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METHODS FOR ASSESSING SOIL DEGRADATION IN EAST AFRICA

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ABSTRACT

Land degradation threatens world populations today by causing hunger and poverty, and especially so in the highlands of East Africa where the public has not incorporated land management strategies. Some of these highlands have also received little research attention, resulting in little available data to use for facilitation of good land use. Whereas restoration interventions are being implemented, the success achieved falls short of what is expected because actual degradation conditions have not been clearly analysed and understood. Throughout the studies that have been undertaken to analyse the degradation situation, several assessment and monitoring methods have been put forward. Through this study, several methods which have been employed to assess degradation in conditions similar to those of the Rwenzori ranges have been identified to assess and monitor conditions of soil and nutrient loss, SOM and SOC, infiltration rate and land quality. The common laboratory, GIS and remote sensing, field experimental plots, and modelling methods are applicable with minor alterations. The use of indicators is important to all categories of land users, because it involves them in identifying indicators of degradation, early warning and relevant interventions, and establishing a sense of ownership that instigates a desire to win.

Key words: Land degradation, assessment, methods, East Africa, highlands.

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1. INTRODUCTION

The world has been aware of the growing threat of land degradation for a long time now. Agriculture, coupled with urbanization and industrialization, stemming from a growing population is said to be the major driver of land use change which in turn accounts for global land degradation (Lambin et al. 2001). Human-induced climate change, however, cannot be ignored as one of the causes of land degradation (Herrick et al. 2013). Brady and Weil (2010) reported that about 5 billion ha of vegetated land, which is equivalent to 43% of Earth's arable land, is degrading as a result of human activities. Africa is often cited as a hotspot for land degradation (e.g. Imeson 2012). In Uganda, the conversion of forests to farmlands is responsible for tremendous decline in the productivity of the soils (Bagoora 1988). According to Lal (1994), the most common types of soil erosion are wind and water erosion.

The issue of land degradation is complex, involving multiple processes of ecological, sociological, financial and human dimensions. It is a slow process such that by the time its effects are visible it is already so devastating that restoration is slow and costly (Bagoora 1988; Barrios et al. 2006). The processes of reversing the effects of soil degradation on infrastructure and food security are expensive; costs that governments of developing countries are not able to meet, especially in instances of irreversible loss (Morgan 1986). Bagoora (1988) fears that if nothing is done, soil degradation may reach irreversible levels in the mountain regions of Uganda. Bagoora (1988) and Stroosnijder (2005) also note that although technical solutions to soil erosion are available, investigations must be undertaken to specify solutions for local environmental conditions.

Zake et al. (1997) observed that the most common form of land degradation in Uganda is soil erosion. UNEP (1987) and NEMA (2010) confirmed that water erosion (rainfall) is the most common driver of land degradation in Uganda. Apart from reducing land productivity, soil erosion is also responsible for siltation of lakes and rivers, especially where adjacent wetlands have been drained (NEMA 2004). In Uganda this has proved to be a threat to aquatic life and water bodies (Olson & Berry 2003).

Land degradation has become a hot topic that is often debated; today, quite a number of researchers have undertaken studies on land degradation and have accumulated reliable information, some of which has provided the required baseline for evaluating global land degradation (Imeson 2010). Bagoora (1988) and Majaliwa et al. (2012) have shown that soil erosion is real in the highland areas and lake regions of Uganda. However, as Oldeman (1994) noticed, some areas still lack scientific facts about land degradation and therefore it has remained a challenge to many countries to obtain an overview of the problem, as in Uganda.

In order to ensure restoration through the available solutions, erosion processes, their causes, effects and magnitude must be clearly understood, which calls for scientific research (Stroosnijder 2005). Research will help planners to identify indicators that can be used in the field for assessment and monitoring of degradation processes. Understanding the key indicators will help communities to identify and remedy situations of degradation before they get out of hand (Murage et al. 2000; Barrios et al. 2006). However, these should not necessarily be presented in scientific terms but should be clearly recognizable by the community in order to be effective (Oudwater & Martin 2003). These investigations should also feed into policy development as well as enriching development planning (Le Roux & Sumner 2013). Bagoora (1988) also recommends a revival of erosion research for Uganda which targets a deeper understanding of steep slope erosion processes.

Several scientific investigations on soil degradation in Uganda and other parts of Africa in general have been conducted. Research topics include sedimentation yield (Majaliwa et al. 2012), infiltration rates (Morin & Benyamini 1997; Magunda et al. 1997; Bamutaze et al. 2010), soil quality (Schloter et al. 2003; Barrios et al. 2006), nutrient loss (Briggs & Twomlow 2002), rainfall erosivity (Moore 1979; Magunda et al. 1997), erosion risk (Mutekanga et al. 2010; Le Roux & Sumner 2013), topography (Brunner et al. 2004) and the use of the Universal Soil Loss Equation (USLE) (Mati & Veihe 2001) and the Revised USLE (Angima et al 2003). These and many more will be the required springboard for understanding soil erosion and degradation in Uganda and East Africa, (Morgan 2009) and helping to identify the most appropriate solutions for each situation (Bagoora 1988; Meyer & Turner 1994).

1.1 Statement of the problem

The subject of land degradation has been widely studied around the globe. Bai et al. (2008) attempted to show the extent of soil degradation for each country in the world. In response to the extensive degradation studies, soil erosion control and land restoration interventions have been designed and are being implemented the world over in a bid to curb the degradation problem. It is not a guarantee, however, that these strategies are effectively restoring the land because they may not take into account the local circumstances of specific areas. Interventions designed for more general situations often need to be customised for specific conditions to produce the desired results.

Very little information is available on land degradation in the Rwenzori highlands of Uganda. Most research dealing with the highlands of Uganda have been concerned with the Mt Elgon or the Kigezi highlands but less information is available on the Rwenzoris (Bagoora 1988). Interventions meant for different conditions are therefore being implemented on the Rwenzoris, whose soil type and other geological conditions are different, with potentially less successful results than expected.

In order to achieve maximum efficiency of the strategies, knowledge about the aspects and processes of degradation in the local context is a prerequisite to ensure that the most suitable strategies are applied for existing conditions. There is, therefore, a need to understand the local situation in terms of causes, extent, indicators, risks and impact. Also, the assessment needs to consider the topography, land use, soil characteristics and climate in order to design relevant interventions. To do this, studies on the soil degradation assessment methods to identify those that best fit local situations must be undertaken and results shared locally.

1.2 Objectives of the study

The overall goal of this project is to review and identify suitable methods to assess land condition changes in the tropical highlands of East Africa.

1.3 Rationale for undertaking the project

Soil degradation creates great challenges for the agricultural development sector. The agricultural sector employs about 80% of Uganda's population and it is evident that crop failures are now a common challenge among the farming communities (Magrath 2008). In the event that land degradation reaches irreversible levels, famine, hunger and poverty will remain a vicious cycle. Poverty will only make worse the situations of vulnerable gender groups such as women who are usually affected badly by hunger and poverty, because the culture expects them to till the land for family food supplies.

Whereas land restoration interventions are widely known and used the world over, degradation has remained a challenge in local situations, making the efforts of implementers sometimes a waste of precious resources. This indicates a need to have local situations studied so that the right interventions are prescribed for each area. Land degradation assessment methods have not been widely used in highland areas of Uganda, owing to limited knowledge and the skills to apply them. No wonder there is insufficient information on the state of degradation of the Rwenzori region, and therefore no baselines. Studying of these methods will pave the way for their application to degradation situations and consequently inform decisions on the strategies to be employed.

Soil erosion is a slow but steady process contributing to land degradation and therefore decline in food production, water resources quality and quantity, and is generally a threat to livelihood. The reversal of this phenomenon requires not just the implementation of conservation interventions but rather the appropriate interventions, on a case by case basis, to ensure lasting results. The challenge therefore is the skill to correctly assess the local soil degradation situation and match it with the most suitable intervention.

Land degradation in Uganda is synonymous with deforestation. In the event of deforestation, the household source of energy will be undermined. Over 90% of the Ugandan population depends on wood for domestic energy. This means that the burden upon the women, who in most developing countries are responsible for providing meals for their families, will increase. Such burdens dictate the time spent looking for fuel wood and other services and does not allow women to engage in other more productive activities that might make their work easier. This further heightens poverty and the consequent dependency on natural resources.

