ASSESSMENT OF PAYMENT FOR ECOSYSTEM SERVICES IN SASUMUA CATCHMENT, KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in other university or any award.

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DEDICATION

To my family,

For your prayers and support during this study.

I wish you God's blessings.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of appendices

LIST OF EQUATIONS

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
BD	Bulk Density
BEF	Bonneville Environmental Foundation
BMPs	Best Management Practices
CEC	Cation Exchange Capacity
CRP	Conservation Reserve Program
DEFRA	Department of Environment, Food & Rural affairs
DEM	Digital Elevation Model
ES	Environmental Service
FC	Field Capacity
GOV	Government
ICRAF	World Agro-forestry Centre
IIED	The International Institute for Environment & Development
KAPSLMP	Kenya Agricultural Productivity and Sustainable Land Management Project
LMPs	Land management plans
MAM	Wet season of March, April & May
MDGs	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
MOA	Ministry of Agriculture
MOE	Ministry of Environment

NCWSC	Nairobi City Water and Sewerage Company
NPK	Macro Nutrients (Nitrogen, Phosphorous and Potassium)
NS	Nash-Sutcliffe
NTU	Nephelometric Turbidity Unit
OND	Wet season of October, November & December
PES	Payment for Ecosystem Services
PRESA	Pro-poor Rewards for Environmental Services in Africa
PWP	Permanent Wilting Point
ROI	Return on Investment
SD	Standard Deviation
SLM	Sustainable Land Management
SLMP	Sustainable Land Management Practices
SOTER	Soil and Terrain Database of East Africa
SWAT	Soil and Water Analysis Tool
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
USGS	United States Geological Survey
WGN	Weather Generator
WHC	Water Holding Capacity
WRC	Water Restoration Certificates
WRO	Wales Rural Observatory
WSDNR	Washington State Department of Natural Resources

ABSTRACT

The study was conducted in Sasumua watershed in Nyandarua County, Kenya. The catchment contains an important reservoir that supplies water to Nairobi. However, the intensive agriculture coupled with unsustainable agricultural practices including; deforestation, clearing of riparian buffers and intensive subdivision of land units leads to proliferation in soil erosion. This degrades water quality downstream leading to high maintenance cost of water infrastructure. The aim of the study was to assess the effectiveness of payment for ecosystem services (PES) approach as an alternative to watershed management. Baseline data on SLM adoption and water quality was collected before onset of PES pilot project. An assessment of PES was conducted one year into the project. Soil sampling was carried out to assess effectiveness of existing SLMPs specifically ‘fanya juu’ terraces on soil fertility and water holding properties. Total Suspended Solids (TSS) was selected as a proxy indicator to monitor water quality changes as SLM status improved under the PES project. Soil and Water Assessment Tool (SWAT) modelling was used to assist in interpretation of effectiveness of observed results against the best scenario of the study micro-catchment. The results showed that PES incentives (KES 4,541 per household), improved adoption of SLMPs from a baseline of 11% to 32% of the target SLM status after one year of PES implementation. Comparison of PES and non-PES farms showed significant differences in terms of SLM adoption. There was strong evidence that PES as an alternative approach led to positive changes towards SLMP adoption. On water quality, it was observed that Total Suspended Solids (TSS) significantly ($p=0.00022$) reduced from a baseline of 71.05mg/L to 42.73mg/L. The PES as an alternative was identified as an effective approach in improving water quality downstream. The PES incentives are expected to further improve soil and water conservation at farm level to ensure sustained delivery of the desired ecosystem services. However, long term research data is recommended to validate the effectiveness of PES over number of years especially on ecosystem services that manifest after long periods and establishing whether PES incentives actually maintain best conditions at farm level. More ecosystem services should also be monitored to validate the TSS results.

CHAPTER ONE

INTRODUCTION

1.1. Background information

Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, fresh water, timber, fibre, and fuel etc (MEA, 2005) which has resulted in a substantial and largely irreversible loss in diversity of life on Earth.

While changes to ecosystems have contributed to substantial net gains in human well-being and economic development, it has been at growing costs in form of degradation of many ecosystems, increased risks of nonlinear changes, and exacerbation of poverty for some people. These problems, unless addressed, will substantially diminish the benefits that future generations can obtain from ecosystems. The Millennium Ecosystem Assessment (MEA, 2005) defines ecosystem services as the benefits human beings derive from the natural environment and include; provisioning services such as food, fresh water, timber and fibre; regulating services such as climate regulation, flood regulation, water purification and erosion regulation; cultural services such as recreational, aesthetic and spiritual benefits and supporting services such as soil formation, nutrient cycling and photosynthesis.

Healthy watersheds provide valuable services to society, including supply and purification of fresh water. Because these natural ecosystem services lie outside the traditional domain of commercial markets, they are often undervalued and under-protected. With population and development pressures leading to rapid modification of watersheds, desired ecosystem services are being lost (Sandra *et al.*, 2005). As watersheds determine water flows (quality and quantity), they are appropriate areas for organizing planning and management of water resources. The conditions of a watershed and the management of the vegetation cover, soils and other land resources within it, are therefore integral to planning water allocation and use (Smith *et al.*, 2006).

The ability of watersheds to moderate water flows and purify drinking water supplies is one of their most tangible and valuable services. The progressive loss of these services risks harm to human health through lowered drinking water quality, higher water costs that may burden poorer populations, and lower crop productivity and hydroelectric output from reduced dry-season flows. As natural watersheds have been converted to alternative land uses, many industrial countries have turned to increasingly sophisticated and expensive technological treatment processes to purify drinking water sources (Sandra *et al*., 2005).

Within a watershed, the quality, quantity and timing of water draining into and flowing along rivers is modified by topography, geology, soil type, vegetation cover, land use and other human activities. Along the way, water is lost – primarily via evaporation from lakes, wetlands, the soil surface and wet vegetation, and through transpiration by plants and trees. Water moving down slopes and stream channels, as well as underground, may carry sediment, nutrients and other chemicals or contaminants. The quality and quantity of water available to downstream users in a watershed thus depends on the particular types and distribution of vegetation, the underlying geology, soil types present and the way land is used and managed (Sandra *et al*., 2005).

Adoption of sustainable land management practices (SLM) by upstream farmers can improve water quality and reliability for downstream users. These practices can reduce chemical and sediment pollution, improve rainwater retention, ground water recharge, regulate flows, reduce risk of floods, landslides and increase agricultural production. However, the rate of SLM adoption is still low through conventional approaches as reported in several studies. Kihiu, 2016 estimated that in Kenya, adoption rates of sustainable land management (SLM) practices in areas where SLM practices are highly needed (dry lands) due to unfavourable conditions are alarmingly low (14.2%), despite the declining productivity of the ecosystems. Other studies report a generally low adoption or no adoption at all in Kenya through conventional approaches (Tanui *et al*., 2014; Branca *et al*., 2011; World Bank, 2008; Mulinge *et al*., 2016; Ministry of Livestock Production, 2014; Shiferaw *et al*., 2009; Liniger *et al*., 2011; Jairo, 2013; MOA & MOE, 2011). Farmers are also unable to adopt SLM practices due to lack of knowledge and financial resources (Harvey *et al*., 2014). Reward mechanisms such as PES can increase adoption of SLM technologies by farmers (Pagiola, 2008; Porras *et al*., 2013).

Payments for environmental services (PES) are a class of economic instruments designed to provide incentives to land users to continue supplying an environmental service that is benefiting society more broadly (Wunder, 2005). Payments may be made to land users to adopt land use practices that will produce the required services (e.g. planting grass filters for buffering sediments loads). Although PES has several definitions the one fairly well-accepted is by (Wunder, 2005), which defines PES as: A voluntary transaction in which a well-defined environmental service (ES), or a form of land use likely to secure that service is bought by at least one ES buyer from a minimum of one ES provider if and only if the provider continues to supply that service.

Payment for ecosystem services is in line with goal six, thirteen and fifteen of the SDGs. These SDGs include ensuring availability and sustainable management of water for all, taking urgent action to combat impact of climate change and promoting sustainable use of ecosystems to reverse land degradation respectively. PES is also in line with Kenyan Vision 2030, the national long-term development policy that aims to transform Kenya into a newly industrializing, middle-income country providing a high quality of life to all its citizens by 2030. The vision recommends to government, through collaboration and other mechanisms, to aim in creating jobs and enhancing food security through rural environmental conservation.

1.2. Problem statement

Sasumua watershed is one of the many examples of degraded watersheds in the globe given that the erosion rate from the watershed is estimated at 162.48 tons/ha/year (Mwangi, 2014). According to European commission, (2006), soil erosion rates exceeding 10tons/ha/year are considered severe. Human activities in the watershed have caused changes in the ecosystem limiting its capacity to provide the desired goods and services (Mwangi, 2014). Unsustainable agricultural practices and deforestation have contributed to land degradation in form of increased soil erosion and soil fertility loss, which has affected the quality and supply of water resources downstream and declining agricultural productivity. In the last 3-4 decades much of the forest in the upper catchment has been cleared for intensive (small scale) agricultural activities (Vagen, 2009). Swamps, wetlands and riparian buffers that previously functioned as natural water filters have been cleared for cultivation. Subdivision of land into small uneconomical units and reduction in fallow periods have led to increased soil erosion, depletion of nutrients, declining soil fertility and crop yields (ICRAF, 2009). The poor water quality that reaches Sasumua reservoir leads to high treatment costs for Nairobi City Water and Sewerage Company (NCWSC) (Mireri, 2009). The cost of treating water at Sasumua treatment plant is estimated at *Kshs 2,080 per 1000* m^3 against *Kshs 1,120 per 1000* m^3 at Ndakaini treatment plant (Mwangi, 2014). Other problems include unsustainable agricultural practices, and lack of knowledge and capacity to invest in new technologies. PES as an alternative approach to watershed management has a potential to accelerate adoption of sustainable land management practices which consequently improves water quality downstream (Pagiola, 2008). The aim of the study was to assess the effectiveness of PES approach as an alternative to watershed management. This involved evaluating effectiveness in adoption of SLM technologies and impact to water quality.

1.3. Research questions

i. What is the baseline status of the study micro-catchment on sustainable land management practices (SLMPs) and water quality?

ii. Are soil and water conservation measures under conventional approach effective on maintenance of soil fertility and water holding properties?

iii. To what extent is payment for ecosystem services as an alternative approach, effective in enhancing adoption of sustainable land management technologies and improving water quality?

1.4. Objectives of the study

1.4.1. Broad objective

The broad objective of the study was to evaluate the effectiveness of the PES approach in delivering desired ecosystem services in Sasumua watershed.

1.4.2. Specific objectives

i. To establish baseline status of the study micro-catchment on sustainable land management practices and water quality.
ii. To assess the effectiveness of soil and water conservation measures on soil fertility and water holding properties.
iii. To evaluate the effectiveness of payment for ecosystem services approach on adoption of sustainable land management technologies and water quality.

1.5. Justification and significance of the study

The motivation for this study is informed by the fact that watersheds under conventional approaches hardly deliver desired ecosystem services due to unsustainable practices (Hou *et al*., 2016). This calls for a need to search and pilot for effective alternatives to watershed management. The study produces important findings that contribute to existing knowledge on PES as an alternative approach to watershed management. The study is also an important reference for watershed management policies. Given that some of the ecosystem services take years to manifest, the study contributes to existing knowledge by presenting a methodology for monitoring and modelling proxy indicators in a short period. The study provides a baseline situation and performance within the first year of PES implementation. This provides crucial findings that can inform policy considerations and guide improvement in future PES schemes in Sasumua and other potential watersheds in the country. With information on effectiveness of PES approach, the study provides information that promotes stewardship and behavioural change towards adoption of SLM technologies that can deliver desired ecosystem services downstream.

1.6. Scope and limitations

This study evaluated the effectiveness of the PES approach in delivering desired ecosystem services using TSS as the proxy indicator. PES was expected to have an impact on SLM adoption, crop and livestock productivity, increase in dry weather flows household income, downstream water quality, among others. The scope of this study was limited to SLM adoption and water quality improvement. Majority of other aspects would call for long term data collection which was not feasible given the time and resources available. SWAT modelling requires high resolutions data inputs. In this study, land cover maps were generated from 2016 landsat image obtained freely from USGS website using maximum likelihood method classification. Thirty meters DEM was downloaded from USGS. 1:1,000,000 soils data were extracted from Digital Soil and Terrain Database of East Africa (SOTER). High resolutions data were expensive to acquire for this study.

CHAPTER TWO

LITERATURE REVIEW

1.1 Brief introduction

The literature review starts by giving a background on ecosystem services and economic value associated with managing ecosystems. The section also describes millennium development goals and ecosystem degradation. The review looked at water-related services; detailed descriptions of PES; comparison between PES approach and conventional approaches; effectiveness of sustainable land management practices and common procedures in monitoring and evaluating effectiveness in PES projects. The state of water quality at the start of the study and estimated benefits from PES project in Sasumua was also highlighted. The gaps identified in the literature review were presented at the end of this chapter.

1.2 Ecosystem services

The challenge of reversing ecosystems degradation while meeting increasing demands for their services can be partially met through significant changes in policies, institutions, and practices that are not currently under way (MEA, 2005). Many of the regions facing the greatest challenges in achieving the MDGs coincide with those facing significant problems of ecosystem degradation. Rural populace, a primary target of the MDGs, tend to be most directly reliant on ecosystem services and are thus most vulnerable to changes in those services (MEA, 2005). More generally, any progress achieved in addressing the MDGs of poverty and hunger eradication, improved health, and environmental sustainability is unlikely to be sustained if most of the ecosystem services on which humanity relies continue to be degraded. The total economic value associated with managing ecosystems more sustainably is often higher than the value associated with the conversion of the ecosystem through farming, clear-cut logging, or other intensive uses (MEA, 2005).

1.3 Water-related services of a watershed

Watersheds with a high proportion of land covered by vegetation are particularly effective at moderating runoff and purifying water supplies (Bamlaku & Yemiryu, 2015). The vegetation and soils of wetlands have a remarkable capacity to filter out contaminants and trap sediment that would otherwise enter rivers, lakes, and streams which eventually lead to increase in water treatment costs down streams. The benefits from healthy watersheds have been identified by (Sandra *et al*., 2005) as: (1) water filtration / purification, (2) seasonal flow regulation, (3) erosion and sediment control and (4) habitat preservation.

Sustainable land management practices can provide multiple environmental services by conserving existing natural ecosystems, managing agricultural and agroforestry land, and restoring degraded ecosystems (Porras *et al*., 2013). These efforts are often driven by a range of instruments, from direct regulation through prohibitions and zoning to ‘soft’ approaches such as information and capacity building, market-based instruments such as taxes and fines, and hybrid approaches that combine regulatory approaches and market mechanisms such as cap-and-trade measures (Porras *et al*., 2013).

1.4 Payment for ecosystem services (PES)

A market-based framework for conservation encourages innovative maintenance and restoration of ecological benefits while allowing people to receive financial rewards for providing ecosystem services (WSDNR, 2012). PES is an important innovation in water resources management. Watershed services are crucial in creating water security for downstream water users. Providing incentives to upstream farmers to maintain watershed services is an innovative way of strengthening water security (Smith *et al*., 2006).

The core idea of PES is that external ES beneficiaries make direct, contractual and conditional payments to local landholders and users in return for adopting practices that secure ecosystem conservation and restoration (Wunder, 2005). Lack of information both scientific and economic on the links between land uses in a watershed and the corresponding hydrological services those watersheds provide complicates the task of designing appropriate institutional mechanisms for watershed protection and proving additionality (Aylward, 2002). Payments for watershed services generally encourage adoption of land practices that are expected to influence the biophysical attributes of an ecosystem and consequently deliver the desired ecosystem services (Porras *et al*., 2013).

Environmental outcomes of key indicators are attributable to PES schemes only if there is a baseline allowing for comparison of situations with and without PES. A transparent and technically designed monitoring programme is therefore an integral part of PES schemes. Monitoring should be participatory in order to strengthen accountability and increase transparency.

1.5 Differentiating PES approach from conventional approaches

In most cases, conventional approaches are ways where farmers adopt through own in initiatives – possibly through voluntarily attending to trainings, education background, knowledge acquisition through extension workers and media adverts (Bunyatta *et al*., 2006). PES schemes differ significantly from other conventional approaches. First, PES schemes differ in the vehicles used to achieve conservation effects. The most common type is area-based schemes, where contracts stipulate land- and /or resource-use caps for a pre-agreed number of land units and product-based schemes where consumers pay a 'green premium' on top of the market price for a production scheme that is certified to be environmentally friendly (Wunder, 2005). PES also differs as there are external drivers who influence the day to day land use activities. There exist ecosystem services (ES) buyers (Public or Private Schemes) who pay directly to farmers to continue supplying desired ES services. Depending on financial sources, PES schemes can be categorized as either "government" or "user-financed". In "user-financed" schemes, buyers are the ES users themselves while in "government" financed schemes a public sector agency buys ES on behalf of users (Engel *et al.,* 2008). Government financed schemes are generally larger in scope and may involve paying for multiple ecosystem services.

Sasumua PES pilot project is a public scheme where the government represented by Kenya Agricultural Productivity and Sustainable Land Management Project (KAPSLM) is buying ecosystem services (ES) at the initial pilot stage. It is needed to prove viability of PES to enable replication and scaling up of the PES project. Therefore, assessing effectiveness of PES approach on delivering desired ecosystem services was an integral part of the pilot project.

PES schemes incorporate “use-restricting” to reward providers for conservation (including natural regeneration) for capping resource extraction and land development; or for fully setting aside areas such as for protected habitat. Here, landowners are paid for their conservation-opportunity costs plus possibly for active protection efforts against external threats (Hardner and Rice, 2002). In contrast, in “asset-building” schemes PES aim to restore an area’s ES, for example re-planting trees in a treeless, degraded landscape. Conservation-opportunity and protection costs aside, PES may also compensate the direct costs of establishing ES, often through investments within agricultural systems (Pagiola *et al.*, 2002). Whether PES is an economic rent for basically “doing nothing”, or at least in part a reward for actively improving ES, has some implications for rural employment (Wunder, 2005). Therefore, PES as an alternative approach differs greatly as it influences adoption of most effective SLM practices through incentives or rewards as opposed to conventional approaches where land users implement non-uniformly what is most feasible among other individual priorities. Conventional approaches do not adopt payments/incentives principle.

1.6 Pro-poor payments for ecosystem Services

Payments for ecosystem services are not designed to reduce poverty. Rather, PES primarily offers economic incentives to foster more efficient and sustainable use of ecosystem services (Forest Trends *et al.*, 2008). There are, however, opportunities for designing PES which can enable low-income people to earn money by restoring and conserving ecosystems. This is a critical selling point, because many rural people earn their living from natural resource-based activities, such as forestry and farming. Since PES schemes promote sustainable land use practices, it can lead to higher crop productivity thus increased income. However, the main focus of PES is restoration of ecosystems where degraded ecosystems could also be located in areas of the wealthy class, and not necessarily in areas of low-income people (Forest Trends *et al*., 2008).

Short-term incentives exist for unsustainable forestry and farming practices, which can draw down natural capital and limit options for future development. In certain contexts, PES can present new incentives for sustainable management in the form of regular payments for ecosystem services. These regular payments could in turn promote long-term sustainable use and even conservation of the resource base by providing both a reliable source of supplemental income and additional employment in the community. Even a modest payment, reliably delivered over many years, may in certain contexts provide a meaningful increase in net income as well as a mechanism for adopting more sustainable land management (Forest Trends *et al*., 2008).

PES can also be established to contribute to the formalization of resource tenure and the clarification of property rights (Forest Trends *et al*., 2008). Since PES schemes explicitly recognize the role of environmental stewards, PES agreements could strengthen rural peoples' position in other resource-based negotiations. The most important thing is to carefully consider the benefits that a community, group of sellers, and/or individual sellers of ecosystem services are interested in during the design stage of a PES deal (Forest Trends *et al*., 2008).

Potential Benefits of PES for the Rural Poor include *short term benefits* such as; increased cash income for consumption or investment purposes, expanded experience with external business activities, increased knowledge of sustainable resource use practices and *long term benefits* such as; improved resilience of local ecosystems and flow of ecosystem services and potential for higher productivity land due to ecosystem service investments (Forest Trends *et al*., 2008).

1.7 Valuing and managing watershed services

According to (Smith *et al.*, 2006) the success of PES scheme underlies five areas of considerations:

i. Linking upstream land and water use and downstream benefits

For a payment scheme to succeed and endure, the actions and change brought about by upstream land and water managers should result in identifiable benefits for downstream water users. Therefore, clear cause-and-effect relationships between upstream land and water use practices and the provision of watershed services for downstream users' needs to be identified.

ii. Using indicators and targets to define baselines situations and track progress

Watershed services are controlled by an 'optimal mix and intensity' of land and water use in water-sheds. It is important to define and quantify indicators to track the delivery of watershed services to benefit specific users. These indicators and targets need to relate directly to measurable land and water use variables and should be agreed upon by the stakeholders involved. Planning for new or improved data collection on a limited set of key indicators and targets may be needed as part of the PES scheme. TSS was selected and agreed upon by the PES stakeholders as a proxy indicator to monitor water quality in this study.

iii. Focus investments on agreed actions and locations

It is important to define clearly the goals of the payment scheme based on the causal links established between upstream actions and downstream benefits. Clear goals help to define which locations will be targeted for specified interventions. It also helps to narrow down the group of stakeholders to be involved in the scheme and the mechanisms to be used. It further creates transparency and trust amongst stakeholders in the scheme.

iv. Build a case for investment through valuation of watershed services

The economic valuation of watershed services can be used to raise awareness of the importance of these services and create support for a payment scheme. However, the final prices agreed within a payment scheme will be determined by costs and benefits to stakeholders.

v. Information provision and negotiations among stakeholders are essential

Stakeholders need to be well informed to be able to decide where investments should be made and what changes and impacts are sought. One needs to establish clearly which stakeholders can impact watershed services (sellers) and which stakeholders can benefit from watershed services (buyers). Evidence relating changes in land and water use to levels of watershed services forms an important basis for bringing potential buyers and sellers together.

1.8 Effectiveness of sustainable land management practices at farm level

Land degradation is the loss of productivity and capacity of land to provide ecological and socioeconomic goods and services (Nkonya *et al*., 2008). In sub-Saharan Africa (SSA), land degradation is a serious problem threatening rural poor people who depend on agriculture for their livelihoods.

