THE ECONOMICS OF
LAND DEGRADATION

UNEP

The Economics of Land Degradation in Africa

Benefits of Action Outweigh the Costs

A complementary report to the ELD Initiative

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Foreword

Land degradation and desertification are among the biggest environmental challenges of our time. In the last 40 years, we lost nearly a third of the world's arable farmland due to erosion, just as the number of people to be fed from it almost doubled.

That's why the UN General Assembly declared 2015 as the International Year of Soils. And the good news is that this new report shows that while Africa remains the most severely affected region, the benefit of taking action across the continent outweighs the cost of implementing it: not just by a little, but by a factor of seven.

Land degradation and desertification, including soil erosion, are made worse by climate change and the poor management of agricultural exports. This has serious implications for Africa and for those dependent on the 97% of global food supply coming from terrestrial ecosystems. In other words: anybody who eats.

Desertification already affects between a third and a half of the Africa's land area to some degree. Yet, this report shows that an additional 280 million tonnes of cereal crops could be produced every year, simply by preventing human induced soil erosion. This would be a significant leap towards increasing food security and national income, while reducing food import costs and poverty.

Gathering solid scientific data on these developments is crucial to progress and this report leverages one of the first studies of its kind, focusing on soil erosion and crop productivity on over 100 million hectares of crop lands across 42 African countries. It provides the base line for the much needed imperial data gathering in the next 15 years. It shows that failure to act could impact over 12% of Gross Domestic Product. And, above all, it makes a credible economic and humanitarian case for Africa to achieve a number of Sustainable Development Goals.

That's why I am proud that UNEP has been able to work with the Economics of Land Degradation Initiative supported by the GIZ/BMZ, the European Commission and other valued partners to bring this report to life.

I would like to thank all of them for their dedication in bringing this work to light. I sincerely hope this will justify the much needed investments in sustainable land management, which are crucial to achieve the Sustainable Development Goals in the region and across the world.

Achim Steiner
UN-Under-Secretary-General and
UNEP Executive Director

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Acronyms and abbreviations

AESSTI	Agricultural Ecosystem Services Trade-off Index
ASALS	Arid and Semi-Arid Lands
BCR	Benefit Cost Ratio
DLDD	Desertification, Land Degradation and Drought
DPSIR	Drivers-Preasure-State-Impact-Response
ELD	Economics of Land Degradation
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agricultural Organization of the United Nations Statistics
GDP	Gross Domestic Product
GEF	Global Environment Facility
GLADA	Global Assessment of Land Degradation and Improvement
GLADSOD	Global Assessment of Human-induced Soil Degradation
LADA	Land Degradation Assessment in Drylands
LDD	Land Degradation and Desertification
MSOC	Marginal Social Opportunity Cost
NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Productivity
NPV	Net Present Value
PPP	Purchasing Power Parity
PVB	Present Value of Benefits
PVC	Present Value of Costs
SLM	Sustainable Land Management
SOC	Social Opportunity Cost
SRTP	Social Rate of Time Preference
TEEB	The Economics of Ecosystems and Biodiversity
TLU	Tropical Livestock Unit
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
USD	United States Dollar
WOCAT	World Overview on Conservation Approaches and Technologies

Key messages

1. In Africa, the loss of about **280 million tons of cereal crops per year** from about 105 million hectares of croplands can be prevented if soil erosion is managed.

2. The present value of **the cost of inaction measured in terms of the value of cereal crops loss due to soil erosion induced nutrient depletion** over the next 15 years (2016–30) is about 4.6 trillion PPP USD, with an annual value of 286 billion Purchasing Power Parity (PPP) USD (127 billion USD/year at 2011 constant dollar), which is equivalent to **about 12.3 % of the GDP of the 42 countries[1] considered in this study.**

3. However, taking action through investment in sustainable land management practices will only cost about 344 billion PPP USD over the next 15 years with an annual **cost of action of about 9.4 billion USD or 1.15 % of the GDP of 42 countries in the continent.**

4. The **benefits of taking action as approximated by the World Overview on Conservation Approaches and Technologies (WOCAT) data on capital and recurrent expenditures on Sustainable Land Management (SLM) in Africa are almost 7 times the cost of action.** In other words, Africa could generate about 2.83 trillion PPP USD (or about **71.8 billion USD/year**) if all countries take action against soil erosion, which is causing nutrient losses from the arable land areas used for cereals production, through investment in sustainable land management interventions.

5. Hence, the **net present value of taking action against soil erosion induced nutrient depletion** on arable lands used for cereals production over the next 15 years (2016–30) is about 2.48 trillion PPP USD (or **62.4 billion USD/year**).

6. The sensitivity analysis indicates that for most of the countries covered in this study, the net present value of taking action against soil erosion induced nutrient depletion on the cereal croplands remains positive and considerably high to changes in discount rates, the price of cereals, and the costs and effectiveness of actions to control soil erosion.

7. The study finds a positive and statistically significant relationship between the rate of poverty gap and soil nutrient depletion from cereal croplands in Africa. Countries with a higher rate of poverty gap in the period 2002–04 were also countries with a high average NPK loss from their agricultural lands and vice versa.

8. In order to achieve as many of the Sustainable Development Goals (SDGs) in the region, actions against land degradation must be integrated with poverty reduction measures aimed at harnessing the benefits of sustainable natural resource management towards increased national income, reduced food insecurity and poverty eradication.

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[1] *Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Côte D'Ivoire, Djibouti, DR Congo, Egypt, Eritrea, Ethiopia, Gabon, Ghana, Guinea, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Swaziland, Togo, Tunisia, Uganda, UR of Tanzania, Zambia, Zimbabwe.*

Executive summary

Land degradation and desertification are among of the world's greatest environmental challenges. It is estimated that desertification affects about 33% of the global land surface, and that over the past 40 years erosion has removed nearly one-third of the world's arable land from production. Africa is particularly vulnerable to land degradation and desertification, and it is the most severely affected region. Desertification affects around 45% of Africa's land area, with 55% of this area at high or very high risk of further degradation

It is often considered that land degradation in Africa has been vastly detrimental to agricultural ecosystems and crop production and thus an impediment in achieving food security and improving livelihoods. However, much of the literature lacks empirical underpinnings, quantifying this loss and assessing the cost of inaction, the cost of action, and benefits of action against land degradation. From the viewpoint of land degradation as a state and a process, the cost of action against land degradation includes investments to restore degraded land and reduce the rate of degradation of degradingland. This can be achieved by adopting mechanical and biological measures, and by improving land productivity. The returns to such investments are considered as benefits of action through prevention of crop damages and the derived loss in productivity. There are several other ecosystem services, on-site as well as off-site, but due to the lack of data availability we were constrained in estimating the comprehensive benefits of action. Of course the loss in productivity and hence the benefit of action would vary based on the state and process of land degradation.

The overarching aim of this exercise is to assess the cost of inaction and benefit of taking action by countries to address erosion induced soil nutrient depletion as a part of land degradation in arable lands used for cereal production. By providing continental level empirical analysis of a cropland area of 105 million hectares (accounting for 45% of total arable land in the continent) across 42 countries in Africa over a span of 15 years (starting from 2016), the fundamental objective is to align empirical data and economic valuation to help inform policy decisions in the future.

The report reviews the regional level data on the economic costs of soil erosion related to land degradation. It also analyzes the limitations and challenges of using such data and the discrepancies emerging from various methodologies. It also delves into the methodological approach utilized for regional level estimates and the cost benefit analysis of taking action against soil-erosion-induced nutrient losses on arable lands used for cereal production, which is one aspect of land degradation. This is done by using an econometric modelling approach that estimates the costs of inaction, costs of action and the net benefits of action against erosion-induced soil nutrient depletion using national level economic and biophysical data. It focuses on the regional estimates for Africa and a cost-benefit analysis of soil nutrient inflows versus soil nutrient outflows, or what is considered the overall soil nutrient balance.

The results indicate that in the next 15 years, starting from 2016, inaction against soil erosion will lead to a total annual loss of NPK nutrients of about 4.74 million tons/year, worth approximately 72.40 billion PPP USD in present value, which is equivalent to 5.09 billion PPP USD per year. As a supporting ecosystem service, the loss of NPK nutrients will lead to a cost in the provisioning of ecosystem services in the form of cereal yields. A one percent increase in the total amounts of nutrients depleted from all the croplands of a country causes a 1.254 Kg/ha decline in cereal yield. In other words, countries with a higher rates of total nutrient depletion from croplands have relatively lower cereal yield per hectare than countries with lower nutrient depletion.

Thus, the present value of net benefits of taking action against soil erosion on the 105 million hectares of croplands in the 42 countries over the next 15 years (2016-2030) will account for about 2.48 trillion PPP USD or 62.4 billion USD per year, which is equivalent to 5.31% of their average Gross

Domestic Product (GDP) for 2010–2012. This tells us that by taking action against soil-erosion-induced nutrient depletion in cereal croplands in the period 2016–30, the economies of the 42 countries could grow at an average rate of 5.31% annually compared to 2010–2012 levels. Considering that the annuity value of the cost of inaction is 12.3% of the average annual GDP of these 42 countries over the same period, the cumulative cost of inaction, which in other words measures the maximum benefits of action, is far greater than the cumulative cost of action.

CHAPTER

01

Overview and stocktaking of land degradation in general and in Africa

1.1. Introduction

As per the estimates by the United Nations Convention to Combat Desertification (UNCCD), during 1981–2003, almost a quarter (24%) of the Earth's land surface had become degraded, affecting some 1,500 million people. Out of this area, nearly 20% was cropland and 20 to 25% was rangeland. Every year, about 12 million hectares of land – about the size of Bulgaria or Benin – is lost, and along with it the potential to produce 20 million tons of grain (UNCCD, 2012). The loss of arable land is occurring at an estimated 30 to 35 times of the historical rate (UNCCD, 2011). In this backdrop of status of land degradation, 78% of the degraded land is found to be in non-dryland areas. This scenario of land degradation has been called one of the world's greatest environmental challenges (Pender, 2009). In fact, the Food and Agriculture Organization of the United Nations (FAO) has declared 2015 the International Year of Soils to highlight the importance of protecting this valuable resource from further degradation (FAO, 2014).

Desertification is land degradation in drylands *(Box 1)*. In 2001, at the 2nd International Conference on Land Degradation and Desertification, it was reported that desertification affects about 33% of the global land surface, representing 42 million km^2 (Eswaran, et al., 2001). In 2005, the Millennium Ecosystem Assessment Report suggested that desertification threatens over 41% of the Earth's land area and that 20 to 70% of drylands were already degraded (MEA, 2005; Solh, 2009).

FAO estimates that over the past 40 years, erosion has removed nearly one-third of the world's arable land from production (Fischer, et al., 2011). Estimates of the annual loss of fertile soil range between about 24 billion tons (UNCCD, 2011) and 75 billion tons (Gnacadja, 2012; Eswaran, et al., 2001).

The first part of this report is an assessment of land degradation in Africa, undertaken as part of the ELD initiative, which collates comprehensive and credible data sets on the status and trends of global land degradation and maps regional hotspots as the basis to evaluate the economic impact of soil nutrient depletion in cereal croplands and to inform its scenario development to 2030.

1.1.1. What is land degradation?

As outlined in *Box 1*, land degradation might be viewed as a process that encompasses soil degradation and erosion and it is called desertification when it occurs in drylands. Importantly, our understanding of the scope of this process has broadened to encompass all changes in the capacity of ecosystems affected by land degradation to provide biological, social, and economic services (FAO, n.d., FAO, 2011, p. 108, Nachtergaele, et al., 2011a).

The main processes that lead to land degradation are soil erosion by water and wind; chemical changes such as acidification, salinization, and nutrient loss; and physical degradation through pressures such as compaction (UNCCD, 2013; Eswaran, et al., 2001). As explained in the definitions, erosion is the loss of topsoil through the destructive action of water and wind, especially when the vegetation cover has been removed, which can also result in dramatic erosion in the form of landslides (Eswaran, et al., 2001).

Water erosion is the most widespread process leading to topsoil loss and land degradation; it occurs all over the world, varying in intensity and scope according to climatic and physical conditions as well as human activities (Oldeman, et al., 1991).

Wind can also remove or displace topsoil. Wind erosion is most widespread in arid and semi-arid climates, although humid regions are not immune. Generally, coarse-textured soils are more prone to wind erosion than fine-textured ones. Although it occurs naturally in dry regions, it is usually caused or exacerbated by human activities that remove

BOX 1

Definitions

Land degradation:

UNCCD defines land degradation as "any reduction or loss in the biological or economic productive capacity of the land resource base. It is generally caused by human activities, exacerbated by natural processes, and often magnified by and closely intertwined with climate change and biodiversity loss" (UNCCD, 2014).

Desertification:

Desertification is land degradation that occurs in drylands. UNCCD defines it as "land degradation in arid, semi-arid and sub-humid areas resulting from various factors, including climatic variations and human activities. When land degradation happens in the world's drylands, it often creates desert-like conditions" (UNCCD, 2012). It may also refer to "the irreversible change of the land to such a state it can no longer be recovered for its original use" (FAO, n.d.).

Soil degradation:

Soil is one of the key ingredients of land and soil degradation is more precisely defined (Nkonya, et al., 2011). The *Soil Atlas of Africa* describes soil degradation as the "process that leads to a deterioration of soil properties and functions, often accelerated by human activities" (Jones, et al., 2013).

Soil erosion:

Soil erosion is also more specific than both land and soil degradation. It refers only to the absolute loss of topsoil and nutrients, the most visible effect of soil degradation. Wind and water erosion are the main processes affecting soils. It is normally a natural process in mountainous areas, but poor management practices contribute to the potential for any soils to erode (FAO, n.d., Jones, et al., 2013).

Nutrient depletion:

The net loss of plant nutrients from the soil or production system is due to a negative balance between nutrient inputs and outputs. Major channels of nutrient depletion are nutrient removal through soil erosion, harvest, leaching, and denitrification (Lal 1994; Pieri 1995; Enters 1998).

the protective vegetation, such as tree cutting, overgrazing, and ploughing (Oldeman, et al., 1991).

Salinization usually occurs on land that is irrigated, when high concentrations of mineral salts are left on the surface following the water's evaporation. Globally, it is estimated that salinization affects 950 million ha in arid and semi-arid regions, representing nearly 33% of the world's potentially arable land area (Eswaran, et al., 2001). Salts harm plant life and affect soil fertility, reducing agricultural productivity and yields (Jones, et al., 2013).

Poorly managed irrigation, over-exploitation and other unsustainable land use practices can lead to the loss of soil nutrients and result in soil and land degradation, while the extreme use of agrochemicals can pollute soils and degrade the land (UNCCD, 2012). Finally, the excessive use of heavy machinery and trampling by grazing animals, especially in wet conditions, are both factors that cause soil compaction and land degradation (Jones, et al., 2013).

1.1.2. Overview of land degradation in Africa

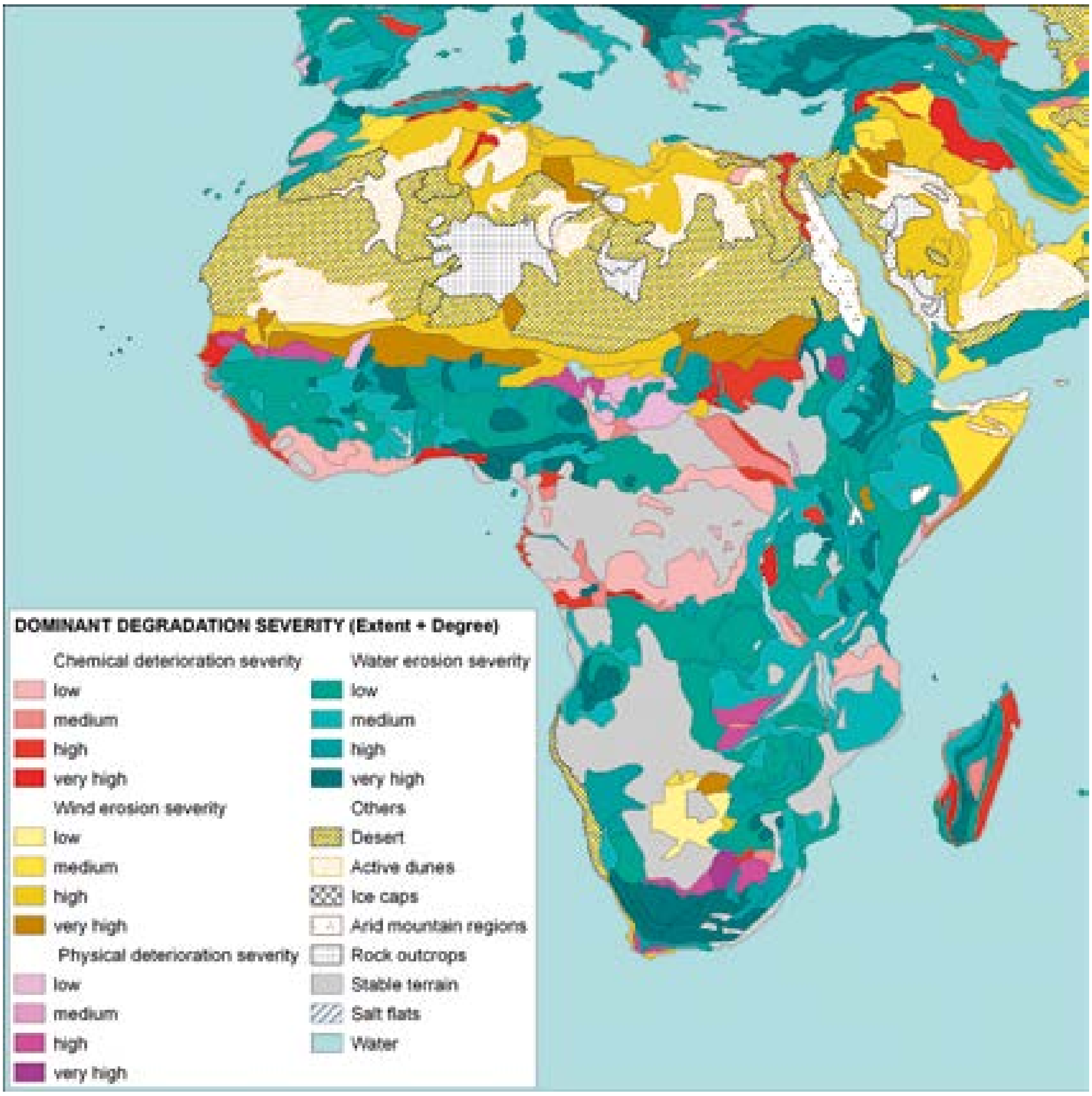
Reviews of global land degradation affirm that Africa is particularly vulnerable to land degradation and desertification and is the most severely affected region (Lal, 1995; Nellemann, et al., 2009; Obalum, et al., 2012). The United Nations Convention to Combat Desertification (UNCCD) estimates that land degradation affects up to two thirds of productive land area in Africa (UNCCD, 2013; Jones, et al., 2013) and the 2007 *Review Report on Drought and Desertification in Africa* stated that it affected at least 485 million people or 65% of the entire African population (ECA, 2007).

Figure 1 shows the type, extent and degree of soil degradation (i.e., wind and water erosion, and physical and chemical degradation) due to human activity in sub-Saharan Africa. The darkest parts of each of the coloured areas represent the highest levels of erosion or land deterioration.

Figure 2 shows that over Africa's total land area (2,966 million hectares), 494 million hectares is degraded.

FIGURE 1

Soil degradation severity, by type extent, and degree
(Source: ISRIC, 1990)



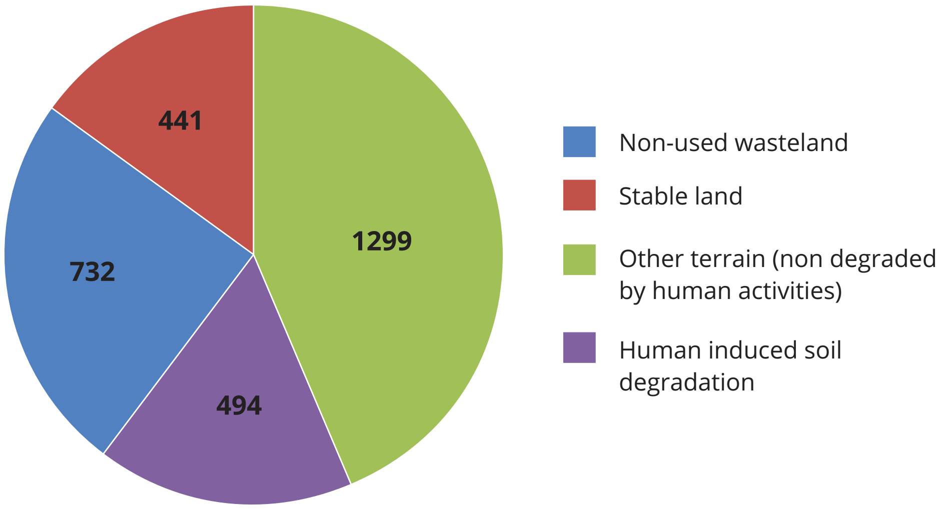
Desertification affects around 45% of Africa's land area, with 55% of this area at high or very high risk of further degradation.

The socioeconomic impacts of land degradation vary with the geographical, political, and economic context. In dryland Africa, people already suffer from poverty, food insecurity, and high mortality rates, among other hardships, and these are exacerbated by land degradation and desertification (LDD), often leading to further impoverishment, migration, and conflict (UNCCD, 2012; Jones, et al., 2013). With LDD, soils lose their structure and fertility, affecting crop yields and vegetation for livestock browsing and in turn local livelihoods and regional and national economies.

At a broader level, LDD affects the ability of the entire ecosystem to provide other valuable goods and services, including carbon sequestration, wood production, wildlife habitat, medicinal and food plants, groundwater recharge, hunting opportunities, and tourism activities (Solh, 2009; UNCCD, 2013). In addition to soil loss and nutrient depletion on-site, land degradation and soil erosion can impact the wider region, causing dust storms,

FIGURE 2

Proportion of Africa's land that is degraded (millions of hectares)
(Source: Oldeman, et al., 1991)



changing stream flow, polluting drinking water, and causing siltation in water bodies, among many other regional effects (UNCCD, 2012; UNCCD, 2013). Impacts can also be felt across borders and globally when it affects the climate, food security, human health, and political stability (UNCCD, 2011).

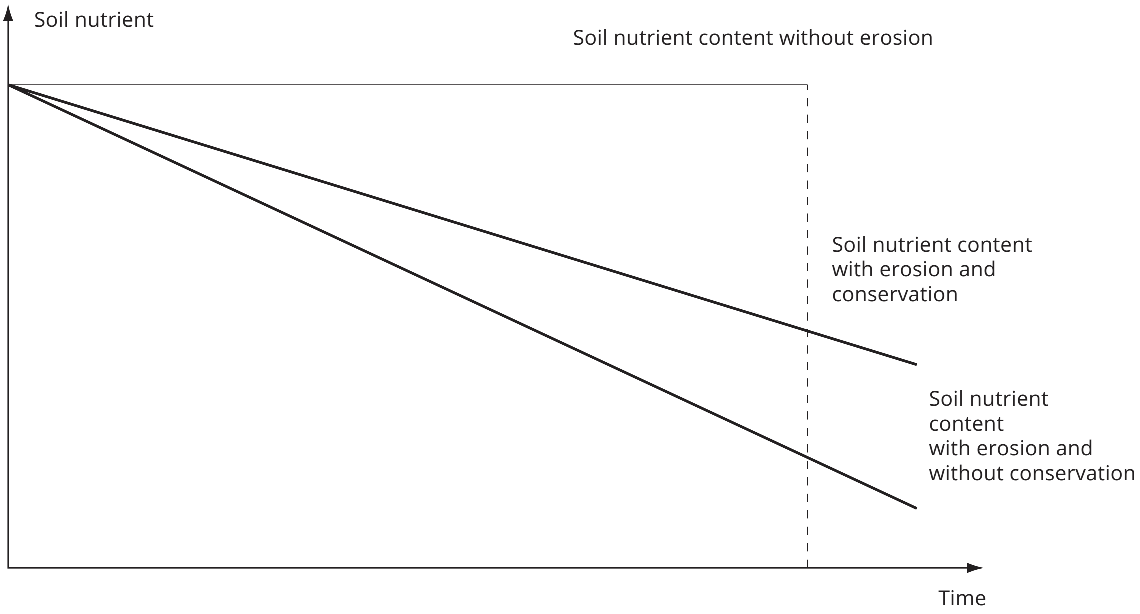
1.2. Objectives of the report

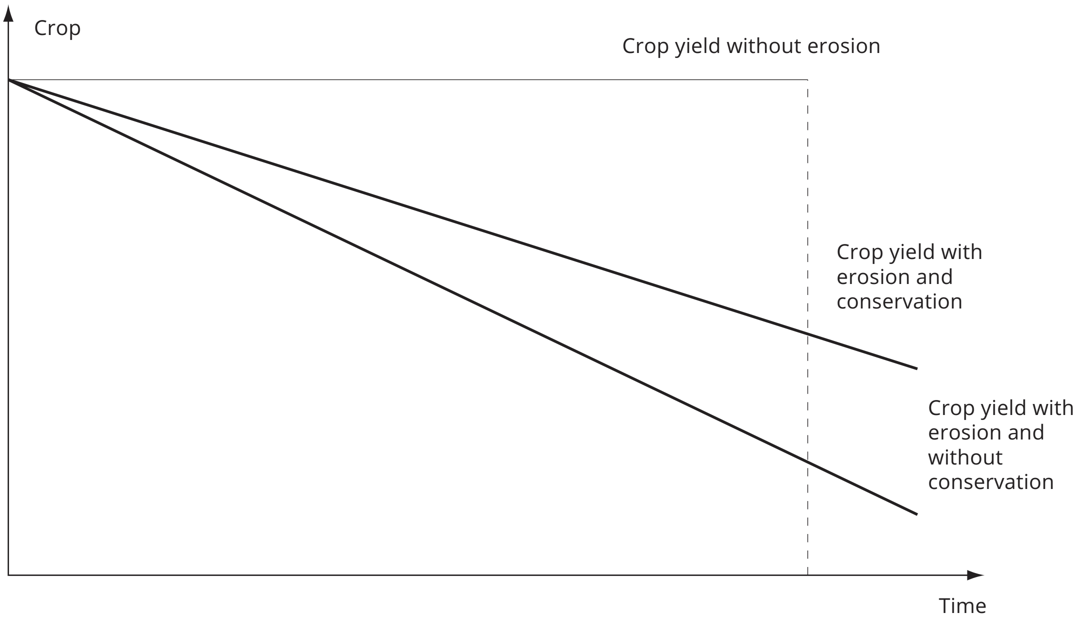
Any form of land degradation including soil erosion and the subsequent loss of ecosystem services may be a phenomenon in the bio-physical realm but its implications for society are purely and predominantly economic. Amongst all environmental problems ranging from biodiversity loss to climate change, land degradation is the most fundamental, as it affects people directly and has far reaching impacts on the life and livelihood options of people, especially the poor. Land degradation ranging from moderate to severe, causes loss in ecosystem services including the depletion of nutrients, moisture loss and biodiversity loss. All of these adversely affect agricultural productivity and erode the base for sustainable farming. In a society where 97% of food comes from terrestrial ecosystems, the problem of land degradation needs serious attention (MEA 2005). The impact of land degradation is usually categorized into on site and off site, and enters into decision making frameworks of stakeholders at various scales. While on site impacts of degradation have direct implications for farmers, their crop's productivity, current and future revenue generation and return on their investment, off site effects impact other farmers, and stakeholders (i.e., industry, navigation) at national, regional and global scales.

The overall objective of this report is to generate national and regional (Africa) estimates of the economic value of LDD by comparing the business as usual scenario (the counterfactual) with the scenario that we would obtain if policy measures (i.e., interventions) were put in place to control LDD, building on the approaches of the two diagrams below. While the first diagram explains the general approach to valuing prevention of nutrient loss, the second diagram explains the prevention of loss in crop productivity.

Specific objectives of the report:

1. Conduct an overall stocktaking of land degradation in Africa;
2. Develop a model of land degradation (measured in terms of soil nutrient loss in African cultivated lands) as a function of biophysical





(Source: Kumar, 2004)

and economic factors based on data from 2002–2004 as base years;

3. Estimate crop productivity loss as a function of land degradation and factor inputs;
4. Estimate the cost of intervention: (biological and mechanical), including the initial cost of capital and operational costs;
5. Recommend concrete policy actions.

Purpose of the work:

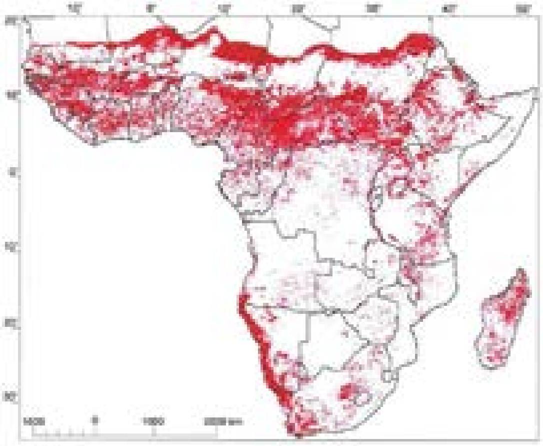
The purpose of economic valuation in general and soil erosion in particular, is as follows, to:

1. Capture some of the un-marketed services of land under degradation;
2. Help resolve trade-offs and alternate courses of action;

3. Resolve conflicting goals in terms of political, social, and economic feasibility of the policies;
4. Enable the integration of natural capital accounting for land resources;
5. Strengthen decision making tools by making them more acceptable, transparent, and credible.

FIGURE 3

Land degradation in sub-Saharan Africa based on declining biomass
(Source: Kirui & Mirzabaev, 2014)



1.3. State of knowledge

Up-to-date, relevant and reliable information about land degradation is needed at regional and continental scales in order to restore, protect, and sustainably manage Africa's soil resources, especially given the uncertainties of climate change and the impacts of increasing human pressures (Dewitte, et al., 2012).

A number of methods have been used to assess the levels and distribution of land degradation at different spatial and temporal scales. On-the-ground field measurements of soil erosion, desurfacing experiments, and expert opinions are methods used to asses advanced degradation that is easily identified because of past erosion (Omuto, et al., 2014).

Since land degradation is a process, however, identifying the geographical areas affected by it and assessing its severity requires time-series data rather than static data sets. Repeated experiments on soil and plant properties in eroded areas, modeling soil and vegetation degradation, and studying the literature about land degradation in specific places over time allow some measure of trend analysis to be identified, but challenges remain. These include the need for ample data, the uncertainty of results over large scales, and a lack of simplicity for users (UNCCD, 2013; Omuto, et al., 2014).

The recent and rapid technological development of remote sensing and satellite imagery has created the superior ability to construct time-series data to inform assessments of land degradation (Omuto, et al., 2014). Advantages include the direct observation of land-use change at different scales, and the ability to infer land degradation from trends analysis and identify "hotspots" where degradation has been significant (Solh, 2009). Ideally, remotely sensed data should be combined with field observations to be most effective (Dewitte, et al., 2012).

A recent paper on the Economics of Land Degradation in Eastern Africa adopted data from a 2010 report on food security and soil quality to quantify land degradation using data from remote sensing. It shows declining biomass as a proxy for land degradation in sub-Saharan Africa, depicting the geographic extent of areas affected by land degradation processes between 1982 and 2003. The long-term Normalized Digital Vegetation Index (NDVI) shows that about 27% of the land is subject to degradation processes, including soil degradation, overgrazing, or deforestation. The red spots in *Figure 3* show the pixels with significantly declining NDVI caused by human activities; some of the key hotspot areas include the west and southern regions of Ethiopia, the western part of Kenya, southern parts of Tanzania, and eastern parts of Malawi (Kirui & Mirzabaev, 2014).

The Global Assessment of Soil Degradation (GLASOD), conducted by the International Soils Research and Information Centre (ISRIC) under the aegis of UNEP, was the first international attempt to map the severity of land degradation at the global level. The map of soil degradation by type in Africa in the introduction to this report *(Figure 1)* is based on the GLASOD project. Data were compiled in cooperation with a large number of soil scientists throughout the world, using uniform guidelines and international correlation. The status of soil degradation was mapped within loosely defined physiographic units (polygons), based on expert judgment (ISRIC, 1990).

The GLASOD results have been criticized for a number of faults, including the misuse of results and its reliance on expert opinion, which scientists felt lacked objectivity and reproducibility (Nachtergaele, et al., 2011b). In addition to acquiring trend data, broadening the picture of land degradation requires information about its institutional, socioeconomic, and biophysical causes, the ways it affects local people, the impacts on ecosystem goods and services, and the financial costs involved. The first edition (1992) of UNEP's World Atlas of Desertification (WAD) used the GLASOD approach but the second edition in 1997 not only depicted desertification, but also discussed methods to combat its related issues, such as biodiversity, climate change, and the role of socioeconomic factors such as population density (Nkonya, et al., 2011).

In 2006, the Global Environmental Facility (GEF) launched the Land Degradation Assessment in Drylands (LADA) project to address this need for a more integrated view of land degradation. The project was implemented by UNEP and executed by FAO (Nachtergaele, et al., 2011a).

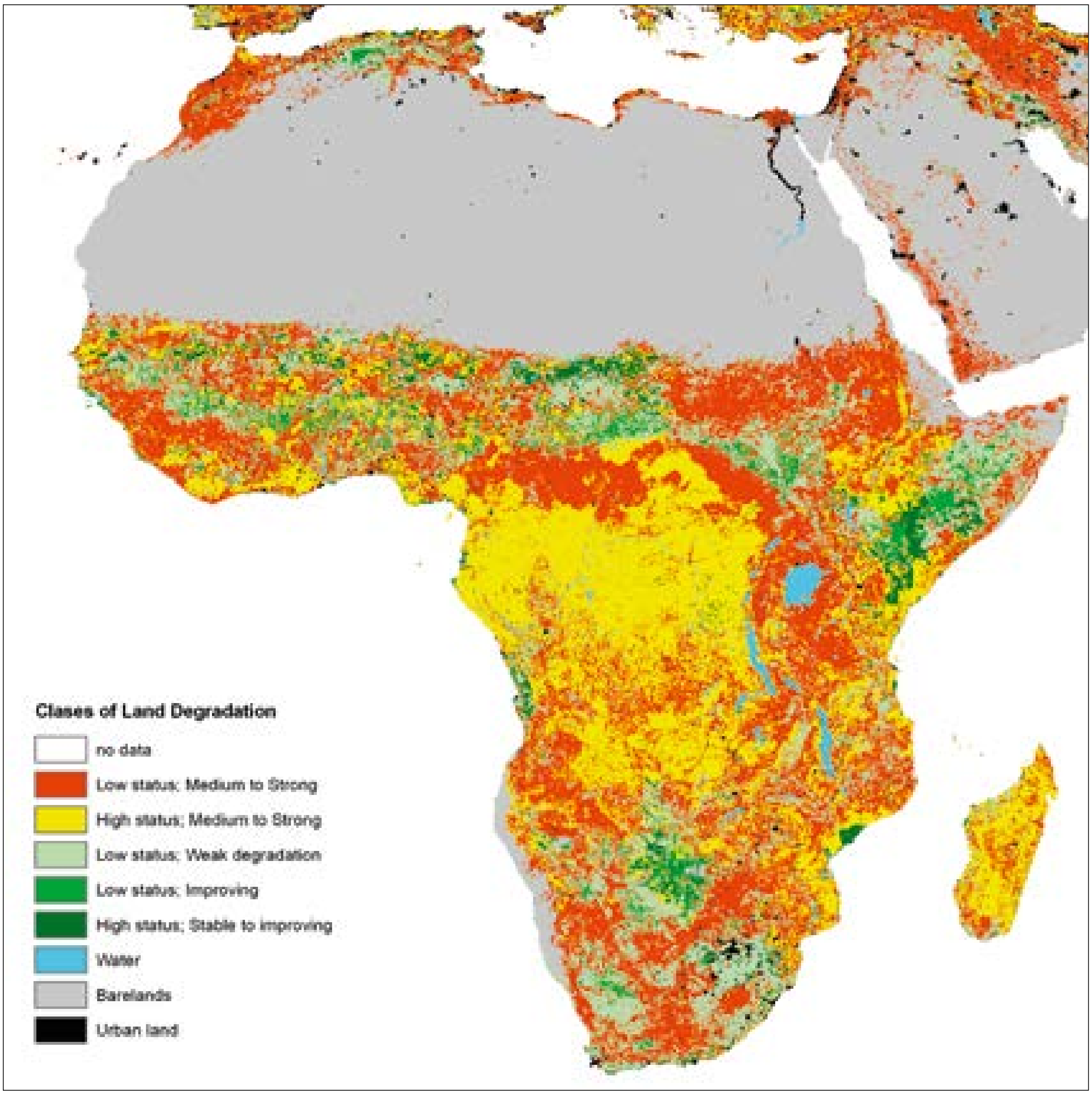
This LADA project updated the GLASOD information with a new Global Land Degradation Assessment (GLADA), which generated trends at the country level. Later, the Global Land Degradation Information System (GLADIS) superseded GLADA. It combined six properties – biomass, soil health, water resources, biodiversity, economic production, and social and cultural wealth – to help assess the status and trends in ecosystem goods and services (Akhatova, 2011) as well as the main causes of land degradation and the priorities for interventions. Results can be obtained for all areas of the globe, by country, or by land-use (Nachtergaele, et al., 2011a). *Figures 4* and *5* are maps from the GLADIS project, the first showing the severity of land degradation in Africa and the second predicting soil loss.

Another attempt to assess land degradation is to co-relate time-series crop productivity trends with changing land degradation characteristics, although the lack of a clear cause and effect relationship makes this method less favorable (Omuto, et al., 2014) and the lack of sufficient data is an ongoing problem.

Two reviews of the extent of soil erosion and its relationship to crop productivity in Africa stand out in the literature, one by Lal in 1995 and the other by Obalum et al. in 2012. Both point to the dearth of data and the difficulty in establishing

FIGURE 4

GLADIS map of land degradation
(Source: Nachtergaele, et al., 2011b)



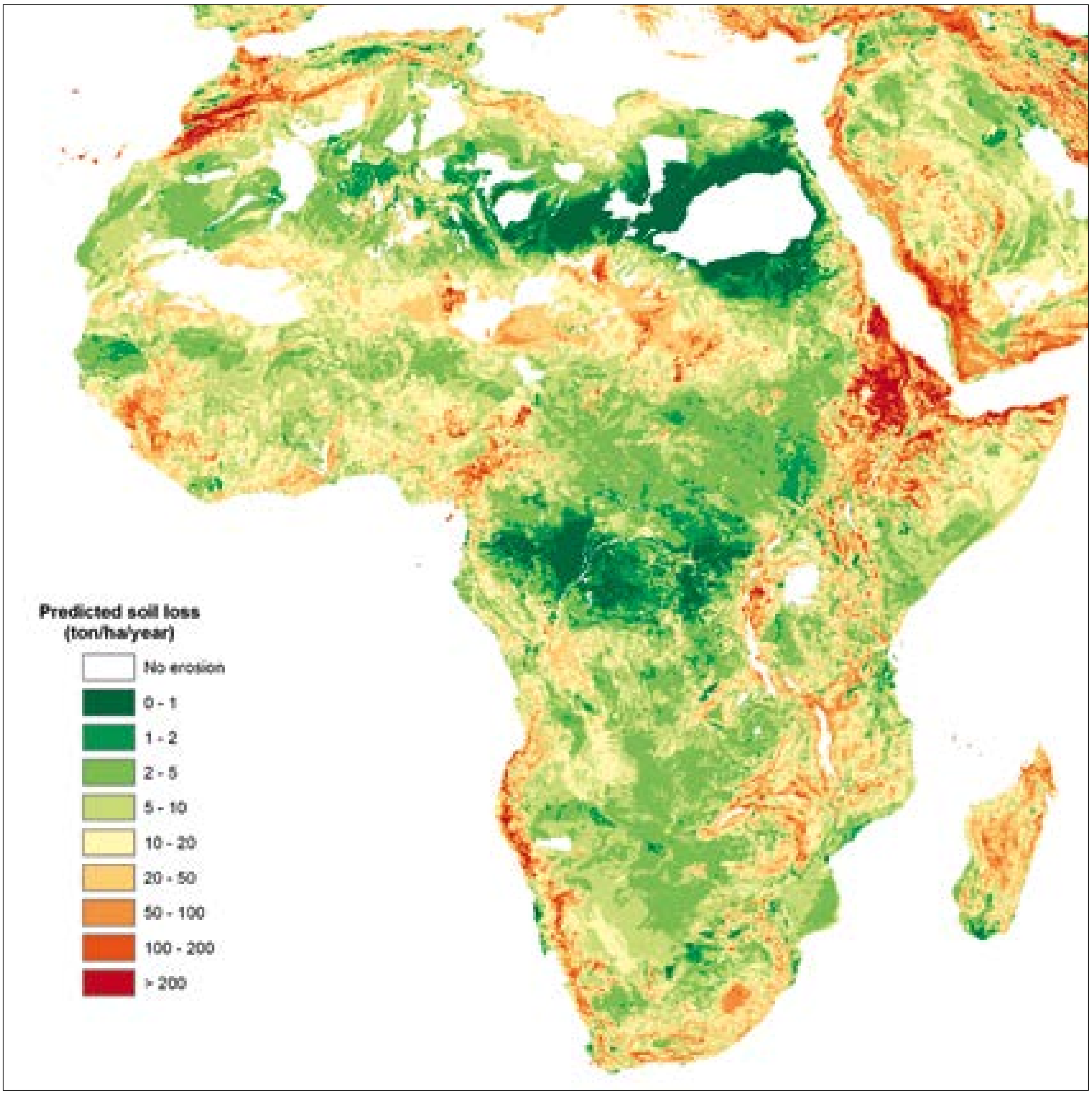
the cause-effect relationship. Lal notes that other variables interact to influence the data, including climate, the incidence of disease and pests, cultural practices, the degree of past erosion, and current erosion rates (Lal, 1995).

In their 2012 review, Obalum et al. note that since the end of the 20th century, no significant research progress has been made in the region to "beef up" the data – both on its extent and on the cause-effect relationship between soil erosion and soil productivity (Obalum, et al., 2012). A more recent study by Kirui and Mirzabaev (2014) reports that previous studies have no consensus on the exact amount of productivity losses due to land degradation in Eastern Africa.

The Appendices of this report provides the major findings about soil erosion and land degradation in Africa from the literature and a section later on in this report looks at the available data on the link between land degradation and productivity.

FIGURE 5

GLADIS map of predicted soil loss in ton/ha/year
(Source: Nachtergaele, et al., 2011b)



1.3.1. Biophysical and socioeconomic drivers of land degradation in Africa

UNCCD reports that almost three quarters of Africa's extensive agricultural drylands are already degraded to some degree. Two thirds of Africa's land base is desert or drylands and frequent and severe droughts affect the continent. Many of its countries are landlocked and its people depend heavily on natural resources for subsistence, experience widespread poverty, and need external assistance. In addition, socioeconomic conditions are difficult, while institutional, legal, and infrastructure frameworks are insufficient, and scientific, technical, and educational capacities are weak (UNCCD, 2009).

Because of pressures to increase production in this fragile setting, people are increasingly cultivating or grazing on marginal land and commercial operations are widely using fertilizers and pesticides and reducing fallow periods. These activities can exhaust the land's productive capacity resulting in declining yields, the loss of vegetation and soils, and, in extreme cases, desertification. The effects of a changing climate exacerbate these impacts (UNEP, 2013).

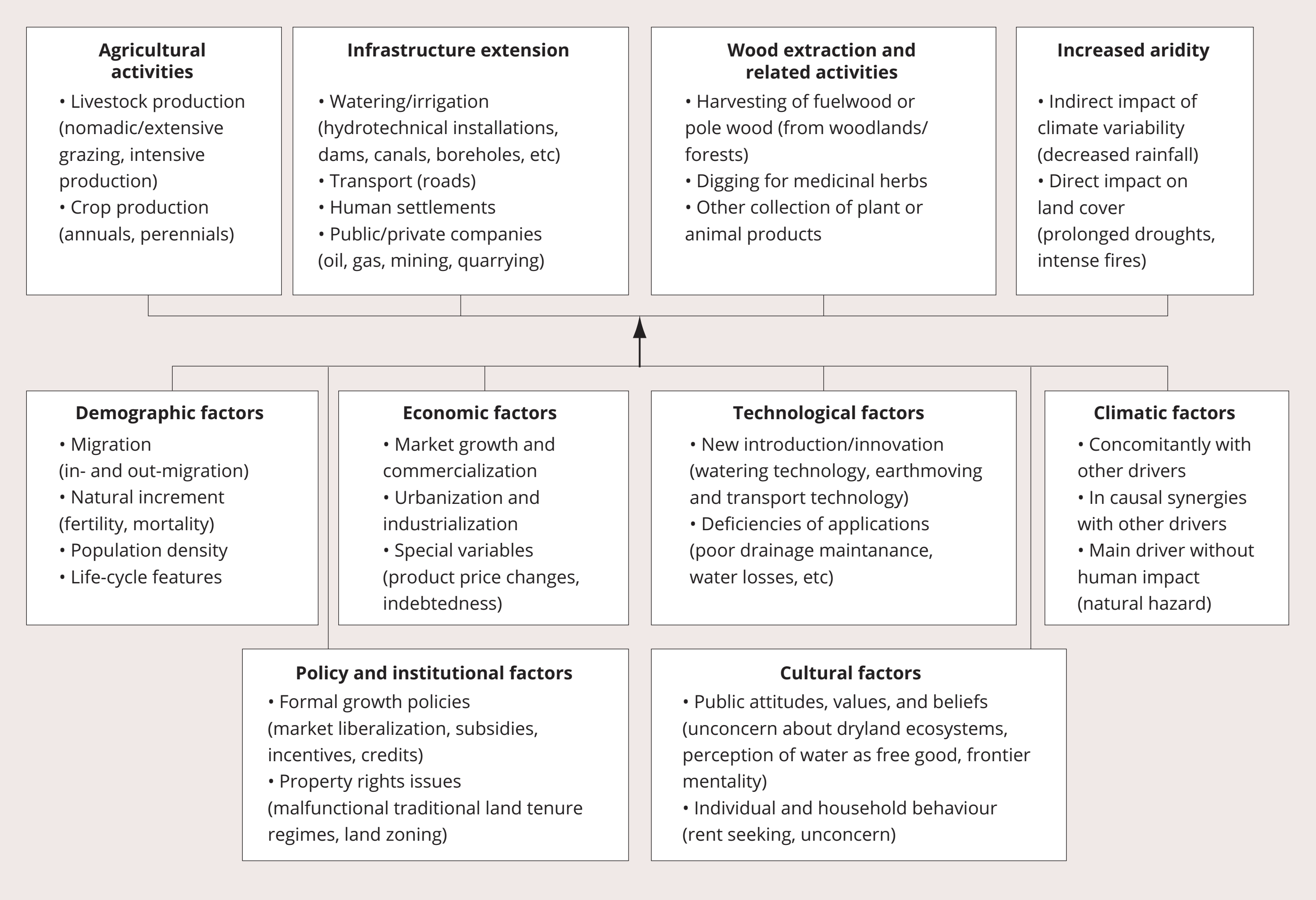
One way of examining the variables that contribute to land degradation described in the paragraphs above is to categorize them according to the role they play. Figure 6 illustrates a scheme that identifies six "root" or underlying causes of land degradation in the middle and bottom rows of boxes (Svensson, 2008). These represent a complex set of interlinked factors related to demographic, economic, technological, political, institutional, and cultural factors, including poverty levels, population growth rates, natural resources tenure and access regimes, conflicts, and climate change (ECA, 2007). In turn, these lead to the more direct, on-the-ground causes, often defined as proximate causes, illustrated in the top four boxes, including the management of agricultural activities, infrastructure, harvesting of wood products, and fires (Svensson, 2008).

Another common framework to help examine the causes of environmental issues such as land degradation is the Drivers-Preasure-State-Impact-Response (DPSIR model). According to this framework, the underlying or root causes are termed "Drivers", as illustrated in the six lower boxes in the diagram. The direct causes, shown in the top four boxes, are termed "Pressures". The DPSIR is used in integrated environmental assessments and includes "Impacts", which refer to the effects of the drivers on the environment (land degradation, in this case), human health, and the economy, while "Responses" look at the way various

FIGURE 6

Causes of land degradation: drivers and pressures

(Source: Geist, H., and Lambin, E. 2004, cited in (Svensson, 2008))



Agricultural activities
- Livestock production (nomadic/extensive grazing, intensive production)
- Crop production (annuals, perennials)

Infrastructure extension
- Watering/irrigation (hydrotechnical installations, dams, canals, boreholes, etc)
- Transport (roads)
- Human settlements
- Public/private companies (oil, gas, mining, quarrying)

Wood extraction and related activities
- Harvesting of fuelwood or pole wood (from woodlands/ forests)
- Digging for medicinal herbs
- Other collection of plant or animal products

Increased aridity
- Indirect impact of climate variability (decreased rainfall)
- Direct impact on land cover (prolonged droughts, intense fires)

Demographic factors
- Migration (in- and out-migration)
- Natural increment (fertility, mortality)
- Population density
- Life-cycle features

Economic factors
- Market growth and commercialization
- Urbanization and industrialization
- Special variables (product price changes, indebtedness)

Technological factors
- New introduction/innovation (watering technology, earthmoving and transport technology)
- Deficiencies of applications (poor drainage maintanance, water losses, etc)

Climatic factors
- Concomitantly with other drivers
- In causal synergies with other drivers
- Main driver without human impact (natural hazard)

Policy and institutional factors
- Formal growth policies (market liberalization, subsidies, incentives, credits)
- Property rights issues (malfunctional traditional land tenure regimes, land zoning)

Cultural factors
- Public attitudes, values, and beliefs (unconcern about dryland ecosystems, perception of water as free good, frontier mentality)
- Individual and household behaviour (rent seeking, unconcern)

social actors address the degrading environment to improve conditions, such as sustainable land management to address land degradation.

The text of the UNCCD's Regional Implementation Annex for Africa sets the conditions that make the continent particularly vulnerable to, and impacted by land degradation and desertification *(Box 2)*. These conditions are part of the underlying drivers of land degradation in Africa.

1.3.2. Underlying biophysical drivers

The "Drivers" or underlying causes of land degradation can be grouped into two categories: those due to natural causes, conditions, and biophysical processes, such as intrinsic land quality, climatic variables, and soil biodiversity and others related to human society, such as poverty, demographic change, and economic, and political factors (Solh, 2009; Eswaran, et al., 2001); examples of the latter category include population pressure, poverty, lack of markets and infrastructure, poor governance, weak institutional frameworks, and inadequate education (Nachtergaele, et al., 2011a). The next section describes the "natural" drivers of land degradation.

Drylands: proportion and distribution

Seventeen of the 54 Africa's countries are classified as Least Developed Countries (LDCs) with the majority of their agricultural lands in semi-arid regions: Burkina Faso; Mali; Chad; Mauritania; Djibouti; Mozambique; Eritrea; Niger; Ethiopia; Senegal; Gambia; Somalia; Lesotho; Sudan and South Sudan; Malawi; and the United Republic of Tanzania. Thus, these countries are more susceptible to land degradation and desertification, given the fragility of dryland soils. Some 66% of Africa is classified as desert or drylands *(Figure 7)* (UNEP, 2013).

