International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 8 Aug 2021, pp: 1218-1226 www.ijaem.net ISSN: 2395-5252

A Numerical Model to calculate Avalanche Runout Distance and its Practical Implication

Arghadeep Dasgupta

Submitted: 05-08-2021 Revised: 18-08-2021 Accepted: 20-08-2021

ABSTRACT: Snow avalanches have always been a big threat for people and infrastructure in mountainous regions. Increased population and climate change leading to global warming is triggering this catastrophic event often across the glacial mountains of the world. Physical criteria and mathematical models to describe avalanche movement are amongst the most important foundations in the planning of technical avalanche mitigation measures.From the physical point of view, avalanches can be described as the gravitational flow process of snow. A physically accurate and mathematically complete description of the avalanche movement does not yet exist; this is due to the large variability of the material snow, geographical terrain, climatic variability etc.

Keywords: Numerical Model, Runout zone, VoellmySalm Model. AVAL-1D, RAMMS, Avalanche modelling, Powder snow etc.

I. INTRODUCTION:

Snow Avalanche is event tumbled due to loss of cohesion between the over and underlying weak layers of accumulated snow cover. Past studies on avalanche event shows that when accumulation of snow starts to build up on steep slope ranging between 35 to 45 degrees inclination, one can expect slide of snow to trigger.

Typical cross section of snowpack comprises thick fresh snow at the top underlain by weak layer, consolidated snow and rock or somewhat bearing strata. Water content/layer which is weak layer being main factor responsible for the snow movement. Overload due to accumulated snow cover over the weak bonded underlying snow layer is the main factor which need to be address. Present invention address the issue, which not only prevent the avalanche, but provide a streamline flow to the underlying water cover of snowpack.Snow-cover evolution, at a given location, is governed by the prevailing meteorological conditions.Modern avalanche protection has to be diverted into two very different fields, which strongly interact with each other. One field is the observation, simulation and estimationof snow covers. This starts at meteorology and field observations toestimate the amount of snow. Closely related is the observation of the structureof the snow cover. Snow can be very different and its consistency changespermanently throughout winter. A snow cover can therefore be from stableto instable state.

The second field is the simulation and estimation of moving avalanches. There are two different kinds of snow avalanches namely powder snow avalancheand dense snow avalanche.All avalanches start as dense ow avalanches. They consist of dense granular materiallike fluids. On steep terrain a powder snow layer can build up abovethe dense ow forming a powder snow avalanche. Such powder snow layersconsist of relatively small ice particles suspended in the air and show gaseousbehaviour.

Avalanche models are used to estimate run out zones of possible avalanchesto protect people and infrastructure in the mountainous areas. As protectionmeasure, breaking dams are often built in the slope to divert the flow intoless powerful and smaller avalanches. Catching dams are built in the run outarea to reduce the run out zone and protect buildings behind the dam. Similar tasks can be fulfilled by deflecting dams or galleries, which are usuallybuilt to protect streets or railroads.

Avalanche Models

Various models have been developed in the last century. These models havetheir advantages and disadvantages. The use of certain models in practice isoften a question of regional practice and knowledge. With global warming and metamorphic changes in Himalayan regions has led to the multiple incident of avalanche and debris flood causing catastrophic devastation in the state of Uttarakhand, Himachal Pradesh, Arunachal

Figure 1: Probale area with a threat of Avalanche based on historical data

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 8 Aug 2021, pp: 1218-1226 www.ijaem.net ISSN: 2395-5252

Pradesh, Ladakh, Kashmir Sikkim etc. In this study simpler numerical modelling for runout distance calculation will be formulated based on literature reviews and analysis of various factors which are so far considered to be limitation of existing numerical models and formulation of the same in the simpler equation can be derived. Also current research goes in many different directions. This section provides a short overview ofsome classical avalanche models.

