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ESTIMATION OF SOIL EROSION RISK USING RUSLE AND DEBRIS FLOW SUSCEPTIBILITY MAPPING USING BIVARIATE SPATIAL MODELS, PALAKKAD DISTRICT, KERALA

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ABSTRACT

Soil erosion is a serious threat that causes degradation of all resources mainly in the production of food and agriculture. Degradation of Soil by erosion adversely affects water quality too. With the aid of remote sensing and geo-information technology the Revised Universal Soil Loss Equation (RUSLE) model has been used to assess and quantify the risk of soil erosion in Palakkad, Kerala, India. The spatial distribution of areas that are in risk of soil erosion in Palakkad were estimated by the union of RUSLE factors (R, K, LS, C &P). These RUSLE model factors map were generated using the (Landsat-8) and ASTER DEM data. Rainfall erosivity factor(R) was estimated using 11 years rainfall data downloaded from the CHRS (CENTER FOR HYDROMETEOROLOGY AND REMOTE SENSING) Portal, ASTER DEM was used to generate the slope length and steepness (LS) factor, soil erodibility (K) factor map was produced using the FAO soil data and William's Equation. The study aims at comparing two bivariate models namely frequency ratio (FR) and Shannon entropy (SE) for deriving the debris flow susceptibility map of the Palakkad region. The debris flow inventory map was obtained by interpreting the data from news reports, different literature, annual reports by NCESS, and some random points are also taken because of the usage of point format for the study instead of polygon format. The soil erosion risk and debris flow results were useful for the hazard mapping. Both the FR and SE model helped to produce debris flow susceptibility maps. Finally, the FR model was more accurate than the SE model.

Keywords: Soil Erosion, RUSLE, Debris Flow Susceptibility, Bivariate Models, Remote Sensing And GIS.

I. INTRODUCTION

Soil is a non-renewable resource, and it cannot be replenished or recovered once it is degraded or lost permanently. "Erosion is a process of detachment and transportation of soil particles by erosive agents (Ellison,1944)". At global level, soil erosion is one of the most important land degradation problems caused due to water and other environmental hazards. Soil erosion is an extremely serious spatio-temporal activity in various countries (Hoyos, 2005; Pandey et al., 2009). India is facing an alarming situation with 5334 metric tons of soil getting detached annually. The sheet erosion was the most serious issue in India, as suggested by Narayan and Babu (1983). Soil fertility is reduced due to soil erosion, it is one of the most serious problems worldwide. In India, the land degradation problem caused due to soil erosion covers more than 50% of the total area. In recent time period, land degradation assessment policy has become very important for sustainable development. Soil erosion in mountain regions is more serious (Dabral et al., 2008; Sharma, 2010). It directly affects the environment, economy, and agriculture in mountain areas (Navas et al 2004; Vanacker et al., n.d 2014.). Rate of soil erosion increases due to heavy precipitation and change in land use that can cause~~s~~ flood and drought (Zhao et al., 2013). Soil erosion leads to reduced soil fertility that affects sustainable agriculture production (Uddin et al., 2016). On the other hand, sediment deposition in dams, reservoirs by soil erosion increases their costs of maintenance and later on makes them unusable (Samaras et al., 2014).

Soil erosion can be estimated using various models such as USLE (Wischmeier et al., 1978), Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS) (Knisel,1980), Agricultural Nonpoint Source model (AGNPS) (Young et al., 1989), Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1993), Modified Universal Soil Loss Estimation (MUSLE) (Williams, 1975). The most commonly used empirical model was USLE, which in turn led to the development of the Revised Soil Loss Equation (RUSLE). While the latter has the same formula as former there are several improvements in determining factors. There are number of studies that have been carried out by the researchers using RUSLE model for soil erosion estimation in different

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regions (Uddin et al., 2016; Prasannakumar et al., 2012; Koirala et al., 2019; Thapa, 2020; Negese et al., 2021; Fayas et al., 2019).

Debris flow is the flow of sediments coupled with water mixture which is driven by the gravity and act as a continuous fluid (Takahashi, 2007). Debris flow is one of the important geomorphic processes in hilly regions having relationship with heavy or prolonged rainstorms (Angillieri p.9 n.d.). Debris flows effect animal life, natural resources and also damage the road and communication lines. Debris flow is highly unsteady as it starts on steep slopes, flows through the down gullies and deposits at the mouth of the gullies (Wang et al., 2015). The study of debris flow is one of the big challenges to the researchers in the management of mountain rivers.

There are various models that have been used for the landslide susceptibility mapping i.e., fuzzy Shannon entropy (Shadman Roodposhti et al., 2016), Analytical Hierarchy Process (Yalcin, 2008), Analytical Network Process for debris flow susceptibility mapping (Sujatha et al., 2017). Frequency Ratio (FR) model and Logistic Regression (LR) model has been used by Esper Angilliors in 2013 for the study of debris flow susceptibility mapping. FR & LR models have been used to study the landslide susceptibility mapping by few researchers (Chauhan et al., 2010; Nandi et al., 2010; Ercanoglu et al., 2011; Yalcin et al., 2011).

In this present study, GIS and remote sensing techniques were deployed to derive various parameters resulting in delineation of soil erosion hazard mapping with the aid of RUSLE Model. Besides, this study attempts to assess the debris flow susceptibility mapping based on the debris flow - inventory map and conditioning factors such as lithology, altitude, slope, aspect, soil types, rainfall, Normalized Difference Vegetation Index, land use/land cover, distance from roads and aridity index. The debris flow susceptibility analysis was executed with the help of Shannon Entropy model and Frequency Ratio Model. The inventory map was generated by interpreting the data gathered through news reports, relevant literature, the annual reports published by NCESS, and some random points generated in the areas having the probability of occurrence of debris flow.

II. STUDY AREA

The study area is Palakkad district of Kerala also known as Palakkattussery. Palakkad district lies in 10.7867º N latitude and 76.6548º E longitude (figure 1). Palakkad has an area of around 4485 sq km with an approximate population of 2,382,240. Palakkad is the largest district of Kerala. The average annual temperature is 27.8º C and the average normal amount of annual rainfall is 2135 mm. The elevation of the study area is 84 m (276 ft.).

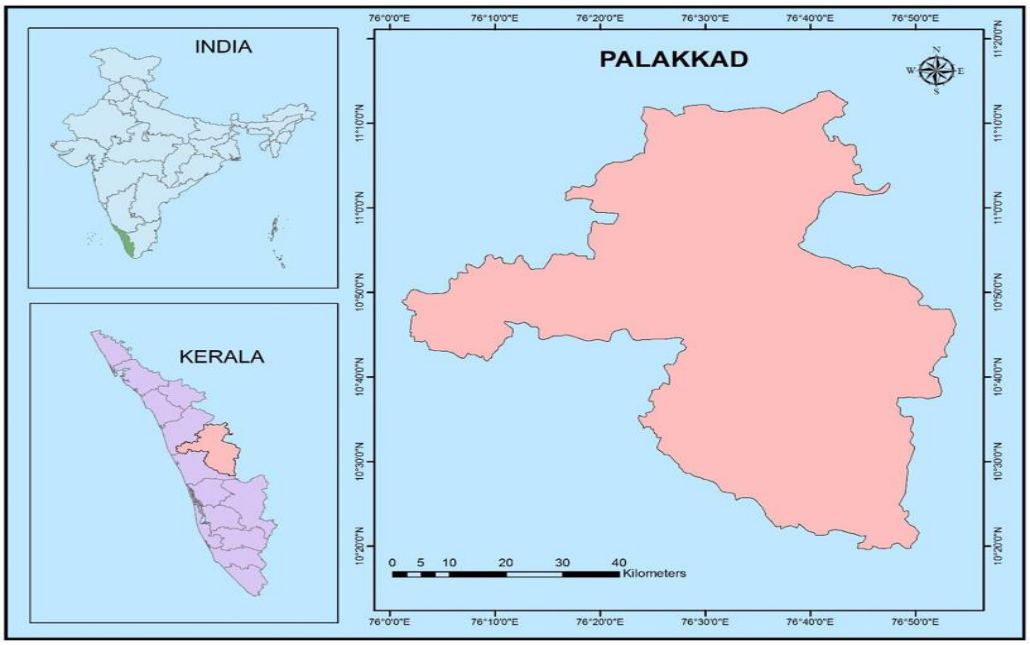

Figure 1: Base map of study area

III. METHODOLOGY

Throughout all geological ages, problems related to geomorphological activities like erosion of soil, movement, and deposition of sediments in water bodies including rivers, lakes and estuaries exist in almost all parts of the

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earth's surface. In the recent era, the increased anthropogenic interventions in the environment have intensified the situation, which demands an alternate course of action to be developed and deployed using empirical models. The data-intensive models such as USPED, WEPP, SWAT (Soil and Water Assessment Tool) have not been adopted for the study due to lack of availability of datasets namely rainfall intensity data (at less than 30 minutes) and sediment deposition data. Based on the availability of the data, the RUSLE model was selected and applied for estimating soil erosion in the study area. Remote sensing images, management practices, soil types, and their properties were utilized in generating the model requirements. RUSLE model was selected also because its parameters can be integrated smoothly into the GIS environment. The main aim of the study is to assess the erosion risk and debris flow by integrating the RUSLE model with GIS and remote sensing techniques in the district of Palakkad. The overall methodology for both Soil Erosion Risk Mapping and Debris Flow Susceptibility adopted in this study is schematically represented in figure 2 & 3.

