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Review of Landslide Research

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***Abstract* - Landslide is a common natural hazard that usually occurs in mountainous areas. Rapid urban development and high traffic intensity movements have been hampered to a great extent by phenomenon of landslides. In ghat road section, vertical cuttings and steep slopes are induced slope failures. An assessment of landslide hazards is therefore a prerequisite for sustainable development of the hilly region. This review paper discussed about four approaches for landslide such as hazard zonation approach, GIS (Geographic Information System) based approach, rock slope stability approach, soil slope stability approach and slope software approach by various researchers in and around the world.**

Keywords: Hazard, GIS, Slope Stability.

I. INTRODUCTION

1.1 General

Landslide is an important geo-environmental hazard, which poses major threat to human settlements, communication links like roads and rail routes as well as civil structures like dams, buildings and other structures. The word 'landslide' represents only a particular type of movement that is slide. However, it is generally used as a term to cover all types of land movements including falls, creeps, spreads, flows and other complex movements. A correct term to represent all these movements may be 'mass movement' or 'mass wastage'. However, the term 'landslide' has been commonly accepted worldwide as a synonym of 'mass wastage'.

A Landslide is a downward and outward movement of slope forming materials, composed of rock, soil, artificial fills (dumping) or a combination of all these along the surface of separation by falling, sliding and flowing under a fast or slow rate, under the action of gravitational force and where the triggering factor may be natural or anthropogenic activities.

II. REVIEW OF LITERATURE

2.1 General

Initially landslide studies have been carried out using various techniques such as hazard zonation approach of BIS, GIS approach, ANN approach, fuzzy approach, probabilistic approach and AHP approach. Later a comparative study was carried out on regional scale. In this context, a concise review of the literature on landslide study is presented and therefore the list of references is by no means exhaustive.

2.1.1 Hazard Zonation approach

Anbalagan (1992) suggested a new quantitative approach based on major causative factors for slope instability on regional scale (1:50,000). A case study of landslide hazard zonation in the Himalaya, adopting a landslide hazard evaluation factor (LHEF) rating scheme and total estimated hazard (TEHD) was presented by him. Gupta et al. (1993) prepared landslide hazard zonation in the upper Satlej valley, Kinnaur District, Himachal Pradesh. Gupta and Anbalagan (1995) prepared landslide hazard zonation mapping of Tehri Pratapnagar area, Garhwal Himalaya. Ajay K Naithani et al. (2007) used landslide hazard evaluation factor scheme for preparing a landslide hazard zonation mapping in a part of Garhwal Himalaya, Uttaranchal, India. Anbalagan et al. (2008) prepared landslide hazard zonation map on meso-scale in Nanital area based on the value of landslide hazard evaluation factor scheme and total estimated hazard following Bureau of Indian Standard code. Sharma (2008) generated macro level landslide hazard zonation in Environs of Bairasul Dam Project, Chamba District, Himachal Pradesh using BIS method. Devala Devi and Kushwaha (2010) used BIS code method for preparing landslide hazard zonation along NH-39 from Kangpokpi to Mao, Manipur India. Saranathan et al. (2010) generated landslide macro hazard zonation of Yercaud hill slopes between km 10/4 to 29/6 using BIS code method. Kishore Kumar et al. (2012) used BIS method for preparing Macro-Hazard evaluation and validation of landslides in a part of North Western Garhwal Lesser Himalaya, India. Zubair et al. (2012) prepared landslide hazard zonation in Rudraprayag District, Garhwal Himalaya using landslide hazard evaluation factor scheme. Many landslide hazard zonation mapping in different terrains have been published (Anbalagan, 1993; 1996; Gupta et al. 1999; Anbalagan and Singh, 1996; 2006; Anbalagan et al. 2007; Saranathan et al. 2012).

