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Landslide Inventory along newly Constructed Ghat road secetion at Vathalmalai Hills, Tamil Nadu, India

G. Kavitha[1], S. Anbazhagan[2], S. Mani [3]
[1,2](Centre for Geoinformatics and Planetary Studies, Periyar University, Salem – 636 011)
[3](School of Civil Engineering, SASTRA University, Thanjavur – 613 401)
Email: gkavitha782@gmail.com, anbu02@gmail.com, mani.mmgk@gmail.com
[2]Corresponding author: S. Anbazhagan

Abstract: *The study aims to conduct landslide inventory and calculate the area and volume of landslide material from the geometrical measurements of landslides occurred at Vathalmalai hills, Dharmapuri district, Tamil Nadu, The study area located in a semi tropical region, India. Empirical relationship was derived between volume estimation and other parameters through the Person correlation coefficient model. Field data were collected through extensive field surveys and using the satellite data. The correlation between the area under landslide and volume of landslide material was studied using different curve estimation models. Various statistical parameters were calculated to relate the models with each other. Among various results, the power of law matches the records better. While, next to power law fit compound, growth and Exponential show high R2 value and low F statistic and less RMSE value. The correlation between area and volume of landslides determined V=0.492A1.224 for 10 landslide locations of the slide area in Vathalmalai. The landslide modeling shows that high R^2 value in power law from 0.90, while it decreased as 0.83 in compound, growth and exponential. It significantly low in inverse model (0.48). According to the suggested relation, the mean of the average depth of landslides was assessed as 1.839 m which was near to mean of actual depth of 2.0 m.*
Key Word*:Landslide inventory, Empirical, Coefficient, Power model, CE model*

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I. Introduction

Landslide denotes wide diversity of processes that effects in the downward and outward movement of hill forming materials comprised of rocks, soils, manmade fills, or combination of these under the impact of gravity (Varnes 1978; Cruden and Varnes 1996). Landslides are unpredictable natural phenomena (Singh et.al 2011) and one of the most damaging natural hazards, which results in loss of life and property. The pavement of road network, widening of ghat roads, and construction of dams, bridges and human intervention in the form of deforestation are the major causes for landslide occurrences (Aleotti and Chowdhury 1999; Sidle and Ochiai 2006; Anbazhagan et.al 2008). Landslides also happened along natural slopes, induced by numerous geo-environmental factors and activated by precipitation and earthquakes (Anbazhagan and Ramesh 2014). It is important to assess the number of landslides, size of the landslide, quantity of displaced material in the susceptible zones to calculate the landslide hazards, assessment risk and restorative measures (Cardinali et al 2002; Guzzetti et al 1999; Malamud et al 2004). The approximation of landslide volume in a huge area includes the use of experimental relations where the expected volume of a specified landslide area calculated (Innes, 1983; Hovius et al., 1997; Guthrie and Evans, 2004; Imaizumi and Sidle, 2007; Guzzetti et al., 2008, 2009; Larsen et al., 2010). The information about the number of landslides in an area, frequency and total area coverage of landslides for diverse periods reasonably complete the inventory maps of landslide, mostly obtained from field investigation (Guzzetti et al., 2002; Galli et al., 2008). The estimation of volume of displaced material due to a landslide is a more complicated job that needs details on the outward and sub-surface geometry. It is a tough task and time consuming to assessment the volume of landslides along slope failures (Malamud et al 2004; Guzzetti et al 2009). Through empirical models, it is possible to link the volume of discrete landslides to geometrical magnitudes of the failure slopes (Korup 2005; Guzzetti et al 2008). The relation between area coverage of landslide and volume of displaced material was studied by numerous investigators (Larsen and Torres Sanchez 1998; Martin et.al 2002; Rice et al., 1969; Simonett 1967; Rice and Foggin 1971; Haflidason et al., 2005; Tenbrink et al., 2006; Imaizumi et.al., 2008; Omidvar and Kavin2011; Tseng et al., 2013;Hadian-Amir et.al., 2014; Amirahmadi et.al., 2016). Different empirical relations were used for estimation of volume of landslide, which are available in the literature from different countries (Table 1). They have appraised landslide volumes by adopting the empirical relationships which link the volume of discrete landslides to geometric measurements of the landslide (Martin et.al 2002). In the present case, landslides were occurred for the first time due to pavement of new ghat road by modifying natural slope condition. Earlier, it was unmetalled path mostly convenient for walking and not for transport. However, it was utilized by the Forest department using four-wheel drives. The road connects the villages located on the Vathalmalai hills, surrounding villages and Dharmapuri town in the plains. Along ghat road of Vathalmalai two episodes of landslides occurred during Nov 2015 and May 2016, due to heavy instantaneous rainfall. We have carried out field investigation on 11th Nov 2015 in the field to assess the nature, and number of landslides. The initial objective of the study is to understand the prime causes, terrain conditions and estimate the area and volume. In present study, the area under landslide and volume of material displaced were assessed from the measurement of topographic contour and appraisal of soil depth. The outcomes of landslide curve estimation models were compared with area and volume of displaced material. Finally, an empirical relationship derived to estimate the volume projected for the landslide occurrences in the study area.

