3D MODELLING & ESTIMATION OF SURFACE AREA AND CHANGE IN VOLUME OF LANDSLIDE USING CLOSE -RANGE PHOTOGRAMMETRY

A DISSERTATION

Submitted in partial fulfillment of the Requirements for the award of the degree

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in

GEOPHYSICAL TECHNOLOGY

By

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DECLARATION OF AUTHORSHIP

I hereby solemnly declare that the work presented in this dissertation thesis titled "**3D MODELLING & ESTIMATION OF SURFACE AREA AND CHANGE IN VOLUME OF LANDSLIDE USING CLOSE -RANGE PHOTOGRAMMETRY**" submitted by me in partial fulfillment of the requirements for award of the degree '**Integrated Master of Technology**' in '**Geophysical Technology**' to the **Department of Earth Sciences, IIT Roorkee**, is an authentic record of my own work carried out during the period May 2018 to April 2019, under the supervision of **Dr. Ajanta Goswami**, Department of Earth Sciences, Indian Institute of Technology, Roorkee. The matter embodied in this dissertation has not been submitted by me for the award of any other degree in any other institute.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

India accounts for 20 % of global landslides ,mostly because of the young Himalayan mountain range. Approximately 11,000 deaths have occurred in last 12 years which is really alarming figure . For monitoring landslide , Close Range Photogrammetry was used and two different sets of data (Pre-monsoon and Post-monsoon) were taken to analyse the change in the volume and surface area of the Kesharwala (near Dehradun) landslide. The detailed and comparative study of the 2 models reviewed the surface area has increased from 75701.5 meter square (Pre-monsoon)to 78903.4 meter square . Where as there has been an evident loss in the volume of the landslide as the change on volume obtained is about 836732.89 M^3 . The average precipitation in Dehradun is about 1802.1 mm and this considerable change in the volume can slowly convert this passive landslide into an active one.

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A. Introduction

India has a one of the biggest and longest mountain range and undoubtably landslide in Himalayas is a major issue from disaster management prospective . According to the report of geological survey of India in last 12 years approximately 11,000 people have died because of landslides . The unsteadiness of landslide is a geomorphologic and geological wonder that influences changing the Earth's surface [1]. It becomes more hazardous when it inspires human activities [2, 3]. Landslides are the general issue which has dependably achieved gigantic loss of lives and money related harm, is of extraordinary significance [4, 5]. It is one of the major geomorphic forms that has influenced development of scene of uneven locales and has caused deplorable episodes [6, 7]. Landslides must be contemplated for urban improvement, on the grounds that the event of landslides is a standard marvel, particularly in the mountainous districts [8] Environmental arranging comprises of land assessment and securing of the proper locales for different land utilises that can be cultivated utilising various elements [9] The geo-natural elements assessed for urban land use arranging [10]. The assurance of the ground establishment conditions giving a valuable manual for urban arranging and for arranging development and specialised ventures [11]. The investigation of these marvels is a valuable device for urban and local arranging [12]. It is considered as a mass development and common peril [13] which is extremely damaging in inclined terrains [14]. Moreover, landslides are made by many driving variables, for example, seismic tremors, precipitation and quick combination of snow. They might be intensified by geology, seismic activities and soil type, breaks, substrate surface, moistness and human-caused reasons[14– 17].

This thesis attempts to make a 3D model of landslide and tries to find out the changes it has undergone before and after the monsoon . Two sets of Image data were taken (before and after monsoon data) and two different 3D model were constructed . The relative comparison between the two models helped us to understand the volume and surface area changes .

3D Modelling of can be done with the help of satellite imagery , LIDAR , Terrestrial Laser scanning , Photogrammetry etc . In difficult terrains and sensitive areas Close Range Photogrammetry is a superior technique as it fast , less instrument oriented and provides results with really good resolution . The data collection is so simple that even a normal mobile camera can be used. The Surface area and change in volume of the kesharwala landslide (near dehradun) is monitored with the help of close range photogrammetry in order to comment on its landslide activity. The pre-monsoon survey was conducted in the month of June 2018 and after a gap of 10 months the Post-monsoon survey was conducted in April 2019. The entire survey was done just by using a Nikon D5300 DSLR camera and multiple overlapping images of the landslide were taken by visiting the site.

Volumetric analysis can screen and assess similarly of the landslide events and can be profitable in executing legitimate hazard the board techniques or authorising ecological guidelines. Beforehand, such examinations have commonly been done through monotonous field estimations, in spite of the way that those will by and large experience the evil impacts of inconveniences in setting up accurate example geography. Photogrammetric strategies have been continuously used in light of their ability to rapidly reproduce the 3-D geography from ethereal photographs [18], [19] and, gave such data exist to different timespans, permit target change recognition.

The aim here is to estimate the change in surface are and volume before and after monsoon .

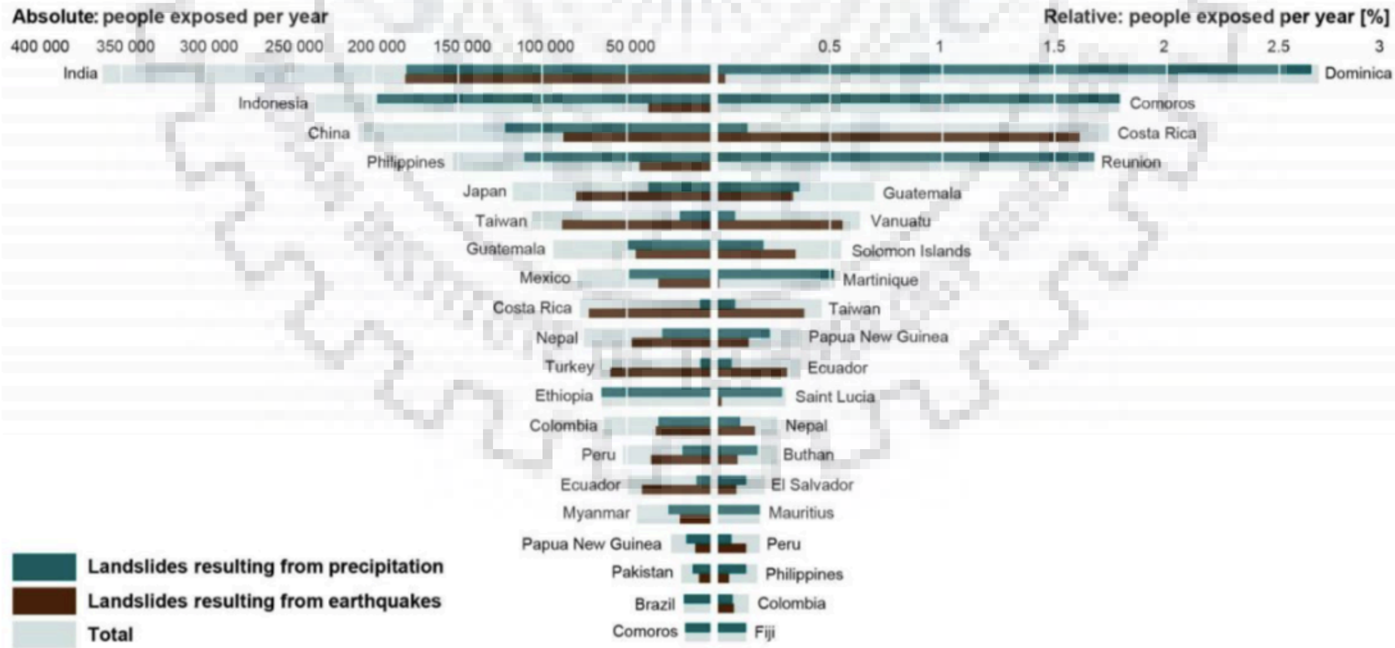


Figure - 1 Country Vs People exposed per year (Maskrey et al. 2009)

B.Study Area

The Kesharwala village is located at a distance of 15 Km from dehradun city (30°19'39.67"N , 78° 6'19.75"E) . Just at a distance of 2 Km from the village , we have a huge landslide located there (30°19'45.47"N , 78° 7'5.71"E). In order to develop an idea of landslide surface close range photogrammetric survey was done along the valley of the landslide. The 3D geometry of the cliffs was extracted and critical areas have been investigated in detail using dense cloud and Texture model obtained from CRP.

Dehradun is situated on the Krol carbonates between the RiversGanga in the east and Yamuna in the west. Both the rivers have their origin from two different Himalayan glaciers, namely Gangotri for Ganga and Yamunotri for Yamuna. Doon Valley falls under the temperate area due to the elevation of 600-800 meters above mean sea level."The Doon Valley is separated by the Lesser Himalayan Neoproterozoic Krol Belt carbonate sediments in the north by Main Boundary Thrust (M.B.T.).The Siwalik Foreland Basin sediments are found in the south of the Doon Valley Thrust over the Indo-Gangetic Plains along Himalayan Frontal Thrust" .

Figure-2 Map of study area (Kesharwala, Dehradun)

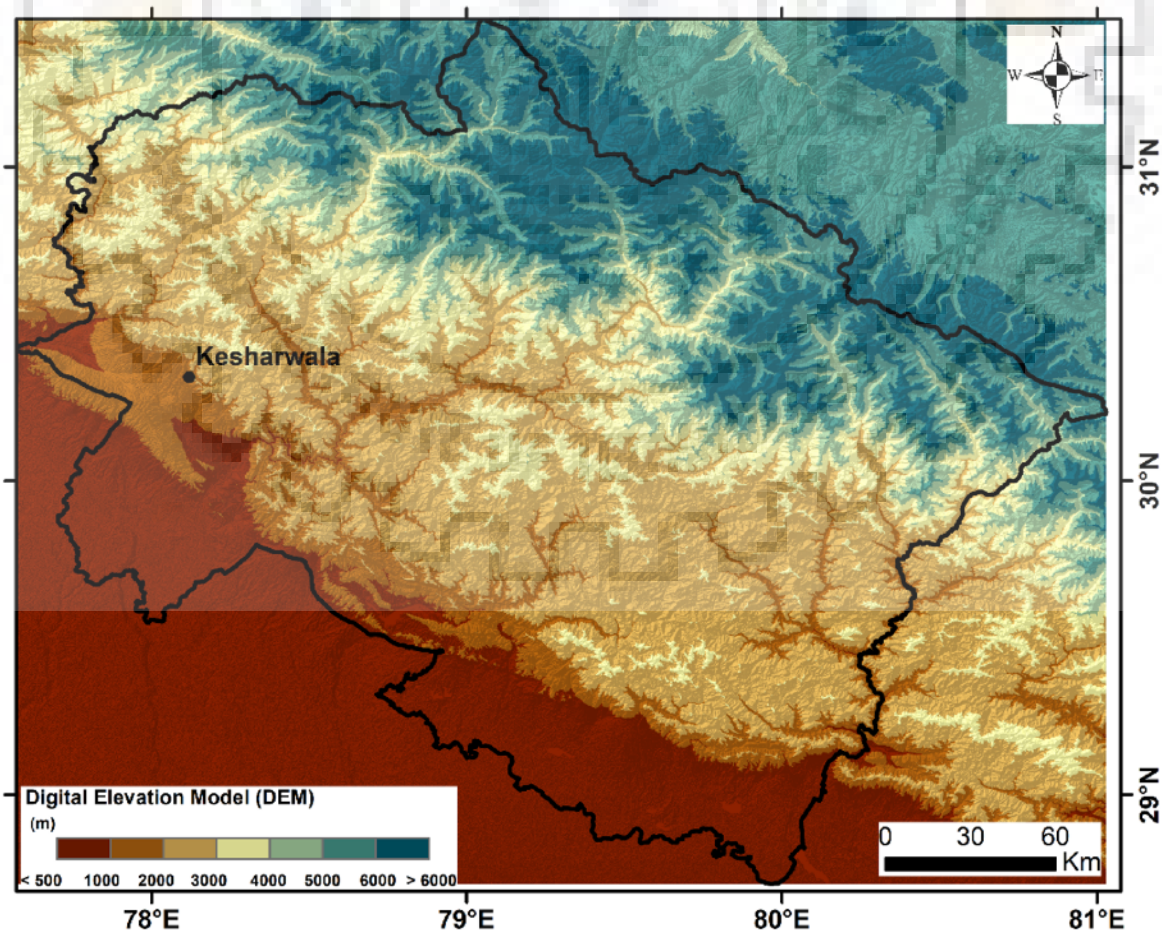


Figure-3 Kesharwala landslide , Field view

Figure-4 Site view , Kesharwala Landslide (Dehradun)

