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LANDSLIDE MAPPING AND DEBRIS FLOW RECONSTRUCTION USING IMAGE INTERPRETATION AND MODELING METHODS: HONGCHUN CATCHMENT, SOUTHWEST, CHINA

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ABSTRACT: Landslide mapping and debris flow reconstruction was carried out in the Hongchun catchment South West, China. The research put into perspective the concept of multi-hazard assessments. Image interpretation was used to map the landslides while the debris flow was model using Flo-2D model. The result of the research was validated by data obtained from fieldwork and back analysis of previous event. The result from the image interpretation revealed a total of 38 landslides which was further characterized according to scarp and body respectively. The field mapping result, supported by historical knowledge gathered through interviews revealed that the co-seismic landslides were the potential source of debris flows in the catchment. The Flo-2D model reconstructed the debris flow volume of 171,350 m^3 representing 80.7% of the total debris flow volume. Other parameters determined for the catchment are viz: maximum flow velocity of 2.9m/s, area extent of 975000 km^2, average flow depth of 11.2 m and impact force of 4,559 N/m^2. This paper, therefore, presents a multi-hazard assessment approach to map landslides (inventories) and model debris flow within the Hongchun catchment. These multi-hazard assessment methods can detects landslides and model debris flow relatively quickly, and hence has the potential to aid risk analysis, disaster management and decision making processes in the aftermath of an earthquake or an extreme rainfall event.

KEYWORDS: Landslides, Debris flow, Hongchun catchment, Reconstruction, Image interpretation

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1. INTRODUCTION: *Landslide*s are mainly triggered by earthquakes and rainfall [(1), (2)]. These events, can also lead to increased secondary hazards like debris flow [(3), (1)]. Landslides and debris flows are common in mountainous areas and present a severe hazard due to their high mobility and impact energy. These two geohazards have brought about extensive damages to properties, engineering projects and loss of life [(2) - (5)]. Therefore, accurate mapping of landslide inventory and reconstruction of debris flow can reduce the risk to these hazards. Essentially; they provide means to delineate hazard areas, estimate hazard intensity for input into risk studies and to provide parameters for the design of protective measures [(4), (6)] .Debris flow is a common type of shallow landslides that occur generally during intense rainfall on water saturated soil (7). These hazards can occur suddenly and inundate entire towns in a matter of minutes. Also, the mass can travel long distances over fairly gentle slopes damaging structures and many other elements that lie in their paths (6). Different elements at risk such as people, building and other critical infrastructures, whether in urban or grass root (rural) environments, are either directly or indirectly affected by the occurrence of these events, disturbing their economic growth, social infrastructural development and sustainability (8).

To discern the actual factors that initiate landslide and debris flow events is often difficult as observed by (3) .The intrinsic factors change most of the times only gradually over time and can be considered as preparatory factors whereas the extrinsic factors are transient and can be regarded as triggers, that is, the disturbance that initiates slope instability or failure. Factors controlling the occurrence and distribution of shallow landslides (debris flow initiations) can be divided into two categories viz: static variables and the dynamic variables (7). Static Variables (Soil properties under which we have: Thickness, Permeability and Material Cohesion, Seepage in the bed rock, Topography (Elevation, Slope, Areas of Convergence and Divergence). Dynamic Variables (this includes: Degree of saturation of soil, cohesion due to the presence of roots and/or partial saturation, Landuse/Landcover). Climatic, hydrological processes and human activities control dynamic variables. They also characterize the temporal pattern of landslides (9). Shallow landslides develop in soils of 1 to 2m depth and the water balance in these soils are characterized by quick response of soil moisture content to the alteration of wet and dry periods during which percolation and evapotranspiration cause a vertical redistribution of soil water (10).

Several authors [Van Asch et al (10) - Quanluna (12)] assert that, it is very crucial to identify the mobilization mechanism of landslide and debris flow. A process largely controlled by the supply of water to the system. Mobilization is the process by which a landslide or debris flow develops from an initial static, apparently rigid mass of water- laden soil, sediment or rock. Mobilization requires failure of mass, sufficient water to saturate the mass and sufficient conversion of gravitational potential energy to initial kinetic energy (11).

