UNIVERSITI PUTRA MALAYSIA

EROSION INDUCED LANDSLIDE SUSCEPTIBILITY MAP FOR AGRICULTURE AREA AT CAMERON HIGHLANDS, PAHANG

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BACHELOR OF ENGINEERING

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Erosion Induced Landslide Susceptibility Map for Agriculture Area at Cameron Highlands, Pahang

By

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Report submitted to the Faculty of Engineering, Universiti Putra Malaysia,

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(Agricultural and Biosystem)

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Approval Sheet

This project, entitled "Erosion Induced Landslide Susceptibility Map for Agriculture Area at Cameron Highlands, Pahang" prepared and submitted by NOORFARHAH JASMIN BINTI JAMALUDIN, in partial fulfilment of the requirement for the Bachelor of Engineering (Agriculture and Biosystem) is hereby accepted.

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Abstract

Cameron Highlands is disaster prone area especially landslide which occur every years and causing many damages including land structure and development sector. Other than that, there is very high demand of production in agricultural sector for example fresh vegetables, fruits, flowers, and also tea without realizing this development can cause soil erosion and landslides to occur. Development of Erosion Induced Landslide Susceptibility Map (EILSM) is very important to identify the expected fail slopes in certain area especially for agriculture land and this map was analysed using Frequency Ratio Model. Comparing the accuracy between terrain data from LiDAR and IfSAR, the accuracy of Interferometric Synthetic Aperture Radar (IfSAR) need to be improved using data fusion techniques. The linear regression model and statistical analysis with Light Detection and Ranging (LiDAR) and also GPS points would prove that IfSAR data could be improved at least 30% from before. The improved IfSAR will be validated by developing the Erosion Induced Landslides Susceptibility Map. The frequency ratio model show the improved accuracy of the EILSM map base on each class. The elevation data was selected to perform the data fusion techniques because the coefficient (r^2) was close to 1 which is 0.8843 respectively compared to the slope data r^2 = 0.2203.

Abstrak

Cameron Highlands merupakan kawasan yang sering berlaku bencana terutamanya tanah runtuh pada setiap tahun dan menyebabkan banyak kemusnahan termasuk struktur tanah dan juga kawasan pembangunan. Selain itu, pembukaan kawasan tanaman yang baharu juga bertambah disebabkan oleh pengeluaran permintaan yang meningkat terhadap sector pertanian seperti pengeluaran buah-buahan dan sayuran segar, bunga-bungaan dan juga teh juga menyebabkan hakisan tanah dan tanah runtuh berlaku. Penghasilan Peta Penyebab Hakisan Bencana (EILSM) amatlah penting untuk mengenalpasti kawasan yang dijangka mengalami hakisan cerun terutamanye pada kawasan sector pertanian dan peta ini akan dianalisis menggunakan Model Nisbah Frekuensi. Ketepatan data ketinggian Interferometric Synthetic Aperture Radar (IfSAR) perlu ditingkatkan menggunakan teknik data gabungan. Model regresi linear dan analisis statistik bersama Light Detection and Ranging (LiDAR) dan juga titik GPS dapat membuktikan bawaha data IfSAR dapat dipertingkatkan sekurang-kurangnye sebanyak 30%. Setelah itu, data IfSAR yang telah diubah tersebut akan disahkan kembali ke dalam peta EILSM. Model nisbah frekuensi menunjukkan peningkatan ketepatan terhadap peta EILSM mengikut kelas iaitu kelas tinggi, sederhana, rendah dan paling rendah. Data ketinggian telah dipilih untuk menjalani teknik data gabungan berbanding data kecerunan kerana pekali r^2 data ketinggian lebih dekat terhadap nilai 1 manakala pekali data cerun adalah r^2 = 0.2203.

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Chapter 1: INTRODUCTION

1.1. Background

Landslide is one of the natural processes that can change the shape the of the earth surface. In Malaysia, landslide was occurred mostly in hilly area and also at cut slopes along the road side in highways and also farm area on hill slope. As we all know, Cameron Highlands is one of the largest agriculture producers in Malaysia that supply the high yield of fresh vegetables, various type of flowers and some fruits to all the peninsular Malaysia and also Sabah and Sarawak state and also are one of the tourism attractions in Malaysia because it has cold weather and also beautiful scenery.

At the same time, Cameron Highlands are undergoing rapid development with land clearing for agriculture sector, hotels and also apartments to meet the density of tourists and demand in the agricultural sector but without realizing that can cause erosion and landslides. Some of the landslides incident that occurs in previous years are in December 2016 where landslide occur at kilometer of 55, Tanah Rata – Ringlet Road nearest to Bharat Tea that causing the left lane from Tanah Rata to Ringlet to be temporary closed for over two hours for cleaning work (Berita Harian, 2016). Recently, in February 2018 the landslide incident was occur at Sungai Koyan – Cameron Highlands Road that due to heavy rain over the last few days around the scene was believed to be the cause of the incident (Berita Harian, 2018).

Therefore, the development of Erosion Induced Landslide Susceptibility Map is very important to identify the expected the fail slopes in Cameron Highlands areas and at the same time is bringing the precautions step for the farmers and residences in the hazard phenomenon that will occur in their areas.

1.2. Problem statement

Cameron Highlands is disaster prone area especially landslide that occur every years and causing many damages including land structure and agriculture sector. The current landslide disaster was occur just a month before on 14 October 2018 in Kuala Terla that destroying a foreign worker's home and at the same time having claimed their lives. Other than that, the elevation at Cameron Highland was considered very high of 1829 meters from means sea level (MSL) that receiving a large amount of rainfall in a year compared to other areas in Malaysia. This also can cause the landslides to be occurs due to highest rainfall precipitation there. A lot of agriculture area at the hillslopes that are drained by only small streams that can cause deeply incised erosion. Rapid increasing of uncontrolled agriculture activity and did not have good irrigation and drainage system at hillside areas also be one of the problem statement for producing of erosion induced landslide risk map in Cameron Highlands.

1.3. Research objective

The aim to be achieved at the end of this project was to develop erosion induced landslides susceptibility map.

The objectives are stated as below:

i. To develop Erosion Induced Landslides Susceptibility Map using GIS techniques.

ii. To develop data fusion techniques to improve Interferometric Synthetic Aperture Radar (IfSAR) accuracy.

iii. To assess Improved IfSAR data in development of Erosion Induced Landslides Susceptibility Map.

Chapter 2: LITERATURE RIVIEW

2.1. Landslide analysis

Landslides are a serious geologic hazard common in most countries of the world. Landslide is the movement of mass of rock, debris or earth (soil) down a slope under the influence of gravity. Landslides are also explained as "mass wasting, a comprehensive term for any type of down slope movement of earth materials" (Keller, 1999). The various types of landslides can be differentiated by the kinds of materials involved and the mode of movement. Landslides or slope movement can be divided into six categories namely falls, topples, slides – rotational and translational (shallow and depth), lateral spreads, flows and composites. (Sabri, 2018)

Landslides can triggered by rainfall, earthquakes, volcanic activities, changes in groundwater, disturbances and change of slope profile by construction activities or combinations of these factors. However, more than 80 percent of landslides are at least partially related to human influence, including poor slope management practices.(Rahman & Mapjabil, 2017)

Due to rapid development since the 1980s, strategic and suitable low-lying areas for development have become increasingly unavailable in Malaysia. As a result, the development of highland or hilly terrain has increased, particularly in areas of risk of landslide occurrence. Thus, many hill and their environs are already being developed and many hills project are in the pipe line.(Rahman & Mapjabil, 2017)

There were ten landslide-related factors considered in this analysis. These were transform into a vector type spatial (DEM) creation, 10m interval contours and survey base points showing the elevation values were extracted from the 1:2500 scale topographic map. Using this DEM, slope angle, slope aspect, and attention has been given for slope conditions. Slope configuration and steepness plays an important role in conjunction with lithology. The slope map was reclassified into four classes following the standard classification scheme. (Ardizzone, Cardinali, Galli, Guzzetti, & Reichenbach, 2007a)

2.2. Landslide susceptibility mapping

Landslide susceptibility map only include the preparatory or conditioning factors because these maps show the landslide susceptibility zones. To obtain a landslide hazard map, the return periods of the triggering factors such as heavy rainfall or earthquake should be considered. For this reason, the precipitation map is not considered in this analysis. (Torkashvand, Irani, & Sorur, 2014)

Many methods for landslide mapping make use of digital elevation models of the same area from two different periods. The subtraction of the DEM allows visualizing where displacement due to landslides has taken place, and the quantification of displacement volumes (Van Westen, 2003). The landslide susceptibility map identifies landslide-prone landforms within a large with sufficient accuracy to permit recognition of general areas in which landslides may be expected. The map is not intended to replace site-specific engineering geologic and geotechnical investigations. As a regional-scale tool, the susceptibility map offers substantial benefits over previous susceptibility maps and Cameron Highlands zoning landslide-susceptibility terrain. Rather than defining only one area in which landslides are expected, as does current zoning, or general qualifiers such as “high” and “low” susceptibility as do many susceptibility maps, the susceptibility map provides variable, relative degrees of susceptibility to landslides in four zones (very low, low, medium, high). (Pradhan, Sezer, Gokceoglu, & Buchroithner, 2010)

2.3. Universal Soil Loss Equation (USLE)

The USLE was developed by scientists W. Wischmeier and D. Smith, has been most widely accepted and utilized soil loss equation for over 30 years. The function is to predict average annual soil loss caused by sheet and rill erosion, the USLE is often criticized for its lack of applications. While it can estimate long – term annual soil loss and guide conservationists on proper cropping, management, and conservation practices, it cannot be applied to a specific year or a specific storm. The USLE is mature technology and enhancements to it are limited by the simple equation structure.

The USLE for estimating average annual soil erosion is:

$$A = R \times K \times L \times S \times C \times P$$

Where :

A – Average annual soil loss in (t/ ha/year)
R – The rainfall erosivity index
K – The soil erodibility factor
LS – Topographic factor (L is for slope length and S is for slope)
C – The crop management factor
P – The conversation practice factor

The Revised Universal Soil Loss Equation (RUSLE) continues to be used for similar purposes. The RUSLE is an index method containing factors that represent how climate, soil, topography, and land use affect rill and intern soil erosion caused by raindrop impact and surface runoff. (Sabri & Solahuddeen, n.d.)

The RUSLE, however, does not explicitly represent the fundamental processes of detachment, deposition, and transport by rainfall and runoff, but only represents the effects of these processes on soil loss.

2.4. Light Detection and Ranging (LiDAR)

Light Detection and Ranging (LiDAR) is remote sensing method that uses light in the form of pulsed laser to examine and measure the surface of the Earth. These light pulses will combined with other data recorded by airborne system, thus, it will generate precise, three-dimensional information about the shape of the Earth and its surface characteristics. The three-dimensional laser scanning is a pioneer of the evolution of the noncontact techniques for built up structures survey and documentations. (Ardizzone, Cardinali, Galli, Guzzetti, & Reichenbach, 2007b)

Point cloud data represent the elevation of landscape features including crops, forests, rivers, railways, building and other urban development. Since LiDAR can be reflected from any object the laser pulse strike, up to five returns are collected per pulse. The multiple returns are recorded and each point is assigned a classification to identify landscape features. The intensity of the reflected energy is also captured and can be analyzed to provide additional information on terrain characteristics. The accuracy of the LiDAR data is comparable to contours with an interval of 1 or 2 feet (Ardizzone et al., 2007a).

2.5. Interferometric Synthetic Aperture Radar (IfSAR)

Interferometric Synthetic Aperture Radar (IfSAR) is a radar technique used in geodesy and remote sensing. This technique uses two or more synthetic aperture radar (SAR) imaged to create maps of surface deformation of digital elevation, using differences waves returning to the satellite or airborne. SAR determines the amount of scattered energy returned to the antenna, it is range and position along azimuth. SAR can work in a number of frequencies 0.3 – 9.6 Ghz. IfSAR mapping is a process of creating 3D map products by processing and post-processing of raw collected by using airborne IfSAR system (Li, Baker, Hutt, 2002). Information of the height for scene is obtained from an IfSAR system by using relative phase difference between two coherent SAR images simultaneously acquired by two antennas separated by an across-track baseline in a single-pass mode. (Wei & Coyne, n.d.)

Interferometric Synthetic Aperture Radar (IfSAR) has been used extensively for measuring surface displacements. Unfortunately, in most environments IfSAR applications are limited by problems related to geometric noise due to the different look angles of the two satellite passes and temporal de-correlation of the signal due to scattering characteristic of vegetation, as well as by atmosphere variability in space and time. (Griffiths, 1995)

2.6. Comparisons between LiDAR and IfSAR

There have many specification in comparing the IfSAR and LiDAR for example the sensor type, imagine geometry, on board GPS, the vertical accuracy, the costing and also the common sampling pattern. In sensor type, IfSAR used the microwave sensor that most often use is X-Band that have 3m wavelength whereby for LiDAR, it used near infrared sensor which is the wavelength is 1m. this sensor is active and coherent system.

For imaging geometry specification, IfSAR is use the side looking that is typical incidence angles ranging from 30° to 60° and the angle of IfSAR collection is very limited due to forest penetration. For LiDAR, the imaging geometry is nadir which is the typical incidence angles is 20° and the maximum is 35°. LiDAR is the scanner that can determinate the direct polar coordinate and also it is unlimited to the forest penetration when the scan angles near the nadir.

For the operational conditions, IfSAR is independent to the weather or the light and the airborne can fly very high up to 6000 m to 10000 m. The speed of the flying is 750 km/hour. For the LiDAR, the operation need the weather and the airborne can fly only at 200 m to 2000 m with the speed of 200 km/hour. In this specification show that the LiDAR scanner is more accurate than IfSAR because it take longer time while scanning to the ground and also it very detail in taking the elevation. For common sampling pattern, IfSAR sampling is around the grid 5 m x 5 m and it is like cell integration. For LiDAR the sampling is very detail up to 10 cm to 100 cm and it is depend on the flying height. For the costing, IfSAR is very cheap compare to the LiDAR which is for IfSAr it cost about RM128/km^2 whereby for LiDAR cost much higher up to RM600/km^2. The Ifsar is suitable for the area that has large are and the LiDAR is need the appropriate for accurate and detailed of ground features in forested area.

2.7. Regression and Correlation analysis

Regression and correlation analysis procedures are used to study the relationships between variables. Regression is used to predict the value of one variable based on the value of a different variable. Correlation is a measure of the strength of a relationship between variables. The variables are data which are measured and/or counted in an experiment. (Comrie, 1997)

Regression analysis is used to predict the value of the variable based on the value of a second variable which is controlled by the experimenter. Results may be plotted on a scatter plot as noted earlier. A linear equation in the form of y = mx + b can be calculated for these data. Sometimes the equation is given as y = ax + b and other times it is given as y = a + bx. No matter which form is used, we are interested in the coefficient accompanying the variable (x). (Becker-Reshef, Vermote, Lindeman, & Justice, 2010)

The simple linear regression model calculation:

$$y + e = a + bx$$

Where :

y = dependent variable (LiDAR)
a and b = coefficient
x = independent variable (IfSAR)
e = residual

For the coefficient (r^2), normally we can get direct from the scatter graph but in manual calculation, there also have the formula that need to calculate to get the r^2 value. (Kurtz & Kurtz, 2009)

2.8. The study area in Cameron Highlands

Cameron Highlands in one of the tourism place in Pahang state because of the temperature that lower than other place in Malaysia. Cameron Highlands also the major producer of the fresh flower, vegetables and also tea for the whole Malaysia and also Asia. Base on the Figure 1 below, the catchment or the CH area have 3 which are on the top is Ulu Telom area, the middle is Bertam area and the bottom is Lemoi area. The Ulu Telom area covers the town of Kampung Raja, Kuala Terla, Tringkap and also Kea Farm. For the Bertam area, it is cover the major town in the CH which are Brinchang, Tanah Rata, Habu and also Ringlet area. For Lemoi area is only for the rain catchment and for the permanent forest reserve.