C. Methodology

1. General overview and algorithm

1.1 Photogrammetry as a tool for 3D modelling

“ Photogrammetry has been characterized by the American Society for Photogrammetry and Remote Sensing (ASPRS) as the art, science, and technology of obtaining reliable information about physical objects and the environment through procedures of chronicle, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic vitality and other phenomena” (ASPRS online Archived May 20, 2015, at the Wayback Machine)

The 3-D co-ordinates define the areas of article focuses in the 3-D space. The picture co-ordinates define the areas of the article focuses' pictures on the film or an electronic imaging device. The outside introduction of a camera defines its area in space and its view direction. The internal introduction defines the geometric parameters of the imaging procedure. This is fundamentally the central length of the focal point, however can likewise include the description of focal point distortions. Further additional perceptions assume a significant job: With scale bars, essentially a known distance of two points in space, or realized fix focuses, the connection to the fundamental estimating units is created.

1.1.1 History of Photogrammetry

Photogrammetry goes back to 1839. Before all else, stereo photogrammetry was utilized. Pictures were taken from balance positions and saw with stereoscopic hardware. With the development of the plane, this procedure turned out to be increasingly relevant. This was calibrated until the innovation of the PC. Computational photogrammetry permitted for computation of separations dependent on point coordinating calculations (Schenk, 2005). The development of digital cameras and quicker PCs has made the current situation with photogrammetry. Preparing methods are accelerating and goals and repeatability are expanding. The phases of photogrammetry are found in Figure :

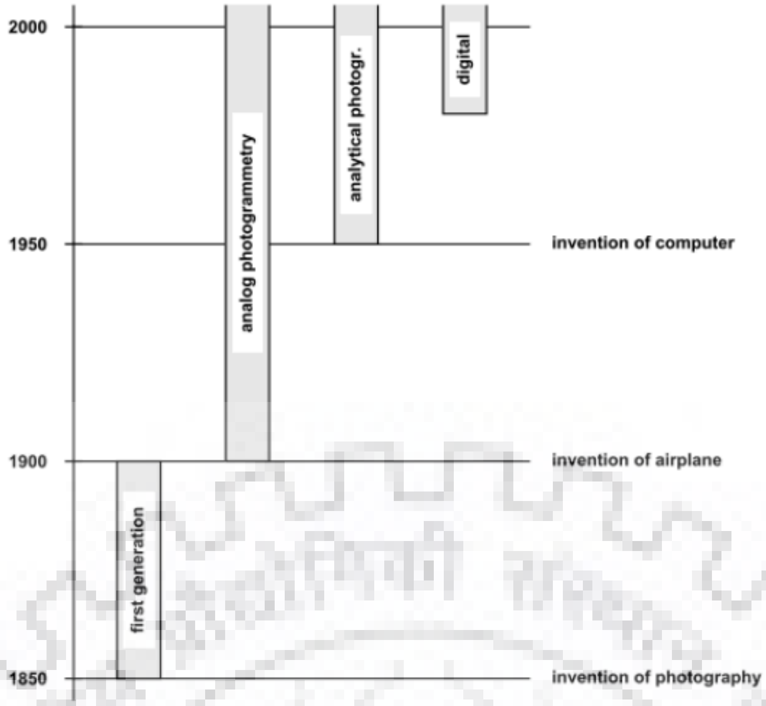


FIGURE 2.5: Plot showing the invention and use of different photogrammetrical methods with respect to time. Important inventions related to photogrammetric innovations are shown. Figure from Schenk (2005).

1.1.2 Applications

Photogrammetric applications are not restricted to a particular field. Imaginative programming has been created for different applications. Snavely et al. (2007) propose a technique with which to utilise geo-referenced pictures from web photograph accumulations to "model the world". This uses globally positioned pictures to recreate urban surface features.

Precision isn't urgent in this application. On the opposite side of the range Koch what's more, Kaehler (2009) depict a technique for profoundly precise surface recreation utilizing photogrammetry and laser scanning. This strategy brought about a goals of +/ - 1 mm over a multi-meter long divider.

In landslide checking, photogrammetry is essentially utilized for two things. To begin with, observing of landslide development can utilize transient photogrammetric information to follow development..

This is finished by rehashing reviews after some time and looking at contrasts in the point-cloud what's more, orthoimages. This can be found out about in Bitelli et al. (2003), Mora et al. (2003), Niethammer et al. (2012), and Wieczorek and Snyder (2009). These investigations spread distinctive estimated districts and picture catch systems. Second, photogrammetry is utilized for deciding fracture orientation. This includes planar component investigation for insitu shake faces (Lato et al. (2012),Lato et al. (2013), Wolter et al. (2014), and Collins and Stock (2012)). These examinations utilise plane fitting calculations to characterize possibly dangerous joints, discontinuities, and slide planes (Collins and Stock, 2012). The favorable circumstances of photogrammetric studies are ending up clear for their capacity to build security and precision while constraining expense (Mart'ın et al., 2013).

1.1.3 Algorithm of Photogrammetry

The algorithm of photogrammetry is based on the twin pillars of

- **Triangulation** - "In trigonometry and geometry, triangulation is the process of determining the location of a point by forming triangles to it from known points" (https://en.wikipedia.org/wiki/Triangulation) . By taking photographs from at least two different locations, purported "observable pathways" can be created from every camera to points on the object. These viewable pathways (sometimes called beams attributable to their optical nature) are mathematically intersected to create the 3-dimensional coordinates of the points of interest. Triangulation is additionally the guideline utilized by theodolites for coordinate measurement. In the event that you are familiar with these instruments, you will discover many similarities (and some distinctions) between photogrammetry and theodolites. Significantly closer to home, triangulation is additionally the manner in which your two eyes cooperate to measure distance
- **Lens formula -** For the implimentation of triangulation technique the radius vector of the point cloud is determined with the help of lens formula.

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

Where ,

U = Position of object.

V = Position of Image.

F = Focal length of lens

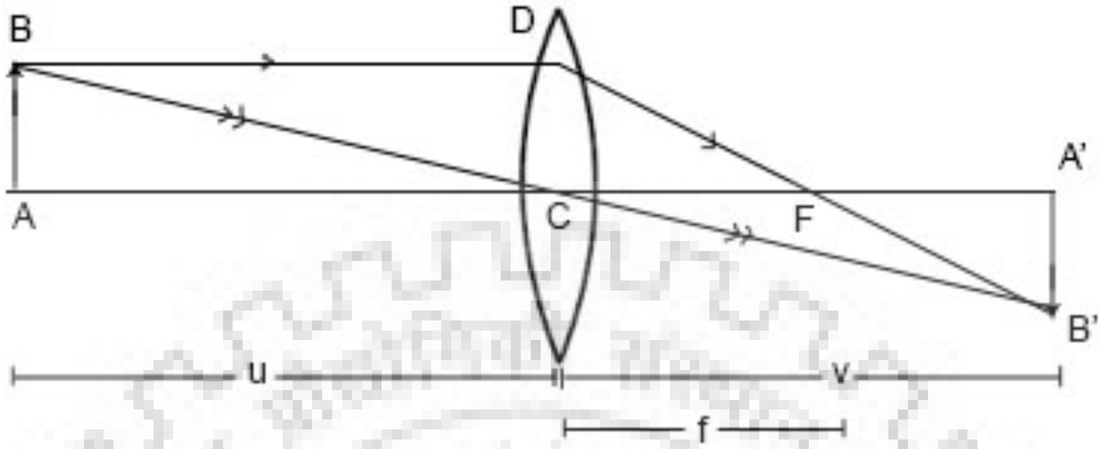
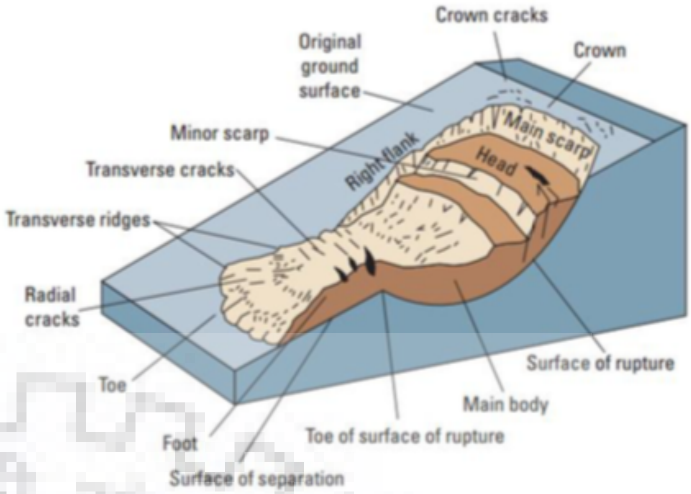


Figure-5 Object Image and convex lens

1.2 Landslide

Landslide, also called landslip, the development downslope of a mass of shake, debris, earth, or (soil being a blend of earth and flotsam and jetsam). Landslides happen when gravitational and different sorts of shear stresses inside a slant surpass the shear strength (protection from shearing) of the materials that structure the slant. Shear stresses can be developed inside a slant by various procedures. These incorporate oversteepening of the base of the incline, for example, by regular disintegration or removal, and stacking of the slant, for example, by an inflow of water, an ascent in the groundwater table, or the gathering of garbage on the slant's surface. Momentary stresses, for example, those forced by seismic tremors and rainstorms, can moreover add to the actuation of landslides. An expansion in water content, coming about because of either normal causes or human movement, regularly debilitates sandy materials through the decrease of interparticle grinding and debilitates dirts through the disintegration of interparticle concretes, the hydration of earth minerals, and the end of interparticle (narrow) pressure

(A)



(B)

Figure-6A Landslide Image (La Conchita, California, USA) (Photograph by Mark Reid, U.S. Geological Survey.)

Figure-6B Labeled diagram of landslide (from Varnes, 1978, Reference 43).

Figure 7 landslide in the Beatton River Valley, British Columbia, Canada. (Photograph by Réjean Couture, Canada Geological Survey.)

