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A Study of Sediment Yield in the Deji Reservoir Watershed Using Risk Analysis

Wen-Wei Chang Cheng-Yu Lin Chao-Yuan Lin

Department of Soil and Water Conservation, NCHU

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Introduction

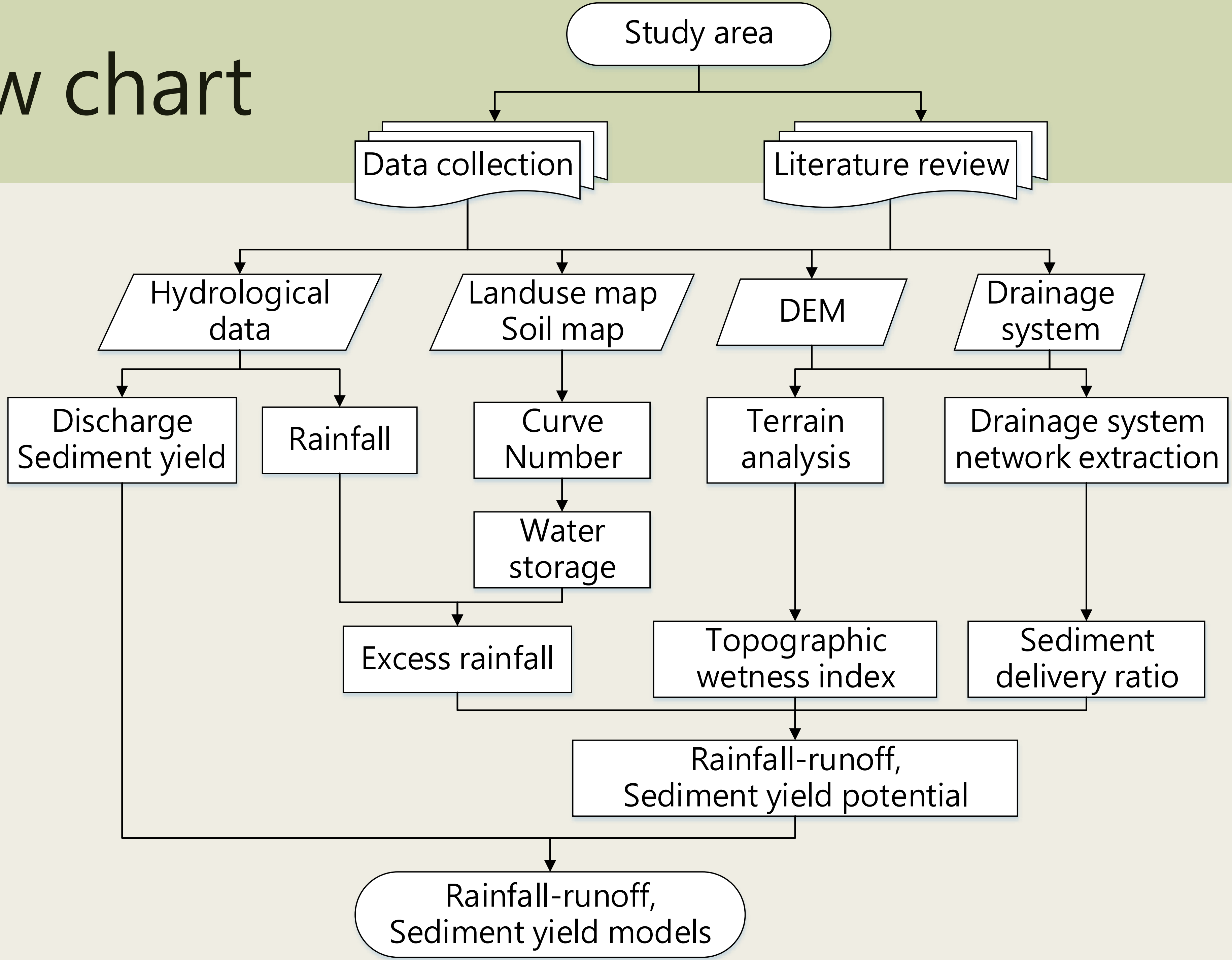
- The purpose of this study is to respond to the "Forward-Looking Infrastructure Planning - Water Environment Construction", strengthen the protection and management of reservoirs in the basin, reduce the amount of sedimentation in reservoirs, and alleviate the decline of water storage capacity in the Deji reservoir.

Study area

Deji Reservoir

- Located in the upper reaches of Dajia River, Heping District, Taichung City.
- The upstream catchment area of Deji Reservoir is about 523.8 square kilometers.
- The storage area of the reservoir is about 454 hectares.
- The dam is a hyperbolic thin concrete arch dam with a height of 180 meters. And it is the highest dam in Taiwan.

Flow chart



Study area
Data collection
Literature review
Hydrological data
Landuse map
Soil map
DEM
Drainage system
Discharge
Sediment yield
Rainfall
Curve Number
Water storage
Terrain analysis
Drainage system network extraction
Excess rainfall
Topographic wetness index
Sediment delivery ratio
Rainfall-runoff,
Sediment yield potential
Rainfall-runoff,
Sediment yield models

Materials

Data	Source	Resolution	Usage
DEM	Department of Land Administration, MOI	5m*5m	Hydrological and Geographical analysis
Rainfall	Central Weather Bureau	Daily rainfall	Runoff estimation
Land use	National Land Surveying and Mapping Center	1/5000	Curve Number
Soil map	Forestry Bureau	1/5000	Curve Number
Discharge	Water Resources Agency	Daily flow	Runoff verification
Suspended load	Water Resources Agency, Taiwan Power Company	Sediment yield	Sediment yield verification

Methods

The SCS Curve Number method was pioneered by the U.S. Soil Conservation Service, and the estimation of rainfall loss in the catchment area is an important basic work for estimating runoff in hydrological analysis.

$$Pe = \frac{(P-0.2\ S)^2}{(P+0.8\ S)},\ (P > 0.2\ S)$$

Pe : Excessive rainfall
P : Rainfall
S : Maximum water storage

The relationship between excessive rainfall and rainfall that derived from hard rain direct runoff. The total effective rainfall depth is equal to the total direct runoff depth of the catchment area.

