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Soil loss assessment in Malawi

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ASWAp	Sector-Wide Approach
FAO	Food and Agriculture Organization
FD	Forest Department
GoM	Government of Malawi
LRCD	Land Resource Conservation Department
ENR	Environmental Natural Resource
MEMP	Malawi Environmental Monitoring Program
MGDS	Malawi Growth and Development Strategy
MoAFS	Ministry of Agriculture and Food Security
NLRMPS	National Land Resources Management Policy and Strategy
NDVI	Normalized Difference Vegetation Index
PEI	Poverty Environment Initiative
RUSLE	Revised Universal Soil Loss Equation
SLEMSA Soil Loss	Estimation Model for Southern Africa
SLM	Sustainable Land Management
UNDP	United Nations Development Program
UNEP	United Nations Environment Programme

Executive summary

Introduction

Soil loss is a major threat to the agricultural development in Malawi and by extension is also a major hindrance to the overall economic development of the country since the Malawian economy is dependent on agriculture. Not only does soil loss reduce the cultivable soil depth but it also takes away the fertile soils from the farmlands. The net effect is loss of agricultural productivity, increased expenditure on fertilizers, and a general decline in profitability of crop production. This study is part of the effort of the Government of Malawi (GoM) and its development partners in determining best approach to control the soil loss problems in the country. The study was set up to establish the current rates and trends of soil loss in Malawi as a baseline for future monitoring of soil loss in the country. The official soil loss rates which the GoM has been using to benchmark its strategies in the agriculture sector were those that were established in 1992 by World Bank (1992). In addition, since the GoM and its development partners started implementing the Agricultural Sector Wide Approach Program (ASWAp) and included soil loss as one of the monitoring indicators, there has been a need to develop a baseline soil loss rate to help with the program indicator monitoring.

Soil and natural resources in Malawi

The major soil types in Malawi are dominated by Luvisols, Lixisols, and Cambisols, occupying three-quarters of the county. Lixisols are dominantly in the northern region, Luvisols in the central, and Cambisols along the Rift Valley and largely in the southern regions. Cambisols and Luvisols are soils with relatively good natural nutrient characteristics; hence, they are quite susceptible to exploitation through agricultural activities. They are also predisposed to soil erosion due to their chemical and physical characteristics. Lixisols do not have good natural fertility. Their low aggregate stability and slaking tendencies are undesirable agricultural characteristics. All together, the three soil types which occupy 76% of Malawi are susceptible to soil erosion. By implication, over three quarters of Malawi is predisposed to soil loss by virtue of soil types.

In terms of vegetation cover, the main cover/land use types are farmlands, natural forests, forest plantation, wetlands, and lakes. These cover types have changed in proportion due to land use dynamics. Some of the changes could be linked to the soil loss problems in the country. For example, during 1991-2010 period, there was a noticeable 9% decline in natural forest cover and almost corresponding proportional increase in areas under agriculture. This suggests that agricultural land could have reclaimed some parts of the natural forest. This observation was particularly evident in the southern and northern regions. Although this change positively increased the areas under agriculture, it could have brought potential negative effects to the soil in case proper soil management did not accompany the transition. Particular attention was drawn to the areas where these changes occurred in the structurally unstable Lixisols in Nkhata Bay and in vulnerable Luvisols and Cambisols in Mulanje, Phalombe, and Nsanje Districts.

In terms of topography, the country can be generally categorized into four major types: the hilly and undulating terrain in the north and some parts in the south; mid-altitude flat/gently sloping plateaux in the centre; steep slopes of the Rift Valley region; and flat/gently sloping plains in the south. Apart from the Rift Valley, the other three relief characteristics form discernable three major drainage basins: north, central, and south. The hilly areas in the north and south receive more rainfall than the plateaux and floodplains. The relatively high rainfall amounts in the north and south regions together with the good agricultural soil types depict these regions as high agriculture potential areas of Malawi.

Previous soil loss studies in Malawi

Many plot-scale studies of soil loss rates have been reported in the literature since 1970 to date. The majority of these studies either used empirical soil loss estimation models such as SLEMSA or RUSLE, or measured soil loss rates in erosion plots in different parts of the country. Over 80% of these studies reported soil loss rates between 0 and 20 ton/ha/yr. Only a few studies can be cited in the literature with a national scale of soil loss assessment. Khonje and Machira (1987) used the SLEMSA model with secondary information and expert opinion to develop national averages of soil loss. Their estimate put the national average soil loss rate at 33 ton/ha/year. World Bank (1992) modified the methodology by Khonje and Machira (1987) and developed a new soil loss rate of 20 ton/ha/year. It can be observed from these previous studies that the soil loss rates in the country is varied, needs a scientific approach, and should be routinely done to assess the time-series trend.

Policies and policy implementation relevant to soil resource use and management

1. *Agriculture development policies*: Since agriculture is the main contributor to the national economy, the majority of GoM policies have been centred on agriculture development. From the time of the colonial government, these policies have been centred on expansion of agricultural land area and intensification of agriculture per unit land area (e.g. increase input and spending, diversification, improved market, etc.). Little focus has been on sustainable land management (SLM) to go along with the agricultural ex/intensification.
2. *Natural resources and sustainable land management policies*: Very good policies are available for natural resources and SLM. The policies have created necessary structures for implementation and monitoring. However, the actual implementation has been weak and inadequately funded. Consequently, no substantial positive improvements can be reported over the years with respect to natural resources management and more specifically SLM throughout the country.

The above challenges in policy formulation and implementation have a role to play in prolonged effective control of soil loss problems in the country.

Study approach

The overall approach used in this study was the implementation of SLEMSA model to estimate national topsoil loss using secondary data, develop a footprint history of topsoil loss rates in the past 10 years, identification of potential drivers of soil loss in the country, and capacity development of local staff to implement future soil loss assessment activities. Application of the SLEMSA model was accomplished by developing a protocol for sourcing the input data, application of appropriate GIS software and hardware to implement the model, and field validating the model outputs. The main activities during the study were: desk modelling using GIS techniques; model field validation and improvement using soil testing kits, mobile laboratory, and mobile tablet-server real-time interaction; final modelling and development of time-series trend of soil loss in the country; identification of hot and bright spot areas; and capacity building.

Main findings

The average national soil loss rates in 2014 was 29 ton/ha/yr. The areas with relatively high rates were the north and some pockets in the southern region. The northern region had soil loss rates ranging between 0.4 ton/ha/yr to 39 ton/ha/yr. Here, Nkhata Bay district was the most affected while Rumphi was the least affected. The main contributing factors for Nkhata Bay were pevalent steep slopes, fragile soil, and high rainfall. Overall, severity of soil loss problems in Malawi in 2014 could be regarded to have been moderate in the north and light elsewhere. The severity of soil loss problems in the northern region seemed to arise from the fragile and shallow soil types, lack of good soil management practices, steep slopes, and high erosive rainfall characteristics.

Time-series analysis of soil loss rates in the country from 2000 to 2014 showed that the northern areas had increasing trends of soil loss. Notably, Nkhata Bay had highest increase in soil loss rates between 2000 and 2014 while some parts of Chitipa, Keronga, Mzimba and Rumpi in the north and Mulanje and Phalombe in the south also had slight increase in soil loss rates. It's interesting to note that NKhata Bay, Mulanje and Phalombe, which had increasing rates of soil loss were also identified to have had change of land use from natural forest to agriculture between 1991 and 2010 in addition to having fragile soil. It was possible that these two factors could have contributed to the increasing trend of soil loss rates over the years. In the south, the majority of the districts were depicted to have had declining trends in soil loss rates. Especially, in the Rift Valley sections, the soil loss rate seemed to have declined to less than 10 ton/ha/yr towards 2014.

In terms of hotspots and bright-spot areas, the Rift Valley ridges in the Central (in Dedza and Ncheu) and in the south (in Zomba, Machinga and Neno) had the majority of bright spot areas while Nkhata Bay and some parts of western Mzimba were the hotspot areas of soil loss. Soil loss hotspot areas are those that have high soil loss rates in addition to increasing rates of soil loss over time while bright spots are those that have high soil loss rates but the rates have declining trends over time. Overall, Nkhata Bay and the border between Phalombe and Mulanje are the soil loss hotspot areas in Malawi. The Rift Valley ridges especially in the central and the southern region are bright spots areas.

The main causes of soil loss rates in Malawi were found to be fragile soils on steep slopes and erosive rainfall. The human activities which can exacerbate these factors are:

- Poor soil management (which contributes to soil loss such as continuous carbon mining, tillage operations, exposure of bare soil to erosive rainfall, etc.);
- Agricultural activities on fragile soil on steep slopes;
- Poor/low vegetation cover management in high risk areas (such as steep slopes and erodible soil in high rainfall areas);
- Inadequate policies/policy implementation especially in sustainable land management (SLM) practices, vegetation cover, and sustainable utilization of non-renewable natural resources such as soil and vegetation.

Capacity development

LRCD staff were trained on state of the art methods and technology for digital soil mapping and soil erosion assessment. Specific training areas were: GIS and remote sensing modelling routines for SLEMSA input data preparation, SLEMSA implementation on GIS layers, field data preparation, and SLEMSA model validation. In addition to training, LRCD was given the following equipment for the soil loss exercise

- Four high-end laptop computers for modelling soil loss and handling input GIS data;
- Relevant software for implementing SLEMSA model;
- Three mobile tablets with powerbanks and mobile application software for real-time data collection in the field (including GPS capacities);
- Three complete soil testing kits for mobile soil testing and measurements (soil physical, chemical and biological properties);
- Protective field gear for field operations;
- Mobile weighing scale and heating ovens for soil testing and measurements.

Recommendations

Adequate dissemination packages are recommended to be developed for the products developed in this study in order to reach intended audience. Since only a selected number of LRCD staff were trained during this study, it is recommended that more modules, software packages, and training sessions should be organized for at least one resource person per district to be able to monitor soil loss in those districts. It is also recommended that assessment of soil loss impact on agricultural productivity be carried out to establish the linkage between soil loss, unsustainable soil management practices, and policy options. In order to establish the impact of prevention measures, it is recommended that a detailed monitoring framework should be developed to continue monitoring the soil loss rates in the country.

1 Introduction

1.1 Background

Soil loss is one of the major threats to agricultural development in Malawi. Since Malawian economy is largely dependent on agriculture, loss of soil especially from the farmlands is conceived as a major hindrance to the overall economic development of the country. Not only does soil loss reduce the cultivable soil depth but also takes away the fertile soils from the farmlands. The net effect is loss of agricultural productivity, increased expenditure on fertilizers (that are required to maintain the yields), and a general decline in profitability of crop production. Besides the negative impact on agriculture, soil loss also affects surface water resources through loss of water quality and quantity, increased flashfloods, and siltation of rivers and irrigation canals. There are also arguments of soil loss increasing emissions of greenhouse gasses. During the soil loss process, there is potential breakdown of soil aggregates and clods into their primary particles (such as clay, silt and sand). Consequently, the carbon that is held within the soil ends up breaking and is released into the atmosphere as CO2 (Lal, 1995). Upland soil loss also affects other key sectors of the Malwian economy such as the fishery and water resources (water supply and hydro-electricity generation), etc.

The Government of Malawi (GoM) and its development partners are quite aware of the negative impacts of soil loss. Therefore, they have sustained the campaign to reduce and control the problem in the country. This campaign has been in the form of appropriate legislation, research studies, awareness creation, and implementation of conservation efforts. The present study is one of the campaign efforts envisaged to contribute to effective control of soil loss in Malawi. It was also initiated as a first step towards the quantification of the negative economic impacts of soil loss by giving accurate estimation of the magnitude of soil loss throughout the country.

Soil loss is a negative environmental process that begins in the early stages as deterioration of soil structure and advancing to particle detachment which are the transported along a gradient and finally deposited in another place. The process is fuelled by agents of erosion (such as wind, runoff, gravity, etc.) and further influenced by factors such as soil management, land use/cover management, topography, and soil type. Some of these factors are often (in) directly modified by human activities in ways that can accelerate or slow down the rate of soil loss process. The endeavor of a soil loss assessment is to determine the spatial distribution, the main contributing factors, and the rate of soil loss at appropriate scales corresponding to the scales for making decisions with regard to soil loss control measures. In Malawi, soil loss assessments in various parts of the country have been carried out. However, these studies lack the completeness of information need at the national scale where the GoM makes decisions for soil loss control. The World Bank (1992) is the only study carried out at the national scale (its limitations notwithstanding) and which the GoM has been using to make decisions on soil loss control measures. There is a need to update these previous assessment study results in order to accurately support current decisions. The present study was initiated to fulfil this need.

The GoM and its development partners have attempted many approaches to soil loss control and soil conservation efforts in different parts of the country with varying degrees of success. These efforts include contour ploughing, ridging, vetivar grass strips, conservation agriculture, crop rotation, manure application, etc. (Ngwira et al., 2014; Mussa, 2013; Chigwiya and Kanazawa, 2008). The success or failure of these efforts in controlling soil loss needs to be evaluated over periods of time in order to provide room for improvement or opportunities for upscaling. Time-series assessment of soil loss combined with a monitoring framework gives the opportunity to assess the effectiveness of these control measures. Presently, there is inadequate information on the trends of soil loss and any monitoring framework which the GoM can use to assess the effectiveness of its efforts towards the control of soil loss in the country. This study attempted to establish a time-series assessment of soil loss in Malawi for the period between 2000 and 2014. It also recommended a framework for future monitoring of soil loss in the country. The study also included a component on capacity building of the GoM staff in order to cater for continuity and sustainability of the soil loss assessment and monitoring activities in the country in future.

Fire activity in natural forst

Contour ridge in farmland

1.2 Evolution of present national soil loss assessment activity

This study was set up to establish the current rates and trends of soil loss in Malawi. The official soil loss rates which the GoM has been using to benchmark its strategies in the agriculture sector were those that were established in 1992 by World Bank (1992). Since soil loss is a dynamic process, the values obtained 5 years or so ago may not be necessarily the same today. This means that the soil loss rates obtained more than two decades ago cannot be adequately used to implement strategies for combating the problem now. This study, therefore, comes in at appropriate time to update the national soil loss rates in a way that will support government efforts in developing the requisite control measures.

In 2008, Malawi and its development partners developed and adopted the Agricultural Sector Wide Approach Program (ASWAp), which provides a framework for further investments across the agriculture sector (MoAFS, 2011). ASWAp was conceived as a priority investment programme based on the following priority agricultural elements of the Malawi Growth and Development Strategy (MGDS) (MoFDP, 2011): increasing agricultural productivity, contributing to 6% annual growth of the agricultural sector, improving food security, diversifying food production to improve nutrition at household level, and increasing agricultural incomes of the rural people. ASWAp is, therefore, viewed by the GoM as the practical vehicle for transforming the agricultural sector. In 2010, UNDP-PEI Malawi supported the agricultural sector in Malawi to develop and include sustainability/soil loss indicators in the ASWAp M&E framework and in the Malawi Growth and Development Strategy. UNDP-PEI argument was based on the preliminary findings of a study they conducted on economic valuation of environmental natural resource (ENR) use in Malawi (Yaron et al., 2011). This study demonstrated a high economic cost of soil erosion on agricultural productivity and poverty reduction. Hence, there was justification to include soil loss in ASWAp results monitoring framework. Eventually the following two indicators were included in the ASWAp M&E framework: *Agricultural land (ha) under Sustainable Land Management (SLM)* and *Estimated total soil loss in cropped areas (Tonnes/ha/year)*. This present study on soil loss was instituted to update the 1992 data on soil loss and establish a new soil loss baseline for effective monitoring of the ASWAp sustainability indicator.

The expected outputs of the study were:

1. A component by component improvement of the ability to capture the impact of each soil loss factors in SLEMSA;
2. An improved soil hazard/soil loss map for Malawi as baseline ;
3. Recommendations and proposals for enhancement of systems to update the soil loss map on a regular basis.

2 Major soil and natural resources in Malawi

2.1 Soil resources

According to the soil map of Malawi, the major soil types in Malawi are dominated by Luvisols, Lixisols, and Cambisols. Lixisols are dominantly in the northern region, Luvisols in the central, and Cambisols along the Rift Valley and largely in the southern regions (Figure 2.1). Cambisols and Luvisols are naturally endowed with good chemical properties that can be exploited for agricultural purposes. They can sustain good crop production especially if they are properly managed. Their vast majority imply that they can benefit the country in supporting crop production programs. Lixisols have relatively higher silt and organic matter content.