1.2.1 Types of land slides

Landslides can be grouped into various kinds on the basis of the sort of development and the sort of material included. In a nutshell, material in a landslide mass is either rock or soil(or both); the last is portrayed as earth if mostly made out of sand-sized or better particles and debris whenever made out of coarser pieces. The kind of development depicts the genuine inward mechanics of how the landslide mass is displaced: fall, topple, slide, spread, or flow. In this manner, landslides are portrayed utilizing two terms that allude individually to material and development (that is, rock fall, debris flow, and so forth). Landslides may also frame an intricate disappointment including more than one kind of development (that is, rock slide-debris flow). Each kind of development can be additionally subdivided by explicit properties and characteristics. The major divisions are mentioned below.

A. FALLS -

"Falls are sudden movements of masses of geologic materials, for example, rocks and stones, that become confined from steep slopes or cliffs . Detachment occurs along discontinuities, for example, fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling. Falls are firmly impacted by gravity mechanical weathering, and the presence of interstitial water"

FIGURE -8 A rockfall/slide at Clear Creek Canyon, Colorado, USA, in 2005, ((Photograph by Colorado Geological Survey.)

B. TOPPLE-

"A topple is perceived as the forward revolution out of an incline of a mass of soil or shake around a point or hub underneath the focal point of gravity of the uprooted mass. Toppling is some of the time driven by gravity applied by the heaviness of material focus of gravity. Once in a while toppling is because of water or ice in breaks in the mass. Topples can comprise of shake, debris (coarse material) or earth materials (fine grained material). Topples can be unpredictable and composite".

Figure-9 A rockfall/slide that occurred in Clear Creek Canyon, Colorado, USA, in 2005, (Photograph by Colorado Geological Survey.)

C. SLIDES -

"A slide is a downslope development of a dirt or shake mass happening on surfaces of break or on moderately slight zones of serious shear strain. Development does not at first happen at the same time over the entire of what in the end turns into the outside of burst; the volume of dislodging material extends from a territory of nearby disappointment.”

D. FLOWS: “There are five essential classifications of flows that vary from each other in basic ways.

a. Debris stream: “A debris stream is a type of quick mass development wherein a blend of free soil, shake, natural issue, air, and water activate as a slurry that flows downslope . Debris flows incorporate <50% fines. Debris flows are generally brought about by exceptional surface-water stream, because of overwhelming precipitation or quick snowmelt, that dissolves and assembles free soil or shake on soak slants. Debris flows additionally regularly prepare from different sorts of landslides that happen on soak inclines, are almost immersed, and comprise of an extensive extent of residue and sand-sized material. Debris-stream source regions are often connected with soak chasms, and debris-stream stores are typically demonstrated by the nearness of debris fans at the mouths of ravines. Flames that expose inclines of vegetation heighten the defenselessness of slants to debris flows”.

b. Debris avalanche: This is an assortment of quick to amazingly fast debris stream

c. Earthflow: “Earthflows have a trademark "hourglass" shape (fig. 3H). The incline material condenses and runs out, shaping a bowl or dejection at the head. The stream itself is stretch and more often than not happens in fine-grained materials or dirt bearing rocks on moderate inclines and under immersed conditions. In any case, dry flows of granular material are likewise conceivable”.

d. Mudflow: “A mudflow is an earthflow comprising of material that is wet enough to stream quickly and that contains in any event 50 percent sand-, sediment , and dirt measured particles”. In certain occasions, for instance in numerous paper reports, mudflows and debris flows are usually alluded to as "mudslides."

e. Creep: Creep is the impalpably moderate, relentless, descending development of slant framing soil or shake. Development is brought about by shear pressure adequate to deliver lasting disfigurement, however too little to even think about producing shear disappointment. There are commonly three kinds of creep:

(1) occasional, where development is inside the profundity of soil influenced via regular changes in soil dampness and soil temperature

(2) ceaseless, where shear pressure constantly surpasses the quality of the material

(3) dynamic, where slants are achieving the purpose of disappointment as different

sorts of mass developments. Creep is demonstrated by bended tree trunks, bowed fences or holding dividers, tilted posts or fences, and little soil swells or edges .”

E. LATERAL SPREADS: “Lateral spreads are unmistakable in light of the fact that they more often than not happen on exceptionally delicate inclines or level landscape . The prevailing method of development is lateral expansion joined by shear or malleable cracks. The failure is brought about by liquefaction, the procedure whereby immersed, free, cohesion-less dregs (normally sands and residues) are changed from a strong into a condensed state. Failure is generally activated by quick ground movement, for example, that accomplished amid a seismic tremor, yet can likewise be misleadingly actuated. At the point when sound material, either bedrock or soil, lays on materials that condense, the upper units may experience breaking and expansion and may then die down, decipher, pivot, crumble, or melt and stream. Lateral spreading in fine-grained materials on shallow slants is typically dynamic. The failure begins abruptly in a little zone and spreads quickly. Often the underlying failure is a slump, however in certain materials development happens for no clear reason. Mix of at least two of the above sorts is known as an unpredictable landslide.”

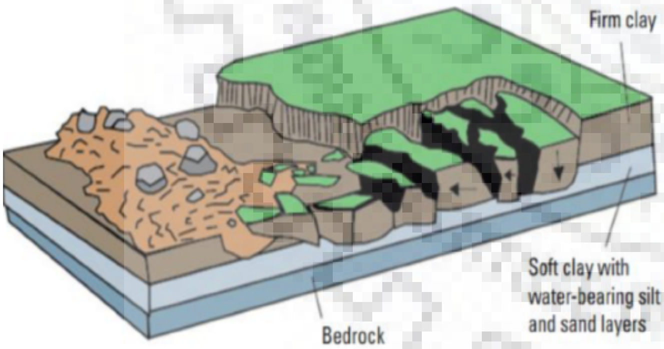


Figure-10 Photo of lateral spread harm to a roadway because of the 1989 Loma Prieta, California, USA, tremor. (Photograph by Steve Ellen, U.S. Geological Survey.)

2.Softwares used

In the entire work 2 softwares

(1) AgiSoft Photoscan

(2) CloudCompare have been used . Major use of AgiSoft was in the construction of 3D point cloud , 3D mesh and texture of the model while CloudCompare was used for data cleaning , comparing both (pre monsoon and post monsoon) models , enclosing the cavity and calculating change in volume .

2.1 AgiSoft

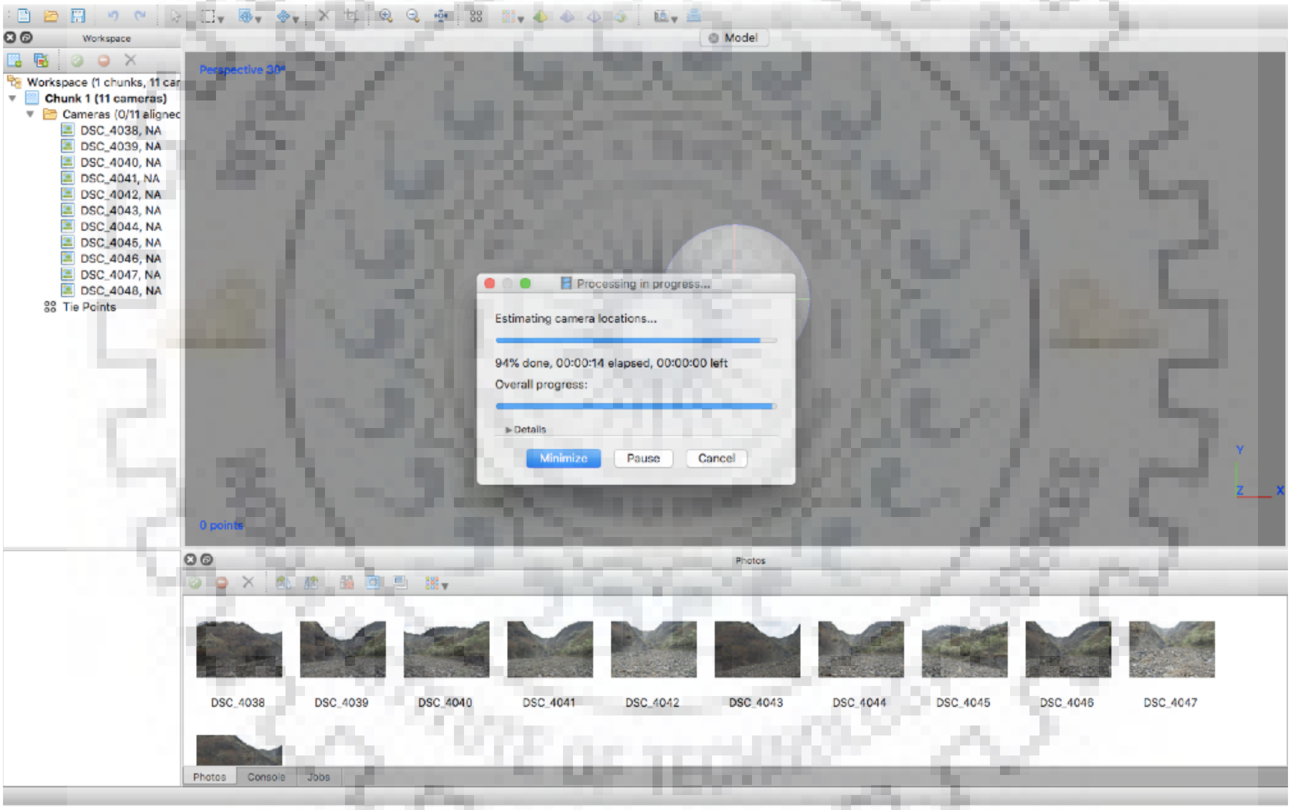


Figure 11 Agisoft Photoscan Interface

For the required prepose licensed AgiSoft Photoscan Version 1.4.5 was used . “Agisoft PhotoScan is a propelled image-based 3D modeling solution aimed at creating proficient quality 3D content from still images. Based on the latest multi-see 3D reconstruction technology, it operates with arbitrary images and is efficient in both controlled and uncontrolled conditions”. “Photos can be taken from any position, giving that the object to be reconstructed is visible on at least two photos. Both image alignment and 3D model reconstruction are completely automated."

2.1.1 How it works ?

Generally the final goal of photographs processing with PhotoScan is to build 3D surface, orthomosaic and DEM. The processing procedure includes four main stages.

1. "The first stage is camera alignment. At this stage PhotoScan searches for common points on photographs and matches them, just as it finds the situation of the camera for each image and refines camera adjustment parameters. Therefore a meager point cloud and a lot of camera positions are shaped. The inadequate point cloud speaks to the aftereffects of photograph arrangement and won't be straightforwardly utilised in further preparing (with the exception of the meager point cloud based reproduction strategy, that isn't prescribed). Anyway it tends to be sent out for further use in outside projects. For example, the scanty point cloud model can be utilised in a 3D proof reader as a source of perspective. Despite what might be expected, the arrangement of camera positions is required for further 3D surface remaking by PhotoScan."

2. The following stage is producing dense point cloud ,that is worked by PhotoScan dependent on the assessed camera positions and envisions themselves. Dense point cloud might be altered and characterised preceding fare or continuing to the following stage.