Researchers have approached landslide mapping and debris flow modeling in several ways. Aleotti (13) uses threshold based warning system for landslide prediction. Tapas et al (2) used semi-automatic detection using object-oriented methods to characterize spectral, spatial and morphometric properties of landslides. In their work, they pointed out that recognition and classification of landslides is a critical requirement in pre- and post-disaster hazard analysis. By so doing, they carried out manual image interpretation. However, the image interpretation can also be done using semi-automatic process. They created a routine object-based classification using the spectral, spatial and morphometric properties of landslides and by incorporating expert knowledge, landslides were mapped. This method, though very effective, has some shortcoming (2) they asserts that, their method is a difficult task since a fresh landslide has spectral properties that are nearly identical to those of other natural objects, such as river sand and rocky outcrops, and they also do not have unique shapes. Their method, involve the extensive use of a combination of spectral, shape and contextual information to detect landslides. The algorithm used was tested with a 5.8 m multispectral data from Resourcesat-1 and a 10 m digital terrain model generated from 2.5 m Cartosat-1 imagery for an area in the rugged Himalayas in India. It uses objects derived from the segmentation of a multispectral image as classifying units for object-oriented analysis. Spectral information together with shape and morphometric characteristics was used initially to separate landslides from false positives. Objects recognized as landslides were subsequently classified based on material type and movement as debris slides, debris flows and rock slides, using adjacency and morphometric criteria. They were further classified for their failure mechanism using terrain curvature. The procedure was developed for a training catchment and then applied without further modification on an independent catchment. A total of five landslide types were detected by this method with 76.4% recognition and 69.1% classification accuracies.

Glade and Peters (14) used antecedent rainfall daily rainfall model to calculate the regional landslides triggering rainfall thresholds in this model. Landslides have also been modeled using the RAMMS (Rapid mass movements). It is a dynamic numerical software package which was originally designed to model snow avalanche (15) but has been applied in the past to model other types of mass movements like lahars (12).and debris flows [(4), (6)]. The dynamic RAMMS model is based on the Voellmy-Salm model which assumes that the total basal friction of the flow can be categorized into two, namely: a velocity independent dry-coulomb friction coefficient (μ) and a velocity dependent turbulent coefficient (ξ).

FLO-2D model was chosen for this research because of the following reasons; firstly, it incorporates rainfall and digital elevation parameter into the model similar to other model mentioned in this work. However, it also incorporates multiple initiation areas unlike the other ones. Secondly, it enables the researcher to model debris flow with the initial volume of materials without entrainment. This is a limitation of the model. However, it enables the researcher better understands the propagation processes without the interferences of other external materials. In all of these approaches, none of them use a multi-hazard assessments concept. That is, combining image interpretation with modeling. In order to fill that gap, the research was undertaking.

The Wenchuan earthquake of magnitude 8.0 on Richter scale occurred on the 8th of May, 2008. This triggered numerous landslides across Southwest, China including the Hongchun catchment in Sichuan Province (1). This led to an abundance of loose landslide debris being present on the slopes and in the gullies in the catchment (1). The debris later served as source material for the July 21st, 2011 high intensity rainfall of 150mm/h. The heavy rainfall subsequently, induced the debris flows in the catchment. As a result of the debris flow event, 35 people lost their lives; several structures/critical infrastructures (houses, schools, road, and rail-lines), ancestral farmland and livestock's were damaged and destroyed. In addition, more than 5,500 residents at high risk were forced to evacuate (1). They are lots of landslides debris still left in the catchment. Thus, posing a threat and indicates future debris flow risk to the catchment and its environs. Therefore, there is an urgent need to map the landslides and reconstruct the debris flow event and probably generates future scenarios, since they are still, re-settlement plans by the Chinese government.

The main objectives of this research are: to map and characterize the landslides bodies using image interpretation and reconstruction of the debris flow using Flo-2D model. This paper, therefore, present a multi-hazard assessment approach to map and model the Hongchun catchment that has witnessed multiple hazards (earthquake, landslide debris flow and flooding [(1), (8)]. However, for the purpose of this research, the landslide and the debris flow are the main focus. It suffice to add that, these multi-hazard assessment methods can detects landslides and model debris flow relatively quickly, and hence has the potential to aid risk analysis, disaster management and decision making processes in the aftermath of an earthquake or an extreme rainfall event.

