Journal of Geosciences and Geomatics, 2015, Vol. 3, No. 1, 17-23
Available online at http://pubs.sciepub.com/jgg/3/1/3

DOI:10.12691/jgg-3-1-3

Hongchun Catchment (Southwest, China) Debrisflow Analysis and Reconstruction: Geomorphological and Coupled Modeling Approaches

Mamodu Adegbe[1,*], Ako Thomas Agbor[1], Chukwu. N. Jacinta[1], Waziri. H. Salome[1], Ofor. N. P[2], Alhassan Defyan Usman[2]

[1]Department of Geology, Federal University of Technology, Minna, Niger state, Nigeria
[2]Department of Physics, Federal University of Technology, Minna, Niger state, Nigeria
*Corresponding author: adegbemamodu@futminna.edu.ng

Received March 29, 2014; Revised February 21, 2015; Accepted February 26, 2015

Abstract The Wenchuan earthquake of May, 2008 led to an abundance of loose landslide debris being present on the slopes and in the gullies of Hongchun catchment, South West, China. The debris later served as source material for the July 21st, 2011 rainfall-induced debris flows in the Hongchun catchment. The main objectives of this research are: to understand the catchment hydrological processes, to inventorize and characterize the landslides bodies as potential sources of debris flow and to reconstruct the debris flow events. Geomorphological mapping of the landslides revealed 38 of them. However, these landslides were characterized according to scarp and body. The geomorphological mapping was supported by field observations and historical knowledge gathered through interviews revealed that the co-seismic landslides were the potential source of debris flows in the catchment. Putting the hydrological processes into perspective, the Limburg soil erosion model (LISEM) shows hydrograph with three peaks corresponding to discharge from rainfall water but produce little runoff. Thus, antecedent rainfall may have saturated the debris/soil on the slope that triggered the debris flow. The LISEM hydrograph from LISEM and Flo-2D models were coupled and reconstructed the debris flow. The debris flow results shows a 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. Finally, the debris flow volume of 171,350 m^3 representing 80.7% of the total debris flow volume was reconstructed.

Keywords: *debris flow, LISEM, FLO-2D, catchment, reconstruction, geomorphological, landslides*

Cite This Article: Mamodu Adegbe, Ako Thomas Agbor, Chukwu. N. Jacinta, Waziri. H. Salome, Ofor. N. P, and Alhassan Defyan Usman, "Hongchun Catchment (Southwest, China) Debrisflow Analysis and Reconstruction: Geomorphological and Coupled Modeling Approaches." *Journal of Geosciences and Geomatics*, vol. 3, no. 1 (2015): 17-23. doi: 10.12691/jgg-3-1-3.

1. Introduction

Debris flows are common in mountainous areas and present a severe hazard due to their high mobility and impact energy. In addition to causing significant morphological changes along rivers and mountain slopes, these flows are frequently reported to have brought about extensive property damage and loss of life [1]. Therefore, accurate prediction of run-out distances and velocities can reduce these losses by providing a means to delineate hazard areas, to estimate hazard intensity for input into risk studies and to provide parameters for the design of protective measures [1].

High slope instability, high seismic activities and extreme rainfall condition are the main triggering factors [2]. Debris flows are also referred to as mudslides; mudflows, debris avalanches, or hyper concentrated flow [3] Debris flow is a common type of landslides that occur generally during intense rainfall on water saturated soil. They 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 [3]. 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 [4].

Strong earthquakes not only trigger serious, co-seismic landslides but can also lead to increased post-seismic slope instability like debris flow for a long period of time [4]. The Wenchuan earthquake of May, 2008 led to an abundance of loose landslide debris being present on the slopes and in the gullies. The debris later served as source material for the July 21st, 2011 rainfall-induced debris flows in the Hongchun catchment.

A debris flow system theoretically has three components: initiation, transportation and deposition (Figure 1). All the three components are largely controlled by the supply of water to the system. [5] identifies 4 sequential phases towards the development of soil slip/debris flow, they are; (1) movement of water to the site of failure, (2) failure of the soil mantle by sliding, (3) mobilization of the soil slip as a debris flow and (4) travel of the debris flow.

