (GIMMS) group from measurements made by the AVHRR radiometer on board US National Oceanic and Atmospheric Administration satellites. The fortnightly images at 8km-spatial resolution are corrected for calibration, view geometry, volcanic aerosols, and other effects not related to vegetation cover (Tucker and others 2004). These data are compatible with those from other sensors such as MODIS, SPOT Vegetation, and Landsat ETM+ (Tucker and others 2005, Brown and others 2006).

To provide a measure of land degradation and improvement open to economic analysis, the GIMMS NDVI time series has been translated to NPP using MODIS (moderate-resolution imaging spectro-radiometer) data for the overlapping period 2000-2003. MOD17A3 is a dataset of terrestrial gross and net primary productivity, computed at 1-km resolution at an 8-day interval (Heinsch and others 2003, Running and others 2004). Though far from perfect (Plummer 2006), the dataset has been validated in various landscapes (Fensholt and others 2004, 2006, Gebremichael and Barros 2006, Turner and others 2003, 2006); MODIS gross and net primary productivity are related to observed atmospheric CO_2 and the inter-annual variability associated with the ENSO phenomenon, indicating that these data are reliable at the regional scale (Zhao and others 2005, 2006).

2.2.2 Climatic data

The VASClimO 1.1 dataset comprises the most complete monthly precipitation data for 1951-2000, compiled on the basis of long, quality-controlled station records, 10 in Cuba, gridded at resolution of 0.5° (Beck and others 2005); monthly rainfall data since January 1981 were used for this analysis, supplemented by the GPCC full re-analysis product (Schneider and others 2008) to produce rainfall values matching the GIMMS NDVI data. Mean annual temperature values from the CRU TS 2.1 dataset (Mitchell and Jones 2005) of monthly, station-observed values also gridded at 0.5° resolution, were used to calculate the aridity index and energy-use efficiency.

2.2.3 Soil and terrain

The global Soil and Terrain database (SOTER) comprises harmonized spatial and soil-attribute data, incorporating the 90m-resolution SRTM digital elevation model (Engelen and others 2005). The updated 1:5million *Soil and terrain database for Latin America and the Caribbean* (Dijkshoorn and others 2005) has been used in this preliminary analysis; a 1:1million soil and terrain dataset for Cuba has been compiling for further analysis of land degradation in relation to soils and terrain (Engelen and others 2008).

2.2.4 Land cover and land use

Land Cover 2000 global land cover data (JRC 2003) (Figure 1) and *Land use systems of the World* (FAO 2008) have been generalised for Cuba for preliminary comparison with NPP trends.

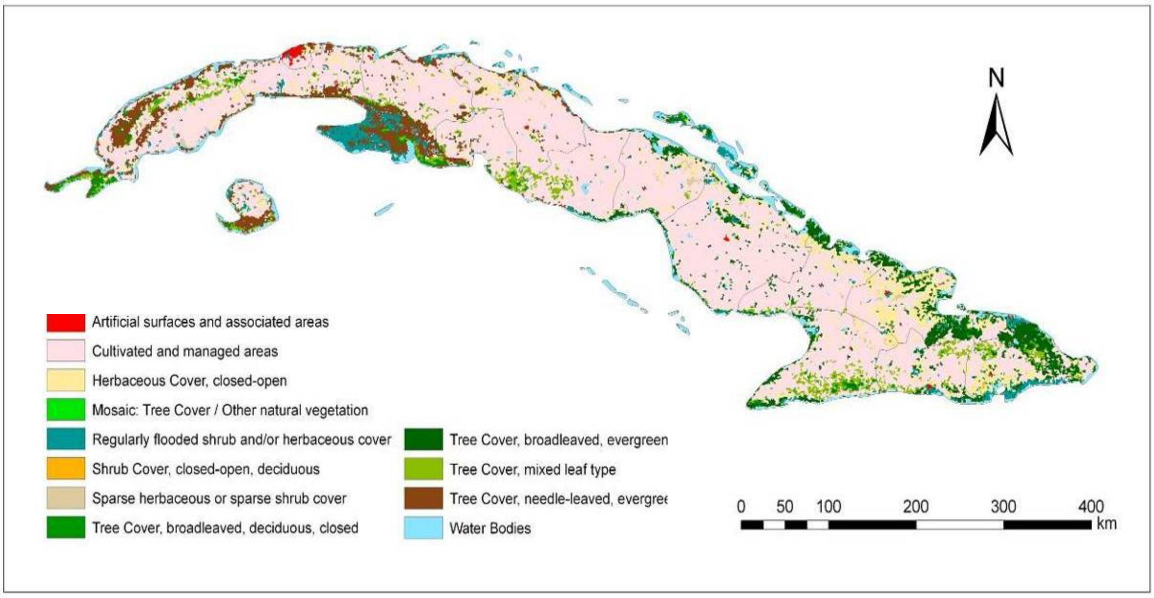

Figure 1. Main land cover types
(JRC 2003)

2.2.5 Population, urban areas and poverty indices

The CIESIN Global Rural-Urban Mapping Project provides data for population and urban extent, gridded at 30 arc-second resolution (CIESIN 2004); for this study, the Urban/Rural Extents dataset is used to mask the urban area. Sub-national rates of infant mortality and child underweight status and the gridded population for 2005 at 2.5 arc-minutes resolution (CIESIN 2005) were compared with indices of land degradation.

2.2.6 Aridity index

Turc's aridity index was calculated as P/PET where P is annual precipitation in mm and $PET = P/\sqrt{(0.9 + (P/L)^2)}$ where L = 300 + 25T + 0.05T^3 where T is mean annual temperature (Jones 1997). Precipitation was taken from the gridded VASClimO data, mean annual temperature from the CRU TS 2.1 data.

2.3 Analysis

Areas of land degradation and improvement are identified by a sequence of analyses of remotely sensed data:

1. Simple NDVI indicators: NDVI minimum, maximum, maximum-minimum, mean, sum, standard deviation and coefficient of variation. Their trends are analysed over the 23-year period of the GIMMS data (Appendix 2).
2. The annual sum NDVI, representing the aggregate of greenness over the year, period is chosen as the standard proxy for annual biomass productivity. NDVI is translated to net primary productivity (NPP) by correlation with MODIS data.
3. To distinguish between declining productivity caused by land degradation and decline owing to rainfall variability, the following procedure was adopted:
    a. Identify the areas where there is a positive relationship between productivity and rainfall, i.e. where rainfall determines NPP;
    b. For those areas where rainfall determines productivity, RUE is considered: where productivity declined but RUE increased, declining productivity is attributed to declining rainfall and these areas are masked;
    c. For the remaining areas with a positive relationship between productivity and rainfall but declining RUE, and also for areas where there is a negative relationship between NDVI and rainfall, i.e. humid and irrigated areas where rainfall does not determine NPP, NDVI trend was calculated as *RUE-adjusted NDVI;*
    d. Land degradation is indicated by a negative trend in RUE-adjusted NDVI and may be quantified as *RUE-adjusted NPP.*

4. Residual trends of NDVI (RESTREND).
5. Energy-use efficiency – ratio of annual sum NDVI to accumulated temperature, combined with RUE-adjusted NPP to arrive at climate-adjusted NPP.
6. Calculation of loss of NPP in degrading areas.
7. Comparison of climate-adjusted NPP with land cover and land use, aridity, soil and terrain, rural population density and indices of poverty.

Details of the analytical methods are given as Appendix 1. Algorithms have been developed that enable these screening analyses to be undertaken automatically.

At the next stage of analysis, areas of land degradation and improvement identified on the basis of NDVI indices will be characterised manually, using 30m-resolution Landsat data, to identify the probable kinds of land degradation and relationships with land use change. At the same time, the continuous field of the index of land degradation derived from NDVI and climatic data will enable a statistical examination of other data for which continuous spatial coverage is not available - for instance spot measurements of soil attributes, and other social and economic data that may reflect the drivers of land degradation, provided that these other data are geo-located.

Finally, field examination of the identified areas of degradation and improvement will be undertaken by national teams within the LADA program.

3 Results

The spatial patterns and temporal trends of several indicators of land degradation and improvement are presented in Appendix 2. The main text deals with interpretation of the annual sum NDVI data which are taken to represent annual green biomass production.

3.1 Trends in biomass productivity

Biomass productivity fluctuates according to rainfall cycles. Countrywide, greenness increased over the period 1981-2003 (Figure 2, Table A1).

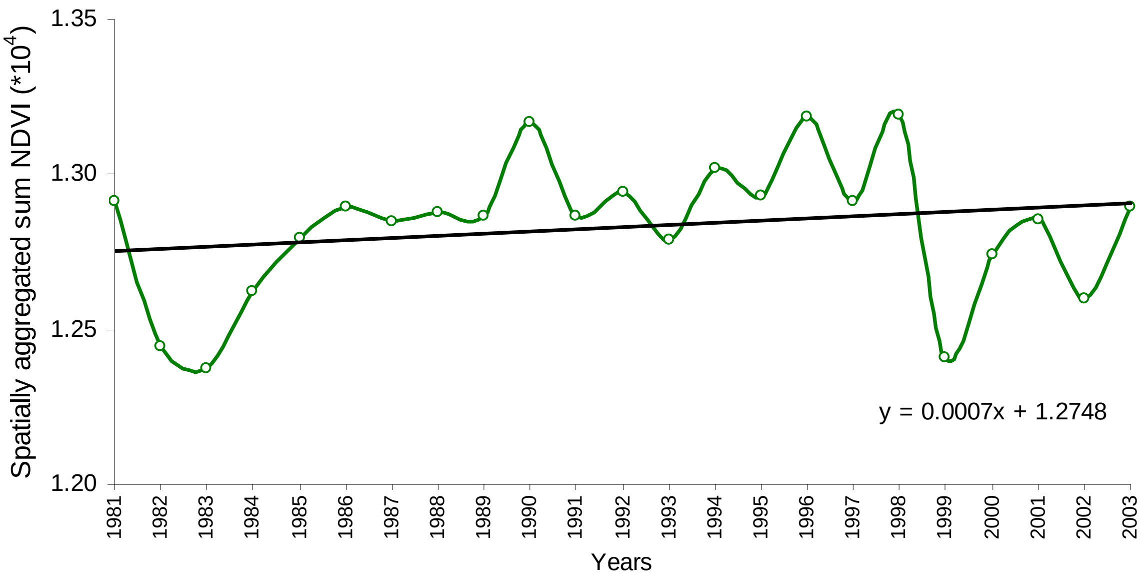

Figure 2. Spatially aggregated annual sum NDVI 1981-2003, $p<0.001$

Figure 3 depicts the pattern and trends of annual sum NDVI indicator for each pixel, determined by the slope of the linear regression equation; the trends increased across 63 per cent of the country and decreased over 37 per cent; confidence levels refer to T-test values.

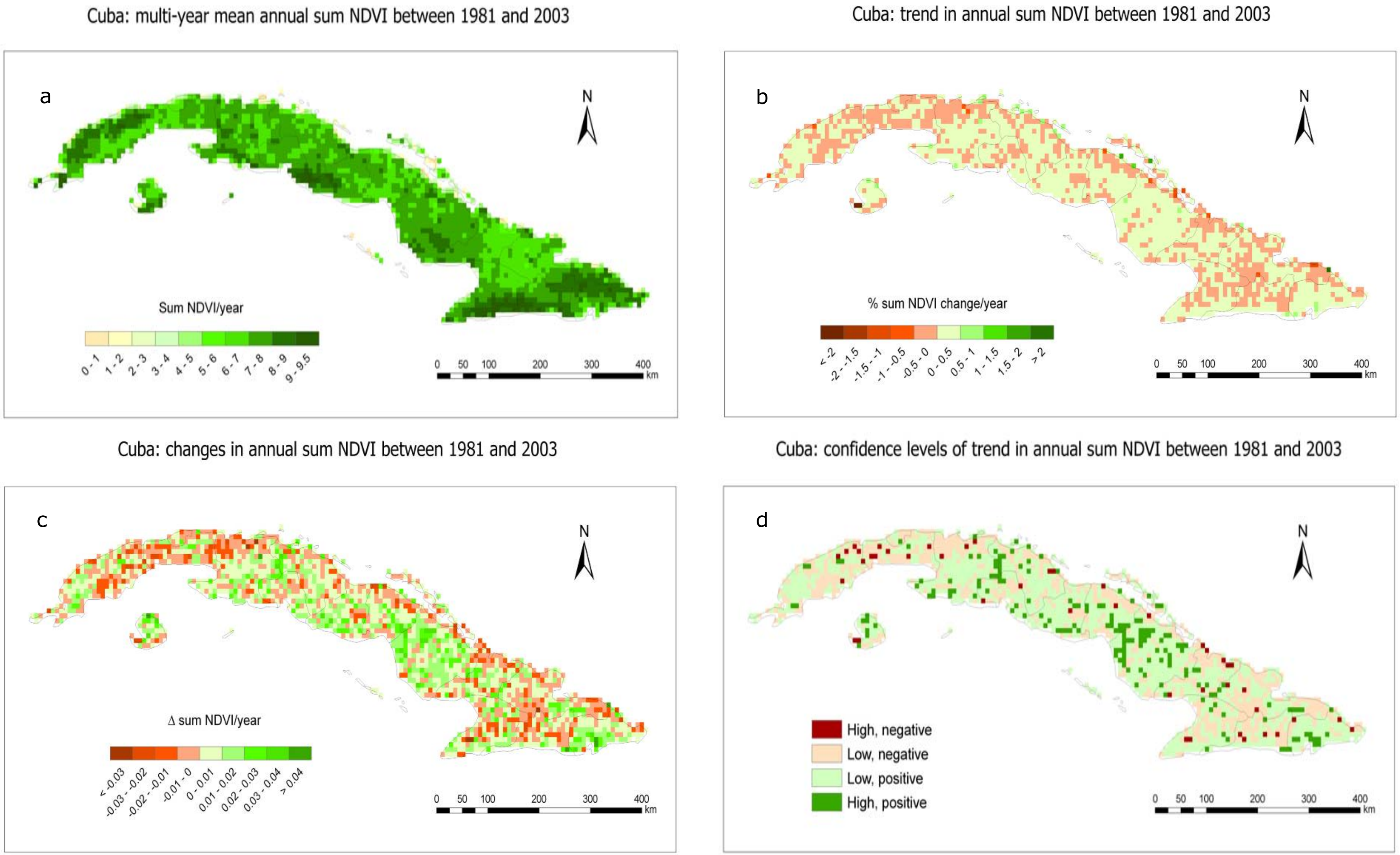

Figure 3. Annual sum NDVI 1981-2003
Pattern (a), trends (b – % change, c – absolute change) and confidence levels (d)

3.2 Spatial patterns of biomass and rainfall

Biomass productivity varies according to rainfall, stage of growth and changes in land use, as well as land quality. Rainfall varies both cyclically (Figure 4) and across the country (Figure 5b, c). Statistics show a weak negative correlation between NDVI and annual rainfall:

$$NDVI_{ann.\ sum} = 0.00059*Rainfall\ [mm\ yr^{-1}] + 8.144 \quad [1]$$

(r=-0.12, n=1 551)

The error in the regression model [1] is: slope (0.00059) ± 0.0003; intercept (8.144) ± 0.306.

