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APPLICATION OF REMOTE SENSING IN URBAN HYDROLOGICAL STUDIES OF DELHI AREAS

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PREFACE

Urbanisation which may ne broadly defined as the process of expanding urban influence, has been taking place for more than 6000 years, its pace has increased markedly since the beginning of the nineteenth century. In view of the considerable expansion of the urban areas and growth of large cities in our country and relative lack of scientific studies in urban hydrology, there is need for increased emphasis. The remote sensing techniques could meet the spatial, temporal and multi spectral database requirements of the urban areas. It helps in monitoring urban sprawl, mapping urban land use patterns etc.

Delhi is a fast growing metropolis in India. It is a Union Territory and has an area for 1483 sq. km. A plan existed for Delhi up to 2001. Another plan is under preparation. The population of Delhi is increasing. Thus various infra structure will not be sufficient. Among these storm water drains, water supply, water harvesting etc. are main concern of a hydrologist. In Delhi, the sewage is discharged inadvertently in storm water drains due to insufficient capacity of sewers, leakage, breakage, overflowing, non existence etc. Thus, many drains are required regular dredging.

The land use map prepared here is very useful in hydrological studies in Delhi. Land cover are easy to identify in remotely sensed data due to typical spectral signature. Digital processing technique is used here on ERDAS Imagine image processing system. IRS LISS- III sensor has better spatial resolution and new channels in the short wave infrared is available. These data are better than earlier available data and are utilized here along with multi date data of other sensor.

An attempt here has been made here to demonstrate the potentials of remote sensing in base mapping and change detection in urban land use. This report is prepared by Mr.D.S.Rathore, Sc.'C' and Mr. Sanjay K.Jain, Sc.'E1' of Remote Sensing Applications Division.

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ABSTRACT

The timely information about the changing pattern of urban land use plays significant role in urban land use planning and sustainable urban development. Also the change in land use effect the runoff behaviour from urban area. The urban planners always look for the reliable information about the rate and direction of growth in the physical limits of the city. Several studies have established the potential of remote sensing techniques in obtaining synoptic and repetitive coverage of the cities necessary in monitoring the patterns of urban growth and urban fringe activity and gobbling of agriculture lands by the growing cities.

Union Territory of Delhi and area east of Delhi up to the Hindon river is selected for the study. Yamuna passes through eastern part of the Delhi. Physiography of area is ridge, plateau. Ridge and plateau are made of quartzite. They have part forest cover. Urban development has occurred on alluvial plain and plateau. A plan has been prepared for year 2001 to accommodate a population of 144 lakh in 488 sq. km area.

The supervised classification is found better than unsupervised classification. The most useful sensor is IRS LISS III due to the presence of short wave infra red channel in it and better spatial resolution. In final classification using LISS-I and III data, Kappa accuracy is 55% and the overall accuracy is 74%. IRS LISS-I (1992) and LISS-III (1998 and 2000) data are used. This is a conservative estimate since the samples are drawn from the urban sprawl classes in various classification. The sprawl area is 33% after adjusting the statistics for the error of classification. The urban area is 383 sq. km. The urban area does not include the urban classes e.g. parks, golf course, play ground etc. that are also urban classes.

1.0 INTRODUCTION

Urban space in India is most modified by man's activity. It encompasses diverse land use patterns, complicated social and economic functions and deteriorating quality of physical environment. The most phenomenal impact of urban processes in general and the adoption of urbanism as a way of life in particular is evident from the transformation of rural economy and society in rural surroundings of the metropolitan and Class-I cities. The complexity of urban development is so dramatic that it demands immediate attention and perspective physical planning of the cities. The dynamic nature of urban environment necessitates both macro and micro level analysis. Remote sensing provides synoptic coverage and temporal data. It helps in monitoring urban sprawls and fringe area activity; mapping urban land use patterns; assessment of environmental impact/ hazards and planning for disaster mitigation and in developing urban information system in near real time.

In India, several studies on urban applications of aerial photography and remote sensing techniques have been completed during the last two decades. A summary of the projects on the urban applications of remote sensing undertaken by the Human Settlement Analysis Group at Indian Institute of Remote Sensing during 1983-96 is given in the Appneidx-1.I. The Report of the Training Course on Remote Sensing for Urban Surveys and Human Settlement Analysis (IIRS & ESCAP/UNDP, 1987), the Proceedings of the Annual Conventions of the Indian Society of Remote Sensing and the special bulletin of Photonirvachak (1989) also provide an overview on status of remote sensing applications in India.

1.1 REMOTE SENSING

Remote sensing technique provides information of the land cover and land use. Over the years, the satellite remote sensing sensors have improved in spectral and spatial resolution. The repetitive nature of satellite remote sensing was always handy to monitor temporal phenomena for change detection. Mapping using conventional technique has its advantages. But, for many applications, the information provided from remote sensing suffices. For example, in the direct runoff estimation, satellite derived land use map have been in use.

Many satellites e.g. Landsat, SPOT, IRS satellite series have sensors on board that operated in these remote sensing windows. The sensors acquired digital data in multi spectral mode. These data were available for digital processing and were also displayed or hard copy of the data were prepared in color mode by combing three spectral channels. In standard False Color Composites (FCC) of these data, many objects are easily identifiable. For example, water, vegetation, urban area, fallow/ barren areas, sand have black to blue, red, cyan, green/ yellow/ dark/ white/ cyan and white colors respectively. Linear features e.g. roads, rail, canals, rivers, embankments are often visible. The rails and canals are run rather straight than road. Canals need not pass through towns, villages, cities. This feature makes its identification easier from transportation networks. Rivers have meanders/ crenellations. Urban/ human settlement areas have approaching pattern of road/ rail. Texture and sizes are other properties, which are used to visually distinguish various land use on the satellite FCC.

