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Case Study **Open Access**

Site Suitability Analysis for Urban Development of a Hill Town Using GIS Based Multicriteria Evaluation Technique: A Case Study of Nahan Town, Himachal Pradesh, India

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Abstract The study illustrates the use of Geographic Information System (GIS) tools and numerical Multi-Criteria Evaluation (MCE) techniques for selection of suitable sites for urban development of a hill town. This study was conducted to identify suitable sites for urban development of a hill town, Nahan using GIS-based multi-criteria evaluation of slope, road proximity, land use, land values, soil and geomorphology factors. Merged spatial data (Cartosat-1 & LISS-IV) and six thematic information layers were analyzed using ArcGIS 9.3 software to identify suitable areas in Nahan town. It focuses on GIS based Overlay Weight age Average (OWA) Sum and Weighted Linear Combination (WLC). The undulating terrain, steep slope, varied soil depth and high building cost give the impression to find out suitable sites for urban development in the Nahan Town. In this study six factors (slope, road proximity, land use, land values, soil and geomorphology) were identified for criteria evaluation. Different thematic information layers were generated using visual interpretation of satellite data for each variable displaying site suitability measured on an ordinal scale. With the generated criteria, maps were standardized using the pair wise comparison matrix method. Weights for each criterion are generated by comparing with each other according to their importance. Criteria weights and maps were combined using OWA and WLC. Pair wise comparison matrix indicates weights for slope (=0.41), road proximity (=0.26), landuse (=0.15), land values (=0.09), soil (=0.06) and geomorphology (=0.03). Consistency Ratio, (CR =0.0117) <0.10 indicated a reasonable level of consistency in the pair wise comparisons. The final suitability map was obtained from both weighted sum overlay and Spatial Analyst Tools covering an area of 3.6 sq. km. After suitability analysis it was found that from the available area 0.1157 sq km falls under very low suitable, 1.6835 sq km under low suitable, 1.2090 sq. km under moderately suitable, 0.3663 sq. km under high suitable and 0.1248 sq. km under very high suitable. The result shows that highly suitable areas for urban development is either agricultural or forest type.

Keywords *Geographic Information System (GIS); Multi-criteria Evaluation (MCE); Overlay Weightage Average (OWA); Weighted Linear Combination (WLC); Analytic Hierarchy Process (AHP); Urban Development; Spatial Analysis*

1. Introduction

Identification of suitable sites for urban development in hilly areas is one of the critical issues for planning. To cater the needs of appropriate site in undulating areas, site suitability analysis has become inevitable. Site suitability is the method of understanding existing site qualities and factors that will determine the location for a particular activity. It involves the detailed investigation of the natural resources and processes that characterize a site and include mapping techniques including GIS tools that help in processing the geographical database that display the areas of the site, suitable for various planning objectives and alternatives. Terrain information is used as a major factor used to evaluate the suitability of a hill town for urban development. The topographic characteristics of an area are one of the most important determinants to ascertain the suitability of an area for developmental activities. Severe limitations to subdivision development occur on slopes over 20 percent. For industrial parks and commercial sites, slopes of not more than 5 percent are preferred. Also, hilly terrain increases the building costs, so steep slopes are unfavorable. The soil texture and drainage conditions also affect site suitability. Well-drained, coarse-textured soils present few limitations to development. Poorly drained or very poorly drained, fine-textured soils can present severe limitations. In general, depths to the water table of at least 2 m are preferred. Depths of 1 to 2 m may be satisfactory where public sewage disposal is provided and buildings are constructed without basements (Lillesand M. Thomas, Kiefer W. Ralph, and Chipman W. Jonathan). The number of input factors required in a particular study depends on purpose, location and circumstances surrounding the area under analysis. The various characteristics of a site (e.g. present land use, slope, road proximity, land values, soil, and geomorphology) each influence its suitability for a specific purpose. A scoring and weighting system can be applied to the various aspects of suitability to assess the overall suitability for a specific urban use. Certain characteristics may lead to non-availability of a site for a specific urban land use. A site suitability analysis adds importance to study by helping to identify suitable sites that meet specific criteria. The results of these analyses can greatly reduce the time and effort, which might otherwise be spent manually searching records, processing data or field surveying. Site location is a key factor and initial step in the design of many projects. Acquiring new site for urban development is increasingly more challenging particularly in an increasing real estate market and can be the result of growth of urban areas, and increased environmental standards or regulations. The results of the site suitability analysis produce a detailed display of the most-suitable to least-suitable areas for consideration of placement of a certain facility, while filtering out unusable or less desirable sites. Certain aspects are more important than others in determining the best location for each site, and might include an areas proximity to existing infrastructure, soil types, slope, land values, geomorphology and land use. These site suitability analyses require unlike measurements to be converted to common values that can be summed and compared to ease the final site selection process.