2. RESEARCH AREA: The Hongchun catchment is located in the Sichuan province, (Fig. I) Southwest China.

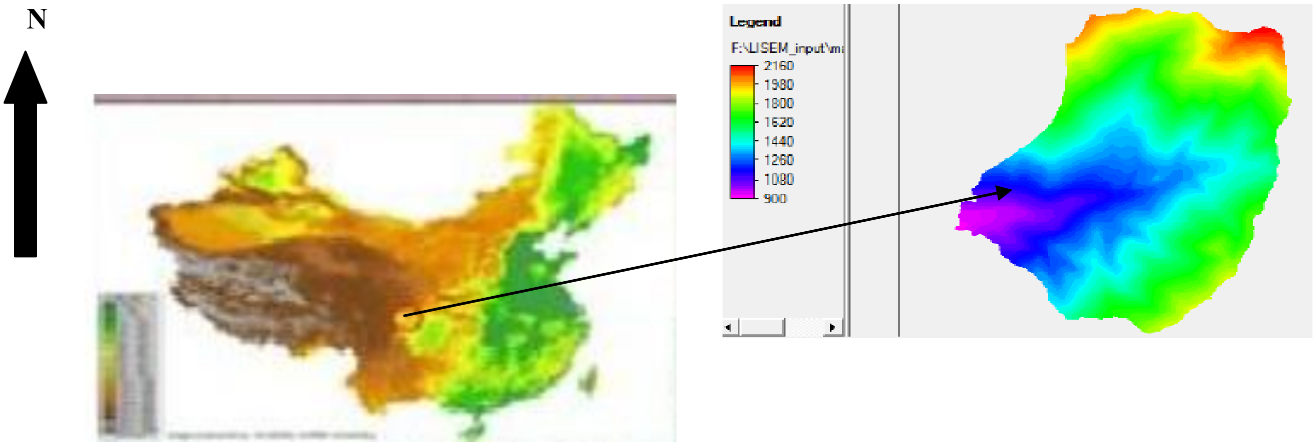

Fig. I, map of the research area and digital elevation model (in meters)

The research area is underlain mainly by Granitic rocks and was mapped during the fieldwork. All bedrock is deeply fractured and highly weathered, and covered with a layer of weathered material. Joints are well developed in the more competent lithologies. When combined with active faulting and bedding, produces many potential failure surfaces in the rock slopes. The geological main structure and the strike of the rock strata in the study area show a NE–SW orientation (1). The study area is situated in the typical humid subtropical, monsoon climate zone with an annual average temperature of 12.9°C. The annual average precipitation over a period of 30 years is 1,253 mm. The catchment has a very steep slope and rugged terrain. The highest point on the catchment is over 2200m above sea level high while the lowest point at the valley floor is above 800m above sea level. Topography has a uniform vegetation cover except for area where the landslides have distorted the vegetation.

3. METHODOLOGY: The method of investigation of this study consisted of fieldwork, mapping landslides using image interpretation and debris flow reconstruction using FLO-2D.

3.1. FIELDWORK: An intensive fieldwork was carried out for two weeks at Hongchun catchment, China. During the period, information on the co-seismic landslides were mapped and characterized. Field mapping of the area was carried out to determine the potential source of debris in the catchment through field observation, mapping and local knowledge (random interviews). This became important because it will elicit the people's perception of the hazards and reveal the historical perspective. However, this was achieved by the help of field assistant who interpreted Chinese into English due to language barrier. The fieldwork provides data to validate the results of the landslide mapped using image interpretation.

