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Identifying potential sources of sediment contribution based on hillslope characterization

Sarkar Arkaprabha[1] and Singh Vimal[2]

[1]University of Delhi
[2]University of Delhi, New Delhi

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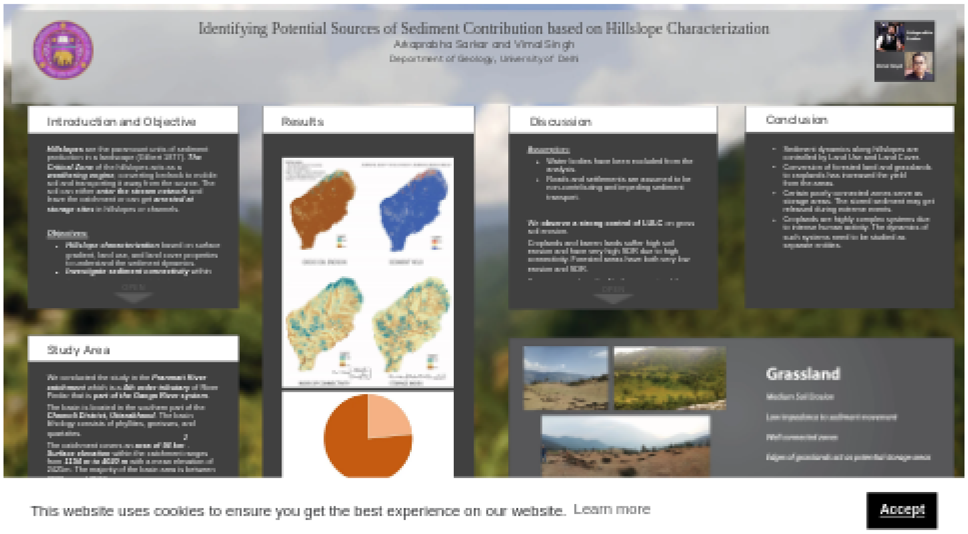
Abstract

Hillslopes are responsible for the production and transport of sediments within a landscape (Gilbert 1877). Since the hillslope gradient and morphology tend to vary across a landscape, it is expected that the erosion and sediment delivery would also be non-uniform. In this study, we explore the probability of the flux at a particular point in the catchment reaching the river mouth using connectivity and the Revised Universal Soil Loss Equation (RUSLE) in the Pranmati river catchment (a small 3rd order Himalayan river catchment within the Ganga River system). Methodology involves characterising the hillslopes of Pranmati river catchment centered on land use and land cover units. Using RUSLE, the sediment yielding capacity of various land cover units are estimated based on which potential source areas are marked. The sediment connectivity within the basin is also calculated by generating a sediment connectivity map of the area using method given by Borcelli et al. (2008). The catchment is categorized into four classes – (A) Highly connected zones with high sediment yielding capacity (B) highly connected zones but low yielding capacity (C) poorly connected zones but high yielding capacity (D) poorly connected zones and low yielding capacity. The area is then mapped on the basis of the defined classes and potential areas of erosion and storage are identified. Our results show that about 62% of the catchment area has low connectivity implying sediment flux generated in these zones have a low probability of leaving the catchment. Only 11% of the catchment area has sediment yield greater than the mean yield per hectare. The sediment generated from this small area of the catchment contributes 93% of the total sediment production of the catchment. References Borselli, L., Cassi, P., & Torri, D. (2008). Prolegomena to sediment and flow connectivity in the landscape: a GIS and field numerical assessment. *Catena*, *75*(3), 268-277. Gilbert, G. K. (1877). *Geology of the Henry mountains* (pp. i-160). Government Printing Office.

Identifying Potential Sources of Sediment Contribution based on Hillslope Characterization



Arkaprabha Sarkar and Vimal Singh

Department of Geology, University of Delhi

PRESENTED AT:

INTRODUCTION AND OBJECTIVE

Hillslopes are the paramount units of sediment production in a landscape (Gilbert 1877). ***The Critical Zone*** of the hillslopes acts as a ***weathering engine***, converting bedrock to mobile soil and transporting it away from the source. The soil can either ***enter the stream network*** and leave the catchment or can get ***arrested at storage sites*** in hillslopes or channels.