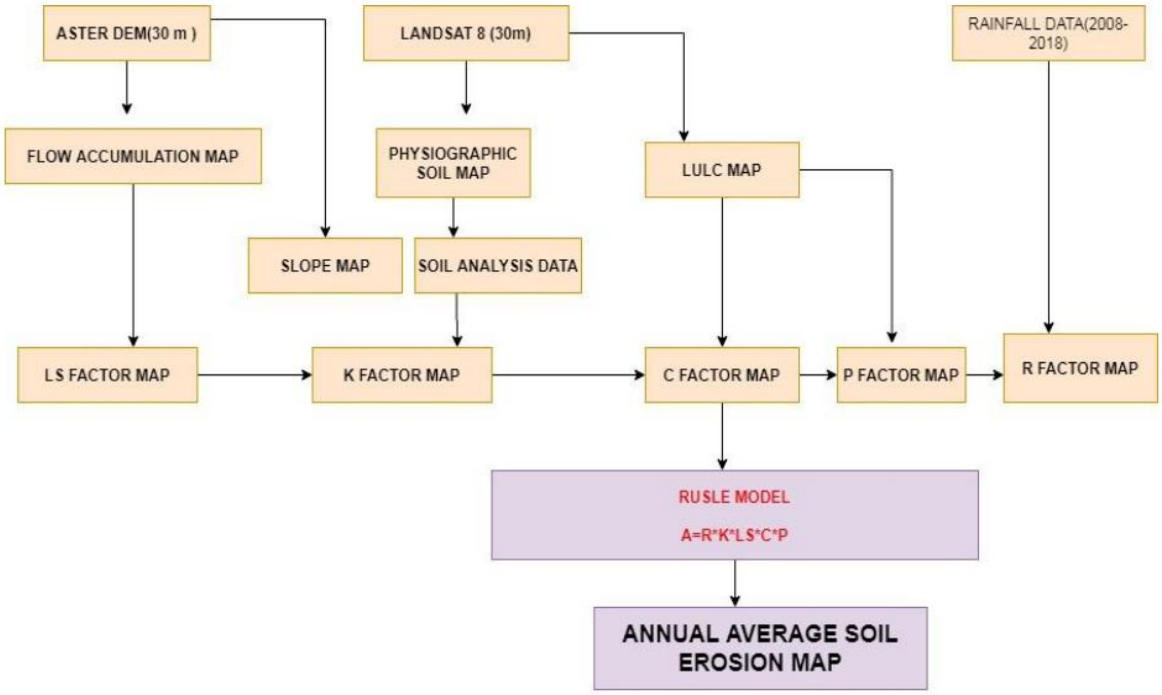

Figure 2a: Methodology Chart for Soil Erosion risk mapping

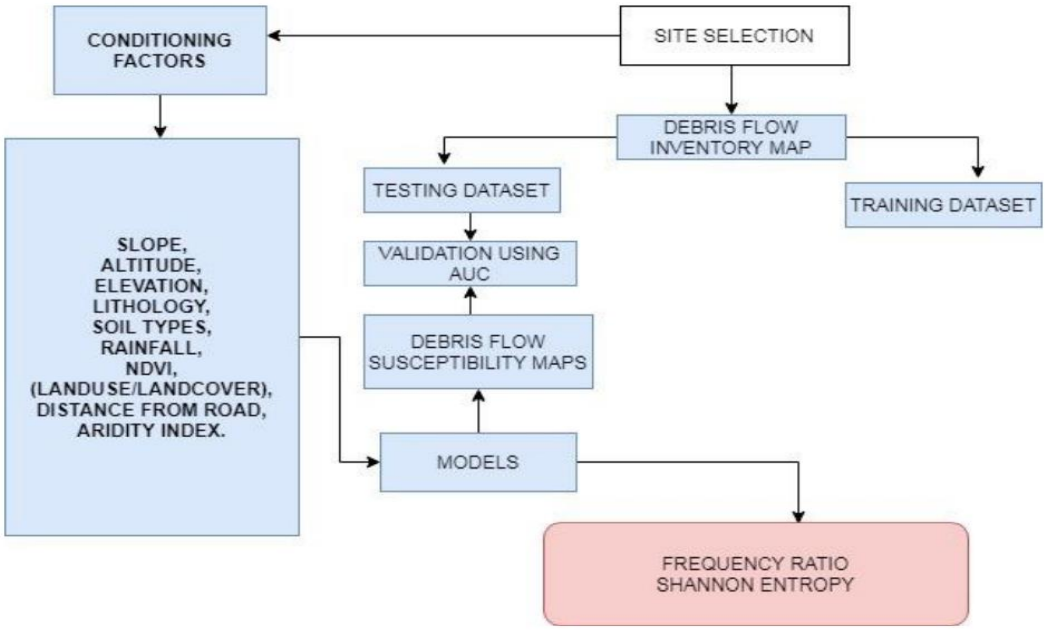

Figure 2b: Methodology chart for debris flow susceptibility mapping.

The RUSLE model assumes that the flow of sediment content determines the detachment and deposition of the soil's top layer. The rate of erosion is limited by the source of eroding materials and their carrying capacity by the flow. When the sediment load and the carrying capacity of the flow become equal detachment halts (saturation) and sedimentation ensues in that region of the hydrograph as the flow rate decreases (Wischmeier et al., 1978).

Combining the Universal Soil Loss Equation and GIS: In this study, RUSLE was used for assessing the long-term annual averages of soil loss. Modern Geospatial inputs and methods make RUSLE model to get easily integrated with the former as they are encoded with physically meaningful digital values in a cell-by-cell manner. To enhance the model, several other parameters such as LULC (land use land cover) data generated using satellite images and DEM derived products namely slope, aspect, etc. can also be easily integrated with RUSLE model. RUSLE can be expressed as follows:

$$A = R \times K \times LS \times C \times P \qquad (1)$$

Where, A=Predicted average annual soil loss per unit area (ton.ha.year $^{-1}$),

R = Rainfall runoff erosivity factor in [M] mm.ha^{-1}.hr^{-1}.year$^{-1,}$

K = Soil erodibility factor [ton.ha.hr.ha^{-1}.MJ^{-1}.mm^{-1}.],

LS = Slope length-steepness factor (dimensionless),

C = Cover-management factor (the ratio of soil loss in a specified area with specified cover and management to that from the same area in tilled continuous fallow) (dimensionless),

P = Conservation support practice factor (dimensionless).

Rainfall Erosivity Index(R): The nature of the soil erosion and its movement is spatially varied owing to the difference in intensity of rainfall. Rainfall Erosivity factor refers to rill erosion influence made by a rain drop on the surface. The R factor represents the erosivity of the weather at a particular location. R-value was greatly influenced by the intensity, duration, volume, and the pattern of rainfall, be it for a single storm or a series of storms, and by the amount and rate of the resulting runoff. For this study, the annual precipitation data from 8 weather stations, for 11 years (2008-2018) was acquired from CHRS portal and the R-factor was calculated using the following equation.

$$R = 79 + 0.363\ X\ a \qquad (2)$$

Where, R=Rainfall erosivity factor, mm.ha^{-1}.hr^{-1}. year^{-1} , X a= Annual rainfall per year. (Mm).