2. LITERATURE REVIEW

2.1 Land degradation

Land degradation is both a process and a condition of reduction or loss of capacity of the land to maintain biological and economic productivity, accelerated by human misuse, according to the meaning advanced by the UNCCD (Imeson 2012). Although there are other equally significant causes of land degradation, it is said to be caused primarily by the insatiable demands of man on the environment in terms of food, energy, housing and transport, which result in biodiversity loss and land degradation (Imeson 2012; Schor & Gray 2007). In a situation where the properties of the land have been compromised such that it is no longer able to maintain ecosystem functions, the land is said to be degraded. As populations grow, the demand for food and settlement increases and this means a bigger demand on the land and water resources (Herrick et al. 2013). It is this demand that has led to the ever increasing change in land use, which in turn is responsible for biodiversity loss, soil erosion, nutrient depletion and the consequent degradation (Meyer & Turner 1994).

Land degradation has been confirmed by many as a serious challenge that has rendered many ecosystems unproductive globally (Lal 2003), in developing countries and in Uganda specifically (Murage et al. 2003; NEMA 2010). By the early 1990s, over 1,100 million hectares had been affected worldwide, with 56% of the loss being blamed on human misuse of the land

(Oldeman 1998). Whereas this accounted for only about 15% of total arable land, Bai et al. (2008) confirmed a further 24%, which is not just a further degradation but an expansion onto cropland, forestland and wetland. Moreover, over 1.5 billion people entirely depend on this degraded land for their livelihood (Bai et al. 2008).

The most important factors of land degradation are soil erosion and nutrient depletion (Majaliwa et al. 2012). Soil erosion is responsible for reduced productivity of both upstream and downstream soils through the processes of dislodging and deposition (Brooks et al. 2003). NEMA (2001), as stated in the National Environment Action plan (NEAP), considers water erosion to be the most serious form of land degradation in Uganda, and this conclusion is supported by many researchers such as Bagoora (1988), Nkonya (2002), Lufafa et al. (2003), Olson & Berry (2003), Mutekanga et al. (2010), Majaliwa et al. (2012). Globally, Judson (1981) reported an increase in river sediment yield that was five times more than before the introduction of agriculture. This results in further degradation of the water resources, biodiversity loss and consequently, climate change.

Whereas technical solutions are available and being applied, the desired response of the environment is often not forthcoming since some of these solutions are quite general and have not yielded the expected results. For instance, Brooks et al. (2003) mention a finding by Trimble (1999) that sedimentation rates have increased in the Minnesota River Basin in spite of the better land management practices, yet the same approach had worked for the Wisconsin watershed. Brooks et al. (2003) blamed this on the extensive tile drainage of fields and drainage of wetlands. This therefore calls for specific situational analyses to ensure that the right solutions are determined and applied for the local situation (Bagoora 1988; Lal 1994). These solutions have to be made clear to the local community in order to transform the methods into workable strategies (Oudwater & Martin 2003). An important aspect to consider when assessing degradation at a given location is the need to develop local indicators of land degradation which the community can identify easily in order to develop early warning systems (Oudwater & Martin 2003).

2.2 Processes and properties to consider when assessing land degradation

2.2.1 Soil organic matter (SOM)

SOM has been defined as the fraction of soil including plant, animal and microbial residues, both fresh and at all stages of decomposition, and the relatively resistant soil humus (Nelson & Sommer 1979). The presence of humus in the soil creates cohesion between large soil particles and is therefore important in the formation of soil structure, but good soil structure reduces soil erosion and improves water infiltration (Brady & Weil 2010). It has been considered as the best indicator for soil productivity (Ssali & Vlek 2000). SOM is an important factor when assessing nutrient availability, soil structure, resistance to erosion, water retention, and the movement and control of spread of pollutants in the soil (Barrios et al. 2006; Kimble et al. 2000).

The level of organic matter (OM) in the soil can inform land users about the quality and potential of the land. Well drained soils are said to contain between 1 and 6% OM in the surface or top layer but much less in the subsoil layer (Brady & Weil 2010). It makes essential plant nutrients such as phosphorus and nitrogen available and is also the primary source of carbon, the energy (food) that drives the soil organisms whose activities maintain the ecosystem functions. Because of its ability to influence plant growth, organic matter increases the pore spaces in the soil, thereby contributing to more rapid infiltration rate, reduced bulk density and higher cation exchange capacity and therefore reducing chances of erosion and consequently degradation.

A change in the SOM content is an important indicator of the level of productivity expected from the soil (Briggs & Twomlow 2002). It can also be an indicator of levels of carbon (SOC) present in the soil. The results obtained from assessment and monitoring of SOC variations can be useful in interpreting and therefore keeping track of those soil parameters that are dependent on SOC and SOM.

2.2.2 Soil organic carbon (SOC)

Soil organic carbon is a very important fraction of organic matter. It is considered the most important indicator of soil quality because of the influence it has on other physical, chemical and biological indicators of soil quality (Reeves 1997), in essence all the factors discussed for SOM above. High carbon levels result in reduced soil vulnerability to erosion, sedimentation and improved rangeland health. It is said to be mainly distributed within the first 30 cm of the top soil (Kamoni et al. 2007) although Eswaran et al. (1993) point out that SOC goes deeper than 1 m. Eswaran et al. (1993) recorded that soils are known to store three times more carbon than that in the above ground biomass and twice that in the atmosphere.

Forest soils are also known to store high amounts of carbon (Eswaran et al. 1993); indeed Kamoni et al. (2007) found that forest soils in Kenya held the highest amount of C stock compared to agricultural soils and the drier parts of Kenya. The degradation of forests, therefore, increases the level of carbon dioxide gas in the atmosphere and triggers soil erosion due to the loss of OM in the top soil layer (Kamoni et al. 2007) and thus land degradation (Eswaran et al. 1993). Twongyirwe et al. (2013), however, found more SOC stock in potato fields than in the forest soils in the highlands of western Uganda. The variations identified between land uses were a result of aspect and landscape position.

2.2.3 Infiltration rates

Brady and Weil (2010) define infiltration as the process by which water enters the soil and replaces the air contained in the pore spaces. As water enters the pores, it percolates into the soil and becomes available for plant use and replenishes the ground water aquifers. The infiltration rate (infiltrability) is the most important biophysical factor influencing the amount of surface runoff (Stolte 2003) and therefore soil loss by water erosion (Bamutaze et al. 2010). The infiltration rate depends on the rainfall rate, soil properties such as pore space, texture, structure, organic matter, but also on land use, vegetation, soil depth and antecedent moisture condition (Harden & Scruggs 2003).

Water infiltration studies are necessary in order to understand the dynamics of erosion and the ecosystem hydrological behaviour (Stolte 2003). Understanding the infiltration details of a site is important in designing appropriate solutions to runoff challenges (Mwanjalolo & Tenywa 1998; Brady & Weil 2010). Infiltration rate can also be affected by rills and inter-rills on steep slopes, according to Morin & Benyamin (1977), Magunda et al. (1997) and Fox et al. (1997), who also noted that due to crust sealing and the formation of rills, the rate of infiltration decreases with slope angle. The infiltration rate is not usually constant, but is high at first and decreases as the pores fill up until finally the soil is saturated.

2.2.4 Nutrient losses

Soil nutrients are lost through various processes such as leaching, cultivation, bush burning and soil erosion (Brady & Weil 2010). Erosion removes nutrients from the soil, dissolved or suspended in sediment loads (Majaliwa et al. 2012), and hence the top layer of the soil subjected to soil erosion is where most soil nutrients are found. Soil nutrients are also commonly depleted by over-utilization of ecosystems. NEMA (2001) confirms that through water erosion, Uganda has suffered a great loss of nutrients like calcium, magnesium and potassium, more than other countries in sub-Saharan Africa, and this has had a negative impact on agricultural production.

Studies in the Lake Victoria crescent demonstrate that agricultural lands are continuously degraded by water erosion and experience relatively high losses of nutrients into the water body (Majaliwa et al. 2012). These nutrients are responsible for siltation and eutrophication of the water bodies, jeopardising their capacity to support aquatic life (NEMA 2010).

2.2.5 Soil Erosion

Soil erosion is a process that indicates a situation of severe degradation, in that its occurrence tells of changes that have been going on unheeded for a long time (Imeson 2010). It involves the movement of soil particles by wind, rainfall and flowing water, but also by ploughing, trampling and below ground herbivores (Imeson 2010). Whereas trampling may cause considerable damage, the most common forms of erosion are by water and wind (Lal 1994).

