Economics of Land Use Management on Ecosystem Services: A Case Study of Aberdare Water Tower in Nyandarua County

An Economics of Land Degradation study carried out in the framework of the "Reversing Land Degradation in Africa through Scaling-up Evergreen Agriculture" project

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Acknowledgements:
This research was funded by the Economics of Land Degradation Initiative with support from BMZ and GIZ. We are very grateful for the training and support.
We thank the staff of GIZ, particularly the organising team led by Lara Beisiegel and Mark Schauer for their involvement with us throughout the project.
We are very thankful to the farmers in Nyandarua who gave us access to their small holder farms and the enumerators who worked so hard to collect the data.
We are also grateful to Maya Suzuki for her editorial assistance and language editing.

Suggested citation:
Gichua K. Moses., Muriuki Cecilia., Wahome King'uru., Shatete Meave., Eregae Justus., and Yatich Thomas. (2020). 'Economics of Land Use Management on Ecosystem Services. A case study of Aberdare Water Tower in Nyandarua County, Kenya.' Report for the Economics of Land Degradation Initiative in the framework of the "Reversing Land Degradation in Africa through Scaling-up Evergreen Agriculture" project.
Available from: www.eld-initiave.org

Economics of
Land Degradation Initiative:

Kenya Rangeland Study: Cost and Benefits of Sustainable Rangeland Management Practices in Northern Kenya

An Economics of Land Degradation (ELD) Initiative study carried out in the framework of the project "Reversing Land Degradation in Africa through Scaling-up Evergreen Agriculture"

February 2020

www.eld-initiative.org

EXECUTIVE SUMMARY

This study was conducted as part of component 1 of the "Reversing Land Degradation in Africa by Scaling-up EverGreen Agriculture Project", which is led by the Economics of Land Degradation (ELD) Initiative and implemented by the European Union with support from the German Ministry for Development and Economic Cooperation (BMZ) and Gesellschaft für Internationale Zusammenarbeit (GIZ). The aim of this component is to strengthen the national ability of eight African countries to assess the costs of land degradation and the economic benefits of investment in Sustainable Land Management.

In Kenya, a study under this component and with the aim of achieving the stated objectives was carried out in Malewa river catchment area in Nyandarua county, which lies in the Western part of the Aberdare Ranges, one of five main water towers in Kenya. This water tower is the main catchment for Sasumua and Ndakaini dams, which provide over 90% of the water to the city of Nairobi. In addition, the water tower provides important ecosystem services to adjacent communities and other beneficiaries further afield. Most of the people in Aberdare area engage in rainfed agriculture for their livelihoods and depend on water originating from the Aberdares ecosystem to sustain their livelihoods.

Increasing population has put a lot of pressure on agricultural landscapes leading to deteriorating productivity of land and subsequently decreasing ecosystem services. Adopting sustainable land management (SLM) practices is key to restoring the productivity of land in the Aberdares as well as to ensure sustained provision of ecosystem service to communities in the area and other beneficiaries. Therefore, conservation of the Aberdare Ranges is not only critical for Kenya but also for the region.

Conservation requires recognition and demonstration of the economic value of the ecosystem services provided by the water tower as the values provide economic arguments for the adoption of sustainable and ecologically resilient approaches. By assigning values to ecosystem services, economic valuation plays a significant role in promoting a strong business case for investments in sustainable land management, including restoration.

To achieve stated objectives, a multi-stage sampling process was employed based on Systematic Unaligned Pattern by McCoy (2005) and applied to 253 households across the region. A questionnaire was used to gather information on personal characteristics of the household head, SLM practices/technologies, the resource endowment of farmers, farm management practices, cropping patterns, crop yields and adoption of improved and indigenous soil and water conservation management technologies. Land degradation patterns were assessed using Normalized Difference Vegetation Index (NDVI) as proxy over a period of about 28 years from 1990 to 2018, and a cost-benefit analysis (CBA) of alternative land management options for the various respondents was undertaken.

Results indicate that as the population in Nyandarua County increased from 233,302 in 2009 to 596,268 in the last census of 2019, the rate of land degradation also increased. Most of the degradation occurred close to the forest in areas where the land was steep and prone to soil erosion. This could partly be attributed to significant conversion of land from other forms into crop land since 91.5% of the respondents had farming as their main source of livelihood. Although the level of literacy was relatively high (88.9%), only a few farmers (3.2%) had taken their soil samples for nutrient analysis.

The CBA shows in the business as usual (BAU) scenario (assuming 8% interest rates and the costs and benefits of different land management practices are discounted over a period of 20 years) that agroforestry and crop rotation present the highest net present value (NPV) followed by vegetative strips while mixed cropping combined with other practices has the lowest NPV. The benefit-cost ratio (BCR) under the same scenario indicated that vegetative strips, cover crops and organic crops, and terracing in that order presented the highest BCRs. In the worst-case scenario, which assumed a 15% discount rate and discounted future values heavily, the resulting values were relatively lower indicating low returns.

The best-case scenario assumed a social discount rate of 3% for all future benefits and costs. The BCR from this scenario shows that vegetative strips still gave the highest rate of returns, followed by cover crops and organic farming, while agroforestry combined with organic farming present the lowest ratios. We therefore concluded that SLM practices of vegetative strips, agroforestry and crop rotation, cover crops and organic farming present the most viable SLM options for farmers. Mixed cropping presents the least viable option.

Policy interventions should therefore be geared towards the promotion of such accessible and easy-to-implement land management options. Policy guidelines should be geared towards SLM programs that act against soil erosion and maintenance of soil fertility that are already showing promise to the land users. Policy guidelines should encourage the farmers to take their soils for nutrient analysis. More sharing of information between the land users themselves and other stakeholders must be encouraged. Lastly, there must be a consistent effort in documenting and evaluating SLM practices and their impact on ecosystem services. This information must always be relayed to the land users, who are the primary beneficiaries.

About the ELD Initiative and the "Reversing Land Degradation in Africa through Scaling-up Evergreen Agriculture" project

Land degradation, desertification, and drought are widespread global issues that increasingly threaten the future of our environment. They lead to a loss of services from land and land-based ecosystems that are necessary for human livelihoods and economic development. Food production, water availability, energy security, and other services provided by intact ecosystems are jeopardised by the ongoing loss of land and soil productivity.

Desertification already affects around 45 % of the African continent (ELD Initiative 2017), indicating an urgent need for action. Failure to act on this threat would have serious negative impacts on the economies and sustainable development opportunities.

The Economics of Land Degradation (ELD) Initiative is a global initiative established in 2011 by the European Union (EU), the German Federal Ministry for Economic Cooperation and Development (BMZ) and the United Nations Convention to Combat Desertification (UNCCD). The Initiative provides specific scientific support to decision makers on national and international level. A broad network of partner experts and institutions supports the Initiative, which aims at transforming the global understanding of the economic value of productive land and improving stakeholder awareness of socio-economic arguments to promote sustainable land management.

The ELD Initiative provides ground-truthed tools and assessments that allow stakeholders to undertake cost-benefit analyses of land and land uses through total economic valuation and include this information in decision-making. The Initiative is coordinated by the ELD Secretariat, hosted by the Sector Project Soil Protection, Desertification and Sustainable Land Management within the German International Cooperation (GIZ) in Bonn, Germany.

Land degradation is explicitly included in objective 15 of the United Nations' sustainable development goals (SDGs), which have been adopted in 2015. SDG 15 aims at *"protecting, restoring and promoting sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss".*

The objectives 15.3. and 15.9. aim at achieving land degradation neutrality as well as at the integration of ecosystems and biodiversity values into national and local planning. On international level, the United Nations Convention to Combat Desertification (UNCCD) has been appointed as custodian agency for SDG 15.3 and, by developing economic arguments, the ELD Initiative complements the work of the scientific and technical committee of the Convention.

Land degradation is a complex and detrimental problem, affecting many aspects of human life, which means that it cannot simply be eliminated by implementing some technical or technological measures. The fight against degradation rather requires holistic measures, which will then simultaneously enable to reduce poverty (SDG 1), improve food security (SDG 2), sustainably manage water and waste water (SDG 6), enhance economic development (SDG 8), encourage sustainable consumption and production (SDG 12), improve adaptation to climate change (SDG 13), and to contribute to freedom and justice (SDG 16).

The Project *Reversing Land Degradation in Africa by Scaling-up EverGreen Agriculture* started in 2017, and aims to improve livelihoods, food security and climate change resilience by restoring ecosystem services. The project target countries are Ethiopia, Ghana, Kenya, Mali, Niger, Rwanda, Senegal, and Somalia. The action is financed by the European Union (EU) and co-financed by the Federal German Ministry for Economic Cooperation and Development (BMZ). It is carried out jointly by the ELD Initiative and the World Agroforestry Centre (ICRAF).

The role of the ELD Initiative within this project is to raise awareness on the threats and opportunities of different land use options by supporting and communicating cost-benefit analyses in each target country. At the same time, the Initiative extends the capacity of national institutions and experts to assess the economic benefits of investments in sustainable land management in consideration of the costs of land degradation.

The present report has been developed in the framework of such a process on national level. It provides decision-makers and administrators with scientific information on the economic consequences of land degradation and optional pathways to rural growth.

