Modern Trends in Landslide Mapping and Investigations

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Abstract

Landslide in general is a natural process, which is a part of geomorphic development of a region. The landslide process gets aggravated due to human intervention in the form of development activities. Hence it is essential that the implementation of development projects should be planned in a more systematic way taking into consideration the existing instabilities of hill slopes. For that purpose, landslide mapping and related investigations are the pre-requisites for the successful implementation of the project. In this context, the paper presents various mapping techniques based on themes and scales as well as the various investigations carried out for evaluating a landslide in a systematic way.

Introduction

Landslide is generally a natural process, which is, in fact, a part of geomorphic development of a region. The fragile Himalayan ecosystem is more vulnerable to natural disasters including landslides and often cause serious damages to life and properties. In addition, the human intervention in the form of nonsystematic constructions has also aggravated existing natural balance of the area. As a result a number of major landslides such as Varunavat landslide, Surbhi landslide, Byung gad landslide, Dadahu landslide and Harmony landslide occurred in the recent times. Hence it is essential that the implementation of development projects should be planned in a more systematic way taking into consideration the existing instabilities of hill slopes. For that purpose, landslide mapping and related investigations are the pre-requisites for the successful implementation of the project. Since the outputs of these studies are to be used for designing the control measures, it is important that the investigations are planned more effectively. The landslide investigations have undergone many improvements in the recent times. Basically landside investigations can be carried out following detailed site specific studies meant for evolving suitable remedial measures or on small regional scales for the purpose of planning development projects. An attempt has been made to provide a comprehensive discussion on the landslide mapping and investigation techniques.

Landslide Mapping Based on Themes and Scales

Mapping techniques are essentially based on themes and scales. While possibilities of various combinations of themes and scales exist, a judicial selection of the two factors will help in the effective utilization of the study as a whole. An elaborate discussion of both the factors has been presented for better understanding.

Landslide Mapping based on Theme

Landslide mapping can be carried out based on three important themes namely danger, hazard and risk.

a) Danger

Danger refers to an existing natural landslide phenomenon, such as debris slide, rock fall or creep (Fig. 1). The description or classification may be done based on any relevant classification such as the one by Varnes (1978). The danger can be an existing one such as slide or creep, or it can be a

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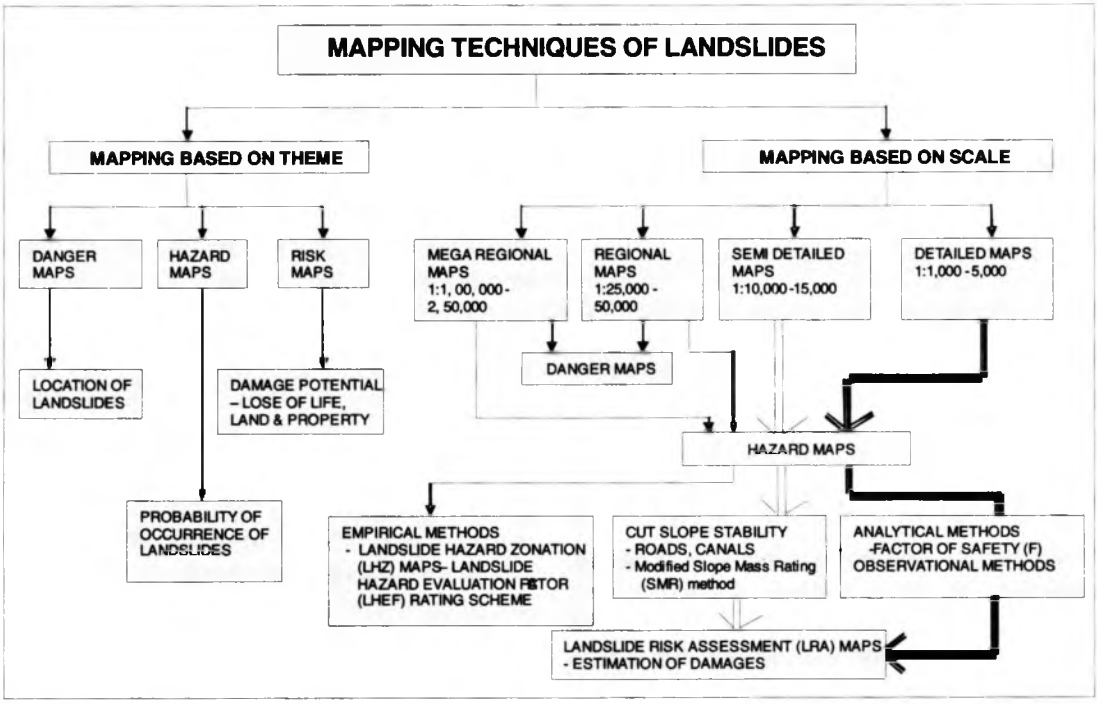