Although soil erosion has been confirmed as a cause of soil nutrient loss, and therefore land degradation (Bagoora 1988; Majaliwa et al. 2012), Sanchez et al. (2003) seem to imply that this is not the case in the tropical highlands but rather that low soil fertility can be a cause of erosion; the two can also be said to have a cause-effect relationship. Tropical soils are highly vulnerable to soil erosion (Brady and Weil 2010). As much as 36% of soils in the tropics are at a high risk of water erosion owing to their forestry nature and the terrain conditions (Sanchez et al. 2003). In areas with limited soil stability, erosion is often succeeded by landslides (Bagoora 1988). This is usually a result of changes in land use, especially where vegetation cover is changed to a less stable type. According to Morgan (2009), for instance, deforestation results in greater erosion than degradation of savannah grassland, due to the vulnerability of forest soils and often steeper slopes.

Soil erosion and loss of organic matter content are related on a cause-effect basis, in that one may be responsible for the other depending on prevailing land use, and topographic and climatic conditions (Imeson 2010). Soils whose SOM has been undermined to the level of affecting soil structure and consequently infiltrability have had their thresholds undermined for a very long time and will consequently give way to erosion and degradation (Imeson 2010).

Whereas some erosion processes are a result of natural factors such as loose soils or glaciation, yet a greater part results from pressure on the land from intensive investments in the agriculture, construction, energy, mining and transport industries (Bagoora 1988; Arnalds & Barkarson, 2003).

Through many millennia, geological erosion has created amazing features such as the Grand Canyon in the western USA, but today, man has exerted more pressure, effecting over ten times more erosion per year than geological erosion (Brady and Weil 2010). It is this erosion that is responsible for global land degradation, reduced agricultural productivity, and a vicious cycle of poverty. Without strategic efforts to reduce erosion, food insecurity is a challenge that threatens the global populations today (Brown 2011).

There are a number of reasons why soil erosion should be measured, according to Stroosnijder's publication, which are "to determine the environmental impact of erosion and conservation practices, for scientific erosion research, development and evaluation of erosion control technologies, development of erosion prediction technology and allocation of conservation resources and development of conservation regulations, policies and programs" (Stroosnijder 2005, p.1).

Soil erosion is a function of five important factors, that is, rainfall erosivity, soil erodibility, length and angle of slope, crop or vegetation cover, and conservation practices (Moore 1979; Islam & Weil 2000). Detailed information on local factors such as topography, canopy cover, ground cover, rainfall intensity and soil properties are, therefore, important to consider when assessing soil erosion. This is recognised by other researchers who have considered particular factors using specific methods (Nigel & Rughooputh 2010). Stroosnijder (2005) also noted that some of the procedures and analyses are quite expensive and should therefore be handled one at a time in order to realise complete results. Erosion increases with slope angle and, since the Rwenzori area has not been researched much, it should be properly investigated because the processes of erosion on steep slopes are complex (Bagoora 1988).

2.2.6 Land quality

Soil/ land quality is defined as the ability of the soil/ land to perform its functions within its ecosystem and land use to sustain biological productivity and maintain plant, animal and human health (Schloter et al. 2003; Brady & Weil 2010). It depends on the state of the chemical, physical and biological soil properties, some of which are inherent (such as texture and mineral content) and define the soil type. Others factors, however, such as structure and organic matter, are often influenced by land use and management and these can indicate the status of the soil quality in relation to its potential.

Land quality indicators are measurable soil attributes that influence the capacity of the soil to perform its ecological functions, ensure crop production and environmental health (Arshad & Martin 2002). LQIs can be categorised by their criteria of identification as local and scientific, with the latter discussed above. These parameters are the key in determining land quality due to their ability to indicate changes in soil quality. They are shown in Table 1 below based on Arshard & Martin (2002, p.4). The earth's soils have been diminishing in quality overtime due to the numerous human activities which have not regarded the complex process of soil formation and loss.

It is important to note the interdependence of these indicators such that any change in one triggers a change in others and this is the characteristic that qualifies them as suitable indicators (Arshad & Martin 2002).

Table 1. Key indicators of soil quality (Source: Arshad & Martin 2002, p.4)

Parameter	Importance for consideration
Infiltration rate	Affects water availability, runoff, leaching of nutrients and erosion potential
Soil organic matter	Indicates nutrient availability, soil structure, water holding capacity, and mobility and breakdown of pollutants
Topsoil-depth	Indicates available soil volume for ecosystem services such as plant growth and crop production and indicates level of soil erosion
Aggregation	Affects soil structure, erosion resistance, crop emergence and is an early indicator of soil management effect
Texture	Affects retention and transport of water and chemicals, modelling use
Bulk density	Plant root penetration, porosity, adjust analyses to volumetric basis
pH	Nutrient availability, pesticide absorption and mobility, process models
Electrical conductivity	Affects crop growth, soil structure, water infiltration; presently lacking in most process models
Suspected pollutants	Plant quality, and human and animal health
Soil respiration	Biological activity, process modelling; estimate of biomass activity, early warning of management effect on organic matter
Forms of N	Availability to crops, leaching potential, mineralization/ immobilization rates, process modelling
Extractable N, P and K	Capacity to support plant growth, environmental quality indicator
Sediment yield	Responsible for nutrient transportation from soils and pollution of water bodies

Land quality indicators suited for local conditions are important because of their relevance to the local community to which they apply. They provide relevant information which can be utilized by farmers, extension officers, NGOs, technicians, researchers and educators (Barrios et al. 2006). Participation of the community in identifying indicators for soil quality is very highly recommended by Sarrantonio et al. (1996). Local soil quality indicators (LSQIs) are of great importance because they are locally understood by communities that need to use them (Habarureme & Steiner 1997). Although they are not scientifically applied, identifying and classifying LSQIs shows how knowledgeable the community is about their surroundings and gives them an opportunity to participate in the making of decisions that matter most to them. LISQs are easier to understand and may combine several aspects into one indicator.

When monitoring changes in land quality, it is important to consider details such as magnitude, rate, direction and extent of change (Oldeman 1994; Arshad & Martin 2002). It is also important to define critical limits or the threshold levels of the indicators and these can be obtained by studying similar ecosystems that have not been disturbed for a long time (Arshad & Martin 2002; Imeson 2010). These stable conditions will provide the thresholds of the indicators in question. The use of LQIs to assess land degradation requires systematic consideration of the land use type because different land uses affect LQIs differently and require different conditions to thrive (Bindraban et al. 2000).

To assess changes in land quality, these indicators need to be measured and compared with critical limits or threshold levels of a particular land use or ecosystem at different intervals (Arshad & Martin 2002). In this way, information will be provided on the effectiveness of the selected practice or intervention of the ecosystem such that the practice that negatively affects the indicators is considered unsustainable or can be modified while the practice that enhances the indicators capability is upheld and disseminated as a sustainable practice or intervention (Arshad & Martin 2002).

A LQI should allow for monitoring of changes and be applicable at different scales (Bindraban et al. 2000). Although farmers' classifications differ from the scientific, especially because of the difference in their objectives and criteria of classification, the underlying concepts are the same (Habarureme 1997). A farmer's interpretation of land quality is not based on scientific background or experience (Barrios et al. 2006). Rather, importance is placed on identifying the missing soil requirements and determining what management practice to employ (Barrios et al. 2006; Murage et al. 2000). The indicators that a farmer uses to determine land quality or its change can be related to the scientific indicators that a researcher has identified in the laboratory (Barrios et al 2000) or in the field.

A community always understands why similar indicators manifest differently in different land uses and topographic conditions (Barrios et al. 2006), but most importantly, LQIs provide an opportunity for early warning systems so that degradation processes can be checked before the system is rendered unproductive (Oudwater & Martin 2003). Considering the fact that both local and scientific knowledge have gaps in sharing information, Barrios et al. (2006) note that it is important to integrate the two using a methodology described by them (2000). In this way, they can be more efficient to all land users. Pellant et al. (2005) came up with indicators and attributes that can be useful to both scientists and the community in land condition assessment of both mild, severe and irreversible situations. These are displayed in Table 2 below.

Table 2. Ecological attribute assignments for 17 indicators used in the qualitative assessment protocol (Source: Pellant et al. 2005).

No.	Indicator	Attribute		
		Soil and site stability	**Hydrologic function**	**Biotic function**
1.	Rills	S	H	
2.	Water flow patterns	S	H	
3.	Exposed rocks or pedestals	S	H	
4.	Bare ground	S	H	B
5.	Gullies	S	H	
6.	Water scoured and soil deposition areas	S		
7.	Litter movement	S		
8.	Surface resistance to erosion	S	H	B
9.	Plant community composition and distribution relative to infiltration and erosion	S	H	B
10.	Soil surface loss			
11.	Compaction layer	S	H	B
12.	Functional or structural groups			B
13.	Plant mortality/ decadence			B
14.	Litter amount		H	B
15.	Annual production			B
16.	Invasive plants			B
17.	Reproductive capability of perennials			B

3. MATERIALS AND METHODS

This study was conducted specifically for the benefit of Kasese District, which is located at the foothills or the Rwenzori Mountains in Western Uganda, but also for areas in the entire country whose conditions are similar to the Rwenzoris.

