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Analytical Hierarchy Process Framework for Residential Landuse Suitability using Multi-Criteria Decision Analysis

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ABSTRACT

Analytic Hierarchy Process (AHP) has emerged as one of the most important structured technique in the field of complex decision analysis. In this paper, an endeavor has been made using AHP for land use suitability of residential land uses in conjunction with five different models like Landscape Characteristics response model (LCRM), socio-economic response model (SERM), environmental response model (ERM), Geophysical response model (GRM) and Utility responses model (URM) together using spatial technique for Pimpri-Chinchwad-Municipal-Corporation (PCMC) area, Maharashtra, India. This is just an amalgamation of a heuristic algorithm that provides good approximate, but not necessarily optimal solution to a given model in the area under consideration. To derive ratio scales from paired comparisons in employing such an algorithm, one may be able to precisely measure the 'goodness' of the approximation. In the present envisaged study, the first LCRM include the factors like slope, drainage density, SBI (Soil Brightness Index), NDVI (Normalized Difference Vegetation Index) and form factor. The second Socioeconomic response model include the factors like Price, Land Use, Land cover, Facilities available and Population Density. The third environmental response model include the factors like water availability, flood hazard, air pollution, water quality index and the distance of waste disposal. The fourth geophysical response model includes the factors elevation, geomorphology and geology. The fifth Utility response model includes the factors like sewage line and road proximity (accessibility). These all factors affecting in the process are analytically and logically encompassed to make a gainful research through a scientifically proven method, which has been depicted in this present paper in a sequential manner.

KEYWORDS: Multi Criteria Decision Analysis (MCDA), Analytical Hierarchy Process (AHP)

I. INTRODUCTION

Land suitability assessment is similar to choosing an appropriate location and the goal of this study is to map a suitability index for the entire study area. It is a fundamental work and an important tool for overall land use planning, which requires a scientific approach to guide development, avoid errors in decision-making and over-investment. For sustainable utilization of land resources [3], [15] map overlays are used to define homogeneous zones, and then classification techniques are applied to assess the residential land suitability level of each zone. The processes of land use involved evaluation and grouping of specific areas of land in terms of their suitability for a defined use. The principles of sustainable development make land-use suitability analysis increasingly complex due to consideration of different requirements/criteria [2]. Research in this area is very important to achieve cost effective and sustainable development of land use in general and residential land use planning in particular.

II STUDY AREA

As emerged from the defined objectives, the study area has been chosen which encompasses the extent of latitude from 18°34'3.417"N to 18°43'22.033"N latitude and longitude 73°42'38.595"E to 73°56'2.726"E.

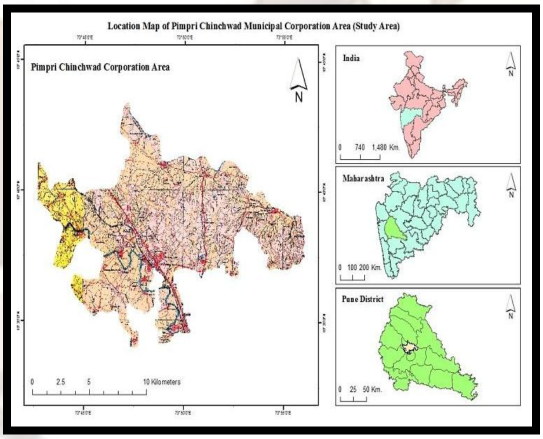


Figure 1. Study Area

The area lies within the domain of PCMC area of Maharashtra, India, as depicted in above Figure 1.The area is situated in the climate zone of hills and plain, it is influenced by common effects of tropical monsoon climatic belt with the three distinct seasons. The annual average temperature is about 250C. The average annual rainfall is about 600-700 mm, but is irregularly distributed. The maximum rainfall is observed in June-September. PCMC a twin city of Pune, is one of the fast growing medium size cities of

Maharashtra with a population of about 1.7 millions as per census of 2011and sprawling over an area of 174 sq. km.

III EARLIER RESEARCH

The Analytic Hierarchical Process (AHP) is one of the methodological approaches that may be applied to resolve highly complex decision making problems involving multiple situations, criteria and factors [14]. Thomas L. Saaty (1970), constructs a ratio scale associated with the priorities for the various items to be compared. In his initial formulation of AHP, Saaty proposed a four-step methodology comprising modelling, valuation, prioritization and synthesis. At the modelling stage, a hierarchy representing relevant aspects of the problem (criteria, sub-criteria, attributes and alternatives) has been constructed. The goal concerned in the problem is placed at the top of this hierarchy. Other relevant aspects (criteria, sub-criteria, attributes, etc.) are placed at remaining levels [1]. In the AHP method, obtaining the weights or priority vector of the alternatives or the criteria is required. For this purpose Saaty (1980) has developed the Comparison Method (PCM), which is explained in detail in next part of the work. This study focuses on the utility of the AHP as a model for capturing expert knowledge on environmental systems where data may be lacking. The AHP method commonly used in multi-criteria decision making exercises was found to be a useful method to determine the weights, compared with other methods used for determining weights. When applying AHP, constraints are compared with each other to determine the relative importance of each variable in accomplishing the overall goal.

