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Multi-Objective Spatial Decision Model for Land Use Planning in a Tourism District of India

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ABSTRACT. Developing tourism in a hilly region has become a thriving process which induces a complex land-cover dynamics. The study area (Shimla District in Himachal Pradesh) is located in the beautiful Himalayan environment in northern India and was the summer capital of India during the days of British rule. The current study has attempted to understand and model the suitability of three major land use forces (agriculture need, forest ecosystem conservation and human development) using the spatial Analytical Hierarchical Process (AHP). Further, the study utilised a multi-objective conflict analysis (MOCA) to understand and resolve the competition amongst these major land use forces. The cross overlay analysis of the existing land use map and the MOCA-derived map infers that the agricultural and human settlement preference can potentially expand into 26% of the current actual forest area. Around 18% of the potentially suitable area for forest class has already been occupied by non-forest classes. The potential future change zones are located in the middle and western regions/sections of the study area. Since the western region is already developed, more attention needs to be paid in the future to the central region of the study area.

Keywords: multi-objective, decision model, planning, land use, allocation

1. Introduction

The developmental needs of the country on the one hand, and the ecological and environmental conservation needs on the other, result in serious conflict between policy planners and forest administrators (Spilsbury and Nasi, 2006). Appropriate utilisation of land is crucial for mankind if he is to reap sustainable benefits from it (Dayawansa, 2003). The impact of humans in activities such as transforming natural ecosystems into croplands and pasture, and in clearing large swathes of land for development has serious consequences for the climate (Brovkin et al., 1999). Guidance for land evaluation and land suitability assessment is provided by the Food and Agriculture Organisation (FAO 1976, 1985, and 1993) in order to benefit the developing countries. It is identified that biophysical and socio-economic factors play a major role in defining land use. In a hilly area, there are many factors (such as elevation, slope, aspect, proximity from road, human settlement, tourist sites, industry, soil fertility, water availability, biological richness and demographic factors), which, either directly or indirectly, contribute to changes in the environment. Sustainable use of land can be understood by identifying the changes that occurred in the past and through simulated land use patterns (Castella et al., 2005). With this context, the modeling and analysis of land use in the study area becomes important. Also, decision making in the environmental domain is very complex and in such applications the main concerns lie with the meanings, relations, proper definition, and understanding of information to arrive at a suitable modeling strategy (Liu et al., 2008; Daily et al., 2009). Biermann (2007) addressed major challenges in undertaking research and governance for the earth system, which is a crosscutting theme in global change research, and such research would certainly depend on the spatial decision-making process. It is challenging but possible when we measure, map and monitor the ground processes and analyse them systematically, and interlink them with policies. In such cases the proper framework through an environmental informatics approach is the way forward in the twenty first century (Huang and Chang, 2003) and hence it provides a natural basis for this research.

The maintenance of the landscape and the sustainability of land use and water depends on natural vegetation, and deforestation has been consistently singled out as a key element within many areas of global change research (Lambin et al., 2003) as forests play a vital role in determining the global climate (Bonan, 2008). Converting forested land into cultivated land has contributed significantly to soil erosion and mass movements on hills (Quincey et al., 2007). The accelerated phase

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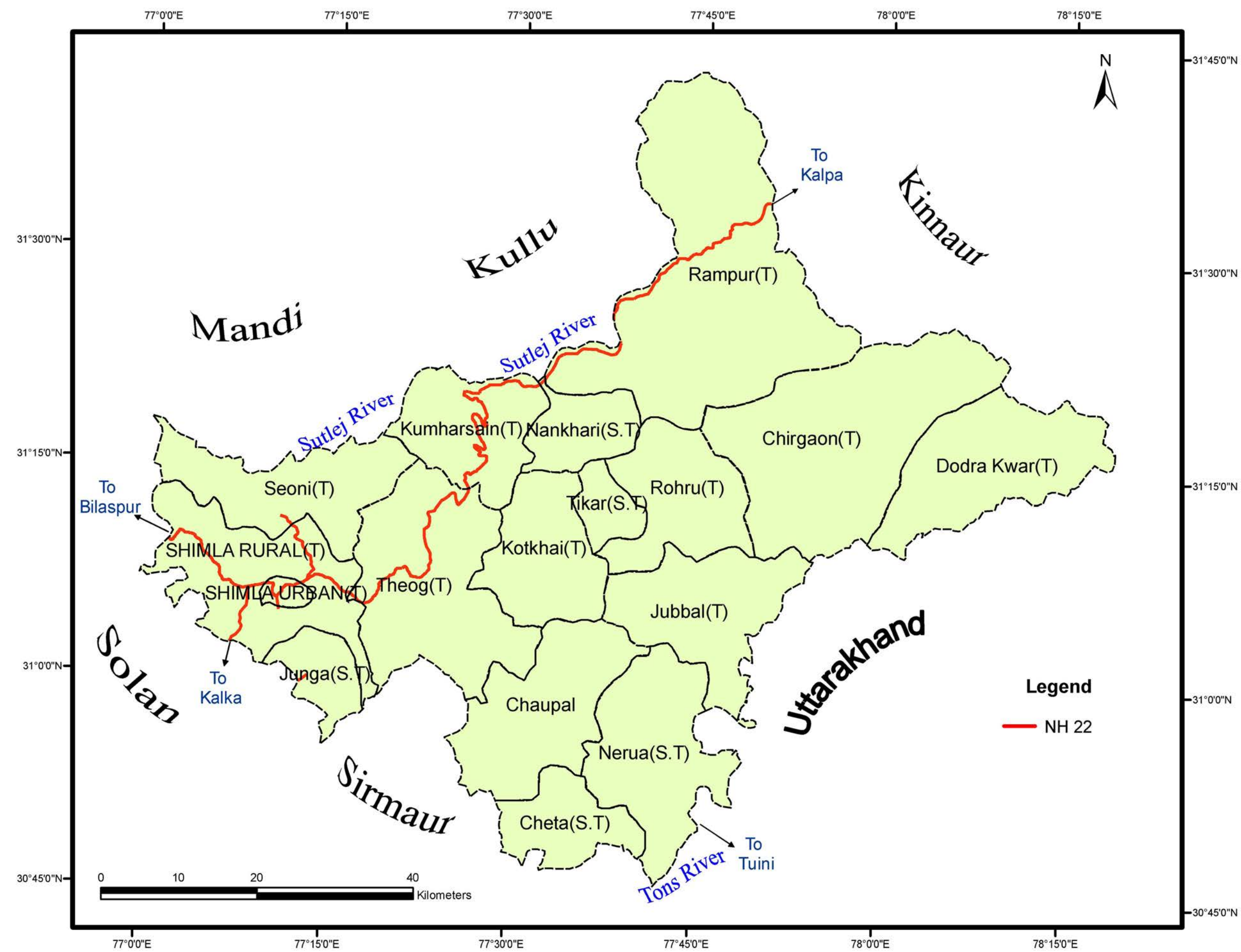

