GEOSTATISTICAL MODELLING FOR ASSESSMENT OF DEVELOPMENT AT MICRO LEVEL

Dr. R.D. Gupta
Assistant Professor
Department of Civil Engineering
Motilal Nehru National Institute of Technology
Allahabad- 211004, U.P., India
Phone: 91-532-2271308 (O), 2645505 (R), Fax: 2445101
gupta_rd@rediffmail.com

ABSTRACT

Development of any region depends upon proper planning based on reliable micro level information about its natural resources, socio-economic conditions and demographic set up. An essential pre-requisite for the success of any developmental plan at district level is the availability of an accurate, comprehensive and up-to-date database of existing facilities and their spatial organization. For planning at micro level in any district, a village may be adopted as the basic spatial unit for data collection, database preparation and subsequent spatial modelling. The main focus of the present work is to develop geostatistical model for assigning weights to different facilities using an objective approach for their integration and analysis under GIS environment as well as to assess the level of development at village level for Dehradun district in India. An integrated geo-database of existing infrastructural facilities, demographic and socio-economic parameters at village level for the district has also been created. For the development of geostatistical model, computer programs using AML (Arc Macro Language of Arc/Info GIS software) have been developed which forms the basis for carrying out various computations such as median population threshold, facility composite index, correlation matrix and village development index. GIS has also been used to prioritize the villages of Dehradun district based upon their existing level of development.

INTRODUCTION

Planning is a widely accepted way to handle complex problems of resource allocation and decision making. District level planning, a concept of decentralized planning, is defined as an area-based integrated planning aimed at supplementing the national and state plans by ensuring the efficient use of local resources. Each district plan specifically deals with the problems typical to its resources, terrain, environmental conditions, agro-climatic set-up and socio-economic profile. These development plans must be designed to meet the basic needs and aspirations of the local people within the overall framework of the multi level planning (Rao *et al.*, 1991). Thus, a systematic and scientific approach is a pre-requisite for planning at district level to generate the development from grassroots.

The development of local economies is generally driven by a number of factors including transportation networks (land, water and air), population increases (both in term of local birth rate and influx from other areas) and the amount of available land for development (Markon, 2003). With the growing pressure of population and increased land degradation, the need for optimum utilisation of land assumes far greater relevance. For this purpose, several developmental schemes have been floated by government/ non-government organizations and a coordinated planning process is therefore essential to facilitate convergence of various programmes and for achieving accelerated development in any district. Further, large volume of data is generally collected whenever preparation of physical plans for any region is taken up, along with the preparation of a number of maps. Thus, there is an urgent need to develop suitable mechanism to compile, store and update this geographically referenced information on a systematic manner for their retrieval and analysis at subsequent point of time.

For the convenience of data availability and management of data for analysis, a standard spatial unit is conventionally adopted for the regional planning process at various levels, from macro to micro. The standard spatial planning unit selected at various levels is termed as the basic spatial unit. For planning at district level, a village may be adopted as the basic spatial unit for data collection, database preparation and spatial modelling (SAC/TCPO, 1992). Nevertheless, the data to any higher level can be aggregated from the digital database generated at smallest planning unit. India has enormous unexploited potential of natural resources and knowledgeable human resources in rural and remote areas. Hence, development of integrated geo-database as well as suitable geostatistical models to assess the level of development at village level will help in inventorying and analyzing these resources for achieving balanced and sustainable development in the district.

GIS FOR MIRCO LEVEL PLANNING

An essential pre-requisite for planning process in a district is the availability of an accurate, comprehensive and up-to-date database on natural/ physical resources, demographic set-up and socio-economic conditions. Geospatial technologies, *viz.*, GIS, remote sensing, GPS play a key role in generating timely and reliable information for planning and decision making at all the levels from macro to micro for a region. GIS (Geographic Information System) helps in efficient storage, retrieval and analysis of large quantum of spatial as well as non-spatial data for better management of facilities and resources and their subsequent use in decision making process (Nagaraja and Gautam, 1994). Further, user-friendly interface and query module can also be developed apart from generating customized maps and reports in the desired format.

There are many definitions of GIS over the years which have suggested that GIS is "a computerized tool for solving geographic problems", "a container of maps in digital form", "a tool for performing operations on geographic data that are too tedious or expensive or inaccurate if performed by hand", *etc.* As per USGS (United States Geological Survey), GIS is a computer system capable of assembling, storing, manipulating and displaying geographically referenced information, *i.e.*, data identified according to their locations. GIS can be used for effective and efficient storage, retrieval and manipulation of spatial and non-spatial data for deriving scientific, management and policy making information. Planners make use of GIS to chart out the progress of citizen participation and community input so as to develop a vision for the community that enhances the quality of life for all the citizens.