Curve Number is affected by factors such as soil type, pre-hydrological status, land use status and soil and water conservation engineering measures.

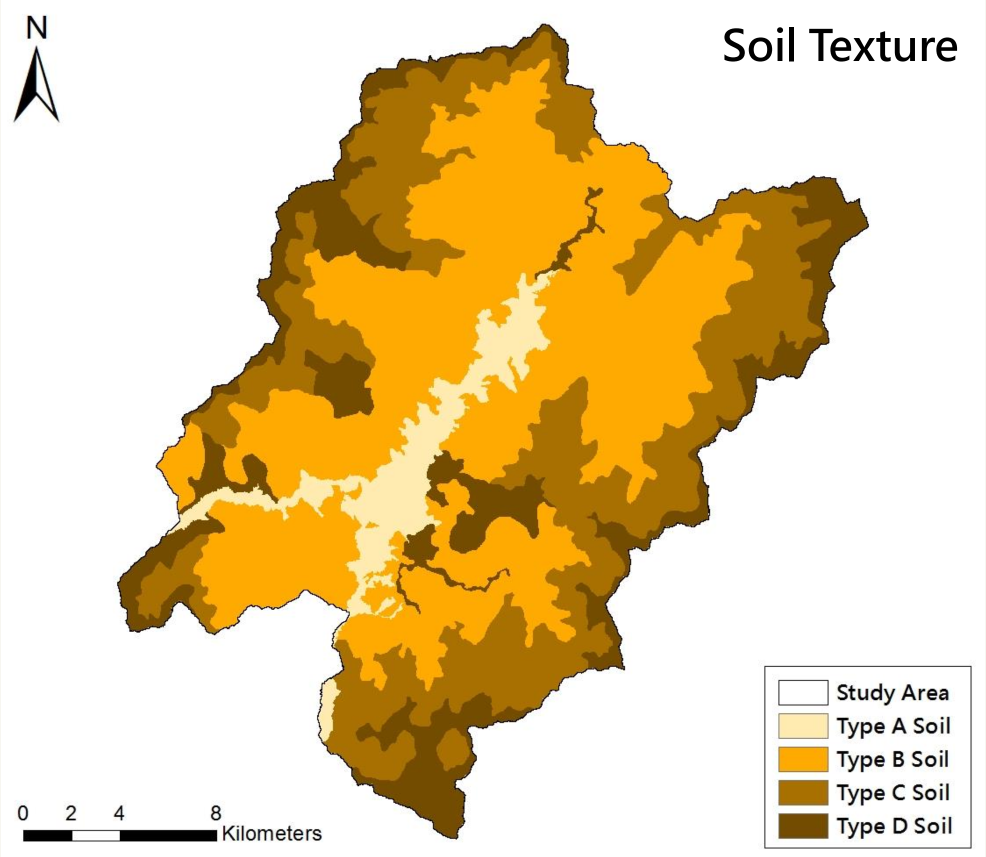
$$S(mm) = \frac{25400}{CN} - 254$$

CN : Curve Number
When the value is higher, it means that it is less likely to infiltrate, causing rain to form surface runoff.

Spatial distribution of soil texture

The CN value is determined by the soil texture and land use. The soil type is determined according to the drainage characteristics by the SCS-CN.Type A soil represents with good water permeability, Type A soil is not easy to produce direct runoff.The permeability of the soil gradually decreases from Type A to Type D,so Type D soil represents with bad water permeability and Type D soil is easy to produce direct

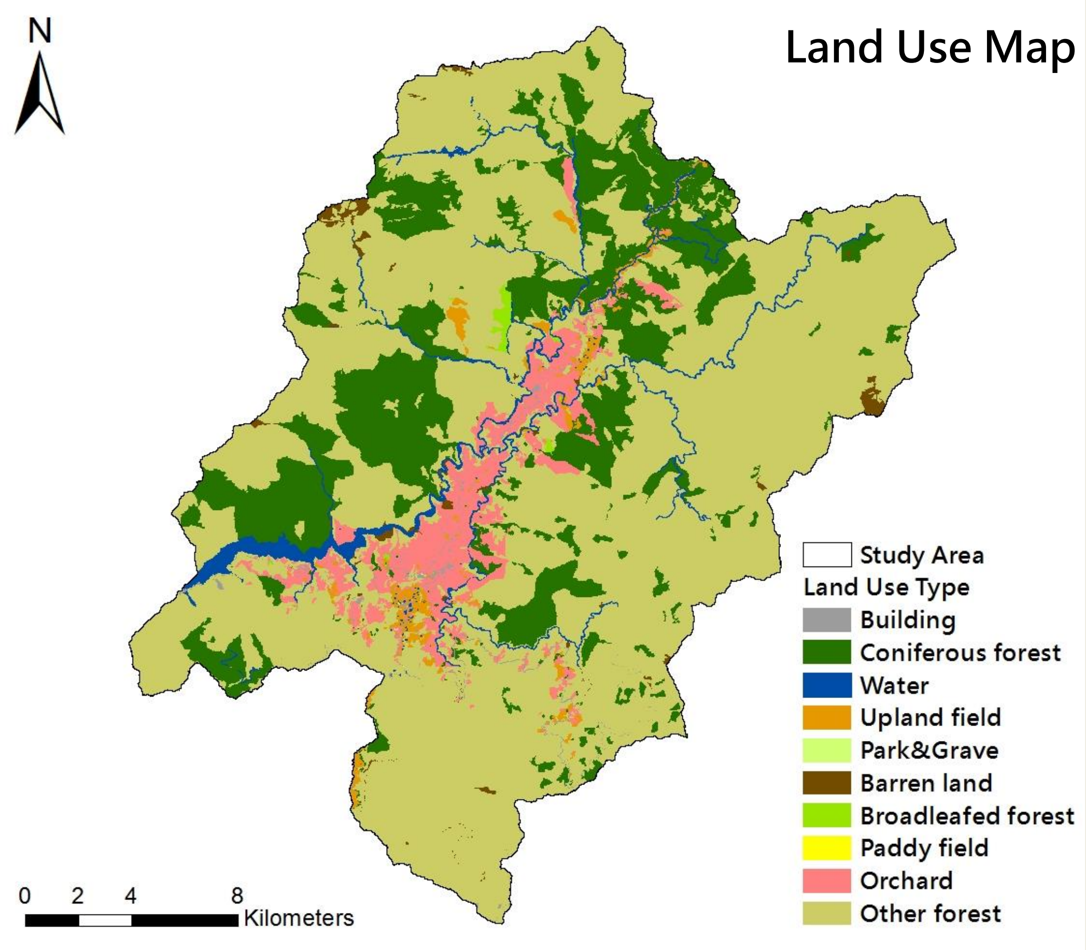
Category	Soil Texture	SCS
0	Coarse sand,Sandy soil	A
1	fine sand,Loamy sand, Loamy coarse sand	A
2	Loamy fine sand,Coarse sand loam, Sandy loam,Fine sandy loam	A
3	Very fine sand,Loamy very fine sand, Very fine sandy loam	A
4	Silty loam,Silt	B
5	Loam	B
6	Sandy clay loam	C
7	Clay loam,Silty clay loam	D
8	Silty clay,Sandy clay	D
9	Clay	D