2. Study Area

Nahan town is situated on the Shiwalik ridge of Himalayan region in Himachal Pradesh of India functioning as districts headquarter of Sirmour District overlooking emerald fields. It is located at 30^{0}33'0" N latitude and 77^{0}17'59" E longitudes with an altitude of 932 meters. Its elevation provides good base for making visits to the nearby pilgrim centres including Renuka, Paonta Sahib, Trilokpur temple and the Suketi Fossil Park. The city was founded as a capital in 1621 by Raja Karan Prakash. Nahan is much acclaimed for its clean and spotless streets. A legend says about a saint who lived with Nahar on the site where the Nahan palace now stands. Nahar means a lion and perhaps the city got its name from this saint. The climate of Nahan is pleasant throughout the year. This area of Himachal comprises mainly of lower Shiwaliks of dense forests, lake and rivers. It has an old Municipal Committee, which is the second oldest municipal committee in the country and oldest in Northern India. Revival of Nahan foundry is the oldest foundry of Northern India. The town is watered by man-made lake and decorated with temples and gardens. The town has a bazaar with narrow cobbled streets, which provides all kinds of things. Three gently level walks; Villa Round, Military Round and

Hospital Round are evocative of the city's past. The hub of Nahan's activities is Chaugan, Bikram Bagh and Khadar Ka-Bagh. Gift shops, Rosin & Turpentine factory and local temples are among the other major attractions.

Location of the Study Area in India

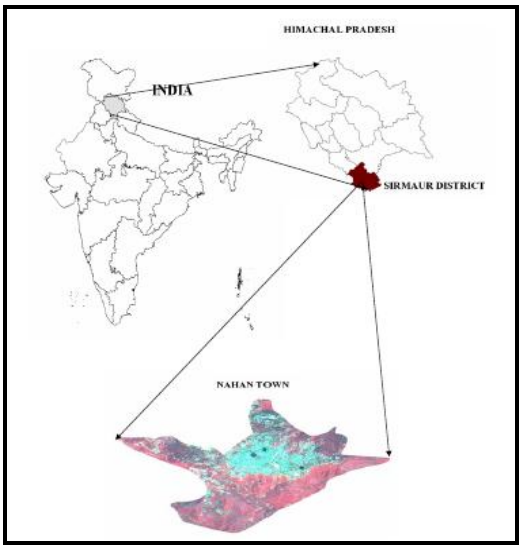

Figure 1: *Location of the Study Area*

3. Materials and Methods

The present study attempts to introduce decision support system used for site suitability analysis. Geographic Information System (GIS) and numerical based methodology has been applied to select suitable sites for urban development. For this purpose, various thematic (information) layers such as slope, road proximity, land use/land cover (LU/LC) (Figure 3), land values, soil and geomorphology maps have been generated in ArcGIS 9.3. Internal weights were assigned to each layer with values ranging from 0 to 8 under attribute field weight. Each vector layers were rasterized by taking weight as a feature class. Water bodies, forest, residential, recreational, commercial and industrial were assigned zero weights. Higher weight was given to vacant/ open lands with slopes less than 15 percent and riparian buffer factors for roads are considered. Using these thematic layers as factors, criteria map was generated by applying Spatial Analytic Hierarchy Process (AHP). In this study different scenarios were produced by giving different preference values to decision factors. The optimization of simulated scenarios developed in this study is applied to choose the best suited alternative based on six conflicting criteria. According to evaluation, scenario was defined from least to the most suitable urban development site. Spatial Analytic Hierarchy Process (AHP) is a type of decision support system that combines GIS and AHP to identify and rank areas that are suitable for urban development, through utilization of knowledge-based user preferences. The method is illustrated through a case study for site suitability of a hill town for its urban development using GIS based multi-criteria evaluation technique. The results generated are reviewed in order to derive conclusions with respect to Urban Development Plan that how well they exactly fit into it.

