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Chapter

Analytic Hierarchy Process (AHP) Applications in Watershed Management Plan, A Case Study of Sub-Watershed

Kartic Bera, Jatisankar Bandyopadhyay and Pabitra Banik

Abstract

Analytical Hierarchy Process (AHP) one of the Multi-Criteria Evaluation techniques is proposed by Saaty's-1980. More than one parameter is equally important for management, as these are very much interrelated. One of the methods is AHP, which is welcomed for supporting procedural justice that regards clearness and equality of decisions. However, the AHP method promises for procedural justice are partly grounded in it is supposed by numerical accuracy. By contrast, AHP method can contribute to the multiple criteria for procedural justice, which may explain AHP's continuing and growing popularity. The actual process of apply- ing the decision rule is evaluation. In order to meet a specific objective, several criteria need to be evaluated. Such a procedure is termed as AHP. The integration of special information technology and multi-criteria methods facilitate the provision of a tool with great potential for obtaining watershed boundary or selecting sites for taking action plan. AHP provides an appropriate framework for the application of multi-criteria evaluation methods, whereas multi-criteria evaluation techniques add to GIS the means of performing trade-offs on contradicting objectives, giving weight-age to both multiple criteria as well as the knowledge of the decision maker.

Keywords: AHP, Dryland, water balance, surface water, prioritization, management plan

1. Introduction

According to Thomas L. Saaty [1] "We are all fundamentally decision makers. Everything we do consciously or unconsciously is the result of some decision". By the objectives, criteria, sub-criteria, alternatives multi-level hierarchical structure are used. Pair wise comparisons pertinent data set derived from pair wise comparison [2]. These pair wise comparisons are used to obtain the weights of rank of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. The mechanism improving is required if the comparisons are not perfectly consistent.

Analytical Hierarchy Process (AHP) one of the Multi-Criteria Evaluation techniques is proposed by Saaty's-1980. The AHP is increasingly used as decision support method along with multiple parameters. AHP is welcomed for supporting procedural justice that regards clearness and equality of decisions. The numerical basis of AHP is not as unequivocal as current 'AHP standard practice' suggests. By contrast, AHP can contribute to the multiple criteria for procedural justice, which may explain AHP's continuing and growing popularity. It is increasingly used as decision support method along with multiple parameters.

Many researches had been applied in several fields, for example, in engineering[3], industry [4], economics [5], environmental management, and water manage- ment [6–10].

Recently researchers have applied AHP to decision-making concerning water resource management [9, 11] focusing on criteria relating to social, economic [12],and environmental factors [13]. Thus, multi-criteria (or multi-parameters) decision support methods are widely applied in evaluation and strategic watershed planning and management, and infrastructure development. Multiple criteria analysis techniques have been used by water resource practitioners to select or to design alternatives in areas such as river basin planning and development, water resources development, land use management, groundwater/surface water allocation,watershed restoration and water resources quality [14, 15].

More than one parameter is equally importance for management [16], as this is very much interrelated. In the present study watershed management, 6 standard methods were used and studied briefly to calculate individual parameters of the study area. Final priority has been evaluated through AHP method [1]. This is useful for water resource management, with diverse malty parameter, for prioritization questions with diverse criteria or for allocation of scarce resources. However, AHP's promises for procedural justice are partly grounded in its supposed numerical accuracy.

Insufficient of hydrologic data, the logical alternative is to use for estimate the hydrologic characteristics of a watershed by using drainage morphometric parameters. These parameters can be precisely estimated in GIS environment. Extensively used techniques for estimating direct runoff depths from storm rainfall proposed by United States Department of Agriculture (USDA) Soil Conservation Service's (SCS) Curve Number (CN) method [17]. SYI model used for quantitative assessment of soil erosion which is basic aspect of watershed management, one can predict the amount of soil loss by using some empirical formulae. Also demographic stretcher information is required for best management practices on these areas and assessment of BMP implementation effectiveness on water amiability improvement through monitoring strategies. The final priority and action plan of each micro-watershed has been taken by Analytic Hierarchy Process (AHP) [18].