In the present study 11 years (2008-2018) of average annual rainfall data has been used to calculate and, they were interpolated over the whole Palakkad district using the Geostatistic model Inverse Distance Weightage (IDW), the average annual R factor values, and the range from 528-647 MJ mm.ha^{-1}.hr^{-1}.year$^{-1.}$

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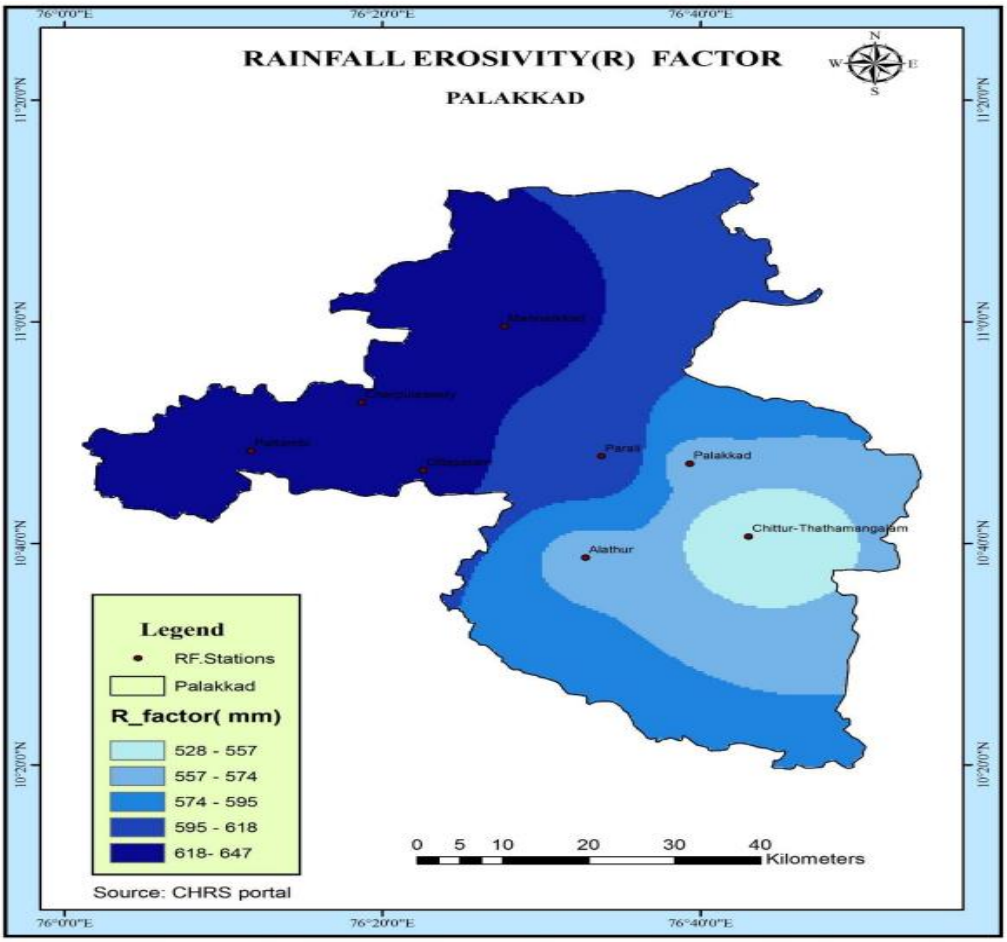

Figure 3a. Map of rainfall erosivity factor

K-Factor (Soil Erodibility): The soil Erodibility (K) factor represents both susceptibility of soil to erosion and the amount and rate of runoff. The soil erosivity factor is dependent on the soil characteristics such as natural resistance and susceptibility, soil texture, grain size and organic content (Ettazarini et al.2017, n.d.; Haregeweyn et al., 2017; Molla et al., 2017; Ayalew et al., 2015; Saha, 2018). The following equation was used to calculate the K factor.

$$K = F(Csand) * f(cl.si) * f(org) * f(hisand) \quad (3)$$

F (Csand) = [0.2+0.3.exp [-0.256.msand. (1-silt%/100)] F (cl.si) = [silt content %/mclay+msilt] power (0.3)

F (org) = [1-0.0256.orgCarbon/orgCarbon+exp (3.72-2.95.orgCarbon)]

F (hisand) = [1-0.7. (1-sandcontent%/100)/ (1-msand/100) +exp (-5.51+22.9. (1-msand/100)].

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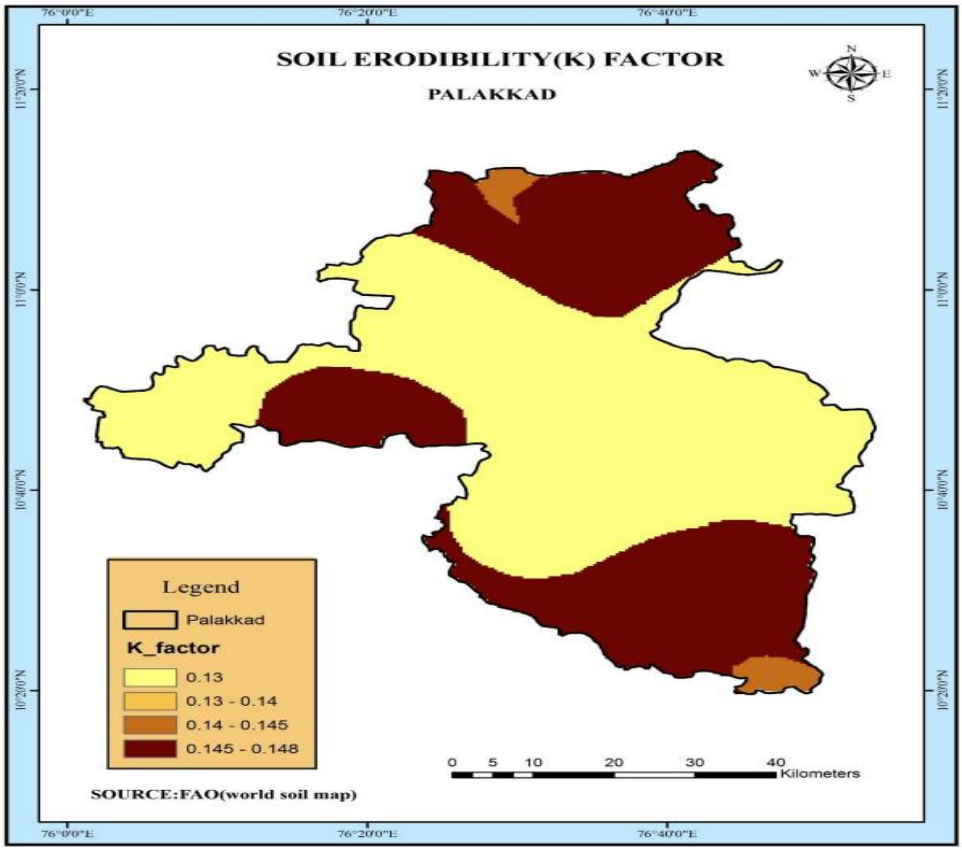

Figure 3b. Map of soil erodibility factor

Slope Length and Steepness Factor: LS-Factor (Topography): The slope length and steepness factor (LS) signifies the erodibility mainly due to combinations of steepness and slope length relative to a standard unit plot. This reveals the effects of topography, focusing the hill slope length and steepness on soil erosion. The LS factor expresses the three factors which are influenced by the local topography namely, soil erosion rate, combined effects of slope length (L) and slope steepness(S). It also states that the longer the slope length the greater the amount of cumulative runoff and vice versa. Also, higher slope steepness leads to higher velocity and runoff causing more erosion. DEM data was utilized to generate slope gradient and LS factor map. Wischmeier & Smith, (1978) has developed the empirical equation, which is derived by the following equation.

$$LS= (f*\text{Cell Size}/22.13)\ ^m*(0.065+0.045s+0.0065s^2) \quad (4)$$

Where,

F=Flow accumulation,

Cell size= DEM grid size,

S= slope and

M=m is a variable plot exponent adjustable to match terrain and soil variants.

M varies between 0.5 (slopes of 5% or more) and 0.2 (slopes of <1%). To implement LS factor in ArcGIS, the below formula of Rahaman, Aruchamy, Jegankumar and Ajeez (2015) was used.