Table 1. Empirical relationship to area (A) and volume (V) of landslide models

S.No.	Number of Landslides	Location	Equation	Source
1	677	Collazzone, central Italy	$V= 0.074A^{1.450}$	Guzzetti et al. (2009)
2	207	Bewani and Torricelli	$V= 0.1479A^{1.368}$	Simonett (1967)
3	29	Southern California	$V= 0.234A^{1.11}$	Rice et al. (1969)
4	30	Scottish Highlands	$V = 0.0329A^{1.3852}$	Innes (1983)
5	124	Coastal British Columbia	$V = 0.1549A^{1.0905}$	Guthrie and Evans (2004)
6	23	New Zealand	$V = 0.00004 A^{1.95}$	Korup (2005)
7	160	Puerto Rico	$V = 4.655A^{1.292}$	Ten Brink et al. (2006)
8	51	Miyagawa Dam, Japan	$V= 0.39A^{1.31}$	Imaizumi and Sidle (2007)
9	529	Tiber River basin, Italy	$V= 0.0844A^{1.4324}$	Guzzetti et al. (2008)
10	11	central Japan	$V = 0.19A^{1.19}$	Imaizumi et al. (2008)
11	37	Southern California	$V = 0.328A^{1.104}$	Rice and Foggin (1971)
12	53	Cosenza	$V = 0.242A^{1.307}$	Abele (1974)
13	45	Central Southern Alps	$V = 0.769 A^{1.250}$	Whitehouse (1983)
14	1019	Puerto Rico	$V = 1.826A^{0.898}$	Larsen and Torres Sanchez (1998)
15	615	Puerto Rico	$V = 1.0359A^{0.880}$	Martin et al. (2002)
16	65	Norway Basin	$V = 12.273A^{1.047}$	Haflidason et al. (2005)
17	1785	Mid-Niigata	$V = 0.224A^{1.262}$	Larsen et al. (2010) for soil based
18	1785	Mid-Niigata	$V = 0.234A^{1.41}$	Larsen et al. (2010) for bedrock
19	442	Mazandaran province	$V = 0.0974A^{1.176}$	Omidvar and Kavian (2011)
20	371	Typhoon Morakot	$V = 0.452A^{1.242}$	Tseng et al (2013) total area
21	314	Typhoon Morakot	$V = 2.510A^{1.206}$	Tseng et al (2013) crown area
22	142	Tajan River Basin, Iran	$V = 0.4763 A^{1.244}$	Hadian-Amir et.al 2014
23	44	NeyshabourBaqi Basin Iran	$V = 2.482A^{1.024}$	Amirahmadi et.al 2016