2. Case study area

Dwarakeswar (also known as Dhalkishor) river originates from the Tilaboni hill near Bangalia Railway Station in Puruliya district of West Bengal state, flows easterward through pedimental landscape and enters into dissected Bankura, then enters in lateritic upland and further downstream into the Gangetic Alluvial Terrain debouching in the Rupnarayan river [19]. Beko is one of the watersheds of Dwarakeswar river in Bankura and Puruliya district. Upper Beko watershed (2A2C8) contains 7 sub-watersheds i.e. Beko, Dangra, Kansachara, Arkasa, Dudhbhariya, Darubhanga and Futuari (**Figure1**). This study was undertaken in sub-watersheds namely Dangra (**Figure 1**).

3. Dangra river

Left hand tributary of Dwarkeswar river flowing through Kasipur, Raghunathpur-I, & Santuri block of Puruliya district and Chhatna block in Bankura district. Dangra sub-watershed contain by proposed 29 micro-watersheds (**Figure 2**). The area of Dangra sub-watershed is 210.16 km^2 and elevation varies between 90 m to 250 m abovemean sea level (MSL).

The area under study constitutes part of a semi-arid region with distinct characteristics in terms of the following elements i.e. Relief, Soil, Geology, Climate, Drainage, and Slope, Land use / Land cover and Groundwater availability.

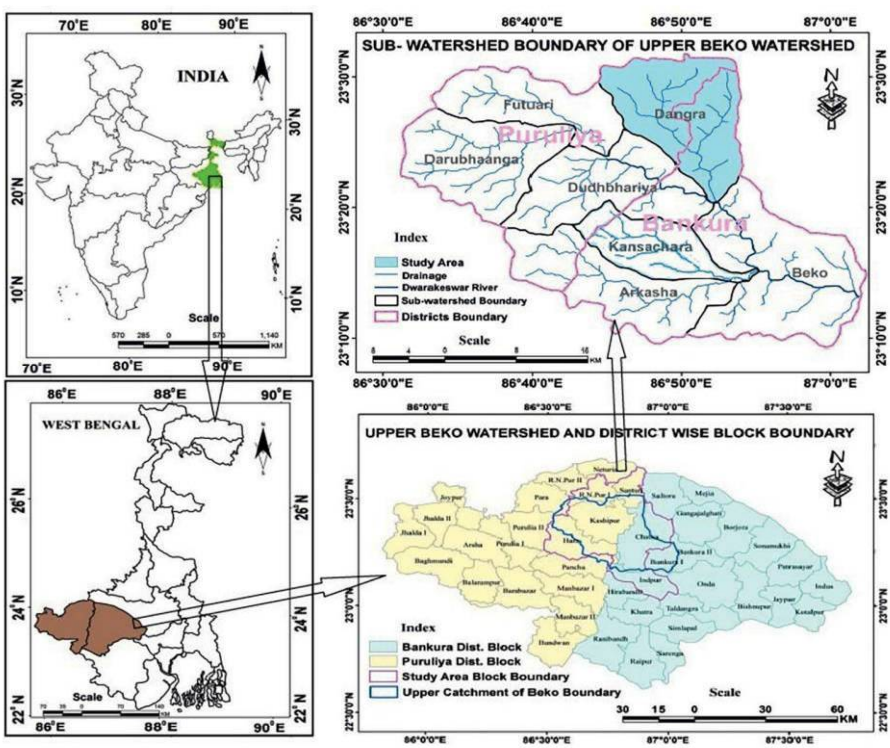

Figure 1.
Location of study area.