Inherent land quality

Another way of depicting the underlying land conditions that make much of Africa vulnerable to land degradation is by assessing inherent land quality *(Figure 8)*. It is based on a **global soil climate map** and a **global soil map**. Inherent land quality is defined as "the ability of the land to perform its

BOX 2

Particular conditions of the African region from the text of the UNCCD

(Source: UNCCD, 2012)

(a) High proportion of arid, semi-arid and dry sub-humid areas;

(b) Substantial number of countries and populations adversely affected by desertification and by the frequent recurrence of severe drought;

(c) Large number of affected countries that are landlocked;

(d) Widespread poverty prevalent in most affected countries, the large number of least developed countries among them, and their need for significant amounts of external assistance, in the form of grants and loans on concessional terms, to pursue their development objectives;

(e) Difficult socio-economic conditions, exacerbated by deteriorating and fluctuating terms of trade, external indebtedness and political instability, which induce internal, regional and international migrations;

(f) Heavy reliance of populations on natural resources for subsistence which, compounded by the effects of demographic trends and factors, a weak technological base and unsustainable production practices, contributes to serious resource degradation;

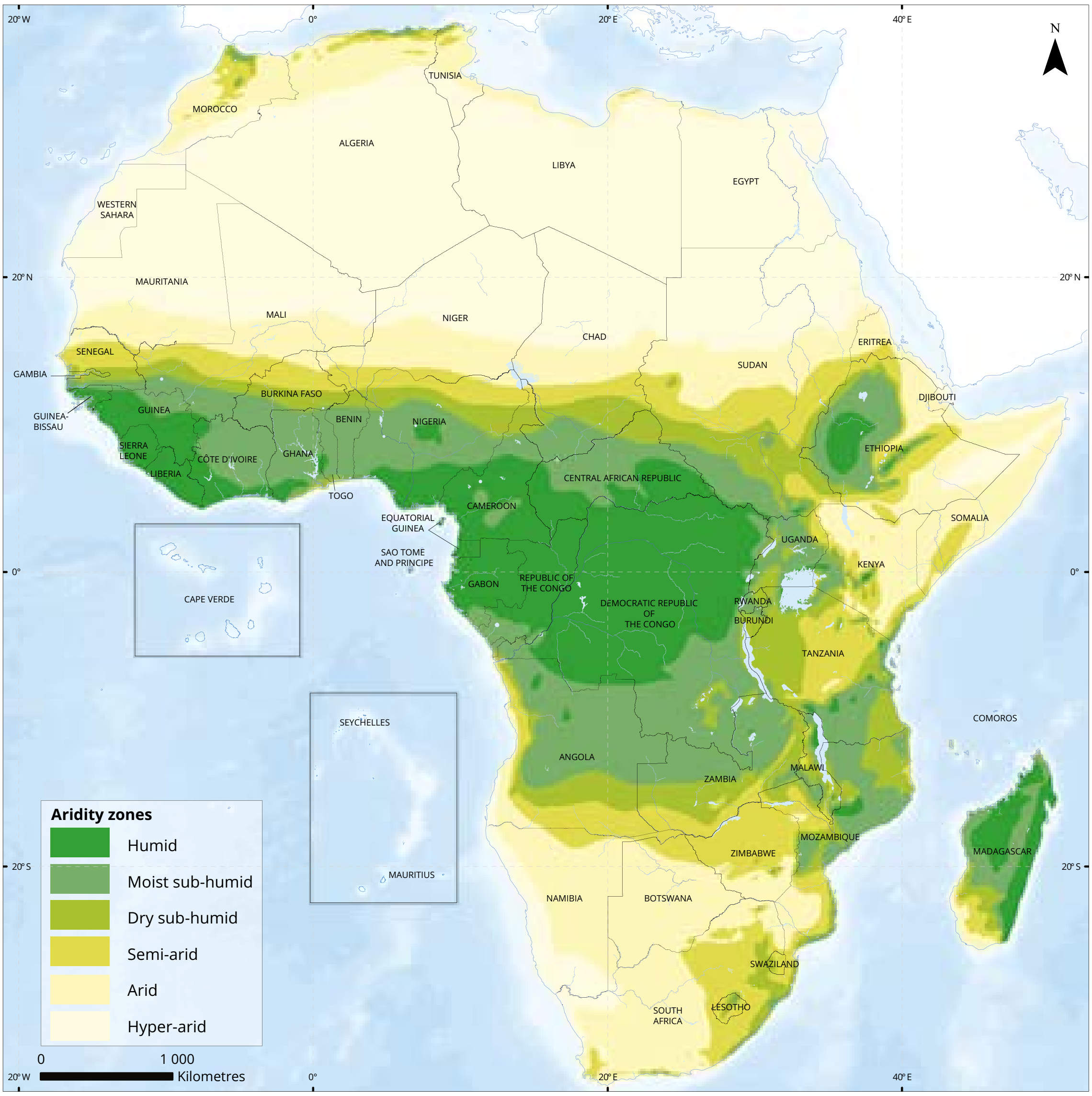
(g) Insufficient institutional and legal frameworks, the weak infrastructural base and the insufficient scientific, technical and educational capacity, leading to substantial capacity building requirements; and

(h) Central role of actions to combat desertification and/or mitigate the effects of drought in the national development priorities of affected African countries.

FIGURE 7

The drylands of Africa

(Source: World Meteorological Organization (WMO), United Nations Environment Programme (UNEP), Climate Change 2001: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), cited in (UNCCD and CFC, 2009))



function of sustainable agriculture production and enable it to respond to sustainable land management" (Kettler, 2014). *Figure 8* maps soil resilience and soil performance. Soil Resilience is defined as "the ability of the land to revert to a near original production level after it is degraded, as by mismanagement. Land with low soil resilience is permanently damaged by degradation". Soil performance is "the ability of the land to produce (as measured by yield of grain, or biomass) under moderate levels of inputs in the form of conservation technology, fertilizers, pest and disease control. Land with low soil performance is generally not suitable for agriculture" (Kettler, 2014). On the map, Class 1 land is the most desirable and class 9 land is the one with the poorest quality. Thus, the areas with the poorest quality are those colored in white, violet and red, which cover an enormous proportion of the continent.

FIGURE 8

Inherent land quality

(Source: USDA, 2003)

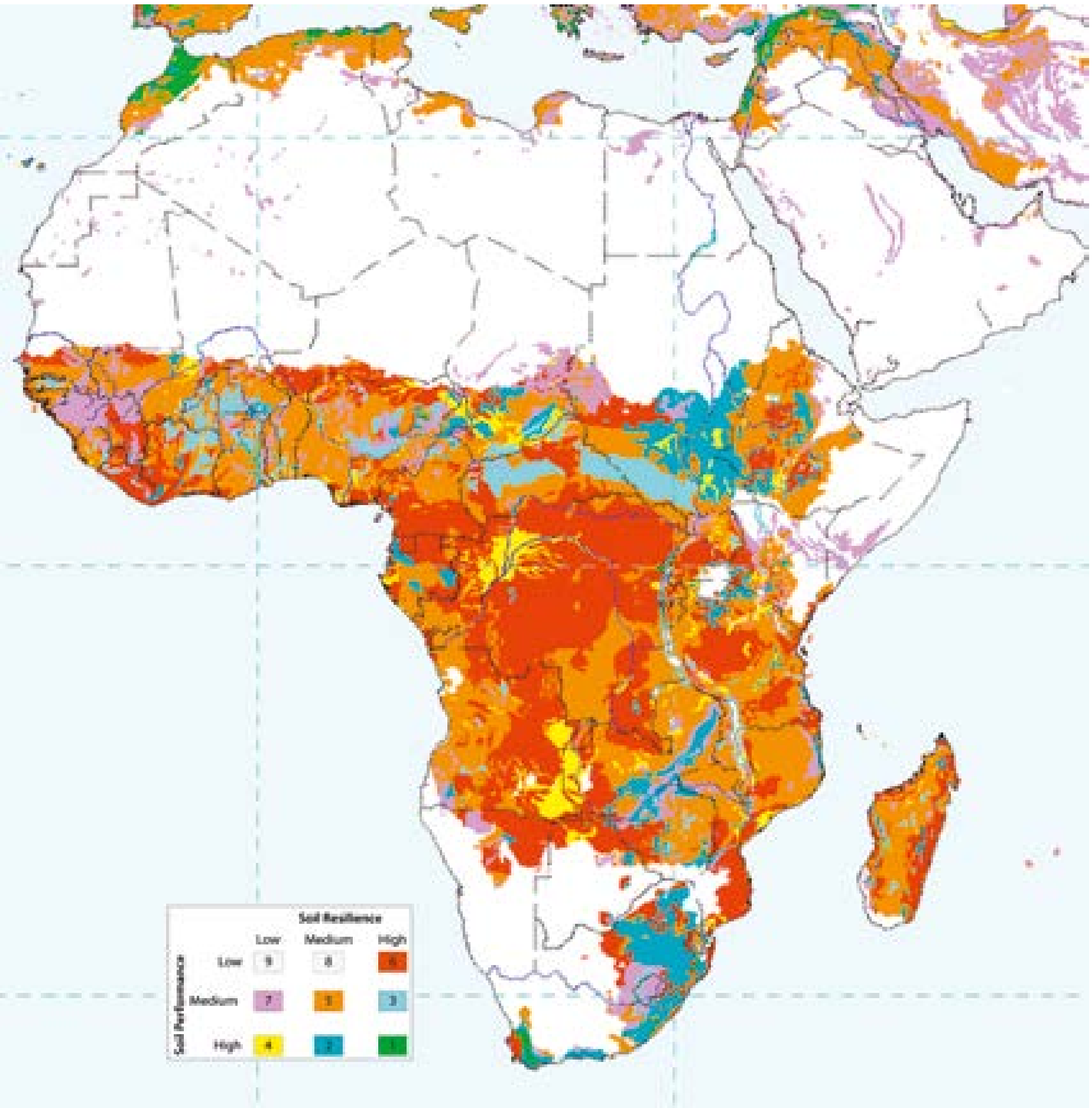
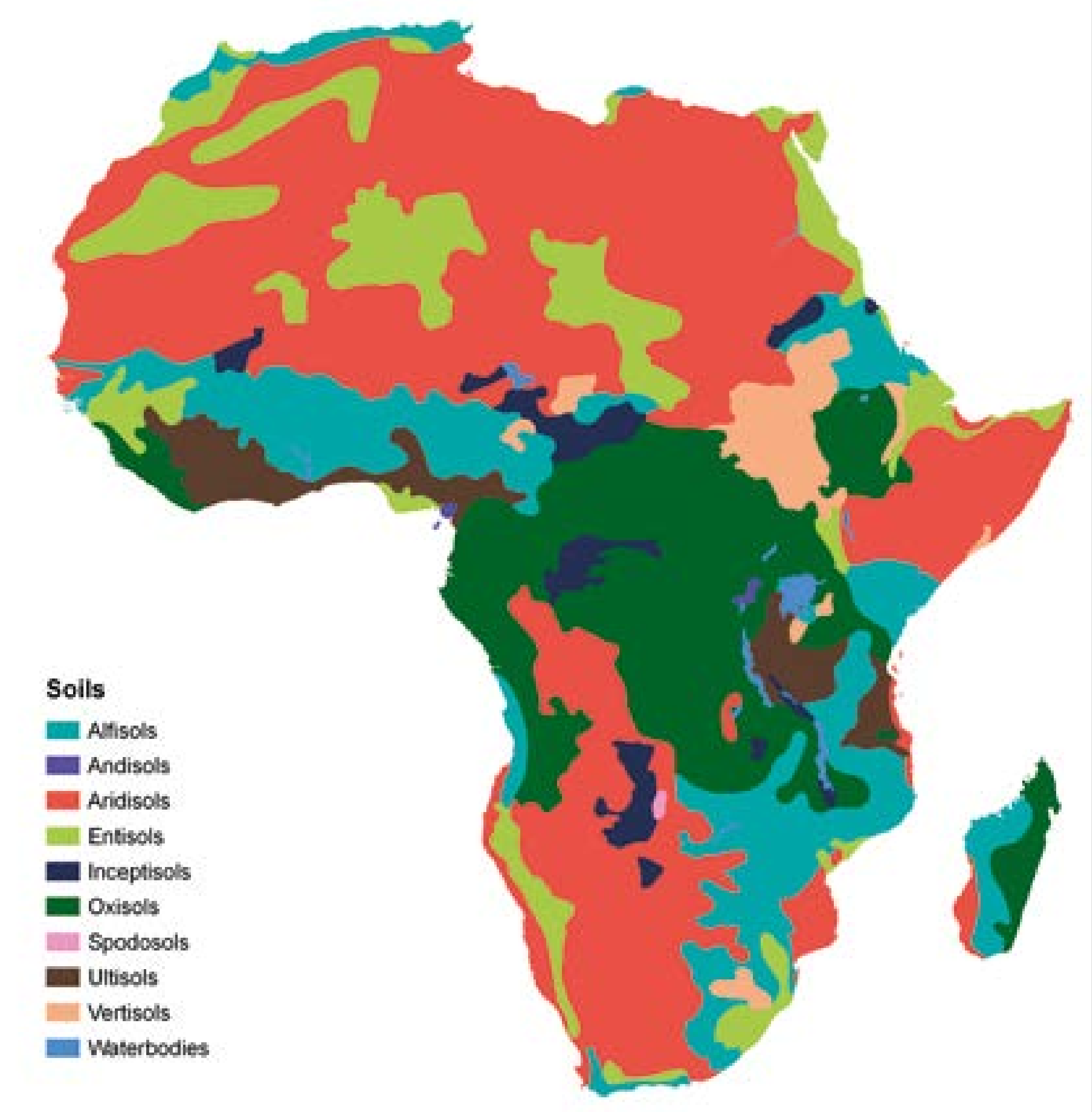


FIGURE 9

Soil classification map

(Source: FAO/EC/ISRIC, 2003)



Soils

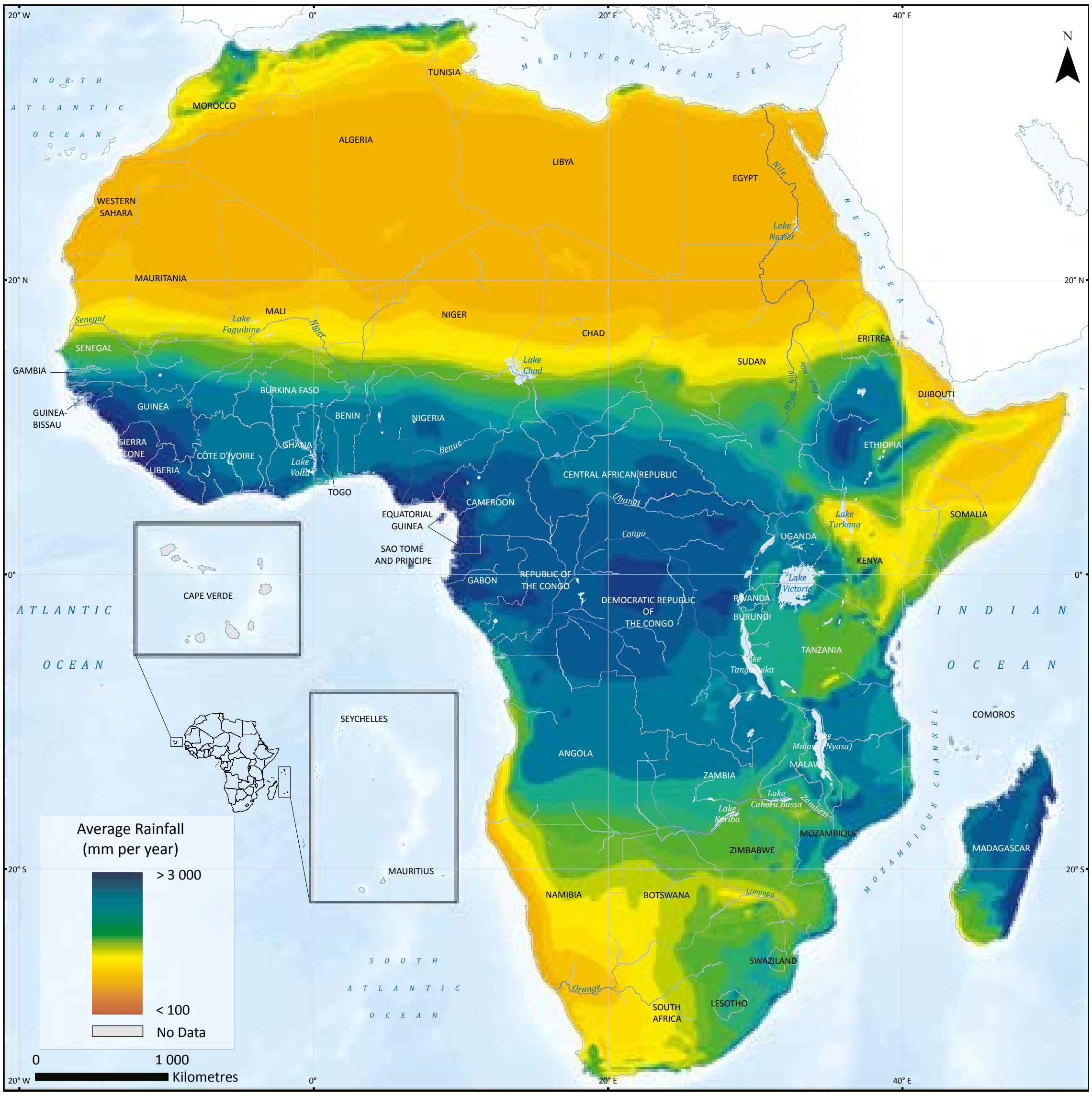
The soils of Africa can be classified into 9 broad classes: Alfisols, Andisols, Aridisols, Entisols, Inceptisols, Oxisols, spodosols, Ultisols, and Vertisols (Figure 9).

The Soil Atlas of Africa reports that "agricultural production in much of Africa is hampered by the predominance of inherently low soil fertility, fragile ecosystems that do not support intensive agriculture." (Jones, et al., 2013). Soil is considered as an underlying condition contributing to land degradation.

FIGURE 10

Average rainfall distribution

(Source: UNEP, 2013)



Climate variability

Climate variability is another natural or underlying condition that contributes to land degradation in Africa (Nachtergaele, et al., 2011a). Climate variability refers to the seasonal and annual temperature and rainfall variations within and between regions or countries.

Most African countries experience large variations in rainfall, both throughout the year and between years, and they are subject to frequent extremes of flooding or drought, both of which contribute to soil erosion and land degradation (UNEP, 2013). *Figure 10* shows the average rainfall and distribution in Africa. As a natural phenomenon, drought occurs when rainfall is significantly lower than normal over a long period of time, which can make soils more susceptible to wind erosion, and to water erosion when the seasonal rains come. But drought and erosion are exacerbated by poor land management that responds inappropriately to climatic variations, which can lead to desertification (UNCCD, 2009).

FIGURE 11

Climate zones: observed climate data, 1975–2000

(Source: UNEP, 2013)

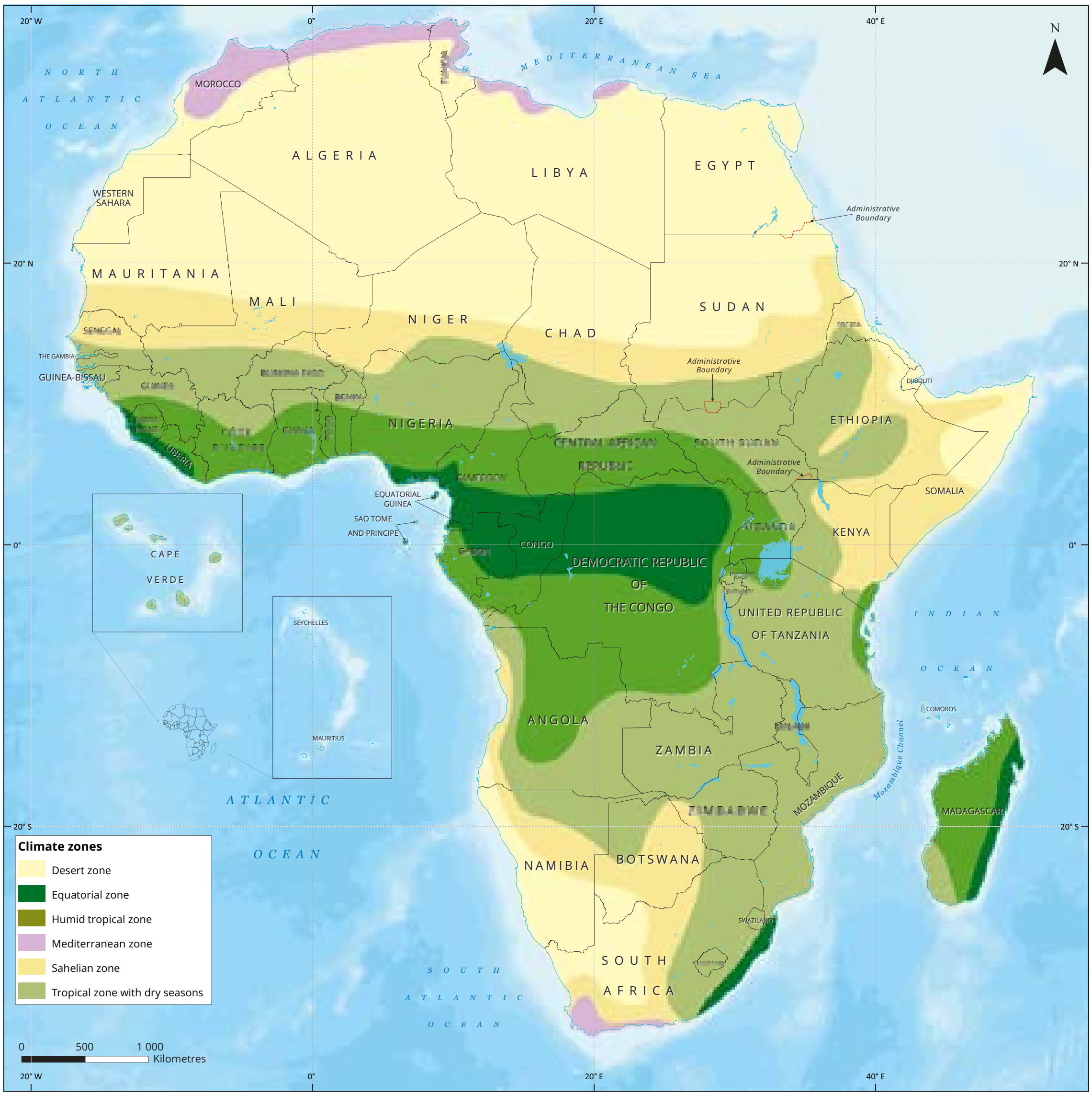


Figure 11 shows Africa's climate zones, according to the Köppen-Geiger Climate Classification, based on annual and monthly averages of temperature and precipitation ranges, showing the large proportion of the continent with naturally dry and hot climates.

Climate change

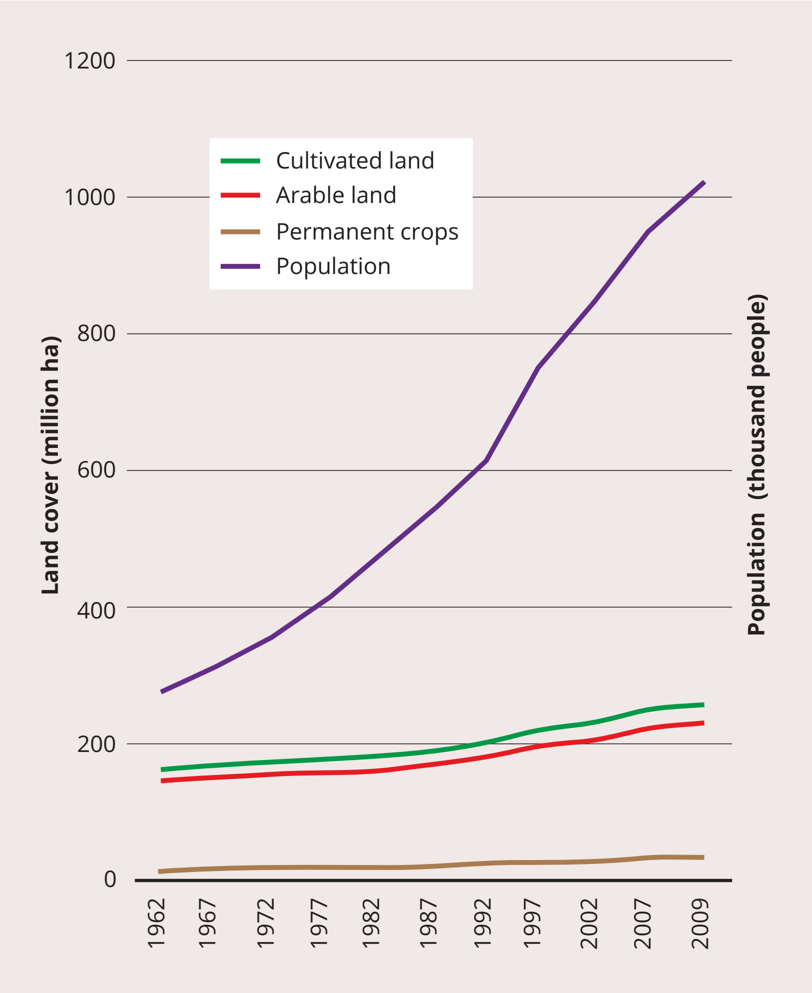
Climate change is another underlying driver of land degradation. UNCCD notes that it exacerbates desertification and vice versa. Hazardous weather events are predicted to increase in frequency and severity due to climate change, which will increase dryland degradation (UNCCD, 2012). According to the IPCC, there is already evidence of declining rainfall in certain arid, semi-arid, and dry subhumid areas, resulting in declines in soil fertility and agricultural, livestock, forest, and rangeland production (IPCC, 2001). It describes a climate change and desertification feedback loop in which vegetation loss caused by desertification reduces the amount of carbon captured by vegetation and increases emissions from rotting plants, resulting in more greenhouse gases in the atmosphere, and the continued vicious cycle of land degradation (UNCCD, 2012).

According to the IPCC's Fifth Assessment Report, surface temperatures in Africa increased by 0.5–2°C over the past hundred years and since 1950, the magnitude and frequency of some extreme weather events has already changed. It projects that northern and southern Africa will become drier and that more frequent heavy storms could cause more soil erosion (CDKN, 2014).

FIGURE 12

Correlation between population growth and the conversion of land to agriculture

(Source: FAO Aquastat/JRC cited in (Jones, et al., 2013))



1.3.3. Underlying socioeconomic drivers

This next section looks at the human drivers or underlying socioeconomic contributors to land degradation.

Poverty

Africa has a disproportionate share of low-income countries compared to other world regions and on the whole, the continent has a very low level of economic development. The Economic Commission for Africa reported that in 2013 Africa's share of the world population was 13%, but its share of global GDP was only 1.6%t. Data from 2010 reveal that 20.6% of Africa's population (excluding North Africa) lived on below USD 1.25 a day, highlighting the high level of poverty that is symptomatic of the continent's low level of development (ECA, 2014).

Poverty can act as a driver of land degradation when farmers, herders, and others who depend directly on land resources cannot wait for soils and vegetation to recover and resort to inappropriate land management. Examples include eliminating fallow periods, farming on already poor soils in marginal areas, and keeping livestock in the same place too long. These circumstances can lead to a vicious cycle in which rising land degradation and lost livelihoods drive people to put increasing pressure on fragile resources (Svensson, 2008; Solh, 2009). Since most African economies are based on agriculture and poverty levels are high, poverty-related agricultural practices and other land-use systems contribute a large proportion to the continent's land degradation problems in rural areas (ECA, 2007).

Population growth and density

Pressures on land from increased human population numbers and densities are potential contributors to land degradation when intensified crop and livestock production in the same region is not accompanied by increased conservation measures to prevent exceeding the land's carrying capacity (Svensson, 2008).

Over the past 50 years, Africa has experienced continuous and rapid population growth, increasing by nearly 300% since the early 1960s and doubling between 1982 and 2009. Similarly, the area of agricultural land (arable land plus land under permanent crops) has grown in parallel over this period. Between 1962 and 2009, there was a 59% increase in cultivated land, over which time the population grew by 271%. In 1962, each cultivated hectare supported 1.91 people but by 2009, one hectare supported 4.55 people. The Soil Atlas of Africa points out that since a significant portion of crop harvests is exported, the ratio of people to the area of land producing food is even higher (Jones, et al., 2013).

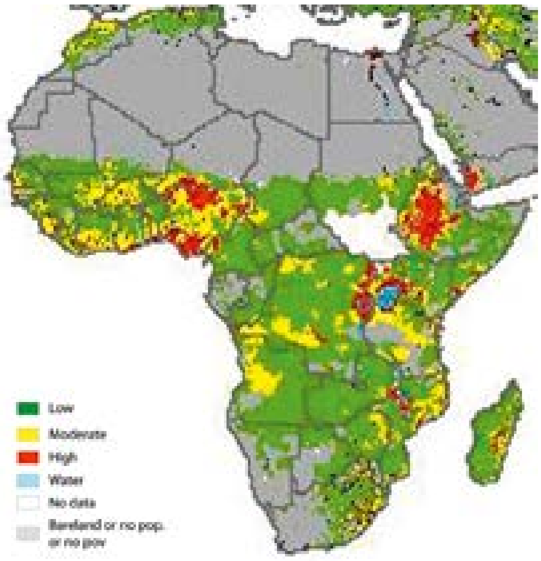
In *Figure 12*, the left Y-axis represents 1,000 ha for the land-cover lines while the right Y-axis represents 1,000 people for the population line (FAO Aquastat/JRC) cited in (Jones, et al., 2013).

Figure 13 shows the relationship between poverty, population, and land degradation. It was produced by the GLADIS project mentioned earlier. It illustrates how land degradation is exacerbated in regions of both high poverty and high population density. The project measured the effect of this confluence of factors through an index that multiplies poverty and population levels in specific areas. In this equation, the measure of sub-national poverty levels uses data on infant mortality rates (Nachtergaele, et al., 2011b).

FIGURE 13

GLADIS land degradation impact index

(Nachtergaele, et al., 2011b)



Other socioeconomic drivers of land degradation

The literature points to a number of other drivers that can contribute to land degradation, including the following: the impact of global economic factors such as trade patterns that encourage the short-term exploitation of land for export crops, or taxes that distort local markets and lead to the over-use of cropland; land tenure arrangements in specific countries or regions that provide no incentives for individuals to invest in maintaining and enhancing land and soils; the presence of conflict that prevents land conservation; the shortage of rural farm hands to practice traditional conservation agriculture that is labour intensive; and a lack of education, which can mean the low adoption of new conservation technologies (Svensson, 2008; UNCCD, 2009).

1.3.4. Human pressures contributing to land degradation

Pressures refer to the direct causes of environmental change in the DPSIR framework. A number of different pressures can signify unsustainable land use and vulnerability to land degradation, including deforestation, overcultivation, overgrazing, poor irrigation practices, and polluting industrial activities (UNCCD, 2009). *Table 1* shows the approximate areas in Africa that are subject to these pressures.

Deforestation

Deforestation can be defined as the removal of natural vegetation (usually forest and bush) from land areas. This is done to claim the land for agricultural purposes (crops and livestock grazing), timber harvesting for large-scale commercial forestry, fuelwood harvesting for subsistence reasons, road construction, and urban development, among others (Oldeman, et al., 1991). Deforestation is a significant direct cause of LDD in Africa.

In 2007, the Economic Commission for Africa (ECA) reported that biomass represents 30% of all the energy used in Africa and over 80% of energy in many sub-Saharan countries, and states that fuelwood production and consumption doubled over the last 30 years of the 20th century and rised

TABLE 1

Land area affected by pressures that contribute to land degradation

(Source: Oldeman, et al., 1991)

	Causative factors of soil degradation, expressed in million ha of terrain affected.				
	Deforestation	**Overgrazing**	**Agricultural mismanagement**	**Over-exploitation**	**Bio(industrial) activities**
Africa	67	243	121	63	+

by 0.5% every year *(Figure 14)*. The removal of vast amounts of trees and bushes for fuel has left large areas of bare ground susceptible to LDD (ECA, 2007).

According to FAO's 2010 Global Forest Resources Assessment, between 2000 and 2010, Africa lost 3.4 million hectares annually, representing the world region with the most area lost to deforestation after South America. *Figure 15* shows the net deforestation when taking annual growth into account during 1990–2000 and 2000–2010. *Figure 16* shows the annual change in forest area by African country.

FIGURE 14

Trends in wood removals, 1990–2005

(Source: ECA, 2007)

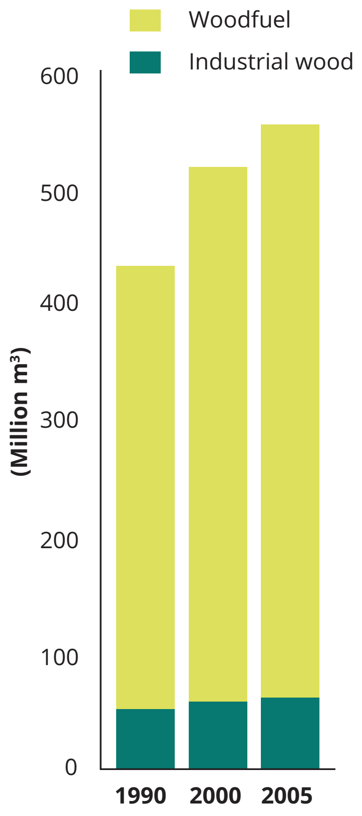


FIGURE 15

Annual change in forest area, 1990–2010

(Source: FAO, 2010)

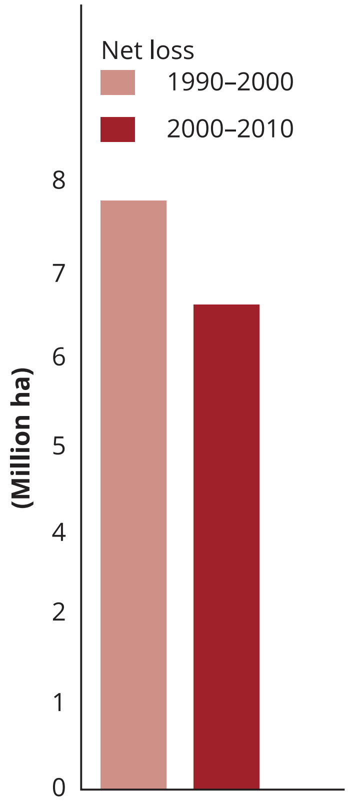
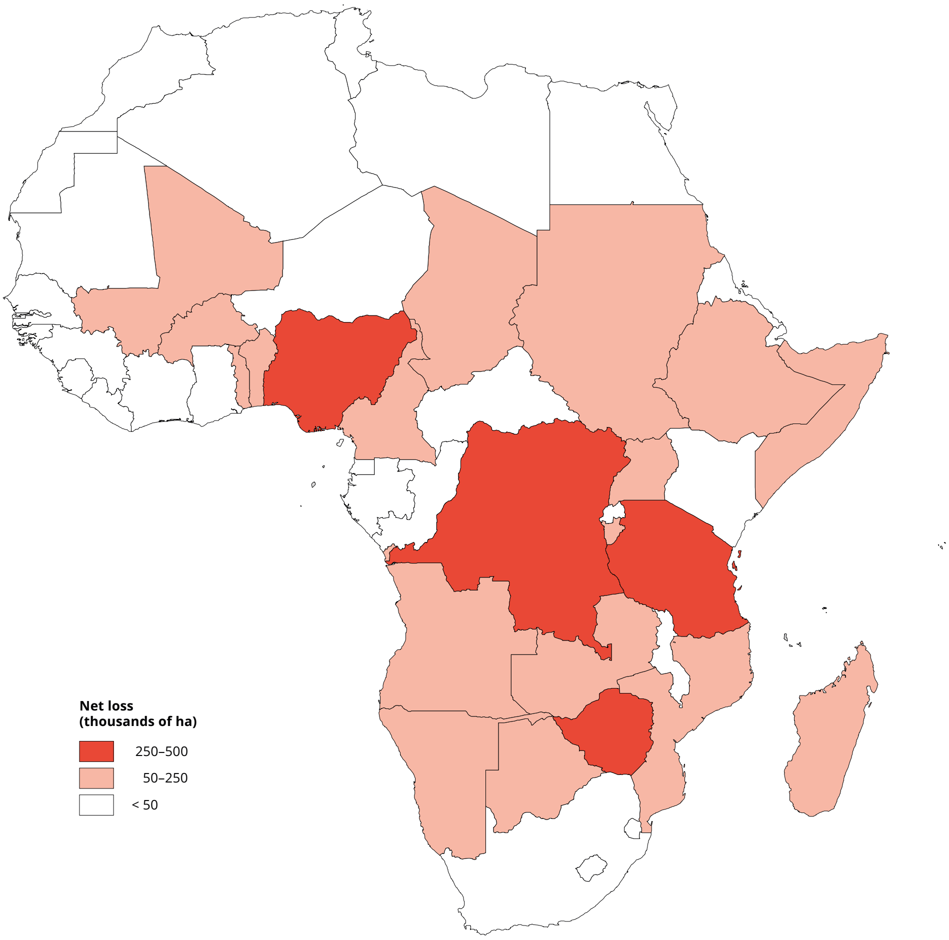


FIGURE 16

Annual change in forest area by country, 2005–2010

(Source: FAO, 2010)



Overgrazing

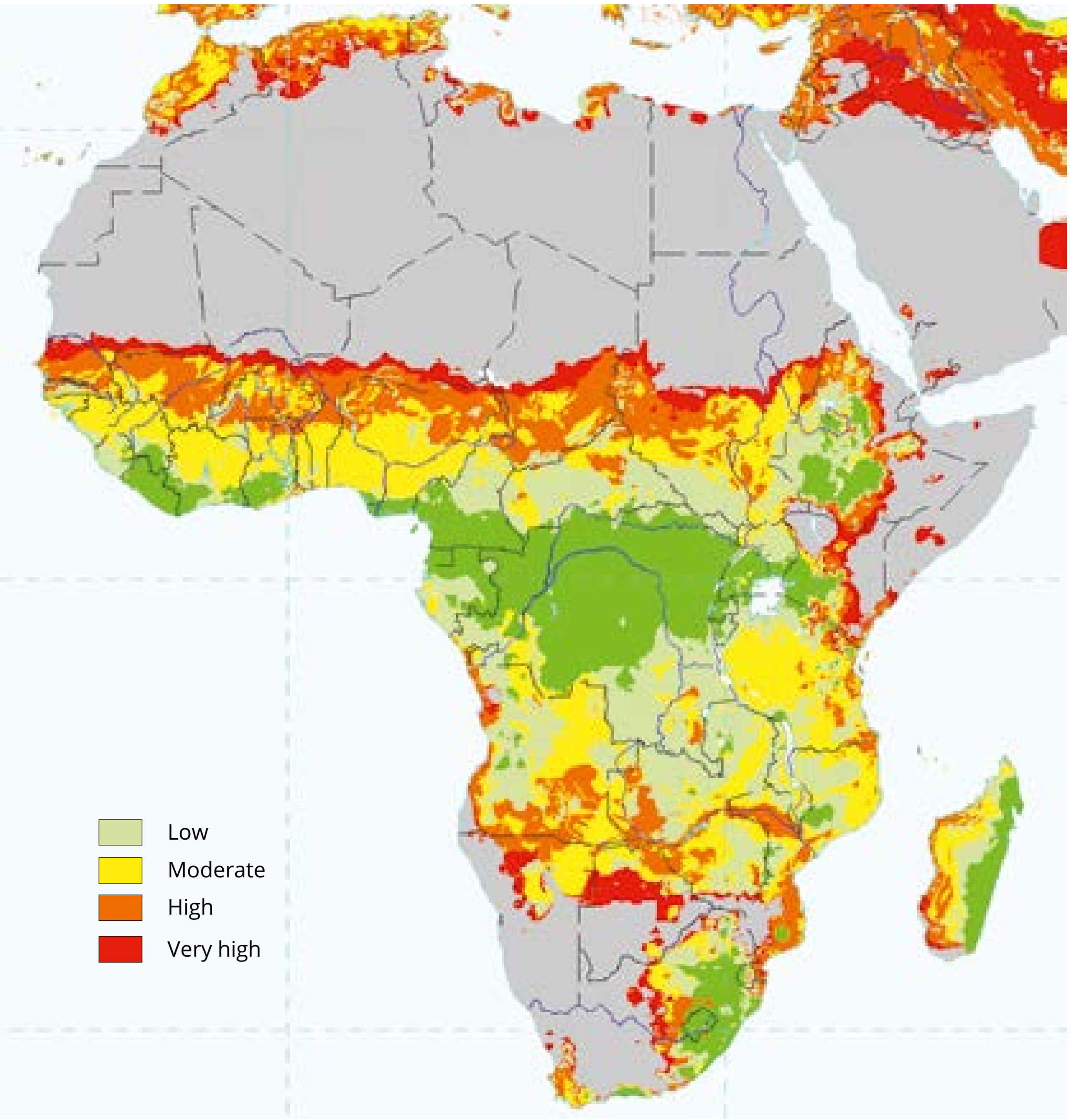
Overgrazing, which means the extensive removal of vegetation by livestock as well as the impact of trampling, usually decreases soil cover, which leaves the area vulnerable to water and wind erosion; trampling also causes soil compaction, another pressure that contributes to LDD (Oldeman, et al., 1991). Overgrazing is especially damaging to soils in marginal areas, on sandy soils, when the livestock responsible is of only one species, and when there are especially high stocking densities (UNEP, 2013). UNEP cites data from the mid-1990s suggesting that overgrazing is responsible for about half of all soil degradation in Africa, followed by poor agricultural management practices (24%); vegetation removal (14%); and overexploitation (13%) (UNEP, 2013).

Agricultural mismanagement

This pressure refers to the improper management of agricultural land, which includes a wide variety of practices that fail to conserve and improve soil quality and vegetative cover, protect soils from water and wind erosion, and degrade them through overexploitation or polluting practices. These include insufficient or excessive use of fertilizers, shortening the fallow period in shifting cultivation, poor irrigation practices, lack of anti-erosion measures, and the use of heavy machinery when the soil is fragile, among others (Oldeman, et al., 1991; Jones, et al., 2013).

FIGURE 17

Vulnerability to desertification
(Source: NRCS, 2003)



1.3.5. Impacts

In the DPSIR framework, land degradation and desertification can be considered the impacts of the drivers and pressures described in the preceding section, namely the underlying geographical conditions and natural factors that make much of Africa prone to soil erosion, a set of socioeconomic conditions that are conducive to the overexploitation of land, especially poverty and population growth, and the direct pressures on land resources that erode soils.

Vulnerability to land degradation and desertification

When many of these variables occur together in specific regions, these places are highly vulnerable to land degradation and desertification. *Figure 17* is a map of areas in Africa that are vulnerable to desertification.

In its definition of desertification, this Geographic Information System (GIS) Desertification Vulnerability map excludes areas that have hyperarid and humid climates: 43% of the continent is characterized as extreme deserts and about 11% of the land mass is humid. The map reveals that of the rest of the land mass, 46% is at risk of desertification, of which 55% is at high or very high risk. Countries at the southern edge of the Sahara are particularly vulnerable. For example, of the 19% of Niger that isn't already desert, 17% is highly vulnerable to desertification processes. Other countries in which large areas are subject to land degradation are the Mediterranean countries of North Africa and those on the fringe of the Kalahari Desert (Reich, et al., 2001).

The approximate land area, proportion of the land, mass, and number of people affected by each category are shown in *Table 2*.

The next part of this report describes and assesses the features, distribution, proportions affected, and severity of land degradation in Africa.

Types and severity of land degradation in Africa

Human-induced soil degradation can be categorized into soil degradation by displacement of soil material, which includes water erosion and wind erosion, and soil degradation by physical and chemical deterioration. *Figure 18* illustrates the proportion of land area in Africa affected by these four types of land degradation, revealing that water erosion is the most significant process. *Table 3* shows the amount of area affected by each of four levels of severity of soil degradation according to the four types of degradation, and *Figure 19* is a GLASOD map showing the distribution of various types of land degradation processes over the continent, which also shows the significance of water erosion.

As shown in these figures and tables, wind and water erosion is widespread in many parts of Africa, and most intense in semi-arid and sub-humid areas (Reich, et al., 2001)

Water erosion

About 46% of degraded land in Africa is as a result of water erosion (*Tables 3* and *4*). Surface wash and sheet erosion wash away a considerable amount of nutrients from the topsoil leading to its impoverishment. In other cases of water erosion, rills and gullies form with mass water movement on susceptible terrain.

Water erosion is particularly destructive in Africa's humid tropical regions where the confluence of population pressures, deforestation, and episodes of torrential rainfall can lead to annual soil losses exceeding of 50 t/ha. Based on the limited data available, it appears that Northern Africa, Madagascar, and South Africa experience the most severe water erosion *(Figure 20)* (Jones, et al., 2013).

Wind erosion

About 38% of degraded land in Africa is as a result of wind erosion *(Table 5)*. It is most evident in areas where annual rainfall is below 600 mm and the dry season lasts more than six months. The Sahel,

TABLE 2

Risk of desertification in numbers

(Source: Reich, et al., 2001)

Category of risk	Total land area affected (million km²)	Percentage of land mass	Number of people affected
Low	2.5	14	485 million
Moderate	3.6	16	
High	4.6	11	
Very High	2.9	5	22 million

TABLE 3

Severity of human induced soil degradation in Africa (millions of hectares)

(Source: UNEP, 1992)

Type	Light	Moderate	Strong	Extreme	Total
Loss of topsoil	53.9	60.5	86.6	3.8	204.9
Terrain deformation	3.6	6.9	11.7	0.4	22.5
WATER	**57.5**	**67.4**	**98.3**	**4.2**	**227.4 (46 %)**
Loss of topsoil	79.1	84.2	7.4	-	170.7
Terrain deformation	9.2	5.1	-	-	14.3
Overblowing	-	-	0.5	1.0	1.5
WIND	**88.3**	**89.3**	**7.9**	**1.0**	**186.5 (38 %)**
Loss of nutrients	20.4	18.8	6.2	-	45.1
Salinization	4.7	7.7	2.4	-	14.8
Pollution	-	0.2	-	-	0.2
Acidification	1.1	0.3	+	-	1.5
CHEMICAL	**26.0**	**27.0**	**8.6**	**-**	**61.5 (12 %)**
Compaction	1.4	8.0	8.8	-	18.2
Waterlogging	0.4	0.1	-	-	0.5
Subsidence organic soils	-	-	-	-	-
PHYSICAL	**1.8**	**8.1**	**8.8**	**-**	**18.7 (4 %)**
TOTAL	**173.6 (35 %)**	**191.8 (38 %)**	**123. (25.0)**	**5.2 (1.0)**	**494.2 (100 %)**

FIGURE 18

Proportion of degraded area by type of impact in millions of hectares

(Source: UNEP (1992), World Atlas of Desertification)

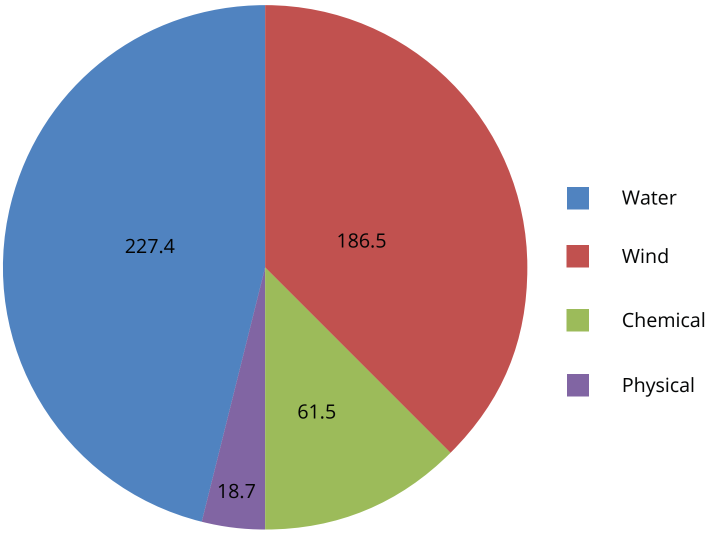
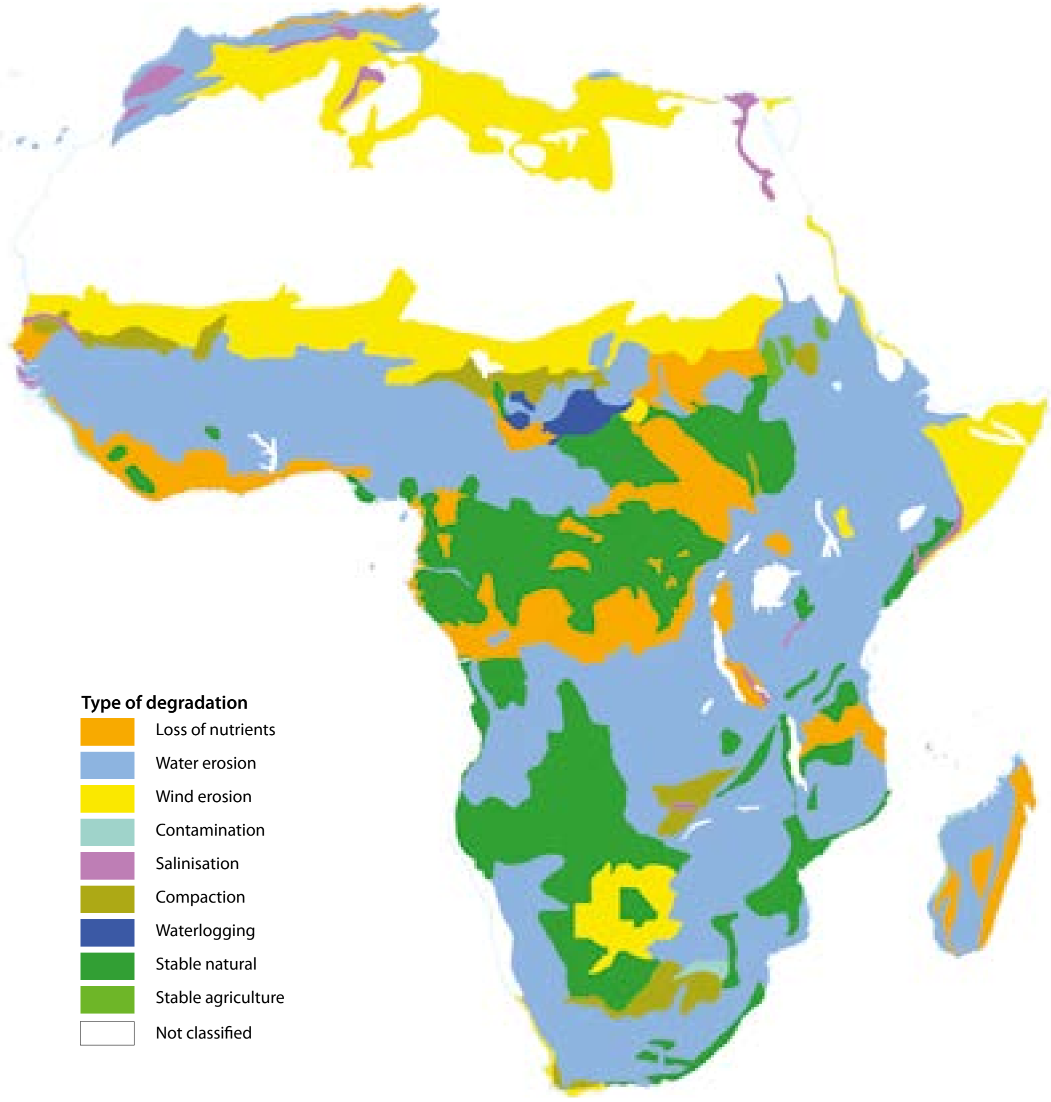


FIGURE 19

Land degradation by type

Source: UNEP, 1992)



the Mediterranean and parts of southern Africa are especially affected (Jones, et al., 2013). In these arid and semi-arid climates, winds can displace topsoil in a uniform pattern, especially where soils are coarse-textured, but wind erosion also unevenly displaces soil in other areas, leading to deflated hollows and dunes (UNEP 1992).

Chemical deterioration

About 12% of degraded land in Africa is the result of chemical deterioration *(Table 6)*. Chemical deterioration includes loss of nutrients and/or organic matter, salinization, acidification, and pollution. The loss of nutrients is the most important form of chemical degradation in Africa.

