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Identification of Potential Sites for Urban Development Using GIS Based Multi Criteria Evaluation Technique. A Case Study of Shimla Municipal Area, Shimla District, Himachal Pradesh, India

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A B S T R A C T

Identification of potential sites for urban development in hilly areas is one of the critical issues of planning. Site suitability analysis has become unavoidable for finding appropriate site for various developmental initiatives, especially in the undulating terrain of the hills. The study illustrates the use of geographic information system (GIS) and numerical multi criteria evaluation (MCE) technique for selection of suitable sites for urban development in Shimla Municipal Area, Shimla district, Himachal Pradesh. For this purpose Cartosat 1 satellite data were used to generate various thematic layers using ArcGIS software. Five criteria, i.e. slope, road proximity, land use/cover, lithology and aspect were used for land evaluation. The generated thematic maps of these criteria were standardized using pairwise comparison matrix known as analytical hierarchy process (AHP). A weight for each criterion was generated by comparing them with each other according to their importance. With the help of these weights and criteria, final site suitability map was prepared.

1. INTRODUCTION

The identification of suitable land for urban development is one of the critical issues of planning [1]. The suitability of the land for urban development is not only based on a set of physical parameters but also very much on the economic factors. The cumulative effect of these factors determine the degree of suitability and also helps in further categorizing of the land into different orders of development. The assessment of the physical parameters of the land is possible by analyzing the land use, terrain parameters, geology, physiography, and distance from road, distance from the existing development etc. and which is much amenable to GIS analysis. Against this, the economic pressures on urban land are very much difficult to be specified and used for analysis. However, the assessment of physical parameters gives an identification of the limitations of the land for urban development. The concept of limitation is derived from the quality of land. For example, if the slope is high the limitation it offers is more than a land which has gentle slopes or a flat terrain. Practically, this would mean that the development of the high slope land would require considerable inputs (finance, manpower, materials, time etc.) and thus may be less suitable as against the flat land where the inputs required are considerably less. The constraints with respect to the terrain characteristics (landform) and their urban suitability are to be assessed.

One of the successful and most widely used approaches which greatly reduces the time as well as effort is pairwise comparison method developed by Thomas

Saaty [2] in the context of the AHP and is one of the methods of multi criteria decision analysis (MCDA) [3]. In general, pairwise comparison is made to choose the most suitable from a given number of alternatives. However this process involves error and limitations. It is so because the capacity of the human brain does not allow evaluating each and every given alternative as a result selection being narrowed down to a fewer ones. Though this reduces the load on our brain and makes the process extremely simple, the rationality of the process based upon intuitive selection may produce unwanted results choosing a wrong alternative and overlooking the best solution. Therefore to sort out these types of errors, the idea of AHP's pairwise comparison was introduced, which involves pairwise comparison from the very initial stage when all the available alternatives are there. That is, pairwise comparison to all available alternatives and not limiting the domain of decision making process to a selected once. That is why pairwise comparison using AHP is more rational, more scientific and considerably more advantageous [4].

Land suitability analysis is similar to choosing an appropriate location, except that the goal is not to isolate the best alternatives, but to map a suitability index for the entire study area. Senes and Toccolini combine UET (Ultimate Environmental Threshold) method with map overlays to evaluate land suitability for development [5]. Hall *et al.* and Wang also use map overlays to define homogeneous zones, but then they apply classification techniques to assess the agricultural land suitability level of each zone [6] [7]. These classification techniques can be based on Boolean and fuzzy theory or artificial neural networks. Combining GIS and MCDA is also a powerful approach to land suitability assessments. GIS enables computation of the criteria while a MCDA can be used to group them into a suitability index. Following a similar approach, Eastman *et al.* produced a land suitability map for an industry near Kathmandu using IDRISI and AHP [8] [9]. Pereira and Duckstein have used MCDA and raster GIS to evaluate a habitat for endangered species [10].

