GLADA Report 1e
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Land Degradation and Improvement in Senegal

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 degrading 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; degrading land is indicated by a declining trend of climate-adjusted NDVI and improvement by an increasing trend.

3. **In Senegal over the period of 1981-2003, net primary productivity increased slightly overall. Degrading areas, suffering declining climate-adjusted NPP, occupy 18 per cent of the country, mostly in Casamance.** One third of the degrading land is cropland (about 10 per cent of the arable), 40 per cent is scrub and 19 per cent is forest (47 per cent of the forested area). There is no correlation between land degradation and aridity.

4. **About 2.1 million people (21 per cent of the Senegalese) live in the degrading areas.** Land degradation is related to population pressure but there is no clear relationship with poverty.

5. **Land improvement, defined by increase of NPP, RUE and EUE, is identified across 37 per cent of the country.** Most of the improving areas are in central-northern Tambacounda province; 29 per cent is cropland, 46 per cent is a mosaic of cropland, shrubs and grassland, and 20 per cent is scrub and grassland.

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

Contents

Figures

Tables

Abbreviations

CIESIN	Center for International Earth Science Information Network, Colombia University, Palisades NY
CRU TS	Climate Research Unit, Time Series
ENSO	El Niño/Southern Oscillation phenomenon
FAO	Food and Agriculture Organization of the United Nations, Rome
GIMMS	The Global Inventory Modelling and Mapping Studies
GLADA	Global Assessment of Land Degradation and Improvement
JRC	Joint Research Centre, European Commission, Ispra, Italy
LADA	Land Degradation Assessment in Drylands
Landsat	NASA Land Resources Satellites
Landsat ETM+	Land Resources Satellite, Enhanced Thematic Mapper
LUS	Land Use Systems, FAO
MOD17A3	MODIS 8-Day Net Primary Productivity
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
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
SPSS	Statistical Package for the Social Sciences software
SRTM	Shuttle Radar Topography Mission
UNCCD	United Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
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 the Millennium Goals (UNCED 1992, UNEP 2007).

Quantitative, up-to-date information is needed to support policies for food and water security, environmental integrity, and economic development but 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 it is now out of date. The present Global Assessment of Land Degradation and Improvement (GLADA) within the FAO program *Land Degradation Assessment in Drylands* (LADA) maps land 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 (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: Senegal

Long-term loss of land productivity is an environment and development issue in Senegal. Since the 1960s, Senegal has seen disruption of farming systems, degradation of natural resources and a decline in production of many staples against a background of increasing pressure on natural resources from its growing population, now increasing at 2.5 per cent annually (World Bank 2007). Large areas are threatened with desertification by pressure on the land: from clearance of forest for farmland and fuel wood, poor agricultural practices, overgrazing of rangelands, devastating brushfires, and recurrent droughts. This is social and economic issue as well as environmental issue; it affects food and water security and economic development. The *National Plan for Town and Country Planning* (1984) reckoned that 47 per cent of the land is are unfit or barely suitable for farming, and 36 per cent of soils to be of "poor to average" capacity, suffering various constraints. Government responses include reforestation programs, gazetting 11 per cent of the country as parks and reserves, and other projects to foster sustainable land management involving agricultural, forestry, water and energy issues.

2.2 Data

2.2.1 NDVI and net primary productivity

This study uses NDVI data from July 1981 to December 2003 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 more tangible measure of land degradation and improvement that is amenable 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 from long, quality-controlled station records, 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 of monthly, station-observed values also gridded at 0.5° resolution (Mitchell and Jones 2005) 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 attributes data, incorporating the 90m-resolution SRTM digital elevation model (Engelen and others 2005). For continuation of this study, a consistent dataset of key soil attributes has been prepared at scale 1:1M (Engelen and others 2008).

2.2.4 Land cover and land use

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

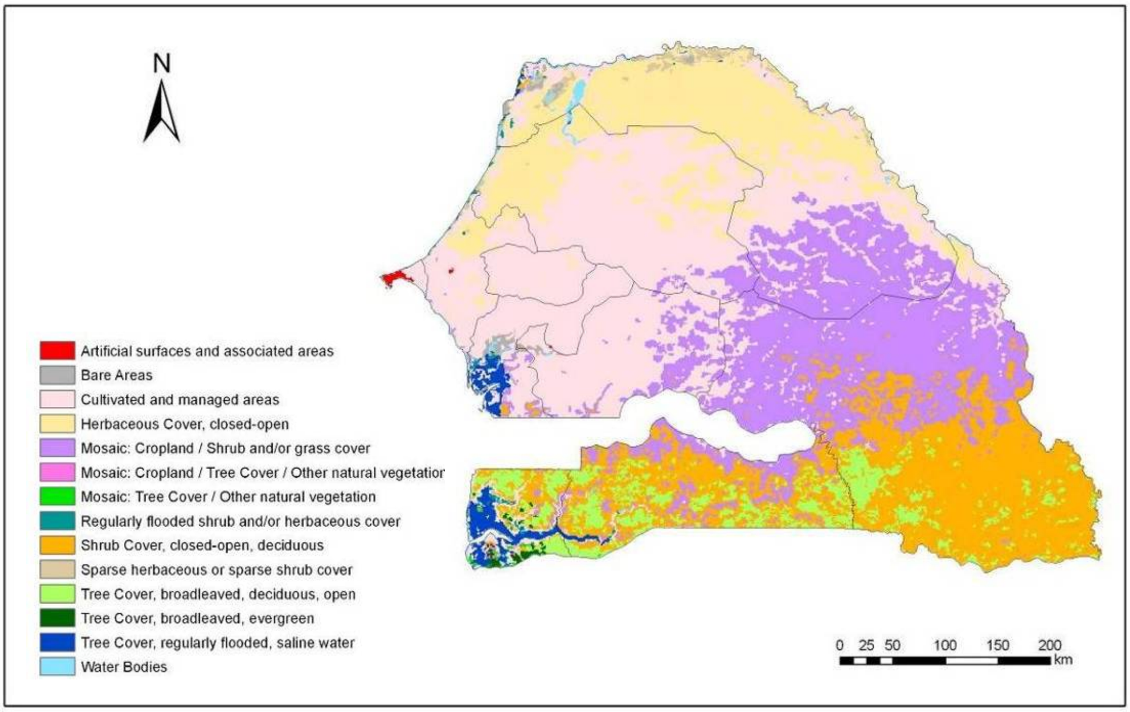

Figure 1. Main land cover types
(JRC 2003)

2.2.5 Population, urban areas and poverty

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 the remotely sensed data:

1. Simple NDVI indicators (NDVI minimum, maximum, maximum-minimum, mean, sum, standard deviation and coefficient of variation) are computed for the calendar year (Appendix 2).
2. The annual sum NDVI, the annual aggregate of greenness is chosen as the standard proxy for annual biomass productivity. NDVI is translated to net primary productivity (NPP) by correlation with MODIS NPP data. Trends are calculated by linear regression.
3. To distinguish between declining productivity caused by land degradation and declining productivity caused by other factors, false alarms must be eliminated. Rainfall variability and irrigation have been accounted for by:
    a. Identifying where there is a positive relationship between NDVI and rainfall, i.e. where rainfall determines productivity;
    b. For those areas where rainfall determines productivity, RUE has been considered: where NDVI declined but RUE increased, we may attribute declining productivity to declining rainfall; those areas are masked (urban areas are also masked);
    c. For the remaining areas with a positive relationship between NDVI and rainfall but declining RUE, and also for all areas where there is a negative relationship between NDVI and rainfall, i.e. where rainfall does not determine productivity, NDVI trend has been 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. As an additional indicator, the residual trend of sum NDVI (RESTREND) is calculated.
5. To take account of the significant lengthening and warming of the growing season at high latitudes and altitudes, energy-use efficiency – ratio of annual sum NDVI to accumulated temperature is calculated and overlaid on RUE-adjusted NDVI to calculate climate-adjusted NDVI and NPP.
6. The indices of land degradation and improvement are compared with land cover, land use, aridity, 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.

Relationships with attributes of soil and terrain will be analysed in the next phase of investigations, along with manual characterisation of degrading and improving areas using 30m-resolution Landsat data to identify the probable kinds of land degradation. 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 *hot spots* of land degradation and *bright spots* of 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).

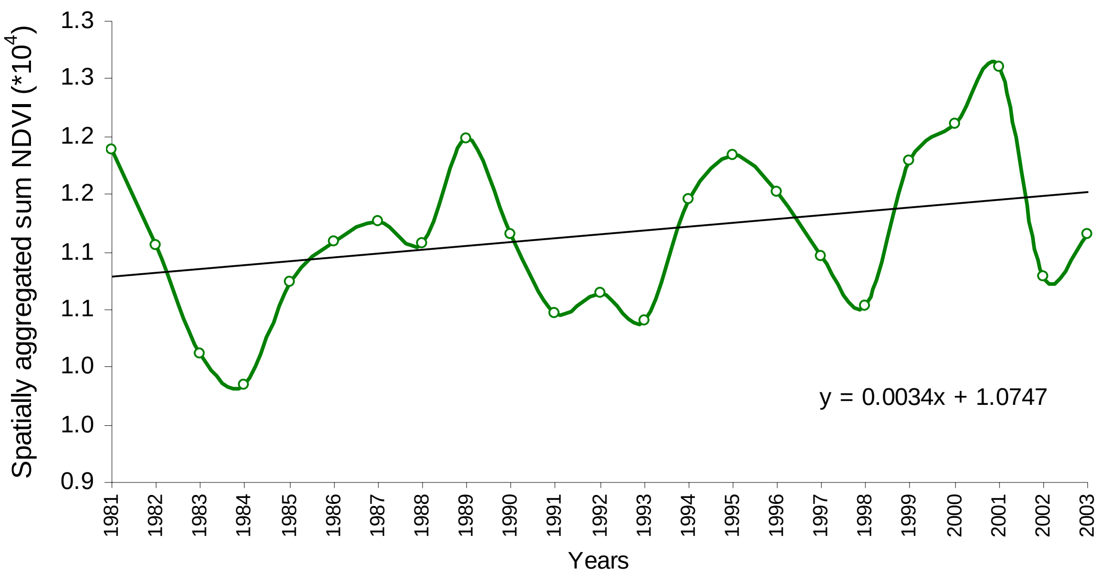

Figure 2. Spatially aggregated annual sum NDVI 1981-2003, $p<0.05$

Figure 3 maps the mean annual sum NDVI and trends over the period 1981-2003, determined for each pixel by the slope of the linear regression equation. The trends increased across 79 per cent of the country and decreased over 21 per cent.