II. Study Area

This Vathalmalai is a small hill terrain situated in the Dharmapuri district belongs to the state of Tamil Nadu, India. The geographical area located in between 12°02'18"N and 12°04'15"N latitudes and 78°10'30"E and 78°13'15"E longitudes. VathalmalaiPeriyur is a small village located at 1140m above mean sea level (msl) and 25km away from Dharmapuri Town. Until 2010 there was no proper road connectivity and transport facility available for the people who living on the hilly region. They couldn't cultivate any cash crops. Majority of the people living on the Vathalmalai hills belong to the tribal community. They have to walk at least 12 km to aerial transport facility at the foot hills. They also force to sell their cultivated products at a lowest rate for their livelihood. In the year 2012, Vathalmalai has been announced as a tourist spot by the Government of Tamil Nadu and proposed various developmental activities for the purpose of tourism & development as well as to improve the live by hood of the tribal people. In continuation to that, a 12 km tract of ghat road sector with 23 hairpin road curves was laid down to connect the Dhinnahalli village at foot hills to PeriyurPotlangadu located at hill top in Vathalmalai (Fig. 1). The ghat road was constructed and maintained by thedistrict forest department. This ghat road covered by highlyweathered gneissic and charnockitic rock formation. The elevation of hill ranges between 500m and 1180 m above msl. The heavy rainfall occurred during northeast monsoon in November 2015 and summer fall in May 2016 triggered several landslides along ghat road section. The transport was totally cut off, due to that tribal people and school students find lot of difficulties.