Soil erosion and nutrient depletion are the major forms of land degradation. In addition to contributing to decreases in agricultural productivity and the consequent food and nutrition insecurity, soil nutrient depletion and erosion may also contribute to deforestation and losses of biodiversity by forcing farmers to abandon nutrient-starved soils and cultivate more marginal areas such as hillsides and rainforests (Nkonya *et al*., 2008). Such a situation has been observed in densely populated areas of Kenya, where encroachment on protected forests is a common problem (Hitimana *et al*., 2004).

Farmers' and public calculations of benefits from SLM investment are different: subsistence farmers are primarily concerned with short-term financial benefits (mainly crop yield) while ignoring ecosystem-wide benefits of SLM investments (Adimassu *et al*., 2012). Managing land sustainably is a huge challenge due to varying factors ranging from harsh climatic conditions, local conditions of farmlands, socio-economic factors, general attitude of land users etc. Adoption of good land use practices by farmers can reduce soil erosion which translates to protection of land resources in terms of soil fertility protection and improving water holding properties. Sustainable land management (SLM) technologies can reduce chemical and sediment pollution, improve rainwater retention, ground water recharge, regulate flows and wetland functions and reduce risk of floods and landslides. However, farmers are unable to adopt good land practices due to lack of knowledge on effectiveness of proposed SLM technologies and lack of financial resources (Harvey *et al*., 2014). Reward mechanisms such as PES can encourage adoption of SLM practices.

With threats from climate change, disputes over water, competing claims on land, and migration increasing worldwide, the demands for sustainable land management (SLM) measures will only increase in the future (Schwilch *et al*., 2013). Mechanisms such as PES will be one of inevitable alternative approaches to promote the SLM practices among land users for the benefit of society at large.

However such approaches will face negative reception among farmers unless there is prove of absolute benefits of adopting SLM technologies at farm level (FAO, 2013a). This can auger well if such effectiveness is proven from the local demonstration or from local farms which have adopted SLM practices for a long time. Neighbouring farmers highly influence each other in decision making as neighbours tend to copy each other (WRO, 2011). Assessing effectiveness of SLM practices in the local settings where farmers can freely observe changes and associate with each other is a key to the success of the PES schemes.

Nutrient losses through soil erosion from agricultural land imply an economic loss to the farmer by both reducing crop yield and increasing the replacement cost of soil nutrients (Yirga & Hassan, 2010). Nutrient losses can contribute significantly to water degradation downstream, (Adimassu *et al*., 2012) investigated the effects of soil bunds on runoff, crop yield, and soil and nutrient (N, P, and K) losses. The results showed that soil bunds reduce runoff, as well as soil and nutrients losses, from cultivated lands.

The major on-site (on-farm) benefit of SLM practices is higher and sustainable crop yields due to improved soil fertility and water holding properties. A study conducted by (Nkonya *et al*., 2008), compared farms with and without SLM technologies in maize production. The study showed that the rate of decline of maize yield in farms without SLM practices was much faster than farms with SLM practices.

1.9 Monitoring and evaluating effectiveness in PES projects

The main components for monitoring and evaluating PES schemes include; conditionality and additionality (Forest Trends *et al*., 2008). Conditionality refers to the conditions attached to PES contracts. They provide assurances that the agreed land management practices have been put in place. Additionality refers to the net positive impact in the provision of ecosystem services created by the payment compared with the controls and/or baseline scenarios.

For many years, PES projects had not invested heavily in assessing effectiveness citing challenges such as; resource constraints, lack of scientific data on program outcomes, complex designs, lack of equipment and technical knowhow, difficulties in attributing watershed-wide environmental outcomes to a specific activity, inherent uncertainty around measuring outcomes and the fact that monitoring results are highly site- and time-sensitive (Bennett and Carroll, 2014). However, PES programs started taking monitoring and evaluation seriously and there was an increase in PES programs that reported ongoing monitoring of hydrological and other biophysical outcomes globally in 2012-2013 to 55% from 45% in 2010-2011 (Bennett and Carroll, 2014).

The increase in assessing effectiveness was attributed to the growing demand by ecosystem services buyers of assurances on additionality of PES projects. This demand has also triggered new interest in quantified outcomes and return on investment (ROI) but methodologies remain experimental.

In PES schemes which employ input-based payments, monitoring can be split into two components (Engel *et al.*, 2008); (a) compliance and (b) ES provision. Monitoring compliance; i.e. whether the ES sellers actually adopt the land use or management paid for. Monitoring ES provision; this for example involves water sampling for programs aiming to improve drinking water quality. For output-based PES schemes, only the second type of monitoring is relevant.

This study focused in assessing the effectiveness of PES approach. Monitoring of compliance was carried out to monitor changes in adoption of SLM technologies. Monitoring changes on TSS as a proxy indicator at selected downstream points was also carried out.

1.9.1 Baseline and effectiveness in PES studies

Establishment of a baseline is important to correctly interpret effectiveness of PES schemes, as it expresses how ES provision would develop through time in the absence of payments (Wunder 2005). Baselines can be established by monitoring the status of ES provision before PES implementation. Where such data are absent; changes in ES provision are then often interpreted by comparing them to trends outside PES area.

1.9.2 Importance of monitoring effectiveness of PES projects

Monitoring effectiveness of PES projects creates confidence to ecosystem buyers on additionality created by PES projects. Scientifically validated monitoring ensures improvements to ecosystem service delivery are demonstrated to funders (DEFRA, 2013). It also helps in tracking progress of PES implementation and quick adjustments to encountered barriers and challenges. Assessing effectiveness of PES schemes forms the basis for payments especially in output based PES schemes. Effectiveness of the agreed land use/management practices in delivering improved ecosystem services is the most critical aspects of PES project as it ensures sustainability of PES, since in the long term, buyers may not be willing to pay for a service that has not been measured or proven to exist (Adrian *et al*., 2014). Monitoring provides the data to assess compliance and ES provision once performance has begun.

1.9.3 Conditionality and additionality in PES projects

In terms of monitoring and evaluation, conditionality is monitored for compliance, and additionality for effectiveness (Porras *et al.*, 2013). The conditionality implicit in PES contracts is typically a necessary step in generating additional benefits to those that would occur without the PES scheme. However, a high degree of compliance does not necessarily equate to a high degree of effectiveness, as several factors such as targeting inappropriate sites (targeting non- hotspot areas), natural havocs (e.g. land slides), stressors factors (e.g. a farmer plants grass strips but does not improve other crucial farming practices for instance; cover crops, mulching etc) may affect the effectiveness of the PES scheme.

1.9.4 Approaches to monitoring effectiveness in PES Projects

The approaches to monitor effectiveness in PES projects differ significantly depending on the scale; nation-wide or small scaled schemes. In nation-wide schemes, formal checks (e.g. site visits) are often implemented. Cross-compliance monitoring is often deployed as a tool (Molenaar, 2013). It is not always clear whether provision of the targeted ES is indeed being promoted by nation-wide PES scheme implementation. In-situ monitoring of ES provision even lacks completely in almost all nation-wide schemes.

In small-scaled PES schemes, ES provision monitoring is active to some degree; however, the applied monitoring method does not always cover all the ES provision targeted by the PES scheme (Molenaar, 2013). Generally, measurements performed before or at the start of the program form the sole reference point (baseline) for the monitoring data.

Frequency of monitoring in PES projects is decidedly mixed. In a survey carried out by (Bennett and Carroll, 2014) about 66.7% of PES programs with active water quality monitoring reported that monitoring only takes place once or a few times a year, and in some cases may entail only a visual inspection rather than sampling for specific parameters.

One of the PES schemes in United States, the Conservation Reserve Program (CRP) demonstrates that, government led PES schemes can successfully achieve ongoing environmental benefits. However as conservation practices become more complex, greater investment is needed to effectively monitor the activities of participants and ascertain the benefits and costs through more precise modelling and data collection capabilities (DEFRA, 2013).

1.9.5 Input- versus output-based monitoring

In almost all PES schemes especially in developing countries, payments are based upon fulfilling conditions agreed in the contract, with less on output-based monitoring (Porras *et al.*, 2013). This is not incidental, but applies to PES schemes in general (Engel *et al.*, 2008, Wunder *et al.,* 2005). Although land use is evidently related to the provision of ES such as regulation of soil erosion, clean water provision etc, the shapes of these links are generally unclear (Kleijn *et al.*, 2009). These effects may for example vary between geographical areas, or can depend on the scale at which the PES measures are implemented (Molenaar, 2013).

It therefore seems more desirable to directly base PES payments on additionality. A difficulty related to such output-based payments is that additionality can often not be perceived by land users, preventing them from managing their land properly (Engel *et al.*, 2008); further, it may discourage potential ES providers as they cannot be sure in advance whether their efforts will pay off (Molenaar, 2013).

It is appropriate to design a monitoring and evaluation plan that combines compliance monitoring and additionality monitoring. This study collected data on both compliance and additionality. Compliance was monitored at farm level through recording changes on SLM technologies through monitoring the individual activities of all PES farms within the study micro-catchment. Additionality was monitored through sampling water and testing for Total Suspended Solids (TSS) at the selected downstream points.

1.9.6 What is monitored to prove effectiveness in PES projects?

In the Vittel PES in north-eastern France, a project whose main goal was to improve water quality, an intermediary institution (Agrivair) carried out monitoring of compliance. Agrivair monitored farming practices, use of new building facilities and livestock stocking rate. Nitrate rates were monitored all year round at 17 sites across four soil types and two types of farming systems to demonstrate effectiveness of the PES project (additionality) (IIED, 2006).

In the Wessex Water's catchment management programme in South West England, a key input to the project was the provision of data demonstrating the relationship between groundwater contamination and land management. This helped to pinpoint at a field scale where the problems were, enabling the company to engage with the land manager to discuss potential improvements that could be made. Data was collected for analysis and feedback to farmers, using sampling points located around the catchment (including soil testing, groundwater monitoring and nitrate sampling) (DEFRA, 2013).

The BEF Water Restoration Certificates (WRC) in United States focused on reducing unsustainable abstraction of water from the Prickly Pear Creek River by collaborative mechanism to allow private sector, urban water users to invest in the restoration of degraded waterways and ecosystems. Monitoring involved measuring and quantifying amount of restored water which formed the basis of PES payments (BEF, 2012).

In Australia, the Bush Tender PES project, focused on protecting native vegetation cover and the species it supports. In monitoring effectiveness; each year of the agreement landowners were required to submit a report on their commitments and management actions or achievement of biodiversity outcomes. Payments were only made subject to satisfactory progress and reporting. Monitoring of sites by field officers also occurred over the five-year Management Agreement period (Victoria-State, 2012).

Another exceptional PES scheme in England is The Environmental Stewardship where the focus was on paying agricultural landowners and managers across England to secure on-going management practices that provide ecosystem services. Monitoring involved; periodic evaluations undertaken by DEFRA and Natural England including on farm interviews and questionnaires (GOV-UK, 2012).

In Cumbria, England, The Bassenthwaite Ecosystem Services Pilot PES project, utilized an integrated approach to manage the catchment for multiple outcomes, and to connect wider public benefits to land management by farmers. A baseline assessment was produced including mapping of ecosystem services and beneficiaries. Potential management actions and locations were identified and mapped onto the baseline, as spatial prioritization was central to the project. It informed the 'what, where, how, and why' of Delivery Plan implementation. Data was shared for monitoring outputs e.g. water quality (DEFRA, 2013). Some measures were proxy indicators for ecosystem services; raw water colour, density of breeding ewes, annual water abstraction in litres, Sediment supply risk ratings among others (Waters *et al*., 2012).

In most of the case studies, the most preferred monitoring design is whereby activities of the participating farmers are tracked (compliance monitoring) as well as collecting information on key proxy indicators at downstream points level to determine the effectiveness (additionality monitoring) of the PES projects.

1.9.7 Design of monitoring and evaluation in PES projects

In many studies conditionality monitoring involves systematic monitoring of levels of provision, with payments scaled accordingly. Concerning additionality, use of baselines are designed to test whether any measured effects are above and beyond those brought about by pre-existing conditions (Adrian *et al.*, 2014). Because of the difficulty in measuring many environmental services directly, payments are based on proxy indicators (Arriagada and Perrings, 2009).

2.10. State of water quality at the start of the study

Simulated annual sediment inflow to the Sasumua reservoir was 40,934 tons/year (Mwangi, 2014). The annual water treatment costs was estimated to rise by Kshs 15,534,720 by 2024 if farming practices continue under the conventional approaches (PRESA, 2014). This problem can be solved by developing partnerships with land owners to implement sustainable land management practices such as terraces, contour farming, grass filter strips and grass waterways under an alternative approach to watershed management (PRESA, 2014).

2.11. Estimated benefits from PES project in Sasumua

The past studies in the Sasumua watershed found that maximum benefits in terms of soil erosion reduction would be realized only if conservation measures were targeted in the pre-identified hotspot areas. According to (Mwangi, 2014) the following were some of the expected benefits under a PES scheme for the larger Sasumua watershed:

i. Implementing a grassed waterway approximately 20 kilometres long and 3 metres wide can reduce soil sedimentation by 20%.
ii. A combination of terraces and grassed water ways would reduce sediment inflow by 75%.
iii. Filter strips of approximately 10 metres width and grassed water way will reduce sedimentation by 73%.
iv. Savings in water treatment and costs under PES are estimated to be Kshs 20,497,040.

2.12. Gaps identified in literature

It is not clear how relationship between adoption of SLM technologies and the impact to water quality downstream differs between conventional approach and alternative approaches to watershed management. The case studies of successful PES projects are limited in Kenya. Therefore, the purpose of this study was to evaluate the effectiveness of the PES as an alternative approach to watershed management on adoption of sustainable land management technologies and water quality. The study covers in detail the farms under conventional approach and those under PES project.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Overview of the study area

Sasumua is located in Central Kenya, southern ridges of Kenya's Aberdare Mountains about 90 km northwest of Nairobi, at an altitude of 2200m-3850m ASL, characterized by steep slopes. Mean annual rainfall is 1000-1600 mm, peaking March-May and October-December in a binomial pattern (Gathenya *et al.*, 2010). The catchment of the Sasumua reservoir operated by Nairobi City Water and Sewerage Company (NCWSC) is 107 km^2 and comprises of three sub-catchments: Sasumua (67.44 km^2) Chania (20.23 km^2) and Kiburu (19.30 km^2) (Figure 3.1). Farming is the main socio-economic activity with potatoes, cabbages and carrots grown for the Nairobi urban market. Intensification of crop production to meet consumer demands in Nairobi has encouraged a low input, high-output horticultural system leading to declining crop yields despite continued use of inorganic fertilizers (Mwangi, 2014).

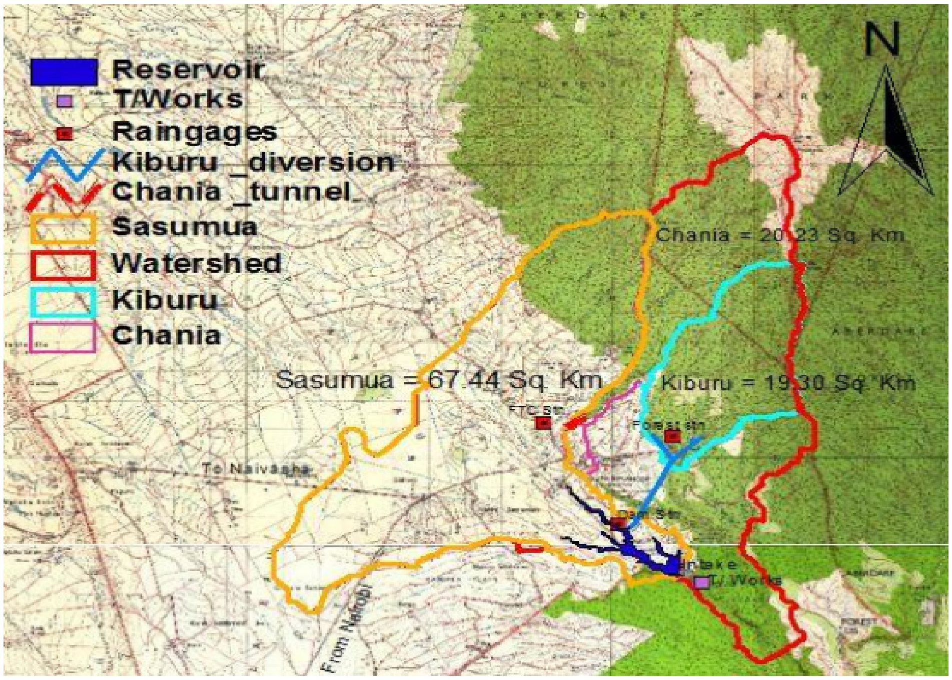

Figure 3.1: The sub-catchments of Sasumua dam reservoir (source: Gathenya *et al*., 2010)

3.2. Description of KAPSLMP PES project

In June 2015, Kenya Agricultural and productivity and Sustainable Land Management Project (KAPSLMP) initiated a PES pilot project in Sasumua. The pilot project was a public scheme where the government represented by KAPSLMP is buying Ecosystem services as a dummy Ecosystem Services (ES) buyer. Prove of PES viability was required to enable replication and scaling up of the PES project. Therefore, assessing effectiveness of PES approach on SLMP adoption and water quality improvement was an integral part of the KAPSLMP PES project. The PES project was being implemented in 4 micro-catchments of Sasumua watershed namely Kiburu, Njabini, Githabai and Mukeu (Figure 3.2).

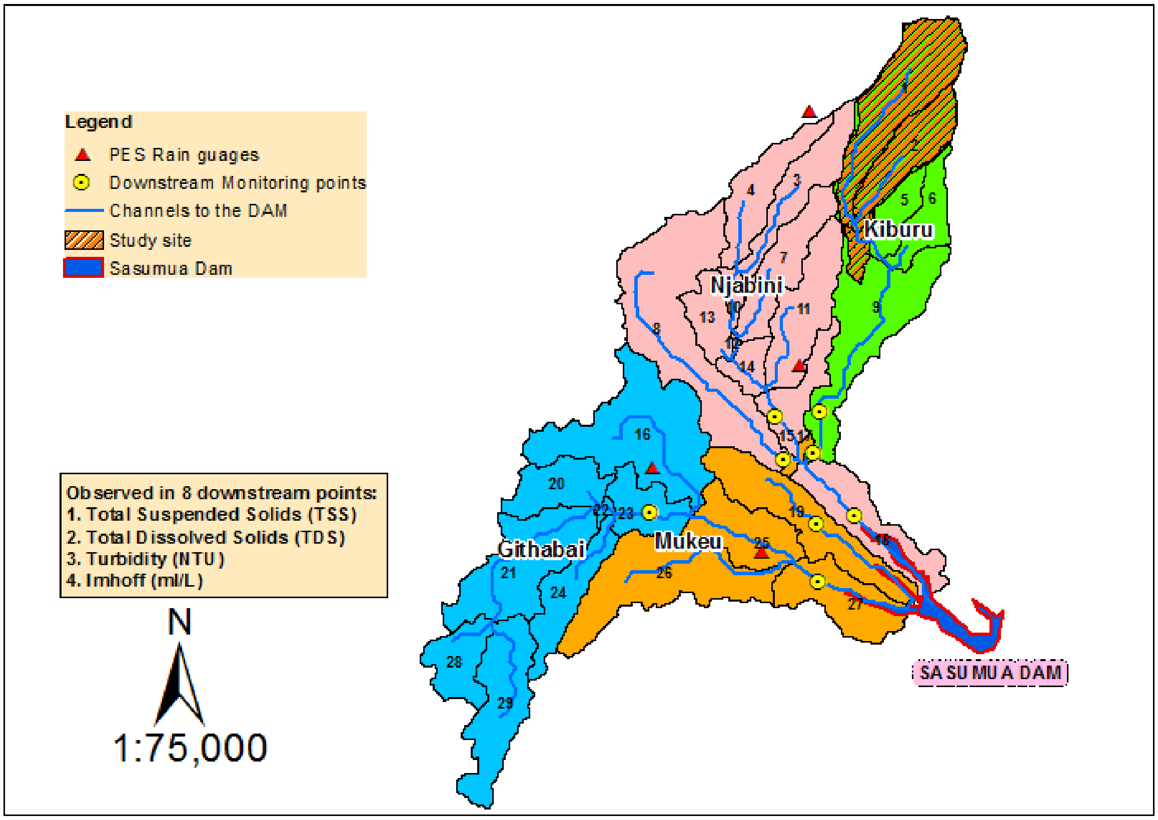

Figure 3.2: The eight monitoring points in the larger Sasumua watershed (source: author, 2016)

By the time of this study, the PES project had been implemented in an area covering approximately 762.9 hectares with a total of 1,017 PES farmers (Table 3.1). Table 3.2 shows the chronology of KAPSLMP PES project implementation in Sasumua watershed.

Table 3.1: Target SLM technologies for the larger Sasumua watershed

SLM Technology	Njabini MC	Kiburu MC	Githabai MC	Mukeu MC	TOTAL Target
No. of farmers	**425**	**237**	**148**	**207**	**1017**
Total hectares targeted	**324.9**	**134.7**	**148.9**	**154.4**	**762.9**
Terraces (M)	46,587	15,613	2,693	18,312	83,205
Drainage channels(M)	6,235	4,855	34,127	9,703	54,920
Retention ditch (M)	3,058	3,285	2,839	4,207	13,389
Cut off Drains (M)	10,861	350	16,933	1,761	29.905
Grass strip (M)	15,391	33,195	11,145	14,622	74,353
Riverbank protection (M)	2,130	79	0	957	3,166
No. of grass splits	206,301	159,756	178,513	126,763	671,333
No. of trees (forest/fodder/fruit)	13,823	25,511	20,229	12,221	71,784

Table 3.2: Chronology of KAPSLMP PES project implementation in Sasumua watershed

Date	KAPSLMP activities	
	Exploratory studies	
2006/2007	PES project conceptualization by world bank and government of Kenya under KAPSLM	
2008/2009	A Study on Hydrological Services in Sasumua Watershed by ICRAF/PRESA funded by world bank for government of Kenya. The components were; Environmental Audit, Hydrological Modelling And Water Quality Assessment, Land Degradation Assessment, Land Use/Land Cover Change And Land Tenure. This study identified erosion hotspots, land use change from 1985-2007 and measured water quality in 13 points.	
2009	From 2009-2016, PRESA continued using Sasumua as one of its research sites and many students did masters and PhD research here. Among them Hosea Mwangi (2011) and John Mwangi (2014).	
2013	In 2013 PRESA produced its policy brief.	
2014	Policy and institutional analysis for PES	
2014	Situational study; A study to assess water quality status of Sasumua Watershed (Baseline Results of key monitoring points)	
2014	A study to evaluate the potential for Payment for Ecosystem Services (PES) and policy implications in Sasumua watershed (Mwangi, 2014)	
Actualizing 'theory into practice'		**M.sc research project activities**
February - March 2015	Preliminary meetings with key stakeholders	M.sc Research Proposal and establishment of a representative watershed
March - May 2015	Awareness creation on PES pilot project to potential small scale	Baseline on water quality in the study site

	farmers, formation of common interest groups (CIGs) and training	
June 2015	Setting out - Establishment of individual Land Management Plans (LMPs) including field demonstrations	Baseline on SLM status in the study site
October 2015	Training PES sub-committee on data collection	
October 2015	Signing of PES contracts between the ES buyers and the sellers	
October - December 2015		Rainy season (Water quality sampling)
March 2016	Auditing for PES rewards	
April 2016	Rewarding of the leading farmers	
March - May 2016		Rainy season (Water quality sampling)
June 2016		Field study to establish SLM progress in the study site after one year of PES implementation

3.2.1. The ES buyers and sellers

The ES sellers were the small scale farmers located in the hotspot areas of Sasumua watershed. The PES farmers were organized into Common Interest Groups (CIGs). There were several CIGs going by the different agricultural value chains supported under KAPSLM project including; Tree tomato, Dairy, Irish potatoes, straw berry, Bee keeping, Agroforestry, Fish farming etc. Farmers received trainings on sustainable land management practices through their respective CIGs.

