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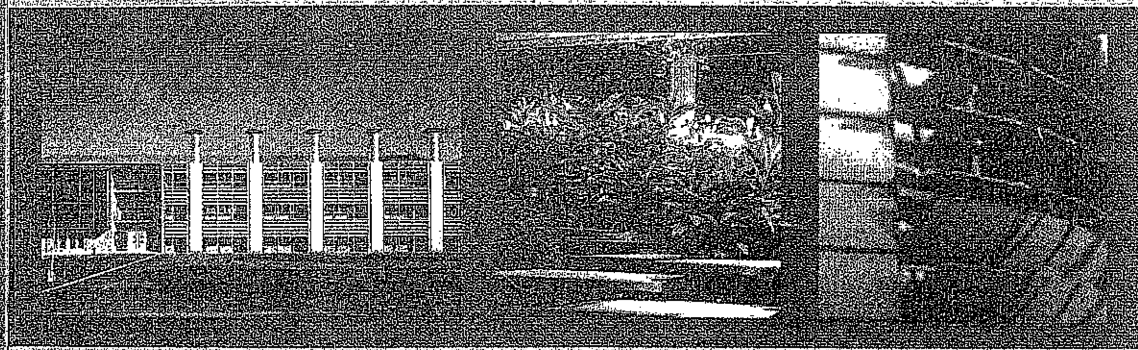

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Integrating GIS and AHP for Land Suitability Analysis for Urban Development in a Secondary City of Bangladesh

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ABSTRACT: *Spatial decision making involving site selection for any particular use requires proper means to handle the multiple socio-economic factors while considering the physical suitability conditions. GIS (Geographic Information System) has been recognized as a useful decision support technology, but it does not provide means to deal with multiple decision factors. Thus, this paper develops a framework for integrating the strengths of GIS and the AHP (Analytic Hierarchy Process) to incorporate the decision maker's preferences on a range of factors in finding areas/ land suitable for urban development in a secondary city of Bangladesh.*

Introduction

Rapid urban growth has been a phenomenon in most of the developing countries of Asia. In Bangladesh, although the level of urbanization is still considered low (23.1%), however, in recent decades, the country has been experiencing a very high growth of urban population ranging between 3.2 to 4.6 percent at exponential rates (BBS, 2003, p.28). Spatially, although major urban growth in Bangladesh is concentrated in the metropolitan cities of Dhaka, Chittagong, Khulna and Rajshahi, nevertheless, secondary cities* which number 17 are also growing at an annual rate ranging between 2.5 to 3.0 per cent. This high rate of urban population growth in the secondary cities has led to indiscriminate conversion of large tract of land for urban uses. As a result, environmental and other problems related to environment, have crop up making it clear that a judicious approach towards suitable urban land use is essential. However,

* Secondary cities in the context of Bangladesh are gazetted urban areas with population of 100,000 and above.

it is also important that these cities should develop further to act as counter-magnets to metropolitan growth in Bangladesh and contribute towards a decentralised urban growth strategy of the country.

Land Suitability, AHP and GIS for Urban Development

Urban planning implies decisions for land use to accommodate future activities in an urban area. Such land use decisions must be very judicious so that these are sustainable and do not inflict major disruptions on the environment. Land suitability is a procedure for mapping the variations in relative suitability for a particular land use across an entire jurisdiction or planning area. The results of land suitability analysis serve as a foundation for the formulation and evaluation of land use plans. Several techniques are available for carrying out land suitability analysis (see Kaiser, et.al., 1995, pp.215-16), but most of these are multi-criteria based but non-hierarchical. Therefore, a hierarchical structure of decision plane is essential and the Analytic Hierarchy Process (AHP) can provide such a platform. The AHP is a multi-criteria decision method that uses hierarchical structures to represent a problem and then develops priorities for alternatives based on the judgement of the user. The AHP has become a popular tool for problems of multi-attribute decision making modelling (see for example Islam, 2003). Saaty and Vergas (1994) describe the basic idea of AHP in the following manner:

> "The Analytic Hierarchy Process (AHP) is a basic approach to decision making. It is designed to cope with both the rational and the intuitive to select the best from a number of alternatives evaluated with respect to several criteria. In this process, the decision maker carries out simple pairwise comparison judgements which are then used to develop overall priorities for ranking the alternatives. The AHP both allows for inconsistency in the judgements and provides a means to improve consistency" (Saaty and Vergas, 1994, p.1).