Nutrient loss refers to general fertility depletion when poor, or moderately poor soils are cultivated without the application of sufficient organic (manure) or agrochemical fertilizers, leading to

FIGURE 20

Areas affected by water erosion

(Source: UNEP, 1992)

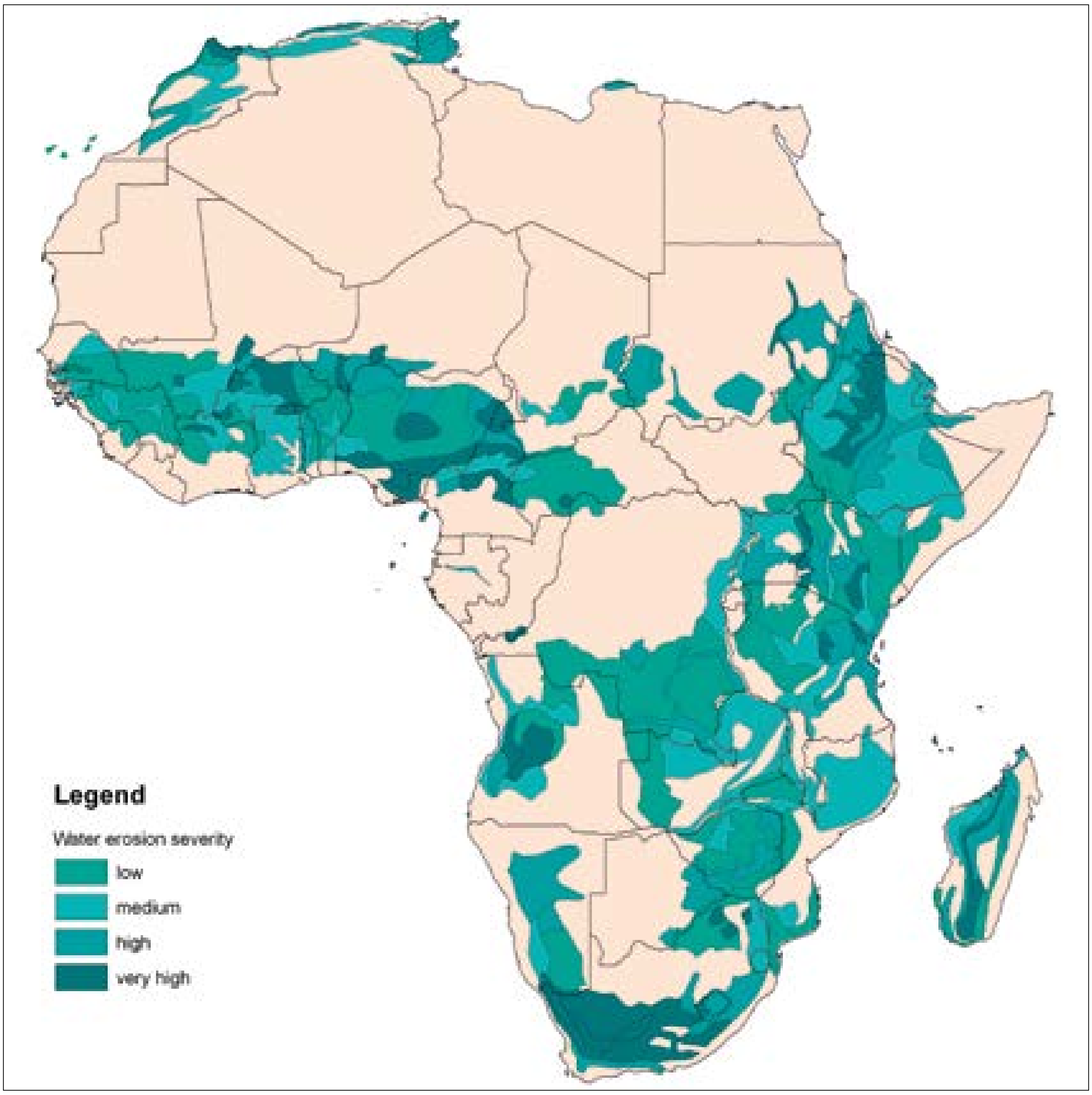


TABLE 4

Area and proportion of land degraded by water erosion

(Source: UNEP, 1992)

	Type	Light	Moderate	Strong	Extreme	Total
Water erosion	Loss of topsoil	53.9	60.5	86.6	3.8	204.9
	Terrain deformation	3.6	6.9	11.7	0.4	22.5
	TOTAL	**57.5**	**67.4**	**98.3**	**4.2**	**227.4 (46 %)**

FIGURE 21

Areas affected by wind erosion

(Source: UNEP, 1992)

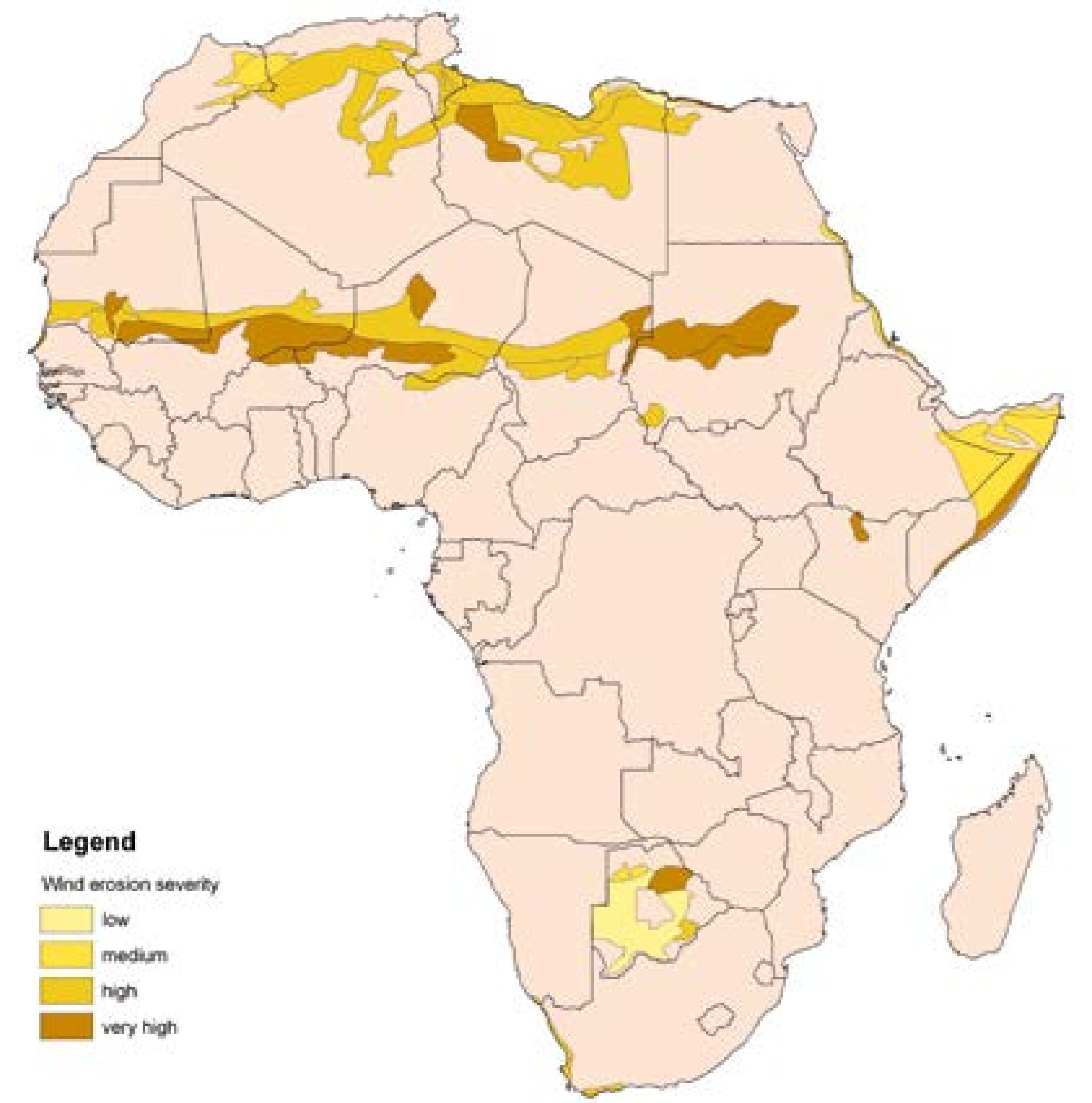


TABLE 5

Area and proportion of land degraded by wind erosion

(Source: UNEP, 1992)

	Type	Light	Moderate	Strong	Extreme	Total
Wind erosion	Loss of topsoil	79.1	84.2	7.4	-	170.7
	Terrain deformation	9.2	5.1	-	-	14.3
	Overblowing	–	–	0.5	1.0	1.5
	TOTAL	**88.3**	**89.3**	**7.9**	**1.0**	**186.5 (38 %)**

FIGURE 22

Areas affected by chemical deterioration

(Source: UNEP, 1992)

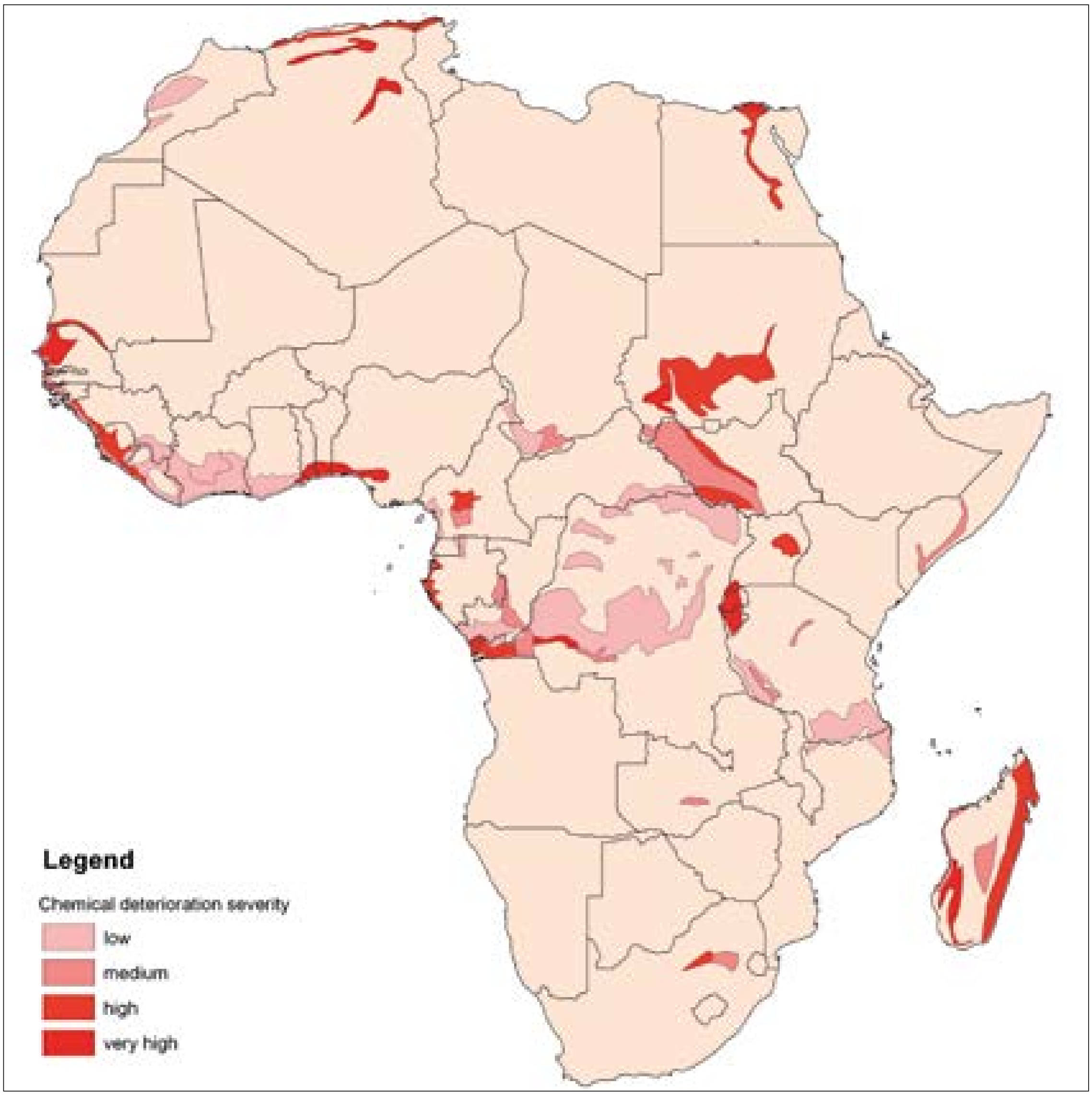


TABLE 6

Area and proportion of land degraded by chemical deterioration

(Source: UNEP, 1992)

	Type	Light	Moderate	Strong	Extreme	Total
Chemical deterioration	Loss of nutrients	20.4	18.8	6.2	–	45.1
	Salinization	4.7	7.7	2.4	–	14.8
	Pollution	–	0.2	–	–	0.2
	Acidification	1.1	0.3	+	–	1.5
	TOTAL	**26.0**	**27.0**	**8.6**	**–**	**61.5 (12 %)**

FIGURE 23

Areas affected by physical deterioration
(Source: UNEP, 1992)

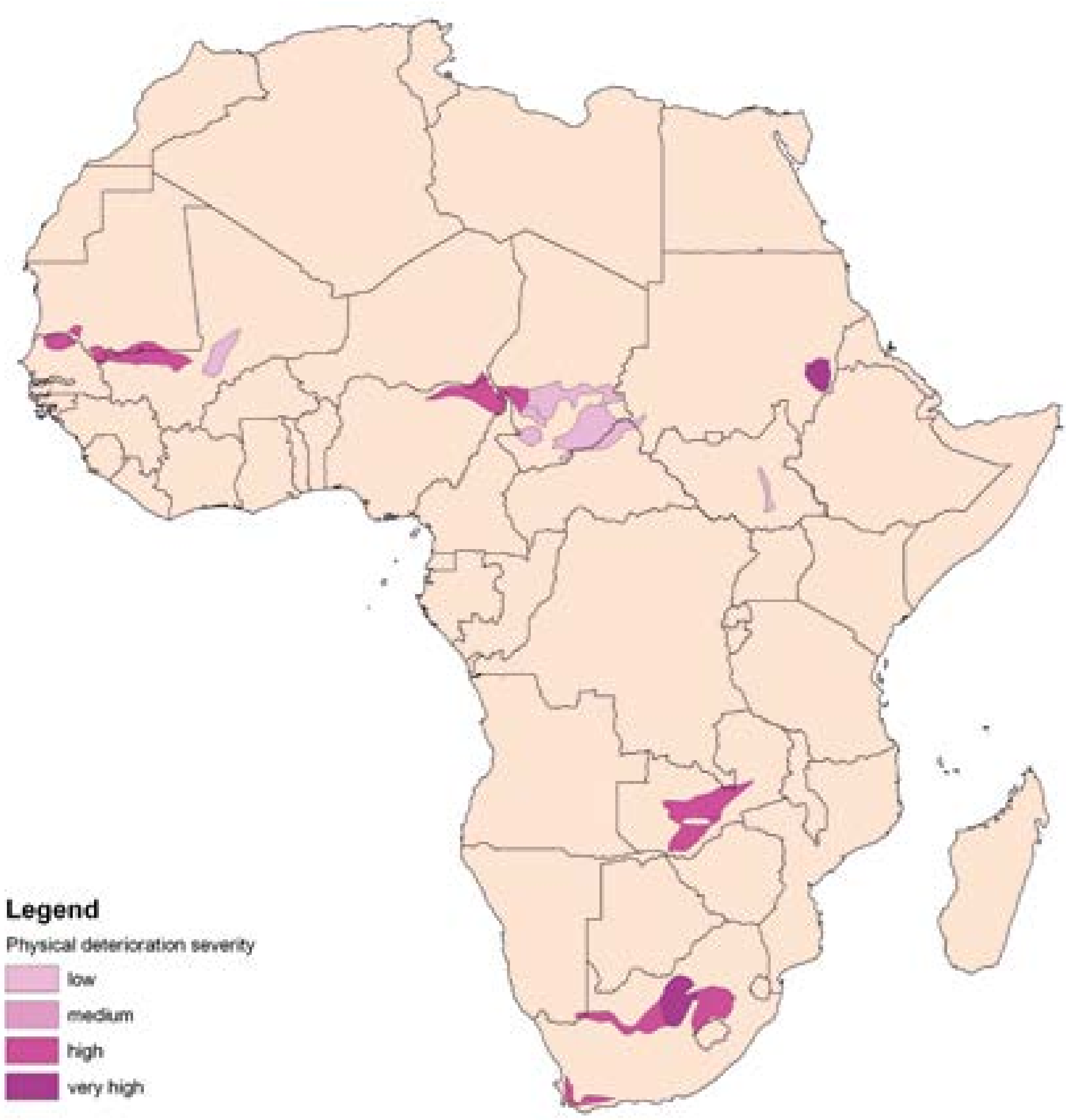


TABLE 7

Area and proportion of land degraded by physical deterioration
(Source: UNEP, 1992)

	Type	Light	Moderate	Strong	Extreme	Total
Physical deterioration	Compaction	1.4	8.0	8.8	–	18.2
	Waterlogging	0.4	0.1	–	–	0.5
	Subsidence organic soils	–	–	–	–	–
	TOTAL	**1.8**	**8.1**	**8.8**	**–**	**18.7 (4 %)**

declining productivity. It also refers to the loss of organic matter in the soil (Oldeman, et al., 1991). This loss of nutrients has led to stagnating or declining agricultural production in many African countries. In some regions like the East African highlands, for example, there is little chance of restoring fertility (Jones, et al., 2013).

Physical deterioration

Four percent of land degradation in Africa is caused by physical deterioration *(Table 7)*.

Physical deterioration of soils includes compaction, sealing and crusting, and waterlogging. Compaction is usually caused by the use of heavy machinery on soils with low structural stability, making tillage more costly, impeding or delaying the sprouting of seedlings, and decreasing water infiltration capacity. In turn, this causes higher surface run-off, which may lead to significant water erosion. *Figure 24* shows the regions in Africa most vulnerable to compaction. Waterlogging is usually caused by human intervention in natural drainage systems.

The FAO estimates that 18 million ha are compacted in Africa. Compaction is particularly evident across the Sahel, South Africa, and Zambia (Jones, et al., 2013).

1.3.6. Topsoil loss

Figure 25 shows sediment transport, field erosion rate, and accumulative soil loss for different regions in Africa. It is taken from Lal (1995), who used data from a 1984 publication on the rates of sediment yields of African rivers, which were converted to on-site erosion rates and then to the denudation rate. Lal summarizes the distribution of erosion as follows: "Estimated current erosion rates are in excess of 75 Mg/ha/year for a small proportion

BOX 3

Overgrazing, compaction and land degradation

"In Uganda, as a result of overgrazing in its drylands known as the "cattle corridor," soil compaction, erosion and the emergence of low-value grass species and vegetation have subdued the land's productive capacity, leading to desertification. In the Gambia, it is reported that fallow periods have been reduced to zero on most arable lands. Between 1950 and 2006, the Nigerian livestock population grew from 6 million to 66 million, a 11-fold increase. The forage needs of livestock exceed the carrying capacity of its grasslands. It is reported that overgrazing and over-cultivating are converting 351,000 hectares of land into desert each year. The rates of land degradation are particularly acute when such farming practices are extended into agriculture on marginal lands such as arid and semi rid lands, hilly and mountainous areas and wetlands" (ECA, 2007). "In West Africa, compaction is thought to cause production losses of between 40 and 90 %" (Eswaran, et al., 2001).

FIGURE 24

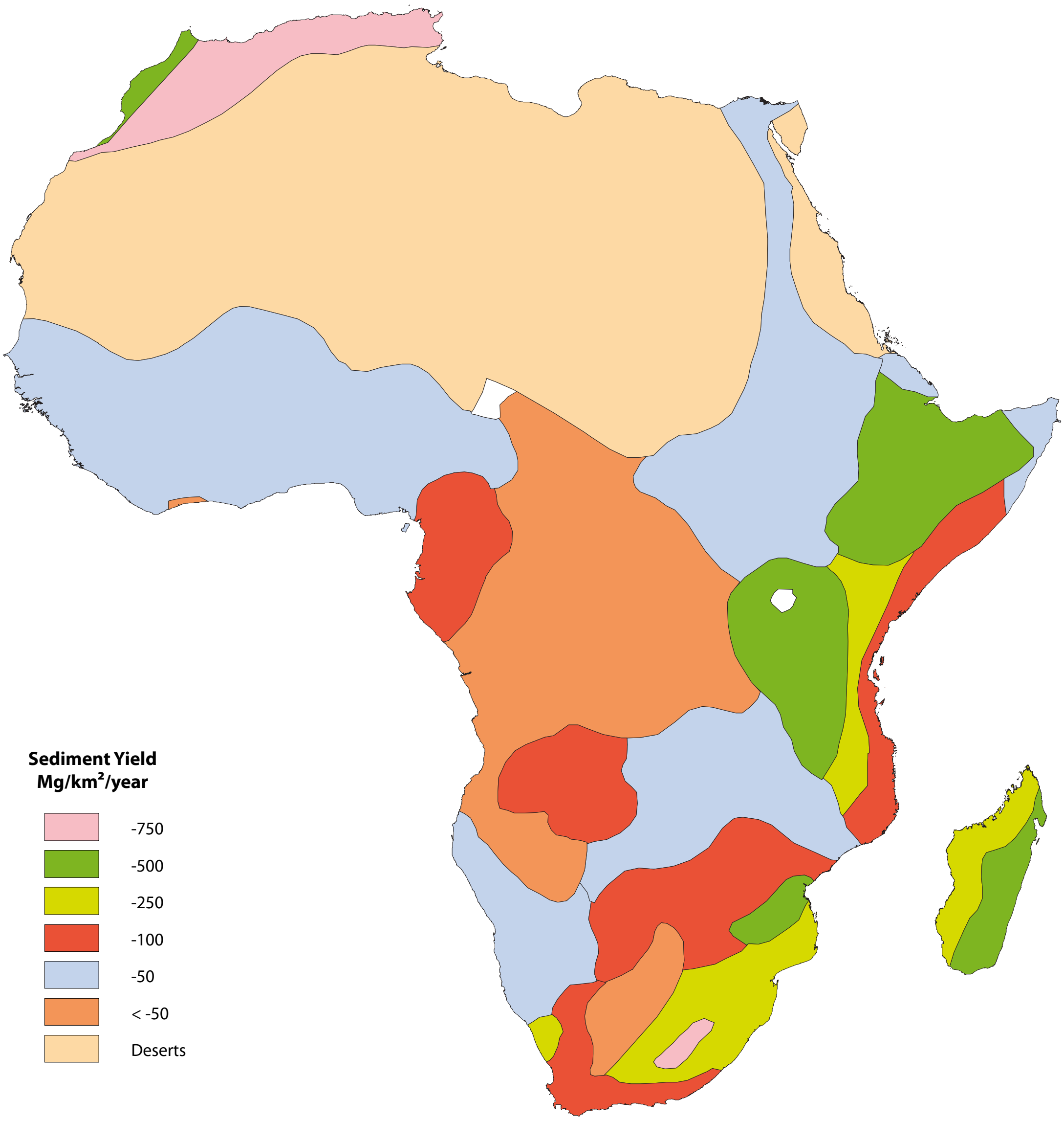
Extent of soils vulnerable to compaction

(Source: Oldeman, et al., 1991 cited in (Jones, et al., 2013))

FIGURE 25

Sediment transport, field erosion rate, and accumulative soil loss for different regions in Africa

(Source: Lal, 1995 (modified from Walling et al., 1984))



of the Maghreb region in the northwestern parts of Africa; 50 to 75 MG/ha/year for east African highlands, eastern Madagascar and parts of southern Africa; 25 to 50 Mg/ha parts of northwest and southern Africa; 10 to 25 Mg/ha for coastal regions of eastern Africa, eastern Congo basin, and some parts of southern Africa; and <10 Mg/ha for most of the West African Sahel and eastern and southern Africa" (Lal, 1995).

1.3.7. Literature review on approaches to value land degradation

Crop productivity-soil erosion relationships

Soil productivity is defined as "the capacity of a soil to produce a certain yield of crops or other plants under a defined set of management practices" (Obalum, et al., 2012) or a specific farming system (Jones, et al., 2013).

FIGURE 26

On-site effects of soil erosion on productivity decline

(Source: Lal, et al., 2004, p. 26)

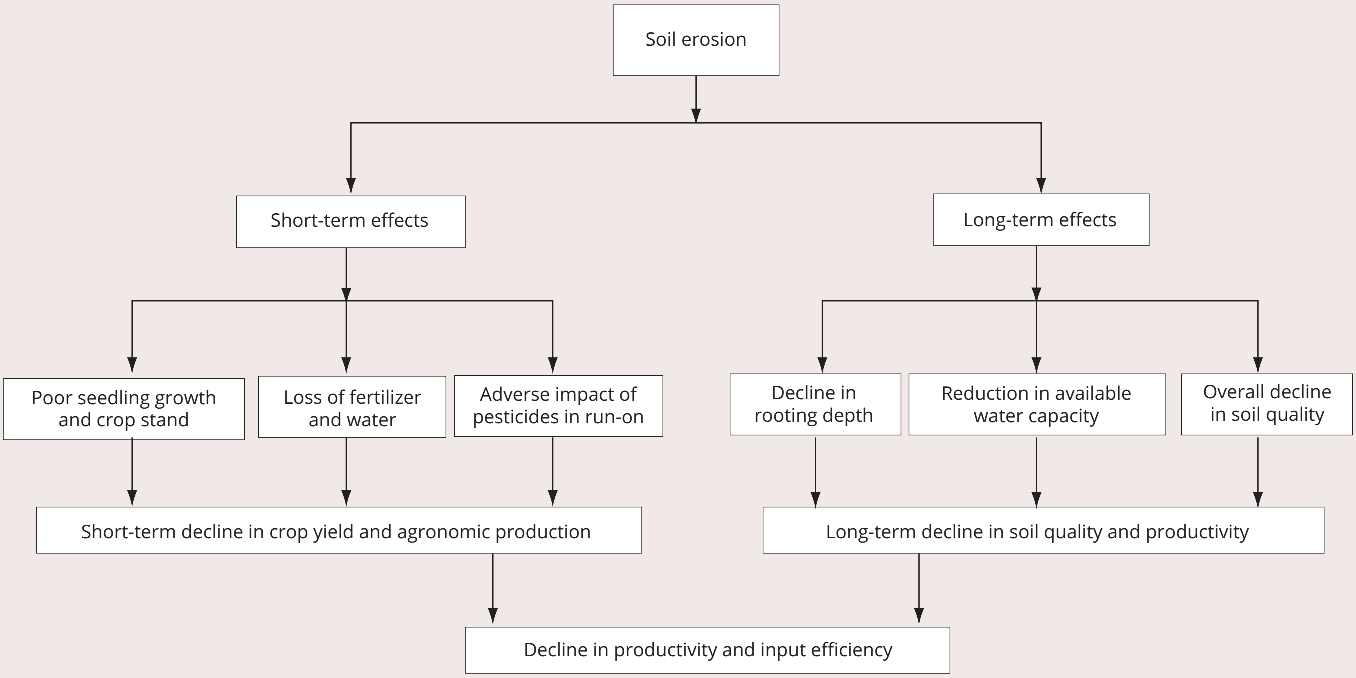
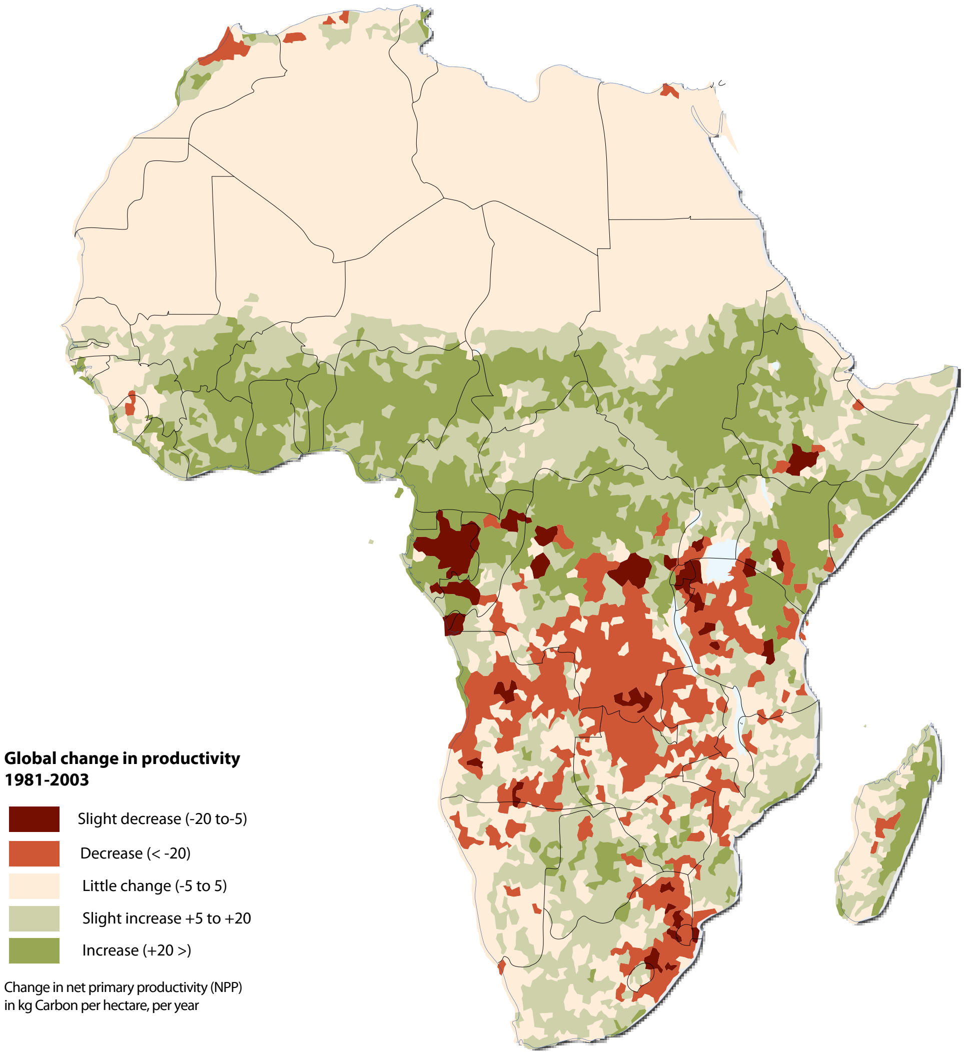


FIGURE 27

Trends in productivity due to land degradation, 1981–2003 (greening and land degradation)
(Source: Nellemann, et al., 2009 after (Bai, et al., 2008))



Soil erosion is a major cause of short and long-term soil degradation, which in turn affects on-site soil productivity (Nill, et al., 1996) and the quality of ecosystem services off-site, particularly in drylands, where it can leave the soil exposed and vulnerable to climatic hazards such as drought (UNCCD, 2013).

On site, the impacts of soil erosion on productivity are the result of poor germination and reduced rooting depth, drought stress due to water runoff, and soil infertility because of the loss of soil nutrients in the water and organic matter in sediment runoff (Lal, et al., 2004; Obalum, et al., 2012) *(Figure 26)*.

Continental-scale studies of soil erosion and productivity in Africa

Figure 27 illustrates estimated changes in productivity due to land degradation from 1981 to 2003, showing the areas with the most severe declines in red. It was produced for the FAO Land Degradation Assessment in Drylands (LADA) program using remote sensing to identify areas where significant biological change is occurring, including hot spots of land degradation and bright spots of land improvement (Bai, et al., 2008).

TABLE 8

Erosion-induced yield losses of different crops at continental and sub-Saharan scales
(Sources: Lal, et al., 2004)

Area	Soil order	Erosion rate (Mg/ha/year)	Water erosion	Wind erosion	Yield reduction due to erosion	Future losses	Yield loss by crop			Total reductions in productivity (millions Mg, 1989)		
							Maize	Barley	Millet	Cereals	Roots and tubers	Pulses
Africa					8.2 %[1]	16.5 % (by 2020)[1]	72 (kg/ha/M)[2]	2 (kg/ha/M)[2]	54 (kg/ha/M)[2]			
	Alfisols	14.10[4]					0.04 % Mg-1[4]					
	Andisols	13.77[4]					0.03 % Mg-1[5]					
	Aridisols	17.17[4]					0.03 % Mg-1[5]					
	Entisols	2.46[4]					0.03 % Mg-1[5]					
	Histosols	12.52[4]					0.03 % Mg-1[5]					
	Inceptisols	18.75[4]					0.01 % Mg-1[5]					
	Mollisols	16.58[4]					0.03 % Mg-1[5]					
	Oxisols	12.21[4]					0.01 % Mg-1[4]					
	Spodosols	n/a										
	Ultisols	11.97[4]					0.05 % Mg-1[4]					
	Vertisols	18.62[4]					0.03 % Mg-1[5]					
Sub-Sahara			50 tons/ha[3]	58–80 tons/ha (West African Sahel)[3]	6.2 %[1]	14.5 % (by 2020)[1]				3.6[1]	6.5[1]	0.36[1]
			46 % of total land[4]	38 % of total land [4]								

1: *(Lal, 1995)*
2: *(Lal, et al., 2004)*
3: *(Obalum, et al., 2012)*
4: *(Kirui & Mirzabaev, 2014)*
5: *(den Biggelaar, et al., 2004, p. 71)*

There have been several attempts to estimate crop production losses due to erosion in Africa, but as already mentioned earlier on in this report, the weak cause-and-effect relationship between erosion and productivity is a shortcoming that makes this method of assessment unreliable. Lal et al. (2004) cite research by den Biggelaar et al. (2001), who "extrapolated plot scale data from around the world to the national, regional and global scales to estimate the potential effect of erosion on crop yields in the absence of changes in farmers' management practices". Extending the same technique to the continental scale, Lal et al. (2004) estimated the value of annual production losses by soil erosion for maize, barley and millet crops, with the results for Africa shown in *Table 8*.

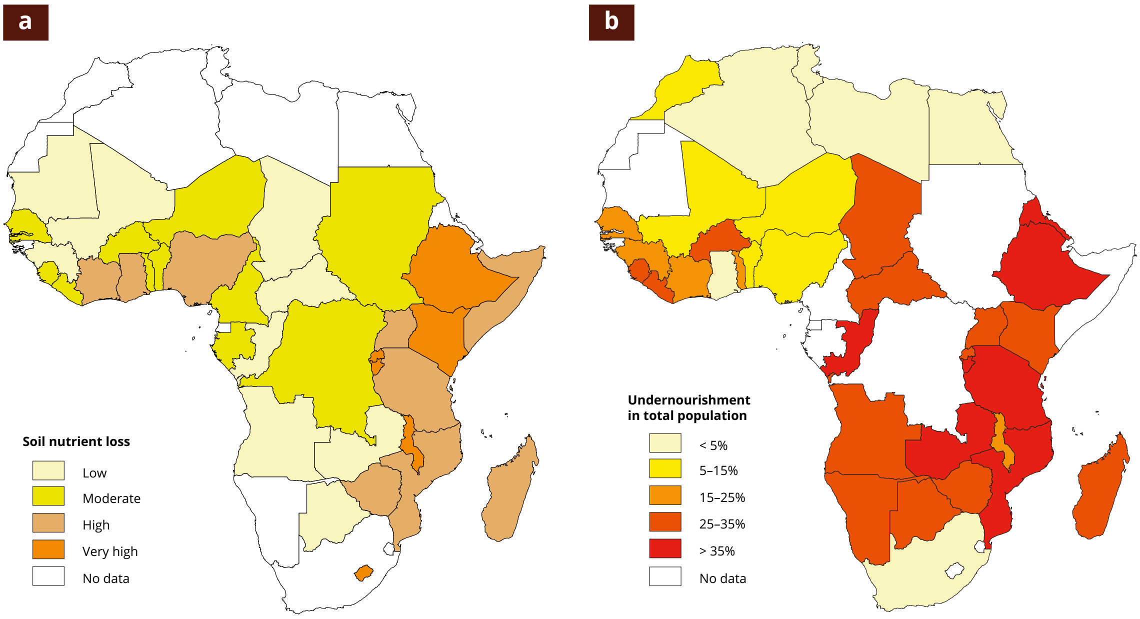
Lal's analyses of 1995, based on data available for a few sites at that time, indicated that yield reductions due to past erosion may range from 2 to 40%, with a mean of 8.2% for the continent and 6.2% for sub-Saharan Africa (Lal, 1995). Estimates from den Biggelaar, et al. (2004), also cited in Kirui and Mirzabaev (2014), reveal that about 200,000 Mg/year of maize production is lost due to soil erosion in Africa, with about two-thirds of the losses occurring on Alfisols and about 14.5% on Ultisols (den Biggelaar, et al., 2004).

A review by Eswaran, Lal and Reich (2001) reports that plot and field-scale studies in some parts of West Africa where shallow soils restrict roots, show that erosion can cause yield reductions of 30 to 90%. They also note research that estimates nutrient depletion for 38 countries in sub-Saharan Africa, with results suggesting annual depletion rates of soil fertility of 22 kg N, 3 kg P, and 15 kg K/ha (Eswaran, et al., 2001). *Table 31* in the Appendices shows country-level erosion and productivity data gleaned from the literature.

Another way to attempt to assess the impact of land degradation on productivity is to note the correlation between loss of soil fertility and levels of hunger and malnutrition. The Soil Atlas of Africa produced a map that shows the close links between the loss of soil productivity and levels of hunger and malnutrition *(Figure 28)*. It states that declining soil fertility in Africa is causing decreases in crop yields and per capita food production, noting that the population is growing at 3% a year, but the

FIGURE 28

Correlation between lost soil productivity and hunger and malnutrition
(Source: Jones, et al. 2013)



number of malnourished people has risen from some 88 million in 1970 to over 240 million in 2010 (Jones, et al., 2013).

Map (*Figure 28a*) shows the estimated nutrient loss from soil for Sub-Saharan Africa in the period 1983–2000. Densely populated and hilly countries in the Rift Valley area show the highest losses owing to high levels of arable land, relatively high crop yields and significant erosion levels. For the area as a whole, the nutrient losses have been calculated as -22 kg/ha in 1983 and -26 kg/ha in 2000 for N; -2.5 kg/ha in 1983 and -3.0 in 2000 for P; and -15 kg/ha in 1983 and -19 kg/ha in 2000 for K. While such data are difficult to measure, more recent studies show no change in this trend (Roy at al., 2003)

CHAPTER

02

Methodological approaches to the economic valuation of land degradation

2.1. Introduction

Land degradation is one of the world's greatest environmental challenges (Pender, 2009). According to the United Nations Convention to Combat Desertification (UNCCD), **land degradation** refers to a reduction or loss of the biologic or economic productivity and complexity of rain-fed as well as irrigated cropland, or range, pasture, forest, and woodland. It is the temporary or permanent reduction of the productive capacity of the land, or of its potential to produce benefits from a particular land use under a specified form of land management (Lal, 1994; Pieri, 1995; Enters, 1998). Processes exacerbating land degradation include soil erosion by water and wind, **soil degradation** that encompasses the deterioration in the physical, biological or economic properties of soils, and the loss of natural vegetation through deforestation (Pagiola 1999). Soil erosion, soil nutrient depletion, soil pollution, salinization, and decline in soil structure are some of the processes contributing to soil degradation. **Nutrient depletion** refers to the net loss of plant nutrients from the soil or production system due to a negative balance between nutrient inputs and outputs. Major channels of nutrient depletion are nutrient removal through soil erosion, harvest, leaching, and denitrification (Lal, 1994; Pieri, 1995; Enters, 1998). Over the past 40 years, erosion has removed nearly one-third of the world's arable land from production (Fischer, et al., 2011). Additionally, desertification, which as defined by the UNCCD refers to land degradation in arid, semiarid and dry sub-humid areas, threatens over 41% of the Earth's land area (MEA, 2005; Solh, 2009).

Reviews of global land degradation affirm that Africa is particularly vulnerable to soil erosion and no doubt, the most severely affected region (Lal, R, 1995; Nellemann, et al., 2009; Obalum, et al., 2012). The UNCCD estimates that up to two- third of the productive land area in Africa is affected by land degradation (UNCCD, 2013). UNEP estimated that up to 25% of the global food production may be lost during the 21st century because of the combined effect of land degradation, climate change, water scarcity, and invasive pests (UNEP, 2009). Concerns of increasing food insecurity are the highest for sub-Saharan Africa where per capita food production has been declining by at least 3% per year since 1990 (Alexandratos & Bruinsma, 2012; McKenzie & Williams, 2015). Yield decline in the continent due to past soil erosion may range from 2 to 40% (Eswaran, et al., 2001). A study in 2004, estimated the value of annual production losses from declines in agronomic productivity in Africa due to water-induced soil erosion at USD 15 million (Lal, R; den Biggelaar, C.; Wiebe, K.D., 2004). In Sub Saharan Africa, soil nutrient depletion accounts for about 7% of the sub-continental Agricultural GDP or close to USD 3.9 billion (Drechsel & Gyiele, 1999) and there was substantial variation by country. For example, annual loss was estimated at about 3% of GDP (or USD 106 million) in Ethiopia (Bojö & Cassells, 1995; Yesuf et al, 2008) but 9.5–11% of Agricultural GDP (or USD 84 to 99 million) in Malawi (Drechsel & Gyiele, 1999). Nkonya et al. (2013) noted the lack of consensus on the magnitude and severity of land degradation plus its effects in the Eastern Africa region or in sub-Saharan Africa (SSA) all together. However, in Eastern Africa the resource loss due to land degradation is believed to be huge (Kirui and Mirzabaev, 2014). This indicates that the validly, accuracy and comparability of current estimates of land degradation is in doubt. This is partly because most estimates are at least a decade old and may no longer be accurate. Large variation in estimates themselves makes it difficult to identify the scope of the problem. Furthermore, results of studies are not comparable due to differences in methodology. Some estimates calculate GDP loss from erosion in agriculture alone; others examine GDP loss from other forms of degradation. Hardly any studies review continental scale costs of inaction, the costs of action, and the benefits of taking action against nutrient depletion induced by economic and biophysical factors in a way to allow cost benefit analysis of alternative land management practices that tackle soil erosion.

Such a methodological approach could allow the scenario analysis of losses of target ecosystem services due to changes in the economic and biophysical factors. Moreover, the approach could help to make a cost benefit analysis and identify the present values of future costs of inaction, the costs of action, and the net benefits of action against soil nutrient depletion induced by a specific factor. The result of such a study will inform decision makers on the most important economic and biophysical factors that can be prioritized as development goals and that need to be addressed through cost effective investments. Thus, this chapter aims to develop an econometric modeling approach in which the costs of inaction, the costs of action, and the benefits of action against soil nutrient depletion can be estimated, by relating nutrient depletion with specific national level biophysical and economic indicators.

The biophysical indicators related with nutrient depletion include national rates of soil erosion, forest cover, and historical rates of nutrient depletion. Economic indicators include poverty rate, per capita income, manufacturing sector GDP, and livestock population. The study focuses on nutrient depletion in agricultural lands cultivated with cereals and both the focus and methodological approach used were following the availability of data for the period 1993 to 2012. Specifically, the focus of the study is on soil nutrient depletion from about 105 million hectares of cereal cropland in 42 African countries, which accounts for about 45 % of the total 230.42 million hectares of arable land of the continent. Besides data availability, cereals are the major food sources in the continent. According to data from FAOSTAT, cereals account about 30 % of the 467 million tons of total food supply or in terms of calories of food close to 50 % of the 2596 kcal per capita daily food supply in the continent for the period 2010–12. Moreover, assessing the effect of soil nutrient depletion on cereal crop production in the region is very important considering the very high concern of increasing food insecurity, particularly in the SSA where per capita food production has been declining by at least 3 % per year since 1990 (Alexandratos and Bruinsma, 2012; McKenzie and Williams, 2015).

Based on national level data from FAO, World Bank, WOCAT, and literature for 42 African countries we developed continental scale econometric models of soil nutrient depletion and cereal crop production. Based on the model results, we selected two of the significant drivers of nutrient depletion from the socioeconomic (Poverty gap, GDP per capita, manufacturing sector GDP, Livestock population) and biophysical (Rate of soil erosion, forest cover, historical rate of nutrient depletion) factors used in the modeling.

The models were then used to estimate production losses per year due to erosion and poverty for 2010–12 based on national level nutrients (Nitrogen, Phosphorous, and Potassium) and cereal crops (Barley, Buckwheat, Canary seed, Fonio, Maize, Millet, Oats, Rice, Rye, Sorghum, Triticale, and Wheat). The annual national level estimates of nutrient losses were valued using the replacement cost method, whereas the crop losses due to nutrient depletion were valued using the producers prices of the crops, which in effect imply that the dose response or production function method of valuation has been used to value the costs of inaction against nutrient depletion. The average of the estimates for 2010–12 was used as a base annual estimate in the cost benefit analysis, in which the national and continental levels present values of future costs of inaction, costs of action, benefits of action, and net present values (NPVs) of action against erosion and poverty induced land degradation were determined for the time horizon of 2016–2030. Sensitivity analysis was conducted to see the impact of changes in discount rates, prices of cereals, costs of action, and effectiveness of erosion control measures on the NPVs of action against erosion induced nutrient depletion.

The remaining parts of the chapter are organized as follows: the second part provides an overview on the concept of total economic value and valuation methods. The materials and methods part describes the data and conceptual framework used for guiding the analysis, the econometric modeling approaches, and estimation procedures. Part four of the chapter presents and discusses results of the empirical models.

2.2. Total economic value and valuation methods

Economic valuation of land degradation has been recognized as an important tool that can help decision makers to evaluate the trade-offs between the social welfare losses of inaction and the net welfare gains of alternative actions against land degradation. The concepts of total economic value and ecosystem services are important frameworks in the broader context of environmental valuation and the valuation of land degradation at different spatial scales.

Economists define the Total Economic Value of environmental resources as the sum of two main sources of value that human beings derive from the environment, namely the 'use values' and 'non-use values' (Perman & al., 2011; Pearce, 1993). The use values are further classified into direct use values (DUV) and indirect use values (IUV).

1. **Direct use values:** are the goods and services that directly accrue to the consumers. Consumers may or may not pay market-clearing prices for these goods and services and therefore some are marketed benefits and others may be non-marketed ones.

2. **Indirect use values:** are special functions of environmental resources that accrue indirectly to either users or non-users. Examples include the services that forest ecosystems provide in regulating climate, carbon fixing and ameliorating weather events, watershed functions like soil conservation, improved water supply and water quality, flood and storm protection, fisheries protection, and local amenity services.

3. **Option value:** Weisbrod (1964) first introduced the idea of option value, which refers to the potential future benefits of all use values. It can be viewed as an insurance premium that one would be willing to pay to ensure the supply of the direct and indirect use values of a resource later in time.

4. **Non-Use values:** These values refer to the elements of value that are unrelated to current, future or potential uses (Krutilla, 1967) of an environmental resource. It measures the value or satisfaction that people get from the knowledge of the existence of environmental assets per se (existence *value*), for the pleasure of others (altruistic *value*) or for future generations (bequest *value*) (Plottu & Plottu, 2007).

The typology of ecosystem services introduced by the Millennium Ecosystem Assessment provides a conceptual structure to identify almost a complete list of all the services that land and land based natural resources provide to society such as provisioning, regulating, cultural, and supporting ecosystem services (MEA, 2005; Noel & Soussan, 2010; Nkonya, et al., 2011). Land provides society with **provisioning services** as direct use values, which for example include food, water, fiber, timber, fuel, minerals, building materials and shelter, and biodiversity and genetic resources for producing medicine. Education, research, aesthetic, and spiritual values that land and its natural resource provide to society are **cultural ecosystem services** which can fall in the categories of direct use value, indirect use values as well as existence value of the total economic value framework. Soils are almost supporting units of all life forms and land provides the soil formation and nutrient cycling as **supporting ecosystem services**, which can be considered as elements of the indirect use values, option values as well as non-use values. Forest resources as land-based ecosystem provide carbon sequestration and stock services as a **regulating service**, which are part of the indirect use value (MEA, 2005).

In the valuation literature, the different components of the TEV of land can be valued using a variety of valuation methods, which can be classified as non-market demand and market demand based economic valuation methods. **Non-market demand approaches** are designed to observe physical changes in the environment to estimate what differences they will make to goods and services, and then to estimate the market value of these changes. Non-market demand approaches include:

1. **Dose-response and/or production function:** it first requires assessing the relationship between environmental quality variables (example: soil nutrient levels) and the output level of a marketed commodity (say crop output) and then the valuation of the loss or improvement in environmental quality is made in terms of the loss or gain in the commodity

with a market price (Garrod & Willis, 1999). This approach requires availability of scientific knowledge on the cause effect relationships between for example supporting ecosystem service and an economic activity that it supports (Barbier & al, 2009).

2. **Preventive expenditure or aversive behavior approach:** the value of the environment is inferred from what people are prepared to spend on preventing its degradation (Garrod & Willis, 1999). The value of an ecosystem service (say a forest near urban areas for example providing air purification service through absorbing dust particles and pollutants) can be inferred from the expenditure on technologies required to reduce the pollutants.

3. **The replacement cost approach:** it values an ecosystem service in terms of the cost required to restore the ecosystem service to its original state after it has been damaged. For example, nutrient depletion due to soil erosion can be valued in terms of the cost of commercial fertilizer required to replenish the depleted nutrient to its original state.

4. **Opportunity cost approach:** this approach values the benefits of an ecosystem service (for example the benefits of assigning a forest area for nature conservation) in terms of the next best alternative forgone to achieve it. For example a forest area assigned for nature conservation could have been used for agricultural crop production as second best alternative. Thus, the opportunity cost of conserving the forest is the forgone net income from crop production.

Market demand based methods include the revealed and stated preference methods. In the revealed preference method, the value of an ecosystem service is measured in terms of the market price for that particular service in the market, or indirectly by examining the purchase of a related service (complementary or substitute service) in the private market place (Garrod & Willis, 1999).

1. **Direct market price:** this involves the valuation of an ecosystem service using its market price. For some of the direct use value elements of forests like timber, fuel wood, and resins there are markets and the prices of these goods can be used directly to value them.

2. **Hedonic pricing:** this is based on the consumer theory that every good provides a bundle of characteristics or attributes (Lancaster, 1966). The value of a real estate near a degraded landscape with a possible risk of flooding, will be different from another real estate with similar conditions but which has a forest nearby. The forest as a public good provides different amenities to the nearby real estate. Therefore, the difference in prices of the two real estates can be attributed to the services that the forest provides.

3. **Travel cost method:** this method helps estimate the demand or marginal valuation curve for recreation sites. These cultural ecosystem services can be inferred from observing how the number of visits to the sites varies according to the prices of private goods (like transport costs) with the travel distance.

The stated (expressed) preference approach involves valuing an ecosystem service by estimating peoples' expressed or stated preference for the service relative to their demand for other ecosystem services. This approach does not require finding a complementary good or service, or a substitute good, to derive the demand curve and hence estimate how much an individual implicitly values the ecosystem service. The stated preference technique asks people explicitly how much they value an ecosystem service. The two basic types of this approach are:

1. **Contingent valuation:** this method first describes the ecosystem service to be valued and then asks how much respondents are willing to pay for the specified service. The conventional contingent valuation method values an ecosystem service in its entirety and nothing is revealed about the values of the different attributes of the service.

2. **Choice experiments:** in choice experiment valuation, the characteristics of the ecosystem service are explicitly defined; they vary over choice cards along with a monetary metric. Then, individuals have to choose different combinations of characteristics of the

ecosystem service over other combinations at various prices.

In the valuation of ecosystem services, it is important to distinguish between values of the asset or stock values and products or flow values; this helps to avoid double counting. A stock is a quantity existing at a point in time and a flow is a quantity per period. Stocks, flows, and their relationship are crucial to the operation of both natural and economic systems (Common & Stagl, 2007).

2.3. Materials and methods

2.3.1. Data and the conceptual framework

The study covers 42 African countries[2], which are selected based on availability of data. *Figure 29* shows the conceptual framework used as a guiding framework of analysis in conducting the study. Land degradation, particularly in the form of decline in soil fertility is one of the most serious challenges threatening agricultural production, food security, and livelihood in Africa. Soil nutrient balance is a common indicator used to assess changes in soil fertility of agricultural ecosystems (Bindraban et al., 2000; Roy et al., 2003; Lesschen et al., 2007).

According to the seminal works of Follett, Gupta and Hunt (1987) and Miller and Larson (1992), soil nutrient balance in agricultural ecosystem at national or regional scales is specified as the difference between the amounts of nutrients in the soil (inflows) and the amounts of nutrients removed from the soil (outflows). The inflows constitute the addition of nutrients to the soil through mineral fertilizer, organic fertilizer (manure), atmospheric deposition, nitrogen fixation, and sedimentation. The outflows include removal of nutrients through crop products, crop residues, leaching, gaseous losses, and erosion.

A negative nutrient balance implies nutrient depletion and occurs when the sum of inflows is less than the sum of outflows. Stoorvogel and Smaling (1990) estimated national level balances of Nitrogen (N), Phosphorous (P_2O_5), and Potassium (K_2O) nutrients for 38 Sub-Saharan (SSA) countries for 1983 and year 2000 and their results showed that soil fertility was declining on the African continent. Furthermore, Henao and Baanante (1999, 2006) applied the nutrient balance approach and reported negative annual average NPK balances for 49 African countries for the cropping seasons of 1993–1995 and 2002–2004 respectively.

Results of national scale studies of nutrient balances for agricultural ecosystems are reported in kg/ha/year. Lesschen et al. (2007) argue that these results do not provide direct entry point for intervention and are not very meaningful for policy makers. They suggest that there is a need to link these results with other applications and data to optimize their use. Econometric modeling approaches can be used to assess the relationship between national level estimates of nutrient balances with policy relevant economic (for example poverty) and biophysical factors (forest cover) as well as the link between nutrient loss and national level crop yield. Such a study is important for valuation of the net benefits of action against nutrient depletion. It also helps in designing optimal policy interventions that can address

BOX 4

Assumptions and caveats

1. Land degradation influences society through its on-site and off-site impacts. We have considered only the on-site impacts.
2. Amongst the on-site impacts, the flow of various ecosystem services gets impaired. Due to unavailability of data at the appropriate scale for all countries of Africa, we have focused on nutrient loss only.
3. Land degradation in cereal croplands has been approximated with the loss of N, P, and K nutrients.
4. Change in productivity due to change in nutrients resulting from soil erosion has been captured.
5. Water borne soil erosion remains the dominant form of land degradation.
6. Data used in the analysis do not explicitly capture and explain spatial variability within a country.
7. In conclusion, this estimate is very conservative and would fall in the lower bound.