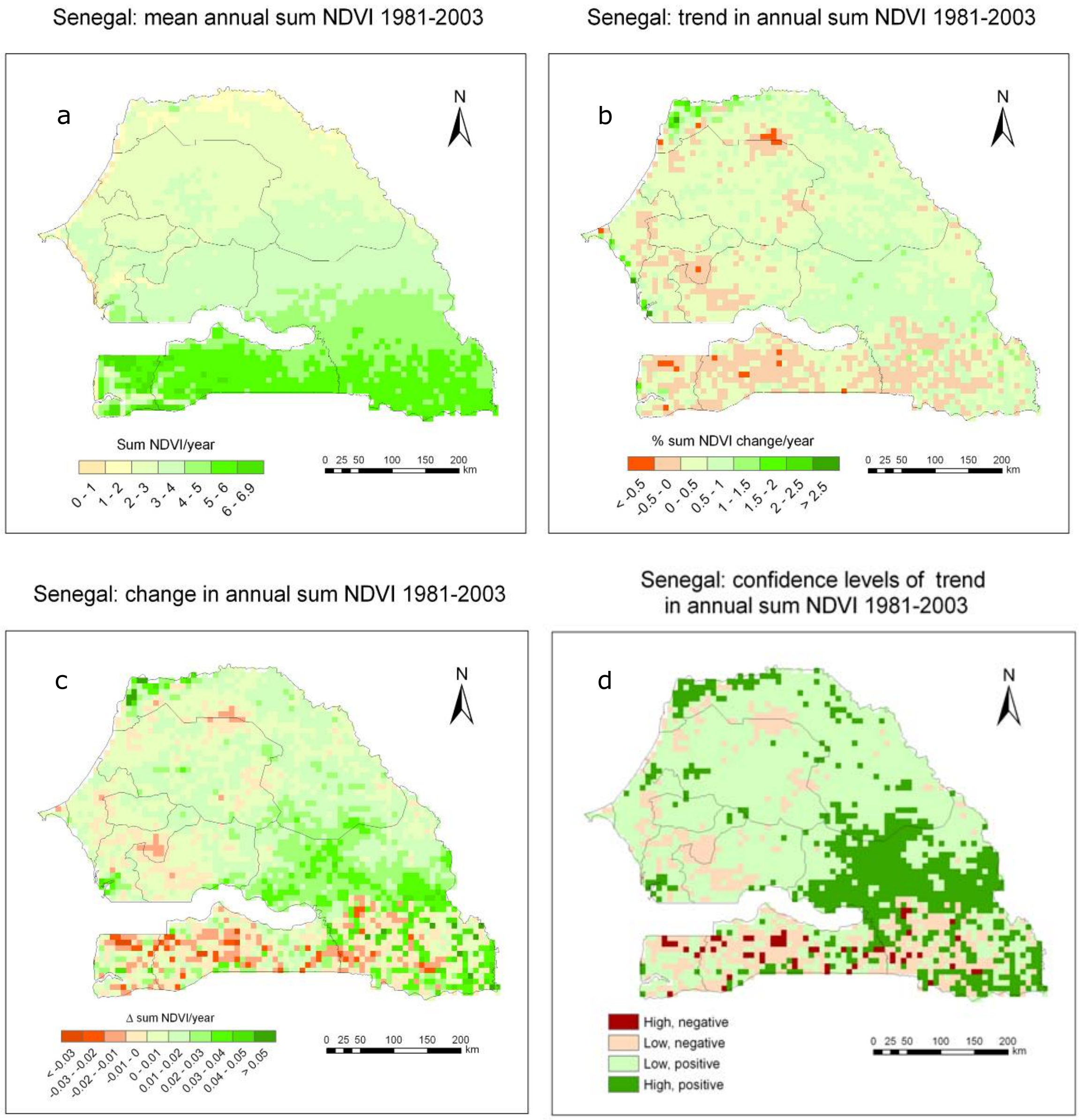

Figure 3. Annual sum NDVI 1981-2003: Mean (a) and trends (b – percentage, c – absolute, d – confidence levels)

3.2 Spatial patterns of biomass and rainfall

Biomass fluctuates according to rainfall, stage of growth and changes in land use, as well as land quality. In Senegal, mean annual biomass productivity (represented by sum NDVI in Figure 3a) essentially follows rainfall (Figure 4a) which has fluctuated significantly, both spatially (Figure 4b, c) and cyclically (Figure 5).

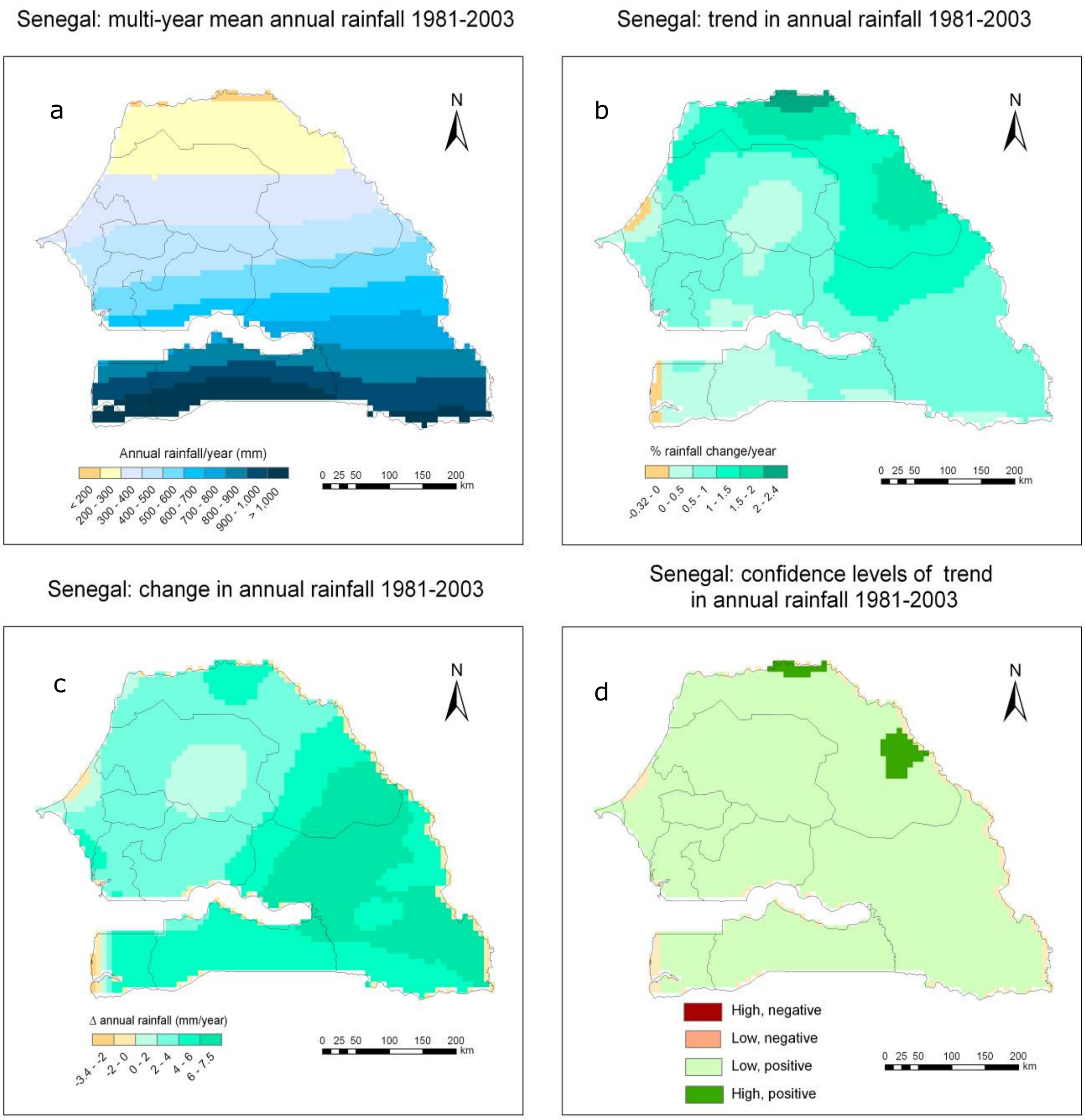

Figure 4. Annual rainfall 1981-2003: Mean (a) and trends (b – percentage change, c – absolute change, d -confidence levels)

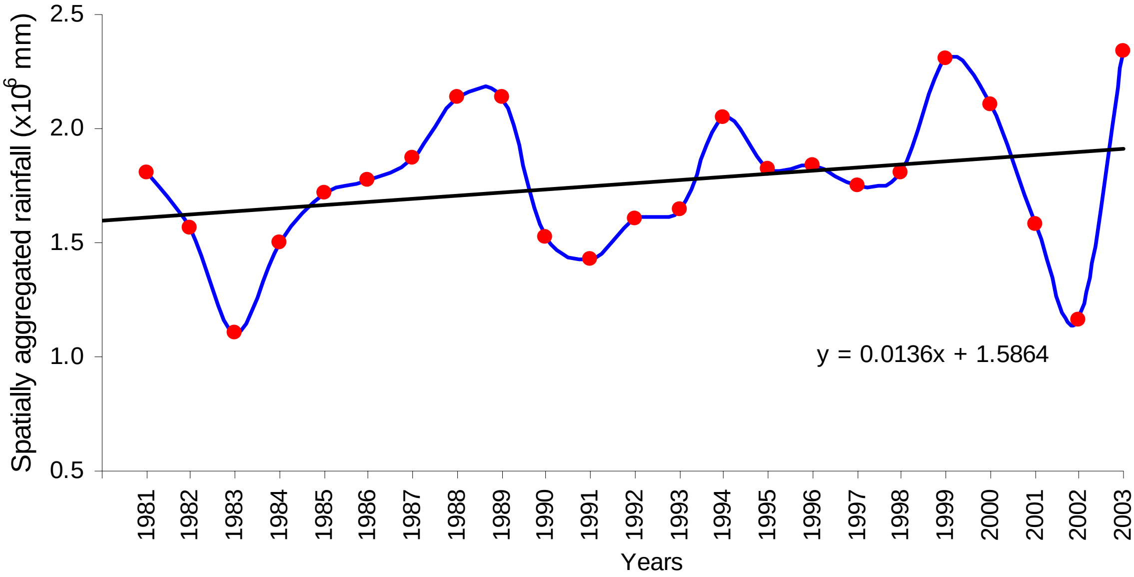

Figure 5. Spatially aggregated annual rainfall 1981-2003, P<0.05

Statistics show a strong correlation between NDVI and rainfall at the pixel level:

$$NDVI_{ann.\ sum} = 0.0041*Rainfall\ [mm\ yr^{-1}] + 1.299 \qquad [1]$$

(r^2 = 0.84, n=3 002)

Error in the regression model [1] is: slope (0.0041) ± 0.000064; intercept (1.299) ± 0.039. The coefficient of variation, r^2, indicates that 84 per cent of the variation in biomass productivity is explained by variation in rainfall.

Over the period 1981-2003, rainfall increased over nearly all of the country, on average by 4.2mm/yr and so did overall biomass production but correlation between spatially aggregated annual sum NDVI and annual rainfall is only moderate (Figure 6); there are other factors in play.

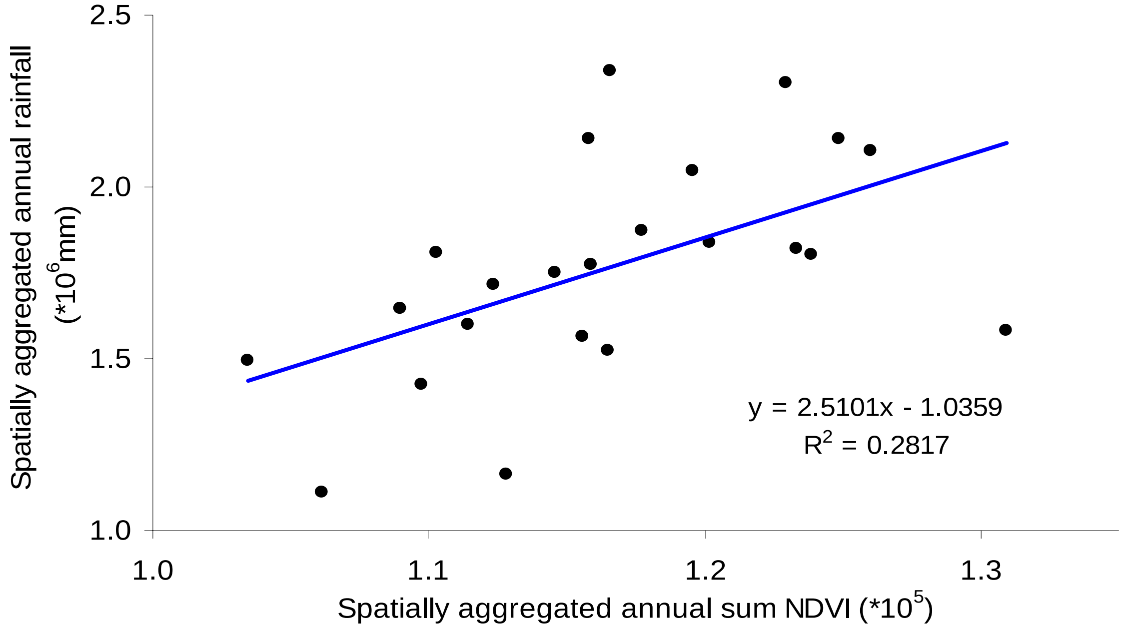

Figure 6. Relationship between annual sum NDVI (all pixels) and annual rainfall (all pixels)
Each dot represents one year, $p<0.05$

3.3 Rain-use efficiency

Allowance may be made for the effects of fluctuations in rainfall on biomass productivity by considering rain-use efficiency (RUE), i.e. production per unit of rainfall. RUE may fluctuate dramatically in the short term and often there is a sharp decline in RUE in a wet year; we may assume that the vegetation, whether cultivated or semi-natural, cannot make 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). Rain-use efficiency 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 field measurements of NPP, which are not easy to obtain. For this analysis, RUE was calculated as the ratio of annual sum NDVI and station-observed annual rainfall.