This study aims to present how powerful the GIS based multi criteria evaluation technique in land suitability analysis for urban development in hilly areas is. This process involves a consideration of five factors, i.e., slope, road proximity, land use/cover, lithology and aspect. With the support of geographic information systems (GIS), and numerical multicriteria evaluation techniques, these five factors were selected to be used in the analysis of the suitability level in Shimla Municipal area, Shimla District, Himachal Pradesh.

2. STUDY AREA

The study area (fig. 1), viz. the Shimla Municipal Corporation, is one of the oldest municipalities of India which extends between 31°04'01" N to 31°08' 19" N latitude and 77°06' 56" E to 77°13' 50" E longitude, encompasses an area of 27.58 km². Its average altitudinal height is 2012.30 meters above mean sea level. Shimla lies in the north-western ranges of the Himalayas. The average temperature during summer is between 19°C (66 °F) and 28°C (82 °F), and between −1°C (30 °F) and 10°C (50 °F) in winter. It enjoys the cool temperate climatic conditions. As a large and growing city, Shimla is home to many well-recognized colleges and research institutions in India. The city has a large number of temples and palaces. Shimla is also well noted for its buildings styled in Tudorbethan and neo-Gothic architecture dating from the colonial era.

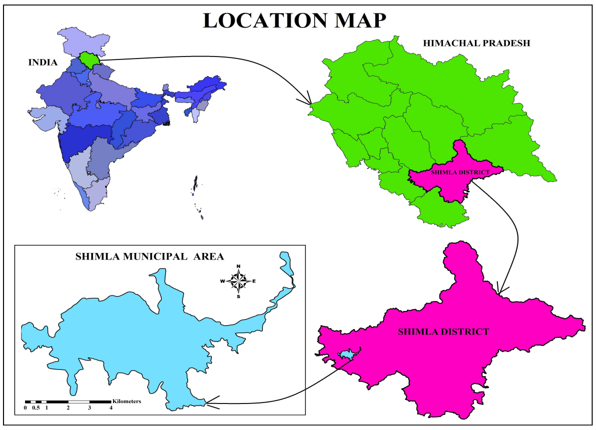

Fig. 1. Location map of study area.

3. METHODOLOGY

3.1. Data collection and integration

In order to develop site suitability map for urban development Cartosat-1 panchromatic stereoscopic satellite data at a resolution of 2.5 m were used. With the help of stereoscopic satellite data a Digital Terrain Model (DTM) was created which was further used for preparing slope and aspect map. A high resolution Cartosat-1 Satellite data was also used for generating land use/cover and road proximity map. A lithology map was obtained through Geological Survey of India, Dehradun. All these information layers were integrated and analysed under ArcGIS environment.

3.2. Selection and preparation of criteria maps

In this study five criteria were selected. The principal criteria that are used for spatial analysis are slope, road proximity, land use/cover, lithology and aspect. These criteria were used in the preparation of criteria maps.

3.3. Suitability scoring/ranking and development of pairwise comparison matrix

For suitability analysis it is necessary to give some score to each of the criteria as per their suitability for urban development. For this purpose the pairwise comparison matrix using Saaty's nine-point weighing scale was applied (table 1). To develop a pairwise comparison matrix different criteria are required to create a ratio matrix. These pairwise comparisons are taken as input and relative weights are produced as an output.

Table 1. Nine point weighting scale for pairwise comparison [11].

Intensity of importance	Description	Suitability class
1	Equal importance	Lowest suitability
2	Equal to moderate importance	Very low suitability
3	Moderate importance	Low suitability
4	Moderate to strong importance	Moderately low suitability
5	Strong importance	Moderate suitability
6	Strong to very strong importance	Moderate high suitability
7	Very strong importance	High suitability
8	Very to extremely strong importance	Very high suitability
9	Extremely importance	Highest suitability

3.4. Computation of the criterion weights

After the formation of pairwise comparison matrix, computation of the criterion weights has been done. The computation involves the following operations:

a). Finding the sum of the values in each column of the pairwise comparison matrix.

b). Division of each element in the matrix by its column total (the resulting matrix is referred to as normalized pairwise comparison matrix).

c). Computation of average of elements in each row of the normalized matrix, i.e. dividing the sum of normalized scores of each row by the number of criteria. These averages provide an estimate of the relative weights of the criteria being compared.

