

Economics of Great Green Wall: Opportunities for improved targeting and efficiency

Alisher Mirzabaev (✉ almir@uni-bonn.de)

University of Bonn <https://orcid.org/0000-0002-5223-7160>

Moctar Sacande

Food and Agriculture Organisation

Farinaz Motlagh

Center for Development Research (ZEF)

Anastasiya Shyrokaya

Center for Development Research (ZEF)

Antonio Martucci

Food and Agriculture Organisation

Article

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Abstract

The Sahel region is confronted with a severe problem of land degradation, which is jeopardizing livelihoods and stymieing efforts to eradicate food insecurity. The Great Green Wall programme is a colossal initiative designed to improve communities' resilience and restore degraded ecosystems by planting locally suitable native trees and grasses. We evaluated the economic costs and benefits of land restoration under this programme. The results show that the average annual costs of land degradation due to land use and land cover changes in the entire Sahel region during 2001–2018 period were equal to 3 billion USD. Every USD invested into land restoration is found to yield from 1.7 USD to 2.9 USD. About 10 years are needed for all land restoration activities to reach positive benefit-cost ratios from the social perspective. The amount of investments needed for land restoration across the Sahel is estimated to be between 18–70 bln USD.

Introduction

The Sahel region in Sub-Saharan Africa is among the regions of the world confronted with a severe problem of land degradation^{1–6}. Land degradation is exacerbating food insecurity and poverty, and increasing vulnerability to climatic changes in the region. To address this problem, the Sahelian countries and the international community are currently implementing the African Union (AU) strategy on the Great Green Wall (GGW). The GGW is a massive initiative that seeks to restore degraded ecosystems by planting locally suitable native trees and grasses^{7,8}. The total length of the GGW is planned to reach 8,000 km from coast-to-coast across the Sahel, while the estimated width ranges between 100 and 200 km. Although initially the programme focused on planting trees, presently, it has become a broad strategy for sustainable development, climate change mitigation and adaptation in the region⁹. The purpose of this study is to assess the economic costs and benefits of the GGW, and thus provide a critical but insofar lacking knowledge helping to improve the efficiency and targeting of land restoration activities.

The current analysis extends the knowledge in several ways. Firstly, the study applies a very high scale of granularity, conducting its cost-benefit analysis at the pixel size of 25 hectares. Secondly, we compiled and applied a unique Sahel-specific database of economic values of land ecosystem services. Thirdly, this estimation of annual costs of land degradation is based on tracing of year-to-year changes in land use and land cover (LULC) for 18 years between 2001 and 2018. This is different from when comparison is done only between baseline and end line years, making the results of the analysis vulnerable to any unusual changes in those particular baseline and end-line years. Finally, we apply country and year specific values of net incomes generated by croplands, providing a further layer of nuance to the analysis.

The results show that the average annual costs of land degradation due to LULC changes for the entire Sahel region during 2001-2018 period were equal to 3 billion USD. Every USD invested into land restoration is found to yield from 1.7 USD to 2.9 USD depending on the scenario considered. About 10 years are needed for all of the land restoration activities to reach positive benefit-cost ratios from the social perspective and about 20 years if only private benefits are considered. The highest returns are observed in

restoring forests degraded to woodlands and shrublands. Most challenging combination is cropland vs. grassland restoration. The social returns from restoring grasslands lost to cropland expansion range from positive to negative across the region depending on the agricultural productivity levels. However, when only the value of food production is considered, grassland conversion to croplands comes out as more economically attractive for private land users in all of the countries of the Sahel despite higher social costs.

Results

Costs of land degradation in the Sahel

The average annual costs of land degradation for the whole Sahel region during 2001-2018 period are estimated to equal 3 billion USD (The estimates range from 0.9 billion USD (minimum ecosystem values) to 8.6 billion USD (maximum ecosystem values). See supplementary material 2.). At the same time, average annual gains of land improvements were equal to 4.2 billion USD (ranging from 1.5 billion USD (minimum ecosystem values) to 10.4 billion USD (maximum ecosystem values)). The analysis of ecosystem services valuation studies from across the Sahel region points at a large dispersion of these ecosystem values by LULC (see Methods, Data). Hence, in this assessment, the median values for the economic valuation are used, but the study also provides the outcomes in terms of costs of land degradation and gains from land improvement when minimum and maximum values are used. Only during 4-5 years out of these 18 years (depending the scenario, see further for details), the costs of land degradation exceeded the gains from land improvement (Figure 1, Supplementary material 3, Figures S3.1 and S3.2). The countries with the highest costs of land degradation are Nigeria (1.4 billion USD per year) and Ethiopia (0.6 billion USD per year), with the key reason being the high rates of deforestation in these countries (Table S3.1 in Supplementary material 3). The spatial analysis of land degradation and land improvement in the Sahel highlights several clear patterns (Figure 2). Firstly, there is an extended line of land improvement from west coast to east coast across the Sahel along the southern margins of the Sahara Desert, with some exceptional areas of land degradation in western Mauritania, western and eastern Mali. Similarly, there is a pattern of land degradation across the central and southern edge of the Sahelian climatic zone.