Figure 7 maps mean annual RUE and its trend over the period 1981-2003: RUE is generally higher in the drylands than the humid areas which generate significant runoff (Figure 7a). Over the period, RUE decreased over 22 per cent of the country and increased over 78 per cent. Confidence levels are assessed by the T-test.

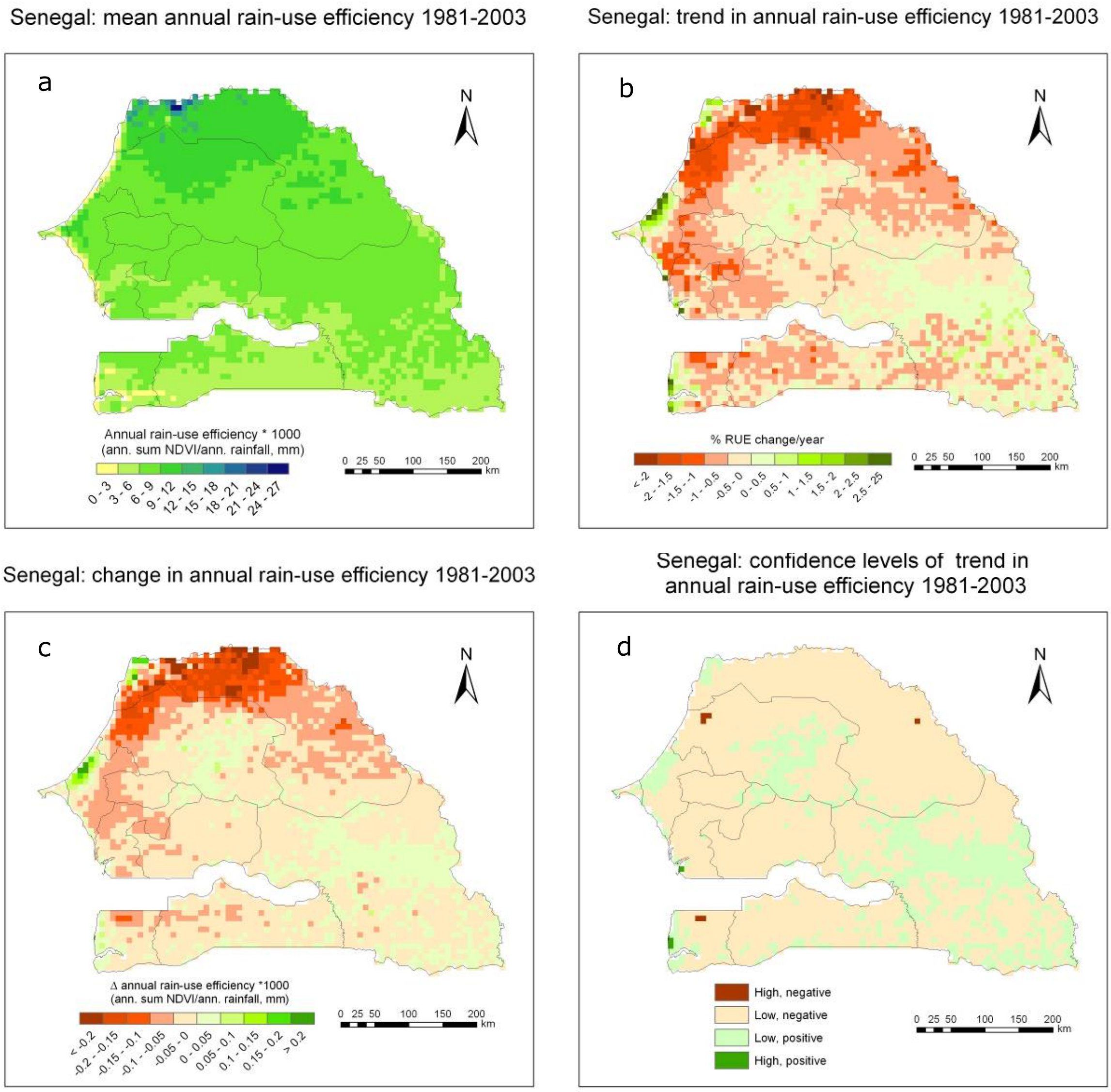

Figure 7. Rain-use efficiency 1981-2003: mean (a) and trends (b – percentage change, c – absolute changes, d - confidence levels)

3.4 RESTREND

Countrywide, there is a significant negative correlation between RUE and rainfall (r=-0.80, n=3002). In other words, RUE used in isolation says as much about rainfall variability as about land degradation. To avoid the correlations between RUE and rainfall, Wessels and others (2007) suggest the alternative use of residual trends to distinguish land degradation from the effects of rainfall variability. Following their general procedure, we have correlated annual sum NDVI and annual rainfall for each pixel. 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. However, its spatial distribution is different from RUE; overall, RESTREND patterns are remarkably close to sum NDVI but of lesser amplitude (Figure 3c).

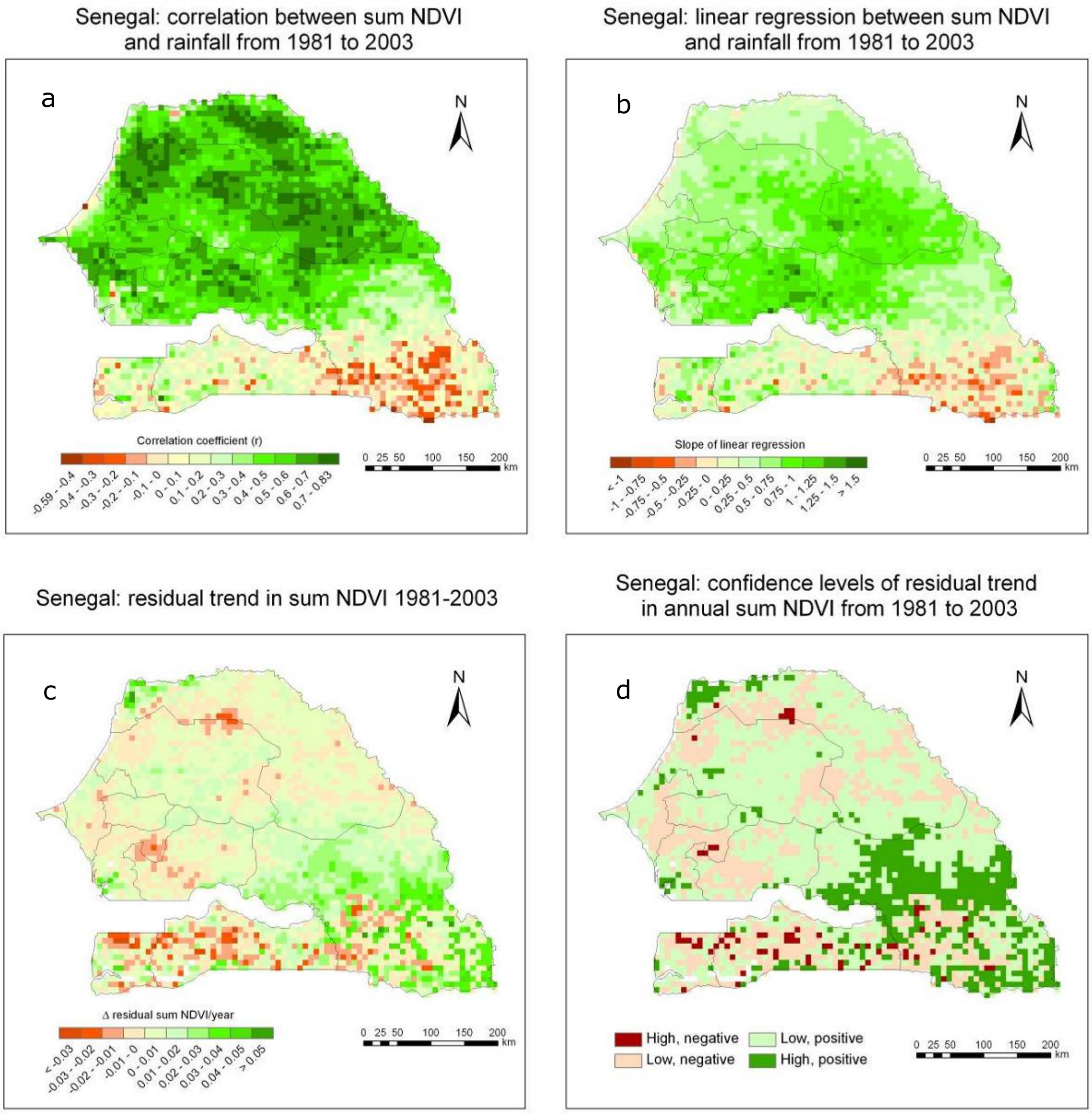

Figure 8. Residual trend of sum NDVI (RESTREND) 1981-2003:
(a) Correlation coefficient between sum NDVI and annual rainfall; (b) Slope of linear regression between sum NDVI and rainfall; (c) RESTREND; (d) Confidence levels

3.5 Net primary productivity

It is hard to visualise the degree of land degradation and improvement from NDVI. To estimate their quantitative effects, 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). GIMMS NDVI data were translated 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:

$$NPP_{MOD17}\ [\text{tonneC ha}^{-1}\ \text{year}^{-1}] = 0.3203 * NDVI_{sum} + 0.3861 \qquad [2]$$

$(r = 0.42, n = 3\ 110, P<0.01)$

Where NPP_{MOD17} is annual net primary productivity derived from MOD17, $NDVI_{sum}$ is a four-year (2000-2003) mean annual sum NDVI derived from GIMMS, and C is carbon. The statistical error in the regression model [2] is: slope (0.3203) ± 0.0668; intercept (0.3861) ± 0.2728. For Senegal, correlation between the two raster data for all land cover types is only moderate, in contrast with a very high correlation globally (Bai and others 2008). This means that, for Senegal, the translation from NDVI to NPP is very approximate.