Geographic Information System (GIS) provides a spatial framework to land use analysis and it has been recognized as a useful decision support technology. The role of GIS is to generate a set of feasible solutions representing the relative land suitability with respect to any given map layers and to display it. Nevertheless, it does not provide means to deal with multiple decision factors. There has been a recent trend to integrate GIS with other software for better decision making in planning. Campbell et al (1992)

and Chuvieco (1993) applied linear programming (LP) in combination with GIS in planning land use strategies. Xiang (1993) employed a multi-objective LP with GIS in environmental planning exercise. Multiple criteria decision making (MCDM) techniques have proved useful in situations that require the selection of the best alternative from among a number of feasible choices in the presence of multiple criteria and diverse criterion priorities. Some applications coupled with the GIS are found in recent research approaches (Carver, 1991). Jankowski and Richard (1994) illustrated how a land suitability problem can be solved using the MCDM-GIS by enabling the procedure to select a site and set priorities in a systematic manner, taking into account spatial and non-spatial information. A study by Hickey and Jankowski (1997) is notable in which the contribution of the GIS was considered not only as a method for data gathering but also as the tool for mapping the result.

The Analytic Hierarchy Process (AHP) has recently gained attention in GIS applications due to its ability for dealing with the multiple factors required in most GIS site analysis. Banai (1993) used this technique in combination with GIS in searching for landfill area guided by the relative weights of the suitability factors obtained in the AHP. Alias Abdullah et. al. (2004) combined AHP and GIS for determining river catchment in one area of Malaysia. The fuzzy set theory by Zadeh (1990) was employed in assigning shadings with the union of various polygon buffers generated by GIS overlay operations. Although the approach is viewed to be notable for addressing the trade-off problem among conflicting criteria, it leaves some room for improvement as a land evaluation technique as follows. First, decision making processes such as site suitability analysis not only require the numerical weighting of criteria as in Zadeh's approach but also involve steps in using judgement. Such qualitative processes can be effectively manipulated using the expert systems. Second, as Zadeh (1990) included in the final remark for future improvements, instead of performing the AHP outside the GIS environment, the applications can be linked 'tightly' by developing a user-interface. Therefore, the AHP as a MCDM technique can be integrated to GIS in order to arrive at many planning decisions pertaining to the future development of urban areas and regions.

Objectives

Against the backdrop of the above context, the objectives set for the paper are as follows:

- Study existing land use of the secondary city;
- Identify and locate suitable areas for urban development by applying AHP and GIS;
- Develop land use policy recommendations for balanced development of the city.

Methodology

In order to achieve the objectives of the study, the Analytic Hierarchy Process (AHP) as a multi-criteria decision making (MCDM) technique was used to arrive at a land suitability analysis which was then integrated to GIS for spatial analysis. The use of expert judgements in weighting land suitability factors was an important part of the study. For each land use type, after discussion with the city planning staff, professionals, and private developers, human experts were identified for value judgements.

Data for three (3) major land uses – residential, commercial and industrial and 27 influential land suitability factors affecting urban development were collected from various sources including field survey (Table-1).

Table 1: Parameters/Factors, Their Measurements and Sources of Data.

Parameters/ Factors	**Data Acquired from**	**Data Sources**
Environmental/ Ecological		
Ground water condition	Hydrological Map	BWDB/ GSB
Quietness of the area	Observation	Field survey
Distance to green area	Base map	Field survey
Air pollution	Perception	Field survey
Quality of view	-do-	Field survey
Physical and Geological		
Soil quality	Geological map	Geological survey of BD
Land slope	Contour map	BWDB/SOB/LGED
Natural/ soil drainage system	Topographic maps	BWDB/SOB/LGED
Vulnerable to flood	Topographic maps	BWDB/SOB/LGED
Possibility of earthquake	Tectonic/ Seismic map	Geological survey of BD
Socio-economic and Demographic		
Population density	-	Municipality
Existing land use	Municipality base map	Field survey
Land value/ price	Market value	Field survey
Social standing of area	-	Field survey