It should be noted that for preventing bias thought criteria weighting the consistency ratio (CR) was used.

3.5. Estimation of the consistency ratio

The next step is to calculate a consistency ratio (CR) to measure how consistent the judgments have been relative to large samples of purely random judgments. The AHP deals with consistency explicitly because in making paired comparisons, just as in thinking, people do not have the intrinsic logical ability to always be consistent [13]. For estimating consistency, it involves the following operations:

a). Determination of the weighted sum vector by multiplying matrix of comparisons on the right by the vector of priorities to get a new column vector. Then divide first component of new column vector by the first component of priorities vector, the second component of new column vector by the second component of priorities vector, and so on. Finally, sum these values over the rows.

b). Determination of consistency vector by dividing the weighted sum vector by the criterion weights.

Once the consistency vector is calculated it is required to compute values for two more terms, i.e. lambda (λ) and the consistency index (CI).

The value for lambda is simply the average value of the consistency vector. The calculation of CI is based on the observation that λ is always greater than or equal to the number of criteria under consideration (n) for positive, reciprocal matrices and λ = n, if the pairwise comparison matrix is consistent matrix. Accordingly, λ-n can be considered as a measure of the degree of inconsistency.

This measure can be normalized as follows:

$$CI = (\lambda - n) / (n - 1)$$

The term CI, referred to as consistency index, provides a measure of departure from consistency. To determine the goodness of C.I., the analytical hierarchy process compares it by random index (R.I.) and the result is what we call consistency ratio (C.R.), which can be defined as:

$$CR = CI/RI$$

Random index is the consistency index of a randomly generated pairwise comparison matrix of order 1 to 10 obtained by approximating random indices using a sample size of 500 [12]. Table 2 shows the value of R.I. sorted by the order of matrix.

The consistency ratio (CR) is designed in such a way that if CR < 0.10, the ratio indicates a reasonable level of consistency in the pairwise comparisons; if, however, CR > 0.10, then the values of the ratio are indicative of inconsistent judgments. In such cases one should reconsider and revise the original values in the pairwise comparison matrix.

3.6. Rasterization of criteria maps

Different criteria maps were converted into raster data environment for further analysis because in raster data format computation is less complicated than vector data format [14].

Table 2. Random index.

Order Matrix	R.I.	Order Matrix	R.I.
1	0.0	6	1.24
2	0.0	7	1.32
3	0.58	8	1.41
4	0.9	9	1.45
5	0.12	10	1.49

3.7. Integration of maps and preparation of final suitability map

After rasterization, these classified raster maps were integrated in raster calculator of ArcGIS and multiplied by weightage, and then the final suitability map was prepared.

4. RESULTS AND DISCUSSIONS

4.1. Site suitability analysis

The effective criteria in site suitability analysis for urban development are briefly given below along with their individual importance.

Slope: Slope is an important criterion in hilly terrain for finding suitable sites for urban development. Steep slopes are disadvantageous for construction. Steeper slopes increase construction costs, limit maximum floor areas and contribute to erosion during construction and subsequent use.

Slope < 10 degree is considered gentle slope having the highest intensity of importance [15]. Slope greater than 10 degree has been classified as unsuitable because it increases the construction cost (figure 2 (a) and table 3).

Table 3. Suitability scoring/ranking.

