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Analytic Hierarchy Process for Urban Environmental Impact Assessment for Bhopal, India

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Abstract: Urban environmental planning is the major channel to control the human activities from polluting the environment. Urban environmental quality evaluation is prerequisite of proper urban planning. Fuzzy Set Theory has been used as an aid to urban planning. In this research work, environmental as well as physical environmental components have been considered to evaluate the urban environmental quality. Because of the fuzzy uncertainty and spatial characteristic of environmental phenomenon, the integration of fuzzy set theory and geographic information system is used in urban environmental quality evaluation of study area, Bhopal (Bhopal municipal corporation limits). Analytical hierarchy process has been used to find out the weights of criteria by pair-wise comparison matrix. Fuzzy overlay is carried out by using fuzzy inference network (fuzzy operators) to coalesce criterion maps. Validation of the final quality map has been done through sample data. Accuracy assessment (error matrix) has been calculated. It reaches to the conclusion that FST approach reflects the urban environmental quality evaluation in more detail and in more precise manner than the conventional (Boolean) approach.

Key words: GIS, fuzzy set theory, urban environmental quality evaluation, analytical hierarchy process.

Introduction

Analytic hierarchy process (AHP) is one of the most commonly used utility-based methods for environmental decision-making (Zimmerman, 1985) Uncertainty is an unavoidable and inevitable component of any environmental decision-making process. Sadiq (2007) has broadly categorized uncertainty into vagueness and ambiguity. The AHP inherently involves both vagueness and ambiguity in assigning pair-wise comparisons and evaluating alternatives. Vagueness (imprecision) refers to lack of definite or sharp distinction, whereas ambiguity is due to unclear distinction of various alternatives, which is further divided into discord (conflict) and non-specificity (Ramanathan, 2001).

Planning and design activities of different level i.e. urban, town, rural, transportation etc. aim to create a better environment which is in the interest of safety, health, aesthetics, comfort and general welfare of people (Odermerho, 1991). It is the major channel to control the human activities that pollute urban environment and perform the managing measures to improve the environmental quality. Therefore, urban environmental quality evaluation (UEQE) is at the heart of urban planning and development. Urban environmental quality evaluation (in terms of air and noise) pertains to interpretation and forecast of the urban environmental quality (UEQ) according to the national regulation about the permitted content of contamination for the sake of protecting human health and subsistence environment.

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The evaluation assists in identifying areas where exigent attention of urban environment management agencies is required. Degradation of environmental quality hinders the economic growth and hence city contribution to national development. Apart from its severe local effects, urban pollution has deep impact on regional and global scale. To convert these favourable conditions into actual improvements in air quality, however, there needs to evaluate the air pollution.

Noise pollution also affects the urban environment and is hereby included in urban environmental quality evaluation. The physical environment represents the external conditions under which human beings live. It includes land use, greenness, population density, topography etc. These factors play a vital role in determining the extent of pollution at a particular spatial location. In this study, these factors have been assigned weights in contributing in UEQE by AHP (Chang, 1996). A kind of ambiguity or fuzziness due to lack of clear defined boundaries between the objects has been incorporated mathematically in Fuzzy Set Theory (FST) (Zadeh, 1977). Because of its ability to deal with uncertain information, it has a lot of potential applicability in urban environmental studies. Much environmental information has the obvious spatial character that can be addressed by geographical information system (GIS). GIS provide a powerful tool for the representing of environmental information in support of environmental evaluation. Here by AHP, weights are found out of all the indicators by pair-wise comparison. The present study undertaken demonstrates the usefulness of remote sensing, GIS, FST and AHP in urban environmental quality evaluation.

Study Area

Bhopal, the capital city of Madhya Pradesh and known as "the city of lakes", is continuously losing its grace and beauty under the growing pressure of up-gradation and densification of activities resulting in increase of service related problems. Geographical co-ordinates of study area (41 wards) are 77 22 04.71 E – 77 26 25.73 E and 23 11 46.59 N – 23 17 38.72 N. Bhopal city nestles in a hilly terrain, which slopes towards north and southeast. Most of the study area falls under slope between 0-4 degrees. Certain areas have slope between 4-7 degrees. The main wind direction is western especially in the upper lake and adjoining areas. On relating aspect and wind direction, those areas come under topography whose aspect is NE have more dispersion of pollution. Bhopal is the second largest city in the state with a population of 14,33,875 in year 2001. The city is distinctly divided into two parts, the old city housing most of the trading and commercial activities and the newly developed area with mainly administrative, institutional and residential activities. The road network in the old city area, with very limited scope of road widening, mainly suffers from very high volume of traffic, heterogeneous traffic mix, and high degree of pedestrian movement and on-street parking. The presence of Bhopal railway station and bus stand in the area adds more problems. One of the critical and most immediate problems faced by rapidly growing cities in developing countries is the impact of urban environmental pollution on health. The reasons being air pollution, inadequate water supply, sanitation, drainage, solid waste services and urban industrial waste management. Bhopal city has been projected as a ***"Global Environment City"*** due to its rich natural legacy (BCDP under JNNURM). There is a need for major investments in environmental up gradation of the city by the way of urban environmental quality management.