3.2.2. Conditions for getting payments

Land management plans (LMPs) (Plate 3.1) were prepared for each farmer participating in the PES pilot project with assistance from extension officers and SLM experts. The land management plan specified the particular SLM recommendations to be adopted which were unique to a farmer depending on the location and SLM status of the farm. The participation was voluntary and a copy of the map was left with the farmer as a guide on specified locations for installing the recommended conservation measures on the farm.

Plate 3.1: Farmers with individual land management plans (LMPs) (source: author, 2016)

To qualify for PES payments, the farmers had to implement the SLM technologies as per specifications in the LMPs. They were also to maintain the SLMP to specified standards. The PES program compensated 30% of the total cost of implementing the SLM practices. PES farmers agreed to cater for the other 70%.

3.2.3. Training of farmers

Through the Common Interests Groups (CIGs), PES farmers received weekly trainings based on topics relevant to the agricultural value chains they were involved in. The aim was to promote good husbandry practices and increase production per unit area while conserving the environment. The training sessions were led by the extension service providers contracted under the KAPSLM project. The service providers were also available for consultation by the PES farmers. They organized on-farm demonstrations and audited the progress of SLM adoption in order to qualify a farmer to PES compensations.

3.2.4. Long term maintenance

In each of the 4 micro-catchments, the PES farmers elected PES committee members. The PES committee worked closely with Water Resources Users Association (WRUA). WRUA are associations of water users and riparian land owners who have associated for the purposes of cooperatively sharing, managing and conserving a common water resource. WRUAs are part of catchment management strategy established under Water Act (2002) of Kenya. The PES committee members were the leaders of the PES scheme in their respective micro-catchments. They were trained on PES concept, good husbandry practices and environmental conservation. They were supposed to lead as examples to other farmers in all PES related activities promoted under the KAPSLM PES project. The PES committee members conducted regular on-farm checks in their respective micro-catchments to encourage adoption of SLM technologies. They represented farmers through forwarding their needs and priorities during PES stakeholder meetings. They provided communication links between the KAPSLM PES management team and the PES farmers. The involvement of PES committee together with the Water Resources Users Association (WRUA) in the PES project activities was expected to maintain the farms in their desired status during and beyond the KAPSLM PES pilot project.

3.2.5. KAPSLMP PES project incentives

The PES-farmers were incentivized by an agreed compensation of 30% of the total cost of implementing the recommended SLM technologies in their farms. Structural measures had a relative high cost of implementation estimated at KES 100 per meter. Non-structural measures costs varied between KES 5 for grass strips and KES 30 for planting different types of trees (Table 3.3).

Table 3.3: Estimation of SLMP costs and PES Incentives

SLM Technology	Estimated actual costs (100%)	PES Incentives (30%)
Fanya Juu Terraces	KES 100 per meter of terrace constructed	KES 30 per meter of terrace constructed
Drainage Channels	KES 100 per meter of drainage channel constructed	KES 30 per meter of drainage channel constructed
Retention Ditches	KES 100 per meter of retention ditch constructed	KES 30 per meter of retention ditch constructed
Cut off Drains	KES 100 per meter of cut off drains constructed	KES 30 per meter of cut off drains constructed
Grass strips	KES 5 per meter of grass strip implemented	KES 1.5 per meter of grass strip implemented
Nappier splits	KES 5 per split planted	KES 1.5 per split planted
Vetiver splits	KES 10 per split planted	KES 3 per split planted
Forest/fodder/fruit trees	KES 30 per tree planted	KES 9 per tree planted

3.3. Study area selection

This study was focused in monitoring individual farmer's progress in the pilot project while correlating the progress to the delivered ecosystem services i.e. effect of SLM adoption to water quality improvement. It was difficult to follow the progress of all participating farmers in the PES project scheme (1,017 farmers) given the resources available and time factor. In this case, this study identified a representative watershed (headwater sub-watershed) considered a hotspot area in Kiburu micro-catchment, Kikuyu village. This is referred to as study micro-catchment in this study. It has very steep lands, slopes ranging between $28^0$and 36^0, the major soils being Nitisols. The study micro-catchment has two rivers emerging from the forest boundaries and merging at a common outlet point (Figure 3.3). This outlet point acted as a reference (monitoring) point for monitoring the water quality changes as new SLM technologies were being adopted by approximately 41 farmers (participating in PES scheme) out of a total of 67 farmers located in the study site. The choice of a study micro-catchment allowed deeper analyses on the effectiveness of PES approach in delivering the desired ecosystem services at a level feasible to monitor progress of individual farmers.

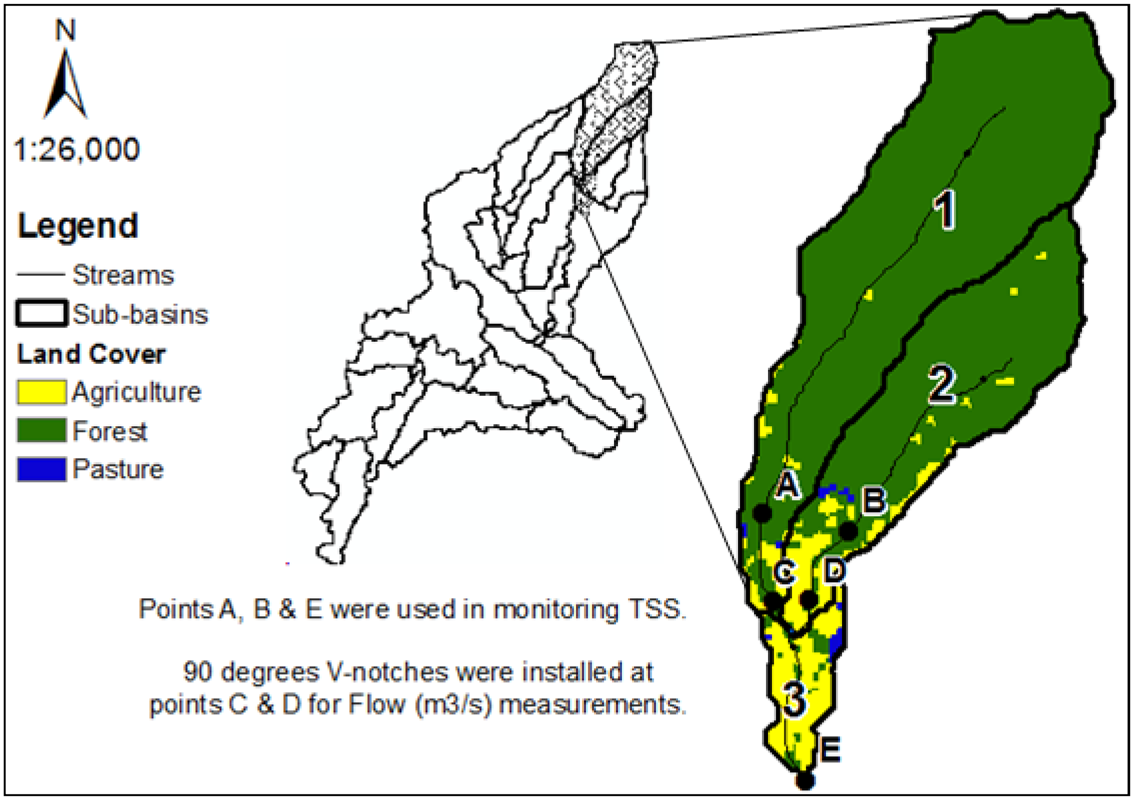

Figure 3.3: The study micro-catchment (source: author, 2016)

The choice of a headwater sub-watershed ensured minimal upstream effects to the study results as there was negligible human interference in the forested areas. The headwater watershed is covered by both forested area (87.6%) and agricultural area (11.7%). This also allowed studying into details the changes in sediments loads as water flowed from the forested area through the agricultural area to the outlet point during rainy periods. Small diversions were excavated to divert runoff water from rural roads to drain beyond the outlet point. This maximized capturing of runoff water generated from agricultural lands within the study site boundaries. The headwater watershed has three sub-basins covering a total area of 6.08 km^2 (Figure 3.2).

3.4. Establishing baseline of the study:

In the study micro-catchment, baseline data on both SLM status and Total suspended solids (TSS) was established before the onset of PES pilot project to represent status under ‘conventional’ approach. This was carried out between March-May 2015. In the larger Sasumua catchment, baseline data on water quality was extracted from existing literature.

3.4.1. Establishing SLMP baseline status

The study utilised checklists to profile farms located within the study micro-catchment. Farm profiling studied household heads – age and education level and the status of SLM technologies adoption. Status of SLM adoption included; meters of grass filter strips planted, meters of terraces constructed, meters of protected riparian strip where applicable, and number of trees (fodder, fruit forest) planted. Data collection focused on households which had voluntarily agreed to join PES pilot project. Data was collected from 41 households out of 67 households located in the study micro-catchment. The baseline on SLMP status was postulated as status under conventional approach, i.e. business as usual. *Assumption: Farmers would still be under these conditions today if no alternative approach was provided*. Each farmer’s LMP indicated the target SLM status for each farm. This presented a good opportunity to monitor the progress of SLM adoption during the study period and measure the effectiveness (i.e. how far the results have been achieved against the target).

3.4.2. Establishing water quality baseline status

Three points were selected for water quality assessment in the study micro-catchment; two points each from the respective stream at the boundary forest/agricultural land and at the point of convergence - outlet point (Figure 3.3). The baseline status on total suspended solids (TSS) was determined before the onset of KAPSLMP PES project. This was carried out in the wet season of March-May 2015 (MAM 2015). Water sampling was done 3 times a week (Monday, Wednesday and Friday) at 9:00am for a period of three months (March, April and May). The samples were tested for Total Suspended Solids (TSS) by photometric determination method using a Lovibond water quality testing kit (Tintometer Group, Bibi *et al*., 2011). The photometric method was also correlated with the conventional gravimetric method to determine the relationship.

The baseline status on water quality for the larger Sasumua watershed for the selected eight points (Figure 3.2) was established from literature particularly (Mwangi *et al*., 2014). The data selected were turbidity, and total dissolved solids (Table 3.4). These were once of measurements done in the wet season of March-May 2014 (Mwangi *et al*., 2014). The water samples collected in October-December 2015 and March-May 2016 were compared with the extracted baseline to work out variations using Box plot analysis.

In the larger Sasumua watershed, water samples were collected on a weekly basis at 9:00 am during October – December 2015 and March-May 2016. Water samples were tested for Total Suspended Solids, Total Dissolved Solids and turbidity using a Lovibond water quality testing kit. The water samples from the larger catchment were also subjected to Imhoff cone measurements to establish a relationship between the Imhoff and Total Suspended Solids. The results from the two wet seasons were compared with the extracted baseline to figure out any differences using Box plot analysis. The analysis was done using Instat Version 3.37 (University of Reading, 2017).

Table 3.4: Baseline data on Turbidity and Total Dissolved Solids for the larger Sasumua watershed – extracted from exiting literature (Mwangi *et al*., 2014)

Sample site	Total dissolved solids (TDS mg/l)	Turbidity (NTU)
Ming'utio River	51	509
Sasumua River at the Nairobi Bridge	21	38
Main Sasumua	54	50
Little Sasumua + Chania	21	46
Little Sasumua bridge to engineer	28	7
Ming'utio reservoir entry	28	39
Sasumua reservoir entry	27	69

The study by (Mwangi *et al*., 2012) observed that sediments are a major indicator of degradation of ecosystem services in Sasumua watershed.

3.5. Assessing effectiveness of SLM practices on soil fertility and water holding properties

During the baseline study on SLMP status, it was discovered that there were farms that had implemented SLM technologies (specifically *fanya juu* terraces) for the last 15 to 20 years. This presented a good opportunity to compare farms which have conserved the *fanya juu* terraces and those which have never installed conservation measures within the same period (Plate 3.2). Out of the 41 farms profiled, three farms which have conserved *fanya juu* terraces for the last 15-20 years and three farms with no conservation were identified and selected for the study.

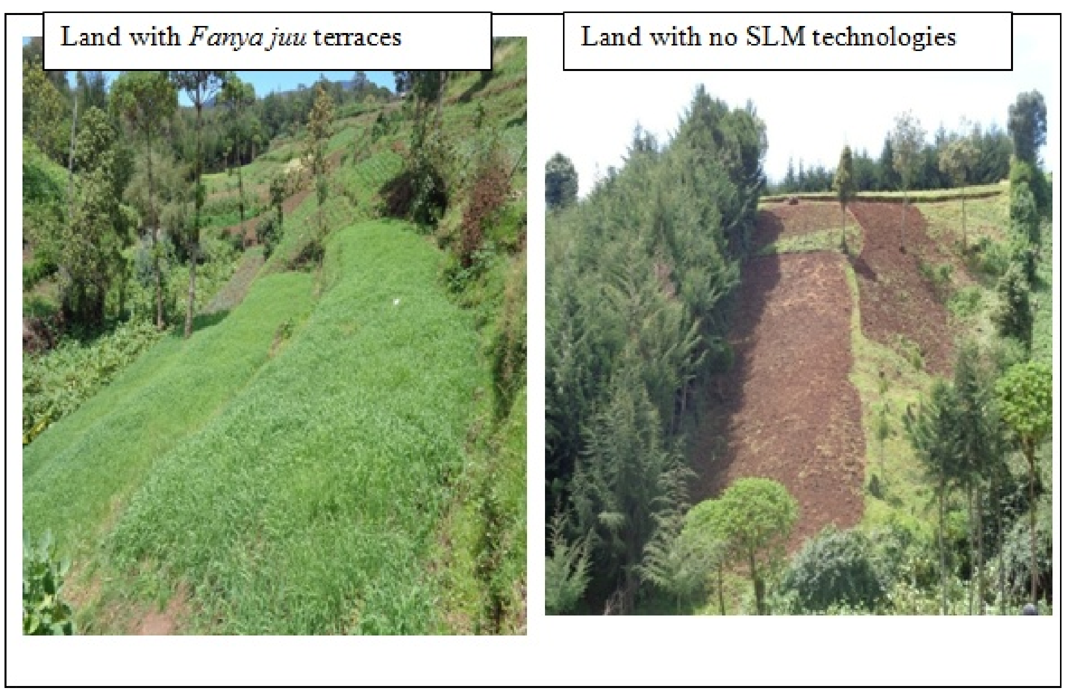

Plate 3.2: Examples of well conserved land versus poorly conserved land (source: author, 2016)

Soil sampling was required to assess fertility and water holding properties. Each farm of approximately one acre was divided into 3 slope sections; (top, middle and bottom) (Figure 3.4). Soil samples were collected from each slope section starting from the top section through to the bottom section. This was done in August 2015.

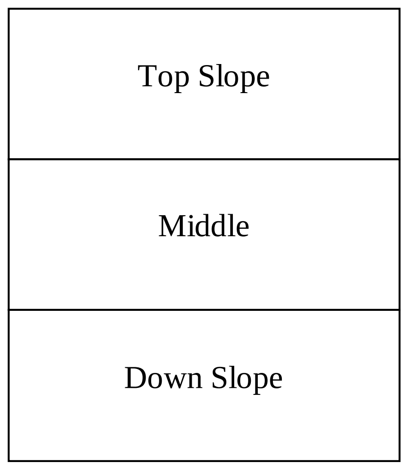

Figure 3.4: A sketch of the land subdivision into three slope sections

3.5.1. Soil sampling for soil fertility assessment

In each slope section, 20 samples were collected on a zigzag pattern for homogeneity (Nambiar & Wainer, 2011) using an auger to a depth of 15 cm and thoroughly mixed to get one representative sample (a grab sample) of a particular slope section. Therefore, 3 representative samples were collected from each farm for soil fertility assessment. The key parameters analyzed were; nitrogen (N), phosphorous (P), potassium (K), organic matter, organic carbon, CEC and soil pH.

3.5.2. Soil sampling for water holding properties assessment

Coring method was adopted (Taft & Jones, 2001) to a depth of 30 cm to collect one soil sample per slope section. A total of 3 soil samples were collected for assessing water holding properties of each farm. The key parameters studied were; water holding capacity (WHC), texture and Bulk density (BD).

3.5.3. Laboratory analysis

Soil fertility analysis was done at Jomo Kenyatta University of Agricultural and Technology. Assessment of water holding properties was carried at Kenya Agricultural & Livestock Research Organization (KARLO). Various laboratory procedures were adopted to analyze different parameters; Nitrogen (N) was analyzed through Micro-Kjeldahl method (Guebel *et al*., 1991). Olsen method (NaHCO3) (pH 8.5) was used for Available Phosphorous (Perez, 1995). Exchangeable Potassium (K) was analyzed through Ammonium Acetate (pH 7.0) method (Normandin *et al*., 1998). Walkley Black Method was used to analyze Organic carbon (Gelman *et al*., 2011). CEC was analyzed through Ammonium Acetate (pH 7.0) Extractant method (Normandin *et al*., 1998). Soil pH was analyzed through Calomel Electrode method (Torres *et al*., 1993). Texture was analyzed through Hydrometer method (Beretta *et al*., 2014). Soil moisture retention and bulk density were determined using standard procedures provided by (Hinga *et al*., 1980). The results from soil fertility assessment and soil and water characteristics were analysed in Microsoft Excel 2007. The results were further subjected to ANOVA analyses to assess significance differences between well conserved and poorly conserved farms.

3.6. Evaluating effectiveness of PES approach on SLMP adoption and water quality improvement

3.6.1. Effectiveness on SLMP adoption

After establishing the baseline on SLMP status, the next step was to monitor the progress in adoption of SLM technologies under the PES scheme. The PES farmers were to implement the SLM technologies according to individual LMPs. The target was to convert all PES farms from the baseline status into LMPs status (i.e. the ideal SLM status that would ensure minimum ecosystem degradation). To evaluate effectiveness on SLMP adoption, the observed SLM status in PES farms was measured against the target SLM status indicated in the LMPs. The average progress in PES farms was established by comparing cumulative progress against the target status as shown in equation 3.1.

$$\%progress = \frac{implementation}{target} X100$$ .... **(Equation 3.1)**

A comparison with farms under conventional approach was done by assessing SLM adoption changes if any on non-PES farms one year into the PES project implementation.

Households' visits were carried out after one year of PES implementation. This was carried out in August 2016. The checklists used during the SLMP baseline status were utilized to minimise data gaps. The visits were done in all the 41 PES farms within study micro-catchment to check and record the newly adopted SLMPs; meters of grass filter strips planted, meters of terraces constructed, meters of protected riparian strip where applicable, and number of trees (fodder, fruit forest) planted. Non-PES farms were randomly sampled to establish the changes in SLM technologies of farms under conventional approach after one year (the same period PES was implemented in PES farms). The study sampled 18 non-PES farms located outside study micro-catchment but within Kiburu micro-catchment. To establish effectiveness of PES approach on SLMPs, the analysis was done to compare conditions before and after PES and changes implemented between PES farms and non-PES farms.

3.6.2. Effectiveness on water quality improvement

After PES implementation for a period of one year, it was paramount to measure the water quality and compare with the baseline to deduce the difference if any as a result of the changes in SLMP adoption. Water sampling was carried out on a daily basis during the wet season of March-May 2016 (MAM 2016) from Monday to Friday at 9:00am. The samples were tested for Total Suspended Solids (TSS) by photometric determination method using a Lovibond water quality testing kit. But to assess effectiveness of any given approach, method or tool, the observed scenarios must be analysed against the target scenarios (ADC, 2009). Therefore, this study adopted Soil and Water Assessment Tool (SWAT) model to establish a model-system for plotting observed water quality results against the target scenario. The best and worst scenarios were generated using the SWAT model. The observed results were interpolated in between the SWAT predictions (Bracmort *et al.*, 2006) to analyse the effectiveness on water quality improvement. The modelling was done using ArcSWAT 2012 (Arnold *et al.*, 2012).

3.6.2.1. Description of SWAT Model Inputs

The most important SWAT model inputs include the digital elevation model (DEM), land use and land cover, soil information and weather data (Table 3.5).

Table 3.5: Model input data information

Data type	Source	Description
DEM	USGS website	30 m resolution, U.S. Geological Survey (USGS)
Soils	SOTER	Soil data was extracted from the Digital Soil and Terrain Database of East Africa (SOTER).
Land use	USGS website	Land cover maps were generated from 2016 landsat image obtained from USGS website using maximum likelihood method classification
Weather (1970-2014)	Weather records for three stations in the watershed; Agricultural training centre (9036152), South Kinangop forest station (9036164) and Sasumua dam station (9036188). Rainfall also obtained from weather station located at the Sasumua dam (between January and May 2016)	Minimum and maximum daily temperature, daily precipitation, relative humidity, solar and wind
Crop management	Field survey, (Mwangi et al., 2014)	Interviews with key informants and individual farmers on historical and current field crops and reviewing available literature.
Stream flow	Observed during March 18th – May 27th 2016 using 90^{o}C V-notch weirs	Daily stream flow (m3/s)
Water quality	Observed during the wet season of March – May 2016	Daily Total Suspended Solids (TSS)

Weather data between 1970 and 2014 was used in generating a weather generator data (WGN) for the study micro-catchment using WGNmaker4 (Boisrame, 2016). This was particularly important in coming up with long term mean and simulating the weather data that was not actually measured during the study period e.g. solar, wind and relative humidity. The rainfall observed during the study period was particularly important in providing the dates of weather input data that coincide with observed data (stream flow and TSS) used for calibration and validation.