3.2. IMAGE INTERPRETATION: Image interpretation is a veritable tool in mapping landslides inventory and characterization. Image interpretation (2) was carried on Google earth images of the Hongchun catchment (3 image bands) of 0.5m resolution. The image was Geo-referenced and then followed by identification of the landslides features in stereoscopic view (3D). Areas of the catchment were the landslides occurs were easily mapped on the image as bright/white zones in contrast to the surrounding green zones reflecting vegetation cover. These bright/white areas on the Google earth image are as result of distortion of the vegetation caused by the landslides. This was then followed by digitization of the landslides features based on key interpretation elements in integrated land and water information system (ILWIS 3.3, academy version) software developed by ITC, Enschede, Netherlands.

3.3. MODELING WITH FLO-2D: FLO-2D is a flood-routing model, which uses a dynamic-wave momentum equation and a finite-difference routing scheme. Its formulation is based on the depth-averaged open channel flow equations of continuity and momentum for unsteady conditions developed on an Eulerian framework. The adopted numerical analysis technique is a non-linear explicit difference method (4).

The general constitutive fluid equations include the continuity equation, and the equation of motion (dynamic wave momentum equation): FLO-2D assumes the following constitutive equation (quadratic model):

$$\tau = \tau_c + \mu_N (du / dy) + C (du / dy)^2$$

Where τ is the total shear stress (Pa), τc the yield stress (Pa), μ_N the dynamic viscosity (Pa s), du/dy the shear rate (s^{-1}) and C is the inertial stress coefficient. Unless a rheological analysis of the mudflow site materials is available, the following empirical relationships can be used to compute viscosity and yield stress.

$$\tau_y = \alpha_2 \quad e^{\beta_2 C_v} \qquad \text{and} \qquad \eta = \alpha_1 \quad e^{\beta_1 C_v}$$

Where αi and βi are empirical coefficient defined by laboratory experiment O'brien, 1993(17).
The viscosity (poises) and yield stress (dynes/cm^2) are shown to be function of the volumetric sediment concentration.

4. RESULTS:

4.1. FIELD WORK: The field work revealed through the landslides debris (Fig. Ⅱ a and Ⅱ b.) were the source of the debris for the subsequent rainfall induced debris flow that struck the town.

Fig. Ⅱ a and Ⅱ b Shows landslides debris in the Hongchun catchment. The debris consists of large, boulders, cobles, gravel, sands (soil) and plant roots of various sizes (source: fieldwork)

Two main source areas were identified during this study, similar to the Yingxiu catchment were 42 landslides were mapped. This view was also shared with teams of geomorphologists and geo-hazard experts during the fieldwork in China (Fig. Ⅲ). These two mapped initiation zones were used in the FLO-2D model as they represent areas with very high susceptibility in the catchment. Slope and topography are seen as the morphological precursor that aided the co-seismic landslides of Hongchun catchment. Field measurements indicated that the area is characterized by steep slope ranging from 25° to 45°; deep valleys and generally rugged relief (Fig. Ⅳ).

Fig. Ⅲ. Shows: the researcher alongside Prof Tang of the Chengdu University of Technology, China. Sharing views on the debris flow initiation areas (susceptible area), probable trigger, debris flow behavior, control measures and chatting possible way-forward with teams of geomorphologists and geo-hazard experts during the fieldwork in China.

Fig. IV. shows one of the researchers on top of the catchment with steep slope during fieldwork. The uppermost part of the catchment is about 2000m above sea level.

This type of slope angle greatly affects the relative magnitude of the driving force on slopes. As the angle of potential slip plain increases, the driving force also increases, assuming that, other landslide causing factors to be constant, landslides should be most frequent on steep slopes. A study of landslides that occurred during the two raining seasons in California’s San Francisco Bay area established that 75 to 80 percent of landslides activities is closely associated with urban areas on slope greater than 15% or 8.5) (16).

4.2. IMAGE INTERPRETATION RESULT:

The image interpretation results shows a total of 38 landslides were mapped in the catchment and were characterized into body and scarp respectively. The result was validated during the fieldwork exercise (Fig. V).

