Hochschule für Technik Stuttgart

Erosion Modelling with USLE

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Erosion Modelling with USLE

The Universal Soil Loss Equation (USLE) is a predictive model used to estimate the long-term average annual rate of erosion on sloped fields. It takes into account various factors such as rainfall pattern, soil type, topography, crop system, and management practices.

The equation

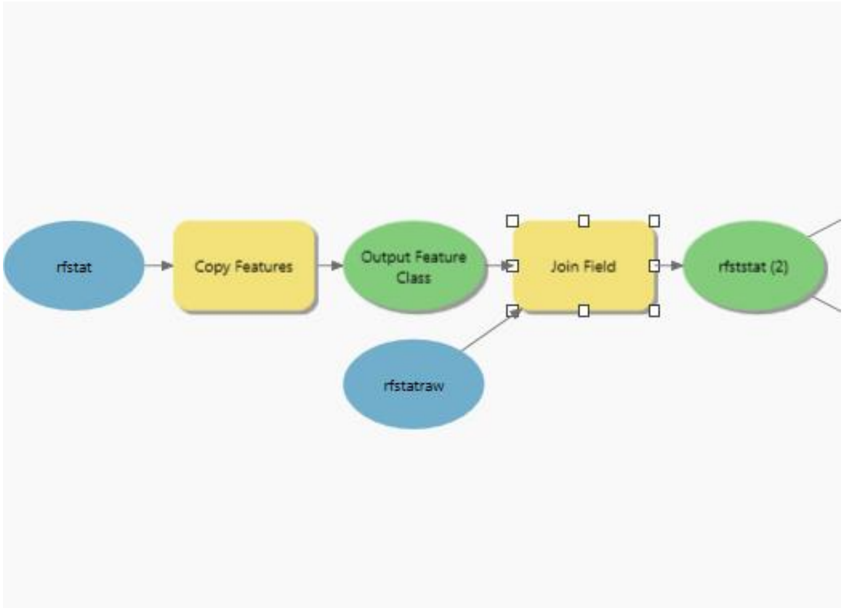
$A=R\times K\times LS\times C\times P$ represents the USLE, where:
A is the potential long-term average annual soil loss in tons per hectare per year.
R is the rainfall erosivity index, indicating the intensity and duration of rainstorms.
K is the soil erodibility factor, dependent on soil characteristics such as organic matter, texture, and permeability.
LS is the topographic factor, influenced by slope length and gradient.
C represents the crop/vegetation and management factor, assessing the effectiveness of soil and crop management systems.
P is the support practice factor, reflecting practices that reduce water runoff and erosion rates.

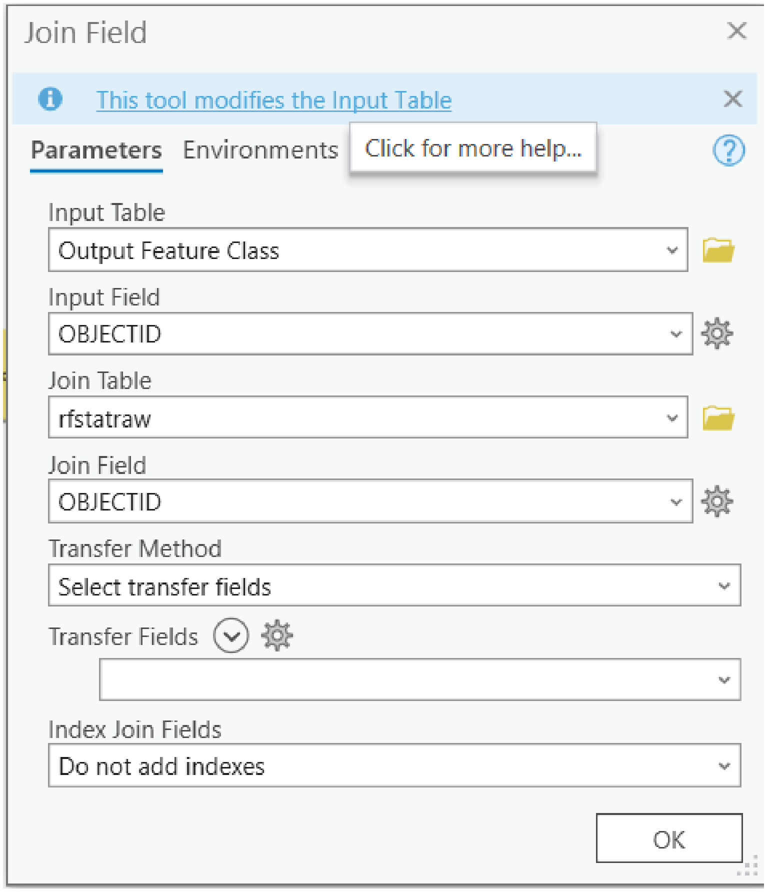
Data Preparation

Convert p-values from the Excel file to a CSV file: Initially, we converted the p-values provided in the Excel file to a CSV file.

Prevent overlapping data by copying features: Data was copied using the "Copy Features" tool to prevent overwriting of the data.

Join the copied data with the provided station points: Then, we used the "Join Tool" to merge these values with the provided station points.





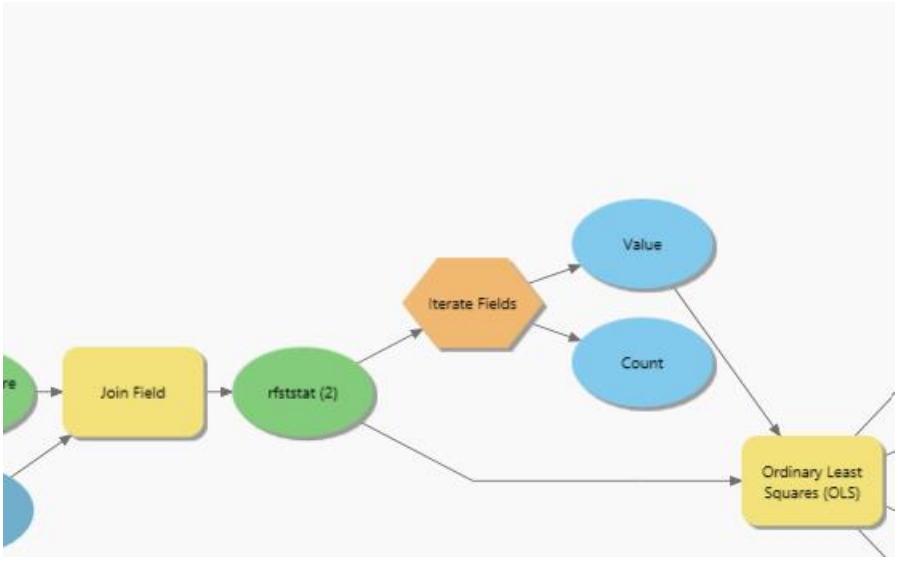
An iteration was created to repeat all analyses for each month. The iteration was repeated 12 times,(once for each month.)

Iterate Field and Adjustments Process

The provided equation for adjustment process was given as;

$$P=a0+a1x+a2y+a3z$$

Therefore, we had to find the coefficients for each month. To avoid doing process manually we created an iteration and connect it to Ordinary Least Square tools. When we connected joined rain stations tablet o iteration we selected the months in the iterate fields. The idea to select number of months and P values in it automatically.



After the iteration, the necessary coefficients were found using the P-values in the table to determine the adjusted P-values. Although the "OLS" tool output includes the adjusted P-value, we need to calculate this value for each month. Therefore, what we need are the coefficient values for each month. These values are generated as both a PDF and a table in the output. However, the table contained test statistic values that were not part of the equation given in the task description, aside from the coefficient values corresponding to X, Y, and Z. Therefore, it was decided to delete everything except for the coefficient values corresponding to X, Y, and Z.

	OBJECTID *	Variable	Coef	StdError	t_Stat	Prob	Robust_SE	Robust_t	Robust_Pr	StdCoef
1	1	Intercept	-28948,679594	5393,580609	-5,367247	0,000007	5606,721056	-5,16321	0,000013	0
2	2	X	-0,002183	0,000436	-5,001501	0,000021	0,000473	-4,618229	0,000063	-0,522683
3	3	Y	0,003321	0,000588	5,649561	0,000003	0,000599	5,549238	0,000004	0,557742
4	4	Z	0,055173	0,008925	6,181975	0,000001	0,006864	8,037676	0	0,636311
	Click to add new row.									

In the image above, the unprocessed output table result is visible. The table created as result consist of a lot variety of statistical information such as t-statistic, robust variables.

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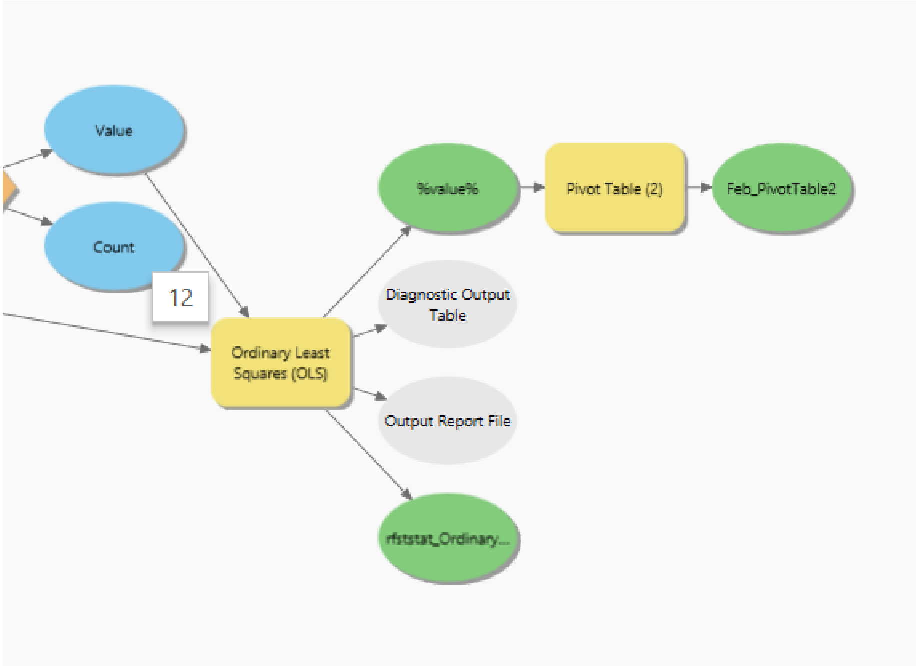
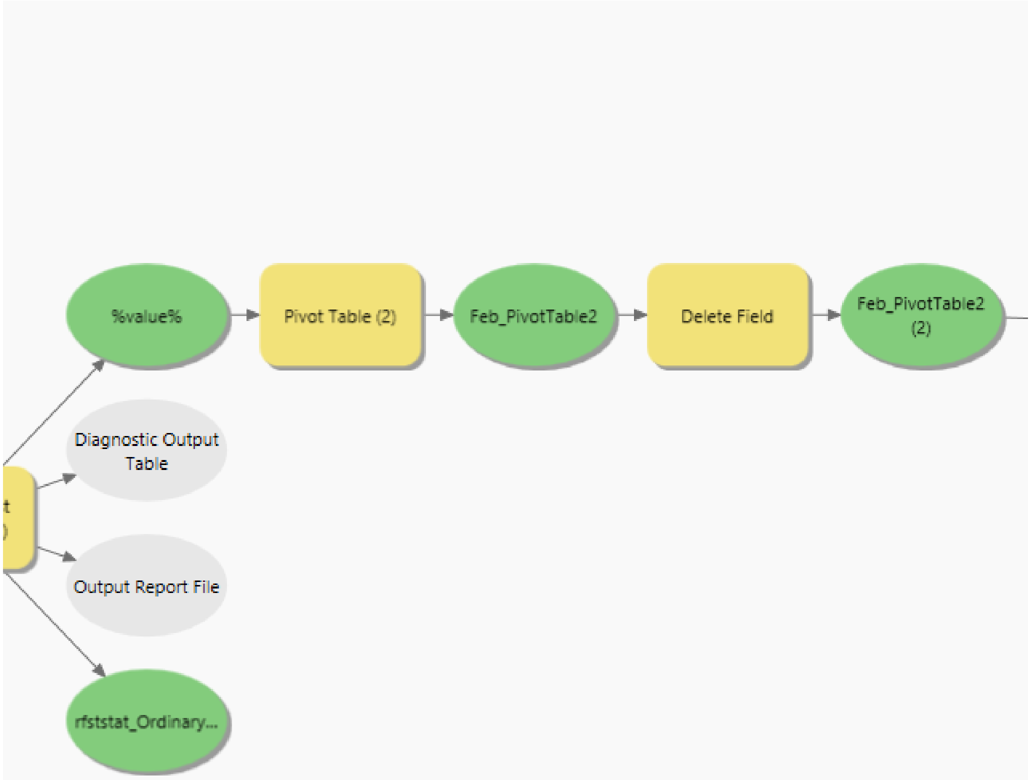


To delete unnecessary values, the Pivot Table tool was first used to create a column for X, Y, and Z values.

	OBJECTID *	Variable	Intercept	X	Y	Z
1	1	Intercept	-35615,078346	<Null>	<Null>	<Null>
2	2	X	<Null>	-0,002681	<Null>	<Null>
3	3	Y	<Null>	<Null>	0,004086	<Null>
4	4	Z	<Null>	<Null>	<Null>	0,067991
	Click to add new row.					

The resulting values from the Pivot Table tool are as shown above. As can be seen, each coefficient value is placed diagonally. Therefore, it was decided to delete the Variable values.

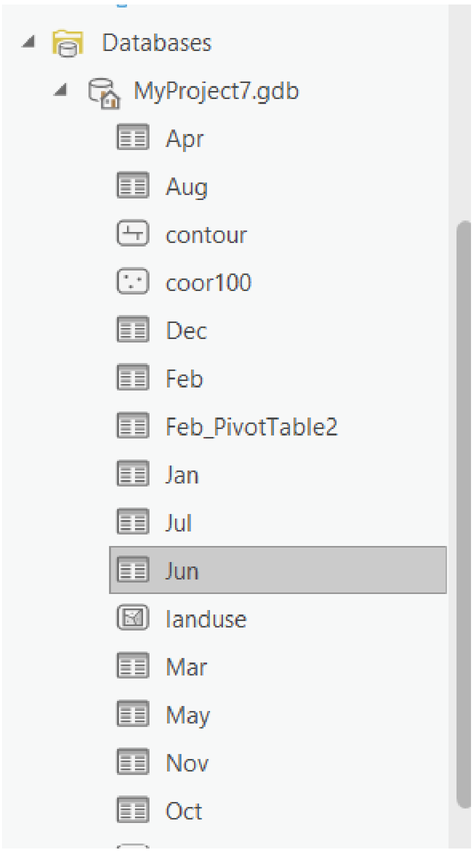


After creating the pivot table, a column was deleted.