Social facilities and Transportation		
Distance to school	Municipality base map	Field survey
Distance to medical facilities	Municipality base map	Field survey
Distance to recreation facilities	Municipality base map	Field survey
Distance to highway	Municipality base map	Field survey
Distance to waterway	Municipality base map	Field survey
Distance to local bus stop	Municipality base map	Field survey
Distance to commercial facilities	Municipality base map	Field survey
Distance to CBD	Municipality base map	Field survey
Utility/ Urban Services		
Distance to sewer lines/ drainage	Utility maps	Municipality/ Field survey
Availability of fresh water supply	Utility maps	Municipality/ Field survey
Distance to power lines	Utility maps	PDB/ Field survey
Distance to tele-com lines	Utility maps	T&T/ Field survey
Available vacant land	Municipality base map	Land record/ Field survey

Sources: Author's analysis.

Notes: BWDB= Bangladesh Water Development Board; CBD= Central Business District; GSB= Geological Survey of Bangladesh; LGED= Local Government Engineering Department; PDB= Power Development Board; SOB= Survey of Bangladesh; T&T= Telephone and Telegraph Board.

The Study Area and Its Land Use Pattern

Pabna City (municipality) is one among the 17 secondary cities of Bangladesh. It is located in the gateway to the northern region of Bangladesh (Figure-1). The global location of the city is between 23^0 80' and 24^0 05' north latitudes and between 89^0 10' and 89^0 25' east longitudes. The city area lies within one of the eleven sub-districts of the district of Pabna and the district headquarters is also located in it (Figure-1). Pabna district has a slightly lower level of urbanization (21.9%) compared to the national average of 23.1% (BBS, 2003, p.28). The city is situated on the bank of the river *Ichamati*. The total area of the city is 19.0 sq. km. with a population of 112,460 (Census, 2001) which is growing at a fast rate (3.2%) and it is projected that at this rate the city will have 149,320 people in 2010 (Bangladesh Planning Commission, 1999).

Table-2: Existing Land Use Pattern of Pabna City.

Land use category	Area in hectares	Percent of total area
Residence	570.0	30.0
Commerce	39.7	2.1
Industry	84.3	4.4
Education	55.1	2.9
Health	53.2	2.8
Administration	96.7	5.1
Recreation	7.6	0.4
Socio-culture	22.6	1.2
Urban services	13.3	0.7
Roads	190.0	10.0
Water bodies	72.2	3.8
Reserves & special use	51.3	2.7
Agriculture	644.1	33.9
Total	1900.0	100.0

Source: Field Survey, 2000 and UDD, 1988.

Table-2 shows that the dominant land use of the city is agriculture followed by residence. Roads occupy a significant portion of urban land but the share of industry and commerce in the city land use do not surpass even 5% of total. The land use implication of the city indicates that the city has adequate land which can be converted for residence, commerce and industry. Figure-1 also shows the existing land use pattern of the city.