Fig. 1: Mapping Techniques of Landslides

potential one such as rock-fall, debris flow or avalanche. This characterization does not include any forecasting of the events. Landslide danger maps are also termed as landslide inventory maps. Such maps can be prepared on mega-regional and regional scales. They only indicate the location of a landslide and may not show anything about its nature of activity, size, type, failure probability and possible damage.

b) Hazard

Hazard refers to the probability of occurrence of a landslide danger. We know that the landslide occurrence can not be predicted in terms of absolute time. However the period of time may be indicated in terms of relative time while classifying the hazards using empirical approach. Hence hazard maps can prepared based on relative hazards in five different hazard levels, namely very high hazard (VHH), high hazard (HH), moderate hazard (MH), low hazard (LH) and very low hazard (VLH) as shown in Fig 3. This classification of landslide hazard is of

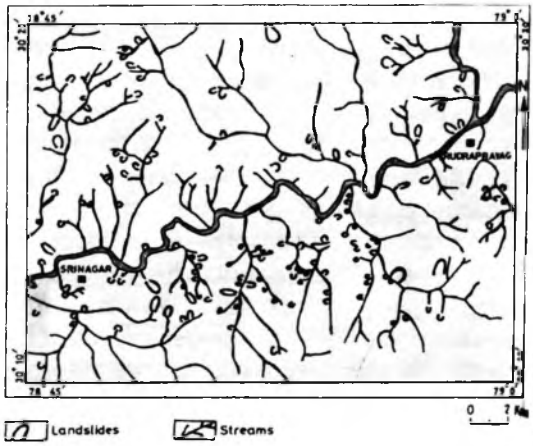

Fig. 2: Landslide Danger map of Srinagar - Rudraprayag area, Uttarakhand

immense significance to indicate very high to very low probability of occurrence for different types of hazards. For example, in a predicted high hazard slope, the landslide may occur early as compared to a moderate hazard or low hazard slope. The hazards may be analyzed and mapped on detailed, semi-regional, regional, or mega -regional scales.

c) Risk

Risk refers to the nature of damage likely to be caused in case of a failure. The damage may be in the form of loss of life and injuries and/or loss of land and property. The extent of damage is dependent on existing land use pattern of the area likely to be affected and its population. For example, a smaller landslide in a thickly populated area may cause extensive damage as compared to a major landslide in a remote area. Therefore, risk is a function of hazard probability and the damage potential (Anbalagan and Singh, 1996).

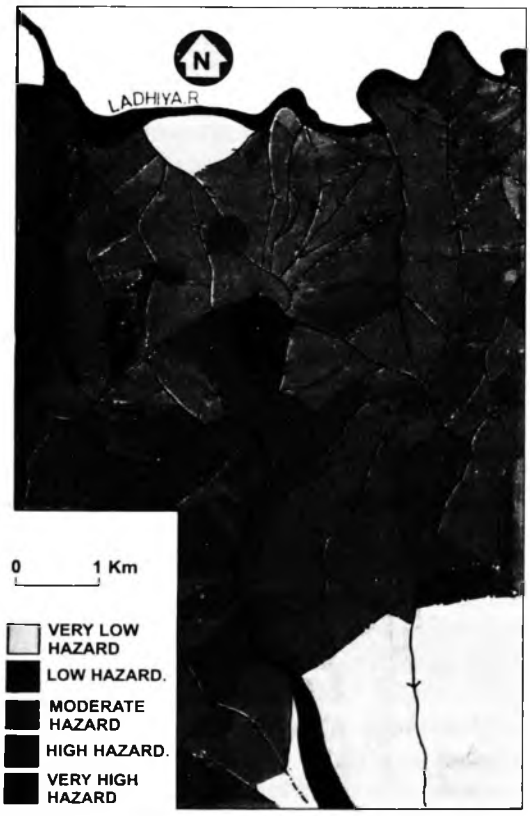

Fig. 3: Landslide hazard zonation map of Sukhidang area (Anbalagan, 1992)

$R = f(Hp, Dp)$

Where, Hp = Hazard probability and Dp = Damage potential

Risk assessment may be undertaken after evaluating the nature of hazard of a slope and its damage potential. The risk maps can be prepared based on a relative pattern of damage to indicate very high to very low damage potential, like very high risk (VHR), high risk (HR), moderate risk (MR), low risk (LR) and very low risk (VLR) as shown in Fig 4. The risk maps can be prepared on detailed (1:1,000-2,000), semi-detailed (1:10,000-15,000) as well as on regional (1:25,000-50,000) scales.