3. "The third stage is generation of a surface: Mesh and/or DEM. 3D polygonal mesh model represents the object surface based on the thick or inadequate point cloud, this type of surface representation isn't constantly required, so the client may skip mesh model generation step. Digital Elevation Model (DEM) can be built in Geografic, Planar or Cylindrical projections according to the client's decision. On the off chance that the thick point cloud had been grouped on the past stage - it is possible to utilise particular point classes for DEM generation."

4. After the surface is reconstructed, it can be textured (relevant for mesh model just) or an Orthomosaic can be generated. Orthomosaic is projected on a surface of client's decision: DEM or Mesh model (on the off chance that it had been generated for the project).

2.1.2 General workflow .

Image processing with PhotoScan includes the following main steps:

1. stacking photographs into PhotoScan
2. investigating stacked pictures, expelling pointless pictures
3. adjusting photographs
4. building thick point cloud
5. building mesh (3D polygonal model)
6. creating surface

2.2 CloudCompare

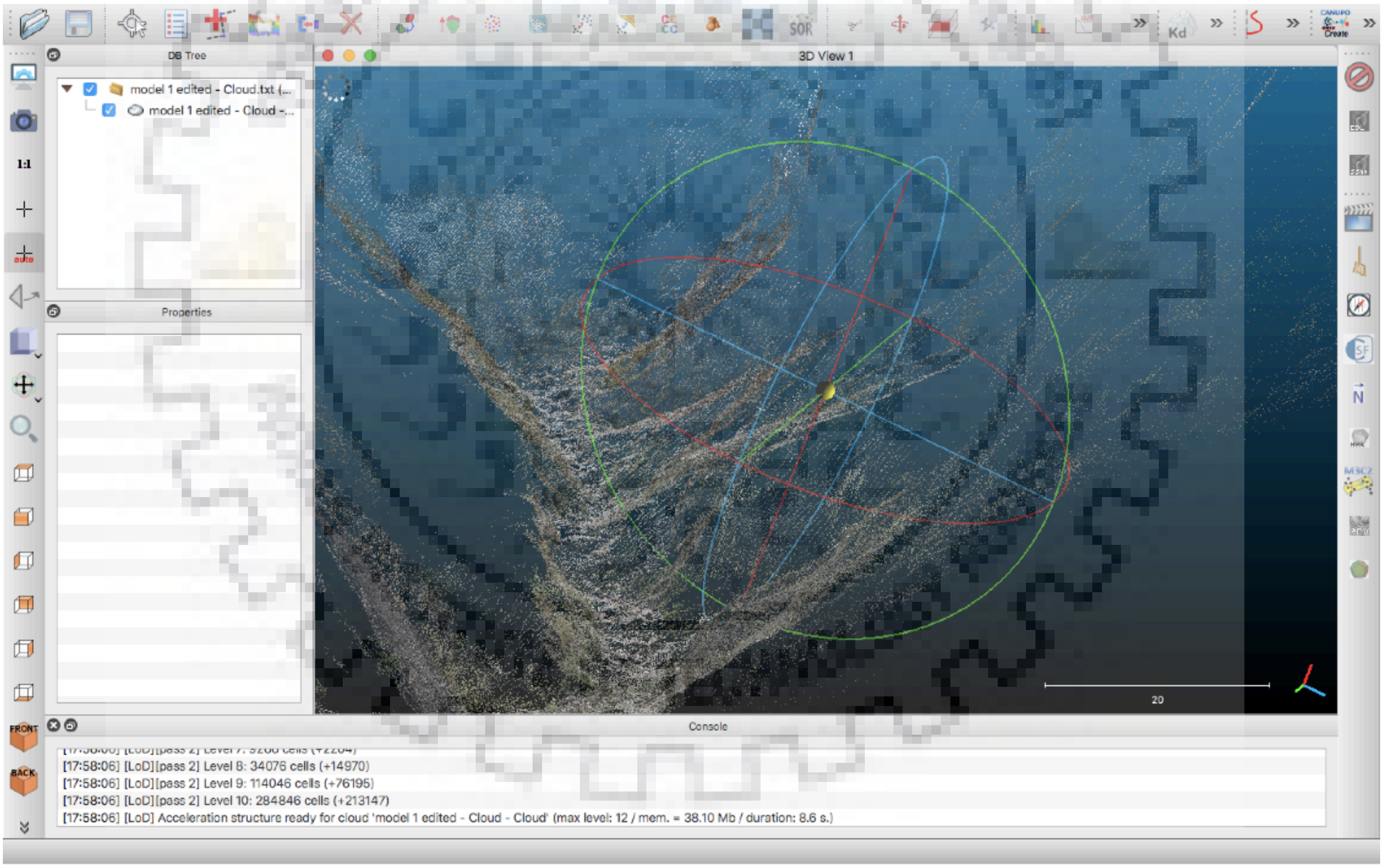


Figure-12 CloudCompare with landslide point cloud

“CloudCompare is a 3D point cloud (and triangular mesh) editing and preparing software. Originally, it has been intended to perform direct comparison between caves 3D point mists. It relies upon a particular octree structure that enables great performances when performing this sort of task. Moreover, as most point mists were gained by terrestrial laser scanners, CloudCompare was meant to manage immense point mists on a standard laptop - typically more than 10 million points . Before long, comparison between a point cloud and a triangular mesh has been supported" . Afterwards, many other point cloud preparing algorithms have sought after (registration, resampling, color/normal vectors/ scalar fields management, statistics computation, sensor management, interactive or automatic segmentation, etc.) just as showcase enhancement gadgets (custom color ramps, color and normal vectors handling, calibrated pictures handling, OpenGL shaders, plugins, etc.).

2.2.1 Graphical User Interface

1. Menus
    - File (open, save, quit, etc.)
    - Edit (edit selected entities and their features - colors, normals, scalar fields, etc.)
    - Tools (segmentation, registration, projection, etc.)
    - Display (display-related options)
    - Plugins (loaded plugins)
    - 3D Views (3D views management)
    - Help (about, help, etc.)
2. Main toolbar (quick access to main editing and processing tools: open/save, point picking, clone, etc.)
3. Scalar fields toolbar (quick access to scalar fields related tools)
4. Plugins toolbar (quick access to currently loaded plugins - standard and OpenGL shaders)
5. View toolbar (quick access to display-related tools)
6. Database tree (for selection and activation of entities and their features)
7. Properties view (information on selected entity)
8. Default 3D view

9.   Another 3D view (created with 3D Views > New)

10. Console

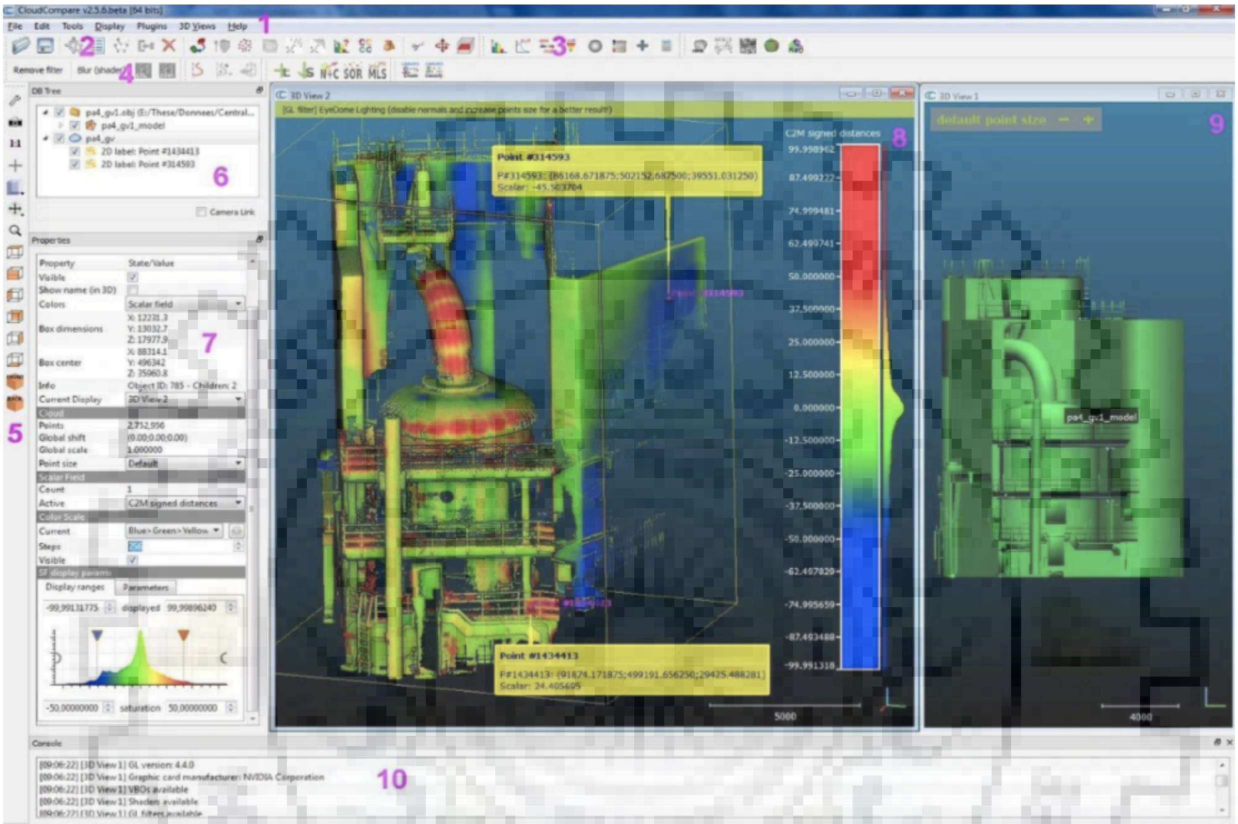


Figure-13 CloudCompare Graphic user interface (CloudCompare user Manuel)

3 Field Work

Since the objective is to estimate the change in the volume of landslide because of monsoon . Hence two field surveys were conducted in order to acquire Pre monsoon and Post monsoon data.

3.1 Pre-monsoon survey

On 17th of June 2018 1st survey was carried out at the landslide near Kesharwala village dehradun . 343 images of the landslide were taken using DSLR Nikon D5300 (18mm) camera (with inbuilt GPS) along the survey profile as shown in the figure. Images were taken in sequence while moving up and going down the landslide . Every next photograph was taken at a distance of 2 feet from the previous image in order to obtain more than 60% overlap in every consecutive image . Four different 360* image sequence were also taken in order to improve the output resolution of the 3D point cloud. Since the survey area was intensely remote , proper GPS signal was not assessable . Hence to improve the accuracy and scaling of the 3D model 5 markers were used in the field and distance between them were measured in order to Improve the accuracy of our coordinate system and scaling 3D model .

