Landslide Inventory and Susceptibility Assessment for the Ntchenachena Area, Northern Malawi (East Africa)

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1. Introduction

Landslides are one of the causes of loss of life, injury and property damage around the world. In many countries socioeconomic losses due to landslides are great and increasing as human development expands under the pressures of increasing populations into unstable hill areas (Msilimba 2002; Huabin et al. 2005; Msilimba and Holmes 2005).

Similar to other parts of the world, landslides are not a new phenomenon in Africa. They have been reported in Cameroon, Kenya, Uganda, Rwanda, Tanzania, and Ethiopia (Moeyerson 1988; 1989a; 1989b; Davies 1996; Westerberg and Christiansson 1998; Ngecu and Mathu 1999; Ingang'a and Ucakuwun 2001; Muwanga et al. 2001; Knapen et al. 2006). The East African region which includes Malawi, is a heterogeneous in terms of physiography, geomorphology and rainfall, and has a high susceptibility to slope movement. The high annual rainfall, high weathering rates, deforestation and slope material with a low shear resistance or high clay content are often considered the main preconditions for landslides (Knapen et al. 2006).

The causes of landslides that have occurred in Malawi are similar to those of the countries in the East African region. Examples include the 1946 Zomba Mountain landslide, the 1991 Phalombe landslide and the 1997 Banga landslide (Poschinger et al. 1998; Cheyo 1999; Msilimba 2002; Msilimba and Holmes 2005).

This chapter is based on data from numerous landslides which occurred in 2003 in northern Malawi following heavy and prolonged precipitation. These landslides killed four people, destroyed houses and crops, flooded the Mzinga River and dammed the Lutowo River. The chapter presents and discusses landslide inventory for the Ntchenachena area of Rumphi District (northern Malawi). The inventory was prepared based on the analyses of aerial photographs, satellite images, and field observations. The inventory presents dating and the dimensions of the landslides, as well as the location, and distribution of the events. A simple classification of landslides is also given based on Coch (1995). It explains details of channel morphometry, materials involved in the movement, slope type and aspect. The chapter also discusses the causes and contributing factors of the landslides and describes a simple susceptibility appraisal procedure for the Ntchenachena Area.

2. Geographical characteristics of the Ntchenachena area

The Ntchenachena area is located in Rumphi District in the northern region of Malawi (**Fig 1**) and covers an area of 264 hectares. The area is comprised of six units identified by the spurs forming the area (**Fig 2**). It is a continuation of the East Nyika escarpments and is part of the Great African Rift Valley System (Kemp 1975). The area is a belt of rugged country, consisting mainly of deeply dissected spurs which are almost V-shaped. Elevation variesfrom 1295m to 1828m above sea level (GoM 1987). Flat areas are concentrated along the valleys.

Geologically, the region consists of a basement complex of Pre-Cambrian to Lower-Paleozoic rocks which is overlain by young sedimentary formations. In northern Malawi, the Pre-Cambrian rocks were affected by both the Ubendian and Irumide Orogenies (Kemp 1975). The resulting basement complex is largely composed of gneisses and muscovite schist of south easterly trend and structurally is a continuation of the Ubendian Belt of south-western Tanzania. The gneisses are of the Karoo Supergroup and experienced a long period of erosion that was followed by deposition, mainly in the Permian and Triassic times (Cooper and Habgood 1959). The Karoo Supergroup rocks comprise sandstones, siltstones and shale with some coal seams near the base (Bloemfield 1968; Kemp 1975). Within the Ntchenachena area, the geology consists of highly jointed muscovite schist and biotite gneisses, with a gneiss foliation trend varying between 278^0 and 114^0. The average dipping angle is 45^0. In some places, the lithology shows the presence of mica schists (GoM 1977; Kemp 1975). Fresh rock outcrops are rare due to rapid chemical weathering.

The soils in this area are derived from the deep chemical weathering of the muscovite schist, the gneiss and the Karoo sediments. The major soil group is ferrellic, of the soil family Luwatizi (Young 1972). The soils are very deep (>10m) and well drained. The surface stoniness is less than one percent. In the elongated valleys, ferrisols predominate. Red clays with a strongly developed blocky structure occur in association with leached ferralitic soils, but are less highly leached and more fertile than the latter. In the dambos, dark coloured or mottled gley or hydromorphic soils occur.

Areas of high elevation suffer less intense temperatures and thus weathering is less deep into the bedrock than lower elevations. The Ntchenachena area is over 1800m above sea level with mean monthly maxima ranging between 18.5^0C and 20^0C and mean monthly minima ranging from 7^0C to 10^0C. This is one of the wettest areas in Malawi, with only 1 or 2 months being considered as the dry period. Most rain occurs between November and April. The mean monthly rainfall is 200mm and the mean annual rainfall range is between 1200mm and 1600mm (Linceham 1972). Rainfall is primarily orographic, with convectional activity between November and April.