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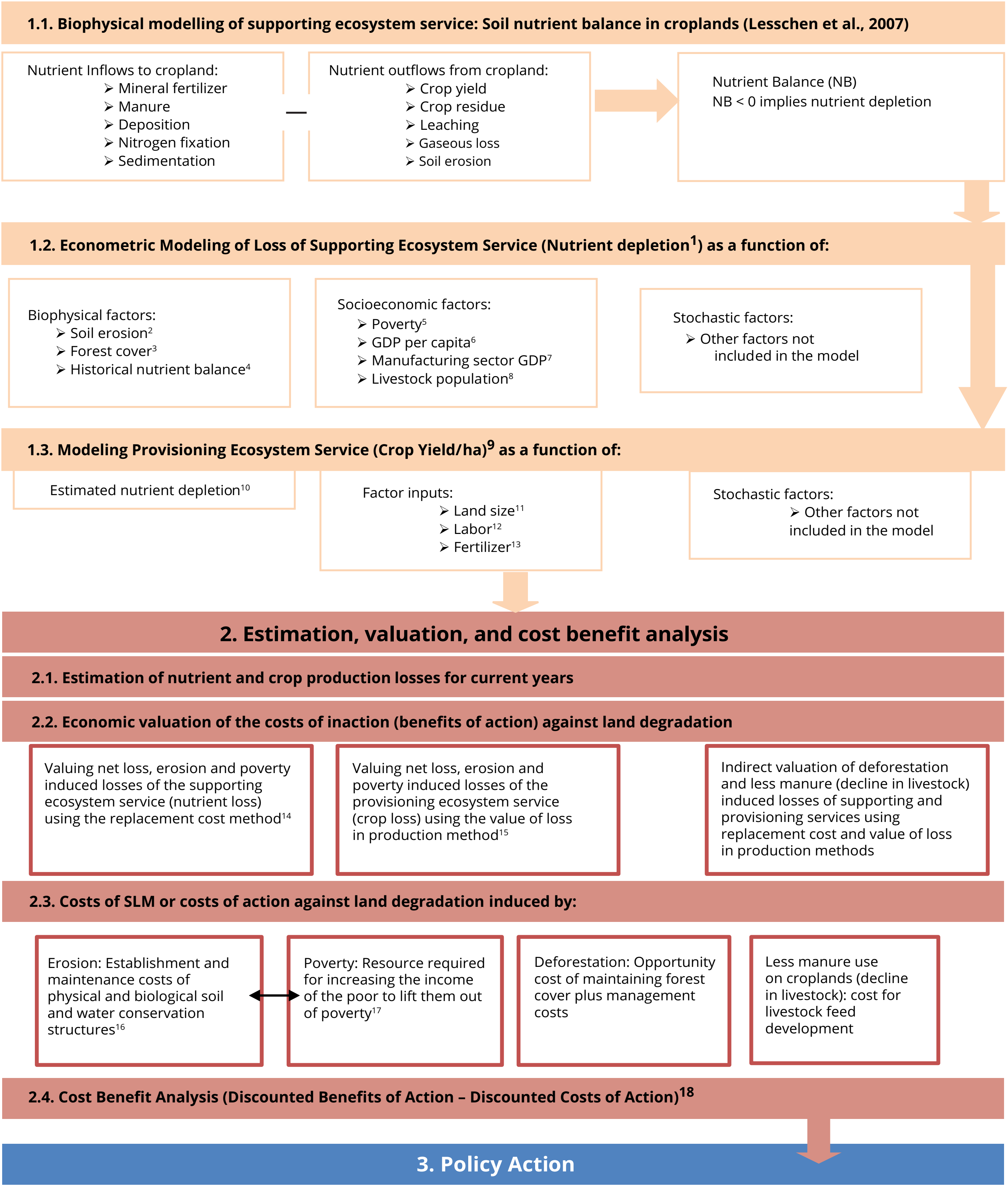
[2] *Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Côte D'Ivoire, Djibouti, DR Congo, Egypt, Eritrea, Ethiopia, Gabon, Ghana, Guinea, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Swaziland, Togo, Tunisia, Uganda, UR of Tanzania, Zambia, Zimbabwe.*

FIGURE 29

Conceptual framework of analysis

(See Appendix 2a for the data sources related to notes 1 to 18)



1.1. Biophysical modelling of supporting ecosystem service: Soil nutrient balance in croplands (Lesschen et al., 2007)

Nutrient Inflows to cropland:
- Mineral fertilizer
- Manure
- Deposition
- Nitrogen fixation
- Sedimentation

—

Nutrient outflows from cropland:
- Crop yield
- Crop residue
- Leaching
- Gaseous loss
- Soil erosion

Nutrient Balance (NB)
NB < 0 implies nutrient depletion

1.2. Econometric Modeling of Loss of Supporting Ecosystem Service (Nutrient depletion[1]) as a function of:

Biophysical factors:
- Soil erosion[2]
- Forest cover[3]
- Historical nutrient balance[4]

Socioeconomic factors:
- Poverty[5]
- GDP per capita[6]
- Manufacturing sector GDP[7]
- Livestock population[8]

Stochastic factors:
- Other factors not included in the model

1.3. Modeling Provisioning Ecosystem Service (Crop Yield/ha)[9] as a function of:

Estimated nutrient depletion[10]

Factor inputs:
- Land size[11]
- Labor[12]
- Fertilizer[13]

Stochastic factors:
- Other factors not included in the model

2. Estimation, valuation, and cost benefit analysis

2.1. Estimation of nutrient and crop production losses for current years

2.2. Economic valuation of the costs of inaction (benefits of action) against land degradation

Valuing net loss, erosion and poverty induced losses of the supporting ecosystem service (nutrient loss) using the replacement cost method[14]

Valuing net loss, erosion and poverty induced losses of the provisioning ecosystem service (crop loss) using the value of loss in production method[15]

Indirect valuation of deforestation and less manure (decline in livestock) induced losses of supporting and provisioning services using replacement cost and value of loss in production methods

2.3. Costs of SLM or costs of action against land degradation induced by:

Erosion: Establishment and maintenance costs of physical and biological soil and water conservation structures[16]

Poverty: Resource required for increasing the income of the poor to lift them out of poverty[17]

Deforestation: Opportunity cost of maintaining forest cover plus management costs

Less manure use on croplands (decline in livestock): cost for livestock feed development

2.4. Cost Benefit Analysis (Discounted Benefits of Action – Discounted Costs of Action)[18]

3. Policy Action

both land degradation and economic problems of a nation.

2.3.2. The empirical models

Modeling soil nutrient depletion: degradation of a supporting ecosystem service

Based on literature on the causes of land degradation (Lal & Stewart, 2013; Nkonya et al., 2013; Pingali et al., 2014) and the empirical results of nutrient budgeting in Africa (Stoorvogel et al., 1993; Henao and Baanante. 199, 2006) an econometric model of soil nutrient loss for agricultural ecosystems in Africa can be specified as:

$$NPK_{it} = \alpha_0 + \alpha_1 X_{1it} + \alpha_2 NPK_{it-n} + \alpha_3 X_{2it} + u_{it} \qquad (1)$$

Where:

NPK_{it} represents the average nutrient balance (in NPK kg/ha/year), as a supporting agricultural ecosystem service, for county i over time period t;

X_{1it} is a vector of **national level biophysical factors** (soil erosion in ton/ha, forest cover in % of total land area) for country i over time period t;

NPK_{it-n} is a **lag biophysical factor** which measures the historical average nutrient balance in NPK kg/ha/year for country i over time period t-n where $1 < n < t$. An assessment of the pairwise correlation between nutrient depletion rate reported by Henao and Baanante (1999) for the period 1993 and the depletion rate reported by Henao and Baanante (2006) for the cropping season of 2002–04 provided correlation coefficient of 0.575, which is significant at $P < 0.001$. Therefore, based on this empirical evidence we included the lag nutrient depletion rate in the model with the intuition that current nutrient balance has a relationship with historical level of nutrient depletion rate.

X_{2it} is a vector of **national level economic factors** (poverty gap in % of population with income below the poverty line (1.25 PPP USD/day). Poverty gap measures the mean income shortfall from the poverty line. It is expressed as a percentage of the poverty line and considers the non-poor as having zero shortfall. It measures the depth of poverty as well as its incidence in a country. GDP per capita is in PPP USD. Manufacturing sector GDP is in PPP USD. Livestock population is in Tropical Livestock Units (TLU)) for country i over time period t;

α represents the parameters to be estimated from empirical data; and

u_{it} is the error or stochastic term that captures the effect of unobserved factors in country i over time period t.

Equation 1 can be estimated efficiently using ordinary least square methods if the error term is uncorrelated with any of the right hand side variables.

Modeling cereal crop yield loss: loss of a provisioning ecosystem service

Based on the microeconomic concept of production as a function of factor inputs, the relationship between nutrient balance and crop production in agricultural ecosystems of Africa can be specified as in equation 2 below.

$$Y_{it} = \beta_0 + \beta_1 TNPK_{it} + FI_{it} + \varepsilon_{it} \qquad (2)$$

Where:

Y_{it} represents actual cereal crop yield (in kg/ha/year), as a provisioning agricultural ecosystem service, for country i over time period t;

$TNPK_{it}$ represents the total nutrient balance on cropped land (in NPK Kg/year) for country i over time period t. TNPK is estimated as a product of the predicted NPK_{it} in equation 1 and the land area cultivated with cereal crops by country i over time period t;

FI_{it} is a vector of national level agricultural factor inputs (land area cropped with cereals in ha/year and total economically active population in agriculture. total fertilizer consumption in NPK ton/year) by country i over time period t;

β represents the coefficients;

ε_{it} it is the error or stochastic term that captures the effect of unobserved factors in country i over time period t.

Similar to equation 1, equation 2 can be estimated efficiently using ordinary least square methods if the error term is uncorrelated with any of the right hand side variables. For modeling the soil nutrient losses and crop yield models in equations 1 and 2 respectively, and estimating the corresponding parameters, national level data on the response and right-hand side variables for the 42 countries were used. Accordingly, data on NPK balance were based on Henao and Baanante (1999) and Henao and Baanante (2006), whereas the data for the right hand side variables in both equations for the years

2002–04 were from World Bank[3] and FAOSTAT[4] databases and we also used data for the years 2010–12 from the same databases for estimation. Detailed description of the data and sources are presented in *Appendix 2a*. All the data used in the analysis are national level macroeconomic and biophysical aggregates in which we have one data point for each country. Therefore, it is important to note that our analysis as well as the data used do not explicitly capture and explain spatial variability within a country. Specifically, our modeling approach assumes that the variation, for example, in nutrient depletion rate across the 42 African countries could be explained by the variations in the biophysical and economic factors, which are stated in equation 1, among these countries. Similarly, we assumed that the variation in cereals crop yield across these countries could be explained by the variations in total nutrient balances in croplands and factor input uses between countries.

The results of the two models allowed us to calculate the crop yield loss per unit of NPK loss for each country, which we call it as agricultural ecosystem service tradeoff index (AESSTI). In other words AESSTI measures the tradeoff between provisioning (crop) and supporting (soil nutrients) agricultural ecosystem services. Thus, AESSTI is calculated as a ratio of the total yield loss due to nutrient depletion and the total nutrient depletion from cultivated croplands of country i at time t (L_{it}).

$$AESSTI_{it} = \frac{L_{it}\,(\overline{\beta}_1 TNPK_{it})}{L_{it}\,(\overline{NPK}_{it})} \qquad (3)$$

2.3.3. Estimation of nutrient and crop production losses (crop seasons 2010–12)

Using the parameter (coefficients) estimated for equation 1 and data on the right hand side equations for the period of 2010–2012 (*Appendix 2a*), we estimated the average annual NPK loss (kg/ha/year) per country for the time 2010–2012. In the estimation, we have taken the NPK loss for the cropping seasons of 2002–04 (Henao and Baanante, 2006) as lag for 2010–12. The hectare level value is multiplied by the total cultivated cropland to get the total national level nutrient losses for each country. Moreover, the parameter estimates of equation 1 also allowed us to decompose the net nutrient loss into nutrient losses or gains induced by each of the factors in the right hand side of the equation. Accordingly, we were able to estimate national level nutrient losses induced by each of the biophysical and economic factors, say factor X_j, for each country i over time t using the following equation where L_{it} represents total cultivated land with cereals.

$$NPK_{j\,it} = L_{it}\,(\overline{\alpha}_j X_{j\,it}) \qquad (4)$$

Accordingly, we have estimated nutrient losses induced by poverty and soil erosion as well as the positive contribution of forest ecosystems and the livestock sector to nutrient balance in croplands. The cereal crop yield for 2010–12 was estimated using the parameter estimates of equation 2, the estimated nutrient loss for 2010–12, and data on factor inputs for 2010–12 (*Appendix 2a*). Similar to equation 1, equation 2 also allows decomposing the effects of nutrient depletion and factor inputs on yield. As a result, we calculated yield loss due to nutrient depletion as:

$$Yield_{it} = L_{it}\,(\overline{\beta}_1\, TNPK_{it}) \qquad (5)$$

Finally, we estimated the yield loss and/or gain induced by each of the most important policy relevant factors (poverty and erosion induced nutrient depletion and gains in nutrient balance due to forest cover and livestock population) using the following formula.

$$Yield_{j\,it} = L_{it}\,(\overline{\alpha}_j X_{j\,it})\,(AESSTI_{it}) \qquad (6)$$

2.3.4. Valuation of costs of inaction and benefit of action

The cost of inaction against land degradation refers to maximum possible benefits of action. In this study, the cost of inaction against soil nutrient depletion is measured in terms of both the values of lost soil nutrients and the value of the associated crop losses. While the value of nutrient loss measures the value of the lost supporting ecosystem service, the value of the crop loss measures the value of loss in a provisioning ecosystem service.

Valuation of nutrient loss: The nutrient losses estimated based on the methods described in section 2.3.3 were in aggregate NPK values. Based on the study of Henao and Baanante (1999) that

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[3] *World Bank: http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx*

[4] *FAOSTAT: http://faostat3.fao.org/download/Q/*/E*

reported depletion rates for N, P_2O_5, K_2O, and the sum of the three nutrients in croplands for 49 African countries for the cropping season of 1993–95, we derived ratios of each nutrient to total NPK nutrient depletion rate for each of the 42 countries covered by this study. We applied the ratios to convert our estimated NPK depletion values for 2010–12 into N, P_2O_5 and K_2O nutrients.

Each nutrient type is valued using the replacement cost method. The method allows estimating the value of an ecosystem service by estimating the cost of replacing with an alternative or substitute good or service (Bishop, 1999). Therefore, taking DAP 18–46-0 fertilizer with 18% N and 46% P_2O_5 in a 100 kg and NPK 15–15-15 fertilizer, which contains 15% of N, 15% P_2O_5, and 15% of K_2O_5 in 100 units of the fertilizer, as substitutes we collected national level monthly price data form *www.AfricaFertilizer.org* for the years 2010–12. Such price data was available only for 13 of the 42 African countries. Thus, we used the three years average annual price of DAP fertilizer to calculate the unit prices of N and P_2O_5 nutrients and the average price of NPK-15–15-15 to calculate the price of K_2O following similar applications in Nahuelhual et al., (2006).

$$CIA1_{j\,it} = N_{j\,it}(P_{N\,it}) + P_2O_{5j\,it}(P_{P\,it}) + K_2O_{j\,it}(P_{K\,it}) \qquad (7)$$

Valuation of crop loss: The crop loss estimated in section 2.3.3 were valued based on the production function (effect on production or the dose response) approach. The method involves first an econometric estimation of the effect of the loss of an ecosystem service (in this study, soil nutrient depletion) as environmental variable enters the production function of a market good, which is crop yield function in equation 2 above. After estimating the function, the economic value is obtained by multiplying the marginal physical product of the environmental variable by the price of the market good (Mäller, 1991).

The cereal yield loss estimated using the yield or production function in equation 2 was in aggregate of all cereals (barley, buckwheat, canary seed, fonio, maize, millet, oats, rice, rye, sorghum, triticale, and wheat). Therefore, based on the 2010–12 data on total cereal production and production of each cereal type (*Appendix 2a*) from FAO database, for each country we constructed a weight for each crop as the ratio of total production of a crop type to total of all cereals. We then multiplied each ratio by the average producers' price (USD/ton) of the particular cereal for the 2010–12 production years. Then for each country, we took the summation of the products as a weighted average price (USD/ton), WP_{ij}. Then we multiplied the weighted price by the cereal yield loss ($Yield_{jit}$) estimated for each country to get the annualized value of loss in production for the years 2010–12.

$$CIA2_{j\,ij} = WP_{ij}(Yield_{j\,it}) \qquad (8)$$

Valuation of benefit of action: Theoretically, the costs of inaction is the maximum level of benefit from action against land degradation. In this study, the theoretical maximum benefits of action refers the cost of inaction against soil nutrient depletion in cereal croplands. The actual benefit of action, however, depends on the level of efficiency of the type of intervention or action in averting soil nutrient depletion and hence the level of reduction in the associated cereal crop losses as a provisioning ecosystem service. For example, different soil and water conservation technologies have different levels of efficiency in controlling soil erosion. It is not also possible to realize all of the costs of inaction into benefits at a time for the fact that action or intervention requires both time and resources. Therefore, it is important to make realistic assumptions in estimating the benefits of action for making cost benefit analysis for decision making, which will be discussed in chapter 4. Thus, the benefits of action were estimated as fraction of the costs of inaction using the following equations where the fraction (λ) represents the rates by which cost of inaction is converted into benefits.

$$B1_{j\,it} = n\lambda CIA1_{j\,it} \qquad (9a)$$
$$B2_{j\,it} = n\lambda CIA2_{j\,it} \qquad (9b)$$

Where,

$BA1_{j\,it}$ represents the value of avoided NPK loss due to action against nutrient depletion induced by factor j in country I at time t
$BA2_{j\,it}$ is the value of avoided crop production loss due to action against nutrient depletion induced by factor j in country I at time t
λ is the rate by which the factor causing the nutrient depletion is reduced in country i at time t.
n = t-1 indicating that at the initial year of intervention n = 0 and hence zero benefits of action.

2.4. Empirical model results and discussion

2.4.1. The econometric model of nutrient balance

The result of our study indicates that the national level average nutrient loss (NPK kg/ha/year) for the cropping seasons of 2002–04 has statistically significant correlation with national level socioeconomic and biophysical factors.

Economic factors: The ordinary least square regression model in *Table 9* shows that among the national level economic factors poverty gap, manufacturing sector GDP, and livestock population have statistically significant (at P < 1%) coefficients with signs consistent with our expectation.

1. **Poverty Gap:** The coefficient for poverty gap is positive indicating that countries with higher rate of poverty gap in the period 2002–04 were also the countries with high average NPK loss from their agricultural lands and vice versa. In other words, a one percent increase in poverty gap causes on average a depletion of about 48 kg/ha of NPK nutrient per year and vice versa. This is consistent with our expectation and the well-established literature that commonly identifies poverty as one of the proximate causes of soil nutrient losses, mainly in SSA (Lambin & Geist, 2006; Lal & Stewart, 2013; Nkonya, E; von Braun, J; al., et, 2013; Pingali, et al., 2014).

2. **Manufacturing sector GDP:** We found negative relationship between manufacturing sector GDP and nutrient depletion. The result shows thats the higher the manufacturing

TABLE 9

Model of nutrient loss from croplands in Africa and summary statistics of variables.

Variable	Model coefficients	Summary statistics of the variables (N=42)		
		Mean(SE)	Min	Max
NPK nutrient loss (kg/ha/year)		53.93(2.36)	9.00	77.00
Economic factors				
Poverty gap (%)	47.633(14.688)***	0.21(0.02)	0.004	0.53
GDP per capita (100's of PPP USD)	0.109(0.062)*	30.73(5.24)	5.43	168.91
Manufacturing sector GDP (billions of PPP USD)	-0.364(0.084)***	8.01(3.244)	0.043	1.06.86
Livestock in 1000s of Tropical Livestock Units (log transformed)	-4.617(1.585)***	8.91(0.22)	5.53	11.73
Biophysical factors				
Forest cover (% of total land area)	-0.250(0.087)***	25.49(3.23)	0.06	82.19
Soil erosion (ton/ha/year) (log-transformed)	4.965(1.450)***	8.25(0.23)	3.98	10.25
Historical nutrient balance in kg/ha (crop seasons of 1993–95)	0.224(0.061)***	58.82(4.38)	-14.10	136.40
Constant	37.024(12.591)***			
Statistics:				
F (7. 34) statistics	14.17***			
R^2	0.745			
Adjusted R^2	0.692			
Root MSE	8.471			
Mean VIF	2.27			

*Values in () are standard errors. Significance levels: ***p < 1 %; **p < 5 %; and *p < 10 %.*

sector GDP of a country the lower the average nutrient loss from its agricultural lands used for cereal cultivation. The following might explain this inverse relationship. *Reducing pressure or dependence on land:* This implies that in countries where the manufacturing sector is relatively well developed and the sector contributes more to the economy, people have better chance to get employment in the sector and hence this creates opportunity for reducing the pressure on agricultural lands. *Capacity to invest on land management and agricultural input use:* Countries with relatively higher manufacturing GDP can also be considered as relatively well developed at least in economic terms. Thus, they have better capacity to invest on agricultural land management and application of inputs than their counterparts do.

3. **Livestock population:** The negative coefficient for the log-transformed value of livestock population indicates inverse relationship between livestock population and nutrient depletion rate from croplands in Africa. For every 1% increase in the livestock population (measured in 1000s of TLU), nutrient loss decreases by 0.0462 kg/ha/year. The result is consistent with soil nutrient budgeting framework that soil scientists use to estimate nutrient balance (Lesschen et al., 2007). In the nutrient balance method, manure from livestock is one of the elements considered as source of inflow of nutrient to the soil.

Biophysical factors: The coefficients for the variables forest cover, log transformed soil erosion, and historical nutrient balance are significant (at P < 1%). The coefficients of each of the variables

TABLE 10

Model of cereal crop yield in Africa and summary statistics of variables

Variable	Model Coefficients	Summary statistics of the variables (N=42)		
		Mean(SE)	Min	Max
Cereal crop yield (kg/ha/year)		1279.71(170.22)	235.03	7506.06
Land degradation				
Total nutrient depleted from cereal cropland in NPK kg/year (log transformed)	-125.40(43.17)***	17.38(0.37)	5.51	20.77
Factor inputs				
Land (total land area harvested with cereals in millions of ha)	-50.042(26.930)*	2.18(0.49)	6.00e-06	17.72
Labor in agriculture (log transformed)	246.34(79.72)***	7.739(0.20)	4.96	10.23
Fertilizer (NPK fertilizer consumption in 1000s of tons)	3.616(0.264)***	100.29(42.33)	0.00	1582.48
Constant	1299.34(600.89)**			
Statistics:				
F (4. 37) statistics	51.93***			
R^2	0.849			
Adjusted R^2	0.833			
Root MSE	451.55			
Mean VIF	1.70			
Adjusted R^2	0.692			
Root MSE	8.471			
Mean VIF	2.27			

*Values in () are standard errors. Significance levels: ***p < 1 %; **p < 5 %; and *p < 10 %.*

have the expected signs as well. While forest cover is negatively related with nutrient loss, both erosion and lag value of nutrient loss are found to be positively related with nutrient loss. In other words, countries with high forest cover had relatively lower nutrient depletion from their croplands whereas countries with high rates of erosion and previous high rates of nutrient depletion (as of 1993–95) were also countries with high rates of nutrient depletion for the cropping seasons of 2002–04.

The model in *Table 9* is robust in that the value of adjusted R^2 indicate that close to 70% of the variation in nutrient loss among the countries considered in the study could be explained by the variations between the countries in terms of the economic and biophysical factors used in the modeling.

2.4.2. Cereal crop production function

The cereal crop yield is modeled as a function of soil nutrient depletion and factor inputs. *Table 10* below shows that soil nutrient depletion and the factor inputs, mainly labor and fertilizer, are statistically significant (at $P < 1\%$) in affecting cereal yield of Africa's agricultural ecosystems. A one per cent increase in the total amounts of nutrients depleted from all the croplands of a country causes a 1.254 kg/ha decline in cereal yield. In other word, countries with higher rates of total nutrient depletion from croplands have relatively lower cereal yield per hectare than countries with lower nutrient depletion. The model also shows that both labor and amount of commercial fertilizer use were positively related with cereal yield per hectare.

2.4.3. The base periods costs of inaction 2002–04 and 2010–12

Our study shows that in the about 92 million hectares of land cultivated with cereals during the cropping seasons of 2002–04 in the 42 African countries, there was a total net depletion of 5.16 million tons of NPK nutrients per year (*Figures 30 and 31a*). This is equivalent to about 56.2 kg/ha/year. The area cultivated with cereal croplands in the 42 countries during the period 2010–12 was about 105 million hectares and there has been an estimated 5.2 million tons of NPK nutrient depletion per year during this period from the

FIGURE 30

Replacement cost values of annual NPK nutrient balances in cereal croplands of Africa

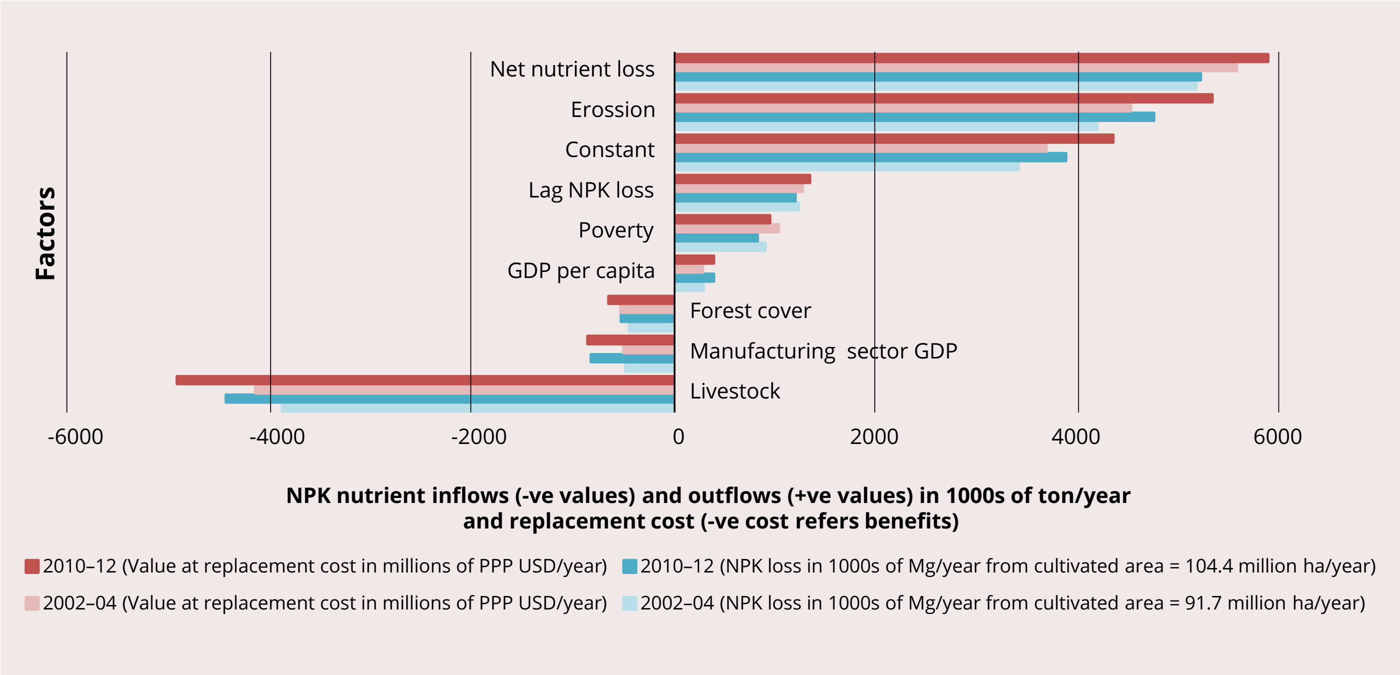
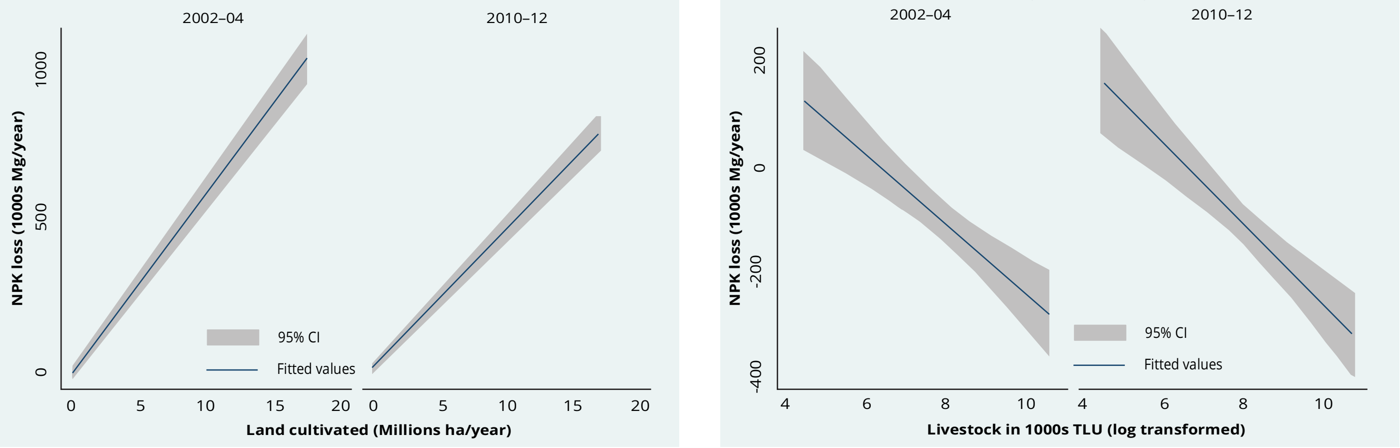


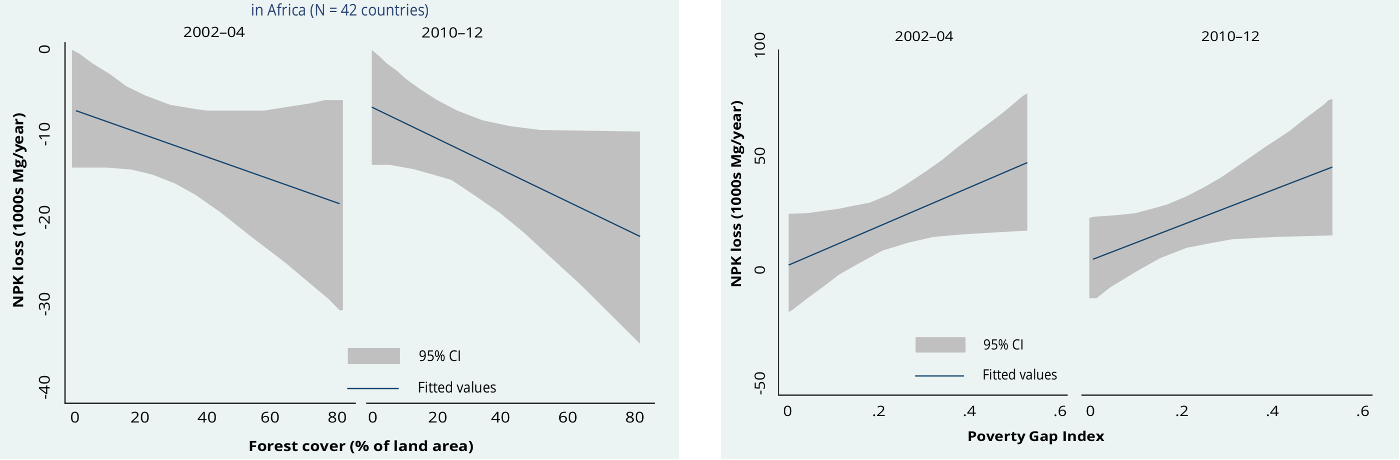
FIGURE 31

Relationship between NKP depletion and cultivated land area (panel a), NPK depletion and livestock population and forest cover (panel b), and NPK depletion and soil erosion and poverty gap (panel c) for the cropping seasons of 2002–04 and 2010–12.

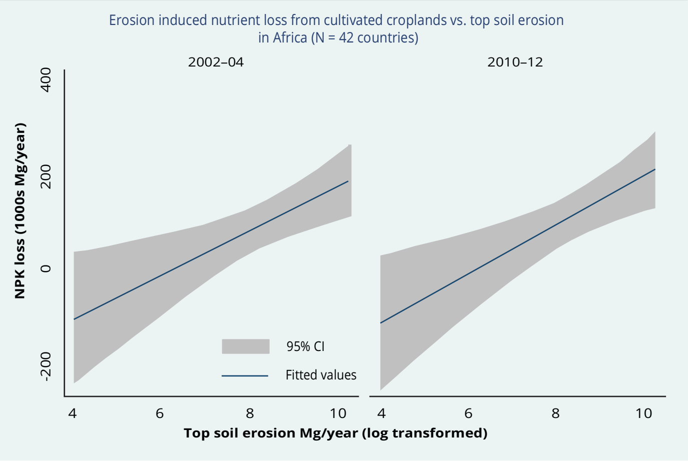
panel a)



panel b)



panel c)



Note: NPK values on the y-axis represent estimated values based on the econometric model in Table 9 and the estimated results were regresses against the socioeconomic and biophysical factors.

total area, which was equivalent to about 49.6 NPK kg/ha/year. Net nutrient balance is the sum of inflows and outflows of nutrients to the soil of the agricultural ecosystem. The total out flow NPK nutrients from the cultivated area of the period 2010–12 was estimated at about 10.97 million ton/year. The nutrient outflow (*Figures 30* and *31c*) through soil erosion accounted 43.19% of the outflow; poverty induced nutrient loss constituted 7.37% of the total outflow. GDP per capita induced outflow of nutrients accounted about 3.4%, lag nutrient depletion accounted 10.8%, and the rest was an estimate related to the constant term of the model used for the estimation. Whereas for the same period the nutrient inflows (*Figures 30* and *31b*) to the total cultivated area was estimated at about 5.77 million ton/year which was the sum of nutrient inflows attributed to livestock population (77.14%), forest cover (9.02%), and manufacturing sector (14.14%).

The value of the net nutrient that was depleted from the total cereal crop cultivated areas during the two periods at the replacement cost of commercial fertilizer was estimated at about 5.56 billion PPP USD per year (at constant 2011 USD) for the cropping seasons of 2002–04 and 5.87 billion PPP USD per year over the period 2010–12. According to FAO database on agricultural input use, the total commercial NPK fertilizer nutrient consumption for the whole of agricultural lands, which cereal production is only part of, by the 42 countries in our study was about 4.9 million ton/year (with a value of 5.53 billion PPP USD). This was equivalent to only 44.65% of the annual outflow and 94.19% of the net nutrient loss from the 104 million hectare cereal croplands alone.

FIGURE 32

Costs of inaction, actual cereal production and value, and potential benefits of action against nutrient depletion in croplands of Africa

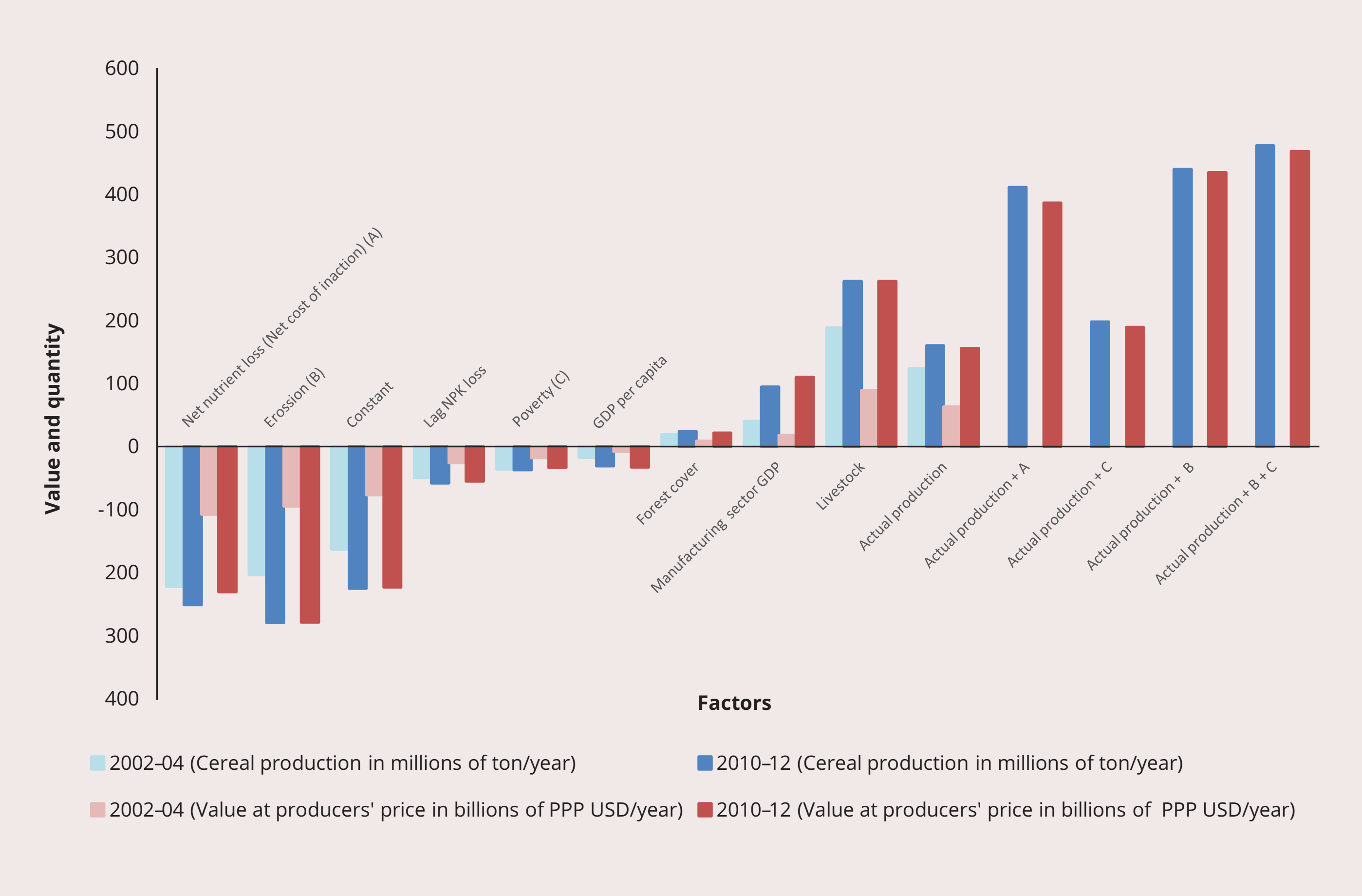
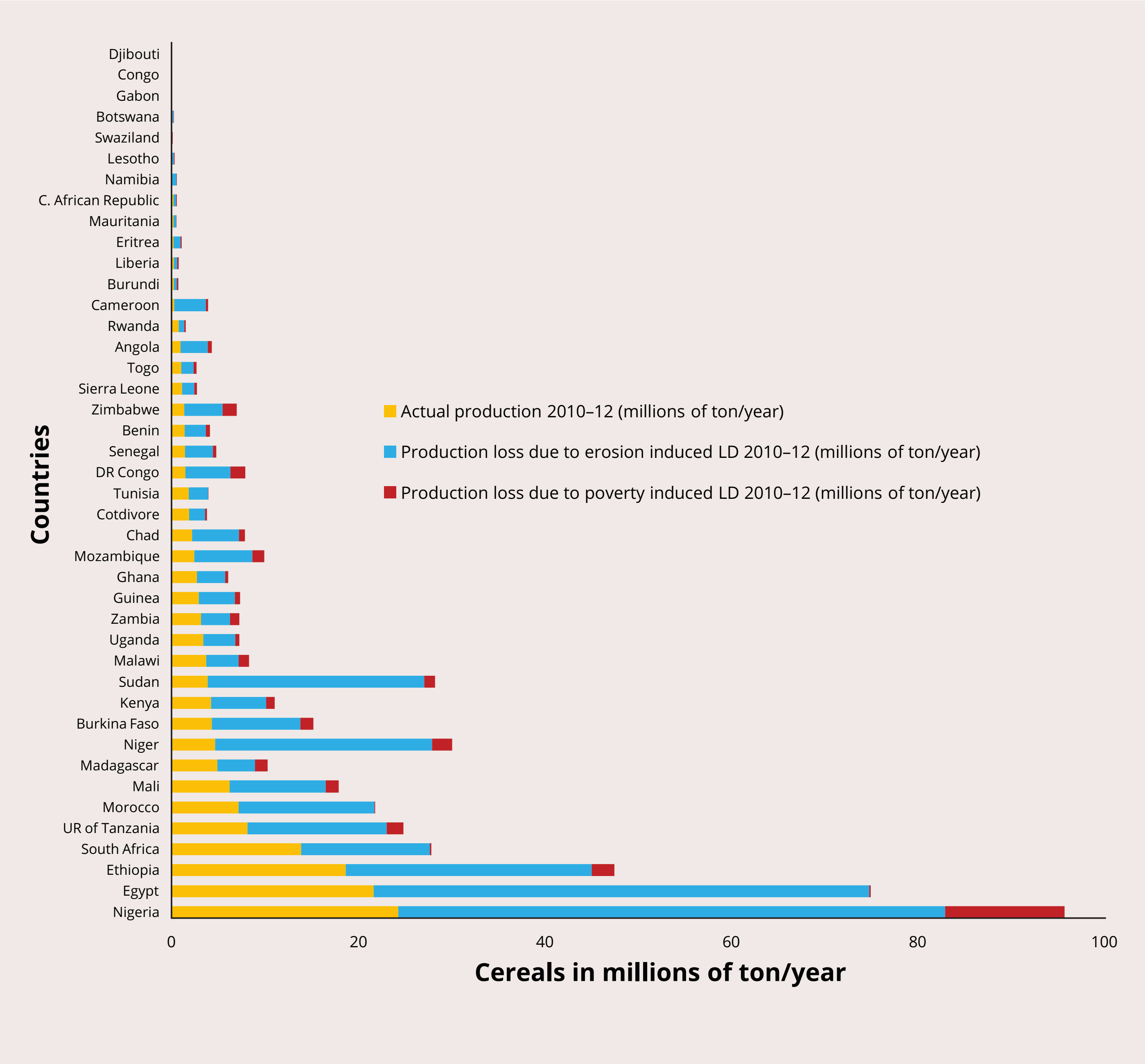


FIGURE 33

Actual cereal production and production loss due to erosion and poverty induced nutrient depletion in Africa.



Provisioning ecosystem service loss: The study also indicated that because of the net depletion of NPK nutrients from agricultural lands cultivated with cereal crops, the loss in production was estimated at about 222 and 251 million ton/year for the cropping seasons of 2002–04 and 2010–21 respectively *(Figure 32)*. Compared to the net NPK depletion, this indicates that the average ecosystem service trade off was 43.04 for the period 2002–04 and it increased to 48.29 in the period 2010–12. In other words, for every 1 kg of NPK being depleted. African countries were losing cereal output of 43.04 Kg per year as provisioning services in the production period 2002–04 and 48.29 Kg cereals per year in the years 2010–12.

According to the FAO database, the actual cereal production was about 124 and 160 million ton/year for the indicated periods respectively, which implies that the average productivity was 1.35

ton/ha/year in 2002–04 and 1.53 ton/ha/year in the period 2010–12, further indicating a very low and stagnant level of productivity. This study also indicates that there is a great potential to increase the productivity of agricultural lands in Africa through the application of sustainable land management practices that can reduce the existing level of nutrient depletion. For example, keeping all the other factors constant, reducing the NPK loss through action against erosion induced nutrient depletion would result in maximum additional output gain of 280 million ton/year (*Figure 32* for all countries and *Figure 33* for specific country) from the 104.4 million cultivated areas in the 42 African countries. This implies that there is a potential for increasing the productivity of land from the 1.53 ton/ha/year to 4.21 ton/ha/year by controlling soil erosion.

In terms of value at the producers' price for cereals, the value of net loss, which represents the cost of inaction against all factors related to induced nutrient depletion, was estimated at about 108 and 231 billion PPP USD/year for the periods 2002–04 and 2010–12 respectively. The costs of inaction against erosion induced nutrient depletion were 95 and 279 billion PPP USD per year whereas the costs of inaction against poverty induced nutrient depletion were 18 and 33 billion PPP USD per year for the respective periods. The very high costs of inaction for the period 2010–12 compared to the 2002–04 was mainly due to the rise in global food prices following the 2008 global financial and economic crises that led to the so called land grab in Africa.

CHAPTER

03

The costs of sustainable land management in Africa

3.1. Introduction

The UN Earth Summit (1992) defined sustainable land management (SLM) as “the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions”[5]. TerrAfrica (2005) defines SLM as “the adoption of land use systems that, through appropriate management practices, enables land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources”[6]. According to the FAO, agricultural production in sub-Saharan Africa is falling by three percent a year as a result of land degradation[7], with potentially disastrous implications for sustainable development. This provides a strong justification for governments to pro-actively mitigate the impacts of land degradation.

In response to this demonstrated policy need, the objective of this section is to use data currently available from different published sources to estimate the unit establishment and recurrent costs of SLM by countries in Africa following the value transfer approach (see Brander, undated). Value transfer is the procedure of estimating the value of an ecosystem service of current policy interest (i.e. the “policy site”) by assigning an existing valuation estimate for a similar ecosystem elsewhere (i.e. the “study site”). In the present case we will specifically use the meta-analytic transfer function approach[8], which involves using a value function estimated from the results of multiple primary studies representing multiple study sites in conjunction with information on policy site characteristics to calculate the unit value of an ecosystem service at the policy site.

The rest of this section is presented as follows. Section 2 describes the general framework we used to value the costs of action due to soil erosion induced nutrient depletion. Section 3 describes the different databases that were queried to estimate the establishment and recurrent costs of SLM by country in Africa. Section 4 describes the procedure that was used to select a sample of case studies from Section 3 that were subsequently used to estimate the meta-analytic transfer function. Section 5 describes the dependent and independent variables that were used to estimate the meta-analytic transfer function. The empirical results and discussions are presented in Section 6, while Section 7 discusses the limitations of using the meta-analytic transfer function approach to estimating the establishment and recurrent costs of SLM in Africa by country.

3.2. Valuation of the costs of action

Action against land degradation refers to interventions required to mitigate and/or if possible totally reduce the effects of the drivers of land degradation and optimize the benefits of taking action. Among other things the type of intervention and its cost may depend on the type of the driver of land degradation. In this study context, the costs of policy actions considered include costs of action against erosion and poverty induced nutrient depletion.

Costs of action against erosion induced nutrient depletion: We developed a cost transfer function to estimate for each country the per hectare level capital and recurrent costs of sustainable land management structures as action against erosion induced nutrient depletion. The total annual cost of action against erosion induced nutrient depletion is then calculated using the following equation.

$$C_{slm\,it} = \sigma L_{it}(FC_{it}) + n\sigma L_{it}(VC_{it+1}) \qquad (10)$$

Where,
$C_{slm\,it}$ is the total cost of establishing and maintaining sustainable land management structures on a given proportion (σ) of the total cropland (L) for controlling soil erosion in country i at time t.

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[5] *http://www.fao.org/nr/land/sustainable-land-management/en/*

[6] *http://www.fao.org/nr/land/sustainable-land-management/en/*

[7] *ftp://ftp.fao.org/docrep/fao/010/ai559e/ai559e00.pdf*

[8] *There exist two other approaches to value transfer: unit value transfer and value function transfer (see Brander, undated)*

FC_{it} represents the fixed or capital cost (USD/ha) for establishing the SLM structures in county i at time t.

VC_{it+1} is the cost of maintaining the established structure starting from t+1 year in country i at time t and n is a constant and equals t-1.

Costs of action against poverty induced nutrient depletion: Reducing the impact of poverty on nutrient depletion requires reducing poverty itself, which has been and will continue to be the main challenge for many Sub Saharan African countries. Poverty gap index is among the three variants of poverty indices, namely poverty head count, poverty gap, and poverty severity that were developed by Foster, Green, & Thorbecke (1984). We applied the poverty gap index to calculate the income or resource required to lift the poor population of each country in our sample to an income level equal to the poverty line (1.25 PPP USD daily income per capita) using the following equation.

$$C_{pov\,it} = \varphi FGT_{it}(HP_{it})(I_{it}) \qquad (11)$$

Where,

$C_{pov\,it}$ is the total income required to reduce poverty by a given rate, say φ, in country i at time t.

FGT_{it} represents the poverty gap index of county i at time period t.

HP_{it} is the total human population of country i at time t

I_{it} represents poverty line income per capita per year for country i at time t.

3.3. Databases for estimating the costs of SLM in Africa by country

The primary source of information for this study was the World Overview on Conservation Approaches and Technologies (WOCAT) database that is describe in section 3.1. In addition to WOCAT, we also sourced data from the sources described in section 3.2.

3.3.1. The WOCAT database

The WOCAT database consists of about 350 case studies of promising and good practices of SLM collected, documented and assessed by the WOCAT network (Giger, Liniger and Schwilch, 2013)[9]. The WOCAT network encourages countries across the globe to fill-out a standard questionnaire that collects site specific background biophysical and socioeconomic data on SLM technologies, and their perceived benefits and costs as enumerated below:

- **Background land use problems that triggered the need for the SLM at the site:** land use before degradation, climate, kind of land degradation experienced prior to the SLM intervention, the SLM conservation measure that was implemented, the stage of the intervention (was the SLM intervention designed to prevent, mitigate or rehabilitate land degradation?), who motivated the intervention (was it the land users, experimenters or researchers or externally imposed?), level of technical knowledge required to implement the SLM intervention, the main causes of land degradation at the site, and main technical functions of the SLM intervention.

- **Background information on the natural environment:** average annual rainfall, altitude at the SLM site (meters above sea level), land form at the SLM site (plateau, plains, ridges, mountain slopes, hill slopes, foot slopes, valley floors), slope at the SLM site (flat, gentle, moderate, rolling, hilly, steep, very steep), soil depth, soil texture and biodiversity at the SLM site.

- **Background information on the human environment:** hectarage of forests or woodlands per household at the SLM site, population density, land ownership patterns, land use rights, relative level of household wealth, importance of off-farm income, access to services and infrastructure, market orientation, and the goods and services provided by forests or woodlands at the site.

- **Establishment inputs and costs (USD/ha):** quantity and capital costs of labour, equipment and construction materials initially used in the SLM intervention.

- **Maintenance or recurrent inputs and costs (USD/ha/year):** quantity and recurrent costs of labour, equipment and construction materials required to maintain functionality of the SLM intervention.

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[9] *https://www.cde.unibe.ch/Pages/Publication/2481/Economic-benefits-and-costs-of-technologies-for-sustainable-land-management-(SLM)-A-preliminary-analysis-of-global-WOCAT-data.aspx*

Finally, the questionnaire collects additional information that can be used to qualitatively assess the onsite and offsite costs and benefits of the SLM intervention: production and socioeconomic, socio-cultural, ecological, off-site, contribution to human wellbeing and livelihoods, and the land user perceived benefits and costs.

Giger, Liniger and Schwilch (2013) have categorized the SLM technologies in the WOCAT database into four broad classes:

- **Agronomic measures:** measures that improve soil cover (e.g. green cover, mulch), measures that enhance organic matter/soil fertility (e.g. manuring), soil surface treatment (e.g. conservation tillage), sub-surface treatment (e.g. deep ripping).

- **Structural measures:** terraces (bench, forward/backward slopping), bunds, banks (level, graded), dams, pans, ditches (level, graded), walls, barriers and palisades.

TABLE 11

Variables used to estimate the meta-analytic transfer function[8]

Variable	Source of data
Population of the country (2012)	World Bank statistics
Rural population (2012)	World Bank Staff estimates based on United Nations, World Urbanization Prospects.
Gross Domestic Product (GDP 2012)	World Bank statistics
Agriculture GDP (2012)	World Bank national accounts data, and OECD National Accounts data files.
Rural population growth (2012)	World Bank statistics
Rural population as a percentage of total population (2012)	World Bank Staff estimates based on United Nations, World Urbanization Prospects.
Area of agriculture land (2012)	Food and Agriculture Organization, electronic files and web site.
Agriculture land as a percentage of total land area (2012)	Food and Agriculture Organization, electronic files and web site.
Area of arable land (2012)	Food and Agriculture Organization, electronic files and web site.
Arable land as a percentage of total land area (2012)	Food and Agriculture Organization, electronic files and web site.
Land under cereal production (2012)	Food and Agriculture Organization, electronic files and web site.
Land under permanent cropland (2012)	Food and Agriculture Organization, electronic files and web site.
Land under forestry (2012)	Food and Agriculture Organization, electronic files and web site.
Land under forestry as a percentage of total land area (2012)	Food and Agriculture Organization, electronic files and web site.
Average precipitation (2012)	Food and Agriculture Organization, electronic files and web site.
Land area (2012)	Food and Agriculture Organization, electronic files and web site.
Crop production index (2012)	Food and Agriculture Organization, electronic files and web site.
Food production index (2012)	Food and Agriculture Organization, electronic files and web site.
Livestock production index (2012)	Food and Agriculture Organization, electronic files and web site.
Surface area (2012)	Food and Agriculture Organization, electronic files and web site.
Cereal yield (2012)	Food and Agriculture Organization, electronic files and web site.
Agriculture value added (VA) per worker (2012)	Derived from World Bank national accounts files and Food and Agriculture Organization, Production Yearbook and data files.
Agriculture VA as a percentage of GDP (2012)	World Bank national accounts data, and OECD National Accounts data files.
Total livestock units 2012 in 1000s (2012)	FAOSTAT

- **Vegetative measures:** plantation/reseeding of tree and shrub species (e.g. live fences, tree crows), grasses and perennial herbaceous plants (e.g. grass strips).

- **Management measures:** change of land use types (e.g. area enclosure), change of management intensity level (e.g. from grazing to cut and carry), major change in timing of activities, and controlling/change of species composition.

For the purposes of estimating meta-analytic transfer functions, 157 case studies of SLM interventions were downloaded located in the following African countries: Ethiopia (48), South Africa (24), Kenya (22), Tanzania (15), Tunisia (7), Niger (6), Botswana (4), Burkina Faso (4), Rwanda (4), Morocco (3), Senegal (3), Zambia (3), Cameroon (2), Cape Verde (2), Togo (2), Eritrea (2), Ghana (1), Madagascar (1), Mali (1), Chad (1) and Zimbabwe (1).

3.3.2. Other data bases queried

In addition to the WOCAT data described above, the variables listed in *Table 11* were also collected and used to test whether they improved the fit of the resulting meta-analytic transfer function.

3.4. Case studies selected for estimating the meta-analytic transfer function

For a study to be included in the meta-analytic transfer function, it had to satisfy 2 criteria. First, its establishment inputs and capital costs had to be quoted in **USD/ha** at the date of establishment. In addition, its maintenance or recurrent inputs and costs had to be quoted in **USD/ha/year** at the date of establishment. Since all studies did not meet these two criteria, this process resulted in the 90 studies reported in *Table 12*.

The following information was collect for each of the 90 SLM interventions recorded in *Table 12*:

- Capital costs in USD per ha at the date of SLM establishment (continuous variable),
- Recurrent costs in USD per ha per year at the date of establishment (continuous variable),
- Region in Africa where case study was located (categorical variable),
- Land use at the study site before degradation (categorical variable),
- Climate at the case study site (categorical variable),
- Stage of intervention at the time of the SLM intervention (categorical variable),
- Average annual rainfall at the case study site (categorical variable), and
- Population density at the case study site (categorical variable).

Section 5 justifies selection of the above information for each of the studies.

3.5. Description of variables used to estimate the meta-analytic transfer function

Two **dependent variables** were used in this study to estimate 2 separate meta-analytic transfer functions:

- Capital costs in USD per ha at the date of establishment (**y1**), and
- Recurrent costs in USD per ha per year at the date of establishment (**y2**).