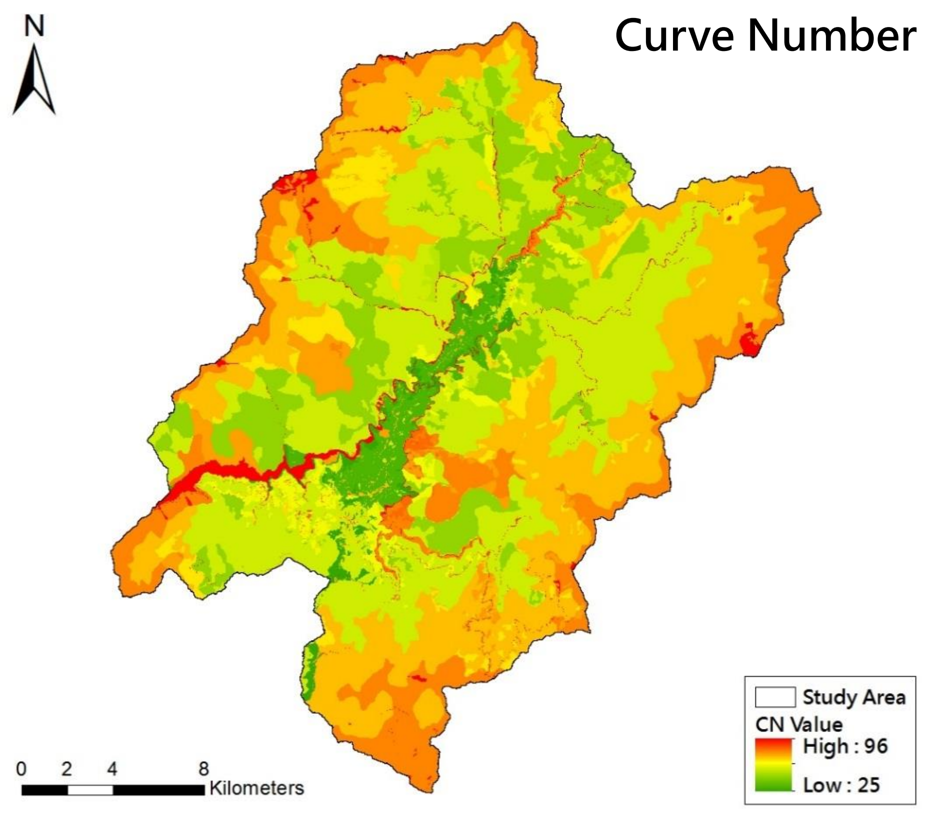
Spatial distribution of land use

The land cover conditions vary according to different land use, farming type, and hydrological conditions. With soil texture and land use, Curve Number can be checked by the SCS-CN table.