3.6.2.2.Representation of SLM practices in SWAT

For this study, four sustainable land management practices were considered including; (a) terracing, (b) contouring, (c) filter strips and (d) strip cropping. These were based on key SLM practices being promoted by the PES pilot project in the Sasumua catchment.

A terrace is an embankment within the field constructed to intercept runoff and prevent erosion (Arnold *et al*., 2012). Terracing in SWAT is simulated by adjusting both the run-off and erosion parameters. The USLE practice (TERR-P) factor, the slope length (TERR_SL), and curve number (TERR_CN) are adjusted to simulate the effects of terracing (Arnold *et al*., 2012).

Contour planting is a practice of tilling and planting along the contour of the field as opposed to straight row. Contour planting is simulated by altering the curve number (CONT_CN) to account for increased surface storage and infiltration and USLE practice (CONT_P) factor to account for decreased erosion (Arnold *et al*., 2012).

A filter strip is a strip of dense vegetation located to intercept runoff from upslope sources and filter it. Filter strips are simulated by altering the ratio of field area to filter strip area (VFSRATIO), fraction of the HRU (VFSCON) which drains to the most concentrated 10% of filter strip, and fraction of the flow (VFSCH within the most concentrated 10% of the filter strip which is fully channelized (Arnold *et al*., 2012).

Strip cropping is the arrangement of bands of alternating crops within an agricultural field. Strip cropping is simulated by altering the Manning' N value for the overland flow (STRIP_N) to represent increased surface roughness in the direction of flow, curve number (STRIP_CN) to account for increased infiltration, USLE cropping (STRIP_C) factor to reflect the average value of the multiple crops within the field and USLE practice factor (STRIP_P) to represent strip cropping conditions (Arnold *et al*., 2012).

3.6.2.3. Model parameterization

For this study, data on status of key SLM practices played a key role in model parameterization. After one year of PES project, the status of SLM adoption had improved from 11% under conventional approach to 32% under an alternative approach (Table 3.6).

Table 3.6: Progress of SLM adoption by the 41 PES farmers in the study micro-catchment

	A	**B**	**C**	**D**	**E**	**F**
SLM Technology	**Baseline status**	**After 1 year**	**Target**	**Baseline status** $= A/C$	**Status after 1 year** $= B/C$	**Change** $= \frac{B-A}{C}$
Terrace (M)	821	1,561	8,819	9%	18%	8%
Retention ditch (M)	123	551	3,117	4%	18%	14%
Grass strip (M)	918	3,725	8,819	10%	42%	32%
Riverbank protection (M)	212	520	1,015	21%	51%	31%
No. of Napier splits	--	10,865	22,925	--	47%	--
No. of Forest trees	--	183	1,185	--	15%	--
No. of Fruit trees	--	1,095	1,145	--	96%	--
Average SLM adoption				**11%**	**32%**	**21%**

But there was a challenge interpreting the SLM practices into the SWAT model as the progress was mainly recorded in metres e.g. terraces had improved to 1561 metres, retention ditches to 551 metres, grass strips to 3725 metres etc. Since there is no way to enter the lengths (metres) in the model, a method adopted by (Gitau *et al*., 2004; Bracmort *et al.*, 2006) was used where the current condition of SLM practice was simulated based on condition scores (established at the time of study). In this study, the values of the four SLM practices considered (terracing, contouring, filter strips and strip cropping) were entered based on interpretation of the SLM status at the time of the study and what that means in the SWAT parameter ranges as guided by literature (Arnold *et al*., 2012). For instance, the 1561m of terraces means 18% towards the target status (Table 3.6). One of the parameters to consider is TERR-P to reflect reduced sediment losses. The P-factor ranges between 0-1 in SWAT model. A value of 0 means 100% reduction and a value of 1 denotes 0% reduction (Arnold *et al*., 2012). Therefore, a value of 0.82 was used (Table3.7) for P-factor when status of terraces in the study micro-catchment was recorded at 18% in the study micro-catchment. Other values considered during parameterization included the soil and crop management.

Table 3.7: Model parameterization based on SLM status after one year

Main SLM Technologies promoted under PES pilot project	Land Management selected for representation in SWAT	SLM status after one year	Adjusted Parameters in SWAT	Parameter ranges	Values used for base scenario (given the SLM status)
Fanya Juu terraces and retention ditches	Terraces	18%	TERR-P	0-1	0.82
			TERR-SL	0-100	82
			TERR-CN	20-100	85.6
Contour farming	Contour planting	27%	CONT_CN	20-100	78.4
			CONT_P	0-1	0.82
Grass strips	Filter strip	42%	VFSRATIO	0-300	174
			VFSCON	0.25-0.75	0.54
			VFSCH	0-100	58
			FILTERW	0-100	2.9
Planting of fruit/ fodder trees along the contour (deep rooted) and planting crops (shallow rooted) in between the strips	Strip cropping	41%	STRIP_N	0.001-0.5	0.3
			STRIP_CN	20-100	67.2
			STRIP_C	0-1	0.59
			STRIP_P	0-1	0.59

3.6.2.4. Sensitivity analysis, model calibration and validation

SWAT input parameters are process based and must be held within a realistic uncertainty range (Abbaspour, 2015). Parameters for sensitivity analysis were selected from literature and documentation from SWAT user manuals (Neitsch *et al*., 2002; Arnold *et al*., 2012). Firstly, the model was calibrated for flow before calibration of sediment parameters (Abbaspour, 2015). The flow data observed during the study period (observed between March 18, 2016 and May 27, 2016 - (Figure 3.3) was used in calibration of discharge. The daily TSS observed during the same period was converted to metric tons for calibration purposes. Model calibration was done automatically using SUFI12 principle in SWAT-CUP (Abbaspour, 2015) using parameters identified as sensitive to discharge and sediments as shown in Table 3.8.

Model calibration was considered satisfactory when the P-factor (percentage of the measured data bracketed by the 95PPU – 95% prediction uncertainty) was above 0.6 and when Nash-Sutcliffe efficiency (NS) (how well the plot of observed versus simulated data fits) was above 0.5 as recommended by (Bracmort *et al.* , 2006). There were no long term observed data to allow temporal validation (i.e. division of data into calibration period and validation periods). Spatial validation was adopted in this study (Santhi *et al*., 2008). This is where calibration is done using data from some selected sub-basins and another sub-basin within the study site is used as a check to validate the calibrated model. The TSS observed in sub-basins 1 and 2 were used in calibration and TSS observed in Sub-basin 3 was used in validating sediments simulation. The summation of discharges observed in sub-basins 1 and 2 was used as hypothetical discharge at sub-basin 3 for validation purposes. The assumption here is that the drainage area and topography would not cause a significant change in discharge due to small differences in catchment size between A and C and B and D (Figure 3.3). The distance between points A and C is approximately 356 meters and that between point B and D is approximately 286 meters.

Table 3.8: Model parameters considered for SWAT-CUP calibration

Parameter	Description	Minimum-maximum	Default values	Final calibrated values
Parameters sensitive to Discharge				
CN2.mgt	Initial SCS runoff curve number for moisture condition II	35 - 98	83	81.4
ALPHA_BF.gw	Base flow alpha factor (1/days)	0 - 1	0.048	0.6
GW_DELAY.gw	Ground water delay time (days)	0 - 500	31	19.9
GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O)	0 - 5000	1000	2809.3
ESCO.hru	Soil evaporation compensation factor	0 - 1	0.95	0.1
EPCO.hru	Plant uptake compensation factor	0 - 1	1	0.6
SOL_K.sol	Saturated hydraulic conductivity (mm/hr)	0 - 2000	65	252.7
SOL_AWC.sol	Available water capacity of the soil layer (mm H_2O/mm soil)	0 - 1	0.3	0.2
SLSUBBSN.hru	Average slope length (m)	10 - 150	60.98	74.8
CH_K2.rte	Effective hydraulic conductivity in main channel alluvium (mm/hr)	-0.01 - 500	0	27.9
OV_N.hru	Manning's N value overland flow	0.01 - 30	0.14	29.9
HRU_SLP.hru	Average slope steepness (m/m)	0 – 0.6	0.0766	0.5
Parameters sensitive to sediments				
SPEXP.bsn	Channel re-entrained exponent parameter	1 - 1.5	1	1.2
SPCON.bsn	Channel re-entrained linear parameter	0.0001 - 0.01	0.0001	0.00237
CH_EROD.rte	Channel erodability factor	0 - 1	0	0.2
CH_COV.rte	Channel cover factor	-0.001 - 1	0	0.6
USLE_P.mgt	Support practice factor	0 - 1	1	0.8

3.6.2.5. SWAT model simulations

SWAT model simulations were performed to assess the effectiveness of changes in SLM technologies to water quality downstream by specifically checking on the Total Suspended Solids (TSS) generated in two different scenarios (best and worst scenarios). The adjusted parameters (to reflect worst and best scenarios) were obtained from different tables provided by (Arnold *et al.*, 2012) and judgement based on observation and field experience. For instance, appropriate USLE practice factors for well terraced field based on field slope are given in Table 33-1 page 487 (Arnold *et al.*, 2012). Based on the slope of the study micro-catchment, the appropriate P-factor was selected as 0.18 as shown in Table 3.9. To represent worst scenario, the P-factor was adjusted to 1 which reflects increased sediment losses (Arnold *et al.*, 2012).

Table 3.9: Selected land management operations with their adjusted parameters to reflect best and worst scenarios in SWAT

Main SLM Technologies promoted under PES pilot project	Land Management selected for representation in SWAT	Adjusted Parameters in SWAT	Description	Parameter ranges	Adjusted to reflect Best scenario	Adjusted to reflect Worst scenario
Fanya Juu terraces and retention ditches	Terraces	TERR-P	To reflect reduced sediment losses	0-1	0.18	1
		TERR-SL	To represent the minimum distance between the terraces in meters	0-100	5	100
		TERR-CN	To account for increased	20-100	76	99

Main SLM Technologies promoted under PES pilot project	**Land Management selected for representation in SWAT**	**Adjusted Parameters in SWAT**	**Description**	**Parameter ranges**	**Adjusted to reflect Best scenario**	**Adjusted to reflect Worst scenario**
			infiltration			
Contour farming	Contour planting	CONT_CN	To account for increased surface storage and infiltration	20-100	76	99
		CONT_P	To account for decreased erosion	0-1	0.18	1
Grass strips	Filter strip	VFSRATIO	Ratio of field area to filter strip area	0-300	30	300
		VFSCON	Fraction of the HRU which drains to the most concentrated 10% of filter strip	0.25-0.75	0.75	0.25
		VFSCH	Fraction of the flow within the most concentrated 10% of the filter strip which is fully channelized	0-100	5	100
		FILTERW	To account for increasing trapping efficiency of the filter strip	0-100	5	0
Planting of fruit/fodder	Strip cropping	STRIP_N	To represent	0.001-0.5	0.5	0.001

Main SLM Technologies promoted under PES pilot project	Land Management selected for representation in SWAT	Adjusted Parameters in SWAT	Description	Parameter ranges	Adjusted to reflect Best scenario	Adjusted to reflect Worst scenario
trees along the contour (deep rooted) and planting crops (shallow rooted) in between the strips			increased surface roughness in the direction of flow			
		STRIP_CN	To account for increased infiltration	20-100	76	99
		STRIP_C	To reflect the average value of the multiple crops within the field	0-1	0.4	0.4
		STRIP_P	To account for decreased erosion	0-1	0.18	1

3.6.2.6.Description of scenarios

Scenario before PES-project (field observation): This scenario was determined from actual field measurements on TSS during the rainy season of March-May 2015. This was carried out before the onset of KAPSLMP PES project to represent conditions under conventional approach. The average TSS in the three month rainy season was determined to represent conditions before PES project.

Scenario after one year of PES project (field observation): This scenario was also determined from actual field measurements on TSS during March-May 2016 rainy season, one year after PES project implementation. The average TSS was determined to represent a scenario after one year of PES project implementation– improved conditions observed under PES scheme.

Best scenario (SWAT generated): This scenario was determined by adjusting SWAT parameters as shown in Table 3.9 for selected SLM technologies to their best considered status guided by literature (Arnold *et al*., 2012) at which they are assumed to be highly effective in improving water quality downstream. All SWAT parameters are within certain ranges e.g. TERR-P ranges between 0-1. A value approaching 1 reflects increased soil loss and a value approaching 0 reflects reduced soil loss (Arnold *et al*., 2012). Other parameters adjusted are as shown in Table 3.9.

Worst scenario (SWAT generated): This is where expert judgement played a key role based on observation and field experience which was further supported by interpretation of parameter ranges from literature (Arnold *et al*., 2012). This scenario was represented by adjusting the SWAT parameters to their worst considered status when the modelled SLM practices are assumed to be in poor state and not effective in improving water quality downstream. Table 3.9 shows selected SLM practices modelled in SWAT and the adjusted parameters.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This section is divided into two sub-sections. Sub- section 4.1 discusses general findings observed in the larger Sasumua watershed. Sub-section 4.2 is the core part of this study. It discusses in detail the findings observed in the study micro-catchment to give a synopsis of what is happening under KAPSLMP PES project. This is vital as the findings in representative watershed (the focus of this study) are used to describe the effectiveness of PES approach in delivery of desired ecosystem services in the Sasumua watershed.

4.1. Findings in the larger Sasumua watershed

4.1.1. Status of SLM adoption after one year in the larger Sasumua watershed

In April 2016, an evaluation on the progress made by the KAPSLMP project was carried out. Purposive random sampling was carried out. 20% of PES farmers (203 farmers out of possible 1,017) in all the four micro-catchments were randomly sampled. The average progress was established by comparing cumulative progress against the target status as shown in equation 3.1.

The average progress in SLM adoption for the sampled PES farmers after one year was established at 45.5% of the target SLM status (Figure 4.1). This is the cumulative progress against the target status as recorded in the LMPs of the sampled PES farms. In general, grass strips and terraces achieved the highest achievement with 59.9% and 56.5% respectively. This is because, farmers concentrated on those SLMs that attracted more costs to justify higher shares of the PES incentives.

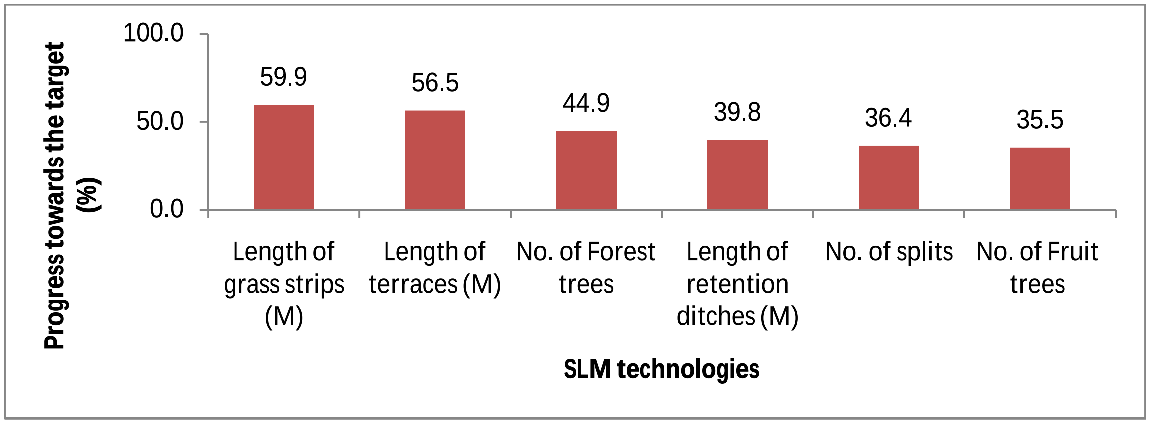

Figure 4.1: Progress towards the target set by the LMPs for the sampled PES farms in the larger Sasumua catchment

Cross tabulation on adoption of SLM practices against age and education of PES farmers produced interesting results as shown in Table 4.1. In the conditional formatted table, the colour green represents extreme positive adoption changes while colour red represents low adoption changes. Interestingly, the most active farmers are above 40 years where more adoption changes were observed, particularly those between 40 and 50. Those farmers between ages of 40 and 50 years and have attained college and/or university education are seen to perform relatively better. Such farmers ought to be studied and mapped in establishment of demo plots and when surveying for farmer who can act as lead farmers to the community in the watershed.

Table 4.1: Analysis of newly adopted SLMPs against age and education levels

	Structural measures				Non- Structural measures			
Row Labels	Average length of Terraces (m)	Average length of Retention ditches (m)	Average length of Drainage channels (m)	Average length of COD (m)	Average length of Grass strips (m)	Average length of Riverbank protection (m)	Average number of Fruit trees	Average number of Forest trees
Below 30 years	35	7	0	0	60	0	6	10
Primary	0	0	0	0	30	0	0	0
Secondary	31	7	0	0	60	0	10	17
College	80	15	0	0	90	0	0	0
30 - 40 years	38	58	60	5	75	0	21	43
Primary	14	38	30	10	31	0	26	-1
Secondary	28	95	108	0	153	0	12	59
College	180	0	0	0	-38	0	32	176
40 - 50 years	60	65	99	5	52	0	33	-47
No formal education	0	274	0	0	-25	0	8	37
Primary	7	63	25	10	17	0	6	10
Secondary	-45	47	111	3	68	0	64	-129
College	1300	14	633	0	20	0	24	77
University	0	402	0	-30	550	0	0	60
Other	-100	85	0	0	100	0	6	0
50 - 60 years	-19	66	105	6	108	0	41	143
No formal education	0	0	245	0	325	0	20	60
Primary	-54	111	109	0	110	0	38	12
Secondary	-4	15	96	15	51	0	43	261
College	104	67	70	0	254	0	61	386
More than 60 years	17	54	46	2	114	0	28	124
No formal education	0	25	87	0	17	0	18	340
Primary	3	70	42	0	121	0	22	127
Secondary	81	35	-9	11	146	0	41	-20
College	0	0	185	0	177	0	100	25

Key	
(dark green)	High adoption
(light green)	Medium adoption
(yellow)	Low adoption
(orange)	Very low adoption
(red)	No adoption at all/reduction

Education is a key factor for general success in adoption of SLM technologies (Whitten *et al.*, 2007; Temu, 2013). By and large, majority of farmers who implement SLM technologies through their own initiatives are the most educated in the society (Stanley *et al.*, 2006). Majority of young farmers below 30 years were found to be underperforming. This is not surprising; several studies have observed that youths are not active in agricultural fields (FAO, 2014; Paisley, 2014). According to (Estrada *et al*., 2009), PES is one unique scheme that can promote rural development through ecosystem conservation but this requires broader investigation to understand all the derived socio-economic benefits of land use/management changes at different scales. To realise this, there is need for a detailed study on youth and ecosystem conservation in order to inform strategies of engaging youths in PES projects.

4.1.2. Comparison of SLM technologies before and after PES project

There were positive changes in sustainable land management practices after implementation of payment for ecosystem services project compared to the period before inception of PES in Sasumua catchment. There was a significant increase in the length of grass strips planted by farmers upon implementation of PES program ($p<0.001$) (Table 4.2). This was also noted on number of fruit trees planted ($p<0.001$). The length of drainage channels increased significantly after implementation of PES program ($p<0.001$). Retention ditches had increased eight fold between inception of PES and its implementation. These findings conquer with past research where it has been found that PES motivates farmers to increase the adoption of SLM technologies (Lipper & Neves, 2011; Kwayu *et al*., 2013).

Table 4.2: Comparisons of sustainable management practices before and after PES program implementation in the larger Sasumua watershed

SLM status per farm	Mean		N	Sig. (2-tailed)
	Before	After		
Number of Forest trees	755.00	823.00	184	0.077
Length of Terraces (m)	111.84	132.09	187	0.422
Length of Grass strip (m)	58.75	140.39	181	<0.001
Number of Fruit trees	13.00	46.00	180	<0.001
Length of Drainage channel (m)	11.50	92.25	187	<0.001
Length of Retention ditch (m)	7.09	56.18	177	<0.001
Length of COD (m)	0.16	3.86	190	0.043
Length of Riverbank protection (m)	0.05	0.06	192	0.319

4.1.3. Baseline and observed changes on water quality

The baseline status on water quality for the larger Sasumua watershed was extracted from existing literature. Data from a study conducted by (Mwangi *et al*., 2014) in assessing water quality status in the larger Sasumua watershed was adopted as a baseline data on water quality for the entire watershed. Similar gauging stations studied by (Mwangi *et al*., 2014) were used in this study. This was particularly important for Box plot analysis.

4.1.3.1. Turbidity analysis

The baseline data retrieved from the available literature is comparatively short (Figure 4.2). This shows, the overall measurements had a high level agreement (ranging between 9 NTU and 69 NTU), hence less variable. During the wet season of Oct-Dec 2015, there was some relatively slight variations (22.3 NTU and 139.2 NTU) giving a comparatively elevated Box plot (Figure 4.2). The overall observation is that the turbidity measurements fall below 100NTU in Sasumua watershed.

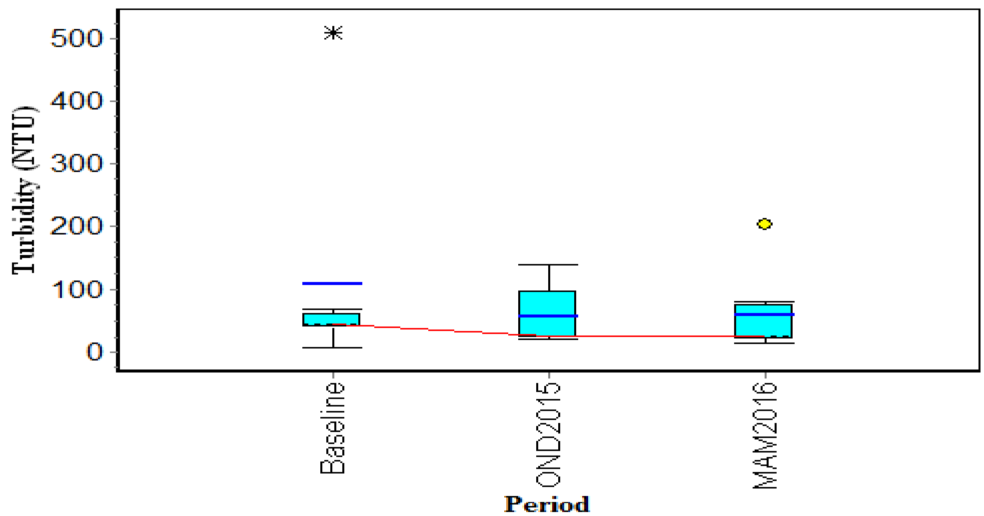

Figure 4.2: Box plot analysis on turbidity for the 8 downstream points

The outliers especially during the baseline indicate variation in one of the monitoring points - Ming'utio river, which could result due to high erosion in some areas within the watershed. Figure 4.3 shows that Ming'utio river had the highest variation which resulted to skewing of distribution. (More information is as shown in appendix 1).

