Suitable land assessment for urban expansion around Shimla, Himachal Pradesh (India) – MCE approach

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Abstract: The present study aims to identify suitable zones for future urban expansion and development of new satellite township around Shimla using Geographic Information System (GIS) and Multi Criteria Evaluation (MCE). Shimla being located in the high altitude zone, several factors play important roles in guiding the urban development pattern and its form. There are several physiographic and natural limiting factors, which need to be taken into consideration while identifying suitable sites. The study aims to identify suitable sites and plots of above 100 ha by taking into consideration natural factors prevailing in seven surrounding tehsils of Shimla and Solan districts. While assessing suitable lands, different thematic layers were taken into account for GIS based multi-criteria evaluation such as elevation, slope, aspect, land use/cover, geomorphology, lithology, soil texture, lineaments, drainage network, road network and geology. Produced suitability map is intended to help in the selection of suitable sites/lands for development of future satellite township.

Keywords: Geographical Information System (GIS), Multi Criteria Evaluation (MCE), Weighted overlay analysis, Landsat, Thematic layers, Urban expansion

1. Introduction

Land-use suitability mapping and analysis is one of the most useful applications of GIS for spatial planning and management (Collins et al., 2001; Malczewski, 2004). Previously, various methods of spatial analysis for land use are commonly used in the suitability assessment studies. The problem of land use suitability assessment has often been tackled using multi-criteria decision analysis (MCDA) since 1980s (Antoine et al., 1997; Collins et al., 2001; Kiker et al., 2005; Sharifi et al., 2006; Kunwar et al., 2010). Cheng et al. (2003) have reported an integrated MCDA linear programming approach to support selection of an optimal landfill site. To create visualized suitability map for users and decision makers, the integration of MCDA and GIS has been widely promoted for solving spatial problems in urban assessment and planning (Phua and Minowa, 2005; Joerin et al., 2001). The land-use suitability problem involves evaluation and classification of the areal units according to their suitability for a particular activity. This has been very useful in evaluating suitable plots for sustainable urban expansion. It is necessary to explore suitable lands for future urban expansion quantitatively and objectively to provide a reliable basis for improving the persuasiveness of the effective decision-making. The rapid development of remote sensing technology and gradual maturing of GIS technology applications provide the foundation for such analysis. These advanced technologies are recognized worldwide as valuable technologies in environmental applications and are very useful in monitoring the environmental changes due to human activity (Gao and Skillcorn, 1995; Migul-Ayanz and Biging, 1997; Riaza et al., 1998; Yeh and Li, 1998). Some of the medium coarse resolution satellite data such as Landsat based MSS, TM, ETM+, OLI-TIR and IRS based LISS-III in public domain do offer basic inputs to the researchers to conduct such independent studies aimed at planning for better/suitable urban environment.

Shimla has been experiencing massive urban expansion for last two decades. It is also observed that sub-urban areas experienced more consolidation and expansion during last two decades. During these years, the city has been attracting lots of tourists from within and outside country by virtue of its England like climate and disturbance in its neighboring state i.e. Jammu and Kashmir. Moreover, the city has been recipient of major share of its migration from all parts of the state by virtue of its multi-functional role with respect to administration, commerce and tourism.

All these led to unprecedented expansion of the city in all direction and also in areas, which were otherwise not suitable for further human habitation growth. Age-old barriers for urban expansion of Shimla such as high slope, north aspect and dense vegetation cover started crumbling down and development is taking place on otherwise marginal sites.

With the unprecedented growth of concrete structure, the city has turned into concrete jungle and road network is choked with burgeoning personalized vehicles all around. There is not a single stretch of road where parking of vehicle is not observed. Consequently not a single day goes without traffic jam in the city. With the advent of rainy season, loose strata also give in to the massive development pressure on high slope in the form of landslides/landslips, which is also a regular occurrence of the city now. All above activities have continuous impact on the sentitive land uses of Shimla. Such impacts might lead to a series of complexities toward environment and land resources development

(Huang and Xia 2001) It is in this context, it is being felt that there is a need to decentralize some of the basic functions of the city or identify satellite township to ease the growing pressure of Shimla.