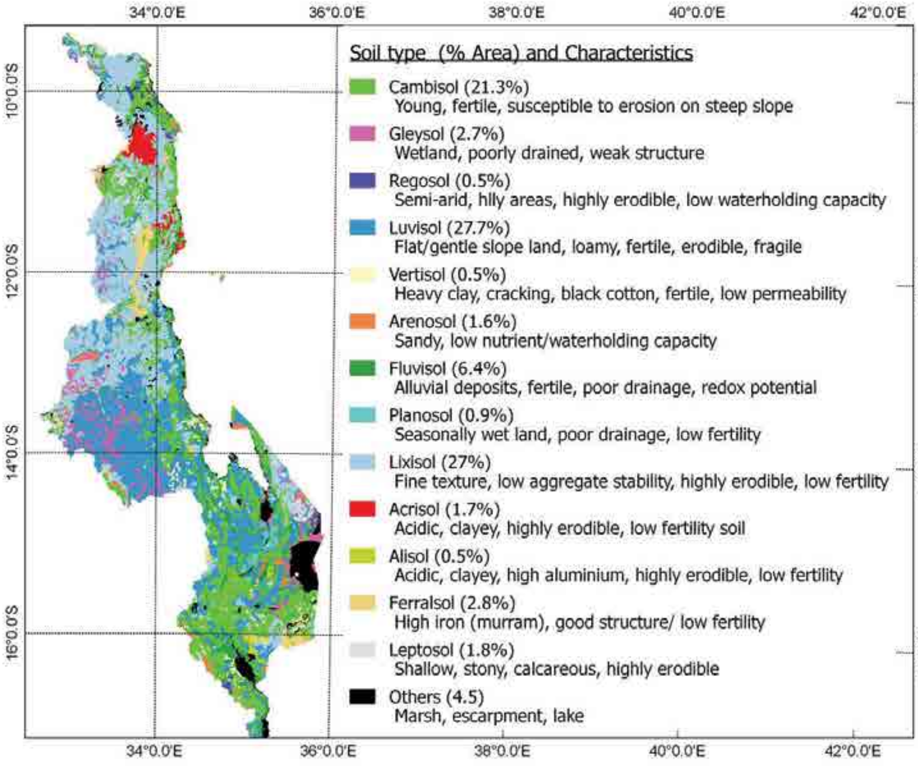


Figure 2.1: Major soil resources of Malawi (Data source: GoM)

However, they need appropriate fertilizer application in order to guarantee good performance in crop production. Furthermore, they may also take a long time to regenerate if excessively exploited through continuous nutrient mining (such as crop harvesting without nutrient replacement).

Although Malawi is endowed with naturally good soil for agriculture (and bricks for civil construction), the soils are highly susceptible to soil erosion processes. All together the three major soil types comprise about 76% of Malawi. Due to their chemical and physical characteristics, these soil types have inherent predisposition to erosion. This implies that about three-quarters of Malawi is already predisposed to soil erosion by virtue of soil type.

A deeper look at the natural soil endowment of Malawi reveals some of the underlying soil erosion problems facing the country. The Cambisols and Luvisols that are regarded as soil with relatively good natural nutrient characteristics are quite susceptible to exploitation through agricultural activities. They are also predisposed to soil erosion due to their chemical and physical characteristics. The tendency to exploit these soils for agricultural production makes them more vulnerable to soil erosion in the absence of proper soil conservation and management practices. For Lixisols, they have low aggregate stability and slaking characteristics. These characteristics form a bad combination with high erosive rainfall and low vegetation cover that is typical of some parts of the country where these soil types may be found. In general, the major soil types in Malawi have potential threats for degradation under poor management.

2.2 Vegetation cover

The main land use/cover types in Malawi are farmlands, natural forests, forest plantation, wetlands, built-up areas, and lakes. Farmlands have the highest proportion in addition to having improved its spatial coverage by 9% between 1991 and 2010 (Figure 2.2). Majority of the farmlands have seasonal ground/vegetative cover owing to the seasonal types of crop grown in them. They provide the agricultural produce for the country. The increase in spatial proportion shows that there was an expansion of land under agriculture between 1991 and 2010.

The natural forest is dominantly used as game parks or forest reserves. They provide the country with tourist attraction benefits, fuelwood, medicinal plants, timbre, food, water catchment areas, above-ground carbon stocks, and the ground cover that protects the soil from agents of erosion. Some parts of it have been replanted with forest plantations such as pines, rubber, etc. All together, the forests occur mainly in the north and upper parts of the central region. In spite of the importance of the natural forest, deforestation is a major challenge in Malawi with deforestation rates conservatively estimated to be 1% per annum (Ministry of Natural Resources, Energy and Environment, 2010) (Figure 2.2). For the wetlands, they have been predominantly in the central and southern regions. There are also some wetlands in the north, such as Limphasa, Wovwe, Kazuni, etc. A good fraction of these have been reclaimed between 1991 and 2010. Examples are those that were mainly those along Lake Malawi in Nkhotakota and Salima Districts.

In terms of changes in land use/vegetation cover, it was observed that the decrease in spatial coverage of the natural forests was almost corresponding to the proportional increase in areas under agriculture during the 1991-2010 period. This suggests that agricultural land could have reclaimed some parts of the natural forest. This observation was particularly evident in the southern and northern regions. Although this change positively increased the areas under agriculture, it could have brought potential negative effects to the soil in case proper soil management did not accompany the transition. Interesting attention could be drawn to the areas where changes of land use from natural forest to agricultural land occurred in the structurally unstable Lixisols in the northern region and vulnerable Luvisols and Cambisols in the south especially in Mulanje, Phalombe, and Nsanje Districts (Figure 2.2). The soil types in these regions have a high risk of erosion due to the removal of the protective vegetative cover.

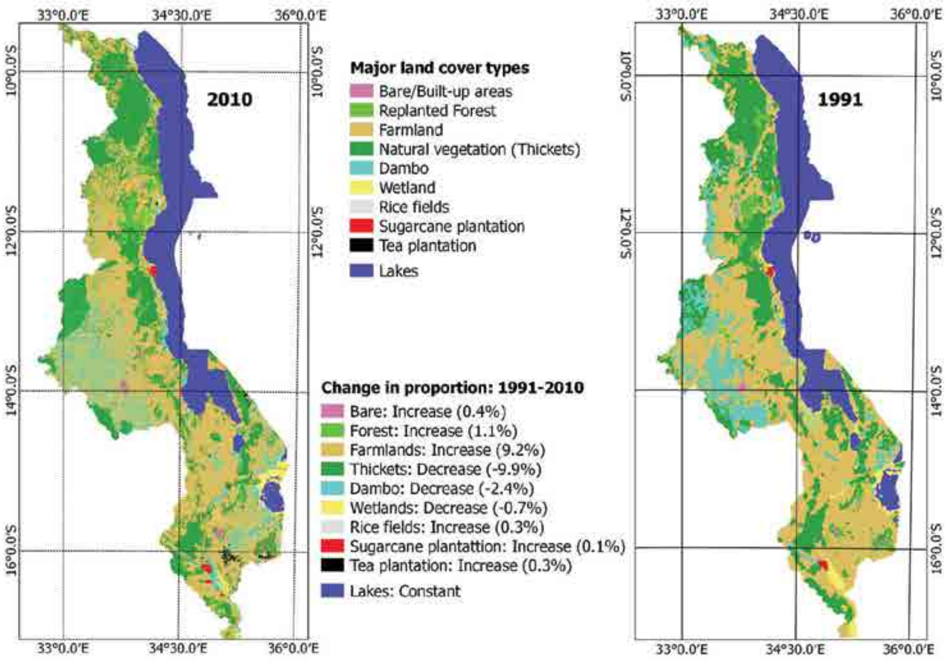


Figure 2.2: Main land use/cover types in Malawi in 1991 and 2001 (Data source: GoM)

2.3 Topography

Malawi lies between the Longitudes 32° 40’17.8” E and 350 55’6.2” E and between the Latitudes 17° 7’ 34.7” S and 9° 21’ 49.2” S and covers about 118,484 km². The altitude generally drops from a high of 2603 m above sea level in northern part of the country and in Mulanje in the south to 32 m above sea level in the south (Figure 2.3). The topography of the country can be generally categorized into four major types: the hilly and undulating terrain in the north and some parts in the south; mid-altitude flat/gently sloping plateaux in the centre; steep slopes of the Rift Valley region; and flat/gently sloping plains in the south and lakeshore regions (Figure 2.3). Apart from the Rift Valley, the other three relief characteristics form discernable three major drainage basins: north, central, and south. Their slopes together with the forest cover make a good combination for water catchment areas for the drainage basins.

The steep slopes in the north, along Rift Valley ridges, and in the south are largely covered by natural forests (Figure 2.2 and 2.3). They also have Cambisol as the major soil type. Since Cambisols are vulnerable to erosion in to steep slopes, any threat of removal of the protective natural vegetation cover will definitely put these areas at high risk of erosion.

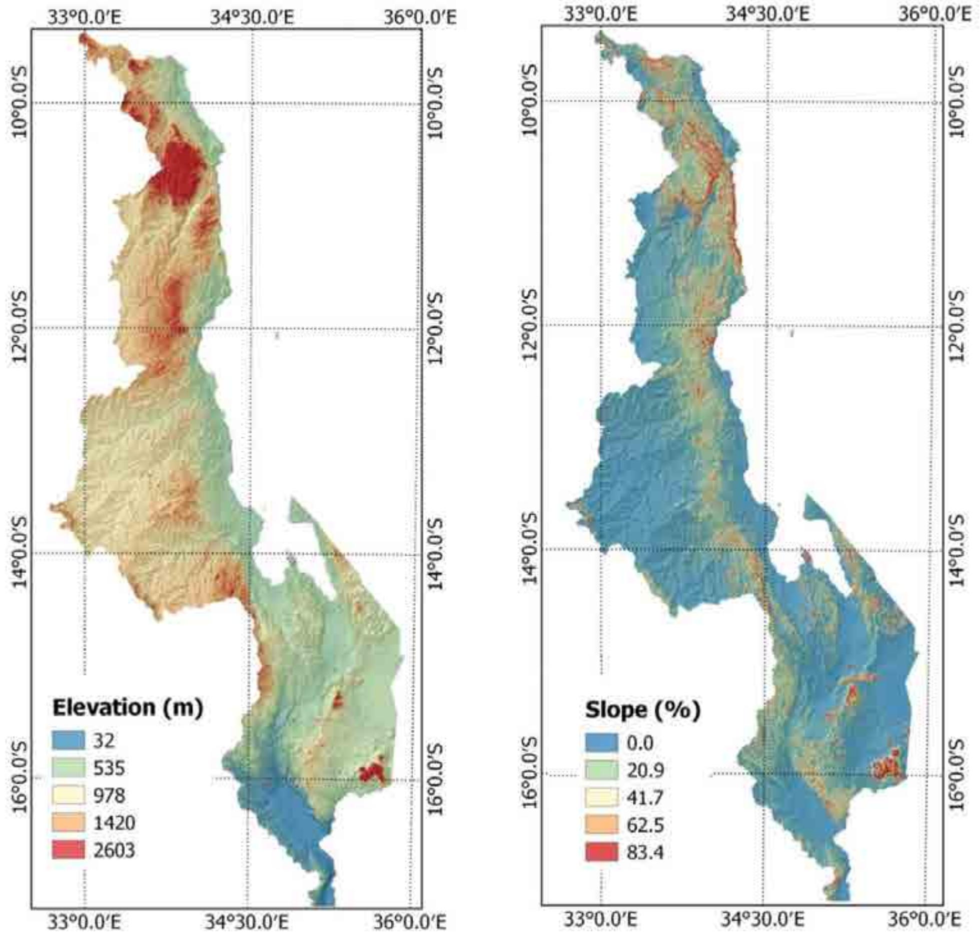


Figure 2.3: Altitude and slope map of Malawi (Data source: GoM)

2.4 Rainfall

Mean annual rainfall amount in Malawi ranges from 725 mm to 2500 mm. This rainfall fall in two seasons that are separated by a small window (of less than three weeks), making it appear as a one-season rainfall. About 95% of this rainfall falls between November and April. The majority of this rainfall is received in the north and southern region (in Mulanje and Phalombe) (Figure 2.4). Every year, the rains seem to begin first in the south and followed by the north before spreading to the whole country (within the first three weeks of the rainy season).

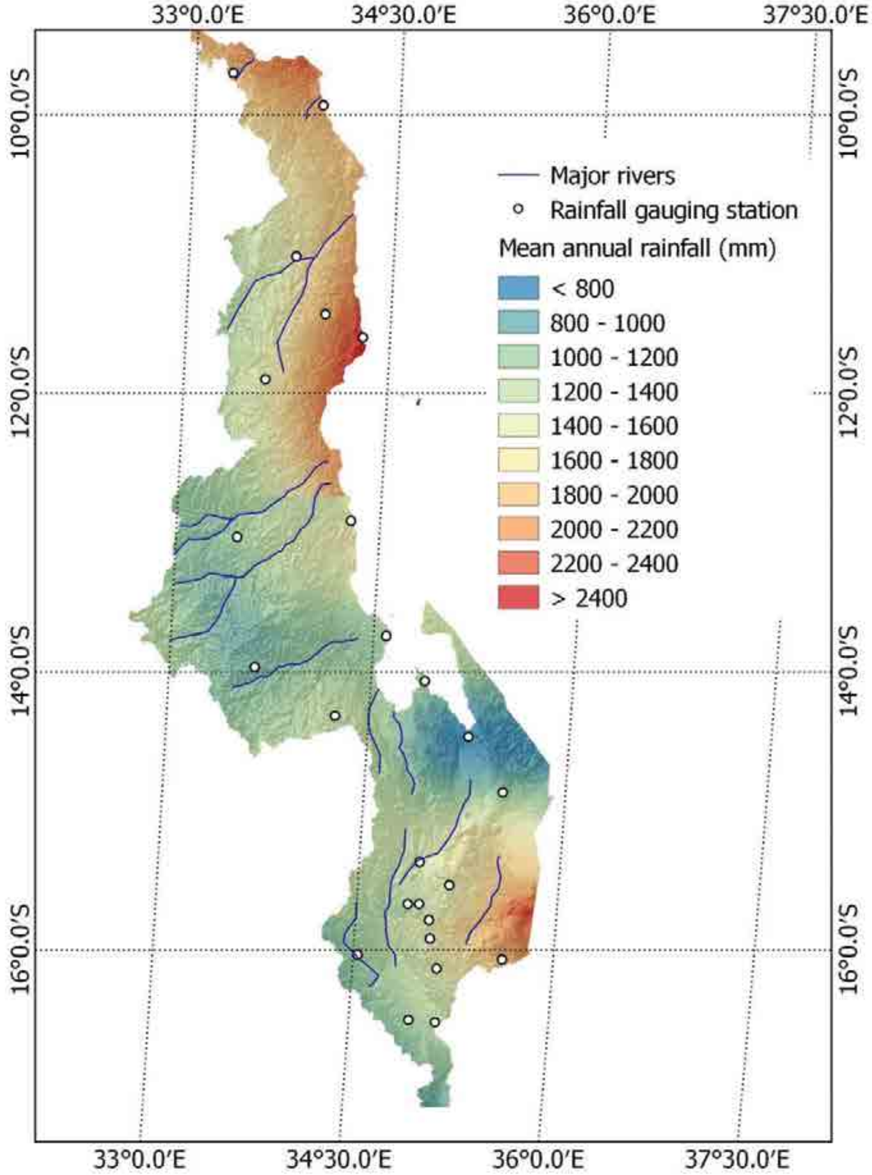


Figure 2.4: Mean annual rainfall distribution in Malawi (Data source: GoM)

The relatively high rainfall amounts in the north and south regions together with the good agricultural soil types depict these regions as high agriculture potential areas of Malawi. However, limitations owing to steep slopes, threat of soil erosion, and lack of proper soil management may discourage the full realization of their agriculture potential.

2.5 Natural predisposition to soil loss vulnerability

From the soil and natural resource perspective, it is possible to identify areas with high vulnerability to soil loss. Such areas have the following combination of the features of the natural resources:

- Structurally unstable (susceptible to erosion) and shallow soils
- Steep slopes
- High erosive rainfall
- Reduced/low/sparse vegetation cover

Combinations of the above characteristics seem to be dominant in Rift Valley escarpments, west of the northern region, and high altitude areas in the south. Consequently, these areas are expected to register higher soil loss rates compared to other regions. Together with problems of unsustainable land management, these areas easily qualify as soil loss problem areas in the country. Some previous studies had shown these areas to be having the highest soil loss rates in the country (see for example World Bank, 1992).