IV DATA AND METHODOLOGY

The Linear Imaging Self Scanner (LISS III) digital data having spatial resolution of 23.5 m for April, 2008 and May, 2008 have been taken in conjunction with Aster Digital Elevation Model (DEM) data of 30 m resolution downloaded from Aster GDEM website. Analog and other ancillary data were collected from Survey of India Toposheets47/F/14 and 47/F/10 of 1:50000 scales for the area under PCMC. The entire methodology of the present work is focused on the application of AHP and GIS for land use suitability analysis for residential land uses. The principal steps involved in the methodology are as follows:

i. Raster map creation
ii. Geo-referencing
iii. Extraction of study area
iv. Preparation of various raster layers
v. AHP and GIS analysis

The three main AHP criteria of selection, weighing and overly are described below.

A. SELECTING CRITERIA

In this study criteria were selected using the literature reviews of internal and external references, interviewing with experts (questionnaires) and availability of data.

B. WEIGHING CRITERIA

For determining the relative importance of the criteria the pair-wise comparison matrix using Saaty's nine-point weighing scale has been applied. In AHP, all identified factors are compared against each other in a pair wise comparison matrix which is a measure of relative importance/preference among the factors. Therefore, numerical values expressing the relative preference of a factor against another.

Table 1.Nine-point weighing scale for pair-wise comparison

Descriptions of Preference	Scale
i) Equally	1
ii) Equally to moderately	2
iii) Moderately	3
iv) Moderately to strongly	4
v) Strongly	5
vi) Strongly to very Strongly	6
vii) Very Strongly	7
viii) Very Strongly to extremely	8
ix) Extremely	9

Saaty (1977) suggested a scale for comparison consisting of values ranging from 1 to 9 which describe the intensity of importance, by which a value of 1 expresses equal importance and a value of 9 is given to those factors having an extreme importance over another factor as shown in Table 1 [7]. Then by using the information from table 1, the factors were pair wise compared. In order to compare criteria with each other, all values need to be transformed to the same unit of measurement scale (from 0 to 1).Overall results of weights &scores for each factors are then calculated to generate the final weight as multiplication of all associated weights. Then the consistency ration is calculated using the formula given below to ensure the credibility. After standardization all criteria and sub criteria were weighted using pair wise comparison method. An factors that are considered as main criteria, sub criteria (SC) & indicators are given in Table 2 to 6 respectively.

Table 2. Weighing matrix for first main criteria (Landscape Characteristics response model)

Criteria	SC &Weight	Indicators
Landscape Characteristics Response Model	Slope	More than 15%
		10 – 15 %
		05 – 10 %
		03 – 05 %
		00 – 03 %
	Drainage Density	More than 3.20
		2.4 – 3.2
		1.6 – 2.4
		0.8 – 1.6
		Less than 0.8
	SBI	More than80
		70 -80
		60 – 70
		50 - 60
		Less than 50
	NDVI	Less than (-)0.03
		(-)0.03 – 0.05
		0.05 – 0.15
		0.15 – 0.30
		More than 0.30

Table 3.Weighing matrix for second main criteria (Environmental response model)

Criteria	SC & Weight	Standards Adopted
Environmental Elements	Water Availability	> 4000
		3000 – 4000
		2000 – 3000
		1000 – 2000
		0 – 1000
	Flood Line Distance	> 400
		300 – 400
		200 – 300
		100 – 200
		0 – 100
	Air Pollution Data	1
		2
		3
		4
		5
	WQI	> 55.5
		53.5 - 55.5
		51.5 - 53.5
		< 51.5
	Distance From Waste Disposal Site	> 4000
		3000 – 4000
		2000 – 3000
		1000 – 2000
		< 1000

Table 4. Weighing matrix for third main criteria (Socio-economical response model)

Criteria	Sub-criteria	Standards Adopted
Socio Economic Parameters	Price Factor	< 2250
		2250-4500
		4500-6750
		6750-9000
		> 9000
	LU/LC	Scrub
		Vegetation
		Agriculture
		Harvested
		Settlement
	Available Facility (Hospital, school. fire station, land mark,garden etc)	5
		4
		3
		2
		1
	Population Density	< 5000
		5000-10000
		10000-15000
		15000-20000
		> 20000