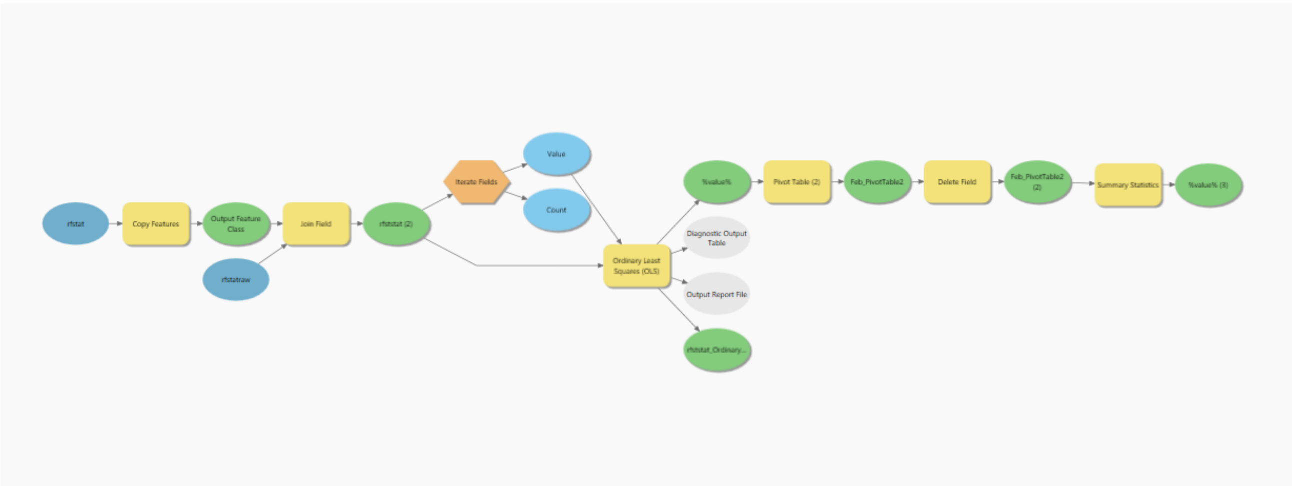
	OBJECTID *	Intercept	X	Y	Z
1	1	-35615,078346	<Null>	<Null>	<Null>
2	2	<Null>	-0,002681	<Null>	<Null>
3	3	<Null>	<Null>	0,004086	<Null>
4	4	<Null>	<Null>	<Null>	0,067991
	Click to add new row.				

In the final step, the maximum values for X, Y, and Z were selected to generate coefficient values. The purpose of creating values in a table with 4 columns and 1 row is to ensure that these tables can be used with different data management tools in later stages of the project if necessary. These tables can be merged with the X, Y, and Z coordinates corresponding to the respective month through a one-to-many join operation. Subsequently, the precipitation (P) and rainfall erosivity index (R) can be calculated within the table and later converted to raster for use.

	OBJECTID *	FREQUENCY	MAX_X	MAX_Y	MAX_Z	MAX_Intercept
1	1	4	-0,002183	0,003321	0,055173	-28948,679594
	Click to add new row.					



The tables created after the running the model

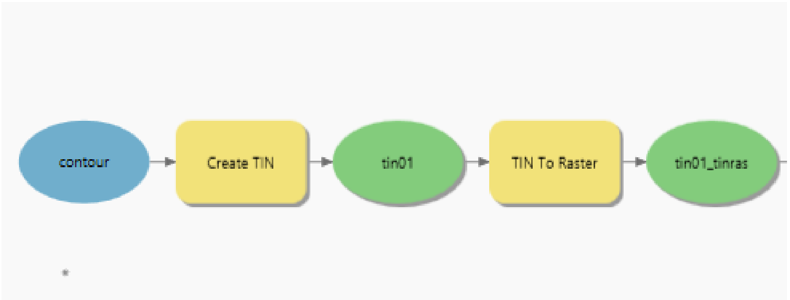


The entire model builder which utilized for least square adjustment process.

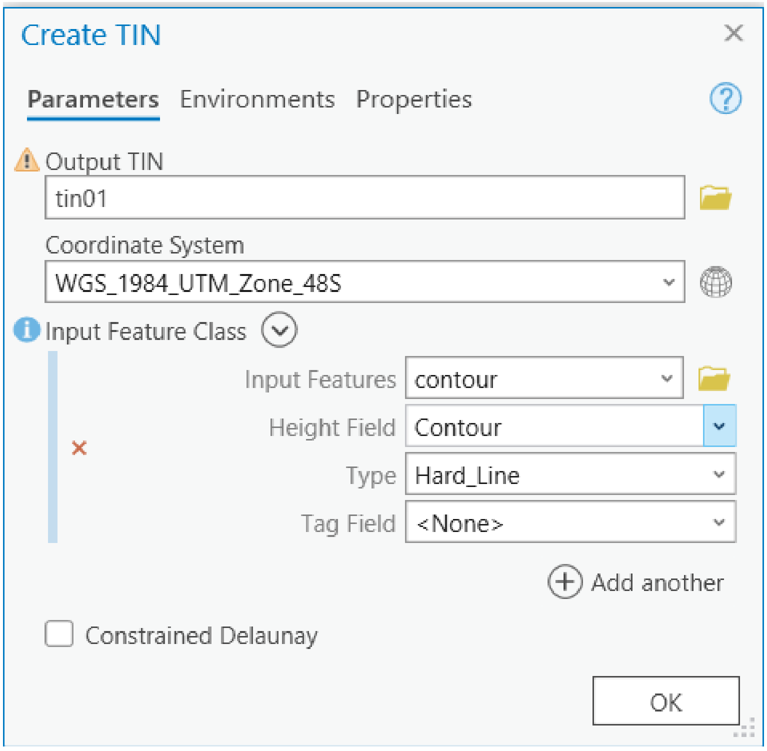
Creating of DEM, X raster, and Y raster layers

In the first stage, we manually calculated the DEM and raster layers in their entirety. During these processes, we chose a pixel size of 25 meters. We observed that selecting a smaller pixel size and scaling it to 1:10000 resulted in visually appealing maps. However, we noticed that selecting a smaller pixel size of 1 meter resulted in files consisting of millions of points. Considering the size of the data and the iterations, we realized that choosing a smaller pixel size might not be a good idea. In addition to all of this, we also found that selecting a 25-meter pixel size posed challenges for statistical comparisons and analyses at the result stage because the formulas provided in the task were given tonnes in per m^2, but the results were given in tonnes per hectares. Therefore, we decided to use Model Builder again to select a pixel size of 100 meters that would give us results in tonnes per hectares.

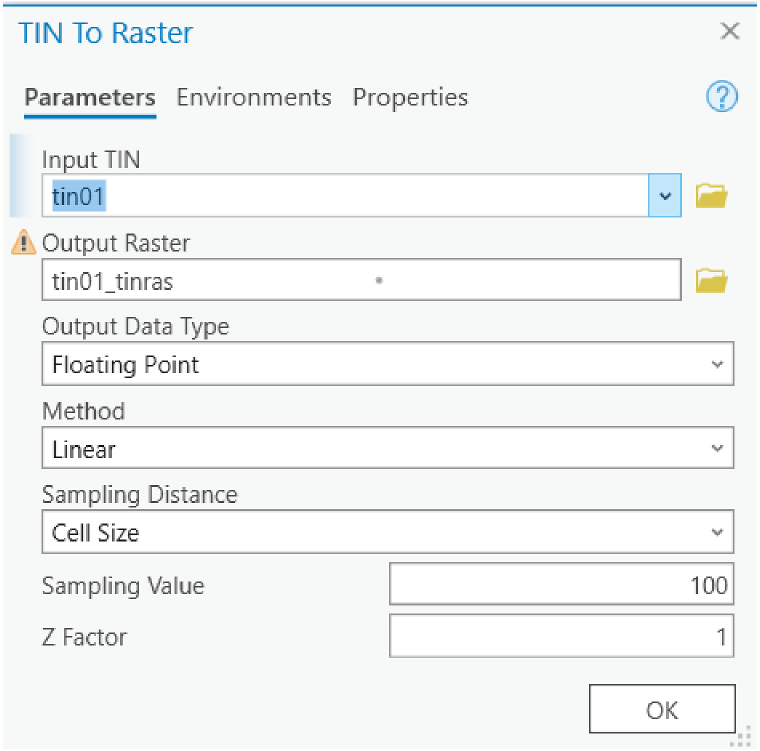
Creating a Model Builder for DEM, X raster, and Y raster layers



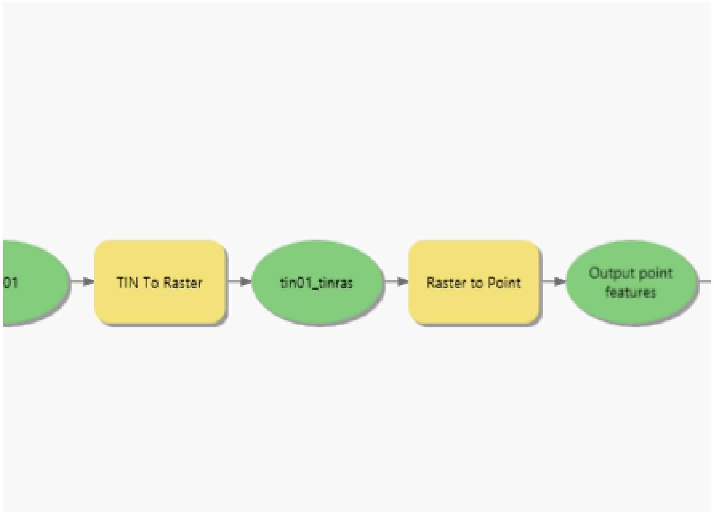
In the first stage, TIN was generated from contours.



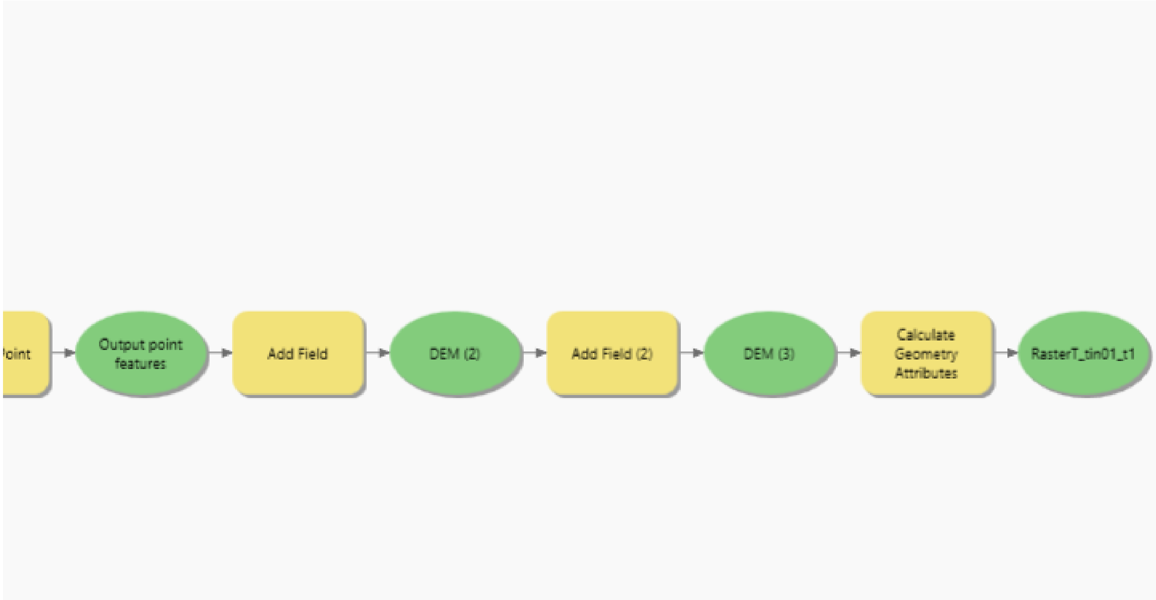
We arranged the TIN settings, and selected coordinate system. Then, the TIN data was converted to raster to create the DEM model.



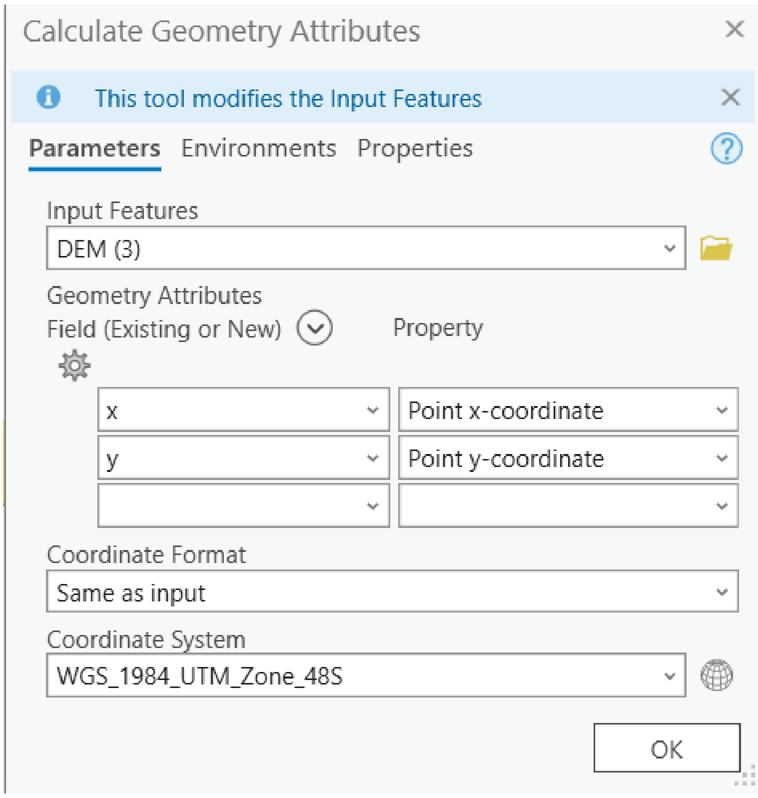
When creating the DEM model, the pixel value was again selected as 100 meters.



The previously created DEM model was used to convert raster data into vector format, specifically points. For this process, the "Raster to Point" tool was used.
The reason for converting to vector format is to find the necessary X and Y coordinate values required for adjusting the P values.