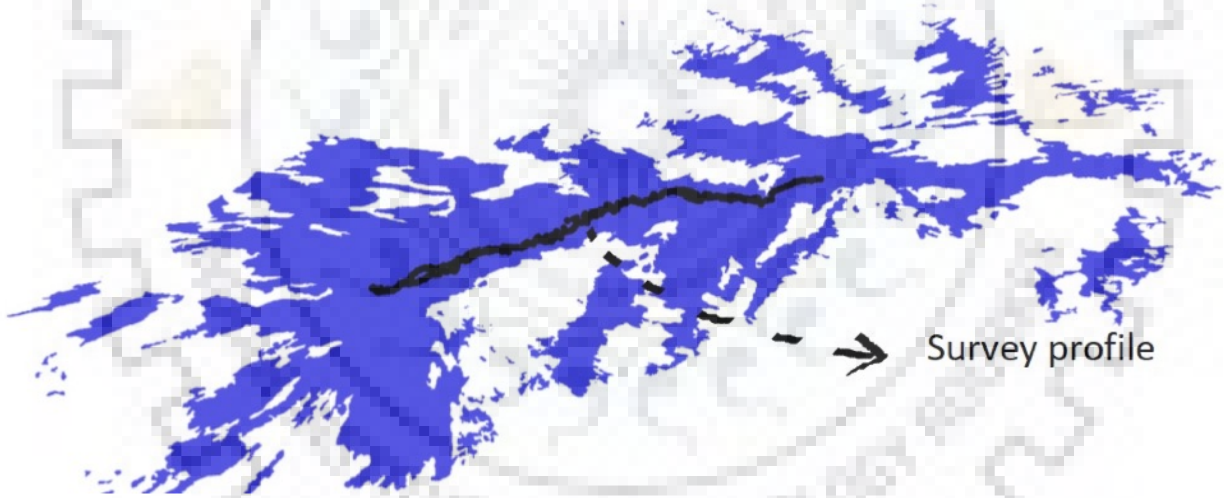


Figure-14 Pre-monsoon landslide horizontal projection with survey profile

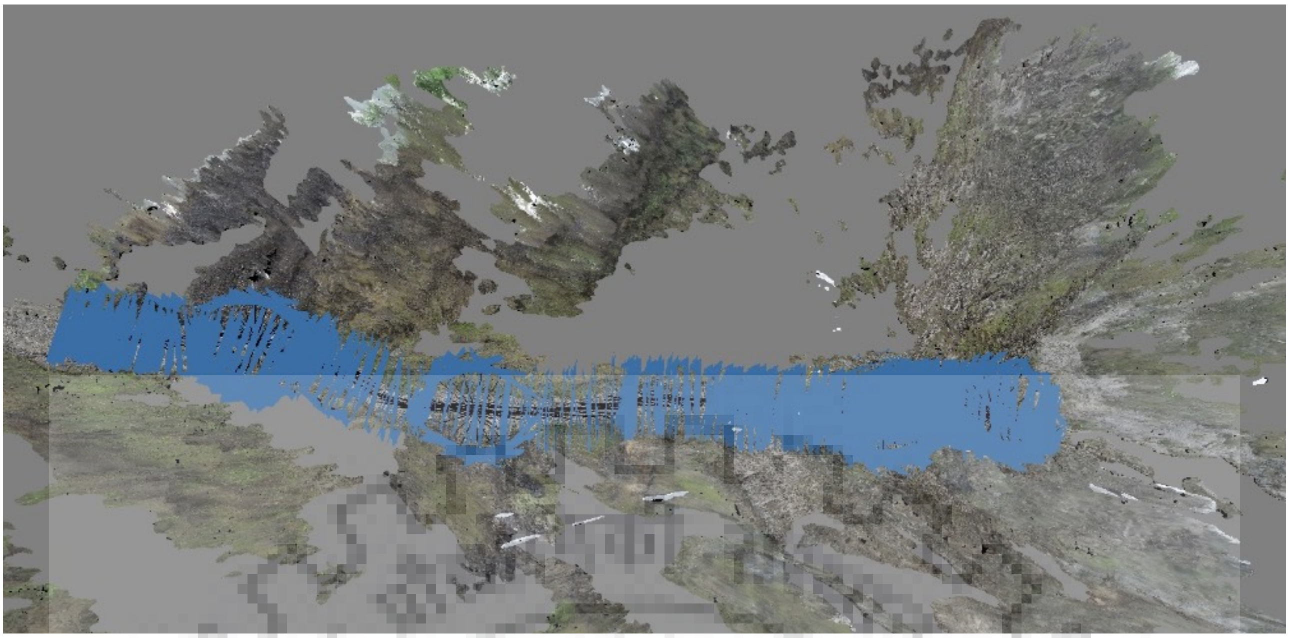


Figure-15 Aligned image dataset in landslide (Top view)

3.2Post-monsoon survey

On 8th of April 2019 the second round of field survey was carried out to the same site with Nikon D5300 camera (18mm) . 339 images were taken out of which 337 were used for the processing . Although the number of images taken was more or less same but the survey pattern was more extensive this time as more number of images were taken at each location at different angles . Thus the data set gathered is more wide than the previous one , also 7 of 360 degree image sequence were taken . Hence the area coverage of this data set is greater than last data set. Every next photograph was taken at a distance of 5 feet from the previous image in order to obtain more than 60% overlap in every consecutive image . For the purpose of proper scaling of the model 4 different markers were used and distance between them were measured in order to Improve the accuracy of our coordinate system .

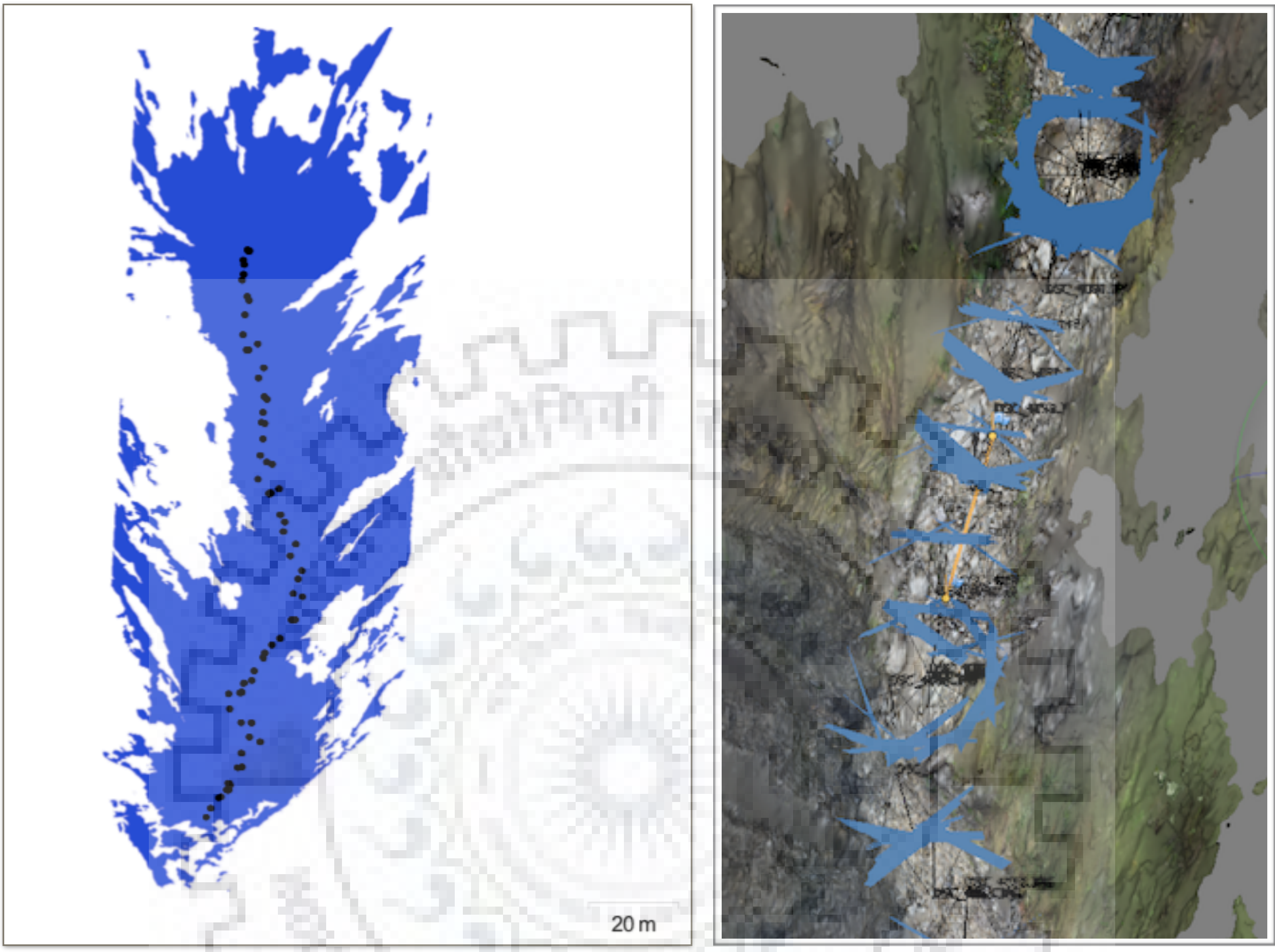


Figure -16 Survey profile and image alignment data set on Landslide model (Top view)

4 Data processing

After the Image data was collected , it was uploaded on the laptop. These images were now imported to Agisoft- photoscan and processing was done according to the general workflow .

4.1 Image Alignment

Aligning images can be done in three different ways :

1. Disabled :- when the latitude and the longitude data obtained from the GPS are either missing or inconsistent .
2. Generic :- when the markers applied are uniform and their exact location are well known.
3. Reference :- when the latitude and longitude data obtained from the GPS are good and consistent

In our case since the data acquired was from a very remote dense forest area , so the GPS data were inconsistent and hence we aligned the photographs in disabled mode.

4.2 Point cloud generation

Now once the data set is aligned we will obtain a tie cloud as shown on above picture.

Algorithm :

Building a tie point cloud is basically based on the method of triangulation (In trigonometry and geometry, triangulation is the process of determining the location of a point by forming triangles to it from known points.)

We have the overlapping images , we know the size of image and we know the focal length of the camera . Hence we determine the position vector of the different points of the point cloud.

4.3 Dense point cloud

Further the density of the point is increasing the sampling of the points and thus building the dense point cloud. The dense point cloud thus built have 20,786,313 points in its Pre-monsoon model and 29,259,877 points. Also it is more comprehensive in texture and about the geomorphology .

Figure-17 Tie point cloud

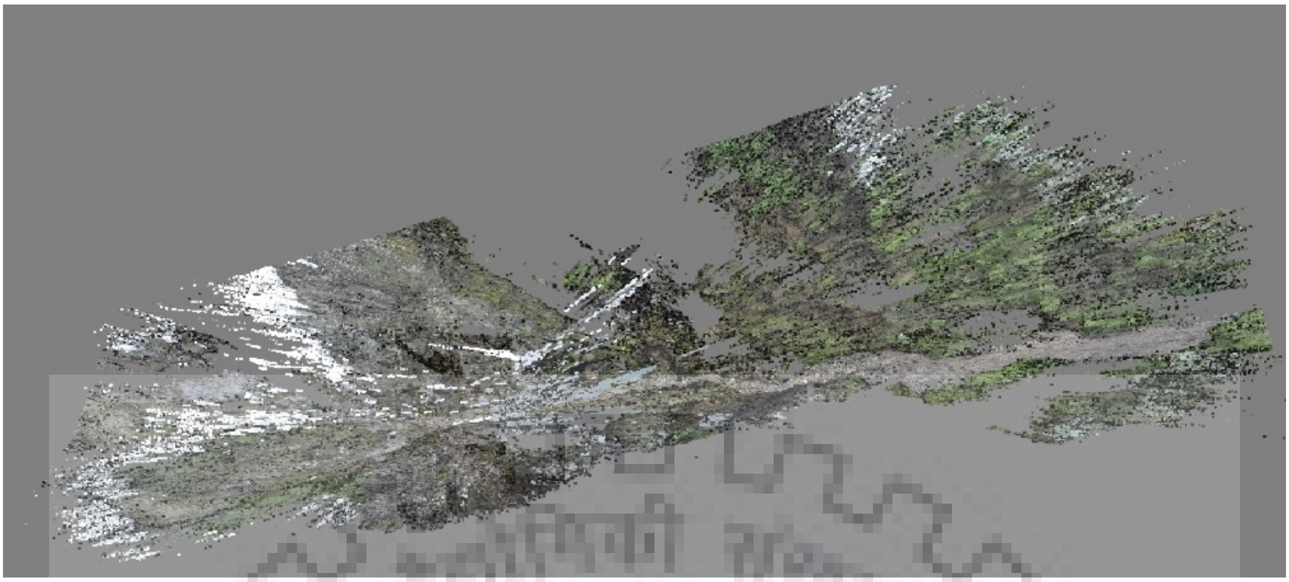


Figure-18 Dense Point Cloud

4.4 3D Modelling

After we are done with building the point cloud , we start to build mesh which provides a solid framework to our model .