Objectives:

- ***Hillslope characterization*** based on surface gradient, land use, and land cover properties to understand the sediment dynamics.
- ***Investigate sediment connectivity*** within the catchment and identify high yielding zones.
- **Identify Potential Storage Zones** within the catchment

STUDY AREA

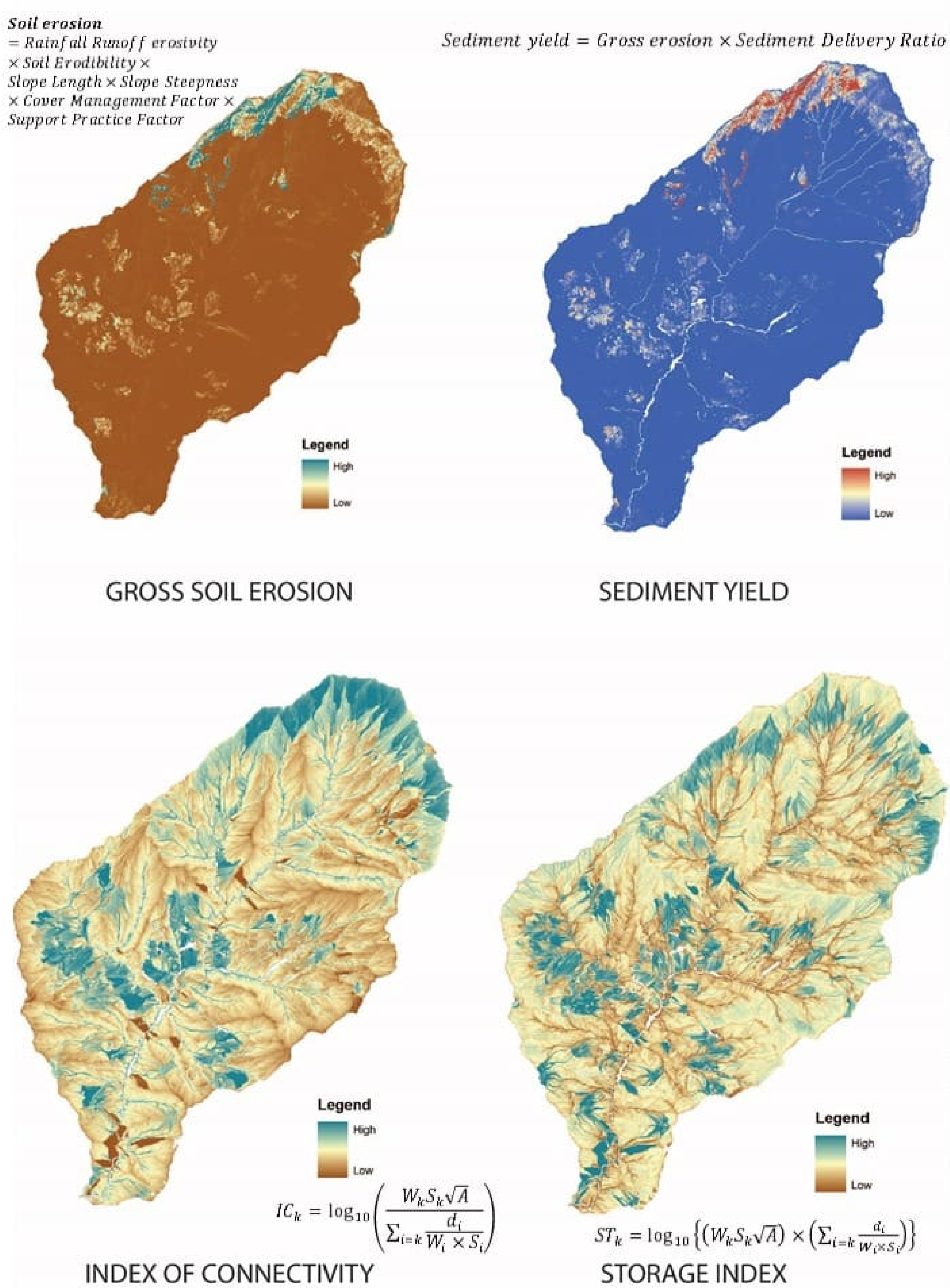
We conducted the study in the ***Pranmati River catchment*** which is a ***4th order tributary*** of River Pindar that is ***part of the Ganga River system***.

