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Multi-Criteria Decision Analysis For Residential Land Use Suitability Using Socio-Economic Responses Through AHP

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ABSTRACT

Analytic Hierarchy Process (AHP) has emerged as one of the most important structured techniquein the field of complex decision analysis. In this paper, an endeavor has been made using AHP for land use suitability of real estates in conjunction with Erosion Response using spatial technique for Pimpri-Chinchwad-Municipal Corporation (PCMC) area. 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 factors like Price, Land Use, Land cover, Facilities available and Population Density 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),socio-economic factors, land-use suitability.**

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. These classification techniques have been based on Boolean and fuzzy theory or artificial neural networks. The processes of land useinvolved 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. THE STUDY AREA

As emerged from the defined objectives of the research, 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 . The area lies within the domain of PCMC area of Maharashtra, India, as depicted in Figure 1.The area is situated in the climate zone of hills and plain, it is influenced by common effects of

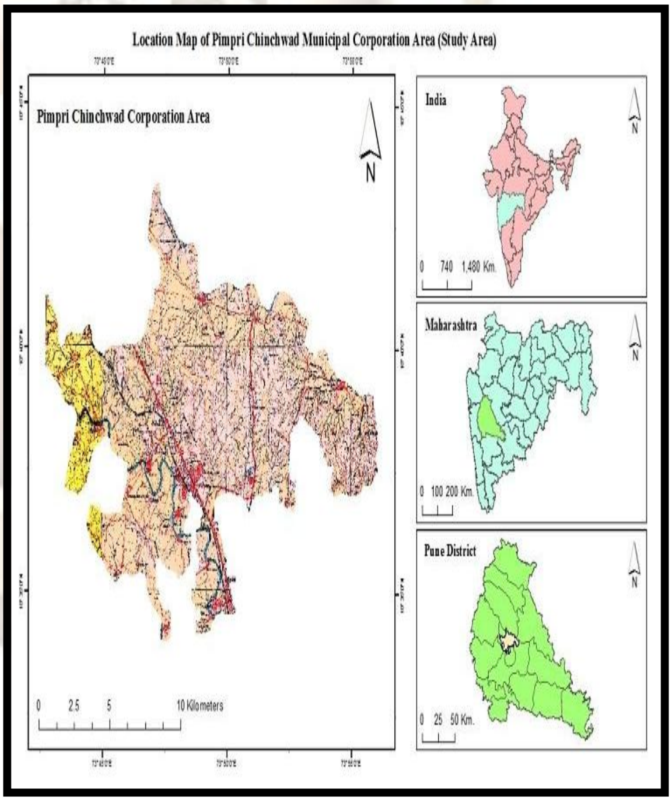

Figure.1 The study area

tropical monsoon climatic belt with the three distinct seasons. The annual average temperature is about 25^{0C}. 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 formulationofAHP, Saaty proposed a four-step methodology comprising modeling, valuation, prioritization and synthesis. At the modeling 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 USED 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 theapplication of AHP and GIS for land use suitability analysis for residential land uses. The principal steps involved in the methodologyareas 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.

4.1 SELECTING CRITERIA

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

4.2WEIGHING OF CRITERIA (SCALE FOR PAIR WISE COMPARISON)

For determining the relative importance of the criteria thepair-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. 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), whereas the various input maps have different measurement units (e.g. distance maps, temperature etc.).

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

After standardization all criteria and sub criteria were weighted using pair wise comparison method. An example of main criteria and sub criteria weighing is given in Table 2 and 3respectively.

TABLE 2: Weighing matrix for main criteria

Criteria	**Sub-criteria**	**Standards Adopted**	**Weight**
SocioEconomic Parameters	PriceFactor	< 2250	9
		2250-4500	5
		4500-6750	2
		6750-9000	1
		> 9000	1
	LU/LC	Scrub	9
		Vegetation	5
		Agriculture	3
		Harvested	2
		Settlement	1
	Available Facility	5	9
		4	5
		3	3
		2	1
		1	1
	Population Density	< 5000	9
		5000-10000	5
		10000-15000	3
		15000-20000	2
		>20000	1

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

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

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

Where; n = Number of Items Being Compared inthe Matrix

λ_{max}= Largest Eigen Value

RI = Random Consistency Index

4.3 OVERLYING

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

Suitability Index, $SI = (RI * A1 * \Sigma RI.Bi * RI.KBi$

$$+ (RI * A2 * \Sigma RI.Cy * RI.KCy) + (RI * AN * \Sigma RI.Dz * RI.KDz)$$

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.

