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Determinants of revegetation on landslide scars in an agro-based socio-ecological system in Bududa, Uganda

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Landslides cause displacement or loss of plant cover, soil and other materials on slopes. Exposure of soil accelerates erosion processes thus contributing to stream sedimentation. Though playing a crucial role in stabilising scars there is limited understanding of the plant species colonisation process. This study aimed at examining the determinants and status of plant revegetation on a recent landslide scar in Bududa on Mt Elgon in Uganda. Field investigations involved set up of quadrats on the one-year-old landslide scar in Bunakasala in Bushika. Plants were sampled, counted and identified from established quadrats. The morphological characteristics of the scar and species were also recorded. Results indicated that plant regeneration on the scar started within a short period of six months. A total of over 39 pioneer plant species were recorded. Most of these could have germinated from the seeds in the soil pool. The distribution pattern of the plant species was regular as determined using the Morista's index. Plant cover is very important in stabilising the soil against erosion hence fast recovery of the disturbed area. For initial healing process of the scars such pioneer plants should be left intact and human activities with least impact promoted during the early stage of recovery.

Key words: Landslide scar, plant species, revegetation, Bududa, Uganda.

INTRODUCTION

Landslides are increasingly a great contributor to the dynamics in plant diversity and composition in the mountain regions (Hu et al., 2018: Velázquez and Gómez-Sal, 2009; Dalling 1994; Miles and Swanson, 1986). Landslides are simultaneously depositional and erosional processes that influence sites by redistributing materials and changing surface expression- usually creating a complex microtopography that can include very dry ridges and hummocks, and sometimes depressions with standing water (Geertsema and Pojar, 2006). From an ecological point of view, landslides represent an important ecosystem disturbance (Rodrigues et al., 2018; Cheng et al., 2015; Walker and Shiels, 2008), especially in tropical montane forests (Vorpahl, 2012) and human disturbed areas. Restrepo and Vitousek (2001) found that the ordination of sites and species establishing on landslides were different from those found in the undisturbed forest. A large fraction of

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the species establishing on young landslides were represented by aliens, mostly grasses and orchids. They further observed landslides strongly affected soil characteristics; the areas where vegetation and soils were removed experienced colonisation by a narrow array of species that thrive under harsh and ephemeral conditions found in the recently disturbed substrate. According to Miles and Swanson (1986) the newly exposed subsoil in landslide scars holds few residual root crowns or seeds to sprout and occupy the site, but deposits of landslide debris may have some surviving crowns or seeds near the surface. Plant colonization can also impact the persistence of erosion both through indirect influences on litter inputs and outputs and soil C content, and direct influences on stabilization through root growth and reduction of rain impacts (Walker and Shiels, 2008).

Despite the increasing realisation of landslides in shaping the landscape and causing loss of life and property, there is limited representation in studies of their influence on biodiversity and role in stabilising slopes. Landslides can promote the spread of weeds and alien plants through unknown mechanisms. They break the soil profile thus disrupt the seed bank and expose infertile soils. Through the removal of soil nutrients and organic matter landslides alter the succession of mountain ecosystems (Restrepo et al., 2003; Paolin et al., 2005; Lundgren, 1978). The species composition of pioneer plant communities on landslides is usually very different from those of the surrounding habitat (Velázquez and Gómez-Sal, 2008). Thus the landslides act as a filter (Hu et al., 2018) permitting the growth of some species and denying others. Plant colonization on landslides is very different from colonization in tree fall gaps or on sites opened by other disturbances, such as fire (White, 1979; Dalling, 1994 cited by Velázquez and Gómez-Sal). Typically, landslides create high abiotic heterogeneity, and there are marked differences in species composition within pioneer plant communities depending on the stability and productivity of substrates. Deforestation of the slopes in the area of Bududa has increased slope instability (Knapen et al., 2005). Studies by Knapen (2003) on stability analysis revealed that deforestation decreased the safety factor, which is a measure of the slope stability, through root decay by 30 to 60% on the slopes in this area.

Limited studies of vegetation dynamics and their contribution to slope stability have been undertaken particularly in humanised environments in the mountains of Uganda. Most studies on landslides in Uganda (Bagoora, 1988; Kitutu, 2006; Claessens et al., 2007; Kitutu et al., 2009; Mugagga et al., 2012) have focused on the causes and processes. This paper dwells on creating an understanding of the changes in vegetation following occurrence of a large landslide in Bunakasala in Bududa district. Specifically, the paper (1) characterises the landslide scar (2) describes the plant species diversity, composition, pattern and environmental determination and (3) examines the role played by plant colonising species in stabilising the disturbed landslide scar. Knowledge on colonising plant species is important in decision making for improved planning in stabilising disturbed sites in fragile regions. Stability of disturbed landscapes due to landslides ensures resilience and continued ecological service of the area.