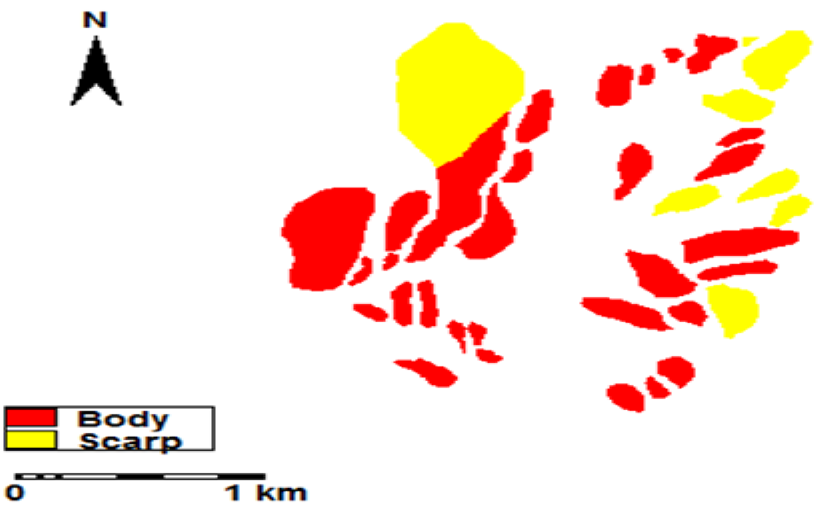

Fig. V shows the landslides inventory for the Hongchun catchment characterized into body (red) and scarp (yellow).

4.3. FLO-2D RESULTS: The debris flow result shows the maximum flow velocity of 2.8m/s (Fig. VI), maximum depth of 22.3m, and the impact force of 4,559.6 N/m^2 area of inundation of the is 955000m^2 .The result also indicated that the velocity of the debris flow varies across the catchment (Fig. VI). The steep nature of the terrain contributed to the downward movement of the debris flow. Besides, this is may also be partly due to the volume of materials entrained along as the debris moves and the basal friction component of the flow at various point. Furthermore, increasing the basal friction reduces the velocity of the debris flow (Fig. VII).

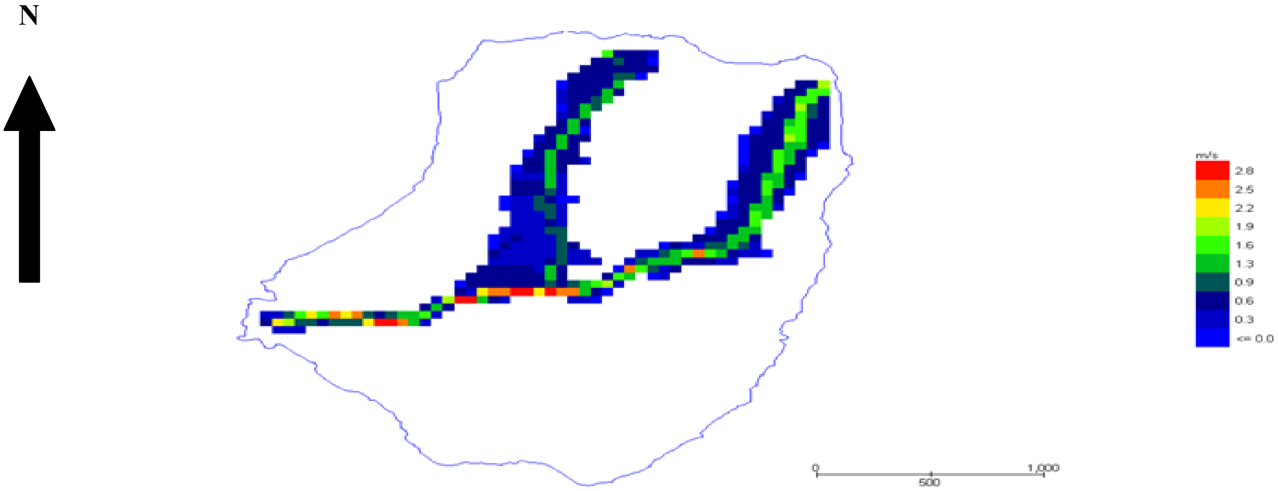

Fig. VI: Debris flow velocity of the Hongchun catchment varies across the catchment, due to, channel topography, basal friction, dynamic nature of debris and entrained materials