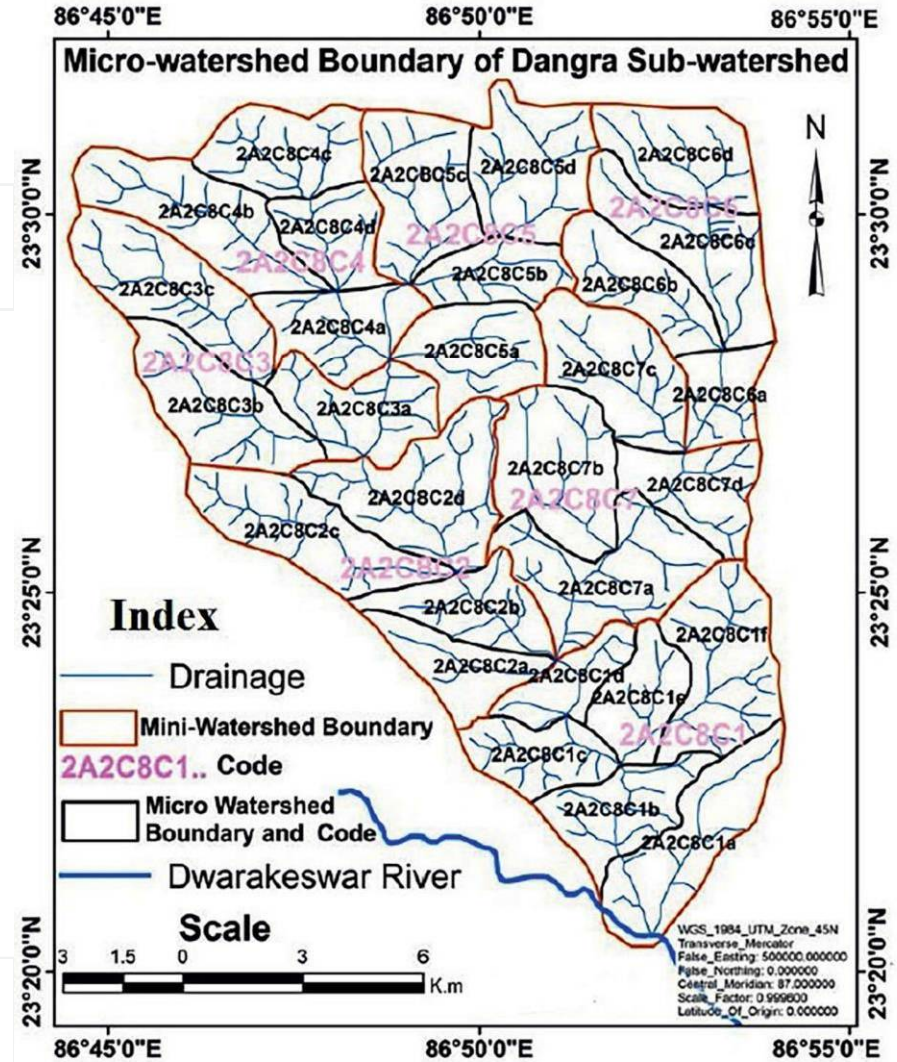

Figure 2.
Study area watershed.

4. Methodology

Watershed management is described by the different natural parameters for tacking appropriate action plan or implementation. Watershed management is a complex attribute of watershed that has a direct effect on micro watershed. Most micro watershed parameters are determined by the interaction of several characteristics and measurable natural attributes of the region [19, 20]. In this study, selected numbers of parameters have been selected for evaluation the micro watershed. Once the problem has been recognized, the set of criteria for assessment needs to be designated.

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Assigned value	Definition	Explanation
1	Parameters are of equal importance	Two parameters contribute equally to the objective
3	Parameter j is of weak importance compared to parameter i	Experience and Judgment slightly favor parameter i over j
5	Essential or strong importance of parameter i compared to j	Experience and Judgment strongly favor parameter i over j
7	Demonstrated importance	Criteria i is strongly favored over j and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring parameter i over j to the highest possible order of affirmation
2,4,6 & 8	Intermediate values between two adjacent judgment	Judgment is not precise enough to assign values of 1,3,5,7,and 9

Table 1. *Scale for pair-wise comparison.*

Since the evaluation criteria are related to geographical entities and the interlinking between them, they can be approximately represented.

The actual process of applying the decision rule is evaluation. In order to meet a specific objective several criteria need to be evaluated. Such a procedure is termed as Multi-Criteria Evaluation. The integration of special information technology and multi-criteria methods facilitate the provision of a tool with great potential for obtaining micro watershed boundary or selecting sites for taking action plan [19].

AHP provides and appropriate framework for the application of multi-criteria evaluation methods, whereas multi-criteria evaluation techniques add to GIS the means of performing trade-offs on contradicting objectives, giving weightage to both multiple criteria as well as the knowledge of the decision maker.

The multi-criteria decision analysis method is widely used for pair-wise com- parison techniques. Analytic Hierarchy Process (AHP) is developed by Saaty [1] for decision making process. The pair-wise comparison of related parameters results into the 'importance matrix' which is based on a scale of importance intensities. **Table 1** is elaborately discus about scale of importance. The importance matrix can then be analyzed by various methods-"Eigen-Vector method" or "Least Square" method, to arrive at the weightages of each parameter in the matrix. However, in the present study a ratio (reciprocal matrix) is constructed, where each factor or criteria is compared with the other criteria, relative to its importance on a scale from 1 to 9.

