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1.0 Introduction

Landslides are a serious concern in steep-lands where agriculture is a major activity by the communities living there (Perotto-Baldiviezo, H.L., Thurow, T.L., Smith, C.T., Fisher, R.F., & Wu, X.B., 2003; MUIENR, 1999). Most areas around the Echuya watershed consist of steep sided slopes and are prone to landslides and soil erosions. The watershed has slopes exceeding 18% and most of the cultivation is done on the slopes (MUIENR, 1999; MUIENR GIS data 2006).

Echuya watershed is located in South-western part of Uganda in Bufumbira County, Kisoro district and Rubanda County, Kabale district. It lies between $1^{o}14^{/}$-$1^{o}21^{/}$S and $29^{o}47^{/}$-$29^{o}52^{/}$E (Langdale-Brown *et al*, 1964; Banana and Tweheyo 2001; Bitariho & McNeilage in press). The altitudinal range of the Echuya watershed ranges between 2270 to -2570m above sea level running between Lake Bunyonyi, Mgahinga National Park and Bwindi Impenetrable National Park in S.W Uganda (Bitariho & McNeilage in Press).

The watershed is associated with up warping of the Western rift valley and the underlying rocks are generally phyllites and shales of the Ankole- Karagwean system. The soils are predominantly humic red loams, moderately acidic and deficient of bases. These soils are also dark, weakly structured or loose and friable when dried and therefore susceptible to erosion ((Langdale-Brown *et al*, 1964; NFA, 2005). Annual precipitation in the area averages 1,092mm and is bimodal; the first rainy period begins from March and ends in May followed by a dry period which begins in June to August. The next rains start from

September to November and are not normally heavy like the first ones (Langdale-Brown *et al*, 1964).

Agricultural activities in the area focus mainly on forest clearings and traditional ‘slash and burn’ practices. The Echuya watershed area has got one of the highest human population density in Uganda of about 500 people per Km^2 that has continually had a negative impact on land use practices therein (Uganda population census, 2002; Bitariho & McNeilage in press). Although the traditional method of farming is shifting cultivation, increased land use pressure due to high population density has caused farmers to shorten or eliminate fallow practices, thereby increasing the percentage of steep-lands under cultivation. A small percentage of the land has been managed with soil conservation practices such as trenches and agro-forestry that were introduced by development organisations (NatureUganda, Africa2000 network, NEMA) and the local government working there.

Landslides/soil erosions are natural processes but their rates, spatial and temporal distributions are influenced by the interaction of biophysical and human activities. Current rate of agricultural land degradation world-wide by soil erosion and other factors is leading to an irreversible loss in soil productivity of about six million ha of fertile land a year (Kokh-Shrestha, 2002). Resources such as soil, water and forests can be managed effectively, collectively and simultaneously within a watershed. Inventory on soil loss and prediction of soil erosion hazard (modeling) is vital for effective soil conservation planning of a watershed for sustainable development (Kokh-Shrestha, 2002). This study used a Geographical Information System (GIS) to produce a model of areas around the Echuya watershed most prone to landslides/soil erosions. The study also determined the effectiveness of the watershed management interventions introduced by the different development organizations by comparing two parishes of Kashasha and Chibumba.

2.0 Study objectives

The major aim of the study was to determine the effectiveness of watershed management interventions in reducing landslides/soil erosions in the study area. Other specific objectives were to;

i) Produce predictive maps of the different causes of landslides/soil erosions and their extent in the Echuya watershed area

ii) Determine landslides/soil erosion hazard areas, prior to introduction of watershed management interventions in the study area

iii) Determine areas less prone to landslides/soil erosions after introduction of watershed management interventions

iv) Assess the effectiveness of the watershed management interventions introduced by the different development organizations five years ago

v) Recommend a way forward for the effective watershed management interventions in the Echuya watershed

3.0 Methods

The study modeled out areas most prone to landslides/soil erosions in the two study parishes using spatial data of Echuya watershed. The spatial data were; Digital Elevation Model (DEM), Soil map layer, Land use cover map layer, watershed management interventions map layers and other ancillary data such as districts and parishes map layers (MUIENR, 1999; Kokh-Shrestha, 2002; Perotto-Baldiviezo *et al*., 2003). All the digital data except that of watershed management interventions were purchased from the remote sensing and GIS laboratory of Makerere University Institute of Environment and Natural Resources (MUIENR).

