05 Landslides

5.1 Background

Among the natural hazards, landslides are attracting more and more attention due to its increasing effect on economic and human losses. **Landslide is a general term covering a wide variety of mass movements and processes involving down slope transport of soil and rock material in mass under gravitational influence.** Although this is a part of the Earth's denudation process and thus considered as a natural phenomenon, slopes which stood safe for centuries are now frequented by landslides and hence socioeconomic losses due to its impact are growing. This is mainly due to the expand of human activities into more vulnerable hill slopes under the pressure of rising population and associated demands for lands and infrastructure facilities, without an adequate attention to the problem.

The term landslide comprises almost all varieties of mass movements on slopes including rock falls, topples and debris flows that involve little or no true sliding (Varnes, 1984). According to Cruden (1991), the term landslide is used to denote the movement of a mass of rock, debris or earth down a slope. Therefore, the phenomena described as landslide is not limited either to the land or to sliding. The word is now used with more extensive meaning (Jayathissa, 2010).

Slope movements have been classified in many ways, with each method having some particular usefulness or applicability related to the recognition, avoidance, control, or correction of the hazards (Sidle and Ochiai, 2006). Landslide classification systems have been developed from either geo-morphological or geotechnical perspectives and they provide detailed description of the mode of failure, materials, velocity, failure mechanism, and kinematics (motion of the mass) of landslides. The widely used classification scheme developed by Varnes (1978) distinguishes five types of mass movements such as falls, topples, slides, spreads, and flows plus combinations of these principal types as complex.

Varnes (1978) provided an idealized diagram showing the features of landslide which he called complex earth slide-earth flow which has been reproduced here as Fig 5.1.

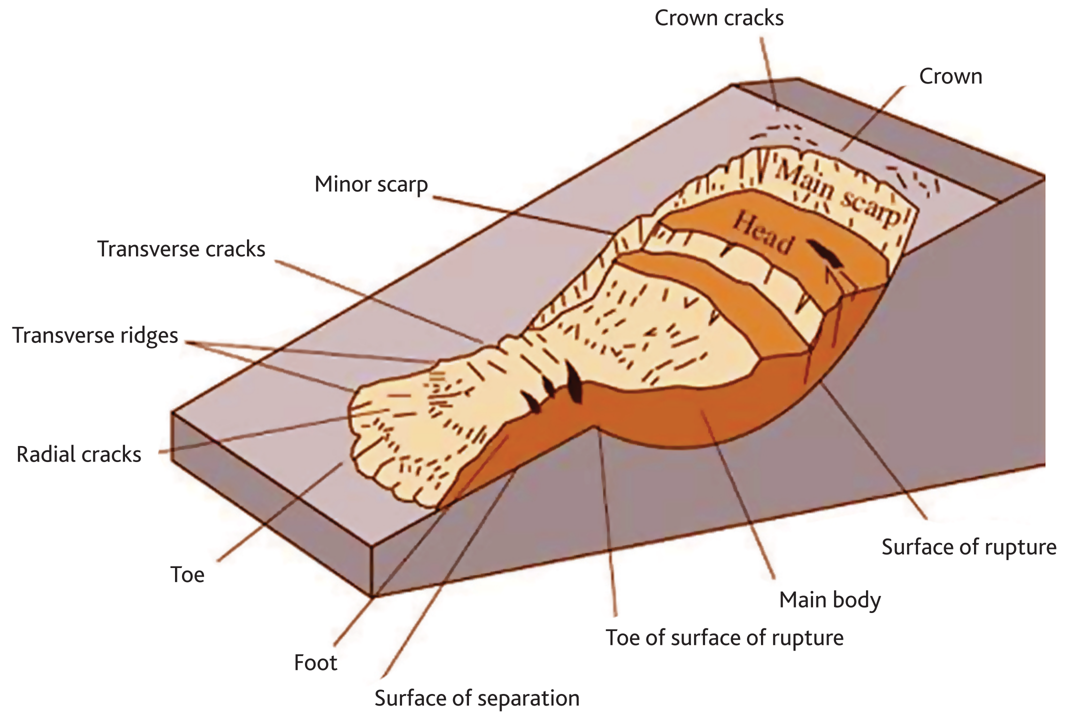

Fig 5.1: Block diagram of idealized complex earth slide-earth flow (Varnes, 1978).