MATERIALS AND METHODS

Study area

The area of study is located in the district of Bududa toward the south western part of Mt Elgon in Uganda (Figure 1). The climate is relatively humid montane type. The area receives about 1800 mm of rainfall per annum. Rainfall is mainly concentrated in two peaks in April to June and August to October. Maximum temperature averages 18 to 25°C during the long dry spell from December to March. The area's underlying geology is constituted of volcanic rocks (tuffs, agglomerates) and Pre-cambrian basement rock complex (gneiss, granites and schists). Soils mainly include the humic andosols, nitisols on lower slopes, the lithosols on exposed ridges and hills, and the Entisols in the low-lying and valley areas (Isabiyre, 2001). The morpho-structural unit include the ridges and hills separated by v-shaped or flat valleys. Cliffs separating the mountain terraces occur mainly in the forested area, and at the border between the park and the community.

The main land use in the area of landslide occurrence is agriculture (Figure 1); the dominant farming system is the montane banana-coffee interspersed with annual crops such as maize and vegetables. Cultivation is carried out even on very steep slopes of > 30°C thus high risk of erosion. Agro-forestry technologies (e.g. eucalyptus tree woodlots) are being adopted in different systems though still inadequate on the degraded slopes. The population density is very high; some areas have > 1000 people km^{-2} (UBOS, 2014). Such dense population contributes to tremendous pressures on the limited natural resources thus forcing some people to encroach on the fragile steep slopes. Disturbance of steep slopes coupled with poor land management practices undermines ecological resilience hence accelerated soil movements (e.g. erosion, debris flows and landslides). Landslides are common in the area causing vegetation disturbance and also accelerated soil loss, loss of life and property.

Bunakasala landslide in Bududa district was purposively selected. Landslide scars in the area are commonly cultivated within a short time of barely a month after the hazard event thus not permitting plant regeneration. This landslide scar was thus ideal for the investigation because it had been left uncultivated for a year. Ten quadrats were established on the scar. Two quadrats were set up outside the scar to act as a control. The 2×2 m^2 quadrats similar in size to what Lundgren (1978) applied, were laid out (Figure 2) across in three transects; on lower (4), mid (3) and upper (3) slope positions. Tree, shrub and herbaceous (grass, forbs, sedges) plant species were identified, counted and sampled in all the quadrats. A few species (*Tephrosia vogelli* and *Adenostemma viscosum)* morphological characteristics (root depth, stem height) were recorded. Plant species not identified in the field were taken to the Herbarium at Makerere University for identification. Presence and absence of each species in the sampling quadrats were recorded. For herbaceous plants the percentage cover was obtained by estimating the proportion of the ground covered by each species. Landslide scar micro topographic features recorded included slope aspect, slope gradient, soil depth, erosion features and bare soil surface. These were hypothesised to be important factors

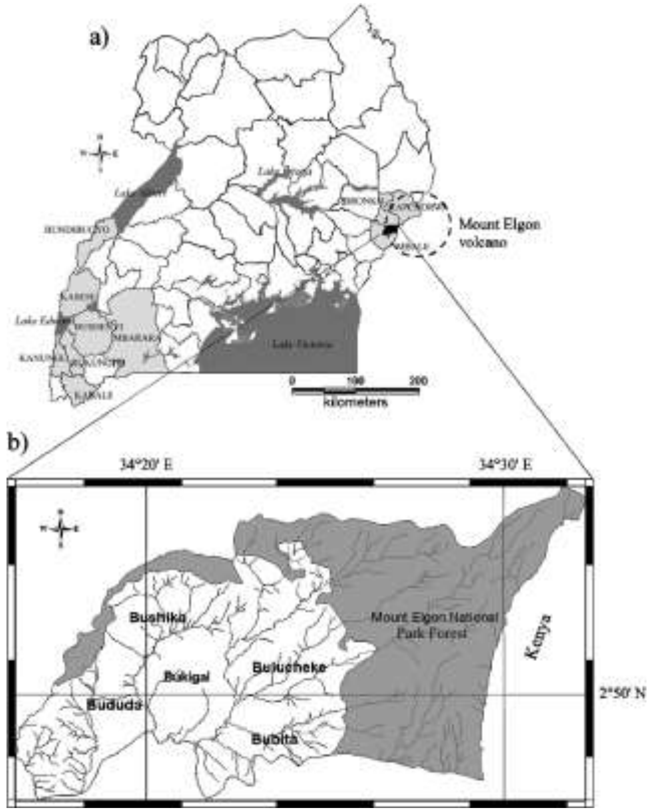

Figure 1. Bunakasala landslide in Bududa district, Uganda.