The watershed interventions digital map layer was processed from GPS points recorded in Kashasha and Chibumba parishes using ArcView 3.2. Other digital data had been previous developed from topographic sheets (1:50,000), aerial photographs and SPOT panchromatic imagery in October 1997 by the National Biomass Study and MUIENR GIS laboratory (MUIENR, 1999). The digital data were processed and analyzed using ArcView 3.2 spatial analyst toolpak and all the data was registered using Universal Transverse Mercator projection-UTM zone 35 (MUIENR, 1999; Perotto-Baldiviezo *et al*., 2003). Each category within the layers was then reclassified to generate hazard maps for each map layer (Perotto-Baldiviezo *et al*., 2003).

First the map layers of soil types, land use and watershed management interventions were converted to a raster grid using the spatial analyst of ArcView 3.2 (Figure 1). After converting the shape files into raster grids, I derived slopes from the DEM of the Echuya

Watershed and reclassified the slopes into two classes of those ≥18% slopes and those ≤18% slopes to develop a slope hazard map (MUIENR, 1999; Perotto-Baldiviezo *et al*., 2003). The raster map grid of soil type was also reclassified into two classes of; those with sandy particles and those without sandy particles to develop a soil hazard map (Figure 1). The land use raster map layer was also reclassified into two classes of; those areas with land cover (forests and woodlots) and those areas without land cover (farmlands and pastoral areas) to develop a land use hazard map (MUIENR, 1999; Perotto-Baldiviezo *et al*., 2003). Then last but not least the watershed management raster grid map was also reclassified into two classes of; those areas with interventions (trenches and terraces) and those areas without or little interventions. All the reclassified map layers were then overlayed to produce a map of the areas most prone to landslides/ soil erosions (see analytical model in figure 1).

Areas around Echuya watershed that were considered prone to landslides/soil erosions met the following criteria:

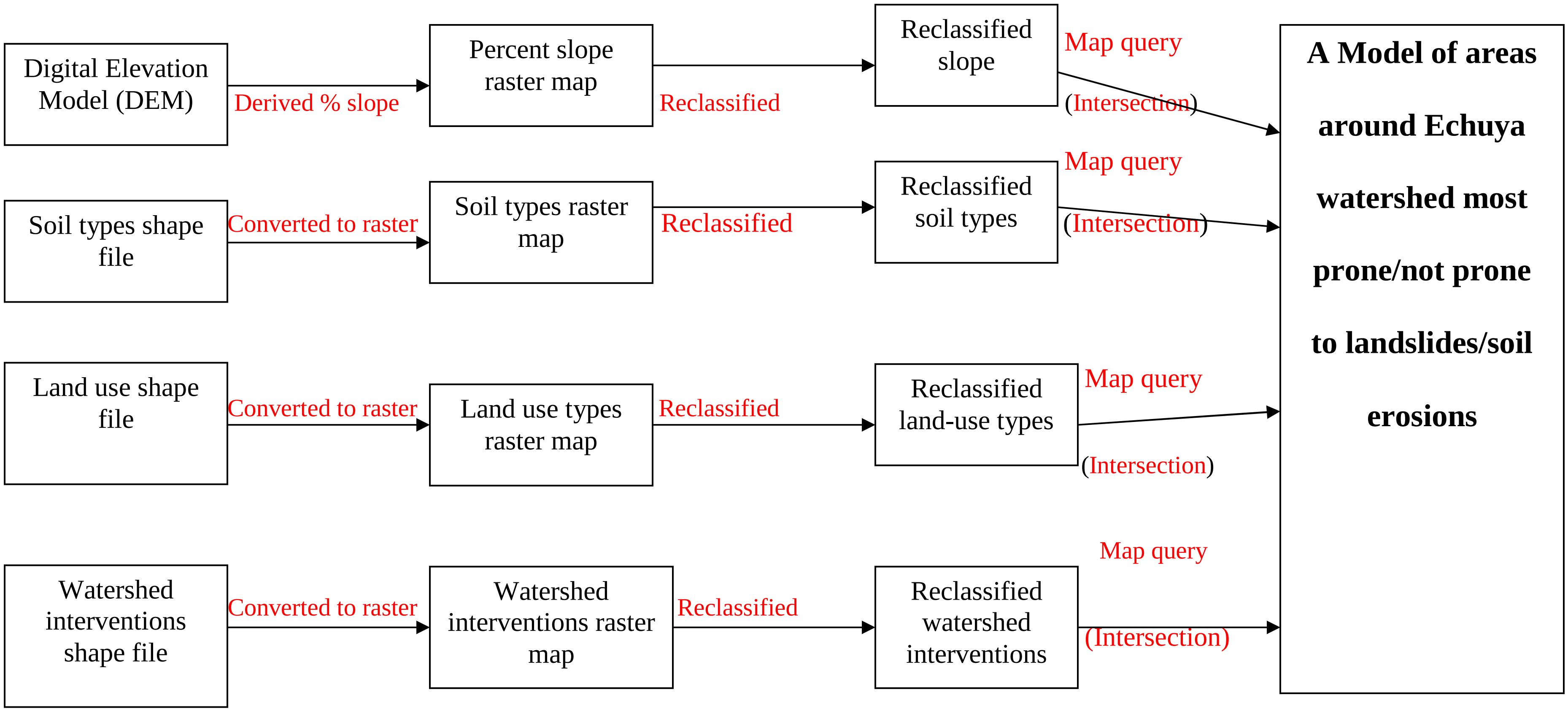
I) Had slope percentage of ≥18% (MUIENR, 1999; Perotto-Baldiviezo *et al*., 2003)