Acronyms and abbreviations

AEZ	Agro-ecological zones
ASAL	Arid and Semi-arid Lands
BCR	Benefit-cost ratio
CBA	Cost Benefit analysis
ELD	Economics of Land Degradation
EU	European Union
FGD	Focus Group Discussions
Ha	Hectares
LDN	Land Degradation Neutrality
NPV	Net Present Value
SLM	Sustainable Land Management
UNCCD	United Nation Convention for Combating Desertification

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1. INTRODUCTION

This case study was implemented in the Aberdare Ranges, which is one of Kenya's five main water towers. Located in Central Kenya and covering an area of 181,594 hectares (Kenya Forest Service 2010), the Aberdare forest is a gazetted nature reserve that hosts the Aberdare National Park (Muiruri 1974) and is a catchment for some main rivers in Kenya (Chepyegon and Kamiya, 2018). The eastern slopes are catchments of Kenya's largest river, the Tana River, which supplies water to the Seven Forks hydropower plants, providing over 55 percent of Kenya's total electricity. It also feeds major irrigation schemes such as Mwea rice irrigation scheme, Bura settlement scheme and the Tana Delta irrigation scheme. The south-eastern slopes form the upper catchments of the Athi River, the main tributary of the Sabaki River that drains into the Indian Ocean. The northern slopes are catchments for the Ewaso Nyiro River, the main river draining the semi-arid of Laikipia plateau and the Samburu plains. The Malewa River, the major surface source of water for Lake Naivasha, originates from the north-western slopes with topography ranging from about 1,900 to 3,990 m above mean sea level. The tower also acts as the catchment for Sasumua and Ndakaini dams, which provide over 90 per cent of the water to the City of Nairobi (Kilonzi and Ota 2019). It is also the main source of water for much of Nakuru county in the Rift Valley and other adjoining counties and, in particular, the densely populated areas on the eastern and southern slopes which rely primarily on the water flowing from the Aberdare Ranges (Nyukuri 2012).

The Aberdare water tower provides important ecosystem services to adjacent communities and beneficiaries further afield. These ecosystem services include inter alia

i) provisioning services including food, fresh water, timber, fuel wood, fodder, manure, fruits and fishing;
ii) regulating services such as climate regulation, soil stabilization, carbon sequestration, water purification and pest control;
iii) cultural services such as recreation, ecotourism, education and research and wildlife; and
iv) supporting services such as soil formation, nutrient cycling, and flood regulation.

Most of the people in Aberdare area engage in agriculture as their main source of livelihood. These people depend on rainfed agriculture and water originating from Aberdares to sustain their agricultural activities. However, increased population has put increasing pressure on agricultural landscapes leading to deteriorating productivity of land and subsequently the ecosystem services it provides.

Adopting sustainable land management (SLM) practices is key to restoring land productivity, as well as ensuring the provision of ecosystem services to sustain continued supply of fresh water, food, carbon sequestration, climate regulation and sustenance of primary productivity. Conservation of the Aberdare Ranges in a sustained manner to provide these ecosystem services is not only critical for Kenya, but also for the region. Therefore, providing economic values to each of the ecosystem services will provide the economic argument for their conservation (Kilonzi and Ota 2019) and encourage adoption of sustainable and ecological resilient approaches. It also promotes a strong business case for investments in sustainable land management, including restoration.

Various valuation methods and techniques have been applied to quantify the value ecosystem services and natural capital. These include revealed preference methods (e.g. travel costs, hedonic prices etc.), stated preference methods (e.g. contingent evaluation and choice modelling etc.), and cost-based methods (avoidance/replacement costs). Costanza et al. (2014) noted that valuation methods would vary across sites and ecosystem services and depend on whether the benefits accrue to individuals or communities or are considered for long term sustainability.

Lack of or inadequate information and knowledge is considered to be one of the major obstacles for reducing land degradation, improving agricultural productivity and facilitating the uptake of SLM among smallholder farmers and households in rural areas. Low income countries may lack information on available inputs, input and output prices, weather, SLM practices, increasing crop yields, negotiating better prices, improving farm competitiveness and other factors needed in making production decisions (Kirui and Mirzabaev 2014). Reliable estimates on the impact of land degradation on the welfare of farm households are also not available. Although investments in SLM are seen as smart and worthwhile, there is an urgent need for evidence-based science using more data and robust economic tools to evaluate the economic returns from SLM (Nkonya 2013).

1.2 Land degradation status in Kenya

Over the period 1981–2003, the productivity of land in Kenya declined across 40 per cent of croplands in the country (Dent 2008). Some estimates report that irreversible productivity losses due to soil erosion has occurred in about 20 per cent of the area of large parts of Ethiopia and Kenya over the last century (Dregne 1990). The estimates could be higher because according to Waswa (2012), there is no sufficient monitoring of land degradation issues both at national and local scales in Kenya. The International Monetary Fund (2010) estimates that land degradation has huge economic costs in Kenya—about USD 390 million or (about 3% of GDP) annually. These costs are associated with the decline in the quality of land as a result of the impact of unsustainable farming practices, the impacts of climate change, soil erosion, pollution and toxicity from agro-chemicals and alien and invasive species such as Ipomea kituiensis, Prosopis juliflora, and the water hyacinth.

Most of the documented unsustainable management practices in Kenya relate to land use and land cover changes experienced in significant sections of the country and these changes are often associated with deforestation, loss of natural vegetation, biodiversity loss and land degradation (Maitima et al., 2009). The drivers linked to these changes include, but are not limited to, unsustainable fuel wood extraction, logging for charcoal and commercial timber and land clearing for purposes of agriculture (Kiage et al. 2007; Serneels and Lambin 2001).

1.3 Economics of land degradation

Causes of land degradation can be grouped into two categories, namely: proximate and underlying causes. Proximate causes are those that have a direct effect on the terrestrial ecosystem and include natural conditions related to climatic conditions and extreme weather events (Kirui 2014). They are also related to anthropogenic causes such as over-cultivation, overgrazing and excessive forest conversion. On the other hand, the underlying causes are those factors that indirectly affect proximate causes and include lack of institutions, poverty and insecure land tenure that may underlie land degradation by hampering incentives to invest in SLM practices (Kirui 2014). It is estimated that 1 to 1.5 billion people in all parts of the world are already directly negatively affected by land degradation and that by 2050, at least a 70–100% increase in food production from existing land resources may be needed in order to be able to feed current and future generations. If agricultural land productivity remains at its current levels, an estimated 6 million hectares (ha) of land would need to be converted to agricultural production every year until at least 2030 to satisfy this growing demand (ELD Initiative 2013).

Several studies in the recent past indicate that land degradation is expensive to all players over multiple time and space scales (Costanza et al., 2014; von Braun et al., 2013). It results in the reduction in the economic value of ecosystem services and goods derived from land as a result of anthropogenic activities or natural biophysical evolution (ELD Initiative 2013; Favretto et al., 2019). Ecosystem services are adversely affected by the effects of land degradation (Bojö 1996; Pimentel, Zuniga & Morrison 2005; Sutton et al., 2016; von Braun et al., 2013). Degradation also threatens fertile land throughout the world and the consequent results are food insecurity, increased pests, reduced availability of clean water, increased vulnerability of affected areas and their populations to climate change, biodiversity loss and presence of invasive species. Soil fertility decline due to unproductive nutrient losses (through leaching, erosion, loss to the atmosphere) and 'nutrient mining' is a major problem in Sub Saharan Africa. An improvement to the current imbalance between removal and supply of nutrients can be achieved through various means. These include ground cover improvement, crop rotation, fallow and intercropping, application of animal and green manure and compost through integrated crop-livestock systems, appropriate supplementation with inorganic fertiliser and trapping sediments and nutrients (Linger et al., 2011).

In order to increase production from the land, water use efficiency and productivity need to be improved. The first priority must be given to improving water use efficiency in rainfed agriculture; and herein lies the greatest potential for improved yields with all the associated benefits (Linger et al., 2011). The United Nations Convention to Combat Desertification (UNCCD) at RIO+20, set a target of zero net land degradation (ELD Initiative 2013). The need to restore degraded lands and prevent further degradation is important especially in tropical regions that are already vulnerable to other stresses, including the increasing unpredictability of rainfall patterns and extreme events as a result of climate change (Alley et al., 2007; Foley et al., 2011). However, most small-scale farmers lack the decision-making tools to develop robust and effective solutions to land degradation. Better initiatives for land management are therefore needed to quantify the scale of the problem globally and calculate the cost of business-as-usual (BAU) and benefits of restoration (Favretto et al., 2019). Modelling and simulation techniques to enable the creation and evaluation of scenarios of alternative futures and decision tools to address this gap are available (Farley and Costanza 2002).

A contribution to the development of solutions is the Economics of Land Degradation (ELD), which if fully adopted in Kenya, will advance the level of Ecosystem Services Valuation (ESV) and SLM for academia, policy and decision-makers in the country. ESV will also make it possible to convince farmers to adopt SLM practices in order to enhance ecosystem services. It is hoped that ESV will be used to inform agricultural practices being adopted not only in the Aberdare water tower but also in other Water Towers in the country. This is critical in helping to inform decisions of government agencies such as the Kenya Water Towers Agency (KWTA) through the linking of livelihood improvement and environmental conservation and to potentially inform the design of Payments of Ecosystem Services (PES).