Charcoal production ...

Example of steep slope, shallow soil and low vegetation cover

Burnt vegetation on steep slopes

...and sale

Examples of combinations of natural conditions and unsustainable human activities on the resource base

3 Soil loss in Malawi

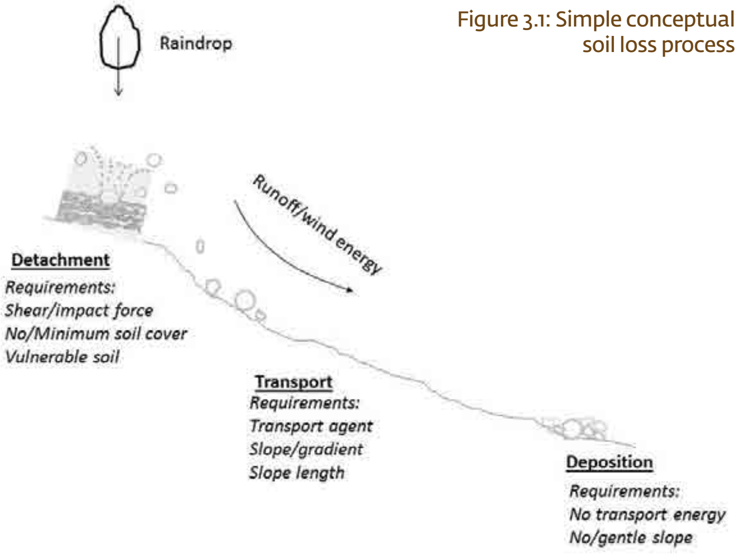
3.1 Soil loss process and modelling

3.1.1 Soil loss process and contributing factors

Before modelling soil loss, it's important to understand the soil loss process, its contributing factors, its various forms, and the commonly used models. Soil loss is a negative environmental process that begins in the early stages as structural deterioration and advancing to sheet and rill erosion, and finally to gully and riverbank erosion. Prevention and/control of soil loss at the early stages is much easier and less expensive than at the late stages.

During soil loss, the soil particles are first detached then transported before being deposited some distance away from the initial position. Particle detachment occurs when the individual soil particles are broken off from the soil mass due to shearing force (e.g. from tillage equipment, hooves of animal, surface runoff, etc.) or due to impact force (e.g. from raindrop) on the soil (Figure 3.2). The detachment forces are effective where the soil is vulnerable (easily detachable). Soil vulnerability is brought about by the inherent soil properties (due to weak chemical and physical soil properties), continuous poor soil management, and prolonged exposure to the weathering actions (Morgan, 1986). The forces also produce maximum effect if there is minimal restrictive soil cover (such as vegetation cover, mulches, abandoned crop-residue on farm, etc.).

Figure 3.1: Simple conceptual soil loss process



After detachment, the soil particles are moved away from their original place through a gradient. The most common sources of energy for transport are surface runoff or wind. These forces carry the detached soil particles either in suspension or by dragging them along the soil surface. They transport the soil in a sheet of moving water/wind or in concentrated channels such as rills or gullies. Sheet/rill/gully types of erosion derive their names from this aspect of soil loss transport. The transport energy, slope, and length of slope (for travel time) must be available for the transport phase of soil loss to be accomplished. Deposition usually occurs at the end of the transport phase when sufficient energy is no longer available to transport the particles.

The simple conceptual model in Figure 3.1 illustrates the following basic contributing factors to soil loss:

1. Vulnerable soil: Soils with weak structure, shallow depth, and medium to fine texture.
2. Detachment or transport energy: It's also known as agents of erosion and comes in the form of rainfall, runoff, or wind energy. They initiate the erosion process and transport the detached particles.
3. Land use/cover: It represents human intervention/acceleration in the erosion process as well as the vegetative cover to protect the soil against agents of erosion.
4. Topographic factors: They include slope and slope length. They provide the gradient for translating the detached soil.

3.1.2 Soil loss modelling

Soil loss models are mathematical/empirical relationships between lost soil and soil loss contributing factors. They are developed based on defining the most important factors in a given locality and relating them to soil loss through the use of observation, measurement, experiment and statistical techniques. In Africa, and particularly southern Africa, two popular models can be found: the Revised Universal Soil Loss Equation (RUSLE) and Soil Loss Estimation Model for Southern Africa (SLEMSA) (Elwell 1978; Wischmeier & Smith 1978). They both estimate the rate of soil loss in ton/ha/year.

In RUSLE, the rate of soil loss is estimated using the expression

Soil loss rate = $R * K * L * S * C * P$ (3.1)

where R is the rainfall erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the crop management factor and P is the erosion-control practice factor. The input data for using this model are:

1. Rainfall intensity and amount. These are used to derive rainfall erosivity. Rainfall erosivity is a function of its kinetic energy which is used in detaching soil particles. The most suitable expression for deriving rainfall erosivity is the one involving rainfall kinetic

energy (which is also obtained from rainfall intensity). There are numerous models that have been tested to give reliable estimation of erosivity from rainfall intensity-kinetic energy relationships (Morgan, 1986).

2. Soil properties. These are mainly texture, structure, organic matter content, and permeability. Monographs or mathematical models are available in the literature for combining these soil properties to estimate erodibility factor.
3. Relief or terrain parameters: These are slope (S) and length of slope (L) attributes of topography. These attributes are often combined in a single index (LS), which expresses the ratio of soil loss under a given slope steepness and slope length to the soil loss from the standard condition of a 5° slope, 22 m long, for which LS = 1.0. The appropriate value can be obtained from nomographs (Wischmeier & Smith 1978) or from tested models.
4. Land use/cover: Land use depicts type of management or use the soil is subjected to while cover takes care of the P factor in the RUSLE model. The appropriate value can be obtained from nomographs (Wischmeier & Smith 1978) or from tested models such as

$$LS = \left(\frac{x}{22.13}\right)^n (0.065 + 0.045S + 0.0065S^2) \qquad (3.2)$$

where x is the slope length (m) and S is the slope gradient in per cent, n is an index that varies according to the slope steepness (n = 0.4 for slopes of 3°, 0.3 for slopes of 2°, 0.2 for slopes of 1° and 0.1 for slopes of less than 1°)

Soil Loss Estimation Model for Southern Africa (SLEMSA) is an empirical erosion assessment model that was developed by Elwell (1978) for Zimbabwean conditions to predict long term average annual soil loss by sheet and rill erosion. It has since been used to

- Predict soil erosion rates
- Determine sediment sources
- Develop soil loss hazard maps

The model has been shown to be inadequate in estimating sediment yield into rivers as well as modelling soil deposition in depressions and gully erosion (Schulze, 1979). According to this model, soil loss is estimated using three sub-models (popularly known as input factors sub-models): crop ratio model (C), model for soil loss from bare soil (K), and topography model (X). The outputs of these sub-models are numerically multiplied to yield the soil loss rate. Each of these sub-models is further developed from modifications or combinations of the following input factors: climate (rainfall), soil texture, crop cover fraction, and topographic slope-length (Figure 3.2).

The crop ratio sub-model (C) is obtained from the following expression:

$$C = \begin{cases} \exp(-0.06i & i < 50\% \\ \\ \frac{2.3-0.01i}{30} & i \geq 50\% \end{cases} \qquad (3.3)$$

where *i* is the proportion of rainfall energy intercepted by crop cover. It can also be obtained as the product of the proportion of rainfall and crop cover fraction corresponding to the time of the rainfall.

The soil loss from bare areas sub-model (K) is obtained from

$$K = e^{(2.884-8.1209F+nl(E)(0.4681+0.7663F))} \qquad (3.4)$$

where *F* is the soil texture factor for erodibility and E is the rainfall energy.

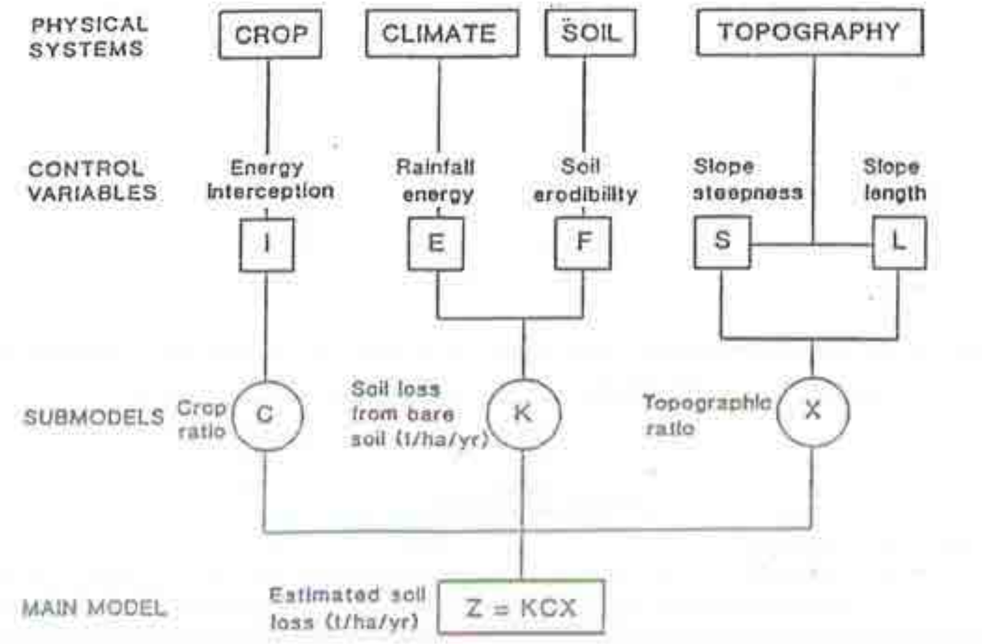


Figure 3.2: Framework for SLEMSA modelling

Elwell (1978) gave the guidelines for estimating F from soil textural class and E from long-term mean annual rainfall amounts for Guti and non-Guti rainfall patterns. The F value in these guidelines ranges from a scale of 1 to 10, from most erodible to least erodible (i.e. F is inversely proportional to soil loss). No direct way exists to measure F, so that its values are produced by a simple indexing method based on soil texture (light, medium, or heavy) and soil type. The preferred way is to obtain the basic index from the textural classes and then modifying by adding or subtracting an incremental value, which represents the soil treatment from past and present management practices that are deemed to reduce infiltration and increase runoff or alter the soil's resistance to detachment.

$$E = \begin{cases} 18.846 * annual\ rain & guti \\ 17.368 * annual\ rain & non - guti \end{cases} \quad (3.5)$$

The topographic factor is obtained from the following expression

$$X = \sqrt{l}(0.76 + 0.53s + 0.076s^2)/25.65 \quad (3.6)$$

where l is the slope length (m) and s is slope (%).

The input parameters for modeling soil loss using SLEMSA are derived from the modelling factors in Figure 3.2. They include soil texture, soil and water conservation measures, relief, climate and land use/cover. Table 3.1 gives a summary of the relevant input parameters and potential data sources.

Table 3.1: SLEMSA modelling factors and input data

SLEMSA sub-model	Control variable	Input data	Typical input data
Crop ration (C)	Rainfall intercept *i*	Annual rainfall seasonal distribution	Mean monthly rainfall
		Crop cover seasonal distribution	Remote sensing images
Soil loss from bare soil (K)	Rainfall energy *E*	Annual rainfall amount	Mean monthly rainfall
	Soil erodibility *F*	Soil texture	Soil map
		Soil and water conservation	Land use map
Topographic ratio (X)	Slope length *L*	Upslope area	DEM
	Slope *S*	Surface slope	

3.1.3 SELMSA and RUSLE model potential and limitations

SLEMSA and RUSLE soil loss models are both empirical models that have been widely applied in the southern Africa regions (Smith, 1999). They are useful in estimating soil loss rates from agricultural land, in planning land use strategies and soil conservation, in providing relative soil loss indices and for guiding government policy and strategy on soil and water conservation. Since they are empirically derived, they are simple and parsimonious, and their input data can be relatively obtained from meteorology departments, and land survey and soil department (Table 3.2). Furthermore, the data, pre-processing models, and the soil loss model applications can be easily implemented in many freely downloadable GIS and database software. This makes them easily adaptable for application in many regions of the world.

Table 3.2: Data and pre-processing needs for SLEMSA and RUSLE models

Model	Parameters	Input data	Pre-processing models	Data source
RUSLE	R	Rainfall	Spatial interpolation, rainfall energy models	Climate data
	K	Texture, structure, organic matter, permeability	Spatial interpolation, Erodibility model	Soil map
	L	Relief	Digital terrain modelling	DEM or contour map
	S	Relief		
	C	Land use/cover, Remote sensing image	Image correction and analysis	Land use/cover map, remote sensing images
	P	Soil conservation	Normograph	Soil map, Images
SLEMSA	K	Rainfall, soil texture, soil conservation	Spatial interpolation, rainfall energy models	Climate data
	X	Relief	Digital terrain modelling	DEM/contour map
	C	Land use/cover, Remote sensing image	Image correction and analysis	Land use/cover map, remote sensing images

In spite of their suitability, SLEMSA and RUSLE models have some limitations which should be noted while using them. The models:

1. are based on statistical analyses of important factors in the soil erosion process and yield only approximate and probable outcomes;
2. are not practical for the prediction of soil loss on an event basis;
3. estimate soil erosion on a single slope, instead of within catchments;
4. do not represent the process of sedimentation/deposition;
5. are restricted to sheet and/or rill erosion;
6. soil losses and gains over neighbouring areas are not considered; and
7. have poor performance in sandy soil.

In addition to the above limitations, empirical models such as RUSLE and SLEMSA should normally be considered valid only within the range of experimental conditions under which they were derived. However, since the equations employed represent the major factors affecting erosion, transferring them to other locations throughout requires only the determination of appropriate values for the different factors. For SLEMSA model, its application in Malawi should present few limitations since the model was developed in neighbouring Zimbabwe conditions.

3.2 Soil loss studies in Malawi

Pockets of soil loss studies in Malawi can be cited in the literature. The majority of these studies have been conducted in experimental plots or small watersheds in different parts of the country. Amphlett (1984) carried out soil loss studies in small plots in Bvumbwe, Mindawo, and Mphezo basins in the South Malawi and found seasonal soil loss rate to be between 0.15 and 16 ton/ha. Mwendera (1988) compared SLEMSA results with measured soil erosion values from a long-term soil erosion study site on four catchment areas near and around the Bvumbwe Agricultural Research Station in the south region of the country. The estimated erosion was 10 ton/ha/yr for an area without proper conservation and 0.0445 ton/ha/yr from a Eucalyptus tree plantation. in 1996, Mkandawire (1996) calculated SLEMSA values for the Chilindamaji in northern Malawi and reported average soil loss rate as 5.7 ton/ha/year for tobacco farmland and 33 .6 ton/ha/year for a plot under fallow conditions. In 1998, Malawi Environmental Monitoring Program (MEMP) studied soil loss in five small catchments located in various parts of the country and found the soil loss rate between 1 and 5 ton/ha/yr (Mahmoud and Burger 1998). In 1999, Jamu and Brummett (1999) studied soil loss in Zomba and found the soil loss rate between 1.2 and 100 ton/ha/year.

In a bid to extend soil loss estimation to the whole country, Khonje and Machira (1987) used the SLEMSA model with secondary information and expert opinion to develop national averages of soil loss. Their methodology was designed to make relative assessments of the risk of erosion over large areas, expressed in Erosion Hazard Units (EHU). These EHUs results were displayed in 10 km square grid map of Malawi with an eight-category legend that estimates the expected annual soil loss in tons per hectare. Overall, the study found the national average soil loss rate as 33 ton/ha/year. This approach was used with slight modification by World Bank (1992) to develop new soil loss rates. While recognizing the danger of exaggeration inherent in converting EHU into soil loss rates, the World Bank (1992) developed a general equation for converting EHU into expected soil loss through the use of simple regression analysis. The World Bank (1992) found the best fit using three equations which divided the EHU into three: EHU < 500, 500 < EHU < 1000, and EHU > 1000. This approach gave the average national soil loss rate as 20 ton/ha/year.