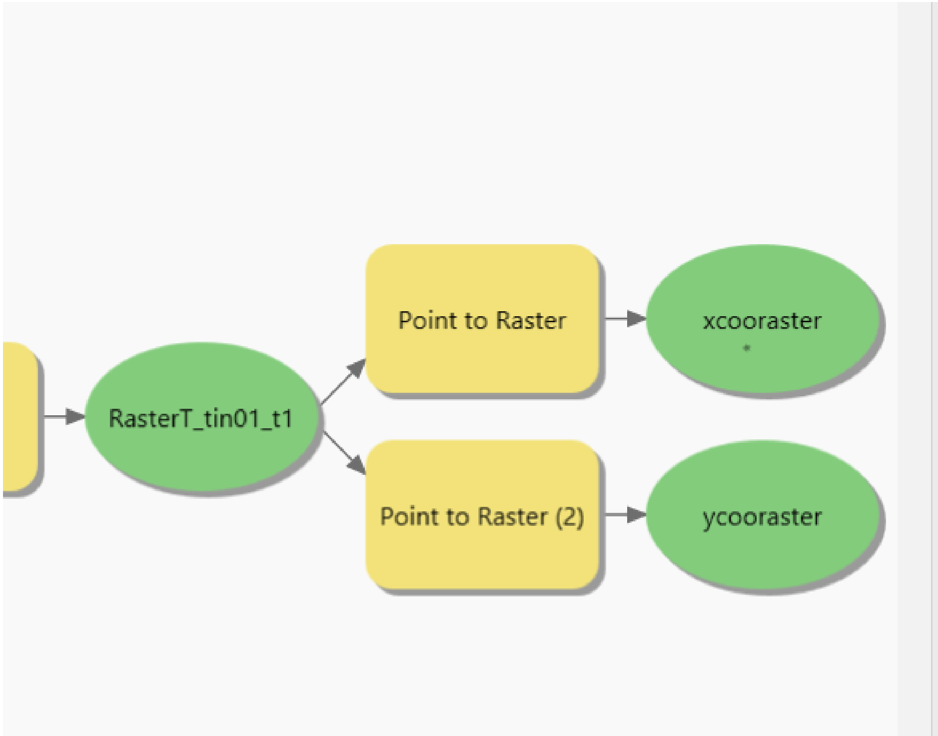
Following this process, X and Y fields were added to the created vector layer. The added X and Y values were calculated using the "Calculate Geometry Attributes" tool.



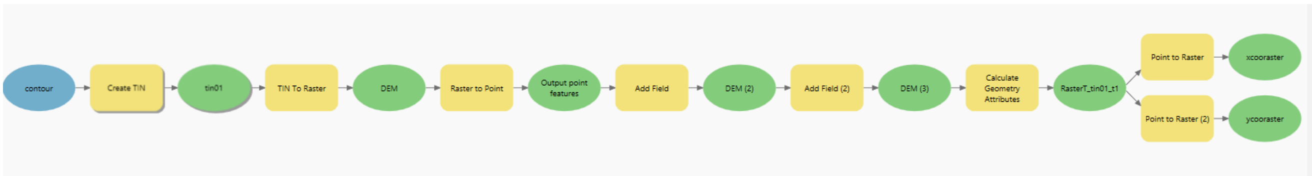
The fields that we needed to populate within this tool were chosen, and we matched them with the X and Y coordinates.

	OBJECTID *	Shape *	pointid	grid_code	x	y
1	1	Point	1	376,4408	686917,231423	9267507,307745
2	2	Point	2	378,4376	687017,231423	9267507,307745
3	3	Point	3	378,3728	687117,231423	9267507,307745
4	4	Point	4	378,308	687217,231423	9267507,307745
5	5	Point	5	378,2433	687317,231423	9267507,307745
6	6	Point	6	378,1785	687417,231423	9267507,307745
7	7	Point	7	378,1137	687517,231423	9267507,307745
8	8	Point	8	378,0489	687617,231423	9267507,307745
9	9	Point	9	375	687717,231423	9267507,307745
10	10	Point	10	375	687817,231423	9267507,307745

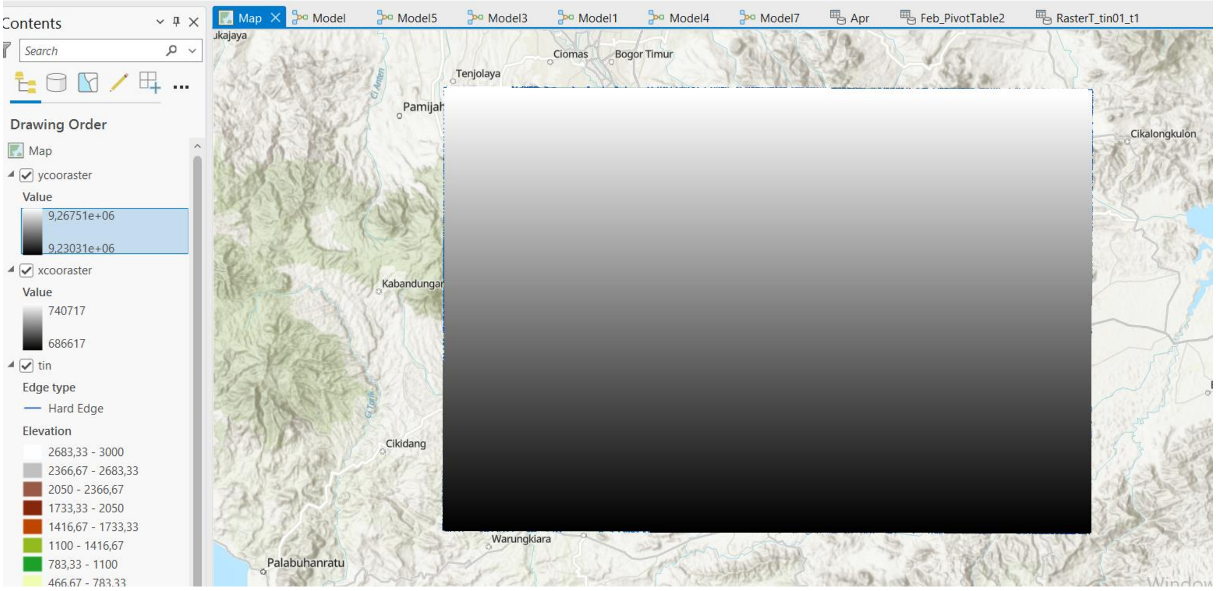
As a result, X and Y coordinates were calculated for each pixel.



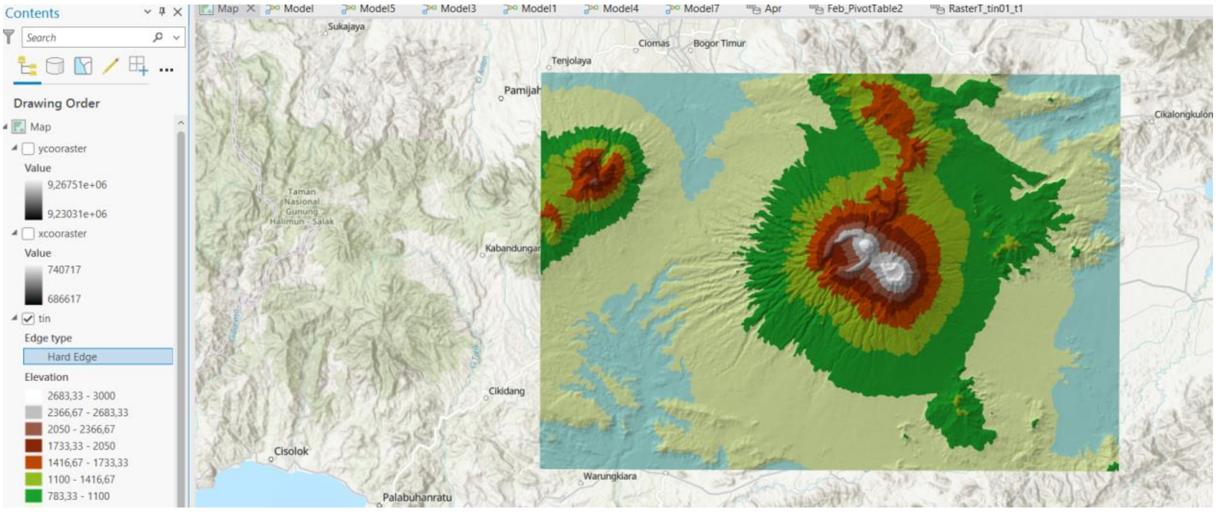
In the final step, the created X and Y coordinates were converted to raster using the "Point to Raster" tool.



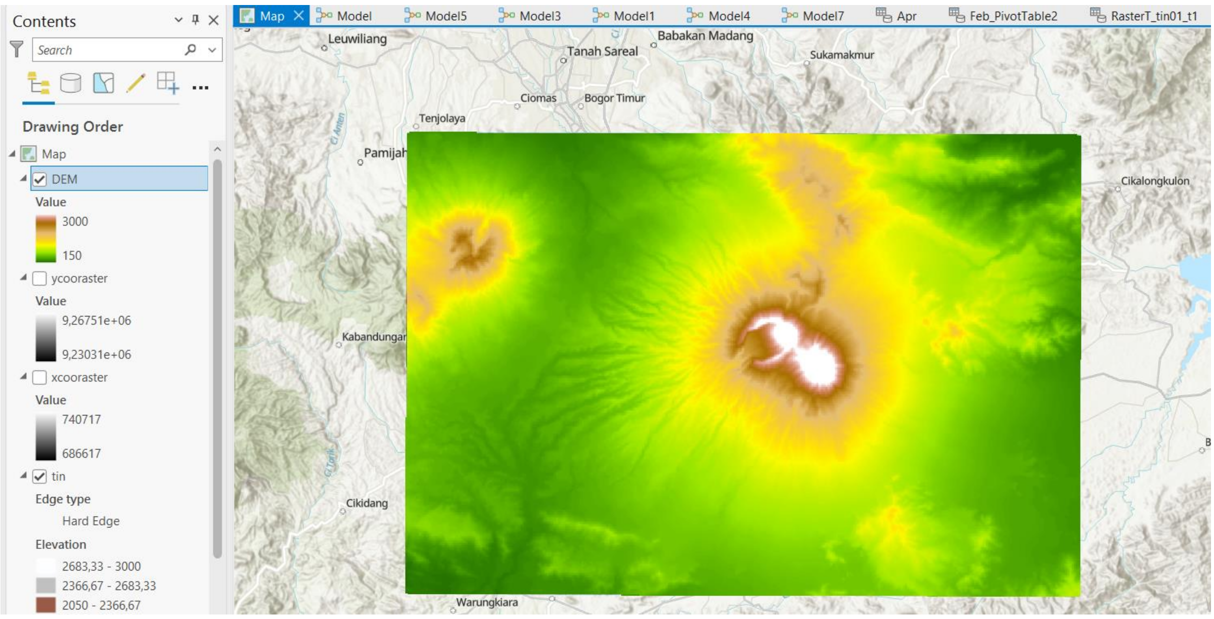
It’s seen above that the entire model used to perform these processes in Model Builder.



The Y raster layer was created as a result of the Model Builder process with a 100-meter pixel size.



Triangulation of contour lines created as result of Model Builder process with 100 meter pixel size.



The Digital Elevation Model (DEM) created with a 100-meter pixel size using Model Builder.

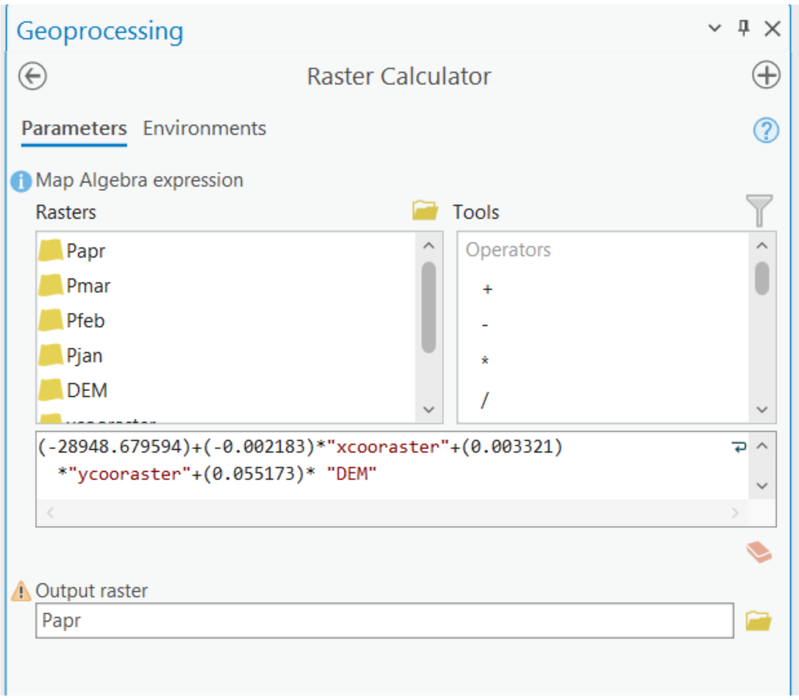
Months	A1	A2	A3	A0 (intercept)
January	-0,002764	0,004213	0,069841	-36722,90034
February	-0,002159	0,003269	0,054519	-28487,256
March	-0,002739	0,004171	0,069254	-36358,16943
April	-0,002183	0,003321	0,055173	-28948,67959
May	-0,002173	0,003299	0,054975	-28748,96729
June	-0,001809	0,002745	0,045801	-23919,83949
July	-0,001543	0,002344	0,038948	-20423,78529
August	-0,002009	0,003047	0,050769	-26555,07362
September	-0,002105	0,003191	0,053164	-27802,57495
October	-0,002043	0,003109	0,051726	-27097,74609
November	-0,002652	0,004029	0,067085	-35110,11944
December	-0,002681	0,004086	0,067991	-35615,07835

Adjustment Process of precipitation P data and creating raster layers

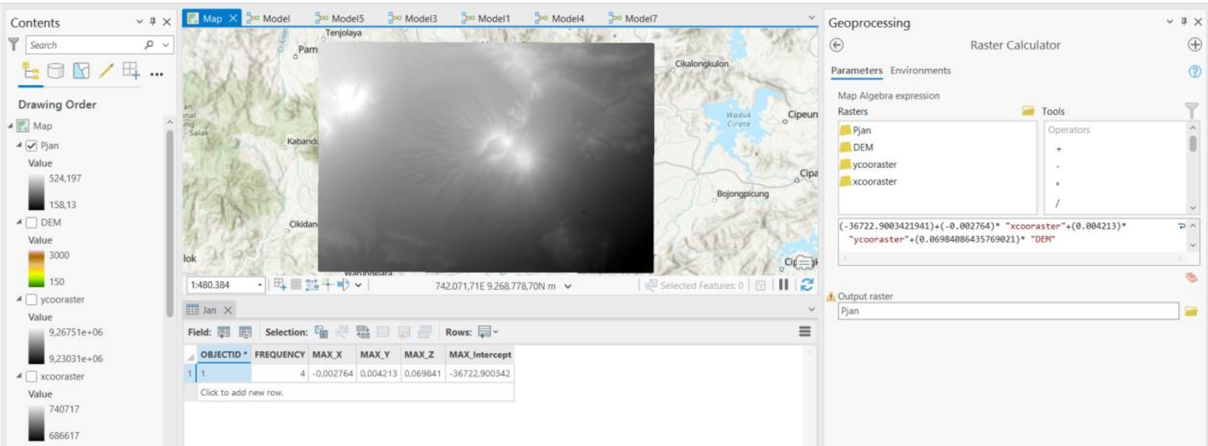
The equation for adjustment process was given as;

$$P=a0+a1x+a2y+a3z$$

Thus, to find the adjusted P values, we used the necessary raster X and Y coordinates, along with the coefficient values we previously found, to calculate the P values for each month. For this process, we used the Raster Calculator tool.