1.4 Conceptual Framework

The Economics of Land Degradation (ELD) Initiative focuses on land degradation and SLM in an economic context at the global level. This includes the development of approaches and methodologies for total economic valuation (TEV) that can be applied at local as well as at global level (ELD Initiative, 2013). The goal of the ELD Initiative is to make economics of land degradation an integral part of policy strategies and decision-making by increasing the political and public awareness about the costs and benefits of land and land-based ecosystems (ELD Initiative, 2013; Nkonya, 2013). Specifically, ELD Initiative seeks to look at livelihood options within and outside of agriculture to establish a global approach for the analysis of economics of land degradation, and to translate economic, social, and ecological knowledge into topical information and tools to support improved policy-making and practices in land management suitable for policy makers, scientific communities, local administrators and practitioners and the private sector. This enables informed decisions towards strengthening sustainable rural development and ensuring global food security (ELD Initiative, 2013).

ELD research seeks to test two hypotheses. First, which geographic, demographic, economic, technological, institutional and cultural factors, such as climate and agricultural practices, population density, poverty, absence of secure land tenure, lack of market access and others are significant causes of land degradation. Secondly, it hypothesises that the benefit of taking action against land degradation through SLM measures is greater than the costs of inaction (Nkonya et al., 2016).

This study uses the ELD concept to assess the costs of land degradation and farmers' preferences for the adoption of different SLM practices in order to enhance fresh water and soil conservation for urban water supply and crop production respectively. We have done this by identifying land degradation patterns and conducting a cost-benefit analysis (CBA) in order to determine farmers' preferences for adoption of different SLM approaches to freshwater and soil fertility ecosystem service productivity. Although water supply and availability are key issues for the sites, we have not undertaken specific efforts to determine the effects of SLM options on water supplies as this requires further studies and hydrological expertise. We are hopeful that the proposed options will be taken up through better farm practices and policy adoption.

2. METHODOLOGY

2.1 Study Area

The study area was the Malewa river catchment area which covers an area of 3,304 km^2 and lies in the Western part of the Aberdare ranges in Nyandarua County, a high-altitude area of the north eastern part of Central Kenya. The area has a population density of 145 per km^2 and 104,401 households (Kenya Central Bureau and Statistics, 2010). The study was carried out in three of six sub-counties (Ol-Kalou, Kipipiri and North Kinangop) in Nyandarua County, Central Kenya (see Figure 1 and 2). Temperature in the county ranges from 2^0 to 25^0 C. It falls under Upper Highlands (UH) and Upper Midlands (UM) agro-ecological zones, with altitude and rainfall of between 2,000 – 4,000 meters and 1,400 – 2,200 mm respectively. The study area is characterised by two rainy seasons: from April to May, and October to November. According to the 2009 Census, Nyandarua County had a population of 596,268 with a population growth rate of 2.4 % annually, and this population was projected to be at 722,498 persons in the year 2017 (Kenya Central Bureau and Statistics, 2010).

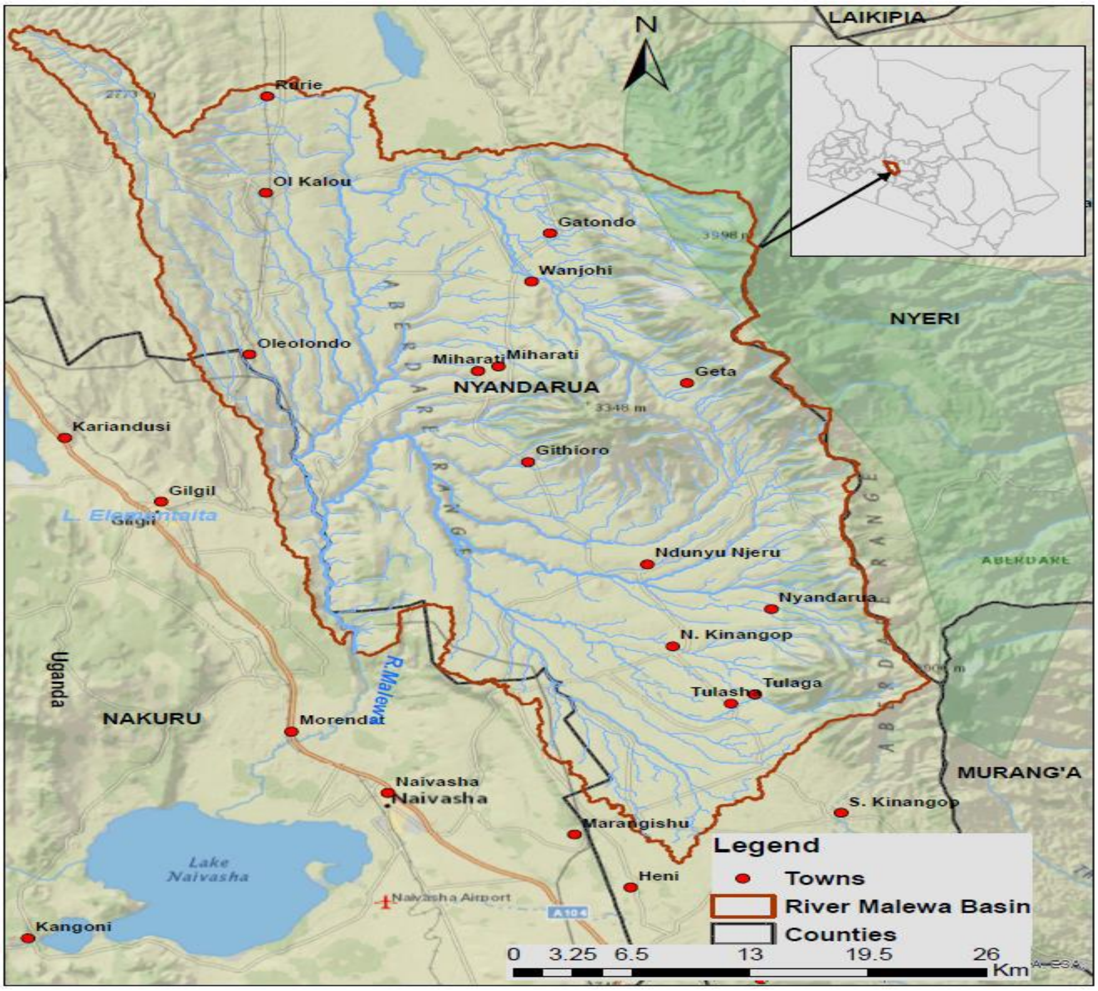
The soils in the upper highlands are moderately well drained, deep to very deep, dark brown to very dark grayish brown, firm clay and silt loam clay while in the lower highlands, the soils are well drained, moderately to very deep, dark grayish brown to dark reddish brown, clay loam to clay with humid

top soil (Speck, 2016). Among the different dairy cattle production systems, three distinct cattle grazing systems associated with dairy intensification levels were identified in this region (Romney *et al*., 2004).

Nyandarua county has a bimodal rainfall which decreases rapidly from east to west with annual rainfall varying from 1,400 mm in the Aberdare Ranges to about 700 mm in the lower areas bordering the rift valley. The temperatures are moderate but can get as low as 7 to 10^0C in the cold seasons of July, which may result in frosts, which adversely affect horticultural crop growing (Sombroek, Braun, and Pouw 1982). These climatic conditions make the county an ideal place for horticultural crop production, according to the Ministry of Planning, National Development and Vision 2030 (Miriti et al., 2015).

The Malewa river drains to Lake Naivasha, a wetland of international importance, with rich biodiversity. River Malewa catchment has been under pressure from increasing populations, dwindling farm sizes and deforestation leading to pollution and siltation and subsequently threatening critical biodiversity (Everard and Harper, 2002). The catchment is drained by numerous small streams which generally join and flow to the river Malewa (Fig 1). It consists of a complex terrain configuration consisting of rugged and strongly dissected mountainous landscapes with steep slopes, deep ravines, and multiple small sub catchments. The Malewa River catchment is 1,730 square kilometres and provides about 90% of the water flowing into Lake Naivasha, with most of the remainder coming from the Gilgil River (Gherardi, 2007). The headwaters of the main channel of the Malewa originate at an elevation of 3,700 metres in the Aberdare mountains, while its tributary Wanjohi is fed by several small rivers running from the slopes of the Aberdares. Other tributaries are Turasha, Simba, Nyairoko and Ol Kalou. The rivers in the Malewa basin are relatively shallow but are all perennial (Harper and Mavuti, 2004).

Figure 1: River Malewa basin showing the network of rivers and streams (Source: Shatete M. -KWTA)



2.2 Sampling Design

In this study, a multi-stage sampling procedure was employed based on Systematic Unaligned Pattern (McCoy, 2005). First, Nyandarua County was purposively selected in a Stakeholders Conference during the scoping period because the county is one of the areas severely affected by land degradation and a source of most of the water consumed in Nairobi and Nakuru Counties. Nyandarua County is highly vulnerable to land degradation, particularly deforestation and environmental degradation because of the complex mountainous terrain with steep slopes and high rainfall. Stratification was done geographically along the whole Malewa Catchment area and households selected from the different strata by simple random technique. The sample size was

253 households based on the proportion to the population size in each of the administrative wards according to Fearon et al. (2017).

2.3 Data collection

To identify the SLM practices and their implementation, a questionnaire was prepared to probe different agricultural activities in the area and sampled 253 farming households. The questionnaire included information about personal characteristics of the household head, both men and women, SLM practices/technologies, the resource endowment of farmers, farm management practices, cropping patterns, crop yield and adoption of improved and indigenous soil and water conservation technologies. Pilot tests of questionnaires were made by distributing the questionnaire to ten farmers during the training period to assess whether the instruments were appropriate and suitable for the study at hand. Necessary adjustments were made based on the comments obtained from pre-test responses from farmers to ensure reliability and validity. Enumerators were trained with respect to the survey techniques and confidentiality issues. Due to its stratified random nature of the sample, the questions were expected to provide comprehensive data on farming systems and household characteristics for the water catchment area.

