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Land-Use/ Land-Cover Changing Trends and their Relation to Landslides: A Case Study of Hali-Ela in Badulla District, Sri Lanka

A.M.R.N.K. Alahakoon[1], K.L. Thisara Sathsara[2*], Udara S.P.R. Arachchige[3] and Shyamantha Subasinghea

[1]Nuwara Eliya District, Disaster Management Center, Sri Lanka
[2]Faculty of Humanities and Social Sciences, University of Sri Jayewardenepura, Sri Lanka
[3]Faculty of Technology, University of Sri Jayewardenepura, Sri Lanka
[4]Department of Geography, University of Peradeniya, Peradeniya 20400, Sri Lanka

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ABSTRACT

The study has evaluated the impact of Land-use/Land Cover (LULC) in a period of 65 years from 1956 to 2021 on landslides occurrence in Hali-Ela Divisional Secretariat Division (HDSD) in Badulla District, Sri Lanka. LULC distribution patterns were evaluated by comparing thematic maps prepared for three different years. These maps were overlaid with spatial distribution of total landslides and each type of landslides in a Geographic Information System (GIS) to assess their spatial frequency distribution and relative failure potentials related to selected topographic attributes LULC type in that particular area. The spatial analysis results revealed a close relationship between the topographic attributes of the post-landslides, local surface and LULC changes. And also, in the study area the forest area has decreased by more than 45%, whereas home garden has increased by 27% for the study period of 65 years. It is clear that changes in vegetation cover affect the landslide frequency distribution and landslides are highly dependent on LULC changes. Poorly managed tea land, home gardens on steep slopes and poorly managed open forest areas are more vulnerable to landslides.

Key words: *Land-Use/Land Cover, Forest Plantation, Landslide, Sri Lanka.*

Introduction

The spatial distribution of landslides is the consequence of environmental setting, including climate, topography, hydrology, geology, and land use/land cover (LULC) conditions. In slope stability analysis, lithology and geological structure can be considered constant over long periods whereas morphology, climate and LULC can be affected by major modifications seasonally or over a period of decades. It is well known that different land use type may control the stability of slopes (Greenway, 1987). LULC is an important factor influencing the occurrence and movement of rainfall triggered and changes to vegetation cover which often result in modified landslide behavior (Mugagga *et al.*, 2012). Recent studies have shown that human-induced LULS changes to the initiation and reactivation of landslides (Chen *et al.*, 2019; Pisano *et al.*, 2017; Vanacker *et al.*, 2003). However, it is difficult to relate the occurrence of landslides directly to variation in land-use and land-cover, especially in some Asian Countries.

The traditional resource use structure in the central hill country of Sri Lanka has transformed con-

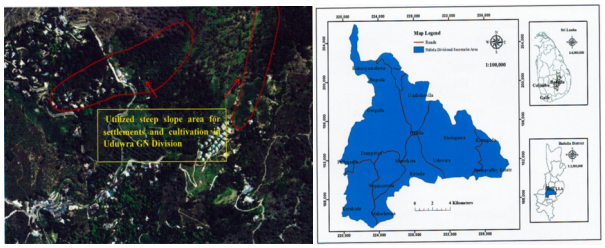
siderably during the recent past, mainly owing to the growth of population, agriculture and forestry in the region (Rogan, 2009). This transformation in resource use practices is particularly significant in the densely populated tracts of sloping lands. As a result, cultivated land, forests, pastures and rangeland have been deteriorated and depleted steady and significantly leading to their conversion into degraded and nonproductive lands. These rapid land use changes have not only disrupted the fragile ecological equilibrium in the mountains trough indiscriminate deforestation, degradation of land resources and disruption of hydrological cycle, but also have significant and irreversible adverse impacts on the rural economy, society, livelihood and life quality of communities in the areas concerned (Sugathapala *et al.*, 2009). It has been observed that the agricultural production has declined, water resources are drying up fast due to decreased groundwater recharge and a large number of villages are facing enormous deficit of critical resources, such as food, fodder, firewood and water, mainly due to unabated land use framework for the conservation of the biophysical environment and sustainable development of natural resources in the landslides area in the country.