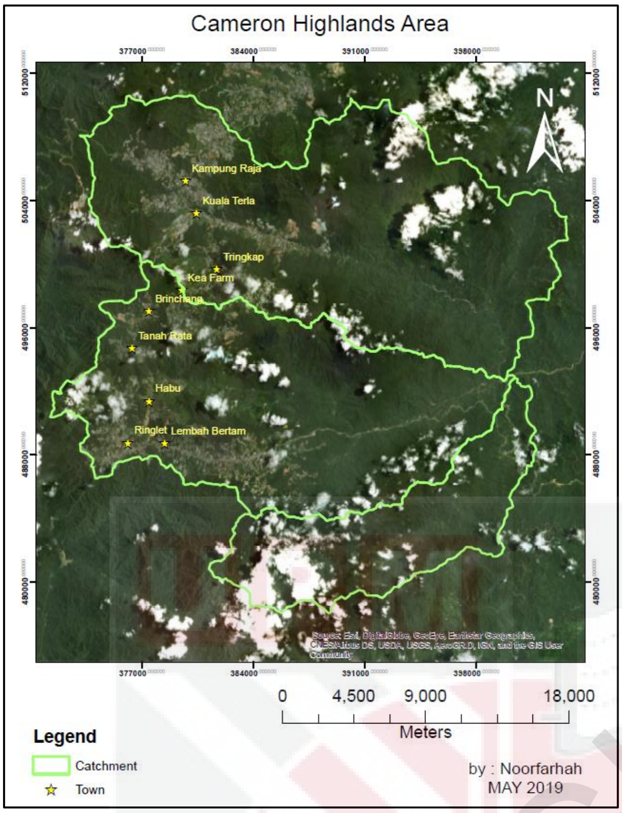


Figure 1: The Cameron Highlands area

Chapter 3: METHODOLOGY

This chapter covers the methodology of the research from the beginning until the end which includes the study area of Cameron Highlands, data collection, data processing in the ArcMap software and also the method of analysis of the data. Figure 2 shows the flow chart for overall process of this project. Erosion induced landslide susceptibility map was being produce by this three objective which it can be differentiate by the column at the side of the chart below. The first one is combination of the Landslide Susceptibility Map and Soil Erosion Map to produce Erosion Induced Landslide Susceptibility Map (EILSM) with analysis of Frequency Ratio Model. The second objective is to develop the data fusion to improve the elevation data of the Interferometric Synthetic Aperture Radar (IfSAR) and the last objective is to validate the data fusion in ArcMap software by producing the new layer of EILSM.

Overall methodology:

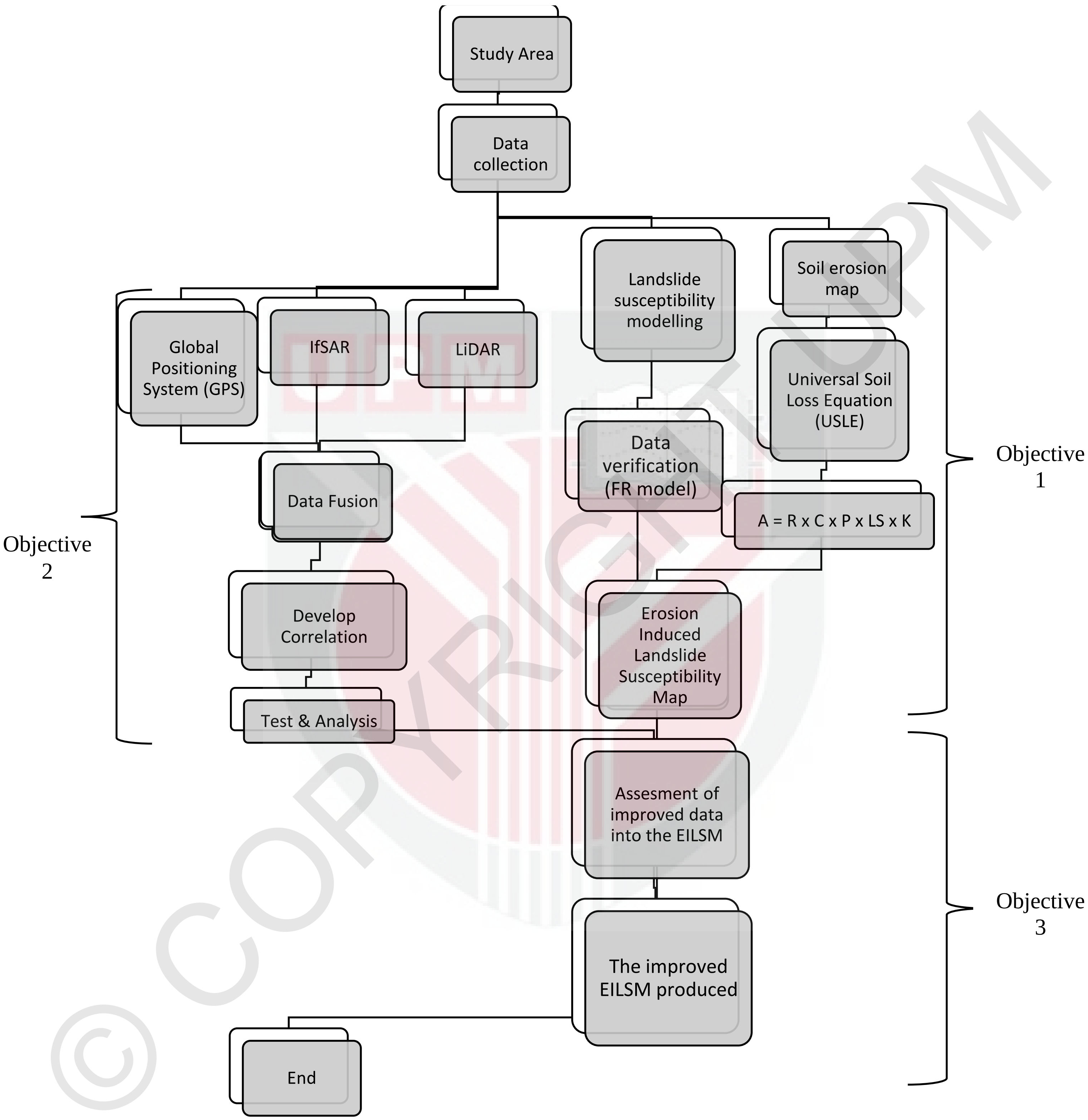


Figure 2 : Flowchart for overall process of this project

3.1. Development of Erosion Induced Landslide Susceptibility Map (EILSM)

This section will discuss the first objective which is development of erosion induced landslide susceptibility map using GIS techniques. By using GIS technique, there two types of map layers that need to combine or overlay which is landslide susceptibility modelling and soil erosion map. The landslide susceptibility modelling were taken into account of the geological factor, slope factor, and annual rainfall factor. Within these factors, the first erosion induced landslide susceptibility map was produce. The step is similar for soil erosion map of Universal Soil Loss Equation (USLE). Some of the factor that involved in this equation are rainfall runoff erosive factor (R), soil erodibility (K), terrain factors (LS), land cover and management factor (C), and also conservation practices factor (P).

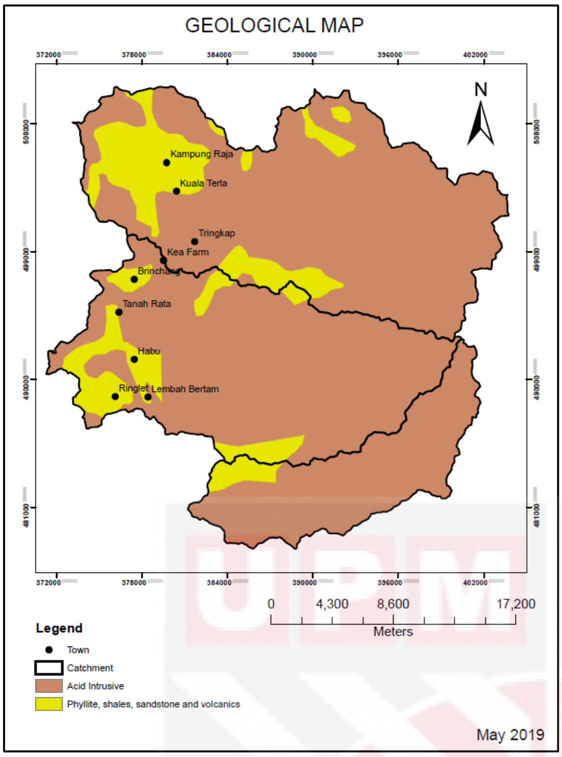
3.1.1. Landslide Susceptibility Modelling (LS)

In order to prepare the susceptibility maps, normally 11 thematic layers (slope gradient, slope aspect, plan curvature, altitude, SPI, TWI, lithology, land use, distance from faults, distance from rivers, and distance from highway) were used as the input data but in this study, only 3 factors (geological, slope and annual rainfall) has been used. The landslide susceptibility map is able to identify and characterize the susceptibility of the different zones and also can help to focus on the specific hazardous areas in Cameron Highlands.

The step in the landslide susceptibility model involved the combination between geological data, slope data and also annual rainfall data using the Spatial Analyst Tool that use the Fuzzy Overlay method in ArcMap 10.3 software. Figure 2 below shows the Geological Map that has two classes. The brown class colour is for Acid Intrusive lithology and for the yellow class is for Phyllite, Shales, Limestones, Sandstone and Volcanic lithology. The original Geological data is from Jabatan Mineral and Geosains Malaysia (JMG) in year 2004. This yellow lithology is very prone to landslide than the intrusive rocks because this intrusive rock was form deep in the earth crust and it will not easily collapse due to hard rock characteristic.

For Annual Rainfall Map provides 4 classes of rainfall stages which are High (blue), Medium (light blue), Low (light brown) and Very Low (dark brown) as shown in Figure 3. This annual rainfall data source from the annual rainfall information starting year of 2007 until 2017 and there also have 11 Rainfall Stations places in Cameron Highlands area and it were managed by Tenaga Nasional Berhad (TNB) and also Department of Irrigation and Drainage (DID) there. This annual rainfall data will use the IDW interpolation in Spatial Analyst Tool which called the Inverse Distance Weighted technique that can interpolate a raster surface in ArcMap 10.3 software.

For the slope data, there are two data which from different sources of Digital Elevation Model (DEM). The first one is from radar techniques of Interferometric Synthetic Aperture Radar (IfSAR) and the other one is the remote sensing method of Light Detection and Ranging (LiDAR) (see Figure 4 and 5). The classification of this map have 4 classes which are very low (dark green), low (light green), medium (orange) and also high (red). This three maps were combined to produce the Landslide Susceptibility Map that classified into High (red), Medium (orange), Low (light green), and Very Low (dark green). Both slope data will use the Surface Hillshade and Slope method in Spatial Analyst Tool in ArcMap 10.3 to identify the slope gradient from each cell of the raster surface.



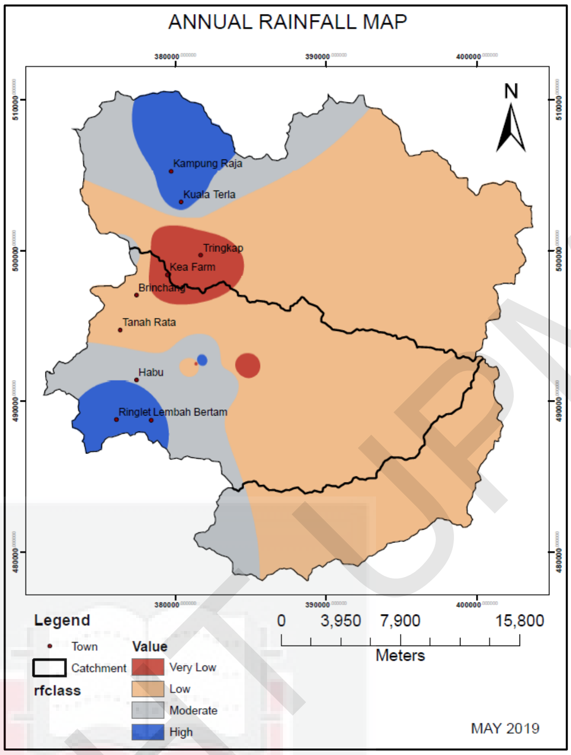
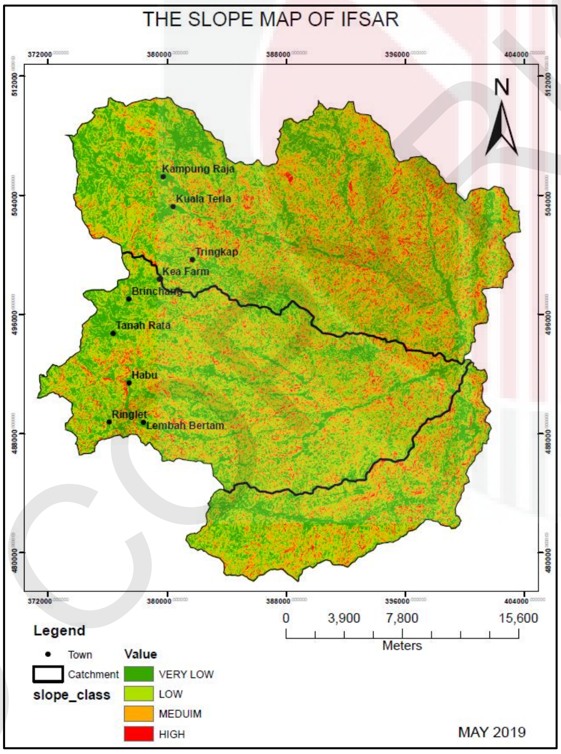


Figure 3: The Geological map

Figure 4: Annual Rainfall map



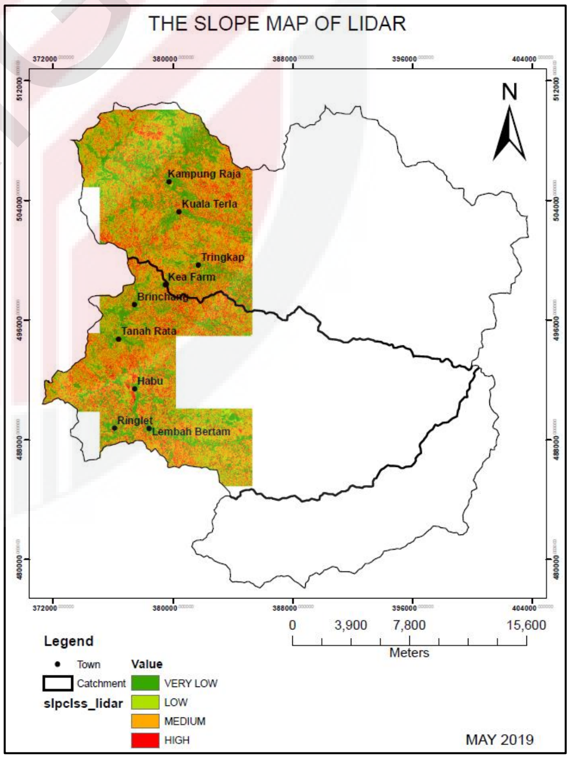


Figure 5 : The Slope map of IfSAR

Figure 6 : The Slope map of LiDAR

3.1.2. The Soil Erosion map

In producing the Erosion Induced Landslide Susceptibility Map (EILSM), the Landslide Susceptibility Map needs to combine with the soil erosion factor that uses the equation of Universal Soil Loss Equation (USLE). This USLE is widely used in mathematical model to describe the soil erosion process. There have 5 factors that involved in this equation are rainfall runoff erosive factor (R), soil erodibility (K), terrain factors (LS), land cover and management factor (C), and also conservation practices factor (P). All of this factor will be multiplied and the soil erosion rate can be produced. This process perform in ArcMap 10.3 software that use the Raster calculator of Map Algebra in Spatial Analyst Tool and the function is to build and execute a single map algebra expression using Python syntax in a normal calculator and it form like interface method.