Materials and Methodology

Data Products

There are 66 wards (as per year 2001) in BMC. Due to lack of availability of sufficient data in other wards and considering the density, volume of traffic and traffic congestion, forty-one wards are selected for study. In this research, spatial data, socio-economic statistic data and environmental data are required. Remote sensing data in the form of fused satellite imagery of CARTOSAT-1 PAN (2.5 m resolution) dated January 2007 and IRS P-6 LISS IV MX (5.8 m resolution) dated January 2007 of Bhopal Municipal Corporation area are used. City guide map (MCB), wind direction and wind speed from meteorological department, ward map year 2005 from Bhopal Municipal Corporation, Bhopal Development Master Plan 2005 from Madhya Pradesh Directorate Town and Country Planning, and road map from Madhya Pradesh Road Development Corporation are used as reference data. Socio economic data is the ward-wise population from Census of India 2001-2010 Town Directory of Madhya Pradesh Census.

Environmental statistic data is the annual mean concentration of air and noise pollution (ward-wise and along four major traffic corridors) of year 2006 has been collected from Madhya Pradesh State Pollution Control Board, LEA Associates South Asian. Figure 1 gives the geographical location of sample points taken in wards as well as along four major traffic corridors in the study area of Bhopal (BMC). The sample data includes the pollution value of air and noise which is annual mean concentration of year 2006.

Methodology

The first step in evaluating UEQE is to identify the relevant environmental components (environment pollution, physical environment) and then use these components to establish the relevant evaluation criteria (Table 1). Selection of the evaluation criterion will directly influence the reliability of the evaluation result (National Statistical Institute of Italy, 2001).

In this research, the experts' interview is used to get the relative importance of every criteria and indicator. Twenty experts from academic institution, State Pollution Control Board and Urban Planning field were interviewed about the rank of the criteria involved in this research. In

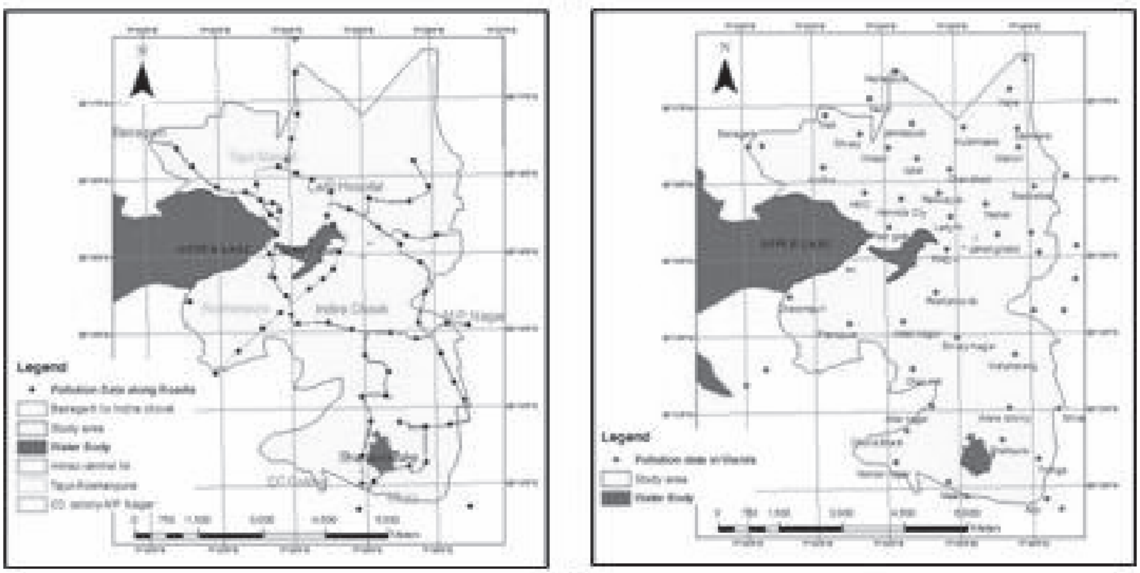

Figure 1: Location of sample stations (for air and noise) in (a) along major traffic corridors and (b) in 41 wards of the study area, Bhopal.