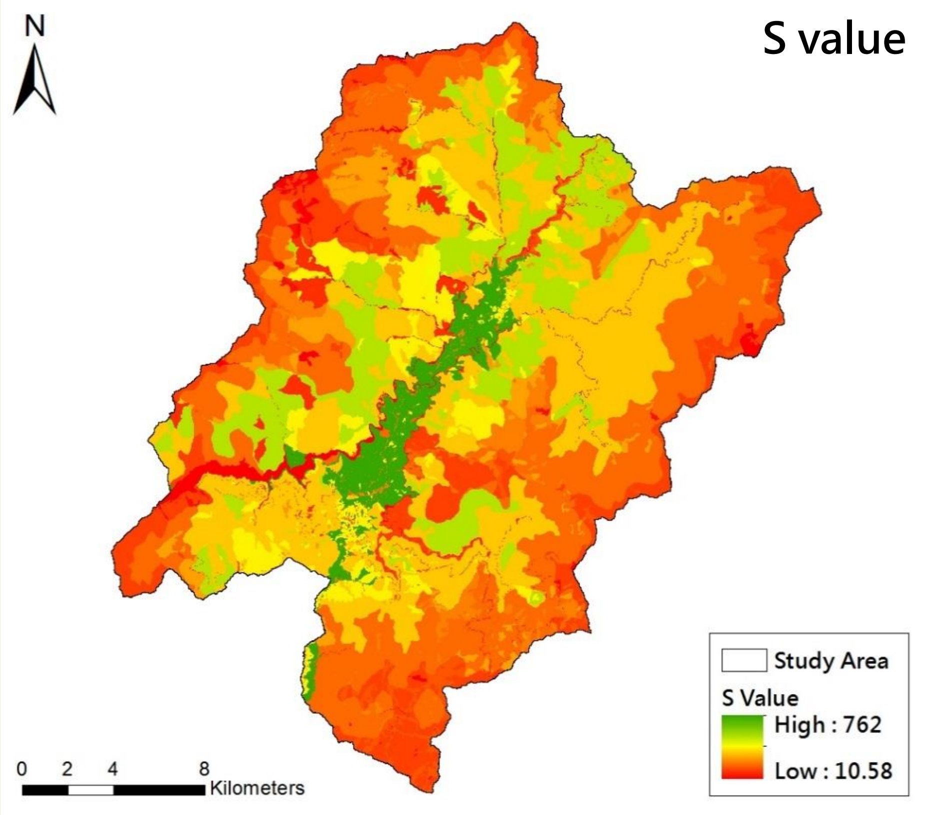
Land use \ Soil Texture	A	B	C	D
Building	74	84	90	92
Coniferous forest	25	55	70	77
Water	94	93	95	96
Upland field	62	71	78	81
Park & Grave	39	61	74	80
Protection forest	25	55	70	77
Barren land	77	86	91	94
Wet Land	92	93	94	95
Broadleafed forest	36	60	73	79
Paddy field	70	79	84	88
Orchard	45	66	77	83
Other forest	38	62	74	80



Spatial distribution of maximum water storage

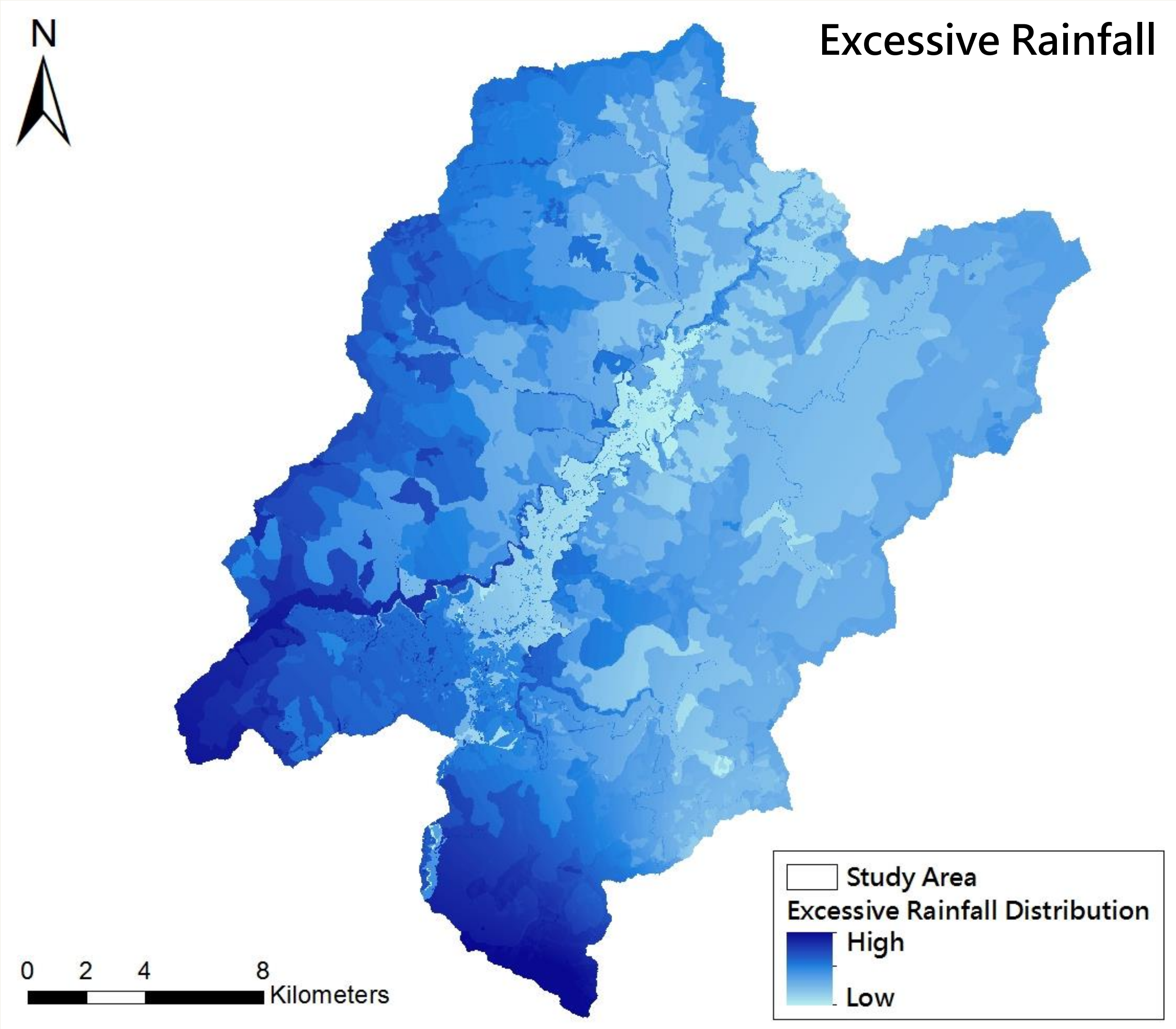


$$S_{(mm)} = \frac{25400}{CN} - 254$$



Spatial distribution of excessive Rainfall

After the rainfall data of each event is made, and the maximum water storage is used in accordance with the empirical formula, the excessive rainfall of each event can be obtained.