	MAM 2014	OND 2015		MAM 2016	
Turbidity (NTU)	Baseline Mean	Mean(n=12)	SD	Mean (n=12)	SD
Engineer Bridge	7	25.3	17	21.3	20.5
Nairobi Bridge	38	28.7	24.7	25.5	16.2
Little Sasumua	46	23.3	15.4	20.9	16.4
Main Sasumua	50	23.6	16.3	28.1	22.3
Mingutio river	509	125.9	63.9	202.9	129.6
Mingutio entry	39	139.2	114.1	75.2	34.8
Middle Entry		72.4	55.8	81.2	70.9
Sasumua Entry	69	22.3	15.4	13.9	4.1

Figure 4.3: Turbidity data bars for the 8 downstream points – Once off measurement in MAM 2014 and season averages in OND 2015 and MAM 2016

4.1.3.2. Total dissolved solids

One key observation in total dissolved solids (TDS) is that the Box plots are in different positions suggesting differences between the three periods (Figure 4.4). Even though, the observation is for one year after PES project, the Box plot analysis for TDS indicates some stability in MAM2016 as the Box plot is comparatively shorter.

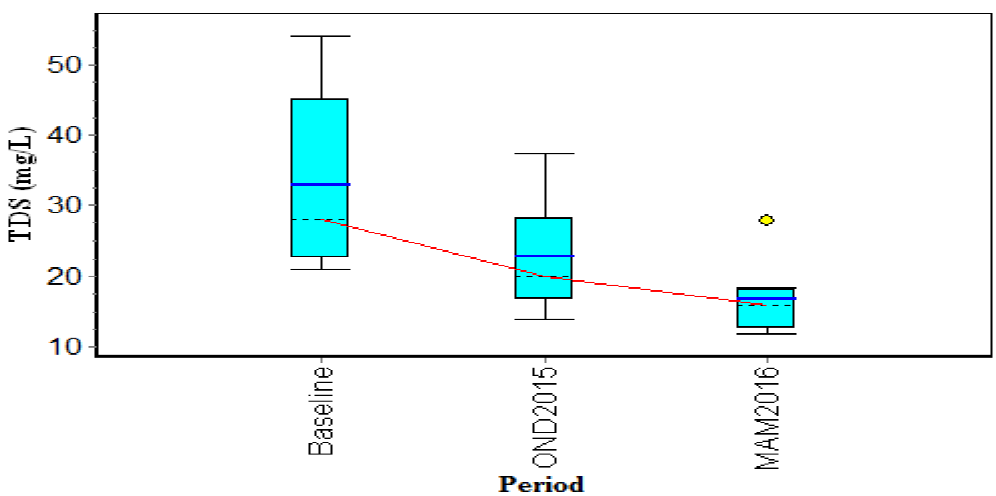

Figure 4.4: Box plot analysis on TDS for the 8 downstream points

The baseline data shows comparatively high variations as indicated by an elevated box plot ranging between 21 mg/L to 54 mg/L. In OND2015, the variations are moderate (13.9mg/L to 37.3 mg/L) and a shorter Box plot is observed in MAM2016 (11.8 mg/L to 27.9 mg/L). The TDS data bars indicate that Ming'utio river is one of the critical points that signals relatively high soil erosion as shown in Figure 4.5.

	MAM 2014	OND 2015		MAM 2016	
TDS (mg/L)	Baseline Mean	Mean(n=12)	SD	Mean (n=12)	SD
Engineer Bridge	28	15.2	8.8	12.3	8.4
Nairobi Bridge	21	18.2	10.4	13.1	9.1
Little Sasumua	21	13.9	8.5	11.8	8.1
Main Sasumua	54	19.8	9.1	18.2	10.1
Mingutio river	51	32	15.8	27.9	14.3
Mingutio entry	28	37.3	34.4	18.1	5.7
Middle Entry		25	13.2	18.2	7.4
Sasumua Entry	27	20	12	13.8	6.1

Figure 4.5: TDS data bars for the 8 downstream points – Once off measurement in MAM 2014 and season averages in OND 2015 and MAM 2016

4.1.3.3. Totals suspended solids and Imhoff readings

There was no baseline data for TSS and Imhoff readings for the larger Sasumua watershed. However, the two wet periods are comparatively different as the Box plot for OND2015 is comparatively elevated ranging between 14.3 mg/L to 194.6 mg/L for TSS and 0.4 ml/L to 1.1 ml/L for settleable solids as shown in Figure 4.6. This could indicate an improvement from high variations to stable conditions but long term data would be paramount to confirm the observation. Since most of the SLM technologies were being implemented between June and August 2015, the higher variations of TSS and Imhoff readings in the OND 2015 could indicate a system disturbance resulting to high soil sediments.

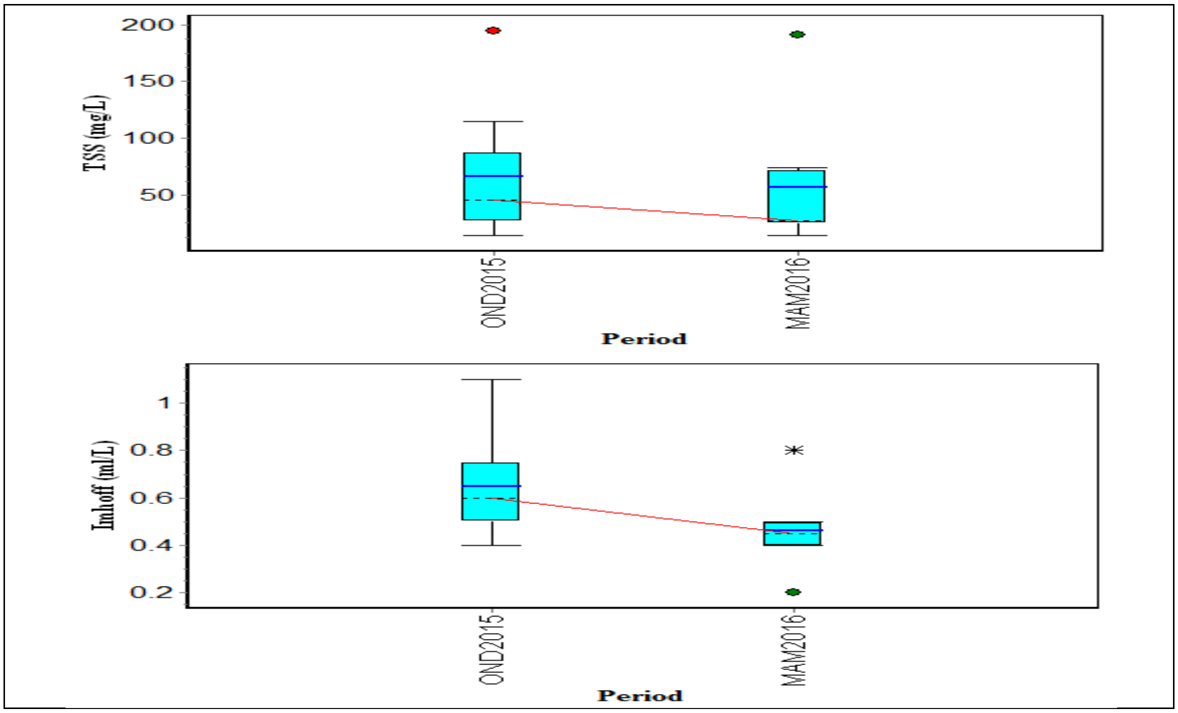

Figure 4.6: Box plot analysis for TSS and Imhoff readings for the 8 downstream points

Again the data bar distribution for TSS indicates Ming'utio river is a major concern with high variations recorded in both wet seasons (Figure 4.7).

TSS (mg/L)	Mean (n=12)	SD	Mean (n=12)	SD
Engineer Bridge	43.6	29.3	24.8	24.4
Nairobi Bridge	30.7	21.5	25.9	17.3
Little Sasumua	24.6	18.7	25.1	19.6
Main Sasumua	47	24.6	29.5	22.9
Mingutio river	194.6	118.1	190.9	130.2
Mingutio entry	114.6	81	73.7	31.9
Middle Entry	61.9	41.3	70.2	62.6
Sasumua Entry	14.3	7.6	14.3	5.7
	OND 2015		MAM 2016	
Imhoff (ml/L)	Mean (n=12)	SD	Mean (n=12)	SD
Engineer Bridge	0.5	0.6	0.5	0.7
Nairobi Bridge	0.5	0.5	0.4	0.5
Little Sasumua	0.5	0.4	0.4	0.3
Main Sasumua	0.7	0.7	0.5	0.7
Mingutio river	1.1	1.2	0.8	1.1
Mingutio entry	0.7	0.9	0.4	0.6
Middle Entry	0.4	0.2	0.2	0.2
Sasumua Entry	0.8	0.9	0.5	0.8

Figure 4.7: Data bar for TSS and Imhoff readings for the 8 downstream points – Season averages in OND 2015 and MAM 2016

4.1.3.4. The relationship between settleable solids and total suspended solids (TSS)

TSS is a gravimetric determination of suspended particles in water (mg/L). Imhoff is a volumetric determination of settleable particles in water (ml/L) (Ellis *et al*., 2004; Scholes *et al*., 2008). Therefore, Imhoff cones can be a measure of heavier particles in water that is no longer suspended and settles to a certain volume (ml) in the cone an indicator of intensity of erosion taking place carrying heavy particles. The Pearson correlation was performed to establish the strength of the linear relationship between TSS and Imhoff readings. The correlation is moderate with an r factor of 0.5 suggesting a positive association between ml/L and mg/L. The coefficient of determination shows a weak linear association between TSS and settleable solids (r^2 = 0.24) (Figure 4.8). This study establishes that only 24% of total variation in TSS can be explained by the linear relationship between TSS and settleable solids. However, it is paramount to point out that, the scale used in the Imhoff cone of this study does not allow measurement of data in more than one decimal place. For more comprehensive science based interpretation, more research is needed using Imhoff cones that allow more than one decimal places. There were a lot of estimations during reading perhaps one of the possible reasons of a weak correlation between TSS and settleable solids as shown in Figure 4.8. The key observation was that for most of Imhoff readings ranging between 0 and 0.3 ml/L, the TSS measurements were recorded between 0 and 350 mg/L.

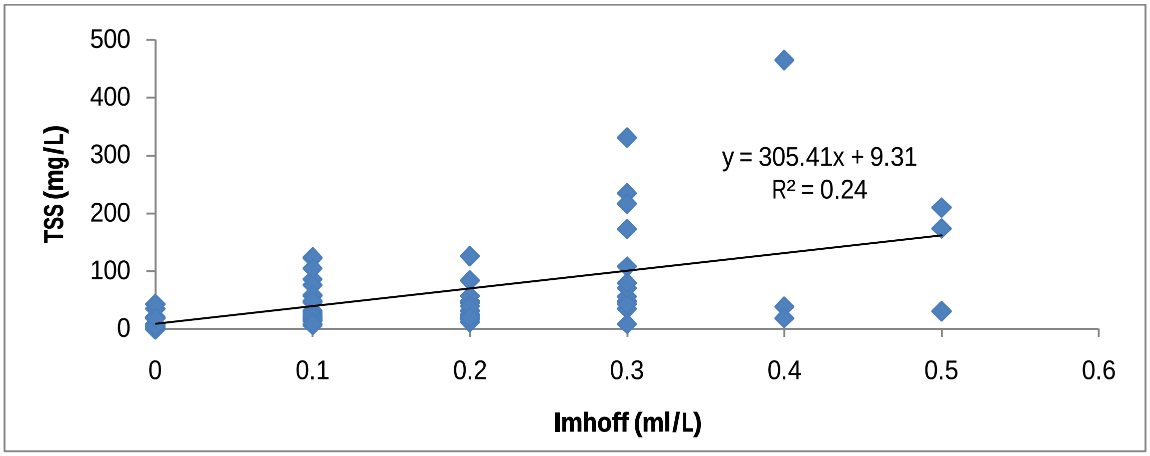

Figure 4.8: Pearson correlation between the settleable solids and TSS

4.1.3.5. The relationship between lovibond TSS and gravimetric TSS

The relationship is linear (Figure 4.9). Generally, the Lovibond reads a relatively higher reading from that of gravimetric method with an average factor of 1.12. This means if gravimetric method reads (X), the Lovibond reading can be estimated at (1.12X). Information on relationship between the two is limited or undocumented in the literature. Nevertheless, (Orbeco, 2011) reported that photometric determination of suspended solids is based on a gravimetric method. When higher accuracy is required, a gravimetric determination of a water sample can be performed and the result can be used to calibrate the photometer with the same water sample.

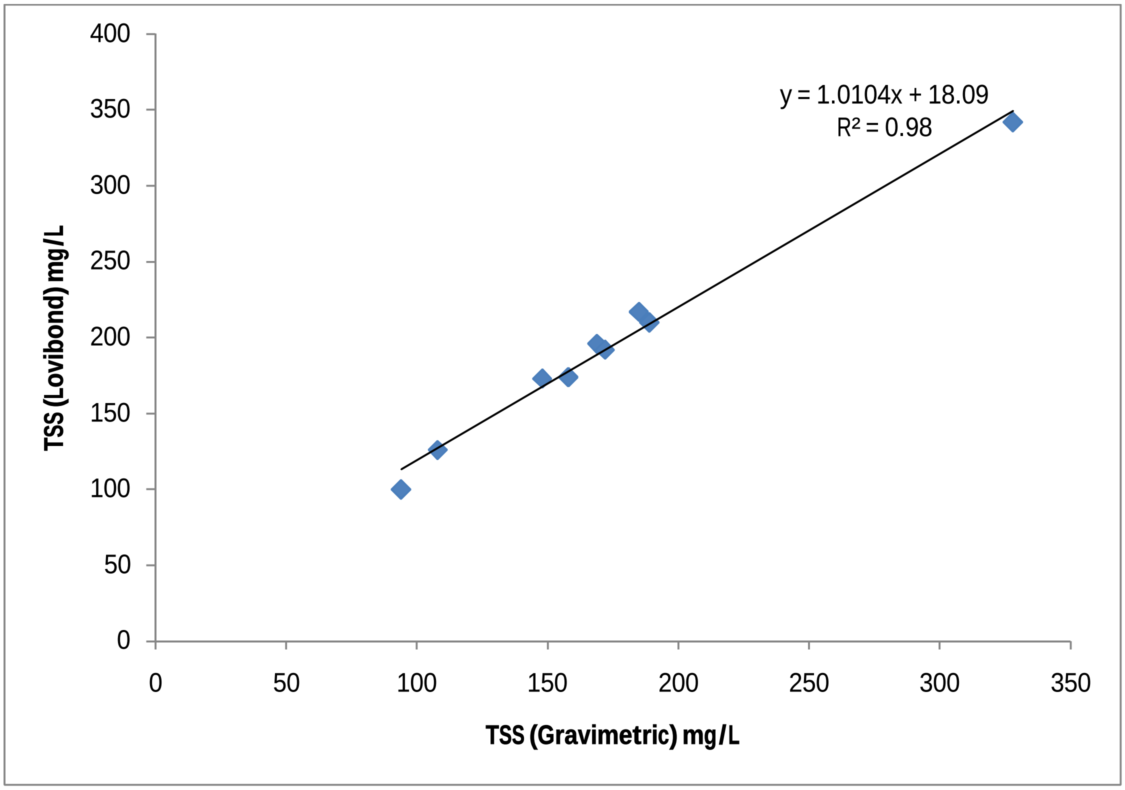

Figure 4.9: Pearson correlation between Lovibond TSS and gravimetric TSS

4.2. Findings in the study micro-catchment

4.2.1. Baseline and observed changes on SLM adoption

Key SLM practices (terraces, retention ditches, grass filter strips and riverbank protection) were used in estimating the baseline of SLM adoption in the study site as they were easily measurable during the baseline and in subsequent periods. The baseline SLM status in PES farms (under conventional approach) before the onset of KAPSLMP PES project was established to be 11% of the target status in June 2015 (Table 3.6). This indicates a very low SLM adoption in the study site. Generally studies have shown that SLM adoption in Kenya through conventional approaches is very low (World Bank, 2008; Shiferaw *et al*., 2009; Branca *et al*., 2011; Liniger *et al*., 2011; Jairo, 2013; Tanui *et al*., 2014; Kihiu, 2016; Mulinge *et al*., 2016).

Farmers were required to utilize individual Land Management Plans (LMPs) to implement SLM technologies on their farms. The PES project encouraged adoption of sustainable land management practices in the watershed and SLM status improved (under alternative approach) to 32% of the target status after one year. What was observed is that the project progress was highly impactful on SLM practices that were perceived to be beneficial especially in contributing to farm income e.g. planting of fruit trees (Figure 4.10). (Pender, 2008; Kernecker *et al*., 2017) reported that, high level of compliance is mainly observed on SLM technologies that are easy to implement and have potential of increasing farm income. Low implementation is observed on activities involving intensive labour such as construction of terraces, retention ditches etc. This conforms to the results in this study as shown in Figure 4.10.

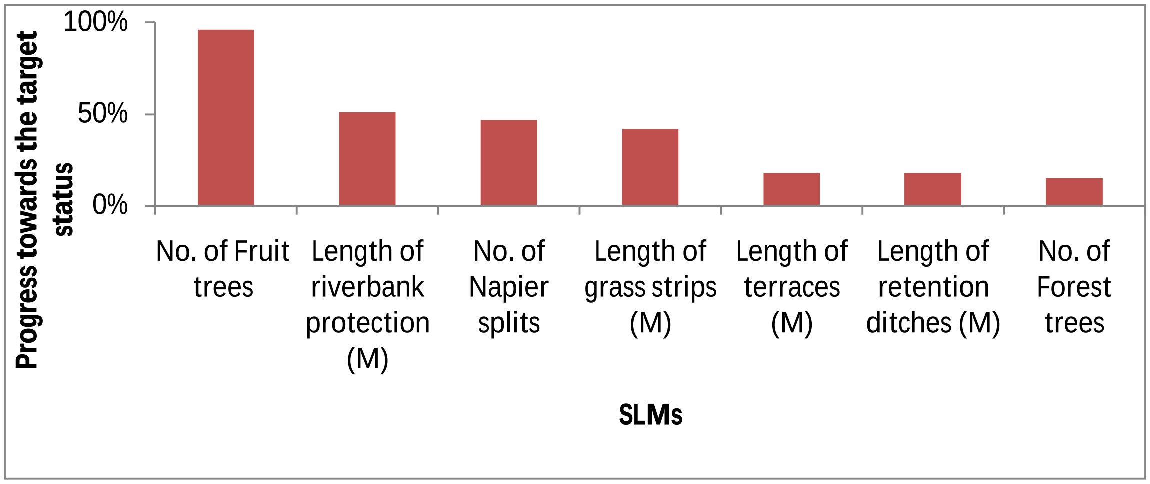

Figure 4.10: SLM progress after one year of PES implementation in the study micro-catchment

4.2.2. Comparison of SLMP changes between PES farms and non-PES farms

There was a significant change in increase in length of terraces in PES farms (p=0.007) after one year (Table 4.3). Length of retention ditches, drainage channels, and riverbank protection had relatively increased in PES farms, an indication that PES as an alternative approach had resulted in positive changes towards SLMP adoption. Grass strips significantly increased in PES farms (p=0.004) than in Non-PES farms. There were more number of fruits and forest trees planted in PES farms though the differences were not significant (p= 0.369 and p=0.369 respectively) (Table 4.3). Significant changes observed in terraces and grass strips could be attributed to the model of PES payments in Sasumua. Incentives were based on total cost of implementing the SLM technologies. A

Fanya juu terrace was one of the costly technologies, thereby attracting more payments. There are also other factors that contribute to significance changes in some of the SLM technologies. A study by (Miheretu & Yimer, 2017) reported that factors that positively and significantly affect adoption of land management practices include; education, family size, slope of the plot, tenure security, training, access to farm credit and extension service provision. PES project introduced new ways of implementing the SLM technologies in the study site. Regular field checks by the SLM experts lead to significant changes in some of the SLM technologies. There is strong evidence that PES farmers had installed more changes in their farms as compared to Non-PES farmers. This finding conquers with past studies where PES approach has been proven to increase adoption of SLM technologies (Pagiola, 2008; Porras *et al*., 2013).

Table 4.3: Independent means comparison of SLMPs changes in PES and Non-PES farms after one year

	Mean (per acre)			
SLM status per farm	**PES Farms**	**Non-PES farms**	**t-value**	**Sig. (2-tailed)**
Length of Terraces (M)	78.3	0.0	2.810**	0.007
Length of Retention ditches (M)	43.1	0.0	1.800	0.077
Length of Drainage channels (M)	2.5	1.7	0.300	0.768
Length of Grass strips (M)	158.5	12.2	2.990**	0.004
Length of Riverbank protection (M)	0.1	0.1	0.070	0.946
No. of Fruit trees	12.1	4.0	0.910	0.369
No. of Forest trees	85.3	25.6	0.860	0.396

****. Means are significantly different at 0.01**

4.2.2.1. Some of the SLM technologies implemented in the PES farms

The grass strips were expected to grow to an effective width of more than 1 meter for significant filtering of sediments to occur (Schmitt *et al*., 1999; Humberto *et al*., 2006). This is a long term manifestation expected to be observed from the second/third year of KAPSLMP PES project (Plate 4.1).