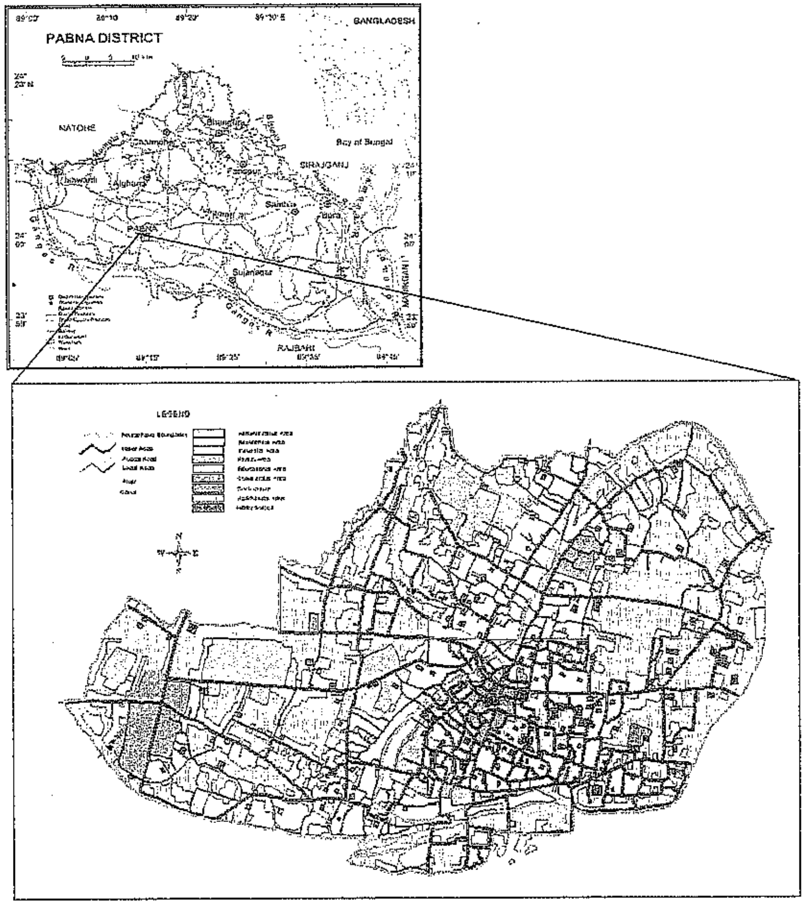

Figure 1: Location of Pabna City within Bangladesh and Its Existing Land Use Pattern

Application of AHP for Land Suitability Analysis

Analytic Hierarchy Process (AHP) organises the various factors of a problem into a hierarchy similar to a tree type structure. The top level contains the goal. Intermediate levels represent the factors/ criteria, sub-criteria/ parameters of the problem. At the bottom of the tree are the leaves, which represent the choice. At each hierarchy level, the criteria are examined through pair-wise comparison matrix. The weights attributed to the different criteria are then calculated as the components of the normalized *Eigen* vector for the maximum *Eigen* value of this matrix. This process is repeated for each hierarchical level of the decision tree. The hierarchy is constructed so that the lower levels of hierarchy are refinements of its upper levels. The decision alternatives are placed on the lowest level of the hierarchy. In the policy choice method for the application of AHP model for land suitability analysis, the selection process was divided into four levels.

Figure-2 shows the hierarchical structure of almost all the decision factors which were applied in the present study.

The operational approach of land suitability analysis for urban development based on three possible land use types - residential, commercial and industrial involved the following steps:

- Identification of land suitability factors to be included in the planning exercise.
- Defining nominal types and determination of scores for nominal types. Higher scores indicate greater suitability for development.
- Acquisition of preferences through questionnaire survey.
- Determination of weights for each factor and preparation of inventory maps for each factor by weighting various categories in terms of suitability.
- Division of study area into grid cells and labelling the cells.
- Computation of the sum of weighted factor scores for each grid cell.
- Producing composite maps by overlaying two or more inventory and sums of weighted scores for each land use.

First, the factors relevant to assessing the suitability of land for urban development were selected. Based upon literature survey and discussion with experts, five types of land suitability factors were identified. The factors were again subdivided into a total of 27 parameters (ref. Table-1).