II) Had soils with a texture of either sandy clay, sandy clay loam, loam sand or sand (MUIENR, 1999; Perotto-Baldiviezo *et al*., 2003)

III) Had land use types classified as farmlands (croplands) and pastoral areas (MUIENR, 1999; Perotto-Baldiviezo *et al*., 2003)

IV) Had no watershed management interventions (Kokh-Shrestha, 2002; Perotto-Baldiviezo *et al*., 2003)

Figure 1 A flow chart showing analytical steps used to model the areas prone to landslides/soil erosions

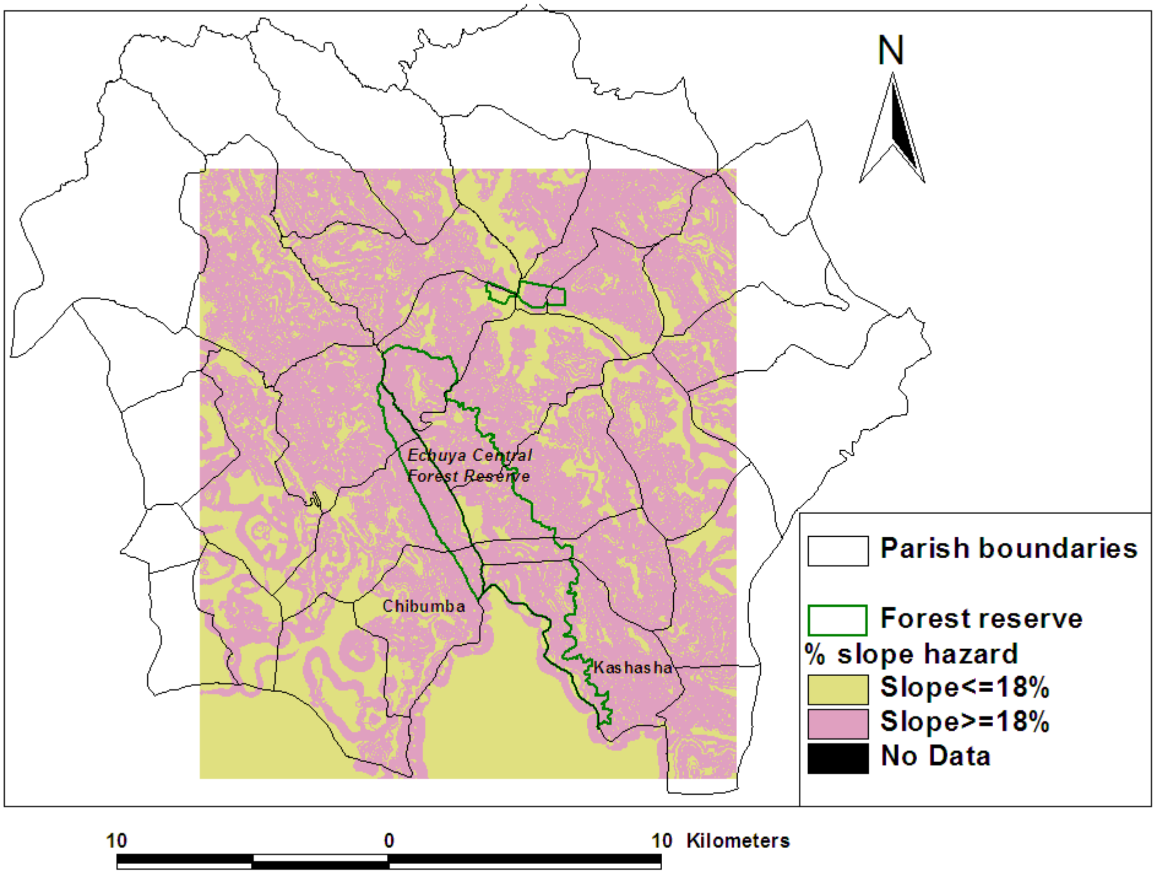


4.0 Results and discussion

4.1 Effect of slope on landslides/soil erosions

Figure 2 is a percent slope map showing landslides/soil erosions hazard areas as a function of slope. The slope map was generated from the DEM of the Echuya watershed and classified into two categories of steep-lands (≥18% slope) and lowlands (≤18% slope).The Echuya watershed is characterized with very steep slopes. Seventy eight percent of the watershed is very steep (≥18%) and can be described as a steep-land (Figure 2). The rate of landslides/soil erosions (soil loss) increases as slope increases (Kokh-Shrestha, 2002; Perotto-Baldiviezo *et al*., 2003). This therefore implies that 78% of the Echuya watershed is prone to landslides/soil erosions when slope percent is used as a variable (Figure 2). The situation in the Echuya watershed is almost similarly to that of the southern Honduras (South America) where 80% of the watershed is under steep-lands and therefore prone to soil erosion/landslides (Perotto-Baldiviezo *et al*., 2003). Figure 2 also shows that Kashasha parish has more steep areas than Chibumba parish and therefore more prone to landslides/soil erosion. The soil conservation intervention measures need to be concentrated more in Kashasha parish (which is now the case).

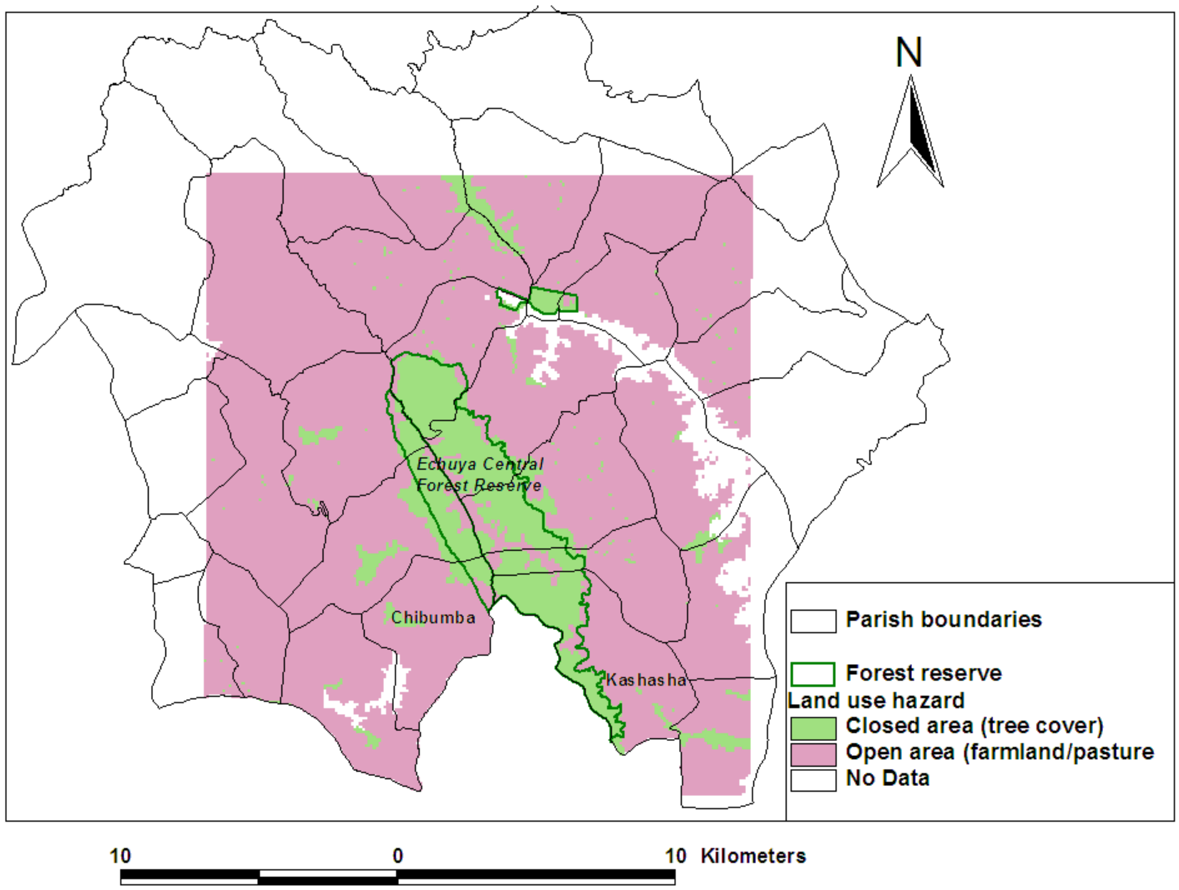
Figure 2 Percentage of land most prone to landslides/soil erosions due to slope steepness