5.1.1 Causative Factors

In the context of Sri Lankan case, many of the natural hill slopes that stood safe for centuries are now frequented by landslides. This is mainly due to human intervention into vulnerable hill slopes. Hence landslides associated with intense rain during monsoon and inter-monsoon seasons have became the most frequent and pressing natural disaster within the central highland of the country (Fig 5.2). Nearly 13,000 km^2 (20% area of the country) covering ten administrative districts such as Badulla, Nuwara Eliya,

Fig 5.2: Human intervention into vulnerable hill slopes and landslide disaster in Sri Lanka; Kiriwanaella, Walapane landslide in which 12 people were killed and 5 houses were buried - Jan. 2007;

Matale, Kandy, Kegale, Rathnapura, Kalutara, Galle, Matara and Hambanthota are considered to be highly prone to landslides (Fig 5.3).

5.1.2 Frequency & Impact

Occurrence of landslides and their reactivation have become a frequent natural phenomenon in the hill country causing severe damages to life and property. The extent of loss of forest cover, wild life, damage to the eco-systems and losses to investment on various development projects etc., caused by landslides cannot be easily estimated and will probably remain unknown. Landslides are likely to have a greater economic impact on the urban and semi urban environment where the elements at risk e.g., human settlements, infrastructure facilities and the human lives are large in number.

Records maintained by National Building Research Organization (NBRO) over the past 25 years show that not many disastrous landslides have been reported during and before the first half of 20th century with only 03 lives reportedly lost in 02 fatal landslide incidents out of a total of 09 incidents reported. However within the next quarter of the century, the death toll due to landslides had exceeded 44 in number in 02 fatal incidents out of the 17 reported landslides (Landslide, 1986).

The last quarter of the century witnessed disastrous landslides occurring almost every year killing over 108 people in 26 fatal landslides out of 75 incidents recorded, making thousands of people homeless and wreaking havoc to the economy (Landslide, 1986). The distribution of previous landslides and the areas with landslide potential are represented by Fig.5.3.

5.1.3 Landslide Related Studies in Sri Lanka

With the disastrous landslides that occurred in mid 1980's, the Government of Sri Lanka took the initiatives of studying the landslide phenomena in the country. On June 16th 1986, the Cabinet of Ministers of the Sri Lankan Government decided (Cabinet Paper 116 of 16th June 1986) to launch Landslide Hazard Zonation Mapping Project (LHMP) to study and identify the distribution of landslide potential in the central highlands (Ambalavanar & Lankanesan, 1994). Phase I of LHMP was carried out between 1990 and 1995 with technical and financial assistance from the Government of Sri Lanka (GOSL), United Nations Development Programme (UNDP) and United Nations Commission on Human Settlements (UNCHS). The National Building Research Organisation (NBRO) was selected as the executing agency of LHMP, mainly due to availability of multidisciplinary expertise at NBRO (Ambalavanar & Lankanesan, 1994) and Tissera, 1994).

During the five year period that Phase I of LHMP was in operation, 863 landslides in Nuwara Eliya district (Wijewickrama et al., 1994) and 213 landslides in Badulla district (Bandara et al., 1994) were studied in detail to identify the major causative factors of landslides and their relative contribution. The result of those field studies along with both national and international expertise in the fields of Geology, Geography, Geotechnical Engineering, Hydrology and Sociology were heavily utilized and a probabilistic methodology for landslide hazard zonation was developed at NBRO (Manual, 1995). The major tangible output of this project was the 30 landslide hazard zonation maps prepared at 1:10000 scale covering 1200 sq. km of land area within above two districts. Development of general guidelines for construction and development of landslide prone areas and building the capacity of NBRO to continue the subsequent Phases were the other major outcomes of LHMP-Phase I.