For Cuba as a whole, rainfall increased over the study period, at an average of 7.4mm annually; increasing over 83 per cent of the country (with an annual rate of 9mm); decreasing over 11 per cent (average rate of 6mm), in particular across north Pinar del Rio, Ciudad de la Habana, La Habana and east Villa Clara; there was no overall change across 6 per cent of the country.

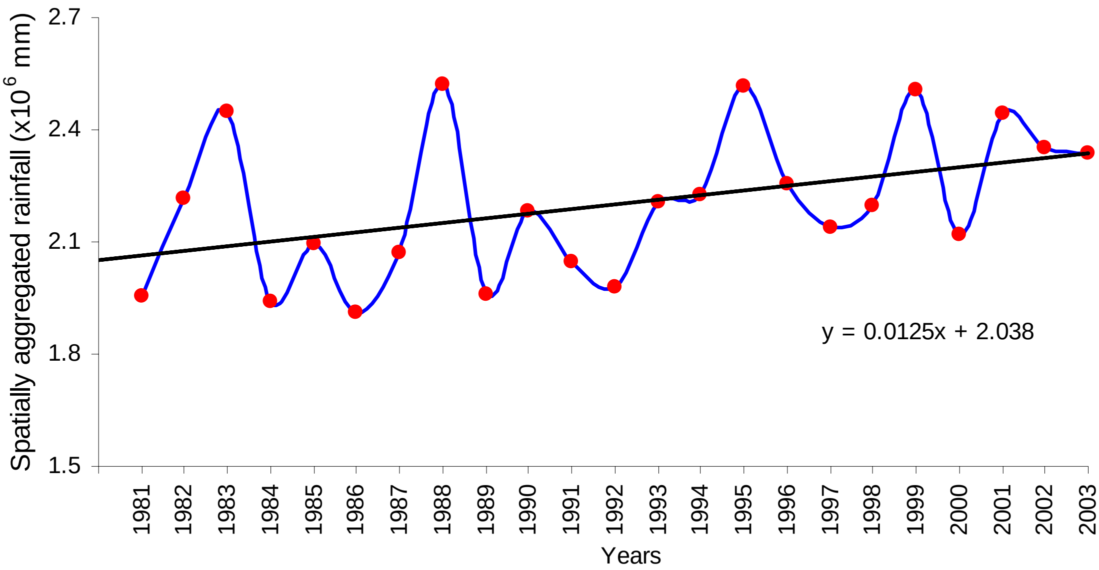

Figure 4. Spatially aggregated annual rainfall 1981-2003

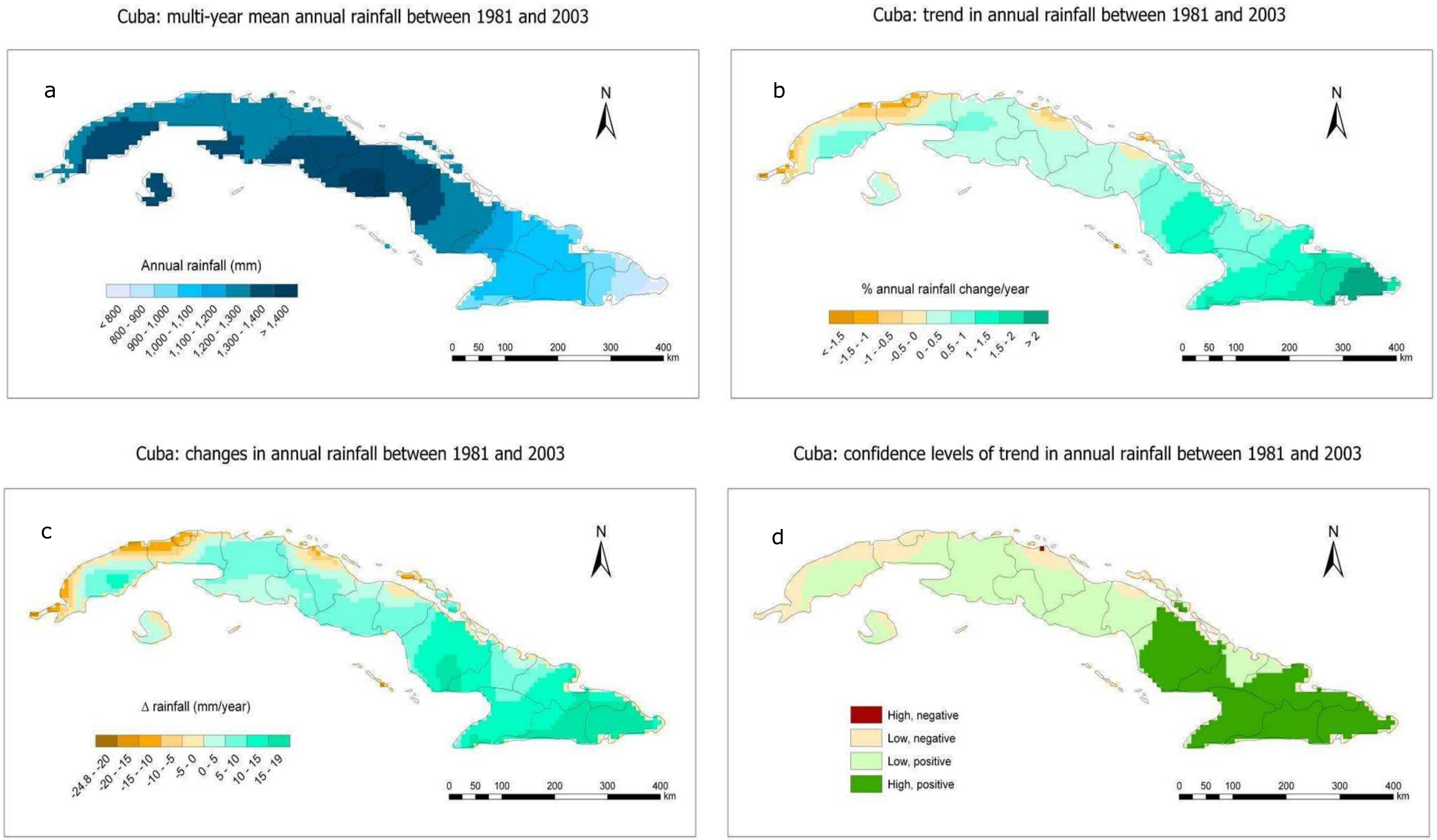

Figure 5. **Annual rainfall 1981-2003**
Spatial pattern (a), temporal trends (b – percentage change, c – absolute change, confidence levels d)

Over the same period, biomass productivity increased overall. However, the correlation with rainfall is weak at pixel level, equation [1], and also for the country as a whole (Figure 6). This situation contrasts with most other LADA partner countries, such as South Africa (Bai and Dent 2007), where rainfall is the dominant factor explaining variation in biomass productivity.

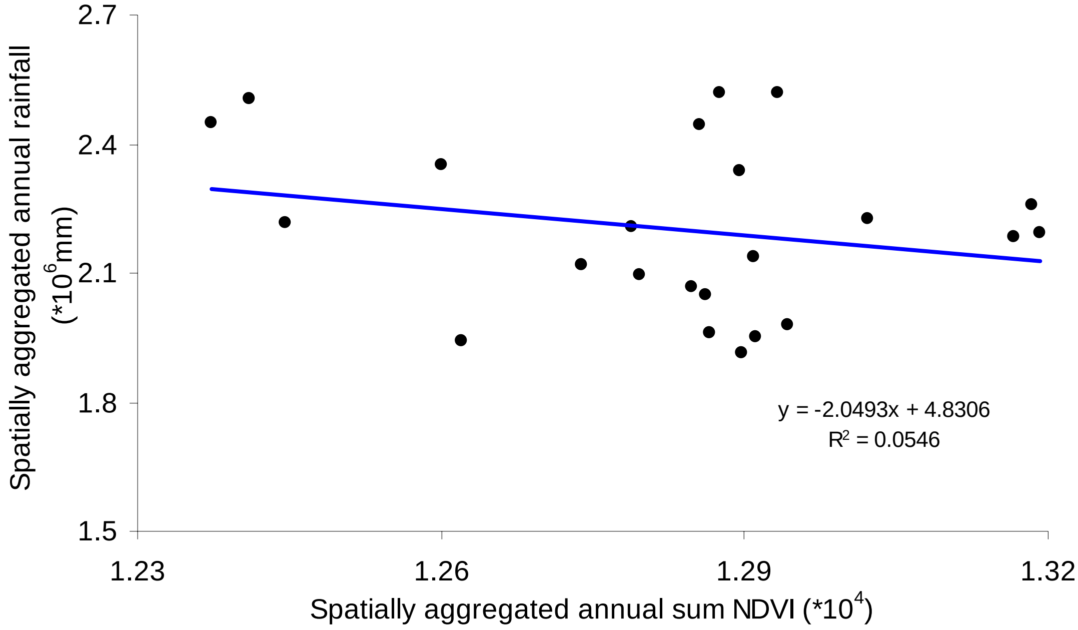

Figure 6. Relationship between annual sum NDVI (all pixels) and annual rainfall (all pixels)
Each dot represents one year, $p<0.01$

3.3 Rain-use efficiency

Allowance may be made for the effect of fluctuations in rainfall on biomass productivity of by considering rain-use efficiency (RUE), i.e. production per unit of rainfall. RUE may fluctuate dramatically in the short term - often, there is a sharp decline in RUE in a wet year and we may assume that the vegetation, whether cultivated or semi-natural, cannot make immediate use of the additional rain. However, where rainfall is the main limiting factor on biomass productivity, we judge that the long-term trend of RUE is a good indicator of land degradation or improvement (Houérou 1984, 1988, 1989; Snyman 1998; Illius and O'Connor 1999; O'Connor and others 2001). RUE also accommodates the effects of local variations in slope, soil and vegetation (Justice and others 1991).

In North China and Kenya, Bai and others (2005, 2006) demonstrated that values for RUE calculated from NDVI, *which are easy to obtain*, were comparable with those calculated from measurements of net primary productivity, which are not easy to obtain. For Cuba, RUE was calculated as the ratio of annual sum NDVI and station-observed annual rainfall.

Figure 7 shows mean annual RUE and its trend over the period of 1981-2003: RUE is generally higher in drylands than in humid areas - which generate drainage to streams and groundwater (Figure 7a). Over the period 1981-2003, RUE decreased over 87 per cent of the country, notably in the south-east, and increased over 13 per cent of the country. Confidence levels are assessed by the T-test.

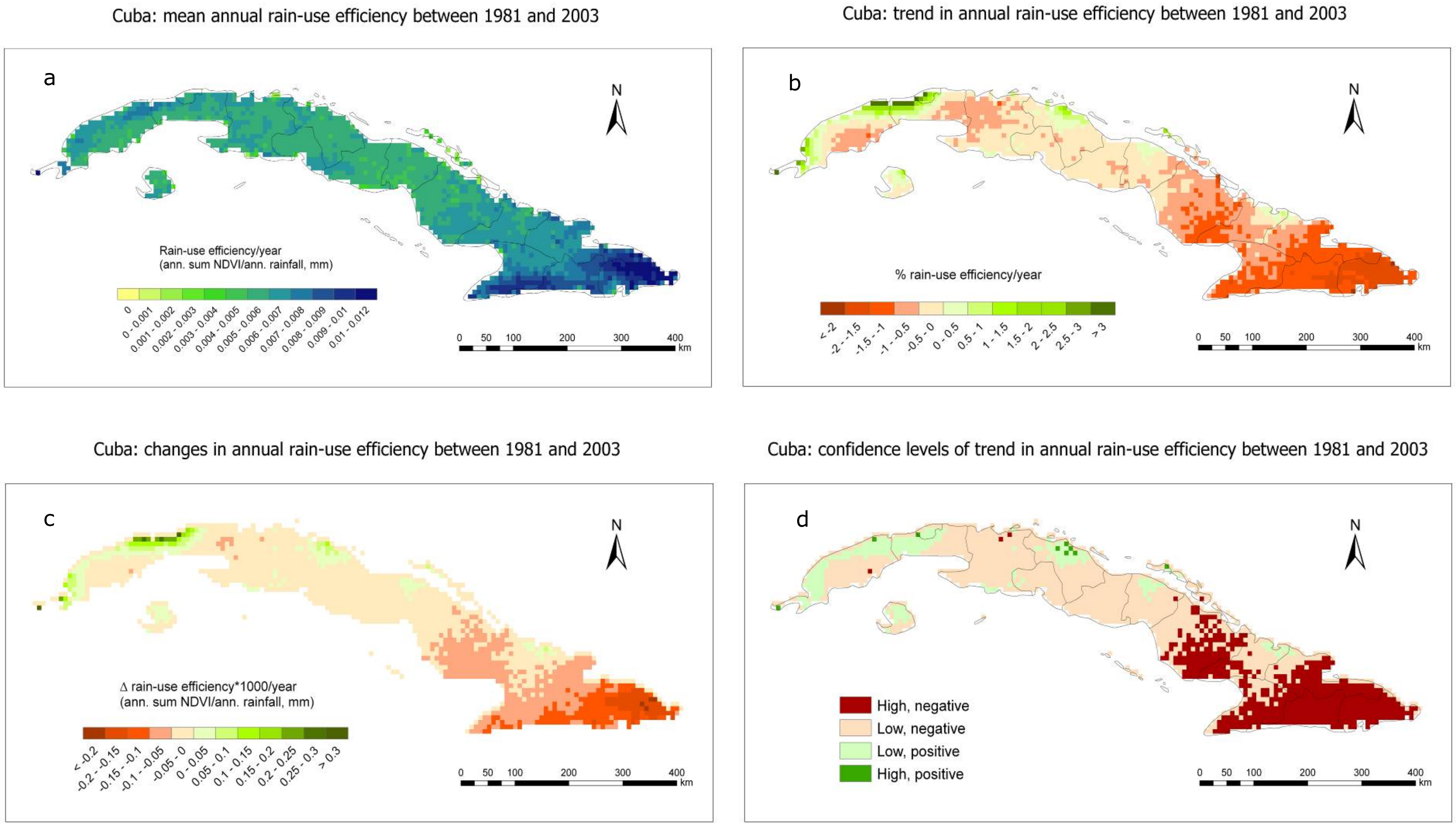

Figure 7. Rain-use efficiency 1981-2003: spatial pattern (a) and temporal trend (b – percentage changes, c – absolute changes, confidence d)

3.4 RESTREND

Countrywide, there is a significant negative correlation between RUE and rainfall (r=-0.81, n=1551) and RUE fluctuates wildly from year to year so that RUE, used in isolation, says as much about rainfall variability as about land degradation. To avoid the correlations between RUE and rainfall, and to distinguish land degradation from the effects of rainfall variability, Wessels and others (2007) suggest the alternative use of Residual Trends (RESTREND).