Table 1: Components for Urban Quality Assessment

Components	*Criteria*	*Sub criteria*	*Indicators*
	Air Pollution	Air in Wards	Carbon monoxide (CO)
			Sulphur dioxide (SO_2)
Environment pollution		Air along Major Roads	Nitrogen dioxide (NO_2)
			Suspended particulate matter (SPM)
	Noise pollution	Noise in wards	Noise in decibel (db)
		Noise along Road	Noise in decibel (db)
	Urban Greenery	Nil	NDVI
	Topography	Nil	Slope
			Aspect
	Population	Nil	Urban Population density ward-wise
Physical environment			Commercial
			Residential
			Institutional
	Land use	Nil	Open space
			Vegetation
			Recreational
			Transportation
			Others

the second stage, the rank of the importance of each criterion is used to construct the pair-wise comparison matrix for AHP. Consistency is checked.

When taking into account the raster based analysis, the fuzzy overlay operation is shown in Figure 2. In this process, each factor of the evaluation is represented as a raster data layer. Why the fuzzy approach excels the conventional approach (Boolean) is because it allows the continuous classification of actual objective and has an ability to perform overlay operations. Every bottom indicator of each criterion is overlaid based on fuzzy operation, which is also called intermediate hypothesis. For example, in air pollution criteria, the criterion consists of four indicators (SO_2, NO_2, SPM and CO) in wards as well as along four major traffic corridors. The first phase evaluation is to overlay these four indicators based on fuzzy operation (Fuzzy Algebraic Sum). That is to say, it is a bottom to top approach. Secondly, the fuzzy operation is carried out to overlay air pollution in wards and air pollution along road (Fuzzy OR). Finally, the final hypothesis performing the fuzzy overlay operation of environment pollution and physical environment component to get the Final Quality Map (fuzzy GAMMA).

Data Base Creation

AHP Weights to Indicators

As per the interviews of twenty eight experts, consisting of scientists of M.P. State Pollution Control Board, Town Planners, Urban Planners and Environmental Planners in Bhopal, the comparison matrices have been prepared by using the AHP scale. For example, the AHP weights for air pollution have been described in Tables 2 to 6.

A general multi-criteria evaluation model characterized by fuzzy information can be described with a group of sets. The decision problem is formulated as the hierarchical structure (Kwang, 2002) and the relationship among these decision elements contained in each hierarchical level is illustrated in Figure 2. Based on the fuzzy set theory, the evaluation factors set in this research can be expressed as the following:

Table 2: Indicator scores

	SO_2	*NO_2*	*SPM*	*CO*
SO_2	1	3	1/3	1/7
NO_2	1/3	1	1/5	19
SPM	3	5	1	15
CO	7	9	5	1

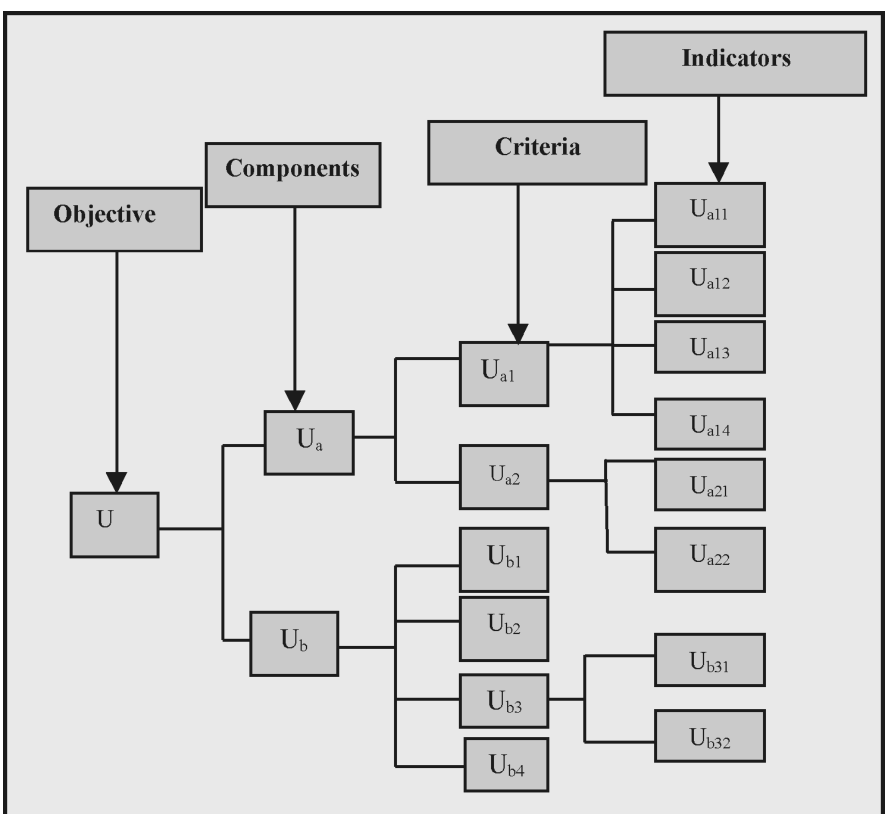

Figure 2: Hierarchical structure of the objective.

$U = \{U_a$ (Environment pollution), U_b (Physical environment)$\}$ (1)
$U_a = \{U_{a1}$ (Air pollution), U_{a2} (Noise pollution)$\}$ (2)
$U_{a1} = \{U_{a11}$ (SO_2), U_{a12} (NO_2), U_{a13} (CO), U_{a14} (SPM)$\}$ (3)
$U_{a2} = \{U_{a21}$(Ward-wise noise), U_{a22} (Noise along major traffic corridors)$\}$ (4)
$U_b = \{U_{b1}$ (Urban population), U_{b2} (Urban greenery), U_{b3} (topography), U_{b4} (land use)$\}$ (5)
$U_{b3} = \{U_{b31}$ (Aspect), U_{b32} (Slope)$\}$ (6)

In AHP, a pair-wise comparison matrix for each alternative on each criterion is prepared.

Further the values have been normalized (divide by the sums of the columns, and average across rows to get the relative weights of each job with regard to location). In this case, Table 3 is obtained.

Table 3: Relative indicator score

	SO_2	*NO_2*	*SPM*	*CO*	*Average*
SO_2	0.088	0.166	0.050	0.98	0.1005
NO_2	0.029	0.055	0.030	0.076	0.047
SPM	0.264	0.277	0.153	0.137	0.208
CO	0.617	0.50	0.765	0.687	0.642

The final weights for the four indicators are obtained (Table 4).

Table 4: Weight for the parameters of air pollution

Indicators	*Average*
SO_2	0.1006
NO_2	0.047
SPM	0.208
CO	0.642

Table 5: Consistency measure (C)

Indicator	*SO_2*	*NO_2*	*SPM*	*CO*	*sum*
SO_2	0.1006	0.141	0.069	0.0916	0.4022
NO_2	0.334	0.047	0.0416	0.0712	0.1932
SPM	0.3018	0.235	0.208	0.1284	0.8732
CO	0.6694	0.423	1.04	0.642	2.7744

Consistency Index (CI) = (lambda – n) / (n – 1)
where lambda is sum of consistency measures.
Here lambda is 4.243 and n is the number of indicators that is 4.
CI = (4.243 – 4)/(4 – 1) = 0.081
CR = CI/RI which should be $\leq$ 0.10
where RI is Random Index and CR is Consistency Ratio.

Table 6: Value of RI for number of indicators

RI =	0.00	0.58	0.90	1.12	1.24	1.32	1.41
For n =	2	3	4	5	6	7	8

Here, indicators are 4 in number, so RI is 0.90.
CR = 0.081/ 0.9 = 0.09

CI is a factor to measure the deviation of judgement. RI is a constant corresponding to the dimension of the impact matrix. If CR $\leq$ 0.10, the concordance of the comparison matrix is good. Otherwise, the comparison matrix should be adjusted.

The weight of evaluation criteria is shown in Table 7.

Further, each indicator has four evaluation classes. These are Low (L), Moderate (M), High (H) and Critical (C).

As per fuzzy set theory, for SO_2 which has overall weightage of 0.1567 (Table 8).

Zimmerman (1991) discusses a variety of fuzzy operations. The combined fuzzy membership values tend to be small with this operator, because of the effect of multiplying several numbers less than 1. The output is always smaller than, or equal to, the smallest contributing fuzzy membership value, and is thus ‘decreasive’. Fuzzy Algebraic Sum is applied to get the final weights of indicators.