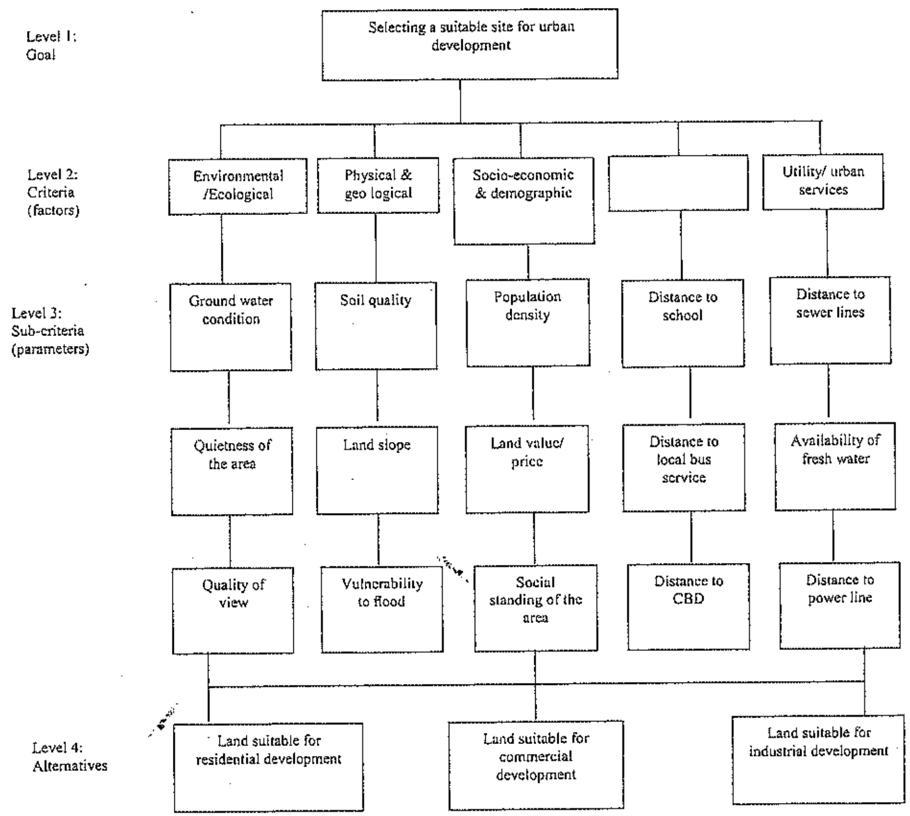

Figure 2: Hierarchical Structure of Selecting Land Suitability Factors for Urban Development in Pabna City.

For each parameter, degree of impact with scores was defined. A six-point scale – 5 (High), 4 (Moderately High), 3 (Moderate), 2 (Moderately Low), 1 (Low) and 0 (Excluded) was used to measure degree of impact (*Vi*) of surveyed parameters. The degree of impact and corresponding scores are given in Table-3.

Table-3: Degree of impact of land suitability parameters (*Vi*)

Factors	Parameters	Degree of Impact with Score		
		5	3	1
Environmental/ ecological	Ground water condition	Good	Fair	Poor
	Quietness of the area	No	Moderate	High
	Distance to green area	<2000m	1000-2000m	>2000m
	Air pollution	No risk	Moderate risk	High risk
	Quality of view	Good	Fair	Poor
Physical and geological	Soil quality	Good	Fair	Poor
	Land slope	<10%	10-20%	>20%
	Natural/ soil drainage system	Good	Moderate	Poor
	Vulnerable to flood	No risk	Moderate risk	High risk
	Possibility of earthquake	No risk	Moderate risk	High risk
Socio-economic and demographic	Population density	<4000	4000-5000	>5000
	Existing land use on site	Parent	Mixed	Conflicting
	Land value /price per acre	Low	Medium	High
	Social standing of area	Good	Fair	Poor
Social facilities &transportation	Distance to school	<500m	500-1000m	>1000m
	Distance to medical facilities	<500m	500-1000m	>1000m
	Distance to recreation facilities	<1000m	1000-2000m	>2000m
	Distance to highway	<1000m	1000-2000m	>2000m
	Distance to waterway	<500m	500-1000m	>1000m
	Distance to local bus stop	<500m	500-1000m	>1000m
	Distance to commercial facilities	<1000m	1000-2000m	>2000m
	Distance to CBD	<1000m	1000-2000m	>2000m
Utility/ Urban Services	Distance to sewer lines/ drainage	<500m	500-1000m	>1000m
	Availability of fresh water supply	<500m	500-1000m	>1000m
	Distance to power lines	<500m	500-1000m	>1000m
	Distance to tele-com lines	<500m	500-1000m	>1000m
	Available vacant land	Vast	Fair	Limited

Source: Based on Expert Opinions on Pairwise Comparisons.

Note: Scale points 2 and 4 did not come up from pairwise comparisons.

In order to elicit the value judgement of human experts on the relative importance of land suitability factors with respect to land use type, five steps were utilized, viz., familiarization with the domain, identification of human experts, selection of acquisition method, preparation of questionnaire, elicitation of preferences. Table-4 lists the specialisations of experts and their roles in weighing the land suitability factors.