The vegetation of this area is classified as Afromontane, with scattered grass and shrubs. Most of the slopes are under cultivation, and this has resulted in large scale deforestation, although isolated patches of pine trees still occur along the ridges. The rate of deforestation has accelerated in recent years mainly due to increased seasonal burning of the trees, bushes and shrubs for shifting (slash and burn) cultivation and hunting. The increase in seasonal burning is due to growing population levels in the area.
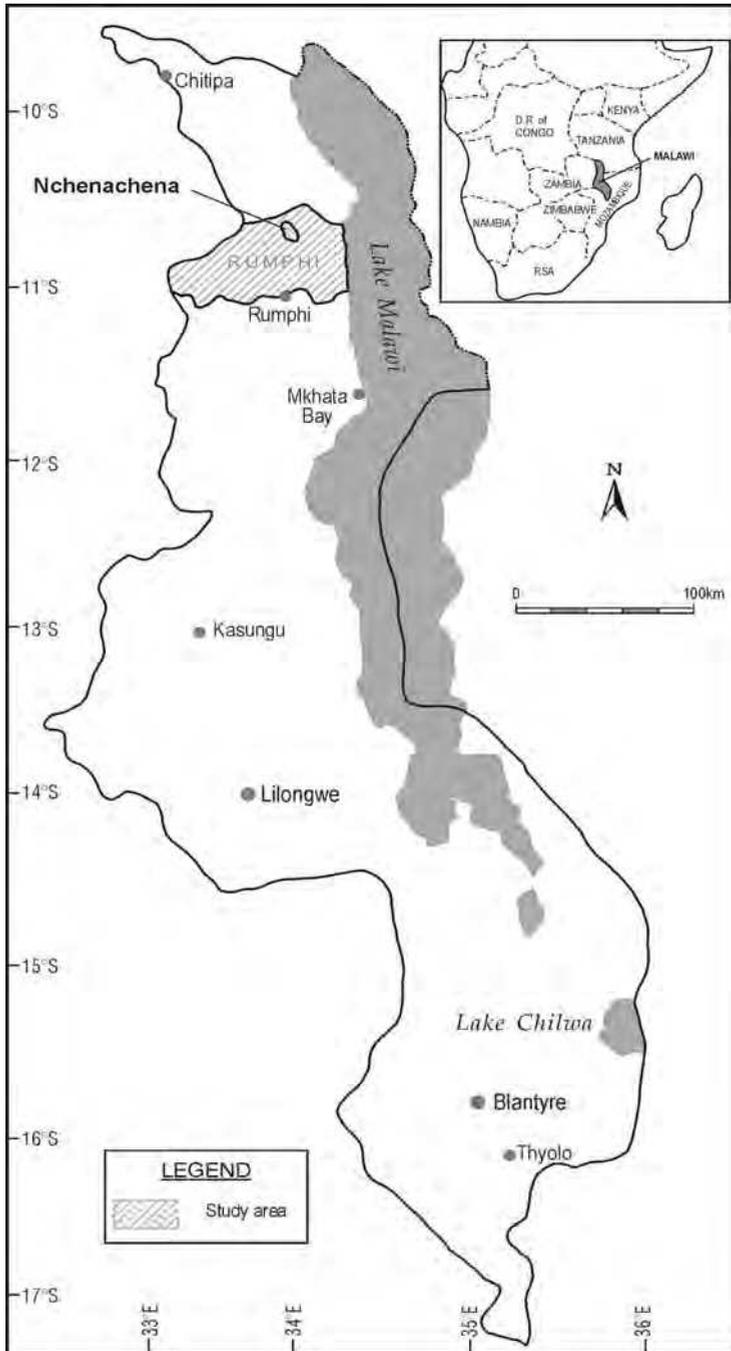
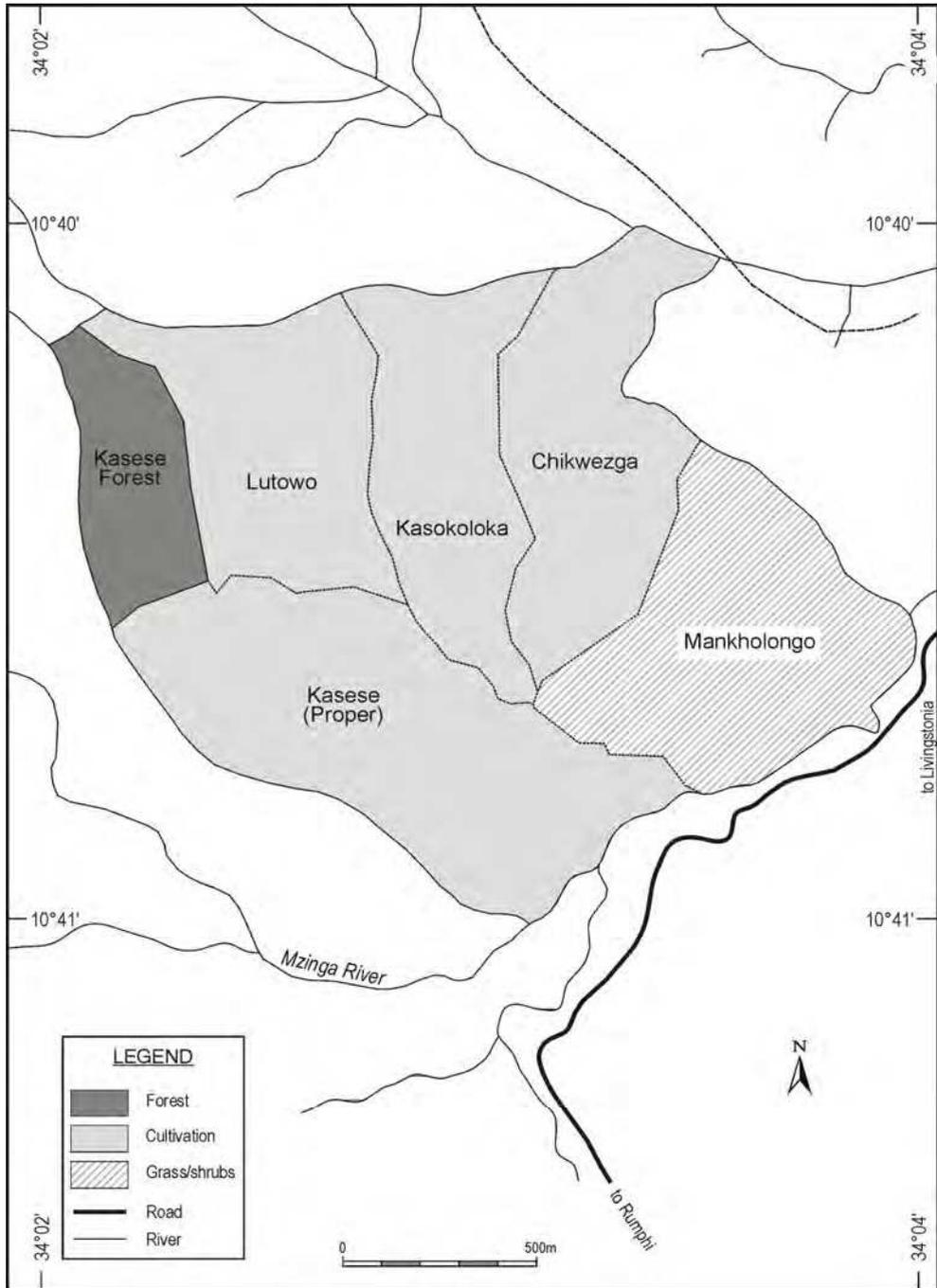Fig. 1. Map of Malawi Showing Location of Rumphi District