Understanding the landscape patterns, changes and interactions between human activities and natural phenomena are essential for proper land management and decision improvement. To address the spatio-temporal variability of landslide risk, one aspect is to analysis past land cover changes, as well as future development of the LULC using scenario-based approaches (Promper *et al.*, 2014). For this purpose, present study mainly focuses to investigate the history of LULC change patterns and history of landslides in the Hali-Ela Divisional Secretariat Division (HDSD) to identify landslide risk and vulnerability in the area. It is also expected to investigate the inter-relationship with the landslides and land use.

Materiels and Methods

Study area

This study was carried out covering the entire area of Hali-Ela Divisional Secretariat area in Badulla district of the province of Uva, Sri Lanka (Fig. 1) According to the National Kilometric Grid (NKG), is situated between 185- 286 Km North and 219- 239 Km East, gridline, 6^0. $50^{'}$ and 7^0. $10^{'}$ longitude and 80^0. $50^{'}$ and 81^0. 10' latitudes. The total land area of the division is 165 Km^2 (16, 500 hectares) and is 5.6% of the total land area of the District. Administratively the Divisional Secretariat is divided in to 57 Grama Niladari Division (GND) and 319 villages.



a **b**

Fig. 1. Study area. (a) Study area represented with a Landsat-8 image in true color composite (bands 4, 3, 2 (RGB); 05 May 2021) South Asia; (b) Hali-Ela DSD

Datasets and Data Preprocessing

We digitized1:63; 360, land-use map (Survey Department, Sri Lanka) 1: 100,000 Coordinate Reference System (CRS) land-use map (Survey Department, Sri Lanka) and 1: 10, 000 land use map (Land-use Policy Planning Department, LUPPD). A detailed landslide inventory map of 1:10,000 scales prepared based on landslide prone area map of National Building Research Organization in Sri Lanka (NBRO) for the entire HDSD. The inventory obtained through a combination of: (I) field survey, (II) visual interpretation of pre-event and post-event of satellite images were obtained from United States Geological Survey (USGS)(Meneses *et al.*, 2019) and (III) stratospheric and pseudo-stereoscopic aerial photographs (Karsli *et al.*, 2009). The inventory map shows the distribution and types of the event landslides in the past and distribution and type of the pre-existing landslides.

Global Position System (GPS) registered location were used for validating computational results and 1:10,000 map of landslide prone areas NBRO were digitized as landslides have been occurred in the past, landslides are most likely to occur, landslides are to be expected, modest level of landslide hazard exit, landsides are not likely to occur.

Field visits were done to check the interpretation key and the mapped units and field verification. This filed visit also included informal group discussion with officials and local community, especially on matters of land management and agriculture

practices in the area (Rawat *et al.,* 2015). Observations were made to understand the physiographic relationship of various map-interpretation units. Due to the large-scale changes in land-use and some changes in physical infrastructure, sighting of observations (ground truth) on the proper location were rather difficult.

Data analysis

Land-use Changes Trend Analysis

The land-use changes analyzed overlying land-use maps from three time periods; 1956, 1984 and 2021 using GIS(Paul, 2013). Hence, scale, data definitions and classifications are different and not matching with each other, the three sets of land-use map of 1956 and 1984 were digitized and reclassified in this study (Rogan and Chen, 2004). For the in depth analysis, satellite images were used from United States Geological Survey (USGS, 10th January 2021) and LULC classification has done (Moran *et al.,* 1994). Various vector datasets were also utilized such as administration boundaries, roads, cities, and hydrology.

Loss and Gain Analysis

To get an accurate picture of changing land-use types in the study area as well as at the particular sites, the loss and gain analysis was applied. This analysis has shown dynamic changes in each land use types (Alawamy *et al.,* 2020).

Overlaying

In order to identify the relationship in landslide areas and their location with existing land-use types in the study area, different map themes were overlaid (Arnous, 2011; Arnous and Green, 2011).

Results and Discussion

Major LULC in the area

The major catogaries of land-use in the area are tea (Plantation and small holder lands), home garden, dense forest, open forest, scrub and grass land, paddy (Table 1). These land uses are describe in detail below.