1.2 LAND USE MAPPING

Land use map is required for various application e.g. planning, water resources management, flood management, drainage design etc. The quantity of runoff and peak discharge from a watershed depends on the land use. Land use mapping requires a land use classification system. In a land use classification system, land use classes are listed and clearly defined. If possible, a hierarchical classification is designed. There are many land use classification system available e.g. United States Geological Survey (USGS) classification system, waste land classification and other individual classification systems.

USGS classification system is a hierarchical classification designed for use with remotely sensed data. The first comprehensive land use classification system for aerial photo-interpretation was developed by Anderson in 1971. It is open ended. The level I and II land uses are rigid where as other level can be user defined. Level I classes are very broad classes e.g. urban or built up land, agricultural land (that includes crop land and pasture, orchard etc.), range land etc. The urban land is classified at the level II in to residential, commercial and services, industrial, transportation, communication and utilities, industrial and commercial complexes, mixed urban and built up land and other urban and built up land. The mixed urban land use includes mixture of urban land use categories that can not be separated at the mapping scale. These typically include development along transportation routes etc. Industrial and commercial complexes are areas where many activities occurs e.g. mainly industrial and commercial and followed by other uses. Many of the classes, will be reclassified at level III and IV to other level II classes with use of additional data, ground survey etc. Commercial, residential and industrial classes at level II are obvious classes. It is envisaged to use coarse resolution satellite data for level I land use mapping and to use high altitude aerial photograph (altitude >12400 m and scale 1:80000) for level II land uses etc.

The timely information about the changing pattern of urban land use plays significant role in urban land use planning and sustainable urban development. The mapping and monitoring of urban land use/land cover require a land use classification system. Several attempts have been made to modify USDA classification system to meet the requirements of varying data base situations. NRSA, in discussions with Urban Development Authority (UDA), Town and Country Planning Organisation (TCPO) and several other users departments, had developed an Urban Land use Classification System for use with satellite data in 1986-89 (Sokhi & Rashid, 99).

Several studies on land use/land cover mapping have been completed using both aerial photographs and satellite imageries. The most significant contribution in this respect has been made by the Human settlement Analysis Group, IIRS. Using large scale aerial photographs and Landsat TM, SPOT and IRS LISS-II data, it has so far undertaken land use/land cover mapping of Jaipur (1983 & 1989), Coimbtore (1984), Ujjain (1985), Rohini, Delhi (1987), Kanpur (1988), Delhi, Dehradun and Lucknow (1989), Bhubaneshwar (1990), Saharanpur (1992), Bangalore (1994) and Jammu (1995). Similarly, Space Application Centre has undertaken the land use/land cover mapping of

Bombay (1989), Ahemdabad (1991) and Calcutta (1992) and NRSA of Chennai (1990) and Hyderabad (1994) under the Remote Sensing Applications Mission of the Department of Space (Pathan, 1989, 1991 & 1992; NRSA, 1990 & 1994; Raghvaswamy et al, 1994 and Krishnamurthy and Bothale 1988). These studies has been referenced in first chapter of the book Remote sensing of urban environment by Sokhi and Rashid, 99.

1.3 URBAN CHANGE DETECTION

The cities as dynamic 'organism' never remain static. While ground methods identify certain urban processes and changing forms, the easiest and least expensive way of accomplishing urban information systems that could correlate spatial and physical changes in the city is by remote sensing techniques. The information as obtainable by sequential aerial photography and orbital remote sensing helps urban planners and decision makers in detecting land use conversions from agricultural to non-agricultural, urban fringe activities, loss of greenery and water bodies, developments along the transport corridors and drainage lines, and the changing quality of urban environment. Besides, the remote sensing techniques also provide information base in evolving an integrated urban development plan and the strategy for its implementation.

The urban planners always look for the reliable information about the rate and direction of the growth in the physical limits of the City. Several studies have established the potential of remote sensing techniques in obtaining synoptic and repetitive coverage of the cities necessary in monitoring the patterns of urban growth and urban fringe activity, and the gobbling of agricultural lands by the growing cities. The early studies on urban growth/sprawl were carried out using large-scale aerial photographs. The Landsat TM, SPOT HRV and IRS LISS-II data with improved spatial resolution since early 1980's provide an opportunity to make use of the remote sensing techniques in mapping and monitoring urban sprawls and its impact on surrounding rural areas. For example, the urban built-up area in Bangalore city and its surroundings has been found to be at the cost of agricultural land and surface water bodies (Bahera et al, 1985). A similar study has identified the encroachment of the margins of Dal lake as a consequence of the urban sprawl of Srinagar (Raghvaswamy et al, 1992).

1.4 HYDROLOGICAL ANALYSIS AND SYNTHESIS

The design of hydrological structures e.g. culverts, drains etc. require hydrological analysis and synthesis. The information generated from such analysis provides input to designing methods. The hydrological analysis and synthesis require various hydro meteorological data, physical data etc. Various data are processed to gain understanding of hydrological processes. The resulted data are input to various hydrological models to get design variables. For example from analysis of hourly rainfall series intensity- duration- frequency relationship is derived. This relationship along with another hydrological variable namely time of concentration will help in computing design rainfall for selected frequency. Since the direct runoff is more efficiently delivered to basin outlet in urbanised basins, the time of concentration and these the design flood is modified in urban basin as compared to the rural basins.