Table-4: Identity and Specialty of Experts and their Roles in Weighing Land Suitability Factors

Identity	Specialisation	Land use type assessed
Investor	Investment analysis	Commercial
Investor/ Industrialist	Economic developer	Industrial
Private developer/ Govt authority	Residential development	Residential

Table-5: AHP Scale for Pair-wise Comparisons

Intensity of importance	Definition and explanation
1	Equal importance (Two factors contribute equally to the objective)
2	Slight importance (Experience and judgement slightly favour one factor over the other)
3	Moderate importance (Experience and judgement moderately favour one factor over the other)
4	Strong importance (Experience and judgement strongly favour one factor over the other)
5	Extreme or absolute importance (One is of the highest possible order of affirmation as compared to the other)
0	One of the factors has absolutely nothing to do with the selection of this particular land use.

Derivation of relative factor weights of land suitability factors was done through a pair-wise comparison matrix constructed in Table-6. In the right margin of the table is the normalised solution of this pair-wise comparison matrix which shows the relative weights of the factors, *Wi*. Saaty states that if A is 'n' time preferred to B, then B is 1/n times as preferred as A. The preference information from the experts is entered into the matrices and saved as files in a spreadsheet package. A computer programme was developed and then it was applied to these matrices to calculate the weighting scores. The results of the calculations were then presented to the experts who provided the preference information for approval. Table-7 lists the final weighting scores of the 27 land suitability factors with respect to all three land use types.

Table-6: Derivation of Relative Weight-age of Land Suitability Factor

Suitability factor	Envir'nt/ ecological	Physical/ geological	Socio-economic & demographic	Social facilities & transportation	Utility/ urban services	Weight (*Wi*)
Environment/ ecological	1	½	½	½	1/3	0.1
Physical/ geological	2	1	1	1	½	0.2
Socio-economic & demographic	2	1	1	1	½	0.2
Social facilities & transportation	2	1	1	1	½	0.2
Utility / urban services	3	2	2	2	1	0.3
Weightage (Σ*Wi*=1.0)						1.0

The study area was divided into 220 grid cells. The size and shape of the cells were determined using professional judgement and it was assumed that the areas within the cells are, in some sense, homogeneous. The 300 m^2 grid cell is accurate enough for land suitability mapping (for example, see Ortlando, 1990).

Table-7: Weight of Land Suitability Factors and Parameter for Each Land Use Type (*Wi*)

Factors	Parameters	Land use type		
		Residential	Commercial	Industrial
Environmental/ ecological	Ground water condition	3	2	2
	Quietness of the area	3	2	2
	Distance to green area	1	2	2
	Air pollution	1	2	2
	Quality of view	2	2	2
		10	10	10
Physical and geological	Soil quality	3	6	4
	Land slope	2	2	1
	Natural/ soil drainage system	2	2	3
	Vulnerable to flood	10	6	10
	Possibility of earthquake	3	4	2
		20	20	20
Socio-economic and demographic	Population density	6	7	7
	Existing land use on site	5	7	3
	Land value /price per acre	6	6	10
	Social standing of area	3	0	0
		20	20	20
Social facilities &transportation	Distance to school	5	0	3
	Distance to medical facilities	2	1	2
	Distance to recreation facilities	2	1	
	Distance to highway	2	2	4
	Distance to waterway	0	0	5
	Distance to local bus stop	2	2	1
	Distance to commercial facilities	4	10	3
	Distance to CBD	3	4	2
		20	20	20
Utility/ Urban Services	Distance to sewer lines/ drainage	4	5	3
	Availability of fresh water supply	6	5	4
	Distance to power lines	6	5	5
	Distance to tele-com lines	4	5	3
	Available vacant land	10	10	15
		30	30	30
Total weight of land suitability factors		100	100	100

The composite or final analysis identified and evaluated the grid cells by taking into account the results from weighted factor method. The weighted factor method provided a procedure where each suitability factor (*Vi*) with a score (Table-3) was multiplied by the weight of that factor (*Wi*) of Table-7. The results of the multiplication were added and then a composite score (*Wi* * *Vi*) for each suitability factor was determined. Table-1A in the annexure gives a sample for grid no. 146.

Total composite score (relative impact) of each cell was calculated by using the following equation:

$$E = \sum_{i=1}^{n} Wi*Vi$$

Where, *Wi* = relative importance or weight of parameter *i*.
Vi = relative change in the value of quality of parameter *i* with respect to existing situation.
n = total number of parameter related to the study.
Total composite score (relative impact) for each grid cell was ranked according to their numerical value. The cells with higher scores indicate land more suitable for urban development. Boundary grids were considered as full grids for analysis.