4. Site Suitability

High resolution Quick bird Images (0.61m) available on Google Earth was used for image interpretation and field check and merged data (Cartosat-1+LISS-IV) was used for land use classification. Spatial database of various thematic information of the study area was generated by using GIS Software (Arc GIS 9.3). The features like road network, residential, commercial, public and semi-public, agricultural and forest, recreational and green spaces etc. were derived from satellite images. Spatial Analyst tool available with ArcGIS was used for slope map generation from the DEM (10m) obtained from Cartosat-1(Stereo-pair) data. In this case study of Nahan Town, formation of main factors uses the Saaty's normal AHP technique. The assumption is that the weightings derived from hierarchical comparison in normal AHP would be influenced by the preferences given to a particular criterion factor. Therefore a sensitivity test was carried out on the criterion preferences. It was evaluated based on six preference factors thought to influence weightings. The preferences given to the factors are: (1) slope; (2) road proximity; (3) land use; (4) land values; (5) soil; and (6) geomorphology. Six separate hierarchical pair wise comparisons (Table 1) of main criterion factors were made for each preference to analyze the sensitivity of the weights obtained. The pair wise comparisons of criteria factors were carried out independently and given same judgments for all the preferences. To reflect the preferences towards a certain factor, a definite to very strong preferences was given to that factor in their pair wise comparison (Table 2). The next stage in the analysis is that the consistency must be checked to verify the reliability of the judgment of the decision maker. In this study the CR= 0.0117, and depend on Saaty, if CR ≤ 0.10 the ratio indicates a reasonable level of consistency in the pair wise comparisons (Malczewski, 1999).

This study performs a GIS Spatial analysis in which models are represented as a set of spatial processes, such as buffer, classification, and reclassification and overlay techniques. Each of the input themes is assigned a weight influence based on its importance, then the result is successively multiplied with their factors. This process is often used in site suitability studies where several factors affect the suitability of a site (ESRI, 2000). The result is summed up producing a site suitability map as shown by the formula;

$$\textbf{Site Suitability} = \sum [\textbf{factor map } (C_n) \textbf{ x weight } (W_n)]$$

Where, Cn=standardized raster cell,
Wn=weight derived from AHP pair wise comparisons