Geoprocessing
Raster Calculator
Parameters
Environments
Map Algebra expression
Rasters
Tools
Papr
Pmar
Pfeb
Pjan
DEM
Operators
+
-
*
/
(-28948.679594)+(-0.002183)*"xcooraster"+(0.003321)
"ycooraster"+(0.055173) "DEM"
Output raster
Papr



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Operators
Output raster
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MAX_X
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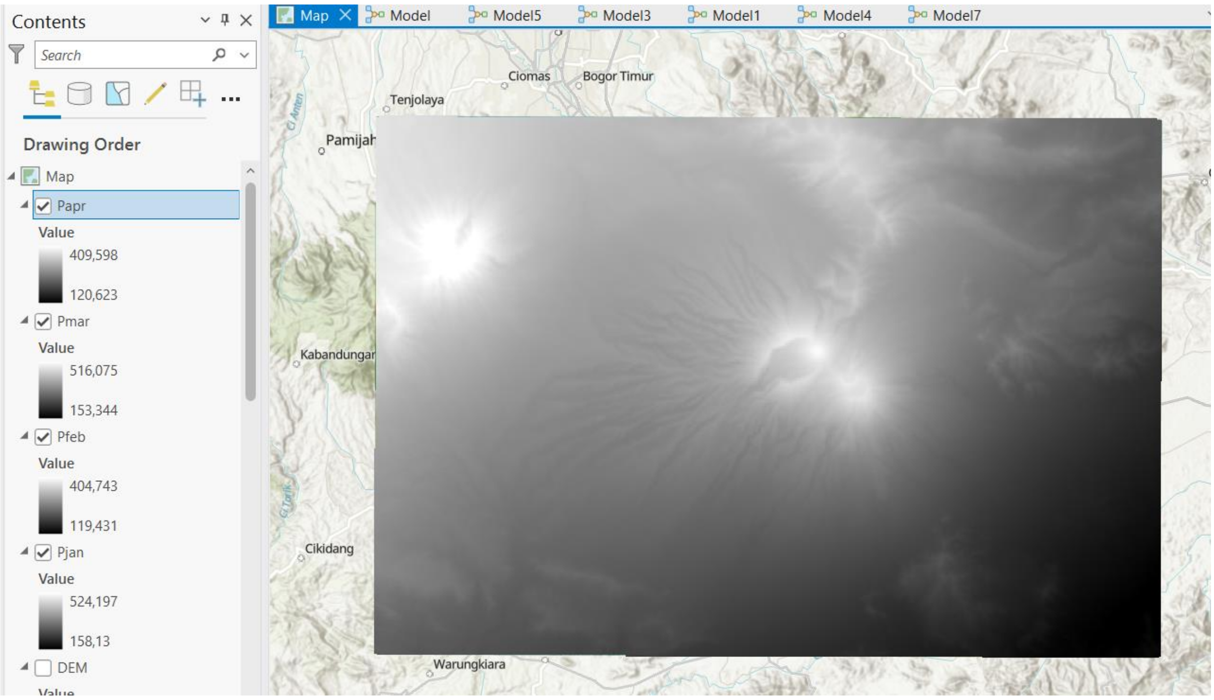
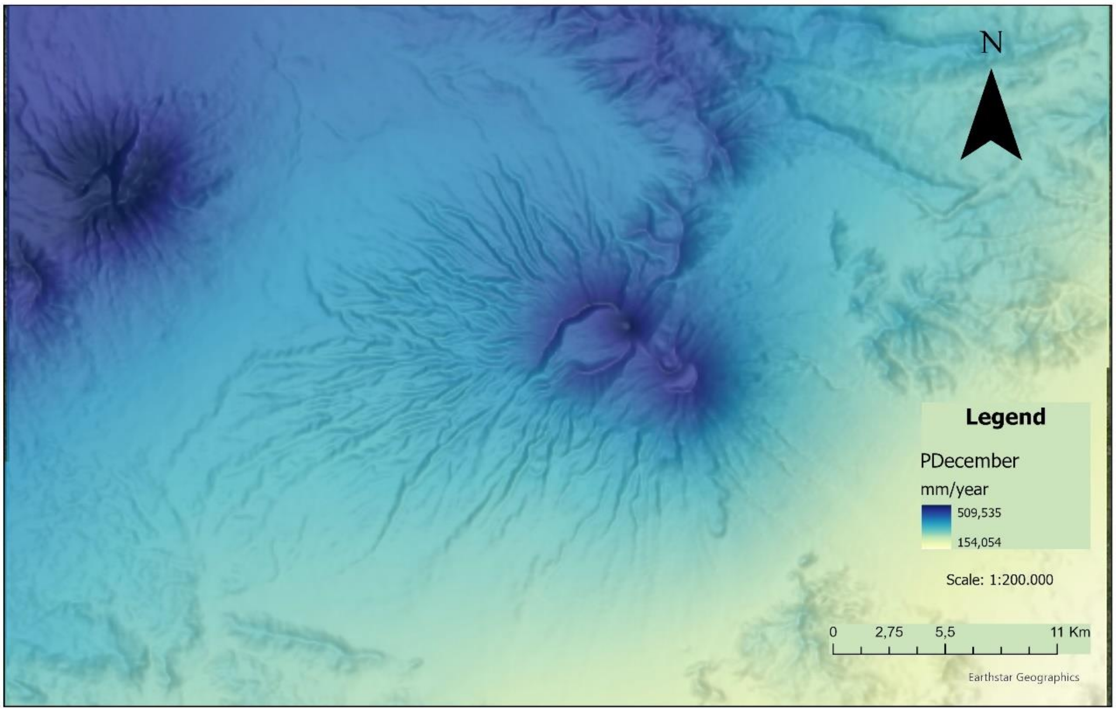
MAX_Z
MAX_Intercept



Precipitation(P)

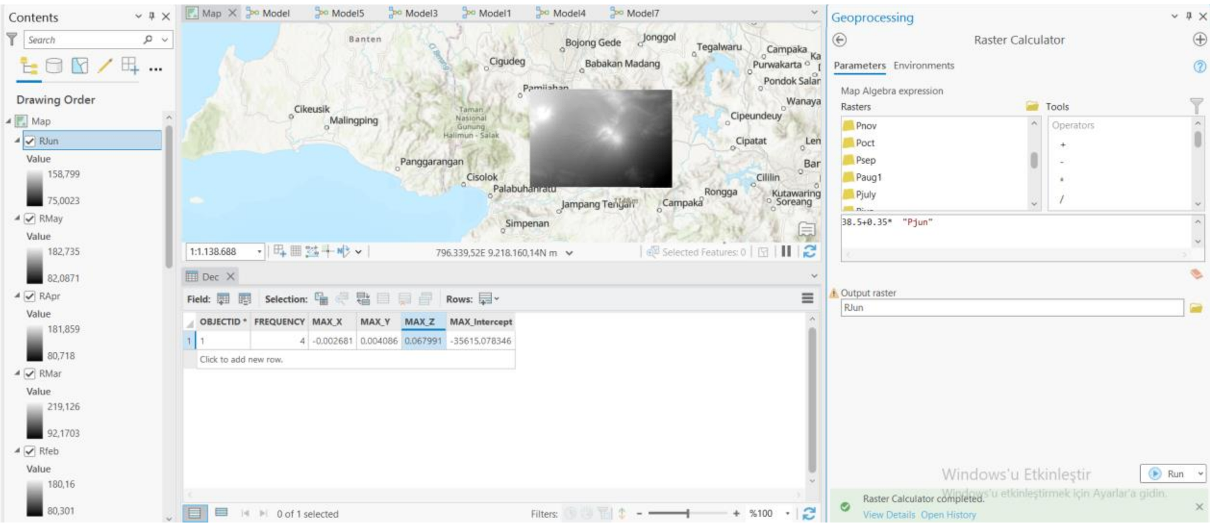


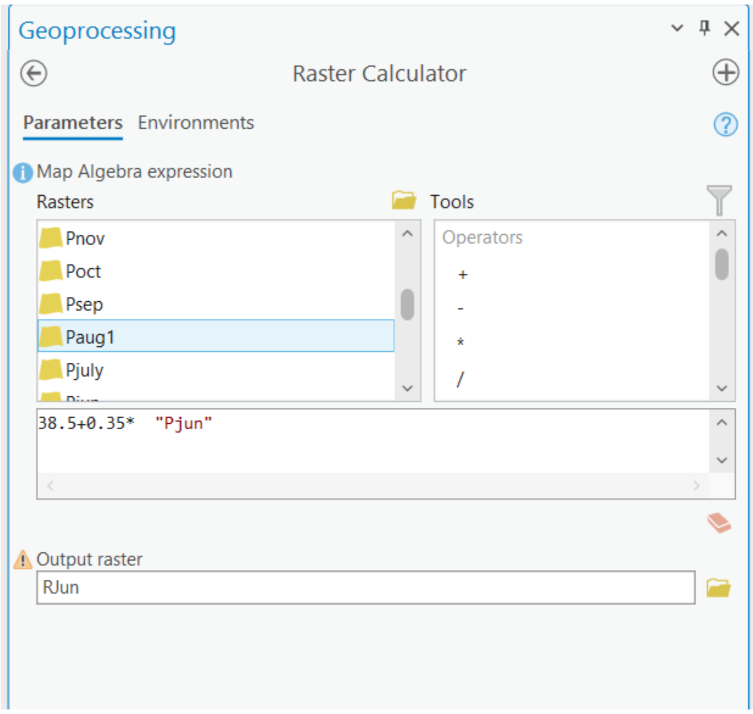
R, the rainfall erosivity index

R, the equation of rainfall erosivity index, is

R = 38.5 + 0.35 * P

After calculation of each P layers, we calculated R layers.

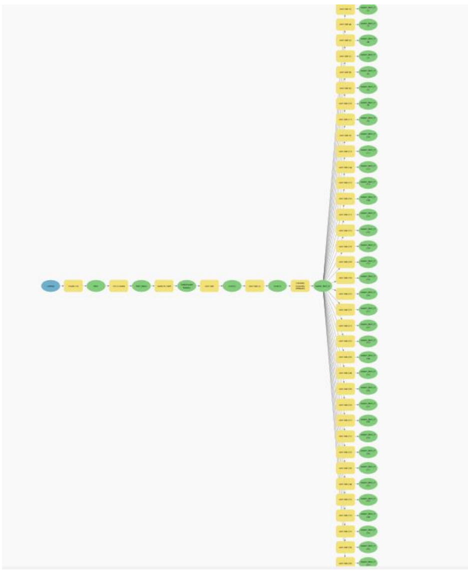




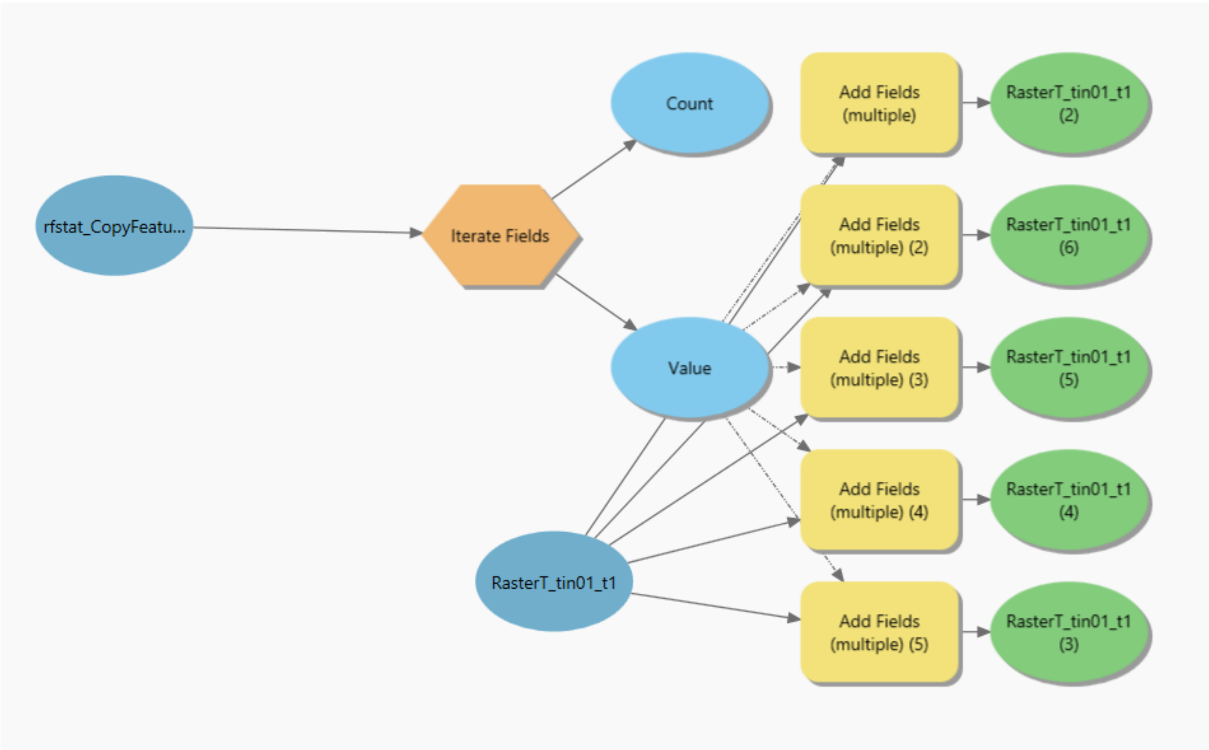
%Bonus Step % Creation of P Values and rainfall erosion index values from Vector data

This process can also be done using the attribute table besides raster calculator. We had converted the Raster DEM data into point vector format and added x and y coordinates. In the adjustment process, after each iteration, the coefficients we had found for each month. These can be added to the table through a one-to-many join operation. Then, the rainfall values (P) corresponding to each coordinate can be found, followed by the rainfall index (R).