2. Study area

While identifying suitable lands for urban expansion, it is desired that suitable lands should not be far away from the current city, at the same time it has limited dependence on the old city. Therefore, all the tehsils surrounding the city have been selected for the study. Of all, five tehsils, are from Shimla district and two from neighbouring Solan district. Total population and their population density as per Census of India 2011 are given below.

Table 1: Tehsils in study area

Sr. No.	Tehsils	District	Population as per Census of India 2011	Population density (calculated from map area)
1	Shimla (R)	Shimla	84,382	257
2	Shimla (U)	Shimla	1,69,578	2828
3	Theog	Shimla	84,684	180
4	Junga	Shimla	13,398	129
5	Kandaghat	Solan	40,529	176
6	Arki	Solan	56,908	151
7	Sunni	Shimla	35,379	132
Total population			**4,84,858**	**264**

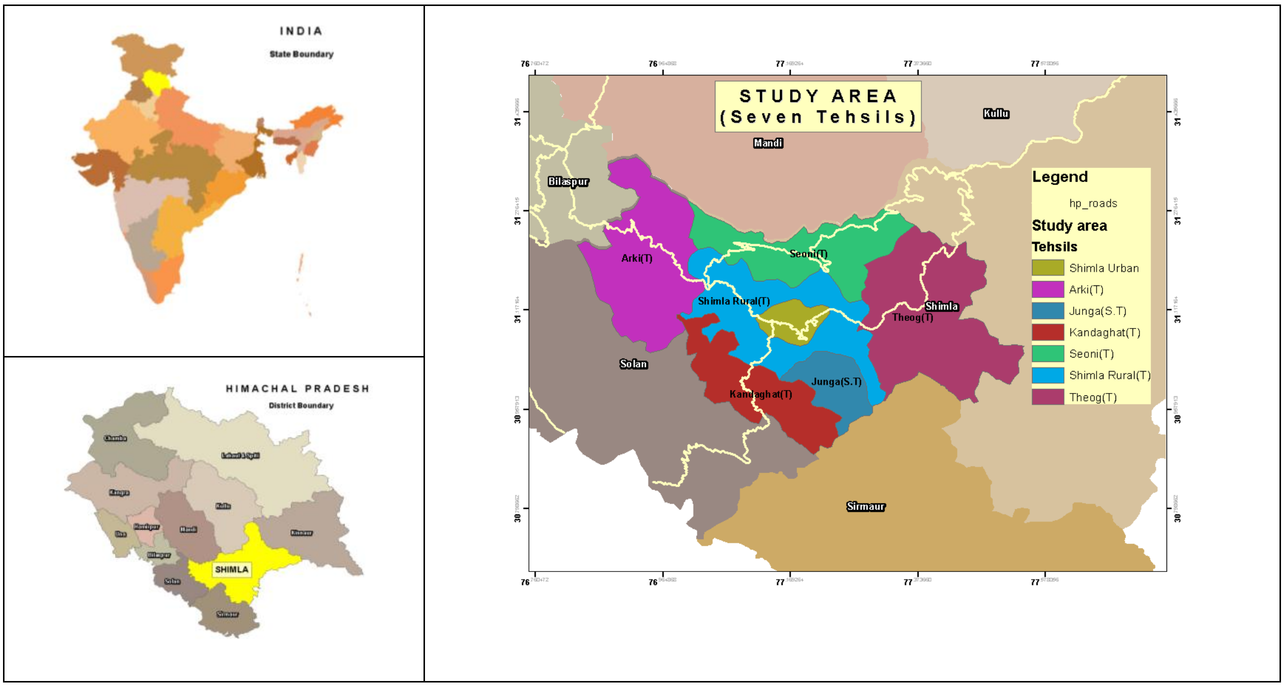


Figure 1: The study area

3. Emerging need

There has been an emerging need to look for suitable lands to decentralize some of the functions of the city with the objective to decongest the crowded city and identify satellite town to act as counter magnet to ease the growing pressure of the city and check Shimla bound migration. As it is observed from Table 1, except Shimla Urban & Rural tehsils, the tehsils have population density of less than 200 persons per km^2. This also offers some space for further urban expansion in such areas. However, Himachal Pradesh being a mountainous state, it has many constraints with respect to topography, sensitive environmental resources such as vegetation cover, high slopes, aspects, numerous cultural heritage and complex geological formations etc.