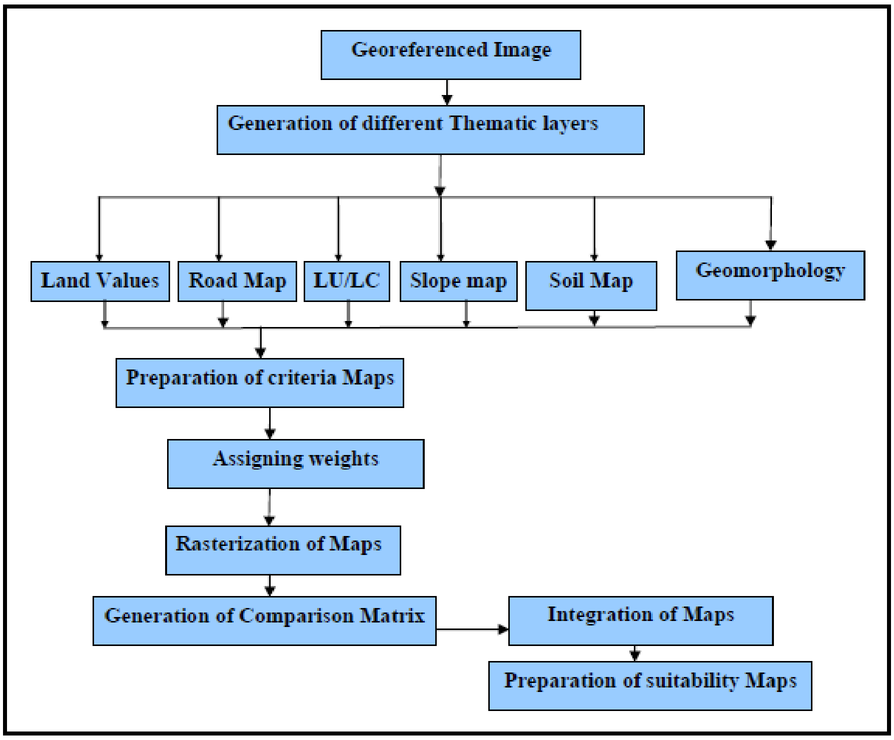

Figure 2: *Flow Chart for Site Suitability Analysis*

4.1. Pairwise Comparison Matrix

Table 1: *Showing Pairwise Comparison Matrix*

	Slope	Road Proximity	Land use	Land values	Soil	Geomorphology	Weight	Lambda Consistency Vector
Slope	1.00	2.00	3.00	5.00	7.00	9.00	0.41	6.15
Road Proximity	0.50	1.00	2.00	3.00	5.00	7.00	0.26	5.96
Land use	0.33	0.50	1.00	2.00	3.00	5.00	0.19	6.20
Land values	0.20	0.33	0.50	1.00	2.00	3.00	0.09	6.03
Soil	0.14	0.20	0.33	0.50	1.00	2.00	0.06	5.40
Geomorphology	0.11	0.14	0.20	0.33	0.33	1.00	0.03	6.70
Sum	2.29	4.17	7.03	11.83	18.50	27.00	1.00	36.44

4.2. Normalized Pairwise Comparison Matrix

Table 2: *Showing Normalized Matrix for Pairwise Comparison*

	Slope	Road Proximity	Land Use	Land Values	Soil	Geomorphology	Weight	Priority Vector
Slope	0.44	0.48	0.43	0.42	0.38	0.33	0.41	0.17
Road Proximity	0.22	0.24	0.28	0.25	0.27	0.26	0.26	0.16
Land use	0.14	0.12	0.14	0.17	0.16	0.19	0.19	0.17
Land values	0.09	0.08	0.07	0.08	0.11	0.09	0.09	0.17
Soil	0.06	0.05	0.05	0.04	0.05	0.07	0.06	0.15
Geomorphology	0.05	0.03	0.03	0.03	0.03	0.04	0.03	0.18
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

4.2.1. Calculation

Suitability = ([Classified Slope] x 0.41) + ([Roadsuit1] x 0.26) + ([Lulcratsuit] x 0.19) + ([Landvaluesli1] x 0.09) + ([Soilrassuit] x 0.06) + ([Geomorrastersuit] x 0.03)

Slope=(1)(0.41+(2)(0.26+(3)(0.15)+(5)(0.06)+(9)(0.03)=6.15

Land values=(0.50)(0.41)+(1)(0.26)+(2)(0.15)+(3)(0.09)+(5)(0.06)+(7)(0.03)=5.96

Road Proximity=(0.33)(0.41)+(0.50)(0.26)+(1)(0.15)+(2)(0.09)+(3)(0.06)+(5)(0.03)=6.20

Soil=(0.20)(0.41)+(0.33)(0.26)+(0.50)(0.15)+(1)(0.09)+(2)(0.06)+(3)(0.03)=6.03

Geomorphology=(0.14)(0.41)+(0.20)(0.26)+(0.33)(0.15)+(0.50)(0.09)+(1)(0.06)+(2)(0.03)=5.4

Calculation of lambda (λ)

λ = (6.15+5.96+6.20+6.03+5.40+6.70)/6=36.44/6=6.073

Consistency Index, CI = (λ-n)/(n-1)=(6.073-6)/(6-1)=0.073/5=0.0146

Consistency Ratio (CR)=CI/RI=0.0146/1.24=0.0117, (RI-1.24 for n=6), (Source: Adopted from Saaty, 1980)