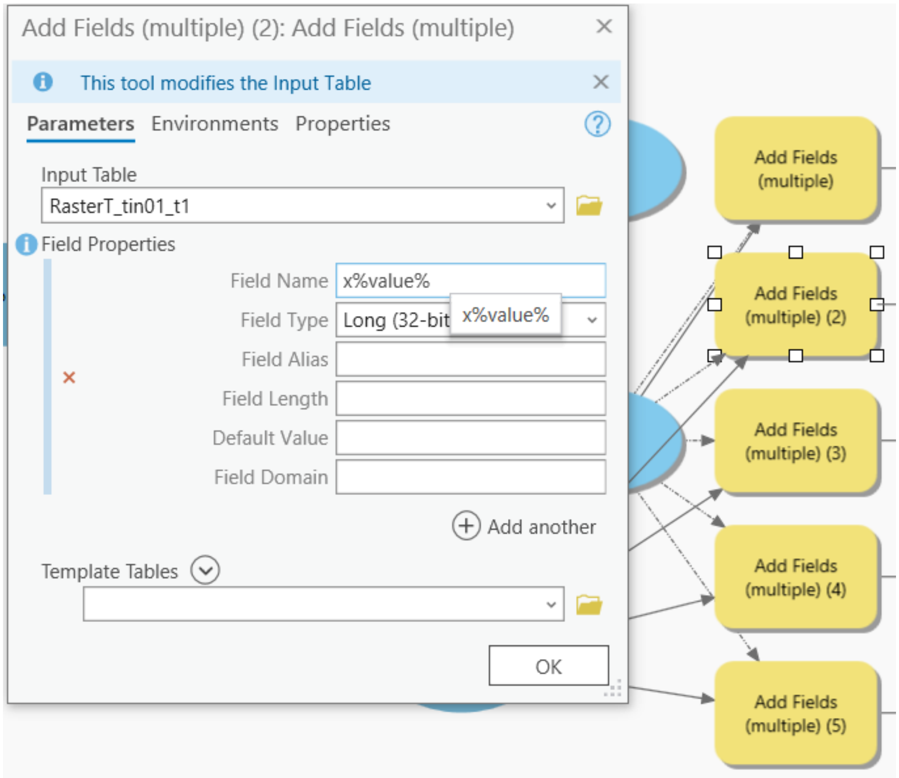
In the first step we had to add coefficient field which are x%months%, y%months%, z%months% p&month% and R%month% to point vector data consist of all pixels coordinates. That means, since there are 12 month this process had to be repeated 60 times. Instead of doing this manually 60 times as such;



It’s better to use iteration and model that add necessary fields for each month to table. That’s why we created a model for this.



The iteration above scans all months in the table and adds the x, y and z coefficient field, as well as the P and R fields, to the table



The inline operator used for adding fields can be seen in the image above.

grid_code	x	y	yJan	xJan	zJan	PJan	RJan	yFeb	xFeb	zFeb	PFeb	RFeb	yMar	xMar	zMa
376,4408	686917,231423	9267507,307745	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Nu
378,4376	687017,231423	9267507,307745	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Nu
378,3728	687117,231423	9267507,307745	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Nu
378,308	687217,231423	9267507,307745	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Nu
378,2433	687317,231423	9267507,307745	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Nu
378,1785	687417,231423	9267507,307745	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Nu
378,1137	687517,231423	9267507,307745	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Nu
378,0489	687617,231423	9267507,307745	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Nu
375	687717,231423	9267507,307745	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Nu

After creating the table given above the values can be joined with the table with one-to-many join. But as result all field would contain millions of values that cause getting error from arcgis and crashed. So, we used raster calculator manually to avoid Arcgis crashes.

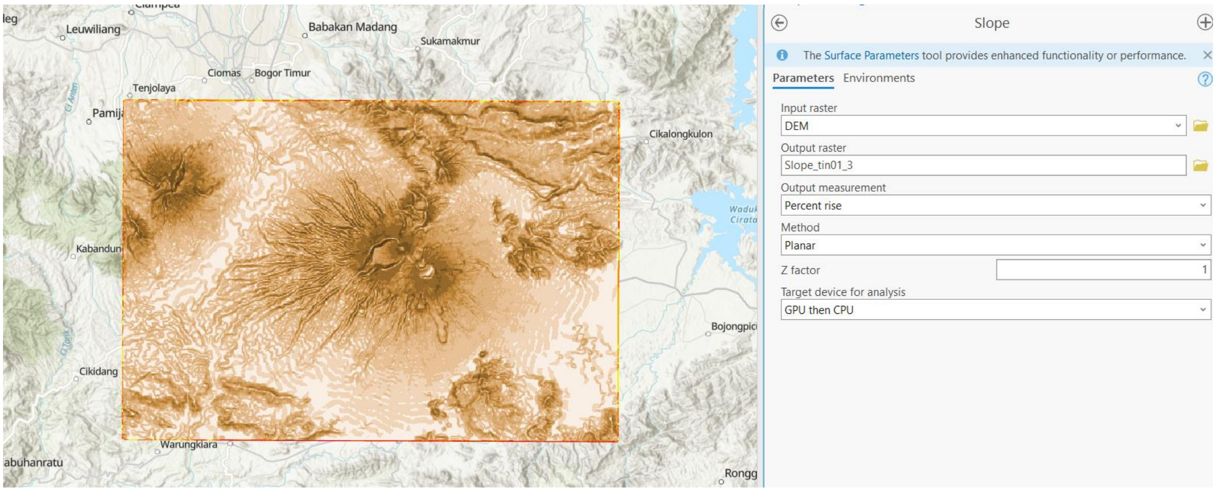
Slope Raster layer creation

$$SL = (L/22.13)^{m} (65.41 \sin^2 s + 4.56 \sin s + 0.065)$$

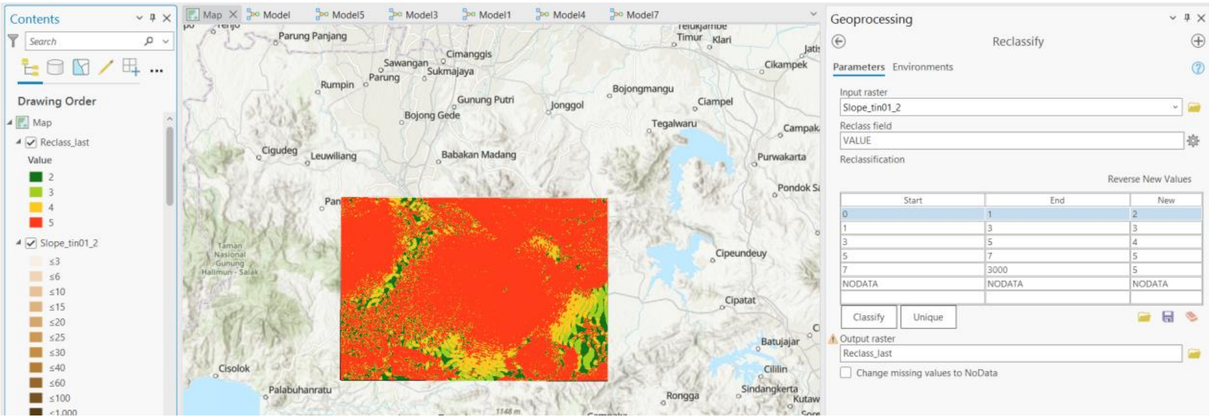
where L is the slope length, s the slope gradient and the exponent m depends on the slope:

S	< 1%	1% ≤ S < 3%	3% ≤ S < 5%	5% ≤ S< 7%	≥ 7%
m	0.2	0.3	0.4	0.5	0.6

We used the slope analysis tool from the DEM data to find the slope raster values in the equation given above. Here, we selected percentage as the unit.

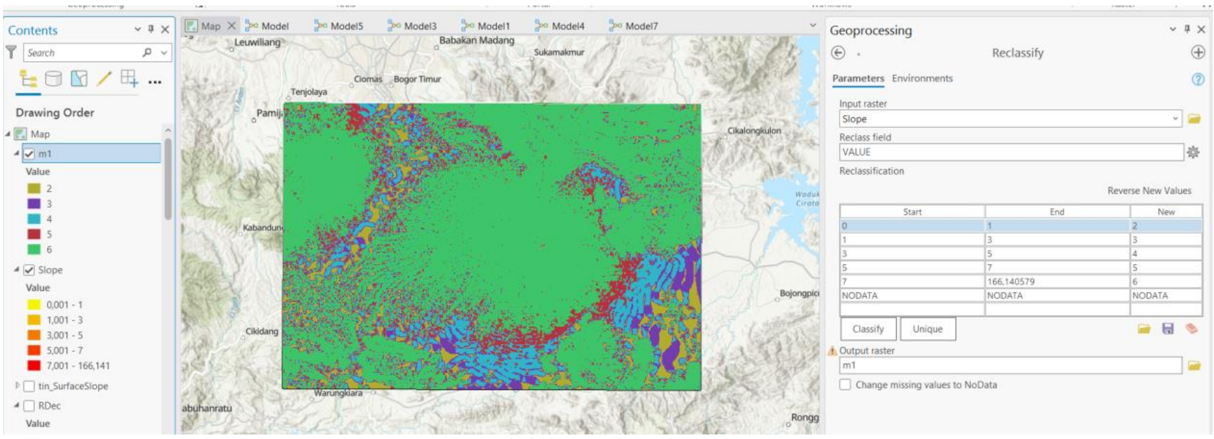


The created slope raster image output can be seen.

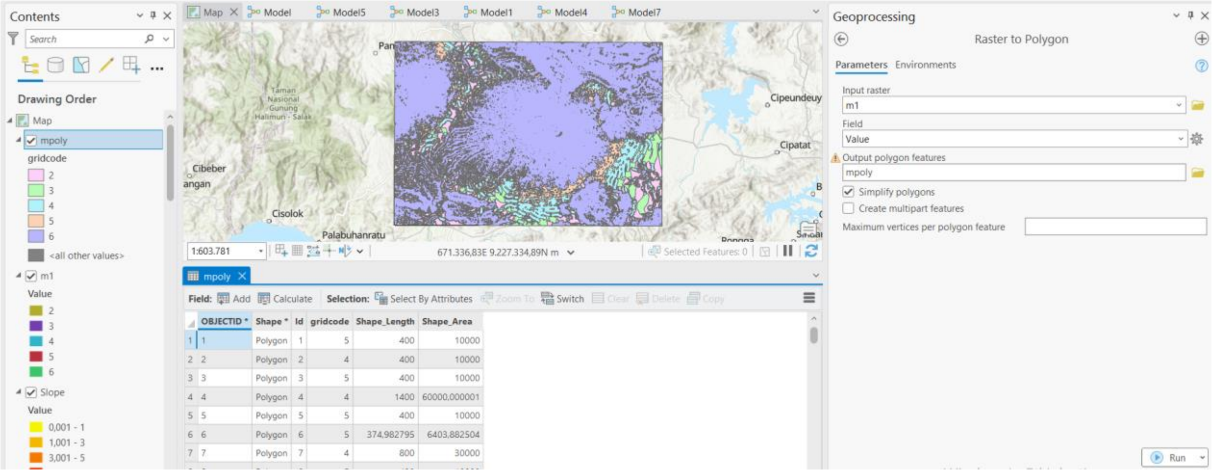


Following this process, we used the reclassify tool to reorganize the slope raster values into categories: less than 1%, between 1% and 3%, between 3% and 5%, between 5% and 7%, and greater than 7%.

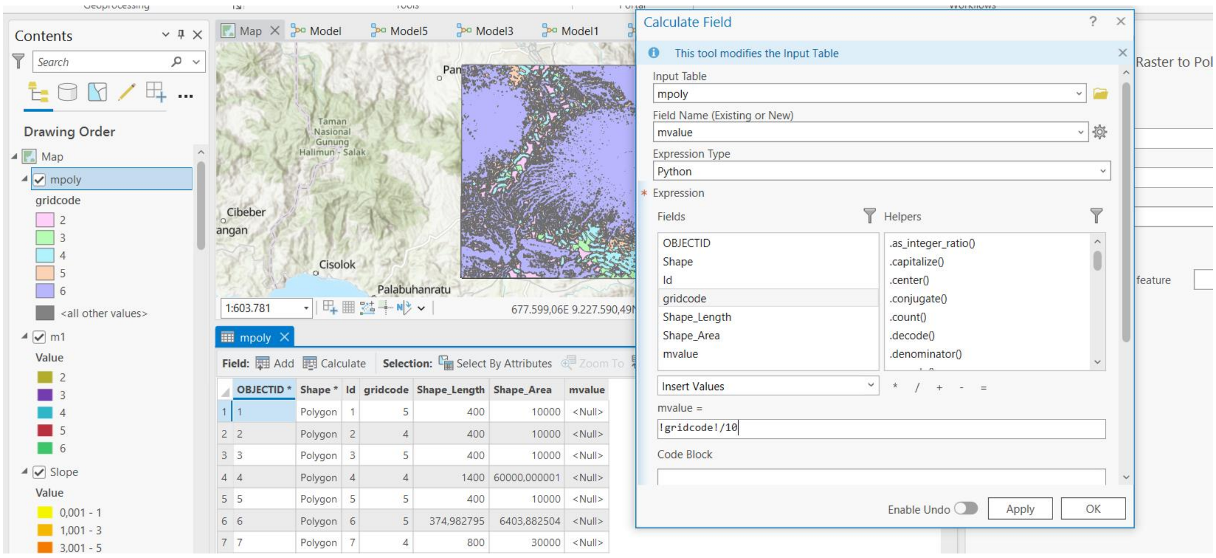
M values raster creation



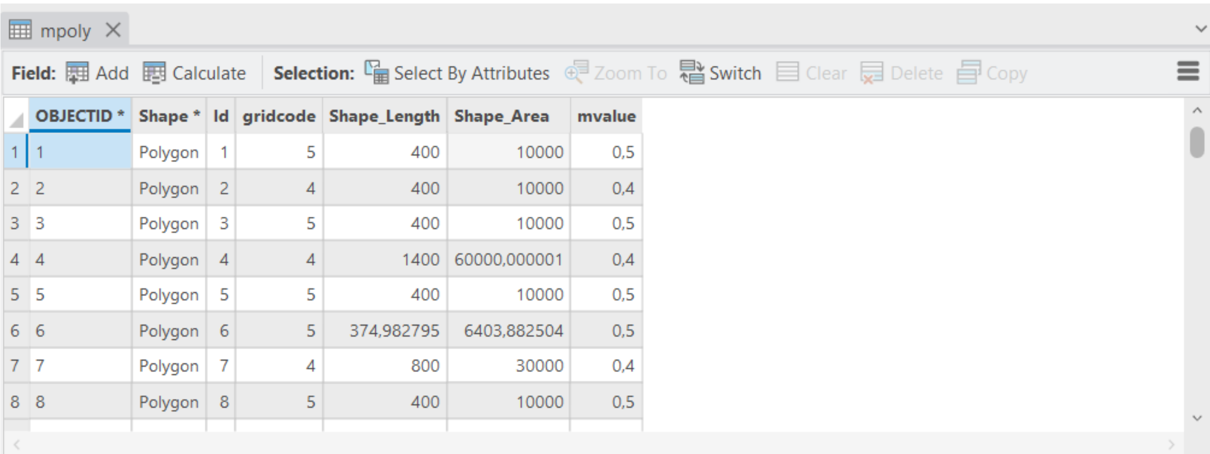
We reclassified the slope layer and assign scores which are 0.2, 0.3, 0.4, 0.5, 0.6. However the scores must have been integer to insert them as class number that’s why we wrote them as integer initially.