(a) (b)

Figure 2. a) Panoramic view of the Bunakasala landslide scar in Bududa district (b) Quadrat (2x 2 m^2) used for vegetation sampling.

influencing colonisation process.

Patterns in species composition and abundance associated with the formation of the landslide were analysed using the Dentrended Component Analysis (DCA). Correspondence Analysis is sensitive to species that occur only in species-poor sites (Jongman et al., 1995), therefore a method was developed by Hill (1979) to deal with this by 'down-weighting' species that occur in a few sites thus minimising their influence. The spatial distribution pattern of plant

Table 1. Characteristic features of Bunakasala land slide scar.

Features	Observations		
Slope position	Lower	Mid	Upper
Slope aspect	EW	EW	EW
Slope gradient	12-18°	10-15°	25-35°
Soil depth	4.5m	0.2- 4m	<0.5
Erosion	Gully, sheet and rill	Gully, sheet and rill	Gully, sheet and rill

(a) (b)

Figure 3. Patchy revegetation; (a) on the upper slope position of the scar*;* note, however, the luxuriant growth of *Tephrosia vogelli. (*b) gullying on landslide scar retards re-vegetation.

species on the scar was determined using Morista's index:

$I_\delta = x\ ni(ni-1)/N(Ni-1)$

Where: X is the number of 2x2 quadrats, ni is the number of individuals in the ith quadrat, N is the number of individuals in all the quadrats, Morista's index (I_δ) = 1.0 when a population is randomly distributed; $I_\delta > 1.0$ if the population is clumped; $I_\delta < 1.0$ if the population is regularly distributed.

RESULTS

Characteristic micro-topographic features and human activities on the Landslide scar

The various features identified on Bunakasala landslide are summarised in Table 1. The scar formed from a slide that occurred in 24th July 2011, on a moderately steep gradient (12-25°) on the mid-lower slope position and EW aspect. It is bottle shaped complex rotational slide with a stream running in the midline and occupies an estimated area of 156 acres. Gully erosion was a prominent feature along the midline and rills were evident on the sloping sides of the scar (Figure 3a).

Fresh cultivation was being carried out on the scar by smallholder farmers, who were impacted by the hazard. When interviewed why the farmers started cultivating on the un healed scar, they indicated that there was lack of sufficient land for cultivation to meet their household food demand. However, the farmers were using poor cultivation practices such as clean cultivation, which induces soil erosion. This points to the need for extension service in the area to advise on best land use and management practices such as conservation tillage that cause minimum soil disturbance. Bare soil occupied approximately 40% of the scar. The scar portion especially the rocky and more unstable parts not colonised by vegetation were observed to be experiencing rills and gully erosion (Figure 3a and b). Gullying was observed to be the prominent erosional feature on the scar; wide and deep gullies stretched from lower slope position to the steeper upper section near the head scarp. Gullies on the scar have largely resulted from the action of the