Intensity of importance	Slope (Degree)	Lithology	Road proximity (mts.)	Land use/cover	Aspect
9 (Highest)	0-10	…	0-50	Barren land	South
8 (Very high)	…	Shimla formation	50-100	…	South-West
7 (High)	…	…	100-150	…	South-East
6 (Moderate high)	10-20	…	150-200	…	West
5 (Moderate)	20-30	…	200-250	…	East
4 (Moderate low)	30-40	…	250-300	…	North-West
3 (Low)	40-50	…	300-350	…	North-East
2 (Very low)	50-60	…	350-400	Agriculture land	North
1 (Lowest)	>60	…	>400	Vegetation	…

Road Proximity: Road is also an important criterion in site suitability because of the need to transport raw products and finished materials. Construction of new road is expensive in hilly regions. Therefore, effort is made to locate the site nearer to any existing road if possible. Moreover, in order to find out better accessibility to the existing road, buffer zones have been created by taking 50 meter distance from the road. Table 3 and figure 2 (b) show the buffer zones and their intensity of importance for road proximity criteria.

Land use/cover: Land use/cover map of Shimla Municipal area has been categorized as follows: built-up, barren, agricultural and vegetation. In this study, built up area is not suitable for the future development because once a building is constructed, it remains there for minimum of 50-75 years. Thus barren land is considered highest suitable for the development (figure 2 (c) and table 3).

Lithology: Shimla town is situated on the rocks of Jutogh Group and Shimla Group. Jutogh group occupies most of the Shimla area and extends from Annadale-Chura Bazaar-Prospect Hill-Jakhoo-US Club and highland area. Shimla Group comprising of earlier Chail Formation and Shimla Series represented by shale, slate, quartzite greywacke and local conglomerate is well exposed in Sanjauli-Dhalli area. Therefore, the rocks mainly found in the study area are metamorphic rocks which are harder and relatively more resistant to erosion [16]. Thus, a highest intensity of importance has been given to Jutogh Group and Shimla Group rocks (figure 2 (d) and table 3).

Aspect: Aspect generally refers to the horizontal direction to which a mountain slope faces. In the northern hemisphere north facing slopes receive very little heat from the sun in mid winter. Conversely, south facing slopes receive much more heat. Therefore, south facing slopes tend to be warmer than the northern ones. In hilly areas people prefer building their houses on the sunny faced slopes. Thus, southern facing slopes have higher intensity of importance. East facing slopes catch sun only in the morning when temperatures are colder while west facing slopes catch the sun in the warm afternoon. Consequently, east facing slopes are colder than west facing slopes (figure 2 (e) and table 3).

4.2. Scoring/ranking of criteria

The suitability scoring used in this study for each of the criteria map and their category at 9 point weighting scale are given in table 3.

4.3. Calculation of the consistency ratio

It is required to check whether our comparisons are consistent. Table 5 shows the determination of weighted sum vector and consistency vector.

Calculation of lambda (λ) = (5.44+5.11+5.42+ 5.14+4.50/5) = 5.132

Note: Lambda (λ) is the average of consistency vector.

Condition 1: λ should be equal or greater than the number of criteria under consideration. The value calculated above satisfies this condition.

Calculation of consistency index (CI)

CI = (λ – n)/ (n-1)

= (5.132-5)/ (5-1)

= 0.033

Calculation of consistency ratio (CR), CR = CI/RI = 0.033/1.12 (Since RI= 1.12 for n = 5) = 0.029