Our original idea was to estimate a value function from the results of many primary valuation studies, combined with information on policy site characteristics, to calculate the unit value of an ecosystem service at the policy site. The multiple primary valuation studies of interest were the individual SLM interventions of *Table 12*, which had very location specific data. The policy sites of interest on the other hand were at the level of a country. The immediate challenge was thus to estimate a meta-function from data collected at specific sites of SLM interventions (i.e. 90 study sites distributed across 14 African countries) and use it to estimate the establishment and recurrent costs of SLM interventions at policy sites defined at the country level. This required us to select independent variables from the WOCAT data set that could be used in conjunction with country level information. Consequently data on the following six **independent variables** were collected for the selected case studies:

- Region in Africa where case study was located (**x1**),
- Land use before degradation (**x2**),
- Climate (**x3**),

TABLE 12

Case studies selected for estimating the meta-analytic transfer function

	Country	# of case studies	Nature of SLM intervention
1	Eritrea	1	Afforestation and hillside terracing.
2	Ethiopia	33	Area closure for rehabilitation of degraded hillsides, Area closure for rehabilitation, Area closure, Boreda soil bund, Dawa-Cheffa traditional check dam, Dejen stone bund, Dire Dawa traditional check dam, Graded soil bund, Grazing land improvement, Haraghie stone bund, Haraghie soil bund, Haraghie stone faced soil bund, Homestead development, Improved grazing land management, Jatropha curcas hedge, Micro catchment and ponds, Rehabilitation of degraded lands (area closure), Rehabilitation of degraded lands, Ridge bund, Runoff or flooding water farming, Soil bund and Fanya Juu combined, Soil bund with contour cultivation, Sorghum terrace of Dire Dawa, Stabilized stone faced soil bund, Stone bund of Tigray, Stone faced level bund, Stone faced soil bund of South Gonder, Stone faced soil bund of Tigray, Stone faced trench bund, Stone faced trench, Stone faced check dam, Stone faced soil bund stabilized with grass, and Vegetated Fanya Juu.
3	Kenya	8	Agroforestry land use in bench terraces with cut-off and grass strips, infiltration ditches and napier, Agroforestry system (intercropping beans/maize) with contour ditches, strips of napier grass, manure and organic fertilizers, Fanya Juu terraces, Grevillea agroforestry system, Planting bamboos and Grevillea for riparian land conservation, Push-pull integrated pest and soil fertility management, Stone lines, and Water harvesting.
4	Rwanda	4	Banana manure pits and mulching, Lining geo-membrane plastics for water harvesting and storage, Radical terraces, and Trenches combined with living hedges or grass lines.

	Country	# of case studies	Nature of SLM intervention
5	Tanzania	10	Buyana agroforestry system, Gully healing for growing bananas, Improved Kibanja cropping system, In-situ mulching of coffee using Cordia Abbysinica, Increasing groundnuts pod number in a soil head, In-situ compost cultivation or 'pattern farming', Local compost making,, Natural forest conservation using apiaries Small pit cultivation for maize, sorghum and millet (Chololo pits), and Traditional forest establishment in semi-arid land.
6	Zambia	3	Animal draft zero tillage, Conservation tillage with Magoye ripper, and Strip tillage conservation farming.
7	Burkina Faso	3	Assisted natural regeneration of degraded land, Composting associated with planting pits, and Organic cotton.
8	Cape Verde	2	Afforestation, and Aloe vera living barriers.
9	Niger	6	Couloirs de passage, Farmer managed natural regeneration, Improved well distribution for sustainable pastoralism, Night corralling, Rotational grazing, and Sand dune stabilisation.
10	Togo	2	Shelterbelts, and Small stock manure production.
11	Cameroon	1	Forest beekeeping.
12	South Africa	11	Chemical bush control, Communal grazing management, Controlling of soil erosion during crop production, Earth dam for stock water, Grass strips. Rehabilitation of degraded rangeland, Re-vegetation and re-seedling, Rotational grazing, Strip mine rehabilitation, Traditional stone wall terraces, and Vetiver grass soil conservation.
13	Morocco	2	Assisted cork oak regeneration, and Olive tree plantation with intercropping.
14	Tunisia	4	Area closure and reforestation with Acacia, Jessour, Rangelands resting, and Tabia.

- Stage of intervention (**x4**),
- Average annual rainfall (**x5**), and
- Population density (**x6**).

Assuming that we could successfully use OLS to estimate a meta-analytic function of the form $\gamma_i = \alpha + \beta_1 \chi_{1i} + \ldots + \beta_6 \chi_{6i}$ using this data, the estimated function would have allowed us to use the betas and country level data on the right hand side variables to predict **y** (the mean establishment and recurrent cost per ha of SLM by country).

We hypothesized that the following variables will have a **positive relationship** with the capital and recurrent costs of SLM interventions: quantity of agriculture land in a country, agriculture land as a proportion of total land area, cereal yield, and agriculture value added per worker. We based these hypotheses on our observations of land degradation in Africa. Areas in Africa that are very intensively farmed (e.g. the East African highlands) are also observed to have very high levels of on-farm land degradation. Such areas produce large quantities of cereals, which translates to high agriculture value added per worker. It follows that by the time a particular SLM intervention is being implemented in such areas, the land will be in a relatively poor condition, which translates to high capital and recurrent expenditures to bring it back to sustainable production.

We hypothesized that the following variables will have a **negative relationship** with the capital and recurrent costs of SLM interventions: the rate of rural population growth, rural population as a percentage of total population, crop production index and the food production index. Our basis for this hypothesis is drawn from experiences in East Africa, where we observe Arid and Semi-Arid Lands (ASALS) having rural populations, low populations, low population growths and relatively perform poorly in terms of the crop and food production index. Relatively speaking, these areas suffer from severe land degradation. This is not to deny that there might exist strong possibilities that in such areas, climate might also confound the impacts of land degradation.

3.6. Empirical results and discussions

This section provides the results and discussions from this investigation. Section 3.6.1 provides the descriptive statistics. Section 3.6.2 explains why it was not possible to obtain meta-analytic transfer functions with desirable statistical properties based on the WOCAT data alone. Section 3.6.3 explains how the WOCAT data combined with variables from *Table 11* were used to estimate meta-analytic transfer functions that were subsequently used to predict the capital costs (2012 USD/ha) and recurrent costs (2012 USD/ha/year) of SLM interventions in Africa in Section 6.3.1.

3.6.1. Descriptive Statistics

Date of establishment: the results show that the dates of establishment for the different SLM interventions ranged from 1970 to 2015: 1970 (17 studies, 18.89%), 1995 (1 study, 1.11%), 1997 (1 study, 1.11%), 1999 (7 studies, 7.78%), 2000 (1 study, 1.11%), 2001 (4 studies, 4.44%), 2002 (2 studies, 2.22%), 2003 (8 studies, 8.89%), 2004 (1 study, 1.11%), 2005 (7 studies, 7.78%), 2007 (2 studies, 2.22%), 2008 (3 studies, 3.33%), 2009 (2 studies, 2.22%), 2011 (20 studies, 22.22%), 2012 (6 studies, 6.67%), 2013 (4 studies, 4.44%), 2014 (3 studies, 3.33%), and 2015 (1 study, 1.11%).

Capital costs in USD per ha (2012): capital costs were deflated from current year (i.e. date of establishment) to 2012. The results show that the minimum cost of establishment was USD 0.4788 per ha (the push and pull integrated pest and soil fertility management SLM intervention in Kenya, 1970), the maximum was USD 86,992.35 (the chemical bush control SLM intervention in South Africa, 2003), with a median of USD 344.2103. The Shapiro-Wilk test (W = 0.29661) rejected the null hypothesis of normality for the deflated capital costs at the 1% level of significance.

Recurrent costs in USD per ha per year (2012): recurrent costs were deflated from current year (i.e. date of establishment) to 2012. The results show that the minimum annual recurrent cost was USD 0.0324 per ha per year (the radical terraces SLM intervention in Rwanda, 1970), the maximum was USD 21,748.09 (the chemical bush control SLM intervention in South Africa, 2003), with a median of USD 63.32133. The Shapiro-Wilk test (W = 0.24554) rejected the null hypothesis of normality for deflated recurrent costs at the 1% level of significance.

Region in Africa where case study was located: the results show that Eastern Africa had the highest share of the case studies (56 studies, 62.22%), followed by Southern Africa (14 studies, 15.56%), Western Africa (13 studies, 14.44%), Northern Africa (6 studies, 6.67%) and finally Central Africa (1 study, 1.11%).

Land use before degradation: the results show that in the majority of cases, the land was being used for annual cropping prior to (37 cases, 41.11%), followed by annual cropping and extensive grazing (17 cases, 19.89%), extensive grazing (14 cases, 15.56%), agro-pastoralism (5 cases, 5.56%), forests, woodland rests and woodlands (4 cases, 4.44%), perennial non-woody cropping (3 cases, 3.33%), agroforestry (3 cases, 3.3%), silvo-pastoralism (2 cases, 2.22%), intensive grazing, fodder production and agroforestry (2 cases, 2.2%), agro-silvo-pastoralism (1 case, 1.11%), natural sustainable rainforest management (1 case, 1.1%) and tree and shrub cropping (1 case, 1.1%). This allows us to conclude that annual cropping is by far the most dominant land use that precipitates in land degradation.

Stage of intervention: the results show that in 41 cases (45.56%), the purpose of SLM intervention was to mitigate or reduce the impacts of land degradation. In 25 instances (27.78%), the purpose of SLM intervention was to rehabilitate degraded land, while in 24 case studies (26.67%) the purpose of SLM intervention was to prevent land degradation. Since it is well acknowledged that preventing land degradation is cheaper than either mitigation or rehabilitation, policy should pay attention to prevention rather than mitigation or rehabilitation.

Climate: The results show that semi-arid (41 cases, 45.56%) and sub-humid areas (40 cases, 44.44%) contributed the lion's share of land degradation cases. Arid areas contributed 6 case studies (6.67%), while humid areas contributed 3 cases (3.33%). This suggests that policy should pay attention to land management in semi-arid and sub-humid areas.

Average annual rainfall: the results show that 20 of the case studies (22.22%) came from regions where the average annual rainfall was between 750 and 1000 mm, 19 (21.11%) came from regions where the average annual rainfall was between 500 and 750 mm, 19 (21.11%) came from regions where the average annual rainfall was between 1000 and 1500 mm, 19 (21.11%) came from regions where the average annual rainfall was between 250 and 500 mm, 5 (5.56%) came from regions where the average annual rainfall was less than 250 mm, 4 (4.44%) came from regions where the average annual rainfall was between 1500 and 2000 mm and 4 (4.44%) came from regions where the average annual rainfall was between 2000 and 3000 mm. This allows us to conclude that most cases of SLM interventions are required in humid to sub-humid regions.

Population density: the results show that majority of studies came from areas where population densities were low to medium: 23 studies came from areas where the density was 50 persons per km^2, 17 from areas where the density was 200 and 500 persons per km^2 respectively, 13 came from areas where the density was 100 persons per km^2, 5 from areas where the density was 10 persons per km^2 and 1 from areas where the density was 550 persons per km^2. The population density was not reported in 14 studies.

To summarize, the sample of case studies analysed suggests the following messages about experiences with land degradation in Africa:

- Annual cropping is the most prevalent land use that precipitates in land degradation.
- Land degradation is prevalent in semi-arid and humid areas, with humid to sub-humid climate.
- Most SLM interventions are designed to mitigate (reduce) the impacts of land degradation or to rehabilitate degraded land rather than preventing land degradation.

3.6.2. Estimating meta-analytic transfer functions from WOCAT data

In section 6.1, we showed that the two dependent variables of interest in this study were non-normal. They were thus initially logged prior to using OLS to regress them against the following independent variables: region in Africa where case study was located (x1), land use before degradation (x2), climate at the place of the SLM intervention (x3), stage of SLM intervention (x4), average annual rainfall (x5), and population density (x6). Many specifications of the transfer function were attempted in a bid to get a model with desirable

TABLE 13

Bivariate regression analysis

Independent variables	ln (real capital costs/ha)	ln (real recurrent costs/ha/year)
ln (rural population as a percentage of total population)	*** (negative)	** (negative)
ln (agriculture land as a percentage of total land)	*** (positive)	* (positive)
ln (crop production index)	** (negative)	** (negative)
ln (food production index)	* (negative)	** (negative)
ln (country population)	Not statistically significant	Not statistically significant
ln (rural population)	Not statistically significant	Not statistically significant
ln (GDP)	* (positive)	Not statistically significant
ln (rural population growth)	** (negative)	Not statistically significant
ln (extent of agriculture land)	Not statistically significant	Not statistically significant
ln (arable land)	Not statistically significant	Not statistically significant
ln (arable land as a percentage of total land)	Not statistically significant	Not statistically significant
ln (land under cereal production)	Not statistically significant	Not statistically significant
ln (land under permanent cropland)	Not statistically significant	Not statistically significant
ln (land under forest area)	Not statistically significant	* (positive)
ln (land under forest area as a percentage of total land)	* (positive)	** (positive)
ln (average precipitation)	Not statistically significant	Not statistically significant
ln (extent of land area)	Not statistically significant	Not statistically significant
ln (livestock production index)	** (positive)	Not statistically significant
ln (surface area)	Not statistically significant	Not statistically significant
ln (cereal yield)	* (positive)	Not statistically significant
ln (agriculture VA per worker)	** (positive)	Not statistically significant
ln (agriculture VA as a percentage of GDP)	*** (negative)	** (negative)
ln (total livestock units 2012 in 1000s)	Not statistically significant	Not statistically significant

statistical properties that could explain variations in the dependent variables. Unfortunately this process proved unwieldy: after experimenting with many specifications, the function that could best explain variations in the dependent variables proved to be complicated, with cross terms that did not have straightforward economic interpretations. In addition, the function performed poorly in predicting what we observe. As a result, the attempt to estimate the meta-analytic transfer function based on the WOCAT dataset alone was abandoned.

3.6.3. Estimating meta-analytic transfer functions from the larger database

An attempt was initially made to use OLS to regress the dependent variables from the WOCAT database (real capital costs/ha and real recurrent costs/ha/year) against the independent variables of *Table 9* using multi-variable regression analysis. This attempt also proved unwieldy: we could not obtain a multi-variable function with desirable statistical properties and expected signs for the coefficients[10]. As a consequence, we regressed the dependent variables against each independent variable using bivariate regressions *(Table 13)*.

[10] *This result should not be surprising given that this is an attempt to relate data sets from different sources collected for different purposes in a multivariable regression.*

TABLE 14

Real capital costs for SLM in Africa 2012 USD/ha

	Agric. land as a % of total land area	Rural pop as a % of total population	Crop production index	Food production index
Mean (USD)	376.82	703.28	636.82	563.91
Median (USD)	275.92	334.55	530.07	494.55
Maximum (USD)	1,060.11	9,229.18	2,460.44	2,148.61
Minimum (USD)	0.75	135.38	118.63	80.75

TABLE 15

Real recurrent costs for SLM in Africa 2012USD/ha/year

	Agric. land as a % of total land area	Rural pop as a % of total population	Crop production index	Food production index
Mean (USD)	61.19	145.98	142.55	146.75
Median (USD)	55.21	66.28	114.22	116.05
Maximum (USD)	131.98	1,956.08	600.50	701.57
Minimum (USD)	1.20	27.35	22.64	12.60

Section 6.3.1 explains the procedure that was used to select the subset of bivariate regressions from *Table 11* to use in the rest of the analysis.

3.6.4. Selection of meta-analytic transfer functions

The following criteria was used to select the meta-analytic transfer functions from *Table 11* to be subsequently used in estimating the capital and recurrent costs of SLM in Africa (by country):

- First, the beta coefficients were required to be statistically significant in both equations (i.e. the equation for capital costs and recurrent costs). This criterion excluded the bivariate regressions having the following independent variables from consideration: country population, rural population, GDP, rural population growth, extent of agricultural land, arable land, arable land as a percentage of total land, land under cereal production, land under permanent crop production, land under forestry, average precipitation, general extent of land area, livestock production index, surface area, cereal yield, agriculture value added per worker and total livestock units.
- Beyond statistical significance, the beta coefficients were additionally required to have the expected signs in both equations. This criterion excluded the bivariate regressions having the following independent variables from consideration: land under forest area as a percentage of total land, and agriculture value added as a percentage of GDP.

These criteria left us with bivariate regressions which had the following independent variables:

- Rural population as a percentage of total population,
- Agriculture land as a percentage of total land area,
- Crop production index, and
- Food production index.

The following meta-analytic functions were thus estimated from the data set:

Real capital costs USD/ha (2012)

ln. (real capital costs USD/ha) = 14.9268 – 2.219921 ln. (rural pop as a % of total pop) (12)
(t = -2.78) (R^2 = 0.0824)
ln. (real capital costs USD/ha) = -3.1921 + 2.297315 ln. (agriculture land as a % of total land) (12)
(t = 3.00) (R^2 = 0.0947)
ln. (real capital costs USD/ha) = 25.92648 – 4.07868 ln. (crop production index) (14)
(t = -2.52) (R^2 = 0.0688)
ln. (real capital costs USD/ha) = 31.00077 - 5.148744 ln. (food production index) (15)
(t = -1.88) (R^2 = 0.0393)

Real recurrent costs USD/ha/year (2012)

ln. (real recurrent costs USD/ha/year) = 13.47728 – 2.258501 ln. (rural pop as a % of total pop) (16)
(t = -2.52) (R^2 = 0.0690)
ln. (real recurrent costs USD/ha/year) = -1.69767 + 1.487594 ln. (agric. land as a % of total land) (17
(t = 1.69) (R^2 = 0.0321)
ln. (real recurrent costs USD/ha/year) = 26.01122 – 4.419321 ln. (crop production index) (18)
(t = -2.45) (R^2 = 0.0653)
ln. (real recurrent costs USD/ha/year) = 35.16794 – 6.320925 ln. (food production index) (19)
(t = -2.08) (R^2 = 0.0479)

TABLE 16

Real capital costs for SLM in Africa 2012 USD/ha (mechanical)

	Agric. land as a % of total land area	Rural pop as a % of total population	Crop production index	Food production index
Mean (USD)	2,828.65	932.55	197.64	620.68
Median (USD)	416.07	667.74	110.58	371.45
Maximum (USD)	84,843.55	4,841.15	2,607.71	3,199.60
Minimum (USD)	102.79	96.74	2.83	93.44

TABLE 17

Real recurrent costs for SLM in Africa 2012 USD/ha/year (mechanical)

	Agric. land as a % of total land area	Rural pop as a % of total population	Crop production index	Food production index
Mean (USD)	998.23	191.90	33.74	109.56
Median (USD)	77.72	126.78	18.69	63.23
Maximum (USD)	35,895.09	1124.88	451.20	582.87
Minimum (USD)	15.49	15.08	0.47	15.12

TABLE 18

Real capital and recurrent costs for SLM in Africa 2012 USD/ha/year (biological)

	Permanent crop land	
	Real capital costs for SLM in Africa 2012USD/ha	Real recurrent costs for SLM in Africa 2012USD/ha
Mean (USD)	404.21	97.91
Median (USD)	241.84	57.62
Maximum (USD)	2002.65	794.29
Minimum (USD)	12.42	2.82

In the next step, we used 2012 data for each country plugged to the right hand sides of equations 12 – 19 to predict the real capital costs (USD/ha) and real recurrent costs (USD/ha/year) of SLM interventions. This process enabled us to have 4 estimates of real capital costs (2012 USD/ha) and 4 estimates of real recurrent costs (2012 USD/ha/year) for country. Equations 20–27 provide an example of how equations 12–19 were used to predict the average real capital (USD/ha) and real recurrent (USD/ha/year) costs of SLM interventions for Kenya:

Real capital costs for Kenya USD/ha (2012)

$$194 \text{ USD/ha} = \exp.[14.9268 - 2.219921 \ln.(75.63)] \tag{20}$$

$$288 \text{ USD/ha} = \exp.[-3.1921 + 2.297315 \ln.(48.195523)] \tag{21}$$

$$129 \text{ USD/ha} = \exp.[25.92648 - 4.07868 \ln.(172.94)] \tag{22}$$

$$184 \text{ USD/ha} = \exp.[31.00077 - 5.148744 \ln.(148.17)] \tag{23}$$

Real recurrent costs for Kenya USD/ha/year (2012)

$$39 \text{ USD/ha/year} = \exp.\,[13.47728 - 2.258501 \ln.\,(75.63)] \quad (24)$$

$$57 \text{ USD/ha/year} = \exp.\,[-1.69767 + 1.487594 \ln.\,(48.195523)] \quad (25)$$

$$25 \text{ USD/ha/year} = \exp.\,[26.01122 - 4.419321 \ln.\,(172.94)] \quad (26)$$

$$35 \text{ USD/ha/year} = \exp.\,[35.16794 - 6.320925 \ln.\,(148.17)] \quad (27)$$

The model predicted capital costs for SLM interventions (2012 USD/ha) by country in Africa are presented in *Appendix 3a* and the model predicted recurrent costs for SLM interventions (2012 USD/ha/year) by country in Africa are presented in *Appendix 3b*. *Tables 14* and *15* provide a summary of the capital and recurrent costs of SLM interventions in Africa.

For the purposes of implementing cost benefit analysis of SLM interventions by country later in the chapter, we needed a “single figure” for capital (USD/ha) and recurrent costs (2012 USD/ha/year) (instead of the 4 estimates presented in *Tables 12–13*). We used 3 different approaches to obtain such an estimate. In the first approach, we computed the arithmetic mean of the predictions given by the 4 regressions reported in *Appendices 3a* and *3b* by country. This is what we refer to as estimate 1 in *Appendix 3c*. In the second approach, we used t-tests to group the predictions reported in Appendices 3a and 3b into subsets that were statistically similar. For example, one can use a t-test to verify whether the mean predictions provided by the regressions “agriculture land as a percentage of total area” and “rural population as a percentage of total population” are statistically similar (i.e. null hypothesis of equality of means). This approach showed that the predictions provided by the regressions “agriculture land as a percentage of total area” and “rural population as a percentage of total population” were statistically similar. Estimate 2 (*Appendix 3c*) averages the predictions provided by the regressions “agriculture land as a percentage of total area” and “rural population as a percentage of total population”. Estimate 3 (*Appendix 3c*) averages the predictions provided by the regressions “rural population as a percentage of total population”, “crop production index” and “food production index”. Estimate 2 (*Appendix 3c)* most closely reproduces the capital and recurrent costs of SLM interventions observed in the data used to estimate the meta-transfer functions.

Finally we disaggregated the total costs of SLM in Africa reported in *Tables 14–15* into the costs of mechanical and biological techniques. The results from this analysis is presented in *Tables 16–18*, with the details presented in *Appendix 3d–3f*.

3.7. Limitations of using meta-analytic transfer function approach to estimating the cost of SLM in Africa by country

The ability of OLS to predict the unknown population parameters critically depends on the satisfaction of the independence and identically distributed (iid) assumption. This assumption will most likely be guaranteed if observations are randomly selected from the population. Unfortunately in our instance, we did not have the luxury to select a simple random sample. We used data that is based on self-reporting, with no guarantee that the (iid) assumption will be satisfied. However fundamentally for our purpose, as long as the rest of the Gauss Markov assumptions are satisfied, theoretically it will not be wrong to use OLS on this data even if (iid) is not satisfied. The estimates one obtains from OLS given (iid) is not satisfied will not be wrong, they will be biased. It is for this reason that we preferred to provide 3 estimates for each country in *Appendix 3c* to provide a range rather than providing a point estimate.

The other major limitation we had with this sample is that there was huge variability in the values reported for the dependent variables resulting in outliers that might impact on the predictive ability of OLS. Thus for example the establishment cost ranged from 2012 USD 0.4788 per ha to 2012 USD 86,992.35. The recurrent cost ranged from 2012 USD 0.0324 per ha per year to 2012 USD 21,748.09. Since we logged these dependent variables prior to estimation, we hope that we were able to limit the influence of these outliers.

There exist other issues that could potentially limit the predictions from the present analysis: the case studies analysed were not drawn from all countries in Africa; this study estimates an average cost of SLM in Africa yet in reality there exist huge

variations in the costs of agronomic measures, structural measures, vegetative measures and management measures; with the exception of probably Ethiopia, Kenya, Tanzania and South Africa, the sampled studies in the other countries are too small to give a good indication of the average costs of SLM in the countries, etc. All these are valid concerns. If it was possible, we would have designed our own samples, collected our own primary data and based our inferential statistics on analysing the samples we would have designed. However in this exercise we are using best practice to analyse data that is currently available, it is the best that one can hope for, our estimates should be interpreted in this context.

CHAPTER

04

Cost benefit analysis and benefit cost ratio

4.1. Introduction

The analysis in the previous chapters provides insights on the losses faced by African countries derived by a lack of action against nutrient depletion. The objective of this chapter is to make a cost benefit analysis of taking action against nutrient depletion in Africa based on the results of the previous chapters. The chapter specifically aims to assess what will be happening in the future:

- If countries are not going to take action, in other words, what is the future cost of inaction?
- If countries are taking action, how much will it cost to address soil erosion induced nutrient depletion in the next 15 years (2016–2030)?
- How much is the present values of the benefits of such action?, and
- Finally, compare the benefits of action with the costs of action for decision-making.

Thus, the next section of the chapter discusses how the net present value and benefit cost ratios of taking action against nutrient depletion induced by erosion and poverty are calculated. The section also provides assumptions on the flows of future benefits and costs. Section 3 of the chapter presents the results of the cost benefit analysis and is followed by the results of the sensitivity analysis. Conclusions and policy recommendations are provided in *Chapter 5*.

4.2. Methods: the net present value and benefit cost ratio

We applied the net present value (NPV) as a main decision criterion to evaluate the economic profitability of taking action against nutrient depletion. NPV sums up the discounted annual flows of net benefits, which in turn is the difference of discounted benefits of action and discounted costs to action against nutrient depletion, over the life of the project. The NPV of a project is the amount by which it increases net worth in present value terms. Therefore, the decision rule is to accept a project, in this case take action against nutrient depletion, with non-negative NPV and reject otherwise:

$$NPV_{ij} = \sum_{t=0}^{T} [(B_{ijt} - C_{ijt})(1 + r_i)^{-t}] \qquad (28)$$

Where,
NPV_{ij} is Net Present Value (in PPP USD) for country I for taking action against nutrient depletion caused by factor j
B_{ijt} is benefit of action for country i at time t (in PPP USD) from taking action against nutrient depletion caused by factor j
C_{ijt} is country i's cost of taking action against nutrient depletion caused by factor j at time t (in PPP USD)
r is real discount rate in country i
t is time in years (t = 0, 1, 2, ...T)
j is the factor causing nutrient depletion
I is a subscript for country

Calculating NPV of taking action against nutrient depletion caused by a particular factor requires decision on three important parameters that may necessitate making some plausible and policy relevant assumptions. These are the discounting period, the flows of costs and benefits over the discounting period, and the discount rate.

Discounting period: The first is to determine a reasonable period over which countries make action against nutrient depletion. In the determination of the discounting period, taking national and global scale development goals and the time set to achieve such goals are important factors to consider so that the results of the study can be integrated to national, regional, and global scale development goals. In this regard, we have selected a period of 15 years (2016–2030), which is also a period that the world is in the process of launching the post-2015 sustainable Development Goals after taking lessons from the last 15 years of efforts for achieving the Millennium Development Goals.

i *www.unstats.un.org/unsd/methods/m49/m49regin.htm*

Flow of costs and benefits of action: Once the project period is determined, the next step is to estimate the flows of costs and benefits of action for each year of the discounting period. Plausible assumptions were made in determining the flows of costs and benefits of taking action against erosion and poverty induced nutrient depletion. These are outlined in *box 5*.

Rate of discount: The choice of discount rate for cost benefit analysis, which has critical role in the evaluation of public projects, has been a focus of continuous debate in the economics literature. There are two schools of thought, namely the descriptive and prescriptive approaches to choosing the social discount rate (Arrow, et al., 1996). The descriptive approach relates social discount rates to financial market interest rates (Baum, 2009). Some economists in the descriptive school argue that a positive rate of discount is required by the logic that consumers have positive time preference in that they require an incentive, in the form of payment of interest, to postpone consumption by saving. Based on the notion of consumer sovereignty and considering society as the summation of individual consumers, this school argues that positive social discount rate reflecting society's positive time preference should be applied in making intertemporal choices (Perman & al., 2011). As indicated in Baum (2009), supporters of the descriptive approach include (Bauer, 1957), (Nordhaus, 2007) and (Anthoff, et

BOX 5

Assumptions on the flows of costs and benefits

Assumptions on flows of costs and benefits of action against erosion induced land degradation:

- We assumed that each country will establish sustainable land management structures on 20 % of the cropland area (average of the 2010–12 land area harvested with cereals) and all the croplands will have these erosion controlling structures by the end of the first 5 years. Thus, the value of σ in equation 10 is 0.2. For the fact that establishing conservation structures on croplands require labor, we considered the labor in agriculture and the total land area under cereal crop cultivation in determining the ratio. The total labor force in agriculture for the year 2012 in all of the 42 countries was about 218 million and the total cropland cultivated was 104 million ha. Therefore, the average land per labor was about 0.478. Assuming a plan of developing 20 % of the land with conservation structures implies 1 labor in agriculture need to develop a conservation structure on 0.095 ha of land per year, given the technical and financial resource.
- We assumed that maintenance costs start from the 2nd year on wards.
- In the case of flows of benefits of action, we assumed zero benefits of action at $t = 1$. The benefits of action for the following years are assumed as a product of $n\lambda$ and the cost of inaction as described in equations 9a and 9b where $\lambda = 0.75\sigma$ with 0.75 representing the effective rate of sustainable land management structure in controlling soil erosion. Soil and water conservation measures vary in their effectiveness in reducing soil erosion owing to different factors. Bench-terraces for example are reported to have more than 75 % effectiveness in reducing soil erosion (Tenge, et al., 2011).

Assumptions on flows of costs and benefits of action against erosion induced land degradation:

- We assumed that each country would set poverty reduction as a priority policy goal and work to achieve a zero poverty gap by the year 2030. In a period of 15 years, it means a country has to reduce the poverty gap by an average of 6.67 % per year from its current level. Thus $\varphi = 0.067$ in equation 11, which is applied to determine the flow of cost of poverty reduction.
- Similarly, $\lambda = 0.067$ was applied in equations 9a and 9b to calculate the flows of benefits of action.

al., 2008). The other school, which is termed as the prescriptive, argues that society should not adopt the preferences of individuals and hence the market rate of interest. Rather this school suggests the use of prescribed discount rates derived from fundamental ethical views, which for example has to consider the issue of intergenerational equity in the analysis of projects and societal issues with long-term effects, for example, climate change (Ramsey, 1928; Stern, 2008; Dasgupta, 2008).

In a perfectly competitive market where there is efficiency and optimal allocation of resources, the market interest rate is considered as the appropriate social discount rate. However, in the real world where markets are imperfect, there are four alternatives in the choice of social discount rate. These include the social rate of time preference (SRTP), marginal social opportunity cost of capital (SOC), the weighted average of the two, and the shadow price of capital. The SRTP is the rate at which a society is willing to postpone a unit of current consumption in exchange for higher consumption in future. Proponents of the use of SRTP as a social discount rate argue that public projects displace current consumption, and flows of costs and benefits to be discounted are flows of consumption goods either postponed or gained (Sen, 1961; Marglin, 1963; Diamon & al, 1968; Kay, 1972). The SRTP is mostly approximated by after tax rate of return on government bonds. The second alternative is the marginal social opportunity cost (MSOC) of capital, which is based on the notion of resource scarcity. Proponents of this alternative (example: Mishan, 1967; Baumol, 1968; Diamond and Mirrlees, 1971) argue that public and the private sector compete for the same pool of funds and hence public investment crowds out private investment. Public sector investment should yield at least the same return as the private investment, otherwise, social welfare could be better increased by reallocation of resources to the private sector, which gives higher returns. Real pretax rate of return on top-rated corporate bonds is considered as good proxy of the marginal social opportunity cost of capital (Moore et al., 2004). The third alternative is taking the weighted average of the SRTP and MSOC, however this approaches lack of clear rule on how to set the weights. The fourth alternative is the shadow price of capital, which is based on the contributions by (Feldstein, 1972), (Bradford, 1975), and (Lind, 1982) among others. This method tries to reconcile the three other alternatives. Further details on this and all the alternative approaches can be found in the review of (Zhuang, et al., 2007).

The above review indicates that there is no one-fit-for all method or way of choosing the discount rate. Therefore, for our analysis we used real interest rate of each country for discounting. We were able to get data on the real interest rates for the period 2010–12 for 21 of the 42 countries in our sample from the World Bank Database. We took the geometric mean of the three years data to determine the real interest rate for a country. For countries with no data, we took the average of the real interest rates of the 21 countries.

Benefit cost ratios and annuity: As a second decision criterion, we also calculated the benefit cost ratio. Moreover, for each country the annuity values of the PVC, PVB as well as the NPV were calculated and compared with the average GDP and agricultural GDPs of the respective countries. All values are in terms of PPP USD at the 2011 constant dollar value.

Sensitivity analysis: We conducted sensitivity analysis to observe the sensitivity of NPVs and BCR to changes in important parameters used in the cost benefit analysis. These include changes in the discount rates, prices of cereals, capital and maintenance costs of sustainable land management (SLM) interventions against soil erosion, the effectiveness of soil and the SLM interventions in controlling soil erosion, and the rate or number of years required to implement the SLM interventions.

4.3. Results of the cost benefit analysis

4.3.1. The present values of the future costs of inaction (2016–2030)

Cost of inaction against erosion induced nutrient depletion: *Table 19* below shows the present values of the costs of inaction against erosion and poverty induced nutrient depletion in Africa. In the next 15 years, inaction against soil erosion from the 105 million hectares of croplands will lead to a total annual loss of about 4.74 million ton of NPK nutrients per year worth of about 72.40 billion PPP USD in present value, which is equivalent to 5.09 billion PPP USD per year. The loss of this supporting

TABLE 19

Present value costs of inaction against erosion and poverty induced nutrient depletion in Africa (-0.13 ≤ r≤ 0.43; t = 15 years (20016–30))

Factor	Cereal cropland area in millions of ha	NPK loss millions ton/yr	Value at Replacement cost in billions of PPP USD (constant 2011 USD)		Crop loss in millions of ton/yr	Cost of inaction (value of crop loss) in billions of PPP USD (constant 2011 USD)			
			PV	Annuity		PV	Annuity	Annuity as % of 2010–12 average	
								GDP	Agri GDP
Erosion	104.44	4.73	72.40	5.090	279.69	4585.76	285.84	12.29	42.72
Poverty	104.44	0.81	13.62	0.811	37.44	665.27	27.55	1.75	6.22

ecosystem service will further cost the 42 countries in the continent in terms of loss of cereals as provisioning agricultural ecosystem service worth of about 4.59 trillion PPP USD in present value over the 15 year. This means that cereal output loss is worth about 285.84 billion PPP USD (= 127 billion USD) per year in present value as an annual cost of inaction against soil erosion. This annuity value of cost of inaction is equivalent to 12.29% of the average annual GDP and 42.72% of the agricultural GDP of the 42 countries over the period 2010–12.

The mean annual cost of inaction against soil erosion induced nutrient depletion is higher for countries with the largest annual rate of soil erosion and vice versa. For example, the mean annual cost of inaction for countries in the top erosion quantile group, ER5, is 17.38 billion PPP USD (*Appendix 4a*). These countries include DR Congo, Egypt, Mali, Mauritania, Namibia, Niger, South Africa, and Sudan. Whereas the corresponding mean annual cost of inaction for the bottom erosion quantile countries (ER1) is 1.08 billion PPP USD and these countries include Burundi, Djibouti, Guinea, Lesotho, Malawi, Ruanda, Sierra Leone, Swaziland, and Togo (*Appendix 4a*).

Cost of inaction against poverty induced nutrient depletion: If the current poverty gap in African countries remains unchanged in the next 15 years, it will cause a total annual loss of about 0.81 million ton of NPK nutrients per year. This is worth about 13.62 billion PPP USD in present value, which is equivalent to 0.811 billion PPP USD per year *(Table 19)*. The loss of this supporting ecosystem service will further cost the continent, in terms of loss of cereals as a provisioning ecosystem service, about 665.27 billion PPP USD in present value over the 15 years. This means a cereals output loss of 37.44 million ton/year with worth of 27.55 billion PPP USD (= 11.34 billion USD) per year in present value as an annual cost of inaction against poverty induced nutrient depletion. This annuity value of cost of inaction is equivalent to 1.75 and 6.22% of the average total and agricultural GDPs of the 42 countries for the period 2010–12. The mean annual cost of inaction against poverty induced nutrient loss is highest for countries in the fourth poverty gap quantile (PGI4 that refers countries with poverty gap index in the range of 0.21 to 0.33) and lowest for bottom poverty quantile countries with poverty gap less than 0.07 (*Appendix 4b*).

4.3.2. The present value of the future costs of action

Cost of action against soil erosion induced nutrient depletion: This study indicates that establishing sustainable land management structures on the 104.4 million hectares of croplands in the 42 countries over a period of 5 years plus maintaining the established structures over the 15 years period until 2030 costs about 344 billion PPP USD in present value. The annuity value of this cost amounts to 21.17 billion PPP USD (= 9.40 billion USD), which is equivalent to 1.15% and 4.53% of the annual total and agricultural GDPs of the 42 countries for the period 2010–12. For erosion classes of 1 to 4, the present value of the cost of action against erosion induced nutrient depletion is highest for the top erosion class countries and vice versa (*Appendix 4c*)

TABLE 20

Present value costs of action against erosion and poverty induced nutrient depletion in Africa (-0.13 ≤ r≤ 0.43; t = 15 years (20016–30))

Factor	SLM Establishment cost (PPP USD/ha)	SLM Maintenance cost in PPP USD/ha/year	Cost of Action (Resource needed to lift the poor to the poverty line) billion of PPP USD (constant 2011 USD)			
			PV	Annuity	Annuity as	
					% GDP	% AgriGDP
Erosion	1082.45	203.81	344.312	21.17	1.15	4.53
Poverty			763.80	61.474	5.02	23.19

The cost of reducing poverty induced nutrient depletion: By next year 2016, the human population in the 42 African countries will reach 1.11 billion, with about 206 million living on income below the poverty line. The population will grow to 1.53 billion by 2030. If these African countries strive to reduce the poverty gap to zero by 2030, a total of about 764 billion PPP USD in present value (about 61.5 billion PPP USD per year) is required to lift the poor out of poverty and provide a level of income equal to the poverty line (1.25 PPP USD per capita per day). The annual required cost of action against poverty and hence poverty induced nutrient depletion accounts for about 5% and 23% of the total and agricultural GDPs of the 42 countries. The cost of action against poverty and hence poverty induced nutrient depletion is proportional to the poverty level of the country (*Appendix 4d*).

4.3.3. Present values of benefits of action versus present values of costs of action and inaction

Benefits of action against erosion induced nutrient depletion: This study indicates that over the next 15 years, about 2.83 trillion PPP USD in present value could be generated as a benefit of action against erosion induced nutrient depletion. This requires all the 42 African countries to invest on sustainable land management on the total 104.4 million hectares of cereal croplands as action against erosion induced nutrient depletion from the croplands. The annuity value of the present value of the future benefits of action against erosion induced nutrient depletion is estimated at about 162 billion PPP USD per year (= 71.82 billion USD/year) for the 42 countries in the continent. These annual benefits of action are equivalent to 6.46% and 22.46% of the average annual GDP and agricultural GDP of the whole countries for the period 2010–12. The mean benefits of action are higher for counties, which are currently experiencing higher rates of soil erosion and vice versa.

Net present value of action against erosion induced nutrient depletion: Our study indicates that the 42 countries in the continent could generate about 2.48 trillion PPP USD in net present value over the next 15 years if all take action against erosion induced nutrient depletion from the 104 million hectares of cereal croplands. For all of the 42 countries in the continent, the annuity value of the NPV accounts for 141 billion PPP USD/year or 62.42 billion USD/year. This is equivalent to 5.31% and 17.93% of the 2010–12 average annual GDP and agricultural GDP of the 42 countries *(Table 21)*. In other words, by taking action against erosion induced nutrient depletion in the next 15 years, the economy of these countries as a whole could grow by an average rate of 5.31% annually compared to their economic status of 2010–12. Specific country level values for the present values of costs of inaction, cost of action, benefits of action and net present values of action against erosion induced nutrient depletion are presented in *Figures 35a* to *35e* by categories of erosion class.

Benefit cost ratio for action against erosion induced nutrient depletion: The mean ratio of benefits and costs of action against erosion induced nutrient depletion is 6.58 indicating that benefits of action are close to 7 times the costs of action. Benefit cost ratios are higher on average for countries with current high rates of soil erosion. Moreover, we have also compared the benefits of action with the costs of in action and found that the

TABLE 21

Present value of costs of inaction, costs of action, benefits of action and NPV of taking action against erosion and poverty induced soil nutrient loss from croplands in Africa (-0.13 ≤ r≤ 0.43; t = 15 years (20016–30))

Factors	PV of cost of inaction	PV of cost of action	Benefits of action				Benefits of action – Cost of action				BCR	BCR2
			PV	Annuity	Annuity as % of 2010–12 average		NPV	Annuity	Annuity NPV as % of			
					GDP	Agri GDP			GDP	Agri GDP		
Erosion	4585.8	344.3	2828.0	161.9	6.46	22.5	2483.7	140.68	5.31	17.93	6.58	0.62
Poverty	665.3	763.8	439.9	15.6	0.88	3.1	-323.9	-45.84	4.14	20.09	0.31	0.66

BRC2 = Benefits of action/cost of inaction

benefits of action on average are 62% of the costs of inaction indicating the possibility of increasing the frontier of benefits of action over the long term. Theoretically, the maximum possible level of benefits of action against nutrient depletion is equal to avoided cost of inaction and hence ratio between benefit and cost of inaction equals 1. However, avoiding the full cost of inaction could only be possible over time and hence the benefits of action could usually be a proportion of the full cost of inaction as least in the short run. *Figures 36a* to *36e* provide details on cost benefit ratios of specific countries grouped by erosion class.

Benefits of action against poverty induced nutrient depletion: Over the period 2016–2030, about 440 billion PPP USD in present value could be generated as benefit of action against poverty induced nutrient depletion. This requires all the 42 African countries to reach a zero level of poverty gap by the year 2030. In other words, on average 6.67% of the poor population should be lifted out of poverty every year to at least a level of income equal to the poverty line.

The annuity value of the present value of the future benefits of action against poverty induced nutrient depletion is estimated at about 15.63 billion PPP USD per year (= 4.58 billion USD/year) for the 42 countries in the continent. These annual benefits of action are equivalent to 0.88% and 3.1% of the average annual GDP and agricultural GDP of the whole countries for the period 2010–12.

Net present value of action against poverty induced nutrient depletion: Our study shows that the total net present value of action against poverty induced nutrient depletion is negative, indicating that the benefit of action is short of financing the costs of action, which is the total income required to lift up the poor to poverty line level of income (*Appendix 4e*).

Benefit cost ratio: The mean ratio of benefits and costs of action against poverty induced nutrient depletion is 0.31 indicating that benefits of action are short by 69% of the costs of action. Benefit cost ratios are higher on average for countries with current lower poverty levels. Moreover, we have also compared the benefits of action with costs of in action and found that the benefits of action on average are 66% of the costs of inaction indicating the possibility of increasing the frontier of benefits of action over the long term (*Appendix 4e*).

4.4. Sensitivity analysis

Sensitivity analysis was conducted to assess the impact of changes in the important parameters on NPV and BCR of action against erosion induced nutrient depletion for all countries. These are presented in Appendices 4a to 4e. The results of the sensitivity analysis are summarized as follows.

Impacts of changes in discount rates: Except for Madagascar, which has the highest base scenario real discount rate, a given percentage change in the real discount rate has resulted in lesser but opposite proportional change in the NPV of action against erosion induced nutrient depletion for all countries. For example, on average, a 50% increase in the real discount rates of all countries will result the sum of all the NPVs of the 42 countries by only 29.84%. Moreover, except for Madagascar, Gabon, and Djibouti, BCR of action against soil erosion

FIGURE 34

Net present values, present values of benefits and costs of action, and present values of costs of inaction for erosion classes 1–5

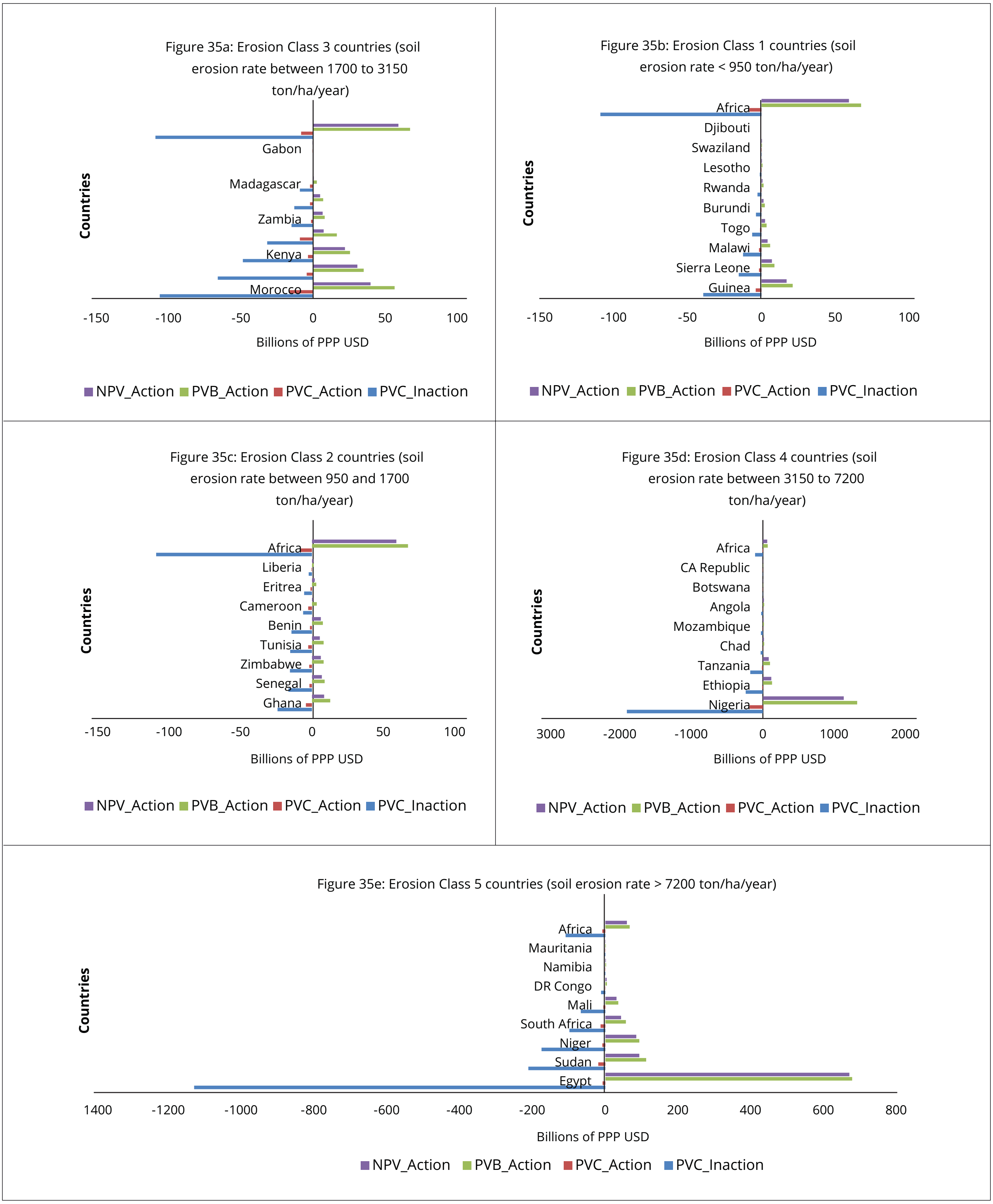
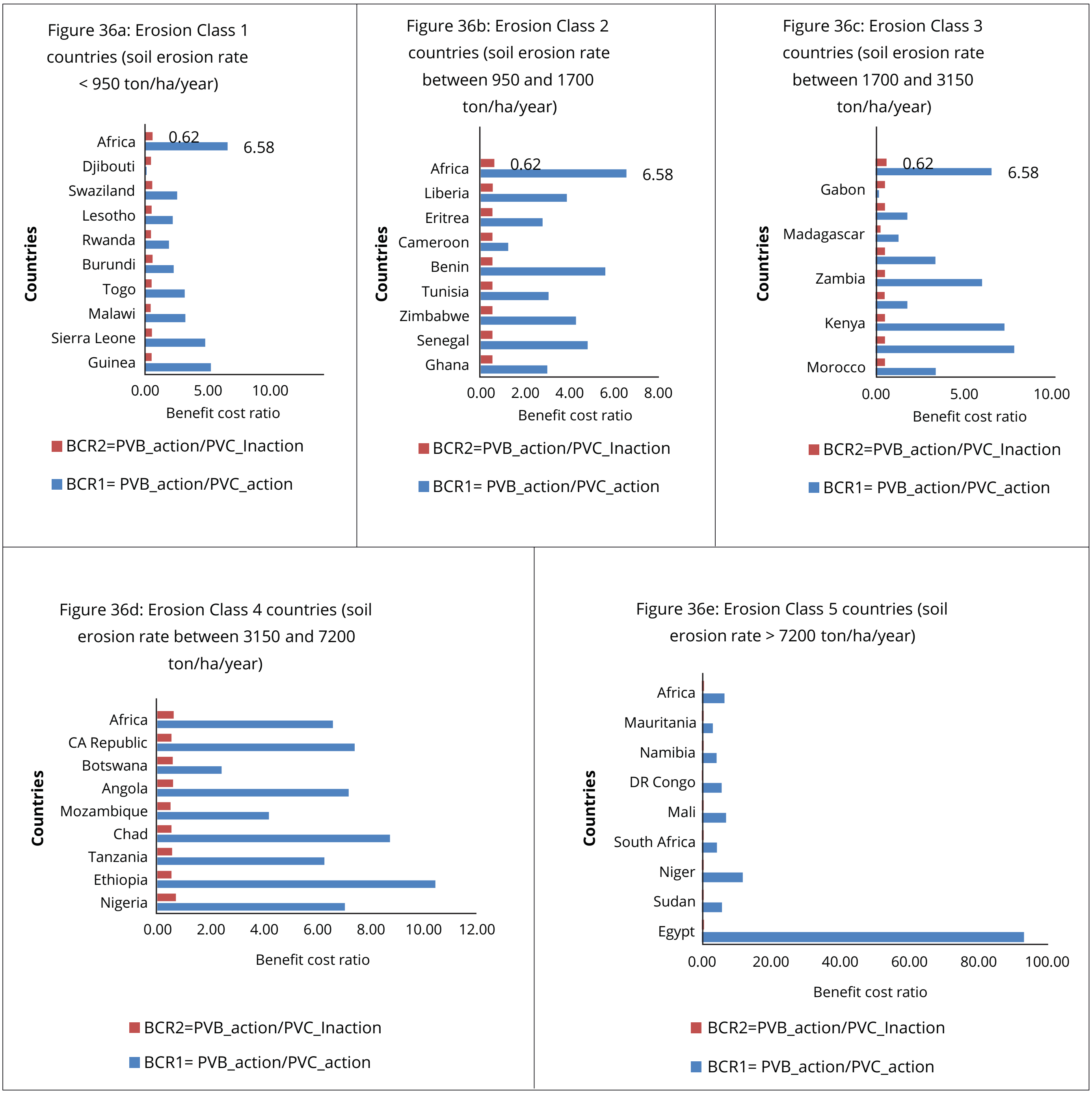


FIGURE 35

Benefit cost ratios for erosion classes 1–5



induced nutrient depletion remains greater than 1 for all countries (*Appendix 4f*).

Impact of changes in prices of cereals on NPVs and BCR of action against soil erosion induced nutrient depletion: A given percentage change in the weighted average producers' price of cereals will result in a direct and higher proportional change in the NPVs of all counties, except the two countries with base scenario negative NPVs. For example, if all other factors remain constant, a 50% increase or decrease in prices of cereals will cause the sum of NPVs of all countries to increase or decrease by 73.78% respectively. Moreover, except for seven countries (Djibouti, Gabon, Cameroon, Madagascar, Congo, Uganda, and Rwanda) the BCR remains greater than one for all the other countries if prices of cereals decrease by 50% from the base case prices (*Appendix 4g*).

Impact of changes in the effectiveness of SLM interventions in controlling soil erosion on NPV and BCR: In the sensitivity analysis, we considered scenarios of SLM interventions with 60%, 40%, 25% and 15% effective rate of controlling erosion induced nutrient depletion. Results indicate that except for Gabon and Djibouti, which have negative NPV in the base case scenario, a decrease in SLM interventions will result in NPV decline by proportionally higher rates. For example, a decrease in the effectiveness of SLM from 75% to 40% will result in a 68.86% decline in the sum of the NPVs of all countries. However, the study also indicates that for a large number of countries, taking action against soil erosion with even less effective SLM technologies yields profit. For a SLM intervention with only 25% effectiveness in controlling soil erosion induced nutrient depletion, 30 of the 42 countries will still have Benefit-Cost Ratio (BCR) of one and above. At this rate, the 12 countries with a BCR minor to 1 are Djibouti, Gabon, Cameroon, Madagascar, Congo, Uganda, Lesotho, Burundi, Botswana, Rwanda, Swaziland, and Eritrea. Furthermore, we found that 5 countries (Burkina Faso, Chad, Ethiopia, Niger, and Egypt) could even generate profits if they invest on SLM technologies as low as 15% effective in controlling soil erosion (*Appendix 4h*).