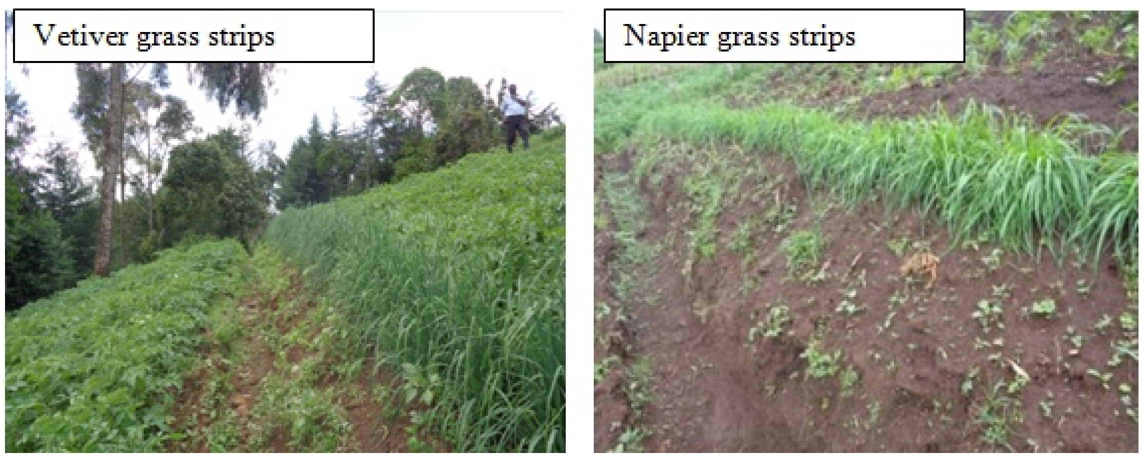

Plate 4.1: Newly established grass strips by PES farmers (source: author, 2016)

Some farmers were also observed to establish trash lines on their farms (Plate 4.2). This was particularly observed in areas where Napier grass (one of the recommended grass strips) was not doing well. In this study, the trash lines were considered as part of metres of grass strips implemented when recording the progress made by individual farmers.

Plate 4.2: Newly established Trash lines by PES farmers (source: author, 2016)

Retention ditches were observed to effectively capture run-off from important sediment sources such as rural rough roads that would have otherwise been detrimental to the sloping farms leading to proliferated quantity of sediments transported to the nearby streams. Instead, retention ditches allowed the runoff to infiltrate in the soil (Plate 4.3).

Plate 4.3: A retention ditch (capturing water from rural rough roads) (source: author, 2016)

4.2.3. Baseline and observed changes on water quality

Water samples were collected in the rainy season of March-May 2015 (MAM 2015) just before the onset of PES project to establish baseline status. Water samples were also collected after one year in March-May 2016 (MAM 2016). The average of each of the wet season was calculated to represent; (a) the baseline and (b) the observations after one year. To perform a solid comparison of the results in the two seasons, it was paramount to analyse the rainfall patterns of the two seasons to infer any differences or similarities. Rainfall is the major driving factor in water related soil erosion (Jiao *et al.*, 2002).

The total rainfall of MAM 2016 was relatively higher at 912.6mm against 811.7mm recorded in MAM 2015 (Table 4.4). There were 46 rain days in MAM 2015 and 58 rain days in MAM 2016. The means of the rain days in MAM 2015 and MAM 2016 were not significantly different (p=*0.538)* at significant level of 0.05 (Table 4.5).

Table 4.4: Rainfall characteristics for MAM 2015 and MAM 2016

Seasonal Totals		**MAM 2015 (mm)**	**MAM 2016 (mm)**
		811.700	912.600
Monthly Totals		MAM 2015 (mm)	MAM 2016 (mm)
	March	93.800	52.600
	April	384.100	412.100
	May	333.800	447.900
		MAM 2015 (mm)	MAM 2016 (mm)
Number of rain Days		46	58
Average (mm) per rain day		17.650	15.730
Number of rainfall days exceeding 30mm per day		7	8

Table 4.5: Test for significant differences for Rainfall in MAM 2015 and MAM 2016

t-Test: Two-Sample Assuming Equal Variances	MAM 2015	MAM 2016
Mean	17.645	15.734
Variance	234.901	253.621
Observations	46	58
Pooled Variance	245.362	
Hypothesized Mean Difference	0	
df	102	
t Stat	0.617	
P(T<=t) one-tail	0.268	
t Critical one-tail	1.659	
P(T<=t) two-tail	0.538	
t Critical two-tail	1.983	

The two wet seasons were not signifcantly different. This means the changes observed in SLM adoption cannot be attributed to the differences in rainfall but to the changes brought about by the PES project. However, it is important to mention that, the differences in individual rainfall invents were not recorded in this study which may also cause a difference.

Points A and B (Figure 3.3) were at the boundaries of forest land and agricultural land. Point E was the main Outlet point. Human influence in the forested lands was minimal and the observations at points A and B were treated as ‘nature contribution’. Since most of the intensive agriculture was happening below points A and B towards point E, this study used the TSS results of point E to interpret the effectiveness of PES scheme as an alternative approach on water quality improvement.

The average TSS at point A was 48.52 mg/L and 47.39 mg/L in MAM 2015 and MAM 2016 respectively. Point B recorded an average TSS of 46.31 mg/L and 44.12 mg/L in MAM 2015 and MAM 2016 respectively. The means of both points A and B were not significantly different (Table 4.6). At the main outlet point, the observed baseline status for Total Suspended Solids (TSS) was an average of 71.05mg/L in MAM 2015. The TSS significantly (p=*0.00022)* reduced to an average of 42.73mg/L in MAM 2016. From Figure 4.12, it is observable that TSS at the outlet reduced to almost what the nature was contributing i.e. TSS values from undisturbed ecosystems - the forests. This was attributed to the alternative approach provided in watershed management. Studies have reported improvement in water quality after implementation of PES projects (Pagiola, 2008; Porras *et al*., 2013). PES project ensures that the SLM technologies are implemented according to the reccomended standards (Porras *et al*., 2012; Le Velly & Dutilly, 2016). For instance a fanya juu terraces that attracted PES payment in Sasumua, was the one that specifically measured 2 feet wide by 2 feet deep and not in any other measurement. This encourage PES farmers to implement the SLM technologies according to specifications provided in the LMPs.

Table 4.6: Test for significant differences for TSS (MAM 2015 and MAM 2016)

	Mean			
	MAM 2015 (mg/L)	**MAM 2016 (mg/L)**	**t-value**	**Sig. (2-tailed)**
TSS (Forest boundary A)	48.51	46.06	0.128	0.898
TSS (Forest boundary B)	46.31	42.87	0.302	0.763
TSS (Outlet)	71.05	42.73	5.129**	>0.001

****Means are significantly different at 0.05**

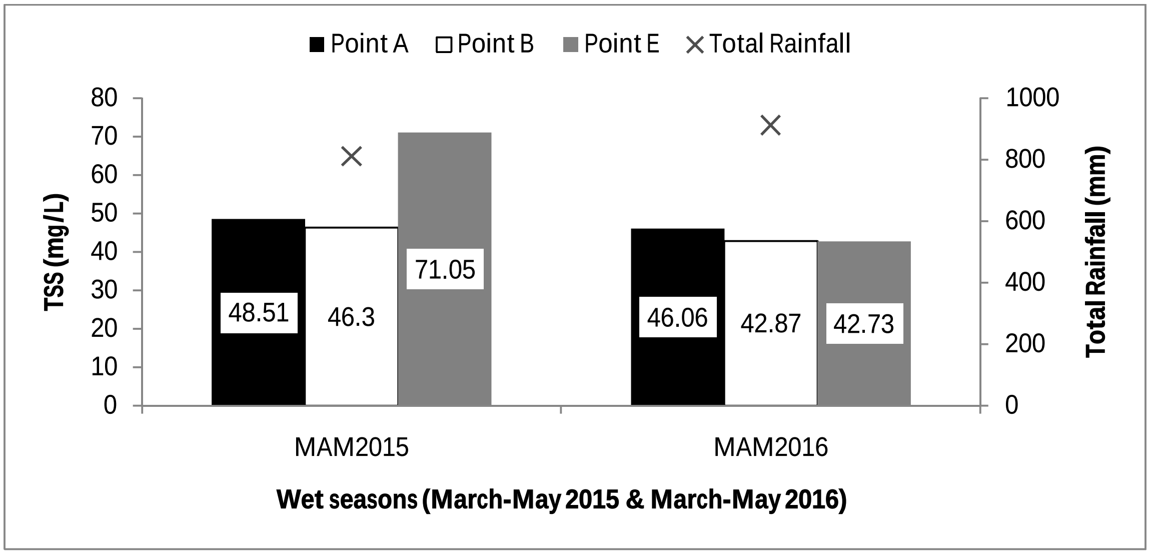

Figure 4.11: TSS results of the three points (A, B & E) during the two rainy seasons of MAM 2015 and MAM 2016

4.2.4. Effectiveness of SLM practices on soil fertility and water holding properties

As mentioned earlier, during the baseline study on SLMP status, it was discovered that there were farms that had conserved SLM technologies (specifically *fanya juu* terraces) for the last 15 to 20 years. This presented a good opportunity to compare farms which have conserved the *fanya juu* terraces and those which have never installed a single SLM technology within the same period. Soil fertility and water holding properties assessments were analysed and significant differences determined to compare well conserved lands and poorly conserved lands.

4.2.4.1. Key soil parameters

Nitrogen (N), exchangeable (K), total organic carbon, organic matter and CEC were observed to increase down the slope especially in poorly conserved farms when compared to farms with terraces (Figure 4.12). Available phosphorous (P) was the only parameter observed to have a different trend from others as it decreased down slope in both types of farms. The high concentration of available phosphorous at the top slope of both types of farms could be attributed to high use of fertilizer applications especially diammonium phosphate (DAP) which is commonly used during planting periods by approximately 77.8% of small scale farmers in the watershed (Nkonya *et al*., 2008). Moreover, research has shown that phosphorus can be lost in runoff in dissolved form and cumulative run off down the slope could deplete its concentration (Baker *et al*., 2007). Soil pH did not vary much between the poorly conserved farms and farms with *Fanya Juu* terraces.

Farms with Fanya juu terraces									
	Soil pH	Available P (mg/Kg)	% Organic Matter (OM)	Electrical Conductivity Ec	Exchangeable K (meq/100g)	% Nitrogen (N)	% Total Organic Carbon (TOC)	CEC (Meq/100g)	Bulk Density (g cm-3)
Top slope	6.03	0.51	19.67	0.14	1.60	0.63	11.33	18.00	1.17
Middle	5.87	0.49	17.67	0.15	1.07	0.60	10.33	17.33	1.15
Down slope	5.30	0.27	18.33	0.19	0.83	0.71	10.67	19.00	1.12
Poorly conserved farms									
	Soil pH	Available P (mg/Kg)	% Organic Matter (OM)	Electrical Conductivity Ec	Exchangeable K (meq/100g)	% Nitrogen (N)	% Total Organic Carbon (TOC)	CEC (Meq/100g)	Bulk Density (g cm-3)
Top slope	5.40	0.70	17.33	0.05	0.63	0.34	10.17	18.67	1.27
Middle	5.50	0.52	24.33	0.09	0.90	0.65	14.00	18.00	1.28
Down slope	5.40	Trace	25.33	0.22	1.10	0.62	14.67	30.00	1.16

Figure 4.12: Averages of key soil parameters between farms with terraces and poorly conserved farms

High bulk density was observed in poorly conserved farms. Bulk density is an indicator of soil compaction. High soil erosion results in loss of finer particles which leaves coarse particles resulting to an increase in bulk densities (Schoonover & Crim, 2015). Research shows relatively high bulk densities in poorly conserved farms (Lal, 1985).

4.2.4.2. Soil moisture retention

The soil moisture retention curve (pF curve) gives the relationship between soil moisture suction and soil moisture content (Figure 4.13). A soil is at F.C. (field capacity) or when has a pF-value of 2, some two to three days the soil has been saturated by rainfall or irrigation. When the soil becomes dry and plants cannot take up water anymore the soil is at W.P (wilting point) or has a pF=4.2 (Lajos, 2008).

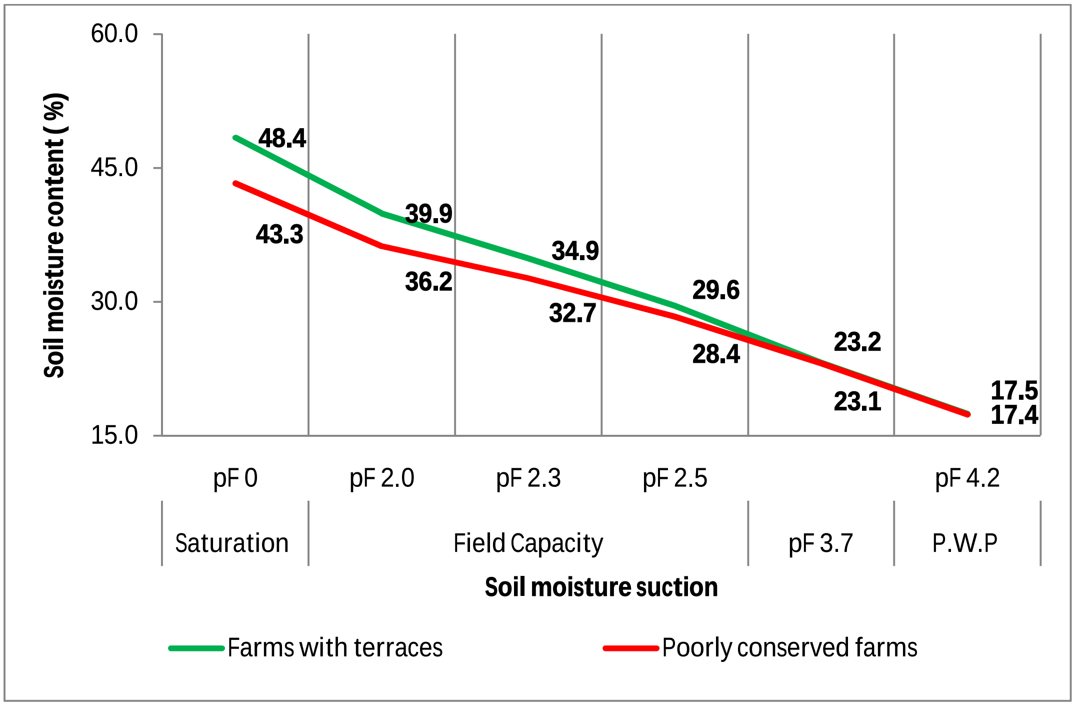

Figure 4.13: Soil moisture retention curve – developed from averages in both types of farms

Available water capacity (AWC) is the amount of water a soil can store that is available for use by plants. It is defined as the water held between field capacity and the water content at permanent wilting point (PWP) (Equation 4.1).

$AWC = FC - \theta_{pwp}$, ...**(Equation 4.1)**

Where AWC is Available Water Capacity, FC is field capacity and θ_{pwp} *is the water content at the PWP.*

In well conserved farms, the AWC was estimated at 22.4%. In poorly conserved farms, the AWC was estimated at 18.8%. Lack of SLM practices results to high soil erosion which affects soil properties (Frye *et al.*, 1982). Sustainable land management practices restore the important soil properties (Pimentel, et al., 1995), and this explains the reason why relative high AWC was observed in well conserved farms.

4.2.4.3. Soil texture

The clay content in poorly conserved farms appears to be minimal at the top slope and increases down the slope (Figure 4.14). The sand content is highly concentrated at the top slope. This could indicate possible effects of continuous erosion in poorly conserved farms as reported by (Schoonover & Crim, 2015). Finer particles are eroded and deposited at the down slope, leaving coarse particles accumulate at the top. This is also reflected in comparatively high bulk density at the top slope of poorly conserved farms as shown in Figure 4.12.

Farms with Fanya juu terraces			
	% Sand	% Silt	% Clay
Top slope	40.70	21.30	38.00
Middle	46.70	22.00	31.30
Down slope	42.00	20.70	37.30
Poorly conserved farms			
	% Sand	% Silt	% Clay
Top slope	50.70	22.70	26.70
Middle	34.70	34.00	31.30
Down slope	39.30	22.00	38.70

Figure 4.14: Soil texture analysis

Analysis of variance was adopted to test significant differences between the results observed in farms considered well conserved and poorly conserved farms. Analysis of variance was carried using Excel Analysis ToolPack with a significance level of 0.05. The ANOVA results are as shown in appendix 5. The differences in percentage sand was observed to be significantly different (p= *0.0192*) between well conserved and poorly conserved farms at significant level of 0.05. This implies relative high soil erosion on poorly conserved farms which results in loss of finer soil particles. This leads to accumulation of coarse particles (higher % sand) at the top slope. The differences observed in the majority of other soil parameters were not significantly different. This finding conquers with available literature on low effectiveness of SLM technologies under conventional approaches. Although some farmers adopt SLM technologies through their own initiatives without necessarily receiving any external incentives, the SLM technologies through conventional approaches are more often than not below the recommended standards due to misinformed decisions (Nkonya *et al*., 2004; INTOSAI, 2013). Low adoption is also another area that decreases the effectiveness of SLM technologies. (FAO, 2010) reported that adoption of SLM technologies has been relatively low globally. (World Bank, 2010) reported that adoption of SLM technologies in sub-Saharan Africa was very low-about 3% of total crop land. (Kihiu, 2016) estimated that in Kenya, the adoption rates of sustainable land management (SLM) practices in areas where SLM practices are highly needed (dry lands) due to unfavourable conditions are alarmingly low estimated at 14.2%, despite the declining productivity of these ecosystems. Even though there is insufficient research done on adoption rates in all agro-climatic zones of Kenya, this value could be lower in semi-humid to humid zones as studies have reported that where lands are relatively productive, there is widespread apathy among small scale farmers to invest in SLM technologies as the perceived net gain is minimal (Sterve, 2010; Molua, 2014; Kirui, 2016). Though it is possible to observe relatively improved soil conditions in farms with *Fanya Juu* terraces when compared to poorly conserved lands, implementation of *Fanya Juu* terraces alone which are the prominent SLM practices in the study site cannot reduce soil erosion to desired levels, there is need to integrate terraces with other SLM technologies to achieve tremendous results. The small scale farmers should also continuously maintain the standards of SLM practices to sustain their effectiveness.

4.2.5. Effectiveness of PES approach in the delivery of desired ecosystem services

This sub-section summarises the key findings in this study as it narrows down to the theme of the study.

PES as an alternative approach introduced incentives (approximately KES 4,541 per household) to encourage adoption of SLM practices that would improve water quality downstream and consequently deliver the desired ecosystem services. The study established that as a result of PES incentives, the SLM status improved from a baseline of 11% to 32% of the target SLM status after one year of PES implementation. TSS significantly (p=*0.00022)* reduced from a baseline of an average of 71.05mg/L in MAM 2015 to an average of 42.73mg/L in MAM 2016. This was attributed to the PES approach as an alternative approach in watershed management. An interpolation of the observed TSS results between worst and best case scenarios was done to interpret effectiveness of observed results against the best scenario. SWAT model calibration and validation was satisfactory with P-factors above 0.6 and NS above 0.5 as recommended by (Bracmort *et al.* , 2006) (Table 4.7).

Table 4.7: SWAT model calibration and validation results

Sub-basins	Flow calibration		Sediments calibration	
	P-factor	**Nash-Sutcliffe (NS)**	**P-factor**	**Nash-Sutcliffe (NS)**
Sub-basin 1	0.760	0.810	0.710	0.590
Sub-basin 2	0.710	0.730	0.690	0.580
	Flow validation		**Sediments validation**	
	P-factor	**Nash-Sutcliffe (NS)**	**P-factor**	**Nash-Sutcliffe (NS)**
Sub-basin 3	0.670	0.710	0.930	0.700

Figure 4.15 and 4.16 presents calibration and validation graphs generated in SWAT-CUP for flow (m^3/s) and sediments (mg/L) respectively. The observed flow was entirely enveloped by the model simulation with little underestimations or overestimations as shown in Figure 4.15. The model consistently overestimated the sediments between 6th May, 2016 and 13th May 2016 (Figure 4.16). This could result due to measurement errors and or uncertainties in modelling (Arnold, et al., 2012a). For instance, the measurement error could occur as sediments were measured at 9 am. The rainfall intensity during the rest of the day could have been different resulting in higher erosion of sediments. This was not accounted for in this study hence a measurement error. Nevertheless, the key focus is the selected objective function where calibration and validation result should fall under the acceptable ranges (Abbaspour, 2015).