2.0 LITERATURE SURVEY

Samant and Subramanyan (1998) have studied the land use in the Mumbai and Navi Mumbai using satellite data and conventional data. The Landsat TM data and the Survey of India (SOI) topographic maps are used. Mumbai is reclaimed from originally seven islands. The Navi Mumbai is located on the west of the Mumbai and is an amalgamation of four townships. The built up land has increased from 12% to 51% out of the study area of 860 sq. km. in the years 1925 to 1994. The built up area in 1994 is 437 sq. km. There had been 23% decrease in the wet land area. The land uses mapped are wet land, lake, built up and forest/ agriculture. The area is divided in to 10 basins. The built up land extent and length of the streams now covered by built up land is estimated. In general the built up land varies from 38 to 54% of sub areas. There are two basins with 10 and 18% built up area. In general the length of streams now covered by built up land varies from 18 to 39%. The two basins had 5 and 8% of the above lengths.

Bisht and others (1995) have mapped the Saharanpur town for the functional land use maps. Aerial photographs (1:10000, 1988) and satellite remotely sensed data (IRS LISS-2 1:50000, 1992) are utilized for the mapping. A stream and its tributary passes through the city. This stream originates in Shivaliks. The eastern Yamuna canal also traverses the city. The growth had mainly taken place in the north and south directions. Land use up to the second and third order are prepared using the aerial photographs and satellite data respectively. Various land uses mapped at the level two are residential, recreational and cultural, institutional, business and commerce, industrials, transport, water bodies and others. There had been a 46% growth is the urban area from 1988 to 1992. The ground truth data are collected in 1993.

Ramesh (1995) has studied a part of the Bhubaneswar for plan appraisal using aerial photograph. The aerial photograph at 1: 8000 for 1988 are used for a part of the city. A level three land use map is prepared. In the residential area, planned and unplanned classes are mapped at the level two of mapping. Other classes are vacant land, open spaces and engulfed villages. Open space includes open spaces in the facilities such as parks, play grounds and cemetery etc. The map and other collateral data are analyzed in a USEMAP-4 GIS.

Bothale and others (1994) have mapped land use in part of Jodhpur. The SPOT PLA and MLA data are used. An study area is a 5 km by 5 km rectangle. A level three functional land use map is prepared. The digital data are merged to aid in the visual interpretation. Determinant analysis, principal component analysis, Intensity-Hue-Saturation (IHS) transformation and filtering techniques of digital data merging are used. The band combination with maximum determinant of the variance-covariance matrix is PLA and MLA: green and infrared bands. The edge enhanced PLA data with Laplasian filter is used. In the PCA and IHS, respectively the first component and the intensity component are replaced with the PLA data. The PCA technique is applied to PLA and MLA bands. After replacing the first PC, the result is transformed back to original space. In the filtering technique, 80% component of special high pass filtered PLA and 20% PLA band is added to all MLA bands and FCC is generated.

Mohanty (1994) has studied the aerial photographs (at 1: 25000, 1:8000) and SPOT data (PLA data at 1: 25000). A 17 sq. km. area, north east of Bhubaneswar, Orisa is studied. Level two land use map is prepared from the SPOT data. The land uses such as project, regular, irregular housing, vacant area in residential, commercial, educational/ institutional, industrial small units, large unit, vacant area in industrial and recreational are mapped. Level three land use map is prepared from the aerial photographs. The SPOT data has not been found suitable for preparation of the land use map for planning exercise. The built up area had increased by 5 sq. km. from 1974 to 1988 in the study area.

3.0 THE STUDY AREA AND DATA AVAILABILITY

3.1 THE STUDY AREA

Delhi is an Union Territory. It comprises of one district and its area is 1483 sq. km. It is surrounded by State of Harayana in the north, west and south and by U.P in the east. Its greatest length and breadth are respectively 52 and 48 km. Geographically it lies between latitudes 28° 25′ and 28° 53′ N and longitudes 76° 50′ and 77° 22′ E. The study area depicting drainage, railway and road network is shown in Figure 3.1.

Physically, Delhi lies between Himalaya and Arawali ranges. It consists of Yamuna flood plain, ridge and plain. The Yamuna flood plain is subject to recurrent floods. After floods the moisture makes the land fertile. Nearly NNE- SSW trending Mewar branch of Arawali ridge lies in the north- west and west of the city. It enters in the south and spans in north-east direction. Southern part near Mahrauli and Tughlakabad is a part of the ridge. This area is a plateau. Total area under the ridge in Delhi is 78 sq. km. (Anonymous 1996 DDA). Highest elevation on the ridge is 319 m. Highest elevation of plains is 228 m and mean elevation is 213 m. This area is wider in north and vanishes in the southern hills.

The ridge and plateau are formed by hard quartzite, which are resistant to erosion. The ridge quartzite has moderate to steep angle of bedding (40°- 90°) towards east and sometimes towards west. The quartzite have large scale eastward overturned folding. The strike is N-S and NE- SW. In the plateau, the dip is irregular and E-W strike is also present. Gullies are formed on plateau on softer impure quartzite. Pleistocene and recent quaternary deposits are located on respectively west and east of the ridge.

Four types of soils are found in Delhi namely soils of rocky tract, older alluvium, younger alluvium and soils of low lying areas. Younger alluvium is found on either side of the Yamuna. It comprises of granular silty loam, loamy sand and sands. The clay content varies from 13 to 17%. Average soil is fertile. Older alluvium is found on north of the ridge and west of the Grand Trunk road. The soil has good moisture holding capacity and is fertile. Land has poor external drainage and is subject to inundation. Some patches of saline- alkali soils are also found. The soil of rocky tract is found in Mahrauli, Tughalagabad area. The soils are formed due to weathering of rocks, alluvial deposition from small streams and aeolian deposits. This soil is sandy loam to clay loam.