3.1 Study area

Uganda generally lies on a plateau of 1000 m to 2500 m a.s.l. according to the National Environment Management Authority (NEMA) 2007. The Rwenzoris, however, rise higher to over 5000 m a.s.l. with communities living as high up as 2500 m a.s.l. (Bagoora 1988). This makes the hill slope aspect very significant in assessment of land degradation in this area. The map of the location of the Rwenzori Region in Uganda is shown in Figure 1 below.

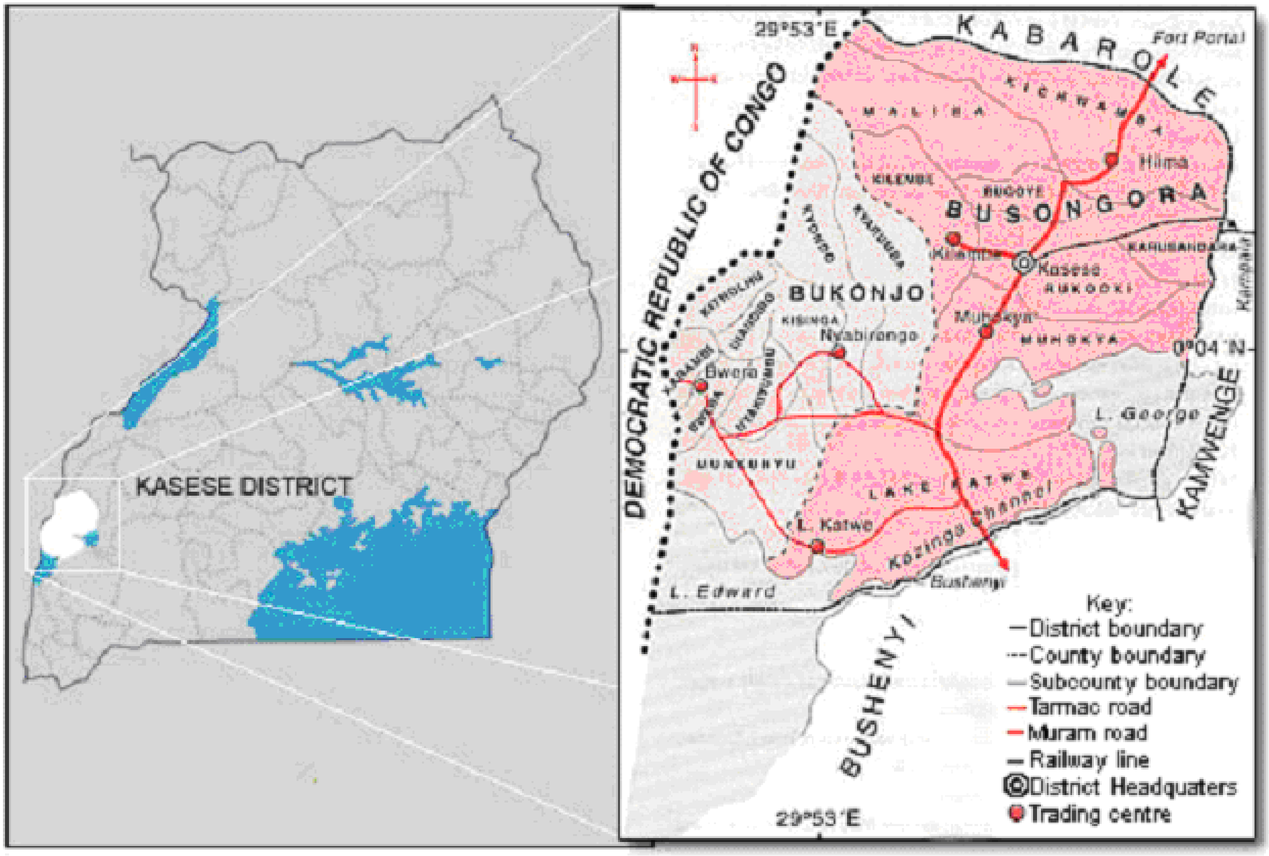

Figure 1. Map of Uganda showing location of Kasese District in the Rwenzori region (Source: Google maps)

The Rwenzori mountains are protected as a UNESCO World Heritage Site because of their water catchment value among others, from which numerous rivers flow that feed the Lake George-Edward basin in the lower part of the Rift Valley floor. The area hosts soils of relatively high fertility and a favourable climate for high agricultural productivity (Bagoora 1988). The mountain slopes have, therefore, attracted a high population density whose pressure has resulted in land degradation over the years. Through deforestation and over-cultivation the soil stability has been compromised, culminating in soil erosion (Bagoora 1988). With most of the vegetation cleared for agriculture, the soils have been exposed to erosion, and the soil laden runoff ends up in the rivers (Rwimi, Mubuku, Nyamwamba, Nyamugasani, and Lhubiriha) and the lakes, thus compromising the water quality and ability to maintain aquatic life and hydrological services.

Roller et al. (2012) found that denudation rates are significantly related to relief, hill slope gradient, and channel steepness, indicating that river incision controls erosion processes. The Rwenzori Mountains have very little natural erosion in comparison to other high relief areas in the world with similar topography (Roller e al. 2012) but in the inhabited areas, due to deforestation and poorly managed agriculture, erosion rates are quite high.

3.1.1 Climate

According to the Kasese District Local Government (KDLG 2004), the district of Kasese experiences a bimodal rainfall pattern. The first rains which occur during March - May are shorter than the rains from August - November. Annual rainfall ranges from 800 mm to 1600 mm and is greatly influenced by altitude. The temperature and humidity in the Rwenzori region varies with altitude, with the temperatures ranging from below 0 to 25^{o}C in the higher reaches and from 8 to 30^{o}C in the lowlands. Similarly the average humidity varies from over 80% in the highlands to 72% in the lowlands (WWF-Rwenzori 2012). In Figure 2 below are the climate details showing mean climate values.

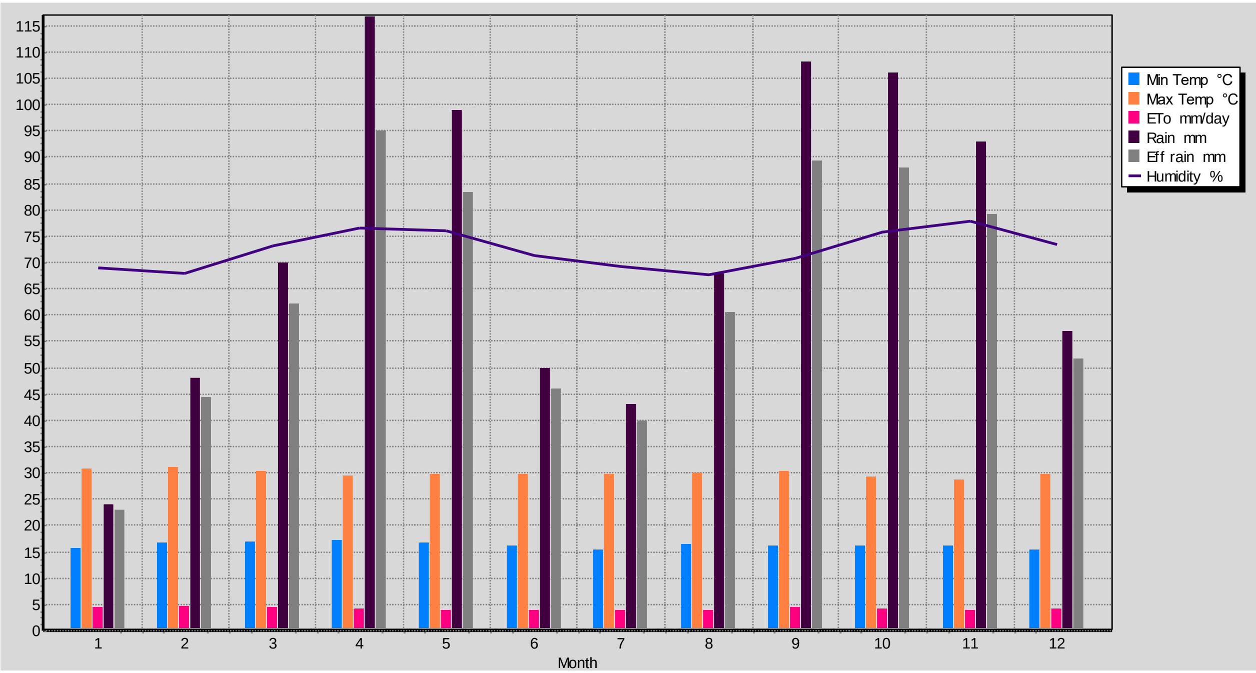

Figure 2. Average climate values for the Kasese District. Values include: mn temp (mean temperature), max temp (maximum temperature), et_o (evapotranspiration in mm/ day), rainfall (monthly rainfall totals in mm) and humidity (mean monthly humidity). (Source: WWF-Rwenzori 2012).