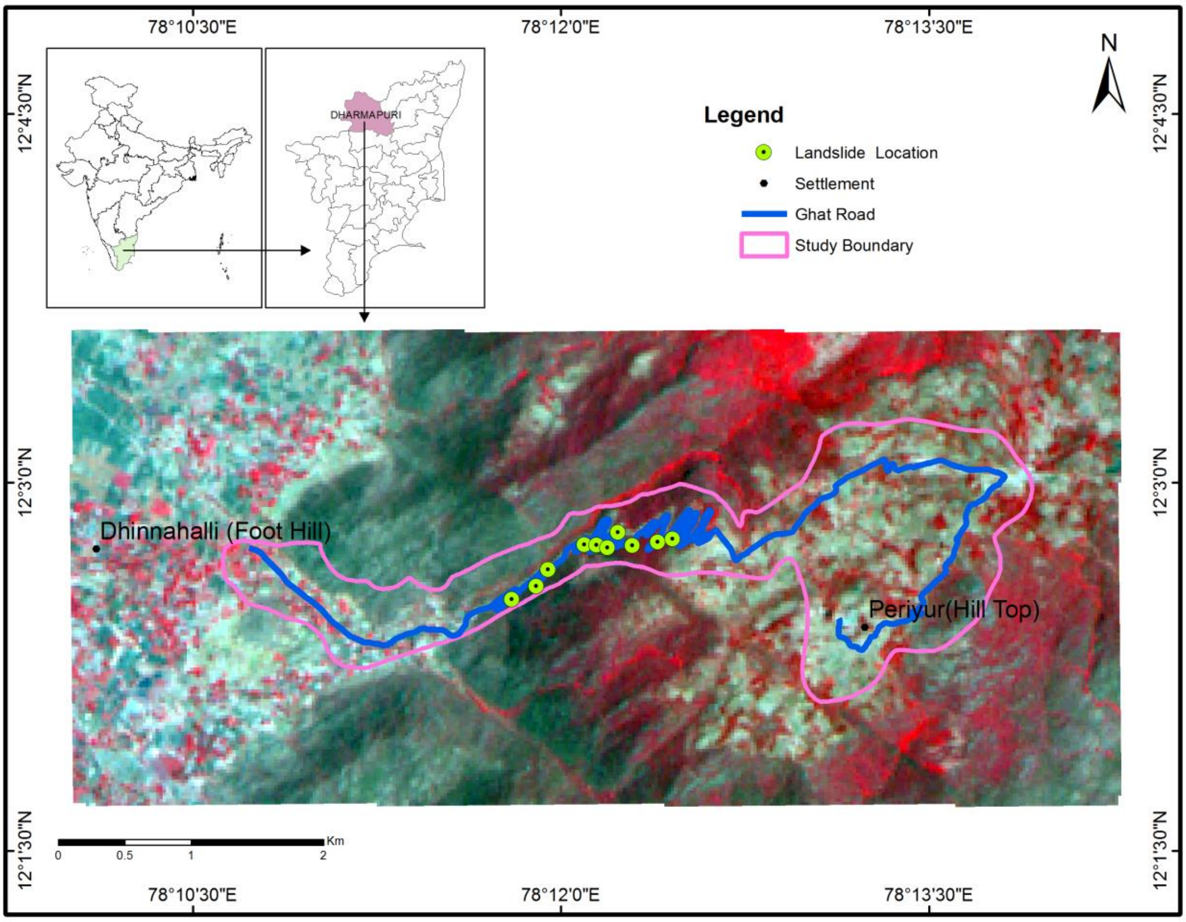

Figure.1 Location map of Vathalmalai hill located in Dharmapuri district, Tamil Nadu, India

III. Materials and Methods

Detailed field investigation was carried out on 19.5.2016 for landslides inventory to evaluate the landslide locations, geometry of landslides. The area coverage of each landslide was attained by measuring the length, and width of the individual landslides in the field data. In the similar manner, volume of displaced material was estimated using area with the depth of material moved downward. Statistical details were calculated from SPSS package Ver.16 for observed landslides including longitude, latitude and relationship between various parameters using correlation matrix at different levels (0.05 and 0.01). Finally, Person correlation coefficient (r) and Root Mean Square Errors (RMSE) methods were used to assess the result of landslide volume estimation.

Rainfall

Rainfall is one of the significant activating mechanisms for occurrence of landslides. Hence, rainfall data were analyzed for 13 years to understand the nature of rainfall patterns in this region. In Vathalmalai hills, there is no rainfall station. The nearest rainfall station is in Dharmapuri. There may be a slight variation in the depth of precipitation between these two locations. However, at present there no other alternative to assess the rainfall pattern. Hence, rainfall data were collected for 13 years (2003 to 2015) from State groundwater department. The rainfall pattern in the study area clustered into January to February months (winter), March to May period (summer),southwest monsoon during the months of June to September and northeast monsoon in between

October and December. The average annual rainfall for 13 years was found to be 1066 mm. The maximum and minimum rainfall received during 2005 and 2006 respectively 1723 mm and 754 mm. The maximum monthly rainfall received in the month of October (Fig.2) during northeast monsoon (210 mm). Similarly, during summer, heavy precipitation occurred during the month of May.