By organizing, integrating and analyzing the available information spatially, planners can get a broad view of the current situation and assess the future scenarios more accurately. GIS plays an extremely important role in resource management, environment monitoring and land use planning activities and can analyze possible planning alternatives more quickly giving decision makers better choices. GIS has the capabilities to provide necessary physical input and intelligence for preparation of base-maps, formulation of planning proposals and to act as monitoring tool during implementation phase of any planning scheme (Kumar *et al.*, 2002). GIS tools help planners analyze problems more quickly and thoroughly and formulate solutions to monitor progress for the ongoing plans/ projects for achieving long-term goals. Thus, GIS-based spatial data infrastructure and geostatistical models would allow administrators to quickly and efficiently create and test alternative development scenarios and determine their likely impacts on future developmental patterns *vis-à-vis* ever-increasing population, thereby, facilitating in making more informed planning decisions.

For the computation of GIS based developmental indices to assess the level of development, weightage to existing facilities is assigned in GIS which reflects its importance in the district. The weight may be assigned subjectively using Saaty's Analytical Hierarchy (Saaty, 1980) or alternatively objectively adopting mathematical formulations. The subjective approach may contain an element of human bias and it is better to adopt an objective approach for achieving higher level of accuracy for data integration and analysis in GIS (Gupta, 2001).

THE STUDY AREA AND OBJECTIVES OF THE PRESENT WORK

Dehradun district, the capital of Uttaranchal State in India, has been selected as the study area. It falls between 29°58′00″N and 31°02′30″N latitudes and 77°34′05″E and 78°18′30″E longitudes, covering an area of about 3088 sq. km. As per Census 2001, it consists of six community development blocks (or simply blocks), namely, Chakrata, Kalsi, Vikasnagar, Sahaspur, Raipur and Doiwala having 153, 204, 61, 120, 129 and 76 villages respectively with nearly half of the total population of the district living in the rural areas.

The main objective of the present work is to develop geostatistical model for assessing the level of development at village level under GIS environment for Dehradun district as well as for assigning weights to existing facilities in a village using an objective approach for their integration and analysis in GIS. For achieving this, computer programs using AML (Arc Macro Language of Arc/Info GIS software) will be developed for carrying out various computations like median population threshold, facility composite index, correlation matrix, *etc.* The developed geostatistical model will be modular and can be modified as per the user requirements. The level of development at micro level will be assessed using GIS by generating village development indices. The present work also includes the creation of an integrated geo-database consisting of thematic maps, existing infrastructural facilities, demographic and socio-economic parameters for Dehradun district.

METHODOLOGY ADOPTED

The methodology for developing the geostatistical model is based on the criteria based analysis of the integrated database of both spatial and non-spatial data under GIS environment. To implement the methodology, Arc/Info-7.2.1 GIS software has been used. Computer programming has been done using Arc Macro Language (AML) of Arc/Info GIS which forms the basis for various computations such as median population thresholds, composite index of each facility, correlation matrix, village development index, *etc.* The eigenvalues and eigenvectors have been computed using MATLAB software. The present work also involves the evaluation of the development in each block so as to find out the least developed block in the district. The GIS based integrated geo-database consists of various thematic maps (*e.g.*, village boundary map, block/ tehsil boundaries maps, *etc.*), demographic data, socio-economic data and infrastructural facilities data (*e.g.*, roads, educational and health facilities, drinking water, *etc.*).

Geo-Database Design and Organisation

GIS has been used for the creation of an integrated geographic database to store, retrieve and analysis both the spatial and non-spatial data. The GIS has two distinct utilisation capabilities pertaining to (i) querying and information extraction, and (ii) integrated analytical modelling required for an application, which make extensive use of integrated geographic database (Burrough and McDonnell, 1997). Thus, the design and creation of spatial as well as non-spatial data, along with their analysis and querying may be performed efficiently under GIS environment. The geo-database should be recent and accurate as this will determine the quality of the analysis and final product. A degree of flexibility exists for upgradation of the integrated geo-database thus created.