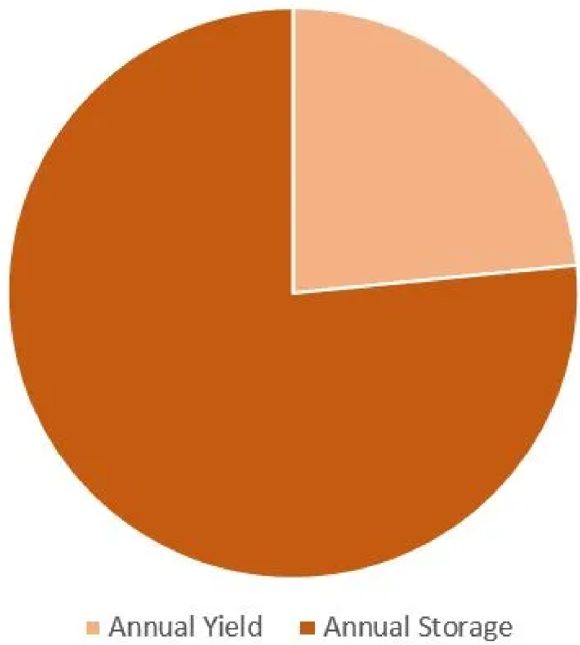
The basin is located in the southern part of the ***Chamoli District, Uttarakhand***. The basin lithology consists of phyllites, gneisses, and quartzites.

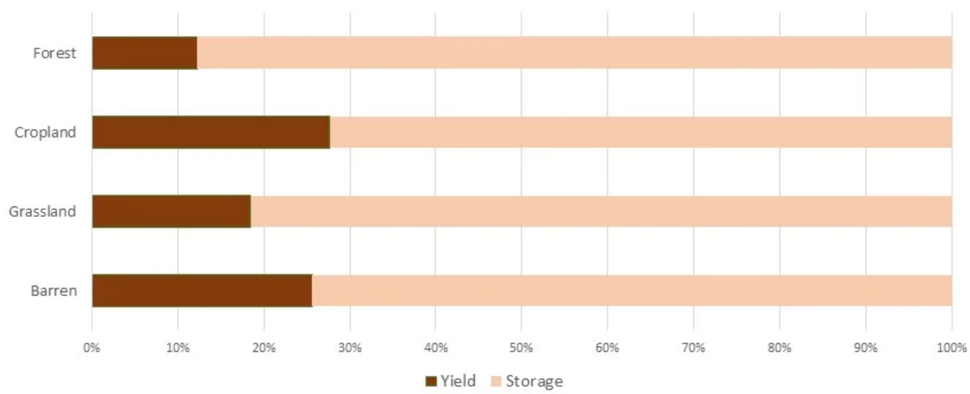
The catchment covers an ***area of 94 km^2***. ***Surface elevation*** within the catchment ranges from ***1154 m to 4020 m*** with a mean elevation of 2425m. The majority of the basin area is between 2000 m and 2500 m.

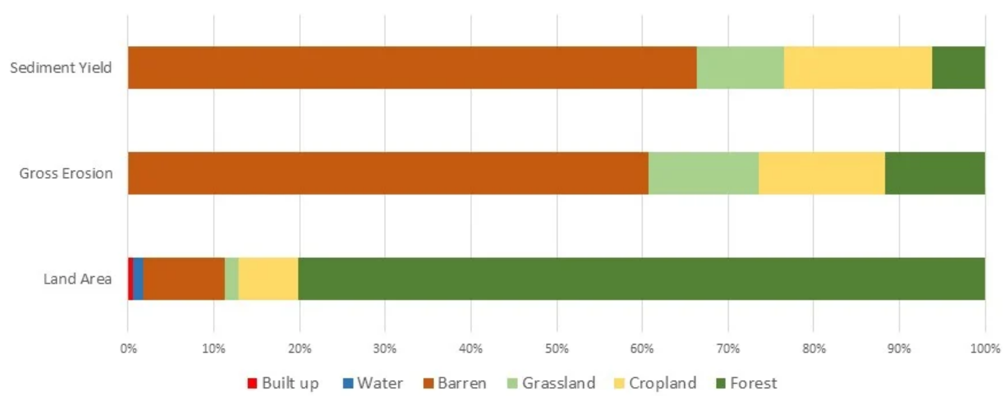
The basin has slopes as steep as 79^0 and an ***average slope of 25.7^0***.