For the rainfall erosivity factor (R) in Figure 7, it being determine by the calculation of R value and this factor also demonstrate the kind of erosion stimulated by rainfall and runoff on soil surface of a particular place. Compared to lowlands, the amount of rainfall in Cameron Highland is higher because of higher humidity and low evaporation. The highest annual precipitation of rainfall that be recorded was in year 2008 which is up to 3358 mm and the lowest is in year 2015 only 605.5 mm. Similar with the annual rainfall factor on LS map, this annual precipitate data source from the annual rainfall information starting year of 2007 until 2017 and there also have 11 Rainfall Gauge Stations places in Cameron Highlands area and it were managed by Tenaga Nasional Berhad (TNB) and also Department of Irrigation and Drainage (DID).

For soil erodibility factor (K) is considering as a static value for the type of soil. Cameron Highlands have only 2 soil types which is the first one is the soil of the hills and mountain series (STP) and the second is the Serdang Kedah Durian Association series (SDG-KDH-DG). In the figure, K factor map show there only has 2 classes which the blue colour is SDG-KDH-DG soil series with K factor of 0.1160 and milky yellow colour is STP series with K factor of 0.1100 as shown in Figure 8. The soil map was obtained from Malaysian Department of Agriculture (DOA).

For terrain factors (LS) is the topographic that influences the transition of the sediment and also the characteristic of the runoff through the line. This LS factor needs to perform some calculation from the flow accumulation, cell size and also slope parameter. In ArcMap 10.3, the DEM Fill and flow Direction of Hydrology method in Spatial Analyst Tool section were used to find the flow accumulation of the LS map as function of creating the raster of accumulated flow by applied the weight factor. After that the calculation was performed in Raster Calculator in Map Algebra to find the LS factor and this dimensionless factor produced the number from 1 up to 30. In this project, LiDAR and IfSAR DEM were used to calculate the LS factor and the raw data is similar to the slope map in Landslide Susceptibility map and the classification of the LS map was same as the slope in degree unit as shown in Figure 9 and 10.

For Land cover and management factor (C) in Figure 11, there have 10 factors the involved from the number 0.0 until 1. The function of this C factor is use to control the vegetation and the soil cultivation so that the erosion can be reduce if the vegetation is higher due to the reforestation. This C factor was identified have some classes to differentiate the activities that held in the land of Cameron Highlands. The 0.0 factor show the water body in area of Ringlet. For the 0.3 factor, it shows the forest land and also scrub that majority covers all the

Cameron Highlands map. Market gardening shows the factor of 0.35 as in the map shows it cover the top of the CH area. Factor 1 (red) listed the mining and also bare land in Tanah Rata area.

For the Conservation Practices factor (P) in Figure 12, there have 5 factors listed which are classified by bare land, contour planning, grass strip, rain shelter and also traditional terraces. The function of this P factor is explaining the effect of practices with some factors for example sheltered and unsheltered crop cover, terracing, contouring land, and also subsurface drainage. The source of this P factor is from Department of Agriculture (DOA) and it performs by digitizing shape file method in ArcMap 10.3 software.

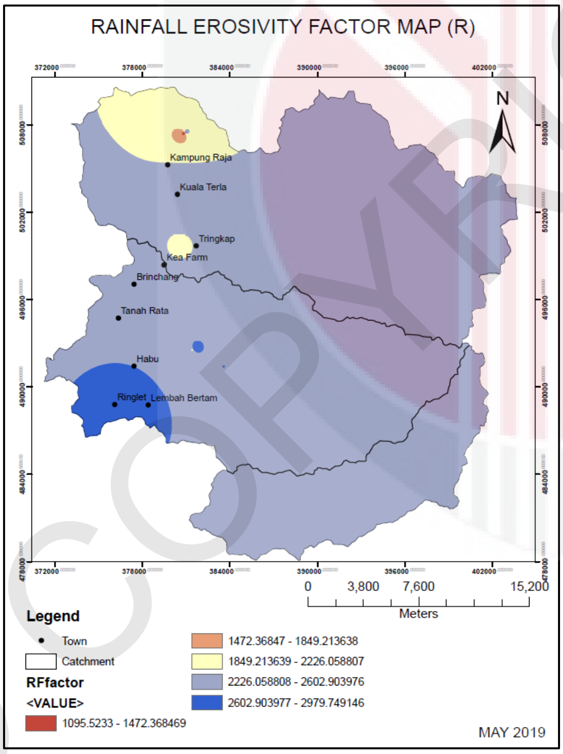


Figure 7 : The Rainfall Erosivity Factor map (R)

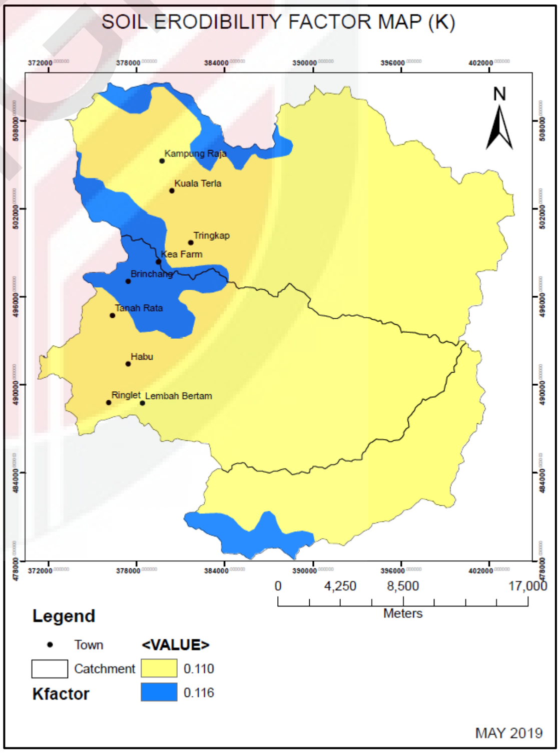


Figure 8 : The Soil Erodibility Factor map (K)

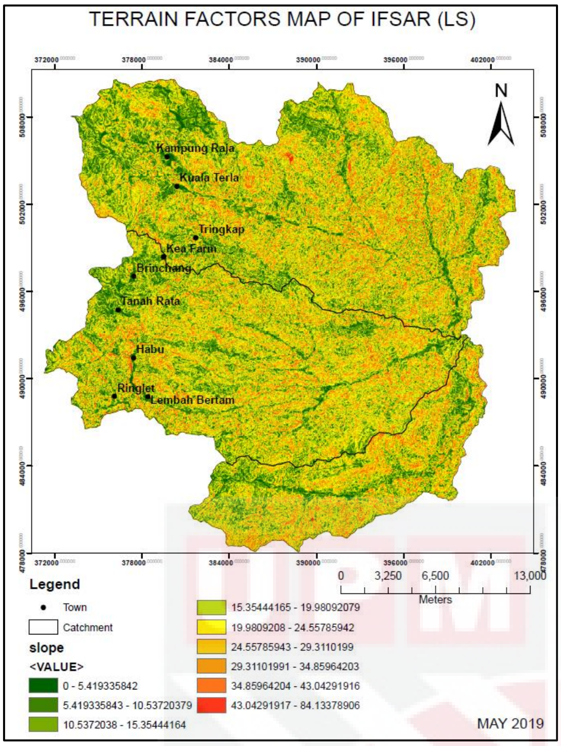


Figure 9 : The Terrain Factors map of IfSAR

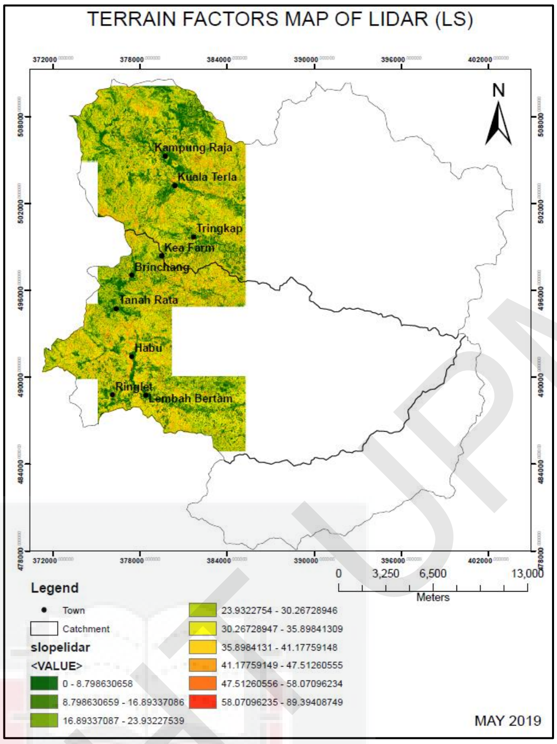


Figure 10 : The Terrain Factors map of LiDAR

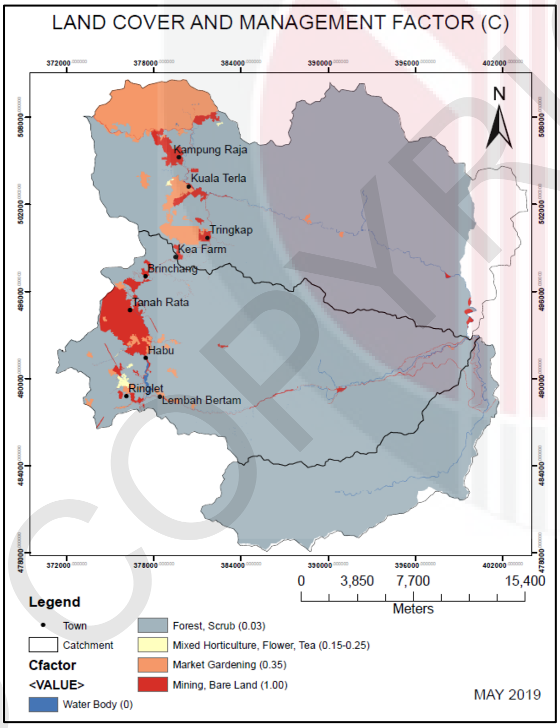


Figure 11 : The Land Cover Factor (C)

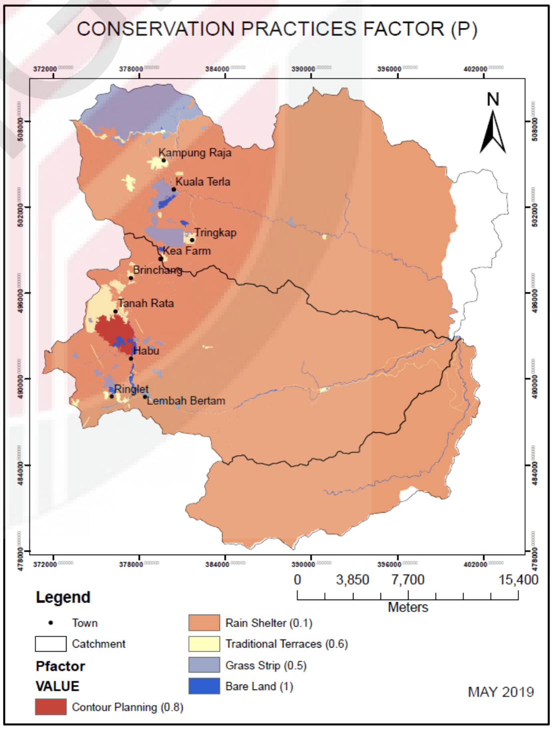


Figure 12 : The Conversation Practices Factor (P)

3.2. The Frequency Ratio Modelling (FR)

The frequency ratio model is the susceptibility analysis modelling that use to verify this landslide susceptibility map using the landslide inventory data. Form the literature, Frequency Ration proved that it can increase the accuracy of the map and at the same time it can be more specific to the weighted of the data. The first step in frequency ratio modelling analysis is to acquire information about the landslides that have occurred in the past which called landslide inventory map. A landslide inventory map provides the basic information for evaluating landslide hazards or risk on a regional scale. Accurate detection of the location of landslides is most important for probabilistic landslide susceptibility analysis. For landslide inventory mapping, both the desk study and field study were performed.

First of all, the aerial photographs of the area were analysed and the landslide inventory map was created, and this was rechecked during the field surveys. Afterward, the ratio of landslide occurrence and non-occurrence was calculated for each factor and the area ratio for each factor to the total area was calculated. Finally, the frequency ratios for each range or factor type were calculated by dividing the landslide occurrence ratio by the area ratio. Below are the formula of frequency ratio and the table of the calculation of the FR.

$$FR = \frac{\%\ of\ the\ occurence}{\%\ N}$$

Where:

N = number of pixels
Occurrence = pixels in domain

In this study at Cameron Highlands, there have about 625 points of landslides inventory data. Some of the points are outside from catchment so this inventory there cannot be validate because for this case, the study area is within inside the catchment only. There have 90 points of landslide inventory that outside from the catchment.

Figure 13 below show the inventory point inside the catchment and here have 535 point of it and this point will be calculate in each of factor of the landslide susceptibility map (geological, slope, annual rainfall) before it be used to develop the EILSM with Frequency ratio model.