Spatial Data: The spatial elements are application specific and depend upon the end objectives. The base maps for the present work have been derived from Survey of India topographical maps 53E, 53F, 53J and 53K at 1:250,000 scale, district census handbook and information collected from other organizations. The various maps for Dehradun district are digitized using a digitizing table and converted into Arc/Info coverages. These maps are then transformed to real world coordinates from digitizer units using nine TIC registration points. Adopting the similar procedure, all the spatial data of Dehradun district is converted to common reference system before carrying out the analysis. The various thematic maps prepared include:

(a) Village Boundary Map: showing district-block-village boundaries
(b) Drainage Pattern Map: showing rivers, canals and other water bodies
(c) Transport Network Map: showing road and rail networks

Non-Spatial Data: The non-spatial data has been collected and compiled at the level of basic spatial unit, *i.e.* village level. The non-spatial data gives the details related to infrastructural facilities, demographic set-up and socio-economic profile. This has been primarily obtained from 2001 Census of Dehradun district and updated from the information collected from tehsils and block development offices. The various facilities considered include:

(a) Education: Primary Schools, Middle Schools, High Schools, Pre-University Colleges and Adult Education Centres
(b) Medical: Primary Health Sub-centres, Primary Health Centres, Health Centres, Child Welfare Centres, Maternity and Child Welfare Centres, Maternity Houses, Family Planning Centres, Dispensaries, Registered Medical Practitioners
(c) Post Office
(d) Approach Road to Village
(e) Power Supply
(f) Market/ Shopping Centre
(g) Literacy Rate in a Village
(h) Irrigated Land Area in a Village

Village-IDs for attribute data tables have been kept the same as used for creation of village boundary map for the study area. These village-IDs are then used in joining the spatial and non-spatial data sets in GIS. Thus, an integrated geo-database has been generated for Dehradun district using GIS. The village boundary map thus obtained and also depicting the demographic pattern is shown in Figure 1.

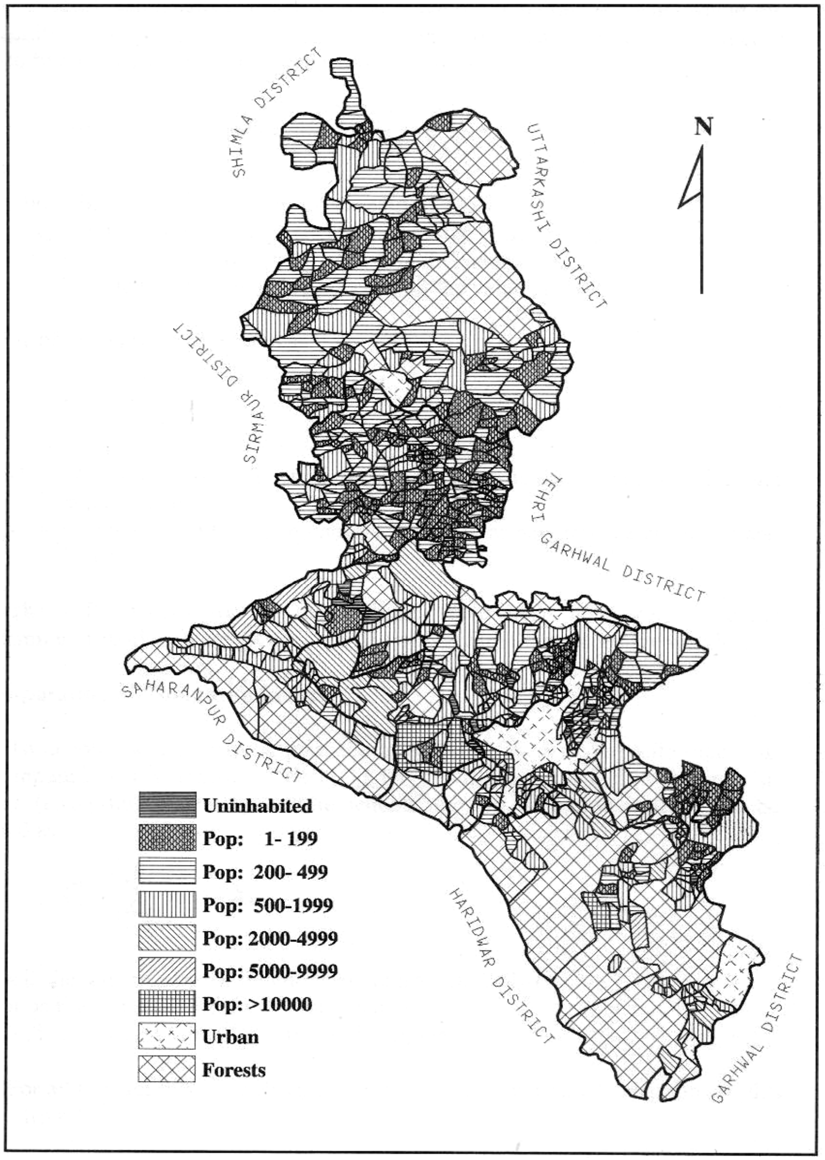

Figure 1. Village Boundary Map of Dehradun District showing Demographic Pattern.