Figure 1. Study area - Shimla District and its environ.

of environmental degradation makes it necessary to study and quantify the extent and rate of change so that the areas prone to deforestation can be predicted. Real time information about the state of the environment is imperative for successful management by the planners and decision makers. Advanced technologies such as remote sensing (RS) and geographical information system (GIS) have given an opportunity to obtain real time data about the ground, to simulate modelling and to extract information for efficient planning (Pielke, 2005).

Since the study area is enriched with a forest ecosystem, the aim of the study is to identify suitable areas of forest; to analyse the suitability of the land in terms of agriculture, human settlement and population growth trends, and to predict possible future changes. Considering the ever increasing demand for land for agriculture and settlement, there will be competition for a piece of land. Hence we have three conflicting objectives in hand; the first is to preserve the forest, the second is to preserve land for agricultural production, and the third is to identify and plan land parcels for expanding human settlement. For this purpose, the study includes two major analyses: a) the AHP-based spatial multi-criteria decision making (MCDM) technique is utilised to integrate the factors influencing each of these major components (forest, human settlement and agriculture), and b) a multi-objective conflict analysis (MOCA) technique is utilised to understand and resolve the competition amongst these major land use forces.

2. Study Area

Shimla district is situated in the eastern region of the Himachal Pradesh state (Figure 1). The study area was the summer capital of India during the days of British rule, and is famously titled 'Queen of the Hills' due to its magnificent and unspoiled environment in the Himalayas. The situation, however, has been changing due to pressure from various human developmental activities. The total geographical area of Shimla district is 5,131 km^2, out of which 47.63% of the district has forest cover encompassing 1,878 km^2 of dense forest, 566 km^2 of open forest and 56 km^2 of scrub, according to the Forest Survey of India (FSI, 2001). From the FSI reports of 1991 and 2001, it is observed that forest cover in the district has increased by around 4%. At the same time, it is found that the dense forest has decreased from 1,921 km^2 in 1991 to 1,878 km^2 in 2001, but that open forest has increased from 299 to 566 km^2.

In Shimla district, compared to 1971 census, the population increased by 72% by 2001. Hence agricultural demand has also increased and consequently there is more pressure on land and forest. According to government records (DES, 1999), net sown area in Shimla district increased from just 4% in 1972 to 14% in 1999. Horticulture, being an important income-generating resource of the district, has led people to encroach further on the remote, which has resulted in increased degradation of these areas. On the other hand, tourism, another revenue-generating state mechanism, attracts thousands of tourists every year, which in turn places more pressure on the environment. The pressures from tourism, agricultural demand and population growth are threatening the valuable forest ecosystem of the district. Since the rate of change in any direction, either positive or negative, cannot be sustained for administrative and ecological reasons, it has become a major challenge for the district administration to sustain the environment while meeting the growing demand. In this regard, the present study may help administrative agencies of the district for better future planning.

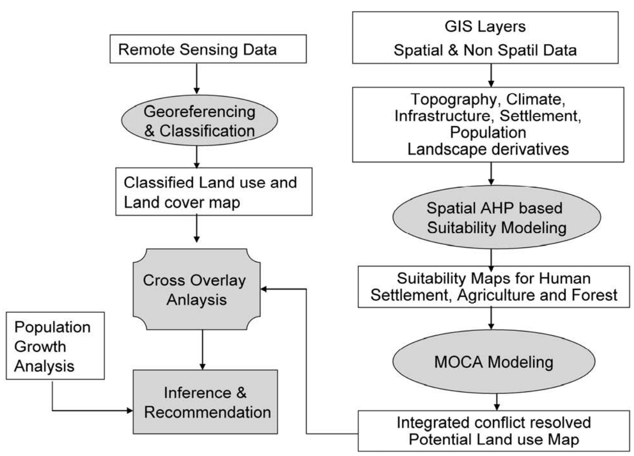

Figure 2. Overall approach.