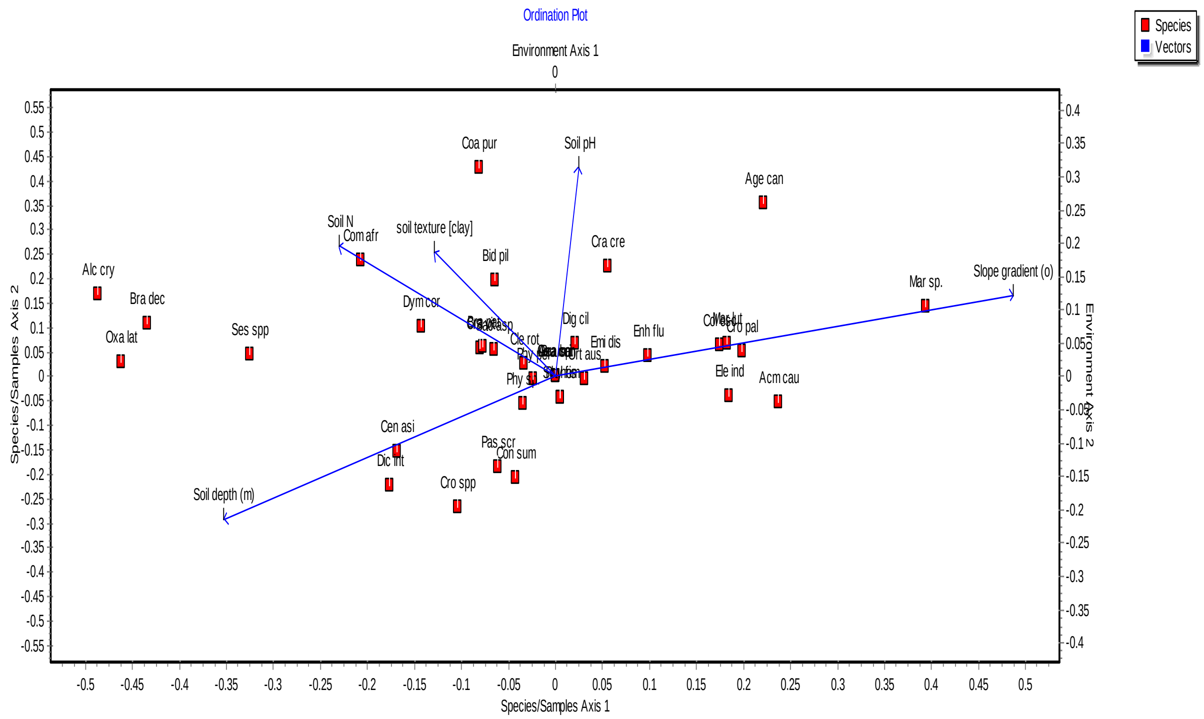

Figure 4. Ordination biplot - redundancy analysis.

stream originating close to the head scarp. According to the respondents interviewed a surface stream existed before the landslide. The gully is developing at a fast rate as evidenced by the active head ward stream erosion and the collapse of the gully side wall due to loose or erodible soil. The measured gully channel was on average 4-5 m at the surface and 0.5 to 1 m width at the bottom, and 3-4 m deep in the mid-lower slope section thus approximating to a V-shape. Observations revealed that the gully channel was cutting deeper on the lower slope probably due to accumulated volume of runoff and previously disturbed soil during the search for the dead after the slope failure. There is a likelihood of the area developing into a wasteland if no immediate action is taken to rehabilitate the scar.

Plant species diversity, composition and pattern

A summary of the plant species identified on the scar in all the quadrats is provided in Table 2. Field observations and sampling of plant recolonisation on the landslide scar positions (toe, mid and head) revealed great spatial variation. In all there were 14 plant families but the dominating family was the asteraceae (29%) followed by poaceae (18%). Amongst the Asteraceae the *Dicrocephala integrifolia* and *Acmella caudirhiza Del* species were dominant and well distributed over the area. For the grasses the species of *Brachiraria decumbens Stapt* was well distributed. Majority of the plant species were herbaceous. A few tree saplings (e.g. Eucalyptus spp. and *Markhamia lutea*) measuring 5 cm on average were observed on the midslope. The general spatial distribution pattern of plant species was found to be regular based on the Morista's index (I_{δ}) computed as 0.14.

Environmental determinants of plant species regeneration

The revegetation on the scar was controlled by different environmental factors and nature of substrate including soils. The rocky areas and dry micro-ridges were less vegetated compared to micro-topographic features (depressions) and the micro-eroded valleys that were wet. The gullies (Figure 3) had scanty plant cover, which was attributed to activeness as evidenced by heard ward erosion and side wall collapse. Further observations revealed that the side wall gully erosion was dominated by slumps and creep erosion, which hampers plant colonisation. The human activities such as farming that is, tree planting, cropping and grazing have also contributed to the observed revegetation on the scar. Observed planted crops included maize, beans and sweet potatoes. Apart from limited patches experiencing less erosion, the shallow and infertile soils on the upper position of the scar toward the head scarp had poor plant growth characterised by stunted and low plant cover. This is further illustrated by the results in Figure 4 which reveal

Table 2. Plant species composition and abundance for all the quadrats sampled.