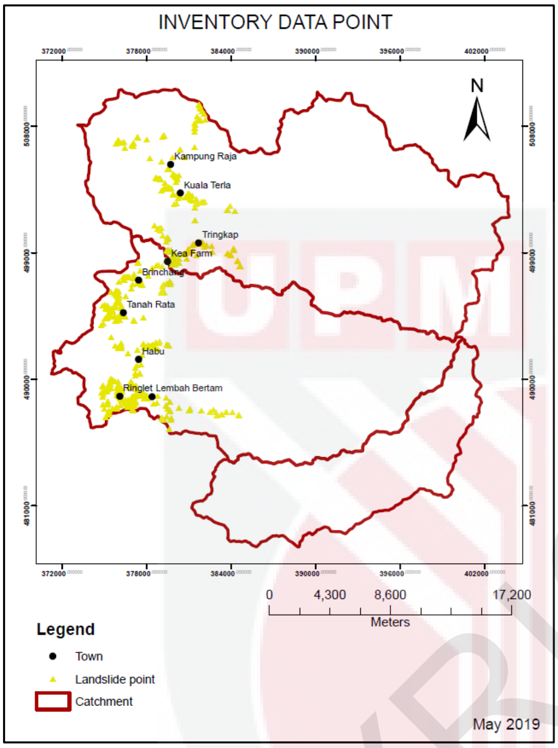


Figure 13 : The Landslide Inventory Data

3.3. Data fusion techniques of improving the Interferometric Synthetic Aperture Radar (IfSAR)

The second objective is the development of data fusion technique to improve IfSAR data accuracy. The linear regression model equation was used in order to create the new IfSAR dataset and the error factor. So for this achievement, the improved of IfSAR data accuracy must similar or slightly same to the LiDAR and GIS data so that the land susceptibility can be decrease in terms of error. After the data fusion is done, the correlation between them will be analysed directly before the final erosion landslide susceptibility risk map was being developed successfully.

3.3.1. The 400 points analysis from slope and elevation of the IfSAR and LiDAR

In this objective, the first step that needed to achieve this objective is extracting the elevation and slope data from the attribute table of ArcMap 10.3 software to the Microsoft Excel. The classes of the slope and elevation data were shown in Table 1 below. The randomly 400 points in all classes which are high, medium, low and very low was picked and each of the class has 100 points in both IfSAR and LiDAR data as shown in Figure 14.

After the extraction of slope and elevation data in to excel, the scatter graph was created with additional of trendline options (equation of chart and r^2 value) and it directly show which of this data that have the highest correlation. Elevation data is more precise than slope data so that the elevation will be proceed with another step. This is because, the graph of the elevation coefficient (r^2 = 0.8843) is nearest to 1 compare to the slope data (r^2 = 0.2203) as we can see in Figure 17 and 18. The Figure 15 and 16 show the elevation map of the IfSAR and LiDAR.

In the linear regression equation, the LiDAR data will be the Y and the IfSAR will be the X. It is follow the equation of the linear regression equation with the function of y=f(x) that represent a mathematical model. The function of this analysis is to find the best fit of the data to predict the value of y from knowing the value of x.

Table 1 : The classes of the data

Classes	Slope	Elevation
HIGH	0° - 15°	0 – 1098.45
MEDIUM	15° - 25°	1098.45 – 1337.24
LOW	25° - 35°	1337.24 – 1544.195
VERY LOW	>35°	> 1544.195

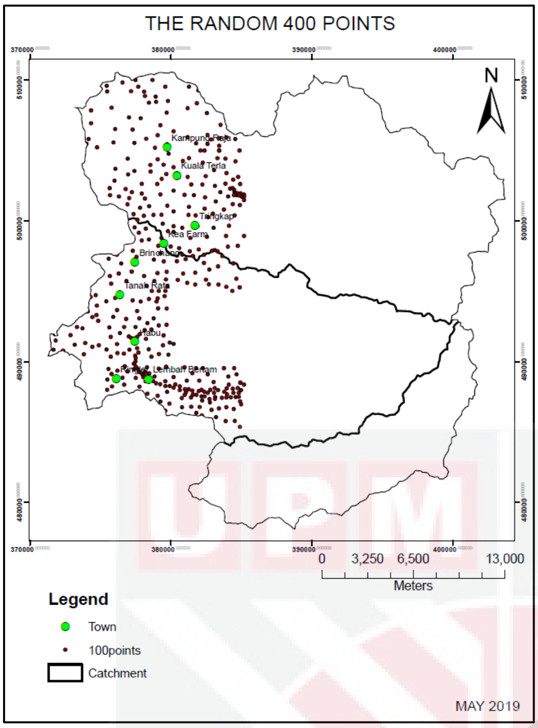


Figure 14 : The random 400 points map

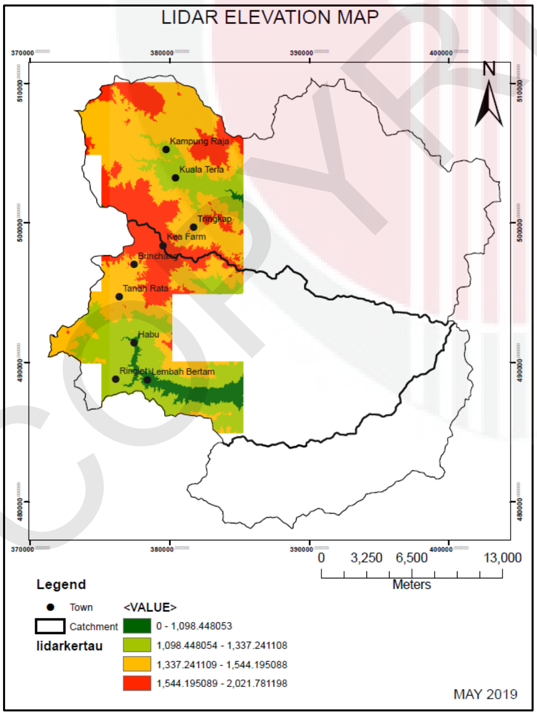


Figure 15 : The LiDAR elevation map

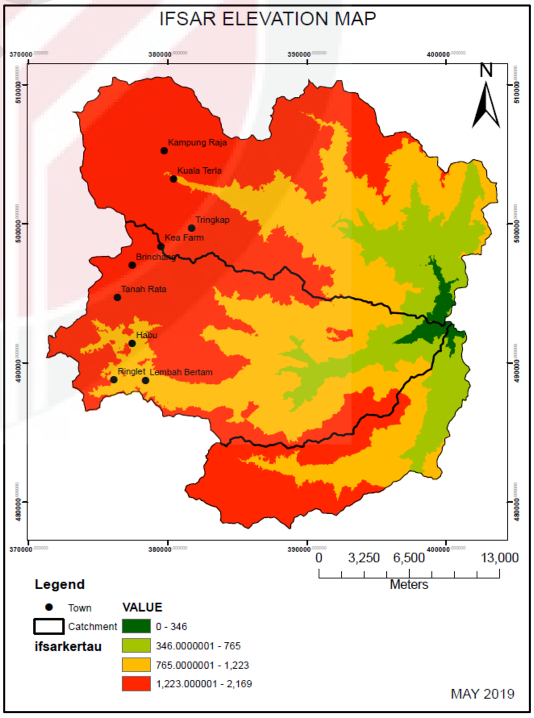


Figure 16 : The IfSAR elevation map

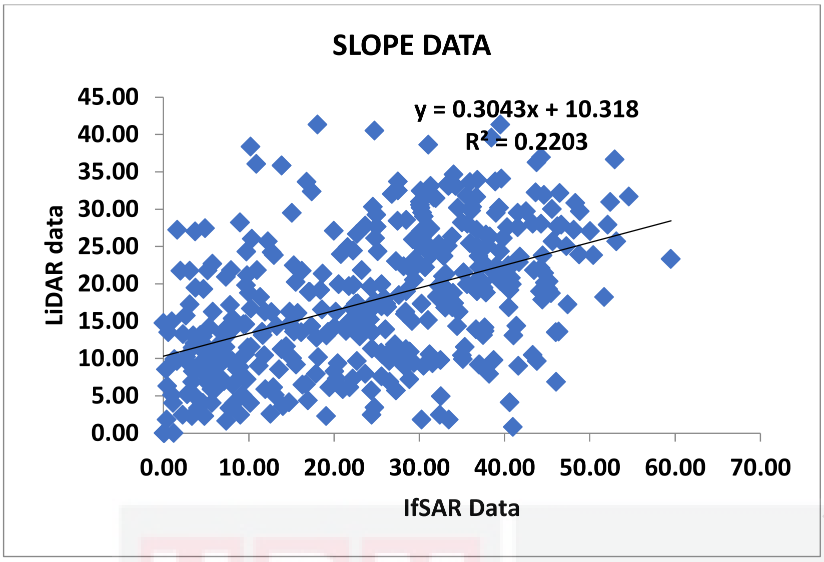


Figure 17 : The slope graph distribution

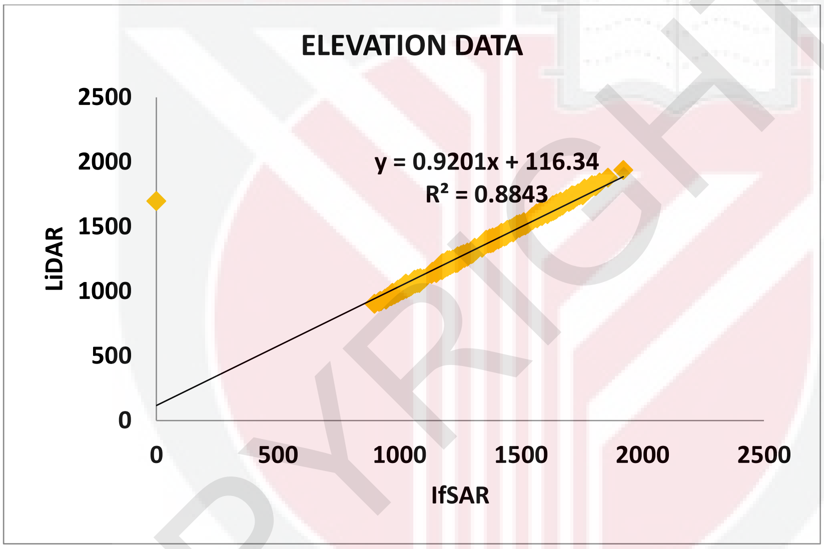


Figure 18 : The elevation graph distribution

3.3.2. The regression modelling of elevation data

The regression analysis model is use to predict the y variable from the x variable while the correlation is to study the strength of the relationship that will exist between variables. In this project, regression model was choose to predict the y which is the improved IfSAR from the y = f(x) equation. The first task in regression is to find the best fit of the elevation data followed by equation like below until getting the square error factor. Then the result of the error factor need to plus with the different of the LiDAR data and improved IfSAR to get the improvement value:

- The simple linear regression model

$$y + e = a + bx$$

Where :

y = dependent variable (LiDAR)
a and b = coefficient
x = independent variable (IfSAR)
e = residual

- The predict $\hat{Y}i$ equation

$$\hat{Y}i = a + b\,x_i$$

Where :

$\hat{Y}i$ = predicted (*improved IfSAR data)*
a and b = coefficient
x = independent variable (IfSAR)

- Sum of square total, SST =

$$SST = \sum_{i=1}^{n} (yi - \bar{y})^2$$

Where :

y_i = LiDAR data
$\bar{y}$ = the mean of LiDAR

- Sum of square error, SSE =

$$SSE = e^2 = \sum_{i=1}^{n} (yi - \hat{Y}i)^2$$

Where :

y_i = LiDAR data
$\hat{Y}i$ = *improved IfSAR data*

- Sum of square regression, SSR =

$$SSR = \sum_{i=1}^{n} (\hat{Y}i - \bar{y})^2$$

Where :

$\bar{y}$ = the mean of LiDAR
$\hat{Y}i$ = *improved IfSAR data*

- Coefficient of the sample, r^2 =

$$r^2 = \frac{SSR}{SST}$$

- Mean square regression, MSR & Mean square error, MSE =

$$MSR = \frac{SSR}{1}$$

$$MSE = \frac{SSR}{n-2}$$

- Square error, Se =

$$s_e = \sqrt{MSE} = \sqrt{\frac{SSE}{n-2}}$$

- Different of LiDAR and improved IfSAR

$$diff = (y_i - \hat{Y}_i) + S_e$$

Where :

y_i = LiDAR data

$\hat{Y}i$ = *Improved IfSAR data*

S_e = Square error factor

3.3.3. The validation of elevation data with JUPEM data

To confirm the probability of the data set, the GPS elevation data point was bought from the Department of Survey and Mapping Malaysia (JUPEM) as the third variables that can be used as the reference to determine the accuracy of the previous elevation data in Cameron Highlands which is LiDAR and IfSAR data. The reason why JUPEM point is valid is because it is updated every year compare to the other survey point. Unfortunately, there are only 5 points in Cameron Highlands available and this data is used to run some of the statistical calculation to identify whether the initial data is in the similarities of the other data as shown in Figure 19. In Table 2, the reason why the value of LiDAR data is zero at the GPS point is the LiDAR limitation coverage due to the cost of the airborne is much higher compare to IfSAR data. Figure 20 and 21 show the JUPEM point the located in the map LiDAR and IfSAR.

The statistic experiments that have been done are the student t-test and also analysis of variance (ANOVA) which also known as F-ratio tests. The t-test and ANOVA test are the parametric test that describe the population of the variable being sampled and test is normal and the measurement of the variables is in the internal or ratio scale. The different of the t-test and ANOVA is the number or test sample that going to held. For the t-test, its only need 2 samples where the ANOVA test need more than 2 samples. The t-test critical region uses the T distribution table where the ANOVA test needs F table distribution to find the critical region.

Table 2 : The elevation data of IfSAR, LiDAR and JUPEM

No	Name	Ifsarkertau	Lidarkertau	Elevation JUPEM & GPS
1	P212	1078	1073.930054	1067.995
2	P352	1247	1236.51001	1291.085
3	P213	1242	1248.349976	1220.961
4	P269	1006	0	996.764
5	TG59	1734	0	1798.45
6	GPS 1	210	0	207.628
7	GPS 2	250	0	210.737
8	GPS 3	279	0	234.027
9	GPS 4	222	0	187.328
10	GPS 5	244	0	227.733
11	GPS 6	203	0	197.157
12	GPS 7	185	0	175.413
13	GPS 8	202	0	173.407