4.4 CALCULATION OF SCORE VALUE FOR EACH CRITERION

The suitability value for price factor, land use land cover, facilities available, population density,inPimpri-Chinchwad area and the criterion for each land mapping unit is determined through the maximum limitation method that affects the land use. The above four representative natural physical characteristics are used in socio-economic response model constitute the sub-criteria under socioeconomic criteria. 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). All of the classifications and ranking values in spatial analysis are obtained according to some studies of Al-Shalabi et al. (2006), Kordi (2008) and based on visiting the study area.

4.5 PREPARING 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) and multi-objective land allocation have shown different classes for which the degree of sensitivity to accept new building for example estates and urban settlements vary from extremely prone areas to weakly prone.

Based on relative weights of the suitability factors for development, suitability ranges were identified as shown in Table 10. Figure 2 depicts the final map (suitability map), which divided to 5 best areas in increasing order: area 1, 2, 3, 4 and 5. According to this map, there are 5 colours (classes): dark Blue, Blue,Green, Yellow and Red.

TABLE3: Weighing Matrix for Facilities Available

Criteria	Sub-criteria	Criteria	Weight
Socio Economic Parameters (Facilities Availale)	Hospital	<1500	9
		1500-3000	5
		3000-4500	3
		4500-6000	1
		> 6000	1
	School	<600	9
		600-1200	5
		1200-1800	3
		1800-2400	1
		>2400	1
	Garden	<1400	9
		1400-2800	5
		2800-4200	2
		4200-5600	1
		>5600	1
	Landmarks	<750	9
		750-1500	5
		1500-2250	3
		2250-3000	2
		>3000	1
	Fire Stations	<2500	9
		2500-5000	5
		5000-7500	3
		7500-10000	1
		>10000	1

TABLE 4: Suitability according to Facilities Available –Hospital (Normalized matrix)

Hospital(meters)	<1500	1500-3000	3000-4500	4500-6000	> 6000	Sum	PV	Score
<1500	0.56	0.63	0.52	0.46	0.36	2.54	0.51	9.00
1500-3000	0.19	0.21	0.31	0.26	0.28	1.25	0.25	4.45
3000-4500	0.11	0.07	0.10	0.20	0.20	0.68	0.14	2.42
4500-6000	0.08	0.05	0.03	0.07	0.12	0.35	0.07	1.25
> 6000	0.06	0.03	0.02	0.02	0.04	0.18	0.04	0.62

TABLE 5: Suitability according to Facilities Available –School(Normalized matrix)

School(meters)	<600	600-1200	1200-1800	1800-2400	>2400	Sum	PV	Score
<600	0.54	0.64	0.47	0.43	0.36	2.44	0.49	9.00
600-1200	0.18	0.21	0.35	0.31	0.28	1.33	0.27	4.91
1200-1800	0.14	0.07	0.12	0.18	0.20	0.71	0.14	2.61
1800-2400	0.08	0.04	0.04	0.06	0.12	0.34	0.07	1.26
>2400	0.06	0.03	0.02	0.02	0.04	0.17	0.03	0.64

TABLE 6: Suitability according to Facilities Available –Garden (Normalized matrix)

Garden	<1400	1400-2800	2800-4200	4200-5600	>5600	Sum	PV	Score
<1400	0.56	0.64	0.52	0.43	0.36	2.51	0.50	9.00
1400-2800	0.19	0.21	0.31	0.31	0.28	1.30	0.26	4.66
2800-4200	0.11	0.07	0.10	0.18	0.20	0.67	0.13	2.40
4200-5600	0.08	0.04	0.03	0.06	0.12	0.34	0.07	1.21
>5600	0.06	0.03	0.02	0.02	0.04	0.17	0.03	0.62