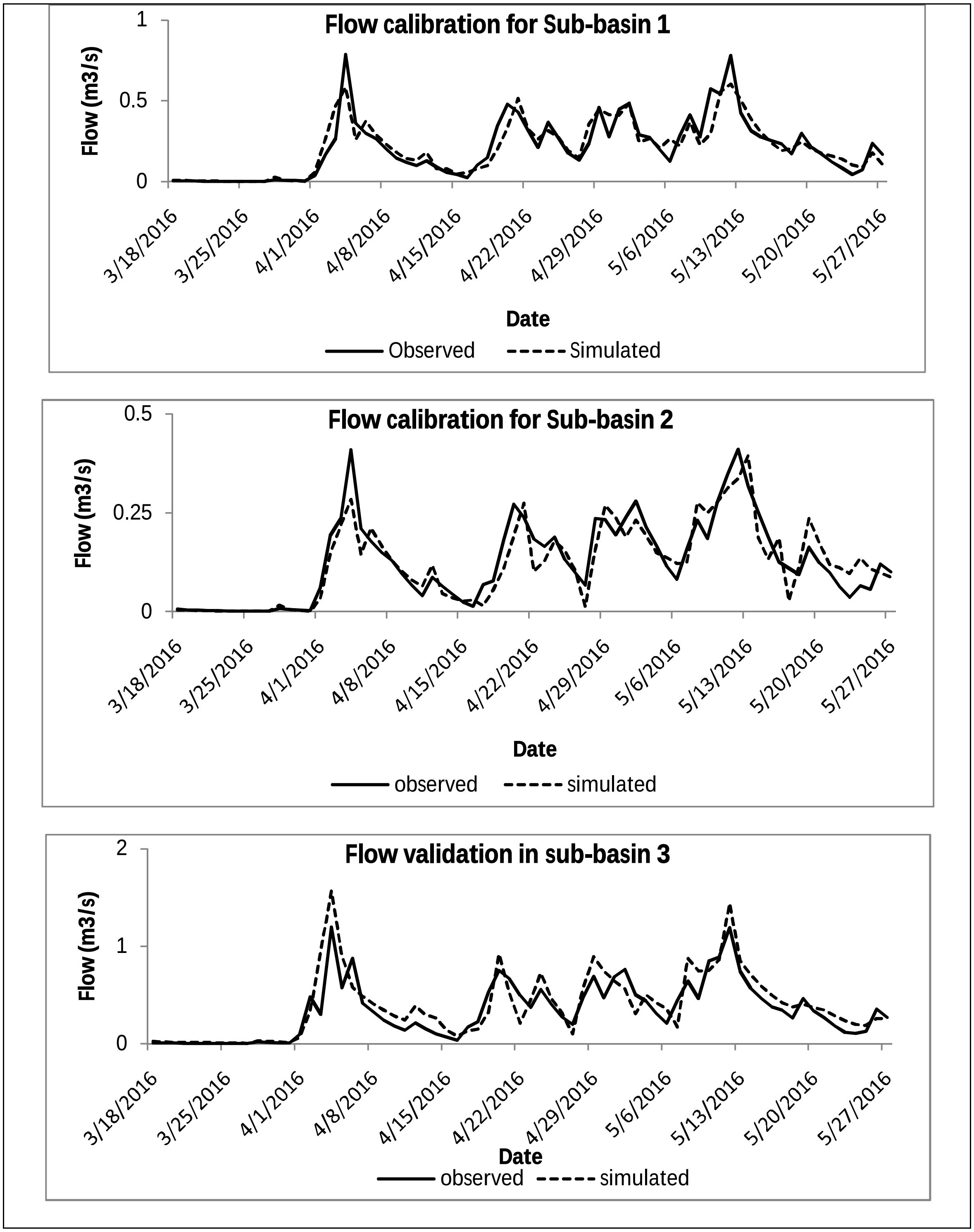

Figure 4.15: Flow calibration and validation

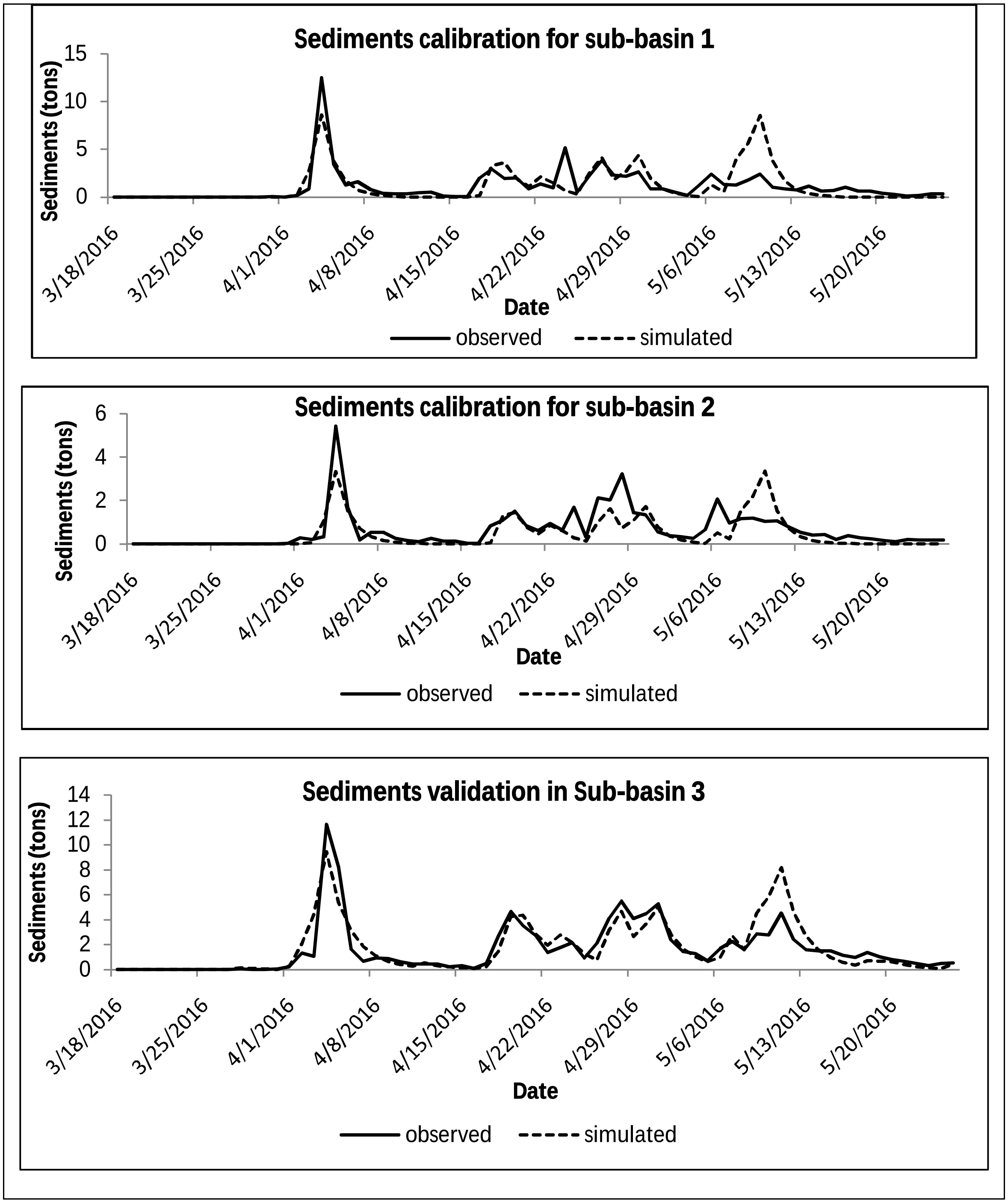

Figure 4.16: Sedimentations calibration and validation

After calibration and validation, the SWAT model was used to check the TSS simulation in MAM 2016. The model simulated TSS of 49.9mg/L against observed TSS of 42.73mg/L. The means of the observed and simulated TSS were not significantly different (p=*0.1038*) (Table 4.8). The model was therefore considered suitable to analyse the effectiveness on water quality improvement.

Table 4.8: Test of significant differences between observed TSS and simulated TSS

t-Test: Two-Sample Assuming Equal Variances

	Observed TSS	**Simulated TSS**
Mean	42.732	49.913
Variance	577.485	787.871
Observations	71	71
Pooled Variance	682.678	
Hypothesized Mean Difference	0	
df	140	
t Stat	-1.637	
P(T<=t) one-tail	0.052	
t Critical one-tail	1.656	
P(T<=t) two-tail	0.104	
t Critical two-tail	1.977	

Figure 4.17 shows the interpolation of observed TSS between the best and worst case scenarios of the study site. This study observed that under conventional approach, water quality is relatively degraded (71.05 mg/L) but not to the worst case scenario (124.15 mg/L). This is because there existed SLM technologies through farmers own initiatives. This is an important finding showing that modest SLM adoption should not be ignored. They have a potential to deliver ecosystem services even if not to desired status. After managing the watershed under an alternative approach for a period of one year,

tremendous changes were observed and water quality degradation decreased to 42.73 mg/L. This suggests that there is a direct course and effect between farming practices and water quality downstream. Positive changes in SLM adoption lead to positive changes in water quality.

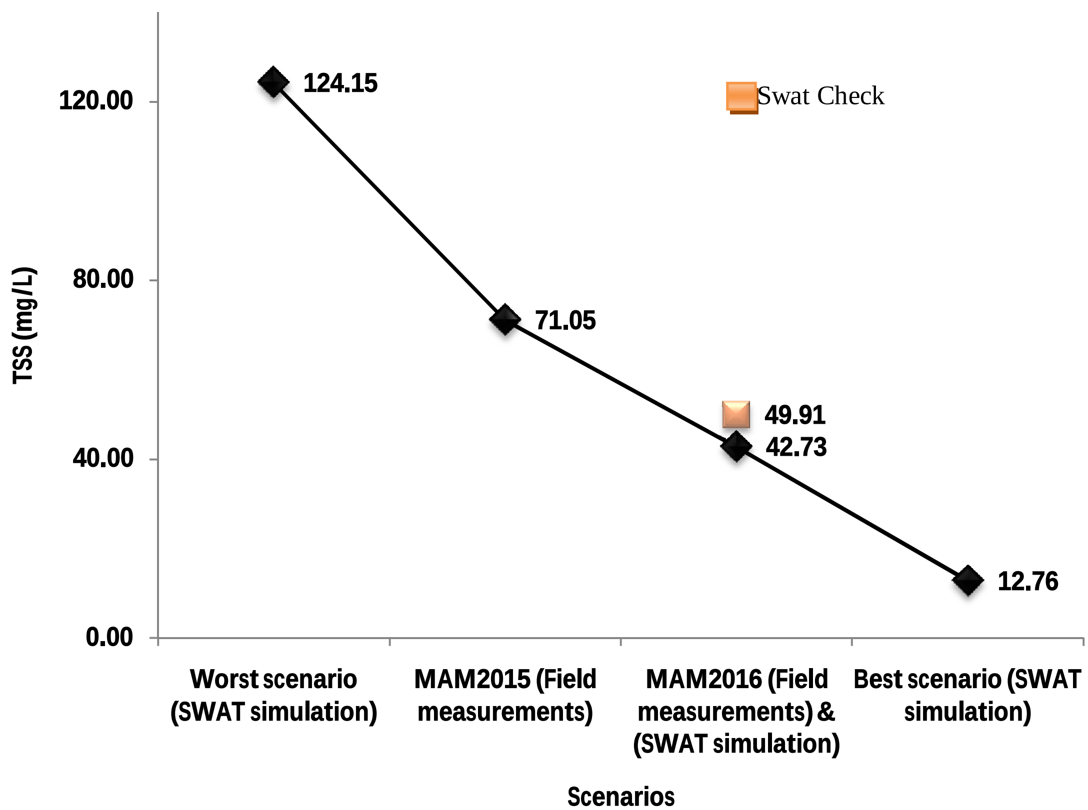

Figure 4.17: Interpolation of the observed TSS of MAM 2015 and MAM 2016 between the SWAT generated scenarios

The SWAT model predicts that the TSS would improve to the best scenario if SLM technologies are fully implemented to their best standards. These conditions will be realized when all farmers fully implement the land management plans to achieve the target status (best scenario).

The absolute values on water quality were converted to percentages (observed versus the target) as shown in sub-section 4.2.5.1. This made it possible to assess the impact on water quality as adoption of SLM technologies increased in the study micro-catchment.

4.2.5.1. Conversion of water quality absolute values to percentages

The difference between the TSS at worst scenario and best scenario was the basis for conversion into percentages. The basis = 124.15-12.76 = **111.39.** According to the SWAT model, this is the maximum reduction of TSS required to achieve the best scenario on water quality. To move the water quality from worst to best scenario, it requires reducing the TSS from 124.15mg/L to 12.76 mg/L. This means the TSS has to be reduced by 100% $\frac{124.15-12.76}{111.39} X100$ = 100%. Therefore, status of water quality at worst scenario is 100%-100% = **0%**.

To move water quality from the status observed before PES project to the target status, it means reducing TSS from 71.05 mg/L to 12.76 mg/L. This means the TSS has to be reduced by 52% $\frac{71.05-12.76}{111.39} X100$ = 52%. Hence, status of water quality before PES project was 100%-52% = **48%**.

To move water quality from the status observed after one year to the target status, it means reducing TSS from 42.73 mg/L to 12.76 mg/L. This means the TSS has to be reduced by 27% $\frac{42.73-12.76}{111.39} X100$ = 27%. So, status of water quality after one year was 100%-27% = **73%**.

According to (NEMA, 2006), the recommended standard of TSS in river systems in Kenya is a maximum of 30mg/L. To move water quality from the recommended status to the target status, it means reducing TSS from 30 mg/L to 12.76 mg/L. This means reducing the TSS by 15% $\frac{30-12.76}{111.39} X100 =$ 15%. So, status of water quality at the recommended status would be 100%-15% = **85%**. The changes in water quality as SLM adoption improved are as shown in Figure 4.19.

The PES as an alternative approach to watershed management was identified as an effective approach in improving water quality downstream. When SLM status was at 11% of the target SLM status, the status of water quality was at 48%. After one year of PES implementation, the SLM status increased to 32% of the target status. This impacted on water quality which improved to 73%. Even though, there was significant improvement in water quality, the recommended status of water quality (standard TSS of 30 mg/L) according to water quality regulations in Kenya was not yet achieved (NEMA, 2006).

This study found that, for water quality to improve to a recommended 85%, it requires increasing adoption of SLM technologies beyond 65% (Figure 4.18). This is an optimistic ambition that requires stability of SLM technologies maintained over five years (McCarthy *et al.*, 2011).

The PES incentives are expected to further improve and maintain the best conditions at farm level which will ensure sustained delivery of the desired ecosystem services. Given that this study was done within one year into PES implementation. Significant changes observed in SLM adoption and water quality improvement is a vital indication that PES is a prospective approach in watershed management. However, there are limited PES case studies in Kenya. More studies should be promoted to develop key lessons for policy interventions. For instance, an SLM adoption of more than 65% of the target status should be tested on various watersheds in Kenya to investigate whether the recommended status of water quality by NEMA would be achieved and possible lessons for further improvement.

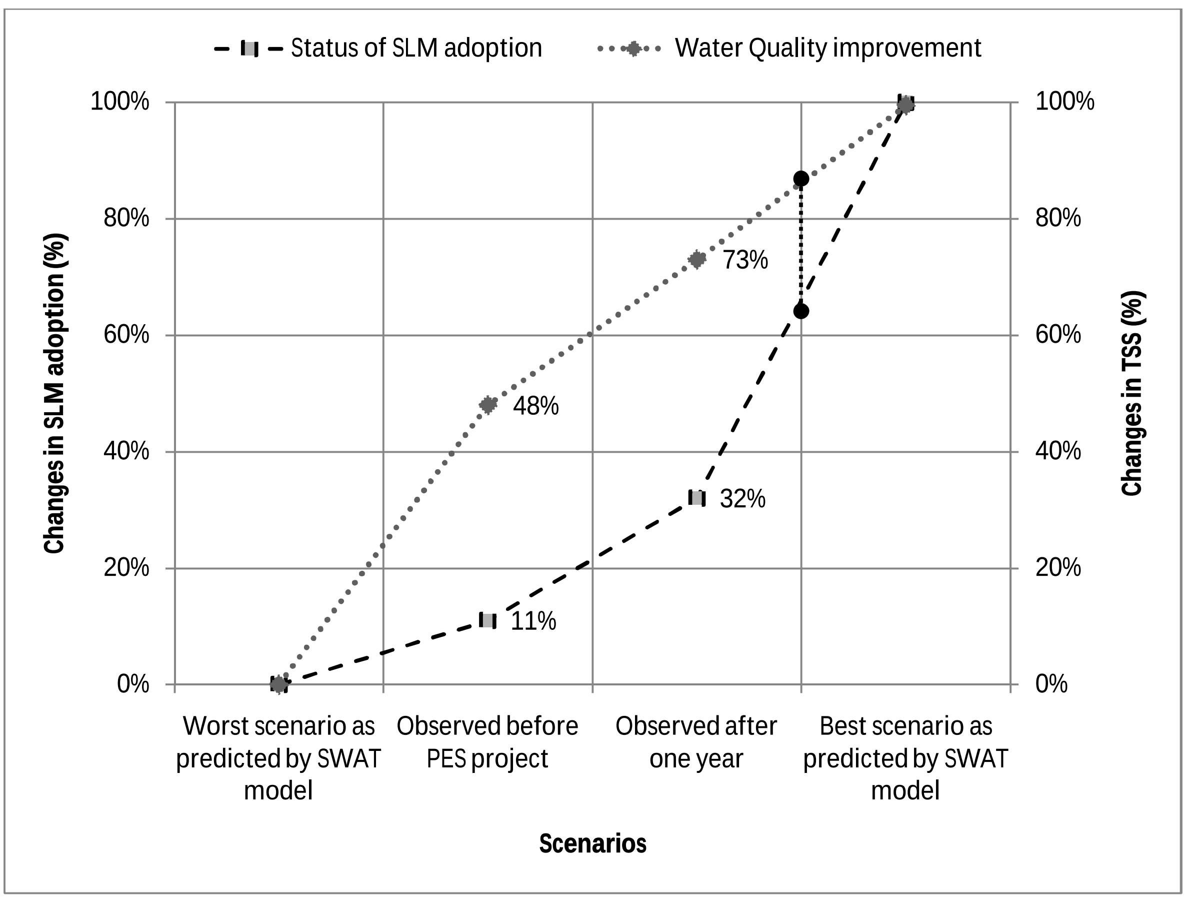

Figure 4.18: Effect of SLM adoption on water quality in the study micro-catchment

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

1) The baseline SLM status in PES farms before the onset of KAPSLMP PES project was established to be 11%. This shows low adoption of SLM technologies under conventional approach. Generally studies have shown that SLM adoption in Kenya through conventional approaches is very low.

    a. The small scale farmers were incentivized by a compensation of 30% of the total cost of implementing the SLM technologies. PES incentives were estimated to be an additional household income of approximately KES 4,541 (approximately 45 US$) per household. The PES incentives encouraged adoption of sustainable land management practices and SLM status improved from an estimated 11% to 32% after one year. What was observed is that the project progress was highly impactful on SLM practices that were perceived to be beneficial especially in contributing to farm income e.g. planting of fruit trees. For activities involving intensive labour such as construction of terraces, retention ditches etc recorded low implementation progress in the first year.

    b. Comparison results between PES and Non-PES farms showed strong evidence that PES farmers had installed more changes in their farms as compared to Non-PES farmers. The changes observed after one year are a clear indication that PES as an alternative approach in watershed management has a direct influence on adoption of SLM technologies which consequently influence water quality status at the downstream points.

2) This study established that, there exists some SLM practices through farmer own initiatives. This could be through education background, influence of extension officers, attending to trainings, through media etc. For instance, in the study micro-catchment, *Fanya Juu* terraces were the prominent conservation measures implemented by farmers voluntarily with no external influence. However, an analysis on soil fertility and water holding properties between farms with terraces and poorly conserved farms showed that there were no significant differences on most of soil parameters between the two categories of farms. Therefore, alternative mechanisms such as PES are inevitable to encourage adoption of integrated SLMPs based on locations requirements and not on what a farmer prefers or deems most feasible to implement.

3) The PES as an alternative approach to watershed management was identified as an effective approach in delivering the desired ecosystem services i.e. improving water quality downstream. It significantly promoted adoption of SLM practices that eventually contributed to water quality improvement. When SLM status was at 11%, the TSS status was at estimated at 48%. After one year of PES implementation, the SLM status increased to 32%. This impacted on water quality which improved to 73%. Even though, there is significant improvement in water quality, the

recommended status of TSS at 85% in the river systems according to water regulations standards in Kenya was not achieved. This study established that for water quality to improve to 85%, it requires increasing adoption of SLM technologies beyond 65% in the study micro-catchment. The PES incentives are expected to further improve and maintain the best conditions at farm level which will ensure sustained delivery of the desired ecosystem services.

5.2. Recommendations

This study identified some key areas for further improvement or investigation. Therefore, it recommended the following:

1) Long term research data is recommended to validate the effectiveness of PES over number of years especially on ecosystem services that manifest after long periods and establishing whether PES incentives actually maintain best conditions at farm level. More ecosystem services should also be monitored to validate the TSS results. This can be done through funding Thesis research (M.Sc and Ph.D researches).
2) Various organisations in climate change and environmental conservation need to establish long term PES projects through which scientific research can be leveraged. This can present an opportunity to study other indicators for instance stream recharge in dry periods, land productivity, infiltration rates etc take longer periods before they manifest.

3) This study would be strengthened by validating the methodology at multiple discretization levels and spatial scales within the Sasumua watershed and other potential watersheds in the country.
4) The government through ministry of environment should increase research work in the area of payment for ecosystem services to develop more lessons in the field. For effective research work, a department focused on rural conservation and rural jobs creation should be established.