Impact of changes in capital and maintenance costs of sustainable land management (SLM) interventions on NPV and BCR: The estimates indicate that a percentage change in the total cost of sustainable land management intervention will result in a proportionally higher and opposite change in the NPV of 7 countries, which are Djibouti, Gabon, Cameroon, Madagascar, Congo, Uganda, and Rwanda. Whereas for the rest of the other countries, a percentage change in cost of SLM will result in a proportionally lower and opposite change in NPV. For example, a 200% increase in the total cost of SLM intervention will result in the sum of all NPVs of the 42 countries to decline by only 27.73%. Furthermore, for a 200% increase in costs of SLM, except for 10 countries (Djibouti, Gabon, Cameroon, Madagascar, Congo, Uganda, Rwanda, Lesotho, Burundi, and Botswana) all the other countries will still have BCR greater than one. This indicates that these 32 countries can still be profitable from taking action against soil erosion induced nutrient depletion at a cost action 200% higher than the base scenario (*Appendix 4i*).

Impact of changes in the number of years required to implement the SLM interventions: In the base case scenario, we assumed that all countries would establish SLM structures on all of the cereal croplands within a period of 5 years and undertake maintenance of the established structures every year from the 2nd year onwards until the planned period (2030). We observe additional to planning horizons, 10 years and 15 years, and see the effect on NPVs and BCR. In other words, 10 years planning horizon for implementing SLM intervention means that every country is assumed to establish SLM structures on 10% of its cereal cropland area per year so that by the year 2025 all the land will be developed with soil and water conservation structures.

The change in the planning horizon from 5 years to 10 years for establishing SLM structures will result in the sum of the NPVs of all countries to decline by 19.21% whereas the change to 15 years planning horizon will result in a 41.17% decline in the sum of NPVs of all countries. However, the BCR will still be higher than 1 for almost all countries except Djibouti and Gabon indicating that these planning horizons will still provide a positive but lower NPVs than the base case planning horizon (*Appendix 4j*).

CHAPTER

05

Conclusions and policy recommendations

Land Degradation in Africa continues to be a serious environmental challenge with significant economic and social implications. Our estimation of the net economic value of crop production losses due to erosion induced nutrient depletion in agricultural ecosystems and the link between soil nutrient depletion has a strong bearing for policy interventions. Moreover, in addition to creating new data, such studies need to utilize the existing wealth of available data and generate policy relevant information in an optimal way, that links for example the biophysical aspects of land degradation with the economic drivers of change.

This study presents an economic valuation of the net benefits of action against soil erosion induced nutrient depletion that 42 African countries could generate through investment on sustainable land management interventions, on a total of about 105 million hectares of cereal cropland. Based on data from FAO, the World Bank, and other sources a two-step valuation approach was applied. In the first step, econometric models were developed: a nutrient depletion model to examine the links between soil nutrient losses and national level economic and biophysical factors, and a crop production function to assess the links between soil nutrient loss and crop productivity. Based on the results from the two econometric models, national level nutrient depletions from cereal croplands were estimated based on their relationship with national level economic and biophysical factors, and the associated yield losses of cereal crops due to nutrient depletion. In the second step, two standard valuation methods were applied (i.e., replacement cost and loss in production approaches) to value the losses of nutrients (NPK nutrients) and the losses of cereal crops due to soil nutrient losses induced by erosion. Finally, a cost benefit analysis associated with conservation (i.e., mechanical and biological) was applied. The following measures were estimated: costs of inaction, costs of action, benefits of action, net present values of action, and benefit cost ratios of action against erosion. Poverty induced soil nutrient losses were estimated for 42 African countries for the period 2016–2030. A sensitivity analysis was carried out to assess the impacts of changes in discount rates, prices, and other important parameters on the NPVs and BCR of each country.

The results of the study indicate that the rate of NPK depletion from croplands in Africa has a positive and statistically significant correlation with soil erosion and poverty. From a cropland area of about 105 million hectares of land in the 42 African countries, there was an outflow of about 11 million tons of NPK nutrient. Whereas the inflow was only 5.8 million ton/year during the cropping seasons of 2010–12. This has resulted in a net depletion of 5.2 million tons of NPK per year, which account for about 50 Kg NPK/ha/year. Soil erosion and poverty induced nutrient depletions contributed for about 43.2% and 7.4% of the outflow respectively, which were equivalent to 91.1% and 15.54% of the net loss per year.

The costs of inaction: The loss of this supporting ecosystem service will cost the 42 countries of about 278 million tons of cereals per year. In present value terms, the **cost of inaction against soil erosion induced nutrient depletion to all countries accounts for about 4.6 trillion PPP USD over the next 15 year. This is equivalent to about 286 billion PPP USD (= 127 billion USD) per year or about 12% of the average GDP** of 2010–12 of all the countries. The **cost of inaction against poverty induced land degradation over the next 15 years accounts for about 665 billion PPP USD in present value,** which is equivalent to 27.6 billion PPP USD (=11.3 billion USD) per year.

Costs of action: The present cost for establishing and maintaining sustainable land management structures on about 105 million hectares of cereal croplands, defined as the **cost of action against soil erosion induced nutrient depletion, was estimated at about 344 billion PPP USD** with an annuity value of about 9.4 billion USD. On the other hand reducing poverty and achieving a zero poverty gap in all countries by the year 2030 and hence reducing poverty induced nutrient depletion requires the continent to increase the income level of the poor to at least the poverty line level of income. This requires resources accounting for about **764 billion PPP USD in present value as the cost of action against poverty and poverty induced nutrient depletion** over the next 15 years, or about 25.2 billion USD per year.

Benefits of action and net present value: For the 42 countries in total, **the benefits of action against nutrient depletion caused by soil erosion account for about 2.83 trillion PPP USD** for the next 15 years, or 71.8 billion USD per year. Thus, taking action against soil erosion from the 105 million hectares of croplands in the 42 countries over the next 15 years will generate about **2.48 trillion PPP USD or 62.4 billion USD per year in net present value.** Whereas the net present value of taking action against poverty induced nutrient depletion accounts for about -323.9 billion PPP USD or -20.34 billion USD per year. In other words, the benefits of action against poverty induced nutrient depletion can cover only about 57.6% of the full cost or income required in the next 15 years to lift all the poor population to an income level equal to the poverty line.

The overarching goal of this cost benefit analysis is to show how taking action against soil erosion induced nutrient depletion can potentially be integrated with poverty reduction measures and hence harness the benefits of sustainable natural resource management for increasing agricultural productivity, reducing food insecurity and poverty in the region. Therefore, our analysis shows that African countries could have the opportunity to address at least the problem of national level food insecurity by the year 2030, if they take optimal action against soil nutrient depletion in agricultural lands cultivated with cereals through by investing in sustainable land management technologies. The sensitivity analyses also indicates that, for most of the countries, the net present value of taking action against erosion induced soil nutrient depletion remains positive and considerably high to changes in discount rates, prices of cereals, the costs and effectiveness of actions to control soil erosion induced nutrient depletion, and the planning horizon.

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Appendix

Appendix 1a

Changes in crops and livestock yields that took place in Africa between 2000 and 2010

For the purposes of this report, we gathered data on land cover and land-use change in Africa as baseline data and to potentially show co-relations that might indicate land degradation.

The following tables show changes in crops and livestock yields that took place in Africa between 2000 and 2010. The first set of tables show changes in Agricultural Lands, Permanent Pastures and Meadows, and Inland Water, using data from FAOSTAT and Global Forest Resource Assessments (FRAs). The data for Forest and Other Wooded Lands (OWL) come from the FRAs for 2000 and 2010. "Treeland" is the combination of Forest and OWL. The estimates of Cropland were derived by subtracting the data for Permanent pastures and Meadows from the Agricultural data. The Adjusted Other Land statistics were calculated by subtracting OWL from the FAOSTAT estimates of Other Land. All numbers are in thousands of hectares (000 ha).

In these tables, nations with green highlighting had the most gain in the respective column. Those with a orange highlight lost the most. It is proposed that a decline in Agricultural, Permanent Pastures, Cropland and Forest land with an increase in Other Wooded Lands and Adjusted Other Lands may indicate land degradation.

According to the available statistics (see the list of data sources at the end of Table 22), 43,830 of Agricultural Lands, 59,402 of Permanent Pastures, 284,904 of OWL and 144,063 of Treeland were lost. The rest of the land classes gained area. Africa as a whole lost 79,300 of OWL and 62,869 of Treeland and showed gains in the other categories. Nigeria lost the most Agricultural land (1,300) and Niger gained the most (6,972). Gambia lost the most Permanent Pastures and meadow (107) and Niger gained the most (5,782). Nigeria lost the most cropland (1,300) and Ethiopia gained the most (5,021). For Forest Land, Kenya lost the most (14,815) while Angola gained the most (51,271). For OWL, Madagascar gained the most (14,216) and South Africa lost the most (39,121). For Treeland, once again Angola gained the most (46,053) and South Africa lost the most (38,076). In the Inland Water category, Eretria gained 1,660 and Cameroon lost the most (731). For the Adjusted Other Lands, DRC gained 16,595 and Ethiopia lost 16,708.

Table 23 compares the five regions of Africa. As in *Table 22*, nations with green highlighting had the most gain in that column. Those with a orange highlight lost the most. South Africa had loses in all the vegetation cover types, but gained in inland water and Adjusted Other Lands. This may indicate land degradation in these vegetation types.

The Southern Region lost the most Agricultural land (1,344) and Western Africa gained the most – 15,629. In the Permanent Pasture class, there were no losses for any region as a whole. South Africa gained the most (6,435). In Cropland, South Africa lost 1,344 and Eastern Africa gained 13,919. On the other hand, Eastern Africa lost the most Forest Land (17,278) and Middle Africa gained the most (58,374). In the OWL, South Africa lost the most – 41,128 – and no region showed any gain at the regional level. Middle Africa gained the most Treeland (56,969) and Western Africa lost the most (51,739). For Inland Waters, the Middle Region lost 733, while Western Africa gained 2,275. In the Adjusted Other Land class, Eastern Africa lost the most (12,533) and Middle Africa gained 14,091.

The Appendix contains the detailed data sheets for changes in land use or land cover in all African countries, arranged by region.

Changes in crop yields

Data were also collected from FAO to obtain the change in yields of Sorghum, Wheat, Paddy Rice, Millet and Maize between 2000 and 2010. It is possible that declines in yield are an aspect of land degradation. Table 24 shows data for all countries and Table 25 shows the results by region. For both

TABLE 22

Change in land use/cover between 2000 and 2010, by country

Country/ Region	Total country area 2010	Total land area 2010	Agricultural land change 2000–2010	Permanent pastures and meadows change 2000–2010	Cropland (Ag – per past) change 2000–2010	Forest land change 2000–2010	Other wooded land change 2000–2010	Treeland (For + OWL) change 2000–2010	Inland water change 2000–2010	Adjusted other land change 2000–2010
	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha
Algeria	238174	238174	1353	1134	219	-652	1023	371	0	-2289
Angola	124670	124670	1090	0	1090	51271	-5218	46053	-1	5376
Benin	11476	11276	245	0	245	1632	-842	790	0	386
Botswana	58173	56673	-90	0	-90	-2260	274	-1986	-1	0
Burkina Faso	27422	27360	2300	0	2300	-1577	-2659	-4236	0	958
Burundi	2783	2568	-34	-64	30	48	722	770	0	-503
Cabo Verde	403	403	4	0	4	5	0	5	0	-6.69
Cameroon	47544	47271	540	0	540	-4084	10715	6631	-731	-9055
Central African Rep.	62298	62298	-69	75	-144	-568	101	-467	0	266
Chad	128400	125920	902	0	902	-2137	-851	-2988	0	741
Comoros	186.10	186.10	9	0	9	-11	0	-11	0	-4
Congo	34200	34150	36	0	36	411	7513	7924	0	0
Côte d'Ivoire	32246	31800	1000	200	800	-1320	-4030	-5350	0	0
DR Congo (DRC)	234486	226705	165	100	65	13459	-13646	-187	0	16595
Djibouti	2320	2318	100.6	100	0.6	1	0	1	0	-100.6
Egypt	100145	99545	380	0	380	70	20	90	0	-411
Equatorial Guinea	2805	2805	-40	0	-40	-148	-11	-159	0	168
Eritrea	11760	10100	62	-67	129	-57	2121	2064	1660	0
Ethiopia	110430	100000	5021	0	5021	6541	13096	19637	799	-16708
Gabon	26767	25767	0	0	0	170	0	170	0	0
Gambia	1130	1012	63	-107	170	32	-58	-26	0	0
Ghana	23854	22754	1190	-30	1220	-1695	0	-1695	0	-36
Guinea	24586	24572	811	0	811	-792	0	-792	0	0
Guinea-Bissau	3613	2812	2	0	2	-379	230	-149	800	0
Kenya	58037	56914	649	0	649	-14818	8066	-6752	0	-6077
Lesotho	3036	3036	-8	0	-8	42	-725	-683	0	569
Liberia	11137	9632	50	0	50	205	0	205	1505	250
Libyan Arab Jamahiriya	175954	175954	-99	0	-99	27	-116	-89	0	215
Madagascar	58704	58154	895	295	600	684	14216	14900	0	-3060
Malawi	11848	9428	955	0	955	-33	-3058	-3091	0	506
Mali	124019	122019	2451	640	1811	-1590	-8793	-10383	0	7133
Mauritania	103070	103070	-39	0	-39	-168	-50	-218	-30	164
Mauritius	204	203	-10	0	-10	19	2	21	0	11.7

Country/ Region	Total country area 2010	Total land area 2010	Agricultural land change 2000–2010	Permanent pastures and meadows change 2000–2010	Cropland (Ag – per past) change 2000–2010	Forest land change 2000–2010	Other wooded land change 2000–2010	Treeland (For + OWL) change 2000–2010	Inland water change 2000–2010	Adjusted other land change 2000–2010
	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha
Mayotte	37.50	37.50	-7.9	0	-7.9	14	0	14	0	9.83
Morocco	44655	44630	-663.7	0	-663.7	2095	-634	1461	0	1183.7
Mozambique	79938	78638	1800	0	1800	8110	-27583	-19473	-450	0
Namibia	82429	82329	-11	0	-11	-1337	-1672	-3009	0	2425
Niger	126700	126670	6982	5782	1200	-566	3106	2540	0	-9964
Nigeria	92377	91077	-1300	0	-1300	-6589	-5557	-23963	0	7948
Réunion	251	250	-4.8	1.1	-5.9	17	28	45	0	-24.2
Rwanda	2634	2467	160.68	-90	250.68	373	-16	357	0	-235.68
Saint Helena	39	39	0	0	0	0	-8	-8	0	8
Sao Tome and Principe	96	96	-0.5	0	-0.5	0	-8	-8	-1	0
Senegal	19671	19253	750	-50	800	1692	-7132	-5440	0	0
Seychelles	46	46	-1	0	-1	11	-7	4	0	2.3
Sierra Leone	7230	7218	1120.38	0	1120.38	1170	-4189	-3019	0	372.62
Somalia	63766	62734	62	0	62	-2303	0	-2303	0	706
South Africa	121909	121309	-1234	0	-1234	145	-39121	-38976	118	0
Sudan	250581	237600	4670	2002	2668	27	-1864	-1837	0	-4128
Swaziland	1736	1720	-1	0	-1	84	116	200	0	0
Togo	5679	5439	35	0	35	-378	898	520	0	-734
Tonga	75	72	1	0	1	5	-3	2	0	2
Tunisia	16361	15536	487	291	196	604	-28	576	825	-628
Uganda	24155	19981	1550	0	1550	-1935	1964	29	255	-2181
United Rep. of Tanzania	94730	88580	3450	0	3450	-5854	-10577	-16431	0	6083
Western Sahara	26600	26600	-1	0	-1	0	-859	-304	0	860
Zambia	75261	74339	938	350	588	-4012	1306	-2706	0	0
Zimbabwe	39076	38685	1140	740	400	-6008	-5502	-11510	0	6861
Total Africa	**3031912.6**	**2964894.6**	**39805.76**	**11302.1**	**28503.66**	**27693**	**-79300**	**-62869**	**4748**	**3654.98**
TOTAL WORLD	**13420507.7**	**13009375.1**	**-43830**	**-59402**	**15572**	**140841**	**-284904**	**-144063**	**74366**	**2948906**

Sources of Data:

- *FAO Land use - http://faostat.fao.org/site/377/default.aspx#ancor . Estimates of change in Cropland were derived from Agricultural minus Permanent Pastures and Meadows.*
- *FRA 2000 - http://www.fao.org/docrep/004/y1997e/y1997e1s.htm#TopOfPage and ftp://ftp.fao.org/docrep/fao/003/y1997E/frA %202000 %20Main %20report.pdf Page 427/511 table 5*
- *FRA 2010, Table 2, Annex 3. P. 224–228. (258–262) http://www.fao.org/docrep/013/i1757e/i1757e.pdf*
- *FRA 2000 and 2010 Forest land http://faostat3.fao.org/download/G2/GF/E Estimates of Treeland were derived from adding Forest Land and Other Wooded Lands together.*
- *Data for Waters came from the FRAs and may differ from FAOSTAT. Data for Adjusted Other Land = FAOSTAT Other Land minus OWL.*
- *Data for country total area and land area came from FAOSTAT*
- *Adjusted Other Land = Other land from FAOSTAT = 4093593.27 OWL = 1144687 = 2948906*

All data were accessed 20–22 November 2014.

TABLE 23

Change in land use/cover between 2000 and 2010, by region

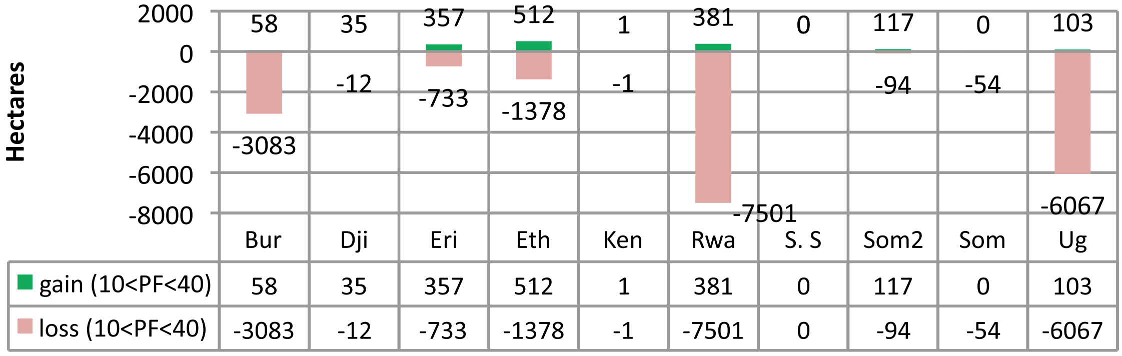
Region	**Total country area 2010**	**Total land area 2010**	**Agricultural land change 2000–2010**	**Permanent pastures and meadows change 2000–2010**	**Cropland (Ag – per past) change 2000–2010**	**Forest land change 2000–2010**	**Other wooded land change 2000–2010**	**Treeland (For + OWL) change 2000–2010**	**Inland water change 2000–2010**	**Adjusted other land change 2000–2010**
	000 ha	**000 ha**	**000 ha**	**000 ha**	**000 ha**	**000 ha**	**000 ha**	**000 ha**	**000 ha**	**000 ha**
Total Eastern Africa	2010	2010	-10	-10	-10	-10	-10	-10	-10	-10
Total Middle Africa	2010	2010	-10	-10	-10	-10	-10	-10	-10	-10
Total Northern Africa	4020	4020	-20	-20	-20	-20	-20	-20	-20	-20
Total Southern Africa	8040	8040	-40	-40	-40	-40	-40	-40	-40	-40
Total Western Africa	16080	16080	-80	-80	-80	-80	-80	**-80**	**-80**	**-80**
Total Africa	**32160**	**32160**	**-160**	**-160**	**-160**	**-160**	**-160**	**-160**	**-160**	**-160**
TOTAL WORLD	**13420507.7**	**13009375.1**	**-43830**	**-59402**	**15572**	**140841**	**-284904**	**-144063**	**74366**	**2948906**

Sources of Data:

- *FAO Land use – http://faostat.fao.org/site/377/default.aspx#ancor . Estimates of change in Cropland were derived from Agricultural minus Permanent Pastures and Meadows.*
- *FRA 2000 - http://www.fao.org/docrep/004/y1997e/y1997e1s.htm#TopOfPage and ftp://ftp.fao.org/docrep/fao/003/y1997E/frA %202000 %20Main %20report.pdf Page 427/511 table 5*
- *FRA 2010, Table 2, Annex 3. P. 224–228. (258–262) http://www.fao.org/docrep/013/i1757e/i1757e.pdf*
- *FRA 2000 and 2010 Forest land http://faostat3.fao.org/download/G2/GF/E Estimates of Treeland were derived from adding Forest Land and Other Wooded Lands together.*
- *Data for Waters came from the FRAs and may differ from FAOSTAT. Data for Adjusted Other Land = FAOSTAT Other Land minus OWL.*
- *Data for country total area came from FAOSTAT.*

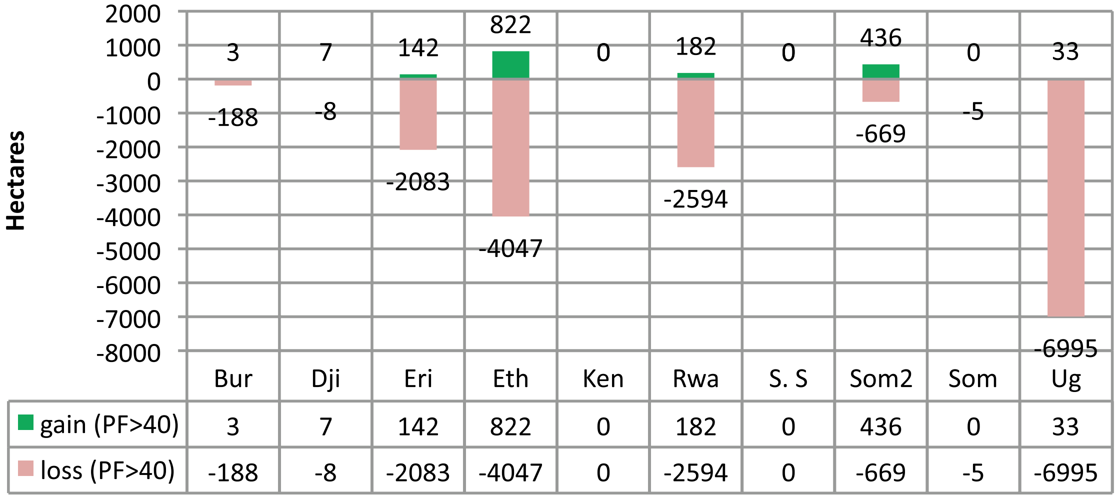
All data were accessed 20–22 November 2014.

Forest loss in areas with 10% to 40% Forest Cover - 2000, 2012 - East Africa Region



	Bur	Dji	Eri	Eth	Ken	Rwa	S. S	Som2	Som	Ug
🟩 gain (10<PF<40)	58	35	357	512	1	381	0	117	0	103
🟥 loss (10<PF<40)	-3083	-12	-733	-1378	-1	-7501	0	-94	-54	-6067

Forest loss in areas with more than 40% Forest Cover - 2000, 2012 - East Africa Region



	Bur	Dji	Eri	Eth	Ken	Rwa	S. S	Som2	Som	Ug
🟩 gain (PF>40)	3	7	142	822	0	182	0	436	0	33
🟥 loss (PF>40)	-188	-8	-2083	-4047	0	-2594	0	-669	-5	-6995

TABLE 24

All Africa change in sorghum, wheat, paddy rice, millet and maize yield (Hg/ha) between 2000–2010

Source: FAOSTAT3: http://faostat3.fao.org/download/Q/QA/E 29 November 2014

Country	Change in sorghum yield Hg/ha 2010–2000	Change in wheat yield Hg/ha 2010–2000	Change in paddy rice yield Hg/ha 2010–2000	Change in millet yield Hg/ha 2010–2000	Change in maize yield Hg/ha 2010–2000
Algeria	-39214.3	5643.99	-1069.6	0	-10358.7
Angola	-519.14	-6487.7	-6051.45	-3241.47	1455.33
Benin	6198.19	0	5443.2	255.42	-453.1
Botswana	4574.34	0	0	1234.34	494.16
Burkina Faso	1741.19	0	-5437.4	2056.06	-3201.5
Burundi	946.7	1748.2	2157.7	184.6	-456.8
Cabo Verde	0	0	0	0	-5747.56

Country	Change in sorghum yield Hg/ha 2010–2000	Change in wheat yield Hg/ha 2010–2000	Change in paddy rice yield Hg/ha 2010–2000	Change in millet yield Hg/ha 2010–2000	Change in maize yield Hg/ha 2010–2000
Cameroon	2646.7	-3852.9	-19166.7	3053.2	-4874.8
Central African Rep.	2301.86	0	8450.1	5040.75	5548
Chad	1798.72	5455.7	2735.7	2822.32	1993.99
Comoros	0	0	1802.9	0	2412.4
Congo	0	0	-398.39	0	0.25
Cote d'Ivoire	936.5	0	12335.8	1354.81	-487.2
Democratic Rep. of the Congo (DRC)	0.83	4.9	21.72	2.15	-204.55
Djibouti	0	0	0	0	-3888.9
Egypt	-7824.5	-7680.4	3192.4	0	-4100.2
Eritrea	-1572.31	5668.46	0	1843.01	6642.07
Ethiopia	9116.6	6753.9	11979.9	6688.54	9194.4
Gabon	0	0	11111.1	0	403.3
Gambia	-190.4	0	-10548	-434.6	-3558.4
Ghana	3153.88	0	5537.7	4253.97	4296.7
Guinea	2591.2	0	1390	-162.8	-2269.2
Guinea-Bissau	1204.97	0	6607.4	2468.41	-2974.05
Kenya	610.19	16499.4	4674.4	645.27	2850.7
Lesotho	-3188.4	8145.98	0	0	2298.04
Liberia	0	0	-994.9	0	0
Libya	0	-95.1	0	313.4	-9566.7
Madagascar	458.99	1424.4	8862	0	5205.96
Malawi	-592.93	7155.18	2179.8	-579.97	2730.3
Mali	1887.48	1485.3	27816	2352.04	14507.1
Mauritania	-274.58	6406.1	9936.5	-61.84	-462.67
Mauritius	0	0	0	0	-20666.7
Morocco	-572.79	12336.49	23270.3	7914.5	8131.7
Mozambique	291.07	3366.7	1549.24	-1394.43	2625.05
Namibia	-1590.91	33622.5	0	-922.69	13142.05
Niger	2207.86	-3447.3	-12538.2	2039.18	1191.52
Nigeria	3197	2628.2	3387.8	1347	5500.6
Reunion	0	0	16454.5	0	-6444.9
Rwanda	3184.24	9214.09	24514.5	4701.1	16398.1
Sao Tome and Principe	0	0	0	0	-8966.7
Senegal	639.24	0	17579.6	744.47	4270.3
Sierra Leone	-384.1	0	7831.1	2364.61	5215.48
Somalia	523.51	373.29	32000	0	501.1
South Africa	-10575.4	-374.2	-3859.5	-820.67	18243.5
Sudan (former)	-1245.22	-5330.9	21832.4	-40.31	5847.94
Swaziland	-785.57	0	-4000	0	-4092.6
Togo	2457.75	0	4005.8	2252.59	-82.5
Tunisia	-415.67	7195.7	0	0	0
Uganda	-1885	-476.2	9931.3	2140	5574.5
United Rep. of Tanzania	4788.09	6868.73	4517.5	1451.07	-3799.4
Zambia	1893.54	1016.7	5445.2	2274.63	8150.8
Zimbabwe	-3194.87	-17999.9	555.6	-649.68	-6129.25
Total Africa	**-14675.45**	**97269.31**	**235045.02**	**53488.98**	**52038.96**

tables, green highlighting indicates the most gain in that column. Those with a orange highlight lost the most. In Table 25, Gambia shows declines in all cereal crops. Several countries show gains in all the types of cereals. Angola had reduced yields in all crops except for maize. Central African Republic showed gains for all five of the cereal crops. Algeria showed declines in yield in three out of the five crops. Morocco showed gains in all but Sorghum. Swaziland showed declines or no change in all 5 crops. Botswana showed gains or no change in all cereals.

In Table 25, we see that Eastern and Western Africa showed gains in yield for all cereal crops.

The Appendix contains the detailed data sheets for changes in crop yields in all African countries, arranged by region.

Changes in livestock

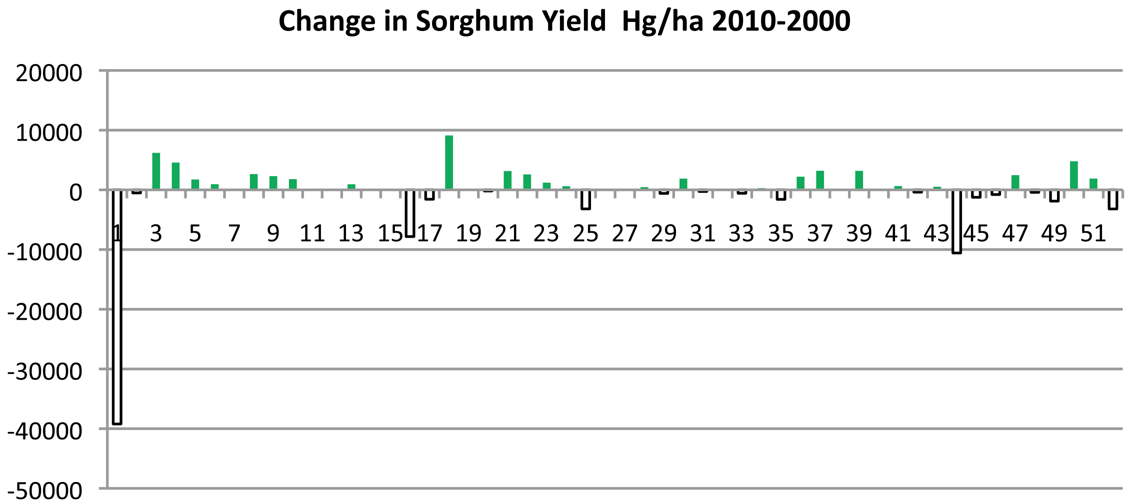
The following tables (Tables 26 and 27) show the data for changes in Goat, Sheep and Cattle yields from 2000 to 2010, by country and by region. A decline in yield may indicate land degradation. Eritrea and Niger showed a decline for all three types of livestock, while the DRC, Egypt, and South Africa showed gains for each. Mauritius also showed gains. Central African Republic showed a decline in yield in goats and cattle.

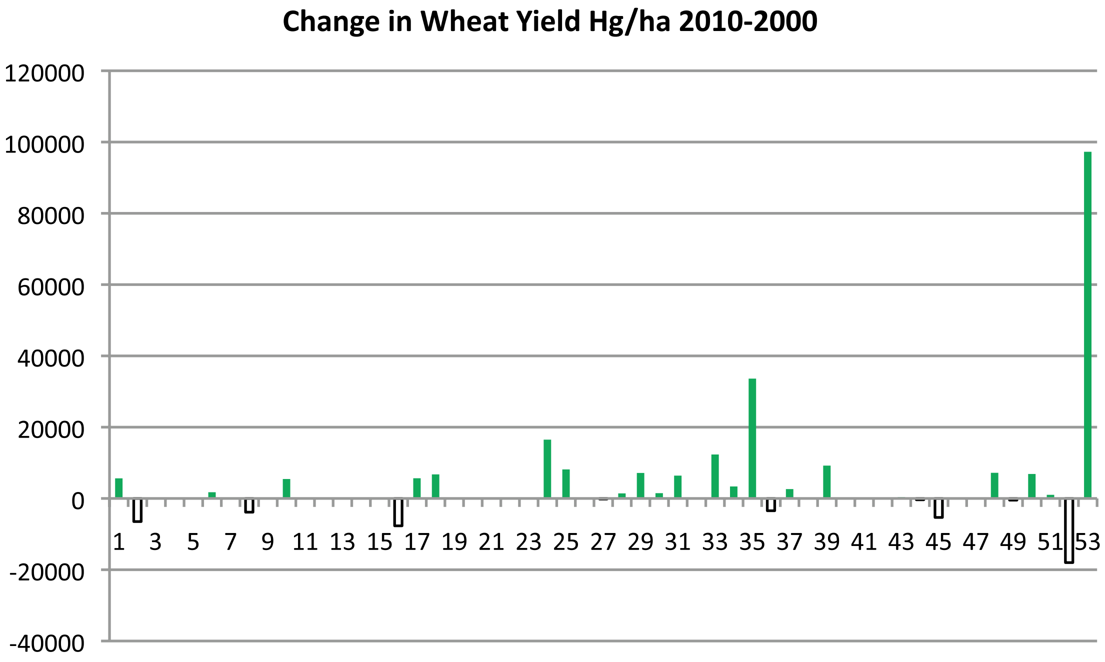
TABLE 25

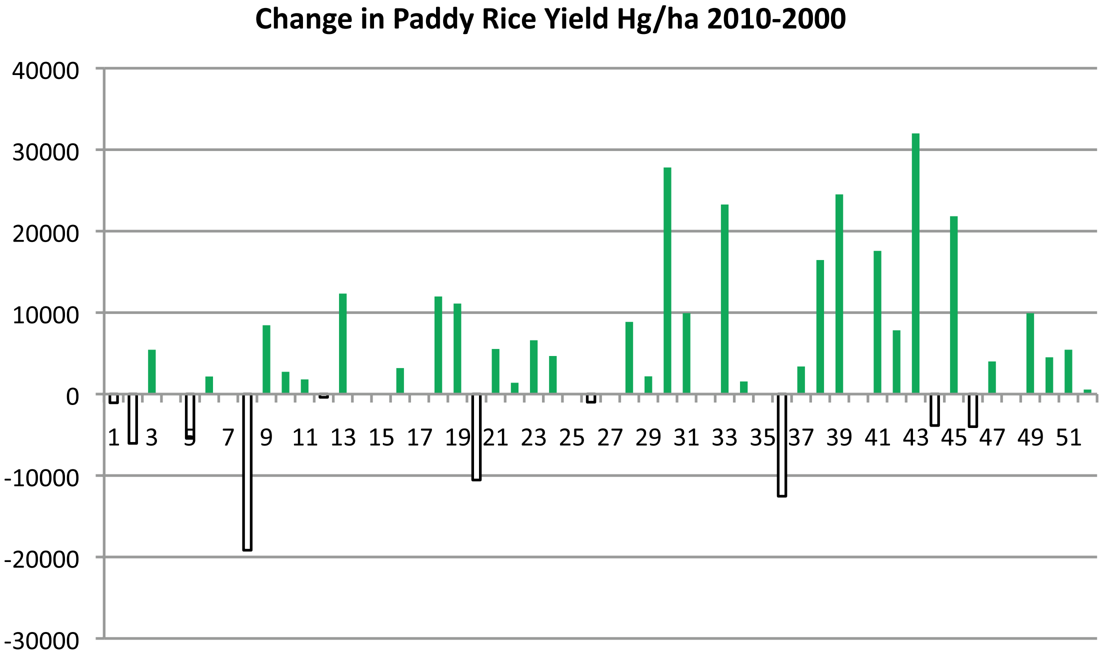
Regional change in sorghum, wheat, paddy rice, millet and maize yield (Hg/ha) between 2010–2000

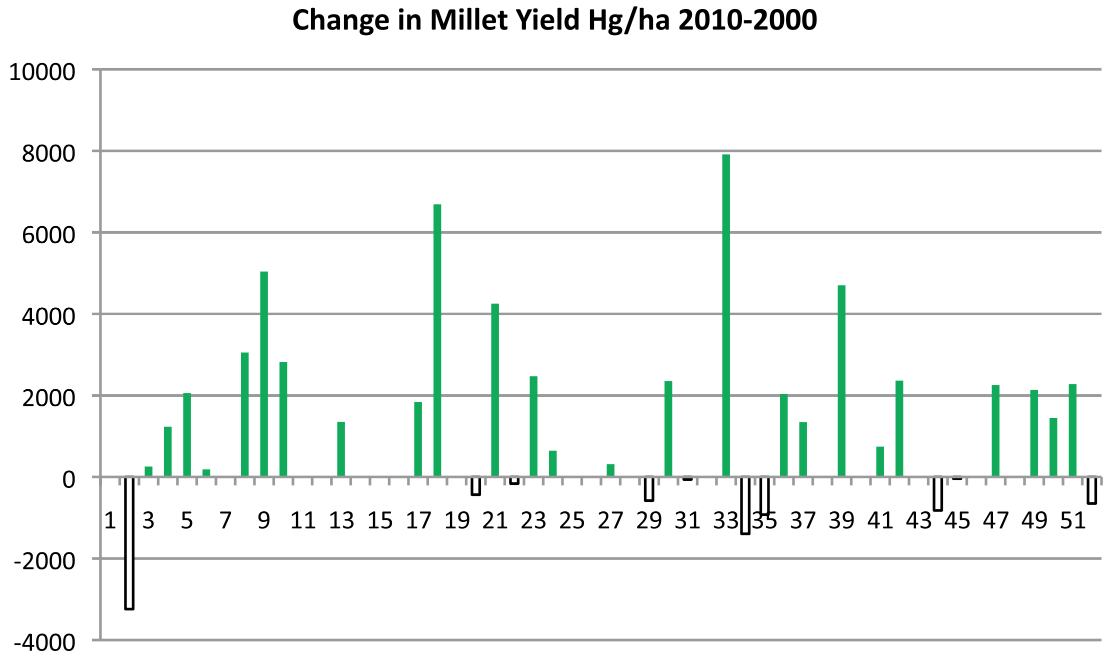
Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E , 29 November 2014

Country	Change in sorghum yield Hg/ha 2010–2000	Change in wheat yield Hg/ha 2010–2000	Change in paddy rice yield Hg/ha 2010–2000	Change in millet yield Hg/ha 2010–2000	Change in maize yield Hg/ha 2010–2000
Eastern Africa	10	10	10	10	10
Middle Africa	10	10	10	10	10
Northern Africa	20	20	20	20	20
Southern Africa	40	40	40	40	40
Western Africa	80	80	80	80	80
	160	160	160	160	160
Total Africa	**320**	**320**	**320**	**320**	**320**


Change in Sorghum Yield Hg/ha 2010-2000


Change in Wheat Yield Hg/ha 2010-2000
120000
100000
80000
60000
40000
20000
0
-20000
-40000
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53


Change in Paddy Rice Yield Hg/ha 2010-2000
40000
30000
20000
10000
0
-10000
-20000
-30000
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51


Change in Millet Yield Hg/ha 2010-2000
10000
8000
6000
4000
2000
0
-2000
-4000
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51

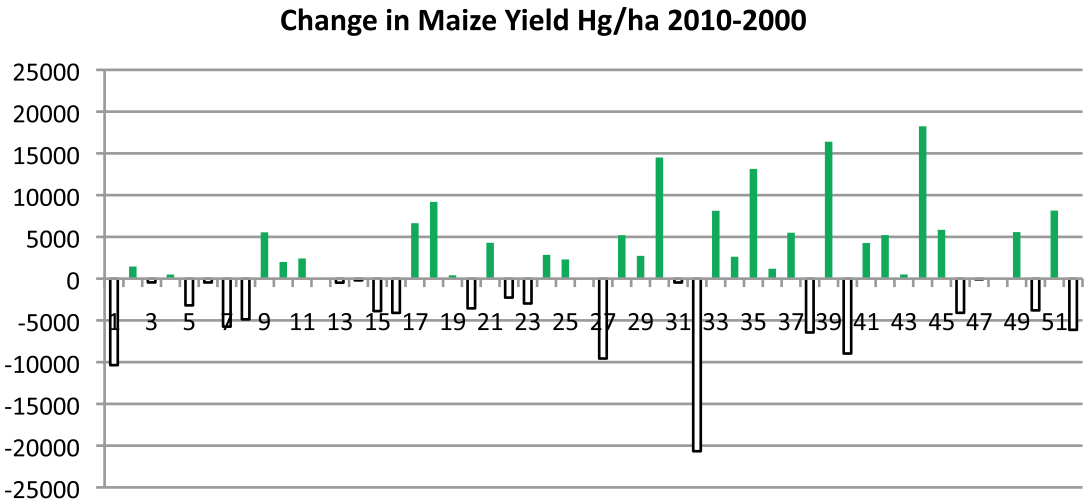

Change in Maize Yield Hg/ha 2010-2000
25000
20000
15000
10000
5000
0
-5000
-10000
-15000
-20000
-25000
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51

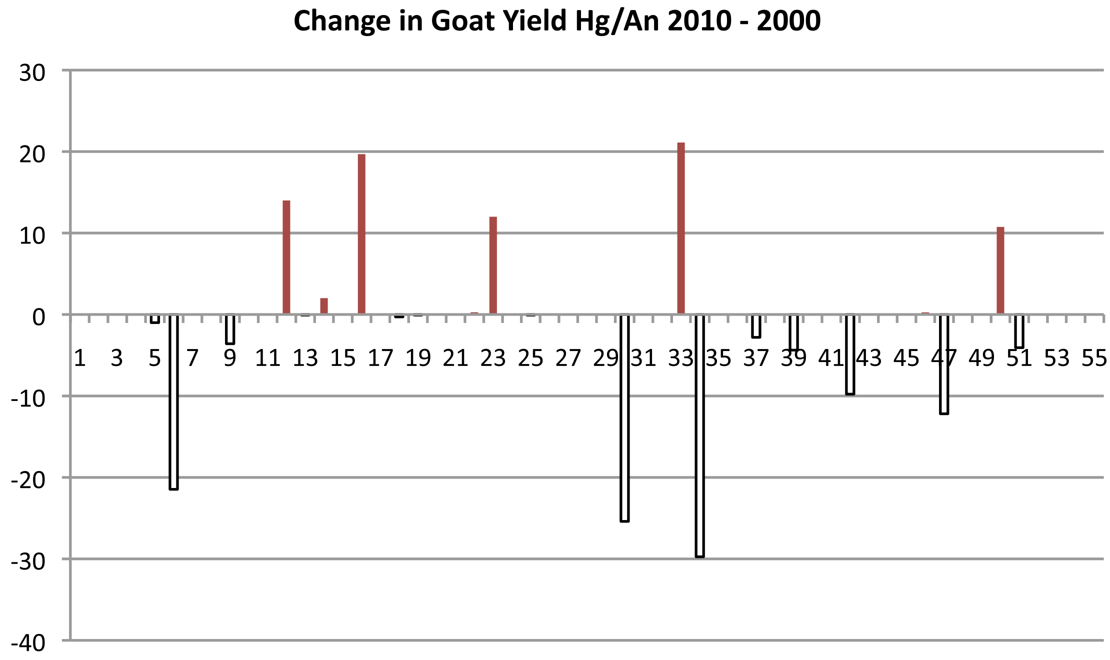
TABLE 26

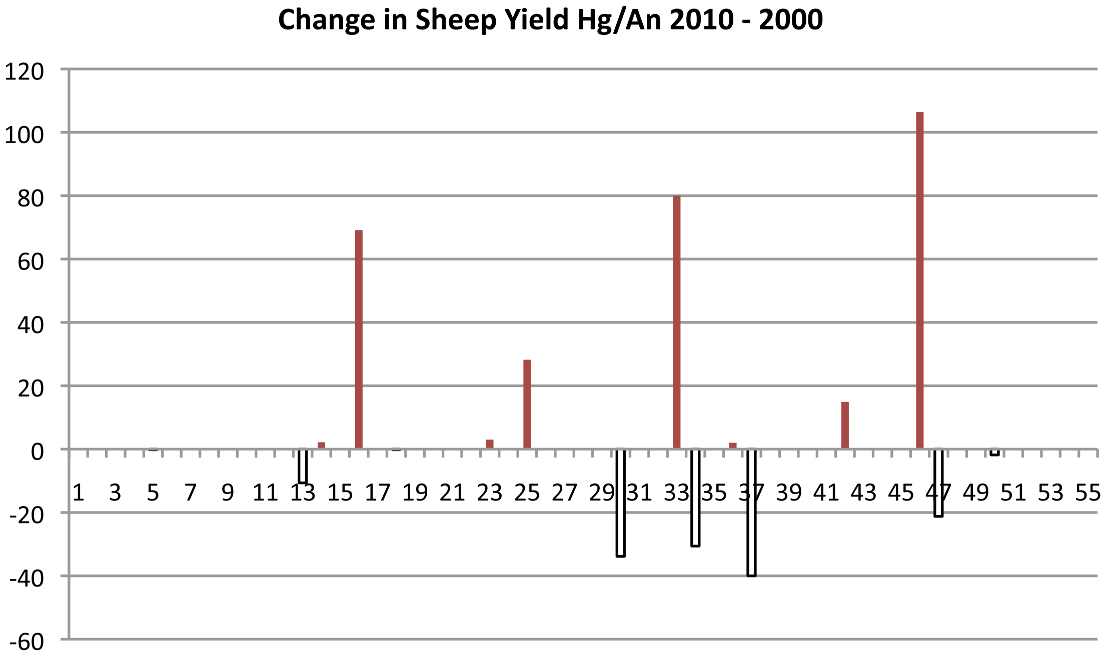
All Africa goat, sheep, and cattle change in yield (Hg/An) per animal between 2000 and 2010

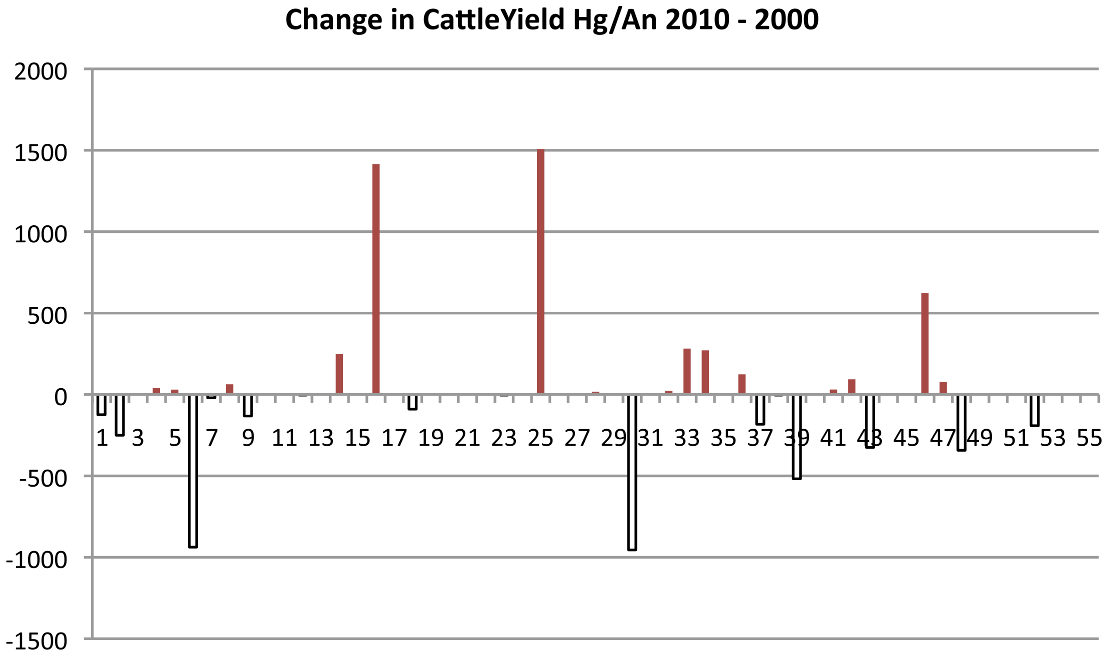
Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E, 29 November 2014

Country	Change in goat yield Hg/An 2010–2000	Change in sheep yield Hg/An 2010–2000	Change in cattle yield Hg/An 2010–2000
Algeria	0	0.056	-124.31
Angola	0	0	-250.23
Benin	0	0	0
Botswana	0	0	40
Burkina Faso	-1.0004	-0.0031	30
Burundi	-21.46	0	-937.56
Cabo Verde	0	0	-20.32
Cameroon	0	0.007	62.6
Central African Republic	-3.589	0	-132.05
Chad	0	0	0
Comoros	0	0	0
Congo	14	0	-3.04
Cote d'Ivoire	-0.0003	-10.658	0.01
Democratic Republic of the Congo (DRC)	2.012	2.1792	248.94
Djibouti	0	0	0
Egypt	19.684	69.125	1415.8
Equatorial Guinea	0	0	0
Eritrea	-0.2941	-0.156	-90
Ethiopia	-0.0017	0	8.04
Gabon	0	0	0
Gambia	0	0	0
Ghana	0.276	0	0
Guinea	12	3	-1.327
Guinea-Bissau	0	0	0
Kenya	-0.056	28.218	1507.727
Lesotho	0	0	0
Liberia	0	0	0
Libya	0	0	17.39
Madagascar	0	0	0
Malawi	-25.3975	-33.859	-954.71
Mali	0	0	0
Mauritania	0	0	23.26
Mauritius	21.111	80	282
Morocco	-29.74	-30.607	271.05
Mozambique	0	0	0
Namibia	0	2	123.79
Niger	-2.806	-39.999	-182.65
Nigeria	0	0	-1.31
Reunion	-4.374	0	-517.81
Rwanda	0	0	0

Country	Change in goat yield Hg/An 2010–2000	Change in sheep yield Hg/An 2010–2000	Change in cattle yield Hg/An 2010–2000
Sao Tome and Principe	0	0	30.57
Senegal	-9.7774	14.909	93.22
Seychelles	0	0	-325.07
Sierra Leone	0	0	0
Somalia	0	0	0
South Africa	0.266	106.443	623.23
Sudan (former)	-12.1875	-21.222	77.85
Swaziland	0	0	-342.62
Togo	0	0	0
Tunisia	10.752	-1.837	0.72
Uganda	-4.072	0	0
United Republic of Tanzania	0	0	-191.747
Western Sahara	0	0	0
Zambia	0	0	0
Zimbabwe	0	0	0.34
Total Africa	**-34.6549**	**167.5961**	**781.783**




Change in Sheep Yield Hg/An 2010 - 2000
120
100
80
60
40
20
0
-20
-40
-60
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55


Change in CattleYield Hg/An 2010 - 2000
2000
1500
1000
500
0
-500
-1000
-1500
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55

As with all the tables, green highlighting indicates the most gain in that column. Those with a orange highlight lost the most. Western Africa as whole lost in yield for all livestock.

Nations with green highlighting had the most gain in that column. Those with a orange highlight lost the most.

TABLE 27

Regional change in goat, sheep, and cattle yields (Hg/An) per animal between 2000 and 2010

Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E

Country	Change in goat yield Hg/An 2010–2000	Change in sheep yield Hg/An 2010–2000	Change in cattle yield Hg/An 2010–2000
Eastern Africa	10	10	10
Middle Africa	10	10	43.21
Northern Africa	20	20	1658.5
Southern Africa	0.266	108.443	444.4
Western Africa	40.266	148.443	2156.11
	80.532	296.886	4312.22
Z2 Total Africa	**161.064**	**593.772**	**8624.44**

Data sources for the following tables:

- *FAO Land use - http://faostat.fao.org/site/377/default.aspx#ancor . Estimates of change in Cropland were derived from Agricultural minus Permanent Pastures and Meadows.*
- *FRA 2000 - http://www.fao.org/docrep/004/y1997e/y1997e1s.htm#TopOfPage and ftp://ftp.fao.org/docrep/fao/003/y1997E/frA %20 2000 %20Main %20report.pdf Page 427/511 table 5*
- *FRA 2010, Table 2, Annex 3. P. 224–228. (258–262) http://www.fao.org/docrep/013/i1757e/i1757e.pdf*
- *FRA 2000 and 2010 Forest land http://faostat3.fao.org/download/G2/GF/E Estimates of Treeland were derived from adding Forest Land and Other Wooded Lands together.*
- *Data for Waters came from the FRAs and may differ from FAOSTAT. Data for Adjusted Other Land = FAOSTAT Other Land minus OWL.*
- *Data for country total area came from FAOSTAT*
- *All were accessed 20–22 November 2014.*

TABLE 28

Eastern Africa's change in land use/cover between 2000 and 2010 for Ag land (pasture and crop) forest, owl, (treeland = forest and owl) other land (FAOSTAT other land – OWL) and inland water

Country/ Region	Total country area 2010	Total land area 2010	Agricultural land change 2000–2010	Permanent pastures and meadows change 2000–2010	Cropland (Ag – per past) change 2000–2010	Forest land change 2000–2010	Other wooded land change 2000–2010	Treeland (For + OWL) change 2000–2010	Inland water change 2000–2010	Adjusted other land change 2000–2010
	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha
Burundi	2783	2568	-34	-64	30	48	722	770	0	-503
Comoros	186.10	186.10	9	0	9	-11	0	-11	0	-4
Djibouti	2320	2318	100.6	100	0.6	1	0	1	0	-100.6
Eritrea	11760	10100	62	-67	129	-57	2121	2064	1660	0
Ethiopia	110430	100000	5021	0	5021	6541	13096	19637	799	-16708
Kenya	58037	56914	649	0	649	-14818	8066	-6752	0	-6077
Madagascar	58704	58154	895	295	600	684	14216	14900	0	-3060
Malawi	11848	9428	955	0	955	-33	-3058	-3091	0	506
Mauritius	204	203	-10	0	-10	19	2	21	0	11.7
Mayotte	37.50	37.50	-7.9	0	-7.9	14	0	14	0	9.83
Mozambique	79938	78638	1800	0	1800	8110	-27583	-19473	-450	0
Réunion	251	250	-4.8	1.1	-5.9	17	28	45	0	-24.2
Rwanda	2634	2467	160.68	-90	250.68	373	-16	357	0	-235.68
Seychelles	46	46	-1	0	-1	11	-7	4	0	2.3
Somalia	63766	62734	62	0	62	-2303	0	-2303	0	706
United Rep. of Tanzania	94730	88580	3450	0	3450	-5854	-10577	-16431	0	6083
Zambia	75261	74339	938	350	588	-4012	1306	-2706	0	0
Zimbabwe	39076	38685	1140	740	400	-6008	-5502	-11510	0	6861
Total Eastern Africa	612011.6	585647.6	15184.58	1265.1	13919.48	-17278	-7186	-24464	2009	-12532.65
Total Africa	1224023.2	1171295.2	30369.16	2530.2	27838.96	-34556	-14372	-48928	4018	-25065.3
TOTAL WORLD	**13420507.7**	**13009375.1**	**-43830**	**-59402**	**15572**	**140841**	**-284904**	**-144063**	**74366**	**2948906**

TABLE 29

Middle Africa's change in land use/cover between 2000 and 2010 for Ag land (pasture and crop) forest, owl (treeland = forest and owl) other land (FAOSTAT other land – OWL) and inland water

Country/ Region	Total country area 2010	Total land area 2010	Agricultural land change 2000–2010	Permanent pastures and meadows change 2000–2010	Cropland (Ag – per past) change 2000–2010	Forest land change 2000–2010	Other wooded land change 2000–2010	Treeland (For + OWL) change 2000–2010	Inland water change 2000–2010	Adjusted other land change 2000–2010
	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha
Angola	124670	124670	1090	0	1090	51271	-5218	46053	-1	5376
Cameroon	47544	47271	540	0	540	-4084	10715	6631	-731	-9055
Central African Rep.	62298	62298	-69	75	-144	-568	101	-467	0	266
Chad	128400	125920	902	0	902	-2137	-851	-2988	0	741
Congo	34200	34150	36	0	36	411	7513	7924	0	0
Dem. Rep. of the Congo	234486	226705	165	100	65	13459	-13646	-187	0	16595
Equatorial Guinea	2805	2805	-40	0	-40	-148	-11	-159	0	168
Gabon	26767	25767	0	0	0	170	0	170	0	0
Sao Tome and Principe	96	96	-0.5	0	-0.5	0	-8	-8	-1	0
Total Middle Africa	661266	649682	2623.5	175	2448.5	58374	-1405	56969	-733	14091
Total Africa	1322532	1299364	5247	350	4897	116748	-2810	113938	-1466	28182
TOTAL WORLD	**13420507.7**	**13009375.1**	**-43830**	**-59402**	**15572**	**140841**	**-284904**	**-144063**	**74366**	**2948906**

Nations with green highlighting had the most gain in that column. Those with a orange highlight lost the most.