Fig. 2. Map of Rumphi District Showing Ntchenachena Area

Numerous streams originate in this area. Most of these are perennial due to the high rainfall of the area and the ability of the soil and weathered basement complex to absorb and store much of the precipitation. However, the perennial rivers show marked seasonal variation according to the amount of rainfall. Water tables are generally high. Human activities in the area are dominated by subsistence agriculture with a small amount of coffee grown as a cash crop and small scale lumbering of both indigenous and exotic timber species. Villages tend to be scattered and isolated with houses primarily built along ridges and slopes.

3. Work approach

Mapping the study area

Evidence of past landslides (scars and gullies), location of settlements, land degradation, and steepness of the slope were considered in delineation of the study area. Aerial photography and topographic map interpretations were used to delineate the areas. The 1995 aerial photographs at the scale of 1:25 000, and the topographic maps of Rumphi District at the scale of 1:50 000 were used.

As more recent maps and aerial photographs (after 1995) were not available, ground reference data and Landsat 7 ETM images were used to delineate the area. Reference data was used to correct errors caused by scale distortions on aerial photographs and topographic maps. Interpretation of aerial photographs was done following the standard procedures (Shaxson et al. 1996).

Ancient landslides inventory

Ancient landslides were identified on 1995 aerial photographs, at a scale of 1:25 000. 2003 Landsat 7 ETM images supplemented the data obtained from the 1995 aerial photographs. This involved the identification of scars and channels and depositional areas. Interpretation of the photographs was carried out using a pair of stereoscopes and a hand lens both of magnification 3X. Mapping of the coordinates for the identified landslides was done, using the Global Positioning System (Trimble Geo Explorer II GPS).

Ground reference data were acquired during fieldwork. These data were also used to verify landslide occurrences and to identify any scars not observed on the aerial photographs and satellite images. Fieldwork involved traversing the areas and inspecting all the spurs and slopes for scars, gullies, evidence of soil creeping and rock falls. Local people, especially those who were eyewitnesses to the landslides, provided information on the location of landslides and assisted with dating landslide events.

Measurements of average widths, depths and lengths of channels and diameter of the scars were carried out, using a 200-meter surveying tape. The angle at which the scar is located was determined by an Abney level while the actual location was determined by GPS. The classification of landslides was based on Coch (1995).

Collection of geological, vegetation and rainfall data

Fieldwork was carried out to determine the dipping angle, slope angle and foliation trends, using a Silva compass. The geological map of South Uzumara at a scale 1:100 000 was also used. (GoM 1977). Additional information was obtained from the Livingstonia Coalfield and the Geology of the Uzumara Area Bulletin (Bloemfield 1968; Kemp 1975). Fieldwork

provided the bulk of geological data because at the scale of 1: 100 000, the geological map could not provide adequate details of the geology of the study area.

Rainfall data were obtained from the local meteorological stations located 500m from the study area. Records for a period of 30 years (from 1976 to 2006) were obtained with additional data being obtained from the Central Meteorological Services.

A vegetation survey was carried out to establish tree heights, canopy cover, and diameter at breast height (i.e. 1.3m above the ground) as a measure of plant density. Quadrants of 20m by 20m were constructed at a spacing of 50m. The vegetation survey was concentrated in the forested areas of the Ntchenachena area. The vegetation survey methodology which was followed is well discussed by several authors (Chutter 1983; Avery and Burkhart 2002).

Sampling rationale and laboratory analyses

Textural and physical properties of soils and sediments have an influence on the susceptibility of such material to failure (Bryant 1976; Msilimba 2002). Soil sampling was undertaken in order to assess physical characteristics that have a bearing on soil structural strength. Both core and clod sampling were carried out using standard procedures (GoM 1988; Fredlund and Riharjo 1993). Two undisturbed and two disturbed samples were collected for each sampling pit, using a core sampler and a soil auger. The sampling interval was 15m by 50m (based on the contour intervals 50m apart). Forty sampling points were identified in six units of the Ntchenachena area namely: Kasokoloka, Lutowo, Kasese Proper, Kasese Forest, Mankholongo and Chikwezga.

In areas where landslides had occurred, the samples were collected from the sides of the scar. Areas which were inaccessible due to thick forest, gullies and very rugged terrain were not sampled. The results from the rest of the spurs were generalised to include unsampled sites. In special cases, the selection of the sample locations was based on indications of slope instability, mainly soil creeping and cracking. The effective soil depth was determined using a screw soil auger, a surveying tape, measurements of the depth of recent landslides, and slope remodeling/cutting.