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APPENDICES

Appendix 1: Water quality results in the larger Sasumua watershed

Turbidity (NTU)	***Oct-15***				***Nov-15***				***Dec-15***			
Engineer Bridge	*27*	*9*	*54*	*19*	*17*	*34*	*48*	*13*	*8*	*18*	*49*	*7*
Nairobi Bridge	*15*	*16*	*89*	*11*	*58*	*41*	*21*	*18*	*9*	*27*	*38*	*1*
Little Sasumua	*1*	*29*	*48*	*16*	*42*	*27*	*28*	*33*	*6*	*9*	*35*	*6*
Main Sasumua	*37*	*39*	*42*	*3*	*45*	*34*	*25*	*7*	*5*	*19*	*26*	*1*
Ming'utio River	*72*	*282*	*115*	*63*	*98*	*211*	*163*	*115*	*90*	*82*	*123*	*97*
Ming'utio entry	*117*	*69*	*67*	*97*	*115*	*79*	*54*	*463*	*76*	*179*	*122*	*232*
Middle entry	*78*	*43*	*67*	*26*	*63*	*203*	*157*	*87*	*28*	*61*	*45*	*11*
Sasumua entry	*9*	*15*	*38*	*41*	*27*	*11*	*13*	*57*	*8*	*20*	*12*	*16*
TDS (mg/L)	***Oct-15***				***Nov-15***				***Dec-15***			
Engineer Bridge	*9*	*17*	*5*	*25*	*6*	*9*	*14*	*21*	*34*	*6*	*17*	*19*
Nairobi Bridge	*16*	*15*	*7*	*31*	*5*	*16*	*16*	*29*	*36*	*5*	*15*	*27*
Little Sasumua	*8*	*13*	*6*	*23*	*5*	*8*	*14*	*19*	*33*	*5*	*13*	*20*
Main Sasumua	*15*	*15*	*15*	*23*	*16*	*15*	*16*	*22*	*47*	*16*	*15*	*22*
Ming'utio River	*21*	*23*	*19*	*51*	*23*	*21*	*23*	*47*	*67*	*23*	*23*	*43*
Ming'utio entry	*20*	*21*	*12*	*113*	*13*	*20*	*20*	*86*	*31*	*13*	*21*	*78*
Middle entry	*17*	*22*	*23*	*49*	*23*	*17*	*21*	*43*	*0*	*23*	*22*	*40*
Sasumua entry	*12*	*13*	*13*	*37*	*11*	*12*	*12*	*43*	*31*	*11*	*13*	*32*
TSS (mg/L)	***Oct-15***				***Nov-15***				***Dec-15***			
Engineer Bridge	*12*	*80*	*35*	*79*	*5*	*24*	*32*	*76*	*45*	*24*	*5*	*75*
Nairobi Bridge	*23*	*57*	*31*	*74*	*9*	*22*	*35*	*6*	*48*	*22*	*9*	*25*
Little Sasumua	*9*	*43*	*39*	*11*	*2*	*17*	*48*	*19*	*56*	*17*	*2*	*17*
Main Sasumua	*19*	*15*	*25*	*50*	*43*	*32*	*30*	*81*	*86*	*32*	*43*	*80*
Ming'utio River	*76*	*465*	*123*	*77*	*235*	*126*	*210*	*119*	*331*	*126*	*235*	*94*
Ming'utio entry	*71*	*58*	*108*	*201*	*27*	*105*	*46*	*167*	*124*	*105*	*27*	*293*
Middle entry	*49*	*173*	*40*	*57*	*41*	*80*	*34*	*61*	*59*	*80*	*23*	*33*
Sasumua entry	*20*	*14*	*9*	*13*	*5*	*19*	*17*	*29*	*21*	*19*	*5*	*6*
Imhoff (ml/L)	***Oct-15***				***Nov-15***				***Dec-15***			
Engineer Bridge	*0.4*	*0.1*	*0.2*	*2.3*	*0.3*	*0.2*	*0.1*	*0.4*	*0.1*	*0.3*	*0.2*	*0.8*
Nairobi Bridge	*1.3*	*0.1*	*0.2*	*1.2*	*0.1*	*0.2*	*0.2*	*1.3*	*0.1*	*0.5*	*0.2*	*0.8*
Little Sasumua	*1.2*	*0.2*	*0.3*	*0.8*	*0.2*	*0.3*	*0.2*	*1.2*	*0.2*	*0.4*	*0.3*	*0.5*
Main Sasumua	*1.8*	*0.2*	*0.1*	*1.8*	*0.3*	*0.1*	*0.1*	*1.8*	*0.2*	*0.2*	*0.1*	*1.1*

Ming'utio River	*2.8*	*0.3*	*0.4*	*3.1*	*0.3*	*0.4*	*0.2*	*2.8*	*0.3*	*0.1*	*0.4*	*2.4*
Ming'utio entry	*2.1*	*0.2*	*0.1*	*0.5*	*0.1*	*0.1*	*0.1*	*2.1*	*0.2*	*0.3*	*0.1*	*2.2*
Middle entry	*0.5*	*0.5*	*0.3*	*0.4*	*0.3*	*0.3*	*0.3*	*0.5*	*0.5*	*0.2*	*0.3*	*0.9*
Sasumua entry	*2.1*	*0.4*	*0.2*	*1.9*	*0.3*	*0.2*	*0.2*	*2.1*	*0.4*	*0.1*	*0.2*	*1.8*

Turbidity (NTU)	***Mar-16***		***Apr-16***				***May-16***			
Engineer Bridge	*3*	*24*	*37*	*8*	*68*	*23*	*9*	*32*	*5*	*4*
Nairobi Bridge	*5*	*26*	*48*	*21*	*51*	*23*	*27*	*38*	*9*	*7*
Little Sasumua	*1*	*36*	*47*	*17*	*38*	*12*	*9*	*35*	*6*	*8*
Main Sasumua	*36*	*30*	*84*	*31*	*15*	*29*	*19*	*26*	*5*	*6*
Ming'utio river	*272*	*247*	*298*	*229*	*484*	*131*	*82*	*123*	*90*	*73*
Ming'utio entry	*27*	*39*	*115*	*79*	*54*	*119*	*179*	*122*	*76*	*42*
Middle Entry			*73*	*198*	*197*	*91*	*61*	*45*	*28*	*38*
Sasumua Entry	*9*	*15*	*17*	*17*	*13*	*18*	*20*	*12*	*8*	*10*

TDS (mg/L)	***Mar-16***		***Apr-16***				***May-16***			
Engineer Bridge	*34*	*7*	*5*	*10*	*6*	*11*	*10*	*9*	*17*	*14*
Nairobi Bridge	*36*	*6*	*7*	*8*	*5*	*9*	*13*	*16*	*15*	*16*
Little Sasumua	*33*	*6*	*6*	*9*	*5*	*12*	*12*	*8*	*13*	*14*
Main Sasumua	*47*	*14*	*15*	*14*	*16*	*15*	*15*	*15*	*15*	*16*
Ming'utio river	*67*	*34*	*19*	*25*	*23*	*23*	*21*	*21*	*23*	*23*
Ming'utio entry	*31*	*13*	*12*	*14*	*13*	*18*	*19*	*20*	*21*	*20*
Middle Entry	*0*		*23*	*24*	*23*	*16*	*18*	*17*	*22*	*21*
Sasumua Entry	*31*	*11*	*13*	*13*	*11*	*11*	*11*	*12*	*13*	*12*

TSS (mg/L)	***Mar-16***		***Apr-16***				***May-16***			
Engineer Bridge	*5*	*32*	*45*	*7*	*80*	*24*	*12*	*35*	*4*	*4*
Nairobi Bridge	*9*	*35*	*48*	*22*	*57*	*22*	*23*	*31*	*8*	*4*
Little Sasumua	*2*	*48*	*56*	*21*	*43*	*17*	*9*	*39*	*9*	*7*
Main Sasumua	*43*	*30*	*86*	*31*	*15*	*32*	*19*	*25*	*8*	*6*
Ming'utio river	*235*	*210*	*331*	*217*	*465*	*126*	*76*	*123*	*71*	*55*
Ming'utio entry	*27*	*46*	*124*	*84*	*58*	*105*	*71*	*108*	*74*	*40*
Middle Entry	*0*		*59*	*174*	*173*	*80*	*49*	*40*	*23*	*34*
Sasumua Entry	*5*	*17*	*21*	*19*	*14*	*19*	*20*	*9*	*11*	*8*

Imhoff (ml/L)	***Mar-16***		***Apr-16***				***May-16***			
Engineer Bridge	*0.3*	*0.2*	*0.2*	*0.4*	*0.3*	*0.1*	*0.2*	*0.3*	*2.3*	*0.3*
Nairobi Bridge	*0.1*	*0*	*0.2*	*1.3*	*0.2*	*0.2*	*0.2*	*0.5*	*1.2*	*0.2*

Little Sasumua	*0.2*	*0.3*	*0.3*	*1.2*	*0.3*	*0.2*	*0.3*	*0.4*	*0.8*	*0.3*
Main Sasumua	*0.3*	*0.1*	*0.1*	*1.8*	*0.1*	*0.1*	*0.1*	*0.2*	*1.8*	*0.1*
Ming'utio river	*0.3*	*0.5*	*0.3*	*2.8*	*0.4*	*0.2*	*0.1*	*0.1*	*3.1*	*0.3*
Ming'utio entry	*0.1*	*0.1*	*0.1*	*2.1*	*0.1*	*0.1*	*0.3*	*0.3*	*0.5*	*0.1*
Middle Entry	*0.3*	*0*	*0.1*	*0.5*	*0.3*	*0.3*	*0.1*	*0.2*	*0.4*	*0.1*
Sasumua Entry	*0.3*	*0.1*	*0.1*	*2.1*	*0.1*	*0.2*	*0.2*	*0.1*	*1.9*	*0.2*

Appendix 2: Estimated average TSS in wet seasons

MAM2015		***MAM 2016***		***SWAT simulation after calibration in MAM2016***	***Worst Scenario***	***Best Scenario***
2-Mar	*20*	*18-Mar*	*15*	*17.52*	*43.58*	*4.48*
5-Mar	*25*	*19-Mar*	*19*	*22.19*	*55.2*	*5.67*
8-Mar	*23*	*20-Mar*	*17*	*19.86*	*49.4*	*5.08*
11-Mar	*23*	*21-Mar*	*17*	*19.86*	*49.4*	*5.08*
14-Mar	*77*	*22-Mar*	*21*	*24.53*	*61.02*	*6.27*
17-Mar	*134*	*23-Mar*	*21*	*24.53*	*61.02*	*6.27*
20-Mar	*141*	*24-Mar*	*27*	*31.54*	*78.46*	*8.06*
23-Mar	*53*	*25-Mar*	*19*	*22.19*	*55.2*	*5.67*
26-Mar	*44*	*26-Mar*	*19*	*22.19*	*55.2*	*5.67*
29-Mar	*35*	*27-Mar*	*12*	*14.02*	*34.87*	*3.58*
1-Apr	*70*	*28-Mar*	*25*	*29.2*	*72.63*	*7.46*
4-Apr	*33*	*29-Mar*	*9*	*10.51*	*26.14*	*2.69*
7-Apr	*44*	*30-Mar*	*13*	*15.18*	*37.76*	*3.88*
10-Apr	*61*	*31-Mar*	*58*	*67.75*	*168.53*	*17.32*
13-Apr	*78*	*1-Apr*	*29*	*33.87*	*84.25*	*8.66*
16-Apr	*96*	*2-Apr*	*43*	*50.23*	*124.95*	*12.84*
19-Apr	*81*	*3-Apr*	*24*	*28.03*	*69.72*	*7.17*
22-Apr	*81*	*4-Apr*	*101*	*117.97*	*293.45*	*30.16*
25-Apr	*52*	*5-Apr*	*106*	*123.81*	*307.97*	*31.65*
28-Apr	*82*	*6-Apr*	*40*	*46.72*	*116.21*	*11.94*
1-May	*133*	*7-Apr*	*18*	*21.02*	*52.29*	*5.37*
4-May	*122*	*8-Apr*	*32*	*37.38*	*92.98*	*9.55*
7-May	*134*	*9-Apr*	*43*	*50.23*	*124.95*	*12.84*
10-May	*101*	*10-Apr*	*39*	*45.55*	*113.3*	*11.64*
13-May	*106*	*11-Apr*	*36*	*42.05*	*104.6*	*10.75*
16-May	*73*	*12-Apr*	*24*	*28.03*	*69.72*	*7.17*
19-May	*51*	*13-Apr*	*33*	*38.54*	*95.87*	*9.85*
22-May	*64*	*14-Apr*	*26*	*30.37*	*75.54*	*7.76*
25-May	*53*	*15-Apr*	*53*	*61.91*	*154*	*15.82*

MAM2015		MAM 2016		SWAT simulation after calibration in MAM2016	Worst Scenario	Best Scenario
28-May	*58*	*16-Apr*	*25*	*29.2*	*72.63*	*7.46*
31-May	*53*	*17-Apr*	*33*	*38.54*	*95.87*	*9.85*
		18-Apr	*46*	*53.73*	*133.65*	*13.73*
		19-Apr	*59*	*68.91*	*171.41*	*17.62*
		20-Apr	*72*	*84.1*	*209.2*	*21.5*
		21-Apr	*61*	*71.25*	*177.23*	*18.21*
		22-Apr	*63*	*73.59*	*183.05*	*18.81*
		23-Apr	*42*	*49.06*	*122.04*	*12.54*
		24-Apr	*37*	*43.22*	*107.51*	*11.05*
		25-Apr	*61*	*71.25*	*177.23*	*18.21*
		26-Apr	*39*	*45.55*	*113.3*	*11.64*
		27-Apr	*122*	*142.5*	*354.47*	*36.43*
		28-Apr	*100*	*116.8*	*290.54*	*29.86*
		29-Apr	*92*	*107.46*	*267.3*	*27.47*
		30-Apr	*101*	*117.97*	*293.45*	*30.16*
		1-May	*76*	*88.77*	*220.81*	*22.69*
		2-May	*80*	*93.44*	*232.43*	*23.89*
		3-May	*55*	*64.24*	*159.8*	*16.42*
		4-May	*38*	*44.39*	*110.42*	*11.35*
		5-May	*48*	*56.07*	*139.47*	*14.33*
		6-May	*40*	*46.72*	*116.21*	*11.94*
		7-May	*44*	*51.39*	*127.83*	*13.14*
		8-May	*40*	*46.72*	*116.21*	*11.94*
		9-May	*40*	*46.72*	*116.21*	*11.94*
		10-May	*49*	*57.23*	*142.36*	*14.63*
		11-May	*36*	*42.05*	*104.6*	*10.75*
		12-May	*44*	*51.39*	*127.83*	*13.14*
		13-May	*38*	*44.39*	*110.42*	*11.35*
		14-May	*33*	*38.54*	*95.87*	*9.85*
		15-May	*37*	*43.22*	*107.51*	*11.05*
		16-May	*46*	*53.73*	*133.65*	*13.73*
		17-May	*38*	*44.39*	*110.42*	*11.35*
		18-May	*43*	*50.23*	*124.95*	*12.84*
		19-May	*34*	*39.71*	*98.78*	*10.15*
		20-May	*35*	*40.88*	*101.69*	*10.45*
		21-May	*35*	*40.88*	*101.69*	*10.45*
		22-May	*43*	*50.23*	*124.95*	*12.84*
		23-May	*50*	*58.4*	*145.27*	*14.93*
		24-May	*34*	*39.71*	*98.78*	*10.15*

MAM2015	MAM 2016		SWAT simulation after calibration in MAM2016	Worst Scenario	Best Scenario
	25-May	45	52.56	130.74	13.44
	26-May	18	21.02	52.29	5.37
	27-May	23	26.86	66.81	6.87
Average 71.05		***42.73***	***49.91***	***124.16***	***12.76***

Appendix 3: Progress towards the target set by the LMPs for the sampled PES farms in the larger Sasumua catchment

SLM Technology	*Target*	*Cumulative progress*	*Achieved after one year*
Length of grass strips (M)	*13,971*	*8,367*	*59.9*
Length of terraces (M)	*16,055*	*9,076*	*56.5*
No. of Forest trees	*6,550*	*2,943*	*44.9*
Length of retention ditches (M)	*5,161*	*2,054*	*39.8*
No. of splits	*138,515*	*50,418*	*36.4*
No. of Fruit trees	*7,035*	*2,495*	*35.5*
Average progress			***45.5***

Appendix 4: Progress towards the target set by the LMPs for the PES farms in the study micro-catchment

SLM Technology	*Baseline status*	*After 1 yr*	*%Baseline*	*Cumulative progress*	*Change*	*Target*
No. of Fruit trees	--	*1,095*	--	*96%*	--	*1145*
Length of riverbank protection (M)	*212*	*520*	*21%*	*51%*	*31%*	*1,015*
No. of Napier splits	--	*10,865*	--	*47%*	--	*22,925*
Length of grass strips (M)	*918*	*3,725*	*10%*	*42%*	*32%*	*8,819*
Length of terraces (M)	*821*	*1,561*	*9%*	*18%*	*8%*	*8,819*
Length of retention ditches (M)	*123*	*551*	*4%*	*18%*	*14%*	*3,117*
No. of Forest trees	--	*183*	--	*15%*	--	*1,185*

Appendix 5: Analysis of variance of soil parameters

Soil pH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Different farms	*0.673333*	*5*	*0.134666667*	*1.074468085*	*0.4295825*	*3.325835*
Along the slope	*0.493333*	*2*	*0.246666667*	*1.968085106*	*0.1902317*	*4.102821*
Error	*1.253333*	*10*	*0.125333333*			
Total	*2.42*	*17*				

Soil Ec

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Different farms	*0.048111*	*5*	*0.009622222*	*1.862766186*	*0.1882426*	*3.325835*
Along the slope	*0.039011*	*2*	*0.019505556*	*3.776080878*	*0.060027*	*4.102821*
Error	*0.051656*	*10*	*0.005165556*			
Total	*0.138778*	*17*				

% Nitrogen

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Different farms	*0.094467*	*5*	*0.018893333*	*0.694863308*	*0.6392679*	*3.325835*
Along the slope	*0.103633*	*2*	*0.051816667*	*1.905725144*	*0.1989773*	*4.102821*
Error	*0.2719*	*10*	*0.02719*			
Total	*0.47*	*17*				

Exchangeable K (meq/100g

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Different farms	*1.411111*	*5*	*0.282222222*	*0.784192652*	*0.5836629*	*3.325835*
Along the slope	*0.081111*	*2*	*0.040555556*	*0.112689102*	*0.8945469*	*4.102821*
Error	*3.598889*	*10*	*0.359888889*			
Total	*5.091111*	*17*				

% TOC

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Different farms	*111.4028*	*5*	*22.28055556*	*2.571657583*	*0.0955447*	*3.325835*
Along the slope	*11.86111*	*2*	*5.930555556*	*0.684514267*	*0.5264816*	*4.102821*
Error	*86.63889*	*10*	*8.663888889*			
Total	*209.9028*	*17*				

% OM

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Different farms	*334.4444*	*5*	*66.88888889*	*2.534736842*	*0.0988105*	*3.325835*
Along the slope	*36.11111*	*2*	*18.05555556*	*0.684210526*	*0.5266223*	*4.102821*
Error	*263.8889*	*10*	*26.38888889*			
Total	*634.4444*	*17*				

Bulk Density (g cm-3)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Different farms	*0.067161*	*5*	*0.013432222*	*1.133308334*	*0.4033859*	*3.325835*
Along the slope	*0.023211*	*2*	*0.011605556*	*0.97918815*	*0.4089205*	*4.102821*

Error	*0.118522*	*10*	*0.011852222*			
Total	*0.208894*	*17*				

CEC Meq/100g

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Different farms	*119.4401*	*5*	*23.88802222*	*0.503640634*	*0.7675216*	*3.325835*
Along the slope	*57.98404*	*2*	*28.99202222*	*0.611250288*	*0.5617613*	*4.102821*
Error	*474.3069*	*10*	*47.43068889*			
Total	*651.731*	*17*				

% Sand

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Different farms	*800*	*5*	*160*	*4.615384615*	***0.0191919***	*3.325835*
Along the slope	*133.3333*	*2*	*66.66666667*	*1.923076923*	*0.1964962*	*4.102821*
Error	*346.6667*	*10*	*34.66666667*			
Total	*1280*	*17*				

% Silt

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Different farms	*557.3333*	*5*	*111.4666667*	*1.52833638*	*0.2652994*	*3.325835*
Along the slope	*401.3333*	*2*	*200.6666667*	*2.751371115*	*0.1116754*	*4.102821*
Error	*729.3333*	*10*	*72.93333333*			
Total	*1688*	*17*				

% Clay

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Different farms	*19.77778*	*5*	*3.955555556*	*0.181262729*	*0.9633583*	*3.325835*
Along the slope	*19.11111*	*2*	*9.555555556*	*0.437881874*	*0.6572055*	*4.102821*
Error	*218.2222*	*10*	*21.82222222*			
Total	*257.1111*	*17*				

Appendix 6: Farm profiling checklist

	Enumerator's Name:	*Date:*
Name of the Farmer:	*GPS coordinates: Southerns (S):__________________Eastings (E):____________________ Elevation_________________*	
	Sub County:	*Ward:*
	Sub location:	*Village:*
Select micro-catchment	*(a)Kiburu (b) Mukeu (c) Njabini (d) Githabai*	
Select age group	*(a) Below 30 years (b) 30-40 (c) 40-50 (d) 50-60 (e) More than 60 years*	
Level of education of respondent:	*(a) No formal educ_____) (c) Primary (Class____) (d) Secondary (A/O-level) Form (e) College (years taken) ______)_____(f) University (specify)____________________________________ (g) Other (specify)______________________*	
Main Sources of household income *Farming crops (2) Livestock (3) Business (4) Employment (5)Remittance (6) Other (Specify___________)*		
Describe main farming enterprises in your farm *Vegetables (2) Fruits (3) Dry cereals (4) Agroforestry (5) Pasture (6) Other (Specify_____________)*		
For how long have you been in farmer in this village? *(a) Less than 5 years (b) 5 - 10 years (c) 10-15 years (d) 15-20 years (e) More than 20 years*		
Are you a PES farmer YES/NO	*(a) YES (b) NO*	
Are you a member of a CIG	*(a) YES (b) NO*	
If Yes, which CIG are you in?	*(1) Dairy cow (2) Dairy Goat (3) Local Poultry (4) Irish Potatoes (5) Tree Tomato (6) StrawBerry (7) Agroforestry (8) Bee keeping (9) Fish Farming (10) Soil Conservation (11) Other specify ……………………..*	
Describe state of soil erosion in your farm (a) Severe (b) Mild (c) Minimal		
Do you have an area/section of your farm that is evidently eroded? (a) YES (b) NO *If YES describe type of erosion (e.g gully, landslide, path down the slope etc)*		
Describe your perception on crop productivity since you started crop production in your farm? *(1) Extremely Increased (2) Moderately Increased (3) Slightly Increased (5) No change (6) Slightly declined (7) Moderately declined (8) Extremely declined*		
Describe your main SLM practice in your farm *(a) Stabilized terraces (b) Water disposal Technologies (c) Grass strips (d) Agro-forestry (e) Mixed cropping/Inter cropping (f) Fertilizer/Manure/compost (g) Water harvesting (h) None (i) rotations with legumes (j) Other(specify_____________________________________)*		
FOR PES FARMERS		
Describe progress of SLM technologies before and after PES project		

SLM Technology	*Before PES project*	*Achieved under PES project after one year*
Length of Terrace (M)		
Length Retention ditch (M)		

Length drainage channels (M)		
Length of COD (M)		
Length of Grass strip (M)		
Length of Riverbank protection (M)		
Number of fruit trees		
Number of forest trees		

Rate your satisfaction with the PES project in your area (micro-catchment)
(a) Very dissatisfied (b) Dissatisfied (c) Unsure (d) Satisfied (e) Very satisfied

please explain why.......................

Would you continue with the SLM practices without PES (incentives)? (a) YES (b) NO

If NO, Please explain...

What are the benefits of PES that you have experienced?
Increased yields (2) reduced soil erosion (3) improved water/moisture retention (4) improved water quality (5) other (specify………..

According to you, what are the main challenges with SLM adoption in your area (micro-catchment)?
High cost of labour (2) Loss of land (3) No time (4) lack of knowledge (5) lack of inputs (6) lack of tools/equipments (7) dying of grass (8) other (specify….

In your opinion, what recommendations would you make to overcome the above challenges?
Provide inputs (2) financial support (3) provide tools and equipments (4) training (5) other (specify……..

FOR NON-PES FARMERS

Describe SLM changes implemented in your farm for the last one year?

SLM Technology	*Changes*
Length of Terrace (M)	
Length Retention ditch (M)	
Length drainage channels (M)	

	Length of COD (M)		
	Length of Grass strip (M)		
	Length of Riverbank protection (M)		
	Number of fruit trees		
	Number of forest trees		
Are you aware of PES project (a) YES (b) NO *If YES, how important is it to you?* *(a) Not a priority (b) Low priority (c) Medium priority (d) High priority (e) Very essential*			
According to you, what are the main challenges with SLM adoption in your area (micro-catchment)? *High cost of labour (2) Loss of land (3) No time (4) lack of knowledge (5) lack of inputs (6) lack of tools/equipments (7) dying of grass (8) other (specify….*			
In your opinion, what recommendations would you make to overcome the above challenges? *Provide inputs (2) financial support (3) provide tools and equipments (4) training (5) other (specify……..*			