With the successful completion of LHMP-Phase I, in 1995, the GOSL decided to extend the project into the other landslide prone areas of the country also (Arambepola and Weerasinghe, 1998). As a result, highly landslide potential areas in Ratnapura, Kegalle Kandy and Matale administrative districts were mapped under the LHMP – Phase II. With the approval of the Cabinet of Ministers of the Sri Lankan Government (Cabinet Paper 03/1372/111/061 dated 17.07.2003), NBRO was requested to extend the landslide hazard zonation mapping programme to the southern districts of Matara, Galle and Hambantota also

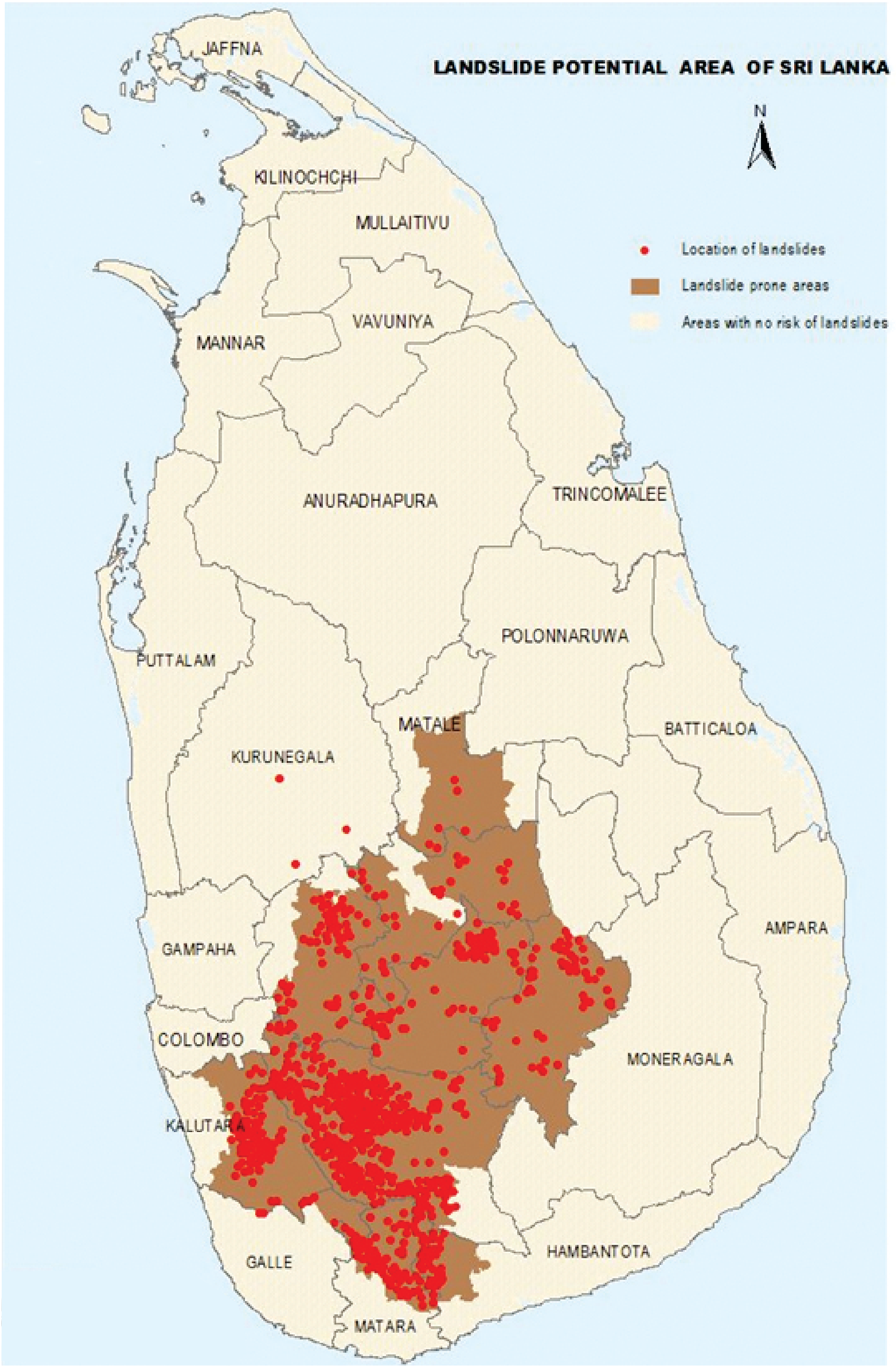

Fig 5.3: Landslide prone areas of Sri Lanka

(Bandara & Weerasinghe, 2011). Presently, NBRO is successfully in the process of establishing sustainable, long-term and short-term mechanisms for landslide disaster management in Sri Lanka.