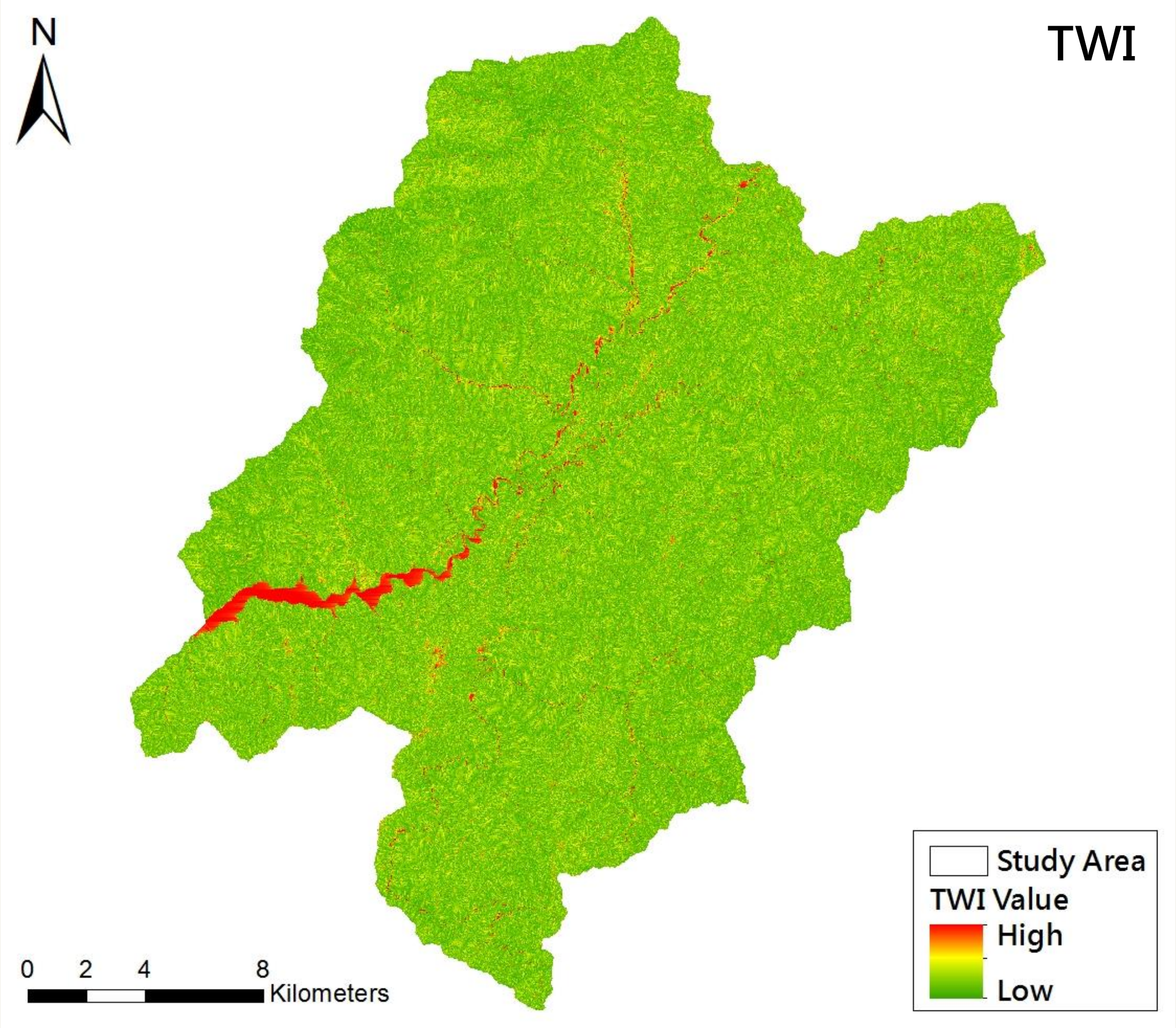


Topographic Wetness Index(TWI)

The formula of Topographic Wetness Index (TWI) is as follows :