Figure 9a shows four-year (2000-2003) mean annual MODIS NPP at 1-km resolution; compared with the long-term mean sum NDVI. Globally, the two datasets are in very good agreement. However, for Senegal the agreement is weaker and in the south-east of the country (Tambacouda Province), there is a discrepancy between the MODIS NPP measurements for 2000-2003 and the GIMMS measurements for the same period: MODIS indicates much lower values than are predicted by the global relationship between GIMMS NDVI and MODIS NPP. This discrepancy has been checked for the whole country by comparing the most recent GIMMS data (2000-2006) with MODIS for the same period. The discrepancy remains, which means that the translation of NDVI to NPP for Senegal is not reliable. *However, the interpretation of the GIMMS NDVI data is robust.*

The percentage and absolute changes in NPP over the period 1981-2003, calculated by equation 2 are depicted in Figure 9b, c; the confidence level (Figure 9d) refers to the T-test (Appendix 1). During the period, NPP increased overall in the vegetated areas which comprise about 60 per cent of the country (Table 1).

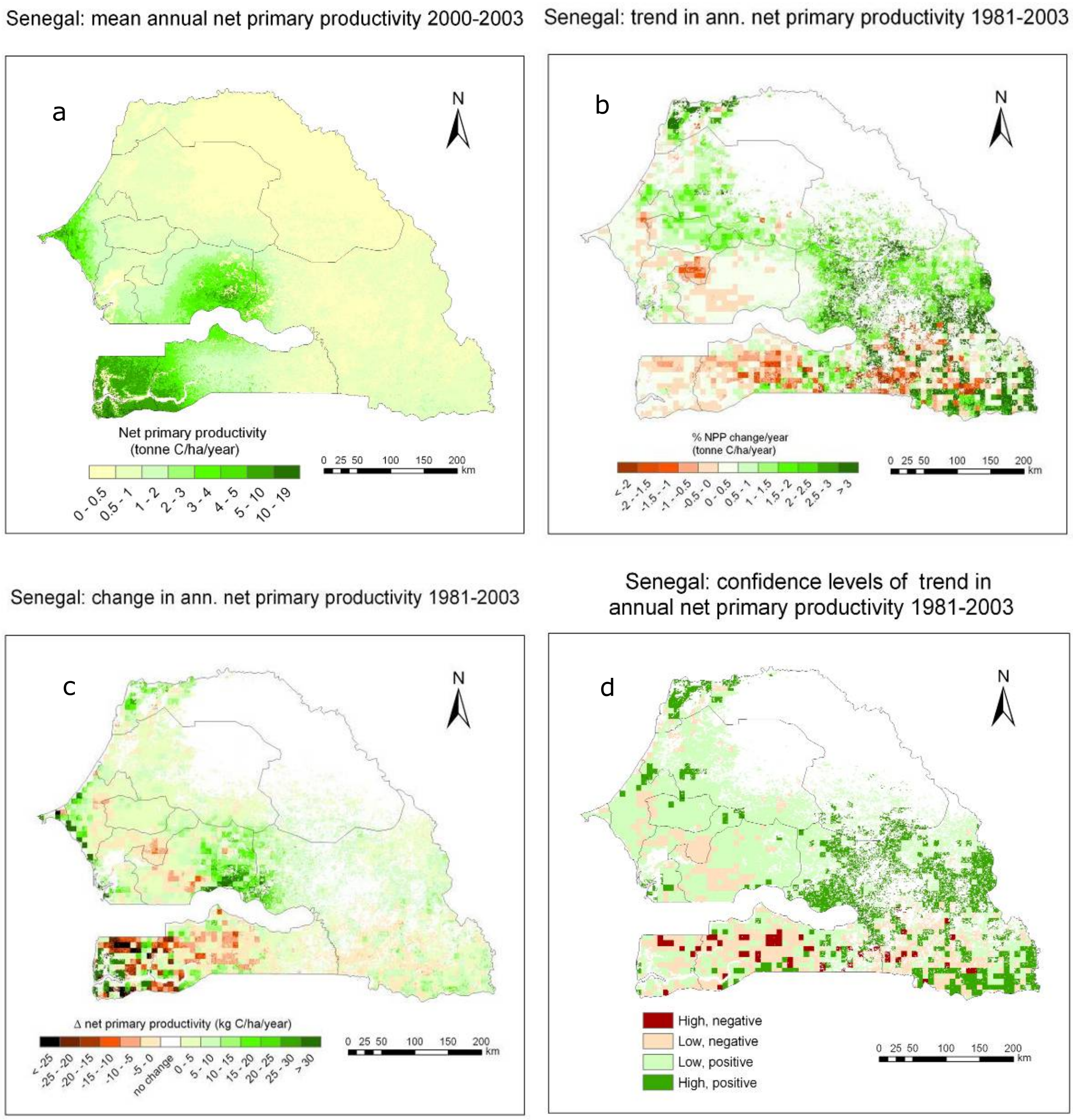

Figure 9. Net primary productivity 1981-2003: mean (a) and trends (b- percentage change, c – absolute change, d – confidence level)

Table 1. Changes in net primary productivity 1981-2003*

	Positive	*Negative*	*Mean*
Land area (pixels, %)	74.5	25.5	
% NPP change/year (tonneC ha^{-1} $year^{-1}$)	1.16	0.49	0.73
Δ NPP (kgC ha^{-1} $year^{-1}$)	8.25	5.79	4.64

*in the vegetated areas, i.e. those with NPP greater than1 gC/m^2/year as measured by the MOD17 Collection 4 data

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.

3.6.1 Rainfall variability

Rainfall variability has been accounted for 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.

Figure 10 depicts the negative trend of RUE-adjusted NDVI 1981-2003. Eighteen per cent of the country suffered declining RUE-adjusted NDVI, mostly in the south of the country and especially in the south-west. Degrading areas are not conspicuous in the drylands.

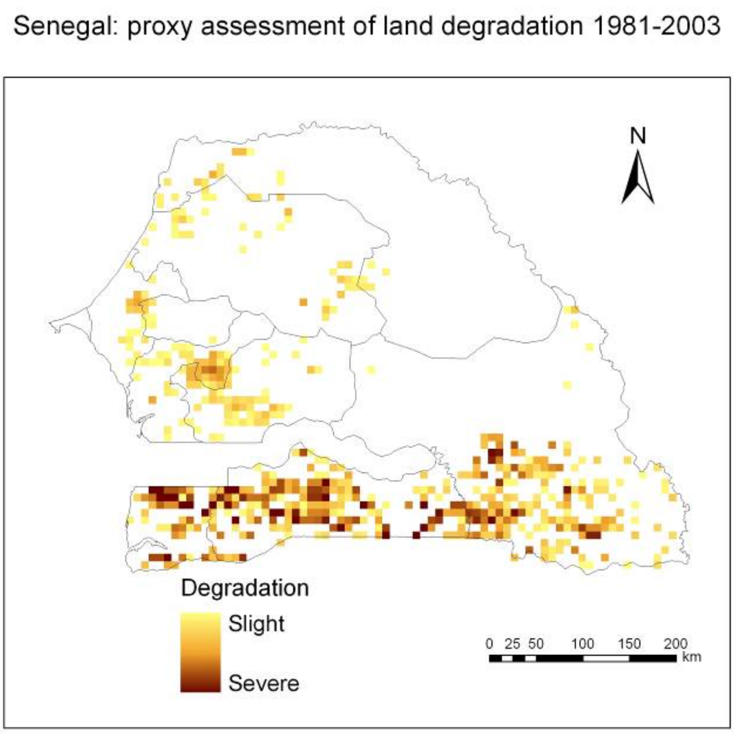

Figure 10. Negative trend in RUE-adjusted annual sum NDVI, 1981-2003

Comparison between RUE-adjusted NDVI and RESTREND: For Senegal, 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; cf Section 3.9.

3.6.2 Net primary productivity

To estimate the decline in productivity in quantitative terms, we have calculated loss of NPP, relative to the average, by translating RUE-adjusted NDVI to RUE-adjusted NPP using the relationship between GIMMS and MODIS data for the overlapping years 2000-2003 (Figure 11, Table 2).

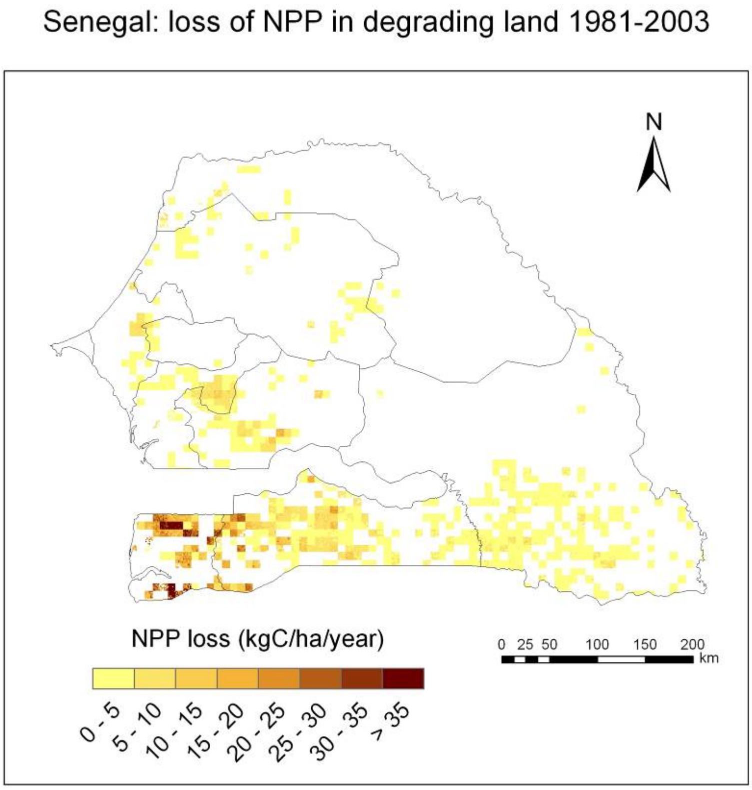

Figure 11. NPP loss in the degrading areas 1981-2003

Table 2. Senegal and the World: NPP loss from degrading land 1981-2003

	Degrading land (km^2)	*% territory*	*% global degrading land*	*NPP loss (kg C/ha/yr*	*Total NPP loss (tonne C/23yr)*
Senegal	34 655	17.7	0.1	5.1	408 833
The World	35 058 104	23.5	100	11.8	955 221 419

3.6.3 Land use change

As with rainfall variability, land use change may also generate false alarms about land degradation. For instance, conversion of forest or grassland to cropland will usually result in an immediate reduction in NDVI (and NPP) but may well be profitable and sustainable, depending on management. Likewise, bush encroachment into cropland or rangeland will result in an increase in NDVI but this would not be considered land improvement by the land users.

Lack of consistent time series data for land use and management precludes a generalised analysis of land use change. However, in a following report, this will be undertaken manually for the potential *hot spots* of land degradation identified in this analysis.

3.7 Land improvement

Land improvement is identified by combination of: 1) a positive trend in sum NDVI for those areas where there is a no correlation between rainfall and NDVI; 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). Figure 13 shows the confidence levels by t-test. These areas account for about 37 per cent of the country. An extensive improving area is indicated in central-northern Tambacounda Province. Figure 14 shows the gain in NPP in those areas.