Following their general procedure, we have correlated for each pixel annual sum NDVI and annual rainfall. The resulting regression equation represents the statistical association between observed sum NDVI and rainfall (Figure 8a, b); the model predicts sum NDVI according to rainfall. Residuals of sum NDVI (i.e. differences between the observed and predicted sum NDVI) for each pixel were calculated, and the trend of these residuals (RESTREND) was analysed by linear regression (Figure 8c). T-test confidence levels are shown in Figure 8d.

RESTREND points in the same direction as RUE: a negative RESTREND may indicate land degradation, a positive RESTREND improvement but the spatial distribution is different from RUE; overall, RESTREND patterns are remarkably close to sum NDVI of lesser amplitude (Figure 3c), see Section 3.9.

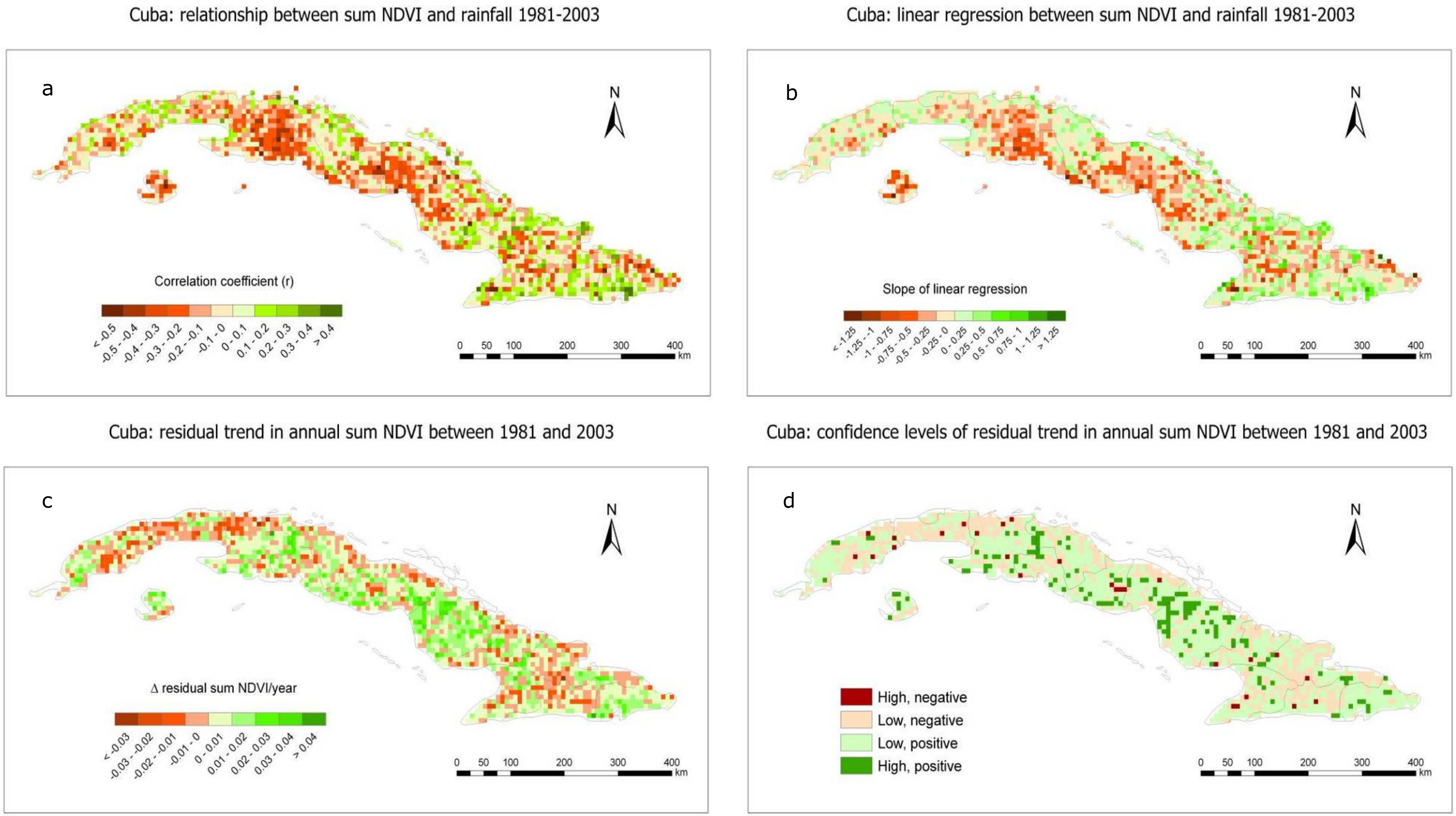

Figure 8. Residual trend of sum NDVI (RESTREND) 1981-2003
(a) Correlation coefficient between sum NDVI and annual rainfall; (b) Slope of linear regression between sum NDVI and rainfall; (c), RESTREND; (d) Confidence levels of RESTREND

3.5 Net primary productivity

It is hard to visualise the degree of land degradation and improvement from NDVI. For a quantitative estimation, NDVI may be translated to net primary productivity (NPP) - the rate at which vegetation fixes CO_2 from the atmosphere less losses through respiration; in other words, biomass productivity – which includes food, fibre and wood.

The most accessible global NPP data are from the MODIS model (at 1km resolution from the year 2000). Figure 9a shows four-year (2000-2003) mean annual MODIS NPP at 1-km resolution; the pattern is similar to the GIMMS annual sum NDVI (Figure 3a) but at finer detail. We have translated the 1981-2003 GIMMS NDVI data to NPP by correlation with MODIS 8-day NPP values for the overlapping period.

MODIS four-year annual mean NPP was re-sampled to 8km resolution by nearest neighbour assignment; the four-year mean annual sum NDVI over the same period (2000-2003) was then calculated. Correlation between the two data sets is moderate:

$$NPP_{MOD17}\ [\text{tonneC ha}^{-1}\ \text{year}^{-1}] = 0.556 * NDVI_{sum} + 4.602 \quad [2]$$

$(r = 0.6, n = 1\ 806, P<0.01)$

Where NPP_{MOD17} is annual NPP derived from MOD17, $NDVI_{sum}$ is a four-year (2000-2003) mean annual sum NDVI derived from GIMMS, C is carbon. Error or uncertainty in the regression model [2] is: slope (0.556) ± 0.077; intercept (4.602) ± 0.555. Correlation between the two raster data for all land cover types is only moderate but very high globally (Bai and others 2008) so the MOD17A3 NPP product has been used to convert the NDVI values to NPP. The translation is approximate.

The percentage and absolute changes in NPP over the period 1981-2003 are mapped in Figure 9b and c; the confidence level refers to the T-test (Appendix 1). During the period, there was a slight overall increase in NPP (Table 1).

Table 1. Changes in net primary productivity 1981-2003

	Positive	*Negative*	*Average*
Land area (%)	63	37	
% NPP change/year (tonneC ha^{-1} year^{-1})	0.13	0.08	0.06
Δ NPP (kgC ha^{-1} year^{-1})	12.2	8.1	4.52

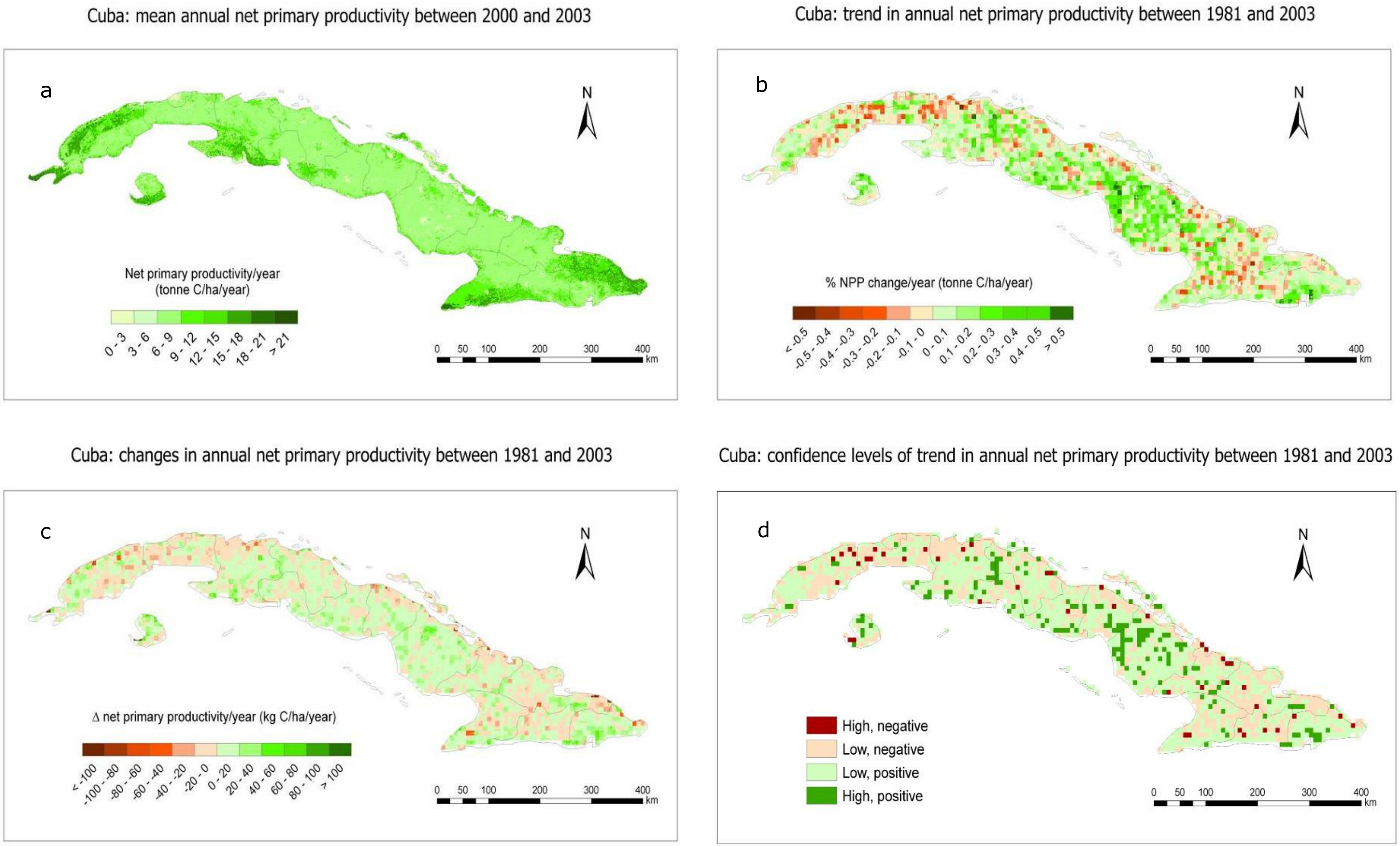

Figure 9. Net primary productivity: mean (a), trends (b, % change; c, absolute change); confidence level (d)

3.6 Land degradation

Land degradation means a loss of NPP but a decrease in NPP is not necessarily land degradation. To distinguish between declining productivity caused by land degradation and decline due to other factors, it is necessary to eliminate false alarms arising from climatic variability and changes in land use and management.

Rainfall variability: has been taken into account by using both rain–use efficiency (RUE) and RESTREND. RUE is considered by, first, identifying pixels where there is a positive relationship between productivity and rainfall. For those areas where productivity depends on rainfall *and* where productivity declined but RUE increased, we attribute the decline of productivity to drought. Those areas are masked (urban areas are also masked). NDVI trends are presented for the remaining parts of the country as RUE-adjusted NDVI.

Countywide, 29 per cent of the country suffered declining RUE-adjusted NDVI (Figure 10).

Cuba: proxy assessment of land between 1981 and 2003

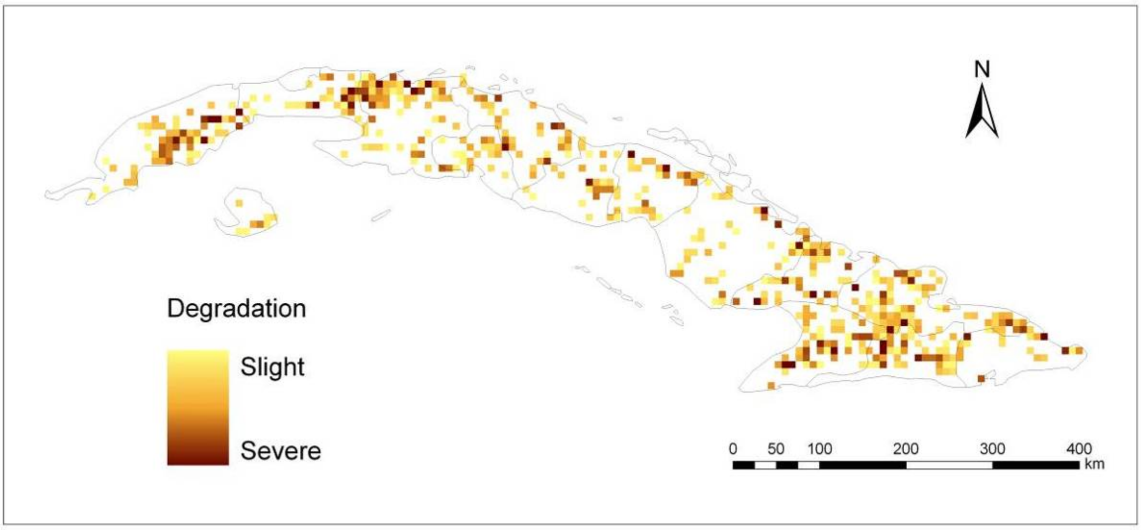

Figure 10. Negative trend in RUE-adjusted annual sum NDVI, 1981-2003

Quantitative estimation: Table 2 and Figure 11 present a pixel-based estimate of the loss of NPP compared with the average over the period 1981-2003.