Apart from model applications, there are reports of studies that carried out on field-based soil loss measurements. Weil (1982) reported actual soil loss measurements at the Bunda Research Farm between 1978 and 1979 growing season. The report showed that weed-free maize plots produced soil loss of 12.1 ton/ha for 1978/1979 growing season, whereas unweeded plots showed soil loss of 4.5 ton/ha. In 1986, Amphlett (1986) reported soil erosion investigations undertaken by the Ministry of Agriculture (GoM) in conjunction with the Overseas Development Unit of the Hydraulics Research near Thyolo, south of Blantyre in the Southern Region. The reports showed soil loss between 0.03 and 0.13 ton/ha for each season in tree plantations and 4-14 ton/ha in traditional farming systems. In 1989, Chrome

(1989) reported average measured soil loss over a six-year period as 7.6 ton/ha/yr for a farming plot using traditional agricultural practices and 3.7 ton/ha/yr for a plot using agroforestry techniques. In 1998, Mohamoud and Burger (1998) reported soil loss measurements under the Malawi Environmental Monitoring Program (MEMP) in five small catchments located in various parts of the country. The reports showed that between 1 and 5 ton/ha/yr was lost in catchments having only mechanical soil conservation measures and between 0.03- 0.21 ton/ha/yr of soil was lost in catchment having a complete land use plan and for the plot with Eucalyptus plantation.

Although the above soil loss study results are not strictly comparable owing to differences in time, methods, and assessment scales, they pointed to a general soil loss pattern in the country. They found high soil loss rate potential in the north, in the Rift Valley, and some places in the south. Furthermore, their national average rates also gave a pointer to a baseline average of less than 50 t/ha/yr from different parts of the country. Nonetheless, it's important to note that these studies were varied, out-dated, and lacked some important aspects for monitoring such as trend analysis, drivers of erosion, and proposition for a monitoring framework.

3.3 Soil related policies and implementation

Soil loss modelling factors contain some characteristics that are directly amenable to human modification and those that are indirectly affected by long-term actions of human beings. The factors which are directly influenced by human actions include soil management and land cover. Rainfall erosivity is indirectly influenced by long-term actions of human beings (e.g. climate change). The GoM has developed policies and legislations that tend to regulate human actions with regard to (in)direct use and management of these factors. This section discusses these policies and the extent of their implementation.

3.3.1 Agriculture development policies

Since agriculture is the main contributor to the national economy, the majority of GoM policies have been centred on agriculture development. The policies touch the agriculture sector in form of expansion of agricultural land area and intensification of agriculture per unit land area (increase in input and spending, diversification, improved market, etc.).

During the colonial government, Malawi arable land was divided into estates (for the fertile land) and reserve (or smallholder) for the remaining land. The majority of smallholder agriculture was on customary land. At independence, the government changed some of the colonial agricultural policies to expand the number of export crops grown in smallholder agriculture; which allowed the smallholder agriculture to produce more export crops. The independent government policy focus was, therefore, on reversing colonial neglect of peasant agriculture and removing the coercion that had been introduced to combat soil erosion. Several policies were implemented to support the government focus. They included the promotion of technology adoption among smallholder farmers particularly hybrid maize and application of fertilizers supported by a government administered credit scheme, provision of extension services through a network of extension offices across the country, subsidies on inputs and a system of guaranteed pan-territorial and pan-seasonal prices for agricultural produce. All together, they facilitated agriculture intensification. This was the onset of continuous cropping and land tilling.

After 1968, the government switched policy focus from smallholder agriculture to estate agriculture to drive the economy. Some parcels of land under smallholder agricultural were converted (in one way or another) into estate agriculture (Chirwa et al., 2008). The government policies facilitated the rapid expansion of estate agriculture at the expense of smallholder agriculture through easy acquisition of customary land. Between 1981 and 1994, the government introduced the structural adjustment reforms which re-targeted the smallholder agricultural sector with the aim of improving its performance. Some of these reforms included phased removal of fertilizer subsidies, deregulation of fertilizer marketing and liberalization of burley tobacco production by smallholder farmers. The liberalization of burley tobacco led to an increase in the number of smallholder farmers growing the crop. It's important to note that prior to these reforms, burley tobacco was mainly grown in estate agriculture and exported directly by the estate owners. This change also brought along the agriculture extensification as many farmers wanted a byte of income from the much promising tobacco farming. More land was opened up for agriculture and more agricultural work was put on the existing farmland.

Between 1995 and 2007, the agriculture sector reforms targeted increase of food crop production particularly maize, promoting livestock development, reducing post-harvest losses in food crops and improving efficiency of markets. The government increased its subsidy roles by providing more subsidies on the purchase of fertilizers and seeds for smallholder farmers. The subsequent increase in productivity introduced a new level of interest in farming which was fertilizer-based. The majority (both policy makers and farmers) got inclined to increase the use of fertilizer to increase productivity. There was silence on sustainable land management.

In 2002, the GoM introduced the Malawi Poverty Reduction Strategy (MPRS) whose strategies were to increase agricultural incomes through access to inputs, technology and extension services, access to domestic and international markets, promotion of irrigation, promoting crop diversification, and livestock development. This strategy was later changed to Malawi Economic Growth Strategy (MEGS) in 2003 with focus on economic and private sector driven growth. In 2006, the GoM again changed MEGS to the first Malawi Growth and Development Strategy (MGDS I) with focus on the agricultural sector in increasing productivity, value addition, market facilitation and irrigation development (GoM, 2006).

The purpose of the MGDS I was to serve as a single reference document for policy makers in Government and its development partners. It identified six key priority areas which defined the direction the country intended to take in the next five years to achieve economic growth and wealth creation. Agriculture and food security and irrigation and water development were among the six key areas. In order to support the six key priority areas, the development framework of the MGDS I was built around five broad thematic areas namely sustainable economic growth, social protection, social development, infrastructure development, and improved governance. It's important to note how the MGDS I was silent on environmental protection and particularly on soil management in its broad terms.

Between 2007 and 2009, the Malawi Government formulated a sector-wide program, the Agricultural Sector Wide Approach (ASWAp), to harmonise investment and support programs in the agriculture sector. The focus in this program, among others, was to expand the land area under agriculture and improving agriculture inputs as a way of improving agricultural productivity (MoAFS, 2011). A study by UNDP - UNEP PEI Malawi in 2011 (Yaron et al., 2011) demonstrated the need to include environmental sustainability in the implementation and monitoring of ASWAp; implying that the program implementation was not addressing the detrimental effects of agriculture intensification and expansion to the environment. The implementation of the program is still on-going.

3.3.2 Natural resource and sustainable land management policies

In 1994, GoM developed a National Environment Action Plan (NEAP) and followed it with a National Environment Policy (NEP) in 1996. The NEP strived to promote sustainable social and economic development through sound management of the environment. It also provided an overall framework against which relevant sectoral environmental policies were to be developed and revised to ensure that they were consistent with the principle of sustainable development. However, policy gaps, conflicts, and duplication, largely affected its effective implementation. The policy was revised and improved in 2004.

In 1995, the Malawi constitution of 1995 included some aspects of environmental protection in Section 13. However, it didn't expressly mention sustainable land management (SLM) phrases or indicated a way of implementing SLM practices. In 1998, the Malawi Vision 2020 was launched and with a rather clear goals on SLM. In 1999, the government undertook a comprehensive review of all agricultural sector policies under the Malawi Agricultural Sector Investment Programme (MASIP) (MoAFS, 2011). This culminated into several sub-sector policies such as Land Resource Conservation Policy, the New Agriculture Extension Policy, the Research Master Plan, the Livestock Development Policy, the Irrigation Policy, etc. In 2000, GoM developed the National Land Resources Management Policy and Strategy (NLRMPS). The Policy was initiated by the then Ministry of Agriculture and Irrigation Development and financially supported by UNDP and FAO. It was a first attempt at documenting a set of policy on land use and management in the history of Malawi. The implementation of this policy is currently done by the Land Resource Conservation Department (LRCD).

Since independence, the GoM first enacted a comprehensive national parks and wildlife act in 1992. The Act consolidated the law relating to national parks and wildlife management and established the Wildlife Research and Management Board. It also had provisions in section 28 that gave some edge to possible changes of any area of land or water within Malawi national park or wildlife reserve.

In terms of forest cover, the GoM started with the establishment of Village Forest Areas (VFAs), which were set aside by the Tribal Authority (TA), with technical support from the Forest Department (FD) in 1940. Forest guards were also appointed and posted to each TA. At the same time, first attempts were made to encourage reforestation of denuded lands although it's reported that the results were unsatisfactory because of unsuitability of the planting sites for the (exotic) species (Mauambeta et al., 2010). Between 1964 and 1985, the FD shifted its attention to establishing industrial plantations for national timber self-sufficiency. During the same time, Forest Guards were withdrawn from Tribal Authority (TA) areas, and placed in the forest reserves. The TAs were weakened and no longer able to protect and manage their VFAs. In addition, the forestry extension service became the responsibility of Agricultural Extension workers, who had little knowledge and interest in forestry. Consequently, many people moved into and cleared large areas of the VFAs. In the early 1990s, the FD took over the responsibility of protection, control and management of customary lands. Due to policy shifts, FD faced financial constraints and was under pressure to generate revenue. Consequently, the department created Customary Land Division within the FD to oversee extraction of royalties for timber and firewood harvesting from customary land. This ended up with large scale extraction of timber and firewood including from VFAs, individual's fields and gardens and along riverbanks. In the late 1990s and early 2000, forest policy implementation was extremely weak and many people turned to the forest to extract timber, charcoal, and expand their agricultural land. The layoffs which the GoM undertook in the FD resulted into further destruction of the forests. Furthermore, between 2000 and 2010, FD experienced low funding and remuneration. This further escalated mismanagement of the forest cover and accommodation of illegal forest management activities.

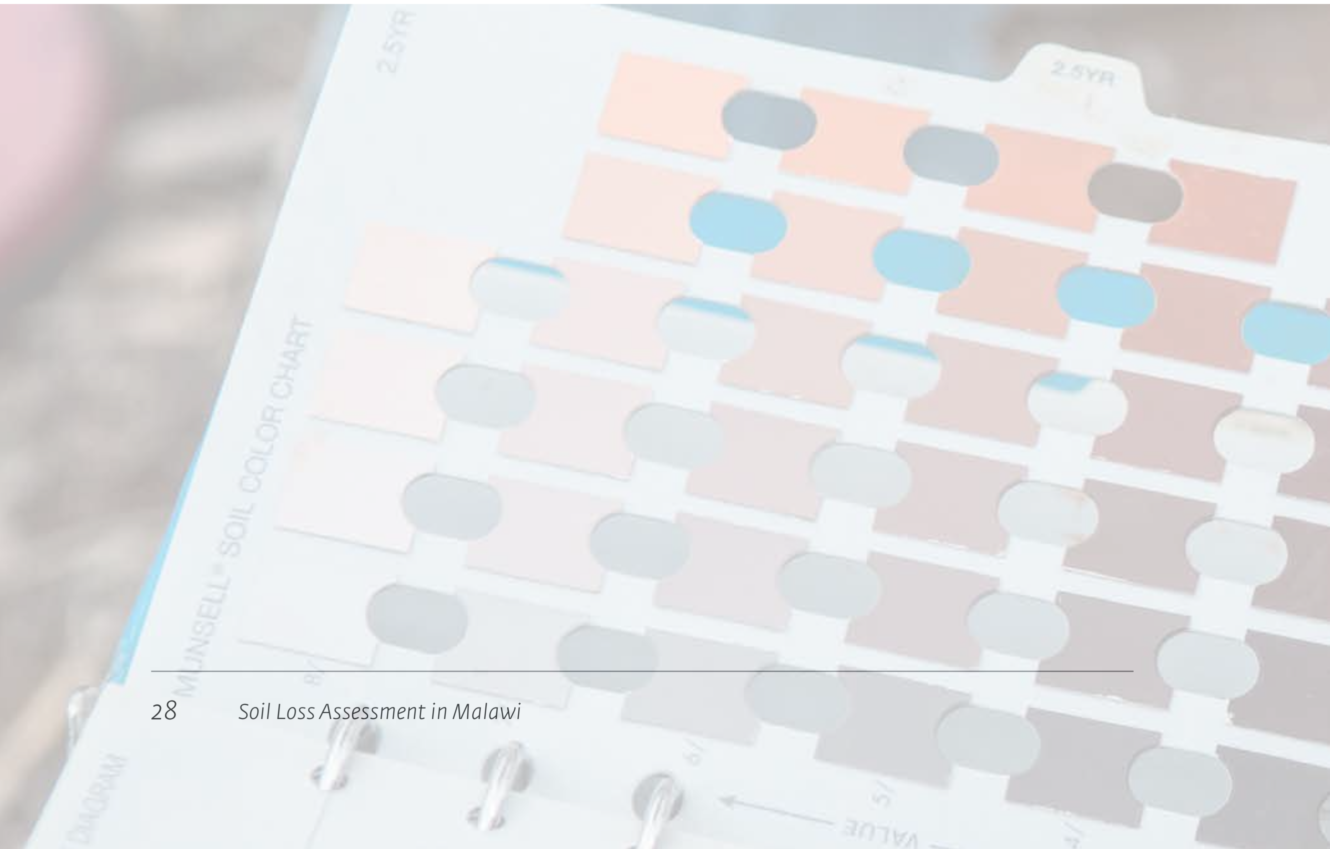
3.3.3 Land policies

Land policies in Malawi started with fragmentation focus as early as the colonial era. During the colonial era, the government introduced the African Order-in-Council and the Foreign Jurisdiction Ac, which gave the government power to issue titles and declared the native land as Crown Land. The Act removed the traditional customary ownership of land and replaced it with freehold, leasehold, and Crown land ownership types. The majority of freehold owners became estate owners while the natives lived in the Crown land. This was the onset of estate and smallholder concepts of agricultural land. In 1924, the Land Commission recommended that land held by the Government as Crown land, other than that reserved for European occupation, were to be converted to Native Trust Land. This recommendation was put into effect in 1936 (Pachai, 1973). The Native Trust Land was later changed to African Trust Land in 1950. In 1962, Africans on Private Estate Bill was tabled in Parliament with the focus of accelerating transfer of estate land to Trust Land. In 1964, the government introduce Malawi Land Bill whose focus was to reclassify the colonial system of freehold, trust land and crown land as private land, customary land, and public land, respectively. This was enacted as Malawi Land Act 1964 and essentially re-introduced the customary land ownership but with overall government control. All smallholder farmers belonged to the customary land (Phiri, 1991). In 1967, the Land Act was amended in which the customary land became private land whose trusteeship was vested in perpetuity of the president (Pachai, 1973). The reason for the amendment was that the traditional patterns of land tenure militated against the emergence of economic farming systems (Phiri, 1991). The amendment effectively gave the government the right to control land. The government later used this act in many instances to expand the area of land under the individually tenured estate sector and restricting the area of land under the customary tenured sector. Furthermore, the act provided an easy mechanism for the transfer of land from customary to leasehold tenure, which led to the alienation of customary land. The majority of fertile (arable) customary parcels of land were alienated to the estate sector by the government (Mkandawire and Phiri, 1987). In addition, customary land alienation and population growth caused a reduction in cultivated land per farmer.

Between 1945 and 1960, general public concern started growing with regard to no financial security on customary land tenure since its usufruct was in perpetuity and inheritable. This lead to the passage of the following three acts of parliaments in 1967: Customary Land (Development) Act, Registered Land Act, and the Local Boards Act. They provided for ascertainment of rights and interests in customary land and conversion of land under customary tenure to individual title, registration of individual titles of family titles and transfers, and institution of boards to control land transactions and the partition of family land to individual members.

In 2002, the GoM developed the National Land Policy (NPL) 2002. The goal of the National Land Policy was to ensure tenure security and equitable access to land, to facilitate the attainment of social harmony and broad based social and economic development through optimum and ecologically balanced use of land and land based resources (NLP, 2002: 1.4.1). The NPL states that the attainment of the broad policy goal hinges on a number of specific objectives, which include:

- The need to promote tenure reforms that guarantee security and instill confidence and fairness in all land transactions, and which assures security on tenure and equitable access to land without any gender bias and/or discrimination to all citizens of Malawi;
- The need to promote decentralized and transparent land administration;
- The need to extend land use planning strategies to all urban and rural areas;
- The need to establish a modern land registration system for delivering land services to all;
- The need to enhance conservation and community management of local Resources;
- The need to promote research and capacity building in land surveying and land management by promoting research and continuous education of the public on all aspects of the duties and obligations of land tenure, land stewardship, and operations of the land market.