Weights are calculated by normalizing the eigen-vector associated with the maximum eigen-value of the matrix. This involves the following operation:

- Computation of sum of values in each column of the Pair-wise comparison matrix;
- Normalization of the matrix by dividing each element by its columan total;
- Computation of mean of the elements in each row of the normalized matrix.

Then the consistency ratio (CR) is computed to check the consistency of comparisons by using the flowing formulas:

$$CR = \frac{\text{Consistancy Index } (CI)}{\text{Random Inconsistency Index } (RI)} \quad (1)$$

$$CI = \frac{\text{ë max} - n}{n - 1} \quad (2)$$

Where.

λ max – Principal Eigen – value = sum of products between each elements of the priority vector and column total.

n = number of comparisons/criteria.

If the consistency ratio (CR) > 0.10, then some pair-wise values need to be reconsidered and the process is repeated till the desired value of CR < 0.10 is reached (**Table 2** and **Figure 3**).

Number of criteria (n)	Random Inconsistency Indices (RI)
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	**1.24**
7	1.32
8	1.41
9	1.45
10	1.49

Table 2.
Random Inconsistency Indices (RI).

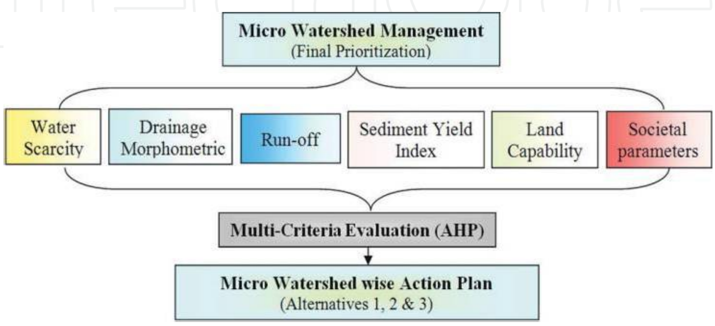

Figure 3. *Flow chart of the work.*

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5. Result and discussion

The methodology described above has been implemented for the Dangra sub-watersheds to determine the suitable of land for micro-watershed management and taking action plan [21]. The prioritization at micro watershed level for the Sub-watersheds based on the following parameters; Water scarcity, Sediment Yield Index, Land Capability, Morphometric parameters, Societal parameters, and Run-off (**Tables 3** and **4**).

Calculation of Consistency Ratio (CR):

$$\text{ë max} = (1.928\times 46.07632855) + (4.923\times 24.29530124) + (10.033\times 12.76595183) + (15.7\times 8.592603084) + (19.5\times 5.026182866) + (27\times 3.243632435) = 6.57014234 \quad (3)$$

$$CI = (6.57014234 - 6)/(6-1) = 0.114028468 \quad (4)$$

$$CR = \frac{0.114028468}{1.24}\left(6\ \text{Parameters,Value of } RI = 1.24\right) = 0.0919584\left[\text{Consistency is acceptable, } as\, CR < 0.10\right] \quad (5)$$

6. Conclusion

As per the analysis in **Table 5** of the total 29 micro-watershed in the sub-watershed eighteen micro-watersheds are fall under fast management stage twelve micro-watersheds, in second management stage seven micro-watershed and four under third management stage, whereas immediate action not required for development based on sub-watersheds (**Figure 4**).

The multi-criteria evaluations of physical parameters of the sub-watersheds indicate that the area is facing a great water resources problem. Thematic information of scarcity zone, morphometric characters, surface runoff, sediment yield, land capa- bility and socio-economy with demography were generated in the GIS environment

Factors	Scarcity	SYI	Land capability	Morphometric	Societal	Run-off
Scarcity	1	3	5	7	7	9
SYI	1/3	1	3	5	4	7
Land capability	1/5	1/3	1	2	5	3
Morphometric	1/7	1/5	1/2	1	2	5
Societal	1/7	1/4	1/5	1/2	1	2
Run-off	1/9	1/7	1/3	1/5	1/2	1
Sum	1.928	4.923	10.033	15.7	19.5	27

Table 3.
Pair-wise comparison of factors for action Plan.