Family	Species	Count									
		Lower slope				Mid slope			Upper slope		
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Apiaceae	*Centella asiatica (L. Jurban)*	100	3	9	4	5	9	7	0	1	1
Araceae	*colocasia esculenta*	0	0	0	0	0	0	0	0	0	9
Asteracea	*Crassophelum crepidiodes benth s.*	3	4	0	0	0	0	15	2	1	6
	Dicrocephala integrifolia	20	8	17	8	3	5	5	1	2	0
	Conyza sumatrensis	4	7	2	4	2	0	1	0	0	1
	Acmella caudirhiza Del	69	9	10	0	10	0	13	1	17	19
	Sachus asper (L.) Hill	1	0	0	0	0	2	0	0	0	0
	Enhydra fluctuaris Lour	0	1	0	0	0	0	0	0	0	4
	Bidens pilosa	0	1	0	0	0	14	0	0	0	7
	Coalinsonga puriflora	0	0	0	0	0	55	0	18	10	0
	Ageratum canyozordes L:.	0	0	0	0	0	0	26	5	2	36
	Emilia discifolia	0	0	0	0	0	0	0	0	0	1
	Crassocephalum vittellinum.	0	0	0	0	0	2	0	0	0	0
Caryophyllaceae	*Dymaria cordatail*	0	0	0	0	0	6	0	0	0	0
Commelinaceae	*Commelina africana L.*	2	1	0	0	5	6	23	3	5	0
Cyperaceae	*Mariscus sp.*	0	0	0	0	0	0	0	1	48	4
Euphorbiaceae	*Phyllanthus fisheri Pax*	0	0	0	1	0	0	0	0	0	0
	Phyllanthus sp.	0	0	0	0	2	0	0	0	0	0
	Acalypha sp.	0	0	0	0	0	0	0	0	0	0
Fabaceae	*Crotolaria spp*	0	0	1	1	30	0	0	0	0	0
	Crotolaria palida	0	0	0	0	0	0	0	0	8	1
	Sesbania spp	1	1	3	3	0	14	12	0	0	0
Lamiaceae	*Orthosiphon australis vatke*	3	0	0	0	0	0	0	0	0	0
	Leucus martinacensis	0	0	0	0	0	0	0	0	0	0
Oxalidaceae	*Oxalis latifolia*	0	1	12	0	3	14	48	0	0	0
Oxalidaceae	*Oxalis coniculata L.*	0	0	0	0	0	0	0	0	0	0
Poaceae	*Brachiraria decumbens Stapt*	36	28	8	1	4	24	22	8	0	0
	Paspalum scrobiculatum (A. Rich)	3	0	8	0	2	1	0	0	0	0
	Brachiaria brizantha	0	0	0	0	0	0	0	0	0	0
	Eleusine indica (L) Gaeestn	0	0	2	0	0	0	0	0	16	0
	Setaria homonyma (Steud) Chiou	0	0	0	1	0	0	0	0	0	0
	Digitaria ciliaris (Retz) Koelar	0	0	0	0	0	0	0	2	0	0
	Brachyanchne patentflora (Stenti rattray)	0	0	0	0	0	0	4	0	0	0
Rosaceae	*Alchemilla cryptantha A. Rich*	0	10	0	0	16	7	44	2	0	0
Solanaceae	*Physalis peruviana L.*	0	1	0	0	0	0	0	0	0	0
Verbenaceae	*Clerodendrum rotundifolia*	0	0	0	0	0	0	1	0	0	0
Bignoniaceae	**Markhamia lutea*	0	0	0	0	0	0	0	0	0	10

Herbs, Grasses, *tree saplings. Q = quadrat.

that 45% of the total variability is accounted for by slope position and soil depth. The influence of soil texture and nitrogen on plant species distribution was more or less equally strong.

There was a particularly more striking observation on the upper slope position within the transect but outside the quadrat. Luxuriant growth of the shrubs *Tephrosia vogelli and Adenostemma viscosum* (Figure 3a) was observed. *Tephrosia vogelli* had good cover, root nodules and intense root system extending to 10-15 cm hence could be a suitable species for restoration of the landslide scars. *Tephrosia vogelli* can fix nitrogen and leaves can be harvested for mulching gardens. Elsewhere this plant has been used and studied for as insecticide and pesticide purposes (Lina et al., 2013). However, further research is required to establish its range of local multi-functionality and farmers' perceptions in the study area. This will provide a scientific basis for promoting its wide utilisation in landslide scar restoration. The mid-slope position had richer plant diversity and composition. This was attributed to relatively deeper soils and translational deposition of slide material. The seeds for germination could have originated from the soil pool at least for plants not planted in the surrounding farmed lands, and due to wind dispersal from surrounding areas.