As far as pollution (air and noise) is concerned, mainly it is due to traffic (Damirel, 2008). Hence to see the impact, four buffers of 50 m distance each on both the sides of road have been created. The area that comes within 50 m distance of both the sides of road is much more influenced than the area which is 150 m away from the road. Hence weightage is given maximum to those areas which comes within 50 m buffer and least to the areas which are farthest from the road.

Fuzzy Approach

The maps so generated by interpolation are classified for their values using ArcGIS 9.2 as per NAAMP. The whole surface is classified into four classes i.e. Low (L), Moderate (M), High (H), Critical (C).

As per the interviews of twenty eight experts, consisting of scientists of M.P. State Pollution Control Board, Town Planners, Urban Planners and Environmental Planners in Bhopal, the comparison matrices have been prepared by using the AHP. Zimmerman (1991) discusses a variety of fuzzy operations. Fuzzy Algebraic Sum is applied to get the final weights of indicators. The final weight is added as

Table 7: AHP weights to indicators

Components	*Weights*	*Criteria*	*Weights*	*Sub criteria*	*Weight*	*Indicators*	*Weight*	*(AHP) Normalized weights*
				Air in ward	0.35	Sulphur dioxide	0.100 6	0.1567
		Air pollution	0.75			Nitrogen dioxide	0.047	0.073
				Air along roads	0.65	Suspended particulate matter	0.208	0.324
Environment pollution	0.65					Carbon monoxide	0.642	1.0
		Noise pollution	0.25	Ward noise	nil	Ward noise in db	0.25	0.33
				Noise along	nil nil	Noise along major roads in db	0.75	1.0
		Urban poulation	0.30	nil	nil	Population density	1.0	1.0
		Urban green space	0.20	nil	nil	Total greenery in urban area	1.0	1.0
		Topography	0.15	nil	nil	Aspects	0.35	0.538
						Slope	0.65	1.0
						Commercial	0.20	0.833
Physical environment	0.35					Institutional	0.17	0.666
						Residential	0.13	0.5
						Open space	.02	0.66
		Land use	0.35	nil	nil	Vegetation	0.04	0.133
						Water bodies	0.01	0.133
						Transportation	0.3	1.0
						Others	0.02	0.066
						Recreational	0.1	0.33

Table 8: Final weights for SO_2 in wards

Classes	*Fuzzy scores*	*Fuzzy weight* (x)	*(AHP) Normalized* weight (z)	*AHP weights* criteria (y)	*AHP wts sub* criteria (K)	*AHP weight* component (a)	*A=1-x*	*B = 1-y*	*C = 1-z*	*D = 1-a*	*F = 1-K*	*E = A.B.C.D.F F*	*W = 1-E*
L	0.5	0.0625	0.1567	0.75	0.35	0.65	0.93	0.25	0.84	0.35	0.65	0.37	0.63
M	0.6	0.075	0.1567	0.75	0.35	0.65	0.92	0.25	0.84	0.35	0.65	0.29	0.71
H	0.7	0.087	0.1567	0.75	0.35	0.65	0.94	0.25	0.84	0.35	0.65	0.190	0.81
C	0.8	0.10	0.1567	0.75	0.35	0.65	0.9	0.25	0.84	0.35	0.65	0.123	0.88

attribute to the classified data set and layers with membership values are obtained (Lee, 2006). Different varieties of fuzzy operators can be used in the same problem (Figure 3). The fuzzy membership values were combined using the fuzzy AND, fuzzy OR, fuzzy algebraic product, fuzzy algebraic sum, and fuzzy gamma operators (Lee, 2006). Generally, Fuzzy Algebraic Sum and Fuzzy OR are used. All the maps can be combined using a suitable operator like Gamma operator. It is to be noted that a single operator would not suffice the combination of maps since it depends on the context of the type of data represented by maps (Kwang, 2002).