2.4 Data Analysis

2.4.1 Land degradation patterns

Degradation patterns were assessed using Normalized Difference Vegetation Index (NDVI) as a proxy. Land use/cover change assessment was done by classifying images for the period 1973, 1988 and 2003. Environmental and ecosystem resources might be used as indicators of ability of the ecological system to return to or near pre-shock or pre-event states. The strong correlation of NDVI with above ground net primary production (NPP) makes this index a useful indicator of ecosystem resilience. NDVI has been used to identify and interpret a range of phenology metrics that describe periodic plant life-cycle events and how these are influenced by seasonal and inter-annual variations in climate and habitat. So the duration of photosynthetic activity (identified using NDVI) can be interpreted to indicate the length of the growing season; time of maximum NDVI corresponds to time of maximum photosynthesis; seasonally integrated NDVI indicates photosynthetic activity during the growing season; and the rate of change in NDVI may indicate speed of increase or decrease of photosynthesis (Yengoh et al. 2016)

2.4.2 Cost-benefit analysis

Alongside crop and livestock husbandry, farmers in the study area have adopted a number of soil and land management practices to boost their production and improve their incomes. A CBA of alternative land management options for the various respondents in the Malewa Watershed was carried out. In order to undertake the CBA, it was necessary to identify a set of alternative land management options either individually or in combination with others, and quantify the impacts of each land management option on the respondents. These practices include terracing, agroforestry, cover crops, vegetative strips, mixed farming, mixed cropping, organic farming and crop rotation among others. Different farmers have adopted different combinations and proportions of these practices depending on their needs and preferences. For instance, a farmer could adopt vegetative strips as the most preferred option but also adopt crop rotation and another practice, or a farmer could adopt only one of the practices e.g. vegetative strips etc. To identify what farmers have adopted and their preferences, they were asked to rank what they have from the most preferred to the least preferred. Given the many practices, we discovered that most farmers had two preferred combinations and to avoid having too many combinations, we narrowed the options to the best two for each household. From their rankings, we classified the farmers into the following 12 categories:

i. agroforestry and crop rotation,
ii. agroforestry and vegetative strips,
iii. terracing and agroforestry,
iv. agroforestry and cover crops,
v. vegetative strips,
vi. agroforestry and mixed farming,
vii. terracing and other practices,
viii. cover crop and organic farming,
ix. crop rotation,
x. agroforestry and organic farming,
xi. terracing and other combinations without agroforestry, and,
xii. mixed cropping and other practices.

Each of these choices produced expected returns for individual famers. Given the costs of production and revenues from the different farming enterprises, we estimated expected returns and projected them into the future (over the next 20 years from the time they adopted the practices i.e. 2010 – 2030), using certain assumptions. These returns were then discounted into present values to determine the most profitable practices. We also estimated the benefit-cost ratios (BCR) to determine the returns from the different practices.

In calculating the net present values (NPVs) of the different land management practices, both revenue and cost streams are required. Given that the data set did not have the different production costs, we used different historical data to determine the proportion of production costs to revenues. We estimated the ratio of costs of production for the different crop and livestock enterprises to that of total revenue. Our estimates relied on historical data and studies done elsewhere in the country. These studies showed that the productions costs for the different enterprises ranged from 25% to 69% of their total revenue as shown the Table 1. (The estimation of mean revenue to cost ratios are shown in Appendix 1).

The costs for SLM implementation for respondents were established through questions on their most recent growing season for which they had finished harvesting and knew the yields. Respondents were also asked to indicate how long the SLM practice has been in existence and its maintenance cost.

Table 1: Production cost of different farm products as % of the total revenue

Product	Production cost as % total revenue	Product	Production cost as % total revenue
French beans	26	Sheep/Goat	20
Carrots	25	Potato	30
Milk	30	Cabbage	27
Beef	30	Fruits	40
Chicken	69	Beans	40
Maize	60	Garden peas	25
		Other Vegetables	25

From the estimated costs, we calculated the total production costs and revenues. These had to be projected in the future, and to get the revenue and cost streams, we made a number of assumptions. First, we assumed that the average annual cost of production increased by 8%, a rate higher than the average annual revenues which are assumed to increase at a rate 5%. The rationale behind the 5% increase is anchored on the average annual rate of inflation. Normally, the cost of production for agricultural products grows at faster rate than that of the revenues and using this logic and historical data, we assumed an 8% increase in cost of production.

Agroforestry takes time for the gains to be realised. In the soil and management choices with agroforestry, we assumed that in the first three years, the revenues were constant as there were no benefits from agroforestry. At the fourth and fifth years, the revenues were assumed to grow at 10% per annum and then stabilised at the sixth year, and grew at 5% per annum. A period of 20 years was assumed for NPV calculation (2010 to 2030). A longer period makes future values very small and insignificant compared to returns in earlier years. The discounting was done at 3%, 7% and 15% representing best case scenario, BAU and worst-case scenario, respectively. The BAU scenario is based on commercial bank deposit rates in Kenya. The best-case scenario, which allows for lower discounting of future benefits, is also assumed to be the social discount (Ramsey discount rate) and the values obtained under this scenario represent the economic values. The estimated total NPVs were obtained by summing NPVs for the 20-year period for each specific practice. These assumptions are summarised as follows:

1. Revenues generated by the practices are immediately reinvested to generate a return at a rate that is equivalent to the discount rate used in the present value calculations;
2. The inflow and outflow of cash other than the initial investment occur at the end of each period;
3. The NPV is calculated using the average revenues and cost;
4. The average rate of change of average production cost for the projected 20 years is constant;
5. The average rate of change of all the projected revenues is assumed to be constant but greater than the cost rate of change of the cost, except for case of agroforestry.

Because the costs incurred and benefits obtained happen over time, we took into account the time value of money by setting a timeframe of 20 years over which to perform the analysis and also discounted future costs and benefits. This allowed calculation of the NPV of investments in SLM practices. Where the NPV is positive, it makes (economic) sense for a farmer to implement an SLM practice. Another related measure is the BCR: the benefits divided by costs over the timeframe of analysis. A BCR > 1 indicates that benefits are greater than costs and the SLM practice should be implemented. To understand how long a farmer might have to wait before benefits exceed costs, we also calculated a return on investment (RoI) period: The length of time (years) after an SLM practice is initiated when total benefits exceed total costs.

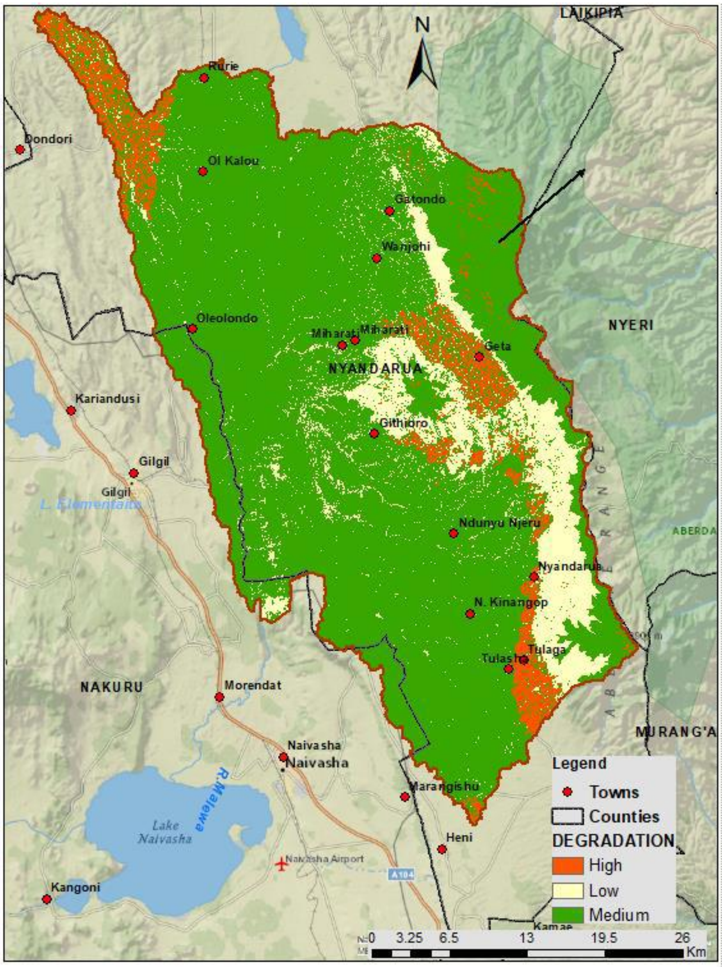
The CBA was based on SLM practices implemented from around 2010-2015 and assuming their continued operation until 2030. This time period was used to parallel Kenya's Vision 2030 ("Kenya Vision 2030"), which seeks to enhance agricultural yields at the national level. Data were used to calculate costs and benefits of cultivation with implementation of different SLM practices.