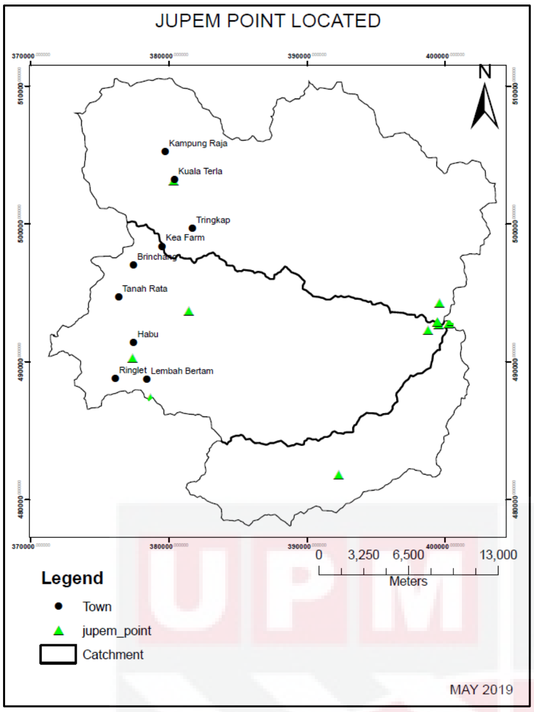


Figure 19 : The location of JUPEM GPS point

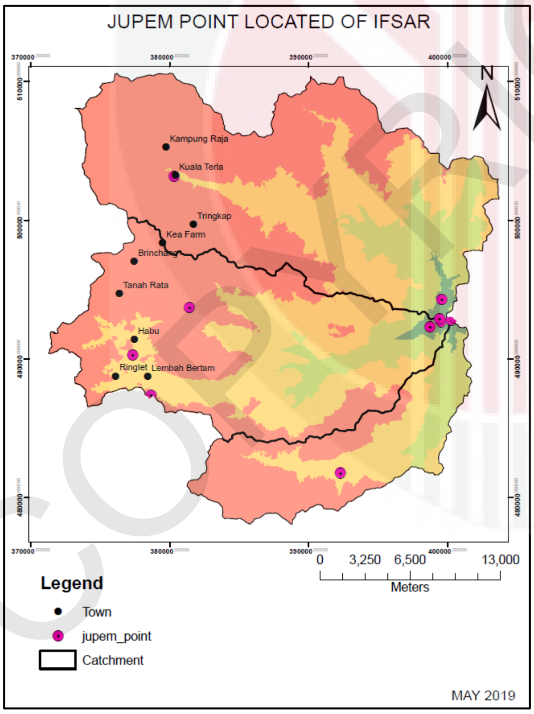


Figure 20 : The JUPEM point in IfSAR

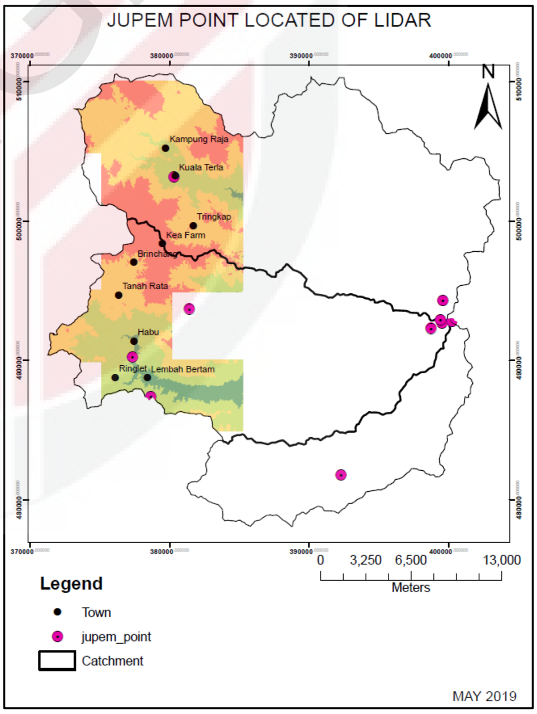


Figure 21 : The JUPEM point in LiDAR

To calculate the t-test, some of the calculation need to be consider as below:

- The degree of freedom, V =

$$v = n_x + n_y - 2$$

- The statistic test (t_{cal}) , t =

$$t = \frac{|\bar{x} - \bar{y}|}{\sqrt{\dfrac{\dfrac{\sum_{i=1}^{n_x} x_i^2}{n_x} - \bar{x}^2}{n_x - 1} + \dfrac{\dfrac{\sum_{i=1}^{n_y} y_i^2}{n_y} - \bar{y}^2}{n_y - 1}}}$$

Where :

$\bar{x}$ & $\bar{y}$ = The mean of sample group x and y

n_x & n_y = The size of two sample groups

To calculate the ANOVA test, some of the calculation need to be consider as below :

- The degree of the freedom, V_1 & V_1 =

$$v_1 = (k - 1)$$

$$v_2 = (N - k)$$

v_1 (variance between groups) and v_2 (variance within groups)

- The variance within group=

$$s_W^2 = \frac{\sum_{i=1}^{nj} (xi - \bar{x}j)^2}{N - k}$$

Where :

$\bar{x}$ = The mean of j

k = The number of sample groups

N = The total number of elements in all sample group

- The variance between group =

$$s_B^2 = \frac{\sum_{j=1}^{k} nj(\bar{x}j - \bar{x}G)^2}{k-1}$$

$$\bar{x}_G = \frac{\sum xi}{k}$$

Where :
$\bar{x}$ = The mean of j
$\bar{x}_G$ = The grand mean of all elements
k = The number of sample groups

- The statistic test (F_{cal}) , F =

$$F = \frac{s_B^2}{s_W^2}$$

If the statistics analysis data is accepted, the linear regression equation can be proceed to the ArcMap 10.3 software that needed to interpolate or do the data fusion of the IfSAR data in the map.

3.4. Development the improved IfSAR data

The last objective is assessment of improved IfSAR data in development of erosion induced landslide susceptibility map. After improving the IfSAR data in objective two, the data must be used as input in EILSM. Once the validation of improved IfSAR was accepted, the linear regression equation needs to be added in the layer of ArcMap 10.3 software using the Raster Calculator method of Map Algebra in Spatial Analyst Tool.

$$Raster\ Calculator, y = 0.9201x + 116.34$$

Where :
x = IfSAR data
y = Improved IfSAR

Chapter 4: RESULT AND DISCUSSION

4.1. The output of Erosion Induced Landslide Susceptibility Map (EILSM)

The Erosion Induced Landslide Susceptibility Map (EILSM) is the combination of potential event and probability of occurrence from Landslide susceptibility and also Soil Erosion map using weighted overlay method in ArcMap 10.3 Toolbox. The map was categorised into 4 classes which are high (red), medium (orange), low (light green) and very low (green) that use natural breaks classification step. Figure 22, 24 and 26 below show the map of the Landslide Susceptibility Map, Soil Erosion Map and also the Erosion Induced Landslide Susceptibility Map. There are 2 types of maps one of which uses Interferometric Synthetic Aperture Radar (IfSAR) data and also Light Detection and Ranging (LiDAR) as input. Basically the difference between these two depends from the Digital Elevation which is the slope factor. As we can see in Figure 23, 25 and 27, LiDAR only cover certain area of Cameron Highlands compared to IfSAR map because the LiDAR scanner was very expensive than IfSAR and the accuracy of was much higher and very detailed.

Table 3 below shows the percentage counting area of the EILSM of LiDAR and IfSAR. The percentage of LiDAR is much higher than IfSAR map and this show that LiDAR data is more accurate and precise than IfSAR. The elevation scanning in LiDAR is more detailed because for the medium class for example, LiDAR can detect more area about 17.84% compared to the medium class in IfSAR 8.33% only. Similar to very low class, LiDAR can produce up to 36.49% of the area and IfSAR only can detect 22.92%. Hence, the Interferometric Synthetic Aperture Radar (IfSAR) need to be improve in term of accuracy so that it might approach or similar to the accuracy of the LiDAR DEM data.

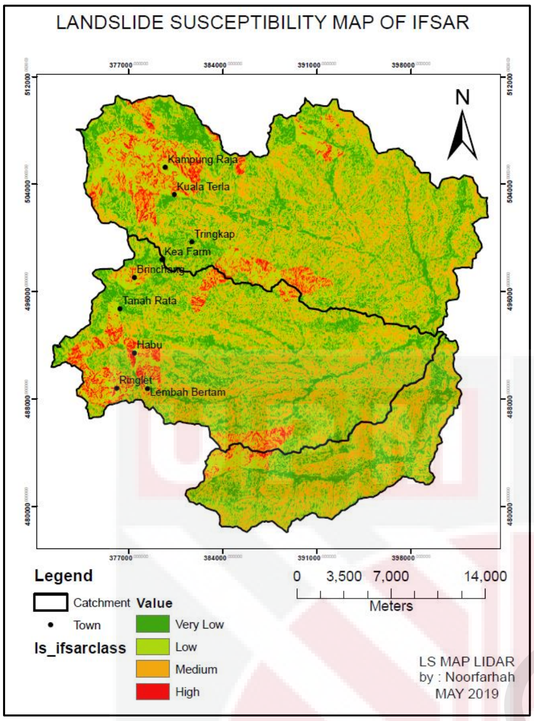


Figure 22 : The LS map of IfSAR

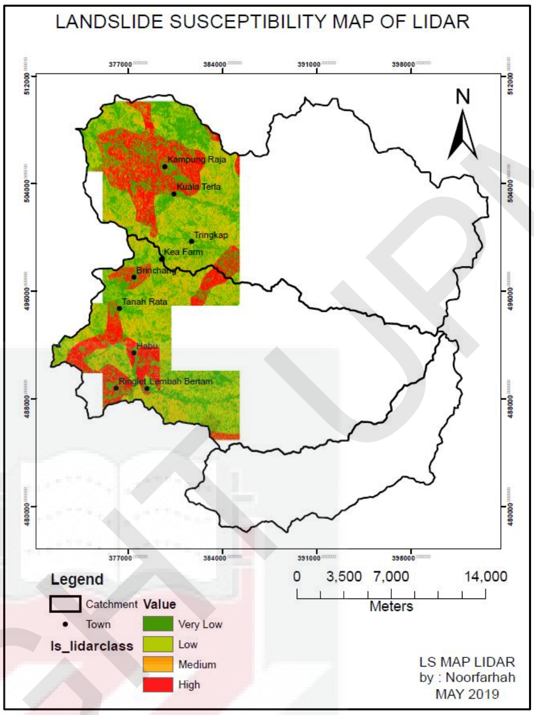


Figure 23 : The LS map of LiDAR

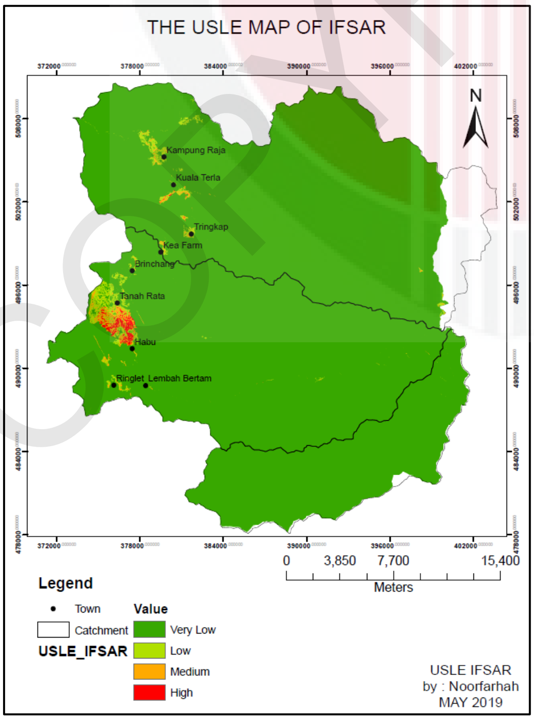


Figure 24 : The USLE map of IfSAR

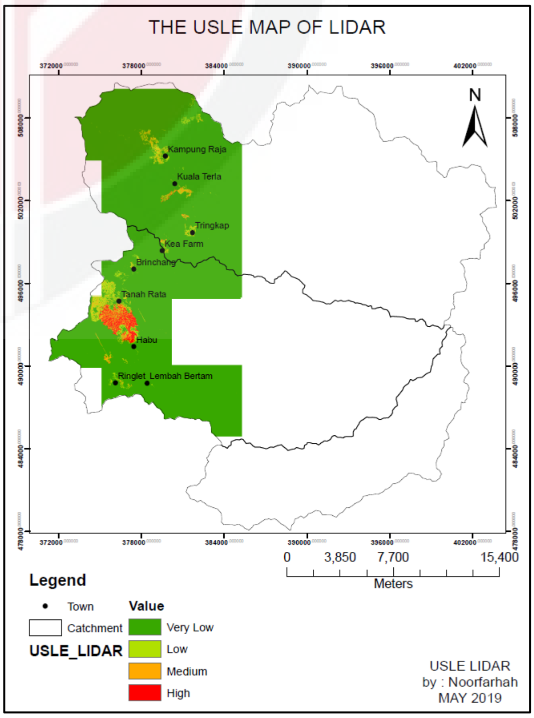


Figure 25 : The USLE map of LiDAR

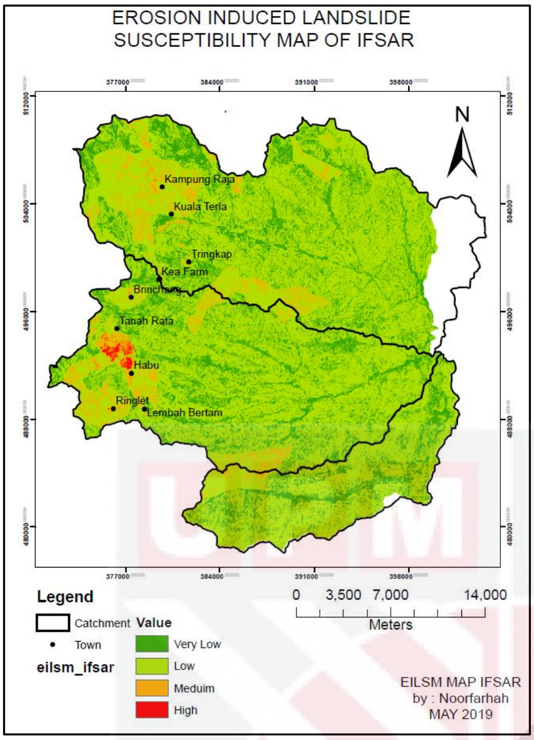


Figure 26 : The EILSM of the IfSAR

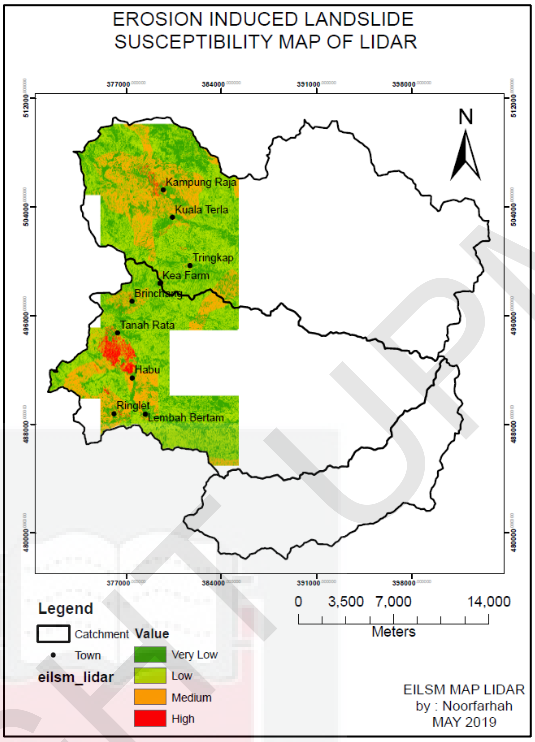


Figure 27 : The EILSM of the LiDAR

Table 3 : Percentage of every class base on the pixel counts

Classes	Pixel count in IfSAR	Percentage, %	Pixel count in LiDAR	Percentage, %	Difference
High	10078	0.64	130984	1.53	0.89
Medium	130458	8.33	1528596	17.84	9.51
Low	1066718	68.11	3781817	44.14	-23.97
Very Low	358887	22.92	3126737	36.49	13.58
Total	**1566141**	**100**	**8568134**	**100**	

4.2. The analysis of the Frequency Ratio Model of Landslide Inventory points

The frequency ratio model is the susceptibility analysis modelling that use to verify this landslide susceptibility map using the landslide inventory data. Table below shows the calculation each factor in the landslide susceptibility. Using the frequency ratio model, frequency ratios for the class or type of each factor were calculated by dividing the landslide occurrence ratio by the area ratio. A frequency ratio value of 1 is an average value for the area landslides occurring in the total area. A frequency ratio value less than 1 indicates a lower correlation which indicates a high probability of landslide occurrence, and a weight value greater than 1 indicates a higher probability of landslide occurrence.