The intermediate hypothesis maps namely air pollution; noise pollution, topography, greenness; road buffer and population are combined using GAMMA operator (Figure 4). Gamma operator needs a value that is γ, which should be decided judiciously. γ value shows the compromise between Fuzzy Algebraic Product and Fuzzy Algebraic Sum operator. γ value is determined based on the trial and error procedure (Kwang, 2002). γ is a parameter chosen in the range (0,1). In the fuzzy gamma operation, when γ is 1 the combination is the same as the fuzzy algebraic sum, and when γ is 0 the combination equals the fuzzy algebraic product. Judicious

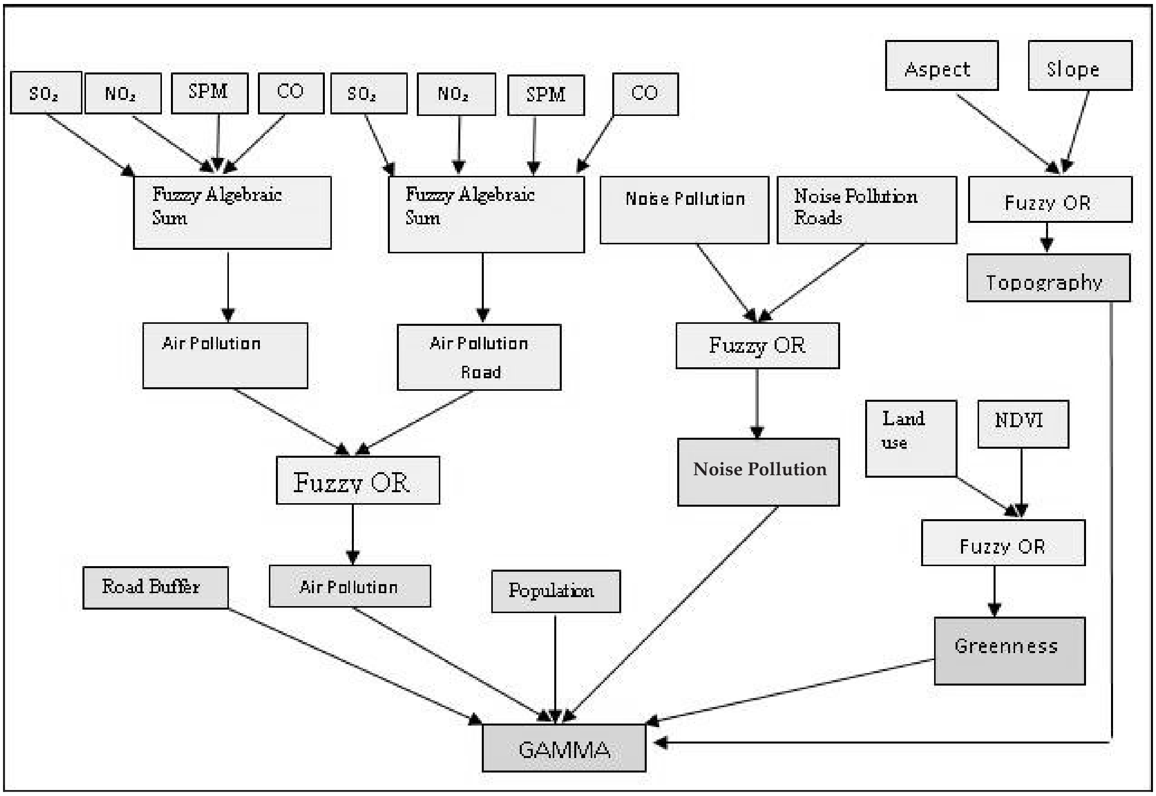

Figure 3: Fuzzy Inference Network.