RESULTS

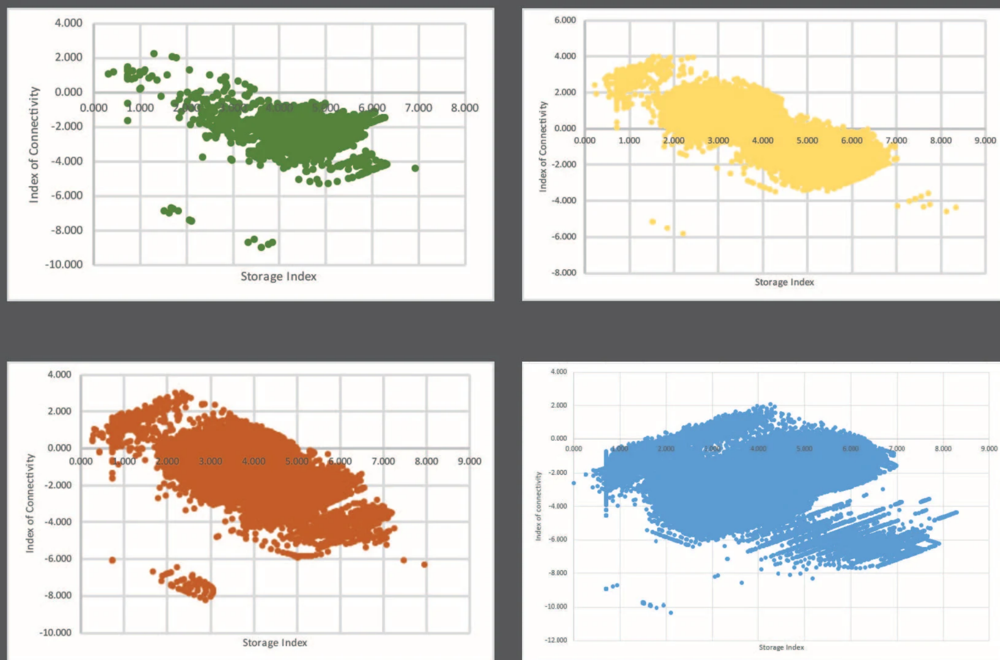

Soil erosion
= Rainfall Runoff erosivity
× Soil Erodibility ×
Slope Length × Slope Steepness
× Cover Management Factor ×
Support Practice Factor
Sediment yield = Gross erosion × Sediment Delivery Ratio
Legend
High
Low
Legend
High
Low
GROSS SOIL EROSION
SEDIMENT YIELD
Legend
High
Low
$IC_k = \log_{10}\left(\frac{W_k S_k \sqrt{A}}{\sum_{i=k} \frac{d_i}{W_i \times S_i}}\right)$
Legend
High
Low
$ST_k = \log_{10}\left\{\left(W_k S_k \sqrt{A}\right) \times \left(\sum_{i=k} \frac{d_i}{W_i \times S_i}\right)\right\}$
INDEX OF CONNECTIVITY
STORAGE INDEX


Annual Yield
Annual Storage


Forest
Cropland
Grassland
Barren
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Yield
Storage


Sediment Yield
Gross Erosion
Land Area
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Built up
Water
Barren
Grassland
Cropland
Forest

Storage Index vs Index of Connectivity



Grassland

Cropland

Barren Land

Forested Land

DISCUSSION

Assumption:

- Water bodies have been excluded from the analysis.
- Roads and settlements are assumed to be non-contributing and impeding sediment transport.

We **observe a strong control of LULC** on gross soil erosion.