Scenarios for the cost-benefit assessment

In order to have a robust assessment of the costs and benefits of land restoration, we conducted the analysis through the following eight scenarios (as earlier indicated, using median values of ecosystem services):

- **Scenario 1:** Period of analysis is establishment years for each restored LULC (cf. Supplementary material 8), discount rate is 10%.
- **Scenario 2:** Period of analysis is 5 years; discount rate is 10%.
- **Scenario 3:** Period of analysis is 10 years; discount rate is 10%.
- **Scenario 4:** Period of analysis is 30 years; discount rate is 10%.

- **Scenario 5:** Period of analysis is establishment years for each restored LULC (cf. Supplementary material 8), discount rate is 5%.
- **Scenario 6:** Period of analysis is establishment years for each restored LULC (cf. Supplementary material 8), discount rate is 2%.
- **Scenario 7:** Period of analysis is 5 years, discount rate is 10%, only the values of provisioning ecosystem services are accounted for.
- **Scenario 8:** Period of analysis is 30 years; discount rate is 10%, impact of climate change halves survival rates and net crop profitability.

Economic returns from land restoration

Out of these eight scenarios, the costs of action, i.e. of land restoration, are lower than costs of inaction in all of the cases at the regional level, providing a strong economic justification for land restoration activities in the Sahel. However, regional aggregates hide complex national patterns: not in all countries land restoration activities make economic sense under scenarios 1, 2, 5, 6 and 7. Only under scenarios 3 and 4, benefit-cost ratios are positive for all countries. The outcomes of the analysis are much more sensitive to changes in the period of analysis, rather than to changes in discount rates. The higher returns to land restoration activities were found to accrue consistently across many of the scenarios in Nigeria, Mali, Ethiopia and Djibouti. Together, these findings are in line with the available evidence and imply that land restoration activities do not always provide with immediate benefits exceeding land restoration costs but require establishment period for the restored biomes which start providing their full benefits only after some time¹⁰. The differences between countries in benefit-cost ratios are determined by the type of land restoration activities needed in each country. For example, restoring a forest takes much more time than restoring a grassland. Restoring a forest from woodland takes less time, then restoring a forest from cropland. Consistently across scenarios, the highest amounts of investment needed for land restoration activities are in Ethiopia and Nigeria (due to the high extent of land degradation), whereas the lowest amounts are in Djibouti and Eritrea (due to their small territory).

Table 1. The range of costs of land degradation vs costs land restoration under GGW Sahel by country under scenarios 1 to 8 (in millions USD 2007)

Countries	Cost of land degradation		Cost of land restoration		Returns from each \$ invested in land restoration	
	Min	Max	Min	Max	Min	Max
Burkina Faso	219	2,416	357	647	0.6	3.7
Chad	944	6,854	901	1,619	1.0	4.2
Djibouti	42	904	68	209	0.6	4.3
Eritrea	141	1,756	190	490	0.7	3.6
Ethiopia	8,040	87,961	6,626	37,674	1.2	2.3
Mali	1,107	9,054	963	2,100	1.1	4.3
Mauritania	148	3,075	342	965	0.4	3.2
Niger	533	6,452	847	1,387	0.6	4.7
Nigeria	17,940	70,661	5,742	20,212	3.1	3.5
Sudan	1,823	12,706	1,818	3,627	1.0	3.5
Senegal	463	4,248	438	1,117	1.1	3.8
Sahel	31400	206087	18292	70047	1.7	2.9

Note: Min: minimum, Max: maximum.