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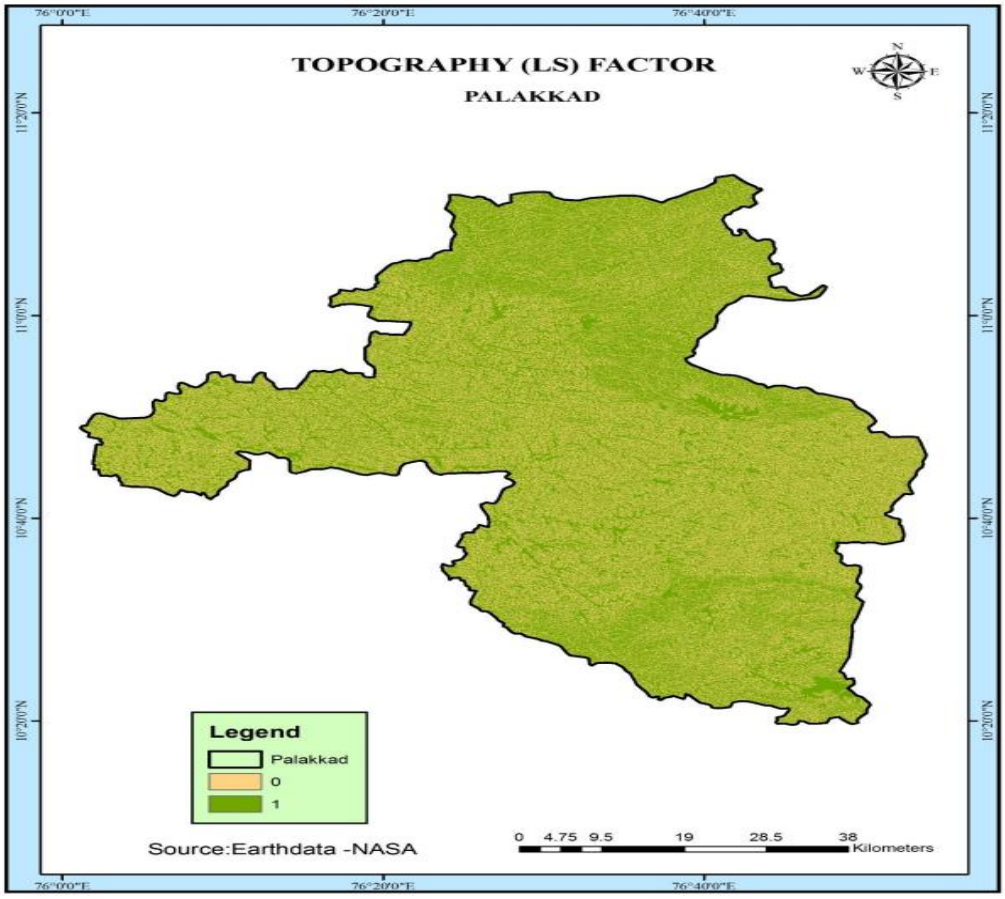

Figure 3c. Map of Slope Length and Steepness Factor (LS)

C-Factor (Vegetation cover management): The Conservation practice factor (C) is based on NDVI. The loss of soil is a very sensitive issue, and it is inversely proportional to vegetation cover. In addition to protecting the soil, vegetation cover serves to dissipate raindrops' energy before they reach the surface. The value of C factor varies between 0 and 1. The C factor values of these areas indicate a greater vulnerability to soil erosion and have been considered to be unprotected barren lands. The C factor is spatially determined through the concentration of vegetation which is of paramount importance in regulating the control of soil erosion level. This Cover management factor represents the result of soil disturbing activities in the form of plant, crop sequences, productivity levels, soil cover and sub-surface biomass in the soil erosion process. The soil loss was highly dependent on vegetation cover, slope steepness, and length factor (Renard et al., 1993). Few researchers used LULC classes to assign the C factor value (Belayneh et al., 2019; Gashaw et al., 2018; Yesuph et al., 2019). Some other researchers estimated NDVI for C values (Ettazarini et al., n.d.;2017 El Jazouli et al., 2017; Koirala et al., 2019; Belasri et al., 2016). Using the equation, the present study assessed C factor based on the Normalized Difference Vegetation Index (NDVI).

$$C= e^{(-2*NDVI/1-NDVI)} \quad (5)$$

Many researchers have effectively used the above equation to find out the spatial distribution of C factor (Kouli et al 2009; Prasannakumar et al., 2012). In this study, the range of C factor lies between 0.16 to 1.67.

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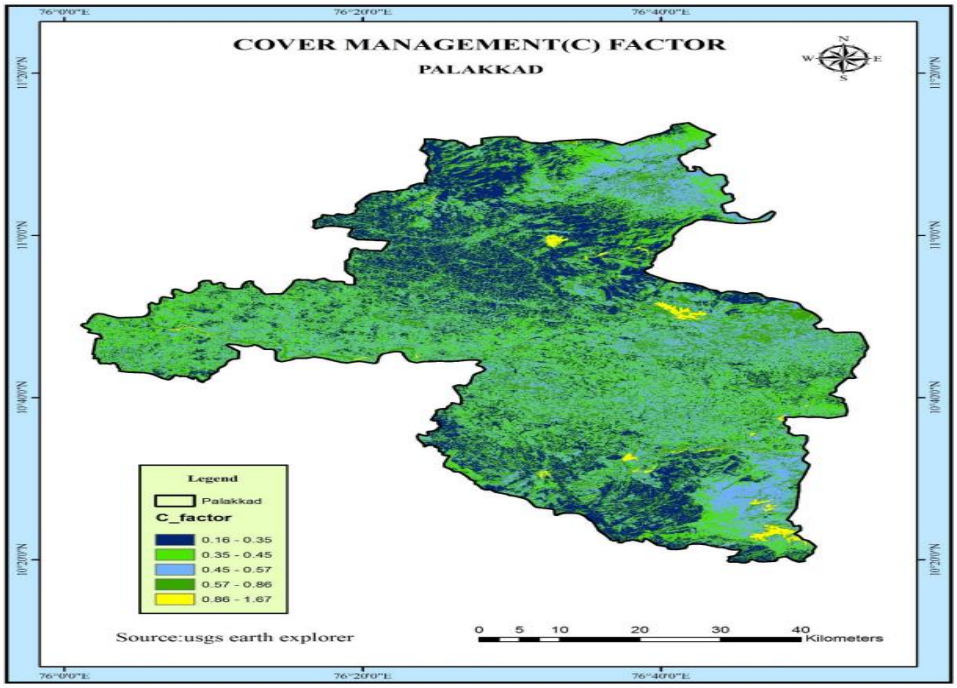

Figure 3d. Map of Vegetation Cover Management (C) Factor

Support Practice Factor (P): P factor elucidates the practices which have been taken up for reducing amount of runoff and erosion of the soil (Fayas et al., 2019; Knisel, 1980; Ellison, 1944). The P factor values were determined from the original table of Wischmeier and Smith (1978). P-Factor refers to the support practice factor, which acts as a deterrent towards erosion process. It reflects the effects of practices that reduces the amount, rate of the runoff and erosion. The P factor represents the ratio of soil loss with contour tillage (up and down slope) (Wischmeier and Smith 1978; Renard et al., 1997; Dabral et al., 2008). The most common support practices include cross slope cultivation, strip cropping, grassed waterways, terracing, and contour farming. A fusion of LULC and support factor was used to calculate this factor for the study area. The P factor ranges between 0 and 1, with the highest value assigned to the areas having no management practice (the forest), and the lowest value assigned to the built-up and water body.

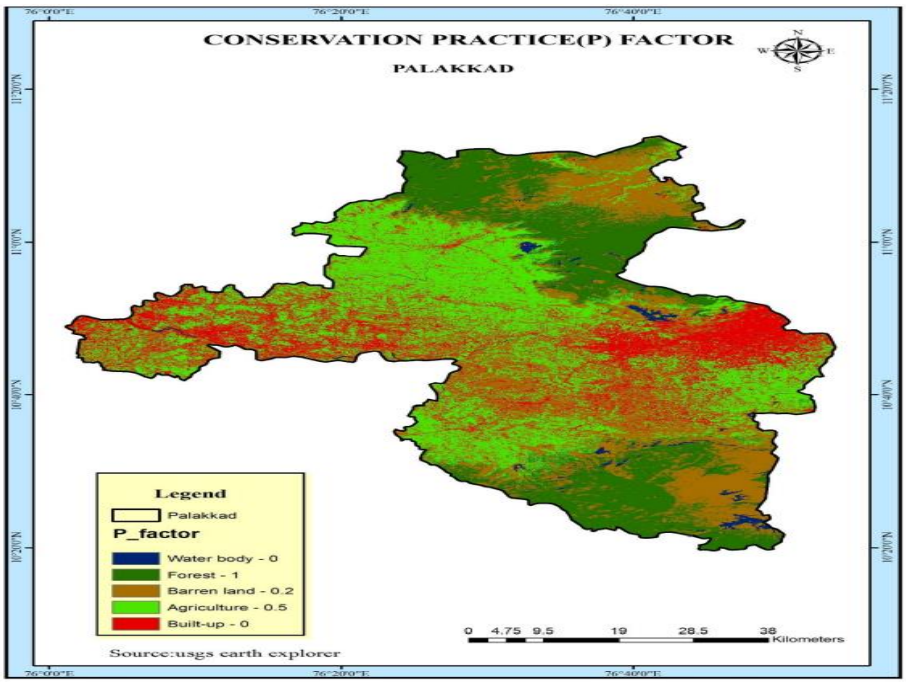

Figure 3e. Map of Support Practice (P) Factor.