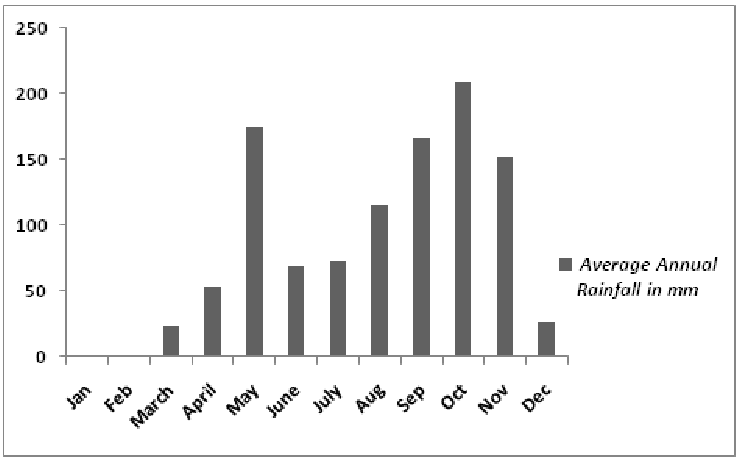

Figure.2 Monthly average rainfall during 2003 -2015

Landslide inventory

In the Vathalmalaighat road, along hairpin bends several landslides were occurred on 17th May 2015 and 11th Nov 2015. The continuous rainfall on 11th Nov 2015 triggered number of landslides at 6 locations in the ghat road hairpin bends 11, 12, 15, 16, 17 and 21. Similar landslides were also occurred during the month of May 2015 at hairpin bends 3, 6 and 7. The distributions of landslides are highlighted in the Figure 1. These locations were critically examined to analyze the geological, topographical as well as anthropogenic contributing factors which impact the incidence of landslides (Fig. 3). The landslide locations were captured through GPS measurements. Most of the landslides are debris type in nature, where water act as lubricant with highly weathered soil. In almost all landslide locations, the parent rock is not visible and slope is totally weathered conditions. The depth, height and length of the 10 landslides at various hairpin bends were measured in the field for further volume estimation. The area of each landslide was estimated through multiplication of length by width of the displaced portion. The width is not uniform for entire length of landslides. In this case, the width which is measured at different points was made into average. The volume of slide material was estimated through multiplication of the average depth and area of the soil movement. The total volume of debris material removed due to slope failure is estimated at 8670 m3 (Table 2).

Statistical Analysis

In the next stage, all the variables were imported to SPSS to assess the correlation using correlation matrix at 0.05 and 0.01 levels. In the study area, the variables such as latitude, longitude, area, depth and volume for 10 landslide locations were entered. From the analysis, the various statistical parameters were obtained (Table 3). Correlation coefficient designates the strength and course of a linear relationship between two variables. A number of diverse coefficients were adopted for different situations. Pearson correlation coefficient or the sample correlation coefficient, is the best-known correlation coefficient. For obtaining the results, covariance of the two variables is divided by the product of their standard deviations (Eq.1).

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \cdot \sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad (1)$$

Where Xi, Yi, X, Y and n are respectively observed data, estimated data equivalent, mean of observed data, mean of estimated data and number of data used. The table 4 shows matrix value obtained different variables.

Figure 3. Field photographs show landslide inventory conducted at Debris flow site, Vathalmalai

Table2. Landslide volume estimation in Vathalmalaighat road section

Location	Area (m^2)	Depth (m)	Volume (m^3)
1	227	1.5	341
2	86	1	86
3	810	2.5	1215
4	861	3.5	3014
5	132	2.5	330
6	170	1	170
7	744	1.5	1116
8	360	2	720
9	522	3	1566
10	75	1.5	112

Table3. Statistical calculation of measured variables of landslides, Vathalmalai

Statistic of Parameter	Area (m^2)	Depth (m)	Volume (m^3)
Standard Error of Mean	9.856	0.27	2.893
Standard Deviation	3.117	0.85	9.149
Mean	3.987	2.0	8.670
Variance	9.714	8.371	0.722
Skewness	0.51	0.51	1.59
Standard Error of Skewness	0.69	0.69	0.69
Kurtosis	-1.61	-0.83	2.70
Standard Error of Kurtosis	1.33	1.33	1.33
Minimum	75	1	86
Maximum	861	3.5	3014
Sum	3987	20	8670

Table 4. Correlation matrix of landslide variables

Variable	Area	Volume	Depth
Area	1	0.855**	0.632**
Volume	0.855**	1	0.832**
Depth	0.632**	0.832**	1

** Correlation is significant at the 0.05 and 0.01 level

In this study, the correlation between landslide area and displaced material volume was studied using ten curve estimation models. In this correlation, the landslides area (m^2) and volume (m^3) of material displaced were respectively considered as independent and dependent variables (Table 5). The coefficient of determination (R^2), F statistic and Root mean square error (RMSE) were estimated to relate with different models. The R^2 was adopted to desire the suitable relation and in comparison, with remaining models. The closer the R^2 value to 1 shows more association of observed and computed data (Freund 1992). The Root Mean Square Error (RMSE) is the measure of the difference between values predicted by a model and the values actually perceived from the field that are being modeled. RMSE indicates the efficiency of a model. It calculates the 2nd root of mean square of subtraction of computed and detected values. In each experimental relation, slide area was placed. The RMSE of computed landslide volume was derived according to Eq.2. The model with the lowest root mean value was identified as the finest one.

$$\mathrm{RMSE} = \sqrt{\frac{\sum o_i - p_i)^2}{n}} \qquad (2)$$

In this equation, oi is the observed landslide volume, pi is the estimated landslide volume by each relation and n is the number of variables (Kim and Kim 2008).