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2.1.2 GIS approach

In recent times, the Geographical Information System (GIS) has been effectively used to interpret remote sensing data in the studies of geology and landslide. In case of landslide hazard zonation different thematic layers pertaining to individual causative factors responsible for landslide incidences are prepared on regional scale (1:25,000/1:50,000). Gupta and Joshi, (1990) developed a technique for risk assessment of landslide hazards using GIS approach. This method was applied to the Ramganga catchment, located in the Lower Himalaya and the investigations were based on multi-data sets. Mantovani et al. (1996) prepared landslide hazard zonation in Europe, acquired from remote sensing techniques. Odajima et al. (1998) carried out studies related to landslide hazards in Cianjur, West Java, Indonesia, based on GIS and Remote sensing analysis. Rowbotham and Dudycha (1998) applied GIS modeling of slope stability in Phewa Tal watershed, Nepal. Nagarajan et al. (1998) used temporal remote sensing data and GIS application in landslide hazard zonation of part of Western Ghat, India. Carrara et al. (1999) used the GIS technology in the prediction and monitoring landslide hazard. Gupta et al. (1999) prepared landslide hazard zonation in a part of the Bhagirathi Valley, Garhwal Himalaya, using integrated remote sensing and GIS. Husein et al. (2000) prepared landslide hazard mapping in Jordan using remote sensing and GIS method. Roy (2001) prepared hazard mapping and prognostic Himalayan landslide modeling in India using GIS. Gritzner et al. (2001) assessed landslide hazard potential using GIS in Payette River, Idaho. Saha et al. (2002) prepared a GIS based landslide hazard zonation in a part of Himalaya. Dai and Lee (2002) used GIS tool for preparing modeling of landslide characteristics and slope instability in Lantau Island, Hong kong. He et al. (2003) prepared GIS based hazard mapping and zonation of debris flows in Xiaojiang Basin, Southwestern China. Lan et al. (2004) prepared a landslide hazard spatial analysis and prediction using GIS in the Xiaojiang watershed, Yunnan, China. Nichol and Wong (2005) carried out a detailed landslide inventory using change detection and image fusion analysis in satellite remote sensing. Many methods and techniques were proposed to evaluate landslide prone area using GIS and/or remote sensing (Rengers et al. 1992; Coppock, 1995; Miller, 1995; Dhakal et al. 1999; Gupta et al. 1999; Hickey, 2000; Van Westen 2000; Dai et al. 2001; Sarkar and Kanungo 2004; Van Westen 2004).

GIS based approaches for LHZ suffer from the subjective weight rating system where weights are assigned to different causative factors responsible for triggering a landslide. Alternatively, artificial neural network (ANN) may be applied. They are considered to be independent of any strict assumptions or bias, and they determine the weights objectively in an iterative fashion. Lee et al. (2003) used artificial neural network for preparing landslide susceptibility analysis at Boun, Korea. Arora et al. (2004) applied an artificial neural network for generating a LHZ map of an area in the Bhagirathi Valley in Garhwal Himalaya, using spatial data prepared from IRS-1B satellite sensor data and maps from other sources. Gomez and Kavzoglu (2005) assessed landslide susceptibility using artificial neural networks in Jabonosa River basin, Venezulea. Choobhasti et al. (2009) generated prediction of slope stability for case study using artificial neural network in Nobad, Mazandaren, Iran. Many of the other investigation have applied artificial neural network methods (Moody and katz, 2003; Lee et al. 2003a; 2004a; Ermini et al. 2005; Lee and Evangelista, 2006; Pradhan and Lee, 2007; Lee et al. 2007; Pradhan and lee, 2009).