Under the specific objectives targeting land use planning and enhanced conservation of local resources, the NLP advocated for the following strategies:

- Land use conflicts to be studied to determine their cause(s) and strategies for resolving them employed. In addition, the agro-ecological zoning studies to be undertaken to determine land potentials and capabilities for the whole country;
- The government to introduce buffer zones in areas where agriculture conflicts with forestry or grazing land. Where possible, multiple land uses such and agro-forestry were to be encouraged;
- The agro-ecological zoning to be used to develop a National Land Use Plan and land use management handbooks, and for developing community development action plans for use by civic educators and extension officers;
- Environmentally friendly and sound human activities to be encouraged to preserve wildlife habitat, forest cover for the headwaters of rivers and water catchments areas;
- Sensitive areas like steep slopes, severe gullies, overgrazed lands, shallow soils and semiarid lands, which form fragile ecosystems to be earmarked for conservation;
- Endemic species, critical habitats and wetlands to be studied in order to determine proper techniques of conservation by designated authorities and community caretakers.

In spite of very good clear guidelines, their actual implementation is still a matter for concern. Presently, the GoM and its development partners are implementing the ASWAp program. This ASWAp is seen as an avenue for implementing the strategies outlined in the NLP (Madola, 2003).

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4 Modelling approach using SLEMSA

4.1 Overall approach

The overall plan of this study was to use the SLEMSA model to estimate national topsoil loss in a way that gives the current rate of topsoil loss in Malawi, a footprint history of topsoil loss rates in the past 10 years and potential drivers of soil loss in the country, and capacity building of local staff to implement future soil loss assessment activities. All these aspects were implemented in two phases: phase 1 involving modelling and validation; and phase 2 which involved capacity building.

Application of the SLEMSA model was accomplished by developing a protocol for sourcing the input data, application of appropriate software and hardware to implement SLEMSA, and validating the model outputs (Figure 4.1). Aspects of capacity building in form of training and equipment transfer were also included in the developed protocol.

The main activities during the study can be summarized into three: desk modelling, model validation and improvement, and final modelling and capacity development (Table 4.1).

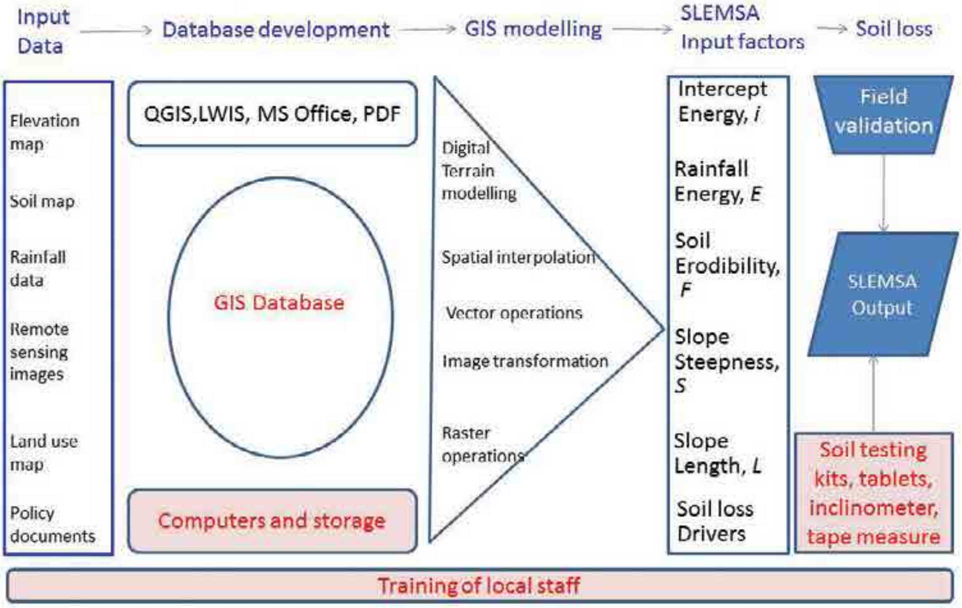


Figure 4.1: Methodological framework

Table 4.1: Flow of activities implementing soil loss study

Approach	Study Objectives
Desk modelling	
Desk review	To model annual topsoil loss in Malawi
	To identify soil loss drivers
Capacity building	To build local capacity for estimating soil loss using SLEMSA
Model validation and improvements	
Field validation	To build local capacity for estimating soil loss using SLEMSA
	To model annual topsoil loss in Malawi
Final modelling and recommendations for a monitoring framework	
Modelling soil loss trends	To model annual topsoil loss in Malawi
	Identify soil loss drivers and hotspot areas for targeted intervention
	Recommend a soil loss monitoring framework for assessing soil loss trends

Activities	Outputs
Desk modelling	
Identify and collect input secondary data	SLEMSA input database developed
Evaluate and Prepare input data	
Run preliminary SLEMSA model	Preliminary recent soil loss map
Identify field validation sites	Identified validation sites and budget
Develop field validation protocol and budget	
Literature review	Identified drivers of soil loss
Equip staff with high-end computers for soil loss modelling	Four laptop computer procured for LRCD staff and software installed
Train local staff in data acquisition and SLEMSA modelling	LRCD staff develop protocol for data acquisition and modelling
Model validation and improvements	
Train local staff in carrying out field validation	Local staff trained in soil loss field validation
Equip local staff with on-site field sampling and soil testing kits	Three pairs on-site field sampling and soil testing kits procured for LRCD staff
Carry out field validation	Field samples and data collected
Final modelling and recommendations for a monitoring framework	
Re-calibrate the SLEMSA model outputs	Validated current soil loss map
Develop soil loss model trends	Soil loss Atlas for Malawi
Identify soil loss hotspot areas	Map of soil loss hotspot areas
	Soil loss trend between 2000 and 2015
Proposal for protocol for monitoring soil loss	A monitoring framework recommended

4.2 Input data

4.2.1 SLEMSA model input data

The input data required for soil loss modelling using SLEMSA were: rainfall amounts and intensity, soil texture and conservation measures, landscape relief, land cover, and NDVI. These datasets were obtained from secondary data sources as shown in Table 4.2. Some of these data are already elaborated in Section 2 of this report. The rainfall data was obtained in monthly rainfall amounts (mm) and annual maximum intensity (mm/hr). The soil data was derived from the soil map of Malawi which contained soil texture attributes, soil depth, and erosion potential. Soil management was derived from the land use types as contained in the land cover map and sites where LRCD has been implementing soil conservation sites. The NDVI images were 16-day MODIS images which are released every 16 days since July 2000.

4.2.2 SLEMSA validation data

SLEMSA validation data included: soil loss measurements for sheet and rill erosion, soil texture, vegetation cover, slope and slope length, and soil management (conservation) practised. These data were collected during field validation exercise from 104 sample sites (at least 4 sites in each district).

In situ measurements were carried out for soil loss rates, soil texture, slope, and slope length while observations were done for land cover and soil management types. Soil loss rates were measured using the Stocking and Murnaghan (2000) approach. According to this approach, sheet erosion was measured using the tree mound method while rill erosion was measured using the rill method. Land slope was measured using an inclinometer while slope length was measured using a tape-measure. Soil texture was determined in two steps. Step one involved in-situ measurement of soil particle composition using modification of the Bouyoucos (1962) method. In step two, particle compositions were combined to classify them into the appropriate textural class. The soil texture package in R was used for the derivation of the textural class (Moyes, 2015).

Table 4.2: SLEMSA input data and sources

Input data characteristics			Duration	Scale/number
Category	Aspect	Type		
Rainfall	Amount	Point (weather station) data	1999 - 2014	25 stations
	Intensity	Point (weather station) data	2000 - 2013	9 stations
Soil	Texture	Polygon map (soil map)	2010	1:200,000
	Management	Polygon map (Land cover map)	2010	1:200,000
		Point (soil conservation sites)	2012-2014	10 sites
Land cover	Cover type	Polygon map (Land cover map)	1991, 2010	1:200,000
	Proportion	Raster map (NDVI)	2000 - 2015	250 m
Relief	Slope	Raster map (DEM)		30 m
	Slope length	Raster map (DEM)		30 m

*16-day MODIS NDVI images from **http://pekko.geog.umd.edu**
ASTER DEM from **http://lta.cr.usgs.gov

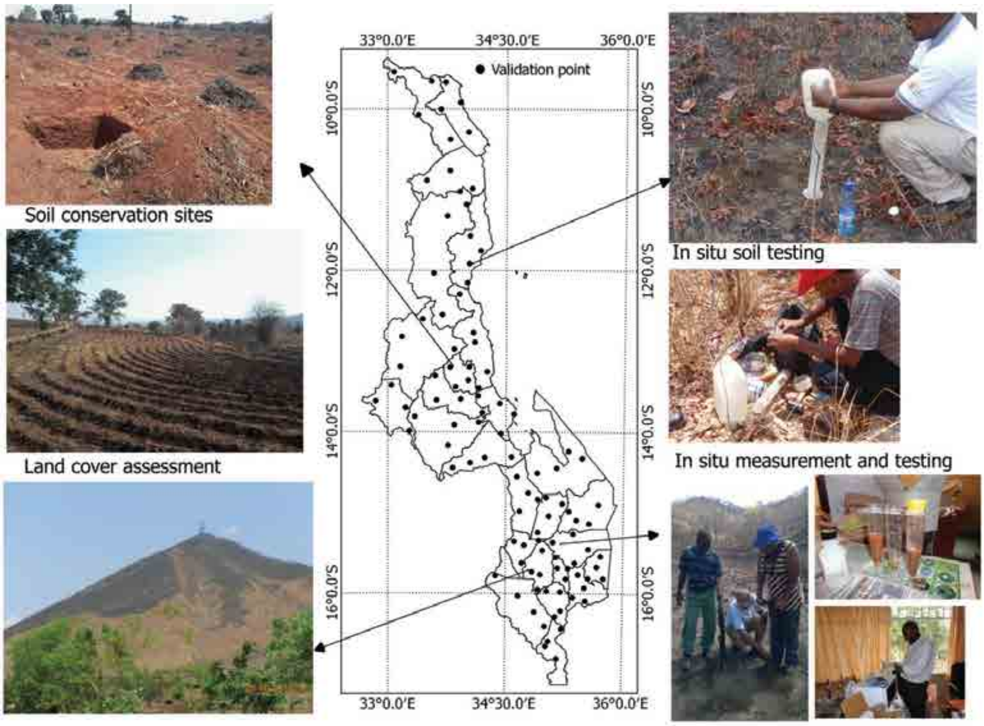


Figure 4.2: Input data collection for validating soil loss model

4.2.3 Input data preparation

The following steps were carried out to shape the input data ahead of SLEMSA modelling in order to make the data compatible with each other and for deriving spatially exhaustive SLEMSA outputs (i.e. gridded SLEMSA products):

1. Spatial interpolation of rainfall amounts

The monthly rainfall data from the weather stations were first summed to give annual rainfall amounts. Then, the annual rainfall amounts were spatially interpolated to convert them into annual rainfall raster maps. After testing different spatial interpolation methods in the literature, the regression kriging method was found to give reliable and accurate results. According to this method, two steps are used: development of regression models between annual rainfall amounts and its predictors (in this case, NDVI and DEM); and then modelling the spatial dependency of the regression models using the kriging approach. This approach was used and implemented in the R software. Example output of spatially interpolated rainfall amounts with background Hillshade map is given in Figure 2.4. All annual rainfall amounts from 1999 to 2015 were interpolated in the same way. The cross-validated correlation coefficient ranged between $r^2 = 0.69$ to $r^2 = 0.77$. Although not so high, the interpolated results were accepted in this study for application in SLEMSA modelling.

2. Determination of slope and slope length

The slope and slope length were established from DEM using digital terrain modelling techniques. The SAGA-GIS software was used to derive these parameters with DEM as the only input data. Example output slope map from this pre-processing is given in Figure 2.3.

3. GIS operations

Some GIS procedures were undertaken to align the soil and land cover maps with other gridded input data. They included attribute map development and vector-to-raster conversions. Attribute map development was done by converting the following attributes in the vector maps into integer factors: soil texture attribute in the soil map and land cover type attribute in the land-cover map. The integer attributes were then used to develop the respective attribute map (or vector maps). The final vector maps were then converted to raster (grid) maps. These grids were co-registered to a common datum (georeferenced) and pixel resolution. NDVI images were also radiometrically corrected according to the metafile information from the download website (*http://pekko.geog.umd.edu/*).

4.3 SLEMSA modelling

4.3.1 Development of input factors and model calibration

The input factors for SMELSA modelling are given in Figure 4.1. They were developed from the pre-processed input data. This section discusses how they were developed.

1) Topographic factor (X)

The topographic factor was developed from the slope and slope length gridded maps as the input into Equation 3.6 model (in section 3.1 of this report). In order to avoid excessively high slopes creeping into the model, a limit was set for maximum slope to use in Equation 3.6. After analysis of rocky steep slopes in the county, more than 20% slopes were screened out. These slopes were mainly rocky without much soil (Figure 4.3)

Figure 4.3: Examples of steep slopes in the country

2) Soil factor (K)

This factor was developed in two steps: step 1 in which rainfall energy was determined and step 2 where soil erodibility factor was determined. In step 1, the rainfall energy was first obtained from the maximum annual rainfall intensity. Since rainfall intensity records were not available for all the years since 2000, a relationship was established between rainfall energy and annual rainfall amounts to predict the rainfall energy for the period of analysis (i.e. 2000 to 20150). The following energy-intensity relationship by Hudson was used (Hudson, 1965; Morgan, 1986),

$$Energy\ (MJmm^{-2}) = 0.298\left(1 - \frac{4.29}{I_{max}}\right) \qquad (4.1)$$

The resultant total rainfall energy was then correlated with the annual rainfall amount and the results compared with Elwel (1978) model for guti and non-guti rainfall which is given by

$$Energy, E = \begin{cases} 18.846 * Annual\ rainfall\ amount\ (mm) & guti \\ 17.368 * Annual\ rainfall\ amount\ (mm) & non-guti \end{cases} \qquad (4.2)$$

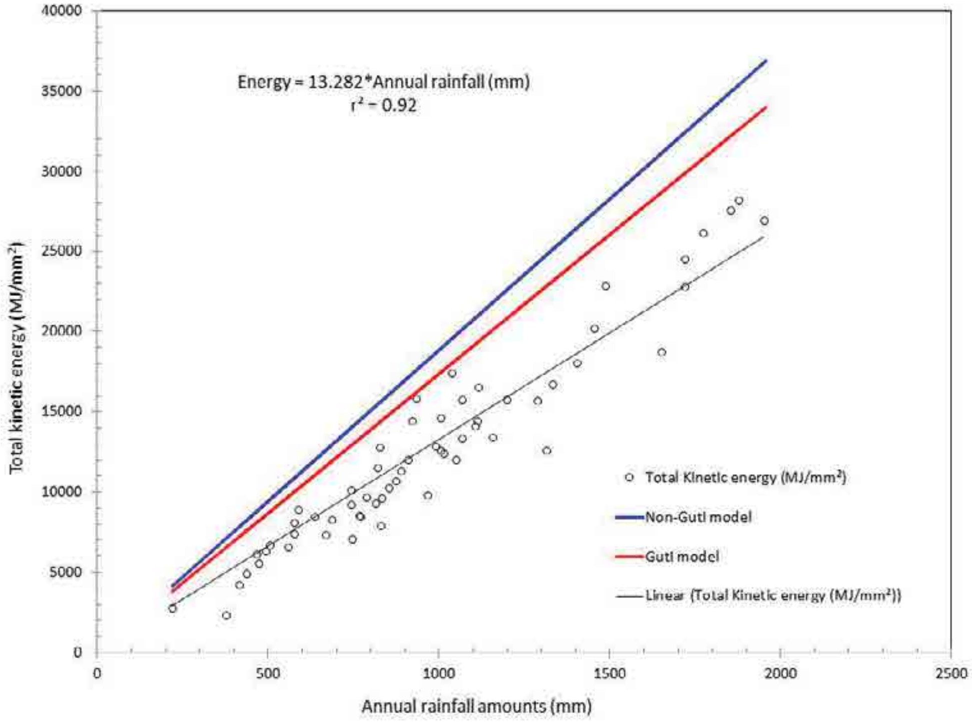


Figure 4.4: Relationship between maximum annual rainfall energy and rainfall amount

The correlation in Figure 4.4 depict an over estimation of the Guti and Non-Guti models for Malawi. Since the Guti and Non-Guti models were obtained in Zimbabwe over 30 years ago, potential difference with the current estimates could be expected. Consequently, the model in Figure 4.4 was used in this study to predict the rainfall energy from the mean annual rainfall amounts.