Land Suitable for Urban Development Based On AHP Analysis

Total composite score (relative impact) based on AHP was used to determine land suitable for various urban development. Total composite score sums ranged from a minimum of 100 to a maximum of 500. Derived sums of scores were then grouped into three classes – most suitable with score between 401 and 500; moderately suitable with score total between 301 and 400 and least suitable with score total between 100 and 300.

The result of the exercise when presented in Table-8 shows that out of 220 grid cells, 158 (71.2% or 14.2 km²) are most suitable, 36 (16.4% or 3.2 km²) are moderately suitable and 26 (11.8% or 2.3 km²) are least suitable for residential development in the city. Similarly, 19 (86% or 1.7 km²) are most suitable, 133 (60.5% or 12.0 km²) are moderately suitable and 68 (30.9% or 6.1 km²) are least suitable for commercial development in the city. Further, 67 (30.4% or 6.0 km²) are most suitable, 136 (61.8% or 12.2 km²) are moderately suitable and 17 (7.7% or 1.5 km²) are least suitable for industrial development in the city. After some adjustments among inter-category it was found (Table-9) that 139 grids (63.2% or 12.5 km²) are suitable for residential, 18 grids (8.2% or 1.6 km²) are suitable for commercial and 63 grids (28.6% or 5.8 km²) are suitable for industrial development. Figure-3 shows the areas suitable for different land

uses in the city.

Table-8: Land Suitable for Residential, Commercial and Industrial Development Based On AHP.

Degree of Suitability	Residential		Commercial		Industrial	
	Grids (%)	Area (km²)	Grids (%.)	Area (km²)	Grids (%.)	Area (km²)
Most suitable	158 (71.8)	14.2	19 (8.6)	1.7	67 (30.4)	6.0
Moderately suitable	36 (16.4)	3.2	133 (60.5)	12.0	136 (61.8)	12.2
Least suitable	26 (11.8)	2.3	68 (30.9)	6.1	17 (7.7)	1.5
Total	220(100.0)	19.8	220 (100.0)	19.8	220(100.0)	19.8

Table-9: Land Suitable for Urban Development.

Land for Development	Grid cell (nos.)	Area (sq.km.)	Percentage
Residential	139	12.5	63.2
Commercial	18	1.6	8.2
Industrial	63	5.8	28.6
Total	220	19.8	100.0

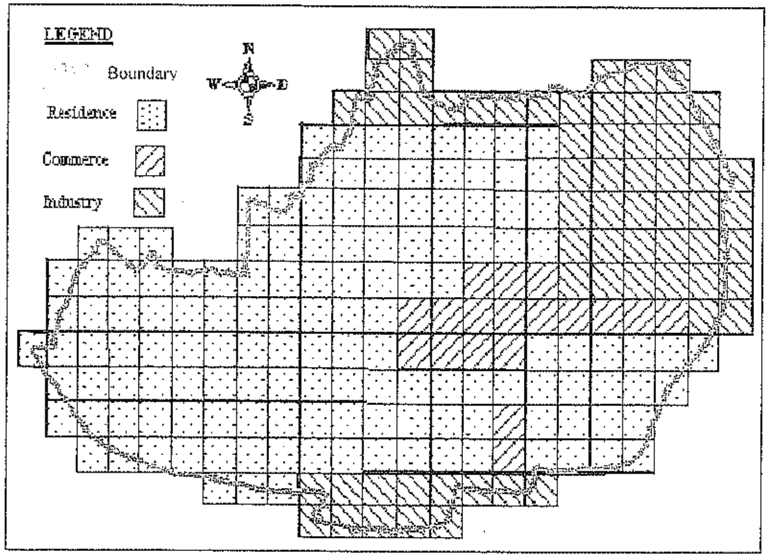

Figure 3: Land Use Suitability for Urban Development in Pabna City.

Comparisons between Existing and Simulated Land Uses

Existing land uses in Pabna City are mixed and almost all flood free areas have been developed. The present land use pattern indicates a dominance of agriculture followed by residential land uses. The comparison between existing and suitable land uses as presented in Figure-4 indicates that the existing commercial area has been developed at the most suitable location of the city. However, a few major industrial land uses of the city have been on residential areas. This has created a situation of incompatibility or conflict in land uses which requires correction.