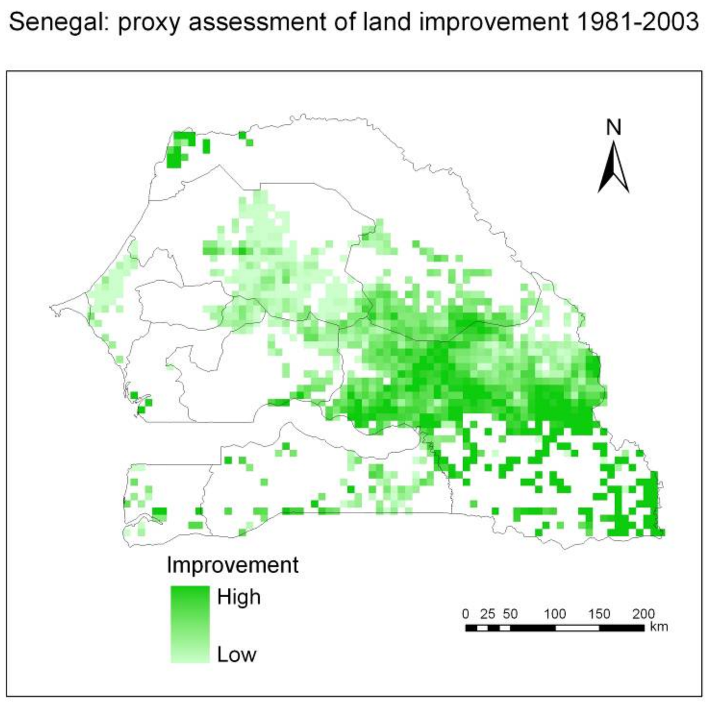

Figure 12. Areas of increasing NPP, RUE and EUE, 1981-2003

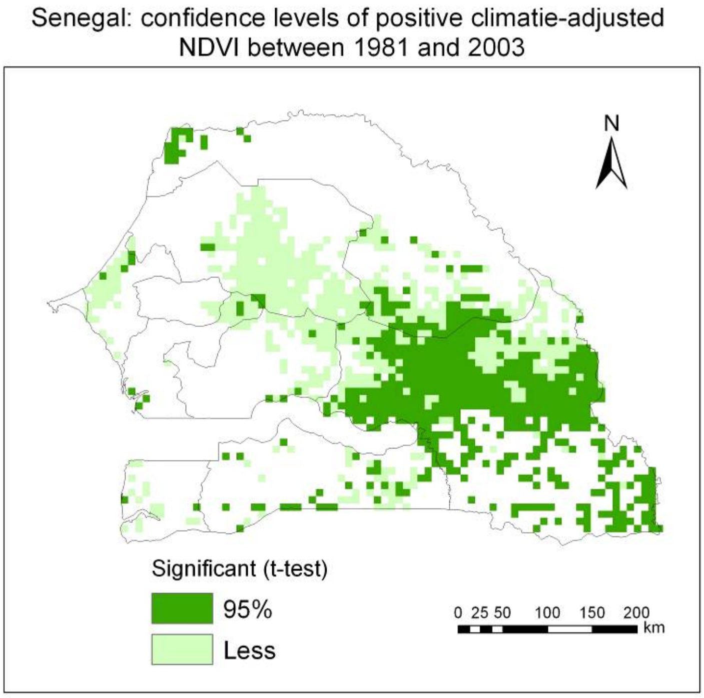

Figure 13. Confidence levels of positive climate-adjusted NDVI, 1981-2003

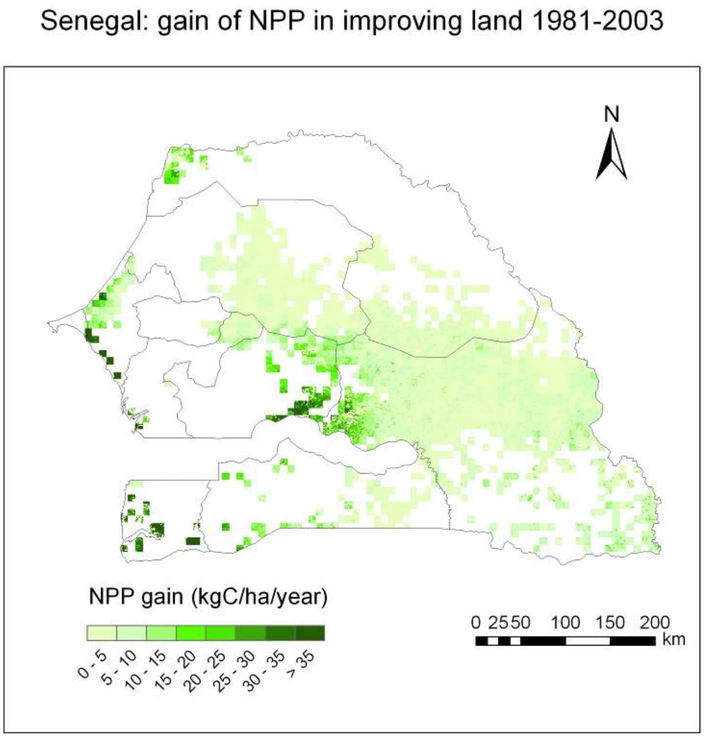

Figure 14. NPP gain in the improving areas 1981-2003

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 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 0.85 per cent of the land area as urban. This area is masked in the maps, which makes only a small difference to the results: a reduction of 1 per cent in the area of identified degrading land, and a reduction of 1.3 per cent for the improving land.

3.9 Comparison of indicators

Annual sum NDVI, i.e. annually accumulated greenness, is our standard indicator of land degradation and improvement. Rain-use efficiency, RUE-adjusted NDVI and RESTREND are different ways of eliminating false alarms caused by rainfall variability (cf Sections 3.3 and 3.4, respectively).

Countrywide, the patterns of the trends in sum NDVI and RESTREND are almost identical (Table 3): about 18 per cent of land area shows negative change in both sum NDVI and RESTREND, 60 per cent shows positive trend in both indictors, 12 per cent no change and 10 per cent gives mixed signals - 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 96 per cent of these areas are also degrading in terms of *both* unadjusted NDVI and RESTREND. Taking a positive trend of RUE-adjusted NDVI as the primary definition of improving land, 99 per cent of the area is also positive in terms of *both* unadjusted NDVI and RESTREND.

Comparing RUE with RESTREND, 27 per cent of the land area shows negative trend in both RUE and RESTREND, 21 per cent shows positive trend in both indicators and 12 per cent no change. But we get mixed signals from 40 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 96 per cent shows negative trend in both RUE and RESTREND, and 51 per cent of the improving area shows positive trend in both RUE and RESTREND.

Table 3. Comparison of indicators, 1981-2003

Indicators	*Total pixel* (%)	*Negative trend* (%)	*Positive trend* (%)	*No change* (%)	*Mixed* (%)
Annual sum NDVI	100	18.4	69.6	12.1	0.0
RESTREND[1]	100	27.6	60.3	12.1	0.0
Sum NDVI ∩ RESTREND	100	17.5	59.6	12.4	10.4
Sum NDVI ∩ RESTREND within LD[2]		**96.0**			
Sum NDVI ∩ RESTREND within LI[3]			**98.9**		
RUE	100	67.2	20.7	12.1	0.0
RUE ∩ RESTREND	100	27.4	20.6	12.1	39.8
RUE ∩ RESTREND within LD		**95.7**			
RUE ∩ RESTREND within LI			**50.8**		

[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 Relationship with land cover and land use

Comparing the combined index of land degradation and improvement with land cover (Figure 1, Table 4), 27 per cent of the degrading area is cropland and a further 7.5 per cent a mosaic of cropland, scrub and grassland; in all, more than 10 per cent of arable land is degrading. Forty seven per cent of the degrading area is scrub and grassland (codes 12-15), one quarter of all scrub and grassland; and 19 per cent of the degrading area is forest (codes 1, 3, 8 and 9), 47 per cent of forest. Of the improving areas, 29 per cent is cropland and a further 46 per cent a mosaic of cropland with other land cover, 21 per cent with scrub and grassland, and 4 per cent forest.

Comparison of degrading areas with land use systems (Tables 5 and 6) indicates that 48 per cent of degrading land is rangeland (herbaceous vegetation in the FAO legend, 23 per cent of this unit), 31 per cent is agricultural land (9 per cent of agricultural land) and 17 per cent is forestry (about 42 per cent of the forest area, with supposedly protected and natural areas faring no better than the average). 76 per cent of improving land is agricultural land, 20 per cent is rangeland, and 3 per cent is classified as forest.

Table 4. Degrading and improving land by land cover

Code	*Land cover*	*Total pixels*[1] *(TP)*	*Degrading pixels (DP)*[2]	*DP/TP*	*DP/TDP*[3]	*Improving pixels (IP)*	*IP/TP*	*IP/TIP*[4]
				(%)	(%)		(%)	(%)
1	Tree cover, broadleaved evergreen	395	201	50.9	0.6	50	12.7	0.1
3	Tree cover, broadleaved deciduous, open	10846	6074	56.0	16.9	2194	20.2	2.9
8	Tree cover, tidal	2681	307	11.5	0.9	481	17.9	0.6
9	Mosaic: tree cover / other natural vegetation	168	43	25.6	0.1	31	18.5	0.0
12	Shrub cover, deciduous	40167	14491	36.1	40.2	13952	34.7	18.5
13	Herbaceous cover, closed-open	29339	2230	7.6	6.2	1703	5.8	2.3
14	Sparse herbaceous or sparse shrub cover	1567	25	1.6	0.1	151	9.6	0.2
15	Shrub and/or herbaceous cover, tidal	565	83	14.7	0.2	71	12.6	0.1
16	Cultivated and managed areas	70036	9565	13.7	26.6	21912	31.3	29.1
17	Mosaic: cropland/tree cover/other natural vegetation	119	38	31.9	0.1	45	37.8	0.1
18	Mosaic: cropland / shrub and/or grass cover	48685	2670	5.5	7.4	34449	70.8	45.8
19	Bare areas	896	99	11.0	0.3	146	16.3	0.2
20	Water bodies	1287	173	13.4	0.5	94	7.3	0.1
22	Artificial surfaces and associated areas	183	5	2.7	0.0	17	9.3	0.0
	Total	206934	36004		100	75296		100.0

[1] Pixel size 1x1km, [2] Urban extents are excluded, [3] TDP - total degrading pixels, [4] TIP - total improving pixels

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

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	0.0
1	Forestry - not managed (natural)	4	2	50.0	0.5	1	25.0	0.1
2	Forestry - protected areas	29	13	44.8	3.4	8	27.6	0.9
4	Forestry - pastoralism moderate or higher	92	44	47.8	11.5	17	18.5	2.0
5	Forestry - pastoralism moderate or higher with scattered plantations	31	7	22.6	1.8	1	3.2	0.1
6	Forestry - plantations	3	0	0.0	0.0	0	0.0	0.0
7	Herbaceous - not managed (natural)	17	4	23.5	1.0	1	5.9	0.1
8	Herbaceous - protected areas	101	46	45.5	12.0	18	17.8	2.1
9	Herbaceous - extensive pastoralism	88	2	2.3	0.5	2	2.3	0.2
10	Herbaceous - moderately intensive pastoralism	358	69	19.3	18.0	103	28.8	12.1
11	Herbaceous - intensive pastoralism	234	64	27.4	16.7	42	17.9	4.9
13	Rain-fed agriculture	43	1	2.3	0.3	15	34.9	1.8
14	Agro-pastoralism - moderately intensive	364	22	6.0	5.7	245	67.3	28.8
15	Agro-pastoralism - intensive	789	93	11.8	24.3	322	40.8	37.9
16	Agro-pastoralism - moderately intensive or higher with large-scale irrigation	6	0	0.0	0.0	4	66.7	0.5
17	Agriculture – large-scale irrigation (> 25% pixel size)	2	1	50.0	0.3	1	50.0	0.1
18	Agriculture - protected areas	139	2	1.4	0.5	60	43.2	7.1
19	Urban areas	21	6	28.6	1.6	6	28.6	0.7
20	Wetlands - not managed (natural)	2	0	0.0	0.0	0	0.0	0.0
21	Wetlands - protected areas	12	0	0.0	0.0	1	8.3	0.1
22	Wetlands - mangroves	18	3	16.7	0.8	2	11.1	0.2
23	Wetlands - agro-pastoralism	3	1	33.3	0.3	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]
		(5'x5')	(5'x5')	(%)	(%)	(5'x5')	(%)	(%)
24	Bare areas - not managed (natural)	3	0	0.0	0.0	1	33.3	0.1
25	Bare areas - protected	6	0	0.0	0.0	0	0.0	0.0
26	Bare areas - extensive pastoralism	2	0	0.0	0.0	0	0.0	0.0
27	Bare areas – moderately intensive pastoralism	2	1	50.0	0.3	0	0.0	0.0
28	Water - coastal or not managed (natural)	1	0	0.0	0.0	0	0.0	0.0
29	Water - protected areas	0	0	0.0	0.0	0	0.0	0.0
30	Water - inland fisheries	10	2	20.0	0.5	0	0.0	0.0
100	Undefined	0	0	0.0	0.0	0	0.0	0.0
	Total	2380	383		100.0	850		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	159	66	41.5	17.2	27	17.0	3.2
Rangeland	7-11	798	185	23.2	48.3	166	20.8	19.5
Agricultural land	13-18	1343	119	8.9	31.1	647	48.2	76.1
Urban	19	21	6	28.6	1.6	6	28.6	0.7
Wetlands	20-23	35	4	11.4	1.0	3	8.6	0.4
Bare areas	24-27	13	1	7.7	0.3	1	7.7	0.1
Water	28-30	11	2	18.2	0.5	0	0.0	0.0
Undefined	0,100	0	0	0.0	0.0	0	0.0	0.0
Total		2380	383		100.0	850		100.0