In Table 4 of Geological data, acid intrusive is the hardest rocks so the frequency ratio of it shows the lowest than 1. For the phylite, limestone and slate is very susceptible to landslide because the frequency ratios show the high value which is 3 (blue colour) as shown in Figure 28. This Geological is only have 2 class compare to other factor because in Cameron Highlands is it only have 2 types of soil.

For Table 5 of the annual rainfall, the pixels were followed by the classes of the precipitate of the rainfall. So the class of precipitation only at medium class and it show the value of 1. The FR of the rainfall map in Figure 29 is only have one colour because it this reason.

For slope data in Table 6 and 7, there have 2 sections which are slope data for IfSAR and slope data for LiDAR. For IfSAR, the FR value at medium and high are below than 1 and for very low and low class the FR value are 1. So it can conclude that slope IfSAR have only 2 classes that join together and produce the slope map like in Figure 30 below. For LiDAR, very low class shows the FR value of 2 and for high it shows the value of 1. The FR for the other class is below than 1 so it can conclude that slope LiDAR has 3 classes like we can see in Figure 31 below.

These all factors above are very important to produce the EILSM with FR modelling method as we can see in Figure 32 and 33 below.

Table 4 : The FR calculation of Geological

Value	Classes	No of pixels	% of no of pixels	Pixels in domain	% pixels in domain	FR
1	Acid Intrusive	24026448	84.697	286	53.458	0.631
2	Phyllite, limestones	4341101	15.303	249	46.542	3.041
Total		**28367549**	**100**	**535**	**100**	

Table 5 : The FR calculation of Rainfall

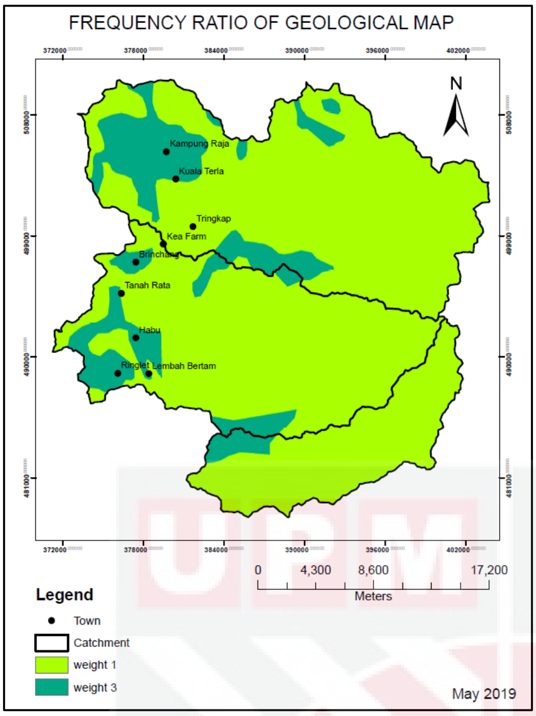
Class	Value	Classes	No of pixels	% of no of pixels	Pixels in domain	% pixels in domain	FR
Very Low	1	0 - 1000mm	0	0	0	0	0
Low	2	1000 - 1500mm	0	0	0	0	0
Medium	3	1500 - 2500mm	42341033	100	535	100	1
High	4	>2500mm	0	0	0	0	0
	Total		**42341033**	**100**	**535**	**100**	

Table 6 : The FR calculation of Slope (IfSAR)

Class	Value	Classes	No of pixels	% of no of pixels	Pixels in domain	% pixels in domain	FR
Very Low	1	0° - 15°	1912510	27.851	196	36.636	1.315
Low	2	15° - 25°	2720704	39.620	224	41.869	1.057
Medium	3	25° - 35°	1797717	26.179	97	18.131	0.693
High	4	>35°	436087	6.350	18	3.364	0.530
	Total		**6867018**	**100**	**535**	**100**	

Table 7 : The FR calculation of Slope (LiDAR)

Class	Value	Classes	No of pixels	% of no of pixels	Pixels in domain	% pixels in domain	FR
Very Low	1	0° - 15°	2355282	16.972	185	35.373	2.084
Low	2	15° - 25°	5021440	36.183	90	17.208	0.476
Medium	3	25° - 35°	3173291	22.866	117	22.371	0.978
High	4	>35°	3327725	23.979	131	25.048	1.045
	Total		**13877738**	**100**	**523**	**100**	



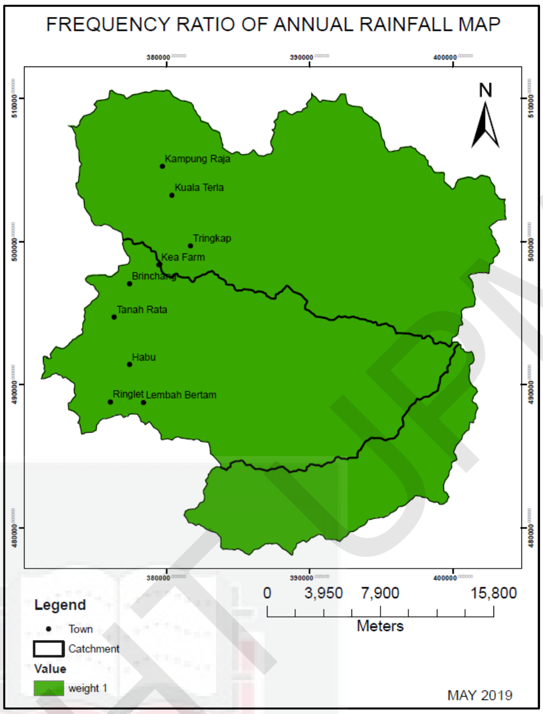
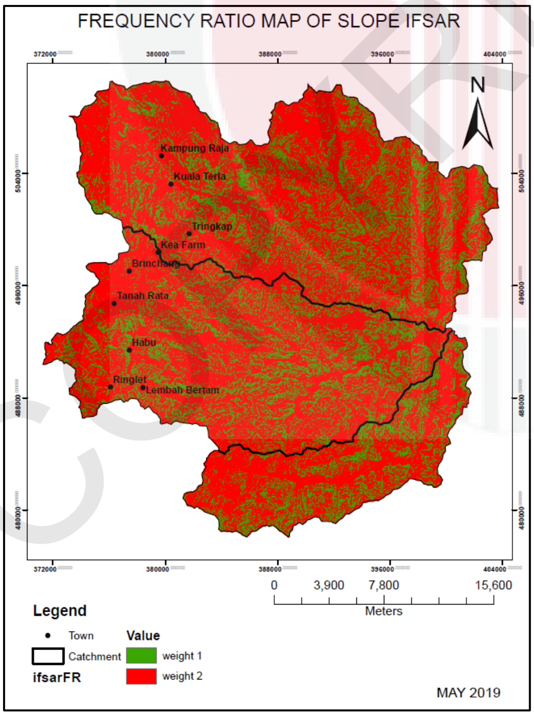


Figure 28 : The FR map of Geological

Figure 29 : The FR map Annual Rainfall



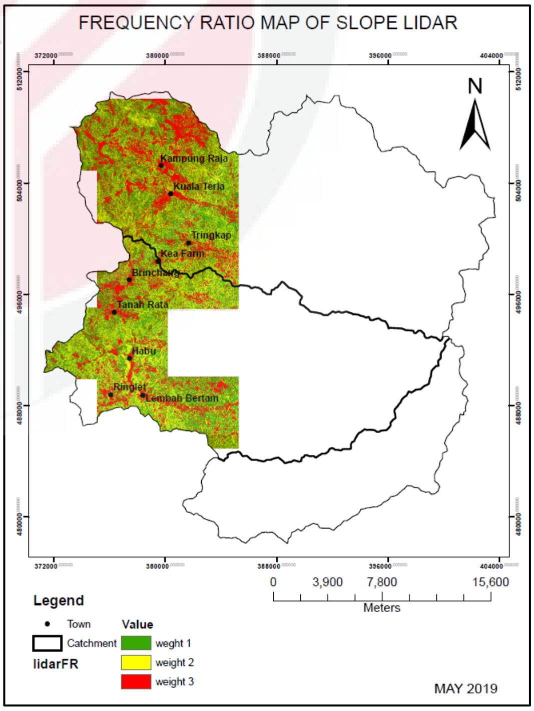
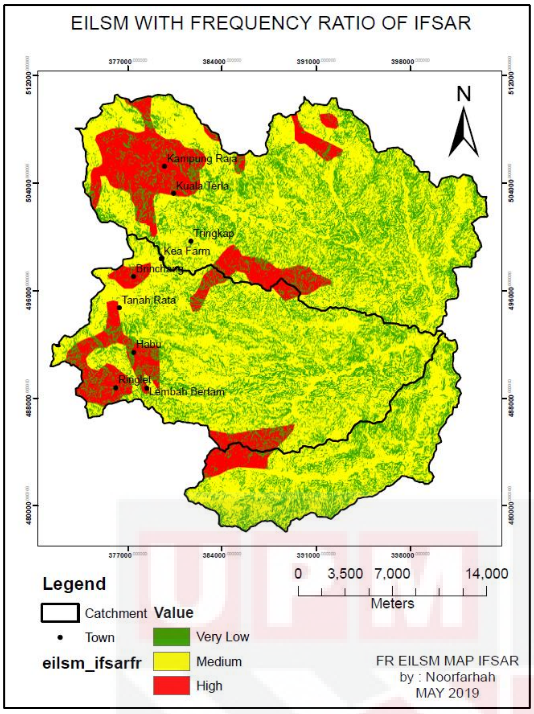


Figure 30 : The FR map of Slope IfSAR

Figure 31 : The FR map of Slope LiDAR



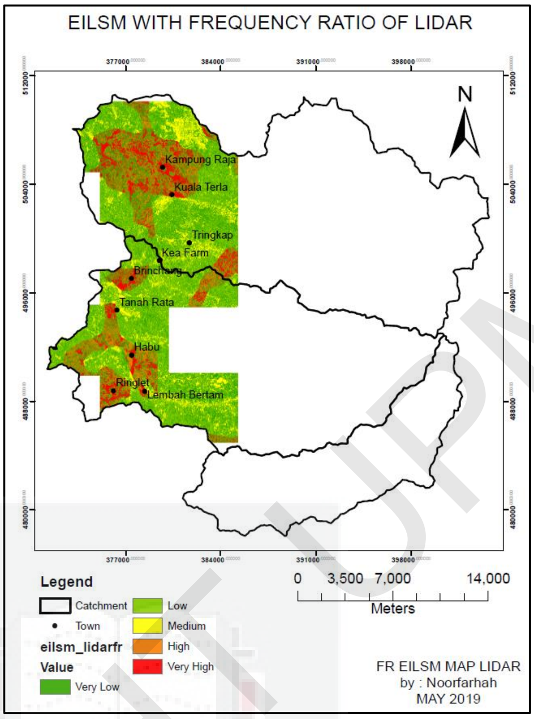


Figure 32 : The EILSM with FR of IfSAR **Figure 33 : The EILSM with FR of LiDAR**

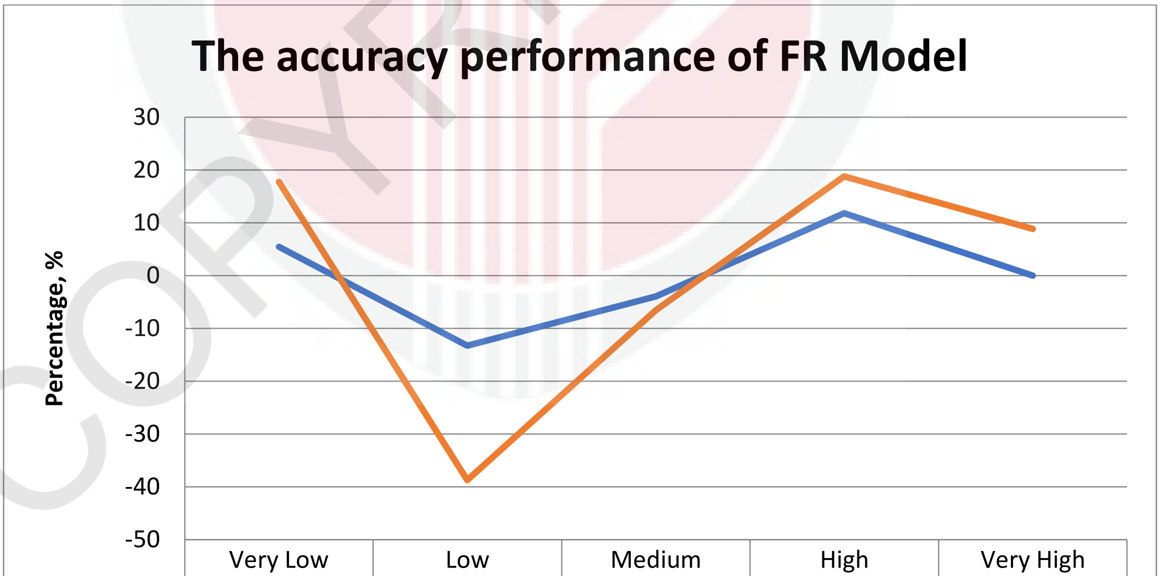
Table 8 shows the numerical rating scheme that the factor of the previous EILSM map only follow this scheme and can able to compare with the new data of the Frequency Ratio Model. The weight for the Schist, phyllite, slate and limestone is 4 and it is different from the rank same goes with the acid intrusive weight which is 2. For the layer of slope and annual precipitate, each rank and weight is the same value.

Table 8 : Ranks and weight for factors and their classes

Data layers	Classes	Rank	Weight
Geology Lithology	Schist, phyllite, slate and limestone. Minor intercalations or sandstone and volcanic Acid intrusive	1 2	4 2
Slope	0° - 15° (Very Low) 15° - 25° (Low) 25° - 35° (Medium) >35° (High)	1 2 3 4	1 2 3 4

Precipitation	0 - 1000mm (Very Low) 1000 - 1500mm (Low) 1500 - 2500mm (Medium) >2500mm (High)	1 2 3 4	1 2 3 4

The graph in Figure 34 below shows the performance of the FR model in every class of LiDAR and IfSAR. For very low class, the FR of LiDAR show the increment 12.25% which is it about 6% higher than IfSAR. Basically this performance was being compared with the original map of EILSM in objective 1. For LiDAR, FR model shows the detail because it comes out with another class which in very high class which is about 8.83%. This can explain that Frequency Ratio in more accurate that using the numerical scheme like previous. Table 9 show the comparison between original EILSM map and the FR map and the highest increment is in LiDAR map.



	Very Low	Low	Medium	High	Very High
LiDAR	12.25	-25.5	-2.58	6.99	8.83
IfSAR	5.46	-13.28	-3.98	11.79	

Figure 34 : The accuracy performance of FR model

Table 9 : Comparison of original EILSM with FR map

Classes	EILSM of IfSAR, %		EILSM of LiDAR, %	
	Original map	FR map	Original map	FR map
Very Low	23.48	28.94	36.52	48.77
Low	72.31	59.03	44.13	18.63
Medium	3.98	0.00	17.84	15.26
High	0.24	12.03	1.51	8.50
Very High	0	0	0	8.83

4.3. The data fusion of the elevation

4.3.1. The linear regression model output

The elevation of LiDAR and IfSAR were divided into 4 classes which is high, medium, low and very low. For this analysis, it already assign in methodology that LiDAR is dependent variable y and IfSAR is independent variable x. Below are the graph for every class and the overall elevation data that perform in Microsoft Excel to calculate and do the scatter graph. These data is from the ArcMap 10.3 software that is converting from the attribute table to excel. Each of the class has 100 points so the total point that being analyse are 400 points.