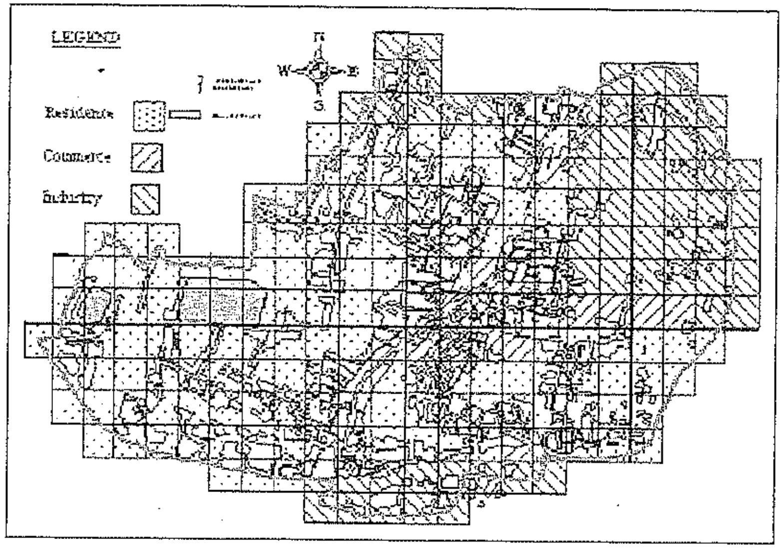

Figure 4: Overlay of AHP based Land Use Suitability on Existing Land Use of the City

Proposal for Future Urban Development

It is not possible to use the existing developed land for future urban expansion. Therefore, the future land use plan should be based on the utilization of vacant/agriculture land for future urban expansion. Based on composite analysis and considering the existing land use and vacant/agricultural land, the land use proposals for 2015 for a population of nearly 200,000 can be formulated. Figure-5 shows that 23 grids for residence, 36 grids for industry and 6 grids for commerce need to be added to the existing land use for the projected urban growth of the city in 2010 without increasing the present population density.

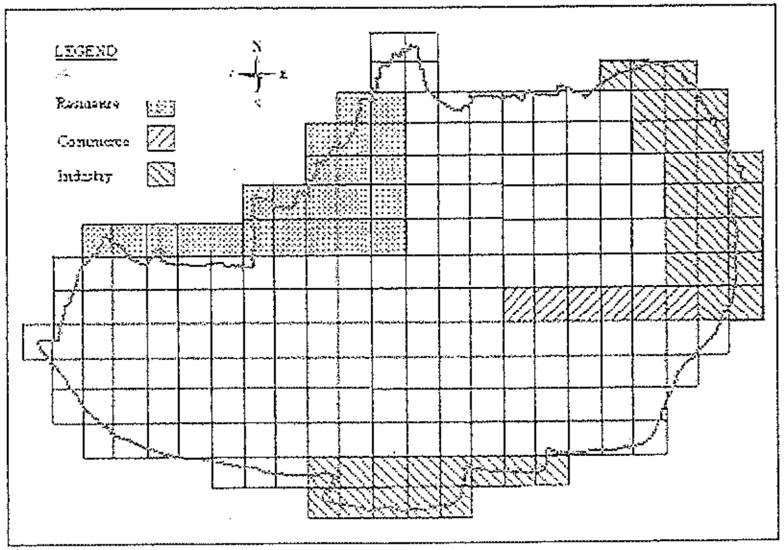

Figure 5: Proposals for Future Land Development of Pabna City

Conclusion

This paper has focussed on the integration of GIS and AHP to deal with land suitability analysis for a secondary city in Bangladesh, which currently is undergoing a process of indiscriminate land use development. The result of the study shows that while the AHP as a MCDM technique can be applied to determine land suitable for urban development, the GIS provides a map-based analysis of the suitability exercise. The integration between GIS and AHP, therefore, helps determine the strategic urban land development framework within which the short-term land use policies can also be formulated. The approach can also help monitor urban land development which planners and policy makers can use towards formulating urban growth policies and strategies of the city. Nevertheless, future research may be directed towards considering other socio-cultural factors for land suitability.

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