After creating the arbitrary m raster layer which have score between 2-6. We converted the layer to vector to calculate actual scores range between 0,2-0,6 by dividing previous scores by 10.

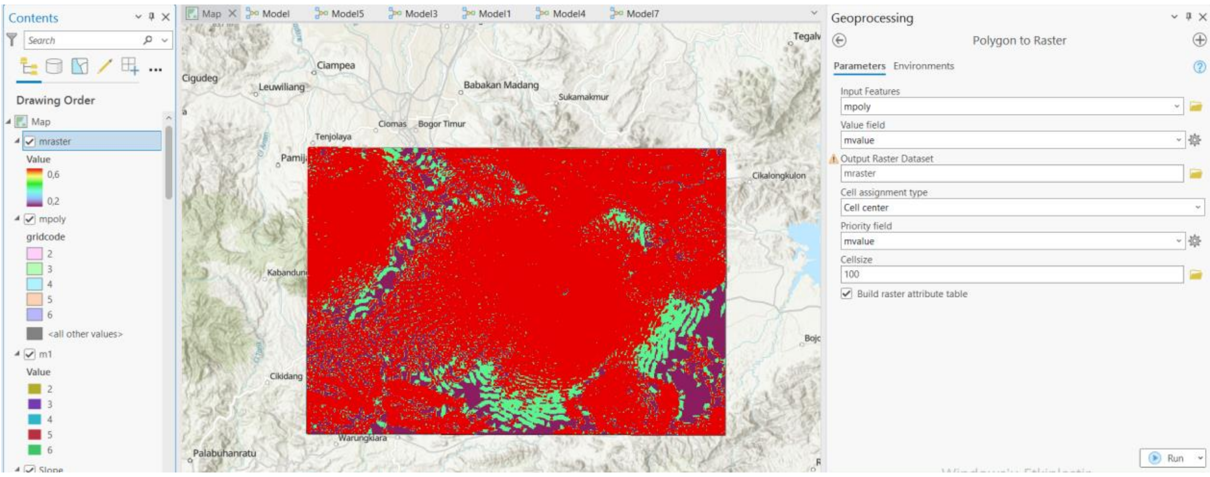


In this step, we added a new column called mvalue then we divide each gridcode which had been classified from 2 to 6 then we created a field consist of 0,2-0,6 scores



	OBJECTID *	Shape *	Id	gridcode	Shape_Length	Shape_Area	mvalue
1	1	Polygon	1	5	400	10000	0,5
2	2	Polygon	2	4	400	10000	0,4
3	3	Polygon	3	5	400	10000	0,5
4	4	Polygon	4	4	1400	60000,000001	0,4
5	5	Polygon	5	5	400	10000	0,5
6	6	Polygon	6	5	374,982795	6403,882504	0,5
7	7	Polygon	7	4	800	30000	0,4
8	8	Polygon	8	5	400	10000	0,5

It is seen above calculated mvalue as how it was given in task description.

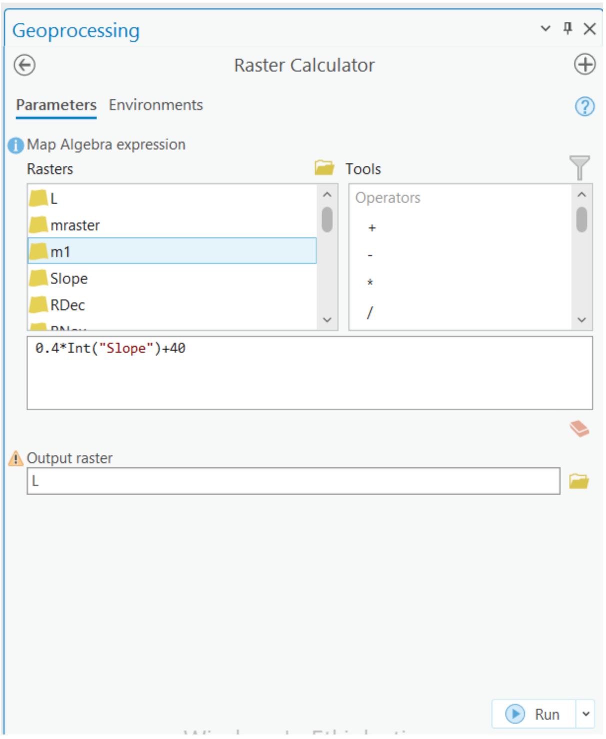


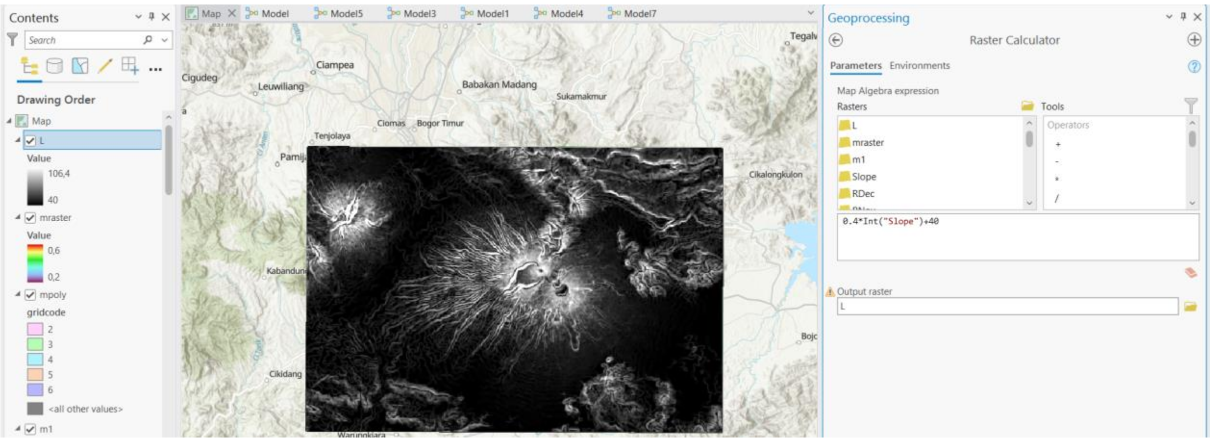
We have to use raster calculator later on therefore we converted the mvalue field to vector by utilizing polygon to raster tool again. The result is seen above the values ranges between 0,2-0,6.

Creating slope length in metres (L)

$$L = 0.4 * S + 40$$

The formula we assign into raster calculator is given above.



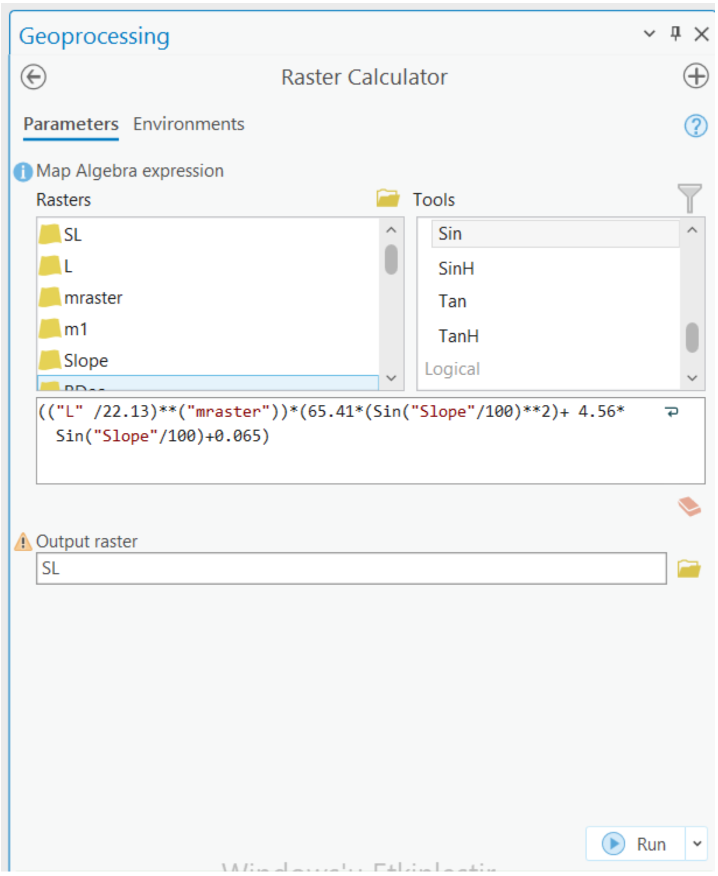


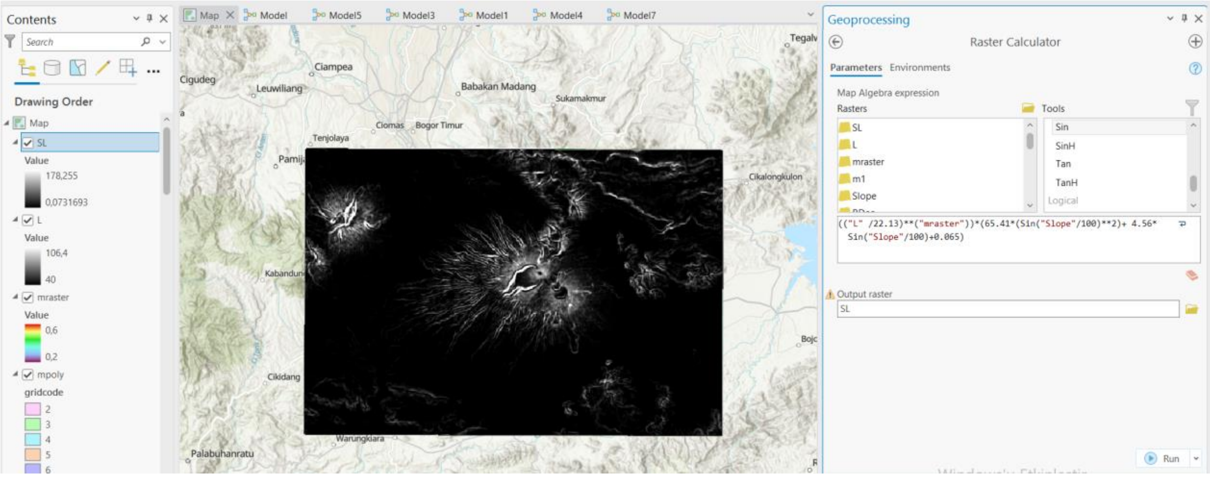
The result of L calculation is given above

Creating the Topographical Factor SL Raster

$$SL = (L/22.13)^{m} (65.41 \sin^2 s + 4.56 \sin s + 0.065)$$

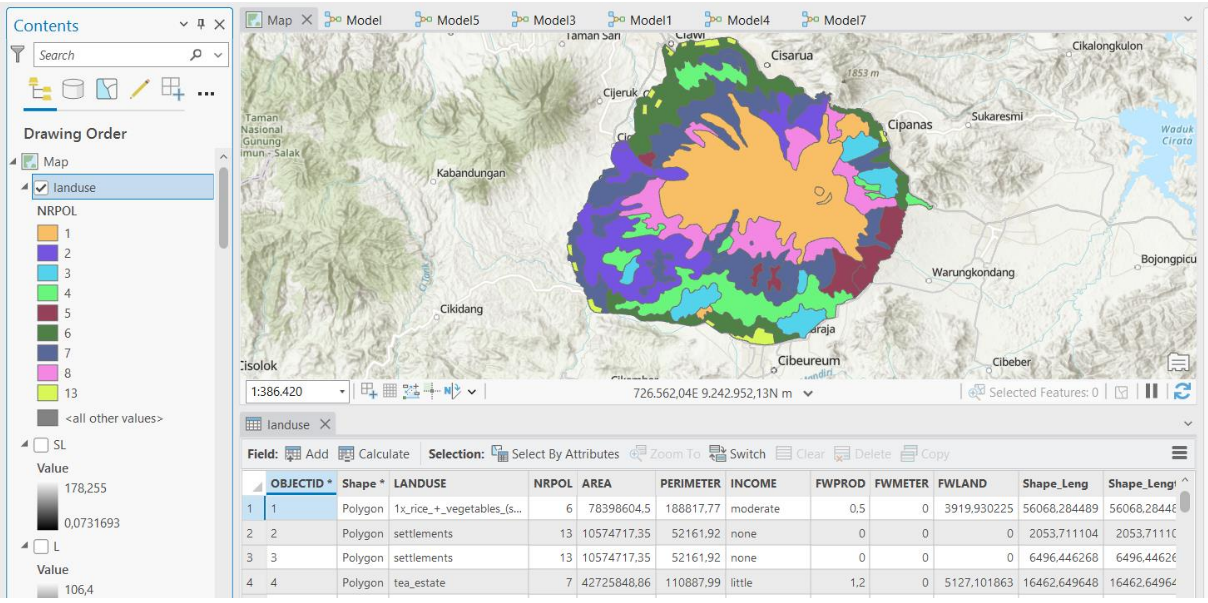
where L is the slope length, s the slope gradient and the exponent m depends on the slope:



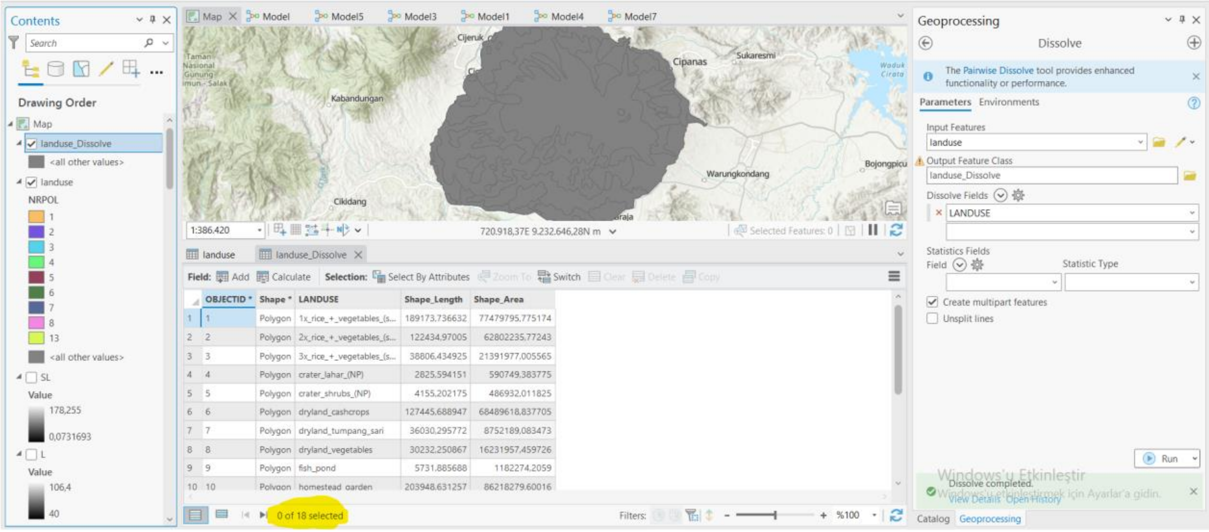


The result of SL is given above

CP land use creating



We added land use and visualize it based on landuse type given in attribute table.