Occasionally calcium carbonate concretion layer is present at approximately 60 cm depth. Fertility of the soil is poor to moderate. Soil is also subject to erosion. Soils of low lying area is found near Najafgarh. The soil texture is sandy loam. Soil becomes heavier with depth.

3.1.1 Climate

Extreme weather is observed in summer and winter month. There are mainly four seasons namely cold (late November- February), hot (March- June), monsoon (July-September) and post monsoon (October- November).

January is coldest month with mean daily maximum and minimum temperatures respectively (21°C and 7°C). Minimum temperature some times reaches to 0°C. May and June are hottest months. Maximum temperature sometimes reaches 46 or 47°C.

Except monsoon months humidity is low. In April and May, morning and afternoon relative humidity is respectively 30 and 20%.

Normal annual rainfall in Delhi is approximately 466 mm. July to September maximum rainfall is received (nearly 80%). Rains are also received due to thunder storms in pre and post monsoon seasons and in the winter months. The sky is cloudy during monsoon months; and occasionally during January to march due to western disturbances. Thunder storms occur during April to June and in winter months. In April to June dust storms also occur. Some storms cause heavy rainfall. Occasionally, fog occurs in winter months.

3.1.2 River and lakes

Yamuna river enter the area near Palla village and leaves the area near Jaitpur below Okhla. The length of river is nearly 51 km and altitude falls from 210 m to 198 m above MSL. The width of river is several km. at several places during monsoon and maximum depth is 7.6 m. Maximum discharge at Okhla is 4100 cusec. Dry weather depth and discharges are respectively 1.2 m and 200 cusec. The river bed consists of sand and at some places rock. The river has embankments on its both banks to keep the flood water away from the city.

Largest natural depression in area is Najafgarh lake on Delhi Harayana border. The lake is located 32 km from Delhi. Its catchment is 906 sq. km. It receives runoff from Harayana, Rajasthan and partly from Delhi. The Sahibi river flood water is stored in this lake. Normal level of the lake is 210 m and water spread at this level is 7500 acres. The excess water from the lake is drained through Najafgarh drain to Yamuna.

Another depression is located near Bhalawa Jahangirpur along GT road in Delhi-Karnal stretch. It is an oxbow lake. Many other smaller lakes are found at abandoned quarrying sites in the hilly region of the Arawali .

3.1.3 Groundwater

Groundwater is not enough for utilization for irrigation. At many location, the water is generally brackish and unfit for drinking and irrigation.

Average yield in tubewells west of the ridge is 26 to 341 thousand litres. Water is potable to saline here. On east of the ridge, the yield is 16 to 164 thousand litre/day (average 36 thousand litre/day). The water is here highly saline and brackish. Wells in quartzites yield potable to slightly saline water (yield 33- 196 Kl/day, average 82 kl/day)(Chopra 1992) .

3.1.4 Land use

The ridge supports stunted trees, thorny shrubs and bushes due to inadequacy of moisture in the soil and rocky nature of soil. Canals passing through the plains are Hindon cut, Western Yamuna canal and Agra canal. But the main sources of irrigation are wells (tube wells and other wells).

Main Kharif crops are Bajra (18%) and fodder (10%). The wheat (rabi) comprises nearly 51% of the area during rabi. Main crops rotations are Bajra- wheat, Maize- wheat, Sorghum (Fodder)- wheat, Sorghum (fodder)- Berseem, Early cauliflower- wheat, Sorghum (fodder)- cauliflower. Occasionally, after wheat, Mug is sown making three crop in a year. In rain fed area, the cropp rotation followed is fallow- wheat, Bajra-wheat, Bajra- gram and fallow- gram.

3.1.5 Planning in Delhi

Two master plans 1981 and 2001 of Delhi have been prepared (respectively prepared in 1961 and 1990) and one is under preparation. In the plan-2001, the Delhi Urban Area (DUA) limit of plan-1981 is partially changed by extending the urban limit slightly. The population density is re planned to accommodate part of the projected population in DUA and remaining population to be accommodated in Urban Extension. A small part of Urban extension has been identified in the plan and rest was to be identified later.

In the plan various aspects of plan e.g. transportation, infrastructure- physical and social, environment- physical and social, energy etc. have been suitably incorporated. Various measures for energy conservation have been planned through mass transportation, restricting the spatial growth etc.

To maintain physical environment for an improved quality of life in Delhi, the ridge area is planned to be preserved through the plantation of indigenous varieties of plants as well as pollution in Yamuna is planned to be reduced. An improved social environment is envisaged by planning of recreational areas with parks, sports stadiums, green belt etc. Various statistics about land use and plan area etc. is given in Table 3.1.

3.2 DATA AVAILABLE

The data in map form are available as topographic maps, atlas and city maps. The topographic maps are from Survey of India (SOI). They provide cultural features, topographic details e.g. contours (10m/ 20m) and spot heights, canals, road, drains, land uses etc. and are available at scales of 1: 250000, 1:50000 and 1:25000.

3.2.1 ISID atlas

An atlas is prepared for Delhi by Institute for Studies in Industrial Development (ISID) in collaboration with Delhi Police. The atlas gives comprehensive area and colony (most of the colony covered) maps along with index for ready reference. In the atlas drains and canals are shown by same symbol, Parks, cemeteries, rivers, lakes are also shown. Various facilities are marked by symbols. The quarter numbers are also shown in colony maps frequently. For reference the maps grids are marked A to AB west to east and 1 to 30 from north to south in the Delhi urban area layout. Area sheets are 41 in number and colony sheets are 240 in number. The colony maps are not north oriented posing difficulty in reference. The areas covered are Rohini, Yamuna Vihar, Basant Kunj and Okhla Phase II on respectively North- west, North- east, south- west and south- east (Anonymous 1993 ISID).