TABLE 7: Suitability according to Facilities Available –Landmark (Normalized matrix)

Landmarks	<750	750-1500	1500-2250	2250-3000	>3000	Sum	PV	Score
<750	0.56	0.63	0.52	0.46	0.41	2.57	0.51	9.00
750-1500	0.19	0.21	0.31	0.26	0.23	1.20	0.24	4.18
1500-2250	0.11	0.07	0.10	0.20	0.18	0.66	0.13	2.32
2250-3000	0.08	0.05	0.03	0.07	0.14	0.37	0.07	1.29
>3000	0.06	0.04	0.03	0.02	0.05	0.20	0.04	0.69

TABLE 8:Suitability according to Facilities Available –Fire station (Normalized matrix)

Fire-station	<2500	2500-5000	5000-7500	7500-10000	>10000	Sum	PV	Score
<2500	0.53	0.64	0.47	0.39	0.32	2.34	0.47	9.00
2500-5000	0.18	0.21	0.35	0.32	0.32	1.38	0.28	5.31
5000-7500	0.13	0.07	0.12	0.19	0.23	0.74	0.15	2.85
7500-10000	0.09	0.04	0.04	0.06	0.09	0.33	0.07	1.25
>10000	0.08	0.03	0.02	0.03	0.05	0.21	0.04	0.80

TABLE 9: Suitability according to Facilities Available –Criteria (Normalized matrix)

	H	S	G	L	F	Sum	PV	Score
Hospital (H)	0.50	0.54	0.52	0.39	0.33	2.30	0.46	9.00
School (S)	0.25	0.27	0.31	0.33	0.29	1.46	0.29	5.71
Garden (G)	0.10	0.09	0.10	0.20	0.21	0.70	0.14	2.74
LandMarks (L)	0.08	0.05	0.03	0.07	0.13	0.36	0.07	1.42
Fire Station (F)	0.06	0.04	0.02	0.02	0.04	0.19	0.04	0.73

TABLE 10:

Sr No	Level	Rank
1	Highly Suitable	5
2	Suitable	4
3	Moderately suitable	3
4	Slightly suitable	2
5	Unsuitable	1

TABLE 11: Suitability according to Price factor (Normalized matrix)

Class	0 - 2250	2250 - 4500	4500 - 6750	6750 - 9000	> 9000	Sum	PV	Score
0 - 2250	0.56	0.64	0.52	0.43	0.36	2.51	0.50	9.00
2250 - 4500	0.19	0.21	0.31	0.31	0.28	1.30	0.26	4.66
4500 - 6750	0.11	0.07	0.10	0.18	0.20	0.67	0.13	2.40
6750 - 9000	0.08	0.04	0.03	0.06	0.12	0.34	0.07	1.21
> 9000	0.06	0.03	0.02	0.02	0.04	0.17	0.03	0.62

TABLE 12: Suitability according to Landuse/Land Cover (Normalized matrix)

Class	Scrub	Vege.	Agri.	Har	Sett	Sum	PV	Score
Scrub	0.53	0.63	0.47	0.38	0.41	2.41	0.48	9.00
Veg	0.18	0.21	0.35	0.30	0.23	1.26	0.25	4.72
Agri	0.13	0.07	0.12	0.23	0.18	0.72	0.14	2.71
Har.	0.11	0.05	0.04	0.08	0.14	0.41	0.08	1.53
Sett.	0.06	0.04	0.03	0.03	0.05	0.20	0.04	0.75

TABLE 13: Suitability according to Facilities Available (Normalized matrix)

Class	5	4	3	2	1	Sum	PV	Score
5	0.51	0.54	0.52	0.43	0.36	2.37	0.47	9.00
4	0.26	0.27	0.31	0.31	0.28	1.43	0.29	5.43
3	0.10	0.09	0.10	0.18	0.20	0.68	0.14	2.59
2	0.07	0.05	0.03	0.06	0.12	0.34	0.07	1.31
1	0.06	0.04	0.02	0.02	0.04	0.18	0.04	0.67