DISCUSSION

Determinants of Plant species diversity and distribution pattern on landslide scar

The dominating early colonising plant species on the scar were the asteraceae and poaceae family. This is in agreement with Restrepo et al. (2003) who found that alien plant species represented mainly by grasses, orchids and rhizomatous plants formed the dominant life forms and therefore biomass on younger slides in Hawaii. Though the pattern of species distribution was regular as determined by the Morita's index (0.14), a detailed examination shows some assemblage or preferences. *Cratolaria palida, Mariscus* sp. and *Emilia discifolia* were confined to the upper slope position, which was largely an erosional zone with dry or waterlogged shallow soils. Bussman (2009) observed that portions of landslides with exposed parent material are set back to the initial stages of soil development and ecological succession. On the lower slope position or depositional area, *Centella asiatica (L. jurthan), Paspalum scrabiculatum (A. Rich)* and *Dicracephalia integrifolia* were more abundant. This is attributed to the fact that the depositional zone had a relatively high content of organic matter that reflects the rich mixture of displaced vegetation, soil, and saprolite (Bussman, 2009; Walker and Shiels, 2008). This is further in conformity with findings by Gonzalez-Ollauri and Mickovski (2017) that landslides control the differentiation of slope habitats in terms of plant species richness and composition particularly through nitrogen variation.

Plant recolonisation and stability of land slide scar under changing climate conditions

Plant cover protects the soil from erosive rains through interception of the raindrops. Field observation showed less or no evidence of sheet or rill erosion on parts of the scar that were densely covered by grass and herbs. On the contrary there was evidence of sheet, rill and gully erosion on bare parts of the scar particularly where water runoff tended to converge. This observation confirms findings (Miles and Swanson, 1986; Walker and Shiels, 2008) that erosion processes delay the recovery of the scars.

The plant roots are important in increasing the soil cohesion thus slope stability (Giovanni et al., 2013; Restrepo et al. 2009). Observed grasses and herbs on the scar contribute to dense fibrous roots that hold the soil particles together. The shrubs and trees (e.g. *Cordia africana*) particularly with taproots penetrating deeper soil layers ensure greater cohesion hence stability of the slope mass. This is particularly important considering intensive rains received in the area. Related studies by Devkota et al. (2006) confirm that plants with deep and dense roots are suitable species to prevent the landslide scars against surface erosion. This finding forms a basis for resource managers and particularly the farmers to adopt planting of such plants while also monitoring future behaviour of slope movement under changing rainfall and land use conditions. However, where planting of such trees and shrubs already exists on farmland, further monitoring could be done together by farmers and researchers under citizen science arrangement for better outcomes.

Initial plant colonisation of the landslides is determined by the availability of propagules and germination sites, soil stability and the presence of soil organic matter and nutrients (Walker et al., 1996). In the current study area, field observation showed that during land sliding the infertile subsoil and regolith were deposited on the surface. Infertile soils hampered rapid plant colonisation particularly on upper slope position of the studied scar. As noted by Geertsema and Pojar (2006) portions of landslides with exposed parent material are set back to the initial stages of soil development and ecological succession. Plant recolonisation if not disturbed can provide organic matter that contributes to improved soil fertility. Thus, as indicated by Schuster and Highland (2007) plant succession is governed by slope stability and nutrient availability.

Conclusion

The study investigated the vegetation status of a one-year landslide scar on agricultural landscape. The vegetation analysis provides vital information for understanding and planning for improved environmental quality and wellbeing. The plant data also forms an important base for monitoring future changes. It was revealed that the initial revegetation of the studied landslide scar contributed to rich biodiversity; largely dominated by herbaceous plants. Over 50 plant species were indentified. Microtopographic features controlling colonisation included the nature of the soil surface, soil depth and erosion activity. Areas with relatively low plant cover were observed to experience intense sheet and rill erosion. High runoff generation particularly from the upper section of the scar concentrated into channel flow along the midline thus the observed gully development. Gullying was also accelerated due to less cohesive sub soils and weathered rock material deposited on or near the surface. Thus protection of early plant species colonisation on scars and/or its enhancement forms an appropriate strategy for reducing the risk of erosive impacts due to climate variation and change. *Tephrosia vogelli* and *Adenostemma viscosum* were found to have good potential for slide scar restoration but more research on its wider use and acceptance by farmers is needed. This research did not investigate the soil properties to account for the plant species dynamics with time. Future research into the dynamics of soil properties including carbon and how these shape the plant succession process in a largely human modified landscape is commendable.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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