Croplands and barren lands suffer high soil erosion and have very high SDR due to high connectivity. Forested areas have both very low erosion and SDR.

Barren areas along the Northern margin of the basin are a major contributor to the final yield, followed by croplands and grasslands. Forests contribute the minimum fraction despite having a large land area.

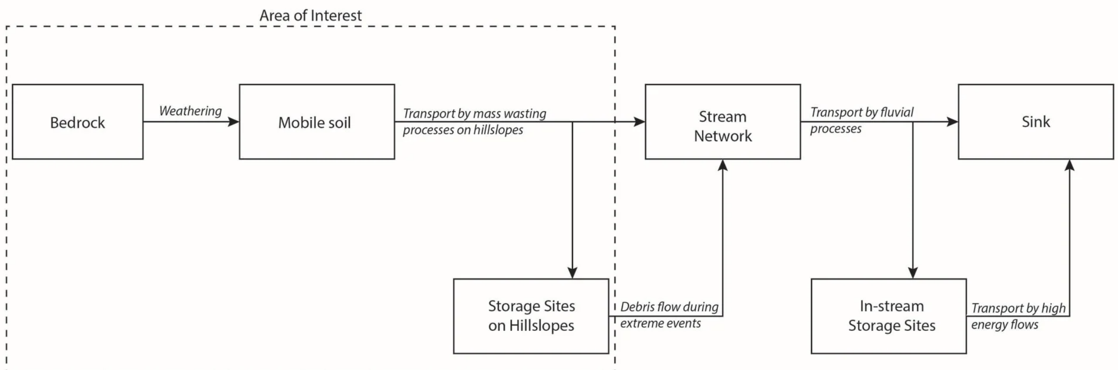
Storage areas can be located at the borders of high and low connected areas (edge of barren lands, grasslands within forests, etc.)

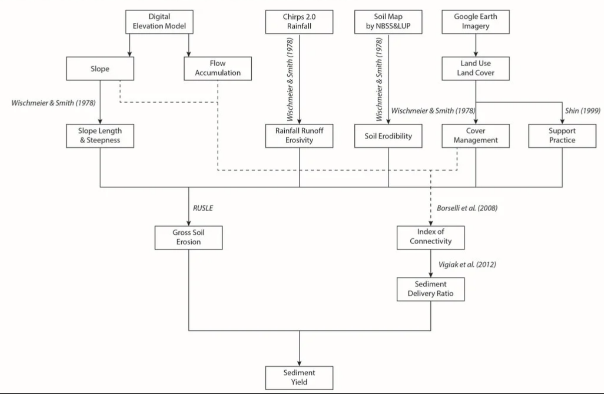
All land cover units show a trend of increasing storage with decreasing connectivity. Thus, poorly connected areas MAY act as potential sediment storage sites.

Croplands have an anomalous behavior of having a high soil erosion capacity, high connectivity, and a high storage index as well.

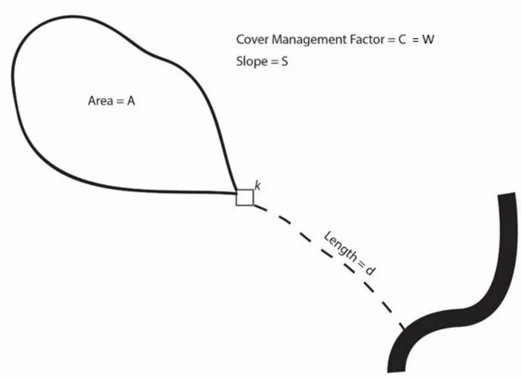
CONCLUSION

- Sediment dynamics along hillslopes are controlled by Land Use and Land Cover.
- Conversion of forested land and grasslands to croplands has increased the yield from the areas.
- Certain poorly connected zones serve as storage areas. The stored sediment may get released during extreme events.
- Croplands are highly complex systems due to intense human activity. The dynamics of such systems need to be studied as separate entities.