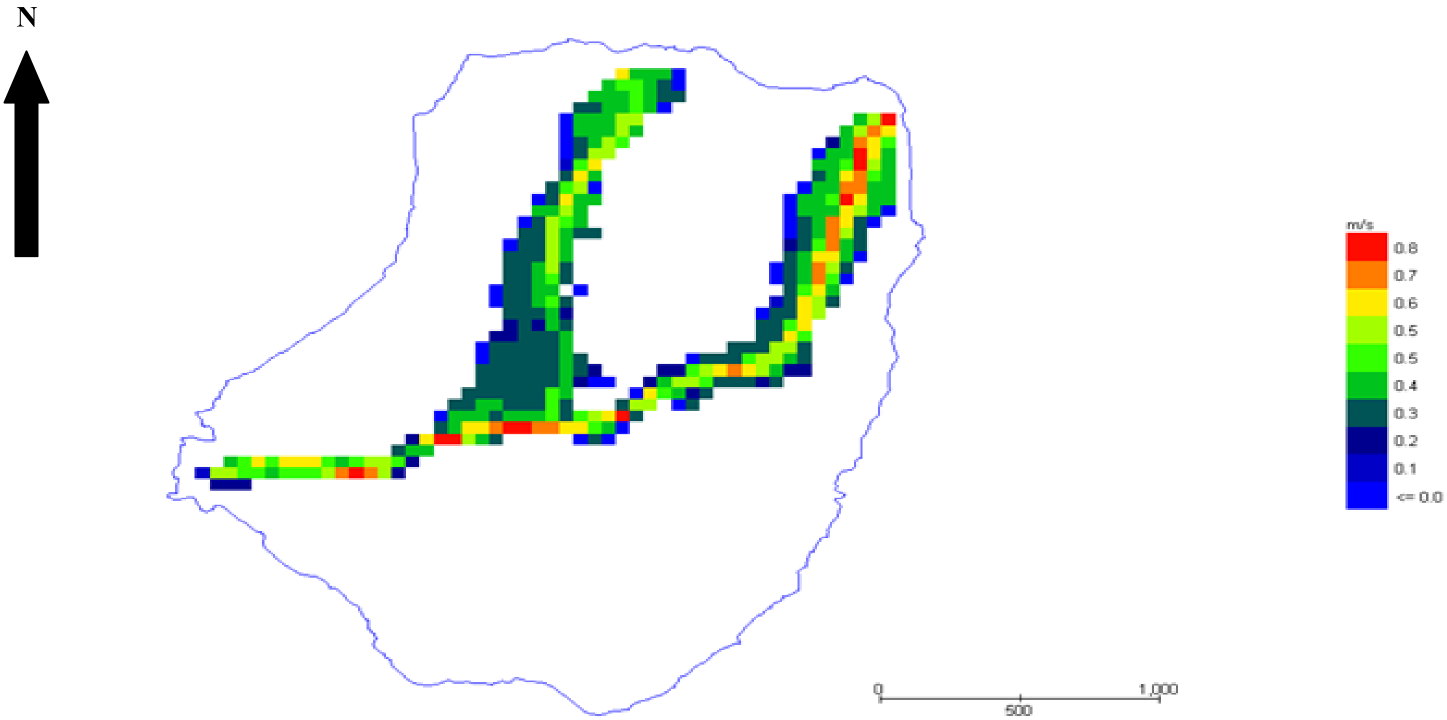

Fig. VII: This shows clearly that the basal friction which is a function of the coefficient of friction (manning's, n) is one of the main components of debris flow dynamics. It tends to reduce or slow the flow of debris.

5. CONCLUSION: Image interpretations of the landslides supported by field observation are very important in determining landslides inventory and characterization. The research concludes that the co-seismic landslides are the potential source of debris flows in the Hongchun catchment. The research also, found that, the earthquake triggered 38 landslides which in turn, generated debris. The Flo-2D model was efficient in the reconstruction of the debris flow. The maximum flow velocity of the debris flow determined was 2.9m/s, the total area extent of the debris flow was 975000 km^2, average debris flow depth of 11.2 m and impact force of 4,559 N/m^2 respectively. The total debris flow volume of 171, 350 m^3 which represents 80.7% of the total debris flow volume was reconstructed by FLO-2D model. Finally, this paper, therefore, presents a multi-hazard assessment approach to map landslides (inventories) and model debris flow within the Hongchun catchment. These multi-hazard assessment methods can detects landslides and model debris flow relatively quickly, and hence has the potential to aid risk analysis, disaster management and decision making processes in the aftermath of an earthquake or an extreme rainfall event.

