Analytic Hierarchy Process for Evaluation Of Environmental Factors For Residential Land Use Suitability

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Abstract

An attempt has been endeavored in the Analytical Hierarchical Process of land use suitability for residential land uses of in conjunction with environmental factors 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 environmental elements factors like Water availability, Flood line distance, Air pollution data, Water Quality Index and Distance of Waste disposal site 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), land-use suitability, environmental factors, Consistency Index(CI), Random Index (RI) , Consistency Ratio (CR)

1. Introduction

Land suitability assessment through environmental factors is an intrinsically complex multi-dimensional process, involving multiple criteria and multiple factors. Multi-criteria methods can serve as useful decision aids for carrying out the case. AHP has the flexibility to combine quantitative and qualitative factors, to handle different environmental groups of actors. Finally, the use of AHP is illustrated for a case study involving environmental impact.This is similar to choosing an appropriate location and the goal is to map a suitability index for the entire study area. It is the fundamental work and an important content of 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]it used map overlays to define homogeneous zones, and then they applied classification techniques 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 useinvolve 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 become increasingly complex due to consideration of different requirements/criteria [2].

2. 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 Pimpri-Chinchwad 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 tropical monsoon climaticbelt 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.Pimpri-Chinchwad city, one of the fast growing medium size cities of Maharashtra with a population of about 1.7 million in 2011(projected) and sprawling over an area of 174 sq. km.

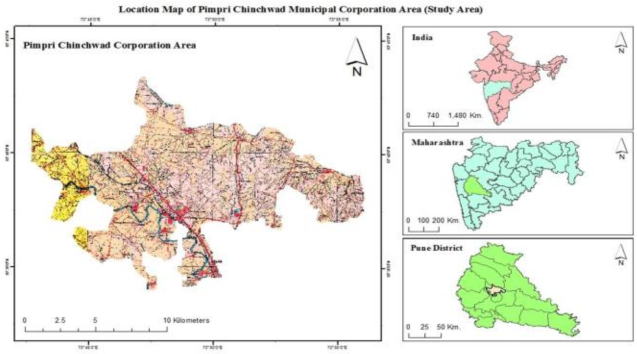

Fig.1. Study area.

3. 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 scenarios, criteria and factors[14]. Proposed in the 1970s by Thomas L. Saaty, it constructs a ratio scale associated with the priorities for the various items compared. In his initial formulation, conventional AHP, 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, at]tributes and alternatives) is constructed. The goal or mission concerned in the problem is placed at the top of this hierarchy. Other relevant aspects (criteria, sub-criteria, attributes, etc.) areplaced in the 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 used and developed the Comparison Method (PCM), which is explained in detail in next part of the work [5]. 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.

4. DATA USED AND METHODOLOGY

AHP is a comprehensive intuitive method for formulating and analyzing decisions. AHP has been applied to numerous practical problems in the last few decades [17]. Because of its intuitive appeal and flexibility, many corporations and governments routinely use AHP for making major policy decisions [3]. A brief discussion of AHP for environmental evaluation is provided in this text. More detailed description of AHP and application issues can be found elsewhere [14].The Linear Imaging Self Scanner (LISS III) digital data of 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 Pimpri-Chinchwad-Municipal Corporation area and PCMC office.

Application of AHP to a decision problem involves four steps:

i. Structuring of the decision problem into a hierarchical model.
ii. Making pair-wise comparisons and obtaining the judgmental matrix.
iii. Local priorities and consistency of comparisons.
iv. Aggregation of local priorities

The entire methodology of the present work is focused on theapplication of AHP and GIS for land use suitability analysis for residential land use has been given below. The principal steps involved in the methodologyareas follows:

- ➢ Raster map creation
- ➢ Geo-referencing
- ➢ Extraction of study are

- Preparation of various raster layers
- AHP and GIS analysis

TABLE 1: NINE-POINT WEIGHING SCALE FOR PAIR-WISE COMPARISON

Descriptions of preference	Scale
Equally	1
Equally to moderately	2
Moderately	3
Moderately to strongly	4
Strongly	5
Strongly to very Strongly	6
Very Strongly	7
Very Strongly to extremely	8
Extremely	9

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

TABLE 2: WEIGHING MATRIX FOR MAIN CRITERIA

Criteria	Sub Criteria	Standards Adopted	Weight
Environmental Elements	Water Availability	> 4000	9
		3000 – 4000	6
		2000 – 3000	3
		1000 – 2000	2
		0 – 1000	1
	Flood Line Distance	> 400	9
		300 – 400	5
		200 – 300	2
		100 – 200	1
		0 – 100	Restricted
	Air Pollution Data	1	9
		2	5
		3	3
		4	2
		5	1
	WQI	> 55.5	9
		53.5 - 55.5	6
		51.5 - 53.5	3
		< 51.5	2
	Distance From Waste Disposal Site	> 4000	9
		3000 – 4000	5
		2000 – 3000	3
		1000 – 2000	1
		< 1000	1

The three main AHP criteria such as 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 the stakeholders.