Landslide Mapping based on Scale

The choice of scale of landslide mapping is basically decided based on the purpose for which the mapping is carried out. The general scales used for mapping are indicated below.

Mega-regional Mapping

The mega-regional mapping generally covers mapping done on scales smaller than 1:50,000, but mostly falls between 1:1,00,000 and 2,50,000 scales. The investigations using mega-regional mapping are based on an

Fig. 4: Landslide risk map of Sukhidang area (Anbalagan, 1992)

integrated approach using topographical, field and remote sensing data. The preparation of landslide danger maps on these scales is relatively simple. The LHZ maps can also be prepared using remote sensing data as well as limited field data.

Regional Mapping

The regional mapping of landslide hazard and risk can be done on 1:50,000 to 25,000 scales. Mapping techniques like landslide hazard zonation (LHZ) (Anbalagan, 1992; and landslide risk assessment (LRA) fall in this category. LHZ technique is based on landslide hazard evaluation factor (LHEF) rating scheme and involves empirical approach. It is a cost effective method, in which large areas can be covered in a comparatively short time span. It is a macro zonation approach based on the basic causative factors, such as lithology, structure, slope morphometry, relative relief, land use and land cover and hydrogeological conditions. The final LHZ map categorises the area into VHH, HH, MH, LH and VLH categories to indicate very high to very low probability of occurrence of landslide (Fig. 3). This technique is useful for preliminary planning of development schemes and help to avoid unstable areas during planning stage. Even if unavoidable, their recognition in the initial stages of planning will help to evolve better preventive measures.

The landslide risk assessment (LRA) mapping can be better estimated on regional scales to cover large areas. In this context, the methodology of Anbalagan and Singh, 1996 is an appropriate technique to study the risk on regional scales. Risk assessment refers to an estimation of the extent of damage likely to result if landslide occurs. The damage may occur on the same slope facet where hazard exists or it may extend into adjoining facets. The damage may be classified broadly into two categories - i) loss of life and injuries and ii) loss of land and properties. The preparation of risk assessment (RA) map can be carried out immediately after the preparation of LHZ map and after carrying out the detailed study of VHH and HH facets for preparing a realistic RA map (Fig. 4). The RA maps can be used for deciding priority areas for landslide hazard management (LHM) as well as for finally deciding the location of development schemes. The risk assessment for individual active landslides can be carried out after assessing the status of stability in terms of factor of safety (F) and the extent of the area to be affected in the event of a landslide.

Semi-detailed Mapping

The semi-detailed mapping is carried out on 1:10,000 to 15,000 scales mainly for evaluation of stability of cut slopes along linear engineering structures such as roads and rail routes. Such studies are also used to evolve stable cut slopes for opencast mines. One of the reliable techniques for such investigations is the Slope Mass Rating (SMR) system of Romana (1985), modified by Anbalagan et. al., 1992. Ranjan et. al. (1996) showed its effective use for cut slope design during road or terrace excavation on hill slopes for building construction.

Detailed Mapping

Detailed mapping of the landslides is carried out on 1:1,000 to 2,000 scales for the evaluation of stability of individual slopes in terms of factor of safety. The investigations can be carried out using observational or analytical methods. The total mobilizing and the resisting forces are calculated to work out the factor of safety (F) of slopes. The studies are used for evolving adequate remedial measures for stabilizing hill slopes. The investigations are generally carried out on already failed slopes or potentially unstable slopes, after regional or semi-detailed studies. A detailed account of detailed analysis of various modes of failures is provided in Anbalagan et al., 2007.

Landslide Investigations

Landslide investigations are carried out

mainly based on three different approaches namely analytical methods, observational methods and empirical methods (Fig 5). Depending on the importance of investigation, details used for analysis, scale, nature of output data required as well as budget, any relevant method may be chosen.

Analytical Methods

Analytical methods are used to carry out detailed study of unstable slopes on scales of 1:1,000 to 1:2,000. This approach is also called the microzonation approach. Analytical methods essentially require data on the properties of rocks/soils, particularly shear strength properties. Such properties are estimated in, both, field and laboratory. In addition, these properties can be estimated by back analysis, where a known slope is analyzed by assigning a suitable value of factor of safety (F) with various combinations of strength parameters. After obtaining strength parameters, the equations of stability are set up considering the resisting and mobilizing forces to work out factor of safety (F).

In India as well as abroad, such methods are used extensively. Several techniques incorporating different factors for various types of failure are available. Besides, standard computer programs are also available for carrying out landslide analysis. These methods are usually carried out on the slopes, which have already failed mainly to understand the status of stability condition as well as to workout suitable remedial measures.