Any decentralization activity must consider these aspects for identifying suitable areas/sites for urban development around Shimla. In addition, there is a need to identify areas which need conservation; protection by virtue of its environmental sensitivity and no development is permitted on such restricted lands.

4. Data used and methodology

There is no dearth of geospatial data/image of coarse or moderate resolution of multi-spectral bands (MS) of 30 meters and 24 meters from Landsat-7 ETM+ and IRS LISS-III respectively. The biggest source of such imagery of high temporal resolution available from the Landsat program helps the researchers to undertake time-series analysis. The IRS series LISS-III is also in public domain now with spatial resolution of 24 meters. Other thematic data have been collected from numerous sources such as Survey of India (toposheets), Bhuvan India, Census of India, Department of Forests and more importantly from open source. Some old spatial data collected by the author have also been updated through the help of Google Earth and OpenStreetMap.

Table 2: Different data layers / maps and sources

Sr. No.	Data layer / maps	Source	
1.	Base map	Topographical Maps of Survey of India (1:50,000) and ArcGIS 10 base map and Bhuvan portal.	
2.	Urban extent and land use mapping	Remote Sensing Data	
		LANDSAT-7 ETM+ (30 m) & PAN (15 m)	22nd October 2011
		Google Earth	
		OpenStreetMap	
3.	Elevation map	ASTER –DEM (30 m)	Version 2 released (October 17, 2011).
	Slope map	Derived from DEM	
	Aspect map	Derived from DEM	
4.	Land use/land cover map	Land use and land cover map has been prepared digitally by using Unsupervised Classification method in ERDAS IMAGINE 9.2 with limited field check and Google Earth maps.	
5.	Geological map	Geological Map has been obtained from Geological Survey of India portal and also available in various reports.	
6.	Geomorphological map	Lithology& geomorphological map have been prepared using Survey of India Toposheets (1:50,000) and remote sensing imagery and State Environment Report, Govt. of Himachal Pradesh.	
7.	Demographic map and tehsil map	Census of India, 2011	
8.	Forest density map	Forest Survey of India, Department of Forests, GoHP and Landsat ETM+ satellite data.	
9.	Road network	Public Works Department, Govt. of HP & Google Earth.	
10.	Soil texture	National Bureau of Soil Survey and Land Use Planning, Nagpur prepared Atlas in collaboration with Department of Agriculture, Govt. of Himachal Pradesh (Scale:1:2,50,000).	
11.	Location map	OpenStreetMap	

4.1 GIS based Multi Criteria Evaluation (MCE)

Suitability analysis in GIS environment is a GIS-based process used to determine the appropriateness of a given area for a particular use. The basic premise of GIS suitability analysis is that each aspect of the landscape has intrinsic characteristics that are either suitable or unsuitable for the activities being planned. Suitability is determined through systematic, multi-factor analysis of the different aspects of the terrain.

The present study is based on land resource data collected from various sources (Table 2), which have been weighted overlaid together using a common measurement scale and weights were provided according to its importance. The same has been implemented through ArcGIS 10 and ERDAS Imagine 9.2.