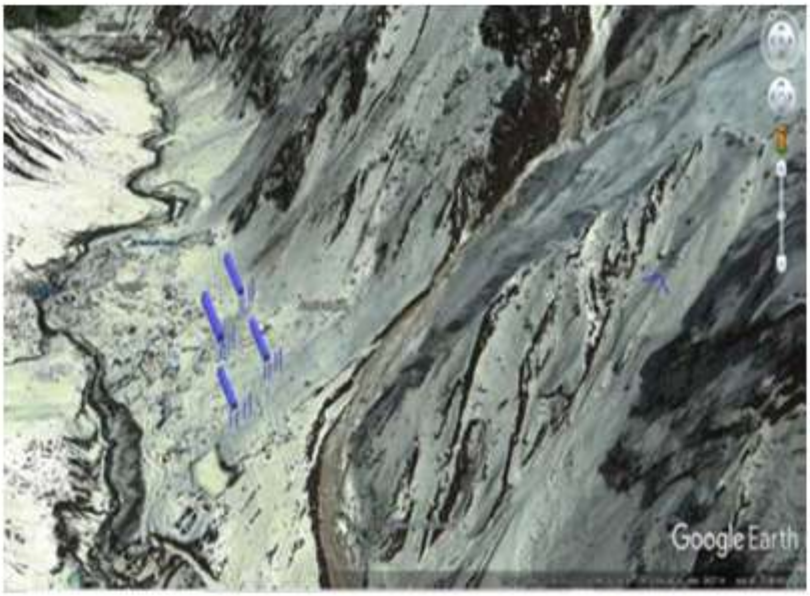

Figure 1: Avalanche Flow and Suggestive Protection Measure

Figure 2: Runout Path of an Avalanche

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 8 Aug 2021, pp: 1218-1226 www.ijaem.net ISSN: 2395-5252

Figure 3: Probale area with a threat of Avalanche based on historical data

II. LITERATURE REVIEW:

Voellmy-Salm Model: The Voellmy-Salm model assumes that the discharge Q from the starting zone is constant along the avalanche path – with the exception of the runout zone where the movement is approximated as a mass point. The velocity v0 is calculated in the starting zone with the following equation:

$v_0=\sqrt{(d0\ \xi \,.\, \sin\psi0\ -\ \mu\cos\psi0)}$, in [m/s]

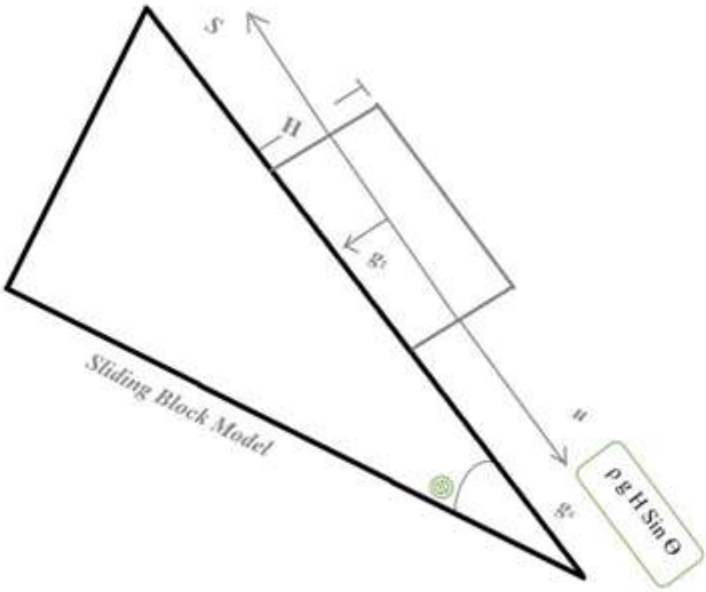

Figure 4: Schematic VoellmySalm Model

$Q = (B_0.d_0.v_0)$, [m^3/s.]
where:
B_0Fracture width, in [m]
ψ_0Inclination of the starting zone, in [°]
d_0Fracture height, in [m]:
v_0Avalanche velocity in the starting zone, in [m/s]
ξ, μ Friction parameter