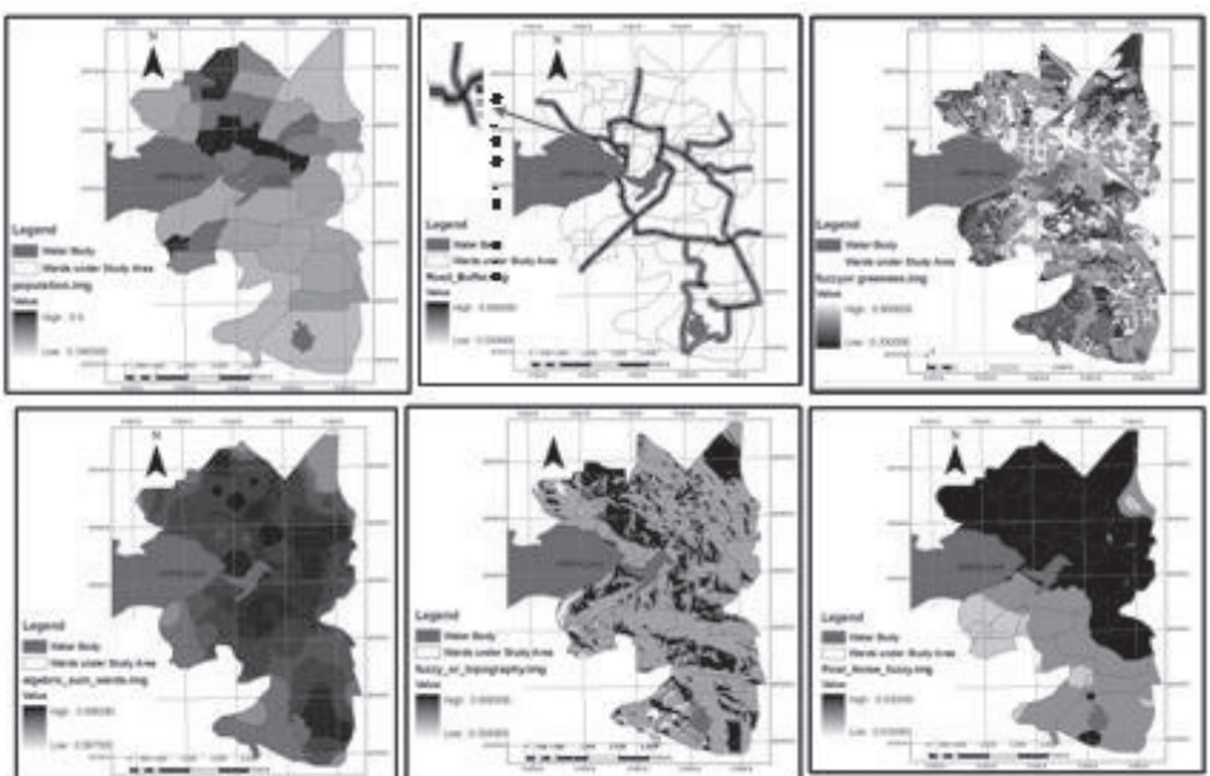

Figure 4: Intermediate Hypothesis for Gamma Operator.

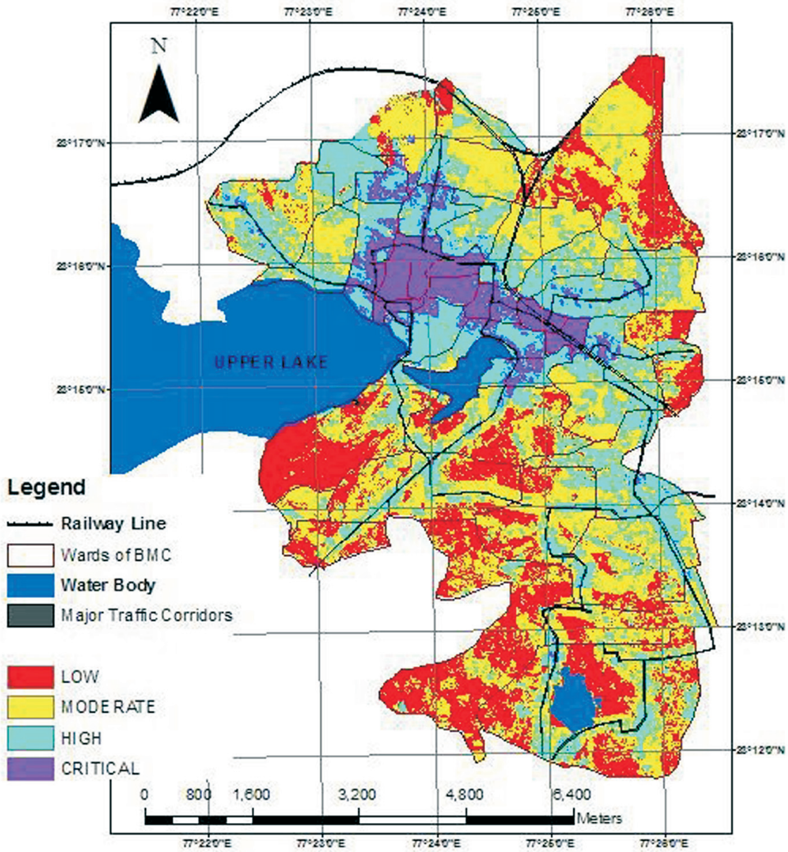

Figure 5: Final Quality Map (NAAMP: National Ambient Air Quality Monitoring Programme).

choice of γ produces output values that ensure a flexible compromise between the 'increase' tendencies of the fuzzy algebraic sum and the 'decrease' effects of the fuzzy algebraic product (Kwang, 2002). Several values of γ were tested and maps were obtained. The γ value for which the final map has shown the resemblance of the true picture has been taken. With the γ value 0.6 which is the intermediate value between the "increasive" tendency of Fuzzy Algebraic Sum and the "decreasive" effects of the Fuzzy Algebraic Product, the final result is obtained (Figure 5).