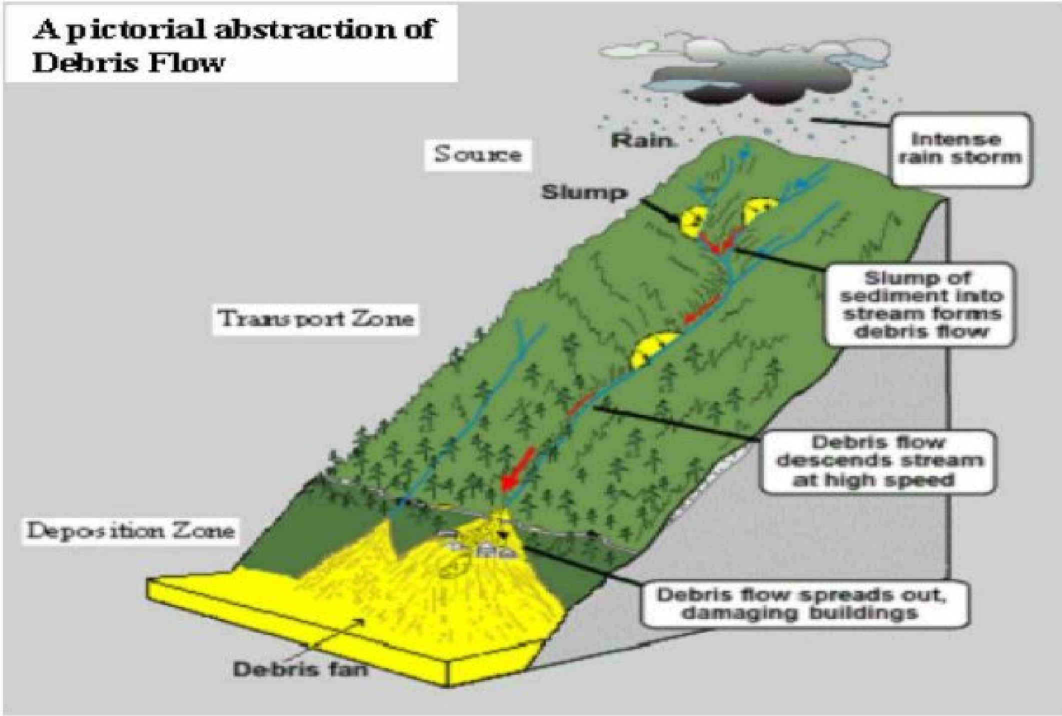

Figure 1. Morphology of debris flow (Adopted from [6] and modified)

To discern the actual factors that initiate debris flow events is often difficult as observed by [7]. 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 [8]. 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 assert that it is very crucial to identify the mobilization mechanism of debris flow. A process largely controlled by the supply of water to the system. Mobilization is the process by which a 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 overtime have approach debris flow initiation modeling in several ways [12] uses threshold based warning system for debris flow prediction. The method results in identifying rainfall events, which are potentially capable of initiating debris flow. [13]Uses antecedent rainfall daily rainfall model to calculate the regional landslides triggering rainfall thresholds in this model. Debris flow have also been modeled using the RAMMS (Rapid mass movements) dynamic numerical software package which was originally designed to model snow avalanche [14].But has been applied in the past to model other types of mass movements like lahars [15]and debris flows [1,3]. 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). In all of these approaches, none used coupled model, hence, the approach used in the research. The main objectives of this research are: to understand the catchment hydrological processes, to inventorize landslides bodies as potential sources of debris flow and to reconstruct the debris flow events

2. Geology and Geography

The Hongchun catchment is located in the Sichuan province, (Figure 2) Southwest China.

The study 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 [16]. 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.

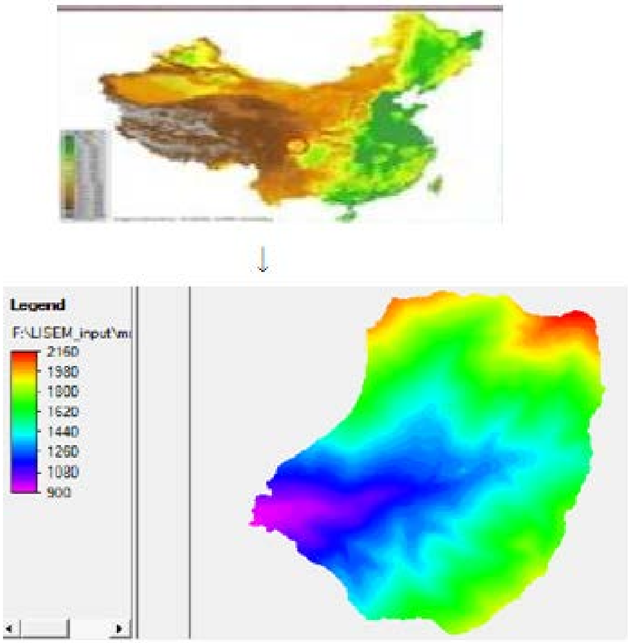

Figure 2. shows the map and digital elevation model (in meters) of the Hongchun catchment