5. Results and Discussion

The study area is located in a hilly terrain and covers an area of 3.6 sq. km (approximately). After suitability analysis it was found that from the available area (Figure 7) 0.1157 sq. km falls under very low suitable, 1.6835 sq. km under low suitable, 1.2090 sq. km under moderately suitable, 0.3663 sq. km under high suitable and 0.1248 sq. km under very high suitable. Percentage distribution of site suitability area (Figure 8) shows that 3% of the total study area very low suitable, 48% low suitable, 35% moderately suitable, 10% high suitable and 4% of the total area are very high suitable. Very high suitable means slope is in between (0-15%), Soil is moderately deep (50-100 cm), land use is either a wasteland or open forest or land with scrub or land without scrub, distance to proximity is 100 m, land values distance is 200 m and geomorphology is low dissected structural hill. The result shows that highly suitable areas for urban development is either agricultural or forest type and the low suitable areas is mostly residential. Site suitability map (Figure 6) is fits into the development plan for 2021 (Figure 4). So, after comparing it can be concluded that site suitability map (Figure 6) obtained is exactly in accordance with the development plan prepared for the town.

5.1. Identification of Suitable Sites for Urban Development

Effective criteria (factor) used in the identification of suitable sites with their individual importance are:

- Slope (Figure 5): is an important criterion for hilly terrain for finding suitable sites for built-up. Steep slopes are disadvantageous for construction purpose because the slope increases the construction cost.

- Road Proximity (Figure 5): Easy access to road helps in movement and transportation at any place. However, the construction of new road is expensive especially in hilly regions. So 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 100 meter distance from the road.

- Land use/cover: Land use/cover map of Nahan town has been categorized as agricultural, commercial, residential and industrial because once a building is constructed, it remains there for minimum 50 to 75 years. River bed is also not suitable for built-up area development. Thus barren land/agricultural land is considered to be the highest suitable for development purpose (Figure 3).

- Land values (Figure 5): Land value means the price of a land at a given point of time based on its location. Land value varies from location to location. Land values are high in the centre of a city whereas low in its periphery. Within a locality, accessibility has an impact on the land value as such values are high for the land nearer to road.

- Soil (Figure 5): Soil type essentially gives a broad idea on the basic soil properties of a location. By knowing a soil type, broad inferences could be drawn on its suitability for its construction. Forest and Hills soils type occur in forest and hill areas. These types of soils are also called as skeleton soils. Soil depth is useful for understanding the depth to foothold and efforts required for making a good foundation during construction. If the depth of soil is very shallow, it requires special type of treatment while making the foundation.

- Geomorphology (Figure 5): The denudational landforms like hills are identified based on stage of denudation, wherein, all the structure gets obliterated. These denudational landforms also can be classified based on dissection. Low dissected structural hills are given higher priority as compared to high dissected structural hills for construction.