Costs and benefits of land restoration for each degraded biome

The analysis of biome-specific benefit-cost ratios of land restoration activities showed that under scenarios 1, 5 and 6, restoring forests, wetlands, shrublands, yielded higher benefit-cost ratios. Similarly, under scenarios 2, 3, 4, 7 restoring croplands, and in some cases, grasslands, had higher benefit-cost ratios (Table 2, Supplementary material 5: Tables S5.1-S5.8). The major driver of these results is the differences in time periods. Croplands and grasslands start providing their full benefits within a shorter period of time, i.e. they exceed their breakeven points already within first 5 years after re-establishment. Although the ecosystem values from forests, wetlands, woodlands and shrublands are higher, their establishment time is considerably longer, and land restoration activities in these biomes reach their breakeven points between 5 to 10 years after re-establishment (Table 3).

The analysis of biome to biome outcomes of land restoration activities provides with directly relevant insights for land restoration actions on the ground (Table 4, Supplementary material 6: tables S6.1-S6.8). Across the scenarios, highest return land restoration activities are restoring forests degraded to woodlands and shrublands. Restoring wetlands from all other biomes (except forests) has also high benefit-costs ratios in most scenarios. Most intriguing and challenging combination is cropland vs. grassland restoration, because it varies a lot from country to country. In some countries (Djibouti, Nigeria, Ethiopia, Mali), croplands generate considerably higher provisioning services than grasslands because of relatively higher agricultural productivity. In those settings, restoring croplands from grasslands, or converting grasslands to croplands provides with more total economic values. In some other countries (Niger, Mauritania, Eritrea, Sudan, Chad), where cropland productivity is now relatively lower, it presently makes more economic sense to convert those low productive croplands to grasslands if we consider the total value of ecosystem services. Still, however, if we consider only the value of provisioning services,

grassland conversion to croplands comes out as more profitable in all of the countries. This cropland vs. grassland dilemma is presently believed to be a major factor in land-related conflicts in Nigeria and elsewhere in the region.^{11,12}

The assessment shows that climate change impacts (Scenario 8) can potentially increase the benefit-cost ratios from land restoration activities (Table 3). This is because, currently, the restoration of forests, woodlands and shrublands back from croplands needs to account for higher opportunity costs of croplands. Since climate change is projected to reduce crop yields across the Sahel, and assuming no major local price effects thanks to regional and international trade, this signifies lower opportunity cost of croplands, making it economically cheaper to convert croplands back to forests, woodlands and shrublands, even if survival rates of newly planted trees is considered to be lowered by climate change to only 30%.

Table 2. Ranges of returns from each USD invested in restoration by biome and country under different scenarios (in USD)

Country	Forest	Wetland	Woodland	Shrubland	Cropland	Grassland
Burkina Faso	0.1 - 5.3	0.2 - 9.8	.	0.7 - 3.0	0.8 - 4.1	0.3 - 4.2
Chad	.	0.2 - 8.0	.	0.7- 5.2	0.7 - 3.6	0.3 - 4.4
Djibouti	.	.	.	0.9 - 11.0	.	0.3 - 5.1
Eritrea	.	0.2 - 11.4	.	0.8 - 9.1	1	0.3 - 5.0
Ethiopia	0.1 - 9.4	0.2 - 8.5	0.7 - 3.0	0.7- 3.3	0.6 - 4.5	0.3 - 5.1
Mali	0.1 - 5.3	0.2 - 7.8	0.7 - 3.0	0.7- 3.6	0.7 - 4.5	0.3 - 5.1
Mauritania	.	0.2 - 7.7	.	0.7- 3.7	1.6 - 1.6	0.3 - 5.1
Niger	.	0.2 - 8.1	.	0.7- 5.2	0.3 - 1.6	0.3 - 4.7
Nigeria	0.1 - 7.7	0.2 - 5.5	0.4 - 2.8	0.4 - 2.8	1.2 - 8.5	0.3 - 5.1
Sudan	0.1 - 5.3	0.2 - 9.1	.	0.7- 4.9	0.6 - 3.2	0.3 - 4.4
Senegal	0.1 - 5.3	0.2 - 8.4	0.7 - 3.0	0.7- 3	0.5 - 3.6	0.3 - 5.1
Sahel	0.1 - 8.2	0.2 - 7.2	0.5 - 2.8	0.7- 3.6	0.9 - 6.4	0.3 - 4.3

Table 3. Benefit-cost ratios of restoring biomes by different scenarios (average for the Sahel)

Biomes	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Forest	5.4	0.7	1.4	5.4	3.9	3.0	0.1	5.4
Wetland	2.2	0.9	2.2	7.1	1.8	1.6	0.2	7.2
Woodland	0.9	0.6	0.9	2.5	0.8	0.8	0.5	2.8
Shrubland	1.4	0.8	1.4	3.6	1.2	1.1	0.7	3.6
Cropland	0.9	3.3	4.8	6.4	0.9	0.9	3.8	4.3
Grassland	0.5	2.0	3.0	4.3	0.5	0.5	0.3	4.2