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

3.10.2 Association with population density

About 21 per cent of Senegalese (2.1 million out of 10.2 million in 2005) live in the degrading areas (Figure 15). There is a weak correlation between land degradation and rural population density (r = 0.33) i.e. the higher the population density, the more land degradation.

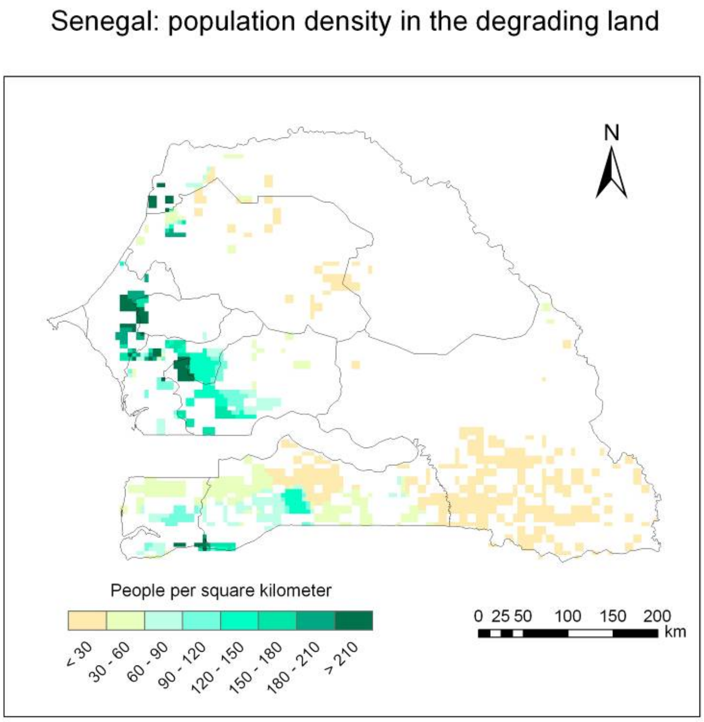

Figure 15. Population counts affected by the land degradation

3.10.3 Relationship with aridity

There is no correlation (r=0.07) between land degradation and Turc's aridity index; 44 per cent of degrading land is in the dry sub-humid zone, 41 per cent in the humid zone, 11 per cent in the semi-arid, 6 per cent in the arid.

3.10.4 Relationship with poverty

Taking infant mortality rate and the percentage of children under five who are underweight as proxies for poverty, there is no clear relationship with land degradation; for infant mortality, correlation coefficient (r) is 0.02; for percentage of children underweight, r is 0.4. A more rigorous analysis is needed to tease out the underlying biophysical and social and economic drivers which would require more specific geo-located data.

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 of GIMMS time series NDVI data, a measure of greenness which is taken as a proxy for NPP. Translation of NDVI to NPP is 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 in land use and management. Rain-use efficiency 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.

- In the particular case of sparsely vegetated dryland, continued soil loss and the resulting sediment loads in the streams is not detected by greenness. There are two issues here: first, historical land degradation - which is not detected by the trend of the last 25 years; secondly, the vegetation of many of these areas has stabilized or even improved, but significant soil loss is still taking place.

- 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 GLADA 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). Apart from a discrepancy between the MODIS and GIMMS data for 2000-2003 in the south-east of the country, 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, 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 or its surrogate NDVI 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. Land use change is not accounted for in this study for lack of consistent time series data.

- As a quantitative measure of land degradation, loss of NPP relative to the normal 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 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 Senegal, over the period of 1981-2003, NPP increased overall. Degrading areas, suffering declining climate-adjusted NPP, occupy 18 per cent of the country, mostly in the Casamance. Twenty seven per cent of the degrading area is cropland and a further 7 per cent a mosaic of cropland, scrub and grassland, in all about ten per cent of the arable; 47 per cent of degrading land is scrub (one quarter of all scrubland); and 19 per cent forest (47 per cent of forested land).

- There is no obvious correlation between land degradation and aridity.

- About 21 per cent of the population (2.1 million out of 10.2 million in 2005) live in the degrading areas. Population pressure is positively related to land degradation but there is no clear correlation between severity of land degradation and poverty.

- Land improvement, defined by increase of NPP, RUE and EUE, is identified across 37 per cent of the country: 29 per cent under cultivation and a further 46 per cent of under a mosaic of cropland, scrub and grassland; 21 per cent with scrub and grassland; and 4 per cent forest.

- 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 and the interpretation is preliminary until validated by fieldwork.

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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 the land degradation/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*

NDVI indicators	*NDVI values*			*Pixels (%)*		*% NDVI change/year*			*Δ NDVI/year*		
	min	max	mean	Pos.	Neg.	Pos.	Neg.	mean	Pos.	Neg.	mean
Minimum	0.108	0.222	0.170	58.6	41.4	0.757	0.397	0.259	0.0013	0.0007	0.0004
Maximum	0.425	0.684	0.560	70.5	29.5	0.545	0.269	0.297	0.0027	0.0017	0.0013
Max-Min	0.253	0.521	0.390	62.9	37.1	0.732	0.434	0.308	0.0025	0.0018	0.0009
Mean	0.263	0.367	0.316	78.7	21.3	0.444	0.153	0.311	0.0013	0.0006	0.0009
Sum	3.154	4.398	3.791	78.7	21.3	0.444	0.153	0.311	0.0157	0.0077	0.0105
STD	0.082	0.169	0.128	71.0	29.0	0.749	0.409	0.406	0.0008	0.0005	0.0004
CoV	0.264	0.538	0.404	59.6	40.4	0.572	0.491	0.145	0.0023	0.0019	0.0006

* 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.

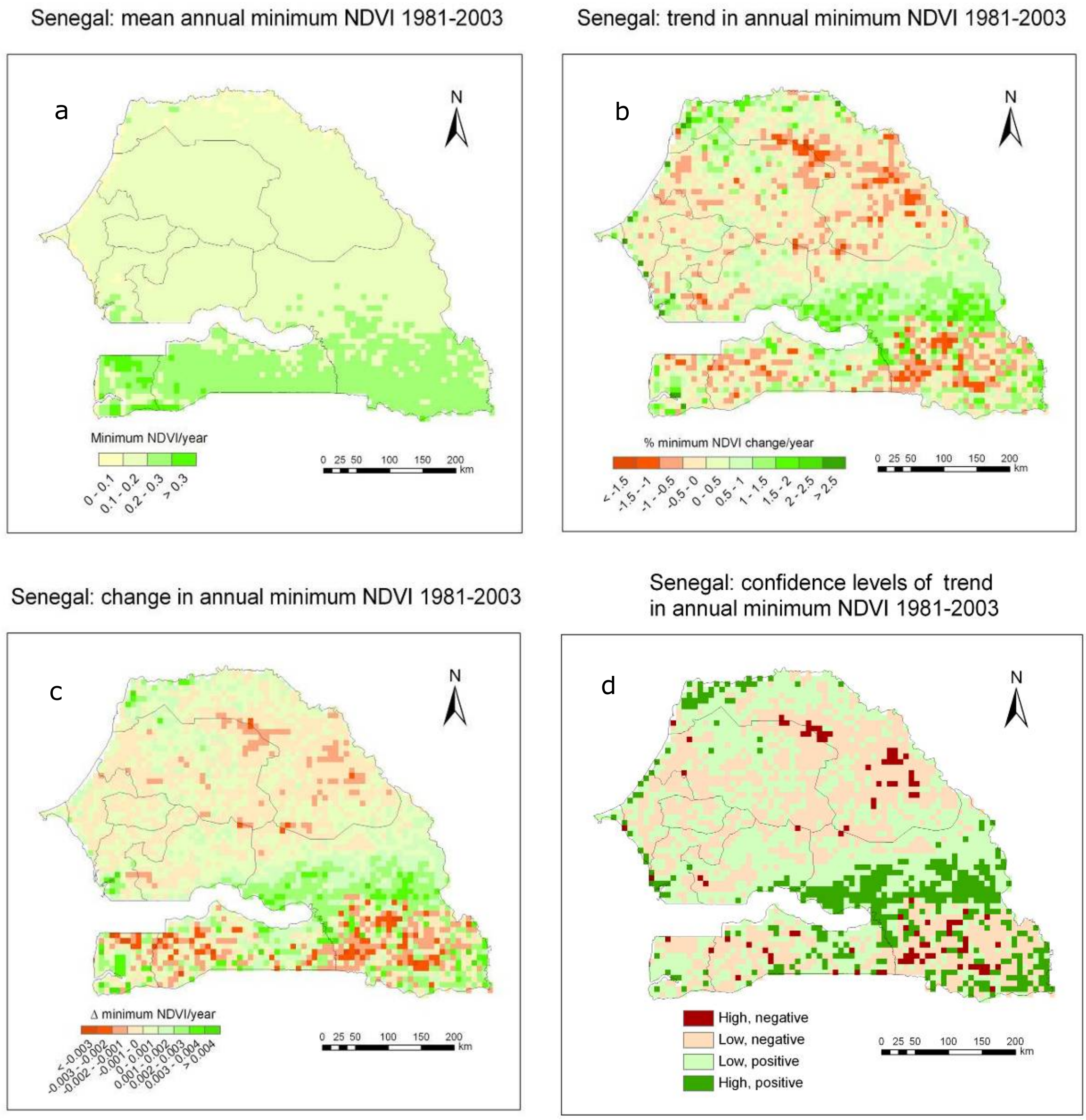

Figure A1. Annual minimum NDVI 1981-2003: mean (a) and trends (b – percentage, c – absolute, d - confidence levels)