3.1.2. The nature and people of the Rwenzoris

The Rwenzori ranges have evolved into three distinct geographical zones, according to the terrain (KDLG 2004). First are the higher and steeper rugged slopes, ranging from 2000 m. to over 5000 m. a.s.l., 5% of which are inhabited by people who are involved in crop cultivation but 95% is protected for wildlife, water catchment and tourism values (Muhumuza & Byarugaba 2009). Not much degradation is expected to occur here because of the vegetation cover and the protection by law, first by the Uganda Wildlife Authority and the United Nations Educational, Scientific and Cultural Organization (UNESCO), but also by the culture of the local people who believe that a god who lives in the caps of snow on the mountains protects the landscape and streams and guards the forest against unnecessary tree felling (Infield & Mugisha 2013). In Figure 3 below is an image of the Rwenzori terrain, rising to 5100 m a.s.l., showing the snow caps at the peaks and the steep rugged slopes. The soils in this zone have been developed in Precambrian igneous and metamorphic rocks which have been affected by glaciation (Bagoora 1988). They are generally sparse and shallow, black, humid soils with a high acidity (pH 3.5).

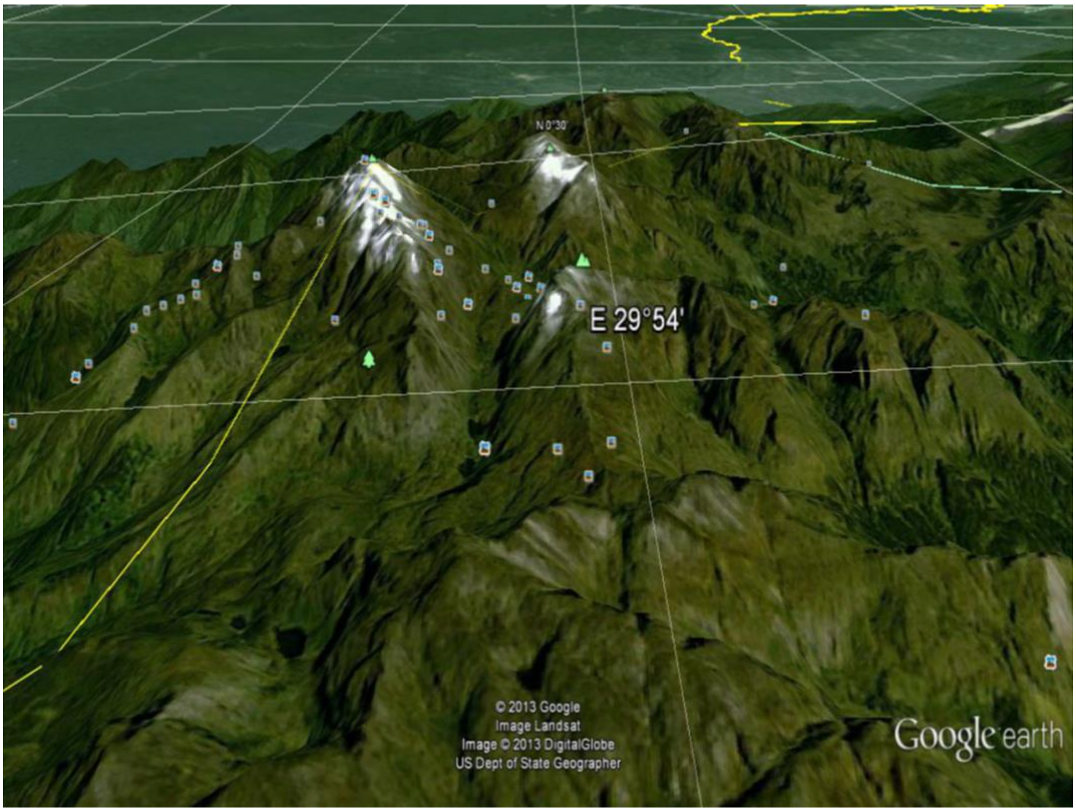

Figure 3. Google Earth image of the higher and rugged steep slopes of the Rwenzoris (Source: KDLG 2013)

The second zone is the gently rolling hills, between 1000 and 2500 m a.s.l., which have suffered serious deforestation to provide settlement and agricultural land, and thus have been exposed to great erosion and fertility loss. The soils here are older, deeply weathered forest acidic soils (pH 4) rather low in bases but with high organic matter content (Bagoora 1988). In Figure 4 below, the image shows gentler slopes that have been inhabited for a long time.

Figure 4. Google Earth image of the gentle rolling slopes of the Rwenzoris from 1000 m to 2000 m a.s.l. (Source: KDLG 2013).

And finally, the flat planes that form the rift valley floor, and host the lakes George and Edward into which the rivers flowing form the Rwenzoris south-eastwards (Kasese) pour their waters (Kasese 2013), as shown in Figure 5 below. The soils here are podsolic, highly leached, in which translocation of iron and aluminium has occurred. They are shallow brown and reddish brown sandy loams, from a quartzite and granite parent rock, and of very low agricultural value (WWF-Rwenzori 2012). They are commonly used for irrigation agriculture and grazing (Muhumuza & Byarugaba 2009). The main vegetation type here is savannah grassland.

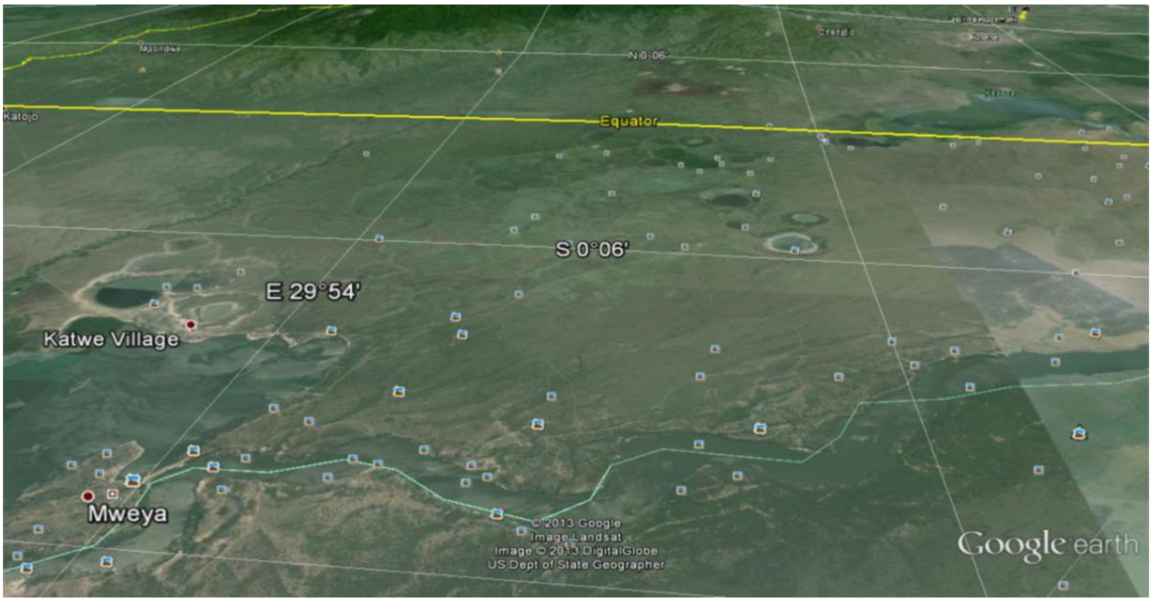

Figure 5. Google Earth image of the flat plains on the rift valley floor of the Rwenzori region below 1000 m a.s.l. (Source: KDLG 2013).

3.1.3 The human population

The Rwenzori Mountains have been inhabited by the Bakonzo, Bamba and Bambuti (possibly since the early 1200s AD) on the higher slopes, engaged in agriculture, and the Batooro and Basongora on the lower plains for many generations, according to the OBR (2013), engaged in agriculture and grazing (Muhumuza & Byarugaba 2009). The cultivation practices on the steep slopes were of a shifting nature that involved slash and burn, and accounted for destruction of a substantial percentage of the forest (Bagoora 1988). Currently, the high rate of population growth, 2.8% per annum, is threatening the mountain with an increasing population that has resulted in land fragmentation as the young generation struggles to survive (Muhumuza & Byarugaba 2009), as is clearly show in the pictures in Figure 6 below.