4.2 Weighted overlay and modelling of criteria

Different thematic layers, which were taken into account for multi criteria evaluation using Weighted Overlay tool by incorporating thematic areas are soil texture, slope, aspect, elevation, land use/cover, geomorphology, lithology, lineaments, drainage network, road network and geology. The Weighted Overlay tool (ArcGIS 10) applies one of the most commonly used approaches for overlay analysis to solve multi-criteria problems such as site selection and suitability models. As with all overlay analysis, in weighted overlay analysis, one must define the problem, break the model into sub-models and identify the input layers. Since the input criteria layers were in different numbering systems with different ranges, to combine them in a single analysis, each cell for each criterion has been reclassified into a common preference scale such as 1 to 10 (or 1 to 5 etc), with 10 being the most favorable. An assigned preference on the common scale implies the phenomenon's preference for the criterion.

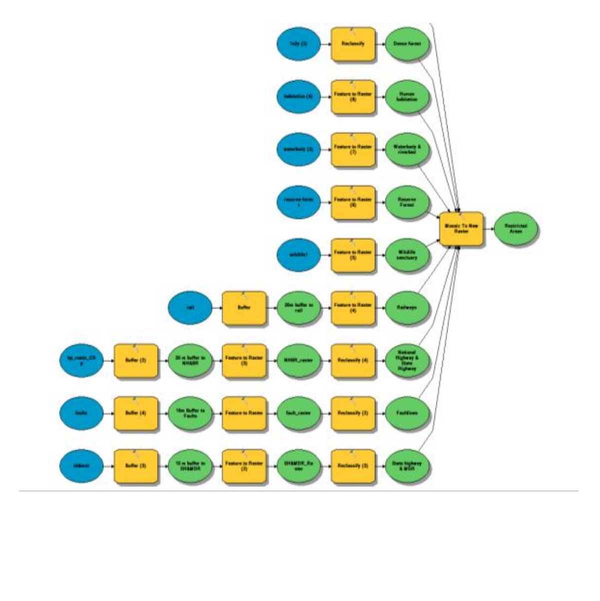
For example, in a simple housing suitability model, you may have three input criteria: slope, aspect, and distance to roads. The slopes are reclassed on a 1 to 10 scale with the flatter being less costly: therefore, they are the most favorable and are assigned the higher values. As the slopes become steeper, they are assigned decreasing values, with the steepest slopes being assigned weight 1. Same is applied for aspect and other layers as well, with the more favorable aspects, in this case the more southerly, being assigned the higher values. The same reclassification process is applied to the distance to roads criterion. The locations closer to the roads are more favorable since they are less costly to build on because they have easier access to power and require shorter driveways. A location assigned a suitability value of 5 on the reclassed slope layer will be twice as costly to build on as a slope assigned a value of 10. A location assigned a suitability of 5 on the reclassed slope layer will have the same cost as a 5 assigned on the reclassed distance to roads layer. (http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-weighted-overlay-works.htm)

Based on the criteria and weightage as mentioned in Annexure-I, suitability map is produced. Landuse, being the central criteria, had maximum weight followed by slope and aspect, which is so important in the case of hill town like Shimla. Nearness to road gives additional advantage to urban growth (ribbon development is a natural occurrence in hill areas) in addition to assigning weights to distance to Municipal Corporation Shimla limit, elevation, geomorphological features geological formation and silt texture.

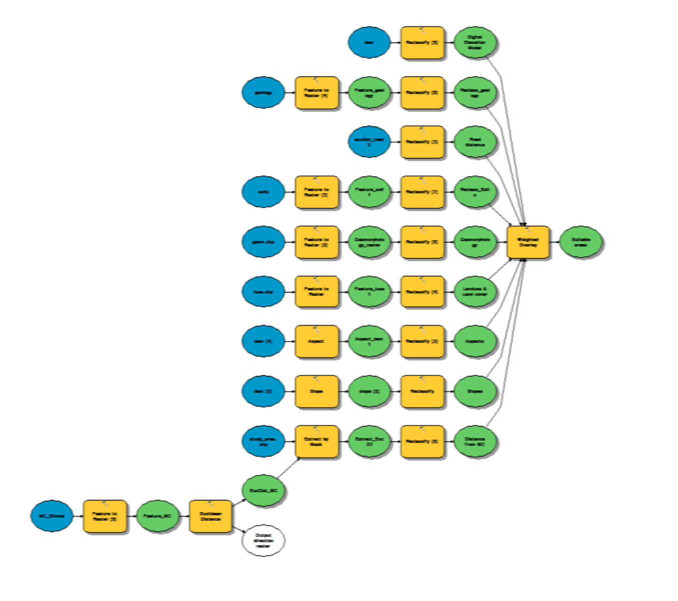
4.3 Modelling workflows of thematic layers