Factors	Scarcity	SYI	Land capability	Morphometric	Societal	Run-off	Sum	Priority vector	% of Weight
Scarcity	0.51867	0.60930	0.4983554	0.4458598	0.3589743	0.333333	2.764579	0.4607632	46.076329
SYI	0.17271	0.20312	0.2990132	0.3184713	0.2051282	0.259259	1.457718	0.2429530	24.295301
Land capability	0.10373	0.0676	0.0996710	0.1273885	0.2564102	0.111111	0.765957	0.1276595	12.765952
Morphometric	0.07365	0.0406	0.0498355	0.0636942	0.1025641	0.185185	0.515556	0.0859260	8.5926031
Societal	0.07365	0.0507	0.0199342	0.0318471	0.0512820	0.074074	0.301570	0.0502618	5.0261829
Run-off	0.05757	0.0284	0.0331904	0.0127388	0.0256410	0.037037	0.194617	0.0324363	3.2436324

Table 4.

rmalized matrix with results.

Factors	Scarcity	SYI	Land capability	Morphometric	Societal	Run-off	Total	Action Plan
MWC								
2A2C8C1a	46.07633	24.2953	12.76595183	8.592603084	10.05237	6.487265	108.2698	1
2A2C8C1b	46.07633	48.5906	12.76595183	8.592603084	10.05237	3.243632	129.3215	1
2A2C8C1c	138.229	48.5906	12.76595183	8.592603084	10.05237	3.243632	221.4741	2
2A2C8C1d	46.07633	48.5906	12.76595183	17.18520617	15.07855	3.243632	142.9403	1
2A2C8C1e	46.07633	48.5906	12.76595183	25.77780925	10.05237	6.487265	149.7503	1
2A2C8C1f	46.07633	24.2953	12.76595183	25.77780925	10.05237	3.243632	122.2114	1
2A2C8C2a	138.229	48.5906	12.76595183	17.18520617	10.05237	6.487265	233.3104	3
2A2C8C2b	92.15266	24.2953	12.76595183	17.18520617	10.05237	6.487265	162.9387	1
2A2C8C2c	138.229	48.5906	12.76595183	8.592603084	10.05237	9.730897	227.9614	3
2A2C8C2d	92.15266	24.2953	12.76595183	8.592603084	10.05237	3.243632	151.1025	1
2A2C8C3a	92.15266	24.2953	25.53190366	17.18520617	10.05237	3.243632	172.4611	2
2A2C8C3b	138.229	24.2953	12.76595183	25.77780925	10.05237	6.487265	217.6077	2
2A2C8C3c	92.15266	24.2953	25.53190366	25.77780925	10.05237	9.730897	187.5409	2
2A2C8C4a	92.15266	24.2953	25.53190366	17.18520617	5.026183	9.730897	173.9221	2
2A2C8C4b	92.15266	72.8859	25.53190366	17.18520617	10.05237	9.730897	227.5389	3
2A2C8C4c	46.07633	24.2953	38.29785549	17.18520617	5.026183	9.730897	140.6118	1
2A2C8C4d	46.07633	24.2953	25.53190366	17.18520617	10.05237	9.730897	132.872	1
2A2C8C5a	46.07633	24.2953	12.76595183	25.77780925	15.07855	6.487265	130.4812	1
2A2C8C5b	46.07633	48.5906	25.53190366	17.18520617	10.05237	9.730897	157.1673	1
2A2C8C5c	46.07633	24.2953	38.29785549	25.77780925	5.026183	9.730897	149.2044	1
2A2C8C5d	46.07633	24.2953	38.29785549	25.77780925	5.026183	9.730897	149.2044	1
2A2C8C6a	46.07633	72.8859	12.76595183	17.18520617	10.05237	9.730897	168.6967	2

Factors	Scarcity	SYI	Land capability	Morphometric	Societal	Run-off	Total	Action Plan
MWC								
2A2C8C6b	138.229	72.8859	25.53190366	17.18520617	10.05237	9.730897	273.6153	3
2A2C8C6c	138.229	24.2953	25.53190366	8.592603084	5.026183	9.730897	211.4059	2
2A2C8C6d	46.07633	48.5906	38.29785549	8.592603084	5.026183	9.730897	156.3145	1
2A2C8C7a	46.07633	24.2953	12.76595183	25.77780925	10.05237	3.243632	122.2114	1
2A2C8C7b	46.07633	24.2953	12.76595183	17.18520617	10.05237	3.243632	113.6188	1
2A2C8C7c	46.07633	48.5906	12.76595183	17.18520617	5.026183	6.487265	136.1315	1
2A2C8C7d	46.07633	48.5906	12.76595183	17.18520617	10.05237	6.487265	141.1577	1

ble 5.