Tea plantation

Tea is the predominant crop extends approximately 36% of the study area and most of this is managed by estate companies. It is growth both in large estates and in smallholdings, while tea smallholdings are comparatively significant of the study area. Basically tea is account for a considerable part of the total land area in the region throughout the period from 1956 to 2021. In 1965 the large-scale tea plantation companies managed all tea plantations. No small-scale tea producers were found in the region during this period. But the situation considerably different in the 1990s and there are three authorities that are handling all these type of tea plantation. They are Sri Lanka Planation Cooperation (SLPC) the Janatha Estate Development Board (JEDB) and Tea Smallholding Development Authority (TSHDA). The JEDB and SLPC manage all large-scale tea plantations.

Home Gardens

Home garden can be describes as residential units surrounded by home gardens covering an area of 4838 Ha (29%). The some home gardens appears as forest garden system in landscape, but some home garden not properly managed. Home garden is a

Table 1. LULC types of the Hali-Ela DS division 1956, 1984, 2021

Land-use/land cover	1956 land extent (Ha)	1956 (%)	1984 Land extent (Ha)	1984 (%)	2021 Land Extent (Ha)	2021 (%)
Dense forest	2,584	16	577	3	325	2
Open forest	2,880	17	1,235	7	1,911	12
Forest plantation	2,804	17	888	5	175	1
Scrub and grass land	2,156	13	1,840	11	550	3
Home garden	307	2	4,233	26	4,838	29
Paddy	907	5	1,931	12	1,410	9
Rubber	110	1	208	2	38	1
Tea	4,062	25	4,376	27	5,880	36
Other land-use/land cover	690	4	1,212	7	1,373	7
Total	16,500	100	16,500	100	16,500	100

mixture of perennial tree crops producing a multi-layered canopy, as in humid tropical forest. Basically, it provides most of the agricultural and forest produce for holder, except paddy. It can even be found in the present land-use and many of the home gardens in the area. Home garden planting ordinarily include tree crops such as mango, banana, jack, papaya, coconut and living fencing (hedgerows) are common. Few other home gardens have change to mixed garden type, where minor export crops are utilized. The most common minor export crops are pepper and coffee growing with the other perennials such as wood-based and fuel based trees, fruit trees, medicinal tress and other food-based trees.

Scrubs and Grassland

Top of the hillsides in the area is covered by the non-planted scrubs and grassland. Scrubs carried out 550 Ha (3%). These hillsides have been originally cleared for tea cultivation but have since been abandoned as the cash returns tea became less favorable. In some areas abandoned land have been handed over to stallholders who have eventually uprooted the tea for firewood. The commercial tea estates abandoned large areas, because these were situated on very steep slopes and rugged landscapes. The scrubs and grassland are burn annually during the short dry period, in January and February to control vermin or acts of vandalism. This annual burning has resulted in pyro-climax vegetation and prevents the re-establishment of woody species through plant succession.

Paddy field

Paddy land, normally terraced is common is the area. Vegetable cultivation takes over in similar areas in the study area. Soil erosion is minimum on well-maintained terraces. Where adequate water supply is assured two crops of rice are grown per year, while in areas where rainfall may be limiting, often in the Yala seasons, vegetables are substituted for one crop of rice in the less reliable rainy seasons. Paddy cultivation is carried out in an area of 1410 hectares (9%).

Natural forest (Dense forest and Open forest)

The worldwide evidence is that high hills and mountains usually have both more rainfall and more natural forest than the adjacent lowlands. Until the turn of 19th century, Badulla district hilly area was almost entirely covered by natural forest including HDSD. By the year 1900 the forest cover was estimated at 70% (Environment and Forest Conservation Division, Mahaweli Authority) of the land area in Badulla District hilly area. The situation changed when the forest were cleared for plantation agriculture. Natural forest resources have been reduced drastically as a result of the introduction plantation crops and other land-use and land cover changed due to population pressure. Natural forest carried out in an area of 2,236 Ha (14%), dense forest 325 Ha (2%) and open forest 1911 Ha (12%). The region forms a part of the humid mountain forest soon although the vegetation in its natural form does not occur in most parts of the area. Prior to the introduction of the plantation economy the peasantry very sparingly utilized the upper slope in order to minimize ecological imbalances. However, the unprecedented growth of mono cropping associated with plantation agriculture and indiscriminate felling of forest of the upper slopes is including soil erosion. Mountain forests are presently found in restricted location such as scrap slopes.