Table 5. Weighing matrix for fourth main criteria (Geophysical response model)

Criteria	Weight	Criteria
Geo Physical Elements	Slope	00 – 03 %
		03 – 05 %
		05 – 10 %
		10 – 15 %
		More than 15 %
	Elevation	< 560
		560 - 575
		575 - 590
		590 - 605
		> 605
	Geomor-phology	Rolling Pediment Plain
		Buried Pediment
		Plateau Fringe Surface
		Plateau Surface Remnants
		River
	Geology	Compound Pahoehoe Basaltic Lava Flow
		Basaltic Lava Flow

It could be seen that for preventing bias thought criteria weighting the Consistency Ratio was used .

$$C.I = \frac{\lambda_{max}-n}{n-2} \quad (1)$$

$$C.R. = \frac{C.I.}{R.I.} \quad (2)$$

Where; n = Number of Items Being Compared in the Matrix

λ_{max} = Largest Eigen Value

RI = Random Consistency Index

Table 6. Weighing matrix for fifth main criteria (Miscellaneous technical response model)

Criteria	Sub Criteria	Standards Adopted	Weight
Misc/ Tech	Sewerage line Availability	> 800	9
		600-800	7
		400-600	5
		200-400	3
		<200	1
	Road proximity	<200	8
		200-400	6
		400-600	4
		600-800	3
		>800	1

C. OVERLYING

After weighing of criteria regarding their importance for land suitability analysis, all criteria maps were overlaid using suitability index (S. I.).

$$\text{Suitability Index (S.I.)} = (RI * A1 * \Sigma RI.Bi * RI.KBi) + (RI * A2 * \Sigma RI.Cy * RI.KCy) + (RI * AN * \Sigma RI.Dz * RI.KDz)$$

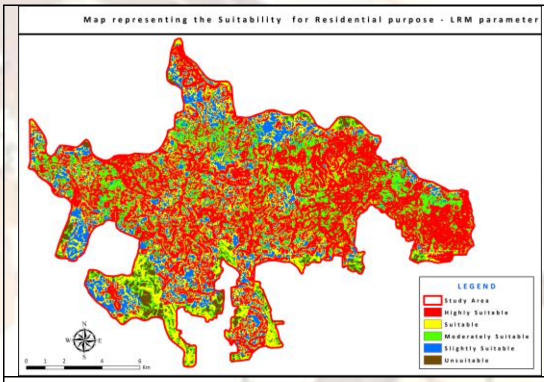
Where, SI is the Suitability Index of each cells; N is the number of main criteria; RI,A1, RI, A2 …R_N,A_N are the relative importance of the main criteria A1, A2 …A_N, respectively; m, i and j are the number of sub criteria directly connected to the main criteria A1, A2 …A_N, respectively. RIB, RIC and RID are the relative importance of sub criteria B, C and D directly connected to the main criteria A1, A2 …A_N, respectively. RIKB, RIKC and RIKD are the relative importance of indicators category k of sub criteria B, C and D and main criteria A1, A2 …A_N, respectively.

D. CALCULATION OF SCORE VALUE FOR EACH CRITERION

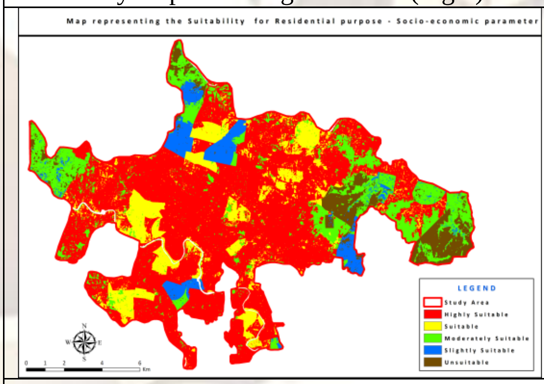
The suitability value for all these main and sub criteria in Pimpri-Chinchwad area and the criterion for each land mapping unit is determined through the maximum limitation method that affects the land use. The above five representative natural physical characteristics are used in the combination to determine the final suitability map of the PCMC area. Before applying weighted linear combination equation to calculated suitability index, these calculated scores are standardized to the measured scale 9 (very high suitability), 7 (High), 5 (medium), and 1 (Low). The total suitability score from each land unit varies between 0 and 1. Thus the data in the maps are then classified to represent the five suitability classes as mentioned above.All of the classifications and ranking values in spatial analysis are obtained according to some studies of Al-Shalabi et al. (2006), Kordi (2008), Kanlaya (2009) and based on visiting the study area.