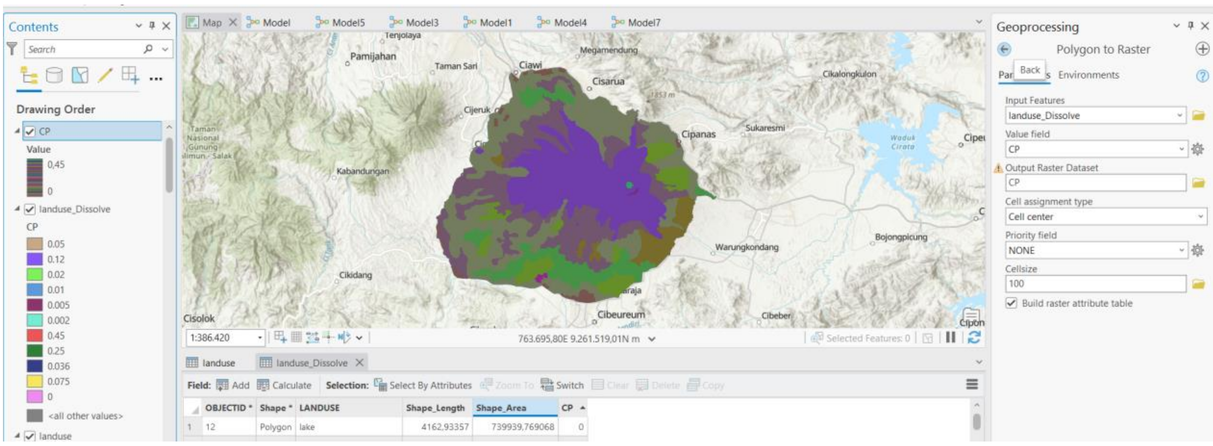


We observed that land use data were independent of each other and not combined. That's why we combined the types with the same land use type using the dissolve tool. The combined landuse types are seen above as 18 selected rows.

Field: Add Calculate Selection: Select By Attributes Zoom To Switch

	OBJECTID *	Shape *	LANDUSE	Shape_Length	Shape_Area	CP
1	1	Polygon	1x_rice_+_vegetables_(s...	189173,736632	77479795,775174	0,01
2	2	Polygon	2x_rice_+_vegetables_(s...	122434,97005	62802235,77243	0,05
3	3	Polygon	3x_rice_+_vegetables_(s...	38806,434925	21391977,005565	0,45
4	4	Polygon	crater_lahar_(NP)	2825,594151	590749,383775	0,12
5	5	Polygon	crater_shrubs_(NP)	4155,202175	486932,011825	0,036
6	6	Polygon	dryland_cashcrops	127445,688947	68489618,837705	0,01
7	7	Polygon	dryland_tumpang_sari	36030,295772	8752189,083473	0,45
8	8	Polygon	dryland_vegetables	30232,250867	16231957,459726	0,45
9	9	Polygon	fish_pond	5731,885688	1182274,2059	0,075
10	10	Polygon	homestead_garden	203948,631257	86218279,60016	0,02
11	11	Polygon	irrigated_land_with_veg...	13861,208211	6053181,58805	0,01
12	12	Polygon	lake	4162,93357	739939,769068	0
13	13	Polygon	mixed_garden	62692,208554	32407727,683965	0,005
14	14	Polygon	National_Park_forest_(NP)	127204,019742	167960634,805208	0,002
15	15	Polygon	production_forest	156486,647202	70399355,623749	0,02
16	16	Polygon	sec._forest_or_abandon...	40954,940619	18587397,217343	0,01
17	17	Polygon	settlements	52161,923816	10574717,379343	0,25
18	18	Polygon	tea_estate	110887,983388	42725848,917009	0,01

We added CP values into dissolved table manually according to given information from task description table. It's seen above the updated table



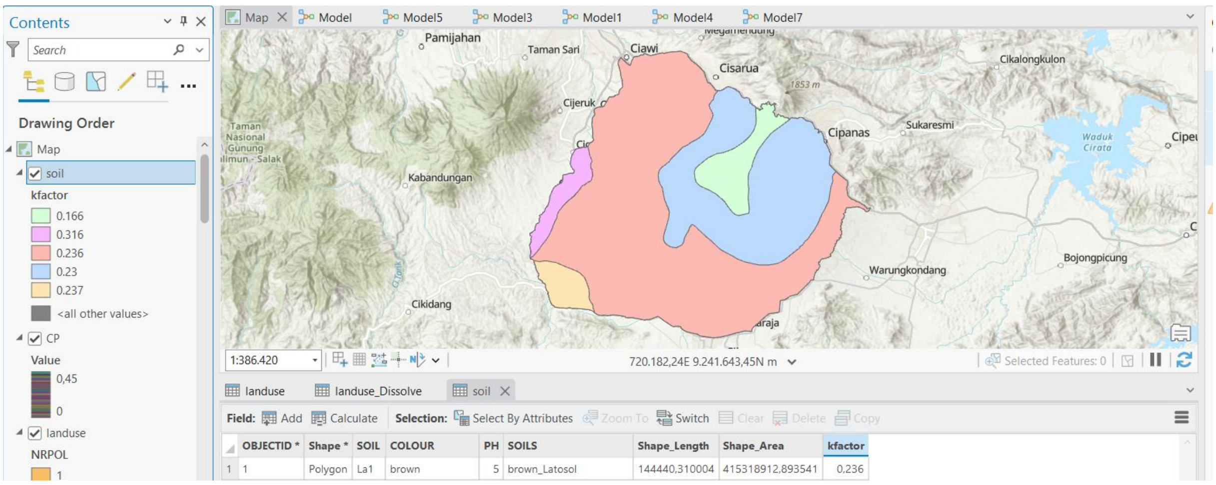
After adding the values we converted the cp polygon to raster again with polygon to raster tools. As what we did before we chose cell size 100 meter. It's seen above the Cp raster value.

K factor Soil type map

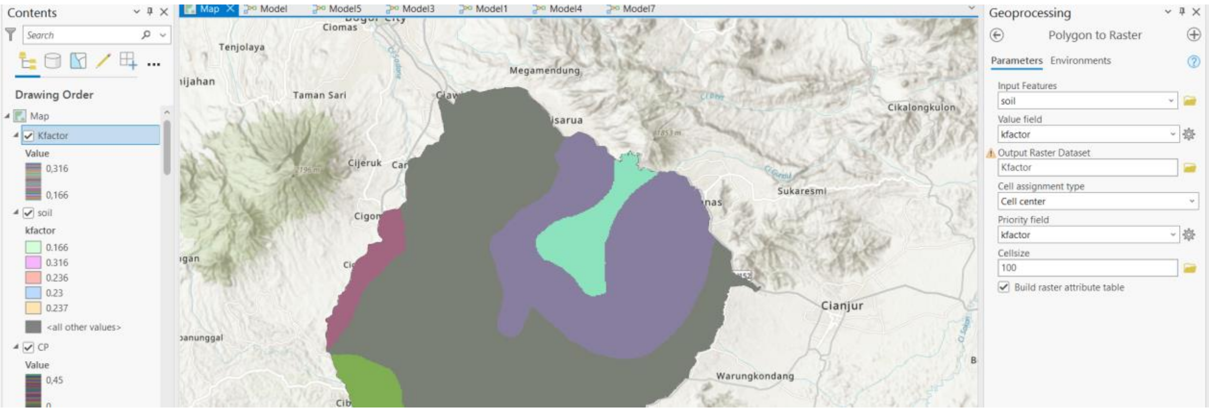
We added the soil type map into arcgis and define its projection then we added new column to insert given kfactor values.

	OBJECTID *	Shape *	SOIL	COLOUR	PH	SOILS	Shape_Length	Shape_Area	kfactor
1	1	Polygon	La1	brown	5	brown_Latosol	144440,310004	415318912,893541	0,236
2	2	Polygon	AnRe	yellow	7	ass._of_yellowish_brown...	91314,134274	195155860,005392	0,23
3	3	Polygon	ReLi	grey	7	grey_Regosol_and_Lith...	38605,863876	39801733,672904	0,166
4	4	Polygon	LaRe	brown	6	ass._of_brown_Latosol_...	30646,997309	22085171,747739	0,316
5	5	Polygon	La2	yellow	5	yellowish_brown_Latosol	19939,826846	20699433,124075	0,237
	Click to add new row.								

The table above shows inserted kfactor values into soil table.



The table above shows kfactors as polygon.



After creating kfactors, we converted the kfactors to raster for further raster calculating steps.

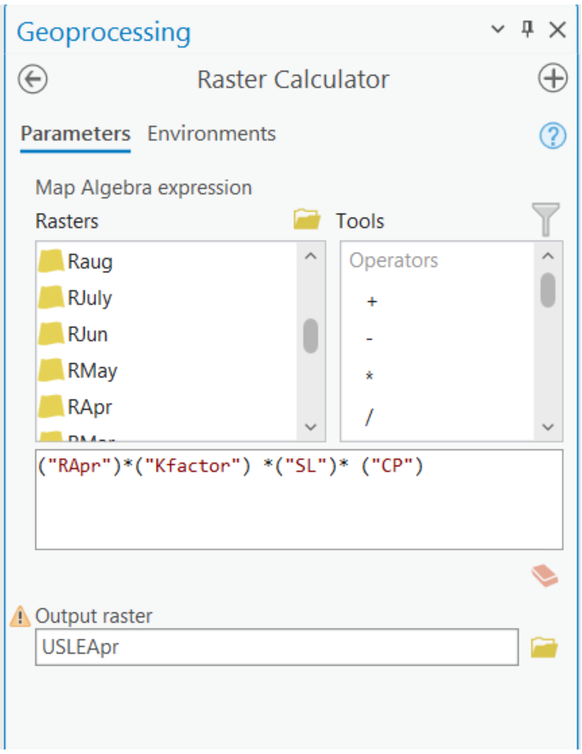
USLE Erosion Loss Equation Implementation

We have utilized all layers to calculate Erosion loss so far. We multiply all raster with raster calculator and find final outputs for each month.

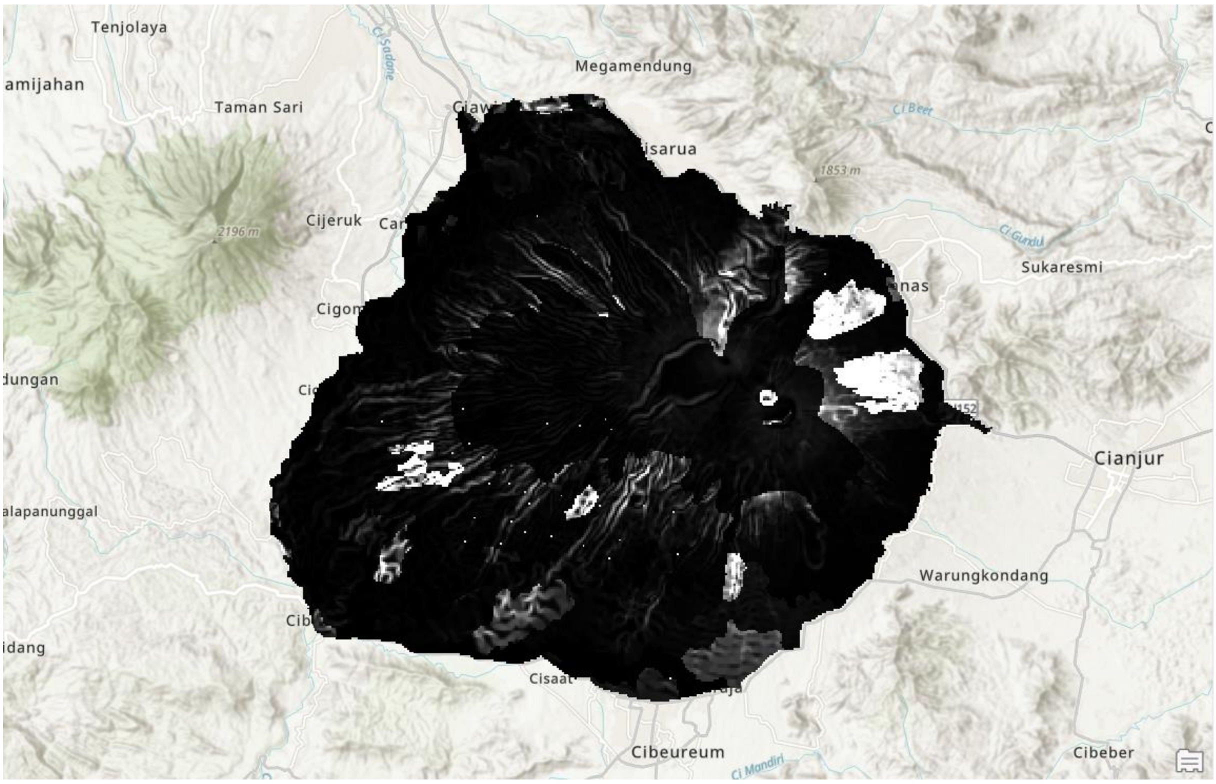
The equation was given as

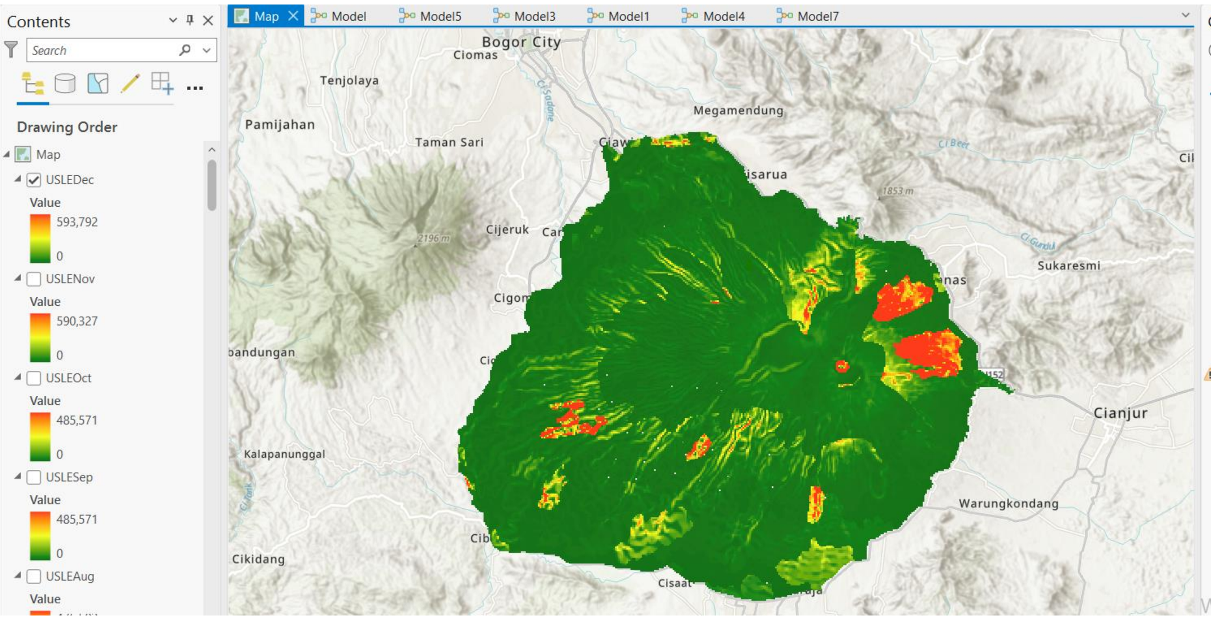
$$A = R \times K \times LS \times CP$$

If we insert this equation to raster calculator we get ;



We repeated this process for each month.