3. Methodology

The overall approach in this study is described in Figure 2. The approach has two major parts: a) database creation and b) modelling. In the database creation, the study used a variety of data from satellite, topo sheets and reports from national agencies (details are provided in section 3.1); in the modelling part, the study utilised multi-criteria and multi-objective decision-making techniques (Section 3.2). The final results (i.e., both modelled and RS derived land use along with temporal population growth) were spatially overlayed and analysed to understand the ground dynamics and to infer meaningful patterns for efficient planning and management.

For digital image processing, the softwares packages ERDAS Imagine, ILWIS and ENVI were used, and for the Geographical Information System (GIS), the analysis and custommisation Arc/Info, ArcGIS and Arc View were used. Customisation was done using Arc Macro Language (AML) as well as in ArcMap using Arcobjects and Visual Basic.

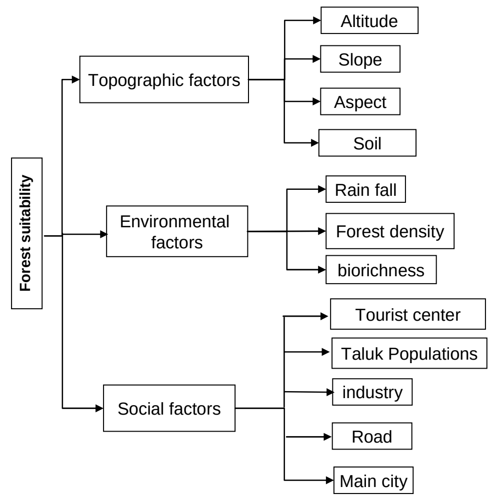

Figure 3. Approach for forest suitability.

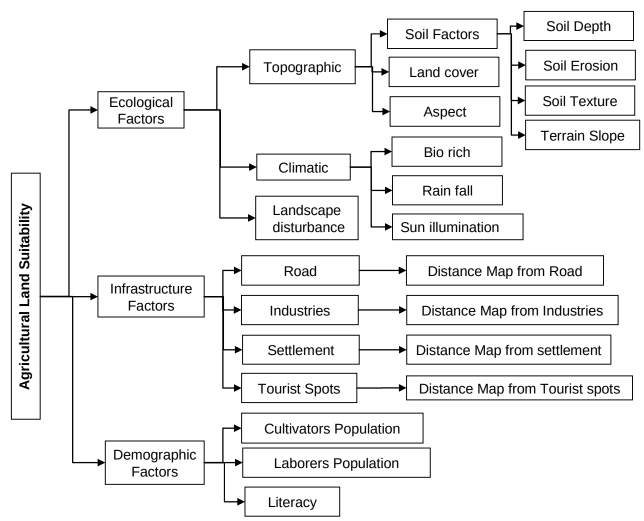

Figure 4. Approach for agriculture suitability.

3.1 Database Creation

The satellite data used in this study were obtained from the sensors IRS-1D LISS III, Landsat-TM and Landsat-MSS. The LISS-III sensor of the Indian Remote Sensing satellite (IRS) has 4 bands with a spatial resolution of 23.5 m, Landsat-TM has 7 bands with a spatial resolution of 30 m and MSS has 4 bands with a spatial resolution of 80 m. Indian remote sensing satellites for the period 1999-2000 have been utilised in this research as IRS data have been successfully used for various ecological applications (Sharma, 2009). Other ancillary data used were: (i) Survey of India Topographic Sheets No. 53 E, 53 I & 53 F of scale 1:250,000 and 53 E/3, 53 E/6, 53 E/8, 53 E/9, 53 F/1, 53 F/4, 53 F/7, 53 I/2 & 53 I/3 of Scale 1: 50,000; (ii) District Plan Map Series (DPMS) map (1: 250,000) of Shimla District made by National Atlas and Thematic Mapping Organisation (NATMO), Kolkata, India; (iii) Census data of Shimla District and tehsils for the years 1971, 1981, 1991 and 2001; (iv) National Bureau of Soil Survey & Land Use Planning (NBSS-LUP) Soil Map of Shimla District; (v) Forest Sur-

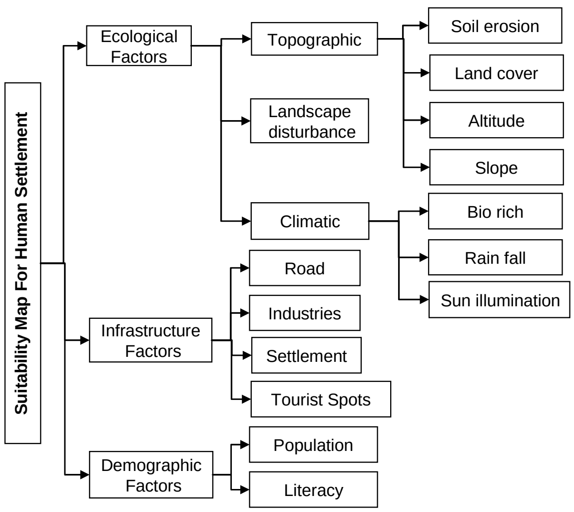

Figure 5. Approach for human settlement suitability.

vey of India (FSI), forest density maps and reports; and (vi) Data and Reports from the National Biodiversity Characterisation project (Roy et al., 2002) of the Department of Space and Department of Bio-technology (DOS-DBT).