The graph elevation data of very low in Figure 35 show the coefficient of r^2 = 0.9645 and the linear regression equation is y = 0.9971x + 3.4767. For the elevation data of low (Figure 36), the coefficient show the value of r^2 = 0.9229 and the equation is y = 0.9707x + 40.805. Figure 37 shows the elevation data of medium coefficient show the result of r^2 = 0.9291 and the linear regression equation is y = 0.9277x + 111.28. For the elevation data of high in Figure 38, the coefficient of the data is r^2 = 0.9734 and the linear equation is y = 0.9924x + 22.018. The overall elevation shows the coefficient of r^2 = 0.8843 and the linear regression equation is y = 0.9201x + 116.34 respectively as we can see in Figure 39.

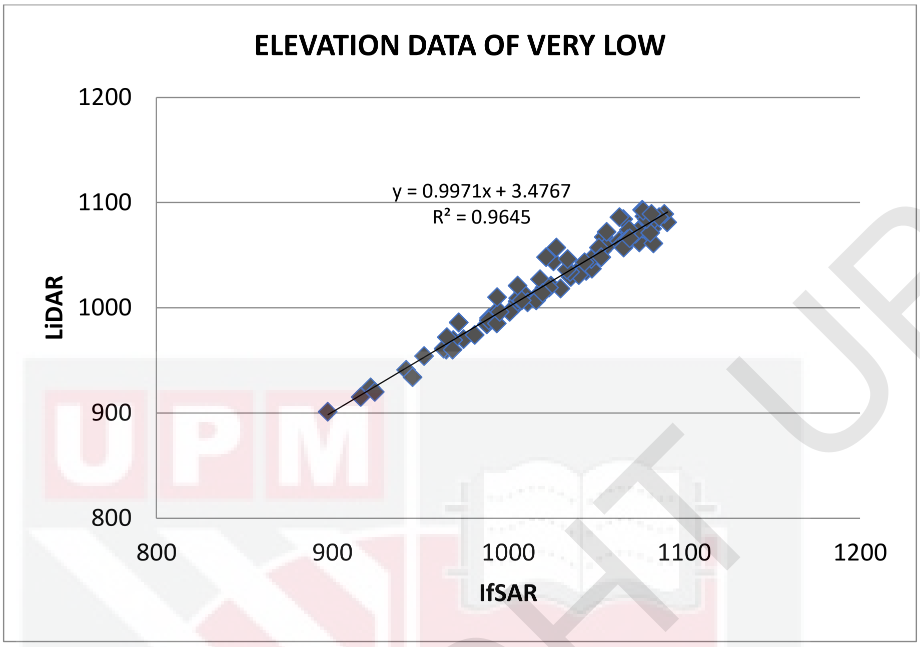


Figure 35 : The elevation graph of very low

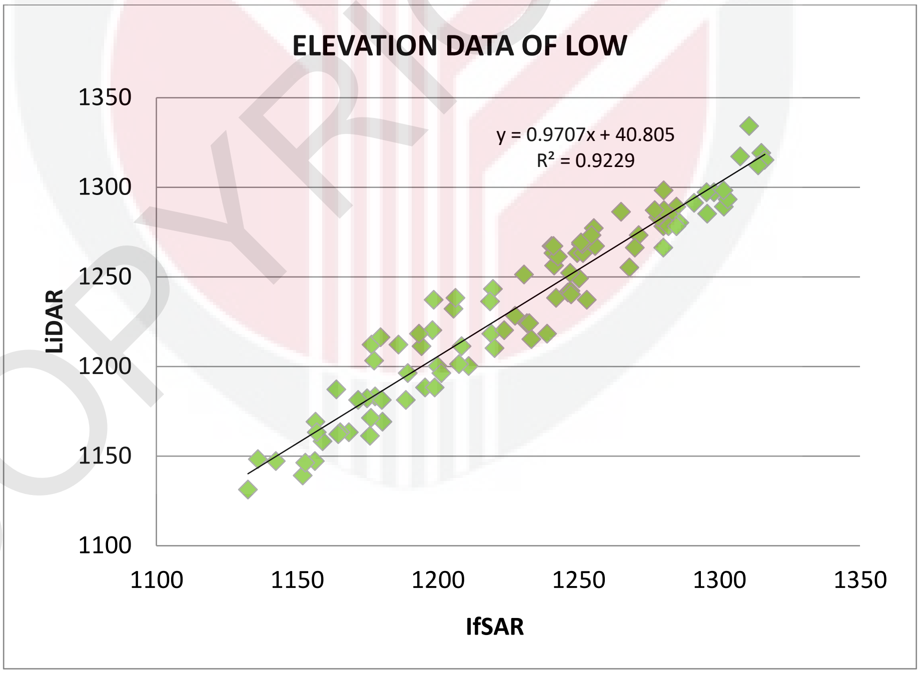


Figure 36 : The elevation graph of low

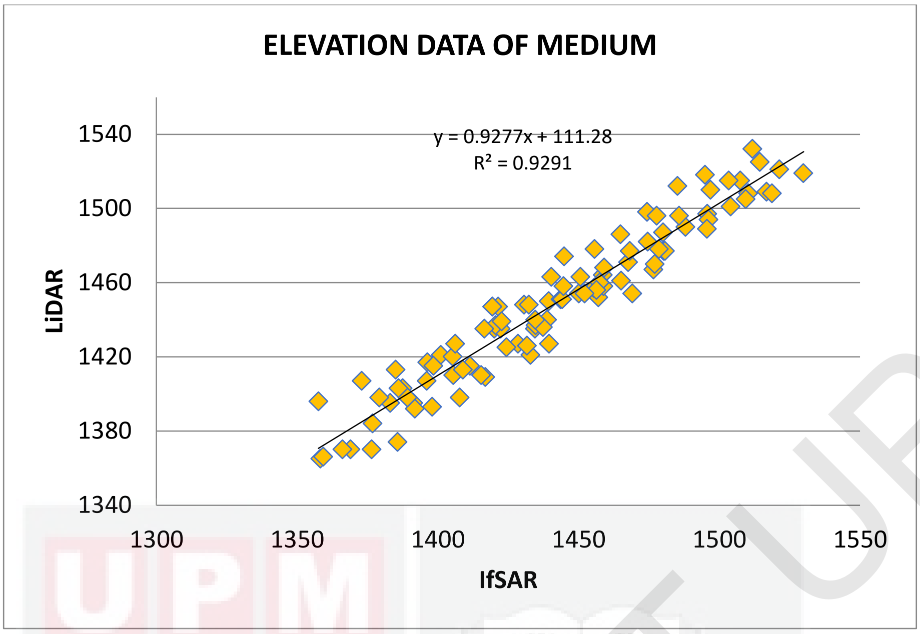


Figure 37 : the elevation graph of medium

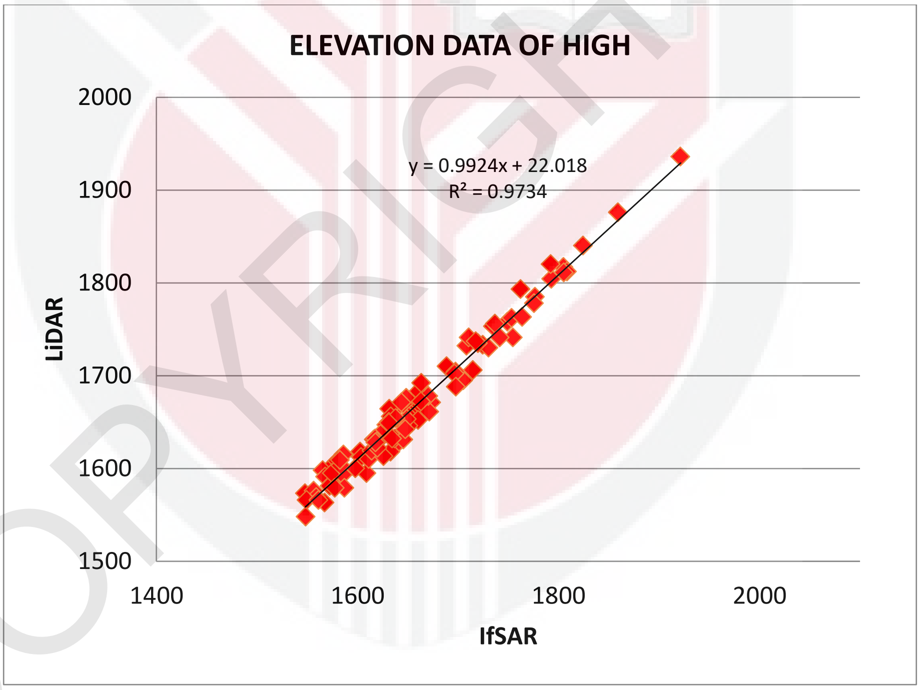


Figure 38 : the elevation graph of high

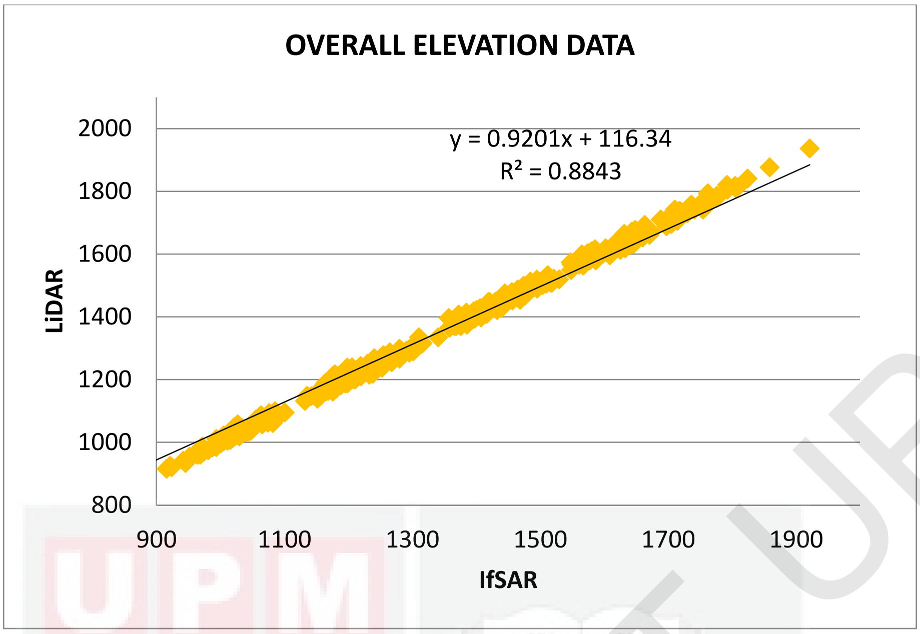


Figure 39 : The overall elevation graph

For the result of the linear regression calculation of getting the squared error for each of the elevation class is display in the Table 10 below:

Table 10 : The overall linear regression equation, coefficient and square error values

Elevation class	The Coefficient Value, r^2	Mean Square Regression, MSR	Mean Square Error, MSE	Square Error Value, Se
Overall	0.8843	21761928	7653.92	87.4867
High	0.9734	521952	518.33	22.7669
Medium	0.9291	157383	336.07	18.3323
Low	0.9229	220191	272.9	16.5198
Very Low	0.9645	199937	78.83	8.8784

After calculate the square error factor of the elevation, the difference of the improved IfSAR need to be verify with the LiDAR data as the formula already mention in methodology. The results of the different were show in the pie chart below. For high data in Figure 40, the improving data is about 69% from the original. This show the highest improvement in IfSAR data and it might be accepted for proceeding to the assessment soon. Figure 41 and 42 show the improved elevation of the medium and lo classes. In Figure 43, the lowest improvement that in very low class (21%). It might have some error or mistaken while running the calculation or while export the data. So analysis of statistical is needed again to ensure that this improve data is accurate.

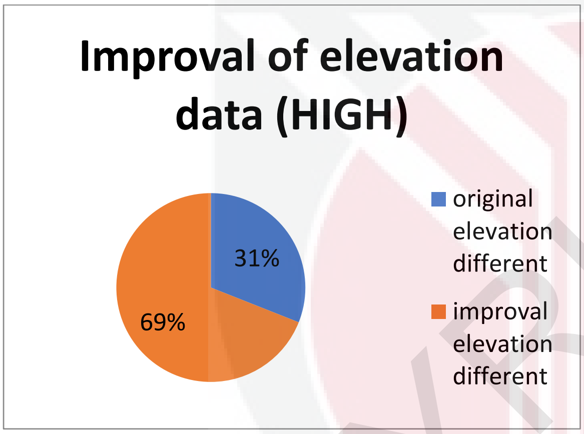


Figure 40 : The pie chart of improved high

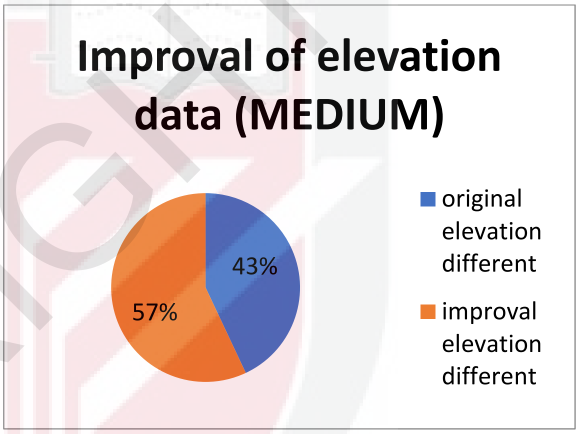


Figure 41 : The pie chart of improved medium

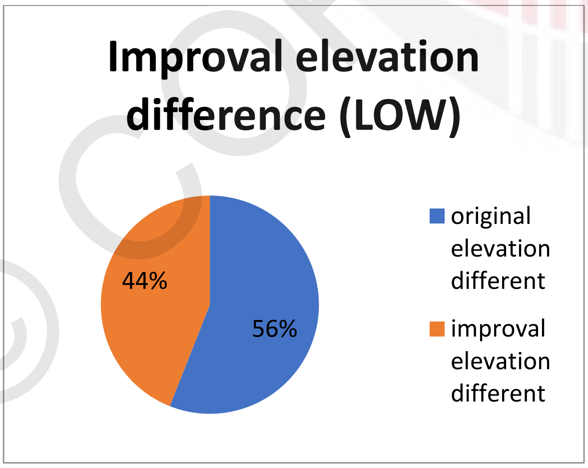


Figure 42 : The pie chart of improved low

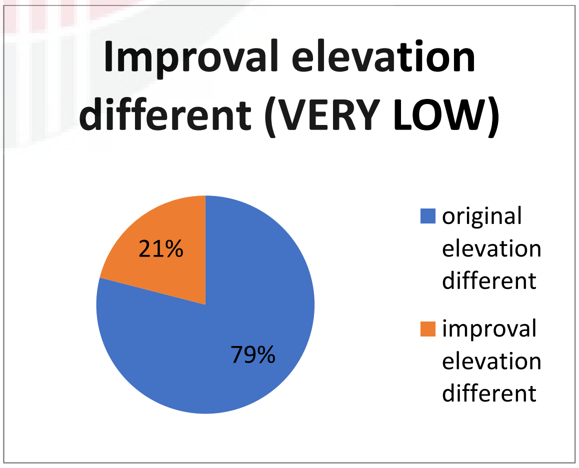


Figure 43 : The pie chart of improved very low

4.3.2. The statistical analysis between LiDAR, IfSAR and JUPEM data

The statistical analyses already done below are student t-test and also analysis of variance (ANOVA) also can call as F-ratio test. The t-test and ANOVA test is the parametric test that describe the population of the variable being sampled and test is normal and the measurement of the variables is in the internal or ratio scale. The different of the t-test and ANOVA is the number or test sample that going to held. For the t-test, its only need 2 samples where the ANOVA test need more than 2 samples. The t-test critical region uses the T distribution table where the ANOVA test needs F table distribution to find the critical region.