Table 5. General equation of Curve estimation models

CE Model	Equation
Linear	$y = a + b_1 x$
Logarithmic	$y = a + b_1 1n\, x$
Inverse	$y = a + b_1 / x$
Quadratic	$y = a + b_1 x + b_2 x^2$
Cubic	$y = a + b_1 x + b_2 x^2 + b_3 x^3$
Compound	$y = ab_1^x$
Power	$y = ax^{b1}$
S curve	$y = e^{a + \left(b_1 / x\right)}$
Growth	$y = e^{a + b_1 x}$
Exponential	$y = ae^{b_1 x}$

IV. RESULTS AND DISCUSSION

The cut slope along the Vathalmalaighat road section is mostly weathered soil profile and fragile in nature. The rainfall data is indicated that the month of May, October and November have high precipitation, which is one of the significant triggering mechanisms for occurrence of landslides in the ghat road. The statistical parameters of landslides were analyzed using SPSS statistical package and the results are presented in the Table 2. The results have shown that wide range of area, depth and volume. The area of smallest and largest landslides in the Vathalmalai hills is respectively 75m^2 and 861 m^2. The minimum and maximum volume of landslide material in the ghat road is 3014 m^3 and 8670 m^3 respectively. The correlation matrix (Table 4) show significant coefficient values between area, volume, and depth, it indicates good correlation among 3 variables. The curve estimation models were plotted as scatter diagram (Fig.4) and the results of comparison between models are presented in (Table 6).

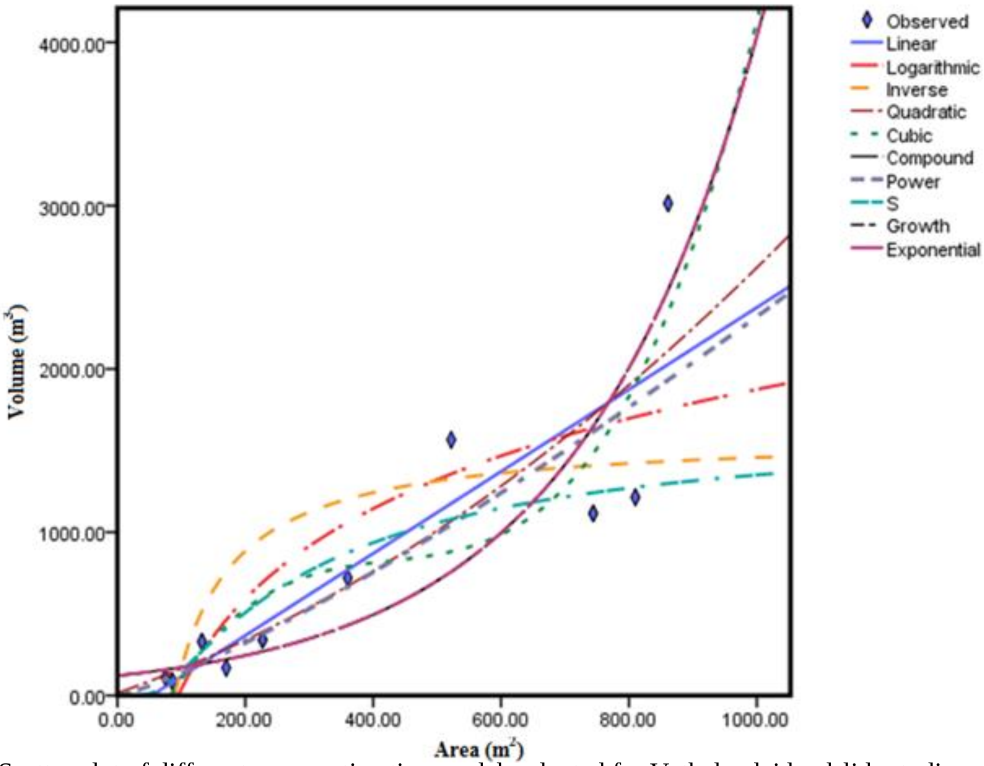

Fig.4 Scatter plot of different curve estimation models adopted for Vathalmalai landslide studies