5.2 Scope of the Study

The scope of this study is to prepare landslide potential maps covering seven mountainous districts of Sri Lanka namely, Matale, Kandy, Badulla, NuwaraEliya, Kegalle, Ratnapura and Kalutara. The 1:50,000 scale maps are developed based on the relative contribution of geological, topographical, land use and land management attributes. Even though lower in accuracy than that of its 1:10,000 scale counterpart, these 1:50,000 scale maps could be used in evaluating the distribution of landslide potential at national level (Arambepola and Weerasinghe, 1998). These maps will be utilized in disaster management activities relating to landslides.

The final objective of this work would be to minimize loss of lives & property in landslide prone areas by taking necessary preventive measures on time. These maps could be utilized in forecasting the potential landslide prone areas in order to protect people and their properties and also to initiate evacuation of people from such areas on short-term & long-term basis via well planed evacuation programmes on time.

5.2.1 Preparation of 1:50,000 Scale Hazard Zonation Maps

An important outcome of LHMP-Phase II was the generation of 1:50,000 scale maps covering the entire land areas of seven mountainous district of Sri Lanka namely, Matale, Kandy, Badulla, Nuwara Eliya, Kegalle, Ratnapura and Kalutara.

At the inception of LHMP, the scale of 1:10,000 was selected as the appropriate scale of mapping as it was the largest scale at which the base data was available at that time (Manual, 1995). However the methodology adopted for 1:10,000 scale landslide hazard zonation mapping is based on an extensive field study and evaluation of six causative factor attributes and their sub factor elements and hence often bound by time and cost factors. Therefore, during the LHMP-Phase II, the 1:50,000 scale mapping was introduced for national and district level mapping while limiting the 1:10,000 scale mapping to the areas with potential to development and are extremely high vulnerability to landslides.

The 1:50,000 scale maps are developed based on the relative contribution of geological, topographical, land use and land management attributes as they are the most influential causative factors which govern the landslide potential at regional scale. Even though lower in accuracy than that of its 1:10,000 scale counterpart, 1:50,000 scale maps are immensely utilized in evaluating the distribution of landslide potential at national level (Arambepola and Weerasinghe, 1998).

The scope of 1:50,000 scale mapping is to identify the relative distribution of landslide potential in the 10 landslide prone district of Sri Lanka. Presently, mapping the districts of Matale, Kandy, Badulla, NuwaraEliya, Kegalle, Ratnapura and Kalutara have been completed and the mapping of Galle, Matara, Hambantota are expected to be completed end of 2012.

However, in the year 2012, under UNDP/DMC project on Strategic Environmental Assessment of Uva Province, NBRO was invited to map the distribution of landslide potential in the Moneragala District at 1:50,000 scale. The mapping is presently in progress and will be available for use at the end of 2012.

Landslide hazard zonation maps are already published at www.nbro.gov.lk the relevant link for the landslide maps for the present work is :

http://www.nbro.gov.lk/web/index.php?option=com_content&view=article&id=168&Itemid=192&lang=en

5.3 Methodology

Intensive heavy rain is the major triggering factor of landslides in Sri Lanka. However, NBRO's studies reveal that, with respect to the national scale mapping, geological and topographical characteristics have major influence among the natural causative factors of landslides.

Additionally, the man made causative factor which incorporates the changes resulting from undue human intervention such as improper land use and cropping practices, unplanned human settlements in unstable areas has caused a phenomenal increase in the incidence of landslides in hilly areas.

Therefore, the methodology of 1:50,000 scale landslide hazard zonation mapping is based on the relative contribution of causative factors; Bedrock Geology, Slope Angle Range and Landuse and Land Management (Fig: 5.4). Those causative factors and their sub-factor elements have been assigned weights and ratings based on their relative contribution to causing landslides. The weights and ratings have been decided on considering expert opinion and statistical analysis of historical data (Table 5.1).