The second step involved deriving the soil factor involved the development of F value maps. Here, the gridded soil texture maps were used according to the guidelines given in Table 4.3 to produce the F-value map (Morgan, 1986). It's important to note that the F value increases with declining probability of soil erodibility.

Table 4.3: Calculation of the F value for soil erodibility (source: Morgan, 1986)

First calculation of the F value		
Soil texture	**Class**	**F value**
Sands	Light	4
Loamy sand		
Sandy loams		
Sandy clay loam	Medium	5
Clay loam		
Sandy clay		
Clay	Heavy	6
Heavy clay		

Adjustments to the 1st calculation of the F Value	
Add	**Soil and manage characteristics**
-1	Light textured soil consisting mainly of sand and silts
-1	Restricted vertical permeability within 1m from the surface or severe crusting
-1	Ridging up and down the slope
-1	Deterioration in soil structure due to more than 20ton/ha/yr in the previous year
-1	Poor management
-0.5	Slight to moderate surface crusting
-0.5	Soil loss 10-20 t/ha/yr in previous year
2	Deep well drained light textured soil
1	Tillage operations encouraging high water retention (contour ridging)
1	First season on no tillage
	Subsequent season on no tillage

3) Crop cover factor (C)

The crop cover factor, like soil factor, was also determined in two steps: step 1 in which vegetation communities/major land use types were established; and step 2 where the average cover in a year was established for the vegetation community. In step 1, the land cover attribute map was used to identify major vegetation communities such as deciduous forest, sparse shrubs and grass, grass, herbaceous vegetation, herbaceous crops, tree crops, etc.

In the second step, the NDVI images were averaged to obtain the mean NDVI for each year. The mean NDVI was then extracted for each polygon of the vegetation community in the land cover attribute map. GIS zonal statistics in a GIS software were used to establish the mean NDVI for each vegetation community. This mean NDVI was used as a proxy estimation of cover proportion for the vegetation community. The cover proportion was then used to determine the i-value for further application with Equation (3.3) (Section 3.1 of this report) to estimate the crop factor (C).

Once the input factors for the SLEMSA had been developed, the model was calibrated according to Figure 3.2. The calibration routines were written as computer codes in R software and the results exported to a GIS software (such as QGIS) for visualization and interpretation.

4.3.2 Validation of SLEMSA model

Several aspects of the SLEMSA data and outputs were validated in the field (Table 4.4). The following equipment were used for the validation: soil testing kits, physical observation, and in-situ measurements. The soil testing kits were used to determine soil erodibility indicators, slope, and slope length values in the field.

All the validation data were captured using mobile application algorithms which were developed and stored in mobile tablets. The captured data were relayed to a server for real-time update of the calibrated soil loss maps (Figure 4.5). The update algorithms (similar to the calibration models) were in- built in the server to perform automatic update and map development of the validated soil loss map.

Figure 4.5: SLEMSA validation data collection

Table 4.4: SLEMSA modelling validation approach

SLEMSA		Validation Approach	Instrument	Validation data
Input factor	Input data			
Topographic factor	Slope	In situ measurement	Inclinometer	Slope percent
	Slope length	In situ measurement	Tape measure	Slope length
Crop cover factor	Cover type	Class confirmation	Observation	Vegetation cover
	Cover (%)	Approximation	Quadrant	Cover percent
Soil factor	Soil loss	Field methods Stocking and Murnaghan,2000)	Tree mound	Soil loss rate
			Rill	Soil loss rate
	Soil erodibility factor	In situ soil testing	Hydrometer	Particle proportion
		In situ soil testing	Compaction tester	Compaction depth
		In situ soil testing	Infiltrometer	Infiltration rate (crusting)
		In situ soil testing	wet sieve	Aggregate stability (crusting)
	Rainfall energy	Correlation	Regression	Energy-annual rainfall relationship

4.3.3 Representation of soil loss severity

The validated soil loss rates were represented in terms of extent, degree, and severity criteria which were developed by FAO (2011). The soil loss extent was determined from the areas occupied by soil loss per district while the degree of soil loss depends on the magnitude of soil loss rates. The degree of soil loss rates was determined from the FAO (2011) with slight modifications for soil depth and soil loss tolerance levels. The degree of soil loss rates and affected areas were combined to give an indication of the severity of soil loss problems. Figure 4.6 illustrates the representation of these criteria.

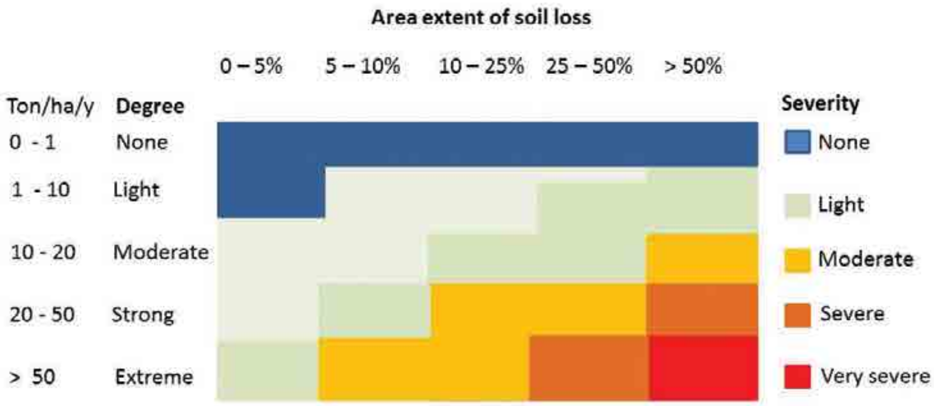


Figure 4.6: Guidelines for representing soil loss (Source: FAO, 2011)

4.3.4 Time-series modelling and identification soil loss hotspot

After SLEMSA model validation, the updated model was then applied to a time-series data for the period between 2000 and 2014. The time-series SLEMSA modelling produced gridded maps of soil loss rates from 2000 to 2014. This analysis was done for each pixel in the gridded maps to establish the trend of soil loss in those pixels. The following linear regression time-series model was applied to the time-series soil loss rates,

$$soil\ loss = m * time + constant + \ error \qquad (4.4)$$

where soil loss is the predicted time-series soil loss trend, m the rate of change of soil loss with time. The model was applied to the whole grid scenes. The areas (or pixels) showing negative m values were interpreted as areas which showed declining trends of soil loss (reducing trend of soil loss) and the areas showing positive values of m were interpreted as having increased in soil loss rates with time. The areas with increasing soil loss trends were identified as hotspot areas.

4.3.5 Identification of drivers of soil loss

Identification of drivers of soil loss was done by: 1) sensitivity analysis of SLEMSA input factors, 2) spatial analysis of hotspot areas, 3) analysis of literature information and relevant data (e.g. population, land use change, policy dynamics, climate change, etc.). The results from each dimension were then integrated into drivers of soil loss. The drivers were then separated into those that are amenable to human intervention in the short and long term and natural factors.

4.4 Capacity building and Monitoring framework

4.4.1 Capacity building

Capacity building was done in form of staff training and equipment support. Capacity building was envisaged to be useful in ensuring adequate local knowledge in validating the soil loss assessment products as well as guaranteeing future soil loss monitoring activities. Staff training was conducted for Malawi LRCD staff in the areas of:

1. Sourcing SLEMSA input data
2. SLEMSA input data preparation using GIS software
3. SLEMSA sub-model and main model development using the R Computing software
4. Field data collection using a tablet with GPS navigator and data collection Mobile Apps
5. Field measurements and soil testing
6. Computer modelling

The equipment support was achieved through procurement and transfer of the following equipment to the Malawi LRCD in Lilongwe:

1. High-end computers
2. SLEMSA modelling, GIS and MS office software
3. Mobile tablets
4. Field data collection support equipment
5. Field measurement and soil testing
6. Equipment Mobile laboratory and soil testing kits

5 Results

5.1 SLEMSA Input factors

In 2014, the SLEMSA input factors had the following ranges (max – min): X factor (23.18), C factor (0.00027), and K factor (20.062) (Figure 5.1). The Rift Valley ridge had the highest topographic factor values owing to its steep slopes. The northern and southern regions, which had high K factor values, were also shown in Figure 2.1 to be dominantly occupied by highly erodible Lixisols and Cambisols. It's interesting that the same is reflected with high values of K factor. These characteristics imply that the northern region and the rift valley seemed to have had more vulnerability than the other parts of the country in terms of soil, relief, and climatic factors of erosion.

The input data for these factors were: soil texture, permeability, compaction, and aggregate stability (for soil factor), rainfall amounts (for climate), and slope and slope length (for topographic factors). Of these input data, soil permeability, aggregate stability, and compaction are easily modified by human influence in the short term through soil management.

The above results show that the northern region and the rift valley are naturally predisposed to soil loss and that soil loss in these regions can be accelerated or reduced by soil management practices. A summary of input data types and main operations needed to produce the SLEMSA input factors is given in Figure 5.2. Detailed methods and steps have been shown in section 4.

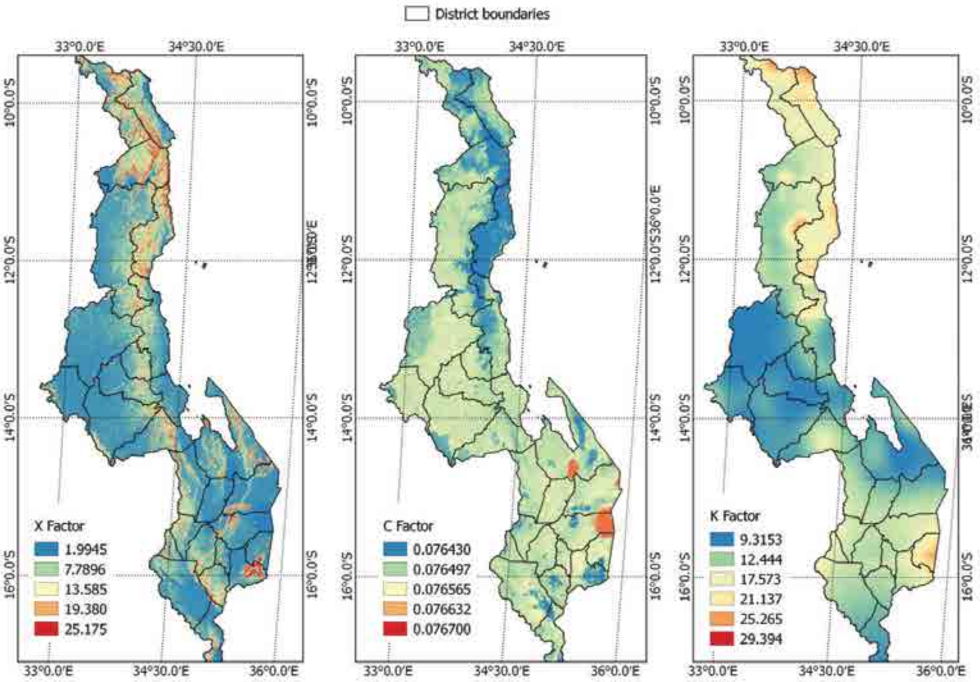


Figure 5.1: Examples of SLEMSA input factors

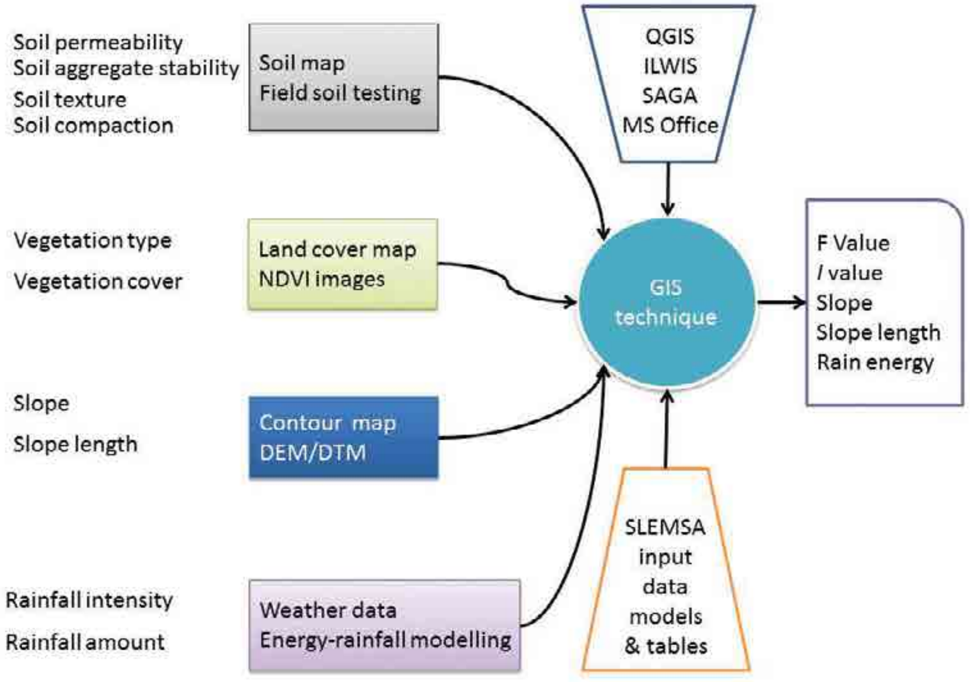


Figure 5.2: Input data requirement for developing SLEMSA model input factors

5.2 Soil loss rates

The SLEMSA model was implemented for all kinetic energy models shown in Figure 4.4 (i.e. for Guti, Non- Guti, and rainfall model in this study). The outputs were then compared with field validation (Figure 5.3). The comparison showed that the Guti model overestimated the soil loss rates throughout the whole range of measured soil loss rates. Although the Non-Guti model also overestimated the soil loss rates, it gave a fairly shrunken standard errors compared to the Guti model. The model developed with the rainfall data for Malawi showed better predictive performance. Its standard errors were low and depicted a rather uniform distribution throughout the range of measured soil loss rates (Figure 5.3).

The comparison between SLEMSA modelled and measured topsoil loss rates showed accuracy level of about 75% (Figure 5.3). The model had a balanced performance throughout the entire values (low and high) of measured topsoil loss rates.

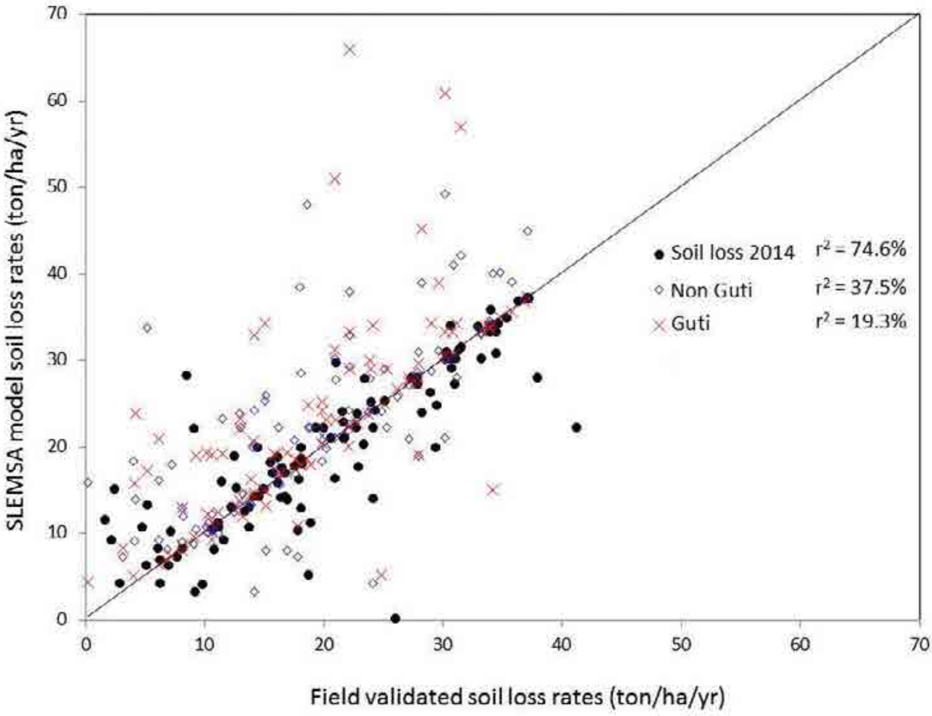


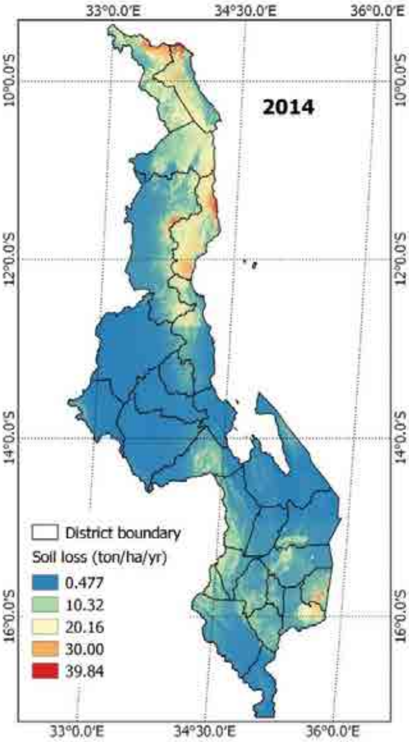
Figure 5.3: Validated and modelled soil loss rates

5.2.1 Baseline soil loss rates

In 2014, the topsoil loss rates were found to be high in the northern and southern regions. The northern region had topsoil loss rate ranging between 0.4 ton/ha/yr to 39 ton/ha/yr. Here, Nkhata Bay was the most affected district while Mzimba was the least affected. It's interesting that the World Bank (1992) report also found Nkhata Bay with the highest topsoil loss rates. Careful assessment of Nkhata Bay District show that it has the majority of steep slopes, fragile soil, and high rainfall, all of which could have contributed to high soil loss rates. These characteristics can be exacerbated by significant decline of natural vegetation and expansion of croplands in the District. Furthermore, recent land cover change analysis by FAO (2012), showed that the district has experience significant decline in natural forest cover and expansion of cropland areas.