A hybrid classification scheme is adopted in this research for preparing the land cover map, in which a particular class is identified, isolated and extracted using the best possible procedure (either supervised or unsupervised), and finally the individual classes extracted were integrated. The classified images were cross checked with Survey of India's toposheets, ground GPS points along with random sample points and training sites, and verified using the confusion matrix. The kappa accuracy of the final classified map was 84%. The NATMO, NBSS-LUP, FSI and DOS-DBT maps were used to derive all the parameters mentioned in Figures 3 to 5 for suitability modelling.

3.2 Multi-Criteria and Multi-Objective Decision Making

3.2.1 Analytical Hierarchical Process (AHP)

The MCDM used in this research, for suitability modeling, is the AHP, which is a well understood and broadly utilised technique (Saaty, 1977; Bantayan and Bishop, 1998; Dai et al., 2001; Zhang et al., 2004; Hill et al., 2005; Ayalew et al., 2005; Vahidniya et al., 2009; Chen et al., 2010). Ayalew et al. (2005) found that AHP had perfor med better than logistic regression in capturing the ground reality in geological applications. Thapa and Murayam (2008) used AHP to develop a framework for evaluating land use policy. Giove et al. (2009) addressed the aspects and importance of different MCDM methods within decision support systems for environmental applications where the scarcity and uncertainty of data are of major concern, and revealed that AHP is one of the most robust approaches for structuring complex problems. Benke et al. (2009) discussed and provided an experimental case to analyse uncertainties and errors associated with the AHP approach for land suitability applications. Yang et al. (2009) attempted to merge AHP with Grey Relational Analysis (Wang et al., 1996) in order to address the uncertainty in the evaluation process. Zhang et al. (2010) used AHP with the agent-based model for analysing urban expansion in China. Malczewski (2010) conducted a detailed GIS-MCDM literature survey and found that, out of 363 papers, around 70% used one kind of MCDM technique and only 30% dealt with multi-objective decision making techniques, and the AHP approach was found to be one of the top three approaches under MCDM preceded by simple weighted sum and ideal point approaches. Advanced techniques like neural network (Yin and Xu, 1991), decision tree (Giarratano and Riley, 1994), genetic algorithm (Stewart et al., 2004), cellular automata (Wu, 1998; Munday et al., 2010) and agent-based models (Matthews et al., 2007, Zhang et al., 2010) have also been used in the land use planning. The current study, however, endeavoured to use simple and established techniques, and did not compare or evaluate other advanced techniques.

3.2.2 Spatial Implementation of AHP

In a traditional decision problem, the situation is analysed using a decision matrix or effect table comprising criteria and alternatives, and each criterion can have a single value (either numerical or categorical) for each alternative. In a spatial decision problem, however, each criterion is a 2-D map instead of a 1-D single unit value, and every pixel (i.e., minimum representable spatial area) within each spatial criterion (i.e., map) is considered as an alternative. The importance of each criterion is assigned as a "weight", which is generally subjecttive, but AHP provides the possibility of quantifying and thus avoiding subjectivity, and the chance to maintain consistency in assigning "weight" by using pairwise comparison (Jeganathan, 2007). AHP can be implemented by a) dividing the problem into a hierarchy, b) comparing elements, c) consistency estimation and performance/priority estimation, and d) final aggregation.

In AHP, each criterion is analysed for its potential contribution by comparing it with all other criteria using a pairwise comparison. This pairwise compared matrix is then aggregated to derive suitable weights for each criterion map. Finally, each criterion map is multiplied by weights derived through AHP and then added with all other criteria occurring in the same hierarchy. The process is repeated at each hierarchical level. The reader is directed to the work of Malczewski (1999) and Nyerges and Jankowski (2010) for more details about AHP, its technicality, comparison scales, consistency check and data standardisation procedures.

In the spatial approach of AHP, four important areas of consideration are: a) each pixel in a raster map (i.e., criterion) representing the study area is assumed as a separate alternative, b) criteria at the lowest level are not single valued attributes but rather maps with many classes, c) criteria at the upper levels of the hierarchy are are more components of conceptual groups rather than actual criteria, and d) the objective is not to get a top-performing alternative nor to select a single pixel, but to make groups, consists of many pixels, based on each pixel's performance or suitability values. Figures 3 to 5 represent the hierarchical structure adapted in this study for

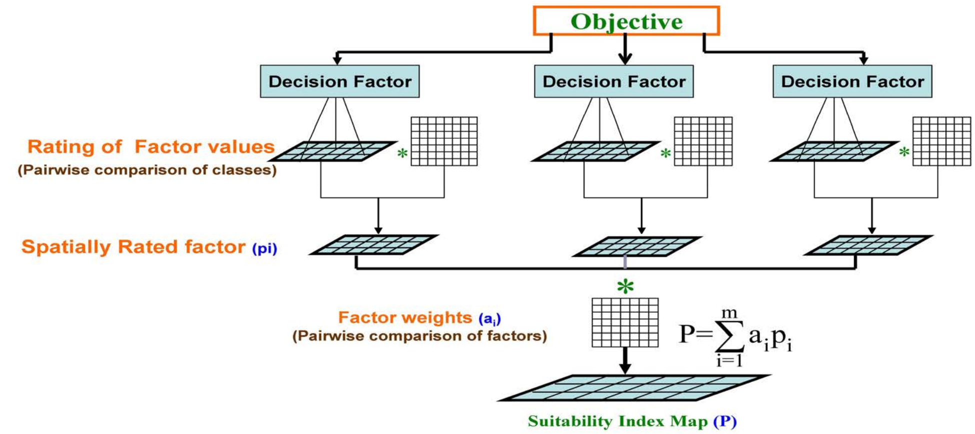

Figure 6. Conceptual implementation of spatial analytical hierarchical process.