HP based Sub-Watershed Final Prioritization.

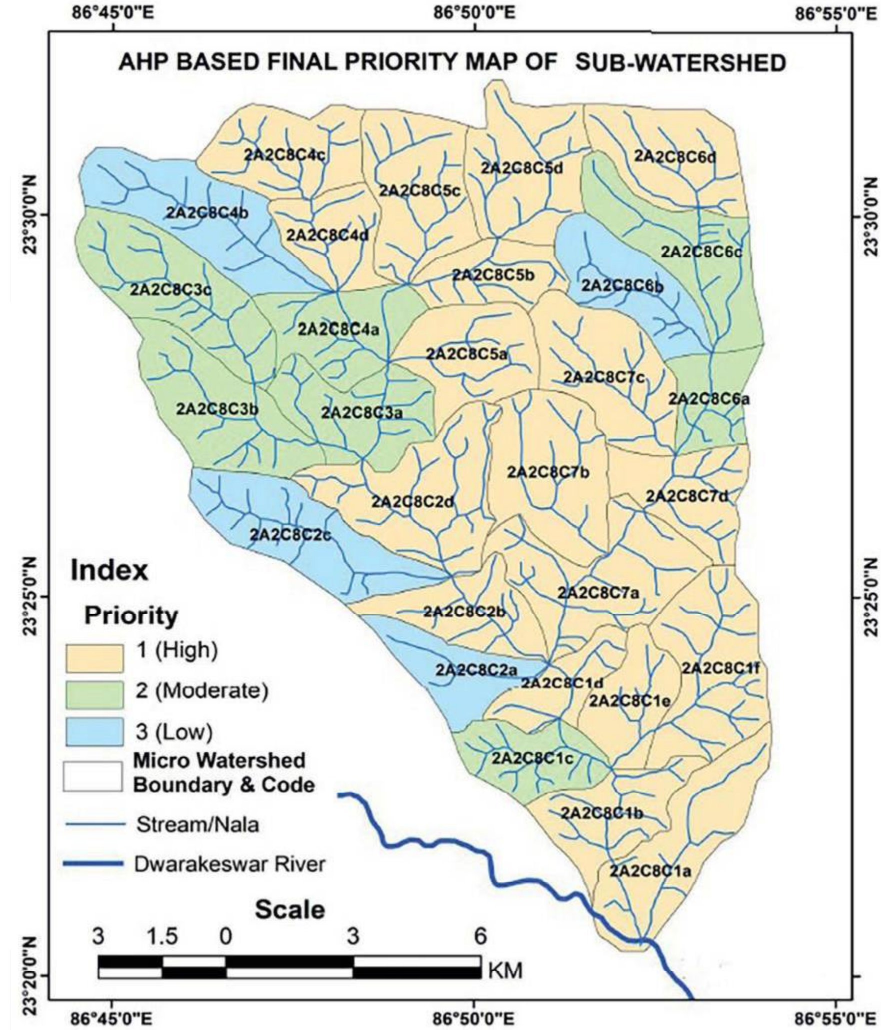

Figure 4. *AHP based final priority.*

using remote sensing data and field data. Therefore, all final prioritized value is assigned weightage to obtain normalized weightage by using analytical hierarchy process. Then all the parameters are integrated in the GIS environment to decide the soil conservation measures at the appropriate site in the watershed.

AHP provides an appropriate framework for the application of multi-criteria evaluation methods, whereas multi-criteria evaluation techniques add to GIS the means of performing trade-offs on contradicting objectives, giving weight-age to both multiple criteria as well as the knowledge of the decision maker. On the whole, this study demonstrated that the remote sensing, GIS and AHP techniques offer a useful integrated tool for the deciding micro watershed management plan with societal perspective towards development and planning.

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