Then the velocity $v_P$and flow height $d_P$are determined at the start point of the runout zone, the

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 8 Aug 2021, pp: 1218-1226 www.ijaem.net ISSN: 2395-5252

point P. Below the point P, $\psi_S$must apply to the average slope of the runout section:
$\tan\psi_s<\mu$
The velocity $v_P$at the point P is calculated for a flow avalanche based on the slope inclination $\psi_P$over point P – measured over a transition distance from around 100 to 200m – and the flow width B_P as follows:

$v_P= [(Q/B_p).\xi (\sin \psi_{P}\_ \mu \cos \psi_P)]^{1/3}$ [m/s]
The flow height dPin point P is: $dP= Q/ (B_p.v_p)$ [m]

The runout distance s of the avalanche from point P is calculated as follows:
$s = (d_s/2). (\xi/g) \ln [1+v^2_p/V^2]$

This contains the average deposit height d_s
$d_S=d_P+\{ v^2_p/10g\}$ [m]

$V^2= d_S\, \xi (\mu \cos \psi S\_ \sin \psi_{S.})$

where:
ψ_SAverage inclination in the runout zone, in [°]
gGravitational acceleration, constant [= 9.81 m/s^2]
d_pFlow depth at point P in the avalanche path, in [m]
v_pFlow velocity at the point P, in [m/s]
V Average avalanche velocity in the avalanche runout zone, in [m/s]

The Voellmy-Salm model is well validated and is suitable for calculating simple avalanches in minimal time. The calculation results can be controlled constantly by entering the parameters step-by-step.

However, the model had a few drawbacks: in the avalanche path, the flow velocities were underestimated and the calculated deposit heights in the runout zone were often not realistic. The position of the point P and the corresponding flow width must bedetermined by an expert opinion, which could cause difficulties in terraced terrain or terrain slopes near the critical angle. It is therefore rarely used today in practice, but is the basis of most of the following models which are widely practiced worldwide.

AVAL-1D

AVAL-1D is the numerical version of the Voellmy-Salm model. As a significant innovation, the avalanche mass is included in the calculation and the modelling is performed along the realistic topography. It contains two independent calculation modules, FL-1D for flow avalanches and SL-1D for powder snow avalanches.
Both modules are based on the solution of differential equations that describe the mass, energy and momentum conservation using the method of finite differences.

FL-1D is a numerical more or less 1-dimensional calculation model based on the Voellmy-fluid material law. The avalanching snow is considered ‘quasi liquid’ with constant snow density. The flow velocity v is constant over the height and the flow height dPis constant across the width. During the fall, the mass remains constant, a possible snow accumulation along the avalanche path is not considered. The flow resistance is described with three parameters – dry friction μ, turbulent friction ξ, internal deformation resistance of snow λ. AVAL-1D provides continuous information about the flow height, velocity and pressure along the entire avalanche path, and the runout distance and mass distribution of the avalanche deposit are calculated.

The avalanche mass has an impact on the length of the runout zone in the modelling, this allows for consideration of the influence of supporting structures in the starting zone. Since no snow accumulation is taken into account in the model, the calculated deposit heights can be too small.

In comparison to the Voellmy-Salm model, the calculated velocities are higher and therefore more realistic. The model does not take centripetal and impact effects into account, in highly meandering avalanche paths the calculation results are therefore conservative.

The powder snow avalanche in model SL-1D consists of a saltation and suspension layer, the flow component is neglected. There is a mass exchange of snow between the snowpack, erosion, the saltation and suspension layer, taking into account the corresponding friction forces at the layer boundaries.

SL-1D provides continuous information about the flow height, velocity and pressure along the entire path of the avalanche. Furthermore, pressure profiles can be created at any point along the path of the avalanche. The selection of the degree of suspension and the erosion parameters requires a lot of experience and has a great impact on the results.