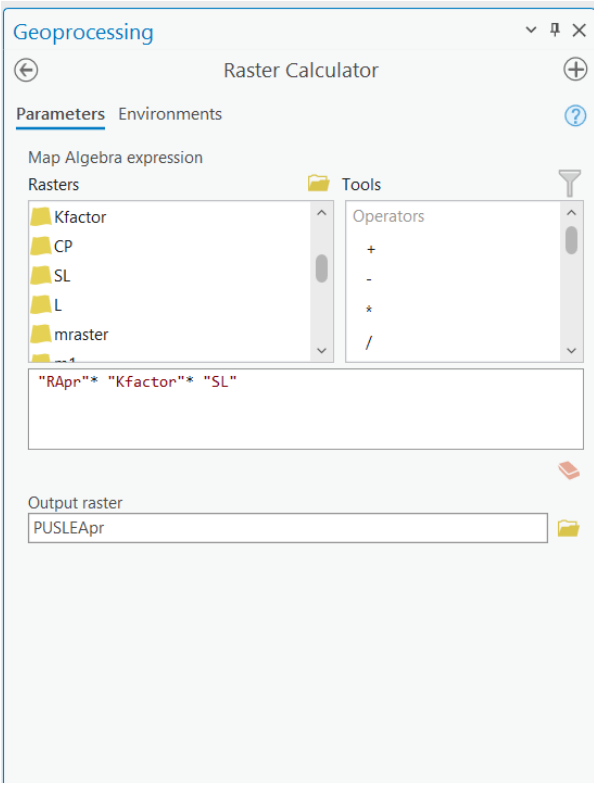
And then we changed its color for better visualization.

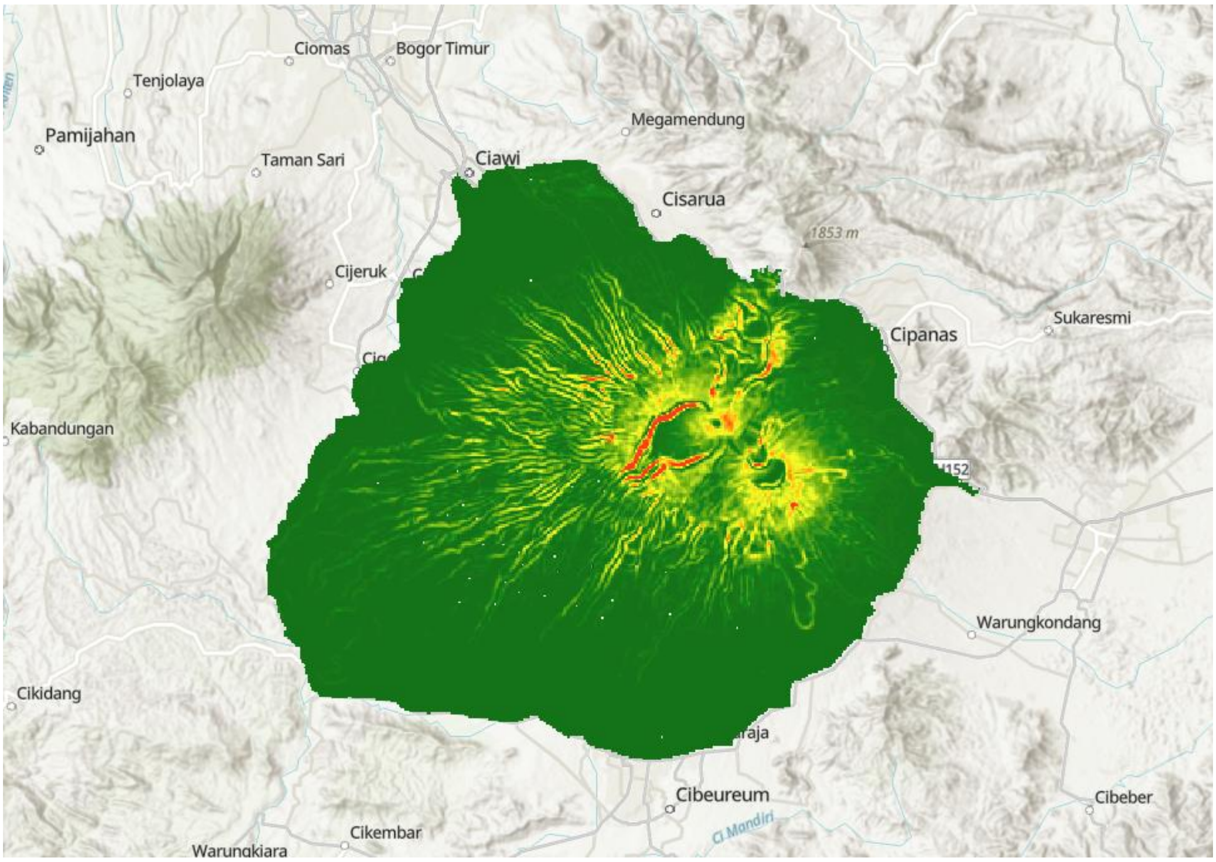
Potential Erosion (RKSL)

The equation was given as

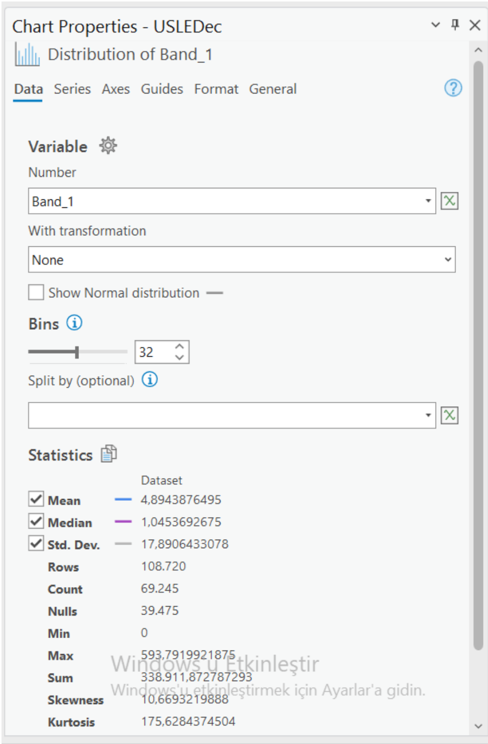
A =R x K x LS

If we insert this equation to raster calculator we get ;





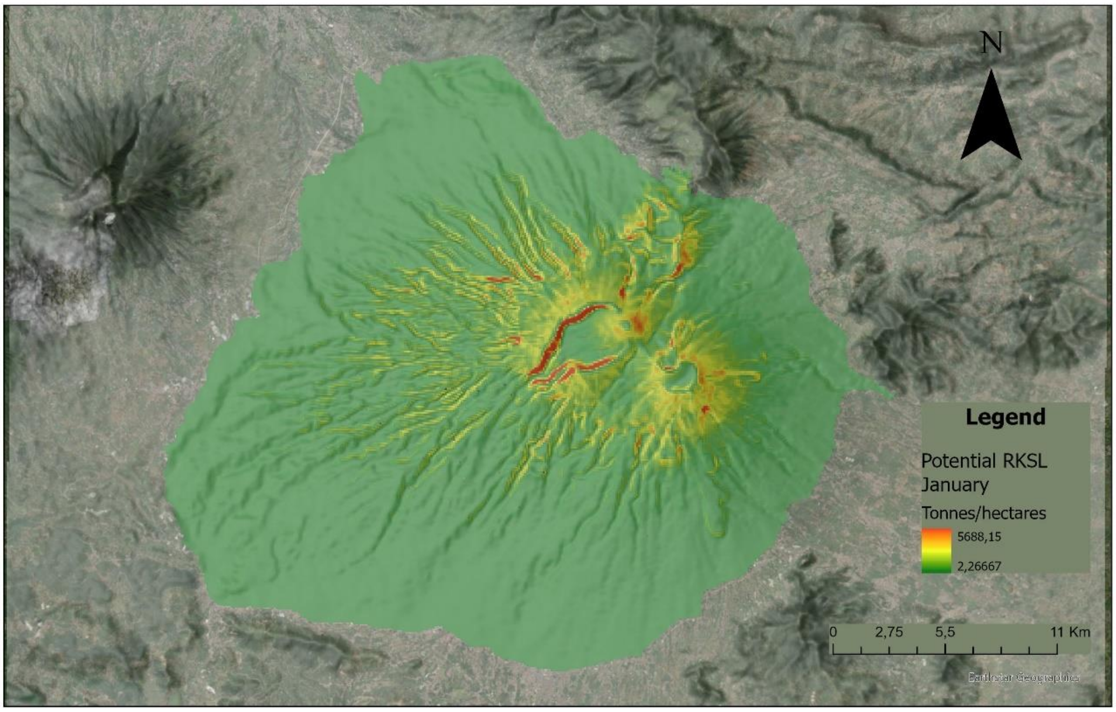
The difference between potential erosion loss (RKSL) and actual USLE are noticible.



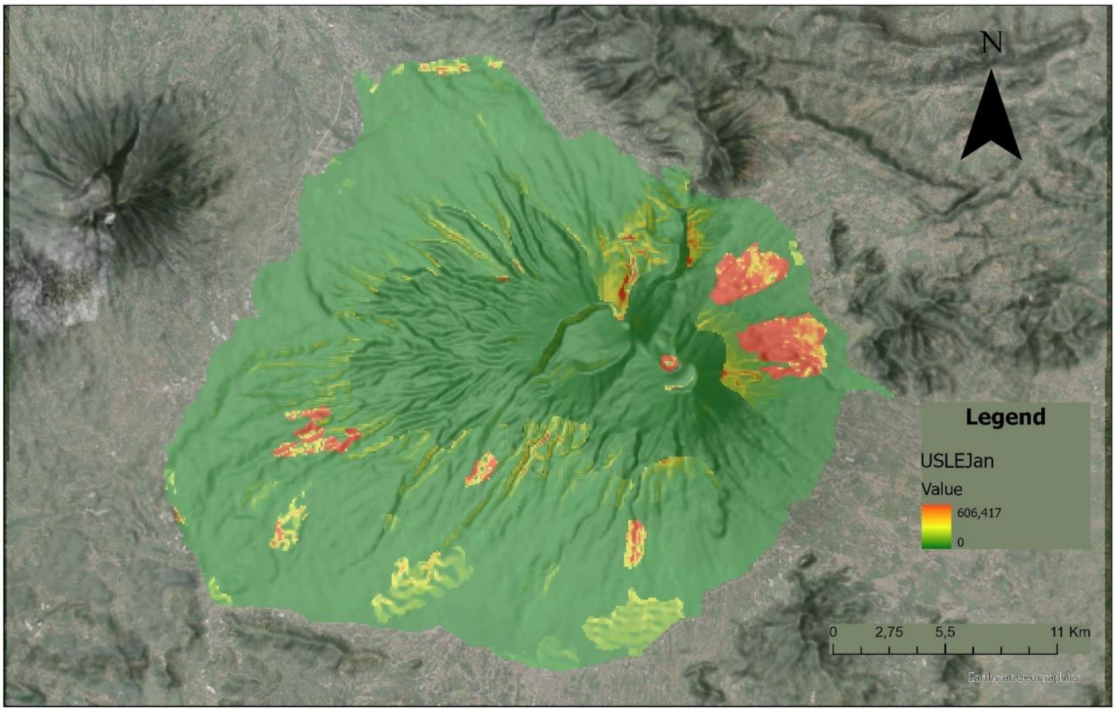
We take out the statistical information with statics tool for all raster layer. We write that information down to table for presentation and to create graphs

Months	USLE ACTUAL	MAX TON/HECTARES	USLE POTENTIAL	MAX TON/HECTARES2
January	346.145,83	606,416	18.939.169,00	5.688,15
February	285.359,07	499,588	15.557.107,79	4.645,10
March	341.189,67	597,785	18.674.992,13	5.612,32
April	287.707,71	503,7603	15.689.467,65	4.686,65
May	290.129,41	507,948	15.808.927,78	4.716,34
June	256.070,08	448,0695	13.903.810,21	4.123,85
July	233.073,58	407,53	12.606.605,35	3.714,89
August	271.649,56	475,501	14.789.418,48	4.405,95
September	285.650,68	499,977	15.547.762,39	4.629,90
October	277.378,47	485,57	15.099.337,62	4.497,35
November	337.006,79	590,326	18.421.564,33	5.524,40
December	338.911,87	593,791	18.535.006,40	5.563,12

Potential Soil Loss (RKSL)



Actual Soil Loss (USLE)



The Most Eroded Area Based on Land Use