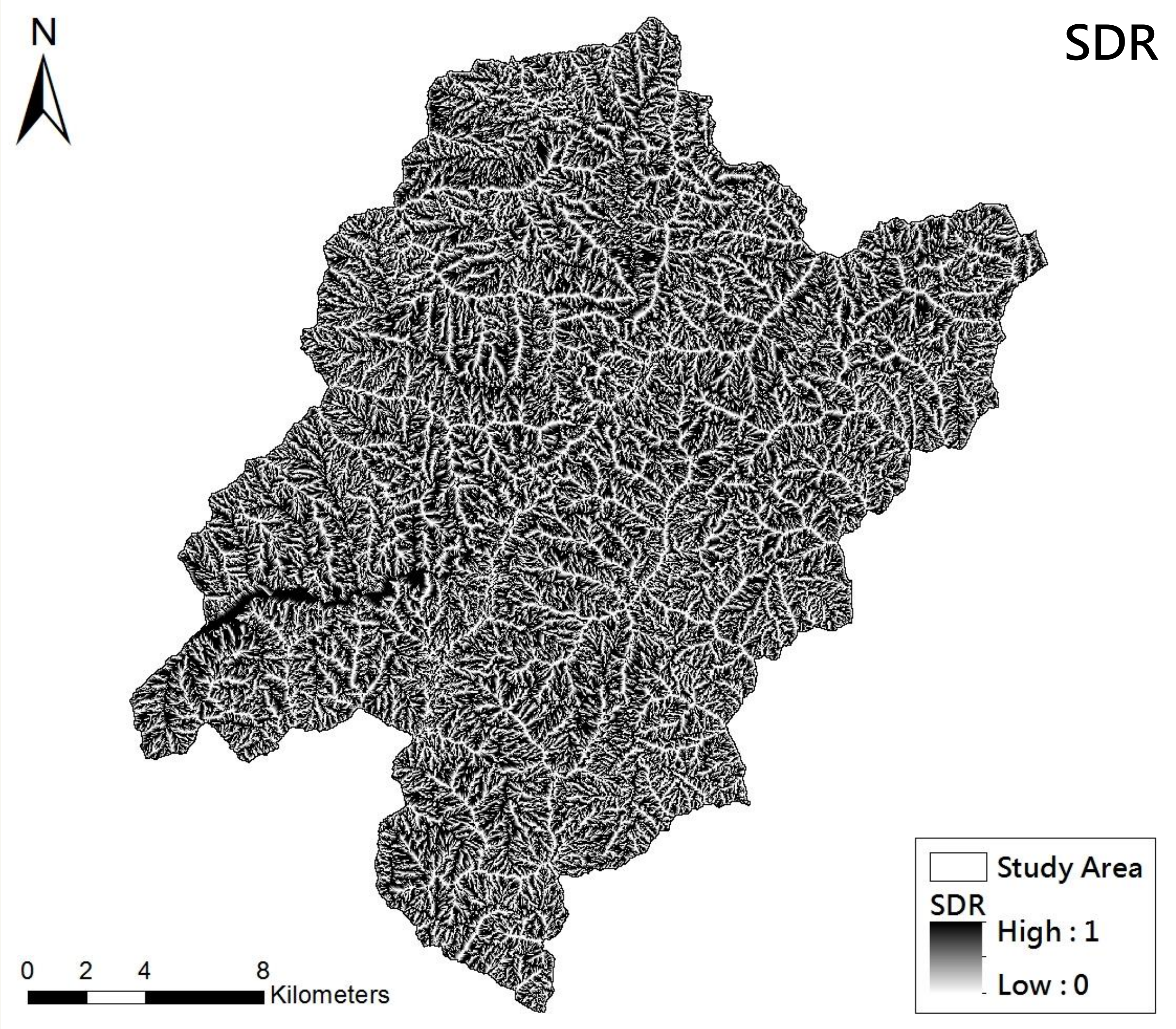
$$\omega = \ln\left(\frac{A_s}{\tan\theta}\right)$$

In the formula, A_s is the specific catchment area; θ is the slope. The larger the TWI value, the easier the water flow is to remain in this area, and the more prone to disasters, so the vulnerability is also higher. On the contrary, the smaller the TWI value, the lower the vulnerability.



Sediment Delivery Ratio(SDR)

The slope sediment yield is transmitted from the erosion to the downstream exporter, which is different from soil loss amount, so SDR should be considered. To calculate the Sediment Delivery Ratio, it is assumed that the slope surface sand is mainly driven by the surface water of the slope surface, and is transported to the channel (steady water) and lost. Therefore, the sand transfer at any grid point on the slope of the catchment area The assumption is the ratio of the area upstream of the grid to the total area of the grid. The closer to the river, the darker the color, the higher the rate of being transfer.



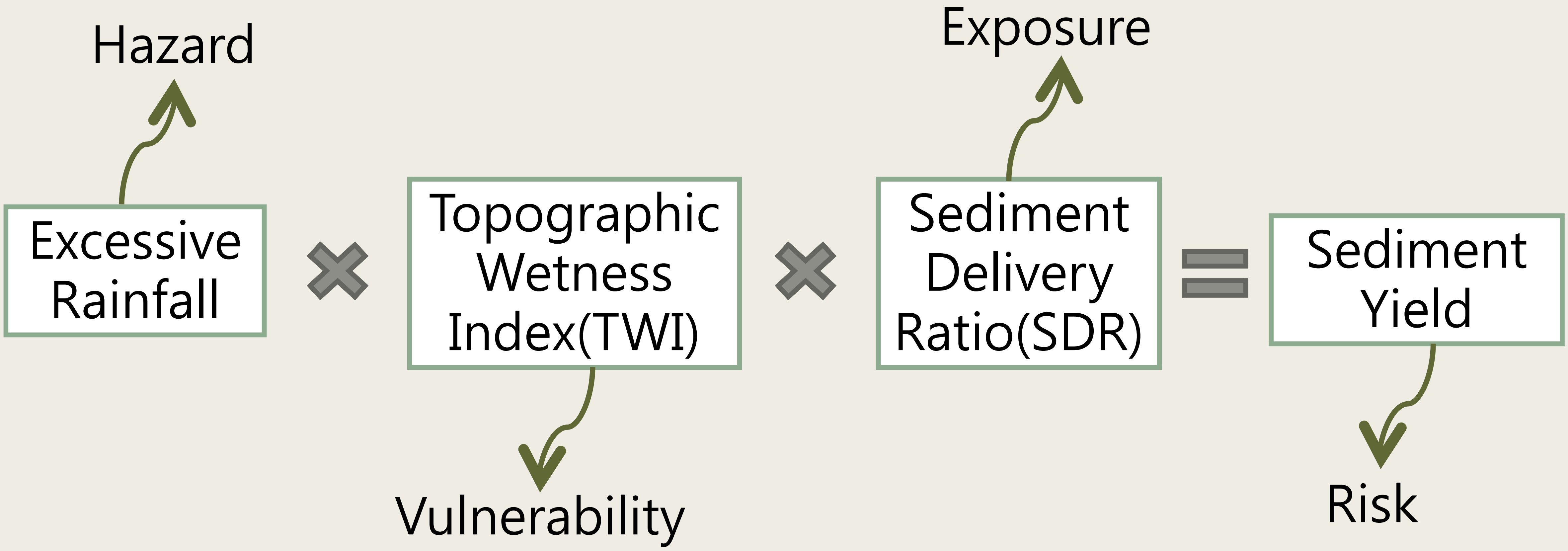
Risk Model

Using the concept of risk analysis, quantify and evaluate each data to consider the impact factors of producing sediment process, the risk formula is as follows：

Risk = Hazard X Vulnerability X Exposure

In the formula, Hazard is the source of external force or the possible impact, Vulnerability is the internal conditions that affect the risk or the ability to bear the risk, and Exposure is the location or facility where the individual is likely to be adversely affected.