3. RESULTS

3.1 Land degradation patterns

The upper part Malewa watershed has faced a sustained and rapid degradation of land as a result of rapid growth in population, poor soil conservation methods and deforestation (Musa et al., 2019). The population in Nyandarua County has increased from 233,302 in 2009 to the population of 596,268 in the last census of 2009. Kipipiri subcounty, where much of the watershed lies had a population of 95,338 according to census results of 2009 (Kenya Central Bureau and Statistics, 2010). The Malewa watershed (Fig 1) with its numerous network of rivers and streams is a highly susceptible and fragile area and prone to water induced soil erosion and associated land degradation due to a number of factors, which includes but is not limited to, the nature of landforms which have steep slopes, rugged terrains and complex ravine networks; inappropriate land use/management practices and inherent properties of the soil; and other anthropogenic activities. Areas that are close to the forest have high levels of land degradation (Figure 2).

Figure 2: Map of River Malewa basin showing the levels of land degradation.



3.2 Land cover changes

Image analysis of the Malewa watershed (Fig 3) indicated that land cover changes had occurred during the three sets of periods analysed: The years 1990-2000, 2000-2010 and 2010-2018 as shown in the land cover maps generated for the years 1990, 2000, 2010 and 2018. The areas under cropland increased from 1990 to 2010 but remained relatively unchanged afterwards. Forestland remained relatively unchanged. The area under grassland decreased until 2010 and seemed to remain unchanged afterwards.

Figure 3: Land cover changes between 1990 and 2018

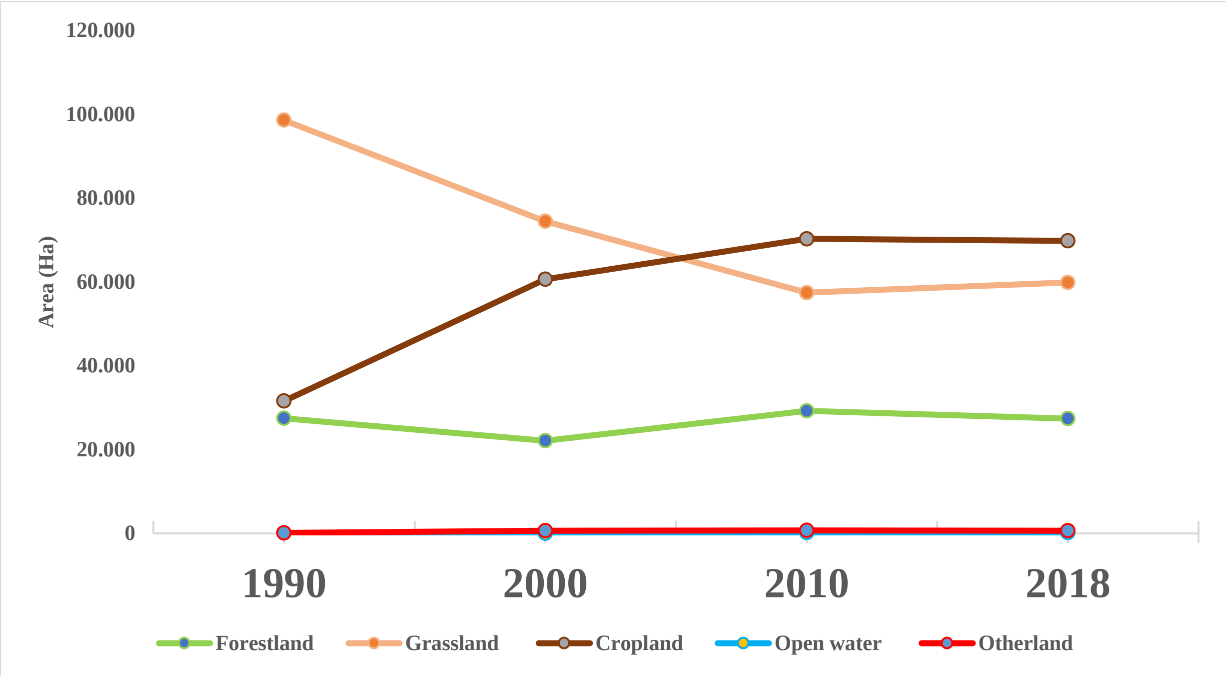


Figure 4: Maps showing the land cover changes between the years 1990 and 2018

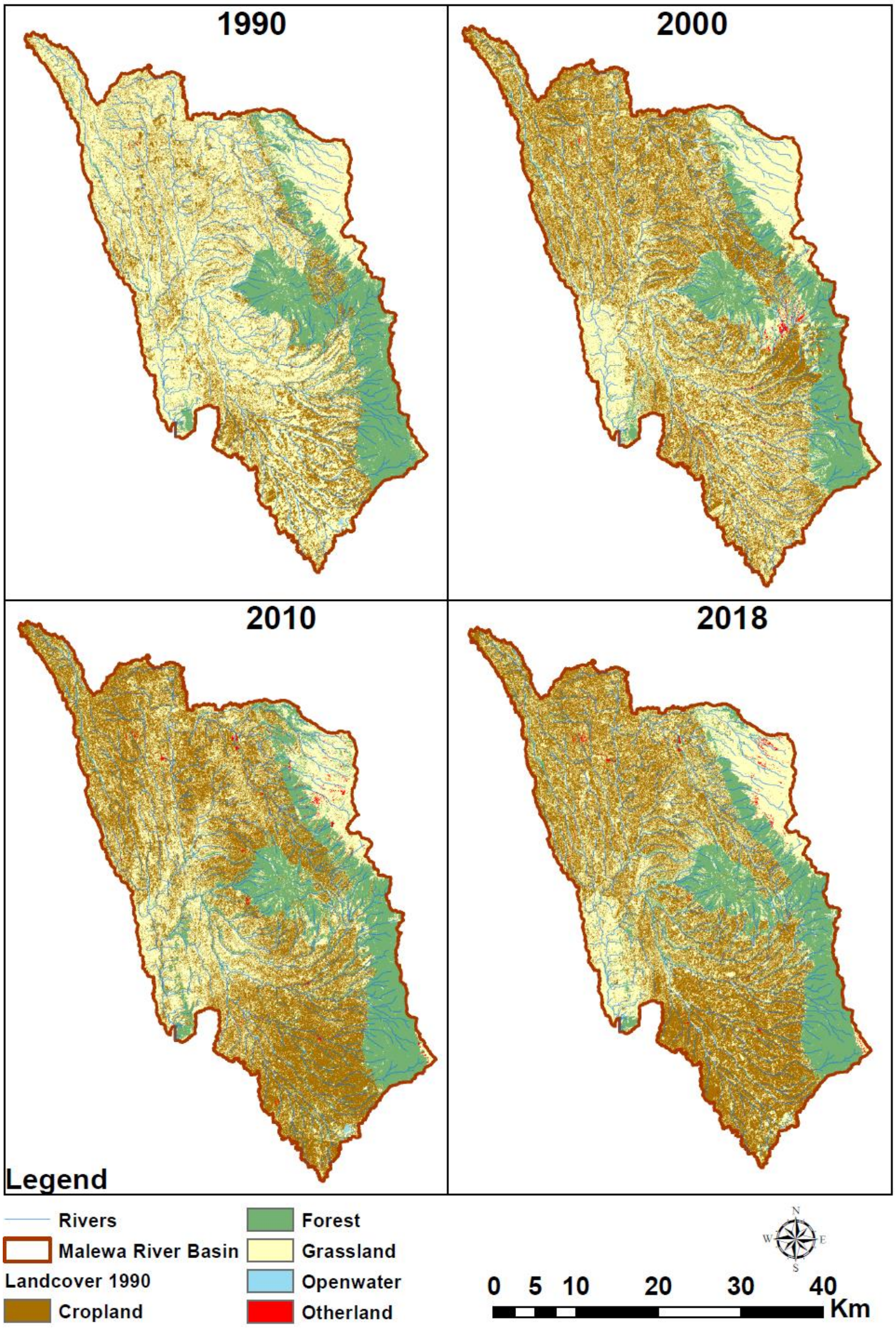


Figure 5: A smallholder farm in the study area where mixed farming is practiced

Source: Gichua M

3.3 Socio-economic and demographic determinants of SLM practices

3.3.1 Demographic Characteristics

Out of the 253 respondents, 56.6% hailed from Kipipiri sub-county, where most of the feeder tributaries to river Malewa begin, while 23.8% and 19.7% of the respondents were from Ol Kalou and Kinangop, respectively. About 82% of the households were male headed and 18.4% were headed by female. Close to 98% of the respondents indicated that they had been in the homestead consistently for the last one year. The ages of household heads were 31-40 years, 41-50years, 51-60 years, 61-70 years and over 71 years at 13.8%, 33.2%, 26.7%, 16.2% and 9.7%, respectively.