Table 4. Returns from each USD invested in restoring a degraded biome compared to its current use under different scenarios (in USD)

2001	2018					
	Forest	Shrubland	Woodland	Grassland	Cropland	Barren
Wetland	0.1 - 2.6	0.2 - 6.0	0.2 - 6.0	0.2 - 7.7	0.1 - 10.2	0.2 - 13.3
Forest		0.1 - 14	0.1 - 14	0.1 - 5.3	0.0 - 3.1	
Shrubland				0.7 - 3.0	0.2 - 4.1	1.0 - 17.0
Woodland				0.7 - 3.0	0.1 - 2.5	
Cropland				0.9 - 6.4		1.9 - 9.8
Grassland					0.5 - 4.1	0.3 - 5.1

Note: Interpreted as benefit-cost ratio of restoring higher value biome in 2001 (horizontal list) degraded to lower value biome (vertical list) by 2018.

Discussion

The LULC changes across the Sahel are an outcome of complex interactions by climatic and human factors¹³. When grasslands shift to barren lands, it is not necessarily due to overgrazing by livestock and other human activities, but could be driven by climatic factors, i.e. less rainfall¹⁴. Hence, when analyzing the costs of land degradation in the Sahel region, we do not assign all these costs to be due to human impact only. But rather, we assess the changes in total economic value of land due to a combination of human and natural factors. The analysis conducted in this study highlights that for the Sahel region, LULC changes are strongly influenced by both human and climatic factors, and they are also dynamic. During the last two decades, there were a lot of shifts in Sahel's LULC which can be interpreted as land degradation, but also even larger shifts related to land improvement (which are also caused by both climatic and human factors)¹⁵. Some of these changes resulting in land degradation could be amenable for remedial action, some others are overwhelmingly influenced by natural factors, hence, human action for influencing or remedying them may not be optimal neither ecologically nor economically. This study highlights those land restoration activities and associated locations across the Sahel region where land restoration is both economically attractive and ecologically sustainable.

Non-provisioning ecosystem services make up more than half of the total value of ecosystem services for all biomes, except croplands for which provisioning services make up most of their value. However, there are no markets for most non-provisioning services and even for those which do have markets, such as carbon, the active participation of the Sahelian countries through land restoration activities requires overcoming significant technical barriers. In such a context, the economic attractiveness of restoring biomes other than croplands is much smaller and will take longer time to reach their breakeven points. At the same time, non-provisioning ecosystem services, particularly carbon sequestration, provides with global public benefits. Hence, more urgent efforts are needed to establish wide-spread, verifiable and easy-to-use mechanisms in the Sahel region that enable earning revenues through carbon sequestration within land restoration activities (e.g. application of Paris agreement, art. 6). Without such mechanisms, land restoration activities will remain limited to isolated and relatively small donor-funded initiatives without long-term sustainability.

Land restoration activities in the Sahel should not be limited to agricultural or forestry sectors. On the contrary, should involve an “all-government” approach. This is because land degradation, land improvement and land restoration provides with significant spillover effects across various sectors. To give an example, major cause of deforestation (including in forests, woodlands and shrublands) in the Sahel is a strong reliance on traditional fuelwood and charcoal to meet energy needs¹⁶. Unless land restoration activities are accompanied by measures to expand access to alternative energy sources, replanting forests, shrublands and woodlands will have only a short-term and limited effect. Long-term investments in land restoration activities are often hindered by lack of clearly defined and legally enforceable land property rights and land tenure security^{17,18}. It is in all likelihood not possible to restore all degraded lands in the Sahel by government actions or donor-funded projects. The only possibility to do so is through a combination of private initiative of farmers and land users themselves together with government and development cooperation action.

Conclusions

There is a strong need to restore and rehabilitate degraded lands in the Sahel region. In this regard, GGW initiative is timely and important. The progress so far, however, has been underwhelming. The global community has now pledged 14.3 billion US dollars for the GGW implementation during the recent One Planet Summit for Biodiversity. This pledge makes a better knowledge of economically efficient targeting of investments and implementation actions on GGW even more urgent. This paper suggests that there are numerous opportunities and locations in the GGW area where land restoration is both economically attractive and ecologically sustainable. The results also show that investments into land restoration and rehabilitation in the Sahel region have positive economic returns, especially from the social perspective.