TABLE 30

Northern Africa's change in land use/cover between 2000 and 2010 for Ag land (pasture and crop) forest, owl, (treeland = forest and owl) other land (FAOSTAT other land – OWL) and inland water

Country/ Region	Total country area 2010	Total land area 2010	Agricultural land change 2000–2010	Permanent pastures and meadows change 2000–2010	Cropland (Ag – per past) change 2000–2010	Forest land change 2000–2010	Other wooded land change 2000–2010	Treeland (For + OWL) change 2000–2010	Inland water change 2000–2010	Adjusted other land change 2000–2010
	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha
Algeria	238174	238174	1353	1134	219	-652	1023	371	0	-2289
Egypt	100145	99545	380	0	380	70	20	90	0	-411
Libyan Arab Jamahiriya	175954	175954	-99	0	-99	27	-116	-89	0	215
Morocco	44655	44630	-663.7	0	-663.7	2095	-634	1461	0	1183.7
Mozambique	79938	78638	1800	0	1800	8110	-27583	-19473	-450	0
Sudan	250581	237600	4670	2002	2668	27	-1864	-1837	0	-4128
Tunisia	16361	15536	487	291	196	604	-28	576	825	-628
Western Sahara	26600	26600	-1	0	-1	0	-859	-304	0	860
Total Northern Africa	932408	916677	7926.3	3427	4499.3	10281	-30041	-19205	375	-5197.3
Total Africa	1864816	1833354	15852.6	6854	8998.6	20562	-60082	-38410	750	-10394.6
TOTAL WORLD	**13420507.7**	**13009375.1**	**-43830**	**-59402**	**15572**	**140841**	**-284904**	**-144063**	**74366**	**2948906**

TABLE 31

Southern Africa's change in land use/cover between 2000 and 2010 for Ag land (pasture and crop) forest, owl (treeland = forest and owl) other land (FAOSTAT other land – OWL) and inland water

Country/ Region	Total country area 2010	Total land area 2010	Agricultural land change 2000–2010	Permanent pastures and meadows change 2000–2010	Cropland (Ag – per past) change 2000–2010	Forest land change 2000–2010	Other wooded land change 2000–2010	Treeland (For + OWL) change 2000–2010	Inland water change 2000–2010	Adjusted other land change 2000–2010
	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha
Botswana	58173	56673	-90	0	-90	-2260	274	-1986	-1	0
Lesotho	3036	3036	-8	0	-8	42	-725	-683	0	569
Namibia	82429	82329	-11	0	-11	-1337	-1672	-3009	0	2425
South Africa	121909	121309	-1234	0	-1234	145	-39121	-38976	118	0
Swaziland	1736	1720	-1	0	-1	84	116	200	0	0
Total Southern Africa	267283	265067	-1344	0	-1344	-3326	-41128	-44454	117	2994
Total Africa	534566	530134	-2688	0	-2688	-6652	-82256	-88908	234	5988
TOTAL WORLD	**13420507.7**	**13009375.1**	**-43830**	**-59402**	**15572**	**140841**	**-284904**	**-144063**	**74366**	**2948906**

TABLE 32

Western Africa's change in land use/cover between 2000 and 2010 for Ag land (pasture and crop) forest, owl, (treeland = forest and owl) other land (FAOSTAT other land – OWL) and inland water

Country/ Region	Total Ccuntry area 2010	Total land area 2010	Agricultural land change 2000–2010	Permanent pastures and meadows change 2000–2010	Cropland (Ag – per past) change 2000–2010	Forest land change 2000–2010	Other wooded land change 2000–2010	Treeland (For + OWL) change 2000–2010	Inland water change 2000–2010	Adjusted other land change 2000–2010
	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha	000 ha
Benin	11476	11276	245	0	245	1632	-842	790	0	386
Burkina Faso	27422	27360	2300	0	2300	-1577	-2659	-4236	0	958
Cabo Verde	403	403	4	0	4	5	0	5	0	-6.69
Côte d'Ivoire	32246	31800	1000	200	800	-1320	-4030	-5350	0	0
Gambia	1130	1012	63	-107	170	32	-58	-26	0	0
Ghana	23854	22754	1190	-30	1220	-1695	0	-1695	0	-36
Guinea	24586	24572	811	0	811	-792	0	-792	0	0
Guinea-Bissau	3613	2812	2	0	2	-379	230	-149	800	0
Liberia	11137	9632	50	0	50	205	0	205	1505	250
Mali	124019	122019	2451	640	1811	-1590	-8793	-10383	0	7133
Mauritania	103070	103070	-39	0	-39	-168	-50	-218	-30	164
Niger	126700	126670	6982	5782	1200	-566	3106	2540	0	-9964
Nigeria	92377	91077	-1300	0	-1300	-6589	-5557	-23963	0	7948
Saint Helena	39	39	0	0	0	0	-8	-8	0	8
Senegal	19671	19253	750	-50	800	1692	-7132	-5440	0	0
Sierra Leone	7230	7218	1120.38	0	1120.38	1170	-4189	-3019	0	372.62
Total Western Africa	608973	600967	15629.38	6435	9194.38	-9940	-29982	-51739	2275	7212.93
Total Africa	1217946	1201934	31258.76	12870	18388.76	-19880	-59964	-103478	4550	14425.86
TOTAL WORLD	**13420507.7**	**13009375.1**	**-43830**	**-59402**	**15572**	**140841**	**-284904**	**-144063**	**74366**	**2948906**

Nations with green highlighting had the most gain in that column. Those with a orange highlight lost the most.

TABLE 33

Eastern Africa's change in sorghum, wheat, paddy rice, millet and maize yield (Hg/ha) between 2000 and 2010

Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E

Country	Change in sorghum yield Hg/ha 2010–2000	Change in wheat yield Hg/ha 2010–2000	Change in paddy rice yield Hg/ha 2010–2000	Change in millet yield Hg/ha 2010–2000	Change in maize yield Hg/ha 2010–2000
Burundi	946.7	1748.2	2157.7	184.6	-456.8
Comoros	0	0	1802.9	0	2412.4
Congo	0	0	-398.39	0	0.25
Djibouti	0	0	0	0	-3888.9
Eritrea	-1572.31	5668.46	0	1843.01	6642.07
Ethiopia	9116.6	6753.9	11979.9	6688.54	9194.4
Kenya	610.19	16499.4	4674.4	645.27	2850.7
Madagascar	458.99	1424.4	8862	0	5205.96
Reunion	0	0	16454.5	0	-6444.9
Rwanda	3184.24	9214.09	24514.5	4701.1	16398.1
Somalia	523.51	373.29	32000	0	501.1
United Rep. of Tanzania	4788.09	6868.73	4517.5	1451.07	-3799.4
Zambia	1893.54	1016.7	5445.2	2274.63	8150.8
Zimbabwe	-3194.87	-17999.9	555.6	-649.68	-6129.25
Zz 1Total Eastern Africa	**16754.68**	**31567.27**	**112565.81**	**17138.54**	**30636.53**
Zz 2 Total Africa	**33509.36**	**63134.54**	**225131.62**	**34277.08**	**61273.06**

TABLE 34

Middle Africa's change in sorghum, wheat, paddy rice, millet and maize yield (Hg/ha) between 2000 and 2010

Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E 29 November 2014

Country	Change in sorghum yield Hg/ha 2010–2000	Change in wheat yield Hg/ha 2010–2000	Change in paddy rice yield Hg/ha 2010–2000	Change in millet yield Hg/ha 2010–2000	Change in maize yield Hg/ha 2010–2000
Angola	-519.14	-6487.7	-6051.45	-3241.47	1455.33
Cameroon	2646.7	-3852.9	-19166.7	3053.2	-4874.8
Central African Republic	2301.86	0	8450.1	5040.75	5548
Chad	1798.72	5455.7	2735.7	2822.32	1993.99
Congo	0	0	-398.39	0	0.25
Democratic Rep. of the Congo	0.83	4.9	21.72	2.15	-204.55
Gabon	0	0	11111.1	0	403.3
Sao Tome and Principe	0	0	0	0	-8966.7
Z1 Total Middle Africa	**6228.97**	**-4880**	**-3297.92**	**7676.95**	**-4645.18**
Z2 Total Africa	**12457.94**	**-9760**	**-6595.84**	**15353.9**	**-9290.36**

TABLE 35

Northern Africa's change in sorghum, wheat, paddy rice, millet and maize yield (Hg/ha) between 2000 and 2010

Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E

Country	Change in sorghum yield Hg/ha 2010–2000	Change in wheat yield Hg/ha 2010–2000	Change in paddy rice yield Hg/ha 2010–2000	Change in millet yield Hg/ha 2010–2000	Change in maize yield Hg/ha 2010–2000
Algeria	-39214.3	5643.99	-1069.6	0	-10358.7
Egypt	-7824.5	-7680.4	3192.4	0	-4100.2
Libya	0	-95.1	0	313.4	-9566.7
Morocco	-572.79	12336.49	23270.3	7914.5	8131.7
Mozambique	291.07	3366.7	1549.24	-1394.43	2625.05
Sudan (former)	-1245.22	-5330.9	21832.4	-40.31	5847.94
Tunisia	-415.67	7195.7	0	0	0
Z1 Total Northern Africa	**-48981.41**	**15436.48**	**48774.74**	**6793.16**	**-7420.91**
Z2 Total Africa	**-97962.82**	**30872.96**	**97549.48**	**13586.32**	**-14841.82**

TABLE 36

Southern Africa's change in sorghum, wheat, paddy rice, millet and maize yield (Hg/ha) between 2000 and 2010

Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E

Country	Change in sorghum yield Hg/ha 2010–2000	Change in wheat yield Hg/ha 2010–2000	Change in paddy rice yield Hg/ha 2010–2000	Change in millet yield Hg/ha 2010–2000	Change in maize yield Hg/ha 2010–2000
Botswana	4574.34	0	0	1234.34	494.16
Lesotho	-3188.4	8145.98	0	0	2298.04
Namibia	-1590.91	33622.5	0	-922.69	13142.05
South Africa	-10575.4	-374.2	-3859.5	-820.67	18243.5
Swaziland	-785.57	0	-4000	0	-4092.6
Z1 Total Southern Africa	**-11565.94**	**41394.28**	**-7859.5**	**-509.02**	**30085.15**
Z2 Total Africa	**-23131.88**	**82788.56**	**-15719**	**-1018.04**	**60170.3**

Nations with green highlighting had the most gain in that column. Those with a orange highlight lost the most. Gambia showed declines in all of the cereal crops.

TABLE 37

Western Africa's change in sorghum, wheat, paddy rice, millet and maize yield (Hg/ha) between 2000 and 2010
Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E

Country	Change in sorghum yield Hg/ha 2010–2000	Change in wheat yield Hg/ha 2010–2000	Change in paddy rice yield Hg/ha 2010–2000	Change in millet yield Hg/ha 2010–2000	Change in maize yield Hg/ha 2010–2000
Cabo Verde	0	0	0	0	-5747.56
Gambia	-190.4	0	-10548	-434.6	-3558.4
Burkina Faso	1741.19	0	-5437.4	2056.06	-3201.5
Guinea-Bissau	1204.97	0	6607.4	2468.41	-2974.05
Guinea	2591.2	0	1390	-162.8	-2269.2
Cote d'Ivoire	936.5	0	12335.8	1354.81	-487.2
Mauritania	-274.58	6406.1	9936.5	-61.84	-462.67
Benin	6198.19	0	5443.2	255.42	-453.1
Liberia	0	0	-994.9	0	0
Niger	2207.86	-3447.3	-12538.2	2039.18	1191.52
Senegal	639.24	0	17579.6	744.47	4270.3
Ghana	3153.88	0	5537.7	4253.97	4296.7
Sierra Leone	-384.1	0	7831.1	2364.61	5215.48
Nigeria	3197	2628.2	3387.8	1347	5500.6
Mali	1887.48	1485.3	27816	2352.04	14507.1
Total Western Africa	**22908.43**	**7072.3**	**68346.6**	**18576.73**	**15828.02**
Total Africa	**45816.86**	**14144.6**	**136693.2**	**37153.46**	**31656.04**

TABLE 38

Eastern Africa's goat, sheep, and cattle change in yield (Hg/An) per animal between 2000 and 2010
Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E

Country	Change in goat yield Hg/An 2010–2000	Change in sheep yield Hg/An 2010–2000	Change in cattle yield Hg/An 2010–2000
Burundi	-21.46	0	-937.56
Comoros	0	0	0
Djibouti	0	0	0
Eritrea	-0.2941	-0.156	-90
Ethiopia	-0.0017	0	8.04
Kenya	-0.056	28.218	1507.727
Madagascar	0	0	0
Malawi	-25.3975	-33.859	-954.71
Mali	0	0	0
Mauritius	21.111	80	282
Reunion	-4.374	0	-517.81
Rwanda	0	0	0
Seychelles	0	0	-325.07
Somalia	0	0	0
Uganda	-4.072	0	0
United Republic of Tanzania	0	0	-191.747
Zambia	0	0	0
Total Eastern Africa	**-34.5443**	**74.203**	**-1219.13**
Total Africa	**-69.0886**	**148.406**	**-2438.26**

TABLE 39

Middle Africa's change in sorghum, wheat, paddy rice, millet and maize yield (Hg/ha) between 2000 and 2010

Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E

Country	Change in goat yield Hg/An 2010–2000	Change in sheep yield Hg/An 2010–2000	Change in cattle yield Hg/An 2010–2000
Angola	0	0	-250.23
Cameroon	0	0.007	62.6
Central African Republic	-3.589	0	-132.05
Chad	0	0	0
Congo	14	0	-3.04
Democratic Republic of the Congo	2.012	2.1792	248.94
Equatorial Guinea	0	0	0
Gabon	0	0	0
Sao Tome and Principe	0	0	30.57
Z1 Total Middle Africa	**12.423**	**2.1862**	**-43.21**
Z2 Total Africa	**24.846**	**4.3724**	**-86.42**

TABLE 40

Northern Africa's change in sorghum, wheat, paddy rice, millet and maize yield (Hg/ha) between 2000 and 2010

Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E

Country	Change in goat yield Hg/An 2010–2000	Change in sheep yield Hg/An 2010–2000	Change in cattle yield Hg/An 2010–2000
Algeria	0	0.056	-124.31
Egypt	19.684	69.125	1415.8
Libya	0	0	17.39
Morocco	-29.74	-30.607	271.05
Mozambique	0	0	0
Sudan (former)	-12.1875	-21.222	77.85
Tunisia	10.752	-1.837	0.72
Total Northern Africa	**-11.4915**	**15.515**	**1658.5**
Total Africa	**-22.983**	**31.03**	**3317**

Nations with green highlighting had the most gain in that column. Those with a orange highlight lost the most. Many of the countries showed decline in yield per animal for all three types of livestock.

TABLE 41

Southern Africa's change in sorghum, wheat, paddy rice, millet and maize yield (Hg/ha) between 2000 and 2010

Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E

Country	Change in goat yield Hg/An 2010–2000	Change in sheep yield Hg/An 2010–2000	Change in cattle yield Hg/An 2010–2000
Botswana	0	0	40
Lesotho	0	0	0
Namibia	0	2	123.79
South Africa	0.266	106.443	623.23
Swaziland	0	0	-342.62
Total Southern Africa	**0.266**	**108.443**	**444.4**
Total Africa	**0.532**	**216.886**	**888.8**

TABLE 42

Western Africa's goat, sheep and cattle change in yield (Hg/An) per animal between 2000 and 2010

Source: FAOSTAT3 http://faostat3.fao.org/download/Q/QA/E

Country	Change in goat yield Hg/An 2010–2000	Change in sheep yield Hg/An 2010–2000	Change in cattle yield Hg/An 2010–2000
Benin	0	0	0
Burkina Faso	-1.0004	-0.0031	30
Cabo Verde	0	0	-20.32
Cote d'Ivoire	-0.0003	-10.658	0.01
Gambia	0	0	0
Ghana	0.276	0	0
Guinea	12	3	-1.327
Guinea-Bissau	0	0	0
Liberia	0	0	0
Mali	0	0	0
Mauritania	0	0	23.26
Niger	-2.806	-39.999	-182.65
Nigeria	0	0	-1.31
Senegal	-9.7774	14.909	93.22
Sierra Leone	0	0	0
Togo	0	0	0
Total Western Africa	**-1.3081**	**-32.7511**	**-59.117**
Total Africa	**-2.6162**	**-65.5022**	**-118.234**

Nations with green highlighting had the most gain in that column. Those with a orange highlight lost the most. There were no loses any of the countries.

Appendix 1b

Literature Review on soil erosion in Africa

This section is an overview of the findings from the major literature reviews on soil erosion in Africa.

Lal 1995

"Accelerated soil erosion by water is a serious problem on agricultural land in several regions of Africa (Brown and Wolf, 1984; Stocking and Peake, 1986; Pimentel et al., 1987; Dregne, 1990; Lai, 1993). Severe soil erosion is reported in Morocco and Algiers in the Maghreb (Boukhobza, 1982; Jayua and Brooks, 1984; Mensching, 1985), in the Ethiopian highlands, particularly the Simien Mountains in the Gondar region (Lamb and Miles, 1983; Hurni, 1983; Griffiths and Richards, 1989; Stahl, 1990), and in the highlands of Kenya (Finn, 1983; Christiansson, 1989; O'Keefe, 1983; Barber, 1983; Ulsaker and Onstad, 1984; Sutherland and Bryan, 1990), Tanzania (Ostberg, 1986; Christiansson, 1986), Uganda (Bagoora, 1989), Rwanda, and Burundi (Lewis, 1988; Roose et al., 1988) in East Africa. Lewis et al. (1988) observed that soil loss in Rwanda ranged from 1 to 143 Mg ha -1yr -1, with an average rate of 5 Mg ha -1yr-1." (Lal, 1995).

"Serious erosion is also observed in Madagascar (Randrianarijaona, 1983). Regions prone to accelerated erosion in southern Africa include Lesotho (Faber and Imeson, 1982, p. 135–144; Seitlheko, 1986; Chakela et al., 1989), Zimbabwe (Wall-Bake, 1987, p. 69–80; Whitlow, 1988a,b), Botswana (Biot et al., 1989), and several other countries of southern Africa (Walling, 1987). There are also several regions in West Africa with serious accelerated erosion. Gully erosion is a very serious problem in south eastern Nigeria. It started around 1850 and now affects large areas in several states. The rate of gully advance is 20 to 50 m yr-1. Some gullies are 5 to 10 m deep and 10 to 100 m wide (Egboka and Okpoko, 1984, p. 335–347). Gully erosion is also a problem in northern Nigeria (Smith, 1982) and in Jos Plateau" (Lal, 1995).

Economic Commission for Africa (2007)

"Two thirds of Africa is classified as deserts or drylands. These are concentrated in the Sahelian region, the Horn of Africa and the Kalahari in the south. Africa is especially susceptible to land degradation and bears the greatest impact of drought and desertification. It is estimated that two-thirds of African land is already degraded to some degree and land degradation affects at least 485 million people or sixty-five percent of the entire African population.21 Desertification especially around the Sahara has been pointed out as one the potent symbols in Africa of the global environment crisis.22 Climate change is set to increase the area susceptible to drought, land degradation and desertification in the region. Under a range of climate scenarios, it is projected that there will be an increase of 5–8% of arid and semi Arid lands in Africa.23 23. Estimates from individual countries report increasing areas affected by or prone to desertification. It is estimated that 35 percent of the land area (about 83,489 km^2 or 49 out of the 138 districts) of Ghana is prone to desertification, with the Upper East Region and the eastern part of the Northern Region facing the greatest hazards. Indeed a recent assessment indicates that the land area prone to desertification in the country has almost doubled during recent times.24 Desertification is said to be creeping at an estimated 20,000 hectares per year, with the attendant destruction of farmlands and livelihoods in the country.25 Seventy percent of Ethiopia is reported to be prone to desertification, 26 while in Kenya, around 80 percent of the land surface is threatened by desertification.27 Estimates of the extent of land degradation within Swaziland suggest that between 49 and 78% of the land is at risk, depending on the assessment methodology used (Government of Swaziland, 2000). Nigeria is reported to be losing 1,355 square miles (1mile =1.6km) of rangeland and cropland to desertification each year. This affects each of the 10 northern states of Nigeria.28 It is estimated that more than 30% of the land area of Burundi, Rwanda, Burkina Faso, Lesotho and South Africa is severely or very severely degraded.29 These rates and extent of land degradation/desertification undermine and pose serious threats to livelihoods of millions of people struggling to edge out of poverty. They also cripple provision of land resources - based ecosystem services that are vital for a number of development sectors (ECA, 2007).

The majority of the populations in most African countries live on marginal lands in rural areas practicing rain-fed agriculture. Desertification threatens agricultural production on these marginal lands (Conserve Africa, 2006; UNCCD, 2004), exacerbating poverty and undermining economic development. Growing levels of entrenched poverty, environmental degradation, desertification, and underdevelopment of rural areas characterize most rural areas of the African countries. The impact of drought and climatic variability in both economic and mortality terms is generally larger for relatively simple and predominantly agricultural economies. These types of economies dominate Africa. In 2004, the UNCCD estimated that some six million hectares of productive land was being lost every year since 1990, due to land degradation. This in turn had caused income losses worldwide of USD 42 billion per year.33 With two-thirds of arable land expected to be lost in Africa by 2025, land degradation currently leads to the loss of an average of more than 3 percent annually of agriculture GDP in the Sub-Saharan Africa region. In Ethiopia, GDP loss from reduced agricultural productivity is estimated at USD 130 million per year.34 In Uganda land degradation in the dry lands threatens to wreck havoc on the country's economy and escalate poverty. This is because these drylands constitute the Uganda cattle corridor, which accounts for over 90 percent of the national cattle herd and livestock production contributes 7.5 percent to the GDP and 17 percent to the agricultural GDP35" (ECA, 2007)

Obalum et al. 2012

"The survey highlights the enormous rate of soil erosion and the attendant decline in the productivity of agricultural soils in SSA. It is therefore unsurprising that, in the face of the advances so far made in biotechnology, agricultural productivity in SSA stagnates and remains perennially low as evident in hunger and poverty levels in the entire region [15, 16]. All the adverse impacts on agronomic productivity and environmental quality are respectively due to a decline in land quality and deposition of sediments" [...] (Obalum, et al., 2012). Dregne [7] reported that irreversible soil productivity losses from water erosion appeared to be serious on a national scale in Algeria, Morocco, and Tunisia in North Africa; in Ethiopia, Kenya, and Uganda in East Africa; in Nigeria and northern Ghana in West Africa; and in Lesotho, Swaziland, and Zimbabwe in southern Africa. He observed as much as 50% productivity loss to wind erosion in part of Tunisia, and delineated areas in Africa where about 20% permanent reduction on crop productivity have resulted from human-induced water and wind erosion" (Obalum, et al., 2012).

The Obalum et al. review observes the links between erosion and soil fertility: "Soil chemical properties that are mostly adversely influenced by erosion or topsoil removal in SSA include pH, organic matter content, total N, available P, exchangeable bases, and cation exchange capacity [3, 21, 24–26, 28, 29, 31]. In an Alfisol in southwestern Nigeria, Lal [32] reported that the enrichment ratio (ER, the concentration of plant nutrients in eroded soil materials to that in residual soil) was 2.4 for organic matter, 1.6 for total N, 5.8 for available P, 1.7 for exchangeable K, 1.5 for exchangeable Ca, and 1.2 for exchangeable Mg. For another Alfisol in Central Kenya recording an annual soil loss of above 60 tons ha–1 , the corresponding values of the ER were 2.1, 1.2, 3.2, 1.5, 1.2, and 1.0, respectively [33]" (Obalum, et al., 2012).

Kirui and Mirzabaev 2014

Finally, the more recent ZEF paper mentioned earlier also reviewed the literature and notes discrepancies in the main findings: "Assessments of land degradation in the region vary in methodology and outcome (Stoosnijder, 2007; Lal & Stewart, 2013; Zucca et al., 2014). The GLASOD survey... concluded that in the early 1980s about 16.7% of SSA experienced serious human-induced land degradation (Middleton & Thomas, 1992; Yalew, 2014). Using standardized criteria and expert judgment, Oldeman (1994) revealed that about 20% of SSA was affected by slight to extreme land degradation in 1990 [...] The data from the FAO TERRASTAT maps 67% (16.1 million km^2) of the

total land area of SSA as degraded, with country-to-country variations." The ZEF paper concludes that the main weakness of these assessments is that they are based on 'expert' opinion and varying time periods. It notes the recent shift from approaches that rely on expert opinion to the more quantitative method that uses aerial photography and satellite imagery using the Normalized Difference Vegetation Index (NDVI). One such assessment by Bai et al. (2008) estimates that land degradation has affected about 26% of SSA and identifies areas that do not overlap with those in the GLASOD and TERRASTAT surveys. They suggest that the GLASOD was a map of perceptions and that it is now out-of-date (Bai, et al., 2008). In concluding, the ZEF authors provide some caveats related to the reliability of NDVI methodologies, including the effects of fertilization, seasonal variations in vegetation, the effect of soil moisture where vegetation is sparse and need for ground-truthing, among others (Kirui & Mirzabaev, 2014).
The following table *(Table 44)* shows country-level erosion and productivity data gleaned from the literature during this scoping exercise. The most severe erosion by country is highlighted in pink from the comparative data from Bai et al. 2008.

Economic losses of land degradation in Africa

As already stated, this scoping exercise does not include a review of the literature that assesses the economic losses of land degradation in Africa. However, the following tables are included since they showed up in the search conducted for this study; they are included for illustrative purposes.

TABLE 43

Data by country

Sources: Modified from (Obalum, et al., 2012) with additional data from other sources (see last column)

Country	Soil type	Climate/ location	Study type	Crop/land use	Soil loss	Yield reduction	Degraded area (% of territory)	Reference
Algeria			Remote sensing				2.67	(Bai, et al., 2008)
Angola			Remote sensing				66.42	(Bai, et al., 2008)
Benin			Remote sensing				12.57	(Bai, et al., 2008)
Botswana			Remote sensing				16.30	(Bai, et al., 2008)
Burkina Faso			Remote sensing				3.38	(Bai, et al., 2008)
	Lateritic Alfisol	Semiarid/ Ouagadougou	Desurfacing experiment	Maize	5, 10 and 20 cm	47, 48 and 63%		(Lal, 1995)
	Aridisol	Semiarid/ Niangoloko	Natural erosion	Pearl Millet	0.0928 cm	51.6%		(Lal, 1995)
Burundi			Remote sensing				48.56	(Bai, et al., 2008)
Cameroon			Remote sensing				31.89	(Bai, et al., 2008)
	Ultisol	Humid/Douala	Desurfacing experiment	Maize	2.5 and 7.5 cm	50 >100%		(Lal, 1995)
Cape Verde			Remote sensing				9.30	(Bai, et al., 2008)
Central African Republic			Remote sensing				20.37	(Bai, et al., 2008)
Chad			Remote sensing				4.11	(Bai, et al., 2008)
DR Congo			Remote sensing				57.43	(Bai, et al., 2008)
R. Congo			Remote sensing				58.95	(Bai, et al., 2008)
Cote d'Ivoire			Remote sensing					
Djibouti			Remote sensing				27.76	(Bai, et al., 2008)
Egypt			Remote sensing				3.65	(Bai, et al., 2008)

Country	Soil type	Climate/ location	Study type	Crop/land use	Soil loss	Yield reduction	Degraded area (% of territory)	Reference
Equatorial Guinea			Remote sensing				54.81 (Kirui & Mirzabaev, 2014)	(Bai, et al., 2008)
Eritrea			Remote sensing				12.84	(Bai, et al., 2008)
		Afdeyu	Soil plots		Annual: 3%			(Stillhardt, et al., 2002)
					Annual: 18.8 tonnes/ha	Crop yield: 0.38%/yr; fodder yield: 0.43%/yr		(Araya, 1997)
			Natural erosion	grazing	2.5 tons/ha/yr			(Araya, 2005)
			Natural erosion	barren	35 tons/ha/yr			(Araya, 2005)
			Natural erosion	woodland	2.5 tons/ha/yr			(Araya, 2005)
			Natural erosion	cropland	21 tons/ha/yr			(Araya, 2005)
			Natural erosion	forest	1.0 tons/ha/yr			(Araya, 2005)
Ethiopia			Remote sensing		1 billion tons/ yr		26.33	(Bai, et al., 2008)
					30,000 ha/yr water erosion			National Review Report 2002 cited in (World Bank, n.d.)
			Soil Conservation Research Project	Annual crop	42t/ha/yr			SCRP study by (Hurni, 1988), and (Bojö & Cassells, 1995) cited in (World Bank, n.d.)
				Perennial crops	8t/ha/yr			(World Bank, n.d.)
				grazing	5t/ha/yr			(World Bank, n.d.)
			Ethiopian Highlands Reclamation Study	Highland crops		2.2% from 1985 level		EHRS study by FAO 1986 cited in (World Bank, n.d.)
			Ethiopian Highlands Reclamation Study	Highland grass		0.6% from 1985 level		EHRS study by FAO 1986 cited in (World Bank, n.d.)
		Amhara	National Conservation Strategy Secretariat scenarios			Estimated t of grain lost due to erosion, 2000–2025: 9,726–113,273		NCSS study by (Sonneveld, 2002) cited in (World Bank, n.d.)

Country	Soil type	Climate/ location	Study type	Crop/land use	Soil loss	Yield reduction	Degraded area (% of territory)	Reference
		Beneshangul-Gumuz	National Conservation Strategy Secretariat scenarios			Estimated t of grain lost due to erosion, 2000–2025: 509–5,087		NCSS study by (Sonneveld, 2002) cited in (World Bank, n.d.)
		Tigray	scenarios			Estimated t of grain lost due to erosion, 2000–2025: 1,324–15,803		NCSS study by (Sonneveld, 2002) cited in (World Bank, n.d.)
Gabon			Remote sensing				64.58	(Bai, et al., 2008)
Gambia			Remote sensing				12.35	(Bai, et al., 2008)
Ghana			Remote sensing				21.11	(Bai, et al., 2008)
Guinea								
Guinea Bissau								
Kenya			Remote sensing				18.02	(Bai, et al., 2008)
		Ndome, Taita Taveta	Aerial photography (1961–1998)				17 % of agricultural land	(Waswa, et al., 2002)
		Ghazi, Taita Taveta	Aerial photography (1961–1998)				50 % of agricultural land	
		Nyando River Basin			43 tons/ha/yr on 61% of the land			(ICRAF, 2004) cited in (de Graffenried, n.d.)
		Kianjuki catchment	Revised Universal Soil Loss Equation (RUSLE)		14.7 tons/ha/yr on low slopes to 60.5 tons/ha/yr on steep slopes			(Angima, et al., 2003) cited in (de Graffenried, n.d.)
		Nyando District	Remote sensing		90 tonnes/ha/yr in worst areas			(Sjors, 2001) cited in (de Graffenried, n.d.)
		Central province	Modeling scenarios	Maize	Mod-severe splash erosion on 80% of sampled field	30% of yield		(Ovuka & Ekbom, 2001) cited in (de Graffenried, n.d.)

Country	Soil type	Climate/ location	Study type	Crop/land use	Soil loss	Yield reduction	Degraded area (% of territory)	Reference
		Central province	Modeling scenarios	Maize	Slight-severe sheet erosion on 68% of sampled fields			(Ovuka & Ekbom, 2001) cited in (de Graffenried, n.d.)
		Central province	Modeling scenarios	Maize	Slight-severere rill erosion on 70% of sampled fields	17.5% of yield		(Ovuka & Ekbom, 2001) cited in (de Graffenried, n.d.)
Lesotho			Remote sensing				34.08	(Bai, et al., 2008)
Liberia			Remote sensing				45.34	(Bai, et al., 2008)
Libya			Remote sensing				0.72	(Bai, et al., 2008)
Madagascar			Remote sensing				27.91	(Bai, et al., 2008)
Malawi			Remote sensing				26.05	(Bai, et al., 2008)
		Bvumbwe	Field measurements	crops	0.1 t/ha/yr			(Bishop, 1995)
		Mindawo	Field measurements	crops	10.6 t/ha/yr			"
		Miindawo II	Field measurements	crops	2.9 t/ha/yr			"
		Mphezo	Field measurements	Eucalyptus plantation	0.1 t/ha/yr			"
		Nkhande	Field measurements	Ridged maize	54.2 t/ha/yr			"
		Nkhande	Field measurements	Maize cropped with Leucaena	7.2 t/ha/yr			"
		M'mbelwa	Field measurements	Maize-ridges along slope	7.9 t/ha/yr			"
		M'mbelwa	Field measures	Maize-ridges across slope	1.2 t/ha/yr			"
		Zunde	Field measures	Maize-unridged	24.5 t/ha/yr			"
		Zunde	Field measures	Maize-ridged	15.3 t/ha/yr			"
		Bunda	Field measures	Maize-weeded	12.1 t/ha/yr			"
		Bunda	Field measures	Maize-unweeded	4.5 t/ha/yr			"

Country	Soil type	Climate/ location	Study type	Crop/land use	Soil loss	Yield reduction	Degraded area (% of territory)	Reference
Mali			Remote sensing				2.87	(Bai, et al., 2008)
						2–10%/yr		(Bishop & Allen, 1989)
		Omarobougou	EPIC-Century model (Erosion Productivity Impact Calculator)	Conventional Cotton	24.5 mm (1985–2000)			(Doraiswamy, et al., 2007)
			"	Conventional Maize	25.3 mm (1985–2000)			
			"	Conventional Millet	36.5 mm (1985–2000)			
			"	Conventional Sorghum	20.7 mm (1985–2000)			
Mauritania			Remote sensing				0.61	(Bai, et al., 2008)
Mauritius								
Morocco			Remote sensing				15.09	(Bai, et al., 2008)
Mozambique			Remote sensing				28.26	(Bai, et al., 2008)
Namibia			Remote sensing				35.01	(Bai, et al., 2008)
Niger			Remote sensing				1.78	(Bai, et al., 2008)
Nigeria			Remote sensing				9.90	(Bai, et al., 2008)
	Alfisol	Subhumid/ Ibadan	Desurfacing experiment	Maize	2.5–12.5 cm	23–56%		(Lal, 1976)
	Alfisol	Subhumid/Ilora	Desurfacing experiment	Maize	5, 10, and 20 cm	72.5, 82.6, and 99.5%		(Mbagwu, et al., 1984)
	Alfisol	Subhumid/ Ikenne	Desurfacing experiment	Maize	5, 10, and 20 cm	30.5, 73.6, and 93.5%		(Mbagwu, et al., 1984)
	Ultisol	Humid/Onne	Desurfacing experiment	Maize	5, 10, and 20 cm	95.4, 95.4, and 100%		(Mbagwu, et al., 1984)
	Alfisol	Subhumid/Ilora	Desurfacing experiment	Maize	5 cm	54.9%		(Mbagwu, 1991)
	Alfisol	Subhumid/ Ikenne	Desurfacing experiment	Maize	5 cm	30%		(Mbagwu, 1991)
	Inceptisol	Subhumid/ Nsukka	Desurfacing experiment	Maize	5 cm	15%		(Mbagwu, 1991)

Country	Soil type	Climate/ location	Study type	Crop/land use	Soil loss	Yield reduction	Degraded area (% of territory)	Reference
	Ultisol	Humid/ Onne	Desurfacing experiment	Maize	5 cm	69.7%		(Mbagwu, 1991)
	Ultisol	Subhumid/ Nsukka	Desurfacing experiment	Maize	5 cm	64.2%		(Mbagwu, 1991)
	Alfisol	Subhumid/ Ibadan	Desurfacing experiment	Maize	10 and 20 cm	39.2 and 81.7%		(Lal, 1995)
	Ultisol	Subhumid/ Nsukka (1)	Desurfacing experiment	Maize	3 and 6 cm	23 and 55%		(Ngwu, et al., 2005)
	Ultisol	Subhumid/ Nsukka (2)	Desurfacing experiment	Maize	3 and 6 cm	50 and 95%		(Ngwu, et al., 2005)
	Oxisol	Subhumid/ Ile-Ife	Desurfacing experiment	Maize	5, 10, 15 and 20 cm	56.0, 82.5, 90.0, and 95.5%		(Oyedele & Aina, 2006)
	Gravelly Alfisol	Subhumid/ Ibadan	Desurfacing experiment	Maize	15 and 25 cm	17 and 67% (upper slope); 65 and 76% (lower slope)		(Salako, et al., 2007)
	Alfisol	Subhumid/ Ilora	Desurfacing experiment	Cowpea	5, 10 and 20 cm	42.6, 33.1, and 80.5%		(Mbagwu, et al., 1984)
	Alfisol	Subhumid/ Ikenne	Desurfacing experiment	Cowpea	5, 10 and 20 cm	1.5, 59.1, and 65.1%		(Mbagwu, et al., 1984)
	Ultisol	Humid/ Onne	Desurfacing experiment	Cowpea	5, 10 and 20 cm	62.0, 70.6, and 68.3%		(Mbagwu, et al., 1984)
	Alsivol	Subhumid/ Ibadan	Desurfacing experiment	Cassava	10 and 20 cm	35.7 and 53.7%		(Mbagwu, et al., 1984)
	Alsivol	Subhumid/ Ibadan 1	Natural erosion	Maize	0.0080 cm	0.1513%		(Lal, 1981)
	Alsivol	Subhumid/ Ibadan 2	Natural erosion	Maize	0.0080 cm	0.1720%		(Lal, 1981)
Reunion			Remote sensing				6.98	(Bai, et al., 2008)
Rwanda			Remote sensing					(Bai, et al., 2008)
							572,000 ha out of 1,144,300 ha	(REMA and PEI, 2006)
Sao Tome and Principe			Remote sensing				12.50	(Bai, et al., 2008)

Country	Soil type	Climate/ location	Study type	Crop/land use	Soil loss	Yield reduction	Degraded area (% of territory)	Reference
Senegal			Remote sensing				17.66	(Bai, et al., 2008)
Seychelles								
Sierra Leone			Remote sensing				50.04	(Bai, et al., 2008)
Somalia			Remote sensing				8.24	(Bai, et al., 2008)
South Africa			Remote sensing				28.82	(Bai, et al., 2008)
			RUSLE				20 (actual risk of moderate to severe soil erosion)	(Le Roux, et al., 2008)
							70 (water erosion); 20 (highly susceptible to wind erosion)	(Republic of South Africa, 2007)
South Sudan			RUSLE		12.6 t/ha/yr average predicted soil loss rate			(Le Roux, et al., 2008)
Sudan			Remote sensing				6.63	(Bai, et al., 2008)
Swaziland			Remote sensing				95.22	(Bai, et al., 2008)
Tanzania			Remote sensing				40.87	(Bai, et al., 2008)
		Kilimanjaro		Maize		Yields decline from 3.5 to 2.9 Mg/ha according to severity of erosion		(Lal, et al., 2004)
		Tanga		Maize		Yields decline from 2.5 to 1.3 Mg/ha according to severity of erosion		(Lal, et al., 2004)
		Morogoro		Maize		Yields decline from 3.5 to 2.4 Mg/ha according to severity of erosion		(Lal, et al., 2004)
Togo			Remote sensing				19.48	(Bai, et al., 2008)
Tunisia			Remote sensing				7.63	(Bai, et al., 2008)

Country	Soil type	Climate/ location	Study type	Crop/land use	Soil loss	Yield reduction	Degraded area (% of territory)	Reference
Uganda			Remote sensing				17.58	(Bai, et al., 2008)
		Kabale					90	(Olson & Berry, 2003)
		Kisoro					85	"
		Mbale					80	"
		Rakai					80	"
		Kotido					75	"
		Kasese					60	"
		Nebbi					60	"
		Moroto					60	"
		Masaka					50	"
		Mbarara					50	"
		Bundibugyo					40	"
		Luwero					40	"
		Rukungiri					30	"
		Kapchorwa					30	"
		Mpigi					25	"
		Arua					20	"
		Bushenyi					20	"
		Kabarole					20	"
		Masindi (Rift Valley)					20	"
Zambia			Remote sensing				60.41	(Bai, et al., 2008)
Zimbabwe							46.12	(Bai, et al., 2008)
	Alfisol	Semiarid/ Harare	Natural erosion	Maize	0.0024	26.9%		(Lal, 1995)

TABLE 44

Magnitude of economic losses from soil degradation, as % AGDP, compiled by Scherr

Source: After Scherr 1999 as cited in (Berry, et al., 2003)

Study region	Authors	Types of degradation	Annual loss (or GAIL) as % AGDP	Discounted future loss as % AGDP
Ethiopian Highlands	FAO (1986)	Soil erosion	<1 (GAIL)	44 (GDCL)
	Sutcliffe (1993)	Soil erosion	5 (GAIL)	<1 (GDCL)
	Bojö and Cassells (1995)	Soil erosion	4 (GAIL)	<1 (GDCL)
	Drechsel and Gylele (1999)	Soil erosion, nutrient depletion	10–11	–
Ghana	Alfsen et al. (1997)	Soil erosion		
	Convery and Tutu (1990)	Soil erosion	5 (GAIL)	–
	Drechsel and Gylele (1999)	Soil erosion, nutrient depletion	4–5	–
Lesotho	Bojö (1991)	Soil erosion	<1 (GAIL)	5 (GDFL), 5 (GDCL)
	Drechsel and Gylele (1999)	Soil erosion, nutrient depletion	5–7	
Madagaskar	World Bank (1988)	Soil erosion	<1 (GAIL)	–
	Drechsel and Gylele (1999)	Soil erosion, nutrient depletion	6–9	–
Malawi	World Bank (1992)	Soil erosion	3 (GAIL)	18 (GDFL)
	Drechsel and Gylele (1999)	Soil erosion, nutrient depletion	9.5–11	–
South Africa	McKenzie (1994)	Soil erosion	<1 (GAIL)	4 (GDFL), <1 (GDCL)
Zimbabwe	Grohs (1994)	Soil erosion	<1 (GAIL)	<1 (GDFL)
	Norse and Saigal (1992)	Soil erosion	8 (GAIL)	<1 (GDCL)
	Stocking (1986)	Soil erosion	9 (GAIL)	
	Drechsel and Gylele (1999)	Soil erosion, nutrient depletion	2.5–4	

** Estimates of GAIL, GDCL, GDFL presented here were calculated and reported by Bojö (1996). CLFP presented here was calculated and reported by Repetto et al. (1989). Figures from Drechsel and Gyiele (1999) Convery and Tutu, Stocking and Norse and Saigal are based on the estimated cost of replacing lost nutrients; others reflect loss in productivity. The range in Drechsel and Gyiele estimates considers price variations of available fertilizers and transport.*

Annual loss = the lost value for that year due to soil degradation.

CLFP: Capitalized Loss of Future Productivity (the value of the stream of future losses due to a particular year's soil degradation; similar to GDFL).

GAIL: Gross Annual Immediate Loss (the lost value for gross cropland output in a single year due to land degradation in the previous year).

GDFL: Gross Discounted Future Loss (the value of the stream of constant future annual losses due to soil degradation in a given year).

GDCL: Gross Discounted Cumulative Loss (the cumulative value of the stream of future losses due to continued soil degradation over time).