Figure 6. Picture of high population density (above) and unsustainable land use practices on the slopes of the Rwenzori.

According to the KDLG (2007), the district population stood at 530,000 people in 2002 (currently projected to 720,000 people in 2013) in an area of 2,724 km^2, with a 3.6% growth rate and an average density of 180 per km^2. The KDLG (2004) shows poor land distribution and therefore the limited arable land available to the community. The land available to a household ranges from 1 to 2.5 acres, on which over 68% of the households depend for commercial crops, food crops and livestock rearing (Muhumuza and Byarugaba 2009).

3.2 Resilience and stability of the Rwenzori region

The mountain ecosystems of Uganda are among the most vulnerable systems in the country, considering the various degrees of destruction from a diversity of land use interests (Muhumuza & Byarugaba 2009). These rugged steep slopes host highly weathered soils which, though, are of relatively high productivity, and have attracted high populations that are dependent on subsistence agriculture (Bagoora 1988). However, the Rwenzoris being of granitic parent rock, they are said to be more stable; Bagoora (1988) and Roller et al. (2012) confirm that unlike Muhavura and Elgon, which are volcanic in nature, Rwenzori is less susceptible to mass wasting, as can be seen in the pictures in Figure 7 below. The aforesaid notwithstanding, erosion is known to increase with slope angle, especially where a gradient of more than 12° and rilling processes amidst high rainfall render soft cultivated soils vulnerable. Bagoora (1988) therefore concludes that these areas are at risk of irreversible damage due to extreme erosion.

Figure 7**.** Pictures showing varying levels of slope stability on Mt Elgon (left) and Mt Rwenzori (right).

In the face of increasing population, land fragmentation has become a common practice that has affected the continuity that existed in the distribution of plant species (Bagoora 1988, Muhumuza & Byarugaba 2009). In pre-colonial times, shifting cultivation was a common practice in the Rwenzoris (Bagoora 1988) because it was a sure way to enable the soils to recover from disturbance through natural fallowing (Zaake 1993). However, in areas of irreversible degradation, herbs and shrubs have taken over (Muhumuza & Byarugaba 2009). This is an indication that although the nutrient availability threshold has been exceeded, the propagule/seed bank threshold may still be active and may aid recovery with the help of improved management and in the worst cases, vegetation manipulation may be employed (Whisenant 1999).

3.3 Data collection methods

This study concentrated on studying the methods that different scholars have applied in areas of similar environmental characteristics to assess land degradation in Uganda, East Africa or Africa at large. Particular factors that control land degradation, such as topography, soil properties, land management and climate factors, especially rainfall, were kept in mind in the study of the different methods used in assessment of aspects such as changes in organic matter, soil carbon, infiltration rates, rainfall erosivity, erosion rates, erosion risk and hill slope factor. The study identified the particular methods that are commonly used and are best suited to assess degradation levels in the research area.

4. RESULTS AND DISCUSSION

4.1 Methods of land condition assessment

4.1.1 Land quality indicators (LQI)

LQIs need to take into consideration the entire ecosystem, that is, the land, water, atmosphere and vegetation because of the interdependences of these systems and their impact on one another (Imeson 2010). When looking at the indicators of degradation on land, the soil quality, productivity of the land, erosion signs, the presence and species of weeds are important to consider (Imeson 2012). Muhumuza and Byarugaba (2009) recognized the fact that plants form a basis to assess land degradation; indicator plant species tell a lot about soil quality and the effect of land use. They actually found characteristic plant species that indicated an over ten years degradation process in the lower Rwenzori reaches, and they found a significant relationship in their distribution to disturbed, undisturbed and degraded areas.

These plants are known by the characteristics (of propagation, dispersal and survival) that they develop to adapt to conditions of varying severity of disturbance and degradation. Muhumuza and Byarugaba (2009) noted that herbs and shrubs were abundant in the area due to degradation, while others such as *Amaranthus hybridus*, *Galinsoga parviflora* and *Oxalis latifolia* were abundant because of lack of natural competitors. *Laterna camara* is a common invasive alien species of this nature that has supressed indigenous species and dominated the lower grazing areas, as shown in Figure 8 below. The absence of other species associated with certain ecosystems can also be an indicator of biodiversity loss and therefore degradation (Imeson 2010).

Figure 8. A degraded rangeland that has been completely taken over by *Laterna camara*, an invasive alien shrub in the flat grazing plains of Kasese District.

Murage et al. (2000) found out that local communities are capable of recognizing and classifying the productivity of their soils and use the information to make decisions on crop type, timing, and management strategy. From research on diagnostic indicators of land quality conducted in the central Kenyan highlands, Murage et al. (2000) noted that the farmers' criteria of classifying productive and unproductive areas included crop performance, ease of tillage, soil moisture retention and soil colour, while the indicator organisms included soil macro-fauna and invading plants. This is similar to what Nandwa and Bekunda (1998) had earlier noted for East and South Africa. In addition, De Bie (2005) noted that the most outstanding indicators of soil erosion are soil accumulation, rills and pre-rills (common in the drier parts of the country), flow surfaces and eroding clods (high prevalence shows low erosion).

Vegetation can also be a very good indicator of the hydrological health of an area. The species, productivity, quality, and the like can be considered to assess and monitor the condition of the hydrological system. Degradation of the hydrological system can also be associated with water shortage, higher costs of water purification and supply, colour and turbidity of surface water, and degradation of river banks can be told by the size and shape of the river valley, depending on terrain.

Whereas local indicators may be a very important tool for assessing and monitoring changes in land quality, they face a number of challenges such as inability to quantify the change that is occurring, being known only to a small community and may not be compared with scientific information as they share nothing in common (Habarureme & Steiner 1997). Deeper studies into the condition of the land therefore need to be undertaken. It is the quantification of the scientific indicators that may require detailed analyses such as laboratory analyses, field measurements, remote sensing, GIS programmes and other models. These give us a scientific understanding of the underlying causes of soil behaviour as recognised by local farmers (Murage et al. 2000). They also provide a useful platform for policy reforms (Vogt et al. 2011). The other, various methods used to quantify baselines and monitor changes in the various conditions similar to the East African highlands are summarised in Table 3 below.

4.1.2 Soil organic matter (SOM) and soil organic carbon (SOC)

SOC can be modelled using GIS based models that require information on soils, climate and land use history of an area. Kamoni et al. (2007) used the Global Environment Facility Soil Organic Carbon (GEFSOC) (Easter et al. 2007) to predict carbon stocks in Kenya. The GEFSOC System is possible in three different approaches, that is, the Rothc, the Century and the IPCC approaches (Easter et al. 2007). This kind of modelling can provide baselines of what carbon levels can be expected in a given terrain and for national carbon budgets, but their usefulness is somewhat limited on the community level. The Century sub-model processes information from plant productivity and feeds the Rothc which is based on soil decomposition. Equipped with these data, the IPCC, another component of the GEFSOC method, then calculates the soil carbon at different points in time. The GEFSOC modeling system was originally designed for the USA but Kamoni et al. (2007) seemed to rely on its results and were convinced that this method would solve their greenhouse gases quantification needs.