ModelBuilder application of ArcGIS has been used to create, edit and manage models for the current study. Models are basically workflows that string together sequences of geoprocessing tools, feeding the output of one tool into another tool as input. ModelBuilder can also be thought of as a visual programming language for building workflows. The follwing three models were applied to reach the final suitable plot identification for the study (figure 2).

Restriction Model 1: Identification of environmentally sensitive zones& restricted areas



Suitability Model 2: Identification of suitable sites based on weighted overlay methods by incorporating all thematic areas



Suitable Plot Model-3. Identification of suitable sites and plots of more than 100 hectares

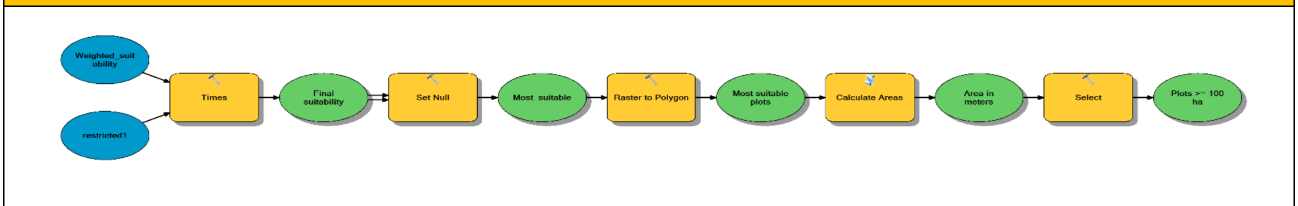


Figure 2: Modelling workflows

4.4 Identification of environmentally sensitive areas and restricted areas

In such assessment, it is also imperative to consider the natural limiting factor, ecologically sensitive factor, ecological protection factor for safeguarding fragile natural resources of hill ecology. Table 3 indicates such areas which have been identified under the restricted zone as no development zone for human habitation growth.

4.5 Thematic mapping

The thematic layers (Figure 3) were prepared based on data and maps collected from multiple sources as mentioned earlier and reclassified as per the weights assigned in the weighted overlay analysis as per Annexure 1. The lower slope obviously shall have lower risk of hazard and weighted as per Geological Survey of India guidelines

Table 3: Environmentally sensitive zones or restricted area

Restricted area	Restricted/buffer in meters
Wildlife sanctuaries	Restricted
Reserve forest	Restricted
Water channel/pond area/river bed	Restricted
Very Dense Forest	Restricted
Dense Forest	Restricted
Cantonment Board & airport	Restricted
Existing Urban and Rural settlements	Restricted
Railway buffer	20 m buffer restriction
Buffer to NH & border roads	20 m buffer restriction
Buffer to SH & MDR	10 m buffer restriction
Lithology fault	10 m buffer restriction