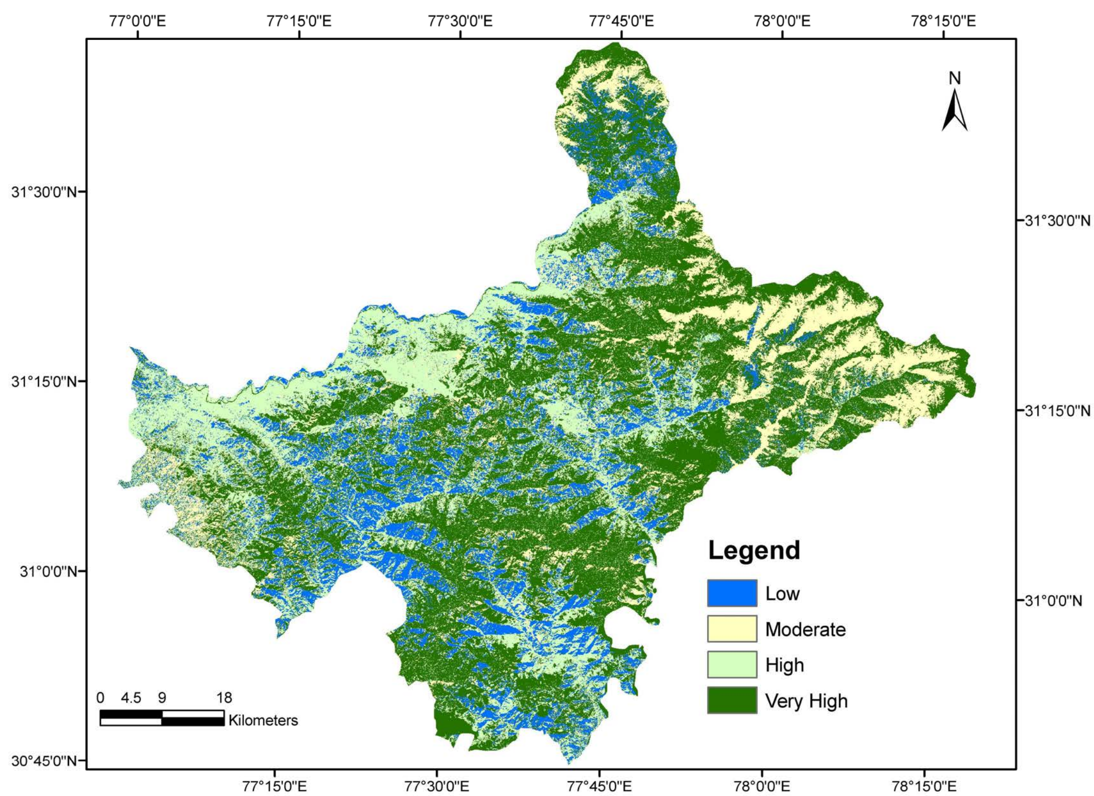

Figure 7. Modelled suitability for forest.

identifying potential areas suitable for forest, agriculture and human settlement. Since each criterion map has many classes, if pairwise comparison is to be made between all classes of all criteria then the number of pairwise comparisons would be enormous. So, in order to avoid such a huge number of comparisons, the classes within the criteria at the lowermost level of the hierarchy can be provided with a direct rating, and pairwise comparison using AHP approach is utilised in the subsequent upper levels of the hierarchy. Figure 6 depicts the step by step implementation process utilising the spatial analytical hierarchical process to derive a suitability map.

Since the measurement units of each of the input parameters (i.e., criterion) are different, they need to be converted to comparable units through a standardisation procedure. The study adopted the "rating" approach as the standardisation procedure to standardise the parameters at the lowest level. In the rating process, each class (or attribute) within a criterion map is assigned a value between 0 and 100. If a class is highly beneficial for a particular land use purpose then a higher rating value is allotted, and if it is not beneficial then a lower rating value is allotted. For example, the fringe area of an already developed human settlement is highly beneficial for

Table 1. Conflict Resolution Score among Competing Clusters

Cluster	Z-scores			Conflict Resolved	
	Agriculture	Forest	Human Settlement	Class Allotted	Area (km^2)
1	-0.0947	0.3392	-0.2444	Forest	890.95
2	0.6924	-1.0955	0.4031	Agriculture	426.92
3	-0.2030	0.4154	-0.2123	Forest	135.12
4	-0.4841	1.4154	-0.9312	Forest	235.29
5	0.7213	-1.4175	0.6961	Agriculture	289.04
6	-0.3571	0.0821	0.2750	Settlement	278.71
7	-0.7583	1.0821	-0.3238	Forest	470.99
8	1.1190	-2.2511	1.1321	Settlement	153.18
9	0.1561	-0.4825	0.3263	Settlement	383.58
10	-0.4777	0.7488	-0.2710	Forest	595.22
11	0.2817	-0.2102	-0.0714	Agriculture	754.10
12	0.0366	-0.2003	0.1636	Settlement	517.89