Forest plantation

Forest plantation has been introduced during the 1980s as possible solution for covering bare, waste and grasslands in order to minimize soil erosion in the area. These forest plantations have mainly come about as a result of the policy formulated by the forest department during that period. In addition to this, plantation companies has launched another kind of forest plantations. The small plot of this type of forest plantation can also be identified in the area. Forest plantation carried out in the area of 175 Ha (1%).

LULC trends in the area

Due to rapid changes, the land-use and land cover has been changing (Fig. 2, 3 and 4). From 1950s, the plantation sector had undergone profound land-use/ land cover changes compared to past few decades, with sustainable forest areas disappearing due to legal timber felling and introducing vegetable cultivation in the estate reservations by the settlers.

At present about 82% of total land area is under agricultural uses while 18% of lands are under forests and forest plantations. The home gardens (29%), paddy (9%), tea (36%) and other crops lands (8%) are dominant. The paddy lands include both irrigated and rain-fed cultivation. Most of the home

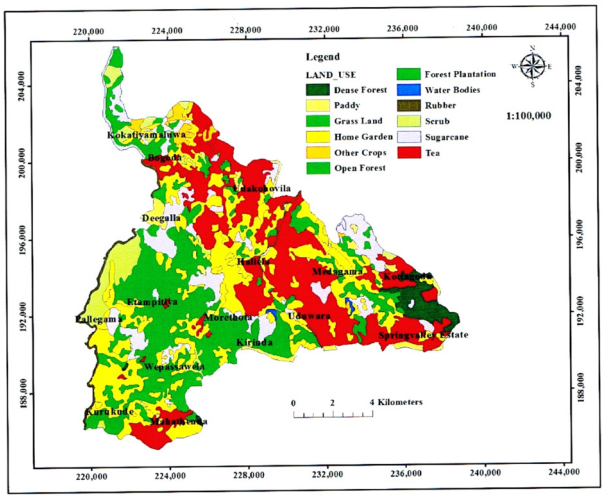


Fig. 2. Land-use/land cover in Hali-Ela DS area, 1956

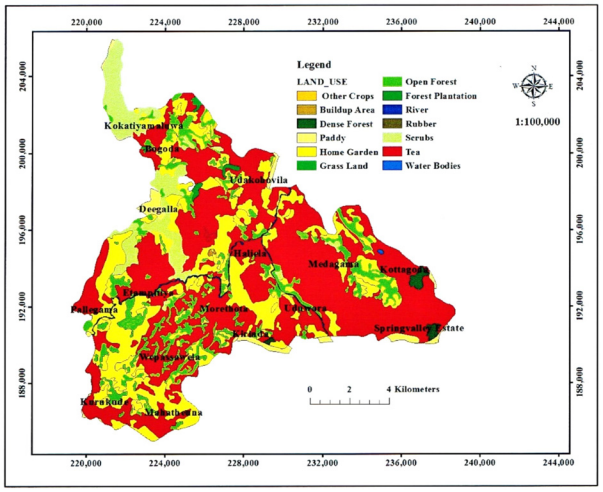


Fig. 3. Land-use/land cover in Hali-Ela DS area, 1984

gardens are having mixed and vegetable agriculture crops. The total extent of homesteads was 2% in 1956 and it has increased to 20% of the total land