Ercanoglu and Gokceoglu (2002) estimated landslide susceptibility using fuzzy approach in North Yenice, NW Turky and they pointed out some important factors in this regard. Chi et al. (2002) used fuzzy logic integration for preparing landslide hazard mapping in Boeun, Korea. Ercanoglu and Gokceoglu (2004) prepared a landslide susceptibility map in a landslide prone area at West black sea Region, Turkey, obtained from fuzzy relations. Tangestani (2004) used the fuzzy gamma approach for generating landslide susceptibility map in Kakan Catchment area, Southwest Iran. Pradhan et al. (2009) prepared landslide hazard mapping in Malaysia, obtained from use of geospatial data for the development of fuzzy algebraic operators. Pradhan (2010a) prepared landslide susceptibility maps in three test areas in Malaysia, acquiring from GIS based fuzzy logic approach. Many of the researchers produced landslide susceptibility mapping by fuzzy approach (Juang et al. 1992; Elias and Bandis, 2000; Gorsevski et al. 2003; Lee 2007a; 2007b; Pradhan 2010b).

Probabilistic approaches are based on the observed relationships between each factor and the distribution of landslides. Probabilistic method is a simple probabilistic model with an acceptable accuracy applied for the deduced thematic layers. Larsen and Torres-Sanchez (1998) prepared a frequency and distribution of recent landslides in montane tropical regions of Puerto, Rico. Lee et al. (2004) evaluated the effect of spatial resolution on the accuracy of landslide susceptibility mapping using the probabilistic frequency ratio model in a case study in Boun, Korea. Lee et al. (2004a) prepared probabilistic landslide hazard mapping using GIS and remote sensing data in Boun, Korea. Lee and Dan (2005) developed probabilistic landslide susceptibility mapping in the Lai chau province of Vietnam. Lee and Pradhan (2006) prepared probabilistic landslide hazards and risk mapping at Penang Island, Malaysia. Lee and Pradhan (2007) prepared landslide hazard mapping at Selangor, Malaysia using

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frequency ratio and logic regression model. Avinash and Ashamanjari (2010) used GIS and frequency ratio based method for preparing landslide susceptibility mapping in Aghnashini River catchment, Uttar Kannada, India. Shabazadeh Karim et al. (2011) used frequency ratio method for landslide case studies at Deyalaman Region. Intarawichian and Dasananda (2011) prepared a landslide susceptibility map in Lower Mae Chaem watershed, Northern Thailand, obtained from Frequency ratio model. Similar probabilistic techniques were used in many studies (Chung and Fabbri, 1999; Randall et al. 2000; Luzi et al. 2000; Refice and Capolongo, 2002; Zhou et al. 2003; Watts, 2004; Zezere et al. 2004; Lee and Talib, 2005; Guzzetti et al. 2005; Pourghasem, 2007) Frequency ratio can be evaluated by the ratio of the area where landslides occurred to the total study areas for a given factor's attribute. Landslide vulnerability map was validated using R-Index (Baeza and Corominas 2001; Ramani Sujatha and Victor Rajamanickam 2011).

The analytical hierarchy process (AHP) was developed at the Wharton school of business by Thomas Saaty in the late 1970s . It is a decision aiding tool for dealing with complex, unstructured and multi-criteria decisions. Barredo et al. (2000) compared heuristic landslide hazard assessment techniques using GIS in Tirajana basin, Gran Canaria Island, Spain. Ayalew et al. (2004) applied GIS based weighted linear combination and produced landslide susceptibility mapping in Tsugawa area of Agano River, Japan. Yalcin (2007) prepared GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen, Turkey. Analytical hierarchy process application for landslide susceptibility can be found in many other studies (Chung and Leclerc, 1994; Bantayan and Bishop, 1998; Satty, 1994; Komac, 2006; Yang et al. 2006; Akgun and Bulut, 2007).

For landslide susceptibility mapping, Lee and Evangelista applied, verified and compared a probability model, a frequency ratio and statistical model, a logistic regression to Baguio city, Philippines, using a Geographic Information System (GIS). Van westen et al. (2003) evaluated the accuracy of landslide susceptibility maps, found out from geomorphology knowledge and with the bivariate weights of evidence method, by calculating a confusion matrix. Suzen and Doyuran (2004a) applied three separate landslide susceptibility zonation maps and then compared using three approaches viz. landslide density analysis, success rate analysis and agreed area analysis.