3. Methodology

The method of investigation of this study consisted of fieldwork and Geomorphological mapping, laboratory analysis, modeling with LISEM and 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. Geomorphological mapping of the area was carried out to:

1. Determined the potential source of debris in the catchment
2. Map the landslide inventory
3. Determination of initiation zone(s)
4. Collection of soil samples from the major landslides site for the determination of physical properties such saturated hydraulic conductivity (Ksat), porosity, bulk density, field capacity and moisture content.

3.2. Laboratory Work

Post field work involved one week intensive laboratory analysis of soil samples to determine soil physical parameters to use in the LISEM and FLO-2D model. Saturated hydraulic conductivity (Ksat), porosity, initial moisture content, field capacity and bulk density were determined as outlined below. The 30 soil samples taken from the field were analyzed in a manner described in [4] at the State Key Laboratory of Geohazard Prevention and Geoenvironmental Protection of the Chengdu University of Technology.

3.3. Modeling with LISEM

The model structures of LISEM outlining important model parameters are shown in Figure 3.

LISEM is a data intensive model, requiring at least 24 maps for runoff simulation. These maps can bederived from five basic maps (DEM, landcover, soil, channel and road) in conjunction with a table of soil physical properties (measured during filed work and laboratory analysis). The database for LISEM was created.

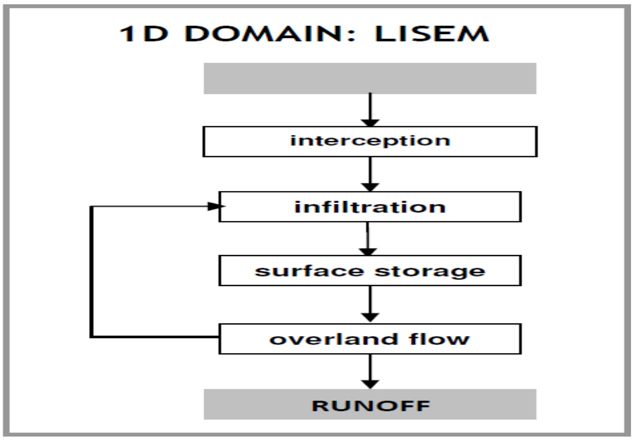

Figure 3. LISEM rainfall-runoff model (Source: [17])

LISEM has four important sub-models that are simultaneously simulated using rainfall input to give runoff output. Rainfall data (input) is the storm event as a time series. Interception loss is modeled using vegetation parameters, infiltration (soil storage) loss by Green and Ampt model while surface storage is based on random roughness parameter. Overland flow is routed using the solution of the kinematic wave [17] and Manning's equation. The channel parameters are useful as the runoff is directed to the outlet.

3.4. 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 [1].

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):

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

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.

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

Where αi and βi are empirical coefficient defined by laboratory experiment [17].

The viscosity (poises) and yield stress (dynes/cm^2) are shown to be function of the volumetric sediment concentration.

4. Result and Discussion

4.1. Fieldwork

The fieldwork revealed through the landslides debris (Figure 4) were the source of the debris for the subsequent rainfall induced debris flow that struck the town.

Figure 4. shows landslides debris in the Hongchun catchment (source: fieldwork)

This was also confirmed from the interview segment of the fieldwork that prior to the May 12th, 2008 Earthquake, there were no record of landslides in the catchment. A total of 38 landslides were mapped in the catchment and were characterized into body and scarp respectively. (Figure 5).