Methods

The calculation of the costs of land degradation includes the total economic values (TEV) of all ecosystem services, both direct use and indirect use ecosystem services. The costs and benefits of land restoration activities are calculated by their net present value (NPV) in year t for the land users planning horizon T:

$$\pi_t^c = \frac{1}{\rho^t} \sum_{t=0}^T (PY_t^c + IV_t - lm_t^c - c_t^c) \quad (1)$$

where, π_t^c = net present value (NPV) of land restoration in year t for the land users planning horizon T; $\rho = 1+r$, r = land user's discount rate; Y_t^c = production of direct use provisioning services after land restoration (food, fodder, timber, non-timber products, etc.); P= unit price of Y_t^c ; IV_t = value of indirect use ecosystem services (e.g. carbon sequestration); lm_t^c = cost of land restoration; c_t^c = direct costs of production, also including maintenance costs after initial land restoration investments.

If land users do not undertake land restoration, the NPV is given by

$$\pi_t^d = \frac{1}{\rho^t} \sum_{t=0}^T (PY_t^d + IV_t - lm_t^d - c_t^d) \quad (2)$$

where π_t^d = NPV of the ecosystem services still derived from the degraded biome. Superscript d indicates a degraded biome.

The benefit of land restoration is given by:

$$BA = \pi_t^c - \pi_t^d \quad (3)$$

The difference $\pi_t^c - \pi_t^d$ is essential in decision making by land users' during their planning horizon T. If the returns to land restoration, after including land restoration costs, are smaller than the corresponding returns from the degraded biome, land users are not likely to conduct land restoration activities.

As the first step, the cost-benefit analysis focuses on LULC changes, as measured by the MODIS Land Cover Type Product (MCD12Q1) global maps of land use and cover at 500-m spatial resolution¹⁹, that have occurred each year between 2001 and 2018, for the evaluation of LULC trends, and their associated costs and benefits in the Sahel region. Analytically, this would mean calculating (4) below. For example, when a forest is cut down and turned into a cropland, this would mean lower values of ecosystem services because forests usually provide higher TEV of ecosystem services than croplands.

$$C_{LULC} = \sum_i^K (\Delta a_1 * p_1 - \Delta a_1 * p_2) \quad (4)$$

where C_{LULC} = cost of land degradation due to LULC; a_1 = land area of biome 1 being replaced by biome 2; P_1 and P_2 are TEV biome 1 & 2, respectively, per unit of area.

Following

the recent IPCC Special report on Climate Change and Land, land degradation is defined here as “a negative trend in land condition, caused by direct or indirect human-induced processes, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity or value to humans”²⁰.

Hence, by definition of land degradation, $P_1 > P_2$.

This means, LULC that leads to higher TEV, i.e. when $P_1 < P_2$, is not regarded as land degradation but rather as land improvement. The analysis of LULC trends differentiates between seven biomes, based on their International Geosphere-Biosphere Programme (IGBP) definitions: forests, woodlands, shrublands, grassland, cropland, wetland and bare land (Supplementary material 7).

Secondly, the costs of land restoration activities are comprised of establishment costs for restoring the degraded biomes, maintenance costs, as well as the opportunity costs of the lower value biome which is being replaced by the higher value biome (Table S2.4). There is one exception in the analysis when the opportunity costs are omitted in the case of planting forest in woodlands and shrublands, since it is

unlikely that remaining trees and shrubs are cut down before a new forest is planted. On the contrary, these remaining trees and shrubs in woodlands and shrublands are likely to be kept and continue providing their ecosystem services.

This study tracked the outcomes of the land restoration activities during the full establishment period (modelled to vary by biome, see Supplementary material 8), after a 5-year period, after a 10-year period, and after a 30-year period. We have also checked the sensitivity of the results for different assumptions on the discount rate, by running the analysis at the discount rates of 2%, 5%, and 10% for the establishment period scenario. Moreover, once restoration activities are done, the newly established higher value biome will not reach its full potential right away, but will take some time to reach its maturity. For this reason, for restored forests, woodlands, shrublands, and wetlands, a staggered time period was introduced during which they will gradually reach their full ecosystem potential. For other biomes, namely, croplands and grasslands, we estimated that they will reach their full potential in one year after restoration (Supplementary material 8). The information on the survival rates of planted trees and grasses from currently ongoing GGW activities was used to calibrate the amount of generated ecosystem benefits from land restoration activities⁸. Climate change is expected to alter survival rates of planted trees and grasses, hence, projected variations in survival rates under climate change are used as the means to assess the impact of climate change on land restoration activities. Moreover, climate change is projected to reduce crop yields across the Sahel region, thus also reducing the net profitability of crop production, which is incorporated into the assessment (cf. Scenarios explained earlier). Biome-specific estimation parameters for land restoration activities are given in Supplementary material 8.

