

# Analytic Hierarchy Process and Multi-criteria decision-making Approach for Selecting the Most Effective Soil Erosion Zone in Gomati River Basin

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**Abstract**---The watershed is segmented into 20 zones based on Area. The watershed is considered by pointing the maximum elevation from sea level from Google earth. The soil erosion is determined using the universal soil loss equation. The different independent variables of soil loss equation bear different weightage for different soil zones. And therefore, to find the weightage factor for all the variables of soil loss equation like rainfall runoff erosivity index, soil erodibility factor etc, analytical hierarchy process (AHP) is used. And thereafter, multi-objective optimization on the basis of ratio analysis (MOORA) approach is used to select the most effective zone causing soil erosion. The MCDM technique concludes that the maximum soil erosion is occurring in the zone 14.

**Keywords**—Soil erosion, analytic hierarchy process (AHP), multi criteria decision making (MCDM), universal soil loss equation (USLE), multi-objective optimization on the basis of ratio analysis (MOORA).

## I. INTRODUCTION

Soil erosion is a natural phenomenon which occurs throughout the drainage portion around the globe. The intensity of erosion depends on natural factors as well as human induced factors. Soil erosion by water is serious global problem. The agents of soil erosion are water and wind, each contributing a significant amount of soil loss each year. Soil erosion is a slow but perennial process that continues relatively unnoticed, or it may occur at an alarming rate causing serious loss of top soil layer. The loss of soil from farmland results in reduced crop production potential, lower surface water availability and damaged drainage networks. The impact of a falling raindrop creates a small crater in the soil, ejecting soil particles. The universal soil loss equation (USLE) [1] method for the calculation of soil erosion is not explicit as the weightage of different variables can't be obtained from the equation. To overcome this problem, analytical hierarchy process is used, which is introduced by Saaty in 1980, which allows interdependences between decision factors to be taken into account.

### A. Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) is a mathematical model to describe the soil loss process. It predicts the long-term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography,

crop system and management practices [2]. Universal Soil Loss Equation (USLE) only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. This erosion model was created for use in selected cropping and management systems, but is also applicable to non-agricultural conditions such as construction sites. The USLE can be used to compare soil losses from a particular field with a specific crop and management system to "tolerable soil loss" rates. Alternative management and crop systems may also be evaluated to determine the adequacy of conservation measures in farm planning. Five major factors are used to calculate the soil loss for a given site. Each factor is the numerical estimate of a specific condition that affects the severity of soil erosion at a particular location. The erosion values reflected by these factors can vary considerably due to varying weather conditions [3]. Therefore, the values obtained from the Universal Soil Loss Equation (USLE) more accurately represent long-term averages [4].

Universal Soil Loss Equation (USLE) is given by the equation:

$$A = R \times K \times L \times S \times C \times P \quad (1)$$

where; A = average annual soil loss in t/a (tons per acre), R = Rainfall runoff erosivity index, K = Soil erodibility factor, L = L is for slope length, S= Slope Steepness factor, C =Cover management factor, P =Support practice factor.

### B. The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach and was introduced by Saaty [5]. The AHP has attracted the interest of many researchers mainly due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain. This method can be used in various fields of science and better results can be obtained for decision-making. AHP has the wider industrial engineering applications and its use include integrated manufacturing, evaluation of technology investment decision making, flexible manufacturing system, and layout design and also in other engineering problems.

1. Structure Of The Decision Problem Under Consideration

The structure of the typical decision problem considered in this paper consists of a number, say M, of alternatives and a number, say N, of decision criteria.[6]. Each alternative can be evaluated in terms of the decision criteria and the relative importance (or weight) of each criterion can be estimated as well. Let  $a_{ij}$  ( $i=1,2,3,\dots,M$ , and  $N=1,2,3,\dots,N$ ) denote the performance value of the  $i^{th}$  alternative (i.e.,  $A_i$ ) in terms of the  $j^{th}$  criterion (i.e.,  $C_j$ ). Also denote as  $W_j$  the weight of the criterion  $C_j$ . Then, the core of the typical MCDM problem can be represented by the following decision matrix.