Ho is the null hypothesis and the meaning of it is the population of the group sample. Ha is the analysis hypothesis and it is the population that is not identical. Alpha or (α) is the significant number and it is same 0.05 value to all analysis. The significant is useful for the determining the critical value in the normal distribution table so that the significant value will be compare to the calculated answer. If the calculated statistic fall in the critical region meaning that it follow the analysis hypothesis (Ha), hence the null hypothesis (Ho) is rejected and vice versa.

The Student t-test needs only two variables so the data were divided into 3 t-test which are IfSAR data with JUPEM, LiDAR with JUPEM and also LiDAR with IfSAR data. For ANOVA test in Table 12 is run only once because it can run more than 2 sample data at one time.

For the result of the manual calculation of statistical test to the elevation data of LiDAR, IfSAR and JUPEM, it shows all of data are accepted in the condition of the null hypothesis (Ho). That means the elevation data was not fall in the critical region of the distribution and it reveal that the all of this data are in similar distribution population. In other way, the elevation data can be precede to the next step which the data fusion of IfSAR into the map (see Table 11 and 12).

Table 11 : The answer of student's t-test

The student's t-test (parametric test)		
LiDAR data with JUPEM data	IfSAR data with JUPEM data	LiDAR data with IfSAR
SOLUTION 1 Ho : μi = μj 2 Ha : μi > μj 3 α = 0.05 4 T cal = 0.0818 5 Tα = 2.132 t cal < t sig 6 **Ho is accepted** because Tcal not fall in the critical region	SOLUTION 1 Ho : μi = μj 2 Ha : μi > μj 3 α = 0.05 4 T cal = 0.0372 5 Tα = 1.771 t cal < t sig 6 **Ho is accepted** because Fcal not fall in the critical region	SOLUTION 1 Ho : μi = μj 2 Ha : μi > μj 3 α = 0.05 4 T cal = 0.035 5 Tα = 2.132 t cal < t sig 6 **Ho is accepted** because Fcal not fall in the critical region

Table 12 : The F ratio test (ANOVA)

The F ratio test Analysis of variance (ANOVA)
SOLUTION 1 Ho : μi = μj = μk 2 Ha : μi ≠ μj ≠ μk 3 α = 0.05 4 F cal = 0.0036 5 Fα = 5.143 f cal < f sig 6 **Ho is accepted** because Fcal not fall in the critical region

4.4. The assessment of the improved IfSAR

The improved IfSAR data is from the linear regression equation that already mention above and it be perform in the Raster Calculator in ArcMap 10.3 software to create the new layer of the IfSAR. Figure 44 below is the elevation data of improve IfSAR that have range from 97.93 to 2112. The elevation maps have 9 classes that use the normal class before it being reclassify into 4 classes using the natural break method in the ArcMap 10.3 software.

Figure 45 is the Landslide Susceptibility map for the new IfSAR data and there have 4 classes with the same like other susceptible map and erosion map. Table 13 shows the percentage different of the Landslide Susceptibility map from the original with the LS improved of IfSAR data. For very low class, the original LS map is 24% percent and for LS improved by new IfSAR show the percent of 28%. This show the accuracy was increased about 4% in improved IfSAR data compare to original data. At low class also the percent of LS in improved IfSAR is increasing about 2%.

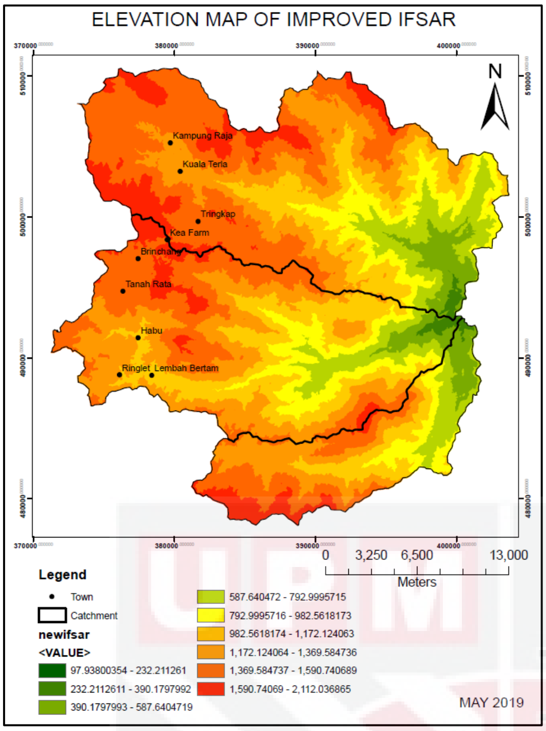


Figure 44 : The elevation map of improved IfSAR

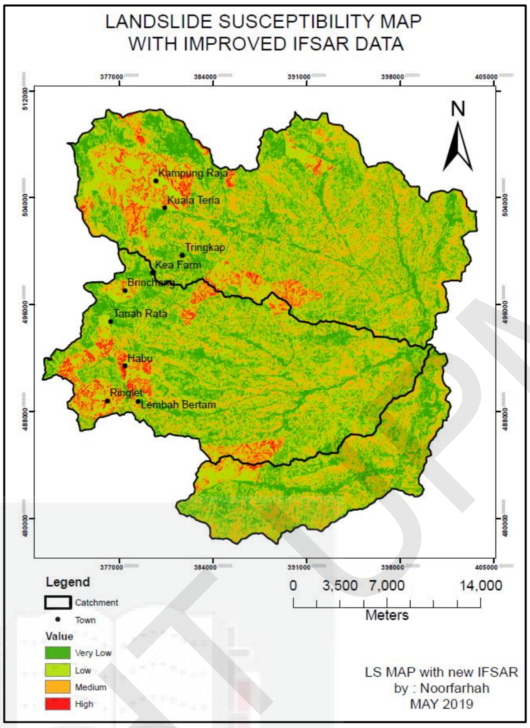
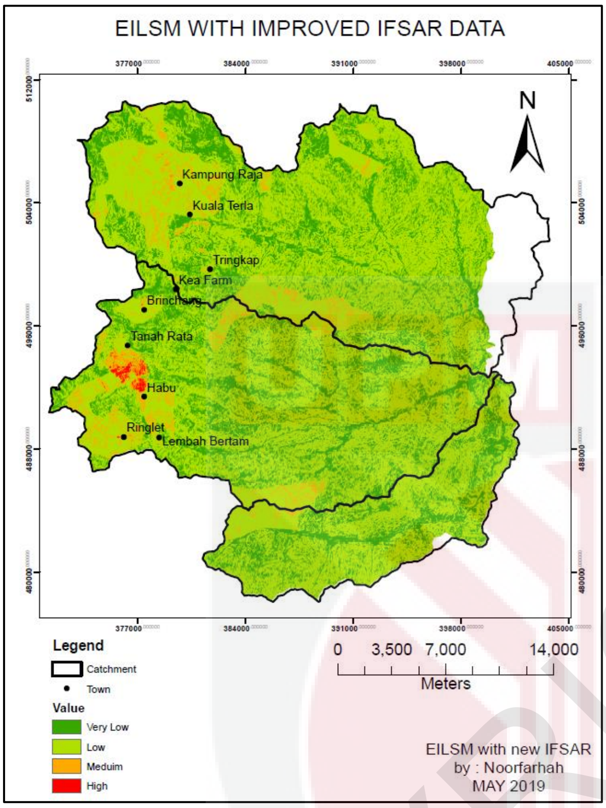


Figure 45 : The LS map of improved IfSAR

Table 13 : The percentage of improvement data

Classes	Pixel count in original LS	percentage, %	Pixel count in LS with improved IfSAR	percentage, %
Very Low	1085899	24.185	1285825	28.3294
Low	1854235	41.298	1980405	43.632
Medium	1405174	31.296	1162925	25.621
High	144513	3.218	109670	2.416
Total	**4489821**	**100**	**4538825**	**100**

Figure 46 below is the new maps of EILSM with improved IfSAR have 4 classes which are Very Low (green), Low (light green), Medium (orange) and High (red). For comparison of Erosion Induced Landslide Susceptibility Map (EILSM), original one (Figure 47) is slightly similar to the improved. But, it has different in in calculation of the percentage as shown in Table 14. For very low class, the map of improved IfSAR is increasing about 4% from the original EILSM. It different at the low class which is the original EILSM is higher than the new map. Medium and high class, both show the same percentage 3% and 0.2% that show that it have the similarity.



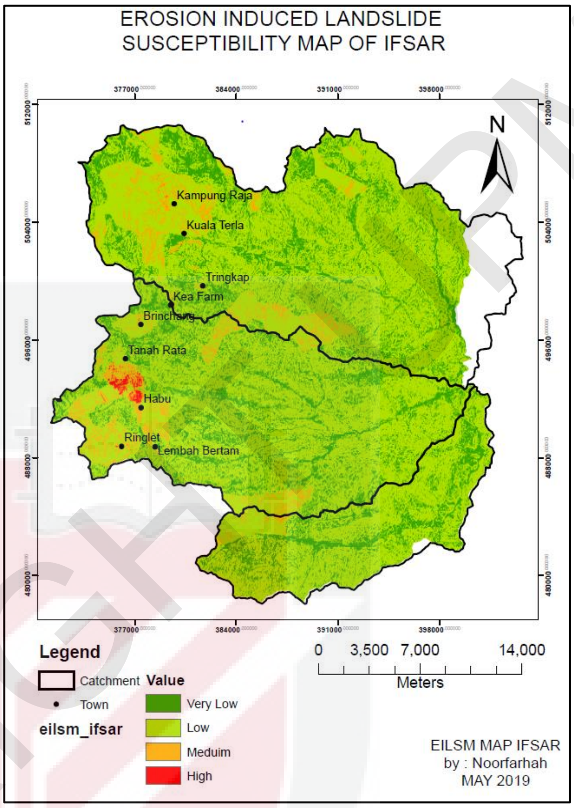


Figure 46 : The EILSM map of improved IfSAR

Figure 47 : The original EILSM of IfSAR

Table 14 : The percentage between original map and improved map

Classes	original EILSM	percentage, %	EILSM with improved IfSAR	percentage, %
Very Low	1006328	23.475	1193452	27.538
Low	3099886	72.312	2995359	69.116
Medium	170471	3.976	136010	3.138
High	10080	0.235	8988	0.207
Total	**4286765**	**100**	**4333809**	**100**

Figure 48 below is the pie chart of the overall improvement of the IfSAR data which is it improve about 48% of the elevation whereby the original data is 52%. Almost half of the elevation is already be improve by the new IfSAR data and hopefully in the next project the improvement of the data will achieved almost 100%.

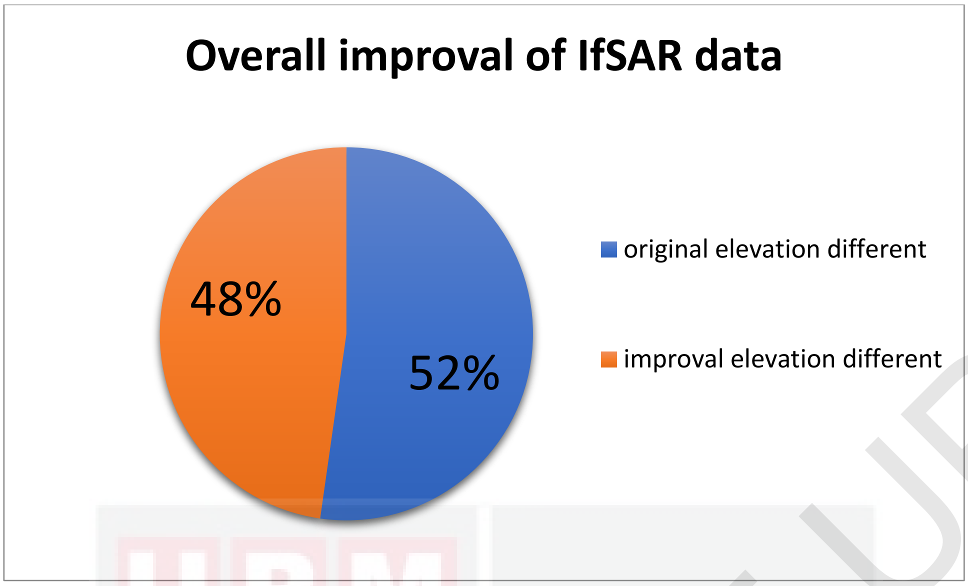


Figure 48 : The chart of total improvement of IfSAR

Chapter 5: CONCLUSION AND RECOMMENDATION

In conclusion, for objective one the Erosion Induced Landslide Susceptibility Map (EILSM) analysis of LiDAR map using the FR model show the increment of Very Low (48%), Low (18%), Medium (15%) and High (8%). The EILSM with IfSAR map show the percent of Very Low, Low and High are 28%, 59% and 12%. The frequency ratio model show the improved accuracy of the EILSM map base on each class which is high, medium, low and very low. The reason why the IfSAR elevation is needed to be improve because the elevation scanning in LiDAR is more detail because for the medium class for example, LiDAR can detect more area about 17.84% compare to the medium class in IfSAR 8.33% only. In objective two, the elevation data is selected to perform the data fusion techniques because the coefficient (r^2) is approach to 1 which is 0.8843 respectively compare to the slope data r^2 = 0.2203. Improving IfSAR data by using data fusion technique can increase the accuracy of the elevation up to 48% from original data. The linear regression equation that be used in Raster Calculator in ArcMap 10.3 for getting the new elevation of IfSAR is $y = 0.9201x + 116.34$. For objective three, the overall percent of the improvement of IfSAR in this project in 48% and Almost half of the elevation is already be improve by the new IfSAR data and hopefully in the next project the improvement of the data will achieved almost 100%.

In recommendation, this project can be continued for further research on the validation of Erosion Induced Landslides Susceptibility Map with Best Management Practice (BMP). In this BMP practice also can find out the best solution to overcome some of the most landslide susceptibility area or the land that expose more to hazard for taking the precaution factor and manage the land so that it can be in good condition. Beside GPS, LiDAR and IfSAR, the Terrestrial Laser Scanning (TLS) also can be used to increase the accuracy of the point data. Even though TLS only can be use in small area but the accuracy of it is much higher than others. Therefore, knowledge in Global Information System (GIS) techniques needs to be expanded and enhanced in all areas to meet the current technology requirements.

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