3.2.2 Delhi guide map

Two Delhi guide maps are prepared by SOI at 1: 25000 scale. The maps are do not have georeference. They have contours, residential area, drain, river, road, rail, parks, water, sand etc. A index is given to read locate an area in the map. The reference numbers is also printed on map. It is not possible to reach the index from the map. The contours (3 m interval) are given wherever land is vacant. The area covered is Mangolpur, Panchvati colony, Nangal Dewat, Tughalagabad in respectively North- west, North- east, south- west and south- east.

3.2.3 SOI toposheets and remote sensing data

The area is covered by SOI topographic maps 53D/13,14 and 53 H/1,2,3,5,6,7. The maps are surveyed in 1968-69 and 1975-77.

IRS LISS-1, LISS-2 and LISS-3 and Pan sensors data are available for Delhi. IRS LISS-1 (path and row 29- 47)data is for date 24 October 1992. The IRS LISS-2 data is available for 11 February 1997. IRS LISS-3 data area available for 26 March 1998, 17 March 2000 and 17 October 2000. IRS Pan data are available for 15 march 2000.

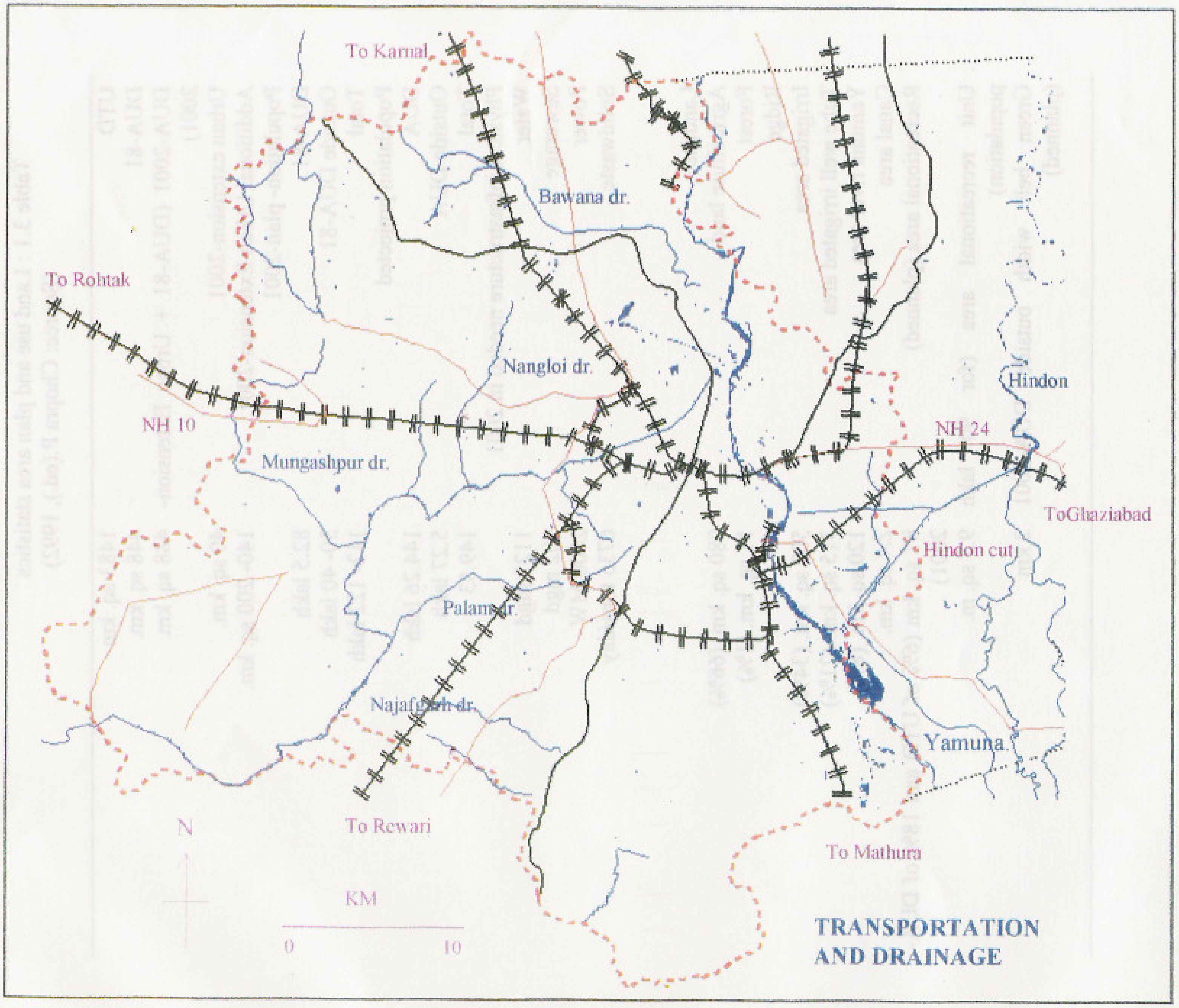

Fig. 3.1 The Study Area

Table 3.1 : Land use and plan area statistics
(Source: Chopra P.(ed.), 1992)