Data

Land Use and Land Cover (LULC)

The MODIS Land Cover Type Product (MCD12Q1, here referred to as Modis500 LULC) global maps of land use and cover at 500-m spatial resolution¹⁹ are used as the source for the LULC data. Modis500 LULC provides global land cover types at annual intervals (2001-2018). Modis500 LULC is derived using supervised classifications of MODIS Terra and Aqua reflectance data. The supervised classifications then undergo additional post-processing that incorporate prior knowledge and ancillary information to further refine specific classes. The definition of each LULC is given in Supplementary material 7. Modis500 LULC captures several types of forests, namely: evergreen needleleaf forests, evergreen broadleaf forests, deciduous needleleaf forests, deciduous broadleaf forests, mixed forests. In this analysis, these forest types were combined together under single forest category. Similarly, Modis500 LULC has croplands category as well as cropland/natural vegetation mosaics, defined as “mosaics of small-scale cultivation 40-60% with natural tree, shrub, or herbaceous vegetation”. Both of these sub-categories were combined together under single cropland category.

In estimating the costs of land degradation, annual LULC data for all of the 18 years between 2001 and 2018 were analyzed to get a more precise information about year-to-year changes in the total economic value of biomes and associated losses and gains. For the analysis of costs of action, two time periods

were considered: 2001 (baseline) and 2018 (end line). The “costs of action” analysis thus provides information about costs and benefits of restoring lands degraded by 2018 to their previous un-degraded state in 2001.

Economic values of ecosystem services

Many previous studies assessing the values of land ecosystem services relied on the economics of ecosystems and biodiversity (TEEB) database (<http://teebweb.org/>) for their assessments^{22,4}. The underlying data in this database was compiled from publications produced more than a decade or two ago and contains only a few observations from the Sahel region. These TEEB values of ecosystem services in the region are not enough for a detailed analysis. We conducted a thorough review of all available data from literature published on the values of ecosystem services specifically from the Sahelian countries since the TEEB database compilation. We have also compiled the values of ecosystem services conducted in countries immediately neighboring the Sahel region. Since it is not possible to derive individual ecosystem values for each pixel of the analysis, we used the benefit-transfer approach to assign economic values to ecosystem services in those settings in the Sahel with missing data by using ecosystem values from other locations in the Sahel and in their neighborhood. The Sahelian countries are very similar to each other in terms of income per capita, reliance on agriculture, overall price levels, especially compared to the rest of the world, hence, such benefit transfer is both the only possible approach for ecosystem valuation at the regional level in Sahel, and also justified due to these similarities. Naturally, having pixel-specific values would have been preferable, but currently, there is no such granular information available for Sahel or any other region of the world. A total of about 600 valuation data points were collected for the GGW countries and applied in this current analysis. The full list of 165 papers from which these ecosystem values were derived is given in Supplementary material 9.

The availability of the data on net production value of croplands by country and by year at the FAOSTAT (<http://www.fao.org/faostat/en/>) enables us to have more precise year and country specific economic net values of what one hectare of cropland in each country was producing during each of the analyzed years. Therefore, the net values of croplands from FAOSTAT were divided by the extent of cropped areas in each country/year to get per hectare values, which were then used in the analysis providing more country-year specific granularity for cropland values. However, these values of provisioning services produced by croplands do not take into account the value of non-provisioning ecosystem services provided by croplands. These values for non-provisioning services by croplands were collected from the literature and added to those values of provisioning services obtained from FAOSTAT.

Costs of land restoration actions

The data on the costs of land restoration actions were similarly collected from existing databases and publications, particularly: WOCAT (<https://www.wocat.net/en/>), TerrAfrica, World Bank SLM sourcebook²³, Economics of land degradation (ELD) database²⁴, FAO publication on Global guidelines for the restoration of degraded forests and landscapes in drylands²⁵. The average values for these costs of land restoration activities used in the analysis are given in the Supplementary material 2.