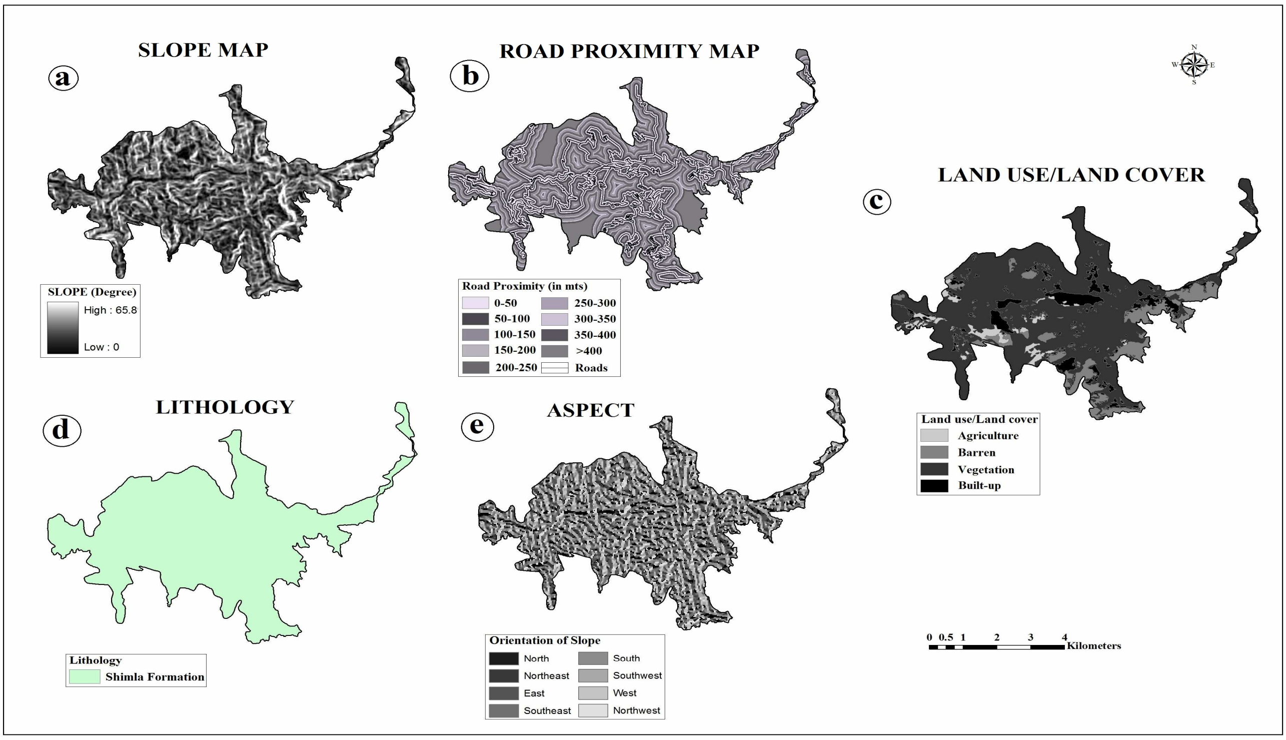

Fig. 2. (a) slope (b) road proximity (c) land use/cover (d) lithology (e) aspect.

Table 4. Pairwise comparison matrix, normalized pairwise comparison matrix and computation of criterion weights.

Criteria	Pairwise comparison matrix					Normalized pairwise comparison matrix					Computation of criterion weights (a+b+c+d+e)/5
	Slope (a)	Road proximity (b)	Land use/cover (c)	Lithology (d)	Aspect (e)	(a)	(b)	(c)	(d)	(e)	
Slope	1	3	4	8	9	0.55	0.64	0.47	0.49	0.36	0.50
Road proximity	0.33	1	3	4	8	0.18	0.21	0.35	0.24	0.32	0.26
Land use/cover	0.25	0.33	1	3	4	0.14	0.07	0.12	0.18	0.16	0.13
Lithology	0.12	0.25	0.33	1	3	0.07	0.05	0.04	0.06	0.12	0.07
Aspect	0.11	0.12	0.25	0.33	1	0.06	0.03	0.03	0.02	0.04	0.04
Total	1.815	4.705	8.58	16.33	25	1.00	1.00	1.00	1.00	1.00	1.00

Table 5. Computation of consistency vector.