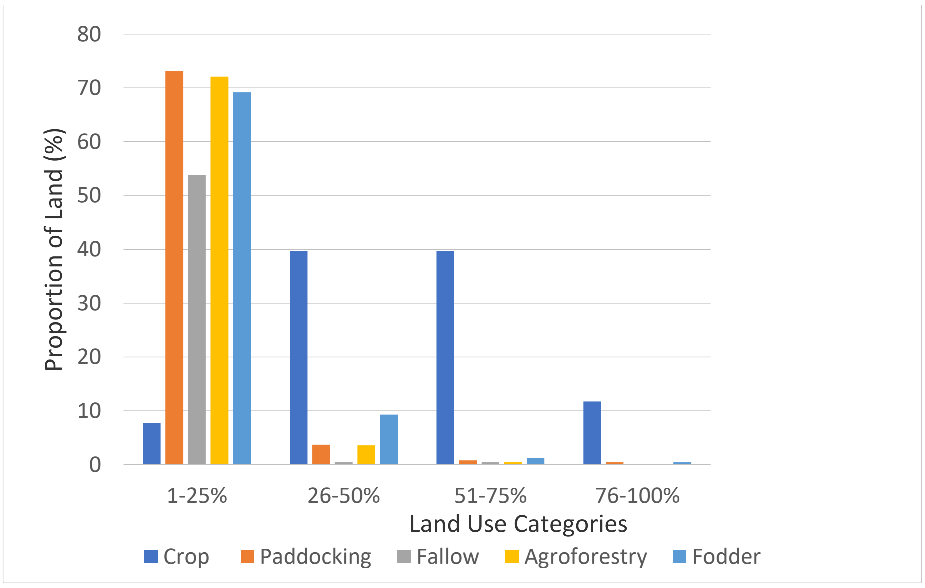
About 89% of the respondents had gone through some form of schooling and could read and write. A majority of the respondents had some years of formal education, with those with primary education making up 48.6% and those with secondary education 31.2%; technical education 6.1% and university level was 6.9%. Those with no formal schooling made up only 7.3 % of the respondents. 91.5% of the respondents had farming as their main income generating activity. We considered the distance from the forest boundary as an indication of proximity to ecosystem services such as pollination and soil fertility. 9.7% of the respondents live less than 1km from the forest boundary, 15% of the respondents live 1-2km from the forest edge, 8.9% live 2-3km away, 9.3% live 3-4km away, 10.1% live 4-5km away and 47% of the respondents live more than 5km from the forest edge.

Respondents had an average household size of 5.8 persons and ranged from one to 15 persons per household. This indicates that the majority of the people in the study are middle aged and they have relatively large families compared to the county average of 5.31 persons per household (Kenya Central Bureau and Statistics 2010).

3.3.2 Land ownership characteristics

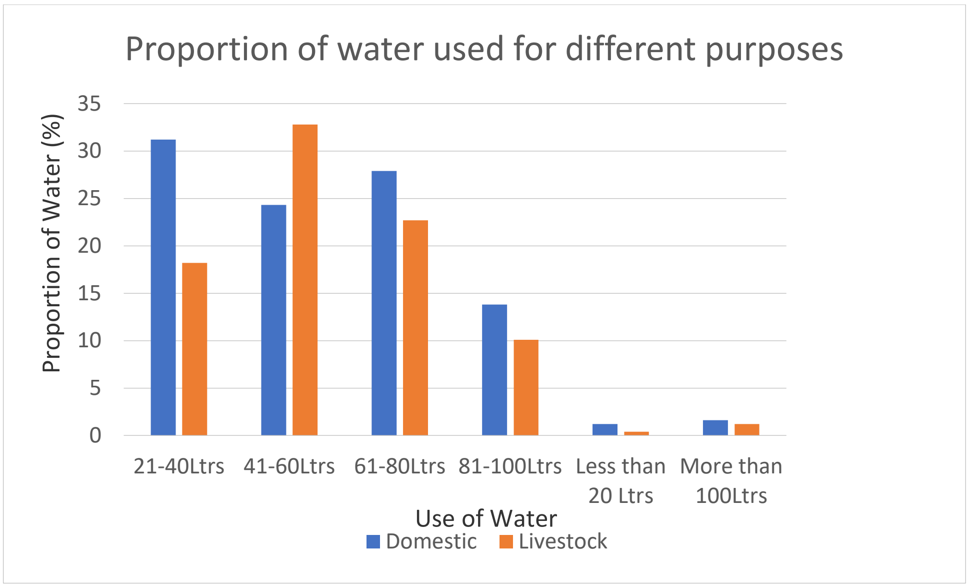
The majority of the respondents (34.6%) own between one to two acres of land, which suggests that most of the farming activities are subsistence in nature. 96.8% own the land and most of them inherited the land from their parents (65.2%). Most of the land in this region is used for mixed subsistence farming (80.6%) but with the percentage of land under crop production varying across the sampled region. 1.2% of the respondents had no part of their land under crop production; 7.7% of the respondents had 1-25% of the land under crop production while 39.7% had 26-50%; 39.7% had 51-75%; and 11.7% had 76-100% of their land under crop production. The proportion of land under various land use categories is indicated in Fig 6.

Figure 6: The proportion of land under various land use categories.



If less of the land was used for different land uses, there was a high likelihood that the various land use categories would relatively be fairly distributed. However, as the extent of the land for each land use category continued to rise, crops had a higher likelihood of taking much of the land (Fig 6).

Figure 7: Proportion of water used for different purposes



The amount of water available is likely to be shared equitably between domestic use and feeding the livestock (Fig 7). The main source of water for most of the households (55.6%) is tap water. The source for another 29.2% is harvested rainwater. A mere 4.4% and 3.6% obtained their water from rivers/streams and wells, respectively. For those who did not have a source of water within their homesteads, 10% had to travel more than three kilometres to get it.

Only 3.2% of respondents had taken their soils for any form of nutrients analysis, and most of them had not done so in the last three years. However, 18.6% were aware of a soil laboratory that could analyse their samples.

Figure 8: The practice of fruits and vegetables farming in an agroforestry set up

Source: Gichua M.

3.4 Cost Benefit Analysis

The NPVs and BCRs for the different technologies are presented in Figures 9a and 9b for the business as usual scenario. This scenario assumes that if farmers decided to invest their money in the bank it will fetch an annual return of 7%, which is the current prevailing deposit interest rate. Using business as usual, the combination of agroforestry and crop rotation had the highest net present value followed by vegetative strips while mixed crops and others had lower positive NPV's. The BCR estimations shows that vegetative strips, cover crops and organic crops, and terracing plus other practices have the highest BCRs.

Figure 9a: NPV at 7%

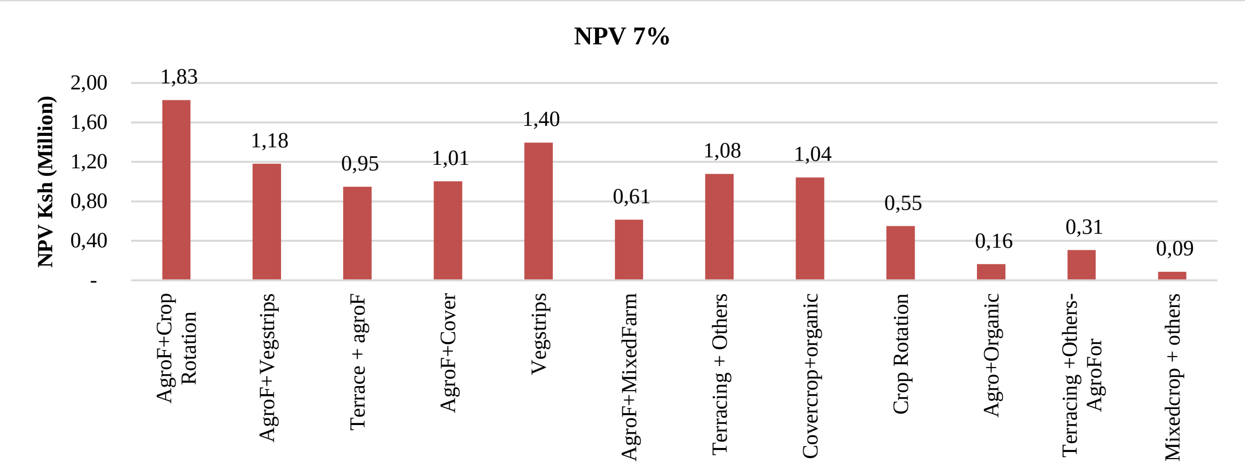
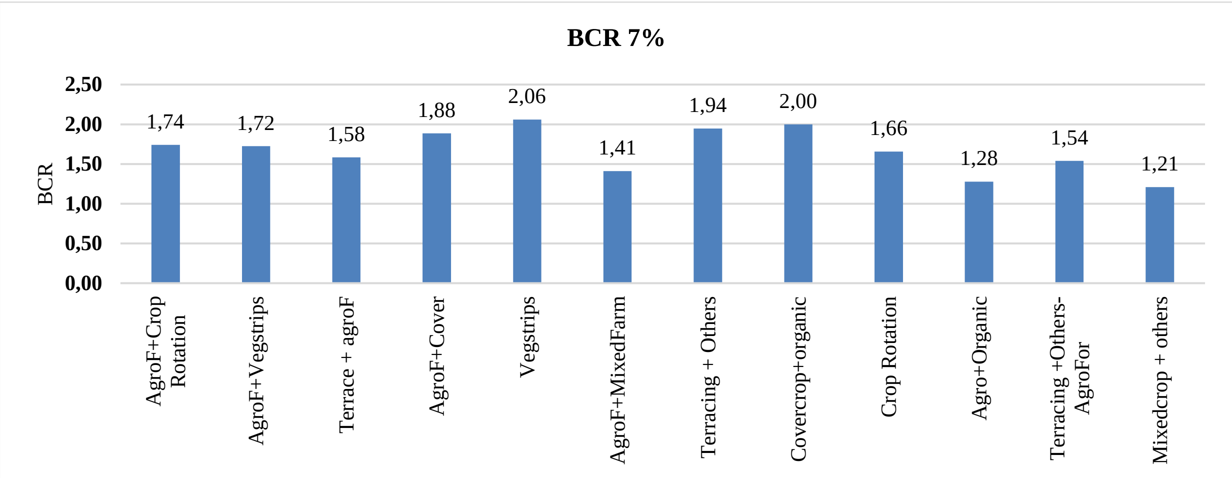


Figure 9b: BCR at 7%



Using interest rates of lower and greater than 7%, we estimated the best- and worst-case scenarios. The social (Ramsey) interest rate of 3%, which allows lower discounting rates of future values, was used as the best-case scenario. Figures 10a and 10b shows the NPV and BCRs of all the practices discounted at the social discount rate of 3%. From the NPV graph, agroforestry and crop rotation had the highest NPV, followed by vegetative strips, while mixed crop and others had the lowest NPV. From the BCR, vegetative strips give the highest ratios, followed by cover crops and organic farming, while agroforestry and organic farming present the lowest ratios.