Methodology



Connectivity

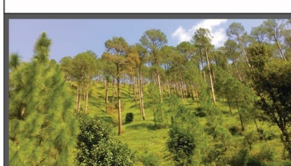
$$IC_k = \log_{10}\left(\frac{D_{up}}{D_{dn}}\right) = \log_{10}\left(\frac{W_k S_k \sqrt{A}}{\sum_{i=k}\frac{d_i}{W_i \times S_i}}\right)$$

Storage

$$SDR_k = SDR_{max}\left(1 + exp\left(\frac{IC_{o,k} - IC_k}{U_k}\right)\right)^{-1}$$

Sediment Delivery Ratio

$$ST_k = \log_{10}(D_{up} \times D_{dn}) = \log_{10}\left\{(W_k S_k \sqrt{A}) \times \left(\sum_{i=k}\frac{d_i}{W_i \times S_i}\right)\right\}$$



Forested Hillslopes

Low Soil Erosion

High impedance to sediment movement

Poorly connected zones

Grassland

Medium Soil Erosion

Low impedance to sediment movement

Well connected zones

Edges of grasslands act as potential storage areas

Cropland

High Soil Production and Erosion

Low to medium impedance to sediment movement

High connectivity within the catchment

Acts as Potential Storage Zones

Complex Systems: Strong Anthropogenic Influence

DISCLOSURES

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AUTHOR INFORMATION

Arkaprabha Sarkar is a Senior Research Fellow at the Department of Geology, University of Delhi, India currently doing his PhD. His research interests are *Geomorphology, Critical Zone, Hillslope Processes* and *Luminescence*. Contact him at arkaprabha.geo@hotmail.co.uk

Vimal Singh is an Associate Professor at the Department of Geology, University of Delhi, India. His research interests are *Quaternary Geology, Tectonic Geomorphology* and *Critical Zone*. Contact him at vimalgeo@gmail.com

ABSTRACT

Hillslopes are responsible for the production and transport of sediments within a landscape (Gilbert 1877). Since the hillslope gradient and morphology tend to vary across a landscape, it is expected that the erosion and sediment delivery would also be non-uniform.

In this study, we explore the probability of the flux at a particular point in the catchment reaching the river mouth using connectivity and the Revised Universal Soil Loss Equation (RUSLE) in the Pranmati river catchment (a small 4th order Himalayan river catchment within the Ganga River system).

The methodology involves characterizing the hillslopes of Pranmati river catchment centered on land use and land cover units. Using RUSLE, the sediment yielding capacity of various land cover units is estimated based on which potential source areas are marked. The sediment connectivity within the basin is also calculated by generating a sediment connectivity map of the area using the method given by Borcelli et al. (2008). Using sediment yield and storage index, potential high yielding areas and storage areas have been identified in the catchment.

Our results show that about 62% of the catchment area has low connectivity implying sediment flux generated in these zones has a low probability of leaving the catchment. Less than 25% percent of the annually eroded sediment contributes to the annual basin yield. More than 75% of the eroded sediments do not leave the basin under normal conditions but may get mobilized during high magnitude extreme events. These sediments are located mostly in poorly connected zones within the catchment.

References

- Borselli, L., Cassi, P., & Torri, D. (2008). Prolegomena to sediment and flow connectivity in the landscape: a GIS and field numerical assessment. *Catena*, *75*(3), 268-277.
- Gilbert, G. K. (1877). *Geology of the Henry mountains* (pp. i-160). Government Printing Office.

REFERENCES

- Borselli, L., Cassi, P., & Torri, D. (2008). Prolegomena to sediment and flow connectivity in the landscape: a GIS and field numerical assessment. Catena, 75(3), 268-277.
- Gilbert, G. K. (1877). Geology of the Henry mountains (pp. i-160). Government Printing Office.
- Shin, G. J. (1999). The analysis of soil erosion analysis in watershed using GIS (Doctoral dissertation, Ph. D. Dissertation, Department of Civil Engineering, Gang-won National University).
- Vigiak, O., Borselli, L., Newham, L. T. H., McInnes, J., & Roberts, A. M. (2012). Comparison of conceptual landscape metrics to define hillslope-scale sediment delivery ratio. Geomorphology, 138(1), 74-88.
- Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses: a guide to conservation planning (No. 537). Department of Agriculture, Science and Education Administration.