E. PREPARATION OF LAND SUITABILITY MAPS

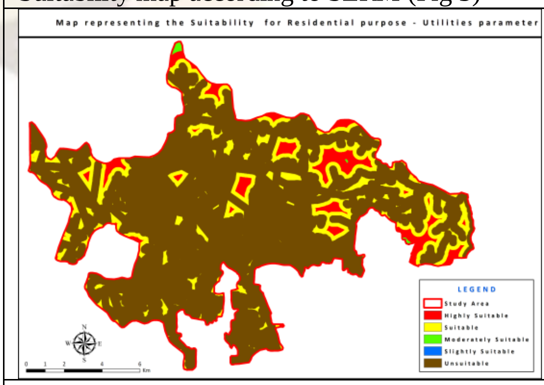
After weighting the criteria, as regards the relative importance of each criterion as well as suitability index, all the criterion maps were overlaid and final rangeland suitability map was prepared. Suitability maps resulting from Multi-Criteria Evaluation (MCE) are based on relative weights of the suitability factors for development, suitability ranges were identified. Figure 2 to 6 depicts the final map (suitability map), according the major criterion under consideration and for combined suitability map over laying all these maps, which are divided to 5 classes in decreasing order of suitability and are indicated in different colours.



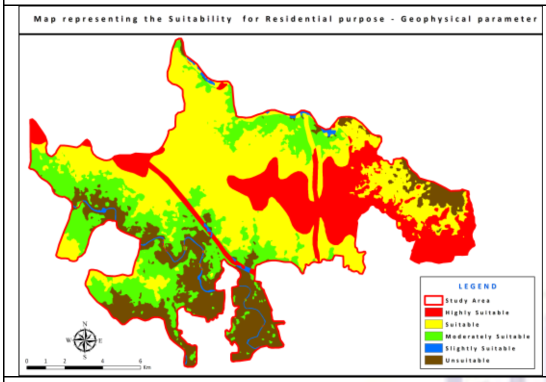
Suitability map according to LCRM (Fig 2)



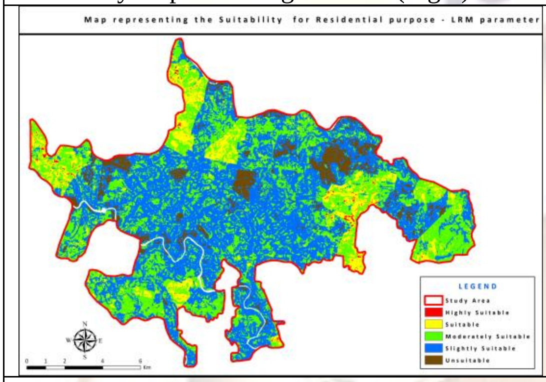
Suitability map according to SERM (Fig 3)



Suitability map according to URM (Fig 4)



Suitability map according to GRM (Fig 5)



Final Suitability Map of PCMC area (Fig 6)

Figure 2 Suitability maps

The following results emerged out of the present study:

i) The Study area has been classified in to nine ranges using supervised algorithm and different suitability classes are obtained which are then reclassified into five classes as shown in figures.

ii) NDVI layer was assigned to the area, which demonstrated the vegetation classes.

iii) Price, land use, land cover, facilities available and population density (5classes each) were derived from the digital image illustrating the suitability of the area.

iv) AHP used hierarchical structures for nine scales with the Socio-economic criteria, and were devised for the design of AHP applicability for residential land use suitability. The AHP was devised for all the sub criteria, evaluating their relative scores for attribute classes to get the land use suitability model for PCMC area using socio economic parameters as mentioned above.

v) It is revealed that about 8% area is found to be unsuitable whereas other area is found to be suitable from SS to HS category.

V CONCLUSIONS

The analysis of this study mainly focused on highly suitable areas as these areas have highest potential for construction purposes i.e. residential land use. AHP model has been to land use suitability analysis based on five criteria layers. The Analytic Hierarchy Process (AHP) method has been found as a useful method to determine the weights, as compare to other methods used for determining weights. The sensitivity utility of this model helped to analyze the decision before making the final choice. The AHP method could deal with inconsistent judgments and can provide a tool to measure the inconsistency of the judgment taken by the respondents. This assessment can be useful in decision-making process for land use planning and can also help in sustainable urban development of PCMC area. It is very important for planners to decide whether land should be developed immediately or to be conserved for future development. This model can help to prepare the strategic urban land development framework and the short-term land use policies can be formulated. The approach, therefore, can help the planners and policy makers to monitor the urban land development for formulating urban growth policies and strategies for a city.

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