TABLE 45

Findings from review by (Berry, et al., 2003)

Source: (Berry, et al., 2003)

Country	Extent of land degradation	Cost of land degradation	Level of Response	Type of response
Ethiopia	Highlands and Drier Areas, 50% highlands	4% GDP Direct, Acute poverty	0.2–0.5% AG GDP, Fertilizer, Physical Structures	
Uganda	Varied, 60% land area	4% GNP?	Hard to quantify	Policy, Terracing in SW
Rwanda	Extreme especially SW	3.5% AG GDP Direct, acute poverty	Hard to quantify	Centralized terracing policy

Appendix 2

Notes on Data Sources and Description

Note	Data	Description	Year (data used for: modelling = M, estimation = E, valuation=V)	Source
1	Nutrient depletion (kg/ha/year)	Average losses of Nitrogen, Phosphorous and Potassium (NPK) from croplands for 42 African countries for the cropping seasons of 2003–04	2002–04 (M)	Henao & Baanante (2006)
2	Soil erosion (Mg/ha/year)	Soil erosion	1992 (M and E)	This study
3	Forest cover (% of total land area)	Land area covered by forest divided by total land area of a country.	2002–04 (M) 2010–12 (E)	FAOSTAT
4	Historical nutrient balance	Average losses of Nitrogen, Phosphorous and Potassium (NPK) from croplands for 42 African Countries for the cropping seasons of 1993–95	1993–95 (M)	Henao & Baanante (1999)
5	Poverty	Poverty gap is the mean shortfall from the poverty line (counting the non-poor as having zero shortfall), expressed as a percentage of the poverty line (1.25 PPP USD per day per capita). This measure reflects the depth of poverty as well as its incidence.	2000–06 (M) 2007–2013 (E)	World Bank
6	GDP per capita	The GDP per capita is GDP converted to international dollars using purchasing power parity rates (constant 2011 international USD) divided by population.	2002–04 (M) 2010–12 (E)	World Bank
7	Manufacturing sector GDP	Manufacturing sector value added (% GDP) multiplied by the GDP at PPP (constant 2011 international USD)	2002–04 (M) 2010–12 (E)	World Bank
8	Livestock	Livestock population (cattle and buffalo, camel, donkey, horse, mule, goats and sheep and poultry). The data was aggregated to Tropical Livestock Units (TLU).	2002–04 (M) 2010–12 (E)	FAOSTAT
9	Crop yield	Cereals (barely, buckwheat, canary seed, fonio, maize, millet, oats, rice, rye, sorghum, wheat, other cereals) yield (kg/ha)	2002–04 (M) 2010–12 (E)	FAOSTAT
10	Estimated nutrient depletion	Estimated NPK loss from cereal croplands in Kg/year = predicted NPK loss (kg/ha/year) from the modeling in 1.2 times total land area harvested (cultivated) with cereals in crop seasons of 2002–04.		This study
11	Land size	Lad land area harvested (cultivated) with cereals	2002–04 (M) 2010–12 (E)	FAOSTAT
12	Labor	Total economically active population in agriculture	2002–04 (M) 2010–12(E)	FAOSTAT
13	Fertilizer	Nutrient (Nitrogen (N), Phosphorous (P2O5) and Potassium (K2O5)) consumption (Mg/year)	2002–04(M) 2010–12(E)	FAOSTAT
14	Replacement cost	Prices of commercial fertilizer	2010–12 (V)	AfricaFertilizer.org
15	Value of loss in production	Producer prices of cereals (USD/Mg)	2010–12	FAOSTAT
16	Cost of SLM	Establishment and maintenance costs of physical and biological structures for soil and water conservation (cost transfer functions)		WACOT
17	Resource for poverty reduction	The amount of money required to lift the people living below the poverty line to a level of income equal to the poverty line.		This study
		Population	2010–12 (V)	FAOSTAT
18	Cost benefit analysis	Discount rate: real interest rates	2010–12	World Bank

Appendix 3a

Model predicted capital costs for SLM interventions

(2012 USD/ha) by country in Africa

Country	Capital costs of SLM in Africa USD2012/ha			
	Ag land as a % of total area	Rural pop. as % of total pop.	Crop prod. index	Food prod. index
Algeria	28	1 436	245	226
Angola	278	349	177	172
Benin	119	363	332	254
Botswana	255	683	1 250	224
Burkina Faso	235	213	467	395
Burundi	804	135	1 440	1 496
Cabo Verde	32	997	363	265
Cameroon	41	559	207	160
Central African Rep.	5	319	596	557
Chad	184	182	377	329
Comoros	1 060	217	771	801
Congo, Dem. Rep.	11	340	900	914
Congo, Rep.	105	1 042	529	330
Cote d'Ivoire	569	543	683	586
Djibouti	759	2 874	327	304
Egypt, Arab Rep.	1	368	696	590
Equatorial Guinea	8	321	653	622
Eritrea	801	178	1 438	808
Ethiopia	152	163	218	221
Gabon	38	9 229	531	547
Gambia, The	473	720	875	984
Ghana	658	543	341	269
Guinea	452	281	547	497
Guinea-Bissau	440	432	316	270
Kenya	288	194	129	184
Lesotho	804	203	2 289	1 514
Liberia	83	463	1 250	437
Libya	6	3 136	778	774
Madagascar	706	257	513	545
Malawi	492	153	135	81
Mali	130	300	233	124
Mauritania	172	732	120	539
Mauritius	220	330	2 460	1 744
Morocco	639	760	664	495
Mozambique	544	242	142	122
Namibia	274	378	639	2 149
Niger	141	162	129	244
Nigeria	900	402	949	837
Rwanda	803	204	134	95
Sao Tome and Principe	340	989	509	494
Senegal	269	365	412	302
Seychelles	3	565	1 460	815
Sierra Leone	420	314	174	110
Somalia	688	306	672	677
South Africa	909	990	762	537
Swaziland	704	178	828	793
Tanzania	257	228	253	258
Togo	698	310	439	289
Tunisia	571	1 199	692	705
Uganda	711	150	932	836
Zambia	113	323	119	143
Zimbabwe	208	254	1 019	1 659

Appendix 3b

Model predicted recurrent costs for SLM interventions

(2012 USD/ha/year) by country in Africa

Country	Recurrent costs of SLM in Africa USD2012/ha			
	Ag land as a % of total area	Rural pop. as % of total pop.	Crop prod. index	Food prod. index
Algeria	12	298	50	44
Angola	56	71	35	32
Benin	32	74	69	51
Botswana	52	141	289	44
Burkina Faso	50	43	100	88
Burundi	110	27	336	450
Cabo Verde	14	206	76	54
Cameroon	16	115	41	29
Central African Rep.	4	65	130	134
Chad	42	37	79	71
Comoros	132	44	171	209
Congo, Dem. Rep.	7	69	202	246
Congo, Rep.	29	215	114	71
Cote d'Ivoire	88	111	150	143
Djibouti	106	601	68	64
Egypt, Arab Rep.	1	75	153	144
Equatorial Guinea	6	65	143	154
Eritrea	110	36	336	212
Ethiopia	37	33	44	43
Gabon	15	1 956	115	131
Gambia, The	78	148	196	270
Ghana	97	111	71	55
Guinea	76	57	118	117
Guinea-Bissau	75	88	65	55
Kenya	57	39	25	35
Lesotho	110	41	555	457
Liberia	25	95	289	100
Libya	4	657	173	201
Madagascar	101	52	110	131
Malawi	80	31	26	13
Mali	34	61	47	21
Mauritania	41	151	23	129
Mauritius	48	67	601	543
Morocco	95	157	146	116
Mozambique	86	49	27	21
Namibia	55	77	140	702
Niger	36	33	25	49
Nigeria	119	82	214	221
Rwanda	110	41	26	15
Sao Tome and Principe	63	204	109	116
Senegal	54	74	87	63
Seychelles	3	116	342	214
Sierra Leone	72	64	34	18
Somalia	100	62	148	171
South Africa	119	205	169	128
Swaziland	101	36	185	207
Tanzania	53	46	51	52
Togo	101	63	93	60
Tunisia	88	248	152	179
Uganda	102	30	210	221
Zambia	31	66	23	25
Zimbabwe	46	52	232	511

Appendix 3c

Model predicted capital and recurrent costs of SLM in Africa

Country	Capital costs 2012 USD/ha			Recurrent costs 2012 USD/ha/year		
	Estimate 1	Estimate 2	Estimate 3	Estimate 1	Estimate 2	Estimate 3
Algeria	483.76	732.01	635.82	101.14	155.26	173.84
Angola	244.11	313.82	232.75	48.38	63.43	53.13
Benin	266.99	240.87	316.36	56.59	53.07	71.54
Botswana	602.80	468.74	718.89	131.40	96.47	214.62
Burkina Faso	327.44	223.88	358.28	70.17	46.48	71.41
Burundi	968.71	469.48	1 023.75	231.10	68.83	181.89
Cabo Verde	414.38	514.51	541.77	87.44	109.87	140.96
Cameroon	241.63	299.97	308.57	50.29	65.41	78.01
Central African Republic	369.12	161.71	490.55	83.22	34.51	97.36
Chad	267.98	182.92	296.04	57.21	39.67	57.94
Comoros	712.25	638.76	596.29	139.18	88.07	107.69
Congo, Dem. Rep.	540.97	175.06	717.76	131.15	38.00	135.89
Congo, Rep.	501.24	573.21	633.46	107.36	122.44	164.65
Cote d'Ivoire	595.31	555.68	604.14	123.22	99.77	130.84
Djibouti	1 065.84	1 816.27	1 168.15	209.74	353.66	334.39
Egypt, Arab Rep.	413.68	184.22	551.33	93.45	38.17	114.22
Equatorial Guinea	401.10	164.48	532.15	91.99	35.52	104.31
Eritrea	806.42	489.52	808.22	173.51	73.08	186.10
Ethiopia	188.24	157.26	200.40	39.32	35.22	38.28
Gabon	2 586.49	4 633.66	3 435.94	554.33	985.71	1 035.31
Gambia, The	762.98	596.50	859.69	173.10	113.26	172.31
Ghana	452.92	600.49	384.66	83.62	104.19	91.23
Guinea	444.04	366.18	441.50	92.00	66.57	87.64
Guinea-Bissau	364.69	436.09	339.44	70.96	81.56	76.88
Kenya	198.83	241.20	169.12	38.89	48.10	32.08
Lesotho	1 202.31	503.16	1 335.22	290.95	75.73	298.22
Liberia	558.39	273.18	716.71	127.21	60.14	191.84
Libya	1 173.62	1 570.90	1 562.94	258.76	330.52	414.79
Madagascar	505.21	481.71	438.19	98.65	76.89	81.27
Malawi	215.19	322.38	122.88	37.47	55.59	28.48
Mali	196.64	214.90	218.79	40.81	47.51	54.04
Mauritania	390.48	451.54	463.47	85.76	95.62	86.82
Mauritius	1 188.53	274.68	1 511.45	314.72	57.45	333.88
Morocco	639.34	699.15	639.57	128.36	125.78	151.14
Mozambique	262.36	393.00	168.59	45.80	67.47	38.35
Namibia	859.82	325.59	1 055.21	243.39	66.04	108.54
Niger	169.26	151.55	178.64	35.60	34.28	28.84
Nigeria	771.96	650.94	729.42	159.11	100.48	148.30
Rwanda	308.93	503.46	144.11	48.19	75.80	33.57
Sao Tome and Principe	582.93	664.39	664.07	123.19	133.78	156.82
Senegal	336.90	316.98	359.39	69.79	64.42	80.67
Seychelles	710.97	284.19	947.00	168.67	59.50	228.86
Sierra Leone	254.39	366.94	199.31	47.28	68.26	49.16
Somalia	585.76	496.75	551.82	120.08	81.05	105.03
South Africa	799.31	949.39	762.71	155.33	161.99	186.75
Swaziland	625.53	440.82	599.53	132.27	68.65	110.49
Tanzania	248.78	242.48	245.96	50.62	49.52	48.76
Togo	433.80	503.65	345.87	79.26	81.91	78.13
Tunisia	791.88	885.01	865.59	167.10	168.37	200.39
Uganda	657.18	430.49	639.21	140.78	66.11	120.28
Zambia	174.27	217.62	194.79	36.20	48.36	44.22
Zimbabwe	785.12	231.21	977.36	210.08	48.86	141.67

Appendix 3d

Model predicted capital costs for SLM interventions

(2012 USD/ha) by country in Africa (mechanical)

Country	Rural pop. as % of total pop.	Crop prod. index	Cereal yield	Agriculture VA per worker
Algeria	4 401	247	169	
Angola	465	162	21	363
Benin	493	366	111	599
Botswana	1 349	2 020	8	423
Burkina Faso	211	567	91	224
Burundi	103	2 424	77	93
Cabo Verde	2 461	410	3	
Cameroon	981	198	154	609
Central African Rep.	401	777	170	471
Chad	165	430	78	
Comoros	218	1 083	119	438
Congo, Dem. Rep.	444	1 322	38	150
Congo, Rep.	2 640	665	47	404
Cote d'Ivoire	935	927	392	
Djibouti	13 261	358	235	
Egypt, Arab Rep.	504	949	2 608	1 114
Equatorial Guinea	406	874		
Eritrea	159	2 422	25	
Ethiopia	138	212	245	168
Gabon	84 844	670	170	1 190
Gambia, The	1 467	1 275	54	180
Ghana	937	378	186	
Guinea	328	695	141	142
Guinea-Bissau	650	343	134	371
Kenya	183	107	166	234
Lesotho	195	4 409	4	216
Liberia	727	2 021	85	394
Libya	15 239	1 096	43	
Madagascar	285	640	405	132
Malawi	124	115	254	145
Mali	364	231	167	461
Mauritania	1 505	99	201	370
Mauritius	423	4 841	628	3 167
Morocco	1 598	893	66	1 656
Mozambique	260	122	33	177
Namibia	525	851	21	1 148
Niger	137	108	19	
Nigeria	581	1 415	139	1 894
Rwanda	197	113	273	194
Sao Tome and Principe	2 432	633	34	
Senegal	497	482	107	226
Seychelles	999	2 469		430
Sierra Leone	392	158	178	488
Somalia	376	907	89	
South Africa	2 433	1 066	736	2 423
South Sudan	138			
Sudan	287		16	829
Swaziland	159	1 186	75	
Tanzania	235	257	107	193
Togo	383	523	95	
Tunisia	3 303	942	168	1 953
Uganda	121	1 383	241	143
Zambia	409	97	409	234
Zimbabwe	280	1 553	43	158

Appendix 3e

Model predicted recurrent costs for SLM interventions

(2012 USD/ha) by country in Africa (mechanical)

Country	Rural pop. as % of total pop.	Crop prod. index	Cereal yield	Agriculture VA per worker
Algeria	1 181	42	29	
Angola	88	27	4	62
Benin	95	65	19	104
Botswana	302	429	1	72
Burkina Faso	36	106	15	37
Burundi	15	525	13	15
Cabo Verde	604	74	0	
Cameroon	209	33	26	106
Central African Republic	74	150	29	81
Chad	27	78	13	
Comoros	37	216	20	75
Congo, Dem. Rep.	84	269	6	25
Congo, Rep.	655	126	8	69
Cote d'Ivoire	198	182	67	
Djibouti	4 218	64	40	
Egypt, Arab Rep.	97	187	451	197
Equatorial Guinea	76	171		
Eritrea	26	524	4	
Ethiopia	22	36	42	28
Gabon	35 895	127	29	211
Gambia, The	333	259	9	30
Ghana	198	68	32	
Guinea	59	132	24	23
Guinea-Bissau	130	61	23	63
Kenya	30	17	28	39
Lesotho	32	1 015	1	36
Liberia	148	430	14	67
Libya	4 952	219	7	
Madagascar	50	121	69	22
Malawi	19	18	43	24
Mali	67	39	28	79
Mauritania	342	15	34	63
Mauritius	79	1 125	108	583
Morocco	367	175	11	298
Mozambique	45	19	5	29
Namibia	102	166	4	204
Niger	22	17	3	
Nigeria	114	290	24	342
Rwanda	33	18	46	32
Sao Tome and Principe	596	120	6	
Senegal	95	88	18	38
Seychelles	213	536		74
Sierra Leone	73	26	30	84
Somalia	69	178	15	
South Africa	596	212	126	442
South Sudan	22			
Sudan	51		3	145
Swaziland	26	239	13	
Tanzania	40	44	18	32
Togo	71	97	16	
Tunisia	848	185	29	353
Uganda	19	283	41	24
Zambia	76	15	70	39
Zimbabwe	49	321	7	26

Appendix 3f

Model predicted capital and recurrent costs for SLM interventions

(2012 USD/ha) by country in Africa (mechanical)

Country	Permanent cropland	
	Real capital costs 2012 USD/ha	Real recurrent costs 2012 USD/ha/year
Algeria	158	37
Angola	120	28
Benin	562	136
Botswana	12	3
Burkina Faso	127	30
Burundi	1 093	267
Cabo Verde	226	54
Cameroon	505	122
Central African Republic	87	20
Chad	36	8
Comoros	1 662	409
Congo, Dem. Rep.	152	36
Congo, Rep.	112	26
Cote d'Ivoire	1 115	273
Djibouti		
Egypt, Arab Rep.	237	57
Equatorial Guinea	400	96
Eritrea	32	7
Ethiopia	285	68
Gabon	212	50
Gambia, The	181	43
Ghana	1 014	247
Guinea	468	113
Guinea-Bissau	867	211
Kenya	255	61
Lesotho	88	21
Liberia	405	97
Libya	108	25
Madagascar	272	65
Malawi	322	77
Mali	85	20
Mauritania	23	5
Mauritius	383	92
Morocco	484	117
Mozambique	157	37
Namibia	23	5
Niger	67	16
Nigeria	782	190
Rwanda	931	227
Sao Tome and Principe	2 003	494
Senegal	147	35
Seychelles	588	142
Sierra Leone	415	100
Somalia	50	12
South Africa	148	35
South Sudan		
Sudan	71	16
Swaziland	246	59
Tanzania	429	103
Togo	537	130
Tunisia	1 172	287
Uganda	985	240
Zambia	51	12
Zimbabwe	127	30

Appendix 4:

Present values of costs of inaction against soil erosion by erosion and poverty classes and results of sensitivity analyses by country in Africa

Appendix 4a: Present value of costs of inaction against erosion induced nutrient depletion in cropland lands of 42 African countries grouped by annual erosion rate (-0.13 ≤ r≤ 0.43; t = 15 years (20016–30))

Erosion class	Mean cultivated land area in Millions of ha/year	Mean NPK loss in 1000s of Mg/year	Value at replacement cost in billions of PPP USD (constant 2011 USD)		Mean crop loss in Millions of Mg/year	Cost of inaction in billions of PPP USD (constant 2011 USD)			
								Annuity as % of 2010–12 average	
			PV	Annuity		PV	Annuity	GDP	Agri GDP
ER1	0.704 (0.753)	24.221 (27.629)	0.205 (0.226)	0.025 (0.029)	0.952 (1.170)	9.130 (12.590)	1.083 (1.487)	9.88 (11.41)	34.51 (50.46)
ER2	1.190 (0.595)	46.107 (24.264)	0.375 (0.185)	0.043 (0.021)	1.702 (0.981)	12.465 (7.176)	1.428 (0.826)	6.11 (3.57)	31.85 (23.70)
ER3	1.952 (1.755)	82.755 (73.539)	0.670 (0.643)	0.089 (0.075)	4.118 (4.630)	32.229 (35.591)	4.067 (3.977)	7.99 (10.02)	35.34 (35.61)
ER4	4.900 (5.723)	229.984 (269.672)	5.444 (10.489)	0.247 (0.258)	11.948 (15.863)	301.634 (654.065)	11.129 (13.448)	11.63 (10.39)	25.17 (20.95)
ER5	3.976 (3.529)	195.854 (173.318)	2.246 (2.082)	0.217 (0.172)	15.330 (17.466)	212.593 (378.904)	17.380 (24.938)	26.67 (48.10)	88.69 (112.38)
ER1-ER5	2.487 (3.339)	112.818 (160.197)	1.724 (4.846)	0.121 (0.162)	6.607 (11.539)	109.185 (335.371)	6.806 (13.440)	12.29 (22.67)	42.72 (59.95)
Africa	104.435	4738.344	72.398	5.090	277.483	4585.760	285.836	12.29	42.72

Erosion rate: 1< 950 Mg/ha/year. 2= 950 to 1700. 3= 1700 to 3150. 4 = 3150 to 7200. 5 = > 7200 Mg/ha/year

ER1: Burundi, Djibouti, Guinea, Lesotho, Malawi, Ruanda, Sierra Leone, Swaziland, Togo;

ER2: Benin, Cameroon, Eritrea, Ghana, Liberia, Senegal, Tunisia, Zimbabwe;

ER3: Burkina Faso, Congo, Côte D'Ivoire, Gabon, Kenya, Madagascar, Morocco, Uganda, Zambia;

ER4: Angola, Botswana, Chad, Ethiopia, Mozambique, Nigeria, UR of Tanzania; and

ER5: DR Congo, Egypt, Mali, Mauritania, Namibia, Niger, South Africa, Sudan.

Appendix 4b: Present value costs of inaction against poverty induced nutrient depletion in croplands of 42 African countries grouped by index of poverty gap (-0.13 ≤ r≤ 0.43; t = 15 years (20016–30))

Poverty class	Mean cultivated land area in Millions of ha/year	Mean NPK loss in 1000s of Mg/year	Value at replacement cost in billions of PPP USD (constant 2011 USD)		Mean crop loss in Millions of Mg/year	Cost of inaction in billions of PPP USD (constant 2011 USD)			
								Annuity as % of 2010–12 average	
			PV	Annuity		PV	Annuity	GDP	Agri GDP
PGI1	2.151 (2.702)	2.616 (6.256)	0.024 (0.050)	0.003 (0.006)	0.165 (0.352)	1.410 (2.768)	0.141 (0.308)	0.10 (0.21)	0.61 (0.81)
PGI2	3.403 (3.535)	18.050 (17.951)	0.180 (0.202)	0.020 (0.022)	0.834 (0.865)	6.596 (7.454)	0.730 (0.800)	2.28 (3.31)	6.73 (9.54)
PGI3	1.891 (1.668)	14.688 (12.367)	0.126 (0.101)	0.014 (0.012)	0.630 (0.543)	4.401 (3.292)	0.479 (0.394)	2.13 (1.78)	6.71 (4.31)
PGI4	3.511 (6.548)	45.256 (85.845)	1.555 (3.477)	0.042 (0.063)	2.460 (5.094)	86.484 (207.573)	1.718 (3.634)	1.59 (0.96)	5.08 (4.35)
PGI5	1.330 (0.783)	27.829 (18.114)	0.153 (0.075)	0.029 (0.024)	0.973 (0.613)	3.501 (2.128)	0.567 (0.319)	3.00 (1.72)	13.88 (7.88)
PGI1-PGI5	2.487 (3.339)	19.251 (35.263)	0.324 (1.323)	0.019 (0.030)	0.891 (1.996)	15.840 (78.280)	0.656 (1.438)	1.75 (2.19)	6.22 (7.41)
Africa	104.435	808.540	13.619	0.811	37.441	665.272	27.550	1.75	6.22

Quantile of Poverty Gap Index: 1 = less than 0.07. 2 = 0.07 to 0.14. 3 = 0.14 to 0.21 million ha. 4 = 0.21 to 0.33 million ha. 5 = 0.33 to 0.53.

PGI1: Botswana, Djibouti, Egypt, Gabon, Mauritania, Morocco, Namibia, South Africa, Sudan, Tunisia;

PGI2: Cameroon, Chad, Congo, Côte D'Ivoire, Ethiopia, Ghana, Guinea, Niger, Senegal, Uganda, UR Tanzania;

PGI3: Angola, Benin, Burkina Faso, Eritrea, Kenya, Mali, Sierra Leone, Swaziland;

PGI4: C, African Republic, Lesotho, Mozambique, Nigeria, Rwanda, Togo; and

PGI5: Burundi, DR Congo, Liberia, Madagascar, Malawi, Zambia, Zimbabwe

Appendix 4c: Present value costs of action against erosion induced cropland degradation in 42 African countries grouped by erosion rate (-0.13 ≤ r≤ 0.43; t = 15 years (20016–30))

Erosion class	SLM structure Establishment cost (PPP USD/ha)	Maintenance cost in PPP USD/ha/year	Total cultivated land area to be developed by SLM structures in Millions of ha over 15 years (establishment in 5 years 20% of land area per year)	Cost of Action in billions of PPP USD (constant 2011 USD)			
						Annuity as	
				PV	Annuity	% GDP	% Agri GDP
ER1	1213.859 (870.474)	211.652 (174.726)	0.704 (0.753)	1.198 (1.237)	0.142 (0.154)	1.35 (1.18)	4.77 (5.26)
ER2	817.237 (367.510)	150.504 (46.158)	1.190 (0.595)	2.007 (1.205)	0.230 (0.139)	0.88 (0.47)	4.82 (4.03)
ER3	1798.285 (2024.470)	356.825 (432.907)	1.952 (1.755)	4.401 (5.331)	0.587 (0.622)	1.10 (1.11)	5.00 (4.69)
ER4	728.554 (411.336)	131.521 (56.638)	4.900 (5.723)	27.947 (64.808)	0.901 (1.159)	0.92 (0.81)	2.38 (2.11)
ER5	748.405 (427.215)	148.425 (73.600)	3.976 (3.529)	6.787 (6.706)	0.696 (0.721)	1.48 (2.17)	5.60 (4.85)
ER1-ER5	1082.449 (1098.575)	203.807 (227.346)	2.487 (3.339)	8.198 (28.788)	0.504 (696)	1.15 (1.23)	4.53 (4.30)
Africa			104	344.312	21.174	1.15	4.53

Erosion rate: 1< 950 Mg/ha/year. 2= 950 to 1700. 3= 1700 to 3150. 4 = 3150 to 7200. 5 = > 7200 Mg/ha/year.
ER1: Burundi, Djibouti, Guinea, Lesotho, Malawi, Ruanda, Sierra Leone, Swaziland, Togo;
ER2: Benin, Cameroon, Eritrea, Ghana, Liberia, Senegal, Tunisia, Zimbabwe;
ER3: Burkina Faso, Congo, Côte D'Ivoire, Gabon, Kenya, Madagascar, Morocco, Uganda, Zambia;
ER4: Angola, Botswana, Chad, Ethiopia, Mozambique, Nigeria, UR of Tanzania; and
ER5: DR Congo, Egypt, Mali, Mauritania, Namibia, Niger, South Africa, Sudan.

Appendix 4d: Present value costs of action against poverty and hence poverty induced cropland degradation in 42 African countries grouped by index of poverty gap (-0.13 ≤ r≤ 0.43; t = 15 years (20016–30))

Poverty class	Average poverty gap	Annual reduction (6.67% per year) in poverty gap (2016 to 2030)	Population (Millions) in 2016	Population (Millions) of 2016 with income below poverty line (per capita income of 1.25 PPP USD/day)	Population (Millions) of 2030 (poverty gap = 0.00)	Cost of action (resource needed to lift the poor to the poverty line) billion of PPP USD (constant 2011 USD)			
								Annuity as	
						PV	Annuity	% GDP	% Agri GDP
PGI1	0.031	0.002	23.750	0.396	28.197	1.078 (1.733)	0.111 (0.198)	0.23 (0.32)	3.27 (5.87)
PGI2	0.114	0.008	30.627	3.422	43.573	9.102 (7.945)	1.025 (0.877)	2.37 (1.29)	9.82 (13.79)
PGI3	0.167	0.011	16.564	2.757	23.569	7.613 (6.479)	0.807 (0.744)	2.93 (1.58)	12.23 (10.23)
PGI4	0.271	0.018	40.593	11.029	58.087	74.100 (165.095)	1.998 (2.734)	6.54 (3.85)	20.75 (16.52)
PGI5	0.424	0.028	23.311	10.850	33.391	21.056 (19.424)	4.378 (5.669)	17.09 (9.40)	87.27 (88.33)
PGI1-PGI5	0.178	0.012	26.515	4.899	36.478	18.186 (63.061)	1.464 (2.825)	5.02 (7.01)	23.19 (46.01)
Africa			1113.634	205.773	1532.073	763.803	61.474	5.02	23.19

Quantile of Poverty Gap Index: 1 = less than 0.07. 2 = 0.07 to 0.14. 3 = 0.14 to 0.21 million ha. 4 = 0.21 to 0.33 million ha. 5 = 0.33 to 0.53.

PGI1: Botswana, Djibouti, Egypt, Gabon, Mauritania, Morocco, Namibia, South Africa, Sudan, Tunisia;

PGI2: Cameroon, Chad, Congo, Côte D'Ivoire, Ethiopia, Ghana, Guinea, Niger, Senegal, Uganda, UR Tanzania;

PGI3: Angola, Benin, Burkina Faso, Eritrea, Kenya, Mali, Sierra Leone, Swaziland;

PGI4: C, African Republic, Lesotho, Mozambique, Nigeria, Rwanda, Togo; and

PGI5: Burundi, DR Congo, Liberia, Madagascar, Malawi, Zambia, Zimbabwe.

Appendix 4e: Net present value action against poverty induced nutrient depletion from croplands in 42 African countries grouped by poverty gap(-0.13 ≤ r≤ 0.43; t = 15 years (20016–30))

Quantiles	PV of cost of inaction in Billion PPP USD	PV of cost of action in Billion PPP USD	Benefits of action				Benefits of action – Cost of action				BCR	Benefits of action/ cost of inaction
			PV in Billion PPP USD	Annuity in Billion PPP USD	Annuity as % of 2010–12 average		NPV in Billions of PPP USD	Annuity in Billions of PPP USD	Annuity NPV as % of			
					GDP	Agri GDP			GDP	Agri GDP		
PGI1	1.410 (2.768)	1.078 (1.733)	0.743 (1.423)	0.073 (0.156)	0.05 (0.11)	0.32 (0.41)	-0.335 (0.676)	-0.038 (0.062)	0.18 (0.29)	2.95 (5.94)	0.42 (0.57)	0.53
PGI2	6.596 (7.454)	9.102 (7.945)	3.371 (3.846)	0.373 (0.411)	1.16 (1.68)	3.41 (4.83)	-5.731 (5.329)	-0.652 (0.612)	1.21 (1.00)	6.42 (12.57)	0.35 (0.35)	0.51
PGI3	4.401 (3.292)	7.613 (6.479)	2.263 (1.653)	0.245 (0.197)	1.10 (0.92)	3.45 (2.16)	-5.350 (5.795)	-0.562 (0.652)	1.83 (1.19)	8.78 (9.31)	0.33 (0.22)	0.51
PGI4	86.484 (207.573)	74.100 (165.095)	60.906 (147.119)	1.171 (2.591)	0.82 (0.44)	2.67 (2.18)	-13.193 (18.425)	-0.827 (0.669)	5.72 (3.76)	18.07 (15.11)	0.24 (0.32)	0.70
PGI5	3.501 (2.128)	21.056 (19.424)	1.692 (1.103)	0.259 (0.137)	1.42 (0.79)	6.57 (3.88)	-19.364 (19.438)	-4.120 (5.612)	15.66 (9.46)	80.70 (88.35)	0.11 (0.07)	0.48
PGI1-PGI5	15.840 (78.280)	18.186 (63.061)	10.474 (55.492)	0.372 (0.998)	0.88 (1.09)	3.10 (3.65)	-7.712 (12.347)	-1.091 (2.604)	4.14 (6.75)	20.09 (44.78)	0.31 (0.36)	0.66
Africa	665.272	763.803	439.905	15.634	0.88	3.10	-323.898	-45.840	4.14	20.09	0.31	0.66

Quantile of Poverty Gap Index: 1 = less than 0.07. 2 = 0.07 to 0.14. 3 = 0.14 to 0.21 million ha. 4 = 0.21 to 0.33 million ha. 5 = 0.33 to 0.53.

PGI1: Botswana, Djibouti, Egypt, Gabon, Mauritania, Morocco, Namibia, South Africa, Sudan, Tunisia;

PGI2: Cameroon, Chad, Congo, Côte D'Ivoire, Ethiopia, Ghana, Guinea, Niger, Senegal, Uganda, UR Tanzania;

PGI3: Angola, Benin, Burkina Faso, Eritrea, Kenya, Mali, Sierra Leone, Swaziland;

PGI4: C, African Republic, Lesotho, Mozambique, Nigeria, Rwanda, Togo; and

PGI5: Burundi, DR Congo, Liberia, Madagascar, Malawi, Zambia, Zimbabwe

Appendix 4f: Sensitivity of NPV and BCR to changes in real discount rates by country

Country	Base case NPV in Billions of PPP USD	Base case discount rate	% change in NPV from the base case if r increase (+) and decreases (-) by:				Base case BCR	Benefit cost ratio if r increases (+) and decreases (-) by:			
			50 %	25 %	-25 %	-50 %		50 %	25 %	-25 %	-50 %
Djibouti	-3.90E-05	0.140	-19.46	-10.85	13.96	32.32	0.14	0.12	0.13	0.15	0.16
Gabon	-0.33	0.077	-14.78	-7.96	9.36	20.44	0.19	0.18	0.19	0.20	0.21
Madagascar	0.60	0.430	-111.90	-70.63	130.67	398.12	1.29	0.95	1.10	1.56	1.94
Cameroon	0.66	0.077	-47.05	-25.83	31.60	70.47	1.25	1.16	1.20	1.29	1.34
Rwanda	0.62	0.137	-44.15	-25.26	34.33	81.82	1.91	1.63	1.76	2.07	2.25
Uganda	7.42	0.090	-34.05	-18.82	23.43	52.84	1.81	1.65	1.73	1.90	1.99
Congo	0.06	0.077	-30.12	-16.45	19.93	44.22	1.80	1.67	1.73	1.87	1.94
Lesotho	0.36	0.063	-24.78	-13.36	15.67	34.15	2.22	2.06	2.14	2.31	2.39
Burundi	1.28	-0.006	-3.01	-1.52	1.54	3.11	2.30	2.28	2.29	2.31	2.32
Botswana	0.57	0.025	-11.03	-5.70	6.11	12.65	2.41	2.35	2.38	2.44	2.47
Swaziland	0.21	0.025	-10.78	-5.56	5.94	12.30	2.57	2.50	2.54	2.61	2.64
Eritrea	1.90	0.077	-26.66	-14.54	17.55	38.86	2.79	2.54	2.66	2.92	3.06
Malawi	3.99	0.158	-38.93	-22.45	31.25	75.82	3.23	2.73	2.96	3.52	3.85
Ghana	8.56	0.077	-25.90	-14.12	17.02	37.68	3.00	2.76	2.88	3.14	3.27
Tunisia	5.45	0.077	-25.93	-14.13	17.04	37.73	3.06	2.80	2.93	3.20	3.34
Togo	2.34	0.077	-25.34	-13.81	16.64	36.82	3.17	2.93	3.04	3.29	3.42
Mauritania	1.07	0.079	-25.77	-14.07	17.03	37.79	3.18	2.94	3.06	3.31	3.44
Côte D'Ivoire	4.90	0.077	-25.27	-13.77	16.59	36.70	3.40	3.12	3.26	3.55	3.70
Morocco	39.90	0.077	-25.26	-13.76	16.58	36.69	3.40	3.13	3.26	3.55	3.70
Liberia	0.93	0.068	-22.50	-12.16	14.36	31.42	3.88	3.63	3.76	4.01	4.14
Mozambique	10.39	0.115	-31.69	-17.78	23.03	53.26	4.18	3.68	3.92	4.46	4.76
Zimbabwe	6.29	0.077	-24.30	-13.23	15.92	35.20	4.30	3.99	4.14	4.47	4.64
Namibia	1.50	0.022	-8.90	-4.58	4.86	10.01	4.24	4.15	4.20	4.29	4.33
South Africa	43.59	0.030	-11.83	-6.14	6.65	13.86	4.35	4.21	4.28	4.42	4.49
Senegal	6.97	0.077	-24.08	-13.11	15.77	34.87	4.82	4.46	4.64	5.02	5.21
Sierra Leone	6.91	0.041	-15.16	-7.97	8.86	18.74	4.79	4.59	4.69	4.90	5.00
DR Congo	3.69	0.248	-42.19	-25.15	38.79	101.81	5.76	4.66	5.16	6.47	7.30
Guinea	17.00	0.077	-24.01	-13.07	15.72	34.76	5.26	4.84	5.05	5.49	5.72
Benin	6.26	0.077	-23.73	-12.91	15.53	34.32	5.63	5.22	5.42	5.84	6.05
Sudan (former)	93.33	0.077	-23.78	-12.95	15.56	34.40	5.84	5.39	5.61	6.08	6.33
Zambia	6.71	0.067	-21.50	-11.60	13.66	29.83	6.04	5.66	5.85	6.23	6.43
UR Tanzania	82.35	0.053	-18.30	-9.75	11.14	23.91	6.27	5.89	6.08	6.47	6.68
Nigeria	1132.98	-0.132	-51.97	-31.61	50.42	133.18	7.04	6.28	6.67	7.36	7.63
Mali	30.83	0.077	-23.42	-12.74	15.31	33.84	7.05	6.54	6.79	7.32	7.59
Kenya	22.05	0.084	-24.86	-13.61	16.59	36.97	7.30	6.69	6.99	7.62	7.95
CA Republic	0.72	0.077	-23.38	-12.72	15.29	33.78	7.40	6.86	7.13	7.69	7.98
Angola	13.72	0.014	-5.78	-2.94	3.06	6.24	7.18	7.08	7.13	7.23	7.28
Burkina Faso	30.65	0.077	-23.34	-12.70	15.26	33.71	7.86	7.27	7.56	8.17	8.48
Chad	15.21	0.077	-23.21	-12.63	15.17	33.52	8.73	8.10	8.41	9.06	9.40
Ethiopia	115.64	0.077	-23.06	-12.54	15.06	33.28	10.43	9.68	10.05	10.81	11.21
Niger	85.40	0.077	-22.97	-12.50	15.00	33.14	11.82	10.98	11.39	12.26	12.70
Egypt	670.99	-3.81E-04	-0.16	-0.08	0.08	0.16	93.09	93.05	93.07	93.10	93.12
Africa Average	**59.14**	**0.078**	**-29.84**	**-17.75**	**27.01**	**69.64**	**6.58**	**6.25**	**6.41**	**6.76**	**6.95**
Africa Sum	**2483.69**										

Appendix 4g: Sensitivity of NPV and BCR to changes in producers' prices of cereals by country

Country	Base case NPV in Billions of PPP USD	Base case weighted average cereals producers' price in PPP USD/Mg	% change in NPV from the base case prices of cereals increase (+) and decreases (-) by:				Base case BCR	Benefit cost ratio if prices of cereals increase (+) and decrease (-) by:			
			50 %	25 %	-25 %	-50 %		50 %	25 %	-25 %	-50 %
Djibouti	-3.90E-05	740.86	8.07	4.03	-4.03	-8.07	0.14	0.21	0.17	0.10	0.07
Gabon	-0.33	586.38	12.00	6.00	-6.00	-12.00	0.19	0.29	0.24	0.15	0.10
Cameroon	0.66	725.69	252.81	126.41	-126.41	-252.81	1.25	1.87	1.56	0.93	0.62
Madagascar	0.60	1025.26	220.37	110.19	-110.19	-220.37	1.29	1.94	1.62	0.97	0.65
Congo	0.06	670.97	112.55	56.28	-56.28	-112.55	1.80	2.70	2.25	1.35	0.90
Uganda	7.42	1204.39	111.70	55.85	-55.85	-111.70	1.81	2.72	2.26	1.36	0.91
Rwanda	0.62	940.52	104.85	52.43	-52.43	-104.85	1.91	2.87	2.39	1.43	0.96
Lesotho	0.36	738.79	91.00	45.50	-45.50	-91.00	2.22	3.33	2.77	1.66	1.11
Burundi	1.28	1115.47	88.47	44.23	-44.23	-88.47	2.30	3.45	2.87	1.72	1.15
Botswana	0.57	616.83	85.53	42.77	-42.77	-85.53	2.41	3.61	3.01	1.81	1.20
Swaziland	0.21	730.18	81.82	40.91	-40.91	-81.82	2.57	3.86	3.21	1.93	1.29
Eritrea	1.90	950.59	78.01	39.00	-39.00	-78.01	2.79	4.18	3.48	2.09	1.39
Ghana	8.56	949.67	74.95	37.48	-37.48	-74.95	3.00	4.51	3.75	2.25	1.50
Tunisia	5.45	789.38	74.28	37.14	-37.14	-74.28	3.06	4.59	3.82	2.29	1.53
Togo	2.34	692.31	73.09	36.54	-36.54	-73.09	3.17	4.75	3.96	2.37	1.58
Mauritania	1.07	1084.24	72.93	36.46	-36.46	-72.93	3.18	4.77	3.98	2.39	1.59
Malawi	3.99	808.85	72.46	36.23	-36.23	-72.46	3.23	4.84	4.03	2.42	1.61
Côte D'Ivoire	4.90	927.44	70.84	35.42	-35.42	-70.84	3.40	5.10	4.25	2.55	1.70
Morocco	39.90	781.55	70.80	35.40	-35.40	-70.80	3.40	5.11	4.26	2.55	1.70
Liberia	0.93	945.79	67.35	33.68	-33.68	-67.35	3.88	5.82	4.85	2.91	1.94
Mozambique	10.39	716.25	65.73	32.86	-32.86	-65.73	4.18	6.27	5.22	3.13	2.09
Namibia	1.50	634.42	65.42	32.71	-32.71	-65.42	4.24	6.36	5.30	3.18	2.12
Zimbabwe	6.29	627.18	65.13	32.56	-32.56	-65.13	4.30	6.46	5.38	3.23	2.15
South Africa	43.59	587.94	64.93	32.47	-32.47	-64.93	4.35	6.52	5.44	3.26	2.17
Sierra Leone	6.91	1338.88	63.19	31.59	-31.59	-63.19	4.79	7.19	5.99	3.59	2.40
Senegal	6.97	666.66	63.07	31.54	-31.54	-63.07	4.82	7.24	6.03	3.62	2.41
Guinea	17.00	1255.63	61.73	30.86	-30.86	-61.73	5.26	7.90	6.58	3.95	2.63
Benin	6.26	839.79	60.81	30.40	-30.40	-60.81	5.63	8.44	7.03	4.22	2.81
DR Congo	3.69	727.21	60.51	30.26	-30.26	-60.51	5.76	8.63	7.19	4.32	2.88
Sudan	93.33	1020.46	60.33	30.16	-30.16	-60.33	5.84	8.76	7.30	4.38	2.92
Zambia	6.71	695.83	59.92	29.96	-29.96	-59.92	6.04	9.06	7.55	4.53	3.02
UR Tanzania	82.35	1264.32	59.49	29.74	-29.74	-59.49	6.27	9.41	7.84	4.70	3.14
Nigeria	1132.98	854.96	58.28	29.14	-29.14	-58.28	7.04	10.55	8.79	5.28	3.52
Mali	30.83	809.96	58.26	29.13	-29.13	-58.26	7.05	10.58	8.82	5.29	3.53
Angola	13.72	686.30	58.09	29.05	-29.05	-58.09	7.18	10.77	8.98	5.39	3.59
Kenya	22.05	1065.94	57.93	28.97	-28.97	-57.93	7.30	10.95	9.13	5.48	3.65
CA Republic	0.72	739.83	57.81	28.90	-28.90	-57.81	7.40	11.10	9.25	5.55	3.70
Burkina Faso	30.65	863.18	57.29	28.64	-28.64	-57.29	7.86	11.79	9.82	5.89	3.93
Chad	15.21	786.52	56.47	28.23	-28.23	-56.47	8.73	13.10	10.91	6.55	4.37
Ethiopia	115.64	1068.28	55.30	27.65	-27.65	-55.30	10.43	15.64	13.03	7.82	5.21
Niger	85.40	884.82	54.62	27.31	-27.31	-54.62	11.82	17.73	14.77	8.86	5.91
Egypt	670.99	1418.09	50.54	25.27	-25.27	-50.54	93.09	139.63	116.36	69.82	46.54
Africa Average	**59.14**	**870.90**	**73.78**	**36.89**	**-36.89**	**-73.78**	**6.58**	**9.87**	**8.23**	**4.94**	**3.29**
Africa Sum	**2483.69**										

Appendix 4h: - Sensitivity of NPV and BCR to changes in the effectiveness of sustainable land management interventions in controlling soil erosion induced nutrient depletion by country

Country	Base case NPV in Billions of PPP USD	Base case effectiveness of SLM (erosion control) in (%)	% change in NPV from the base case if effectiveness of SLM is:				Base case BCR	Benefit cost ratio if effectiveness of SLM in controlling erosion is:			
			60 %	40 %	25 %	15 %		60 %	40 %	25 %	15 %
Djibouti	-3.90E-05	75.00	-3.23	-7.53	-10.76	-13.98	0.14	0.11	0.07	0.05	0.02
Gabon	-0.33	75.00	-4.80	-11.20	-16.00	-20.80	0.19	0.15	0.10	0.06	0.03
Cameroon	0.66	75.00	-101.12	-235.96	-337.08	-438.21	1.25	1.00	0.66	0.42	0.17
Madagascar	0.60	75.00	-88.15	-205.68	-293.83	-381.98	1.29	1.03	0.69	0.43	0.17
Congo	0.06	75.00	-45.02	-105.05	-150.07	-195.09	1.80	1.44	0.96	0.60	0.24
Uganda	7.42	75.00	-44.68	-104.25	-148.93	-193.61	1.81	1.45	0.97	0.60	0.24
Rwanda	0.62	75.00	-41.94	-97.86	-139.80	-181.74	1.91	1.53	1.02	0.64	0.25
Lesotho	0.36	75.00	-36.40	-84.94	-121.34	-157.74	2.22	1.78	1.18	0.74	0.30
Burundi	1.28	75.00	-35.39	-82.57	-117.96	-153.35	2.30	1.84	1.23	0.77	0.31
Botswana	0.57	75.00	-34.21	-79.83	-114.04	-148.25	2.41	1.93	1.28	0.80	0.32
Swaziland	0.21	75.00	-32.73	-76.36	-109.09	-141.82	2.57	2.06	1.37	0.86	0.34
Eritrea	1.90	75.00	-31.20	-72.81	-104.01	-135.21	2.79	2.23	1.49	0.93	0.37
Ghana	8.56	75.00	-29.98	-69.96	-99.94	-129.92	3.00	2.40	1.60	1.00	0.40
Tunisia	5.45	75.00	-29.71	-69.33	-99.04	-128.75	3.06	2.45	1.63	1.02	0.41
Togo	2.34	75.00	-29.24	-68.22	-97.45	-126.69	3.17	2.53	1.69	1.06	0.42
Mauritania	1.07	75.00	-29.17	-68.06	-97.23	-126.40	3.18	2.54	1.70	1.06	0.42
Malawi	3.99	75.00	-28.98	-67.63	-96.62	-125.60	3.23	2.58	1.72	1.08	0.43
Côte D'Ivoire	4.90	75.00	-28.33	-66.11	-94.45	-122.78	3.40	2.72	1.81	1.13	0.45
Morocco	39.90	75.00	-28.32	-66.08	-94.39	-122.71	3.40	2.72	1.82	1.13	0.45
Liberia	0.93	75.00	-26.94	-62.86	-89.80	-116.75	3.88	3.11	2.07	1.29	0.52
Mozambique	10.39	75.00	-26.29	-61.34	-87.64	-113.93	4.18	3.34	2.23	1.39	0.56
Namibia	1.50	75.00	-26.17	-61.06	-87.23	-113.40	4.24	3.39	2.26	1.41	0.57
Zimbabwe	6.29	75.00	-26.05	-60.79	-86.84	-112.89	4.30	3.44	2.30	1.43	0.57
South Africa	43.59	75.00	-25.97	-60.60	-86.58	-112.55	4.35	3.48	2.32	1.45	0.58
Sierra Leone	6.91	75.00	-25.28	-58.98	-84.25	-109.53	4.79	3.83	2.56	1.60	0.64
Senegal	6.97	75.00	-25.23	-58.87	-84.10	-109.33	4.82	3.86	2.57	1.61	0.64
Guinea	17.00	75.00	-24.69	-57.61	-82.30	-106.99	5.26	4.21	2.81	1.75	0.70
Benin	6.26	75.00	-24.32	-56.75	-81.08	-105.40	5.63	4.50	3.00	1.88	0.75
DR Congo	3.69	75.00	-24.21	-56.48	-80.69	-104.89	5.76	4.60	3.07	1.92	0.77
Sudan	93.33	75.00	-24.13	-56.30	-80.43	-104.56	5.84	4.67	3.12	1.95	0.78
Zambia	6.71	75.00	-23.97	-55.93	-79.90	-103.87	6.04	4.83	3.22	2.01	0.81
UR Tanzania	82.35	75.00	-23.79	-55.52	-79.31	-103.11	6.27	5.02	3.34	2.09	0.84
Nigeria	1132.98	75.00	-23.31	-54.40	-77.71	-101.03	7.04	5.63	3.75	2.35	0.94
Mali	30.83	75.00	-23.30	-54.38	-77.68	-100.99	7.05	5.64	3.76	2.35	0.94
Angola	13.72	75.00	-23.24	-54.22	-77.45	-100.69	7.18	5.74	3.83	2.39	0.96
Kenya	22.05	75.00	-23.17	-54.07	-77.25	-100.42	7.30	5.84	3.89	2.43	0.97
CA Republic	0.72	75.00	-23.12	-53.96	-77.08	-100.20	7.40	5.92	3.95	2.47	0.99
Burkina Faso	30.65	75.00	-22.92	-53.47	-76.39	-99.30	7.86	6.29	4.19	2.62	1.05
Chad	15.21	75.00	-22.59	-52.70	-75.29	-97.88	8.73	6.99	4.66	2.91	1.16
Ethiopia	115.64	75.00	-22.12	-51.62	-73.74	-95.86	10.43	8.34	5.56	3.48	1.39
Niger	85.40	75.00	-21.85	-50.98	-72.83	-94.68	11.82	9.46	6.30	3.94	1.58
Egypt	670.99	75.00	-20.22	-47.17	-67.39	-87.61	93.09	74.47	49.65	31.03	12.41
Africa Average	**59.14**	**75.00**	**-29.51**	**-68.86**	**-98.37**	**-127.88**	**6.58**	**5.26**	**3.51**	**2.19**	**0.88**
Africa Sum	**2483.69**										

Appendix 4i: Sensitivity of NPV and BCR to changes in total costs of sustainable land management technologies by country

Country	Base case NPV in Billions of PPP USD	Base case costs of SLM in PPP USD/ha/year		% change in NPV from the base case cost of SLM increases by:				Base case BCR	Benefit cost ratio if costs of SLM increase by:			
		Establishment or capital cost	Maintenance cost	50 %	100 %	150 %	200 %		50 %	100 %	150 %	200 %
Djibouti	-3.90E-05	3433.82	668.63	-58.07	-116.13	-174.20	-232.27	0.14	0.09	0.07	0.06	0.05
Gabon	-0.33	6872.32	1461.93	-62.00	-124.00	-186.00	-248.00	0.19	0.13	0.10	0.08	0.06
Cameroon	0.66	622.96	135.83	-202.81	-405.62	-608.44	-811.25	1.25	0.83	0.62	0.50	0.42
Madagascar	0.60	1447.93	231.13	-170.37	-340.74	-511.12	-681.49	1.29	0.86	0.65	0.52	0.43
Congo	0.06	934.95	199.70	-62.55	-125.10	-187.65	-250.20	1.80	1.20	0.90	0.72	0.60
Uganda	7.42	2678.51	509.59	-61.70	-123.39	-185.09	-246.79	1.81	1.21	0.91	0.72	0.60
Rwanda	0.62	1159.09	174.51	-54.85	-109.70	-164.56	-219.41	1.91	1.27	0.96	0.76	0.64
Lesotho	0.36	931.32	140.16	-41.00	-82.01	-123.01	-164.01	2.22	1.48	1.11	0.89	0.74
Burundi	1.28	1390.55	203.86	-38.47	-76.94	-115.41	-153.88	2.30	1.53	1.15	0.92	0.77
Botswana	0.57	851.58	175.26	-35.53	-71.06	-106.59	-142.12	2.41	1.60	1.20	0.96	0.80
Swaziland	0.21	820.63	127.80	-31.82	-63.64	-95.46	-127.28	2.57	1.71	1.29	1.03	0.86
Eritrea	1.90	1268.76	189.40	-28.01	-56.01	-84.02	-112.02	2.79	1.86	1.39	1.11	0.93
Ghana	8.56	1298.05	225.23	-24.95	-49.90	-74.86	-99.81	3.00	2.00	1.50	1.20	1.00
Tunisia	5.45	1197.41	194.73	-24.28	-48.56	-72.84	-97.12	3.06	2.04	1.53	1.22	1.02
Togo	2.34	532.03	108.65	-23.09	-46.18	-69.27	-92.36	3.17	2.11	1.58	1.27	1.06
Mauritania	1.07	1095.64	232.01	-22.93	-45.85	-68.78	-91.70	3.18	2.12	1.59	1.27	1.06
Malawi	3.99	661.67	114.10	-22.46	-44.92	-67.39	-89.85	3.23	2.15	1.61	1.29	1.08
Côte D'Ivoire	4.90	1148.87	206.28	-20.84	-41.67	-62.51	-83.34	3.40	2.27	1.70	1.36	1.13
Morocco	39.90	1538.27	276.75	-20.80	-41.59	-62.39	-83.18	3.40	2.27	1.70	1.36	1.13
Liberia	0.93	528.33	116.32	-17.35	-34.71	-52.06	-69.41	3.88	2.59	1.94	1.55	1.29
Mozambique	10.39	712.66	122.34	-15.73	-31.45	-47.18	-62.91	4.18	2.79	2.09	1.67	1.39
Namibia	1.50	506.98	102.83	-15.42	-30.85	-46.27	-61.69	4.24	2.83	2.12	1.70	1.41
Zimbabwe	6.29	458.35	96.87	-15.13	-30.26	-45.39	-60.52	4.30	2.87	2.15	1.72	1.43
South Africa	43.59	1444.01	246.39	-14.93	-29.86	-44.80	-59.73	4.35	2.90	2.17	1.74	1.45
Sierra Leone	6.91	1027.51	191.15	-13.19	-26.38	-39.56	-52.75	4.79	3.19	2.40	1.92	1.60
Senegal	6.97	633.01	128.65	-13.07	-26.15	-39.22	-52.30	4.82	3.22	2.41	1.93	1.61
Guinea	17.00	968.11	176.00	-11.73	-23.45	-35.18	-46.90	5.26	3.51	2.63	2.11	1.75
Benin	6.26	531.03	117.00	-10.81	-21.61	-32.42	-43.23	5.63	3.75	2.81	2.25	1.88
DR Congo	3.69	308.44	66.95	-10.51	-21.03	-31.54	-42.06	5.76	3.84	2.88	2.30	1.92
Sudan	93.33	1153.64	220.03	-10.33	-20.65	-30.98	-41.30	5.84	3.89	2.92	2.34	1.95
Zambia	6.71	444.74	98.84	-9.92	-19.85	-29.77	-39.70	6.04	4.03	3.02	2.42	2.01
UR Tanzania	82.35	1295.32	198.93	-9.49	-18.97	-28.46	-37.94	6.27	4.18	3.14	2.51	2.09
Nigeria	1132.98	1354.25	209.04	-8.28	-16.57	-24.85	-33.14	7.04	4.69	3.52	2.81	2.35
Mali	30.83	482.42	106.66	-8.26	-16.52	-24.78	-33.04	7.05	4.70	3.53	2.82	2.35
Angola	13.72	431.50	87.22	-8.09	-16.18	-24.27	-32.36	7.18	4.79	3.59	2.87	2.39
Kenya	22.05	624.55	124.55	-7.93	-15.87	-23.80	-31.74	7.30	4.87	3.65	2.92	2.43
CA Republic	0.72	298.23	63.64	-7.81	-15.62	-23.43	-31.24	7.40	4.94	3.70	2.96	2.47
Burkina Faso	30.65	494.43	102.66	-7.29	-14.58	-21.87	-29.16	7.86	5.24	3.93	3.14	2.62
Chad	15.21	344.65	74.75	-6.47	-12.93	-19.40	-25.87	8.73	5.82	4.37	3.49	2.91
Ethiopia	115.64	540.23	120.99	-5.30	-10.61	-15.91	-21.22	10.43	6.95	5.21	4.17	3.48
Niger	85.40	323.45	73.16	-4.62	-9.24	-13.86	-18.49	11.82	7.88	5.91	4.73	3.94
Egypt	670.99	672.66	139.36	-0.54	-1.09	-1.63	-2.17	93.09	62.06	46.54	37.23	31.03
Africa Average	**59.14**	**1082.45**	**203.81**	**-6.93**	**-13.86**	**-20.79**	**-27.73**	**6.58**	**4.39**	**3.29**	**2.63**	**2.19**
Africa Sum	**2483.69**											

Appendix 4j: Sensitivity of NPV and BCR to changes in number of years required to develop sustainable land management technologies on total cereal croplands by country

Country	Base case NPV in Billions of PPP USD	Cropland area cultivated with cereals	Base case land area (as % of total cultivated area) to be developed with SLM structures per year	% change in NPV from the base case if annual land area to be developed with SLM structures is X% of the total land area:		Base case BCR	Benefit cost ratio if annual land area to be developed with SLM structures is X% of the total land area:	
				10 %	6.67 %		10 %	6.67 %
Djibouti	-3.90E-05	8.00E-06	20.00	-5.33E+04	-5.32E+04	0.14	2.11E-04	1.49E-04
Gabon	-0.33	0.03	20.00	-14.50	-31.28	0.19	0.17	0.16
Cameroon	0.66	1.85	20.00	-43.98	-77.62	1.25	1.18	1.09
Madagascar	0.60	1.85	20.00	-54.02	-73.33	1.29	1.22	1.18
Congo	0.06	0.03	20.00	-54.26	-79.06	1.80	1.38	1.21
Swaziland	0.21	0.07	20.00	-57.73	-82.39	2.57	1.50	1.23
Rwanda	0.62	0.40	20.00	-44.84	-67.93	1.91	1.60	1.45
Uganda	7.42	1.70	20.00	-33.57	-58.12	1.81	1.69	1.56
Lesotho	0.36	0.16	20.00	-39.51	-63.96	2.22	1.80	1.58
Burundi	1.28	0.25	20.00	-27.30	-54.21	2.30	2.07	1.79
Botswana	0.57	0.16	20.00	-27.10	-51.47	2.41	2.23	2.01
Eritrea	1.90	0.45	20.00	-30.75	-53.74	2.79	2.51	2.27
Mauritania	1.07	0.20	20.00	-33.61	-55.84	3.18	2.62	2.34
Togo	2.34	0.91	20.00	-31.48	-53.78	3.17	2.74	2.48
Tunisia	5.45	1.13	20.00	-30.11	-52.72	3.06	2.76	2.50
Ghana	8.56	1.63	20.00	-28.88	-51.47	3.00	2.80	2.57
Malawi	3.99	1.87	20.00	-33.63	-54.86	3.23	3.00	2.81
Liberia	0.93	0.25	20.00	-31.18	-53.16	3.88	3.19	2.85
Côte D'Ivoire	4.90	0.86	20.00	-28.44	-50.70	3.40	3.17	2.91
Morocco	39.90	5.22	20.00	-28.19	-50.45	3.40	3.20	2.94
Namibia	1.50	0.31	20.00	-26.90	-49.34	4.24	3.57	3.15
Zimbabwe	6.29	1.82	20.00	-28.71	-50.47	4.30	3.87	3.53
South Africa	43.59	3.54	20.00	-24.87	-47.33	4.35	4.02	3.60
Mozambique	10.39	2.69	20.00	-30.27	-51.74	4.18	3.90	3.63
Sierra Leone	6.91	0.70	20.00	-26.45	-48.53	4.79	4.22	3.77
Senegal	6.97	1.30	20.00	-28.17	-49.81	4.82	4.38	4.00
Guinea	17.00	1.98	20.00	-27.50	-49.10	5.26	4.89	4.49
Zambia	6.71	1.21	20.00	-27.57	-49.05	6.04	5.30	4.81
Benin	6.26	1.09	20.00	-27.08	-48.54	5.63	5.33	4.95
Nigeria	1132.98	16.73	20.00	-13.51	-36.33	7.04	6.29	4.99
Sudan	93.33	7.82	20.00	-27.16	-48.65	5.84	5.49	5.06
UR Tanzania	82.35	5.70	20.00	-25.79	-47.53	6.27	5.78	5.21
DR Congo	3.69	2.06	20.00	-36.63	-56.65	5.76	5.45	5.24
CA Republic	0.72	0.17	20.00	-28.35	-49.63	7.40	6.23	5.60
Angola	13.72	1.64	20.00	-22.77	-44.51	7.18	6.69	6.01
Mali	30.83	4.51	20.00	-27.01	-48.31	7.05	6.61	6.12
Kenya	22.05	2.64	20.00	-27.52	-48.77	7.30	6.80	6.28
Burkina Faso	30.65	4.02	20.00	-26.81	-48.06	7.86	7.43	6.88
Chad	15.21	2.47	20.00	-26.79	-47.98	8.73	8.21	7.60
Ethiopia	115.64	9.63	20.00	-26.64	-47.75	10.43	9.85	9.14
Niger	85.40	10.28	20.00	-26.62	-47.68	11.82	11.12	10.31
Egypt	670.99	3.10	20.00	-20.88	-41.78	93.09	85.94	76.58
Africa Average	**59.14**	**2.38**	**20.00**	**-19.21**	**-41.17**	**6.58**	**6.00**	**5.43**
Africa Sum	**2483.69**							

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THE GLOBAL
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