Median Population Threshold (MPT)

For computing Village Development Index (VDI), weightage to each facility has been assigned to reflect the true indication of its importance in the district. The weightage to a facility may be assigned either using a subjective approach or through an objective approach by adopting suitable mathematical formulations. In the present paper, an objective approach for assigning weights to different facilities has been developed. The existence of a facility at a particular location can be on account of considerations other than the existence of a threshold population or need or resources. Hence, it would not be expedient to consider either the entry population or the saturation point as the threshold of population (Mukherjee and Bhoosnurmath, 1993). According to the principle enunciated by Hagget (1965), median population in the entry zone, called as MPT, may be taken as population threshold for assigning the weightage to each facility in an objective manner. The MPT stands for the point or population size where fifty percent settlements will have the function and fifty percent settlements below it will not have the function. The MPT value for each facility is computed based upon the method proposed by Reed and Muench (1938) to find out its weight. Mathematically, it may be represented as:

$$MPT = MR_b + (MR_a - MR_b) \times \frac{(50 - B)}{(A - B)}$$

Where: MR_b = Mid- point of size group preceding T = 50
MR_a = Mid- point of size group succeeding the class of MR_b
B = 'T' value of the size group preceding the value of T = 50
A = 'T' value of the size group succeeding the value of T = 50

The value of 'T' may be computed as

$$T = \frac{P_s}{P_s + A_g} \times 100$$

Where: P_s = Settlements with function present at a particular population size and smaller levels
A_g = Settlements with function absent at particular population size and greater levels

The MPT values for all the facilities have been computed by doing programming in AML and are given in Table 1 along with their respective weights computed by adopting the above criteria.

Table 1. MPT Values and Weights of Different Facilities

S. No.	Facility		MPT	Weight
1	Education	Primary School	181	2.7
		Middle School	1122	17.0
		High School	2944	44.6
		Pre-University College	4090	62.0
		Adult Education Centre	2292	34.7
2	Medical	Primary Health Sub-centre	2738	41.5
		Primary Health Centre	8701	131.8
		Health Centre	11035	167.2
		Child Welfare Centre	2616	39.6
		Maternity and Child Welfare Centre	2823	42.8
		Maternity House	6244	94.6
		Family Planning Centre	6999	106.1
		Dispensary	2998	45.4
		Hospital	4440	67.3
		Registered Medical Practitioner	3371	51.1
3	Post Office		1093	16.6
4	Approach Road to Village		612	9.3
5	Power Supply		66	1.0
6	Market/ Shopping Centre		2449	37.1
7	Literacy Rate in a Village		754	11.4
8	Irrigated Land Area in a Village		2367	35.9

Composite Facility Index

To denote the aggregate importance of each facility, its composite index has been computed. The composite index (C_j) for j^{th} village for a facility having 'm' functions (*e.g.*, primary schools, middle schools, *etc.* for education facility) can be computed as:

$$C_j = \sum_{i=1}^{k} w_i \times X_{ij}$$

Where: k is the total number of functions under a given facility
w_i is the weightage to the i^{th} function and
X_{ij} is the value of the i^{th} function in j^{th} village

For all the facilities in each village, a C_j has been computed using the weights obtained from MPT.

Principal Component Analysis (PCA)

For assessing the level of development at micro level, a combined index in the form of VDI has been developed. The objective of constructing VDI for a village is to assimilate the composite indices of all its existing facilities into one final index by assigning them proper weightage. To achieve this, relative weights have to be assigned to each individual facility. These relative weights can also be computed by a subjective procedure but they may contain an element of arbitrariness due to human bias. Alternatively, an objective procedure based upon statistical techniques can be adopted to reduce the human bias involved in deducing the relative weights and for further analysis. One of the objective procedures is based upon PCA approach and has been used in the present study (Gupta, 2001).