Samples were analysed using standard, acceptable soil analysis techniques to determine particle size distribution, hydraulic conductivity, particle density, bulk density, total porosity, aggregate stability and Atterberg limits (GoM 1988; Non-Affiliated Soil Analysis Working Committee 1990). Clay and silt percentages were determined using the hydrometer method (GoM 1988; Non-Affiliated Soil Analysis Working Committee 1990) and sand fraction was determined using standard sieving techniques (GoM, 1988). Hydraulic conductivity and bulk density were measured using standard methods (Punmia 1976). Liquid and plastic limits (Atterberg limits tests) were determined using the Casagrande method, following which plasticity indices were calculated (GoM, 1988; Non-Affiliated Soil Analysis Working Committee 1990).

4. Results and discussion

4.1 Landslides Inventory

A landslide inventory was carried out to give a measure of the past instability of the area. A total of 88 landslides were identified and mapped (**Table 1)**. Within the Ntchenachena area,

there were 55 (62.5%) landslides recorded for Lutowo, followed by 14 (15.91%) for Chikwezga, 12 (13.64%) for Mankholongo, 6 (6.82%) for Kasese Proper and 1 (1.14%) for Kasokoloka.

Unit/area	Number of landslides	Depth (m)	Length (m)	Width (m)	Slope angle^0	Impacts
Kasokoloka	1	21	230	50	41	Crops destroyed, Maize granary swept away, Goats swept away, houses destroyed, four people killed
Lutowo	55	0.4 - 25	7 - 216	6 - 240	53	Crops destroyed, damming of Lutowo river, flooding of Mzinga river
Kasese Proper	6	0.5 - 13	31 - 99	6.7 - 95	58	Crops destroyed
Kasese Forest	Nil	-	-	-	58	-
Mankholongo	12	1.1 – 8.5	24 - 324	14 - 125	54	Vegetation removed
Chikwezga	14	0.4 – 4.2	21 - 406	9 - 57	54	Crops destroyed, pine trees swept away, houses destroyed

Table 1. Mapped landslides and their impacts

No landslides were recorded within the Kasese Forest of the Ntchenachena area. Seventy-nine landslides occurred in 2003 (contemporary) while 9 were undated (ancient) landslides (i.e. local people could not remember when they occurred). Within the study area, landslide dimensions vary enormously with length ranging from 7m (Lutowo) to 406m (Chikwezga). Width ranged from 6m (Lutowo) to 240m (Lutuwo). Depth ranged from 0.4m (Lutowo) to 25m (Lutowo). Slope angles for the mapped landslides were high, ranging from 41^0 (Kasokoloka) to 58^0 (Kasese Proper and Kasese Forest).

Fifty eight landslides (65.91%) occurred on concave slopes, 17 (19.32%) on convex slopes, and 13 (14.77%) on linear/rectilinear slopes. Within the individual units of the Ntchenachena Area; at Lutowo 35 landslides occurred on concave slopes, 12 on convex and 8 on linear/rectilinear; at Kasosokola the landslide occurred on a concave slope; At Kasese Proper, all the landslides occurred on concave slopes; at Mankholongo, 11 were on concave

while 1 was on convex; at Chikwegza, 5 were on concave, 5 on convex while 4 were on linear/rectilinear. In terms of slope aspect, within the Ntchenachena Area, most of the landslides occurred on S, NE, E and SW aspects (29.55%, 17.04%, 21.59% and 15.91%, respectively).

4.2 Classification of the mapped landslides

All the landslides in all the units were rotational although some landslides quickly changed into mud/debris flows with increasing rainfall. The landslides involved curved surface ruptures and produced slumps by backward slippage. This is typical of the East Africa region (Davies 1996; Ngecu and Mathu 1999). Seventy nine landslides were classified as contemporary and the rest were ancient, although these were re-activated in 2003. In terms of degree of stabilisation, 81 landslides were still experiencing erosion and dissection (41 active and 39 partially stabilized) while 7 had been recolonised by grass/shrubs. Channel geometry varied enormously. Steep narrow valleys produced V-shaped channels while gentle wide valleys produced U-shaped channels. Forty-three landslides had U-shape, 33 had V-shape while 12 had irregular channel morphometry. Within the units of the Ntchenachena area, the material involved in the movement ranged from soil mass to soil mass/weathered rocks/quartz floats. The majority of the landslides (57) occurred on middle slopes. Upper slopes recorded 23 landslides while 8 were on the lower slopes.

In some areas, landslide material moved a limited distance before stopping. The motion was probably inhibited by the dilation of the soil and concomitant decrease in pore pressure. The soils, according to eyewitnesses, were looser and in a dilative state, having absorbed water from the continued rainfall or from water ponding behind the slump, as was the case at the Lutowo Unit. As the slump mass became re-saturated, pore pressure increased again, initiating a second failure. This mechanism contributed to the flooding of the banks of the Mzinga River and has been widely researched (Harp et al. 1989; Harp et al. 2002).

4.2.1 General synthesis of landslides Inventory

The Lutowo area recorded the highest number of landslide occurrences. This was due to the high degree of land disturbance caused by cultivation, settlement activities and slope remodelling. Deep channels were common in all the units of the Ntchenachena area due to the deep weathering of the basement which has produced deep soils. Deep weathering is due to relatively high temperatures and high precipitation (Msilimba 2007). However, the length of the channels depended on the initial point of failure, and the length of the individual slopes. This is particularly evident for the Mankholongo and Chikwezga landslides which started on the top of hills and had lengths of up to 324m and 406m respectively.