Suzen and Doyuran (2004b) used Seed Cell Area Indexes and comparison of the landslide susceptibility maps of the Asarsuyu catchment, Turkey acquired from multivariate logical regression and bivariate landslide susceptibility method. Yesilncar and Topal (2005) compared landslide susceptibility maps of Hendek region, Tukey, obtained from logistic regression and artificial neural network methods. Kanungo et al. (2006) prepared landslide susceptibility mapping using from a conventional, ANN black box, fuzzy and combined and compared with neural and fuzzy weighting procedures in Darjeeling Himalaya. Lee and Sambath (2006) compared landslide susceptibility mapping in Damrei Romel area, Combodia, obtained from frequency ratio and logistic regression models. Gupta et al. (2008) compared landslide susceptibility zonation maps of Darjeeling, India got from conventional, artificial neural network black box and fuzzy weighting procedures, using three different approaches i.e. landslide density analysis, error matrix analysis and difference image analysis. Poudyal et al. (2010) compared landslide susceptibility maps at a case study from the Nepal, obtained from frequency ratio and artificial neural networks. Many other researchers carried out comparative studies of different methods. (Lee, 2004; Kanungo et al. 2005; Lee and Pradhan, 2007; Lee et al. 2007; Nefeslioglu et al. 2008; Pradhan and Lee, 2010a; 2010b; Pradhan and Pirasteh, 2010; Pradhan et al. 2010; Pradhan and Buchroithner, 2010).

2.1.3 Rock slope stability approach

Rock slope stability approaches were developed a century ago. The first empirical method was proposed by Ritter (1879). Since then many researchers had developed analytical and empirical techniques and utilize according to terrain conditions. The studies are generally site specific in nature on detailed scale (1:1000 to 2000). The Table 1 summarizes some of the techniques being used by workers frequently. In 1973 Bieniawski introduced a new system of geomechanical classification called Rock Mass Rating (RMR) also known as CSIR (Council for Scientific and Industrial Research) classification system. He initially introduced eight parameters. Later in 1976, Bieniawski has modified his rating and reduced the parameters to five in addition to changing rating values. From RMR values, the cohesion and friction angle of rock mass can also be deduced. Significant revision in ratings was made over the years with revisions in 1979, 1984 and 1989. Selby (1980) suggested rock mass strength classification in geomorphic process and applied the classification in Antarctica and Newzeland.

The slope mass rating (SMR) index, proposed by Romana (1985) is a very useful method for studying rock slope stability and calculated by determining four correction factors to the basic RMR (Bieniawski, 1989). Robertson (1988) had given estimates of cohesion and friction angle values for various values of Slope Mass Rating. He also provided shear strength correlations based on the back analysis of failed slopes in weak rock masses. Rock Mass Rating for mining purposes was developed by Laubscher in

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1990. It is mainly based slope angles versus MRMR independent of slope height. Haines and Terbrugge (1991) modified mining rock mass rating based on presenting slope curves. Chinese slope mass rating (CSMR), provided by Chen, 1995, was based on the slope mass rating and thus had similar problems. CSMR recognized the influence of slope height. Unal (1996) developed the modified rock mass rating M-RMR based on the rock mass rating method with supplementary features for improved characterization of weak, stratified, anisotropic and clay bearing rock masses.

Hack (1998) suggested some modification the slope stability probability classification method and SSPC method of Lindsay et al. (2001) and Hock et al. (2003). Sen and Sadagah (2003) reclassified rock mass classification system by continuous rating method. Thomas et al. (2007) applied the continuous rating functions in slope mass rating method. Chakraborty et al. (2008) applied modified slope mass rating techniques for road cut slope along 28 km long Uttarkashi-Bhatwari road, Uttaranchal Himalaya. Alternative rock mass classification system was proposed by Pantelidus (2010), a system for the quantification of the failure hazard of rock cuttings structured in the form of rating tables. Rock cuttings were classified according to their failure hazard taking into account both their drained condition and the influence that climatic conditions on the stability; the latter being the most common landslide-triggering factor. Among all geomechanical classification listed above said SMR is universally used and it is derived from the basic RMR (Bieniawski, 1989).