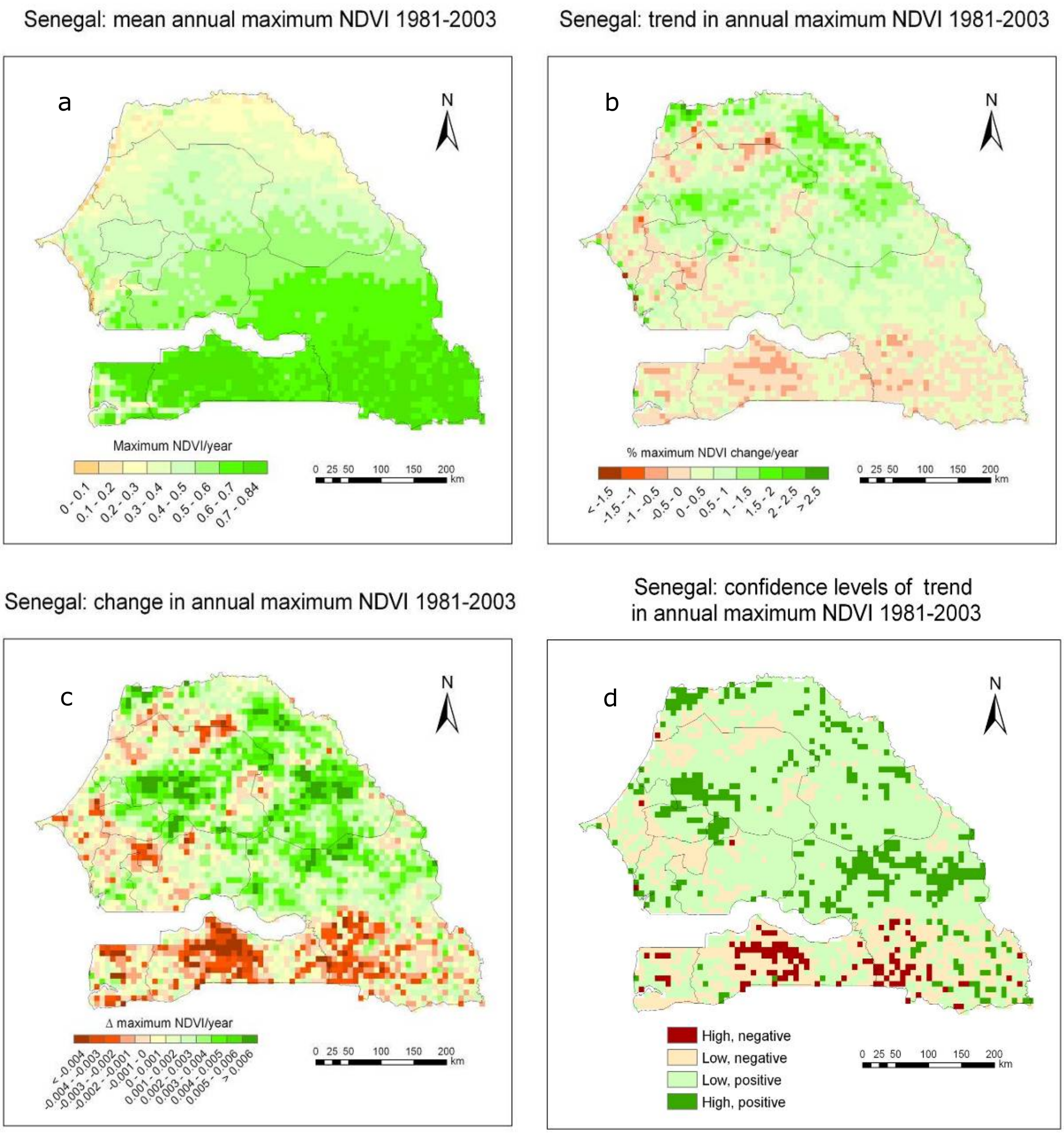

Figure A2. Annual maximum NDVI 1981-2003: mean (a), trends (b – percentage, c – absolute, d - confidence levels)

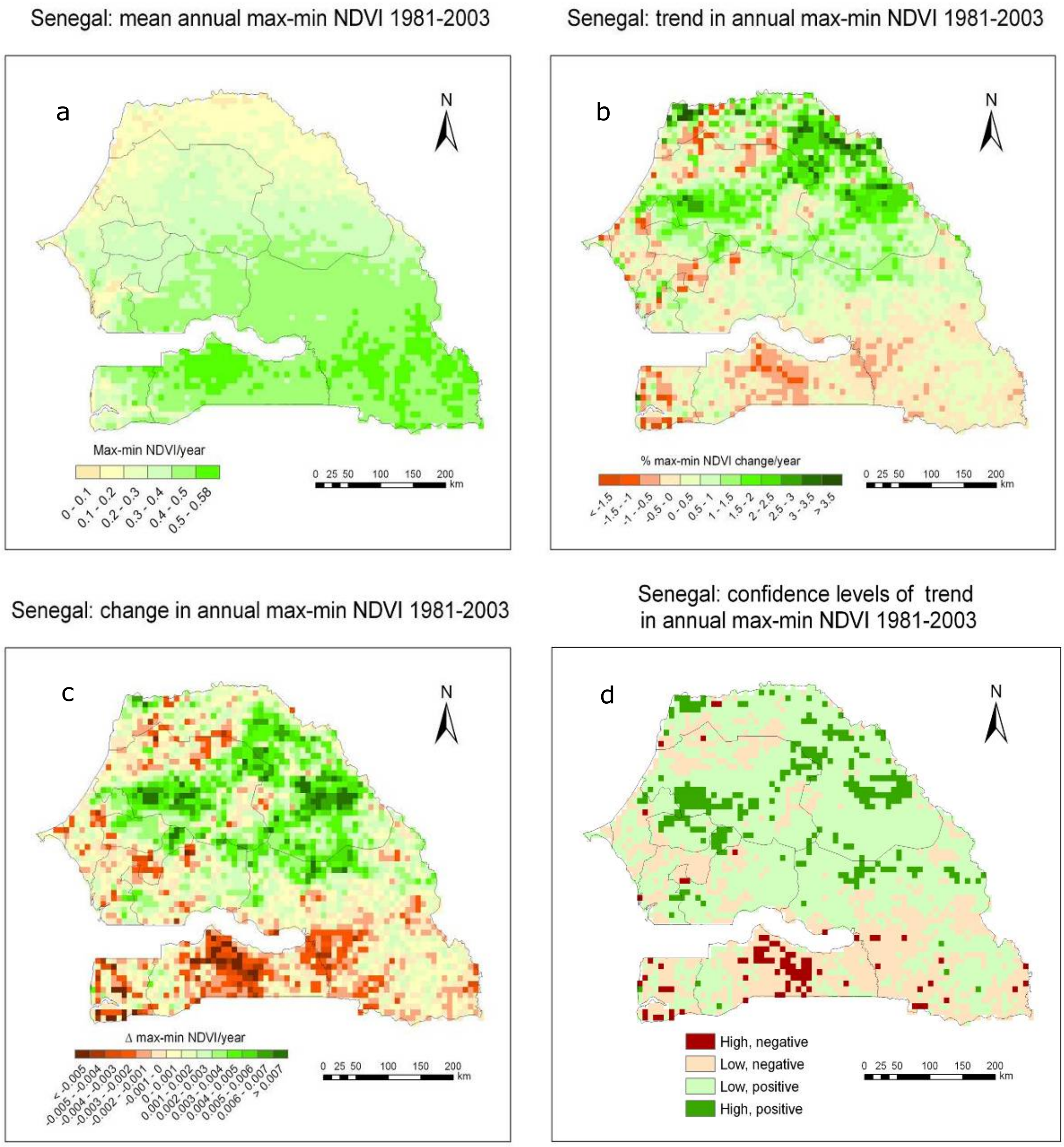

Figure A3. Max-min NDVI 1981-2003: mean (a) and trends (b – percentage, c – absolute, d - confidence levels d)

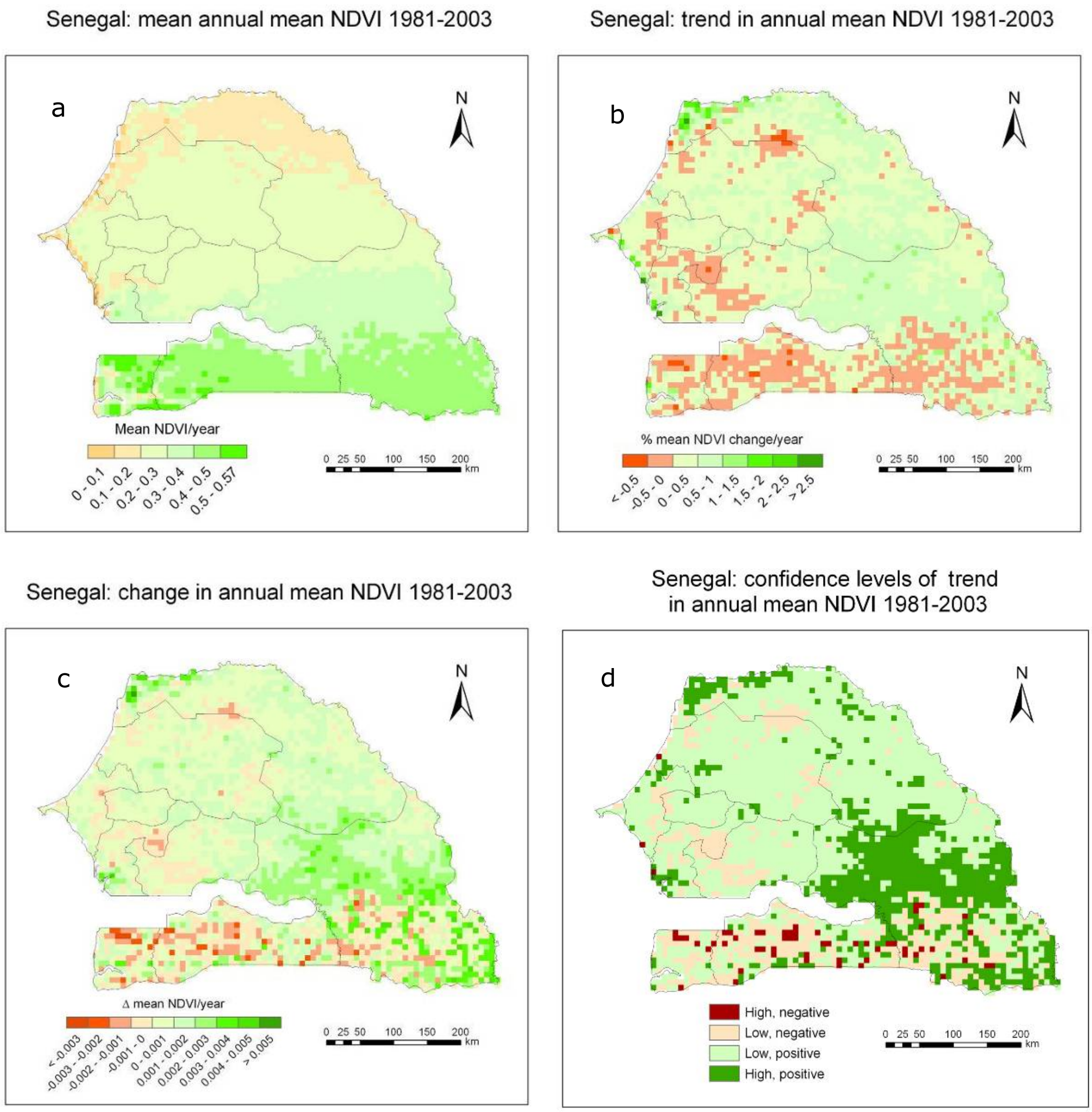

Figure A4. Annual mean NDVI 1981-2003: multi-year mean (a) and trends (b – percentage, c – absolute, d - confidence levels)