4.2 Effect of land-use practices on landslides/soil erosions

Eighty nine percent of the Echuya watershed is under farmland/pastoral land and 11% only with forests or woodlots (Figure 3). Erosion and land use practice are very closely related. Rates of soil loss accelerate quickly to unacceptably high levels whenever land is misused like in the clearing of land for crops (Kokh-Shrestha, 2002; Perotto-Baldiviezo *et al*., 2003).Thus almost all the areas of the Echuya watershed (89%) is susceptible to landslides/soil erosions (Figure 3). This coupled with the fact that 78% of the watershed is steep, the Echuya watershed is under threat of landslides and soil erosions. Also from figure 3, both Kashasha and Chibumba parishes have very little vegetation cover (forests and woodlots) exposing the both areas to high levels of landslides/soilerosion.

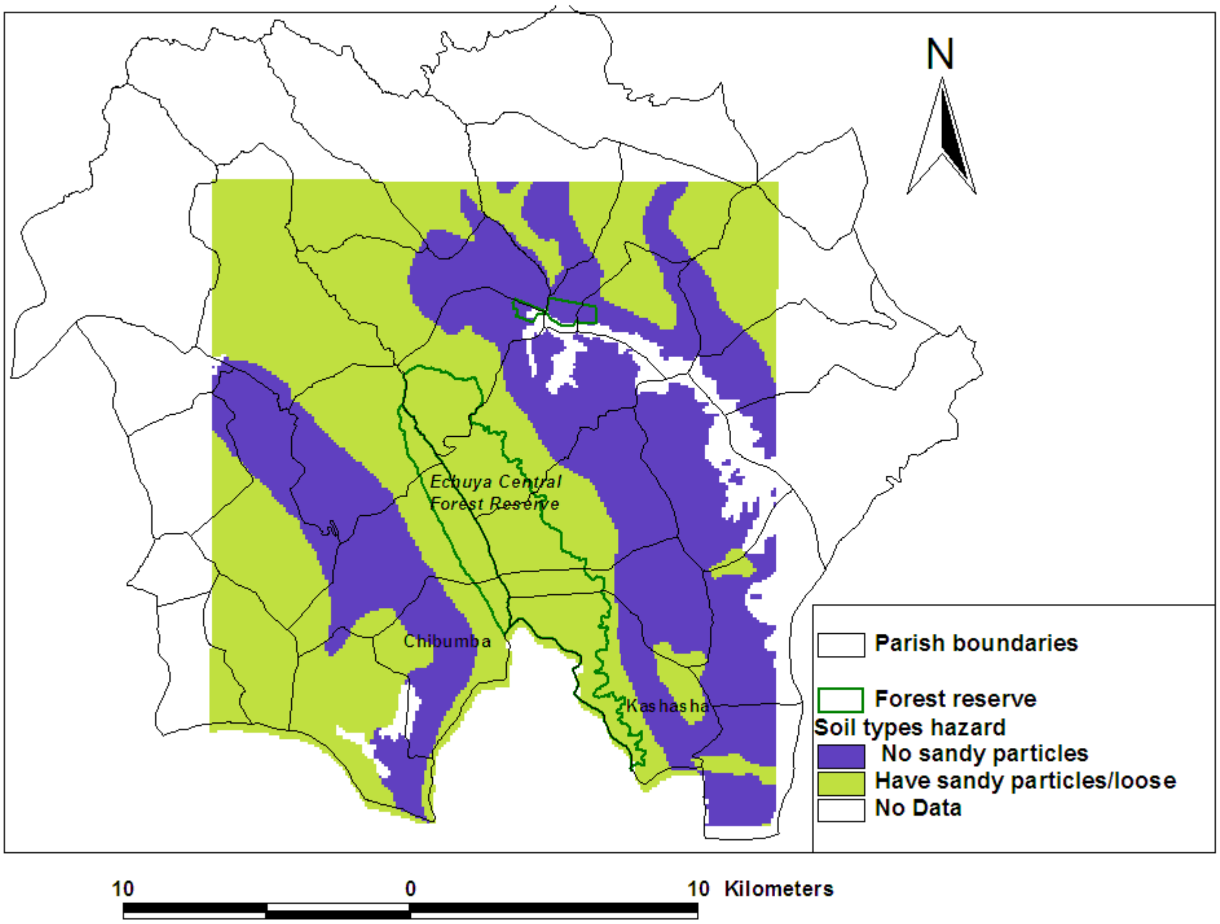
Figure 3 Percentage of land most prone to landslides/soil erosion due land-use practices