Table 2. Cross Comparison of Conflict Resolved Land Use Map

Modeled Potential Land Use	Current Land Use	Area (km^2)	Area (%)
Agriculture	Forest	688.07	13.41
Agriculture	Non-forest	830.98	16.20
Forest	Forest	1359.47	26.50
Forest	Non-forest	945.31	18.42
Human Settlement	Forest	668.01	13.02
Human Settlement	Non-forest	639.16	12.46

future human settlement and hence will receive high rating values like 90 or 100, whereas remote areas further away from the city are assigned lower values like 5 or 10. If a class is in no way suitable for a land use purpose then it will be assigned a '0' value.

The ratings and weights allocated to each criterion are explained in detail in Jeganathan (2007). Since these values vary according to individual views and may lead to difference in opinion, only the resultant suitability maps need to be verified for accuracy. Although the variations in ratings and weights will affect the final suitability value, its effect is minimized if we convert the suitability value map into categorical groups like 'highly suitable', 'less suitable', etc.

A forest Suitability map is generated using 12 spatial criteria: altitude, slope, aspect, soil depth, rainfall, forest density, biorichness, tourism pressure, population of tehsil, proximity with road, industry and main cities, which are grouped into three conceptual groups: topography, environment and social factors (Figure 3). An agricultural suitability map is generated using 18 spatial criteria: land cover, soil erosion, soil depth, soil texture, terrain slope, aspect, rainfall, sun illumination, biorichness, landscape disturbance, cultivators population of tehsil, labourers population of tehsil, literacy population of tehsil, proximity with road, cities, industries and tourist spot, which are grouped into three conceptual groups: ecological, infrastructure and demographical factors (Figure 4). A human settlement suitability map is generated using 14 spatial criteria: land cover, altitude, slope, soil erosion, rainfall, sun illumination, biorichness, landscape disturbance, population of tehsil, literacy of tehsil, proximity with road, cities, industries and tourist spot, which are grouped into three conceptual groups: ecological, infrastructure and demographical factors (Figure 5).

3.2.3 Multi-Objective Conflict Analysis (MOCA) Approach

Using a multivariate statistical approach, one can resolve conflict resolution by assigning the individual pixels to distinct clusters, based on the integrated suitability scores. Then one can estimate the magnitude and likelihood of conflict among the land use systems, which shall act as a mechanism for potential allocation. Noy-Meir, (1973), Digby and Kempton (1987) and Laskar (2003) have used divisive polythetic partitioning for creating the clusters by dividing iteratively the first principle component derived from the input suitability maps. The current research has adopted a simple multivariate unsupervised classification approach, called 'ISODATA cluster algorithm', for extracting the clusters (i.e., segments) out of first principal component derived from principal component analysis (PCA) of the three suitability maps. Next, the competition between the three objectives was analysed through the z-matrix which is derived using the derived clusters and the suitability maps (Digby and Kempton, 1987; Bojorquez-Tapia et al., 2001; Laskar, 2003). A software routine was written to implement the MOCA, which requires two input maps; land use suitability map and cluster map. The MOCA routine was run three times using three suitability maps (i.e., agriculture, forest and human settlement). The routine calculates zonal and global statistics about a) mean suitability within each cluster for each land use, b) overall mean suitability of each land use, c) overall mean suitability of each cluster. Finally, each cluster is analysed for its z-score using equation (1) towards each land use and the cluster is allotted to the land use which has the maximum z-score:

$$Z[g(i),lu(j)] = S[g(i), lu(j)] - S[g(i)] - S[lu(j)] + S[g] \qquad (1)$$

where,

$Z[g(i),lu(j)]$ = Conflict resolution score of cluster i for land use j;

$S[g(i), lu(j)]$ = Mean suitability value of land use j in Cluster i;

$S[g(i)]$ = Mean suitability of cluster i out of all land uses;

$S[lu(j)]$ = Mean suitability of land use j from all clusters;

$S[g]$ = Mean suitability of all clusters out of all land uses;

g = refers to clusters [g contains n user generated clusters - g(1), g(2), …, g(n)];

lu = refers to land use suitability.

4. Results and Discussion

The suitability maps derived using the approaches described above (Figures 3 to 6) for the land use categories; forest, agriculture and human settlement are shown in Figures 7 to 9. These results were evaluated for their accuracy by visual inspection as well as for spatial accuracy through cross overlay