Markland, 1972 introduced the Markland test, a method of kinematic analysis to evaluate the possibility of plane or wedge failure. A refinement to Markland's test was discussed by Hacking (1976). Hoek and Bray (1981) explained that kinematic analysis is a method used to investigate the possible chances of modes of rock slope failures. Romana (1985) developed slope mass rating to underground rock mass failures with wedge and planar failures. The failure pattern can be assessed using stereographic projection of field data related to geological discontinuities and slope. Kliche's kinematic analysis (1999) is purely a geometric examination indicating modes of slope failure in a jointed rock mass. Numerous studies were carried out to understand failure modes by kinematic analysis (Goodman, 1976; Cruden, 1978; Lucas, 1980; Matherson, 1988; Panet, 1969; Yoon et al. 2002; Kentil et al. 2004).

Table 1: Rock Mass Classification Methods

Methods and Abbreviations	Year	Authors	Applications
Rockload	1946	Terzaghi	Tunnels
Stand-uptime	1958	Lauffer	Tunnels
Rock Quality Designation (RQD)	1963	Deere	General
Rock Structure Rating (RSR)	1972	Wickham et al.	Tunnels
Rock Tunneling Quality Index (Q)	1974	Barton et al.	Tunnels
Rock Mass Rating (RMR)	1973; 1976; 1979 & 1989	Bieniawski	Tunnels & cuttings
Mining Rock Mass Rating (MRMR)	1977 & 1990	Laubscher	Mines
Rock Mass Strength (RMS)	1980	Selby	Cut slope
Slope Mass Rating (SMR)	1985	Romana	Cutslope
Slope Rock Mass Rating (SRMR)	1988	Robertson	Cut slope
Modified SMR rating	1992	Anbalagan et al.	Cut slope
Chinese Slope Mass Rating (CSMR)	1995	Chen	Cut slope
Geological Strength Index (GSI)	1995	Hoek et al.	General
Modified Rock Mass Rating (M-RMR)	1996	Unal	Mines
Rockslope Deterioration Assessment (RDA)	1997	Nicholson & Hencher	Cut slope
Index of rock mass Basic Quality (BQ)	1998	Lin	General
Slope Stability Probability Classification (SSPC)	1998	Hack	Cut slope
Volcanic Rock Face Safety Rating (VRFSR)	2003	Singh & Conally	Cut slope
Falling Rock Hazard Index (FRHI)	2004	Singh	Cut slope

2.1.4 Soil slope stability approach

Many researchers has been developed various methodologies for soil slope stability for different field conditions. The soil slope stability studies are generally site specific in nature on detailed scale (1:1000 to 1:2000). Some of these methods are listed in Table 2. Fellenius (1936) established what is called Swedish method for a circular slip surface analysis. The advantage of this method lies in its simplicity in calculating the factor of safety. Bishop (1955) introduced a new relationships taking into consideration base normal force. The equation for the factor of safety thus became non-linear. It is a very popular approach being followed by many investigators even today for detailed slope stability analysis. Janbu (1954) produced a simplified method for non-circular failure surfaces, dividing a potential sliding mass into several vertical slices. Sokolovski (1960) suggested that the method of characteristics can either be an upper or lower bound solution in plasticity theory, which can be used to locate the critical slip surface. Many researchers (Kopacsy, 1961; Dorfman, 1965, 1970; Garber, 1973a, 1973b; Chen and Snitbhan, 1975; Biernatowski, 1976; Ramamurthy et al. 1977) applied variational calculus method to directly compute the shape and location of the critical slip surface. Morgenstern-Price (1965) applied a direction of the resultant interslice forces, which is defined using an arbitrary function. Spencer (1967) introduced resultant interslice forces of constant slope throughout the sliding mass and his method mainly concentrated on circular slip surfaces and further study developed to non circular slip surface. Coates (1970)