Algorithm : So basically a point cloud is made of huge numbers of points . Now every point is joined with their nearest neighbour by a straight lines thus creating a model made of huge number of triangles and forming a mesh.

Wireframe mesh closeup Now once a mesh is built we can improve the model by adding texture to the model.The mesh model thus built have 1,452,285 Facies , 769,642 vertices and 4,096 x 4,096, uint8 texture.

Figure - 19 Textured 3D model of landslide

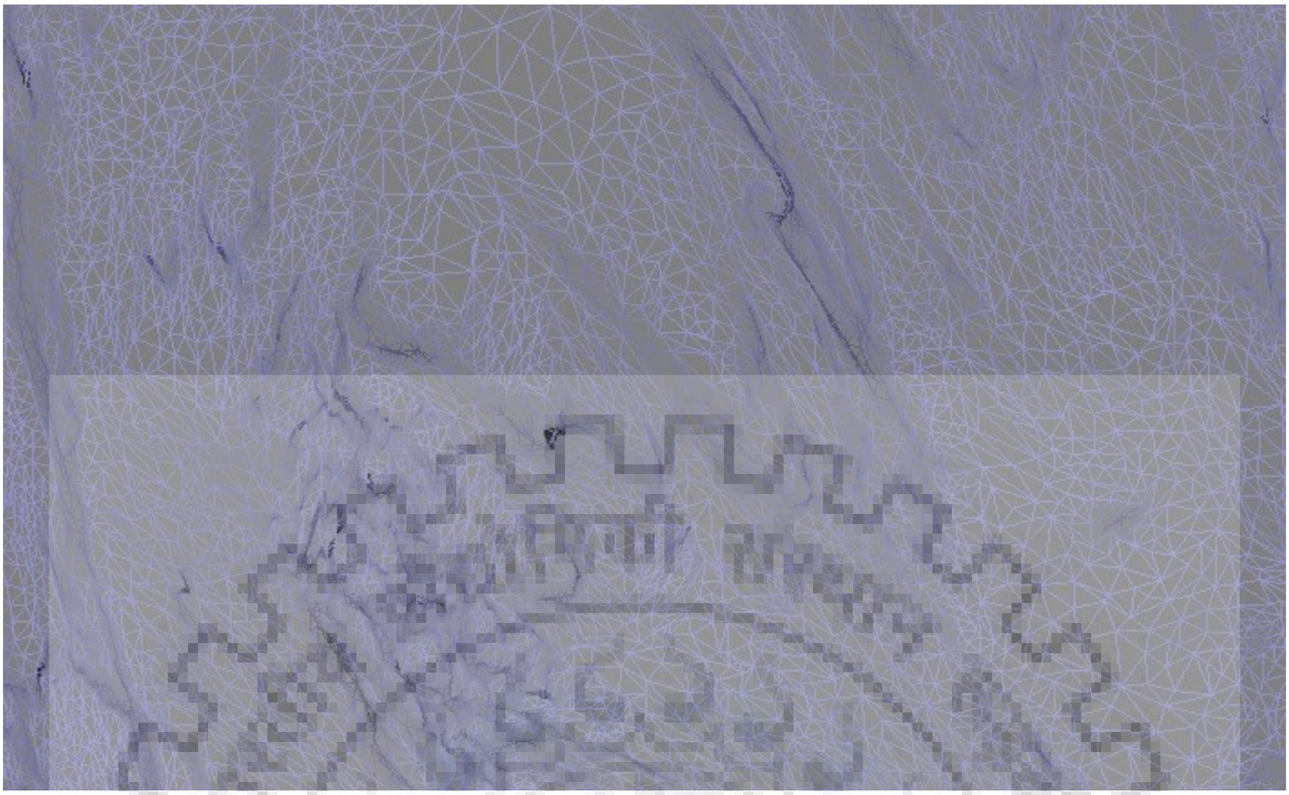


Figure-20 3D Mesh Model of landslide

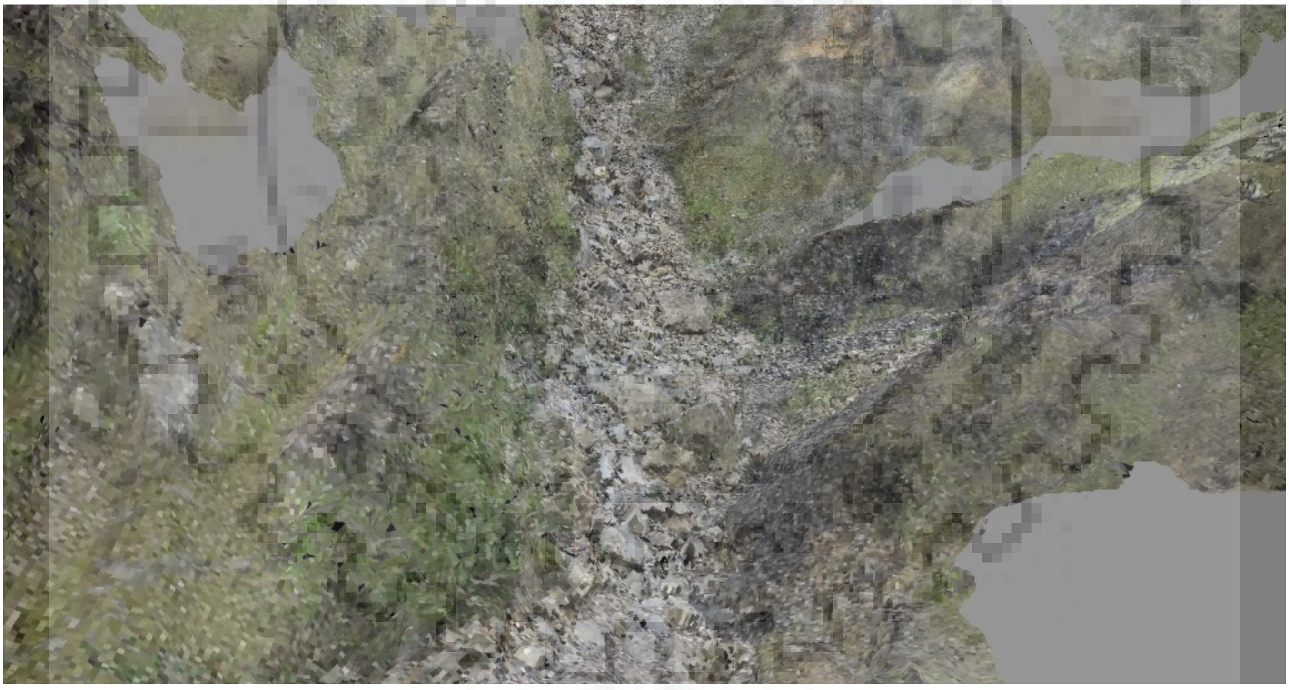


Figure-21 3D Textured model of landslides

4.5 Markers

Since the Gps data was inconsistent , that's why the scaling of the model wasn't done properlyWhile data acquisition we applied markers on the terrain also we had already measured the the distance between them . So now we try to add these markers to the model. Since the size of these markers were much smaller as compared to the size of the model , hence it was not possible to apply them directly from the model itself . In order to add markers to the model we checked each and every photograph from the data set and added the markers manually . Finally when this process is done , the model was retrained again by scaling the distance between markers and thus proper scaling of the model is done.

Figure-22 Site Image with markers

1. **Pre-Monsoon model** :

We applied 5 markers and the measured distances are

Label	Distance (m)	Error (m)
point 1_point 2	11.5218	0.0218449
point 2_point 3	8.07308	0.0730824
point 3_point 4	7.3915	-0.108504
point 4_point 5	6.81279	-0.187207
Total		**0.114715**

2. **Post-Monsoon model** :

We applied 4 markers and the measured distances are :

Label	Distance (m)	Error (m)
point 1_point 2	9.51455	-0.185448
point 3_point 4	12.3555	0.155549
Total		**0.171153**

4.6 CloudCompare

The model generated in form of dense point cloud was exported to CloudCompare software and the models were overlapped by picking 4 points common to both modelled thus aligning the models . Any variation in the model will result in a cavity and the change in volume will be calculated by determining the volume of the cavity. Since there are unwanted holes in both of the models Poission surface construction plugin was used to create a scalar surface and thus eroded volume gets enclosed in form of cavity .