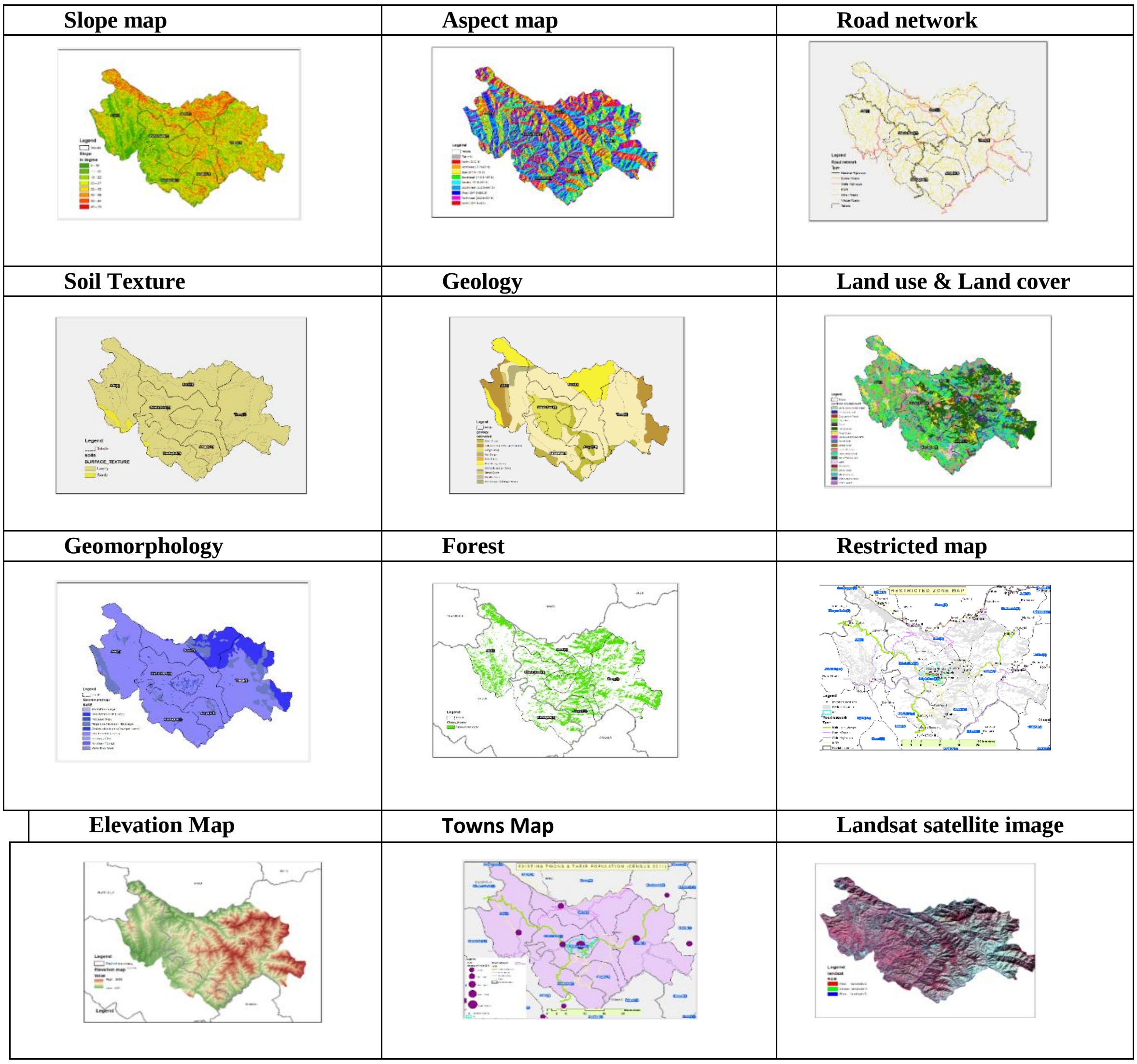


Figure 3: Thematic layers used in the study

4.6 Suitability assessment analysis:

The following criteria have been identified and their thematic maps prepared for the current study along with their assigned weights for suitability analysis as per the breakup indicated in table 4. Higher weights have been assigned to dominating criteria such as land-use/land-cover, slope, aspect, nearness to road as they are very important in guiding spatial pattern of urban development in Himachal Pradesh.