TABLE 14: Suitability according to Population Density (Normalized matrix)

Class	< 5	5-10	10-15	15-20	>20	Sum	PV	Score
<5	0.51	0.63	0.47	0.38	0.32	2.30	0.46	9.00
5-10	0.17	0.21	0.35	0.30	0.26	1.29	0.26	5.07
10-15	0.13	0.07	0.12	0.23	0.21	0.75	0.15	2.94
15-20	0.10	0.05	0.04	0.08	0.16	0.43	0.09	1.67
>20	0.09	0.04	0.03	0.03	0.05	0.23	0.05	0.92

TABLE 15: Final Suitability according to all Socio Economic factors (Normalized matrix)

Class	P	L	F	P	Total	PV	Score
Price	0.52	0.57	0.48	0.40	1.97	0.49	9.00
LU/LC	0.26	0.28	0.36	0.33	1.24	0.31	5.66
Facility	0.13	0.09	0.12	0.20	0.54	0.14	2.49
Popu.	0.09	0.06	0.04	0.07	0.25	0.06	1.14

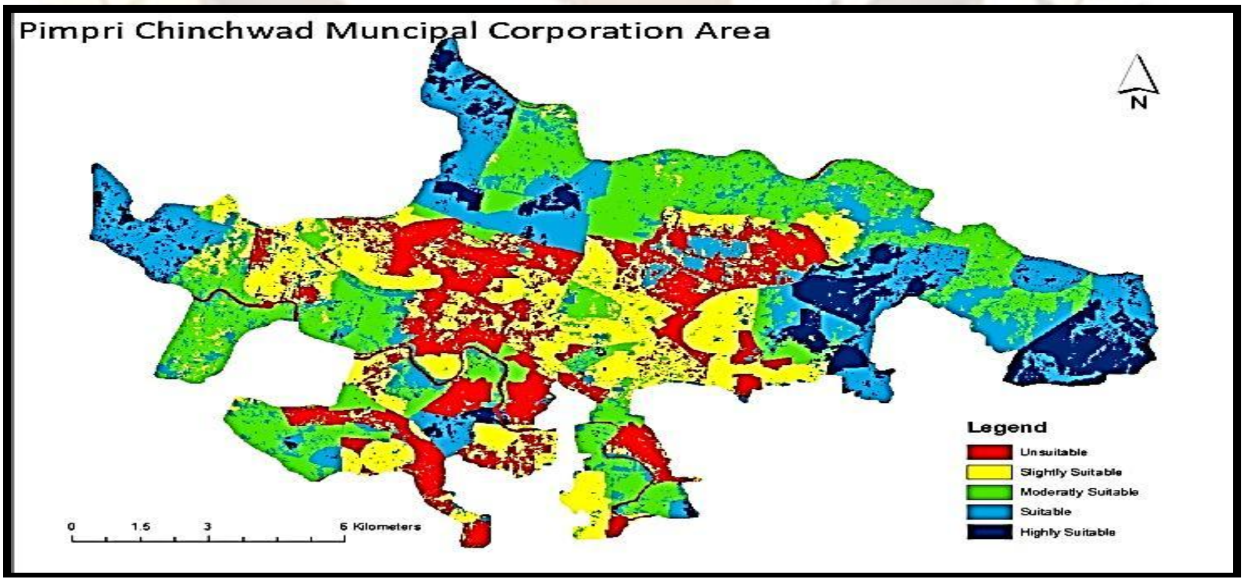

Figure 2 Final Suitability Map

The following results emerged out of the present study:

i) The Study area has been classified in to nine ranges using supervisedalgorithm and different suitability classes are obtained

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

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

iv) AHP used hierarchical structuresfor nine scales with the Socio-economic criteria, and were devised for the designof AHP applicability for residential land use suitability. The AHP was devised for allthe sub criteria, evaluating their relative scores for attribute classes toget the land use suitability model forPCMC area using socio economic parameters as mentioned above.

V. CONCLUSION

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 foundas 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 helpthe planners and policy makers to monitorthe urban land development for formulating urban growth policies and strategies for a city.

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