Figure 10a: NPV at 3%

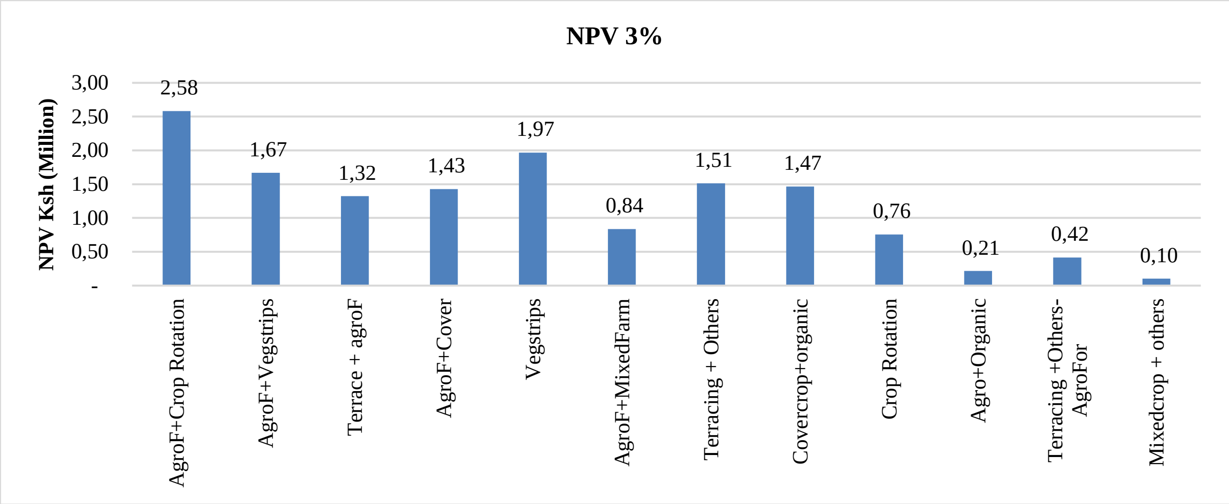
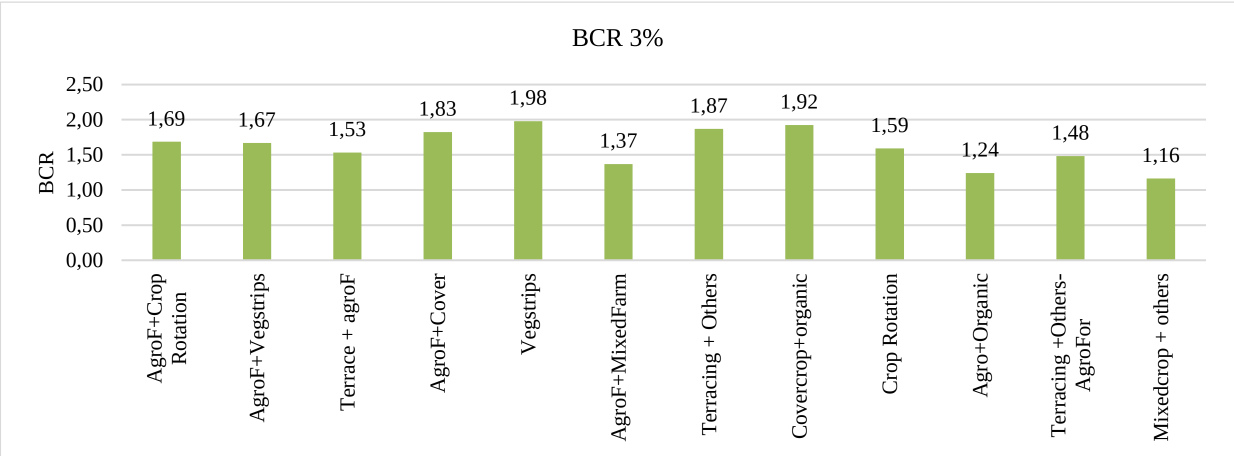


Fig 10b: BCR at 3%



Finally, a worse-case scenario was assumed at 15%. This allowed for heavy discounting of future values, making them small over a relatively shorter period of time. The values are significantly lower compared to those under best case and business as usual scenarios. The results are presented in Figures 11a and 11b. From Figure 11a, agroforestry and crop rotation give the highest NPV followed by vegetative strips, while mixed crops and others give the lowest value.

Figure 11a: NPV at 15%

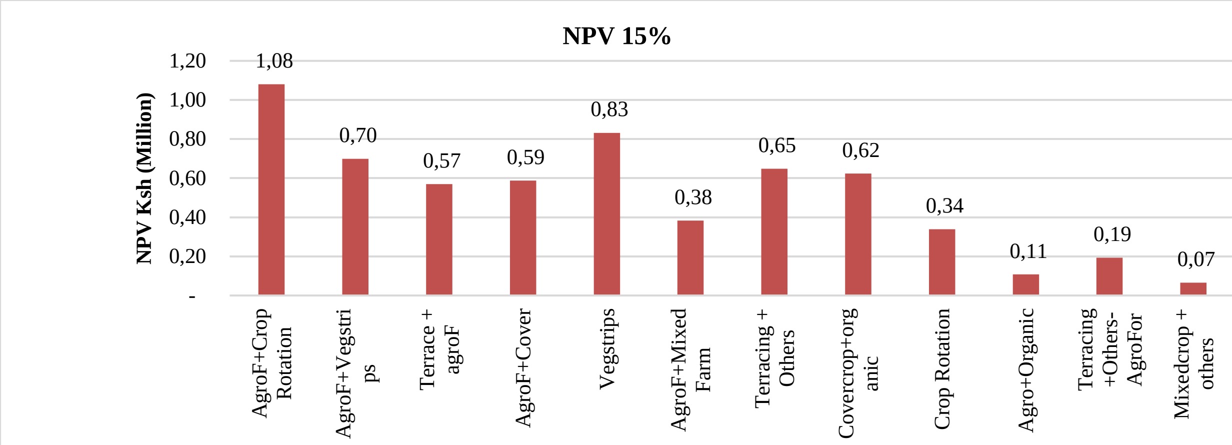
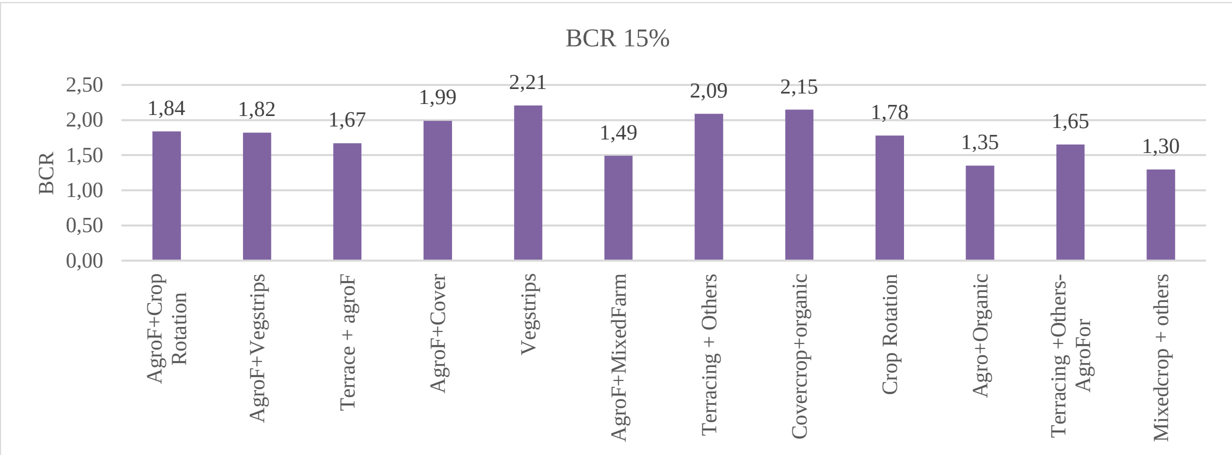


Figure 14b: BCR at 15%



Results from the BCR as shown in Figure 13b show that vegetative strips are the most profitable followed by cover crops and organic farming, and then terracing and other practices combined. Mixed cropping presents the least preferred option.

4. DISCUSSION

Over the years, there has been increased degradation in the Aberdare ecosystem (Kilonzi and Ota, 2019). The population continues to rise against limited availability of land for cultivation. However, it is encouraging to note the high number of respondents in this region who have embraced some form of SLM and the fact that many of the farmers embraced a form of mixed subsistence farming. Land degradation in the region has largely affected the Aberdare ecosystem, which is the source of 90% of water for Nairobi County (Kilonzi and Ota, 2019). All households in this area depend on the Aberdare water tower for their livelihood through an array of ecosystem services it provides. The Aberdare Ranges provide various ecosystem services such as food, water, timber, fuelwood, fodder, manure, fruits, fishing, climate regulation, soil stabilisation, carbon sequestration, water purification, pest control, recreation, ecotourism, education and research, wildlife, soil formation, nutrient cycling, flood regulation. The role of these ecosystem services has been affected by land degradation being experienced in the area. The effect of this land degradation has been manifested through increased rate of sedimentation of water reservoir for water supply and hydro-electric power generation (Kigomo, 2013).