4.3 Effect of soil types on landslides/soil erosions

More than half of the soil types (58%) of the Echuya watershed area are sandy/loose soils and therefore susceptible to landslides/ soil erosions (Figure 4). Most soils of the Echuya watershed are predominantly humic red loams, moderately acidic and deficient of bases and are also dark, weakly structured rendering them to be loose and friable when dry. This makes most of the Echuya watershed very susceptible to landslides/soil erosions ((Langdale-Brown *et al*, 1964; NFA, 2005). Also from figure 4, the soils of Kashasha parish have less sandy particles and are less friable compared to Chibumba parish. Most soils in Chibumba parish and some small portions of Kashasa however, contain sandy particles and are friable and susceptible to landslides/soil erosions.

Figure 4 Percentage of land most prone to landslides/soil erosions due to soil types



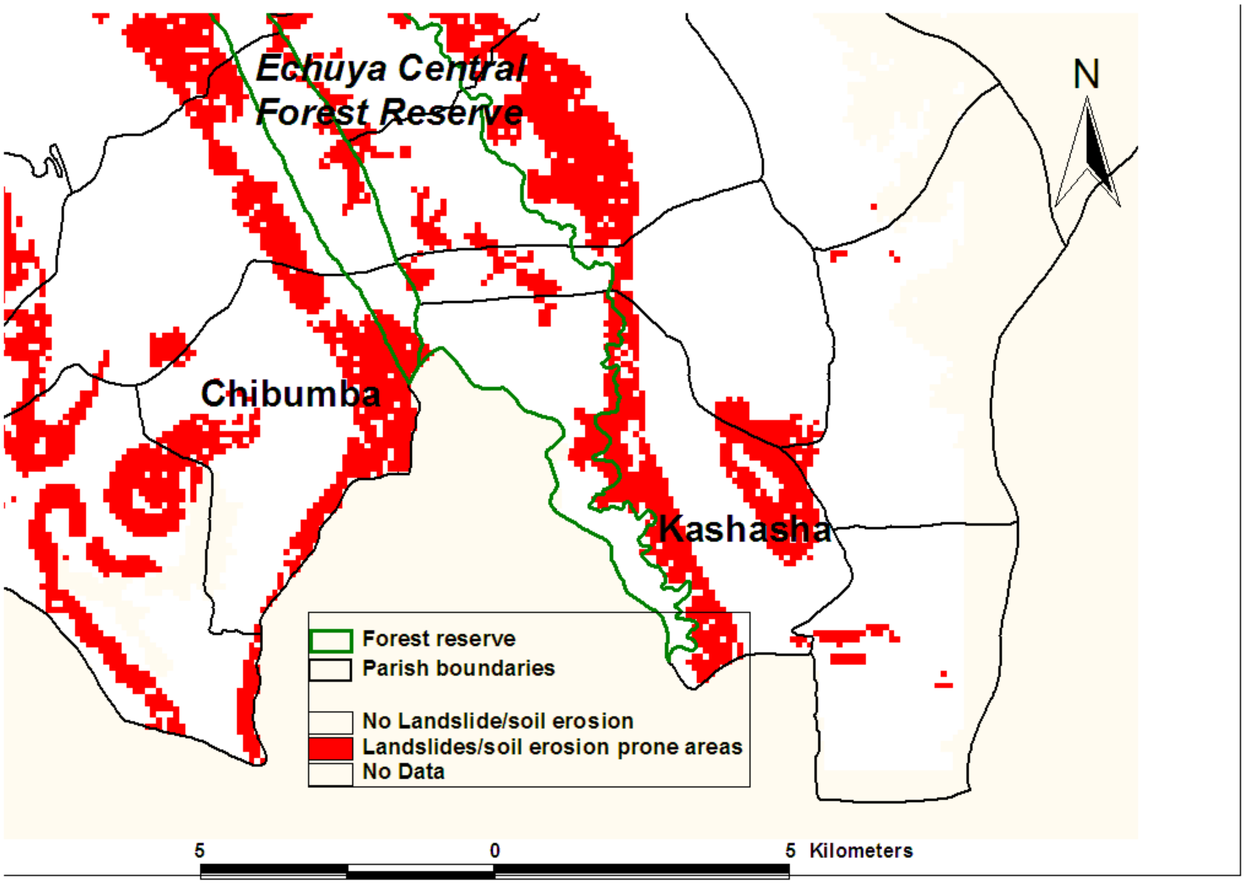
From the results above, it is evident that landslides/soil erosions occurrences could be reliably characterized by slope, land cover type and soil types. Landslides/soil erosions hazards increase as slope increases and are strongly related to land cover and soil types (MUIENR, 1999; Kokh-Shrestha, 2002; Perotto-Baldiviezo *et al*., 2003). Deep- rooted vegetation such as forests and woodlots stabilize top-soils and are very important factors in lowering landslides/soil erosions especially in steep-lands (Kokh-Shrestha, 2002;