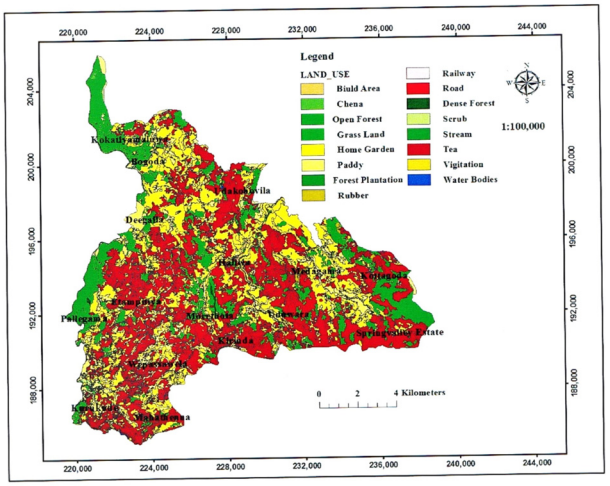


Fig. 4. Land-use/land cover in Hali-Ela DS area, 2021

area in 2016. Among the population crops the land area under tea plantations has increased by 16% while this is also a slight increase of rubber lands. The barren lands have increased during this period indicating poor management of agricultural lands in the study area. A comparative land used analysis between major land uses in 1956 and 2016 shows a decrease of over 45% in forested area from 10,424 ha to 2961 ha.

There was a significant increase in the extent of agriculture lands from 1956 in the study area mainly due to the development of the infrastructure including road facilities. The period from 1984 to 2016 also registered slight increase agricultural land-use in the study area. That is 46% from 1984 to 2021. This is attributed to agricultural policies at national level and regional level. It is observed that the demarcation of wildlife boundaries and forest boundaries restricted further expansion of agricultural lands in the division.

It is clear that (Table 2 and Fig. 5) during 1956 to

Table 2. LULCchanges in Hali-Ela DS Division from 1956 to 2021

Land-use/land cover	1956 -1984 (Ha)	Changes (Loss/Gain)	1984 – 2016 (Ha)	Changes (Loss/Gain	1956-2021 Overall change (Ha
Dense forest	-2,007	Loss	-252	Loss	-2,259
Open forest	-1,645	Loss	+676	Gain	-969
Forest plantation	-1916	Loss	-713	Loss	-2,629
Scrub and grass land	-316	Loss	-1,290	Loss	-1,606
Home garden	+3,926	Gain	+605	Gain	+4,531
Paddy	+1,024	Gain	-521	Loss	+503
Rubber	+98	Gain	-170	Loss	-72
Tea	+314	Gain	+1504	Gain	+1,818
Other land-use/land cover	+522	Gain	+161	Gain	+683

1984 lands under all cultivated crops had shown an increasing trend. The similar trend observed during 1984 to 2021, but extent of chena lands was reduced during this period. The forest landsin the area have gradually decreased due to the expansion of vegetable cultivation, logging and expansion of villages and other forms of human activities.

Spatial distribution of landslides in Hali-Ela and history of landslides

The central highlands of Sri Lanka, which is characterized by a high density of landslide distributions, is the region most prone to landslides due to its rugged topography. The landslide distribution density in Badulla district is relatively high when compared to other districts such as Kandy, Kegalla, Rathnapura, Matale From 1986 to 2021 total of 593 landslides have been recorded in the HDSD, of which the vast majority were cutting failure, 447(75%). The number of all other landslides (Slop failure, Rock Fall, and Earth Falls) were much lower (25%) (Table 3, Fig. 5).

Landslides in different land-use/land cover (LULC)

Thematic layer analysis in GIS shows that the number of landslides were primarily located in tea lands, and then in home gardens, open forest, paddy, grassland and roads respectively (Table 4 and Fig. 5). The landslide ratio for different types of LULCis defined as the landslides area in a given land-use type divided by the corresponding land-use area.

Table 3. Type of landslides in HDS, from 1986 to 2021.