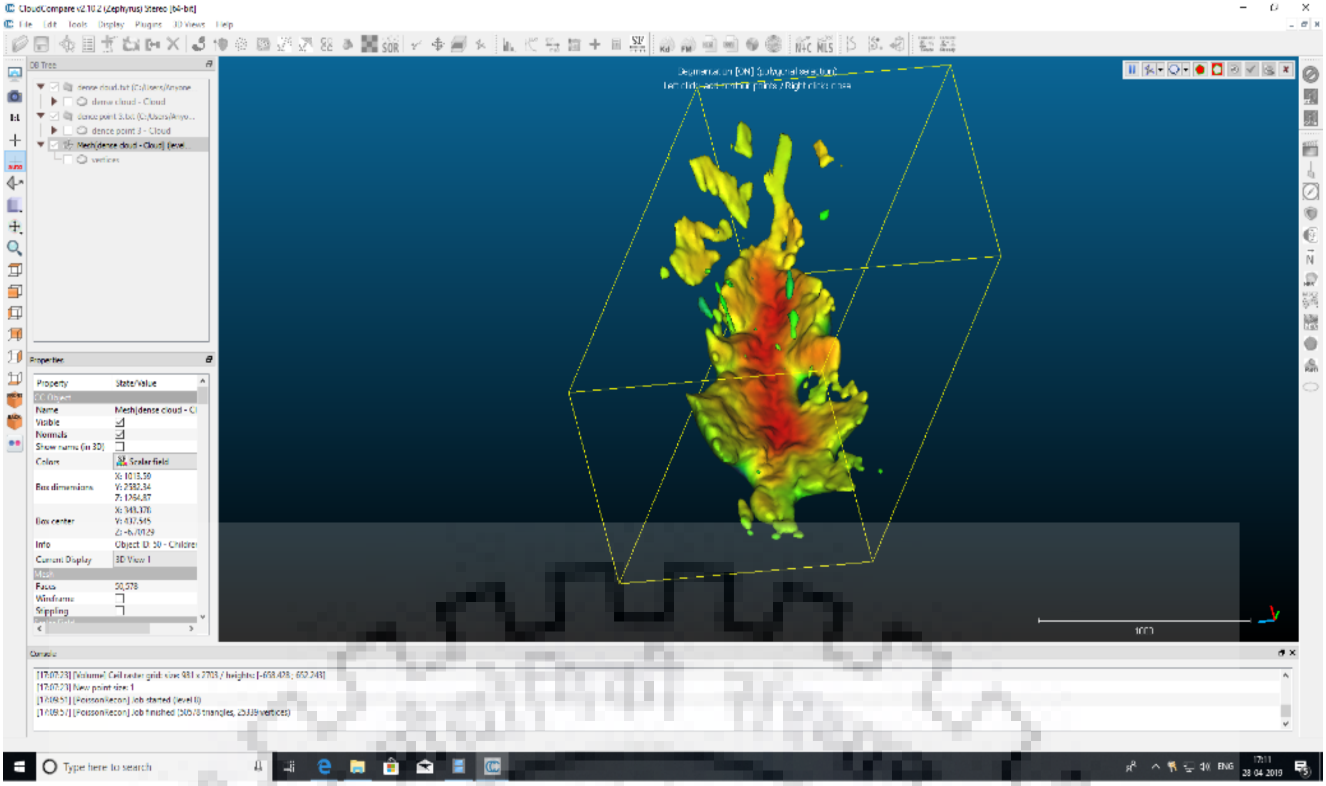


Figure-23 Cavity Enclosed as 3D mesh

4.7 Mesh volume

The volume of cavity thus formed by a solid mesh can be calculated by the mesh volume plugin of CloudCompare software

4.8 2.5D Volume

Volume between two the clouds are computed with desired accuracy by setting up optimum parameters. The missing surfaces were interpolated with the help of cloud interpolation technique in CloudCompare software.