Perotto-Baldiviezo *et al*., 2003). Since 89% percent of the Echuya watershed area is under farmland/pastoral land, it is no surprise that landslides/soil erosions are a regular occurrence there leading to low crop yields (NatureUganda, 2004). Landslides are more pronounced in places with bare soils and crops than areas with forests and woodlots. The removal of vegetation (as practiced in the study area during clearing of land for agriculture) increases the occurrence of landslides/soil erosions due to alteration of the hydrological cycle (Lal, 1987; Thurow & Juo, 1995; Chan, 1998; Glade, 2003; Perotto-Baldiviezo *et al*., 2003).

4.4 Scenario 1: Study area prior to the introduction of watershed management interventions

Figure 5 is a map of areas affected by landslides/soil erosions in the study areas of Kashasha and Chibumba parishes before watershed management interventions were introduced. From the figure and from GIS map query calculations, Kashasha parish had slightly more areas that were most prone to landslides/soil erosions than Chibumba parish. About 8.8km^2 of Kashasha parish (40% of area coverage) was most prone to landslides/soil erosions before interventions measures were introduced. In Chibumba parish, about 6.3Km^2 (35% of area coverage) was most prone to landslides/soil erosions before introduction of intervention measures (Figure 5). The situation in both study areas could have been worse if it were not for the soils in the area being more firm and not being sandy as discussed early on above.

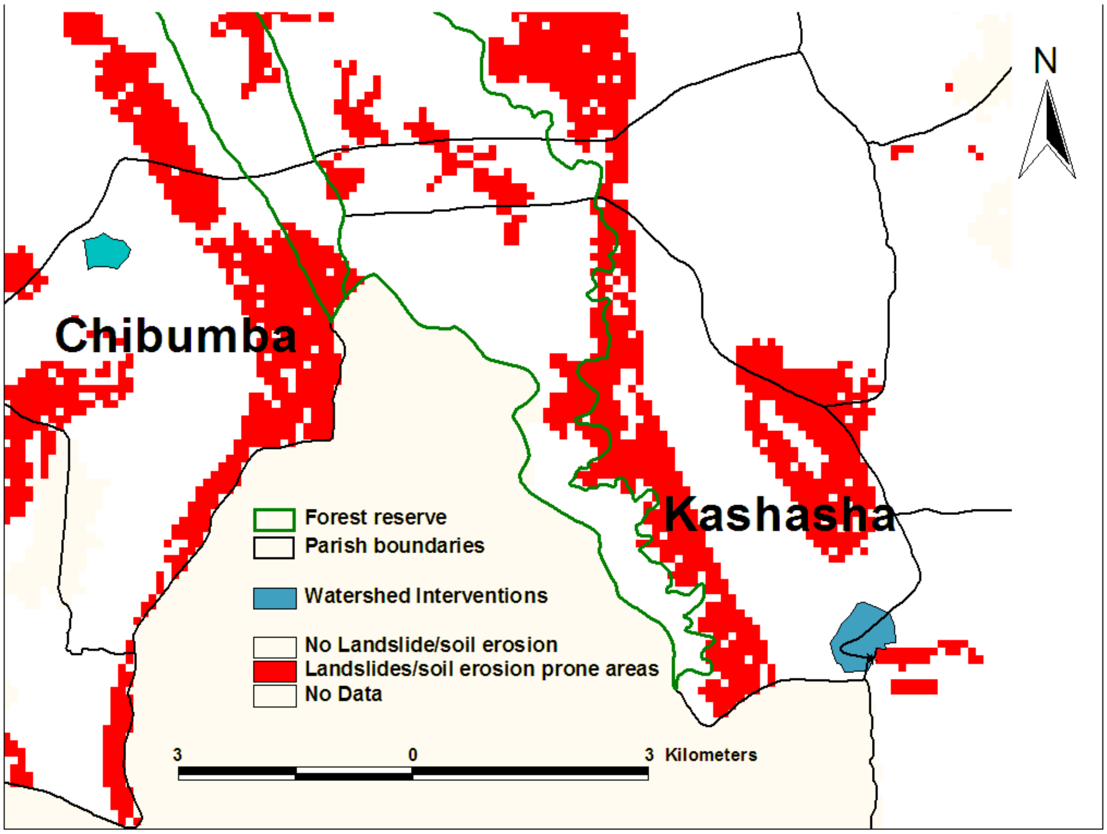
Figure 5 Landslides/soil erosions prone areas prior to introduction of watershed management interventions in the study area