Alt.	Criterion				
	$C_1$ $W_1$	$C_2$ $W_2$	$C_3$ $W_3$	...	$C_N$ $W_N$
$A_1$	$a_{11}$	$a_{12}$	$a_{13}$	...	$a_{1N}$
$A_2$	$a_{21}$	$a_{22}$	$a_{23}$	...	$a_{2N}$
$A_3$	$a_{31}$	$a_{32}$	$a_{33}$	...	$a_{3N}$
...	...	...	...	...	...
$A_M$	$a_{M1}$	$a_{M2}$	$a_{M3}$	...	$a_{MN}$

Fig. 1 Decision matrix

In the AHP the pair wise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding consistency ratio (CR) is less than 10% (Saaty, 1980). First the consistency index (CI) needs to be estimated. This is done by adding the columns in the judgment matrix and multiply the resulting vector by the vector of priorities (i.e., the approximated eigenvector) obtained earlier. This yields an approximation of the maximum Eigen value, denoted by  $\lambda_{max}$ . Then, the CI value is calculated by using the formula:  $CI = (\lambda_{max} - n) / (n - 1)$ . Next the consistency ratio CR is obtained by dividing the CI value by the Consistency index (CI) as given in Table I. When these approximations are applied to the previous judgment matrix it can be verified that the following are derived:  $\lambda_{max} = 3.136$ ,  $CI = 0.068$  and  $CR = 0.117$ . If the CR value is greater than 0.10, then it is a good idea to study the problem further and re-evaluate the pair wise comparison.

TABLE I  
 RI VALUES FOR NUMBER OF CRITERIA

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

After the alternatives are compared with each other in terms of each one of the decision criteria and the individual priority vectors are derived, the synthesis step is taken. The priority vectors become the columns of the decision matrix (not to be confused with the judgment matrices with the pair wise comparisons). The weights of importance of the criteria are also determined by using pair wise comparisons. Therefore, if a problem has M alternatives and N criteria, then the decision maker is required to construct N judgment matrices (one for each criterion) of order  $m \times m$  and one judgment matrix of order  $n \times n$  (for the N criteria). Finally, given a decision matrix the final priorities, denoted by  $A_{AHP}^i$ ,

of the alternatives in terms of all the criteria combined are determined according to the following formula:

$$A_{AHP}^i = \sum_{j=1}^N a_{ij} w_j, \quad \text{for } j = 1, 2, 3, \dots, M \quad (2)$$

In the case of the ideal mode of AHP, the columns of the decision matrix are normalized by dividing each value of the column by the largest entry in each column.

C. The MOORA Method

Multi-objective optimization (or programming), also known as multi-criteria or multi-attribute optimization, is the process of simultaneously optimizing two or more conflicting attributes (objectives) subject to certain constraints. The Multi-Objective Optimization by Ratio Analysis (MOORA) is such a multi-objective optimization technique [7] that can be successfully applied to solve various types of complex decision-making problems in the manufacturing environment. The MOORA method begins with a decision matrix, which shows the performance of different alternatives with respect to various attributes [8]. The following steps describe the MOORA method.

- Step 1. The first step is to determine the objective, and to identify the pertinent evaluation attributes [9].
- Step 2. The next step is to represent all the information available for the attributes in the form of a decision matrix. The data given in Equation (3) are represented as matrix  $X_{m \times n}$  where  $x_{ij}$  is the performance measure of  $i^{th}$  alternative on  $j^{th}$  attribute, m is the number of alternatives, and n is the number of attributes.[12] Then a ratio system is developed in which each performance of an alternative on an attribute is compared to a denominator which is a representative for all the alternatives concerning that attribute.

$$X = \begin{matrix} & x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{matrix} \quad (3)$$

- Step 3. Brauers [13] concluded that for this denominator, the best choice is the square root of the sum of squares of each alternative per attribute. This ratio can be expressed as below:

$$x_{ij}^* = x_{ij} / \sqrt{\sum_{i=1}^m x_{ij}^2} \quad (4)$$

where  $J = (1, 2, \dots, n)$ ,  $x_{ij}$  is a dimensionless number which belongs to the interval [0, 1] representing the Normalized performance of the  $i^{th}$  alternative on  $j^{th}$  attributes.

- Step 4. For multi-objective optimization, these normalized performances are added in case of maximization (for beneficial attributes) and subtracted in case of minimization (for non-beneficial attributes). Then the optimization problem becomes:

$$y_i = \sum_{j=1}^g x_{ij}^* - \sum_{j=g+1}^n x_{ij}^* \tag{5}$$

where g is the number of attributes to be maximized, (n-g) is the number of attributes to be minimized and  $y_i$  is the normalized assessment value of  $i^{th}$  alternative with respect to all the attributes. In some cases, it is often observed that some attributes are more important than the others. In order to give more importance to an attribute, it could be multiplied with its corresponding weight (significance coefficient) [13] When these attribute weights are taken into consideration, Equation.6 becomes as follows:

$$y_i = \sum_{j=1}^g w_j x_{ij}^* - \sum_{j=g+1}^n w_j x_{ij}^* \tag{6}$$

where  $J = (1, 2, \dots, n)$ ,  $w_j$  is the weight of  $j^{th}$  attribute, which can be determined by applying analytic hierarchy Process (AHP), or entropy method.