Overall, in 2014, the national average soil loss rate was 29 ton/ha/yr. The areas with high extremes of topsoil loss rates were found to have had steep slopes, shallow soil, and with low vegetation cover (see some examples in Figure 5.5).

In terms of degree and severity of soil loss rates, the northern region seemed to have had moderate to severe soil loss problems while the rest of the country had light soil loss problem (Table 5.1).



REGION	DISTRICT	MEAN	STDEV	MINIMUM	MAXIMUM
North	Chitipa	15.22	7.8	0.4	39.08
North	Karonga	15.81	8.59	0.69	39.74
North	Nkhata Bay	19.83	7.35	2.28	38.01
North	Rumphi	11.24	6.4	0.78	30.84
North	Mzimba	6.42	5.75	0.43	33.94
Central	Kasungu	0.89	1.19	0.13	14.55
Central	Nkhotakota	6.43	6.11	0.56	30.6
Central	Ntchisi	2.76	1.82	0.34	8.93
Central	Dowa	0.9	0.46	0.24	3.43
Central	Salima	1.11	0.59	0.31	7.23
Central	Lilongwe	1.05	0.74	0.24	8.17
Central	Mchinji	1.07	1.23	0.22	9.81
Central	Dedza	4.17	3.4	0.39	19.88
Central	Ntcheu	4.53	3.5	0.38	19.48
South	Mangochi	1.44	1.35	0.11	9.97
South	Machinga	2.44	2.76	0.2	16.55
South	Zomba	4.92	3.29	0.98	20.49
South	Chiradzulu	5.37	2.85	1.22	18.41
South	Blantyre	5.49	2.9	1.07	16.16
South	Thyolo	6.19	2.13	0.91	15.37
South	Mulanje	9.64	7.76	1.57	33.4
South	Phalombe	10.22	8.15	2.54	35.17
South	Chikwawa	3.35	2.81	0.54	21.33
South	Nsanje	1.46	1.03	0.26	7.97
South	Balaka	2.1	1.05	0.38	12.64
South	Mwanza	9.03	4.51	1.27	23.32
South	Neno	7.44	4.26	1.44	21.07

Figure 5.4: Soil loss rates in Malawi in 2014

Almost bare hill and shallow soil in Neno

Rocky steep slopes in Nkhata Bay

Gentle sloping shrubland in Kasungu

Mixed cover and slopes in Dedza

Figure 5.5: Typical landscapes in selected paces in Malawi

©CIAT/Georgina Smith

Table 5.1: Degree and severity of soil loss rates in Malawi in 2014

Region	District	Mean soil loss rate	Proportion (%) areas occupied by different degrees of soil loss rate					Severity of soil loss problems
			None	*Light*	*Moderate*	*Strong*	*Extreme*	
		ton/ha/yr	0 -1	1-10	10-20	20-50	> 50	
North	Chitipa	15.22	0.0	32.7	41.1	26.2	0.0	Light to moderate
North	Karonga	15.81	0.0	31.7	37.0	31.3	0.0	Light to moderate
North	Nkhata Bay	19.83	0.0	12.1	33.9	54.0	0.0	Moderate to severe
North	Rumphi	11.24	0.0	44.1	47.7	8.2	0.0	Light
North	Mzimba	6.42	0.4	79.8	16.1	3.7	0.0	Light
Central	Kasungu	0.89	81.0	18.9	0.1	0.0	0.0	None
Central	Nkhotakota	6.43	3.9	75.1	15.3	5.7	0.0	Light
Central	Ntchisi	2.76	17.4	82.6	0.0	0.0	0.0	Light
Central	Dowa	0.90	73.8	26.2	0.0	0.0	0.0	None
Central	Salima	1.11	55.4	44.6	0.0	0.0	0.0	Light
Central	Lilongwe	1.05	70.0	30.0	0.1	0.0	0.0	None
Central	Mchinji	1.07	76.8	23.2	0.0	0.0	0.0	None
Central	Dedza	4.17	10.2	82.3	7.5	0.0	0.0	Light
Central	Ntcheu	4.53	8.3	81.8	9.9	0.0	0.0	Light
South	Mangochi	1.44	48.0	51.9	0.0	0.0	0.0	Light
South	Machinga	2.44	26.9	67.6	5.5	0.0	0.0	Light
South	Zomba	4.92	0.0	89.1	10.9	0.0	0.0	Light
South	Chiradzulu	5.37	0.0	89.6	10.4	0.0	0.0	Light
South	Blantyre	5.49	0.0	88.9	11.1	0.0	0.0	Light
South	Thyolo	6.19	0.0	96.5	3.5	0.0	0.0	Light
South	Mulanje	9.64	0.0	67.1	16.5	15.5	0.0	Light
South	Phalombe	10.22	0.0	72.0	15.8	12.1	0.0	Light
South	Chikwawa	3.35	3.7	91.8	4.5	0.0	0.0	Light
South	Nsanje	1.46	37.8	62.2	0.0	0.0	0.0	Light
South	Balaka	2.10	12.8	87.1	0.1	0.0	0.0	Light
South	Mwanza	9.03	0.0	62.4	37.1	0.5	0.0	Light
South	Neno	7.44	0.0	71.6	28.4	0.1	0.0	Light

Dowa, Lilongwe and Mchinji had 70% of their district areas with soil loss rates of less than 1 ton/ha/yr in 2014. Consequently, they were regarded as having had no major soil loss problems in that year. More than half of Nkhata Bay had soil loss rates of more than 20 ton/ha/yr; hence, the District was regarded as having had moderate to severe soil loss problems.

In general, in 2014 the soil loss problems in Malawi could be regarded to have been moderate in the north and light elsewhere. The north region had the highest values of the SELMSA input factor X and K (Figure 5.1). It's possible that these factors were responsible for the high topsoil loss rates in the region. The main contributors to high values of these input factors are slope, rainfall amounts, and soil erodibility. Therefore, it could be said that the steep slopes, presence of easily erodible soil and high erosive rainfall characteristics are the main contributing factors to high soil loss rates in the northern region.

In addition, the northern region had many reported cases of forest cover decline which could have exposed the vulnerable soil to impacts of erosive rainfall. During the validation, the north region also registered relatively low numbers of well-maintained soil conservation efforts and a high rate of destruction of the vegetation cover. Altogether, these factors could be contributed to the high soil loss rates.

In the south, Phalombe and Mulanje had the highest topsoil loss problems. The same regions were also depicted with probable high soil loss rates World Bank (1992). It is important to note that the District naming then is slightly different now (Phalombe included in Mulanje, Neno in Mwanza, and Balaka in Machinga). In terms of relief factors contributing to topsoil loss, Phalombe, Mulanje, Thyolo, Blantyre, Zomba and Neno seem to have the highest contributing factors. However, it's the soil factor (K) which distinguishes Phalombe and Mulanje as the top-risk districts. It can be said, therefore, that soil factors could be the major contributing factors to topsoil loss problems in these Districts.

5.2.2 Time series soil loss rates

Results of the time-series analysis of soil loss rates in the country from 2000 to 2014 are shown in Figure 5.6. It shows the areas which had significant increasing or declining trends of soil loss rates at 5% level of significance. The majority of areas with increasing trends of soil loss were observed in the northern region. Notably, Nkhata Bay had highest increase in soil loss rates between 2000 and 2014 while some parts of Chitipa, Keronga, Mzimba and Rumpi had slight increase in soil loss rates.

In the south, Mulanje and Phalombe had slight increase in topsoil loss rate while the remaining majority of the districts had declining rates or no significant change in topsoil loss rates (Figure 5.6).

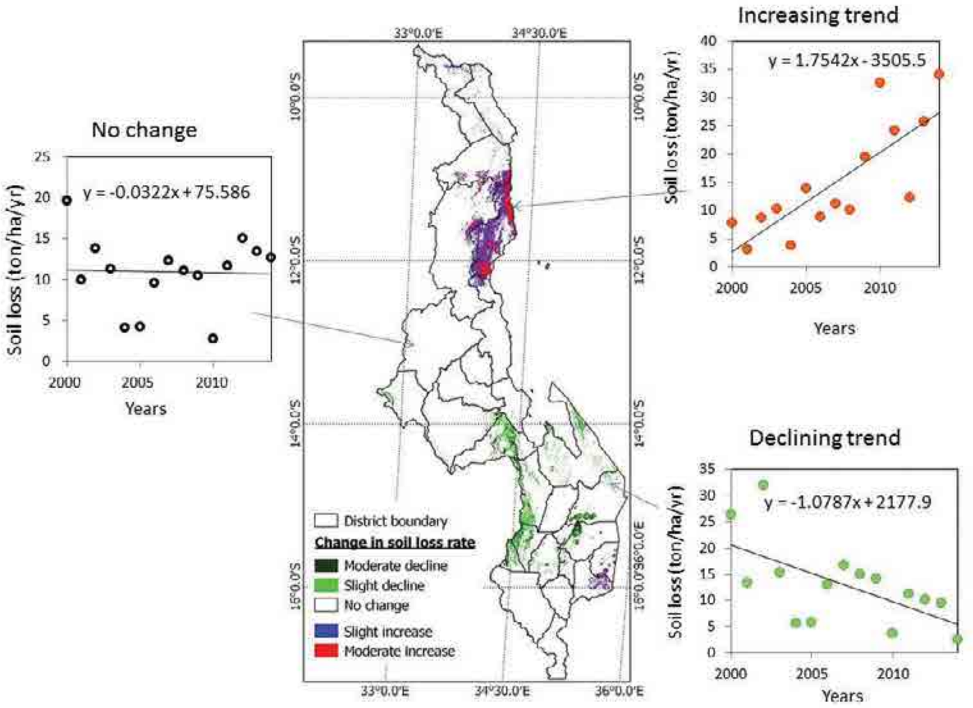


Figure 5.6: Time-series change in topsoil loss rate in Malawi between 2000 and 2014

Not only did Nkhata Bay have high soil loss rates but it also had the highest increasing rate of soil loss between 2000 and 2014. This further shows that the district had major soil loss problems compared to other districts. Its most affected areas are those along the Lake shore and around the border with Mzimba and Nkotakota districts. According to FAO (2012), these are the areas which showed the largest land cover change from natural vegetation to croplands or other land cover types without good vegetation cover between 1990s and 2010. It's probable that these cover changes contributed immensely to the increasing trends of soil loss.

The majority of the districts in the south were depicted to have had declining trends in soil loss rates. Especially in the Rift Valley sections, the soil loss rate seemed to have declined to less than 10 ton/ha/yr towards 2014. Potential increase in vegetation cover in these areas was reported in the FAO (2012) report and also observed NDVI image analysis. All together, the increase in cover point to potential positive human intervention which could have contributed to the decline in soil loss trend.

5.2.3 Bright and hotspots

The soil loss hotspot areas are those that had high (strong) soil loss rates in 2014 and also had increasing rates of soil loss between 2000 and 2014. The bright spots are those that had high (strong) soil loss rates but declining rate of soil loss between 2000 and 2014. The Rift Valley ridges in the Central (in Dedza and Ncheu) and in the south (in Zomba, Machinga and Neno) had the majority of bright spot areas. Nkhata Bay and some parts of western Mzimba were the hotspot areas of soil loss (Figure 5.7).

The bright spot areas should be closely monitored and properly managed lest they turn to major soil loss problem areas. Random points can be selected within the bright and hotspot areas to help with locating the soil loss monitoring points in these areas. The hot and bright spot areas in Figure 5.7 show that the majority of the country does not fall in the category of hot and bright spot areas. This implies that soil loss is majorly a problem in selected areas. However, without continued monitoring, the fragile and vulnerable areas may slip to problem areas.

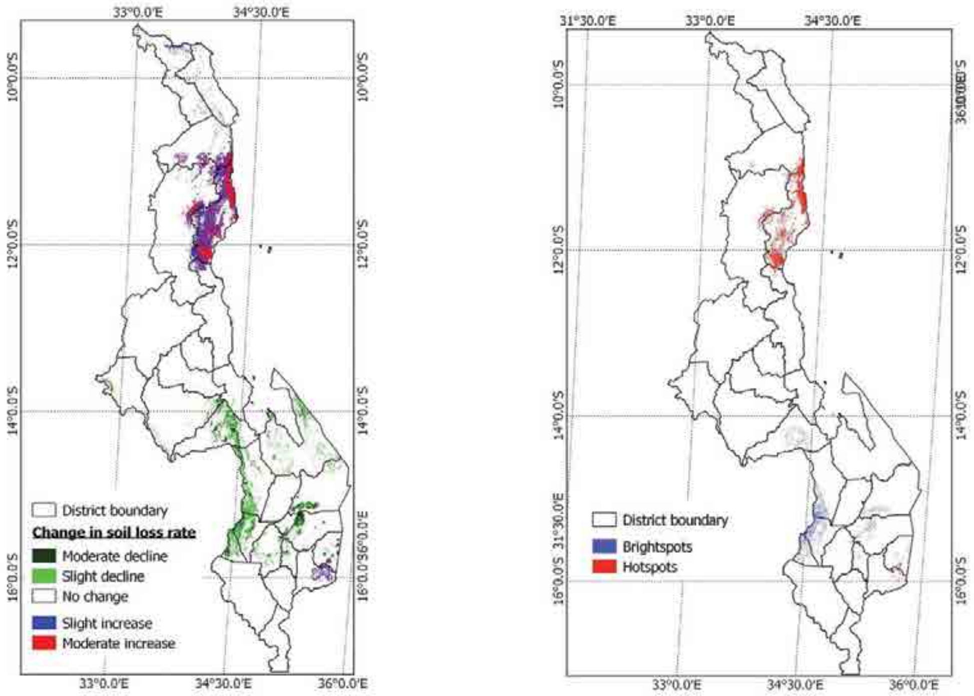


Figure 5.7: Bright and hotspot areas

5.2.4 Soil loss risk factors

Sensitivity analysis of the four main input factors into the SLEMSA model was done by calculating the soil loss per cent difference when varying the input factors from their minimum value to maximum values. The results showed that the SLEMSA model for soil loss estimation was sensitive to rainfall, slope, and soil (Figure 5.8). Slope inputs were the most sensitive contributors to SLEMSA model variations. The soil parameter (F-value) seemed to negative effect (perhaps because high F- value implies low erodibility in Table 4.3).

From the sensitivity chart, the combination of most sensitive input factors which can produce the highest soil loss rates are slope, slope-length, rainfall, and soil factors. This implies that high rainfall on steep slopes is a major risk for soil loss. In Malawi, Nkhata Bay and the border between Phalombe and Mulanje seemed to have this combination. This explains the reason for the high soil loss rates in these regions. Another combination of steep slopes and erodible soil could also produce the next high soil loss rates. In Malawi, this is possible on the Rift Valley ridges where the soil type is easily erodible young Cambisol in shallow areas.