The role of slope type in determining the location and distribution of landslides is well documented (Crozier 1973; Knapen et al. 2006). The majority of the landslides in the study area were on concave slopes and were rotational which is in accordance with the findings of Knapen et al. (2006) in Uganda. Few landslides (13) occurred on linear and rectilinear slopes because there were few of these slopes in the study units. However, this does not indicate a

diminished level of instability to deformation for such slopes. Such slopes (with shallow soils and a sharp contrast between solum and saprolite) are inherently more unstable (Westerberg and Christiansson 1998).

Studies have been carried out to correlate slope aspect and vegetation type and distribution, and also aspect and rainfall type and distribution (Crozier 1973; Sidle et al. 1985). Although rainfall is generally from the SE, E, NE and S in Malawi, there is no rainfall data to suggest that the distribution of landslides in an area is affected by aspect. The fact that most of the landslides occurred on NE, SW, E and S aspects, which coincide with rainfall aspect patterns in the country, could be an issue for further investigation.

Landslides in the Ntchenachena area were rotational which involved curved surface rupturing and produced slumps by backward slippage. Such failures are associated with deep soils as is the case with the Ntchenachena area (Msilimba, 2002; Msilimba and Holmes 2005; Knapen et al. 2006). Scars revealing curved rupture and flat planes are common. Within the Ntchenachena area, complex events started as slides and with increased water content changed into mud-flows and debris-flows.

Most of the landslides are undergoing dissection due to erosion and have not been re-colonised by vegetation. Evidence of instability such as cracking of soils, gullying, fissuring, soil creeping and the removal of basal support was observed. Some landslides had achieved 50% re-colonization by vegetation although erosion was still active in some parts of the channels. Those landslides which had achieved 90% or more of re-colonization were assigned to the stabilized category. Most of the landslides fall in the active and partially active categories because the events were fairly recent and slopes need time to rehabilitate.

The results of the determination of the initial point of failure, where the shear band developed, agree with the findings of Fernandes et al. (2006). According to Fernandes et al (2006), middle and lower slopes (18.6^0 to 55.5^0) are the most frequent to fall, followed by upper slopes of greater than 55.5^0. Most of the landslides occurred on the middle and lower parts of the slope where the landslide potential index (LPI) is highest. LPI is based on the number of landslides recorded in a given segment of a slope (Fernandes, 2006). The index decreases with height due to excessive removal of slope material as the force of gravity increases with height and slope angle (Smith 1996; Fernandes et al. 2006). Within the Ntchenachena area, middle slopes had thick soil or weathered materials while the upper slopes had thin soils (< 1m deep).

4.3 Causes of landslides

The general literature on slopes, mass movement and landslides is vast and is not addressed here (see for example Summerfield 1991; Selby 1993). Rather, this study highlights and examines local factors which contributed to landslides and their mechanisms of generation. The study suggests a combination of natural and anthropogenic factors precipitated the occurrence of landslides in the Ntchenachena area. For the purpose of clarity, the factors are presented separately while in reality they interacted and were inextricably linked. The results from the routine analyses undertaken on soil samples from six units are presented in table form (**Table 2A and 2B**) and are explained below.

Topographic Unit	Clay%	Silt%	Sand%	Hydraulic Con. (cm/hr)	Remark	Porosity Index	Liquid Limit	Plastic Limit	Bulk Density	Aggregate Stability	Plasticity Index
Kasokoloka	29.00	16.75	54.25	5.88	Mode-rate	55.66	44.21	27.86	1.18	2.88	16.35
Lutowo	17.72	15.63	66.63	7.68	Mode-rately rapid	57.77	47.93	28.74	1.119	3.18	19.19
Kasese Proper	22.00	16.08	61.92	7.15	Mode-rately rapid	56.98	46.39	26.95	1.14	2.61	19.44
Kasese Forest	28.00	15.67	56.33	11.09	Mode-rately rapid	60.25	52.23	30.37	1.05	2.72	21.86
Mankholongo	22.53	17.53	59.92	8.73	Mode-rately rapid	59.12	47.72	28.40	1.08	2.67	19.32
Chikwezga	14.11	17.55	68.36	8.22	Mode-rately rapid	58.91	54.70	31.51	1.09	3.18	23.19

Table 2A. Particle size analysis, hydraulic conductivity, porosity, Atterberg limits and densities

Unit	Slope angle [0]	Vegetation/Land-use	Disturbance of land surface	Degree of Weathering
Kasokoloka	41	Cultivation/settlement	High	High weathered
Lutowo	53	Cultivation/settlement	High	High weathered
Kasese Proper	58	Cultivation/settlement	High	High weathered
Kasese Forest	58	Forest	Undisturbed	High weathered
Mankholongo	54	Grass/shrubs	Moderate	High weathered
Chikwezga	54	Cultivation/settlement	High	High weathered

Table 2B. Unit characteristics

Particle size analysis, hydraulic conductivity, porosity, atterberg limits and densities

The Atterberg limits determine the behaviour of soils before deformation occurs (Terzaghai 1950; Crozier 1984; Bryant 1991; Alexander, 1993). The mean values for liquid limit ranged from 44.21% to 54.70%. The mean values were found to be high in all the study units. However, in areas where human settlements occur, liquid limits were found to be low due

to soil compaction. Plastic limit mean values for the units were moderately high ranging from 26.95% to 31.51%. Plasticity Index mean values were generally moderate, corresponding to moderate values of plastic limits

Hydraulic conductivity tests show moderately rapid hydraulic conductivity for all the units. The mean values range from 5.88cm/hr at Kasokoloka to 11.09cm/hr at Kasese Forest. Lower values were observed in areas disturbed by human activities such as settlement construction and deforestation. Soil aggregate stability mean values were high, ranging from 2.61mm (Kasese Proper) to 3.18mm (Chikwezga), indicating a strong structural stability (GoM 1988; Msilimba 2002). Therefore, slopes failures cannot directly be attributed to structural stability of the soils.