Through an extensive study, a site is rated against each of the above mentioned causative factors and States Of Nature (SON) maps of each factor are prepared. These SON maps are then analyzed separately to prepare the derived map of respective factors. The derived maps represent the distribution of landslide hazard potential based only on one causative factor, independent of the influence of other factors. The derived

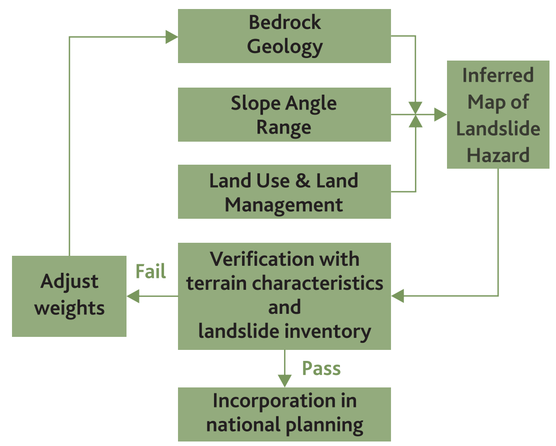

Fig: 5.4: Methodology of 1:50000 scale landslide hazard zonation mapping

maps are then overlaid using Geographic Information System (GIS) and, for each resulting polygon, the cumulative hazard rating value is computed by adding up the individual ratings. The overlaid map is then classified into landslide hazard zones based on the cumulative hazard rating. A sample landslide hazard zonation map is shown in Fig 5.5 and the distribution of landslide potential at national level is shown by Fig: 5.6.

Considering the fuzzy nature of landslide potential which is highly dependent on

Table 5.1 Weights and ratings assigned for major causative factors and their sub-factor elements.

Major factors & maximum weighting	Sub factors & maximum weighting	Sub factor Elements, qualitative ratings, and numerical ratings		
Geology 20	Lithology 8	Marble	very low	0
		Weathered rock	low	1
		All others	medium	3
		Charnockite, Granulite or bedrock not exposed	high	5
		Quartzite	very high	8
	Amount of dip & type of slope 4	Dip & scarp 71-90	very low	0
		Dip & scarp 56-70	low	1
		Dip 11-30, scarp 46-55 & all intermediate slopes	medium	2
		Dip 0-10, scarp 31-45	high	3
		Dip 31-55, scarp 0-30	very high	4
	Deviation angle (degrees) 6	Angle 26-120	very low	0
		Angle 11-25 or 121-155	low	2
		Angle 156-180	high	4
		Angle 0-10	very high	6
	Other discontinuities and lineaments 2	To be decided on case to case basis	very low	0
			very high	2
Slope range & category 25	Slope range & category (degrees) 25	Slope category I (>40)	very high	25
		Slope category II (31 40)	high	16
		Slope category III (17-31)	medium	13
		Slope category IV (11 17)	low	7
		Slope category V (0-11)	very low	5
Land use & Management 15	Land use & Management 15	JT1, JC, JQ, JWb, W1, S1	very low	3
		JT2,JR,JWp,HP,HK,HM,HW,W2,W3,W4, S2,S4	medium	8
		HA, G1, G2, S3, N1, N2, N3, N4	very high	15