Table 3. Results of Population Trend Analysis

Tehsil Name	Actual Household in 2001	Projected Household in 2011	Increase in Household (A)	Household size (B)	Area needed in 2011* (km^2) = (A * B) / population density (PD)		
					If PD = 141	If PD = 160	If PD = 200
Rampur	16006	17823	1817	4.5	58.67	51.11	40.89
Kumharsain	8821	9392	571	4.6	19.09	16.41	13.13
Nankhari	5352	5749	397	4.7	13.60	11.67	9.33
Seoni	6162	6601	439	5.1	16.18	14.01	11.21
Theog	15285	17371	2086	5.1	76.24	66.50	53.20
Kotkhai	7590	8165	575	4.5	19.14	16.16	12.93
Jubbal	7010	7659	649	4.8	22.13	19.45	15.56
Chaupal	5459	6132	673	5.2	25.84	21.86	17.49
Chirgoan	7317	8563	1246	5.4	47.71	42.04	33.64
Shimla R.A	14704	17753	3049	5.0	108.10	95.26	76.21
Shimla U.A	37514	46118	8604	3.8	286.30	204.34	163.48
Dodrakwar	1011	1141	130	5.6	5.02	4.54	3.63
Nerua	5472	6216	744	5.7	29.36	26.49	21.20
Rohru	9351	11040	1689	4.8	56.50	50.65	40.52
Tikkar	2569	2810	241	4.9	8.09	7.37	5.90
Junga	2344	2535	191	5.3	6.94	6.35	5.08
Cheta	2475	2917	442	6.8	20.99	18.79	15.03

* Population Density = 141 persons per km^2, as per 2001 census.

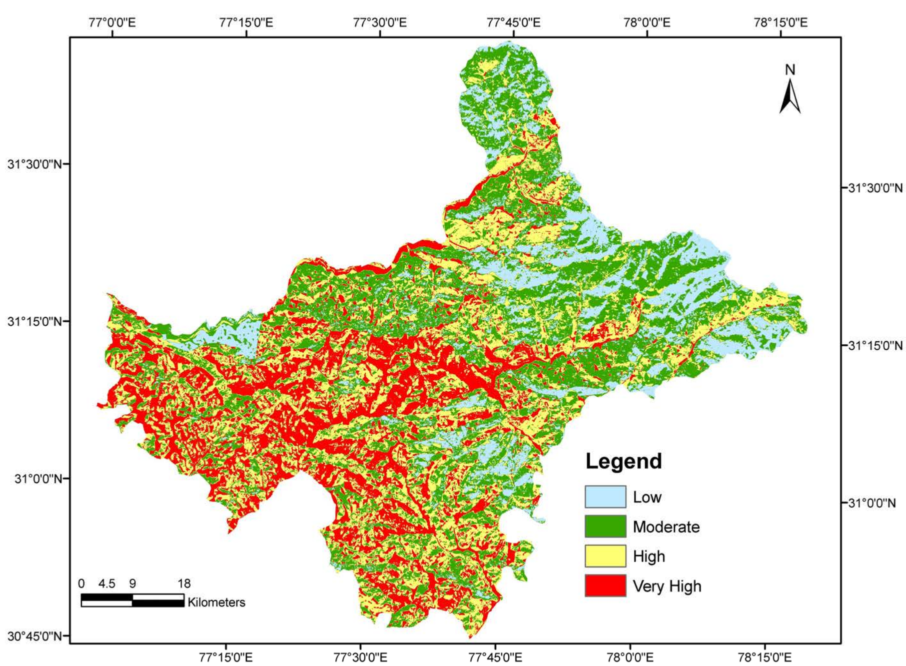

Figure 8. Modelled suitability for agriculture.

analysis using existing land use and land cover maps. These suitability maps were converted into 12 clusters of equal variance derived through ISODATA algorithm on their 1st PCA component. These 12 clusters were analysed for conflict resolution score using equation (1). Table 1 reflects the derived Z-score for all clusters and resultant allotment. Each cluster is allotted to only one land use category for which it received a maximum Z-score. The integrated conflict resolved 'potential land use' map derived using this approach is shown in the Figure 10.

From the analysis it is found that around 45% of the study area is potentially suitable for forest class, 30% of the area for agriculture and 25% of the area for human settlement. It can be assumed that if the study area is left as it is without management and protection, then the resultant process would have led to the derived map (Figure 10). In order to find out how much of these competing land use classes are actually occurring on the ground, the derived map is crossed with the

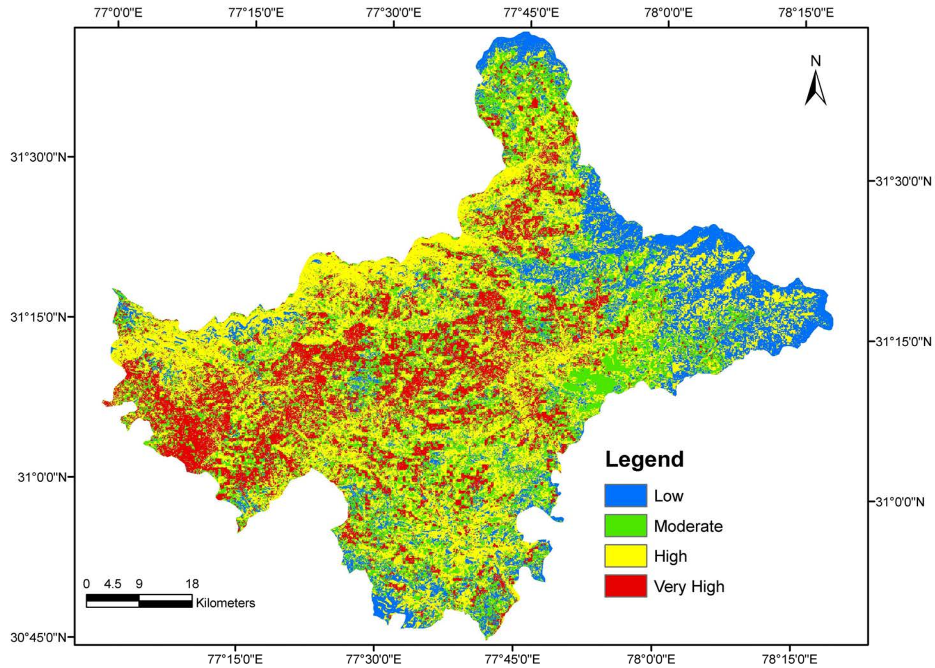

Figure 9. Modelled suitability for human settlement.