Bulk density tests were carried out to determine the degree of soil compaction, porosity, hydraulic conductivity and the packing of soil particles. The results were compared with the average of 1.33g/cm³ for soil which is not compacted (GoM 1988). The results were below 1.33g/cm³ which indicated that the soils were not compacted. These results agree with the moderately high porosity values observed in all the units ranging from 55.66% at Kasokoloka to 60.25% at Kasese Forest. In some isolated areas where human activities were observed, relatively higher values were obtained. Although porosity determines hydraulic conductivity and slope loading, the initial porosity may not necessarily always be a reliable indicator of soil instability (Yamamuro and Lade 1998). The results were, therefore, treated as an indirect measure of soil stability.

Particle size analyses were carried out to determine the percentages of total sand and medium to fine sand which are prone to liquefaction under prolonged precipitation (Alexander 1993; Finlayson and Statham, 1980). In general, in all units within the Ntchenachena area, the soils showed a high percentage of sand ranging from 54.25% (Kasokoloka) to 68.36% (Chikwezga). The proportion of silt was found to be low. The mean values ranged from 15.63% to 17.55%. Mean clay values ranged from 14.11% to 29.00% with Kasokoloka recording the highest value.

Rainfall data analysis

The contribution of rainfall to slope instability has been analysed by several authors (Crozier 1984; Aryamanya-Mugisha 2001; Ingag'a and Ecakuwun 2001; Msilimba 2002; Msilimba and Holmes 2005; Knapen et al. 2006). Rainfall measurements (**Figs 3 and 4**) indicate that the Ntchenachena area receives high precipitation. Annual rainfall ranges from 949mm (1988/9) to 2631mm (1987/8) with an average of 1472mm. Although annual totals for the 2003 period for the area are not available, the study area is one of the wettest areas in Malawi (Linceham 1972; Msilimba 2007). Daily rainfall analysis (Fig 4) shows that the landslides areas occurred after prolonged rainfall of 21mm on 26/27 March and 185mm on 27/28 March, 2003. Total rainfall for the two days was 206mm which was more than half the total for the month of March which was 402mm. Before these rainfall events, the area had received 192mm of rainfall during the month of March. This was also towards the end of the rainy season when the antecedent soil moisture was already high. The landslides occurred in March when the recorded rainfall of 402mm was significantly higher than the normal monthly average of 301.9mm. Eyewitnesses attest to prolonged rainfall of low intensity prior to the landslide events, suggesting inflow exceeded discharge, resulting in higher pore pressure and liquefaction.
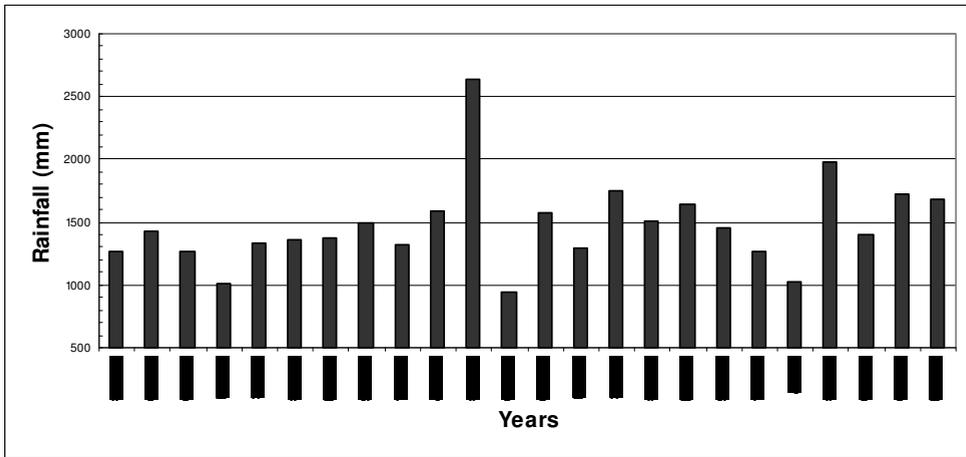
Fig. 3. Annual Rainfall Totals for the Ntchenachena Area from 1977 to 2001 (Note annual totals for years after 2001 were not available
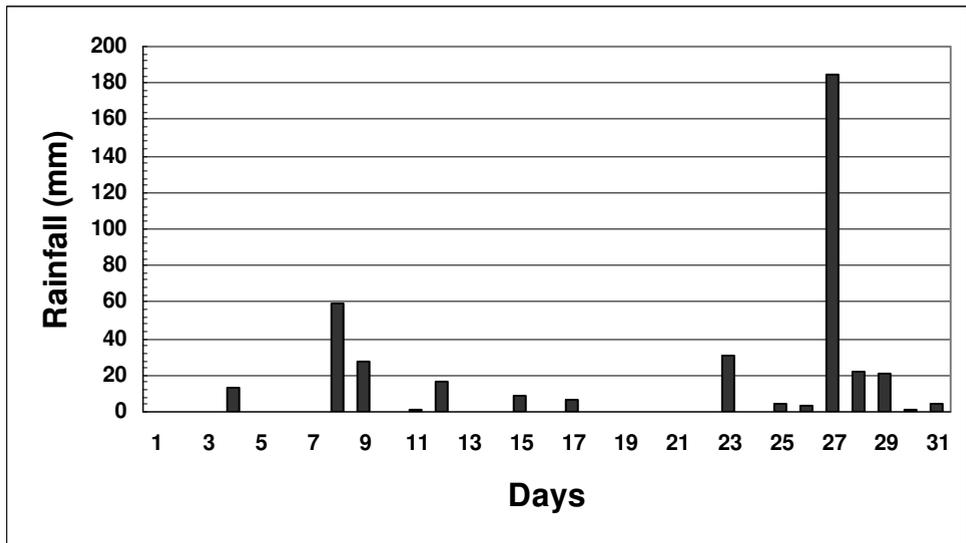

Fig. 4. Daily rainfall for March 2003 for the Ntchenachena Area. Note the critical rainfall that triggered the landslides

While high mean annual rainfall figures and moderate rapid hydraulic conductivity (>7 cm/hr) act as a prerequisite to occurrence by raising ground water tables and pore pressure, the critical factor in the case of 2003 landslides appear to have been prolonged, low intensity rainfall. It is important to note that out of six topographic units of Ntchenachena area (**Table 2A**), five registered hydraulic conductivity of greater than 7 cm/hr (moderate rapid hydraulic conductivity).