SL-1D is a purely 1-D model. The influence of the flow width, spreading/channelling requires expert consideration. The avalanche pressures must be reduced correspondingly, in

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 8 Aug 2021, pp: 1218-1226 www.ijaem.net ISSN: 2395-5252

particular in the runout zone. In the model, the air resistance on the front of the avalanche is neglected; therefore, the delay in the runout zone is too small. Especially in combination with observations, SL-1D allows the realistic calculation of avalanche pressures.

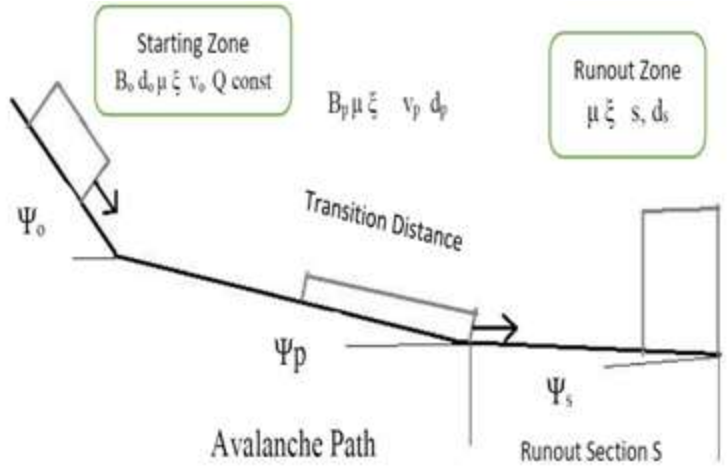

Figure 5: Schematic movement of Avalanche from initiate to runout section

RAMMS

The two-dimensional avalanche calculation model, RAMMS (rapid mass movement system), is a direct development of the one-dimensional numerical model AVAL-1D. The velocity vectoris calculated in the three-dimensional terrain in two directions and therefore the flowdirection and width are determined by the model. The calculation grid is generated from adigital terrain model.

The model is based on the assumption that no internal deformations occur in the body of the avalanche. The friction forces act mostly in a sliding layer located between the avalanche and the substratum. The friction parameters μ and ξ describe the proportion of dry friction from Coulomb or the velocity-dependent frictional resistance. Both friction resistances depend on the size of the avalanche. As with the Voellmy-Salmmodel, the basal resistance is indicated by a Coulomb friction term proportional to the normal force and a turbulent friction term proportional to the square of the velocity. A finite-volume method resolves this in complex terrain with the system related to the shallow water equations.

RAMMS was calibrated on the basis of many observed large avalanches in the avalanche, also on the basis of avalanches from the SLF avalanche database. To visualize the input parameters and results, geo-referenced maps or aerial photographs can be read in as texture data and shown on the topography.

In previous practical experience, RAMMS has proven to be a very useful tool to assess, in particular, flow paths in a complex terrain situation. Furthermore, it has been demonstrated that, in comparison with the Voellmy-Salm model or AVAL-1D, the definition of the location and size of a starting zone is of greater importance.

For the calculation, the quality of the terrain model is very important. Small streams, which are filled with snow in winter, can lead to an unrealistic deflection of the avalanche.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 8 Aug 2021, pp: 1218-1226 www.ijaem.net ISSN: 2395-5252

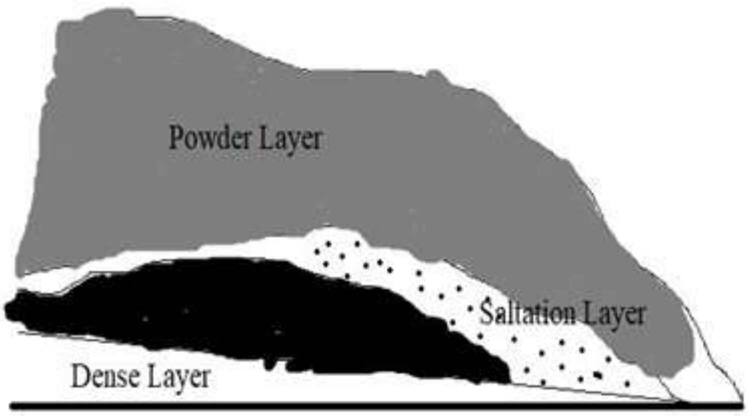

Figure 6: Different layers of snow owing to sedimentation and metamorphism

SamosAT

In the SamosAT model and corresponds to an expanded Voellmy approach using variable friction coefficients μand ξ by observing the shallow water approach. The friction model for flow avalanche calculations was made dependent on both flow velocities as well as flowheights. This results in a stronger deceleration of the runout on the one hand, and less subsequent flow on the other.