UTD	1483 sq. km
DUA-81	448 sq. km.
DUA-2001 (DUA-81 + Urban Extension-2001)	488 sq. km.
Urban extension-2001	40 sq. km.
Additional Urban Extension-2001	140- 200 sq. km.
Population- plan-2001	
DUA-81	82.5 lakh
Outside DUA-81	30- 40 lakh
Total	112- 122 lakh
Population projected	
DUA	144.26 lakh
Outside DUA	5.27 lakh
Total	149.53
Physical infrastructure needed in 2001	
Water	1127 mgd
Sewerage	902 mgd
Power	2000 MW
Solidwaste	6735 tons/day
Landuse	
Agriculture land	980 sq. km. (66%)
Forest	11 sq. km. (1%)
Ridge	
Irrigated area	509 sq. km. (34%)
Tube well irrigated area	315 sq. km. (21%)
Yamuna river area	120 sq. km. (8%)
Canal area	2.4 sq. km.
Recreational area (planned)	87 sq. km (6% of UTD and 18% of DUA-2001)
Unit recreational area (for 90 lakh population)	9.7 sq. m.
Green belt width outside DUA-2001 (planned)	2 km

4.0 STATEMENT OF THE PROBLEM

For the design of urban structures e.g. sewer, detention basin etc. the hydrologic information desired is discharge in drains for various return periods. Where as the rainfall information is available in abundance, the runoff information is frequently unavailable. This has led to development of various analysis and modelling techniques. The rational method is widely used. This method does not require large number of catchment variables. However the method is suitable for smaller catcments. Other more elaborate procedures are available for such catchment.

The land use information is often desired for various models. The up to date and detailed information required by the models are often not easily available in computerized formats. Using remote-sensing data up to date information is easily available due to repetitive coverage by the satellite-based remote sensing sensors. With data available for many spectral channels, the information for land use is easily available from these data. Up to the level two, the land use information can be easily obtained.

Here, it is proposed to use IRS LISS-3 and LISS-1 data to map urban land use in Delhi and compare their usefulness for the urban land cover mapping. The multi year satellite remotely sensed data will be used to study the urban sprawl. Assuming the minimum dwelling size of 60 sq. m., the number of dwelling covered in one pixel of LISS-3 ($\approx$ 625 sqm) is nearly 10. Thus a single pixel will cover few urban dwellings of these sizes (including built up and open land if any within single dwelling), roads, right of way, any vacant land etc. The large size vacant land, parks etc. will be classified as bare/ agriculture etc. are classes. The information such as connectivity of the built up area directly connected to the drains is not available from the remotely sensed data. Information about water harvesting/ conservation measures is also not available from the data.

Thus, there is no way to know the exact built up area unless collateral data are available. With the increase in the footprint of the sensor also the accuracy of the information will deteriorate. As a first step, the level one landuse map can be prepared wing remote sensing technique. The percent of built-up area in urban landuse close can be worked out later through other sources, for input to hydrological models. The landuse of non urban areas can also be determined from collateral information.

5.0 METHODOLOGY

In the present study, digital image processing has been carried using ERDAS IMAGINE software. The data of different dates of IRS LISS III have been used for this purpose. The various operations carried out in ERDAS are as follows

5.1 Georeferencing

The systematic and unsystematic error from the satellite data are removed applying various processing at the data supplying agency. For India, the data are supplied by NRSA, Department of Space, Government of India. For IRS LISS-3 data, Swath models are used in the data product generation. These models help to remove both types of errors using few Ground control points (GCPs). The resultant accuracy is better than 200 m (Anonymous, 1995).

For any geographic area that uses multi date images, one image may be georeferenced to base map through image to map registration and other date images may be gereferenced with respect to already rectified images. For, rectification of one image, GCPs may be selected spread over the area of interest. The GCPs should be well distributed over the image. These should not be distributed in only over one area since many well defined points can be identified there.

In this study, Survey of India (SOI) topographic map at the scale of 1:50000 is selected as base map. The positional accuracy in digitization of GCP can be nearly 0.5 mm. This will be translated to 25 m as ground distance (5 pixels of PAN sensor data). Adding other errors to the positional accuracy for the base map, the accuracy obtained for base map to image rectification (8 PAN pixels) is justifiable. Accuracy of image to image registration is less than one pixel for LISS-3 and LISS-1 data. The GCPs selected are image points namely road/ canal intersections, centre of ponds, canal and road bends, bridges etc. For rectification of PAN data 68 GCPs are taken. Other images are image-to-image rectified using 40- 45 GCPs. The accuracy of classification of less than a pixel (LISS-3 pixel size) is obtained in all cases.

5.2 PREPROCESSING

The banding is observed in band-4 of IRS LISS-3 data. This banding is removed through Fourier transformation. Banding is a periodic noise. The noise is represented by points or line in the transform. Thus, the noise can be easily removed through editing manually the Fourier transform. In this, these points or lines depicting the error are removed. A reverse transformation is applied and clean image is obtained (Jensen 1996).

5.3 MULTISPECTRAL CLASSIFICATION

Satellite data are available is digital numbers (DNs). They do not depict directly the nominal data e.g. land use. The data are processed to extract information from them. To extract information from the remotely sensed digital data, multispectral classification techniques are most often used.

In a multi-spectral classification, DNs in various electromagnatic bands are processed using certain techniques to obtain useful information from them. Two approaches namely supervised and unsupervised classification is used. The supervised classification approach is used where location of land use classes e.g. crops, urban, water, wetlands etc are known a priori. In the unsupervised classification the identification of ground objects is generally not known a priori.

5.3.1 Supervised classification

Various statististical parameters e.g. mean, ranges, variance, co variances etc are computed fron DNs in different bands for the known sites of the ground objects. The sites from where the DN are taken for statistical computations are called training sites. The training sites cover only part of the satellite image. The statistics are used in some mathematic manipulations to identify thematic class of all locations in the area of interest.