Frequency Ratio Model:

Frequency ratio was calculated by taking the ratio of the probability of occurrence versus the probability of non-occurrence for a given attribute. Equation 6 was used to calculate the frequency ratio.

FR= Percentage of pixels of debris flow occurrence / Percentage of pixels in domain (6)

Then in raster calculator using this equation to create the frequency ratio debris flow model for mapping

FR = (Elevation*1.7130) + (Aridityindex*4.570831) +(LULC*5.650108) +(NDVI*6.138199) +(Rain*5.084685) + (Road*2.143466)+(Slope*1.602433)+(Lithology*13.14841)+(soiltype*3.241838)+(Aspect*9.91946).

Shannon's Entropy Method:

The SE model measures the uncertainty or the amount of variability in a random variable according to the Boltzmann concept, which is used in information theory. In calculating the information coefficient, the following formulae are used and Vj represents the parameter value to total value ratio, which is calculated using the equation below.

SE=Pij (7)

(Pij)=Individual FR of each class/Total FR value of class

Pij=FR/∑j=1Mj *FR.

Hj=- ∑j=1toMjPijlog2 (Pij,) J=1, 2…., n

Hjmax=log2Mj,Mj=Number of classes.

Ij= (Hjmax-HJ/Hjmax), I= (0, 1).j=1,…n

VJ=IjFR.

Equation in Raster calculator Shannon entropy model map.

SE=(Elevation*1.19046)+(Aridityindex*0.144987)+(LULC*0.308757)+(NDVI*0.273127)+(Rain*0.328259)+(Road*0.893089)+(Slope*1.098032)+(Aspect*0.067376)+(Soiltypes*0.677035)+(Lithology*1.530044).

IV. RESULTS AND DISCUSSION

In figure 3a, (528-557mm) of rainfall area covers the chittur rainfall station,(557-574mm) of rainfall area covers the Alathur and palakkad rainfall station,(595-618 mm) of rainfall area covers the parali rainfall station and (618-647 mm) of rainfall area covers the 4 rainfall stations namely pattambi, cherpulassery, ottapalam and Mannarkad. In Figure 3b, the estimated K values of the textural groups vary from 0.15(clay soil), 0.2(sandy soil), 0.4(silt loam soil) and 0.4(High silt soil) with 0.14 indicating soils that are highly prone to erosion. In Figure 3c, the m ,variable plot exponent adjustable to match terrain and soil variants ,the value of LS =0 indicates that area having less slope and LS=1 indicates that the area having more slope,so that the cumulative runoff is high. In Figure 3d,the C factor values of (0.16-0.35) covers the area under agriculture,(0.35-0.45) covers the area under builtup,(0.45-0.57) value of C factor covers the Barrenland ,(0.57-0.86) value of C factor covers the forest areas and (0.86-1.67) value of C factor covers the waterbodies, whereas soil loss was very sensitive to vegetation cover with slope steepness and length factor and then very high C factor values indicates the areas more vulnerability to soil erosion. In Figure 3e,P factor called conservation practice factor according to USDA handbook the values from 0 to 1 was given therefore ,the minimum values like 0,0.2,0.5 are given to water body, built up, agriculture and barren land then the maximum value of 1 assigned to the area having no management practice like forest.

Multiplying the developed raster data from the RUSLE model yields the Average Annual Soil Loss (A), which is expressed as A=R*K*LS*C*P. The Palakkad district's average annual soil losses were observed to be around 43.69 ton/ha/year. As suggested by Singh et al., (2017), the soil erosion map has been reclassified according to erosion risk classes appropriate for Indian conditions. In table 1 , the potential erosion of palakkad varies from 8.58t/ha/year to above 43.69t/ha/year (Figure 4) and it is classified into five erosion zones. These zones are very low (8.58ton/ha/year),low(21.84ton/ha/year),moderate(31.50ton/ha/year),high(43.69ton/hec/year) and very high prone zone(above 43.69) .On the basis of erosion risk classification, 14.14 % of the area fell into the very low erosion class,25.58% of the area fell into low erosion class,25.13% of the area fell into moderate,24.43% of the area fell into high prone zone and 10.70 % of the area fell under severe erosion class.

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Table 1: Classification of soil loss based on erosion risk classes

CLASSES	AREA (%)	SOIL EROSION RATE (ton/ha/year)
Very Low	14.14	8.58
Low	25.58	21.84
Moderate	25.13	31.50
High	24.43	43.69
Very high	10.70	Above 43.69

The spatial distribution of soil erosion in the Palakkad district was estimated with the RUSLE model and GIS techniques, and the resulting soil erosion loss map was classified into five different erosion risk classes. In determining soil conservation strategies to effectively counter soil erosion, the annual average loss map will be extremely helpful. The local farmers should practice soil conservation and protection methods on their farms, and the local planners and the decision-makers should adopt long-term and short-term strategies for the management of natural resources. The very low (8.58), low (21.84), moderate (31.50), high (43.69) and very high (above 43.69) ton/ha/ya of soil erosion were classified in ArcGIS 10.3 software. An extremely high and high concentration of erosion prone zones is observed in the eastern part of fallow lands and hilly areas in the Palakkad region. The change in land use and land cover has an effect on influences the rate of soil erosion. Hence, soil conservation practices are needed in hilly regions in order to prevent soil erosion. To conserve soil in agricultural areas, soil conservation practices must be adopted. The very less amount of erosion was noted in cropland.

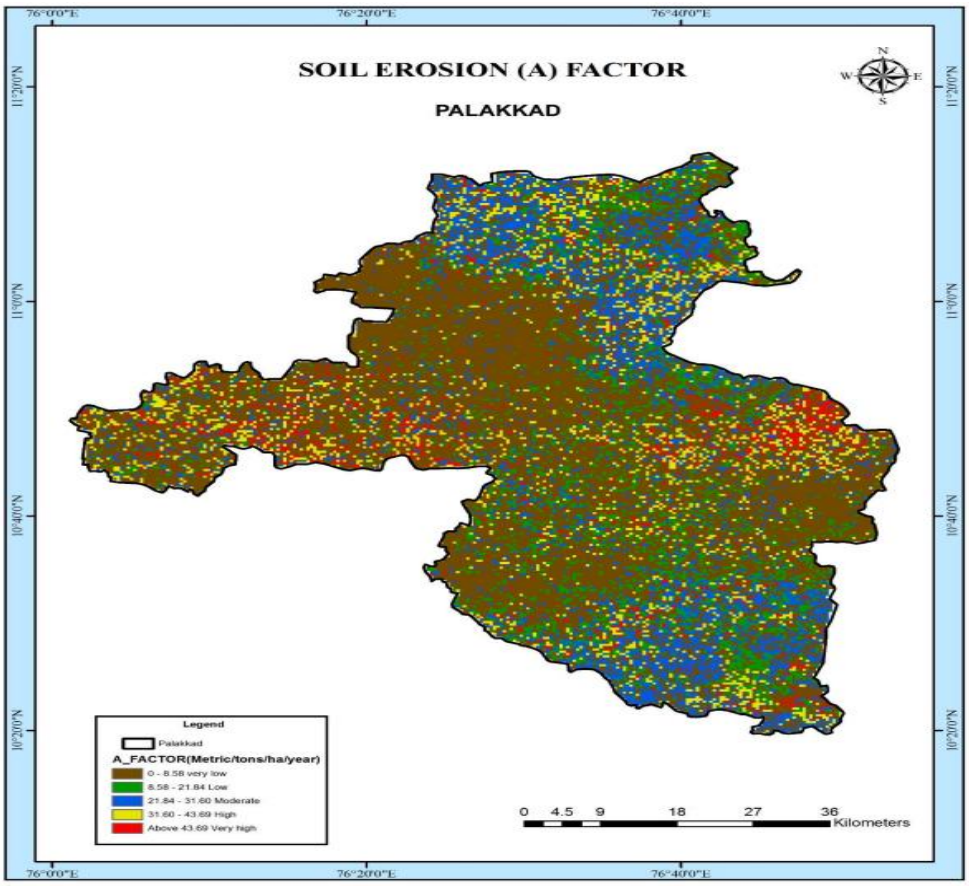

Figure 4. Map of Soil Erosion (A) Factor

Soil erosion also occurred because of human activities like overgrazing, over cropping and deforestation. Due to human activities accelerating soil erosion, all these activities will lead to desertification, which is the spreading of desert-like lands that are highly saline in nature. In future, rate of soil erosion is slated to increase; to

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overcome that, more practices are needed such as windbreaks, planting trees, contour ploughing and stubble planting to conserve the soil; stone walls- like building the walls with stone alongside the contours of the soil will prevent soil erosion down slope while allowing rainwater to percolate through the soil instead of running off the slope. Mulching also helps to prevent the soil erosion. It is important to conserve the soil because soil is the foundation of basic ecosystem function. By filtering the water, the soil provides the necessary nutrients for agriculture crops through proliferation of microbial activity and simultaneously, forests help to regulate the Earth's temperature and many of the greenhouse gases.