$\tau^b_= \tau_0 + \tan\delta\ \{1+ R^0_S/(R^0_S+R_S)\}\sigma^b+\rho u^2/[(1/k)\ln\{(\hat{h}/R)+B\}^2]$

where:

τ_0Minimum shear stress, in [N/m^2]

tanδ Tangent of the bed friction angle, in [°]

R^0_SBed friction elevation

$\sigma.^{b.}$Normal tension, in [N/m^2]

ρFlow density, in [kg/m^3]

uFlow velocity, in [m/s]

hFlow height, in [m]

B Dimensionless constant (Prandl boundary layer)

K Karman constant

R_sRoughness constants

The model construction of a powder snow avalanche, mixed avalanche consists of a dense flow layer, which slides over the surface of the terrain. The flow status without noteworthy temporary air components is referredto as a flowing avalanche, volume component t<1: 10. The density of such a flow is approx. 300 kg/m^3 on average. The re-suspension layer, which is considered to be very thin, follows the flow layer. A powder layer can develop on top of this. This can be considerably larger than the preceding layers.

In the model, a powder snow avalanche is treated as a turbulent, particle-laden gas flow with a small velocity difference between particles and air. The powder component is calculated in SamosAT in the AVL-FIRcalculation platform, which uses the resuspension model to connect the flow component as a boundary condition.

SamosAT enables a real two-stage calculation of ice particles and air layers to be able to more realistically represent the gas-dynamic processes in 3-d. In addition to the increase in mass, this method can also show the mass lost by sedimentation along the avalanche path. Thus, this mass loss can also lead to a slowing of the avalanche. In the program, mass increases can be taken into account using frontal or basal entrainment. Additionally, it is possible to activate a direct snow accumulation in the powder module and therefore achieve higher avalanche velocities.

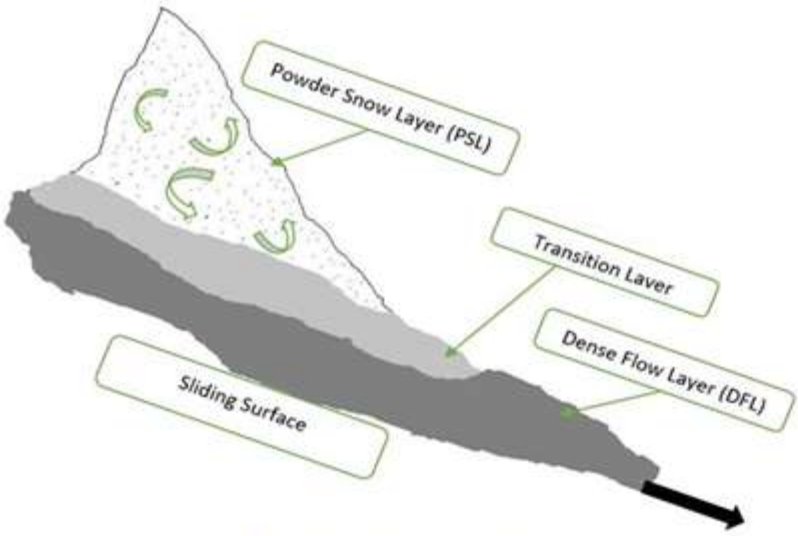

Figure 7: Showing entrainment within snow pack

Formulation of Numerical Model:

Snow avalanches are gravity driven flows. The avalanche core consists of heavy clumps and clods of flowing snow. When ice-dust is blown-out of the core, powder avalanches are formed. Avalanche dynamics is the science concerned with motion of flowing and mixed flowing/powder avalanches.