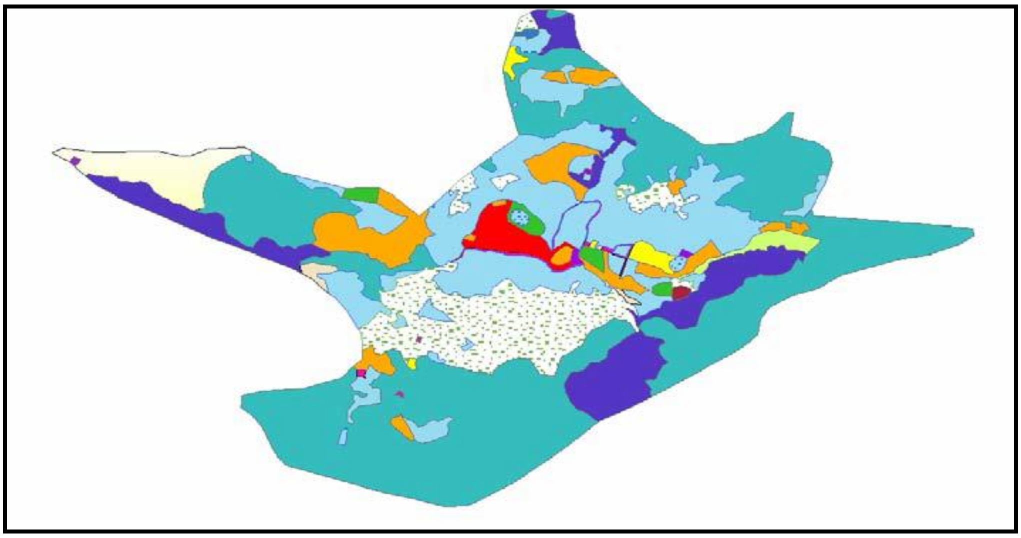

Figure 3: *Land Use and Land Cover of Nahan*

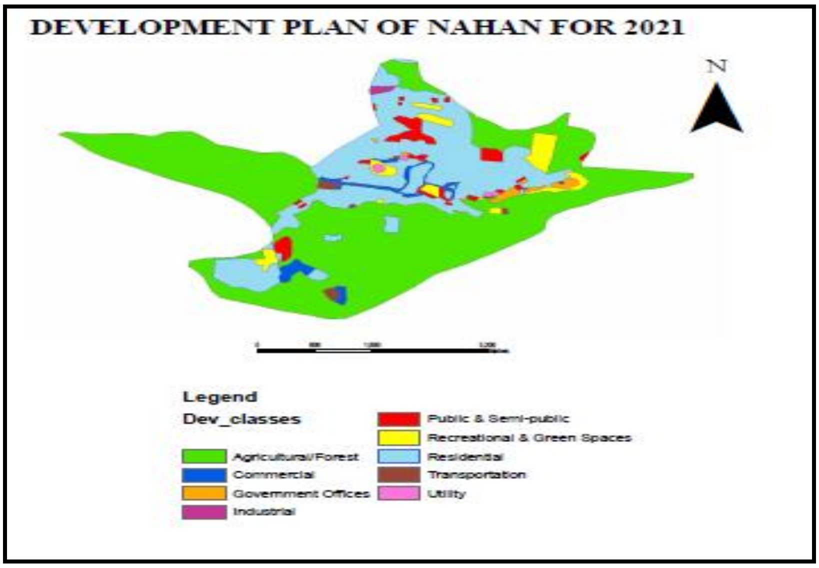

Figure 4: *Development Plan of Nahan for Year 2021*

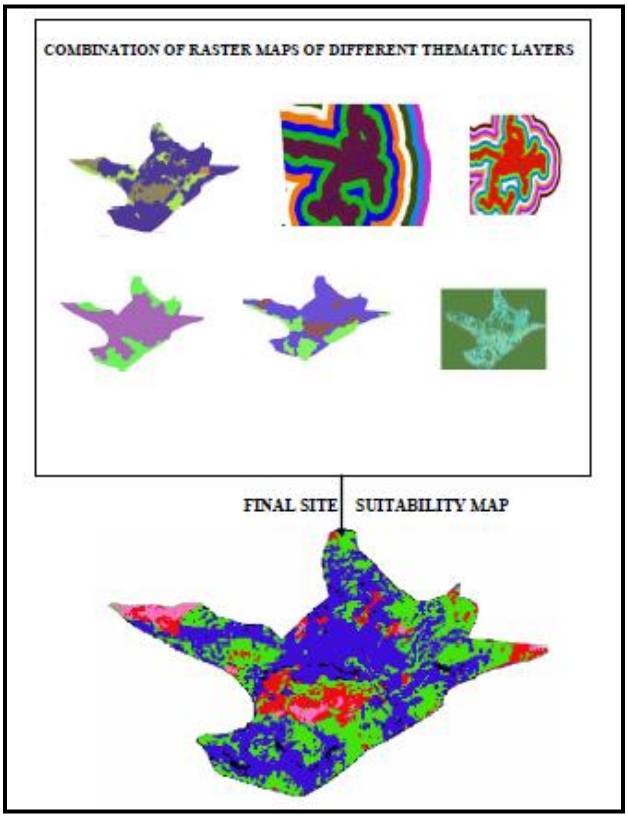

Figure 5: *Combined Raster Thematic Layers*

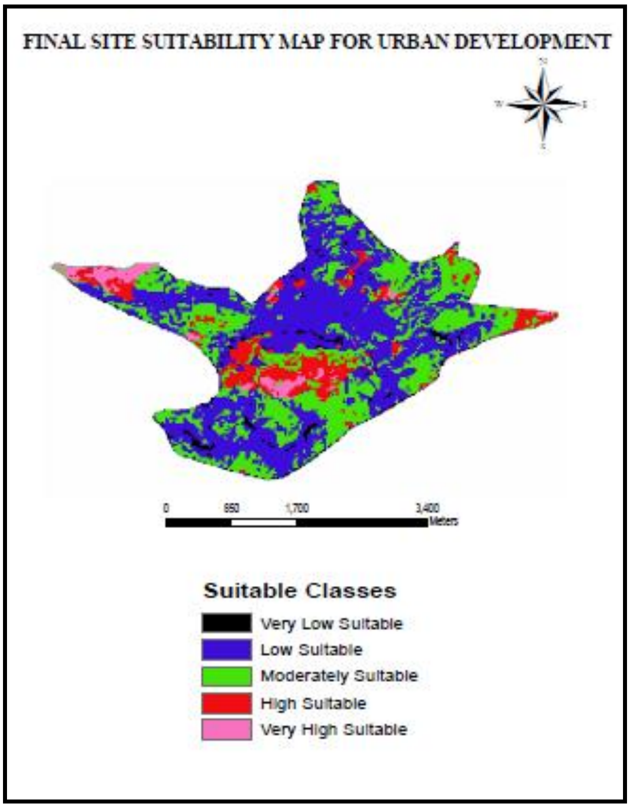

Figure 6: *Proposed Site Suitability for Development of Nahan*

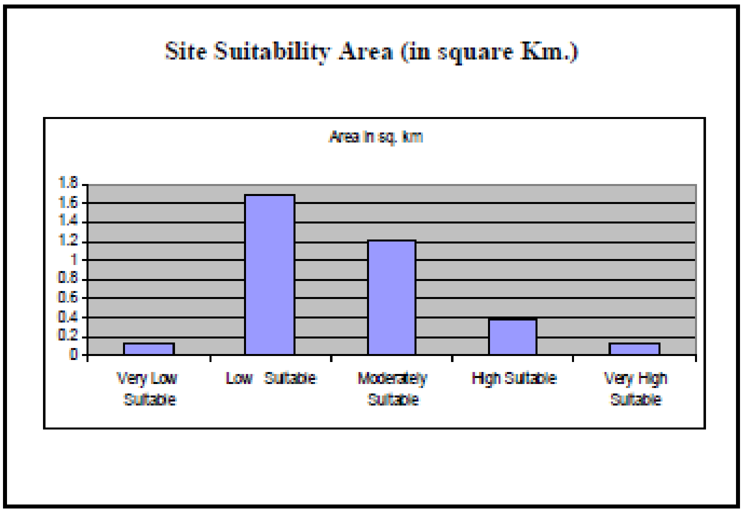

Figure 7: *Area in sq.km for different Suitability Level*

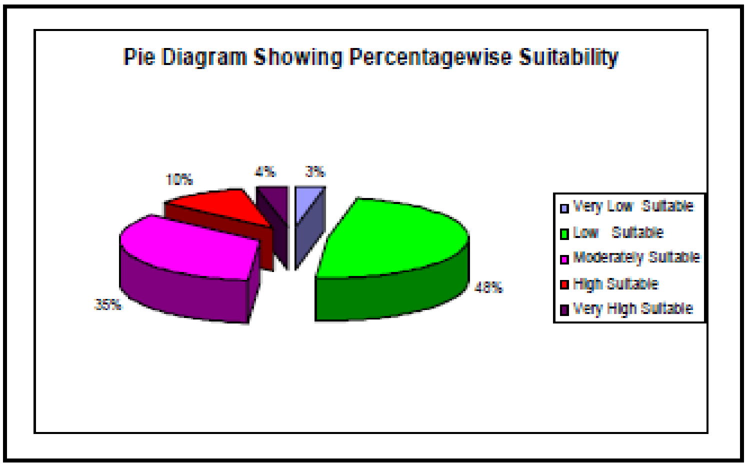

Figure 8: *Area in % Age for Different Suitability Level*

6. Conclusion

The GIS based multicriteria evaluation technique is very simple and flexible which can be used to analyze various suitability of a hill town Nahan. It provides a comprehensive and satisfactory database for availability of suitable sites for urban development which in turn will help in solving any specific problem. This case study can encourage general public to use this method in their real time life and assist various planners and authorities to formulate and implement suitable master plan for development of an urban region.

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