Estimation of Debris Flow Susceptibility Causal Factors

In Figure 5, This debris flow inventory map was compiled based on data and information found in news reports, literary sources, and the yearly reports of NCESS. Most similar natural hazard models used the inventory data in a point format. Total of 462 debris flow events were identified in the Palakkad district. Out of 462 debris flows, 224 locations were used as a validation of the models. In this study, debris flow susceptibility has been mapped using frequency ratio and Shannon's entropy models.

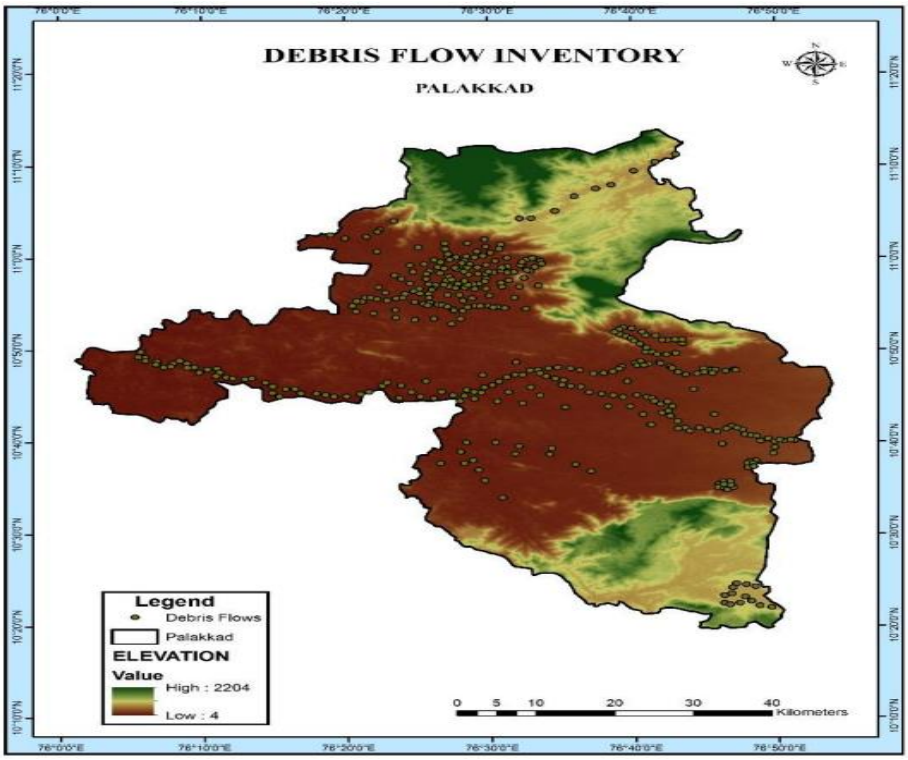

Figure 5. Map of Debris Flow Inventory

The selection of debris flow causal factors was an important task for susceptibility modelling and mapping. In this study, there are totally 10 factors were used namely slope angle, elevation, altitude (direction), lithology, soil types, rainfall, Normalized Difference Vegetation Index (NDVI), Land Use and Land Cover classification, proximity to roads and aridity index.

The slope was selected as a factor for this because, it proved the existence of a strong relationship between the debris flow and the elevation. Greater the slope, greater the debris flow occurrence. Moreover, it increases the water flow speed and reduces absorption time and percolation of the water into the ground. The aspect was chosen because of its influence on the amount of precipitation and variance in sunshine levels. The lithology was an important factor for this analysis because of the water behaviour on the ground. Taking into account the influence of impervious roads and surrounding urban surfaces on debris flow, the distance from road is of utmost importance for this study. Finally, soil types can directly affect/influence the permeability, drainage, and water storage of the soil.

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Table 2. Shows the calculation of frequency ratio for the different parameters.

S.NO	FACTORS	CLASSES	NO.OF PIXELS SHOWING DEBRIS FLOW OCCURRENCE	% OF PIXELS IN DEBRIS FLOW OCCURRENCE	PIXELS IN DOMAIN	% OF PIXELS IN DOMAIN	FREQUENCY RATIO
1	**ELEVATION**	1	344	93.73	3370422	67.83	**1.71**
		2	23	6.27	940383	18.92	
		3	0	0.00	499998	10.06	
		4	0	0.00	116255	2.34	
		5	0	0.00	41976	0.84	
		TOTAL	**367**	**100.00**	**4969034**	**100.00**	
2	**ARIDITY**	1	28	7.67	574356	11.63	**4.57**
	INDEX	2	81	22.19	969658	19.64	
		3	66	18.08	957321	19.39	
		4	158	43.29	1625541	32.92	
		5	32	8.77	810265	16.41	
		TOTAL	**365**	**100.00**	**4937141**	**100.00**	
3	**LANDUSE/L**	1	6	1.63	55033	1.11	**5.65**
	ANDCOVER	2	29	7.90	1236867	24.90	
		3	231	62.94	2545630	51.25	
		4	54	14.71	609253	10.47	
		5	47	12.81	519844	10.47	
		TOTAL	**367**	**100.00**	**4966627**	**98.20**	
4	**NDVI**	1	13	3.54	79787	1.61	**6.14**
		2	85	23.16	1010123	20.34	
		3	102	27.79	1452415	29.24	
		4	102	27.79	1394273	28.07	
		5	65	17.71	1030029	20.74	
		TOTAL	**367**	**100.00**	**4966627**	**100.00**	
5	**RAIN**	1	42	11.54	351685	7.07	**5.08**
		2	49	13.46	1000121	20.10	
		3	45	12.36	981979	19.74	
		4	46	12.64	1035919	20.82	
		5	182	50.00	1605423	32.27	
		TOTAL	**364**	**100.00**	**4975127**	**100.00**	
6	**ROAD**	1	321	88.19	3340507	67.10	**2.14**
		2	38	10.44	816406	16.40	
		3	3	0.82	478951	9.62	

		4	2	0.55	86758	5.13	
		5	0	0.00	4978111	1.74	
		TOTAL	**364**	**100.00**	**9700733**	**100.00**	
7	**SLOPE**	1	339	92.37	3600518	72.46	**1.60**
		2	26	7.08	1074059	21.62	
		3	2	0.00	271554	5.47	
		4	0	0.00	21310	0.43	
		5	0	0.00	1226	0.02	
		TOTAL	**367**	**99.46**	**4968667**	**100.00**	
8	**LITHOLOGY**	1	32	8.79	1613931	32.43	**13.15**
		2	6	1.65	139590	2.80	
		3	6	1.65	197474	3.97	
		4	9	2.47	262957	5.28	
		5	56	15.38	600524	12.07	
		6	199	54.67	1766819	35.50	
		7	22	6.04	219234	4.40	
		8	7	1.92	52691	1.06	
		9	22	6.04	75279	1.51	
		10	5	1.37	48611	0.98	
		TOTAL	**364**	**100.00**	**4977110**	**100.00**	
9	**SOIL TYPES**	1	7	1.92	103472	2.08	**3.22**
		2	53	14.56	1722942	34.62	
		3	10	2.75	274483	5.51	
		4	294	80.77	2875400	57.77	
		5	0	0.00	813	0.02	
		TOTAL	**364**	**100.00**	**4977110**	**100.00**	
10	**ASPECT**	1	20	5.45	276158	5.56	**9.92**
		2	28	7.63	463376	9.33	
		3	37	10.08	498038	10.02	
		4	31	8.45	582586	11.73	
		5	41	11.17	640517	12.89	
		6	58	15.80	675419	13.59	
		7	53	14.44	578412	11.64	
		8	49	13.35	514408	10.35	
		9	30	8.17	448527	9.03	
		10	20	5.45	291226	5.86	
		TOTAL	**367**	**100.00**	**4968667**	**100.00**	

Analysing the spatial relationship between each debris flow-related factor and the debris flow location was performed using frequency ratios and Shannon entropy models.In Table 2,the different factors for frequency ratio was calculated, elevation factor has the frequency ratio value of 1.713,aridity index having 4.570,

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landuse/landcover factor having FR ratio value of 5.650,NDVI having the value of 6.138,the rain factor having the FR value of 5.084,the road factor having the FR value of 2.143,the slope factor having the least value of 1.602,the lithology factor having the maximum FR value of 13.148,soil type factor having the value of 3.224 and aspect factor having the maximum FR value of 9.919..In Figure:6,the area and debris flow rate for FR model was classified into five debris flow susceptibility zones. These zones are very low. (6.7%), low (15%), moderate (18.4%), high(21.5%) and very high(24.8%).In table 4,On the basis of debris flow susceptibility risk classification (9.03%) of area fell into very low debris flow rate,(22.22%) of area fell into low debris flow rate,(31.35%) of area fell into moderate debris flow rate,(23.86%) of area fell into high debris flow rate and (13.52%) of area fell into very high debris flow rate.