Conclusions

In this paper, several advantages of using the analytic hierarchy process (AHP) as a tool while carrying out an environmental impact assessment have been highlighted. A practical application of AHP for conducting socio-economic impact assessment has been discussed. In this application, AHP has been used for capturing the perceptions of stakeholders on the relative severity of different socio-economic impacts, which will help the authorities in prioritising their environmental management plan. Therefore, we conclude that AHP can be a useful tool for systematically analysing the opinions of several groups of experts belonging to diverse fields in an environmental impact assessment study, and hope that the technique will be advantageously employed in environmental impact assessment studies in future. The integration of fuzzy logic and GIS in evaluating urban environmental quality gives good results. Although fuzzy approach has shown promising results as an index of urban environmental quality, still there are some ways which can give more precise results. It has been strongly concluded that it is essential to develop an aggregate index of environmental quality that combines professional viewpoint in a way that would be beneficial to planning in India. More specifically, it is required to develop a method or approach of measuring environmental quality taking into account the drawbacks of existing methods. The combination of AHP and FST has given a platform to bring environmental as well as physical parameters into same environmental quality evaluation unit.

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Calendar of Events

Global Conference on Microbial Contaminants in Drinking Water
5 to 8 October 2009
Singapore
Website: http://www.waterpathogens2009.com
Contact name: Mark Wong
Organized by: PUB, AWWA

Aquatic Biodiversity International Conference Sibiu/ Romania 2009
8 to 11 October 2009
Sibiu, Romania
Website: http://stiinte.ulbsibiu.ro/aquatic_biodiversity_conference
Contact name: Angela Banaduc
Organized by: Lucian Blaga University of Sibiu, Science Faculty, Department of Ecology and Environmental Protection

Symposium Water Management and Spatial Planning
13 October 2009
Arnhem, Gelderland, Netherlands
Website: http://www.nethCID2009.nl
Contact name: Xander de Bruine
Organized by: ICID

Water 2009
14 to 15 October 2009
London, United Kingdom
Website: http://www.marketforce.eu.com/water
Contact name: James Campbell
Organized by: The IEA and Marketforce

International Conference on Emerging Technologies in Environmental Science and Engineering
26 to 28 October 2009
Aligarh, Uttar Pradesh, India
Website: http://www.amu.ac.in/shared/linkimages/toledo.pdf
Contact name: Dr. Izharul Haq Farooqi
Organized by: Department of Civil Engineering and University of Toledo, USA

Advances in Wastewater Treatment and Reuse
27 to 29 October 2009
Tehran, Iran
Website: http://awtr.ut.ac.ir
Contact name: M. H. Sarrafzadeh
Organized by: University of Tehran

Pollution Prevention Network Conference
28 to 29 October 2009
San Diego, California, United States
Website: http://www.wsppn.org
Contact name: Ed Gonzalez
Organized by: EPA's Region 9 & 10

National Seminar on Soil Salinity and Water Quality
4 to 6 November 2009
Karnal, Haryana, India
Website: http://www.cssri.org
Contact name: Dr. Pradip Dey, Organizing Secretary
Organized by: Indian Society of Soil Salinity and Water Quality and CSSRI (ICAR)

First Conference on the Integrated Water Resources Management
10 to 11 November 2009
Batna, Algeria
Website: http://site.univ-batna.dz/images/pdf/circulaire-2009-ressources-en-eau.pdf
Contact name: Dr Menani Redha
Organized by: Earth Sciences Department, Batna University

3rd World Aqua Congress
2 to 4 December 2009
New Delhi, India
Website: http://www.worldaquacongress.org
Contact name: Praggya Sharmaa
Organized by: Aqua Foundation

National Conference on Urban Water Management: Challenges and Options
13 to 15 December 2009
Bangalore, Karnataka, India
Website:http://www.urbanwater.in
Contact name: R. Jagannatha Rao
Organized by: Center for Sustainable Development (CSD) & German Technical Cooperation (gtz)

Water and Sustainable Development in Africa
14 to 16 December 2009
Libreville, Gabon
Website: http://www.eau-afrique.org/libreville2009/en/index.html
Contact name: Dr. Nlombi Kibi
Organized by: Eau-Afrique