In order to implement PCA approach, a correlation matrix showing the correlation between total population and the above computed composite indices of various facilities has been computed to measure the extent of association between different facilities. PCA is then applied to compute the eigenvector that occupies the maximum variance of these constituent variables. The eigenvalues and eigenvectors have been computed using MATLAB software. The relative weights for these composite indices of various facilities are obtained from the eigenvector corresponding to the maximum eigenvalue that is computed from the correlation matrix. The relative weight for the composite index of each facility thus has been computed by doing programming in AML and using MPT and correlation values under GIS environment are given in Table 2.

Table 2: Relative Weights for Composite Facility Indices

S. No.	Composite Facility Index	Relative Weight
1	Education Index	7.14
2	Medical Index	7.05
3	Post Office Index	6.34
4	Approach Road Index	6.78
5	Power Index	2.60
6	Market Index	6.43
7	Literacy Rate Index	5.10
8	Irrigated Land Index	3.78

Village Development Index (VDI)

The VDI for each village is the aggregate index of all the facilities existing in that particular village. It is computed by summing up the weighted composite index of each facility present in that village; the weights being equal to the relative weights.

Block Development Index (BDI)

The BDI for each block is the average of the VDI of all villages in that block. The BDI value of a block indicates the overall level of development in that block based upon the analysis of aforesaid eight facilities. The computed BDI values for all the blocks of Dehradun district are: Vikasnagar- 2611.26, Doiwala- 2148.44, Sahaspur- 1084.31, Raipur- 1029.75, Kalsi- 554.82 and Chakrata- 436.62.

RESULTS AND DISCUSSIONS

For computation of developmental indices, the weights to different facilities have been assigned using an objective approach based upon MPT and PCA under GIS environment. The weights computed through the objective approach are in conformity with the prevalent hierarchical levels generally assigned to these facilities for their prioritized development by the planners and decision makers. For assessing the development at micro level, VDI has been computed for all the villages of Dehradun district using the above weights and the villages have been prioritized for development based upon VDI value. The villages with low VDI reflects poor level of development and should be given priority for taking up developmental activities.

The community development block is a higher administrative unit and hence developmental ranking of all the blocks of Dehradun district has been computed based upon the BDI value of each block. A higher BDI value represents higher level of development in that block. The map showing the developmental rankings of various blocks of Dehradun district is shown in Figure 2, which also includes the drainage network pattern of the district. Rank I mean highest level of development while Rank VI reflects least development for a block in the district.