Table 2. Cuba and World: NPP loss in degrading land between 1981 and 2003

	Degrading land (km^2)	*% territory*	*% global degrading land*	*NPP loss, (kgC/ha/yr)*	*Total NPP loss (TonneC/23yr)*
Cuba	32 430	29.3	0.10	10.1	755 493
Globe	35 058 104	23.5	100	11.8	955 221 419

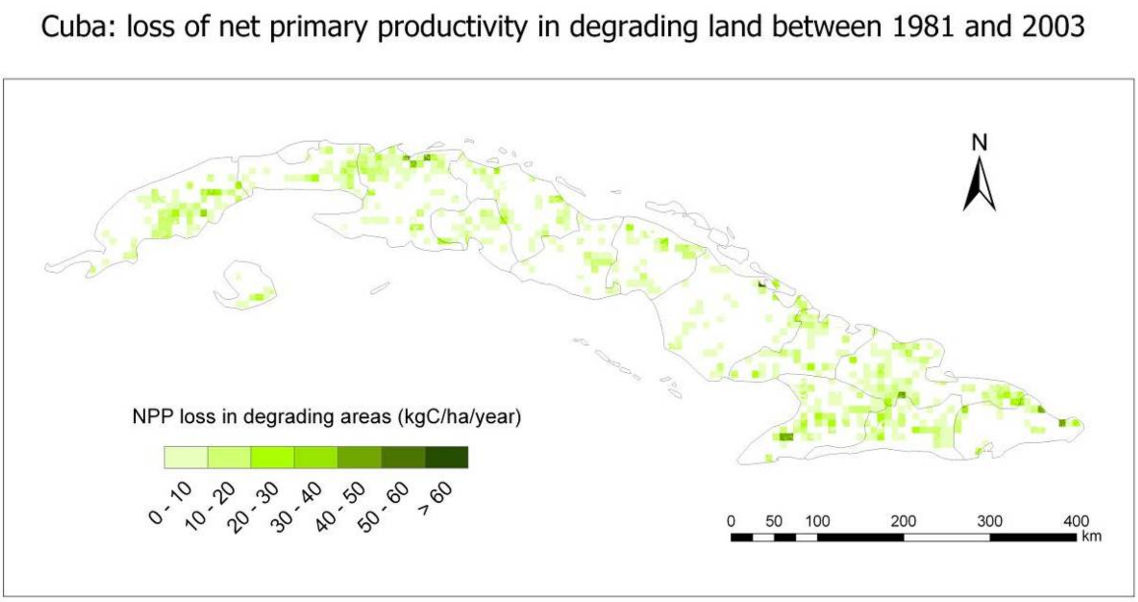

Figure 11. NPP loss in the degrading areas 1981-2003

Comparison between RUE-adjusted NDVI and RESTREND: For Cuba, the two indicators of land degradation show very similar patterns (compare Figures 10 and 8c). Negative RESTREND encompasses a somewhat larger area than negative RUE-adjusted NDVI; their statistical confidence levels are proportional, see Section 3.9.

Land use change: As with rainfall variability, land use change may also generate false alarms. For instance, conversion of forest or grassland to cropland or pasture will usually result in an immediate reduction in NDVI (and NPP) but may well be profitable and sustainable, depending on management. Lack of consistent time series data for land use and management precludes a generalised analysis of land use change. However, this will be undertaken manually for the potential *hot spots* of land degradation identified in this analysis and will be reported later.

3.7 Land improvement

Land improvement is identified by combination of: 1) a positive trend in sum NDVI for those areas where NDVI does not depend on rainfall; 2) for areas where NDVI is correlated with rainfall, a positive trend in rain-use efficiency; and 3) a positive trend in energy-use efficiency (Figure 12). These areas account for little more than 1 per cent of the country (Figure 13).

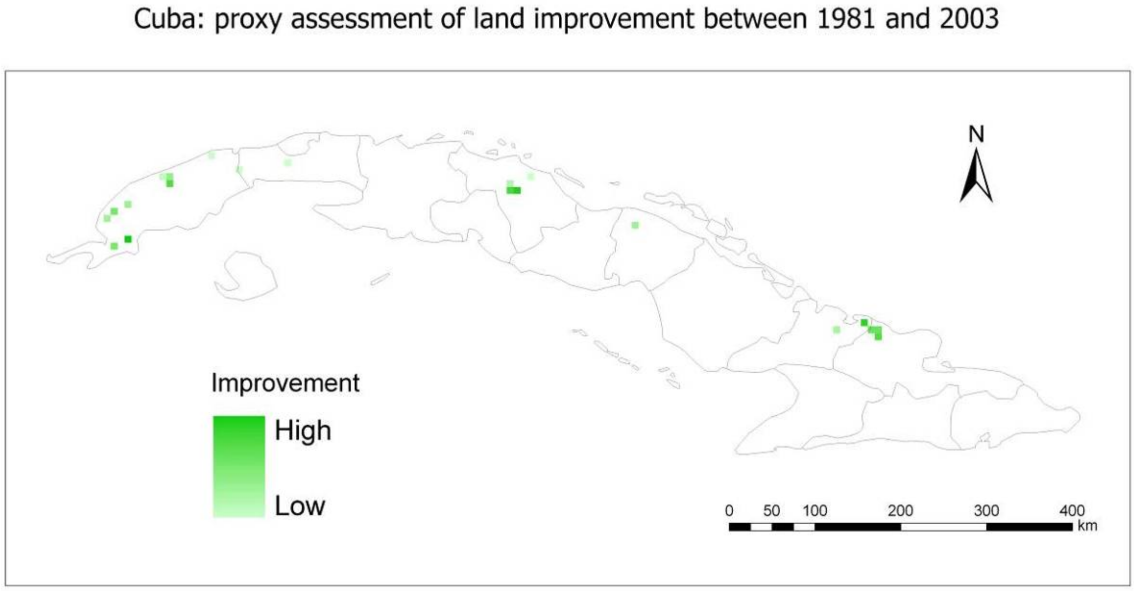

Figure 12. Areas of increasing NPP, RUE and EUE, 1981-2003

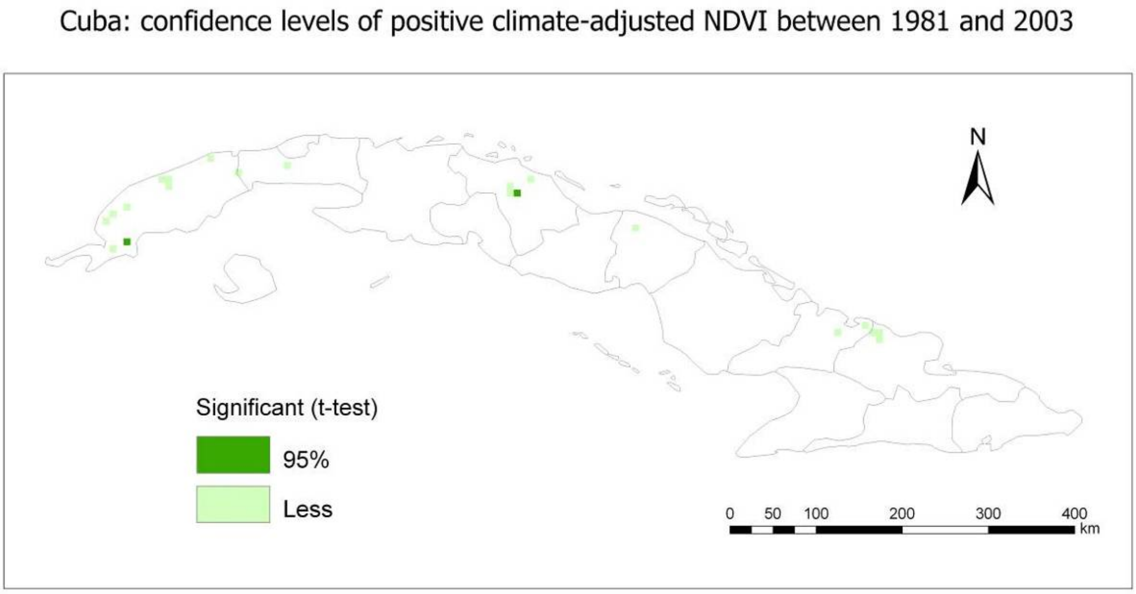

Figure 13. Confidence levels of positive climate-adjusted NDVI, 1981-2003

3.8 Urban areas

Whether urbanisation is degradation is arguable. It brings a huge increase in the financial value of the land but, if it which involves sealing of the land surface, it is degradation according to our criterion of partial loss of ecosystem function. The CIESIN Global Rural Urban Mapping Project shows 8.5 per cent of the land area as urban. These areas are masked in the maps. This makes a difference to the results: a reduction of 14.6 per cent for the identified degrading land, and a reduction of 8 per cent for the improving land.

3.9 Comparison of indicators

Annual sum NDVI is our standard indicator of productivity. Rain-use efficiency, RUE-adjusted NDVI and RESTREND are different ways of eliminating false alarms about land degradation caused by rainfall variability; each of these measures is useful in its own right. An advantage of RUE-adjusted NDVI is that, for areas considered to be degrading or improving, the original NDVI values are retained ad can be converted to NPP, which is open to economic analysis. Negative RUER-adjusted NDVI and negative RESTREND show similar patterns but negative RESTREND encompasses a somewhat larger area.

Table 3 presents a comparison of indicators. Countrywide, the patterns of the trends in sum NDVI and RESTREND are almost identical: about 34 per cent of land area shows negative change in both sum NDVI and RESTREND, 62 per cent shows positive trend in both indicators, 4 per cent gives a mixed signal - either positive sum NDVI and negative RESTREND, or vice versa. If we take negative RUE-adjusted NDVI as the primary definition of degrading areas, then 95 per cent of these areas are also degrading in terms of *both* unadjusted NDVI and RESTREND. Taking a positive trend in RUE-adjusted NDVI as the primary indicator of improving land, the correspondence is even greater: all areas are also positive in terms of both unadjusted NDVI and RESTREND.

Comparing RUE with RESTREND: 30 per cent of the land area shows negative trend in both RUE and RESTREND, 8 per cent shows positive trend in both RUE and RESTREND, 2 per cent shows no change, but we get mixed signals from 60 per cent - either positive RUE and negative RESTREND, or vice versa. If we again take RUE-adjusted NDVI as the primary definition of degrading areas, then 88 per cent shows negative trend in both RUE and RESTREND. Taking a positive trend in RUE-adjusted NDVI as the primary indicator of improving land, 91 per cent of the improving area shows positive trend in both RUE and RESTREND.

Table 3. Comparison of trends in various indicators

Indicators	Total pixel (%)	Negative trend (%)	Positive trend (%)	No change (%)	Mixed (%)
Annual sum NDVI	100	37.3	62.3	0.4	0
RESTREND[1]	100	36.2	63.8	0.0	0
Sum NDVI ∩ RESTREND	100	34.4	61.9	0.0	3.7
Sum NDVI ∩ RESTREND within LD[2]		**95.0**			
Sum NDVI ∩ RESTREND within LI[3]			**100**		
RUE	100	76.7	11.6	11.7	0.0
RUE ∩ RESTREND	100	30.5	7.7	1.6	60.2
RUE ∩ RESTREND within LD		**87.6**			
RUE ∩ RESTREND within LI			**90.5**		

[1] Residual trend of sum NDVI, [2] LD - identified improving land, [3] LI - identified degrading land

3.10 Analysis of degrading and improving areas

3.10.1 Association with land cover and land use

Table 4 compares degrading and improving areas with land cover (Figure 1): 66 per cent of the degrading area is cropland, comprising 30 per cent of all cropland; 13 per cent is grassland and scrub (codes 12-15; 30 per cent of these areas); and 18 per cent under forest (codes 1, 2, 4, and 9). Of the improving areas, 58 per cent is cropland (1 per cent of cropland); 23 per cent forest; and 16 per cent grassland and scrub.

Comparison of degrading areas with global land use systems (Tables 5 and 6) indicates that 60 per cent of degrading land is agricultural land, 15 per cent is forestry, 9 per cent is in grassland (herbaceous vegetation in the FAO legend), 17 per cent is in urban and other lands. 75 per cent of improving land is agricultural land, 25 per cent is under forest and urban.