Various classification algorithms are used in supervised classification. They have differences in mathematical functions, assumption on statistical distribution, computational efficiency and accuracy etc. Parallelepiped and minimum distance to mean algorithms are computationally efficient. But they do not produce very accurate classifications. The maximum likelihood method assumes Gaussian distributions in DNs. The algorithm is computationally intensive, but produces more accurate results.

In supervised classification number of classes taken are 13, 20 and 24 for supervised classification of 1992, 1998 and 2000 (March) satellite images. The Eicher map and PAN data are used to locate the ground truth sites. For 1992 satellite image the signature on the FCC and landuse information on Eicher map are considered in selecting the training samples for the supervised classification. For 2000 image PAN data are used in selecting the training sets. In later image one ambiguous training set in the sprawl area with sparse development is reclassified as bare class. On the other hand, one training set for bare area is shifted to urban class in 1992 image classification. The later training set is selected based on Eicher map (Anonymous, 1996). Signature for, probably, defoliated forested/ scrub/ wood area also included in forest class. The bare class includes urban classes e.g. nursery, grass land, recreational areas, vacant land etc. The bare class also includes agricultural fallow land

5.3.2 Unsupervised classification

In unsupervised classification the computer automatically groups the pixel's DN in the DN space. The thematic classes for the grouped pixels are identified later. Both unsupervised- Isodata techniques are used in classifying the study area. The number of classes are 35 each for unsupervised classification.

5.3.3 Post processing of classification results

In post processing the classification result is processed to enhance it. In maps produced from remotely sensed data, the smallest land use area depicted is equal to the pixel size. This may be a fraction of the minimum mapping unit (MMU). For example in a 1:50000 scale map for 1 mm X 1 mm MMU, the ground equivalent of MMU will be 0.25 ha. The pixel size for LISS-3 sensor is approximately 0.06 ha. Thus, the map will have land use units smaller than MMU. To offset this problem, post-processing techniques are used. These techniques are described here.

Smoothing: In smoothing a majority filter is applied to classified image. The filter size can be 3 X 3, 5 X 5 or 7 X 7 etc. For a finer smoothing, the unfiltered classifed image is resampled to a finer resolution.

Clumping and elimination: This pair of processing technique is used to eliminate map units that are smaller than the specified size. Clumping technique produces clump number and area tables. Using this table, the clumps of sizes smaller than a specified size are eliminated in elimination operation (Yoshida 1997).

5.4 ACCURACY OF CLASSIFICATION

The accuracy of classification is reported in two manner namely non site-specific and site-specific. In former, usually high classification accuracy is reported. If the omission is equal to commission in the classification, even 100% accuracy may be reported. Thus, another method namely error matrix is on better method to express the accuracy of the classification. In error matrix, a table is prepared in matrix form in which columns represent the reference class and the rows represent the classification result. The diagonal represents the correctly classified pixels. The reference information is obtained from training sites or other areas. The reference sites are selected through stratified random sampling to produce unbiased classification accuracy. The reference information should be collected at the time of the remotely sensed data acquisition as far as possible, since the land use is a transient feature.

The accuracy for the urban sprawl map (1992 to 2000)is checked. Both maps are prepared using unsupervised classification technique. Twenty stratified random samples are generated for the sprawl class. Out of 20 samples, reference class for 10 samples could not be determined, 2 correctly classified and 8 incorrectly classified. Thus classification accuracy has been only 20%.

Subsequently, the sprawl area is morphologically filtered followed by application of majority filter, clumping, sieving 400 pixels and multiplying the resultant image with majority output. This operation results in morphological filtering and retaining of only large clumps. Seventeen stratified random samples are generated in the cleaned sprawl area map thus prepared from unsupervised classification results of 1992 and 2000 images (out of 20 generated samples, reference value for three could not be identified). Again, the supervised classified image for year 1992 is overlaid with unsupervised classified image of year 2000 to obtain another urban sprawl map. It is expected the accuracy of the sprawl map should improve in the later map. Similar to above GIS operations are carried out on this sprawl map to produce morphological cleaned large clumps for urban sprawl. On this map also another 17 stratified random samples are generated (out of 20 generated samples, reference value for three could not be identified). Thus, total 34 random samples are obtained for accuracy checking. Out of 34 samples only 29 samples are in urban or urban sprawl reference class. The classification accuracy of 47% (Kappa estimate is 18%) is obtained for sprawl map (1992 to 2000) prepared from unsupervised technique (Table 5.1). It is an improvement in reported classification accuracy for same classification result but in clean . This indicate that many noise pixels generated in a classification and map overlay. Since, it is very difficult to obtain reference for marginal sprawl areas due to large difference in dates of ground truth maps and satellite images, spatial positioning of the reference with respect to satellite images etc. Thus, later samples are more representatives for accuracy determination of the classified image. In present case, this accuracy is also very small (47%) and thus, there is need to improve the classification.

The accuracy is again checked for sprawl map prepared from supervised map of year 1992 and unsupervised map of year 2000 (Table 5.1). The overall accuracy of this map is 71% (Kappa estimate is 48%). This accuracy is achieved by jumping one training sample (1992) fromr fallow class to urban since at check- points the reference class is urban against fallow (one class) in the classified map. This is done with the assumption that due to differences in the dates of the reference information, there might, some urban development have taken place at that site. In PAN data, that site could not be very well identified as urban class.

Clump- seive operation on 1998-supervised classification map

The 1998- supervised classfication map is subject to clump sieve operation for elimination of smaller morphological units. The three set of majority operations are applied to the GIS layer:

1. 3 X 3 majority filtering.
2. 7 X 7 majority on selected 29 central pixels in the window followed by 3 X 3 majority filtering.
3. 7 X 7 majority on selected 29 central pixels out of 49 pixels followed by 5 X 5 majority filtering on selected central 21 pixels in the window.