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developed slope stability analysis of talus materials under static condition in terms of factor of safety. Wright et al. (1973) applied two-dimensional finite element method to compare the normal forces at the base of a slice to normal forces computed from limit equilibrium analysis. Hovland (1977) performed a three dimensional analysis for soil with cohesion and friction, based on the same assumptions as in the Fellenius's ordinary method. Janbu (1980) applied an evaluation of factor of safety for simple slopes composed of soils with both cohesion and friction components of strength. Chugh (1982) produced similar to Spencer's method but a constant acceleration force acts on each slice. Wilson and Fredlund (1983) carried out a detailed study on interslice force functions computed from finite element analysis. The Limit equilibrium was applied by Chugh (1986) as an extension of the Spencer and Morgenstern & Price methods, satisfying both moment and force equilibrium conditions (Abramson et al. 2002; Krahn, 2004). Sarma (1979; 1981) performed assumptions in limit equilibrium analysis that the shear strength is assumed to be mobilized on the sides of all slices and the inclination of slice interfaces is varied to produce a critical condition. Hoek and Bray (1981) introduced the circular failure chart method. This is mainly based on slope geometry and different groundwater conditions to compute factor of safety. Many other researchers carried out and utilized various approaches for calculation of FOS (Lowe and Karafiath, 1960; Kopacsy, 1961; Anon, 1970; Narayan et al. 1976; Baker and Garber, 1977; Castillo and Revilla, 1977; Maksimovic, 1979; Luceno and Castillo, 1980; Azzouz el al. 1981; Fan, 1983; Ranjan and Rao, 2002; Chakraborthy et al. 2008, etc.).

Table 2: Soil slope stability methods

Methods	Year	Authors
Ordinary or Swedish method	1936	Fellinus
Janbu's direct method	1954	Janbu
Bishop's method	1955	Bishop
Lowe and Karafiath's method	1960	Lowe and Karafiath
Morgenstern-Price's method	1965	Morgenstern and Price
New Mark model for seismic	1965	New Mark
Spencer's method	1967	Spencer
Log spital method	1969	Wright
Limiting Equilibrium method	1970	Coates
Thaw Consolidation Theory	1972	Mc Roberts
Sarma's method	1973	Sarma
Probabilistic and Hybrid Approaches	1976	Biernatowski K
Slope Analysis	1978	Chowdhury RN
Circular Failure Chart method	1981	Hoek and Bray
Deterministic Distributed Model	1984	Brunsden and Prior
Finite Element method	1988	Acar
Statistical Prediction model	1988	Yin and Yan

2.1.5 Slope Software Approach

Many softwares were developed for slope stability analysis since 1970. One of the famous softwares in this context is SLOPE/W (2002) developed by GEO-SLOPE international Canada. It calculates slope stability computing FOS for both soil and rock materials. RockPack III software containing relevant programs to analysis rock slopes controlled by discontinuities present in the rock masses. The RocScience (1999) also developed softwares for analysis of slopes characterized by soil and rock. The important software products in this company are: DipAnalyst, Slide, Phase2, Swedge, Dips, RocFall, RocPlane, RocData, RocTopple, Examine 3D, RocSupport and Unwedge. These softwares are used for different field conditions and for different applications. The other softwares SEEP/W and PLAXIS use finite element code for soil and rock analyses (PLAXIS, 2004).

III. CONCLUSIONS

Landslide is a common natural hazard that usually occurs in mountainous areas. Rapid urban development and high traffic intensity movements have been hampered to a great extent by phenomenon of landslides. In ghat road section, vertical cuttings and steep slopes are induced slope failures. An assessment of landslide hazards is therefore a prerequisite for sustainable development of the hilly region. This review paper discussed about four approaches for landslide such as hazard zonation approach, GIS (Geographic Information System) based approach, rock slope stability approach, soil slope stability approach and slope software approach by various researchers in and around the world.

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