Slope angle analysis

The importance of slope angle in initiating landslides has been discussed by several authors (Hoek and Boyd 1973; Bryant 1991; Alexander 1993; Fernandes et al. 2006). All the landslides which occurred within the Ntchenachena area occurred on slopes of between 40^0 and 58^0. All the documented landslides elsewhere in Malawi have occurred on slopes steeper than 30^0 and have been triggered by prolonged precipitation, or high intensity rainfall (Gondwe and Govati 1991; Msilimba 2002; Msilimba 2007**).**

4.4 Mechanisms of landslides generation

Liquefaction of the soil

It was determined from the analysis of the data that the landslides were triggered by liquefaction of the sand and silt fractions of the soil. In all the units, the soils contained a high percentage of sand ranging from 54% to 68%. Medium to fine sand was abundant and the mean percentage exceeded 38.66% of the total sample. These sands satisfy the criteria for liquefaction; they are fine enough to inhibit rapid internal water movement, and coarse enough to inhibit rapid capillary action, while simultaneously displaying little cohesion (Bryant 1991; Msilimba 2002; Msilimba and Holmes 2005). Being unconsolidated, the angle of shearing resistance is low, and failure can occur at an internal angle less than that of the slope upon which the material rests (Finlayson and Statham, 1980)

Although some units within the Ntchenachena area showed a relatively high average percentage of clay (up to 29%), which would have reduced the rate of liquefaction (Finlayson and Statham, 1980), the strength of clay was reduced by high moisture content following 206mm of rainfall over two days. Though the plasticity indices were moderately high, the increased water content in 2003 meant that the soils easily crossed the threshold and liquefied. Evidence of liquefaction in this area is common (Msilimba and Holmes, 2005) However, it should be noted that liquefaction of the soils cannot be linked directly to soil aggregation. The high values of the calculated aggregate stability analysis indicate that the soils were structurally stable. This was supported by rainfall data which also showed high totals for other months in which there were no slope failures. Therefore, any slope instability cannot be attributed directly to the structural instability of the soil. However, since high aggregate stability values contribute to high porosity and permeability (Finalyson and Statham, 1980), the rate of hydraulic conductivity during the rain storms in March 2003, probably raised the water table, resulting in high pore pressure, possibly lowered aggregation and caused eventual liquefaction of the soils.

4.5 Triggering factors

Pore pressure

The mechanism of pore pressure accumulation is well discussed (Crozier 1973; 1984). The rainfall data show that the Ntchenachena area receives high annual precipitation (>1600mm per year). The antecedent moisture content prior to the landslide events was probably high. The 206mm of rain which fell in the Ntchenachana area, was unusual and above average. This unusually high rainfall coupled with high sand content, moderately high porosity, and moderately rapid hydraulic conductivity increased pore pressure between the soil particles contributing to the liquefaction.

Slope remodeling

It was observed that slope remodeling (cutting), though on a small scale, had negative effects on slope stability. Slopes had been remodeled for various purposes. Firstly, house building on steep slopes forced people to excavate large parts of the slope to create flat areas. The construction of foot paths also involved slope excavation. In addition, farmers often dig away parts of the slope in order to level their plots. Leveling was also done to construct irrigation channels. The creation of slope terraces for agricultural purposes and intensified natural processes removed the lateral support, caused water stagnation in some areas and increased slope loading, which led to increased pore pressure and landslide susceptibility. In the Manjiya area of Uganda, it was observed that numerous landslides occurred on slopes which had been remodelled for agriculture and settlement activities (Knapen et al. 2006).

Seismicity

Landslides caused by earthquakes have been reported in Malawi, and throughout the East African Region (Dolozi and Kaufulu 1992; Ingag'a and Ecakuwun 2001). Although the Ntchenachena area falls within the African Rift Valley System, with numerous observed and inferred faults, there is no conclusive evidence to suggest that the landslides were caused by earthquakes and tremors (Bloemfield 1968; GoM 1977). However, the location of these areas and the high percentage of sand indicate that there is a high probability for seismic-generated landslides.

4.6 Predisposing factors

Vegetation

Landslide occurrence as a response to land use change is well documented (Crozier 1984; Msilimba 2005). Field observations indicated that destruction of vegetation contributed to slope failures. The units, dominated by Afromontane grassland, and with poor ground cover of grasses and shrubs, recorded the highest number of landslides. For instance, the Lutowo unit where natural vegetation has been completely destroyed and the area is under cultivation recorded 55 landslides, the highest for the entire area. Within the Ntchenachena area, where the soils are very deep (> 10m), most of the landslides occurred beyond the root zone. This suggests that shallow rooted vegetation (grass/shrubs) did not provide maximum tensile resistance to the soil mass. In areas where vegetation was cleared for cassava cultivation, the instability has been increased because cassava has shallow roots and low root density (Msilimba 2002; Msilimba and Holmes 2005). It is suggested that grasses contributed to rapid infiltration, thereby increasing pore water pressure and slope loading. Grasses support high infiltration rates and have lower transpiration rates than deciduous forests (Scheichtt 1980; Msilimba 2002). It could therefore, be concluded that the rate at which the water infiltrated was greater than the rate at which the vegetation could transpire, thereby increasing both the load and the pore pressure.