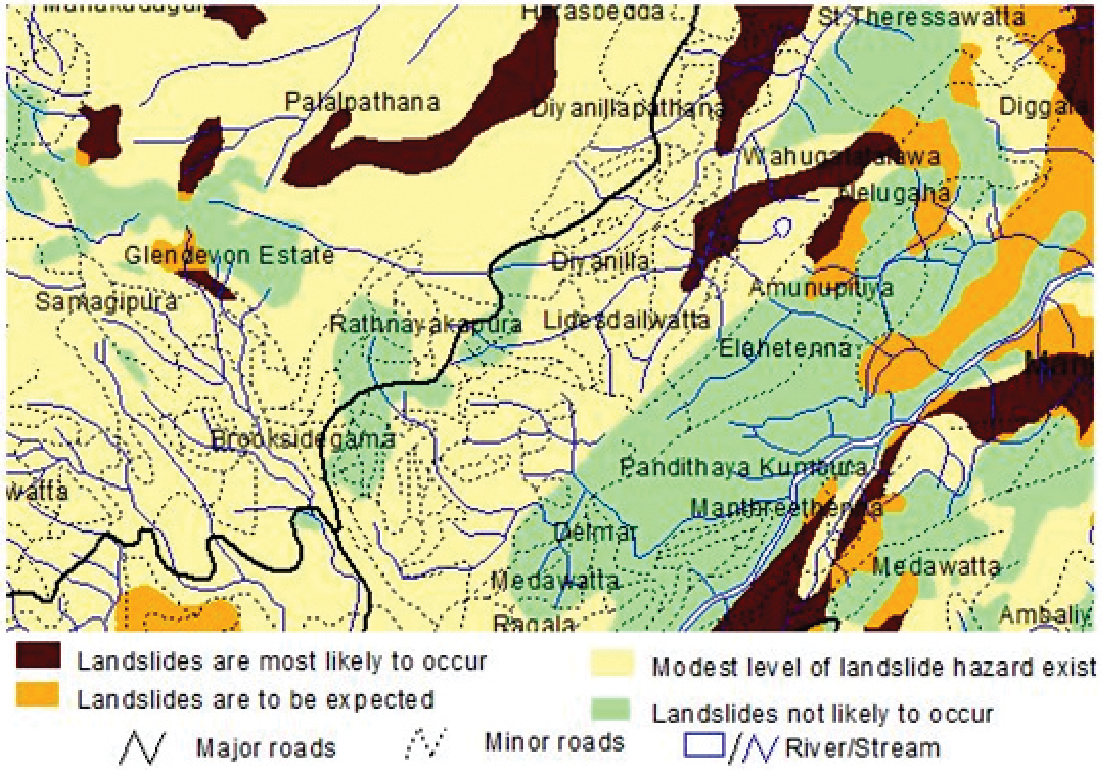

Fig: 5.5: Sample landslide hazard zonation map prepared at 1:50000 scale

Table 5.2 Guidelines to be followed when developing landslide hazard zones identified by the landslide hazard zonation maps.

Landslide hazard zone	Guidelines for development
Landslides not likely to occur	No visible signs of slope instability or danger of landslides exist based on the present state of knowledge. No limitations need to be imposed particularly on well managed lands and engineered construction. Location specific limitations may become necessary particularly for sites that are prone to flooding and erosion.
Modest level of landslide hazard exists	Slight danger of landslide hazard exists. Engineered and regulated new construction and well planned cultivation are permitted. Plans for construction should be technically vetted and certified by specialists.
Landslides are to be expected	Moderate levels of landslide danger exist. New construction should be discouraged and improved land use planning practices should be introduced to halt and reverse the process of slope degradation. All essential cons truction, remediation and new projects should be subjected to thorough landslide hazard assessment.
Landslides are most likely to occur	Danger and potential threat to life and property exists. No new construction should be permitted. Essential additions in the existing structures may be allowed only after thorough site investigation and adequate precautions which are certified by the specialists. Early warning system should be established if symptoms of landslides are clear and risk levels are high.