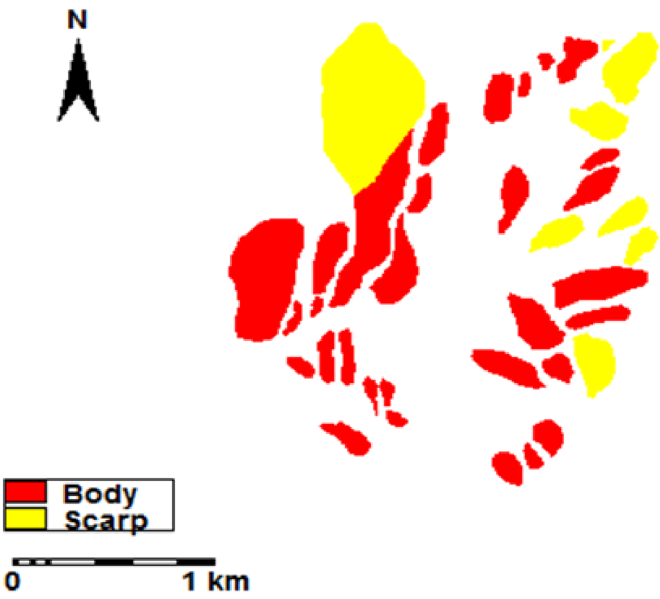

Figure 5. shows the landslides inventory for the Hongchun catchment characterized into body and scarp

Two main source areas were identified during this study, similar to the Yingxiu catchment [4] 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 13° to 25°; deep valleys and generally rugged relief (Figure 6).

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 [19].

Figure 6. shows one of the researchers on top of the catchment with steep slope during fieldwork

4.2. Laboratory Result

Table 1. Summary statistics of soil physical properties

Physicalproperties	Mean	SD	Median	N
Bulk density g/cm^3	1.42	0.24	1.36	30
Field capacity	0.35	0.09	0.36	30
Moisture cont	0.24	0.03	0.24	30
Ksat	0.66	0.11	0.64	30
Porosity	49.25	7	49	30

The result of the 30 soil samples revealed that the saturated hydraulic conductivity, Ksat and the porosity for the catchment is quiet high. This may have facilitated rapid infiltration of the rain water into the landslides bodies, thus saturating the soil. The box plots of the Ksat, bulk density, porosity and moisture content were plotted against the texture respectively (Figure 7–Figure 8). The result reveals that the each of the soil parameters determined did not vary in each of the classes because the box plots for each of the class overlapped significantly with the texture.

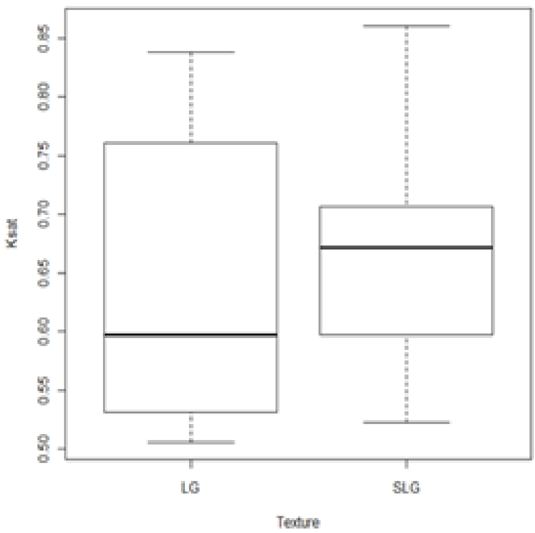

Figure 7. Boxplot of Ksat by texture class

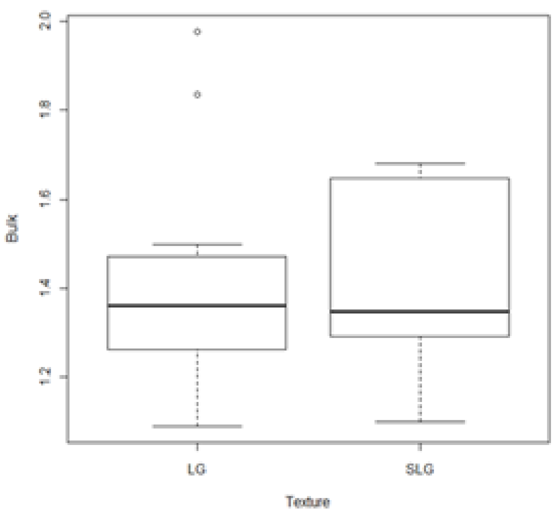

Figure 8. Box plot of Bulk density by texture class

The LISEM result (Figure 9), shows 3 discharge peaks but produced little runoff. This implies that the July 21, 2011 rainfall alone was not responsible for the debris flow in the catchment. Thus, antecedent rainfall may have saturated the landslides debris/soil that led the eventual debris flow.