Step 5. Step 5: The  $y_i$  value can be positive or negative depending of the totals of its maxima (beneficial attributes) and minima (non beneficial attributes) in the decision matrix. An ordinal ranking of  $y_i$  shows

the final preference. Thus, the best alternative has the highest  $y_i$  Value, while the worst alternative has the lowest  $y_i$  value.

## II. STUDY AREA

The Gumati river basin is located in Gomati district in the state of Tripura, situated in the longitudes between  $91^{\circ} 18'$  and  $91^{\circ} 59'$  East and in the latitudes between  $22^{\circ} 56'$  and  $23^{\circ} 45'$  North.[11].The catchment area of river Gumati is 2,492  $km^2$  within Indian Union and it has the largest basin among the rivers of Tripura. 1,921  $km^2$  lies in the hill catchment and only 571  $km^2$ , which is nearly 22.9% of the total catchment, lies in the plains [14]. The region falls under the subtropical and the temperate climatic zone and is under the grip of influence of southwesterly monsoon winds that is popularly known as monsoon in India. Therefore, during the monsoon period, this region experiences heavy rainfall in this region and thus the river gumati flourishes during this time of the year.



Fig. 2 Geographical location of Gumati River in Tripura [10]

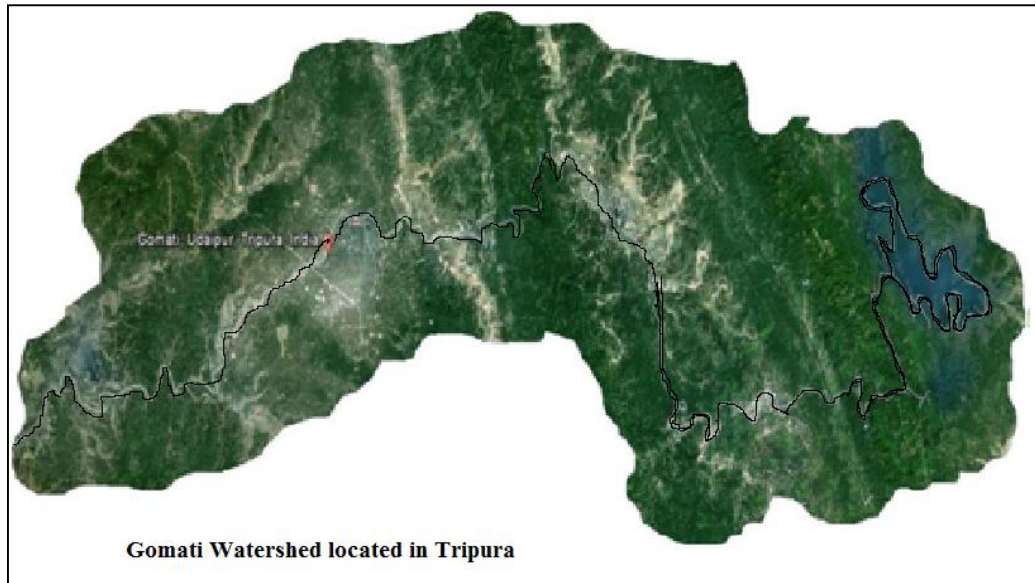


Fig.3 Gumati river basin

III. METHODOLOGY

**Flow chart**

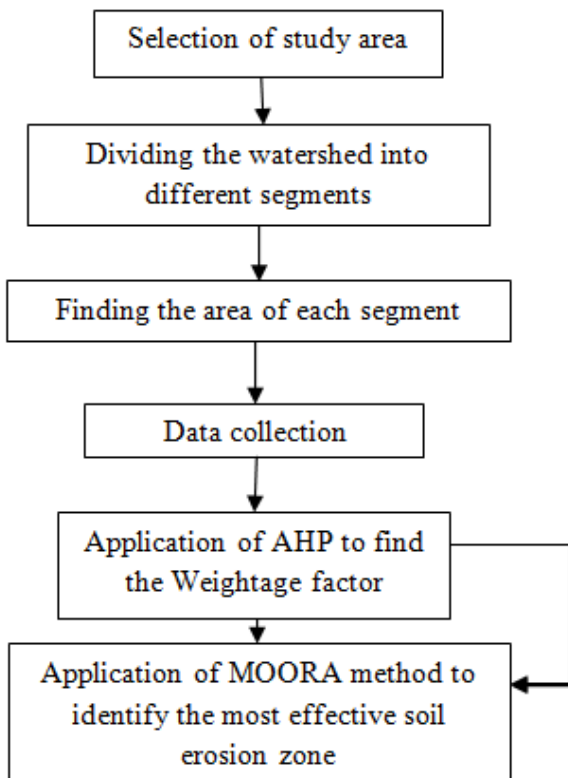


Fig.4 Flow chart of Methodology

For the preparation of Analytical Hierarchy Process model, it is necessary to prepare a comparison matrix and its values are taken based on the Saaty’s comparison scale. The scale is not necessarily to be from 1 to 9 but for qualitative data such as preference, ranking and subjective opinion etc. it is taken here to be from 1 to 9. Number of comparison among the

different criteria could be found out by the formula given below.

$$\text{Number of comparison} = \frac{n(n-1)}{2}$$