Declarations

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Figures

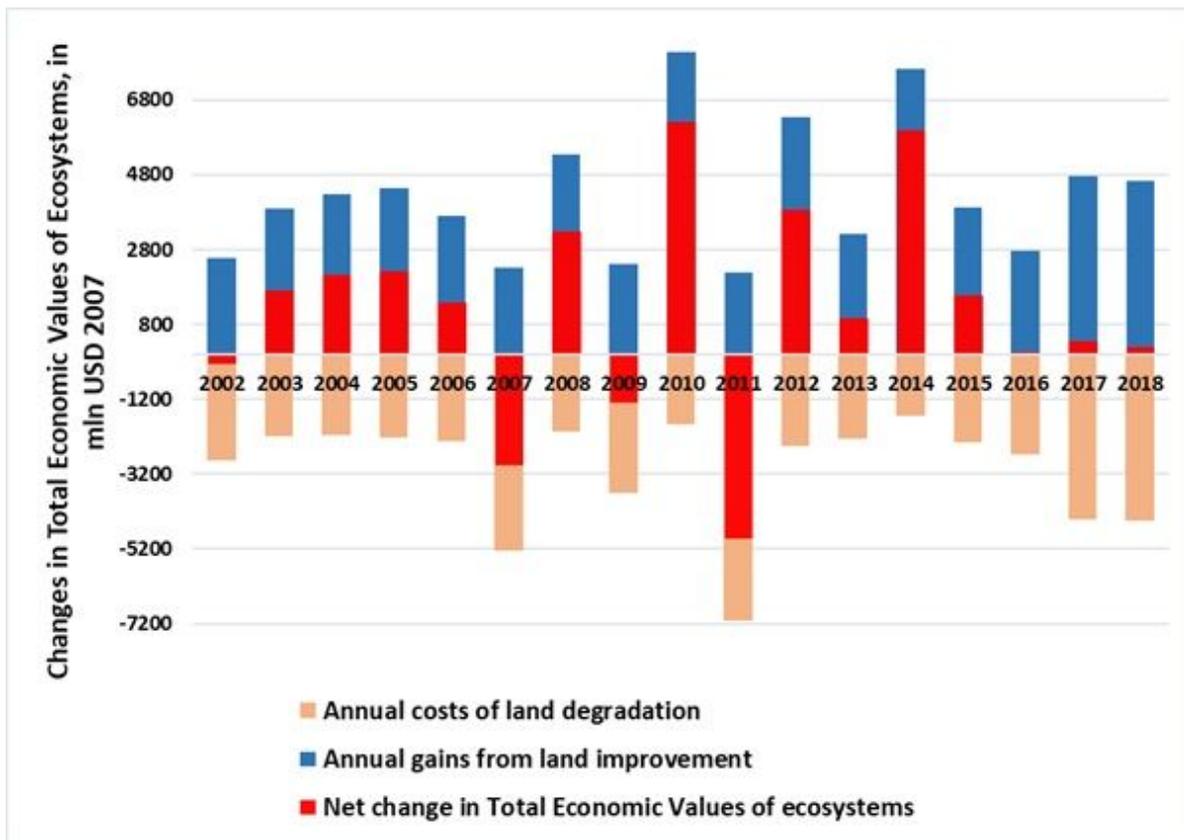


Figure 1

Annual cost of land degradation, gains from land improvement and net changes in the total economic value of land ecosystem services (median ecosystem values).