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REFERENCES:

1. Tang, C., Zhu. J, Qi, X and Ding, J. 2011*. Landslides Induced by the Wenchuan earthquake and the subsequent rainfall event. A case study of in the Beichuan area of China. Engineering Geology*, 12.
2. Tapas R. Martha, Norman Kerle , Victor Jetten , Cees J. van Westen , K. Vinod Kumar.2010. *characterizing spectral, spatial and morphometric properties of landslides for semi- automatic detection using object-oriented methods.* Geomorphology 116: 24–36.
3. Van Beek, L. P. H. 2002. *Assessment of the influence of changes in landuse and Climate on Landslide Activity in Mediterranean*. PhD Thesis, Utrecht University, Utrecht, 363.
4. Cesca.A, M, and D'agostino. V. 2006. *Comparison between FLO-2D and RAMMS in debris Flow Modeling: a case study in the Dolomites*. *International Conference on Monitoring Simulation, prevention and remediation of Dense and Debris flow II, 60*, 161-168
5. Huang.R. Q, and Li, W. L. 2008. *Analysis of the Geo-hazards Triggered by the 12 May 2008 Wenchuan Earthquake, China. Bull Eng Geol Environ, 68*(363-371).
6. Kowalski. J. 2008. *Two-phase Modeling of debris flows*. Ph.D thesis. *Swiss Federal Institute of Technology, Zurich*.
7. Varnes,D. J. 1978. *Slope movement types and processes*. In Special Report 176: Landslides: Analysis and control (Eds: Schuster, R.L and Krizek, R.J), Transportation and Road Research board, National Academy of Science, Washington D.C. 11-33.
8. Mamodu.A, Dinand.A, Jetten, V, Ako.T.A, Idris, N.A, Onoduku.U.S and *Abraham.S.U.2013. Post seismic debris flow modeling using Flo-2D: case study of Yingxiu, Sichuan Pronvince, China*: *Journal of geography and geology, Canada, 5(3), August, p 101-115.*
9. Crosta, G. B, and Frattini. P.2003. Nat *Hazards and Earth System Science, 3*, 81-93.
10. Van Asch, T. W. J, Buma, J. and Van Beek, L. P. H. 1999. *A Review on Some Hydrological triggering systems in Landslides*. *Geomorphology, 30*(25-32).
11. Inverion, R. M. (1997). *The Physics of Debris Flow. Reviews of Geophysics*. *35(3)*, 245-296
12. Quan Luna, B. 2007. *Assessment and Modeling of two Lahars caused by 'Hurricane Stan' at Atitlan, Guatemala, October, 2005*. *MSc.* Thesis, University of Oslo, Oslo.
13. Aleotti .P. 2004. *A Warning System for Rainfall-induced Shallow failures. Engineering Geology, 73. (3-4)*, 247-265.
14. Glade. T, Micheal, C, and Peters. S. 2000. *Applying Probability Determination to Refine Landslide-Triggering Rainfall Thresholds Using an Empirical Antecedent Rainfall Model.* Pure and Applied Geophysics, 157, 1059-1079.
15. Chisten, M., KowalskiI.J, and Bartelt. P. 2010. *RAMMS: Numerical Simulation of Dense snow-avalanches in three dimensional terrains.* Cold Regions Science and Technology, 63(1-2) (1-14).
16. Nilson, T.H, Taylor. F. A, and Dean, R. M. 1976. *Natural conditions that control landsliding in the San Francisco Bay Region*. U. S. Geological Survey, Bulletin 1424.
17. O'brien, J. S, Jullien, P. Y, and Fullerton, W. T. 1993*. Two-dimensional water flood and Mudflow simulation*. Journal of Hydraulic Engineering, 119(2), 244-261.