Risk Model

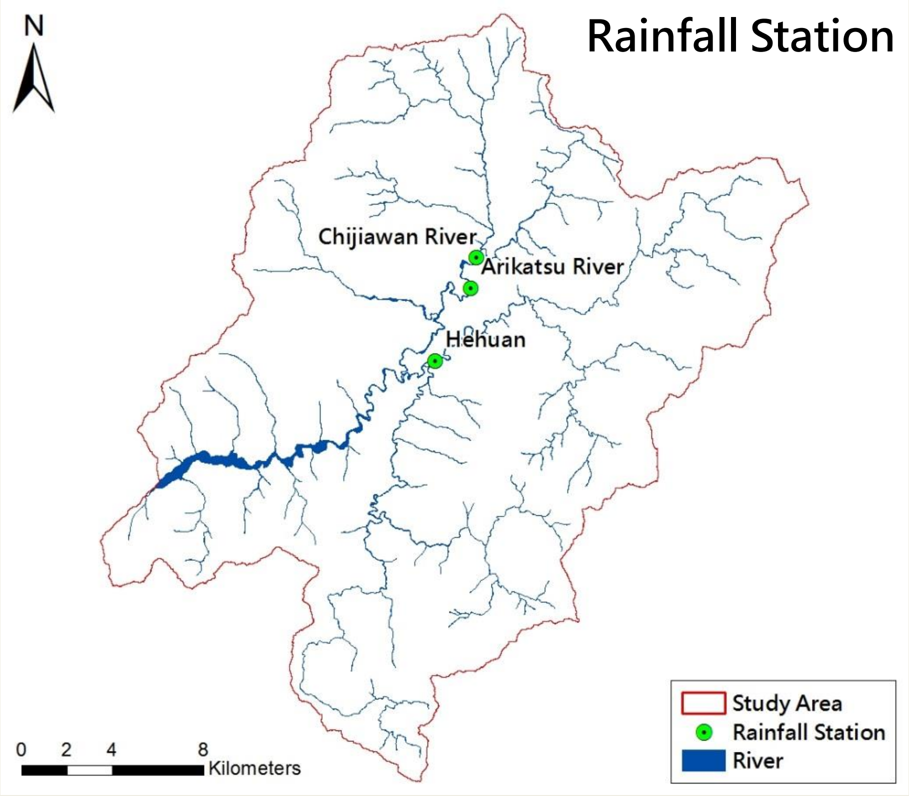


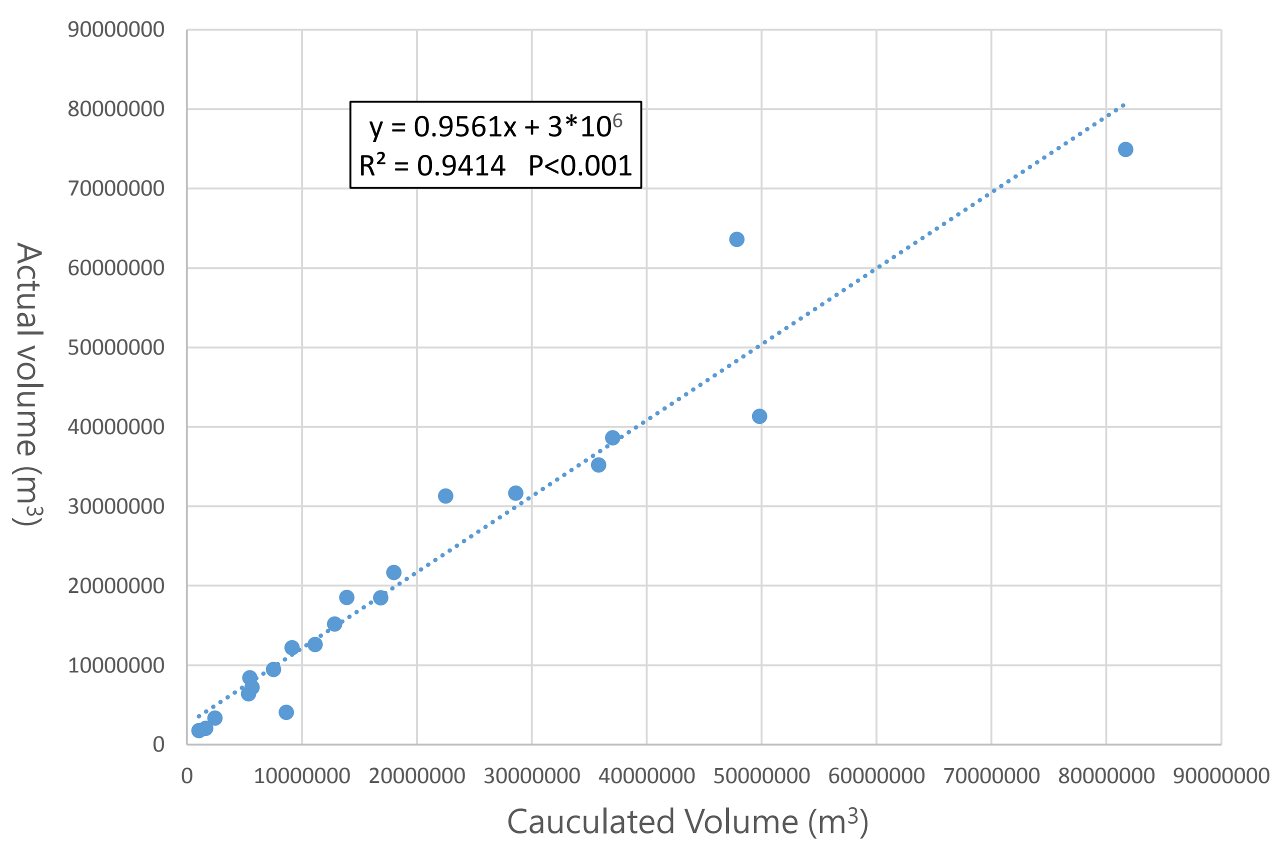
Hazard
Exposure
Excessive Rainfall
Topographic Wetness Index(TWI)
Sediment Delivery Ratio(SDR)
Sediment Yield
Vulnerability
Risk

Results

Verification of runoff volume estimation model

Regression verification was carried out by using the observation data and models of three hydrologic stations in the watershed of Deji reservoir.