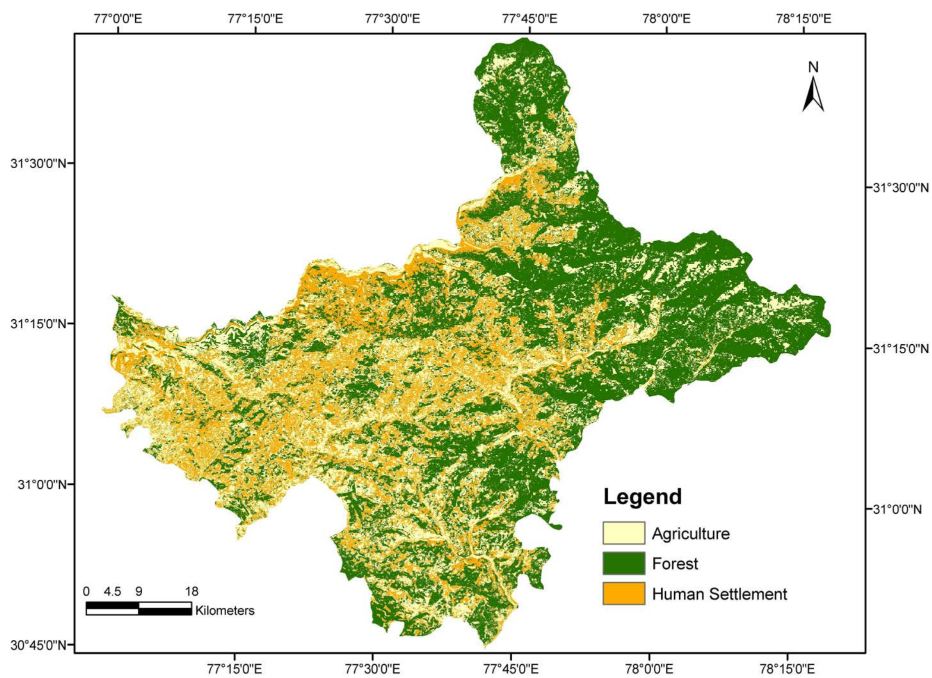

Figure 10. Modelled land use using multi-objective conflict analysis.

remote sensing-based classified map of 1999/2000. Table 2 shows the results of cross comparison. The cross overlay analysis has revealed that only 26.5% of the ground area is actually occupied by forest out of 45% of potential forested area; out of 29.61% of the area suitable for agriculture, around 13.41% of the area is occupied by actual forest; out of 25.47% of the area suitable for human settlement, around 13.02% of the area is occupied by actual forest. This led to the inference that agriculture and human settlement preference can potentially expand into 26% of the current actual forest area. Around 18% of the area suitable for forest class is at present occupied by non-forest classes.

It was found that Theog, Shimla rural, Rampur and Rohru tehsils are highly suited for human settlement in respective order. Rampur, Chirgaon, Chaupal, Theog, Jubbal and Dodra Kwar on the other hand are highly suited, in that order, for forest growth. Theog, Shimla rural, Chaupal and Kotkhai also have high suitability for agriculture. Approximate percentages of 20, 46 and 23 of the study area respectively fell within the 'very high suitability class' for human settlement, forest and agriculture land use. Overall the western region of the study area is more suitable for human settlement and agriculture, while the eastern and northern areas are good for forestry. It was found that tehsils like Rampur, Chirgaon, Theog, Chaupal, Jubbal, Rohru and Shimla Rural have played a dominant role in change dynamics.

The study has also looked into the population growth trend, and estimated the land needed for future human settlement. As per the 2001 census, 141 persons are living per km^2 in the study area. Population density values of 141, 160 and 200 people per km^2 were assumed for estimating different scenarios of future need within each tehsil in 2011. From the simulation (Table 3) it is found that 10 to 15% of additional area would be needed for human settlement over the whole Shimla district. It is also found that Shimla Urban and Rural, Theog, Rampur and Rohru tehsils are in need of more land area for future human settlement and hence proper management would be needed in order to maintain the sustainability of the natural environment.

5. Conclusions

The study has revealed that around 45% of the study area exhibits competing natural tendency for being designated as forest class, which is less than the current overall forest area. This is a very important indication that sustainable development is taking place in the area under study. Further, the model has identified the western region of the study area as highly suitable for human settlement and agriculture. This is true with the ground reality that the important big settlements like Shimla and Theog are located in the western region of the district. Around 26% of the existing forested regions are potentially under threat. The potential change zones are found to be located in the middle and western regions of the study area. Since the western region of the study area is already developed, more attention will need to be given to the central region of the study area in the future. The population trend analysis revealed that 764 km^2 of area would be needed in 2011 for human settlement purposes alone, which is around 15% of the study area. Overall, the study has analysed a mechanism to understand the land use competition in order to resolve the conflict amongst the land use forces, which is important for modern day spatial management activities at the decision-making level.

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