Geology

It appears that the geology of the area did not contribute significantly to the slope failure. In all the occurrences mapped in this area, the basement was not involved in the movement. There were no pre-existing slide planes to suggest that geology contributed to the failures.

Most of the landslides were rotational which indicates that the soil mass was of significant depth. The basement which comprises muscovite schist and biotite gneiss has been reduced by rapid chemical weathering making it more porous and this probably contributed to moderately rapid hydraulic conductivity, thereby raising water pore pressure and reducing the strength of the material.

5. Susceptibility assessment

On the basis of the factors that contributed to and caused the landslides in the six units, an index of susceptibility for each of the units represented by the sample sites (**Table 2A and 2B**) has been calculated. This is a simple index, based on ten empirical, readily determinable variables (**Table 3**). Each variable is graded on a scale comprising three values: 1, 2 and 3. A value of 1 represents low susceptibility in terms of the variable contributing to landsliding, 2 represents intermediate susceptibility and 3 represents high susceptibility.

The sum of the gradings provides the susceptibility score for each site. The score for each site, derived from the data in **Table 2A and 2B** applied against the criteria in **Table 3**, is indicated in **Table 4A**. Areas with natural forests with little human interference are considered undisturbed; areas where forests have been cleared and are dominated by shrubs and grasses without cultivation are categorized as moderately disturbed, while areas under cultivation are considered highly disturbed.

Value	Slope 0	Disturbance of land surface	Vegetation	Sand %	Hydr. Con. (cm/hr)	Porosity index	Plasticity index	Bulk Density	Aggregate Stability	Degree of Weathering
1	≤45	Undisturbed	Forest	<60	≤6.25	<45	>15	>1.25	>2.00	Unweathered
2	45 - 50	Moderate	Grass/shrub	60 - 70	6.25 – 12.5	45 - 50	15 - 10	1.25-1.2	2.00 – 0.5	Partly weathered
3	≥50	High	Cultivation	>70	>12.5	>50	<10	<1.2	<0.5	Highly weathered

Table 3. Criteria used to determine susceptibility scores

Unit	Susceptibility score (see Tables 2B, 2C and 3	Susceptibility index (score ÷ 10)	Stability
Kasokoloka	20	2.0	Unstable
Lutowo	24	2.4	Unstable
Kasese Proper	24	2.4	Unstable
Kasese Forest	19	1.9	Potentially unstable
Mankholongo	20	1.9	Potentially unstable
Chikwezga	24	2.4	Unstable

Table 4A. Susceptibility scores and indices for six sample units

Susceptibility index	Stability
≤ 1.5	Stable
1.5 - 2	Potentially unstable
>2	Unstable

Table 4B. Degree of stability based on susceptibility index

The index of susceptibility (**Table 4A**) is simply the mean total score for variables indicated in **Table 3**. This is a crude index and no attempt has been made to weight the variables in terms of their relative significance in promoting instability. Initially, the midpoints between the variables on **Table 3** appeared to be logical divisions in terms of classifying areas as stable, potentially unstable, and unstable with regard to landslide susceptibility. Subsequently, taking cognizance of the danger of underestimating potential susceptibility, and erring on the side of a conservative classification, the criteria for identifying an area as stable was strengthened by reducing the critical value from 2.5 to 2. Therefore, an index of 1.5 or less indicates stability, between 1.5 and 2 indicates potential instability, and greater than 2 is regarded as unstable (**Table 4B**).

Further, detailed field observations and experimental work are required in order to assess the relative importance of the variables in promoting or retarding landsliding. Nevertheless, this technique provides an elementary, empirically based method which could be applied in the field to identify areas where the potential for landsliding is significant. The technique does not require sophisticated equipment or elaborate training of the practitioner and is, therefore, suited to developing countries which lack resources for high technology identification of vulnerable areas.

Using the susceptibility assessment index, the Ntchenachena area shows high susceptibility to landsliding. All the six units were classified as potentially unstable to unstable (Table 4A). No unit falls in the category of stable. Kasese Forest and Mankholongo areas are the only areas categorized as potentially unstable. Although all the parameters indicate instability, some stability is provided by vegetation. Kasese Forest is undisturbed forest while Mankholongo is dominated by shrubs/grass with no cultivation. Destruction of trees (Kasese) and shrubs/grass (Mankholongo) may soon render these areas unstable.

All the four other units were classified as unstable. A combination of steep slopes, land disturbance, lack of vegetation cover, high sand content, moderately rapid hydraulic conductivity and high degree of weathering of the basement, contributes to the instability.

6. Conclusion

This chapter has assessed the local factors that contributed to and have previously caused landslides in the Ntchenachena area of northern Malawi. Physical and anthropogenic factors contributed to the occurrence of landslides and rendered all the units of the Ntchenachena area susceptible to landslides. Partially unstable units are tenuously stabilized by vegetation. Continued destruction of vegetation may render Kasese Forest and Mankholongo units unstable. Therefore, improvement of public awareness of not only danger-prone areas but also the impacts of human activities is strongly recommended. This landslide inventory is an important step towards hazard reduction in the region and could also provide a framework for landslide inventories throughout Malawi and the region of East Africa region.

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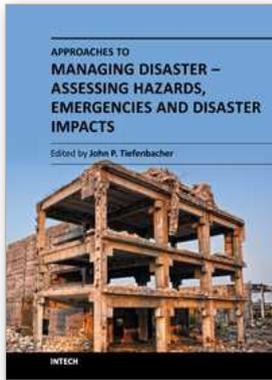
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