Table 4. Degrading and improving land by land cover

Code	*Land cover*	*Total pixels (TP)*	*Degrading pixels (DP)*[1]	*DP/TP*	*DP/TDP*[2]	*Improving pixels (IP)*	*IP/TP*	*IP/TIP*[3]
		(0.536')	*(0.536')*	*(%)*	*(%)*	*(0.536')*	*(%)*	*(%)*
1	Tree cover, broadleaved, evergreen	8103	2483	30.6	7.4	105	1.3	7.6
2	Tree cover, broadleaved, deciduous, closed	2203	392	17.8	1.2	21	1.0	1.5
4	Tree cover, needle-leaved, evergreen	7934	1988	25.1	5.9	169	2.1	12.2
6	Tree cover, mixed leaf type	5096	1114	21.9	3.3	24	0.5	1.7
9	Mosaic: tree cover/other natural vegetation	2	0	0.0	0.0	0	0.0	0.0
12	Shrub cover, closed-open, deciduous	30	3	10.0	0.0	0	0.0	0.0
13	Herbaceous cover, closed-open	9257	3376	36.5	10.0	204	2.2	14.7
14	Sparse herbaceous or sparse shrub cover	912	226	24.8	0.7	4	0.4	0.3
15	Regularly flooded shrub and/or herbaceous cover	4188	642	15.3	1.9	8	0.2	0.6
16	Cultivated and managed areas	74221	22414	30.2	66.4	806	1.1	58.2
20	Water bodies	7882	1089	13.8	3.2	44	0.6	3.2
22	Artificial surfaces and associated areas	405	47	11.6	0.1	0	0.0	0.0
	Total	112351	33774		100	1385		100.0

[1] Urban extent excluded, [2] TDP - total degrading pixels, [3] TIP - total improving pixels

Table 5. Degrading and improving areas by land use systems (FAO 2008)

Code	*Land use system*	*Total pixels (TP)*	*Degrading pixels (DP)*	*DP/TP*	*DP/TDP*[1]	*Improving pixels (IP)*	*IP/TP*	*IP/TIP*[2]
		(5'x5')	(5'x5')	(%)	(%)	(5'x5')	(%)	(%)
0	Undefined	0	0		0.0	0	0.0	0.0
1	Forestry - not managed (natural)	10	1	10.0	0.3	0	0.0	0.0
2	Forestry - protected areas	76	26	34.2	6.6	0	0.0	0.0
4	Forestry - pastoralism moderate or higher intensity	14	3	21.4	0.8	0	0.0	0.0
5	Forestry - pastoralism moderate or higher intensity with scattered plantations	67	23	34.3	5.9	1	4.3	6.3
6	Forestry - scattered plantations	40	4	10.0	1.0	1	25.0	6.3
7	Herbaceous -not managed (natural)	21	10	47.6	2.6	0	0.0	0.0
8	Herbaceous - protected areas	5	1	20.0	0.3	0	0.0	0.0
9	Herbaceous - extensive pastoralism	1	0	0.0	0.0	0	0.0	0.0
10	Herbaceous - moderately intensive pastoralism	8	3	37.5	0.8	0	0.0	0.0
11	Herbaceous - intensive pastoralism	60	21	35.0	5.4	0	0.0	0.0
13	Rain-fed agriculture	151	36	23.8	9.2	2	5.6	12.5
14	Agro-pastoralism - moderately intensive	48	11	22.9	2.8	0	0.0	0.0
15	Agro-pastoralism - intensive	456	142	31.1	36.2	6	4.2	37.5
16	Agro-pastoralism - moderately intensive or higher with large-scale irrigation	72	28	38.9	7.1	0	0.0	0.0
17	Agriculture - large scale irrigation (> 25% pixel size)	23	7	30.4	1.8	3	42.9	18.8
18	Agriculture - protected areas	34	10	29.4	2.6	1	10.0	6.3
19	Urban areas	121	41	33.9	10.5	2	4.9	12.5
20	Wetlands - not managed (natural)	14	5	35.7	1.3	0	0.0	0.0
21	Wetlands - protected areas	23	5	21.7	1.3	0	0.0	0.0
22	Wetlands - mangroves	0	0	0.0	0.0	0	0.0	0.0
23	Wetlands - agro-pastoralism	0	0	0.0	0.0	0	0.0	0.0

Code	*Land use system*	*Total pixels (TP)*	*Degrading pixels (DP)*	*DP/TP*	*DP/TDP*[1]	*Improving pixels (IP)*	*IP/TP*	*IP/TIP*[2]
24	Bare areas - not managed (natural)	2	1	50.0	0.3	0	0.0	0.0
25	Bare areas - protected areas	0	0	0.0	0.0	0	0.0	0.0
26	Bare areas - extensive pastoralism	0	0	0.0	0.0	0	0.0	0.0
27	Bare areas - moderately intensive or intensive pastoralism	0	0	0.0	0.0	0	0.0	0.0
28	Water - Coastal or not managed (natural)	34	11	32.4	2.8	0	0.0	0.0
29	Water - protected areas	17	0	0.0	0.0	0	0.0	0.0
30	Water - inland fisheries	9	3	33.3	0.8	0	0.0	0.0
100	Undefined	0	0	0.0	0.0	0	0.0	0.0
	Total	1306	392		100.0	16		100.0

[1]TDP - total degrading pixels, [2]TIP - total improving pixels

Table 6. Degrading/improving lands in the aggregated land use systems

Land use system (LUS)	*Codes*	*Total pixels (TP) (5'x5')*	*Degrading pixels (DP) (5'x 5')*	*DP/TP (%)*	*DP/TDP[1] (%)*	*Improving pixels (IP) (5'x 5')*	*IP/TP (%)*	*IP/TIP[2] (%)*
Forestry	1-6	207	57	27.5	14.5	2	1.0	12.5
Herbaceous	7-11	95	35	36.8	8.9	0	0.0	0.0
Agricultural land	13-18	784	234	29.8	59.7	12	1.5	75.0
Urban	19	121	41	33.9	10.5	2	1.7	12.5
Wetlands	20-23	37	10	27.0	2.6	0	0.0	0.0
Bare areas	24-27	2	1	50.0	0.3	0	0.0	0.0
Water	28-30	60	14	23.3	3.6	0	0.0	0.0
Undefined	0,100	0	0	0.0	0.0	0	0.0	0.0
Total		1306	392		100.0	16		100.0

[1]TDP - total degrading pixels; [2]TIP - total improving pixels

3.10.2 Association with population density

Twenty-eight per cent of the Cuban population (3.2 million out of 11.3 million in 2005) lives in the degrading areas (Figure 14). There is a weak, positive correlation (r=0.23) between land degradation and $\log_e$ population density (Figure 15).

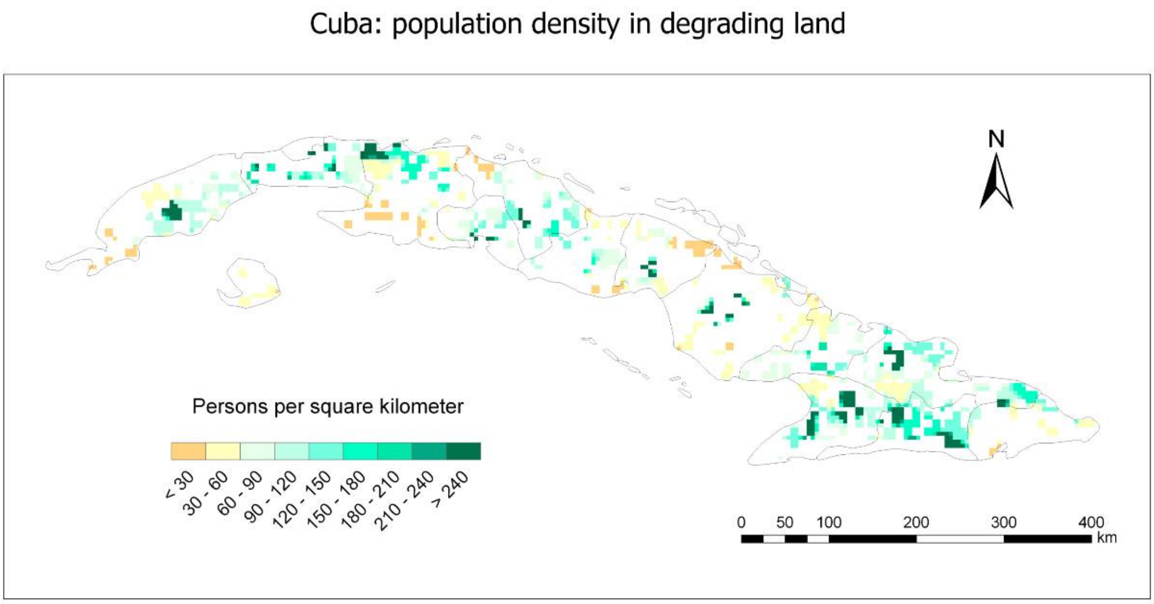

Figure 14. Population counts affected by the land degradation

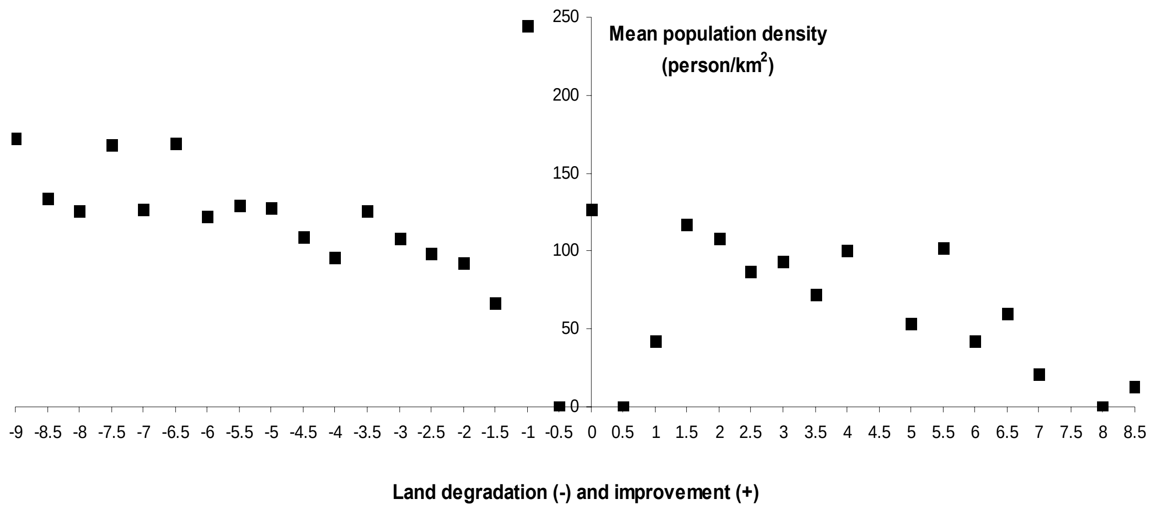

Figure 15. Relationship between population density and land degradation/ improvement

3.10.3 Relationship with aridity

There is no correlation (r=-0.055) between land degradation and Turc's aridity index. 85 per cent of degrading land is in humid and cool regions, 13 per cent in dry sub-humid areas and 1 per cent in the very small semi-arid region.

3.10.4 Relationship with poverty

Taking the infant mortality rate as a proxy for poverty, there appears to be a negative relationship between degrading areas and poverty (r=0.6). This is the opposite of what might be expected; a more rigorous analysis is needed to tease out the underlying social and economic variables.

3.10.5 Relationship with soils and terrain

Various soil and terrain attributes are mapped in Figure 16. There is no obvious relationship between land degradation and any individual biophysical attribute: about 80 per cent of the degrading land is flat, 5 per cent is medium gradient, 9 per cent high gradient, and 5 per cent is ridges (Table 7).

Table 7. Degrading areas in different landforms

SOTER label	*Landforms*	*Total pixels (TP)*	*Degrading pixels (DP)*	*DP/TP (%)*	*DP/TDP* (%)*
LL	Plateau	5	2	40	0.4
LP	Plain	1367	400	29.3	80.3
SH	Medium-gradient hill	92	25	27.2	5.0
SR	Ridges	89	24	27.0	4.8
TE	High-gradient escarpment	48	17	35.4	3.4
TH	High-gradient hill	36	4	11.1	0.8
TM	High-gradient mountain	115	26	22.6	5.2
Total		1752	498	28.4	100.0

*TDP - total degrading pixels

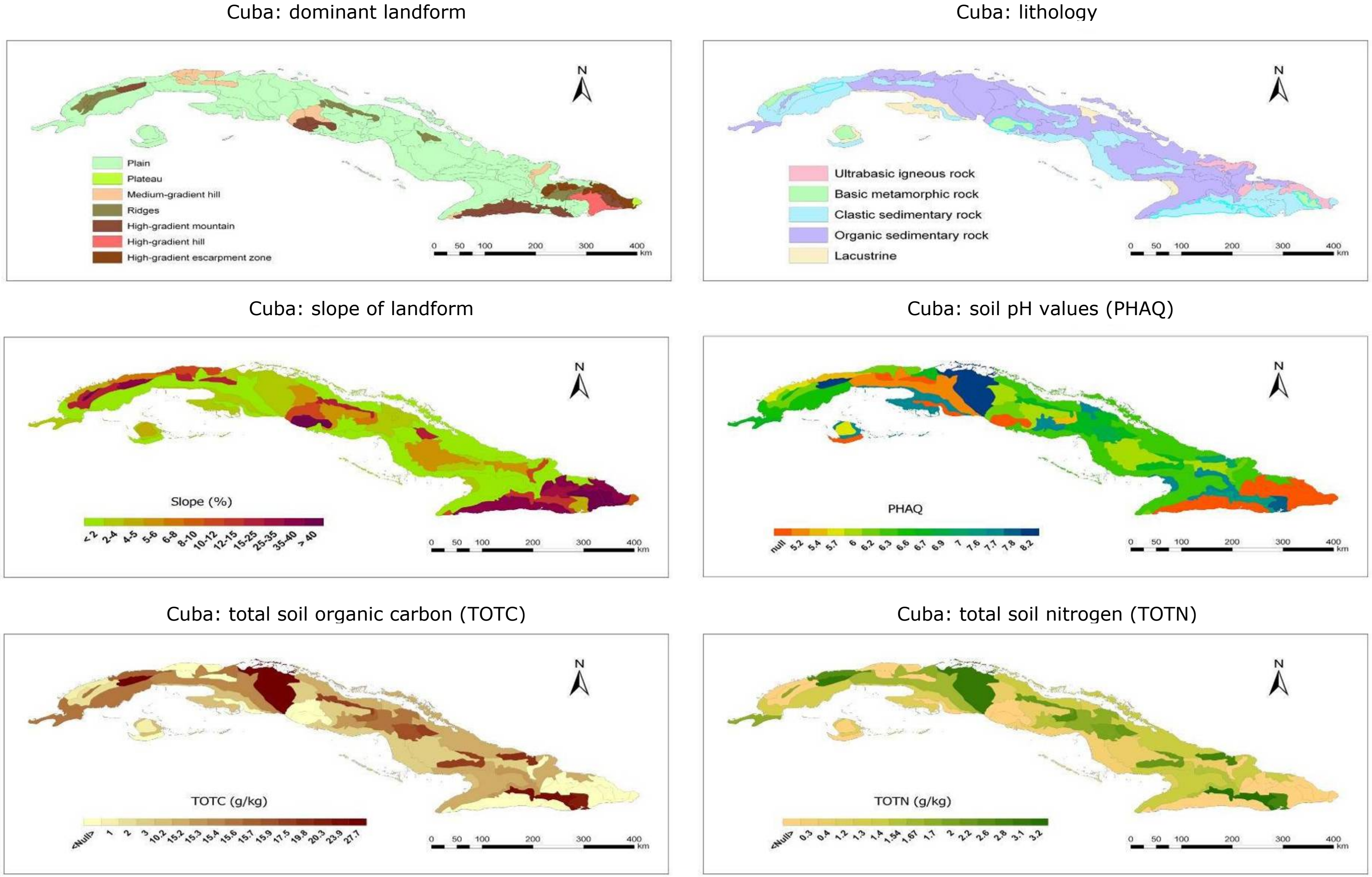

Figure 16. Soil and terrain attributes for dominant soil types

In respect of soil organic carbon, classes defined by 0-5, 5-15, 15-20 and >20 g/kilogram, occupy 33, 4, 53 and 10 per cent of the degrading area, respectively (Figure 17), similar to the national extent of each class (Table 8); there is almost no relationship between total soil organic carbon and land degradation at pixel level;