4.3. LISEM Result

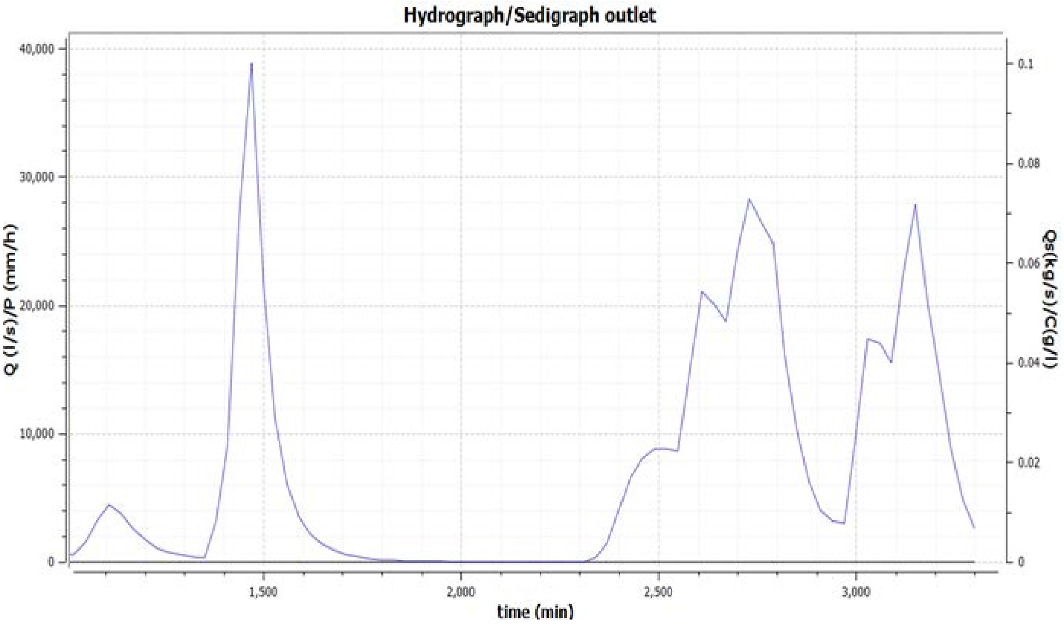

Figure 9. LISEM hydrograph

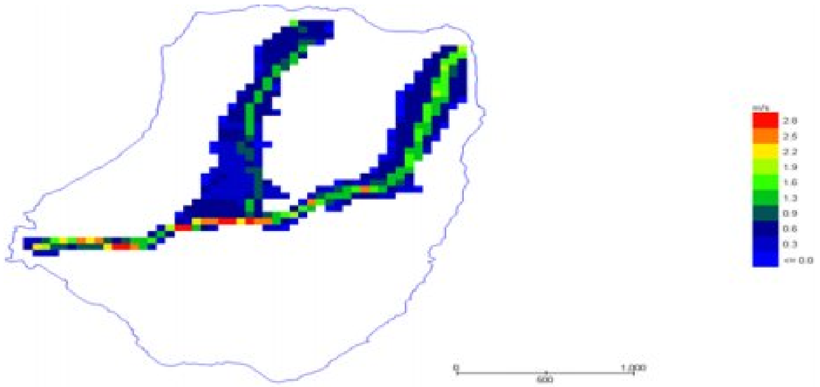

Figure 10. Debris flow velocity

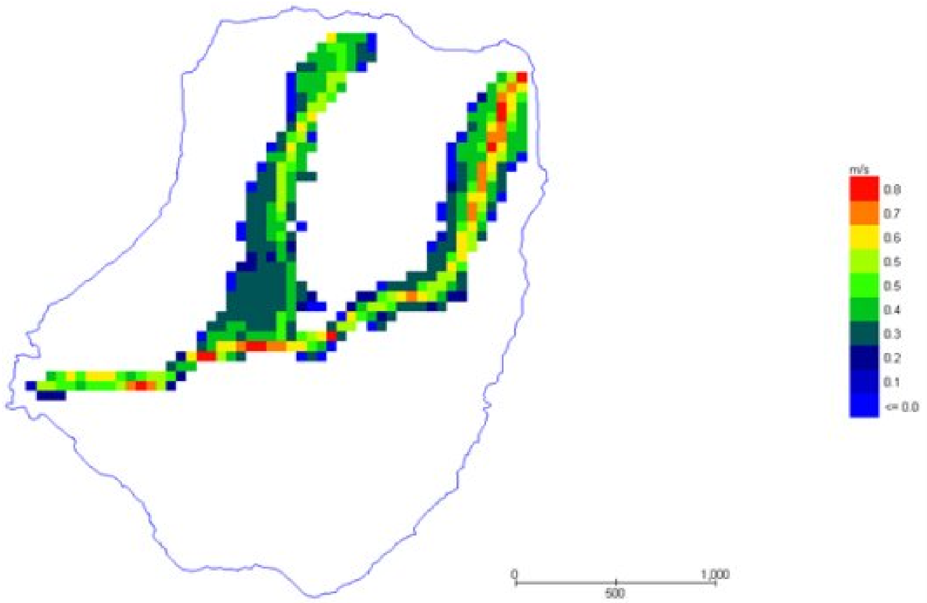

Figure 11. This shows clearly that the basal friction which is a function of the coefficient of friction (manning's, n) is one of the main components of debris flow dynamics. It tends to reduce or slow the flow of debris

4.4. FLO-2D Results

The debris flow result shows the maximum flow velocity of 2.8m/s (Figure 10), 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 revealed that the velocity of the debris flow varies across the catchment (Figure 10). 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 (Figure 11).

5. Conclusion

Geomorphological mapping of the landslides supported by field observation and historical knowledge 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 debris materials were then saturated by antecedent rainfall due to high porosity and permeability of the soil. The numerous faults and steep nature of the catchment topography were the hydrological factors that facilitated the remobilization of the materials as debris flow.

The LISEM hydrograph was coupled with the Flo-2D model were efficient in the reconstruction of the debris flow. The maximum flow velocity of the debris flow determined was2.9m/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^2respectively. 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.

Acknowledgements

We are greatly indebted to the Dutch government, for providing funding for the research.

References

[1] Cesca, M., &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.

[2] Huang, R. Q., & Li, W. L. (2008). Analysis of the Geo-hazards Triggered by the 12 May 2008 Wenchuan Earthquake, China. *Bull EngGeol Environ, 68*(363-371).