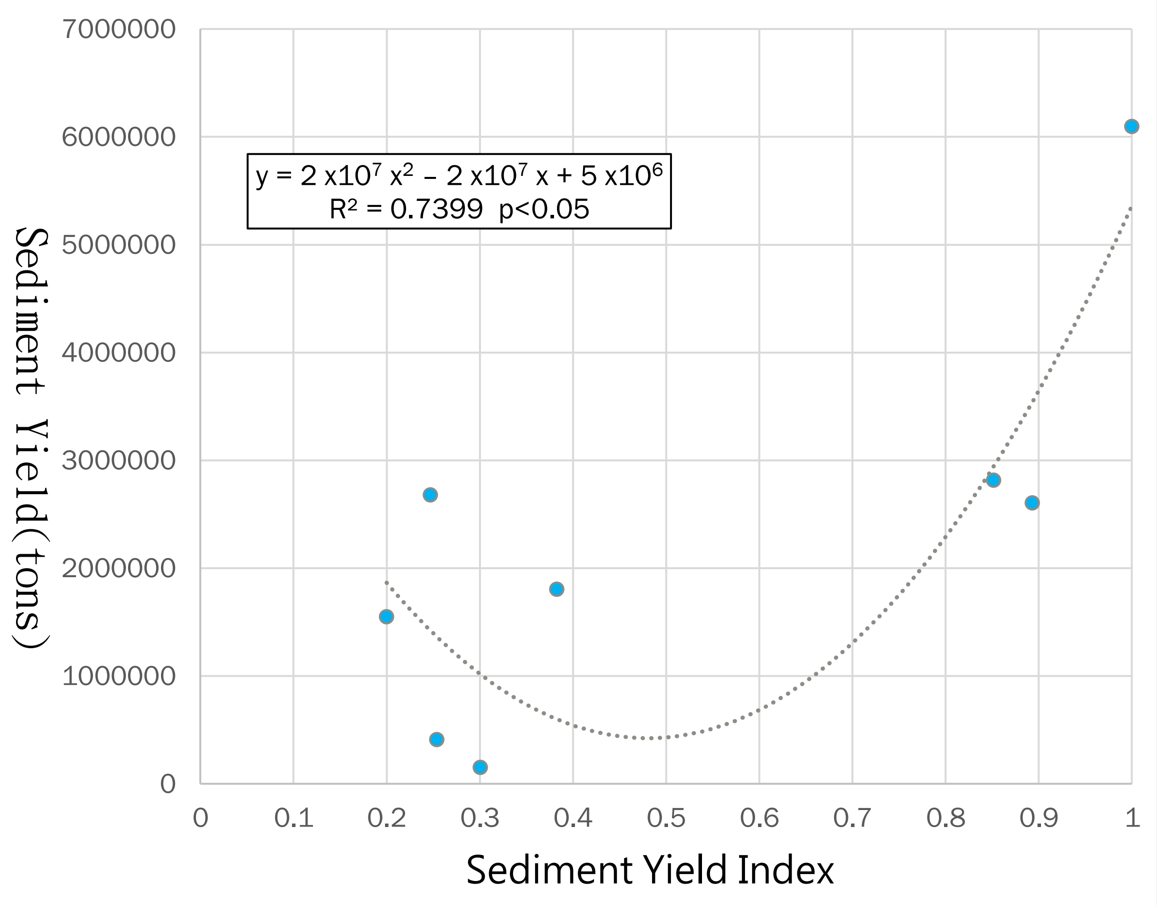
Results

Verification of sediment yield estimation model

Using Taiwan Power Company (2019)" Deji Reservoir overall anti-silting plan", the reservoir siltation volume from 2009 to 2017 is used as the actual measured value, and the sediment yield index is estimated by the formula (X=***Pe × TWI × SDR)***, the model ($y = 2 \times 10^7 x^2 - 2 \times 10^7 x + 5 \times 10^6$) presents a quadratic curve, and $R^2 = 0.74$.

年度	Measure time (year.month)	Current siltation (10^5 m^3)	Desilting amount (10^5 m^3)	Actual siltation (10^5 m^3)
98	98.12	587.47	22.05	609.53
99	99.11	153.16	1.60	154.76
100	100.11	39.16	1.75	40.91
101	101.12	277.26	6.12	283.38
102	102.12	177.04	2.98	180.02
103	103.12	11.82	6.46	18.28
104	104.12	-336.33	3.01	-333.32
105	105.12	258.31	2.17	260.48
106	106.12	265.62	2.12	267.74

Source：Taiwan Power Company (2019)" Deji Reservoir overall anti-silting plan"



Conclusion

- Using the environmental index to calculate excessive runoff and the data of hydrologic station for verification, the relationship between the calculated runoff volume and the measured volume is obtained as :

  $y = 0.9561*x + 3*10^6$ ($R^2 = 0.9414$, $P<0.001$) 。

- The regression analysis of the sediment yield index, the model presents a quadratic curve, and $R^2 = 0.74$.

  When the sediment yield index is greater than 0.55, due to the higher rainfall in the year, the amount of siltation is also high; when the sediment yield index is less than 0.55, the amount of soil sand is inversely proportional. It is relatively difficult to deliver to the reservoir, so there is no obvious positive correlation.

Thank your attention