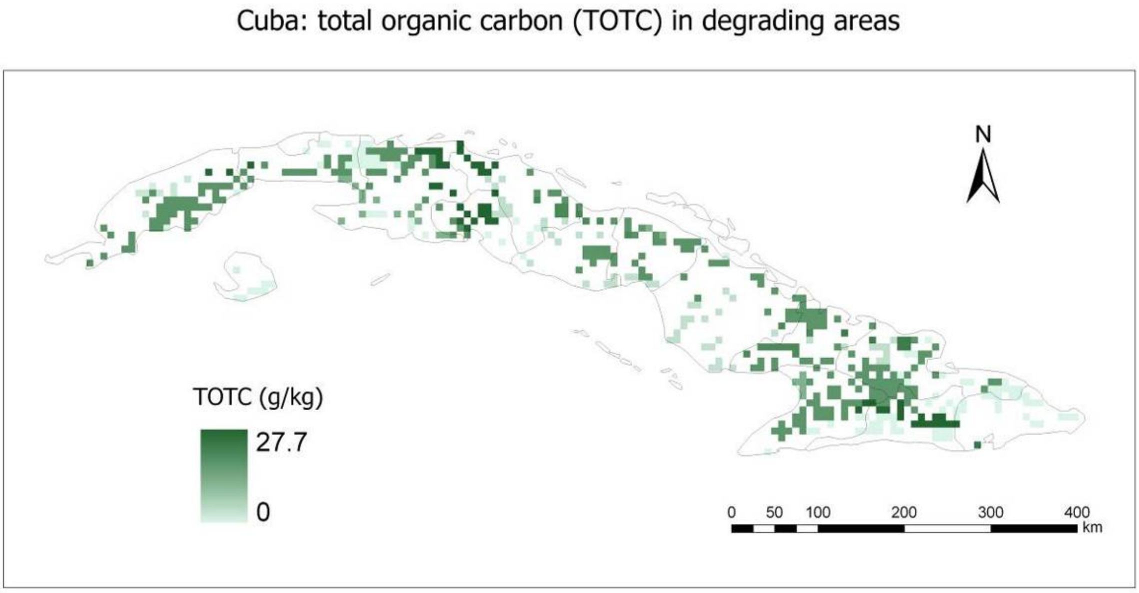

Figure 17. Total soil organic carbon in degrading areas

Table 8. Total soil organic carbon in degrading areas

TOTC (g/kg)	*Pixels in class*	*%*	*Pixels in degrading land*	*% of total degrading land*
0-5	727	40.0	169	32.8
5-15	102	5.6	21	4.1
15-20	823	45.2	273	53
> 20	167	9.2	52	10.1
total	1 819	100	515	100

There is a weak relationship between degradation and soil pH.

In short, it appears that land degradation is influenced more by management, in particular by management under cultivation, than by soils and terrain *per se*.

4 What GLADA can and cannot do

- We have defined land degradation as a long-term loss of ecosystem function and we use net primary productivity (NPP) as an indicator. GLADA is an interpretation off GIMMS time series NDVI data, i.e. a measure of greenness, which is taken as a proxy for NPP. Translation of NDVI is robust but approximate.

- The proxy is several steps removed from recognisable symptoms of land degradation as it is commonly understood - such as soil erosion, salinity or nutrient depletion; the same goes for land improvement. Greenness is determined by several factors and, to interpret it in terms of land degradation and improvement, these other factors must be accounted for – in particular variability of rainfall and temperature and changes I land use and management, Rain-use efficiency (RUE, NPP per unit of rainfall) accounts for rainfall variability and, to some extent, local soil and land characteristics. We assume that, where NPP is limited by rainfall, a declining trend in RUE indicates land degradation. Where rainfall is not limiting, NPP is the best indicator available. Taken together, the two indicators may provide a more robust assessment than either used alone. Alternatively, RESTREND points in the same direction: it shows much the same pattern as NDVI though with lesser amplitude.

  Land use change is not taken into account in this study owing to the lack of consistent time series data.

- Declining NPP, even allowing for climatic variability, may not even be reckoned as land degradation: urban development is generally considered to be *development* – although it generally means a long-term loss of ecosystem function; land use change from forest or grassland to cropland or rangeland is usually associated with a loss of NPP but it may or may not be accompanied by soil erosion, compaction and nutrient depletion, and it may well be profitable and sustainable , depending on management. Similarly, increasing NPP means greater biological production but may reflect, for instance, encroachment of bush or invasive species – which is not land improvement as commonly understood.

- The coarse resolution of the GIMMS data is a limitation: an 8km pixel integrates the signal from a wider surrounding area. Many symptoms of even severe degradation, such as gullies, rarely extend over such a large area; degradation must be severe indeed to be seen against the signal of surrounding unaffected areas.

- As a quantitative estimate of land degradation, loss of NPP relative to the average trend has been calculated for those areas where both NPP and RUE are declining. This is likely to be a conservative estimate: where NPP is increasing but RUE is declining, some land degradation may have begun that is reducing NPP but is not yet reflected in declining NPP.

- By the same reasoning, RUE should be used alone for early warning of degradation or as a herald of improvement. Where NPP is rising but RUE is declining, some process of degradation may be under way which will remain undetected if we consider only those areas where both indices are declining. The reverse also holds true: we might not recognise promising interventions that increase RUE but have not yet brought about increasing NPP.

- GLADA presents a different picture from previous assessments of land degradation which compounded historical degradation with what is happening now. The data from the last 25 years indicate present trends but tell us nothing about the historical legacy; many degraded areas have become stable landscapes with a stubbornly low level of productivity. For many purposes, it is more important to address present-day degradation; much historical degradation maybe irreversible.

- Remote sensing provides only indicators of biomass productivity. The various kinds of land degradation and improvement are not distinguished; the patterns revealed by remote sensing should be followed up by fieldwork to establish the actual conditions on the ground and results are provisional until validated in the field. This is not straightforward: an 8km pixel cannot be checked by a windscreen survey and a 23-year trend cannot be checked by a snapshot. A rigorous procedure must be followed, as defined in the forthcoming *LADA Field Handbook.* Apart from systematically and consistently characterising the situation on the ground across a range of scales, the field teams may validate the GLSAA interpretations by addressing the following questions:

    1. Is the biomass trend indicated by GLADA real?
    2. If so, does it correspond with physical manifestations of land degradation and improvement that are measurable on the ground?
    3. If the answer to either of the above questions is no, what has caused the observed trend?
    4. Is the mismatch a question of timing of observations – where the situation on the ground has subsequently recovered or reverted?

5 Conclusions

- Land degradation and improvement have been assessed by remotely sensed indicators of biomass productivity based on NDVI, the greenness index, which may be translated in terms of net primary productivity (NPP). The indicators show clear decreasing and increasing trends over the period 1981-2003 which may be interpreted, respectively, as land degradation or improvement.

- Greenness is determined by several factors. To interpret it in terms of land degradation and improvement, these other factors must be accounted for – in particular, variability of rainfall and changes in land use and management. Rain-use efficiency (RUE), i.e. NPP per unit of rainfall, accounts for rainfall variability and, to some extent, local soil and land characteristics. We assume that, where NPP is limited by rainfall, a declining trend in RUE indicates land degradation. Where rainfall is not limiting, NPP is the best indicator available. Taken together, the two indicators may provide a more robust assessment than either used alone. Alternatively, RESTREND points in the same direction; it shows much the same pattern as the sum NDVI.

- As a quantitative measure of land degradation, loss of NPP relative to the average has been calculated for those areas where *both* NPP and RUE are declining. This is likely to be a conservative estimate: where NPP is increasing but RUE is declining, some process of land degradation may have begun that is reducing NPP but is not yet reflected in a declining NPP trend.

- By the same reasoning, RUE should be used alone for *early warning* of land degradation, or a herald of improvement. Where NPP is rising but RUE declining, some process of land degradation might be under way that is not yet reflected in declining NPP; it will remain undetected if we consider only those areas where both indices are declining. The reverse also holds true: we might forgo promising interventions that increase RUE but have not yet brought about increasing NPP.

- In Cuba overall NPP increased very slightly over the period of 1981-2003; not enough to match population growth or to provide a sound foundation for development. Degrading areas, suffering both declining NPP and declining RUE, occupy 29 per cent of the country, and suffered an average loss of NPP of 10 kgC ha^{-1} $year^{-1}$.

- Land improvement, defined by increasing NPP, RUE and energy-use efficiency, is identified across only 1 per cent of the country.

- About 3.2 million people (28 per cent of the Cuban population) live in the degrading areas. However, the correlation between land degradation and $\log_e$ population density is weak and there is no obvious relationship with poverty. A more rigorous analysis is needed to tease out the underlying social and economic drivers.

- GLADA presents a different picture from previous assessments of land degradation which compounded historical land degradation with what is happening now. The data since 1981 indicate current trends but tell us nothing about the historical legacy. However, for many purposes, it is more important to address present-day land degradation; much historical land degradation may be irreversible.

- Remote sensing provides only indicators of trends of biomass productivity. The various kinds of land degradation and improvement are not distinguished; the patterns derived from remote sensing should be followed up by fieldwork to establish the actual conditions on the ground.

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Appendix 1: Analytical methods

Derivation of NDVI indicators

ArcGIS Spatial Analyst, ERDAS IMAGINE and ENVI-IDL were used to calculate NDVI minimum, maximum, maximum-minimum, mean, sum, standard deviation (STD) and coefficient of variation (CoV), as well as climate variables. The fortnightly NDVI data were geo-referenced and averaged to monthly; annual NDVI indicators were derived for each pixel; their temporal trends were determined by linear regression at an annual interval and mapped to depict spatial changes (Appendix 2).

A negative slope of linear regression indicates a decline of green biomass and a positive slope, an increase – except for STD and CoV which indicate trends in variability. The absolute change (Δ in map legends, titled "changes in …..") is the slope of the regression; the relative change (% in map legends, titled "trend in ….") is 100(slope of the regression/multi-year mean).

Monthly grids of rainfall for the period 1981-2002 were geo-referenced and re-sampled to the same spatial resolution as the NDVI (8km) using neighbourhood statistics. Spatial pattern and temporal trend of rainfall and rain-use efficiency (RUE, the ratio of annual NDVI and annual rainfall) for each pixel were determined by regression.

Land degradation was identified by negative trends of both biomass and rain-use efficiency. To distinguish between declining productivity caused by land degradation, and declining productivity due to other factors, rainfall variability has been accounted for by, first, identifying pixels where there is a positive relationship between productivity and rainfall; secondly, for those areas where productivity depends on rainfall, rain-use efficiency has been considered: where productivity declined but RUE increased, we attribute the decline of productivity to declining rainfall and those areas are masked. Land improvement was identified by positive changes in sum NDVI where show positive rain-use efficiency which has a positive correlation between sum NDVI and rainfall and energy-use efficiency. Both were masked by the mapped urban extents.

Statistical tests

The trend analysis assumes that the data are spatially and temporally independent. This was tested by examining autocorrelation coefficients following Livezy and Chen (1983). When the absolute values of the autocorrelation coefficients of lag-1 to lag-3 calculated for a time series consisting of n observations are not larger than the typical critical value corresponding to 5 per cent significance level, i.e., $1.96/\sqrt{n}$, the observations in this time series can be accepted as being independent from each other.

The T-test was used to arrange the slope values in classes showing strong or weak positive or negative trends:

$$T = b / se(b)$$

Where *b* is the calculated slope of the regression line between the observation values and time and *se(b)* represents the standard error of *b.*

The class boundaries were defined for 95 per cent confidence level; trends were labelled *high* if the *T*-values of the slope exceeded the 0.025 *p*-value of either tail of the distribution; lesser *T*- values were labelled *low*.

In addition, SPSS and MS Excel were employed to analyze trends, correlations and significances of the non-gridded variables.

Associations between land degradation/improvement and other variables

Maps of the negative trend in climate-adjusted NDVI were overlaid on the other maps. Corresponding comparative values were calculated, pixel-by-pixel and a univariate correlation calculated.

Appendix 2: NDVI indicators of land degradation and improvement

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

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

Maximum-minimum NDVI: The difference between annual maximum and minimum NDVI reflects annual biomass productivity for areas with one, well-defined growing season but may not be meaningful for areas with bimodal rainfall.

Sum NDVI: The sum of fortnightly NDVI values for the year most nearly aggregates annual biomass productivity.

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

Coefficient of variation (CoV): CoV can be used to compare the amount of variation in different sets of sample data. NDVI 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. This represents the dispersion of NDVI values relative to the mean value.

Temporal trends: The long-term trends of the indicators of biological productivity may be taken as indicators of land degradation (where the trend is declining) or land improvement (where the trend is increasing). A positive change in the value of a pixel-level CoV over time relates to increased dispersion of values, not increasing NDVI; similarly, a negative CoV dispersion – which is the case over nearly the whole country - means decreasing dispersion of NDVI around mean values, not decreasing NDVI.

The patterns and trends of all NDVI indicators for each pixel, determined by the slope of the linear regression equation, are depicted in Figures A1-7; their values are summarised in Table A1. No further analyses were made for these indicators except for the sum NDVI which is discussed in detail in the main text. It is recommended, however, that these maps should be considered in the field investigation - in particular the land use change during the study period (1981-2003).

Table A1. Statistics of NDVI indicators*

Indicator	*NDVI values*			*Pixels (%)*		*% NDVI change/year*			*Δ NDVI/year*		
	min	max	mean	Pos.	Neg.	Pos.	Neg.	mean	Pos.	Neg.	mean
Minimum	0.323	0.538	0.448	56.7	43.3	0.430	0.405	0.046	0.00174	0.00167	0.00017
Maximum	0.613	0.754	0.684	64.2	35.8	0.208	0.150	0.066	0.00137	0.00088	0.00047
Max-Min	0.124	0.391	0.235	51.3	48.7	1.034	0.939	0.068	0.00248	0.00197	0.00030
Mean	0.523	0.619	0.578	62.6	37.4	0.161	0.113	0.055	0.00090	0.00061	0.00031
Sum	6.278	7.432	6.932	62.6	37.4	0.161	0.113	0.055	0.01074	0.00737	0.00375
STD	0.039	0.118	0.073	49.7	50.3	0.981	0.949	-0.004	0.00072	0.00059	0.00005
CoV	0.070	0.221	0.131	47.5	52.5	1.053	0.989	-0.050	0.00139	0.00117	0.00001

* In the calculations of the min., max. and mean values of each NDVI indicator, an average value of the all pixels in the vegetated area, defined as areas with net primary productivity greater than 1 g C m^{-2} $year^{-1}$, were calculated. For example, *min.* value of the Maximum NDVI indicator: overlay statistic **minimum** of CELL STATISTIC in ArcMap was performed to extract minimum values of the time series annual Maximum NDVI for each pixel over the period (1981-2003), and the averaged **minimum** value of the maximum NDVI for all pixels was assigned as *min.* for the Maximum NDVI indicator; *max.* value of the Maximum NDVI indicator: overlay statistic **maximum** of CELL STATISTIC in ArcMap was performed to extract maximum values of the time series annual Maximum NDVI for each pixel over the period (1981-2003), and the averaged **maximum** value of the maximum NDVI for all pixels was assigned as *max.* for the Maximum NDVI indicator; *mean* value of the Maximum NDVI indicator: overlay statistic **mean** of CELL STATISTIC in ArcMap was performed to extract mean values of the time series annual Maximum NDVI for each pixel over the period (1981-2003), and the averaged **mean** value of the maximum NDVI for all pixels was assigned as *mean* for the Maximum NDVI indicator.