B. Weighing of Criteria (Scale for pair wise comparison)

For determining the relative importance of criteria the pair-wise comparison matrix using Saaty's nine-point weighing scale were 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) notes that 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 3 :WEIGHING MATRIX FOR SUB CRITERIA OF AIR POLLUTION

Criteria	Sub Criteria	Standards Adopted	Weight
Air Pollution	SOx(%)	>70	9
		63-70	5
		55-63	3
		47-55	2
		<47	1
	SPM	>600	9
		472-600	5
		344-472	3
		216-344	2
		<216	1
	NOx	>67	9
		61-67	5
		55-61	3
		49-55	1
		<49	1

TABLE 4: NORMALIZED MATRIX FOR SUB CRITERIA OF AIR POLLUTION (NOX)

TABLE 8: FINAL SUITABILITY

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

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

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

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

Where,
n= Number of items being compared in the matrix,
λ_{max}= Largest Eigen Value,
RI = Random Consistency Index

C.Overlying

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

Suitability Index, $SI = (RI * A1 * \Sigma RI.Bi * RI.KBi)$
$+ (RI * A2 * \Sigma RI.Cy * RI.KCy) \quad + (RI * AN * \Sigma RI.Dz * RI.KDz)$

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 water availability, flood hazards, air pollution, water quality index, waste disposal 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 Environment response model and constitute the sub-criteria under Environment 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.

E. Preparing of residential 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 residential land suitability map was prepared.

TABLE 5: SUITABILITY ACCORDING TO WATER AVAILABILITY (NORMALIZED MATRIX)

Class	< 200	200 - 400	400 - 600	600 - 800	> 800	Sum	PV	Score
<200	0.46	0.53	0.40	0.38	0.35	2.11	0.42	9.00
200 - 400	0.23	0.26	0.40	0.30	0.25	1.44	0.29	6.14
400 - 600	0.15	0.09	0.13	0.23	0.20	0.80	0.16	3.41
600 - 800	0.09	0.07	0.04	0.08	0.15	0.43	0.09	1.82
> 800	0.07	0.05	0.03	0.03	0.05	0.23	0.05	0.97

TABLE 6: SUITABILITY ACCORDING TO FLOOD LINE DISTANCE(NORMALIZED MATRIX)

Class	>400	300-400	200-300	100-200	0-100	Sum	PV	Score
>400	0.56	0.64	0.52	0.43	0.36	2.51	0.50	9.00
300-400	0.19	0.21	0.31	0.31	0.28	1.30	0.26	4.66
200-300	0.11	0.07	0.10	0.18	0.20	0.67	0.13	2.40
100-200	0.08	0.04	0.03	0.06	0.12	0.34	0.07	1.21
0 – 100	0.06	0.03	0.02	0.02	0.04	0.17	0.03	0.62

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 residential 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 8. Figure 2 depicts the final map (suitability map), which divided to 5 best areas in increasing order are : 1, 2, 3, 4 and 5 and are shown in different colours.

TABLE7: SUITABILITY ACCORDING TO AIR POLLUTION ZONE (NORMALIZED MATRIX)

Class	5	4	3	2	1	Su	Priority Factor	Score
5	0.51	0.63	0.47	0.38	0.32	2.30	0.46	9.00
4	0.17	0.21	0.35	0.30	0.26	1.29	0.26	5.00
3	0.13	0.07	0.12	0.23	0.21	0.75	0.15	3.00
2	0.10	0.05	0.04	0.08	0.16	0.43	0.09	2.00
1	0.09	0.04	0.03	0.03	0.05	0.23	0.05	1.00

TABLE 8: SUITABILITY ACCORDING TO WATER QUALITY INDEX – (NORMALIZED MATRIX)