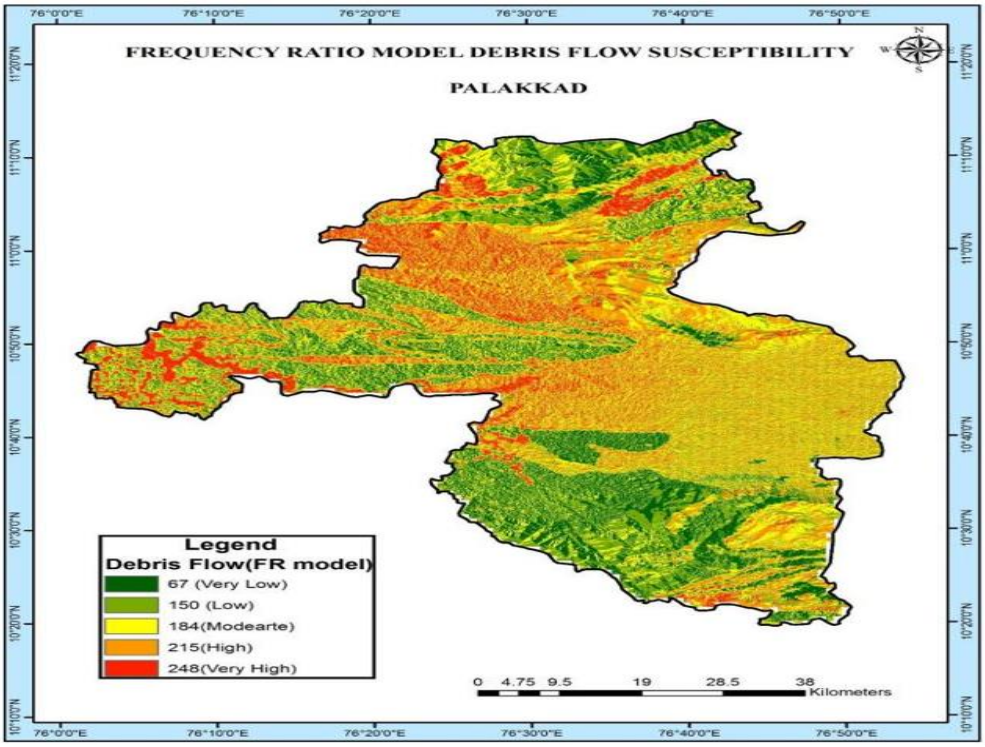

Figure 6. Debris flow susceptibility map using FR model

Table 3. Shows the calculation of SE weightage for the different parameters.

Sl.No	FACTORS	LASSES	Pij	(Pij)	Hj	Hjmax	Ij	SE weightage
1	ELEVATION	1	1.3819	0.8066	0.25			
		2	0.3311	0.1933	0.4583			
		3	0	0	0			
		4	0	0	0	2.321	0.6942	1.19
		5	0	0	0			
		TOTAL	**1.713**	**1**	**0.7083**			
2	ARIDITY INDEX	1	0.6594	0.1442	0.4029			
		2	1.1299	0.2472	0.4984			
		3	0.9325	0.204	0.4678			
		4	1.3147	0.2876	0.517	2.321	0.031	0.144
		5	0.5342	0.1168	0.3619			
		TOTAL	**4.5708**	**1**	**2.2482**			
3	LANDUSE/LANDCOVER	1	1.4754	0.2611	0.5058			
		2	0.3173	0.0561	0.2333			
		3	1.228	0.2173	0.4785			
		4	1.4057	0.2438	0.4993	2.321	0.0546	0.308

		5	1.2235	0.2165	0.4779			
		TOTAL	**5.6501**	**1**	**2.195**			
4	NDVI	1	2.204	0.339	0.53			
		2	1.138	0.185	0.45			
		3	0.95	0.154	0.416			
		4	0.99	0.161	0.424	2.321	0.044	0.273
		5	0.854	0.139	0.395			
		TOTAL	**6.138**	**1**	**2.218**			
5	RAIN	1	1.652	0.321	0.526			
		2	0.669	0.131	0.385			
		3	0.626	0.123	0.372			
		4	0.606	0.1193	0.366	2.321	0.0645	0.328
		5	1.549	0.3044	0.522			
		TOTAL	**5.084**	**1**	**2.172**			
6	ROAD	1	1.314	0.613	0.432			
		2	0.636	0.296	0.52			
		3	0.085	0.039	0.185			
		4	0.107	0.049	0.215	2.321	0.4166	0.893
		5	0	0	0			
		TOTAL	**2.143**	**1**	**1.354**			
7	SLOPE	1	1.274	0.795	0.262			
		2	0.327	0.204	0.468			
		3	0	0	0			
		4	0	0	0	2.321	0.685	1.09
		5	0	0	0			
		TOTAL	**1.602**	**1**	**0.73087**			
					9			
8	ASPECT	1	0.98	0.098	0.33			
		2	0.813	0.082	0.2968			
		3	1.005	1013	0.3348			
		4	0.72	0.0726	0.2747			
		5	0.866	0.0873	0.3072			
		6	1.162	0.1172	0.3625	3.321	0.006	0.067
		7	1.24	0.125	0.375			
		8	1.289	0.13	0.3826			
		9	0.905	0.0912	0.3152			
		10	0.929	0.0937	0.3201			
		TOTAL	**9.919**	**1**	**3.2993**			
9	SOIL TYPES	1	0.923	0.285	0.516			
		2	0.42	0.129	0.382			
		3	0.498	0.153	0.415			
		4	1.398	0.4312	0.523	2.321	0.208	0.677
		5	0	0	0			
		TOTAL	**3.24**	**1**	**1.837**			
10	LITHOLOGY	1	0.2711	0.0206	0.115			
		2	0.5877	0.0446	0.2			
		3	0.4154	0.0315	0.157			
		4	0.4679	0.0355	0.1712			
		5	1.275	0.0969	0.3264			
		6	1.54	0.1171	0.3623	3.321	0.116	1.53
		7	1.3721	0.1043	0.3402			

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8	1.8165	0.1381	0.3945
9	3.9959	0.3039	0.5222
10	1.4064	0.1069	0.3449
TOTAL	**13.148**	**1**	**2.9353**

In table 3, SE weightage for different parameters has been given. The elevation factor having the SE weightage value of 1.190,aridity index having the SE weightage of 0.144,LULC factor having the SE value of 0.308,NDVI factor having the SE value calculated was 0.273,the rain factor having the SE weightage of 0.328,road factor having the SE value of 0.893,the slope factor having the SE weightage value of 1.09,aspect having the SE weightage value of 0.067,the soil type having the SE weightage value of 0.677 and lithology factor having the SE weightage value of 1.5300.