Curve estimation models indicated that the power law fit the data better than remaining curve estimation models because of high value of R^2 (0.90). Although compound, growth and exponential relationships have represented good R^2 (0.83) they have less F statistics (38) than its value in power law relationship (F=74). Hence, the power law has been confirmed as model of the best fit. Results indicated that the power law fit the data on observational model of area and volume of landslides. Finally regression analysis resulted in the study creation of equation (3).

$$V = 0.492A^{1.224} \qquad (3)$$
$$R^2 = 0.90$$

Where, V represent the volume (m^3) and A denotes the area (m^2) of landslide. This Power law model may be adopted for estimating the landslide volume of the slide zone, with known the area of slope failure (Fig 5). The mean depth value of landslides was estimated about 1.839 m which was close to mean of actual depth of 2.0 m, therefore slight difference between observed depth and calculated depth values.

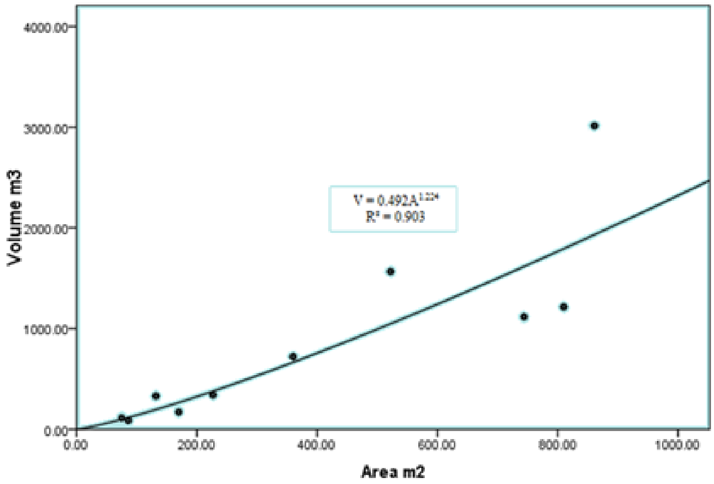

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Table 6. Comparison of curve estimation models between area and volume

Model	R^2	F	RMSE
Linear	0.73	21.799	5511206.840
Logarithmic	0.66	15.251	4941640.437
Inverse	0.48	7.491	3643176.084
Quadratic	0.74	9.811	2776415.050
Cubic	0.77	6.839	1943014.014
Compound	0.83	38.504	10.693
Power	0.90	74.872	11.668
S curve	0.82	36.783	10.607
Growth	0.83	38.504	10.693
Exponential	0.83	38.504	10.693

V. Conclusion

The Vathalmalaighat road is highly prone for occurrence of landslides. The preliminary investigation indicated the highly weathered cut slope profile. Infiltration and piping phenomena are the major causative factors for the landslides. The instantaneous high rainfall during summer and northeast monsoon is the important triggering factor. Further detail geological and geotechnical studies are warranted to prevent recurrence of landslides in the ghat road. In the present study, curve estimation (CE) models were adopted for the area and volume estimation of landslides along ghat road section of Vathalmalai, Dharmapuri district, India. Person correlation coefficient model was adopted for estimating the statistical relationship of landslides area, volume and depth variables. The variables have appreciable correlation coefficients value. Curve estimation models show that the power model show best fit with the observed data than the other CE models. An empirical relationship to link landslides regression equation of $V=0.492A^{1.224}$ volume and area was obtained this study. Therefore, power CE model is recommended to estimate the volume of landslides for slope failure in the region. Further detail study on landslide hazard zonation mapping and geotechnical study are in progress.

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