The rates of the positive and negative pixels were counted from the slope of the regression, i.e., positive slope (pos.) negative slope (neg.).

% NDVI change/year was calculated from the trend maps for each NDVI indicator: positive value (pos.) is the average of the all pixels with a positive trend; negative (neg.) is the average of the all pixels with a negative trend; mean value is the average of the all pixels; Δ NDVI/year is calculated the same as % NDVI change but from the absolute change maps.

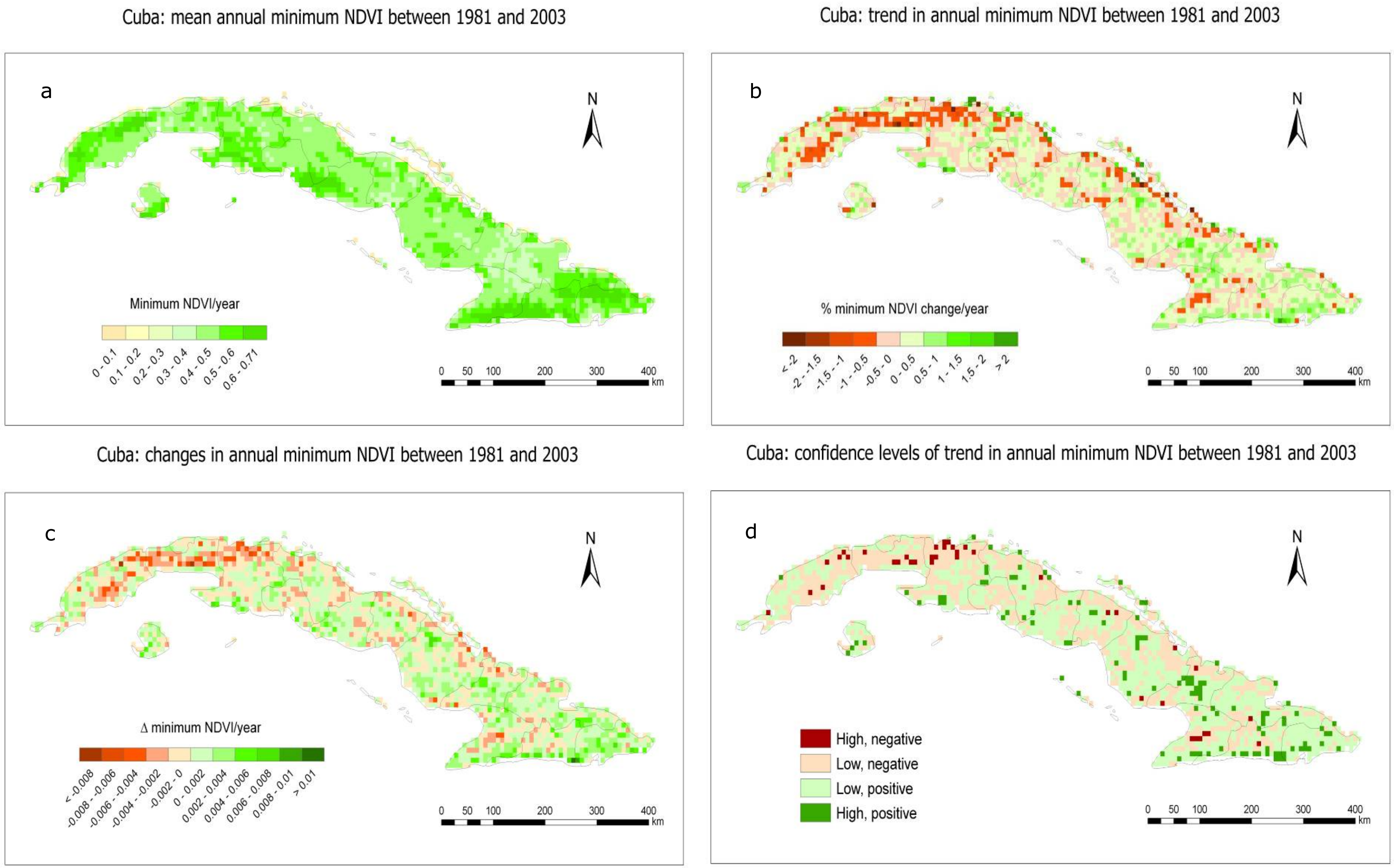

Figure A1. Annual minimum NDVI 1981-2003: mean (a), trends (b – percentage, c – absolute, d confidence levels)

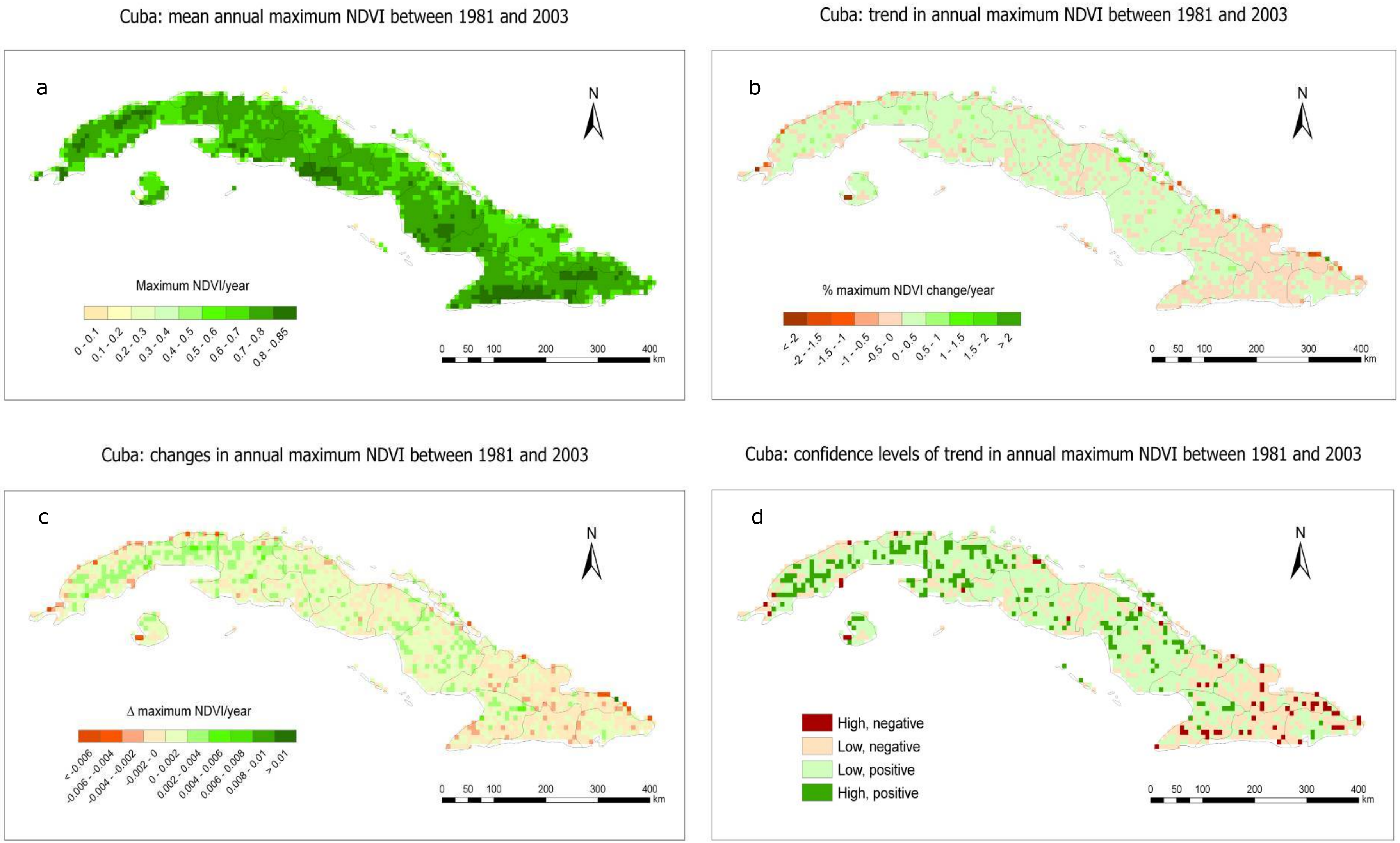

Figure A2. Annual maximum NDVI 1981-2003: pattern (a), trends (b - percentage, c – absolute d - confidence levels)

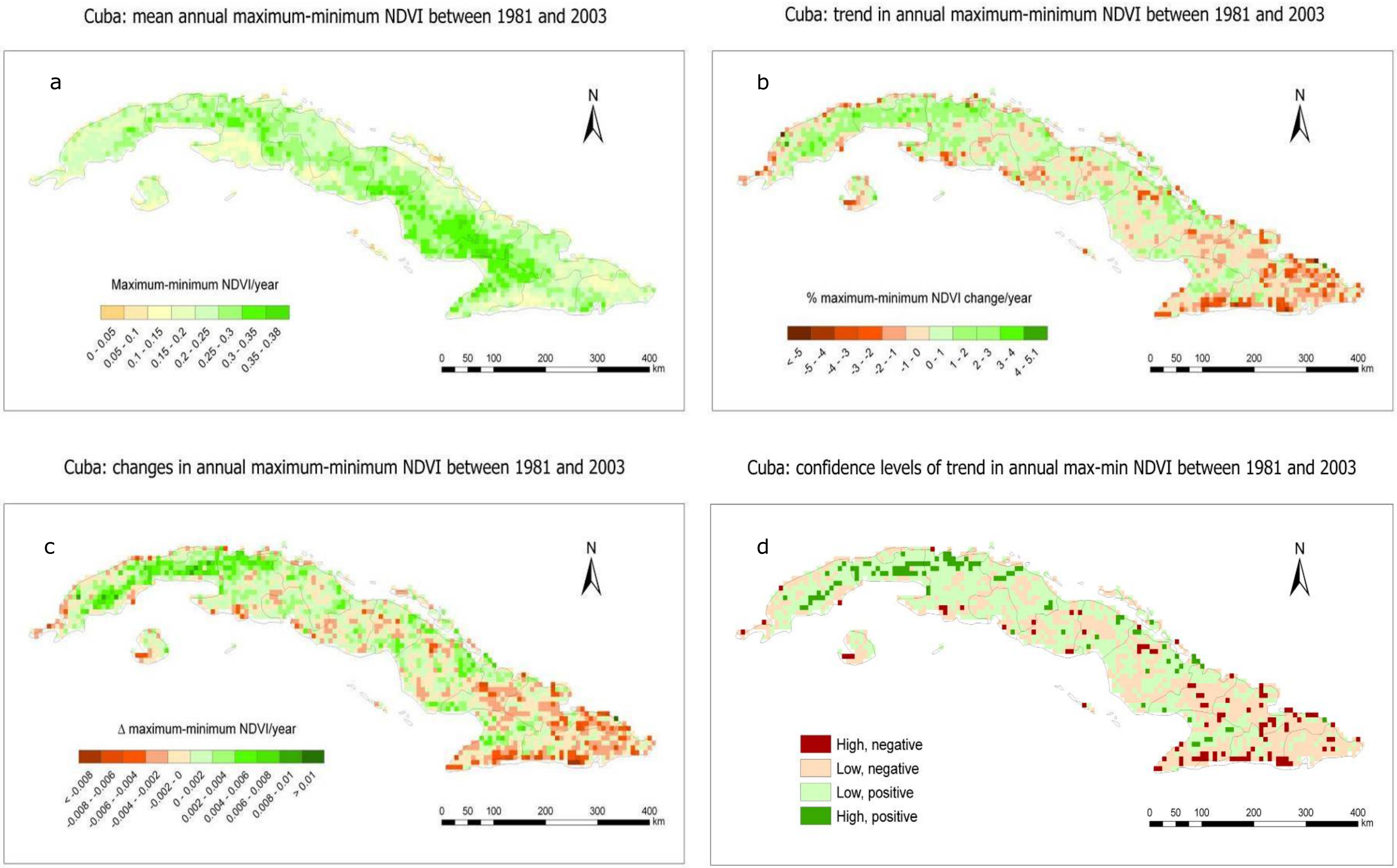

Figure A3. Max-min NDVI 1981-2003: pattern (a), trends (b - percentage, c – absolute, d - confidence levels)