Here, the formulation is worked with AVAL-1D which is the numerical version of the Voellmy-Salm model. As a significant innovation, the avalanche mass is included in the calculation and the modelling is performed along the realistic topography. It contains two independent calculation modules, FL-1D for flow avalanches and SL-1D for powder snow avalanches.

Both modules are based on the solution of differential equations that describe the mass, energy and momentum conservation using the method of finite differences.

FL-1D is a numerical 1-dimensional calculation model based on the Voellmy-fluid material law. The avalanching snow is considered 'quasi liquid' with constant snow density. The flow velocity v is constant over the height and the flow height dP is constant across the width. During the fall, the mass remains constant, a possible snow accumulation along the avalanche path is not considered. The flow resistance is described with three parameters – dry friction μ, turbulent friction ξ, internal deformation resistance of snow λ. (Here I would like to analyse the impact of temperature variation and their impact of on snow flacks and their impact) This factor post multiple experiment can be considered empirically or in the form of (dp/dt) which depicts the changes in the flow height with respect to change in temperature. As metamorphism influences the avalanche behaviour to a great extent.

The avalanche mass has an impact on the length of the runout zone in the modelling. Since no snow accumulation is taken into account in the model, the calculated deposit heights can be too small. In comparison to the Voellmy-Salm model, the calculated velocities are higher and therefore more realistic. The model does not take centripetal and impact effects into account, in highly meandering avalanche paths the calculation results are therefore conservative. So, considering these parameters will enable towards a more precise and accurate result.

In addition to these, Snow entrainment alters the speed and hence the run-out distance of avalanches. In the long runout zone, the path consists of debris, clay, moraine deposits from previous avalanche effect. Whenever avalanche moves in runout zone, they form dense flow model of powder snow along with entrained debris and the accumulated mass which slides over the surface of the terrain. This entrained mass affects the momentum of the avalanche the entire runout zone. Also the deformation of the avalanche owing to metamorphic influence which governs the avalanche layer thickness which in turn regulates the momentum of avalanche flow, as discussed above in the paper avalanche behave as a quasi-fluid. If proper estimation or calculation of this factor is not considered, predicted velocity along the path and the kinetic energy of the avalanche as it enters the run-out zone will change. This affects run-out distances and has direct consequences for avalanche hazard mapping. So an entrainment factor may be (E) should be considered in the modelling for more accurate calculation based on several trial and field experiment.

Also, centrifugal force of the avalanche and the impact factor of the snow mass in the meandering runout zone should be consider based on the topographical factor and the surface morphology of the avalanche terrain. This can be represented as (I_f). This impact factor will largely vary with the types of rock, vegetation on the slope, types of sedimentation on the inclined slope. Proper geological analysis needs to be done during the off season with DTM to determine the empirical factor. Summarizing all the factors and considering them for calculation of Runout distance will result in to factual finding of the distance effectively. The runout distance 's'of the avalanche from point P is calculated as follows:

$$s = [\{(ds/2)(\xi/g)\}\ln\{1+ v_p^2/V^2\}]\{(dp/dt)(\Delta t/t)(\underline{E})(I_p\}]\ldots..(m)$$

$d_S = d_P + (v_p^2/10g)$
$V^2 = dS\ \xi\ (\mu \cos\psi_S - \sin\psi_S)$
where:
ψ_S Average inclination in the runout zone, in [°]
g Gravitational acceleration, constant [= 9.81 m/s^2]
d_p Flow depth at point P in the avalanche path, in [m]
v_p Flow velocity at the point P, in [m/s]
V Average avalanche velocity in the avalanche runout zone, in [m/s]
(dp/dt) Change in the flow height w.r.t temperature
(E) Entrainment Factor
$\Delta t/t$ Deformation of the avalanche thickness owing to metamorphism
I_p Impact factor considering the meandering force of the avalanche flow in
meandering terrain