Table 4: Weights assigned to thematic layers

Criteria	Assigned Weights
Landuse	20
Slope	20
Aspect	20
Nearness to roads	15
Distance from Shimla	12
Elevation	6
Geomorphology	3
Soil Texture	2
Geology	2
Total weights	**100**

5. Results and discussion

The final suitability map indicates that about 42 percent of total geographical area (TGA) of the study area is suitable for urban expansion (Figure 5), while about 34 percent is medium suitable, 9% highly suitable and less than 1 percent most suitable. However, plot size of above 100 ha constitutes of about 10.7 percent of total suitable lands (Figure 4), which is spread across all parts of the study area, which indicates there is scope for small sized satellite towns all around. Final large plots have appeared mostly along State Highways and Major District Roads (MDR) falling in most tehsils of study area.

Table 5: Suitable lands

Suitable lands	Area (ha)	Percent area of TGA of study area
TGA of study area	183727	
Medium Suitable	61553.07	33.50
High Suitable	15471.81	8.42
Most Suitable	126.54	0.07
Total suitable lands	**77151.42**	**41.99**

As far as spatial pattern is concerned, suitable plots are fairly distributed among all tehsils. This pattern shall help in identification of specialized satellite township to ease the pressure on Shimla. Site plans can accordingly be formulated out of the suitable patches for further distribution of lands for the purpose of residential, industrial, commercial and recreational activities as per the UDPFI Guidelines of Institute of Town Planners (India) accordingly. Development of above identified suitable lands will be less susceptible to natural disaster and will not have any adverse impact on ecology and environment of the study area.

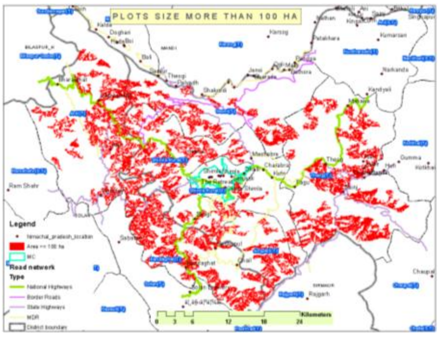


Figure 4: Large plots (over 100 ha) in suitable areas

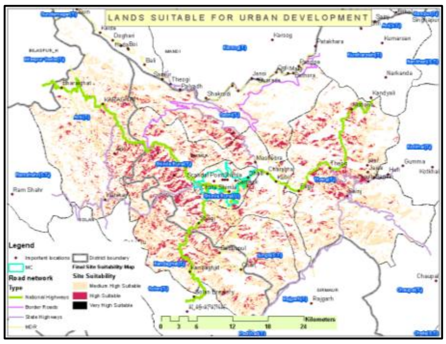


Figure 5: Site suitable for urban expansion

However, most of all, planning any urban expansion or satellite town is going to be an important craft. Respecting the natural limiting factors and judiciously planning on suitable lands is very important for hill town. It is pertinent to mention that a city has several types of land uses, some are highly used and some are sensitive and used as protection area. Therefore, planning of land uses around the suitable land plots are of paramount importance. Some sensitive land uses may be developed, protected, rehabilitated and restored, while some lands of waste nature with moderate and low slope, with southern aspect, solid geological foundation with no geological fault make an ideal location for urban development/expansion in hills. Thus putting a particular piece of land for a particular use is the essence of spatial planning for hill terrain. Hence identifying suitability through the use of available GIS/RS tool is the pre-requisite for sustainable urban expansion.

Furthermore, it would also be appropriate to develop specialized satellite township in different parts of the study area such as horticultural produce based township, which may be located towards Theog in order to market and further value addition of apple production, while other suitable lands may be developed for different specialized township based on the specialized function/character of the region. In addition, several villages have been detected in the areas identified in the suitable zones. These settlements can be strengthened further with appropriate functions/facilities so as to act as catalyst for positive change for its surrounding. Furthermore, it will check Shimla bound migration and ease the growing pressure of Shimla. These urban settlements will also act as marketplace for their hinterland in the long run.