Observational Methods

The observational methods are based on monitoring of the slopes through instruments or repeat ground observations. Instruments like extensometers, inclinometers as well as piezometers are installed in affected slopes. These instruments are very helpful to assess nature of slope movement with time and groundwater conditions in slopes. In general, these studies are costly and time consuming. In repeat ground observations, the ground

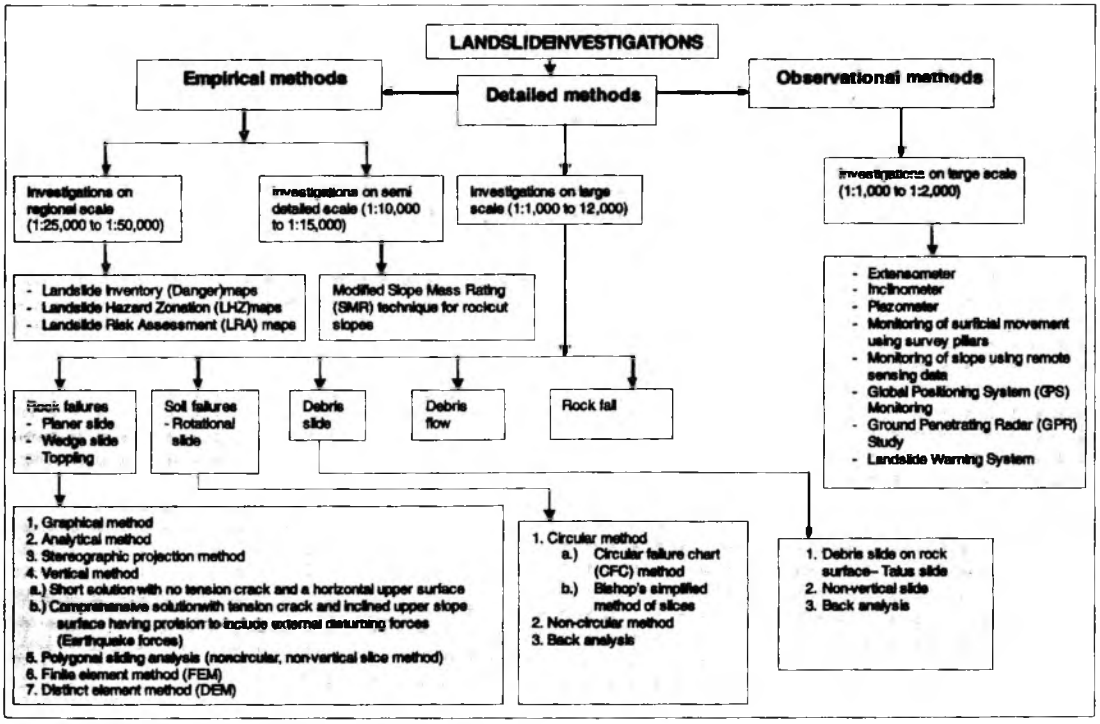

Fig. 5: Methods of Landslide Investigations

slopes are mapped using precision levels at certain time intervals to deduce the extent of displacement. Such studies can also be carried out using ground photogrammetric techniques. These methods are mainly employed on engineering project sites like river valley projects, road projects and other such important projects. They provide useful inputs to carry out better analytical studies. However, it must be noted that these instruments cover a relatively small area and overall cost turns out to be very high as these studies extend over long periods.

Empirical Methods

The empirical method is a rapid hazard assessment technique, which is popular particularly for natural and cut slopes. In this approach, experience and knowledge gained from previous landslide investigations in field are related to the present day slope conditions.

Empirical approach involves identification of causative factors of landslides and their influence in inducing instabilities. The qualitative nature of field conditions are quantified based on a relative rating scheme.

In this approach, large areas can be covered in relatively short durations and therefore they are comparatively economical. Important and well known techniques like Landslide Hazard Zonation (LHZ), Rock Mass Rating (RMR), Slope Mass Rating (SMR) and Q-system fall under this category. Landslide Hazard Zonation (LHZ) approach categorizes the hill slopes into very unstable, unstable, moderately stable, stable and very stable segments. During preliminary planning of a development scheme, this approach is very useful and helps to avoid very unstable and unstable areas. Moreover, if unavoidable, their identification in initial stages of planning helps to evolve suitable preventive measures.

Conclusions

Landslide is a major geological hazard, which poses serious threat to human population and various other infrastructures like highways, rail routes and civil structures like dams, buildings and other structures. Landslide mapping and investigations provide the basic input for evolving control measures as well as for planning development projects more systematically. Landslide mapping is carried out on different themes and scales, depending on the requirement of the studies. Landslide investigations can be broadly classified into three major categories - empirical, analytical and observational methods. Each method had its own importance for specific purposes.

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