Criterion	Weighted sum vector	Consistency vector
Slope	[(1)(0.50)+(3)(0.26)+(4)(0.13)+(8)(0.07)+(9)(0.04)]=2.72	2.72/.50=5.44
Road proximity	[(0.33)(0.50)+(1)(0.26)+(3)(0.13)+(4)(0.07)+(8)(0.04)]=1.415	1.415/0.26=5.11
Land use/cover	[(0.25)(0.50)+(0.33)(0.26)+(1)(0.13)+(3)(0.07)+(4)(0.04)]=0.71	0.71/.13=5.46
Lithology	[(0.12)(0.5)+(0.25)(0.26)+(0.33)(0.13)+(1)(0.07)+(3)(0.04)]=0.36	0.36/.07=5.14
Aspect	[(0.11)(0.50)+(0.12)(0.26)+(0.25)(0.13)+(0.33)(0.07)+(1)(0.04)]=0.18	0.18/.04=4.50

Condition 2: Consistency ratio CR (=0.029) <0.10 indicated a reasonable level of consistency in the pairwise comparisons. Therefore, the values obtained satisfy the noted conditions, which denote that the weights obtained are agreeable.

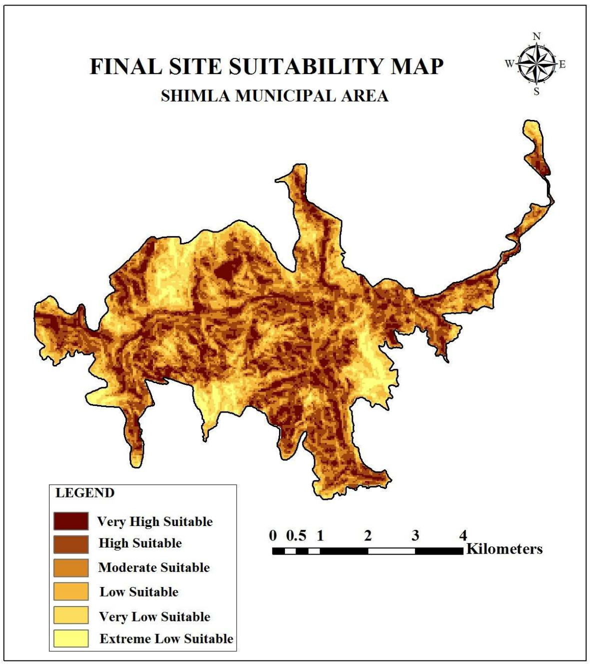

Fig. 3. Final site suitability map.

4.4. Preparation of land suitability map

All five criteria maps were converted into raster format, so that for each pixel, a score can be determined [17]. All the criteria maps were integrated and overlaid and the final site suitability map (figure 3) was prepared by the following formula:

Suitability map= Σ [criteria map * weight]

Suitability index = ([Slope] * 0.50) + ([Road proximity] * 0.26) + ([Land use/cover] * 0.13) + ([Lithology] * 0.07) + ([Aspect] * 0.04).

The final site suitability map (figure 3) reveals that the study area was divided into six different suitability categories. The area under extreme low, very low, low, moderate, high and very high lands stand at 4.95 km^2, 2.8 km^2, 1.18 km^2, 7.23 km^2, 3.74 km^2 and 7.68 km^2 (table 6).

Table 6. Area under different suitability categories.

Suitability categories	Area in km^2	Area in %
Extreme low suitable	4.95	17.94
Very low suitable	2.8	10.15
Low suitable	1.18	4.27
Moderately suitable	7.23	26.21
High suitable	3.74	13.59
Very high suitable	7.68	27.84

Approximately 32.36% of the total area falls under the categories of low, very low and extremely low suitable areas. Only 41.43% of land falls under high and very high suitable categories.

5. CONCLUSION

Considering limited suitable land in the hilly areas and drastic growth in the tertiary and quaternary sectors, the availability of suitable land for developmental work is going down. Land suitability analysis for urban development is essential to overcome this problem. The GIS based multi criteria evaluation technique is very simple and flexible which can be used to analyse the potential sites for urban development in hilly areas. This model can also encourage public participation in the urban decision making process and assist various planners and authorities to formulate suitable plan for sustained development of the region.

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