Data collection for the proposed avalanche modelling:

An essential basis for the use of avalanche calculations is provided by data collection on location. In the terrain, numerous factors must be determined, such as key points for the runout, the location and size of avalanche starting zones, possible accumulation zones, and areas with additional snow entrainment or surface roughness, block dumps, high forest. The avalanche history and surveys of the local population can provide additional information on the process of avalanche events. Apart from all these field determination and assessing terrain report for analysing geological properties of the deposits on the slopes for better entrainment factor calculation, installing various sensors to measure the changes in the thickness of snow cover with temperature variation etc. Determination of realistic input data is extremely important since the results of the calculations are highly dependent upon these input data.

Figure 8: Terrain with installed avalanche barrier

III. CONCLUSION:

Hazards due to snow avalanches flows are in rise due to global warming and climate change owing to man-made activities. Proper assessment of the recorded data from the silent watcher or the local community, analysis of metrological data and DTM recorded information will help to calculate all the possible and factors which regulates the intensity of the avalanche and thus proper calculation of the run out zone. With the calculated velocity time travel for the avalanche can be calculated and thus design of alarm system to avert the catastrophic event and marginally reduce the impact of the event.

Disclosure Statement: No potential conflict of interest was reported by the author.

Acknowledgement: This research was supported by Er. Ankita Das. I thank our colleagues who provided insight and expertise that greatly assisted the research. I thank Prof.ParichitaBasu and to all my associates for their assistance, comments that greatly improved the manuscript.

REFERENCE:

[1]. Aizen, V.B.,Aizen, E.M.,Melack, J.M.,Dozier, J., 1997. Climatic and hydrologic changes in theTien Shan, central Asia. J. Clim. 10, 1393–1404.

[2]. Bajracharya, B., Shrestha, A.B., Rajbhandari, L., 2007. Glacial lake outburst floods in theSagarmatha region. Mt. Res. Dev. 27, 336–344.

[3]. Allen S. Cary 1958 Rockfill Dams: Performance of Mud Mountain Dam Journal of the PowerDivision.

[4]. R D Eckerlin 1992 Mud Mountain Dam Concrete Cutoff Wall - A Case History Environmental andEngineering Geoscience

[5]. Di Risio, M., De Girolamo, P., Beltrami, G.-M., 2011. Forecasting landslide generatedtsunamis: a review. In: Mörner, N.-A. (Ed.), The Tsunami Threat — Research andTechnology

[6]. Evans, S.G., Clague, J.J., 1994. Recent climatic change and catastrophic geomorphicprocesses in mountain environments. Geomorphology.

[7]. Geertsema, M., Clague, J.J., Schwab, J.W., Evans, S.G. An overview of recent largecatastrophic landslides in northern British Columbia, Canada. Eng. Geol. 83, 120–143.

[8]. Haeberli, W.,Alean, J.C.,Müller, P.,Funk,M., 1989. Assessing risks from glacier hazardsin high mountain regions: some experiences in the Swiss Alps. Ann. Glaciol. 13, 96–102.

[9]. Powledge, G.R., Ralston, D.C.,Miller, P., Chen, Y.H., Clopper, P.E., Temple, D.M., 1989a. Mechanics of overflow erosion on embankments.

[10]. Richardson, S.D.,Reynolds, J.M., 2000a. An overview of glacial hazards in the Himalayas.Quat. Int. 65, 31–47.

[11]. Walder, J.S., Costa, J.E., 1996. Outburst floods from glacier-dammed lakes: the effect ofmode of lake drainage on flood magnitude. Earth Surf. Process. Landf. 21, 701–723.

[12]. Worni, R.,Huggel, C., Stoffel, M., 2012c. Glacial lakes in the Indian Himalayas — From anarea-wide glacial lake inventory to on-site and modeling based risk assessment ofcritical glacial lakes. Science of the Total Environment