CHAPTER
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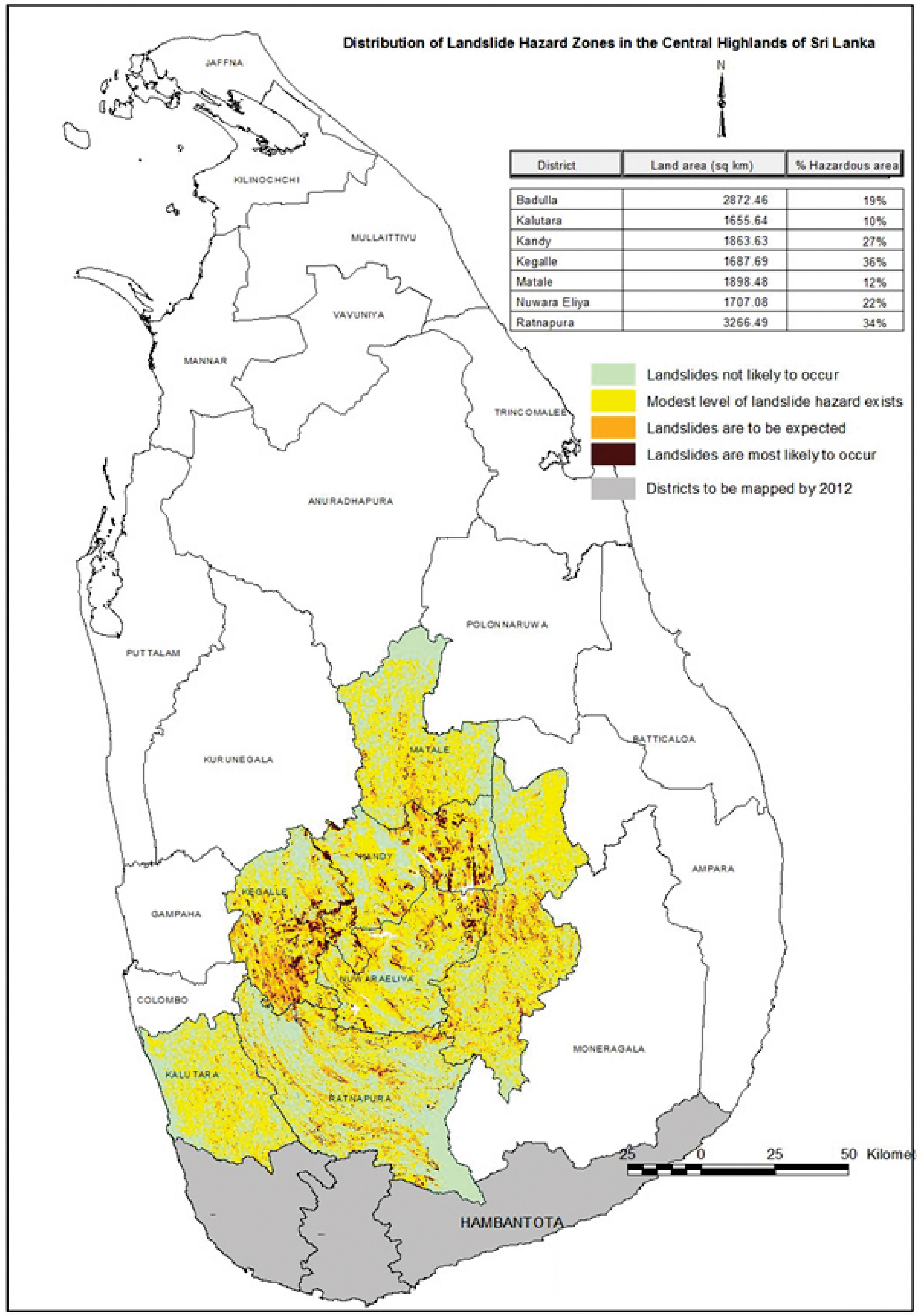

Fig: 5.6: Distribution of landslide hazard zones in Sri Lanka the changes of the causative factors the predicted landslide hazard zones are expressed in descriptive terms such as landslides are most likely to occur etc. (Fig: 5.5) rather than crisp terms such as high, medium and low etc (Manual, 1985).

5.4 Hazard Profile

Landslide hazard zonation maps are intended to be used as a planning tool which identifies the degree of hazard associated with a specific area. Thus, the maps are utilized in planning human settlements, infrastructure and other development activities within the hilly area of the country. Guidelines that are needed to be strictly followed when any development is planned within each landslide hazard zone are also provided along with the landslide hazard zonation maps (Table 5.2). The maps can also be utilized for policy making, selecting suitable land to relocate highly vulnerable communities and infrastructure, economical distribution of relief aids, identifying economical mitigatory measures and issuing landslide early warning.

5.5 Conclusion

Occurrence of landslides and their reactivation have become a frequent natural phenomenon in the hill country causing severe damages to life and property. Under the Landslide Hazard Zonation Mapping Programme at NBRO, the relative distribution of landslide potential is mapped at 1: 50,000 scale for district and national level and at 1:10,000 scale for the areas with potential to development and are extremely high vulnerability to landslides. The 1:50,000 scale maps are developed based on the relative contribution of geological, topographical, land use and land management attributes as they are the most influential causative factors which govern the landslide potential at regional scale.

5.6 Recomendations

Landslide hazard zonation maps are recommended to use as a planning tool which identifies the degree of hazard associated with a specific area, therefore, they shall be utilized in planning human settlements, infrastructure and other development activities within the hilly area of the country. The maps could also be utilized for policy making, selecting suitable land to relocate highly vulnerable communities and infrastructure, economical distribution of relief aids, identifying economical mitigatory measures and issuing landslide early warning. Guidelines that are needed to be strictly followed when any development is planned within each landslide hazard zone are also provided along with the landslide hazard zonation maps.

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