where, n=Number of criteria.

*A. Making Comparison Matrix*

By comparison between different variables (criteria), the following matrix is prepared.

TABLE II  
COMPARISON MATRIX

	R	K	L	S	C	P
R	1	5	3	7	9	9
K	1/5	1	1/3	5	7	9
L	1/3	3	1	3	5	7
S	1/7	1/5	1/3	1	5	3
C	1/9	1/7	1/5	1/5	1	1/3
P	1/9	1/9	1/7	1/3	3	1
SUM	1.8984	9.4540	5.0095	16.5333	29	29.3333

Then each element of the matrix is divided by the sum of its column and the normalized relative weight factor is obtained. The sum of each column is 1, which is the essential condition for the validation of weightage factors.

TABLE III  
NORMALISED MATRIX

	R	K	L	S	C	P
R	0.5268	0.5288	0.5989	0.4234	0.3103	0.3068
K	0.1054	0.1059	0.0665	0.3024	0.2413	0.3068
L	0.1755	0.3173	0.1996	0.1825	0.1723	0.2386
S	0.0753	0.0212	0.0665	0.0605	0.1723	0.1023
C	0.0585	0.0151	0.0399	0.0121	0.0344	0.0114
P	0.0585	0.0118	0.0280	0.0103	0.1033	0.0341
SUM	1	1	1	1	1	1

Each criteria row wise is multiplied and to the power one sixth (i.e. no. of criteria). Then each criteria is divided by the sum to find the weight factor.

TABLE IV  
WEIGHTED NORMALISED MATRIX

Criteria	$(R \times K \times L \times S \times C \times P)^{1/6}$	Weight factor
R	4.5180	0.4674
K	1.6610	0.1718
L	2.1720	0.2247
S	0.7230	0.0748
C	0.2441	0.0253
P	0.3476	0.0360
	9.6657	1.00

where n = number of criteria. The value of  $\lambda_{max}$  is given by the following formula. The value of weight factor is shown in Table IV.

$$\lambda_{max} = (1.8984 \times 0.4674) + (9.4540 \times 0.1718) + (5.0095 \times 0.2247) + (16.5333 \times 0.0748) + (29 \times 0.0253) + (29.3333 \times 0.0360) = 6.65$$

TABLE V  
VALUES OF CI AND CR

CI = Consistency Index, n=6	RI = Random Consistency Index (1.32)
$CI = \frac{\lambda_{max} - n}{n - 1}$	$CR = \frac{CI}{RI}$
= 0.13	= 0.09848

The Consistency Index of normalized matrix (Table III) is calculated using the following formula i.e.  $(\lambda_{max} - n) / (n - 1)$ ,

where, CR stands for Consistency Ratio.