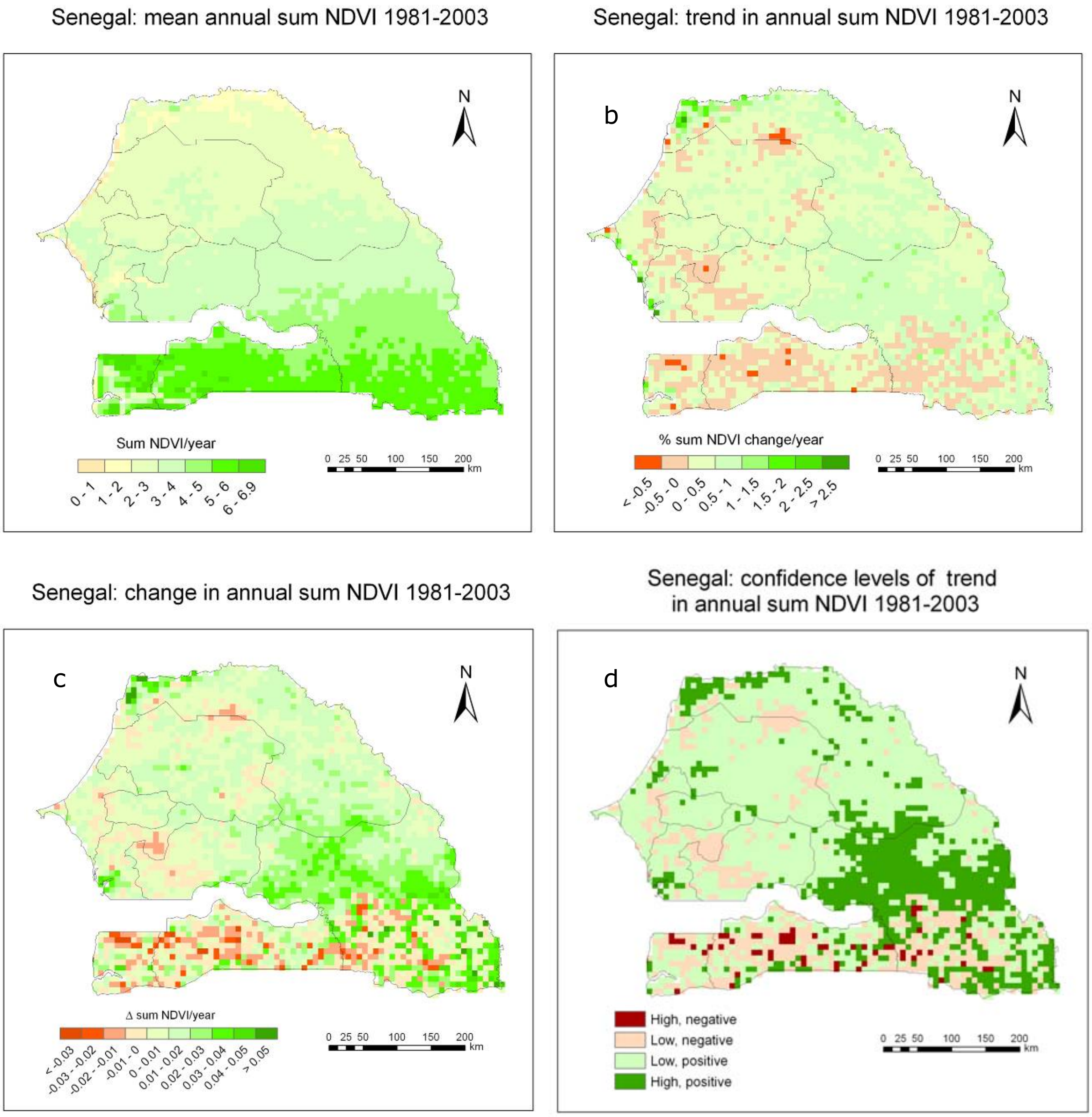

Figure A5. Annual sum NDVI 1981-2003: multi-year mean (a) and trends (b – percentage, c – absolute, d - confidence levels)

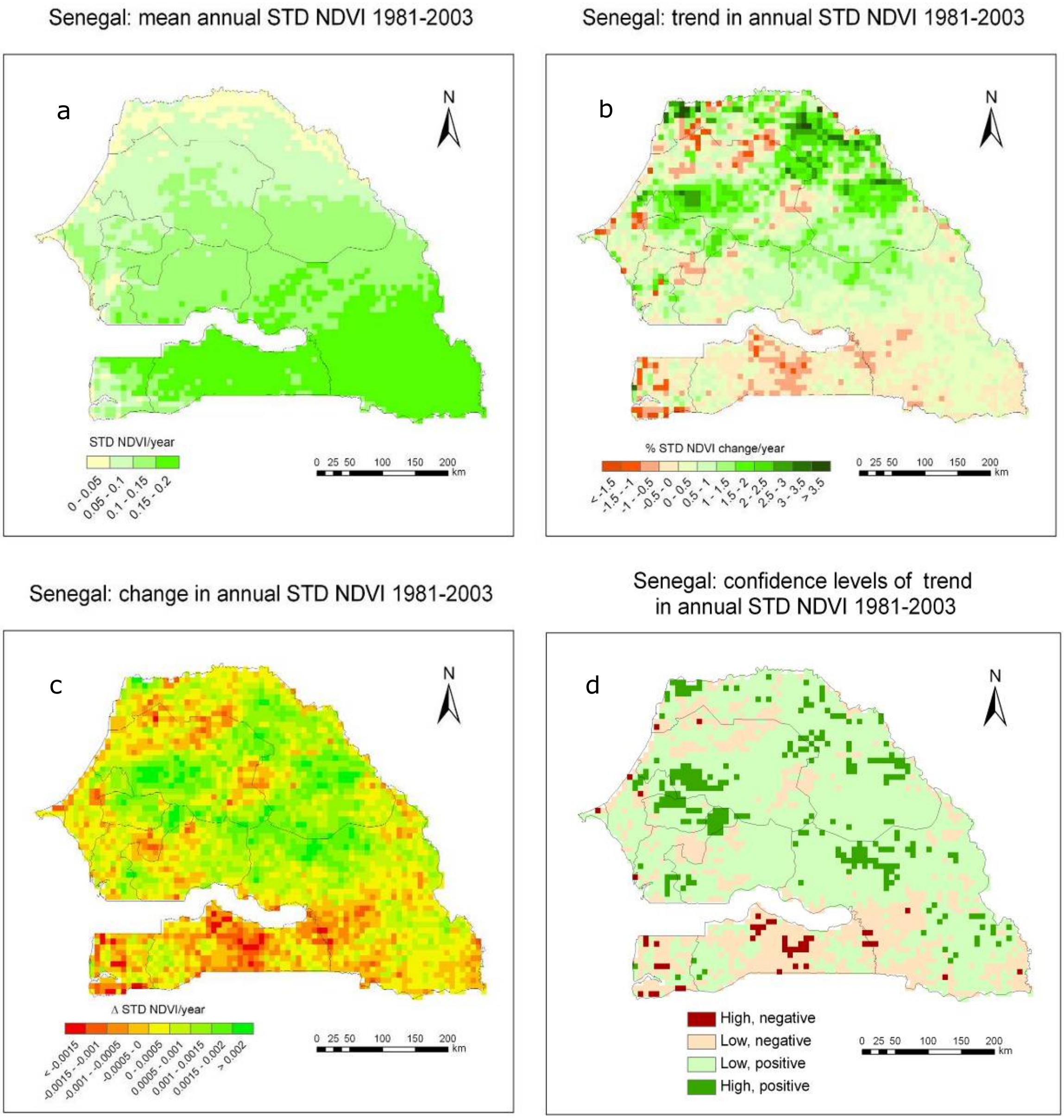

Figure A6. NDVI standard deviation 1981-2003: mean (a) and trends (b – percentage, c – absolute, d confidence levels)

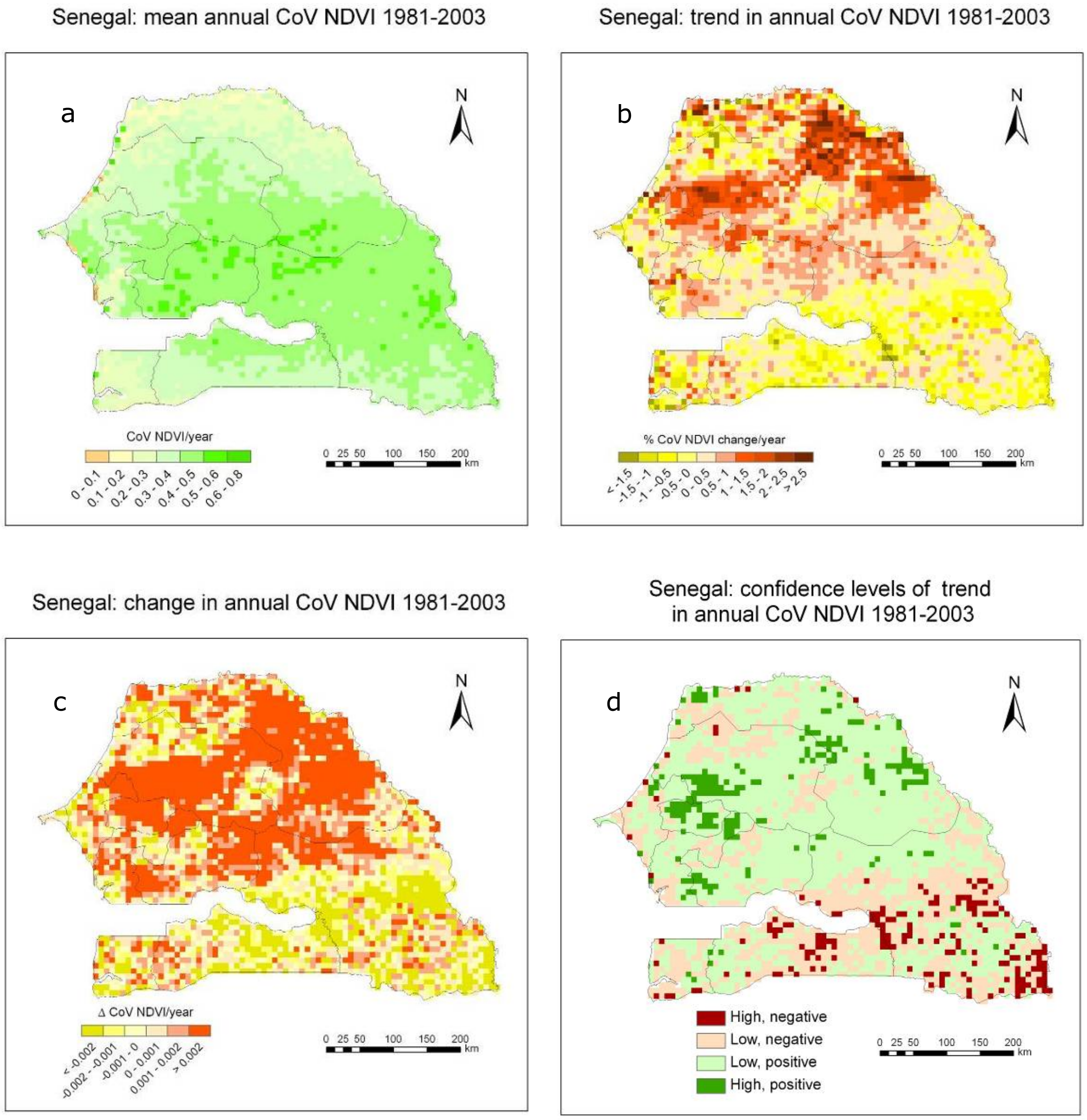

Figure A7. NDVI coefficient of variation (CoV) 1981-2003: mean (a) and trends (b – percentage, c – absolute, d - confidence levels)

World Soil Information

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Our aims:

- *To inform and educate - through the World Soil Museum, public information, discussion and publication*
- *As ICSU World Data Centre for Soils, to serve the scientific community as custodian of global soil information*
- *To undertake applied research on land and water resources.*