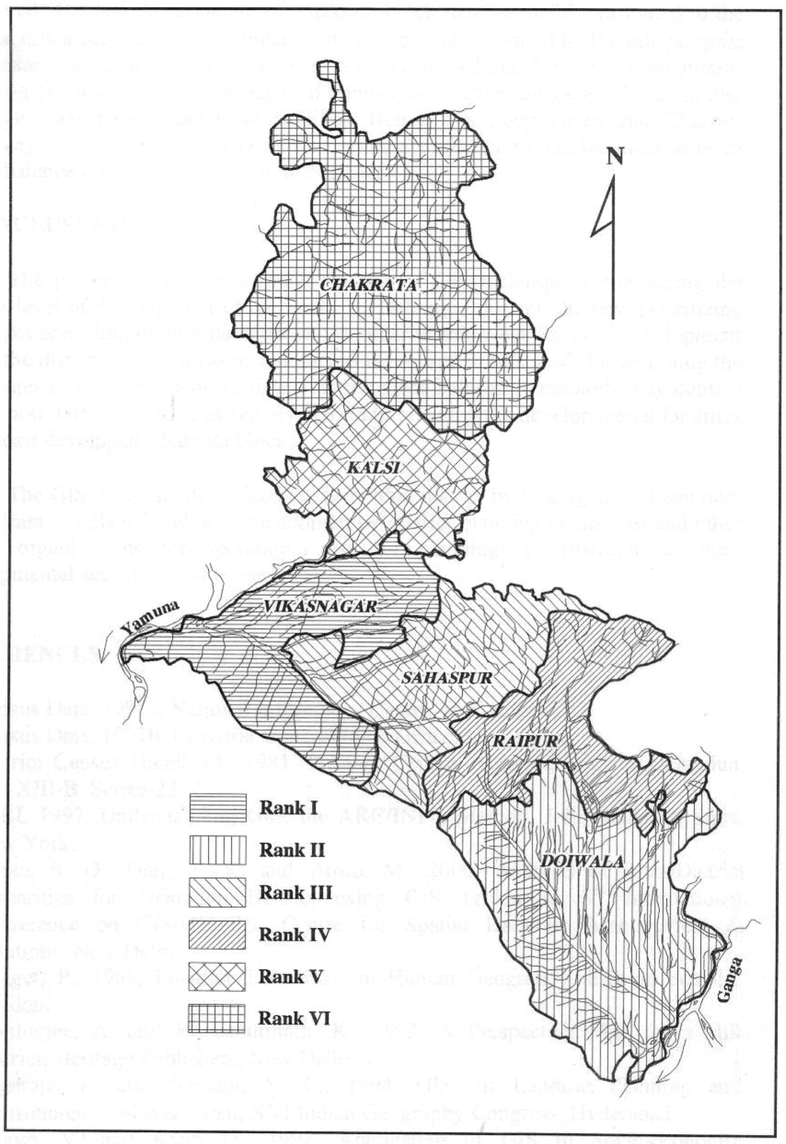

Figure 2: Developmental Ranking of Block of Dehradun District.

It can be observed that Chakrata block is the least developed block and Vikasnagar the most developed one. The less development of Chakrata block may be mainly attributed to the fact that it is a succession of mountains and gorges and is formed by the hill *pargana* of Jaunsar and Bawar. This makes it roughly an elliptical mass of mountains stretching due north from outer ranges of Himalayas. Further, the people living in this block lack basic educational facilities. Hence, Chakrata block may be given more priority in developing the aforesaid eight facilities so as to have a balanced development within the district.

CONCLUSIONS

In the present work, geostatistical model has been developed for assigning the weights to different infrastructural facilities using an objective approach as well as for assessing the relative level of development at micro level under GIS environment for Dehradun district. The objective approach for assigning weights to different facilities for GIS based data integration and spatial modelling may be adopted for other studies and regions. This study also demonstrates the usefulness of GIS for assessing the existing level of development at village level in Dehradun district, thereby, prioritizing the villages according to their developmental status in order to achieve a balanced and sustainable development within the district. The GIS may further prove to be extremely helpful in planning the developmental facilities in the least developed Chakrata block.

The integrated geo-database, developed for Dehradun district by linking spatial and non-spatial data sets at village level, may be adopted by Dehradun district administration for operational use for planning and monitoring the developmental activities in the district.

Disclaimer: Trade and product names are mentioned for completeness and no endorsement is intended by the authors or Institution concerned.

REFERENCES

Burrough, P.A. and R.A. McDonnell (1997). *Principles for Geographic Information Systems*. Oxford University Press Inc., New York.

Gupta, R.D. (2001). *Remote Sensing and GIS based Decision Support System for District Level Planning*. Unpublished Ph.D. Thesis. Indian Institute of Technology (IIT), Roorkee, India.

Hagget, P. (1965). *Locational Analysis in Human Geography*. Edward Arnold, London.

Kumar, R. Siva, P.S. Acharya, D. Dutta, M. Prithviraj, N. Mendiratta and B. Singh (2002). Natural Resources Data Management System (NRDMS)- A Suite of Technologies for Local Level Planning. Proceedings- Map Asia Conference 2002, Bangkok, Thailand.

Markon, Carl J. (2003). A Temporal Study of Urban Development for the Municipality of Anchorage, Alaska. *GeoCarto International*, 18(3): 21-33.

Mukherjee, A. and K. Bhoosnurmath (1993). *A Perspective Plan for a Hill District*. Heritage Publishers, New Delhi, India.

Nagaraja, R. and N.C. Gautam (1994). GIS for Landuse Planning and Environmental Management. Proceedings- XVI Indian Geography Congress, Hyderabad, India.

Rao, D.P., G. Behera, P.R. Navalgund, R.L. Karale and R.S. Rao (1991). IRS-1A Application for District Level Planning. *Current Science*, 61(3 & 4): 260-265.

Reed, L. J. and H. Muench (1938). A Simple Method of Estimating Fifty Percent End Points. *American Journal of Hygiene*, Vol. 27.

Saaty, T.L. (1980). *The Analytic Hierarchy Process*. McGraw Hill, New York.

SAC/TCPO (1992). A GIS based Information System for Regional Planning: A Case Study for Bharatpur District. Project Report- SAC/RSA/NRIS-URIS/PR-15. Space Application Centre (SAC), Ahmedabad, and TCPO, New Delhi, India.