Use of high resolution satellite data coupled with primary/field surveys, integrating them into work of planning activities is of utmost importance. Application of highest resolution satellite data shall completely refine the output of the study, which is mere an indication. The present paper is only a modest attempt to explore the broad opportunities that these geospatial tools offer us, to plan for a better future. Recommendations made for future studies is to improve the efficacy and objectivity of local land use evaluation to support the land use suitability assessment and avoid the subjectivity. As for the accuracy of the real-world case study, the criteria selection and the weight assignment should be widely and deeply discussed and researched.

6. Conclusion

For a sustainable land use plan, land use planning approach requires high resolution satellite data, its seamless integration, multi-disciplinary analysis and need faster or more precise information to the planners and decision makers. This stands very important in view of the topographic complexity of hill town in general and Shimla in particular. Use of high resolution satellite data coupled with primary/field surveys, integrating them into work of planning activities is of utmost importance. The present paper is only a modest attempt to explore the broad opportunities that these geospatial tools offer us, to plan for a better future.

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Annexure 1: Sub-criteria and their assigned weights

Sr.No	1. Land use and Land cover	Weight	Slope in degree	2. Slope Stability	Weight
1	Barren Rocky/Stony waste	9	0^0-15^0	Most stable for urban use	5
2	Crop Land in Forest	3	15^0-30^0	May be utilized for urban development	4
3	Degraded	10	30^0-45^0	Small sized construction where there are in sites rock exposure	3
4	Dense forest	1	45^0-60^0	Should not be normally used without exceptionally sound protective measures.	2
5	Gullied/Ravenouse Land	5	More than 60^0	Should not be used	1
6	Kharif+Rabi	4	**Sr. No.**	**4. Aspect in degree**	**Weight**
7	Land with scrub	5	1	Flat (-1)	10
8	Land without scrub	6	2	North (0-22.5)	1
9	Mixed Built-up land	0	3	Northeast (22.5-67.5)	4
10	Open forest	5	4	East (67.5-112.5)	6
11	Perennial	0	5	Southeast (112.5-157.5)	8
12	Sandy Area	3	6	South (157.5-202.5)	9
13	Scrub Forest	7	7	Southwest (202.5-247.5)	7
14	Habitation	0	8	West (247.5-292.5)	5
15	Water body	0	9	Northwest (292.5-337.5)	3
Sr. No	**3. *Nearness to roads (m)**	**Weight**	10	North (337.5-360)	2
1	0 – 83	5	**Sr. No.**	**5. *Distance from Shimla (m)**	**Weight**
2	83- 193	4	1	523 – 1193	5
3	193- 332	3	2	1193 – 1442	4
4	332- 553	2	3	1442 – 1703	3
5	553- 3514	1	4	1703 – 2012	2
Sr. No	**6. *Elevation in meters**	**Weight**	5	2012 – 3055	1
1	2012 – 3055	5	**Sr. No**	**1. Geomorphology**	**Weight**
2	1703 – 2012	4	1	Alluvial fan Younger	3
3	1442 – 1703	3	2	Denudational Hills (Large)	9
4	1193 – 1442	2	3	Habitation Mask	0
5	523 – 1193	1	4	Ridge type Structural Hills (Large)	8
Sr. No.	**2. Geology**	**Weight**	5	Shallow alluvial plain (Younger/ Lower)	7
1	Balini Group	2	6	Structural Hills (Large)	10
2	Dalhausie-Mandi-KarsogGranitoid	7	7	Terraces – Older	6
3	Jutogh Group	10	8	Terraces – Younger	5
4	Krol Group	6	9	Water Body Mask	0
5	Kullu Group	8	**Sr. No.**	**3. Soil Texture**	**Weight**
6	Shali&Largi Group	1	1	Loamy	5
7	Shimla &Jaunsur Group	9	2	Sandy	2
8	Sirmur Group	5			
9	Siwalik Group	2			
10	Sundarnagar& Rampur Group	3			

**Quantile method of ArcGIS 10 classification applied*– Each class contains an equal number of features. A quantile classification is well suited to linearly distributed data. Quantile assigns the same number of data values to each class. There are no empty classes or classes with too few or too many values.