[3] Kowalski, J. (2008). Two-phase Modeling of debris flows. PhD Thesis.*Swiss Federal Institute of Technology, Zurich.*

[4] 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).*

[5] Ellen, S. D. (1988). Description and Mechanics of soil slip/Debris flow storms. In: S.D Ellen and G.F.Wieczorek (Editors). Landslides, Floods and Marine Effects of the Storm of January 3-5, 1982, in the San Franscisco Bay Region, Califronia, USGS, Washington.

[6] CCI and AD. (2003). Debris flow Origin. *http://adaptation.nrcan.gc.ca/posters/images/bc_05_02_e.gif. Accessed on: 2012, 05, September.*

[7] 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.

[8] 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.

[9] Crosta, G. B., &Frattini, P. (2003). Distributed Modeling of Shallow Landslides Triggered by Intense Rainfall. *Nat Hazards and Earth System Science, 3*, 81-93.

[10] Van Asch, T. W. J., Buma, J., & 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] Aleotti, P. (2004). A Warning System for Rainfall-induced Shallow failures. *Engineering Geology, 73. (3-4)*, 247-265

[13] Glade, T., Michael, C., & 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.

[14] Christen, M., Kowalski, J., &Bartelt, P. (2010). RAMMS: Numerical Simulation of Dense snow-avalanches in three dimensional terrains.*Cold Regions Science and Technology, 63(1-2)*(1-14).

[15] 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.*

[16] Tang, C., Zhu, J., Qi, X., & 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.

[17] Jetten, V. (2002). LISEM user manual. The Netherlands, Utrecht Centre for Environmental and Landscape Dynamics, Utrecht University.

[18] O'Brien, J. S., Julien, P. Y., & Fullerton, W. T. (1993). Two-dimensional water flood and Mudflow simulation. *Journal of Hydraulic Engineering, 119(2)*, 244-261.

[19] 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.