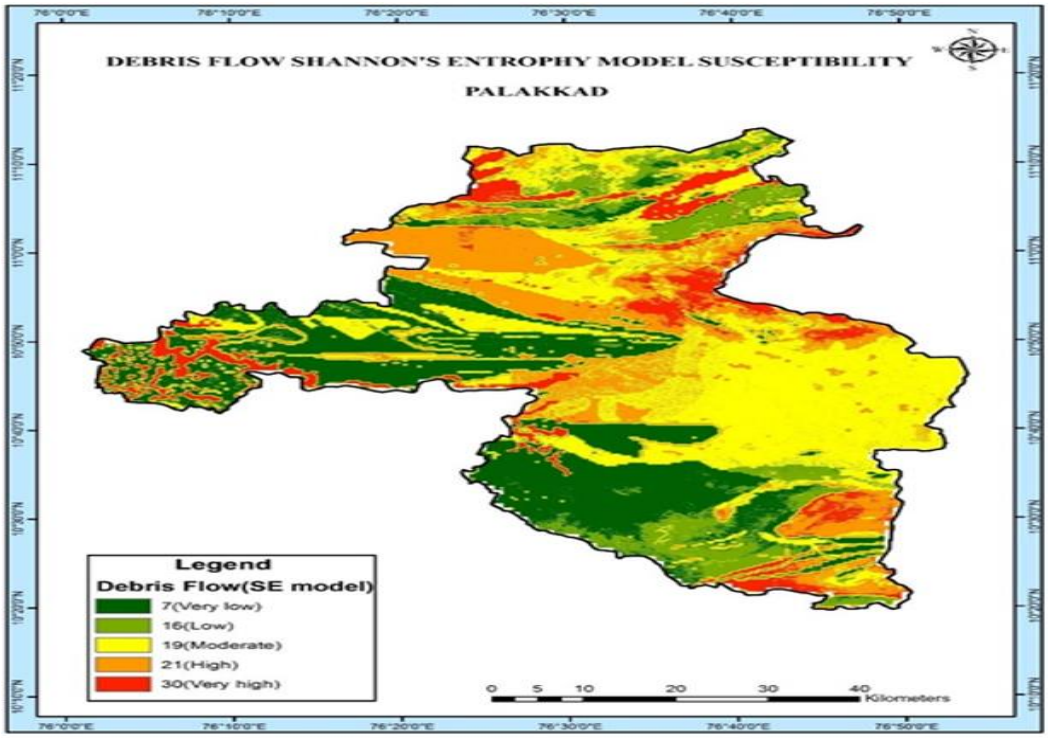

Figure 7. Debris flow susceptibility map using SE model

Models of frequency ratio and Shannon entropy were used to calculate the relationship between variables and debris flow inventory. These two models aided in creation of debris flow susceptibility maps that are categorized into five categories: very low, low, moderate, high, and very high.In Figure:7,the area and debris flow rate for SE model was classified into five debris flow susceptibility zones. These zones are very low (7%),low(16%),moderate(19%),high(21%) and very high(30%).In table 4,On the basis of debris flow susceptibility risk classification (6.61%) of area fell into very low debris flow rate,(17.94%) of area fell into low debris flow rate,(35%) of area fell into moderate debris flow rate,(15.90%) of area fell into high debris flow rate and (24.53%) of area fell into very high debris flow rate.

Table 4. Area of Debris flow susceptibility mapping according to the risk classes.

CLASSES	FR MODEL		SE MODEL	
	AREA (%)	DEBRIS FLOW RATE (%)	AREA (%)	DEBRIS FLOW RATE (%)
Very Low	9.03	6.7	6.61	7
Low	22.22	15.0	17.94	16
Moderate	31.35	18.4	35.00	19
High	23.86	21.5	15.90	21
Very high	13.52	24.8	24.53	30

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Validation with testing datasets

In the field of accuracy assessment, the AUC (Area under the Curve) is considered as the most popular and comprehensive quantitative method which is mainly used to evaluate the prediction rate. The validation process was performed by comparing the known debris flow data with the susceptibility map of acquired debris flow using AUC. An increasing number of disaster studies have used the AUC only to evaluate the efficiency of susceptibility mapping. On that basis of the above, the AUC method was used for the study of debris flow evaluation rate. In Figure8,area under curve for FR model was shown and the AUC value for FR model was 70.91.

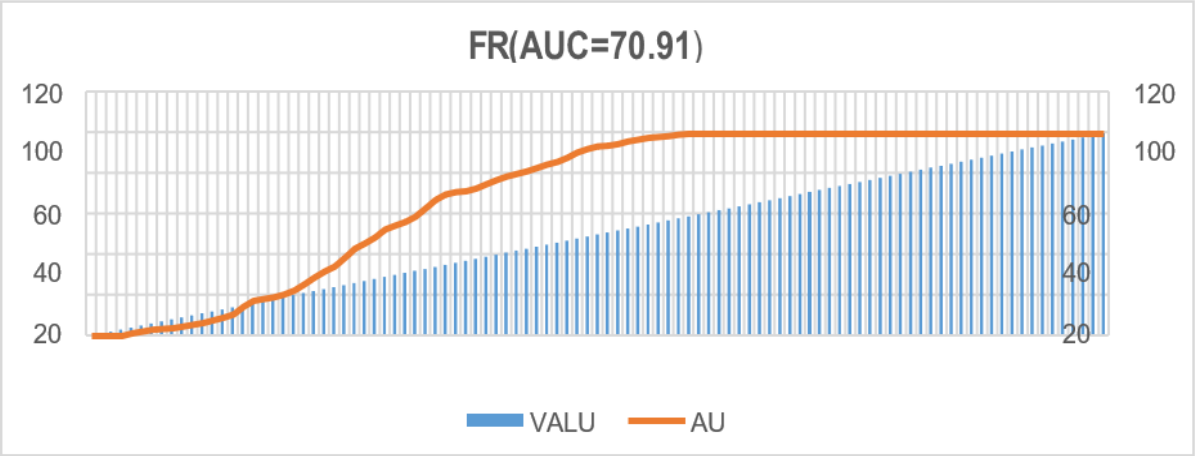

Figure 8. Area under curve (AUC) for Frequency Ratio model

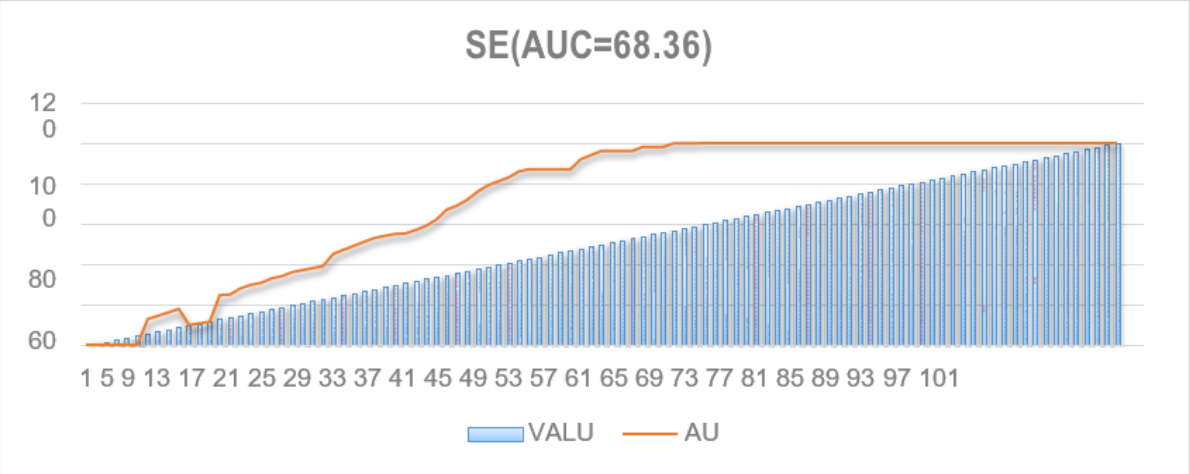

Figure 9. Area under curve (AUC) for Shannon Entropy model

In Figure 9, area under curve for shannon entropy model was shown and the SE value was 68.36. The accuracy of the frequency ratio model (70.91%) was more than the Shannon entropy model (68.36%) for predictions in the categories of the high and very high. In this study, for the precision of the debris flows, the testing validation has to be executed by comparing the known data of the debris flow location. For better validation and accuracy, the aerial photographs and digital satellite image interpretation with higher resolution was necessary to be checked. Based on the ACC value and curve, the results of the frequency ratio model showed better accuracy in debris flow susceptibility mapping. But, in Shannon entropy method, it shows some abnormality, changeability, unstable behaviour, and uncertainty in the AUC curve. The FR and SE techniques divide the susceptibility map into categories with equal area and hierarchically rank these values from minimum to maximum. The AUC curves were used to determine the percentage of debris flow occurrence for each probability category. These AUC curves were created by plotting the percentage of debris flow susceptible areas on the X-axis arranged from the highest to lowest and the percentage of debris flow events on the Y-axis. Finally, the steeper curve indicates that more debris flow events fall into categories of higher susceptibility.

V. CONCLUSION

In this study, the area under the erosion risk and debris flow susceptibility was identified with the aid of RUSLE model, Frequency Ratio and Shannon entropy model respectively and by analyzing both spatial distribution data of soil erosion and debris flow, the future occurrences can be easily predicted, and the damage caused by this can be averted. For the debris flow analysis, the comparative method of bivariate models such as Frequency ratio and Shannon entropy modelling techniques were used for enriching the accuracy of susceptibility mapping via AUC diagrams. Point to be noted is that RUSLE model does not measure the gully erosion which is one of the major problems now a days as it causes dissection of agricultural land. So, further study is required the estimation of gully erosion. Accuracy of frequency ratio model was high than Shannon entropy model for debris flow–susceptibility mapping. The present study will help in better planning and management of environmental hazard and sustainable development in Palakkad district. For the estimation of soil erosion and debris flow susceptibility mapping, the integrated use of different models with remote sensing and GIS techniques can be efficient and cost-effective.

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