Category	Number of Landslides Occurred	Percentage
Cutting failure	447	75
Slope failure	79	13
Rock falls	39	6.5
Earth falls	28	5.5
Total	593	100

Source: National Building Research Organization (NBRO), 2021

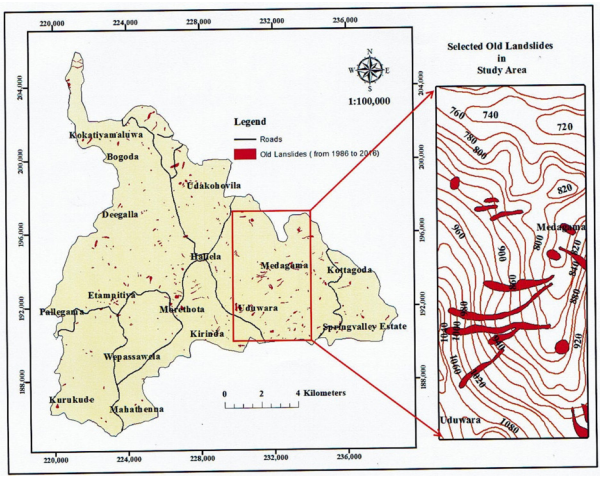


Fig. 5. Landslide occurrences in the HDSD, from 1986 to 2021

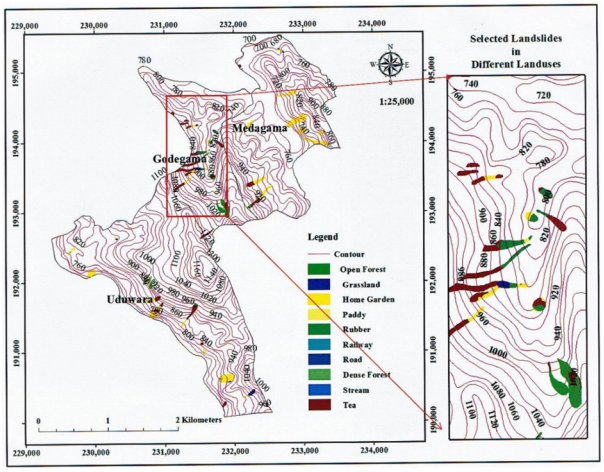


Fig. 6. Map of landslides in different Land-uses/land cover in

Table 4. Relationship between LULC and landslides in Hali-Ela DS division, from 1986 to 2021.

Land-use/ land cover	Number of Landslides	Percentage (%) of total	Total Area Affected (Ha)	Percentage
Tea lands (Poorly managed)	176	30	177	31
Home garden	166	28	159	27
Open forest	74	12	85	14
Paddy	73	12	72	11
Scrub/Grass lands	49	08	52	09
Road/Railway line	22	04	24	04
Other land-use/land cover	33	06	12	04
Total	593	100	581	100

Landslides attained the highest ratio in poorly managed tea lands (30%), followed by poor managed home garden (28%), open forest (12%), paddy (12%), scrubs/grassland (8%), roads/railway (4%) and other land uses (6%), percentage of land-use occurrence is described by dividing the total land extent from the extent faced with landslides corresponding to land-use purpose. Accordingly it is (31%) for tea, followed by home garden (27%), open forest (14%), paddy (11%), scrub (9%), roads (4%) and other land-use.

Conclusion and Recomendations

The present study clearly indicated that in many parts of the study area (HDSD), changing trends of LULChave led to accelerated land degradation, and as consequence, landslides.

Incidences of landslides in Hali-Ela division show a close relationship with land-use/land cover where changes in land-use affect the landslide frequency distribution. Areas with changing land-use/land cover show higher landslide ratios than areas of unchanged land-use/land covers. Tea lands (30%) and Home gardens (28%) are the distinct examples. The Dense natural forests and well-managed tea lands show the lowest landslide ratio. Poorly managed tea lands, home gardens on steep slopes and poorly managed open forest areas are more vulnerable to landslides compared to other LULC. They include areas of low crop density, partly used lands, area without (or with only poor) drainage facility and annually burnt lands. It is clear that the LULC and land management practices are very important aspects to determine the scale and impacts of landslides (Mallupattu *et al.,* 2013).

Since anthropogenic activities on steps have often caused land degradation and as a result landslides, all accessible lands in the study cannot be considered as suitable for economics use or human habitation. On the other hand, all unutilized and underutilized lands with slopes must be maintained as far as possible permanent forest and or grass lands (Nath *et al.,* 2018). Further, already depredated or underutilized agricultural lands with vulnerable zones must be managed with strict conservation regulations and new policy frameworks should be adjusted with minimizing the risk factors in a sustainable manner.

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