Class	>56.5	55.5-56.5	54.75-55.75	52.75 -54.75	< 52.75	Sum	PV	Score
>56.5	0.56	0.64	0.52	0.43	0.36	2.51	0.50	9.00
55.5-56.5	0.19	0.21	0.31	0.31	0.28	1.30	0.26	5.00
54.75-55.75	0.11	0.07	0.10	0.18	0.20	0.67	0.13	3.00
52.75-54.75	0.08	0.04	0.03	0.06	0.12	0.34	0.07	1.00
< 52.75	0.06	0.03	0.02	0.02	0.04	0.17	0.03	1.00

TABLE 9: SUITABILITY ACCORDING TO WASTE DISPOSAL (NORMALIZED MATRIX)

Class	>4000	3000-4000	2000-3000	1000-2000	0 - 1000	Sum	PV	Score
> 4000	0.56	0.64	0.52	0.43	0.36	2.51	0.50	9.00
3000 - 4000	0.19	0.21	0.31	0.31	0.28	1.30	0.26	4.66
2000 - 3000	0.11	0.07	0.10	0.18	0.20	0.67	0.13	2.40
1000 - 2000	0.08	0.04	0.03	0.06	0.12	0.34	0.07	1.21
0 - 1000	0.06	0.03	0.02	0.02	0.04	0.17	0.04	0.62

TABLE 10: FINAL SUITABILITY ACCORDING TO ENVIRONMENTAL FACTORS (RECIPROCAL MATRIX)

Class	W	F	A	WQ	WD	Sum	Priority Vector	Score
Water Avail	0.54	0.64	0.47	0.43	0.36	2.44	0.49	9.00
Flood	0.18	0.21	0.35	0.31	0.28	1.33	0.27	4.91
Air Pollu.	0.14	0.07	0.12	0.18	0.20	0.71	0.14	2.61
WQI	0.08	0.04	0.04	0.06	0.12	0.34	0.07	1.26
Waste Disp.	0.06	0.03	0.02	0.02	0.04	0.17	0.03	0.64

The following results emerged out of the present study:

i. The area of interest has been classified in to nine using supervised algorithm and different suitability classes are obtained.
ii. The criteria used are water availability, flood line distance, air pollution data, water quality index and distance of waste disposal site (5classes each) and their combined effect map is shown in figure no 2 illustrating the suitability of the area. These results are based on the data received and accordingly results are drawn .
iii. AHP used hierarchical structures for nine scales with the Environmental criteria, and were devised for the designof AHP applicability for residential land use suitability .

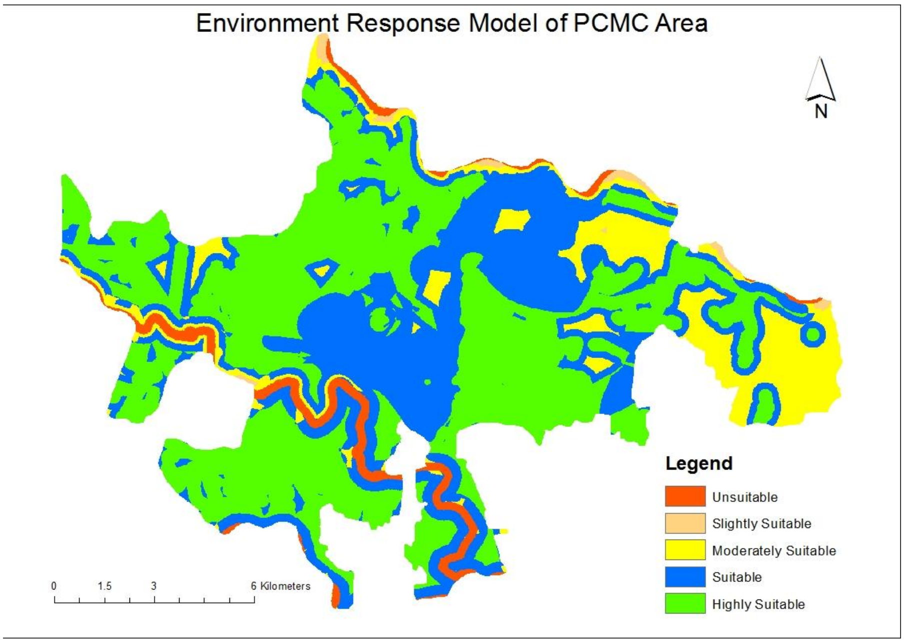

Fig.2 Final suitability map

The AHP was devised for allthe sub criteria, evaluating their relative scores for attribute classes toget the environment response model and residential land use suitability forPCMC area.

5. CONCLUSIONS

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

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