Table 3. Methods for quantifying changes in land condition and their limitations

	Method	Measurements	Advantages	Limitations	Other comments
1	GLASSOD (Vogt et al. 2011)	Type, extent, degree, rate and cause of land degradation	It has been widely used	Considers only soil and no other land resource degradation	Social economic , land fragility
2	WEPP Model (Nearing et al. 1989) Process based model	Soil loss Sediment load	Cannot simulate runoff in a complex landscape (Brunner et al. 2004)	Predicts erosion loss, at a point or on entire slope, monitorable	
3	USLE (Mati & Veihe 2001) & RUSLE (Angima et al. 2003)	Quantification of erosion and sediment yield	More suited for agricultural areas than for rangelands. Accounts for rills and interrills	Does not predict gully erosion and landslides which are more common in the area of study	
4	CAESIUM 137 Model (Ruecker et al. 2008)	Quantify soil erosion and sedimentation	Provides retrospective measurements of long term rates based on one visit Applicable in a wide range of environments	Costly	
5	Erosion plots (Majaliwa et al. 2012)	Runoff, erosion, sediment load and nutrient loss		Time consuming	
7.	GEFSOC Modelling System (Kamoni et al. 2007)	Predicts changes in SOC	Considers land use history to predict carbon loss	Costly software and lack of technical capacity need references (potential) and verification with direct measurements.	
8.	Direct Carbon (OM) methods (Okalebo et al. 1993)	Laboratory measurement of carbon content in soils and aerial stocks	Cheap, provides information about the most sensitive soil quality indicator		

A common method to measure carbon in soils is the "wet acid oxidation" laboratory method (Okalebo et al. 1993). Soil carbon can be presented as % for each depth increment or soil horizon. Information about the first 10 to 30 cm is important, as the topsoil contains most of the organic carbon. Nandwa and Bekunda (1998) quote Foster (1973), who noted that for East Africa, 6% SOC and 200 ppm extractable P are critical levels beyond which no extra benefit from N and P fertilization can be obtained and 15 ppm of P for maize. Barrios et al. (2006), however, admits that identifying suitable critical limits for SQIs is still a challenge. Soil carbon can also be presented for a unit area ($m^{2,}$ ha or km^2). Carbon stocks have been determined in western Uganda to establish the variation of SOC with land use, aspect, altitude, landscape position and depth (Twongyirwe et al. 2013). The SOC per unit area was calculated using the following formula (1):

SOC stock (mg/ha) = % SOC x Bulk Density (g cm^{-3}) x Depth (cm)
X Area (area of plot projected to one ha)

Twongyirwe et al. (2012) found 10 t C ha^{-1} less in forest soils than in potato fields, and about 20 t C ha^{-1} more in grazing land. However, the results depended on latitude and aspect, keeping in mind therefore that potato fields and grazing lands are on the lower slopes and receive the carbon that is lost from forest land by erosion and leaching. The same could also be responsible for the higher carbon content in the sub-surface than in the top layer of soils in the foot slopes than on the back slopes. The results obtained from assessment and monitoring of SOC can be useful in interpreting and therefore tracking those soil parameters that are dependent on SOC and OM.

In a recent study in central Uganda to establish the level of nutrient loss from land that had been continuously used since the 1960s, Ssali and Vlek (2002) noted that during the initial study in the 1960s (the study had covered the whole country), it was found that SOM levels had a higher affinity to soil texture and particularly to silt and clay than to rainfall and farming systems. Where silt and clay content exceeded 26%, OM ranged from 3 to 7% and 1 to 3% where silt and clay was less than 26%. Also, there was little response to fertilizer application if the SOM was higher than 3.5%. In the subsequent study, it was noticed that there was little change in the SOM content, but for other properties such as pH, extractable phosphorus, calcium and potassium had dropped to less than critical levels; their levels within the topsoil had dropped by 20 to 70% less than the 1960 values. This is a clear indication that the state of the soil in the country is fast declining and needs analyses to remedy the situation in time. It also shows the importance of considering many soil/ecosystem factors as analysing only one factor (OM in this case) can give misleading results.

In their quest to understand the infiltration of volcanic soils on sloping terrain in eastern Uganda, Bamutaze et al. (2010) collected samples from the 36 sites and analysed for SOC, pH, and other elements such as nitrogen, calcium, potassium and the like. Below in Table 4 are the results of the analyses done according to Bamutaze et al. (2010).

Table 4. Topographic setting of the agricultural sites, with indication of cropping systems and main soil characteristics of the topsoil (upper 0 to 30 cm). Three soil infiltration tests were made at each field site using the double ring infiltrometer. (Source: Bamutaze et al. (2010, p.3).

Site code	Altitude (m)	Slope (%)	*i* (cmh^{-1}) infiltration	Sand (%)	Silt (%)	Clay (%)	SOC (%)	Cropping system
3	1280	32	195, 118, 363	32	25	43	3.2	Annual (beans, cassava, maize)
5	1269	27	234, 186, 141	26	21	53	2.8	Perennial (banana, coffee)
6	1259	14	56, 34,78	22	20	58	3.0	Annual (cassava, potatoes)
7	1318	13	62, 66, 71	32	22	46	3.0	Perennial (banana, beans)
11	1279	26	108, 209, 126	28	24	48	3.7	Perennial (banana, coffee)
12	1268	22	18.6, 220, 324	34	18	48	2.8	Annual (beans, cassava, potatoes)
13	1287	31	257, 102, 184	32	26	42	3.3	Perennial (banana, maize)
15	1259	12	7.2, 1.2, 11.4	27	19	54	2.6	Annual (cassava, beans, maize)
18	1290	31	122, 54, 39	30	21	49	2.8	Perennial (banana, cassava)
19	1309	14	59, 59, 30	28	24	48	2.7	Perennial (banana)
24	1289	32	143, 204, 86	28	26	46	2.7	Annual (cassava, potatoes)
25	1318	24	28, 50, 12	26	17	57	2.2	Annual (maize)

4.1.3 Infiltration rate

The infiltration rate is known to decrease with slope angle, especially in the presence of rills, but it is also influenced by soil structure and land cover. Bamutaze et al (2010) however found that on the slopes of Mt Elgon the infiltration rate tends to increase due to the heavy rain which washes away the topsoil and does not allow for crust sealing.

The soils in question were Haplic lixic Ferralsols sampled from twelve sites with predominantly annual and perennial vegetation from which a total of 36 sites were selected across a topographic gradient and a slope steepness of 12 to 32%. According to their observation, the steady state of infiltration varied between models, with under and over predictions at different sites. The over-predictions showed 61% for Philip's, 89% for Green–Ampt, 69% for Horton and 61% for Kostiakov, with the Phillips and Kostiakov models giving the highest number of under-predictions of the steady state of infilteration rates at 36%.
This showed a very high infiltration rate for a steep mountain ecosystem, However, Kitutu et al. (2009) found that a layer of course texture overlaying a layer of fine texture could trigger landslides on Mt Elgon.They found that infiltration characteristics were similar for soils under annual and perennial cropping systems and could be attributed to the land use and management history of the land.

Determination of the infiltration rate of a particular soil is commonly done using an infiltrometer. It is determined by the following equation (2) (Brady and Weil 2010)

$$i = Q \ / \ A * t$$

where Q is the volume quantity of water (m^3), A is the area of soil surface (m^2) exposed to infiltration and t is the time (s). The term i is therefore usually expressed as mm/s, mm/h or cm/h. Bamutaze et al. (2010) chose to use the double ring infiltrometer because it reduces the slacking effect and the effect of lateral water flow. Its use on the slopes of Mt Elgon in Eastern Uganda involved the employment of several models, each of which had a role to play considering the ecosystem hydrological characteristics and the nature of infiltration processes on steep slopes (Bamutaze et al. 2010). For clay soils, the critical limit is usually less than 3 cm/h, silt loam 3 to 5 cm/h, and loamy sand almost 12 cm/h (Brady and Weil 2010).

4.1.4 Soil erosion and sediment load

Erosion and sediment yield studies have often been undertaken with several methods used to suit required conditions including gradient, land cover, and so on, to enable researchers to obtain diverse and in-depth inferences of surface observations. The use of USLE (Mati & Veihe 2001) and the RUSLE (Angima et al. 2003), whose concept was developed by Wishmeier and Smith (1978), has frequently been employed on the steep slopes of East Africa (Nyssen et al. 2005) and the world at large.

UNEP (1987), in its bid to develop the Global Environment Monitoring System (GEMS), included Uganda as one of the Global Resource Information Database (GRID) case studies with an aim of assessing and monitoring the productivity of the soils in the country and maintaining a database that could be updated and used to inform decisions in environmental management. Through the use of the USLE (modified) and GIS, maps were developed depicting soil productivity, soil erosion (rainfall erosivity, soil erodibility, slope, land use pressure, population pressure and soil erosion hazard), agro-ecology, forestry and population density. In this exercise, the Rwenzoris were mapped as being over 1000 m a.s.l, > 8^o slope, and with productivity ranging between low to medium and very high. Soil productivity was considered as a function of texture, depth, pH, fertility, organic matter, workability, drainage and water holding capacity. The erosion hazard was mapped between very low and medium. This is in line with Ruecker et al. (2008), who found that the Rwenzoris were less susceptible to natural erosion than other areas of similar conditions.

In 1998, Wortmann and Kaizzi set out to estimate the nutrient balances at the crop, land use type (LUT) and farm levels, for four locations in eastern and central Uganda using the USLE. The four locations included Palissa, Iganga, Mpigi and Kamuli. Erosion loss on banana plantations, fallow lands, pasture and tree lots was estimated from 0.0 to 7.7 t ha^{-1} for Palissa. Among other properties, the SOC was found to be 2.1% for Palissa, 2.4% in Iganga, 2.6% in Mpigi and 2.9% in Kamuli, as well as 2.5% for Banana and 2.3% for other land use types. The mean losses of soil and other major nutrients in the four locations were estimated as shown in Table 5 below as presented by Wortmann and Kaizzi (1998). In the table, deposition of eroded soil and nutrients is not considered.