In general, the major risk factors for soil loss in Malawi are: steep slopes, erosive rainfall, and erodible soil types.

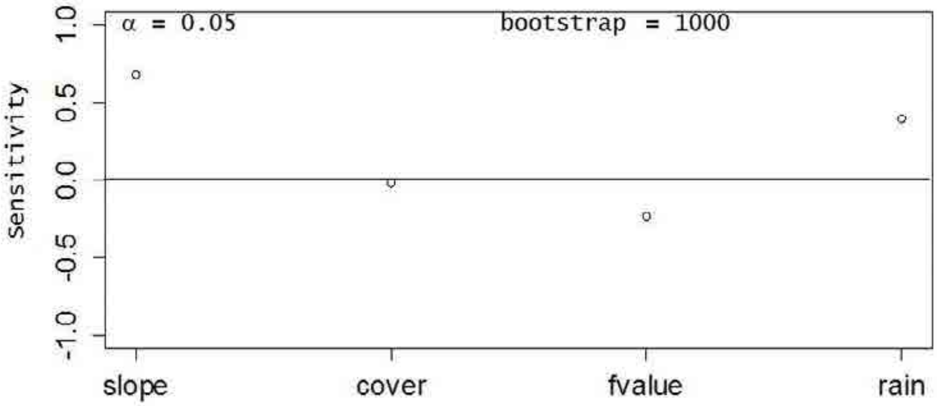


Figure 5.8: Sensitivity indices analysis of SLEMSA input factors

Although vegetation cover has low sensitivity to soil loss (Figure 5.8), it is a significant contributor by reducing the rainfall erosivity and protecting erodible soil. Consequently it can be regarded as an indirect risk factor to soil loss.

From the foregoing and literature review, the main contributors to increase in soil loss rates in Malawi are fragile soils on steep slopes and erosive rainfall. Human activities which can exacerbate these factors are:

- Poor soil management (which contributes to soil loss such as continuous carbon mining, tillage operations, exposure of bare soil to erosive rainfall, etc.)
- Agricultural activities on fragile soil on steep slopes
- Poor/low vegetation cover in high risk areas (such as steep slopes and erodible soil in high rainfall areas)
- Lack of policies/policy implementation of sustainable land management (SLM) practices, vegetation cover, sustainable utilization of non- renewable natural resources such as soil and vegetation
-

These factors can be grouped into direct and indirect causes of topsoil loss in Malawi.

a) Direct causes of soil loss in Malawi

The direct causes of soil loss in Malawi are those that directly influence the magnitude of SLEMSA input factors. They are also known as direct drivers (FAO, 2011). They include:

- Cultivation on steep slopes
- Vegetation cover decline
- Agricultural activities in structurally unstable shallow soils
- High erosive rainfall
- Agricultural expansion into vulnerable soil
- Lack of sustainable soil and water conservation measures

b) Indirect causes of soil loss in Malawi

Indirect causes of soil loss are those that condition/influence the direct causes of soil loss. They are known as direct pressure factors and include:

- Lack of policy/policy implementation on SLM and sustainable land use practices
- Continuous cultivation and nutrient mining
- Lack of awareness on soil loss control and drivers of soil loss
- Human and livestock population pressure
- Climate change
- Demand for fuelwood, food, and housing
- Urbanization and industrial development
- Politics and land tenure systems

5.3 Capacity building

LRCD staff were trained on GIS and remote sensing modelling routines for SLEMSA input data preparation, SLEMSA implementation on GIS layers, field data preparation, and SLEMSA model validation. Figure 5.9 illustrates example sessions during the capacity building.

Field validation and data collection training session

GIS and remote sensing analysis training session

Soil testing and measurements

Figure 5.9: Examples of training during capacity building with LRCD staff

During the GIS and remote sensing sessions, LRCD staff were exposed to script development in GIS software for the purpose of executing routine GIS steps. All together, the training was envisaged to help LRCD staff to be able to model soil loss using the SLEMSA model, carry out routine assessment of soil loss on the monitoring sites, and validate the soil loss model outputs.

In addition to training, LRCD was given the following equipment for the soil loss exercise

- Four high-end laptop computers for modelling soil loss and handling input GIS data
- Relevant software for implementing SLEMSA model
- Three mobile tablets with powerbanks and mobile application software for real-time data collection in the field
- Three complete soil testing kits for mobile soil testing and measurements (soil physical, chemical and biological properties)
- Protective field gear for field operations
- Mobile weighing scale and heating ovens for soil testing and measurements

Figure 5.10 gives an example of the equipment given to LRCD for future soil loss modelling.

Figure 5.10: Example of equipment support to LRCD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6 Conclusions and recommendations

6.1 Conclusions

The study was set up to establish the current rates and trends of soil loss in Malawi as a baseline for future monitoring of soil loss in the country. The study used the SLEMSA model to estimate national topsoil loss using secondary data. It also developed a footprint history of topsoil loss rates in the past 10 years, identified potential drivers of soil loss in the country, and carried out capacity building of the local staff to implement future soil loss assessment activities. Application of the SLEMSA model was accomplished by developing a protocol for sourcing the input data, application of appropriate GIS software and hardware to implement the model, and field validating the model outputs.

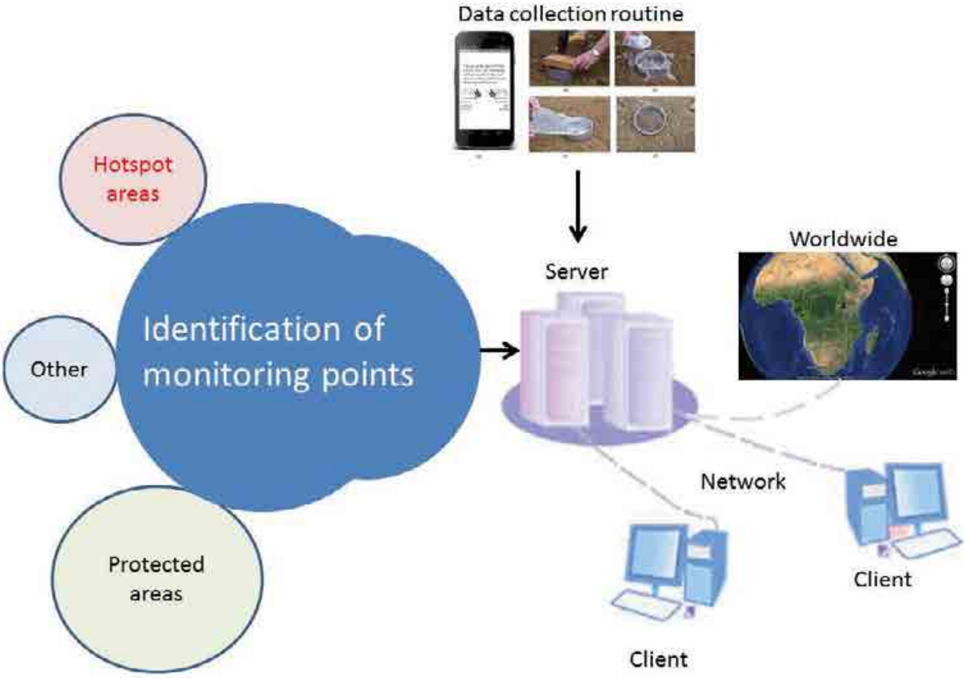
The study established that the national average soil loss rates in Malawi in 2014 was 29 ton/ha/yr. The most affected districts are Nkhata Bay, Mulanje and Phalombe. In these districts, the soil loss rates have been increasing since 2000. Consequently, they are the soil loss problem hotspots in the country. The majority of the districts in the south were depicted to have had declining trends in soil loss rates. Especially in the Rift Valley sections, the soil loss rate seemed to have declined to less than 10 ton/ha/yr towards 2014. It was not apparent from the study the potential causes for the declining trends in soil loss rates. Further assessment may be necessary to elucidate the results shown in this study.

The main causes of soil loss rates in Malawi were found to be fragile soils on steep slopes and erosive rainfall. The human activities can exacerbate these factors through unsustainable soil management practices, inappropriate agricultural activities on fragile soil on steep slopes, and lack of clear policy on SLM.

This study also established a clear structure for obtaining SLEMSA input factors, model validation in the field, and local capacity to carry on with the soil loss monitoring activities.

6.2 Recommendations

1. It's recommended that adequate dissemination packages be developed for the products obtained in this study in order to reach intended audience.
2. Only a selected number of LRCD staff were trained during this study. More modules, software packages, and training sessions are needed targeting multi sectors related to agriculture, environment, climate etc. in each district to be able to monitor soil loss and environmental resources in those districts. In this regard, a comprehensive capacity building framework is recommended.
3. It is recommended that assessment of soil loss impact on agricultural productivity be carried out to establish the linkage between soil loss, unsustainable soil management practices, and policy options.
4. Results from this study can be used as a spring-board to develop a strategy, policy, programme, and extension services for implementing the following actions: good agricultural and sustainable soil management practices, sustainable land use, soil conservation programme, water resource management and catchment rehabilitation for improved water quality, etc.
5. This study focused mainly on topsoil loss by sheet and rill erosion driven by rainfall and runoff. Other significant soil loss types such as gully erosion, riverbank erosion etc. need to be assessed and their results interpreted alongside the findings in this study.
6. The SLEMSA model was used with modifications to suit Malawian conditions. Rigorous research and testing of further modifications and scale of applications is further recommended.
7. Further studies are recommended to establish the reason behind declining rates of soil loss in the southern region and possible lessons drawn with potential for upscaling o other problem areas.
8. Monitoring network: It is recommended that a detailed monitoring framework should be developed to continue the pilot protocol developed in this study. Such a monitoring framework should entails Identification of monitoring points, development of monitoring routine (parameters to monitor and monitoring frequency), identification of minimum monitoring parameters, development of new soil loss products, and dissemination protocol. This study identified hotspot areas, established sampling protocol, and a field validation framework using online data capture and relay. A monitoring framework can take advantage of these structures. The monitoring points should be identified from the hotspot areas, field validation sampling points, and strategic locations such as protected areas (and which should remain stable for a long time). The monitoring routines should incorporate the calibration and validation modules in section 4.3, collaborative work with other GoM agencies such as forestry Department, Meteorological service, Agricultural research service, etc. A framework is recommended with a protocol for developing new products and dissemination of results using online techniques and portals.

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References

1. Amphlett, MB. 1984. Measurement of soilloss from experimental basins in Malawi. Challenges in African Hydrology and Water Resources (Proceedings of the Harare Symposium, July 1984). IAHS Publ. no. 144 .
2. Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soils. Agronomy Journal 54:464-465
3. Chigwiya J. and Kanazawa, H. 2008. Survey results on soil erosion control technologies in Malawi. Covams, Lilongwe
4. Chirwa, E.W.; I. Kumwenda; C. Jumbe; P. Chilonda; I. Minde, 2008. Agricultural growth and poverty reduction in Malawi: Past performance and recent trends. ReSAKSS Working Paper No. 8. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Food policy Research Institute (IFPRI) and International Water Management Institute (IWMI).
5. Elwell, HA. 1978. Modeling soil losses in Southern Africa. Journal of Agricultural Engineering Research 23; pp. 117-127
6. FAO, 2011. Land Degradation Assessment in Drylands: LADA Project. FAO, Rome
7. GOM. 2006. 2006/07 Budget Statement, Lilongwe: Ministry of Finance
8. Hudson N.W. 1965. Field measurement of accelerated soil erosion in localized areas. Rhodesia Agricultural Journal 31(3); pp.46-48
9. Jamu, DM and Brummett, RE. 1999. Fish reproduction in Lake Chilwa with special emphasis on Barbus paludinosus and the status of the watershed. State of the Environment Study No. 5, Danida./Ministry of Natural Resources and Environmental Affairs. Lilongwe, Malawi
10. Khonje CS and Machira SK. 1987. Erosion hazard mapping of Malawi. Land Husbandry Branch, MOA, Lilongwe
11. Mohamoud and Burger 1998 Mohamoud, Y. and Burger, K. 1998, An Overview of the Malawi Environmental Monitoring Programmes' Small Catchment Monitoring Component with Recommendations to Meet Malawi's National Environmental Monitoring Requirements. University of Arizona, Tucson, AZ
12. Madola, S., 2003. Review of Land Policy Reforms in Malawi, FANRPAN Discussion Paper, February, 2003
13. Mauambeta, DC, Chtedze D., Gama, S. 2010. STATUS OF FORESTS AND TREE MANAGEMENT IN MALAWI: A Position Paper Prepared for the Coordination Union for Rehabilitation of the Environment (CURE). Malawi.
14. Ministry of Natural Resources, Energy and Environment, 2010.*State of the Environment and Outlook Report*. Lilongwe.

15. Mkandawire, V., 1996. Soil Loss Estimation for Chilindamaji Malawi Environmental Monitoring Program Catchment. Land Resources and Conservation Branch. Ministry of Agricultural and Livestock Development. Unpublished Report
16. Mkandawire, R, and Phiri. 1987. "Land Policy Snidy: Assessrnent of Land Transfers from Smallholder to Estates." Lilongwe: Bunda College of Agriculture-Mimeo
17. MoAFS, 2011. Malawi Agricultural Sector Wide Approach: A prioritised and harmonised Agricultural Development Agenda: 2011-2015. Ministry of Agriculture and Food Security
18. Moeys J (2010-2014). "The soil texture wizard: R functions for plotting, classifying, transforming and exploring soil texture data." CRAN. 99 pp.
19. MoFDP, 2011 Malawi growth and development strategy II 2011-2016. Ministry of Finance and Development Planning
20. Mohamoud and Burger 1998 Mohamoud, Y. and Burger, K. 1998, An Overview of the Malawi Environmental Monitoring Programmes' Small Catchment Monitoring Component with Recommendations to Meet Malawi's National Environmental Monitoring Requirements. University of Arizona, Tucson, AZ
21. Morgan, RPC. 1986. Soil erosion and conservation. Blackwell, London.
22. Mussa,JJ. 2013. Status and management of land resources in Malawi. Presented at the Global Soil Partnership for Eastern and Southern Africa. Nairobi, Kenya
23. Mwendera, E J. 1988. Preliminary evaluation of soil loss estimation model for Southern Africa (SLEMSA) under Malawi conditions. Land Husbandry Senior Staff Seminar
24. Ngwira A, F.H. Johnsen, J.B. Aune, M. Mekuria, and C. Thierfelder,. 2014. Adoption and extent of conservation agriculture practices among smallholder farmers in Malawi. JOURNAL OF SOIL AND WATER CONSERVATION, 69: 107- 119
25. Pachai, B. 1978. Land and Politics in Malawi. Ontario: Limestone Press
26. Phiri, C.D. 1991. Agricultural Policy in Malawi: 1971- 1987. Thesis, Ph.D.
27. Smith, H.J. 1999. Application of Empirical Soil Loss Models in southern Africa: a review. South African Journal of Plant and Soil, 16(3): 158-163
28. Stocking and Murnaghan (2000)
29. World Bank. 1992. Malawi Economic Report on Environmental Policy. World Bank, Lilongwe, Malawi
30. Weil (1982)
31. Wischmeier, W.H. & Smith, D.O., 1978. Predicting rainfall erosion losses - a guide to conservation planning. USDA, Agric. Handbook No. 537. Washington
32. Yaron, G, Mangani, R, Mlava, J, Kambewa, P, Makungwa, S, Mtethiwa, A, Munthali, S, Mgoola, W and Kazembe, J. 2011. Econoic Study: Economic Analysis of Sustainable Natural Resource Use in Malawi.

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The 68th UN General Assembly declared 2015 the **International Year of Soils (IYS)**. The Food and Agriculture Organization of the United Nations was nominated to implement the IYS 2015, within the framework of the Global Soil Partnership and in collaboration with Governments and the secretariat of the United Nations Convention to Combat Desertification. The IYS 2015 was very successful in increasing awareness and understanding of the importance of soil for food security and essential ecosystem services.

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The **Global Soil Partnership (GSP)** was established in December 2012 as a strong interactive partnership to promote sustainable soil management. It is a mechanism that fosters enhanced collaboration and synergy of efforts between all stakeholders, from land users through to policy makers. Its mandate is to improve governance of the planet's limited soil resources in order to promote the sustainable management of soils and guarantee healthy and productive soils for a food secure world, as well as support other essential ecosystem services. Awareness raising, advocacy, policy development and capacity development on soils, as well as relevant implementation in the field are among the main GSP activities.

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