D. Result

1.Pre-monsoon model

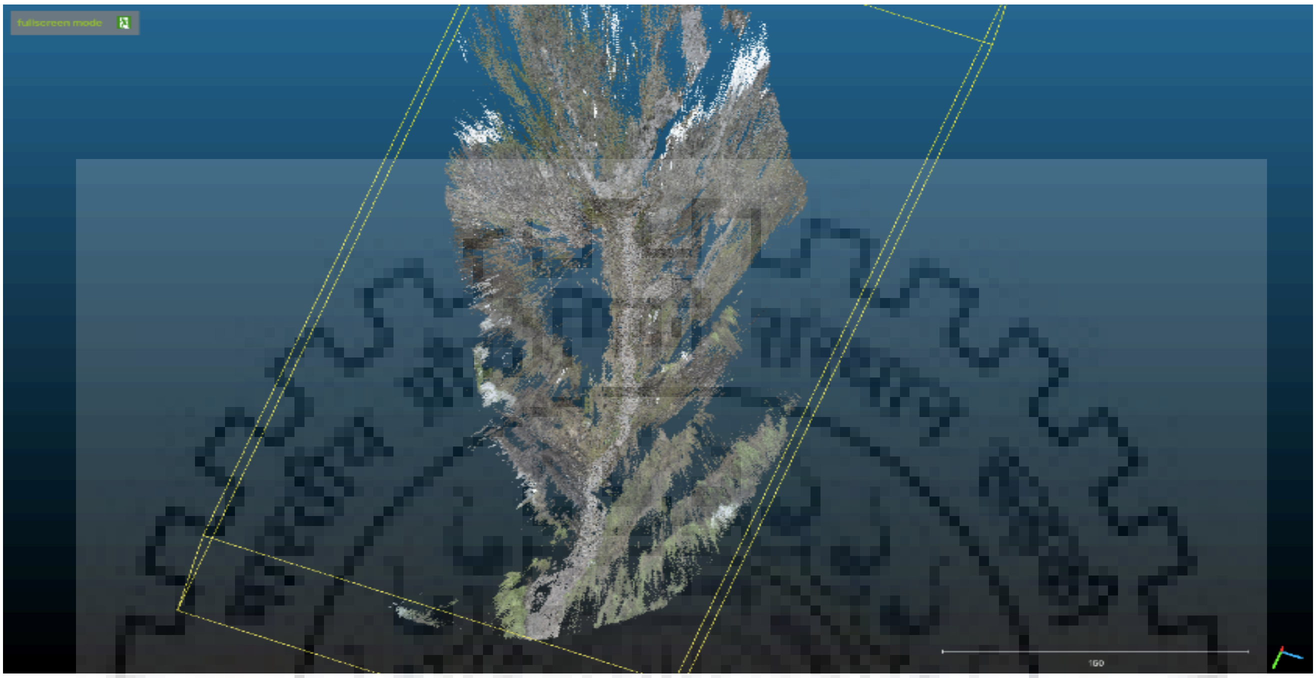


Figure 24 Dense point cloud , Pre-monsoon model

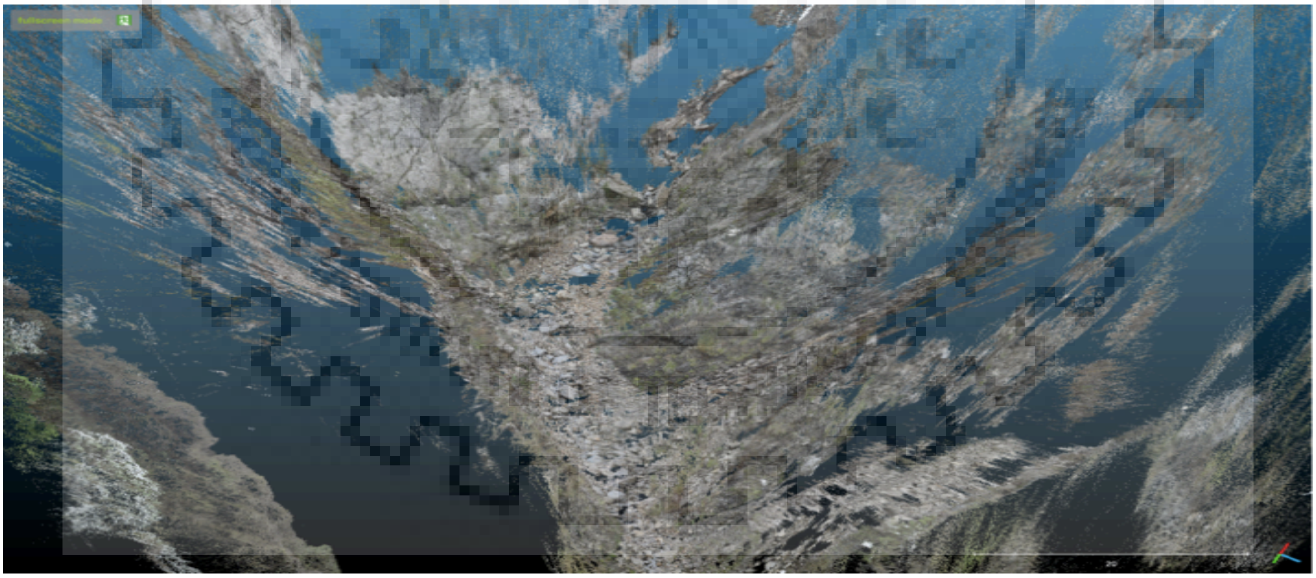


Figure-25 Zoom Image of dense point cloud , Pre-monsoon model

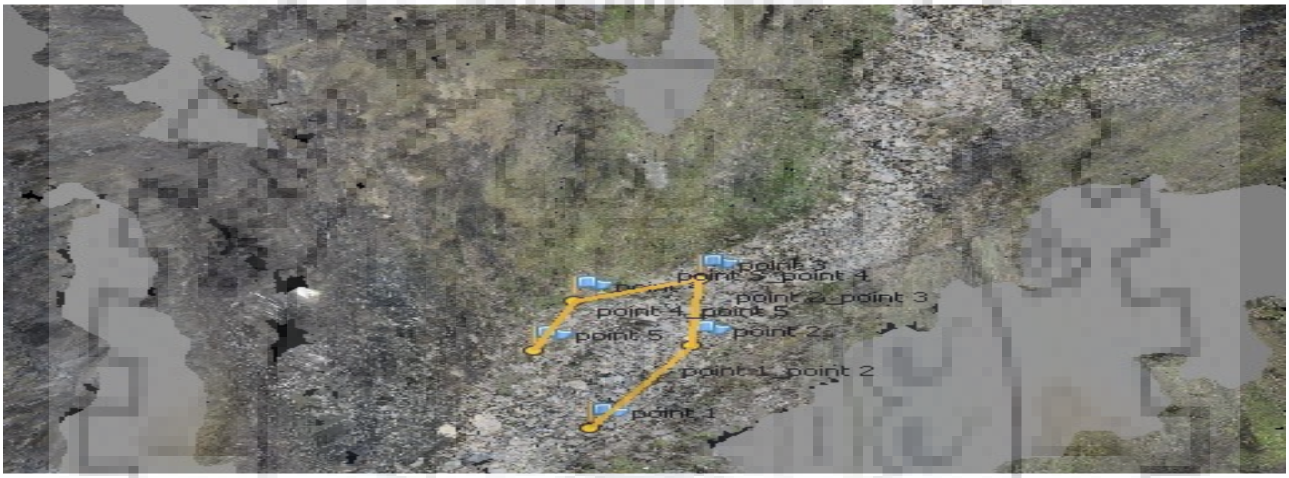


Figure-26 3D solid model with texture and marker , Pre-monsoon

2. Post-monsoon model.

Figure 27 Dense point cloud and solid 3D model Post-monsoon

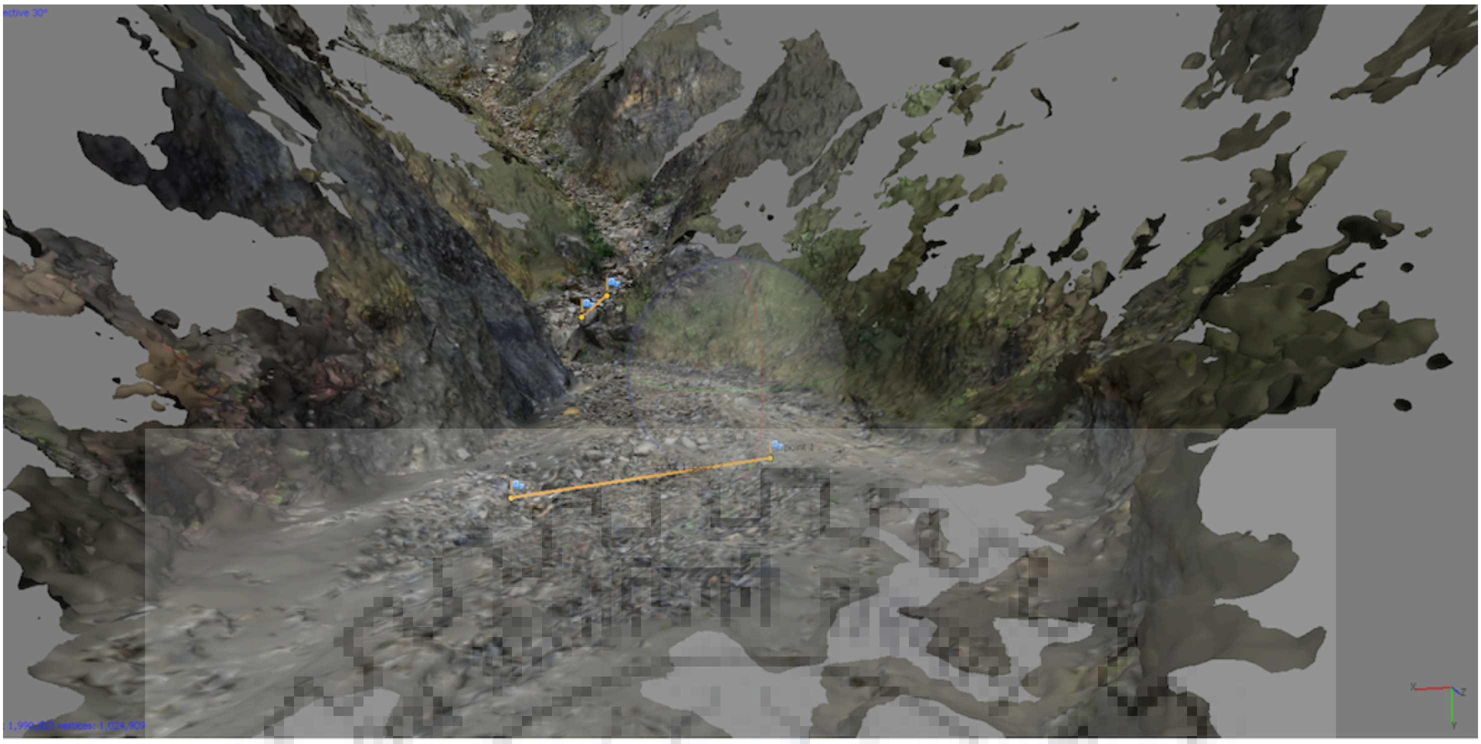


Figure 28 3D model of landslide with texture and markers

3. Surface Area

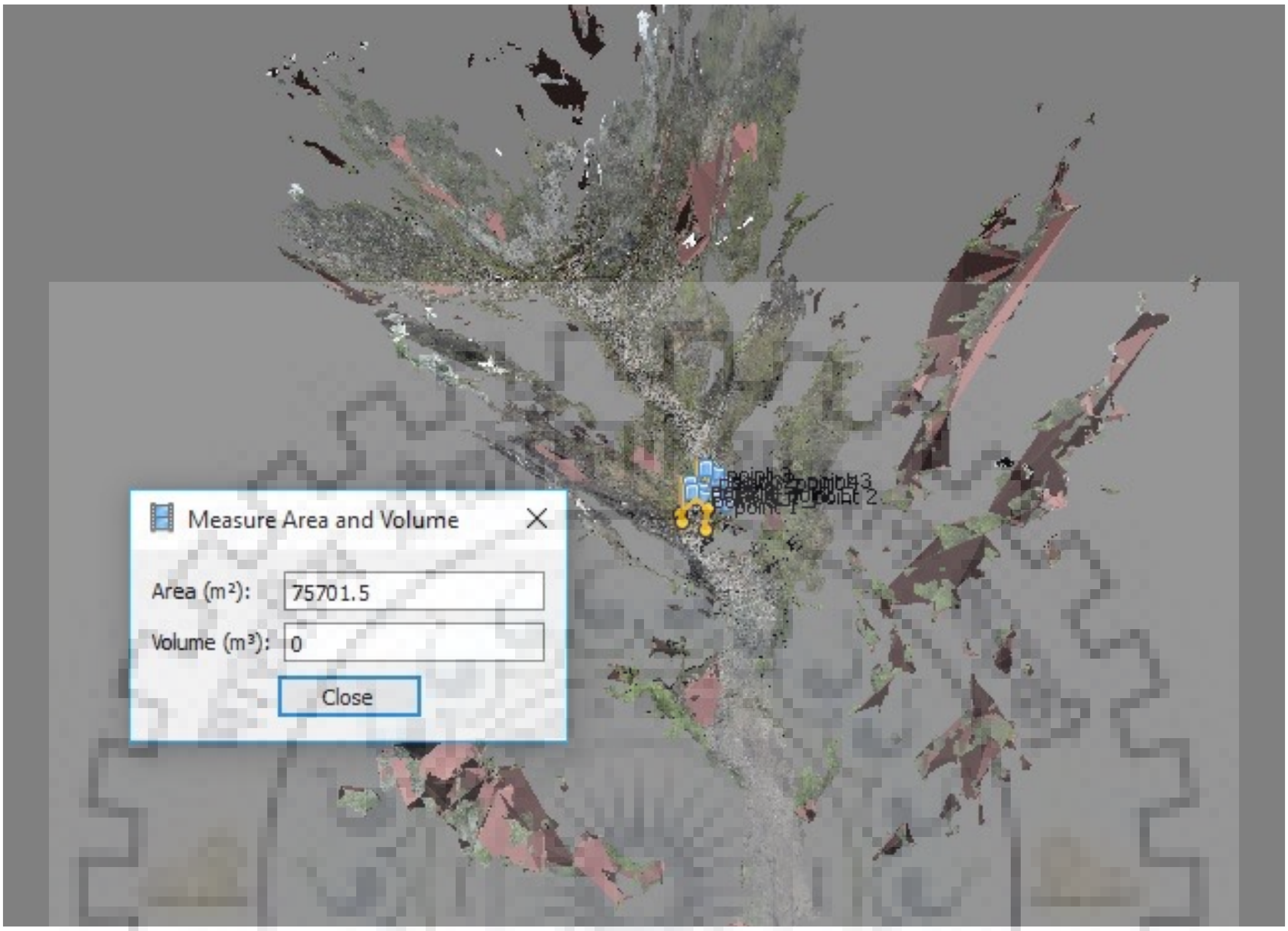


Figure 29 Pre-monsoon 3D model with Surface Area

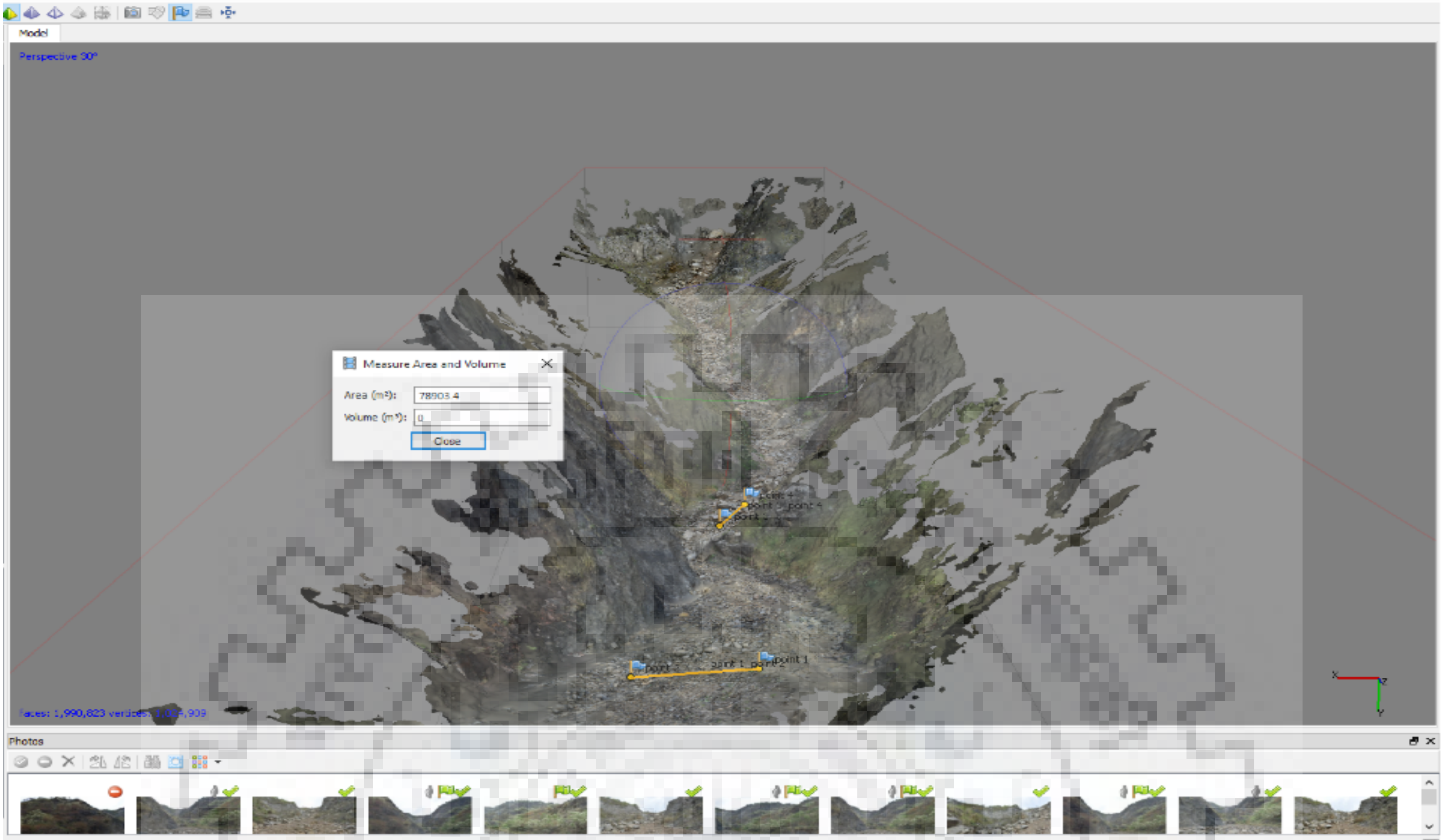


Figure 30 Post-monsoon 3D model with surface area

4. Change in volume

Figure 31 Volume of cavity calculated using Cloudcompare

Discussion

The estimated surface area is :

- Pre-monsoon = 75701.5 meter square
- Post-monsoon = 78903.4 meter square

And the estimated change in volume is = 836732.89 M^3

This confirms that during the whole cycle of monsoon there have been a considerable erosion . Also our results shows a good correlation with the result obtained by Tapas R. Martha, Norman Kerle, Victor Jetten, Cees J. van Westen, and K. Vinod Kumar (Landslide Volumetric Analysis Using Cartosat-1-Derived DEMs) where change in volume was 947000 M^3.

E. Conclusion

Kesharwala (Dehradun) area received an average 1807.2 mm of rainfall throughout the year. The change in the structure of a passive landslide is considerably affected by the erosion taking place because of precipitation. The estimated surface area for Pre-monsoon is 75701.5 meter square and for Post-monsoon is 78903.4 meter square also the estimated change in volume is 836732.89 M^3 .

Using different photogrammetric tools such as satellite data , LIDAR , Terrestrial Laser Scanner have there own limitations and benefits . Close range photogrammetry on the other hand is more simple , less time consuming and cost efficient . Our results shows good co-relation with the previous works done in this area and there for I can say that CRP can be used to monitor the activity of the landslides.

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