Table 5. Estimated mean losses of soil and major nutrients in four locations of eastern and central Uganda using the Universal Soil Loss Equation: [a] control practices proposed would change P from 1.0 to 0.5, e.g. by the use of living barriers or micro-catchments on fields with 2% or greater slope and slopes longer than 50 m in Palissa and on fields with greater than 3% slope in Iganga. [b] non-crop land includes pasture, fallow and trees. (Source: Wortmann & Kaizzi 1998, p. 7)

	Soil (t ha^{-1} $year^{-1}$)	N	P	K
		(kg ha^{-1} $year^{-1}$)		
Cropped land, present practices				
Palissa *(nˆ26)*	7.5	13.4	5.3	26.4
Iganga *(nˆ30)*	4.4	9.2	2.4	11.9
Kamuli *(nˆ27)*	2.7	6.0	2.2	5.4
Mpigi *(nˆ19)*	2.3	4.8	1.7	4.3
Banana-based				
Palissa	6.0	13.0	4.7	30.4
Other locations	2.3	5.7	2.0	6.0
Annual crops				
Palissa	8.0	13.4	5.4	24.3
Other locations	3.3	6.9	2.2	7.5
Non-crop land[b]	0.7	1.1	0.4	2.3
Home area	2.8	6.7	2.5	12.0
Cropped land with additional control practices[a]				
Palissa	4.4	6.4	2.5	11.9
Iganga	2.8	3.7	1.0	4.6

More soil and nutrient losses were noted for Palissa because farmers often burn the crop residue rather than use it for mulch, as is done in other areas.

A rather rare technology is the employment of available radionuclides in the soil to predict erosion loss and sediment yield. The fact that the Caesium 137 Model (Ruecker et al. 2008) has been used in Uganda indicates the possibility of its development as a viable technology, especially because of the advantage of being quick to provide results and ability to determine suitable strategies for restoration. However, it has also been deemed a costly mechanism by other researchers who also doubt its continued use owing to insufficient quantities of ^{137}Cs in the southern hemisphere. The retention of caesium in soils over 40 years after the major fallout period is quite varied between soil types, making interpretation of such results difficult.

The water erosion prediction model (WEPP) has an advantage for predicting soil erosion on hill slopes and is capable of estimating the distribution of spatial soil loss. It takes into account spatial variability in topography, surface roughness, hydrology, soil properties and land use condition on the hill slope (Nearing et al. 1989). It has been successfully modified and applied to the erosion in the highlands of Uganda (Brunner et al. 2004).

Majaliwa et al (2012) sought to quantify runoff, soil and nutrient loss from major agricultural land use practices in the Lake Victoria region. Using erosion sample plots, whose slope ranged from 14 to 15% for coffee and banana (mulched and un-mulched), and 29 to 49% for rangelands, they were able to determine runoff and soil losses after every storm event. They noted that surface runoff was just a small fraction of the rainfall received, that is, annuals 1%, banana 0.3%, and coffee 0.8%. The degraded rangelands had, however, lost 23% of rainfall as runoff. Local factors such as topography, canopy and ground cover were observed to influence the rate of soil and runoff loss because the annuals and degraded rangelands had insufficient canopy cover and were often located on hilltops or on steep slopes (Ssali & Vlek 2002).

From their observations, Majaliwa et al (2012) found that the eroded sediments had higher nutrient levels, with nitrogen (N) and OM variation considered within seasons and land uses. The short rains were observed to erode more OM than the longer rains which eroded more N. Within one year, the sediments sampled in the longer rains for the annuals measured OM 4.6% and N 0.4%, banana (un-mulched) OM 4.8% and N 0.3%, banana (mulched) OM 9.1% and N 0. 4%, coffee OM 6.2% and N 0.4% and degraded lands OM 4.03% and N 0.28%. The shorter rains sediments for the annuals measured OM 5.6% and N 0.3%, banana (un-mulched) OM 6.3% and N 0.3%, banana (mulched) OM 7.3% and N 0.4%, coffee OM 8.5% and N 0.4% and degraded lands OM 7.97% and N 0.2%. This indicates a great loss of soils and nutrients from cultivated lands and degraded areas, which is a common site in the Rwenzori region where canopy cover has been greatly reduced through deforestation and the steep slopes worsen the situation.

4.2 Customisation of methods to local situations

As discussed in previous sections, in areas where data are required, resources, in terms of equipment, funds and skilled manpower are also a major limitation. In order to collect the required data, several alterations can be made to the prescribed scientific methods and scaled down to available data that can be comparable to that collected scientifically.

Wildlands School Videos (2010) is an educational website that has posted several videos showing methods to determine various soil properties on 'YouTube' and these can be helpful to extension workers and farmers who may need to understand the soils they are dealing with cheaply. Some of the parameters shown include determining soil organic matter and moisture content, soil texture, and sampling procedure, to mention but a few. With this, farmers can also determine the soil texture, water content, and bulk density as needed.

This can encourage the development of home-based techniques that are customised from laboratory and field experiments. For example, we can measure soil erosion locally with the use of local available materials as shown in Figure 9 below. In the same way soil infiltration experiments can be done. Slope angle can be achieved by propping the sample to a desired angle and slope length by reconsidering the size of sample. In the absence of a global positioning system, pacing from important landmarks and following the direction of the sun can provide both location and direction of one sample from the other.

Alternatively, today with new technology, mobile telephone gadgets which have been loaded with GPS can be employed to supply locations, distances and direction. The important aspects to keep in mind are the properly measured quantities and volumes of samples, size of equipment used, and duration of the experiments.

Figure 9. Picture showing home-based determination rates of soil erosion, with different land cover types of bare ground, forest soils with twigs and leaf fall, and grasslands.

5. RECOMMENDATIONS AND CONCLUSIONS

5.1 Conclusions

The study revealed that there are still insufficient data about the parameters in question for the East African highlands. This calls for intensive research, by both government and farmers, to enable planning and decision making.

An array of different methods of assessing land degradation has been revealed by the study, even in conditions similar to those of the East African highlands. Many methods are applicable but require skill and data in order to be effective. Some of these data are easy to generate while some are costly and not readily available. With the improvement in capacity, technology and data availability, analysis of local situations will be a lot easier and will encourage more research in this area.

Of all the methods that are applicable, none can be used in isolation but a combination of several methods ensures the collection of all the required data.

Among others, is the methodology of identifying local indicators of land quality; involving the community will be one very important tool in assessing degradation and ensuring a reversal of the degradation challenge in the short term. This will pave the way for sustainable land management.

On the other hand, other laboratory and field prediction technologies have the advantages of using controls in order to mimic different environmental conditions, though the opportunity to conduct measurements at different scales and in consideration of real environmental and temporal changes is of great benefit (Stoosnijder 2005). Moreover, in the face of improved technology, the use of GIS and other computer programs and models can come in handy by replacing symbols with figures, real data that can be projected and interpolated to arrive at the most relevant and timely interventions that will save Earth from degradation and related disasters.

5.2 Recommendations

- The UNEP (1987) soil erosion hazard mapping was a good step for Uganda; however, there has been no deliberate effort to update it. With the improvement in GIS capacity and data availability in the country, efforts should be geared towards updating the erosion map, both as a monitoring and planning tool.

- It is true that there are a lot of data available about the country's degradation status, but these data are handled and securely guarded by generating agencies and institutions. Research reports are posted over the internet, and it is costly for a local farmer or local extension workers to obtain them for reference. There should be a deliberate attempt to consolidate this information into a database that can be accessed easily and used to inform agricultural and research options for farmers, extension workers and the nation as a whole.

- Barrios et al. (2000) put forward a very useful methodology of developing LQIs. This methodology emphasises the active participation of farmers, extension workers, and researchers, and therefore ensures their willingness to share ownership of the decisions and strategies made to safeguard the land while ensuring improved land productivity. This approach can be very useful in restoration of hope among the communities and all other land users.

- In the Rwenzori region, there are absolutely no data on the SOC and SOM and their critical levels in the soils. It may be imperative that effort is deliberately put into establishing these properties of the soils in order to pave a way for affording better advice to the farmers who interact with the land on a daily basis for survival. This, in combination with identification of LQIs, will go a long way in achieving our restoration targets.

- Farmers, with the help of extension workers, should engage in the cheaper ways of locally understanding the properties of the soils they are working with. With the help of the Wildlands School Videos on YouTube, farmers could improve their soil management practices and slowly reverse land degradation.

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