TABLE VI  
CALCULATION FOR SOIL EROSION IN SUB ZONES

Zones	R(+)	K(+)	L(+)	S(+)	C(-)	P(-)	Sub Basin(tons/yr)
1	2143.38	2.09546	9.701825	5.080214	13.83399	13.88889	2132.535
2	2143.38	5.471478	8.2332	4.679144	0.988142	13.88889	2146.887
3	2143.38	6.111758	6.052514	4.144385	0.988142	6.944444	2151.756
4	2143.38	2.09546	6.853583	3.877005	4.940711	27.77778	2123.488
5	2143.38	2.09546	7.788162	3.074866	14.22925	13.88889	2128.221
6	2143.38	2.09546	10.99243	3.342246	8.300395	10.27778	2141.232
7	2143.38	2.09546	10.36938	4.010695	0.711462	13.88889	2145.256
8	2143.38	4.307334	9.167779	4.679144	0.711462	6.944444	2153.879
9	2143.38	1.571595	9.657321	3.074866	3.557312	6.944444	2147.182
10	2143.38	3.259604	7.343124	4.545455	12.45059	27.77778	2118.300
11	2143.38	4.19092	7.165109	3.475936	11.85771	27.77778	2118.577
12	2143.38	3.259604	10.5919	4.679144	8.300395	20.83333	2132.777
13	2143.38	5.471478	10.5919	4.411765	3.952569	27.77778	2132.125
14	2143.38	2.09546	16.59991	5.080214	4.940711	6.944444	2155.271
15	2143.38	1.804424	21.58433	6.417112	4.841897	13.88889	2154.455
16	2143.38	2.968568	7.343124	4.946524	13.83399	10.27778	2134.527
17	2143.38	4.307334	9.390298	7.219251	3.458498	20.83333	2140.005
18	2143.38	1.280559	9.52381	16.04278	11.85771	20.83333	2137.537
19	2143.38	2.09546	11.12595	2.540107	3.557312	20.83333	2134.751
20	2143.38	2.735739	10.32488	2.406417	0.197628	20.83333	2137.816

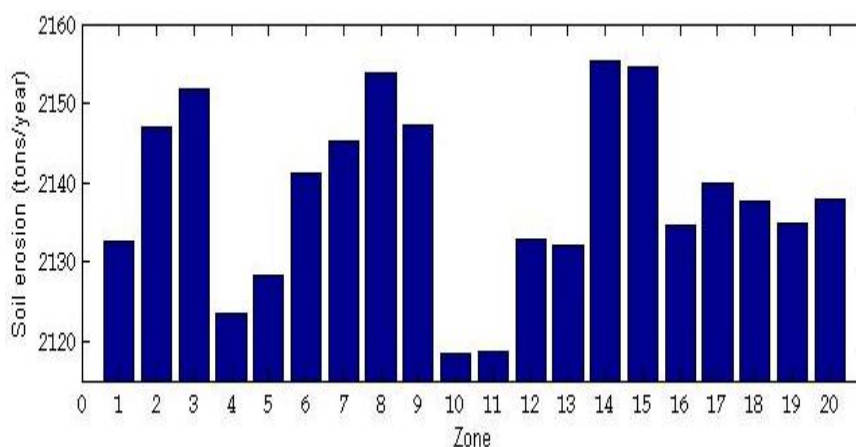


Fig. 4 Soil loss in each zone of the river basin

So,  $CR < 10$  i.e. 9.848% is less than 10%. As per Saaty's argument, the consistency ratio should be in the range of  $0.1 < CR < 10$  for a proper consistency of the judgment. CR values limiting towards 10 are considered to be just and acceptable. CR values of 10 and more is considered to be random and completely untrustworthy. Thus, evaluation of different criteria of soil erosion calculation preference is consistent.

#### B. Soil Loss in Different Sub Basin

Soil loss in different sub basin are calculated and tabulated in the table VI.

#### IV. RESULT

The criteria of soil erosion are compared with each other by developing comparison matrix. The criteria are compared as the importance of one with respect to another and accordingly given rating as per Saaty's scale. The present study is conducted to determine the zone of a river basin which contributes highest amount of soil erosion in the whole river basin. Here, it is found that zone 14 is contributing maximum soil erosion, which is shown graphically in Fig. 4.

#### V. DISCUSSION AND CONCLUSION

The model presented in this study illustrates the possibility of the use of the analytic hierarchy Process (AHP) method by using expertise to calculate soil erosion. Unlike other methods, that use sample data (e.g. USLE/RUSLE), the proposed method is based on expert opinion. Moreover, by using the AHP and multi-criteria decision-making method to optimize the criteria contributing to soil loss is unique in its approach. In general, the use of expertise is not a new approach. However, the method proposed here is based on analytic hierarchy Process (AHP), which takes in to consideration interdependence of the processes responsible for soil erosion. The information used by the model is collected from the experts' opinion and field survey to form the pair wise comparison. The experience of authors' concerned shows that all the information gathered from field survey and expert opinion is difficult to be taken in to consideration in preparation of the model. Thus, even with the relatively simple network structure of this case study, a large number of pair wise comparisons are performed in this study. Therefore, the model presented here is a site-specific model & can be used to conduct related works in future by adding soil erosion impact factors and interdependences that depend on local conditions. Another interesting objective for the future is to accurately calibrate the analytic hierarchy Process (AHP) model in order to quantify accurate soil losses.

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