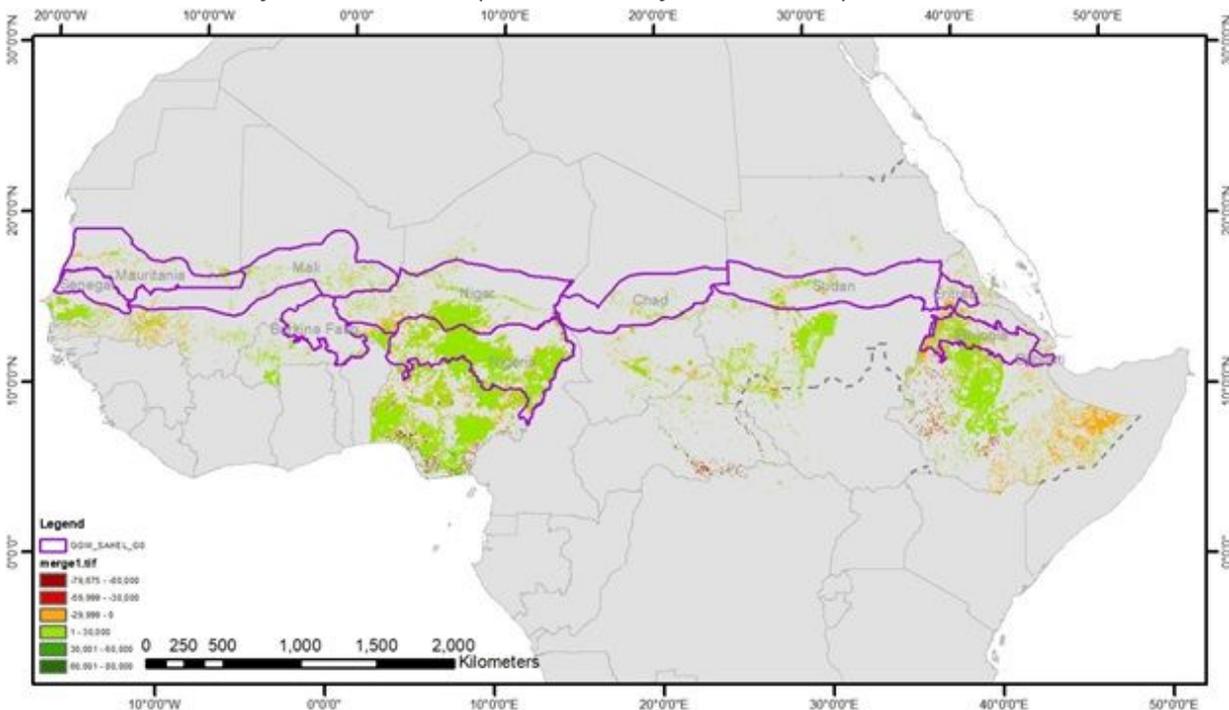


Figure 2

The costs of land degradation and gains from land improvement between 2001-2018 (median ecosystem values). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

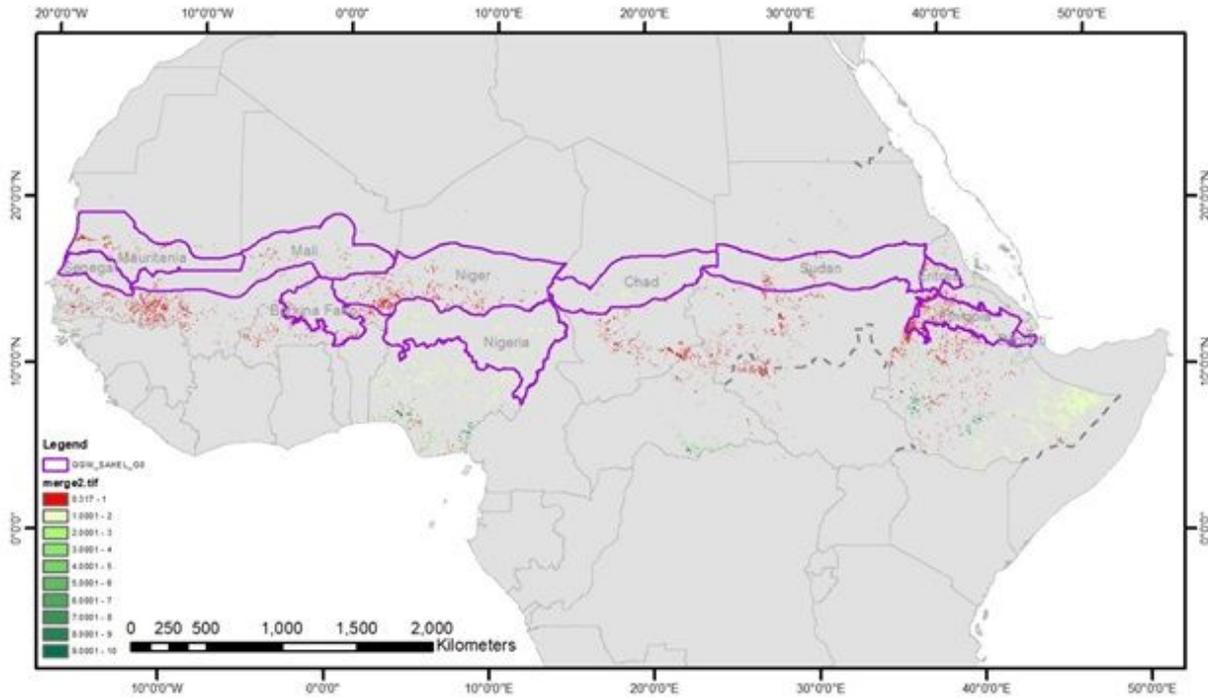


Figure 3

Benefit-cost ratios of action under Scenario 1. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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