Due to the fact that Malewa catchment has a complex network of rivers and streams, it is highly susceptible and fragile and prone to water-induced soil erosion and associated land degradation. However, the steep slopes and complex tributary networks are very sensitive to inappropriate land use/management practices and inherent properties of the soil and water. It is imperative that policy guidelines in this area are geared towards SLM programs that act against soil erosion and maintenance of fertility. Practices that encourage the exposure of topsoil to vagaries of weather should be discouraged.

Although forest cover changes in Malewa watershed does not seem to have changed drastically over time, there is an evident reduction in the area converted from grasslands into crop farming. Extreme degradation is evident on land next to the forest. It also follows that these are the areas with the highest population density. The main reason why the conversion from forest to crop land is minimal is because Aberdare National Park is a government secured protected area. Areas where illegal harvesting of trees have occurred have largely been replaced by shrublands.

Land use changes that lead to loss of plant cover leads to land degradation. This in turn leads to a decline in organic matter, degradation of soil structure and loss of other soil physical qualities, reduction in availability of major nutrients (N, P, K) and micronutrients and increased toxicity, due to acidification and salinization (Maitima et al., 2009). Only 3.2% of respondents in this study had taken their soils for nutrient analysis. This is despite the continuous and consistent use of different forms of fertilizers. The clearest indication is that farmers apply fertilisers without really knowing the real status of fertility in their soils. Soils in areas with continuous cultivation without appropriate management practices have low fertility levels due to over-utilisation (Maitima et al., 2009). It is imperative that any form of policy engagement considers finding a way to encourage the farmers to take their soils for nutrient analysis. Otherwise there will be a consistent misuse of fertilisers that will eventually pollute the waterways and subsequently the water used downstream for domestic and industrial purposes.

The CBA results indicated that if the smallholder farms were going to be run with a 7% discount rate (the BAU criterion), agroforestry and crop rotation would consistently have the highest NPV, followed by vegetative strips while mixed crops and others would have the lowest NPV. Highest BCR would be obtained where vegetative strips, cover crops and organic crops and terracing plus other practices were practiced. The benefits of agroforestry are usually long-term in terms of providing shade for other crops, provision of food in form of fruits and in the conservation of soils among others. However, this form of land management requires a higher initial investment and the benefits usually take long to accrue.

Under the best-case scenario using a 3% discount rate, agroforestry and crop rotation would have the highest NPV, followed by vegetative strips, while mixed crop and others had the lowest NPV. However, for the BCR, vegetative strips would give the highest ratios followed by cover crops and organic farming, while agroforestry and organic farming present the lowest ratios. This could again be explained by the long time it takes for revenues to be realised under agroforestry.

Under the worse-case scenario using a 15% discount rate, where heavy discounting of future values was done, the values were significantly lower compared to those under best-case and BAU scenarios. Agroforestry and crop rotation gave the highest NPV followed by vegetative strips, while mixed crops and others give the lowest value.

The results from the BCR therefore indicate that vegetative strips are the most profitable option, followed by cover crops and organic farming, and then terracing and other practices combined. Mixed cropping presents the least preferred option. Vegetative strips are easy to establish and maintain as are the cover crops and the organic farming. A similar study carried out in western Kenya indicated that SLM practices with low input costs, such as manuring and intercropping, offer very high BCRs for farmers and they provide a positive NPV over the time (Dallimer et al., 2018). Practices such as vegetative strips, use of cover crops and organic farming have the highest returns to farmers, hence are most profitable and they do not require a significant investment to establish. A realistic policy in the short-term should consider giving incentives to land users that subsidises the initial investment costs of soil conservation practices such as these.

Policy actions for SLM remain inconsistent and often ineffective (Nkonya et al., 2015). Such policy frameworks to combat land degradation need to be supported by evidence-based and action-oriented research (von Braun et al., 2013). In the past, studies on land degradation have played a useful role in highlighting land degradation as a globally critical issue. However, most of them have tended to focus only on simpler relationships, such as, for example, soil erosion and its impact on crop yield, while ignoring the broader values of land ecosystem services, various off-site and indirect costs in their analytical frameworks (Foley et al., 2011).

There is need for developing land use policies and planning that will ensure that forests and grasslands are protected to continue providing ecosystem services both to local communities and to the global community. Successful conservation planning and associated land management strategies that will slow the degradation patterns requires establishment of initiatives that will involve small-scale farmers policy decision-making. This ensures that the livelihoods of farmers are guaranteed while maintaining the integrity of the ecosystem.

The cost of land degradation due to land use cover changes accounts for 78% of the total global cost of land degradation of about 300 billion USD, and hence high priority should be given to addressing land degrading land use and cover change (Nkonya et al., 2015). The Kenya Vision 2030 commits the country to mitigate unintended adverse land degradation.[1] It is imperative that the policy makers ensure that pristine ecosystems that act as a buffer to land degradation are maintained and protected from more exploitative uses. If this is not done, the degradation of land eventually leads to social and economic losses to small-scale farmers themselves as a result of declining agricultural yields and higher costs to maintain current production levels.

One of the key responses to increasing agricultural production is countering land degradation challenges through the adoption of appropriate SLM practices. Although Kenya has a national investment framework to support the SLM subsector (KSIF 2016), there has been limited resource mobilization and action. There has also been a low level of awareness of the importance for SLM and the potential profits from investments in SLM techniques at the farm, landscape and leadership levels and this has become a fundamental barrier to wide adoption of SLM measures in the country. Besides technical SLM practices and technology alternatives, farmers are not provided with information on proven economic profitability of SLM investments (Mati, 2016). Information about SLM practices must be made broadly available for land users, researchers and the private sector in order to provide a range of options for decision-making at different levels. A key aspect in adoption of SLM options is to ensure genuine participation of land users and professionals during all stages of implementation to incorporate their views and ensure commitment.

[1] See https://vision2030.go.ke.

5. RECOMMENDATIONS

It is important to note that due to resource limitations, this study did not consider all benefits and costs associated with SLM practices. Other future studies should look at the role of on- and off-site impacts to society such as the cost of soil erosion downstream, the cost of emigration and associated loss of labour, vagaries of weather, loss of plant and animal biodiversity, the role of climate change among others. Benefits such as accessibility to credit for the improvement of SLM practices and the role of interest rates should be looked at. Other benefits include carbon sequestration and payment for ecosystem services such as the role of a water fund to farmers and its associated reduction in water treatment costs and increased hydropower production.

Key recommendations to:

Land users:

- Establishment of a platform for sharing information between the land users that are practicing different forms of SLMs so that that information on uptake of practices giving better returns are available to the land users. This can be done by promoting of farmers focus groups which are non-existent in this area.
- Adoption of soil quality assessment by land users as a prerequisite to planting of any form of crops. This will save the land user from wastage through purchase of fertiliser that may be of no use to the farmer. This will in turn be useful to conservation of soils and buffer against pollution and eutrophication.

Private sector:

- Adoption of soil quality as an indicator of SLM by land managers by promotion of easy access of farmers to soil nutrient analysis. The private sector players have an opportunity to make the access to soil nutrient measuring kits closer and accessible to farmers. This will reduce costs, complexity of transporting the soil far from home and minimize time delay between sampling or testing and receipt of results.

Public decision-makers:

- Establishment of a system that improves the spread of information between the land users that are practising different forms of SLMs so that the uptake of important practices is accessible at the local scale. This can be done by promoting extension services or creation of farmers field groups.
- Promotion of guidelines geared towards SLM practices that act against soil erosion and maintenance of fertility.
- A deliberate effort in investing towards documenting and evaluating SLM practices and their impact on ecosystem services. Various studies about SLM need to be identified, documented and assessed in an exhaustive and interactive way jointly by all stakeholders, including land users, extension officers, and researchers.

Appendix 1

Calculating mean revenue to cost ratios for different crops

In the calculation of gross margins,
$GM_{it} = TR_{it} - TC_{it}$where GM_{it} is the gross margin of crop i at period t; TR_{it} is the total revenue from crop i at period t, and TC_{it} is the total cost of crop i at period t, Given the total revenues and total costs of different crops e.g. maize, beans, peas etc. over a number of years, it is possible to estimate the gross margin for the different years. Using historical information, it is possible to establish a trend of how these variables for different crops evolve over time and determine the mean total revenue to total cost ratio. This ratio can be used to estimate the costs of production if the revenues are given as was the case with the current study. Given an historical data set of T years, the TR: TC ratio can be given by:

$$TR{:}TC = \frac{TR}{TC} = \left[\sum_{t=1}^{T} TR_{it}\right]/T \div \left[\sum_{t=1}^{T} TC_{it}\right]/T$$

This operation shows that we are summing all the revenue over the years and dividing it by time. The same is done to the costs. The resulting mean revenue is divided by mean cost overtime. If one if given the revenue and no costs, one can use this ratio to get a credible estimate of the cost of production.

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Co-financed by the European Union

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Co-Funded by the European Union (EU) and the German Federal Ministry for Economic Cooperation and Development (BMZ).