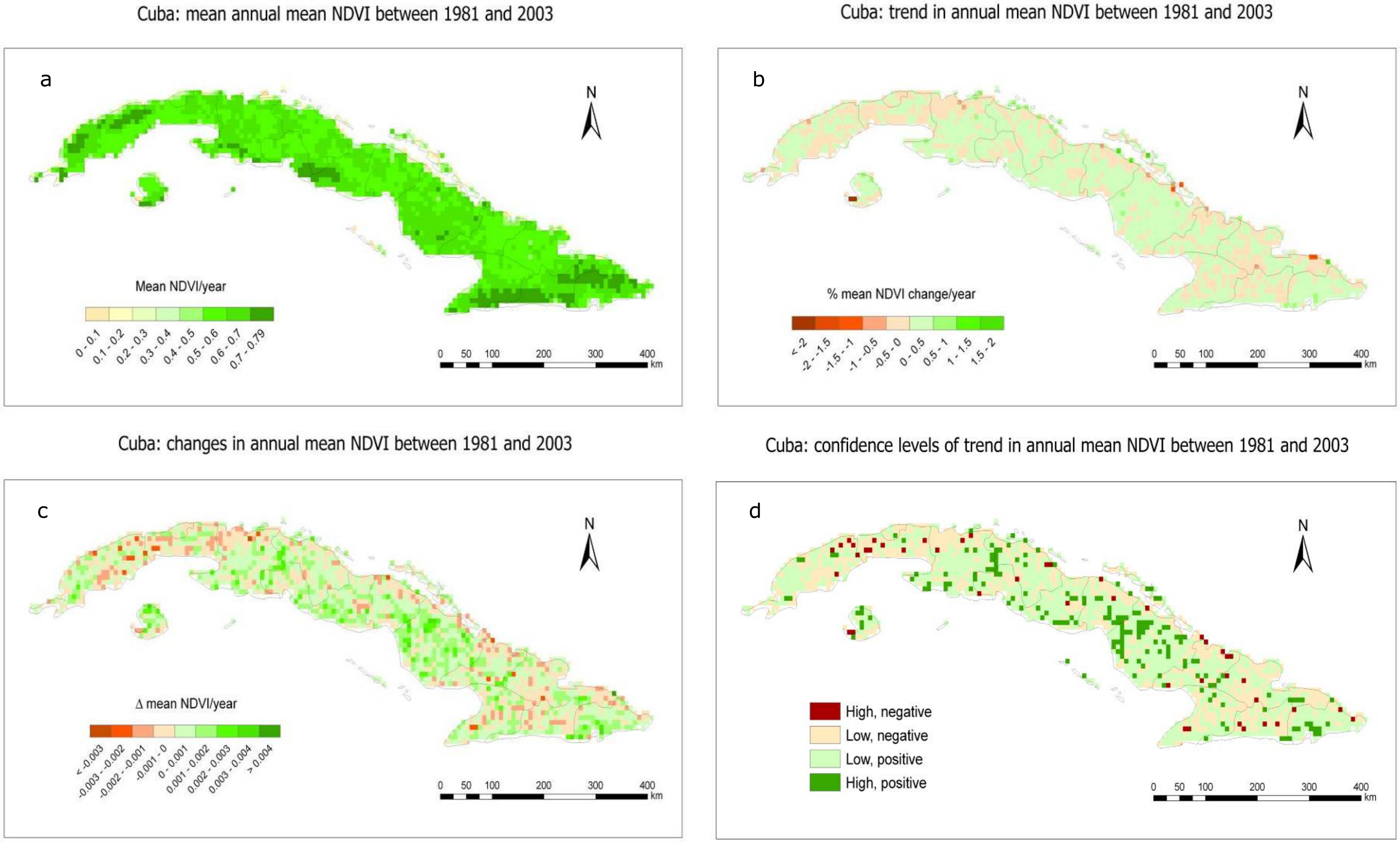

Figure A4. Mean NDVI 1981-2003: pattern (a), trends (b - percentage, c – absolute, d - confidence levels)

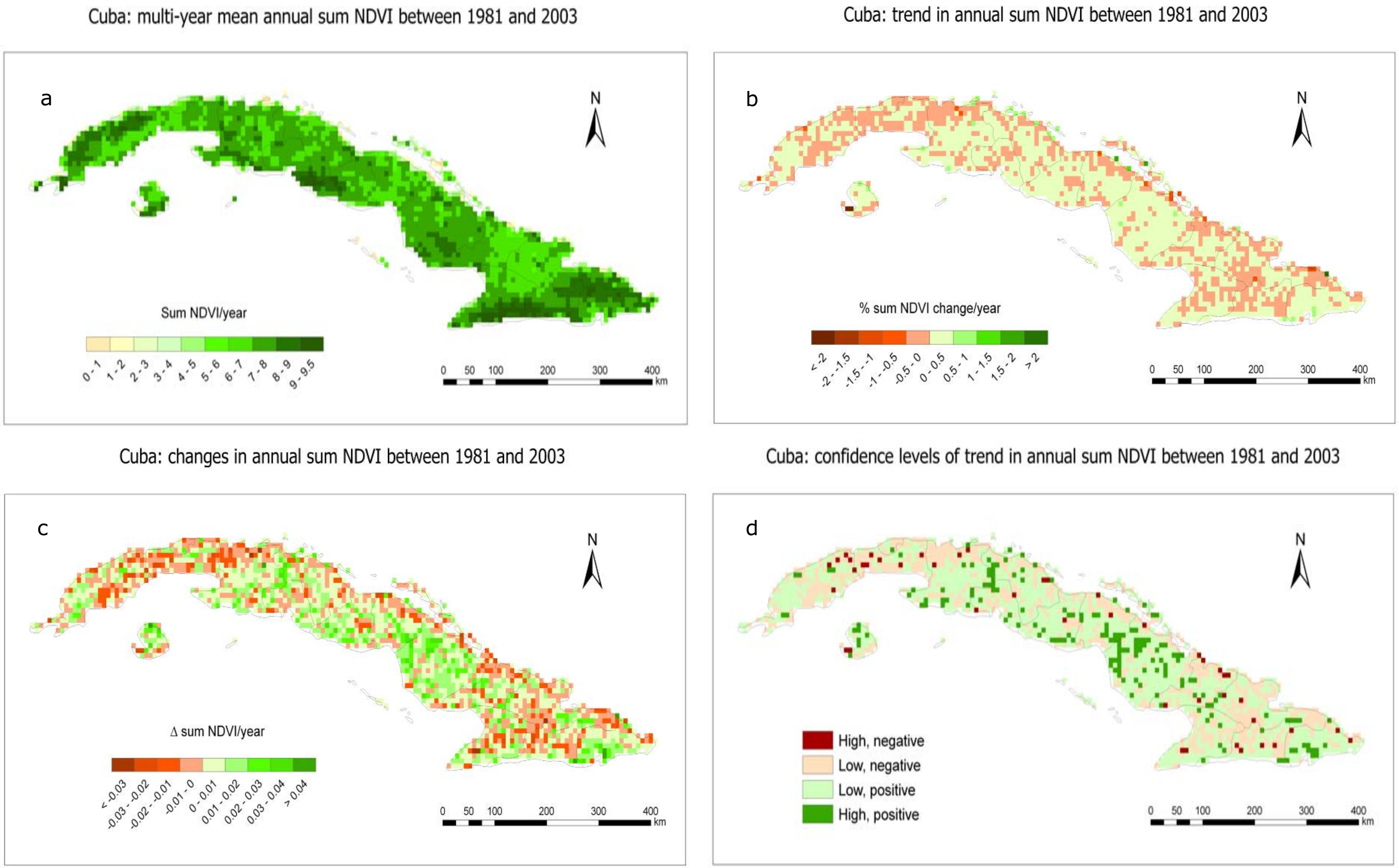

Figure A5. Annual sum NDVI 1981-2003: pattern (a), trends (b – percentage, c – absolute, d - confidence levels)

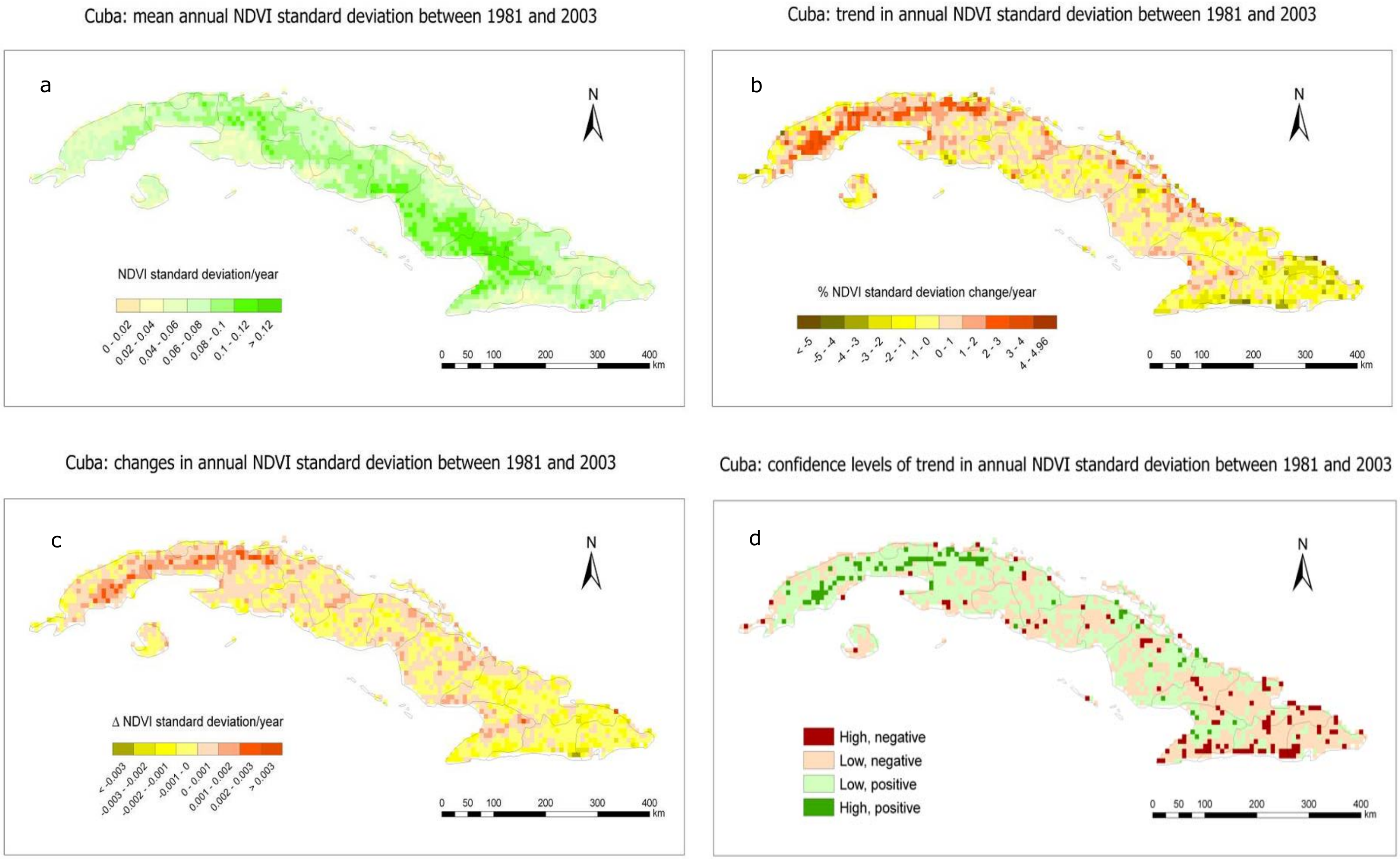

Figure A6. NDVI standard deviation 1981-2003: pattern (a), trends (b - percentage, c – absolute, d - confidence levels)

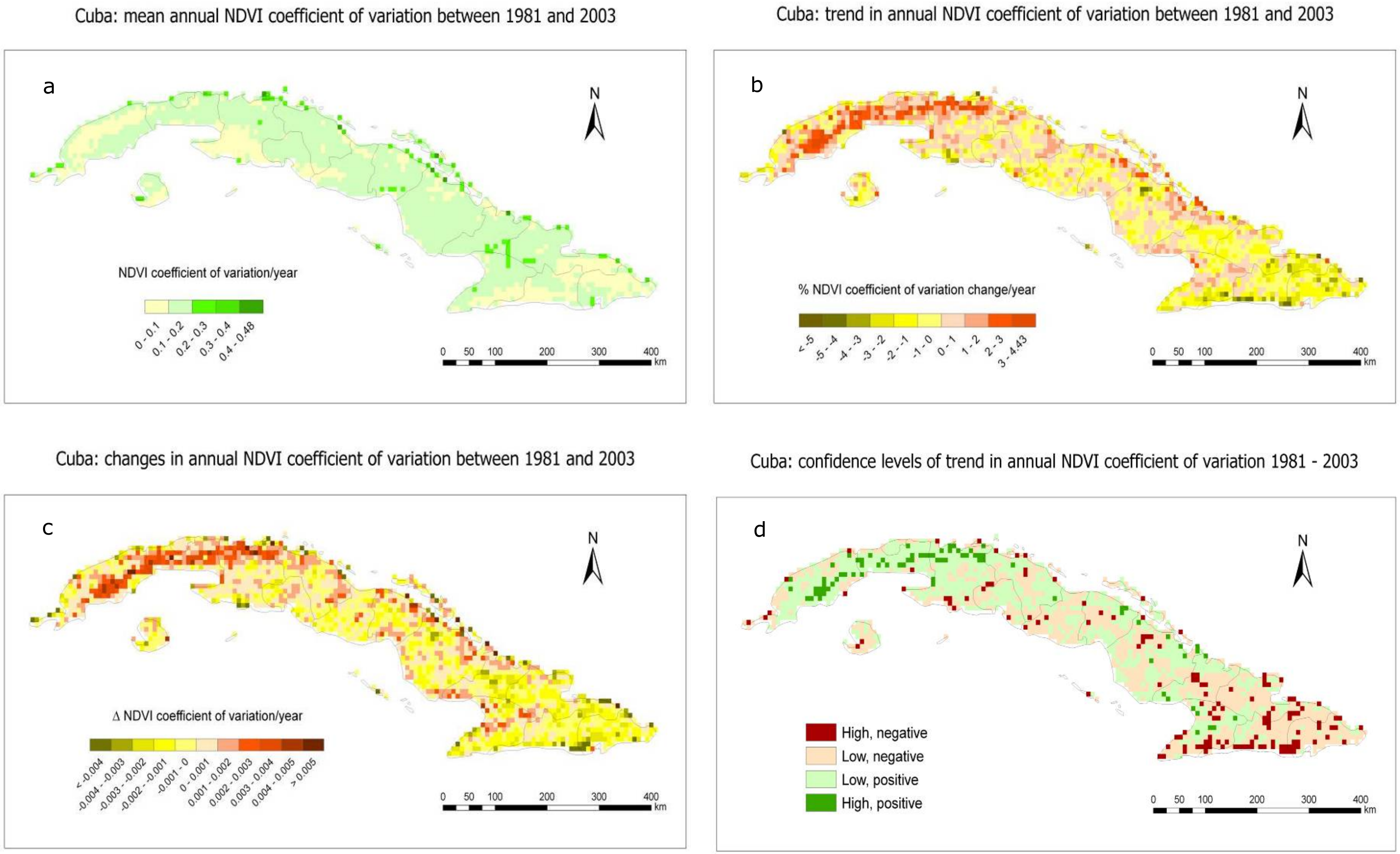

Figure A7. NDVI coefficient of variation 1981-2003: pattern (a), trends (b - percentage, c – absolute, d - confidence levels)

World Soil Information

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