4.5 Scenario 2: Study area after introduction of watershed management interventions

Figure 6 shows a map of the study area affected by landslides/soil erosions after introduction of watershed management interventions. From the figure it is evident that vast areas of the watershed are still prone to landslides/soil erosions even after introduction of the interventions. The interventions introduced by the different organizations working there have covered only a very small proportion of the area affected by landslides/soil erosions. Only 0.5km^2 (6 % of prone area) of Kashasha parish has watershed management interventions. The landslides/soil erosions prone area of Kashasha parish was reduced to 34% from 40% after introduction of the interventions. Also for Chibumba parish, only 0.2km^2 of the parish has watershed management interventions and yet is not the most affected. The landslides/soil erosions prone area of Chibumba parish has not reduced at all since it did not cover the most prone areas (still 35% of parish area). Figure 6 also shows that most landslides/soil erosion prone areas are located near the forest peripheral of Echuya and yet most of the interventions have been concentrated far away from the forest. There is need by the different development organizations working there to refocus their interventions in the most prone areas as shown in figure 6. Also from the figure, it is evident that even after introduction of watershed management interventions; Kashasha parish is still more prone to landslides/soil erosions than Chibumba parish.

Figure 6 Landslides/soil erosions prone areas after introduction of watershed management interventions in the study area



5.0 Conclusions and Recommendations

The study shows that factors affecting landslides/soil erosions include but are not limited to topography, soil types, soil interventions and land use practices. Steep-lands are bound to be very susceptible to landslides/soil erosions so are areas with sandy soil textures, no soil intervention measures and little or no vegetation cover. The four parameters of land are very useful when developing potential land use patterns and are essential in identifying capability of land for agriculture purposes. The four tools together enable a more comprehensive approach for spatial explicit watershed planning to improve agricultural production while minimizing landslide hazards (Ministerio de Desarrollo Sostenible y Medio Ambiente, 1998; Perotto-Baldiviezo *et al*., 2003). A risk of erosion exists on cultivated land from the time trees, bushes and grasses are removed. Therefore soil conservation strategies should aim at establishing and maintaining good ground cover (Kokh-Shrestha, 2002).

The study has also shown that there is need to expand and refocus the watershed management interventions to the most prone areas such as those bordering Echuya forest. The interventions introduced five years ago by the different development organizations have covered only a very small proportion of the landslides/soil erosions prone areas and have not tackled the most prone areas shown by this study. There is need to replicate what so far has been carried out by the development organizations to cover other parts of the study area and beyond most especially areas immediate to Echuya forest. It is however recognized that financial and organizational constraints can be a liming factor in replicating and expanding elsewhere within a short time but priority needs to be focused on the most prone areas. Focusing on the most prone areas of watersheds should obviously be a priority to evolve appropriate soil conservation management strategies that maximizes benefits out of any money-time effort making scheme (Kokh-Shrestha, 2002). Further research is needed to assess the effectiveness of the different watershed management interventions in the study area and beyond.

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