The result of first filtering is subject to clumping and sieving (25 pixels). This results in clump number map for clumps larger than 25 pixels. The non zeros (clumps > 25 pixels) in the map is replaced with second filtering result and zeros are replaced with third filtering output. The effect of third filtering is that the smaller morphological units sieved are replaced by larger surrounding morphological units. The blurring effect in the map after filtering is not visible in this overall procedure. This procedure reduces size of remained small morphological units. Many small morphological units are eliminated.

5.5 OVERLAY OF MULTIDATE LAND USE MAP

The land use change map e.g. the urban sprawl map can be prepared by overlaying the multidate land use maps. In this study the land use map of 1992 is overlaid on the land use map of respectively 1998 and 2000. The rule based classification technique is used to refine the classification result. The area with urban land use in 1992 and non urban land use in 2000 or 1998 is reclassified to the land use in the later map. This rule is adopted since land use change from urban to non urban is most unlikely land use change.

In 1992 land use map, a large area is classified as urban area as indicated above. This may be due to differences in the sensor type for the two date. In 1992, LISS-1 sensor is used. The other data are from the LISS-3 sensor. This sensor has short wave infra red channel in place of blue visible light channel. It is likely that this new channel is better suited for urban area discrimination. And/or the blue channel is unsuitable for the application.

Table 5.1 Accuracy table for year 1992-2000 land use map

	From unsupervised classification of 1992 and 2000					From supervised classification of 1992 and unsupervised classification of 2000				
	Urban sprawl	Urban	Bare	Total	User's accuracy	Urban sprawl	Urban	Bare	To tal	Us er's accuracy
Urban sprawl	10	13	3	26	38	10	5	1	16	63
Urban	0	6	2	8	75	0	14	4	18	78
Bare	0	0	0	0	-	0	0	0	0	-
Total	10	19	5	34		10	19	5	34	
Producer's accuracy	10	32	0			10 0	74	0		
% Kappa	18					48				
Overall % accuracy	47					71				

6.0 RESULTS AND DISCUSSION

The land use mapping is done here using IRS LISS –3 data and digital analysis technique (Fig. 6.1). The statistics for the overlay map (1992-2000) is given in the table 6.1.

The crop and bare/ fallow area (57.5 %) is of same order as the agricultural area (66%) reported in the literature. The overall forest statistics is not available in Delhi. The planned forest etc. and ridge forest (7%) are together nearly half that determined here using remote sensing. The urban area as on 2000 is 25.5% (395 sq. km). After accounting for the classification errors it is nearly 25.9% (383 sq. km). This is of the order of DUA-2001 area. The remote sensing based area does not include parks, stadiums, golf course etc. urban classes. Thus, the urban development is close to the planned development.

The urban sprawl is taking place at fast pace. The sprawl is 50% (33% after incorporating errors) The yearly rate of sprawl is 5% (after error is incorporated it is 3%). Although the sprawl might not have occurred at a uniform yearly rate. But this figure can be used as a long term rate. The distribution of the sprawl indicated that it has occurred mostly in the urban periphery, mainly in west Delhi (east of Najafgarh drain), north-east of Delhi with Loni road and Saharanpur railway line passing through the area; and south of the Mehrauli- Badarpur road etc.

Accuracy checking for year 1992 to 1998 sprawl map is done with overlay map of 1992 supervised- 1998 unsupervised and overlay map of 1992 supervised- 1998 supervised. Respectively 11 and 14 samples have either urban or urban- sprawl class. The overall accuracy for two overlay maps are 44% and Kappa estimates are respectively 21% and 16% (Table 6.2).

The accuracy of the land use map prepared from overlay of supervised classification maps of 1992 and 2000 is given in Table 6.3. The overall percentage accuracy and percentage Kappa estimate has improved to respectively 74 and 55. The low accuracy may be due to various reasons e.g. differences in dates of the image and collateral data such as maps; classification error, small sample size etc. The sample for the urban area is biased here, since it is generated for sprawl areas in various classifications e.g. supervised and unsupervised etc. If more points are included from all the urban area and also the other classes, the accuracy will improve. Thus, this accuracy estimate is too conservative. However, this map can be very useful in hydrological applications.

Table 6.1 Land use statistics (1992-2000)

	Area in ha		% area	
	East of Delhi	Delhi	East of Delhi	Delhi
Bare	15533	50229	32.4	34.0
Crop	19953	34796	41.7	23.5
Forest	4268	22055	8.9	14.9
Water	689	1420	1.4	1.0
Urban	3949	25950	8.2	17.5
Urban sprawl	3505	13452	7.3	9.1

Table 6.2 Accuracy table for year 1992-1998 land use map

	From supervised classification of 1992 and unsupervised classification of 1998					From supervised classification of 1992 and 1998				
	Urban sprawl	Urban	Bare	Total	User's accuracy	Urban sprawl	Urban	Bare	Total	User's accuracy
Urban sprawl	0	0	0	0	-	0	1	1	2	0
Urban	0	11	1	12	92	0	13	2	15	87
Bare	10	8	4	22	18	10	5	2	17	12
Total	10	19	5	34		10	19	5	34	
Producer's accuracy	0	58	80			0	68	40		
% Kappa	21					16				
Overall % accuracy	44					44				

Table 6.3 Accuracy table for year 1992-2000 (supervised classification) land use map

	Urban sprawl	Urban	Bare	Total	User's accuracy
Ur ban sprawl	10	3	1	14	71
Ur ban	0	14	3	17	82
Bare	0	2	1	3	33
Total	10	19	5	34	
Producer's accuracy	100	74	20		
% Kappa	55				
Overall % accuracy	74				

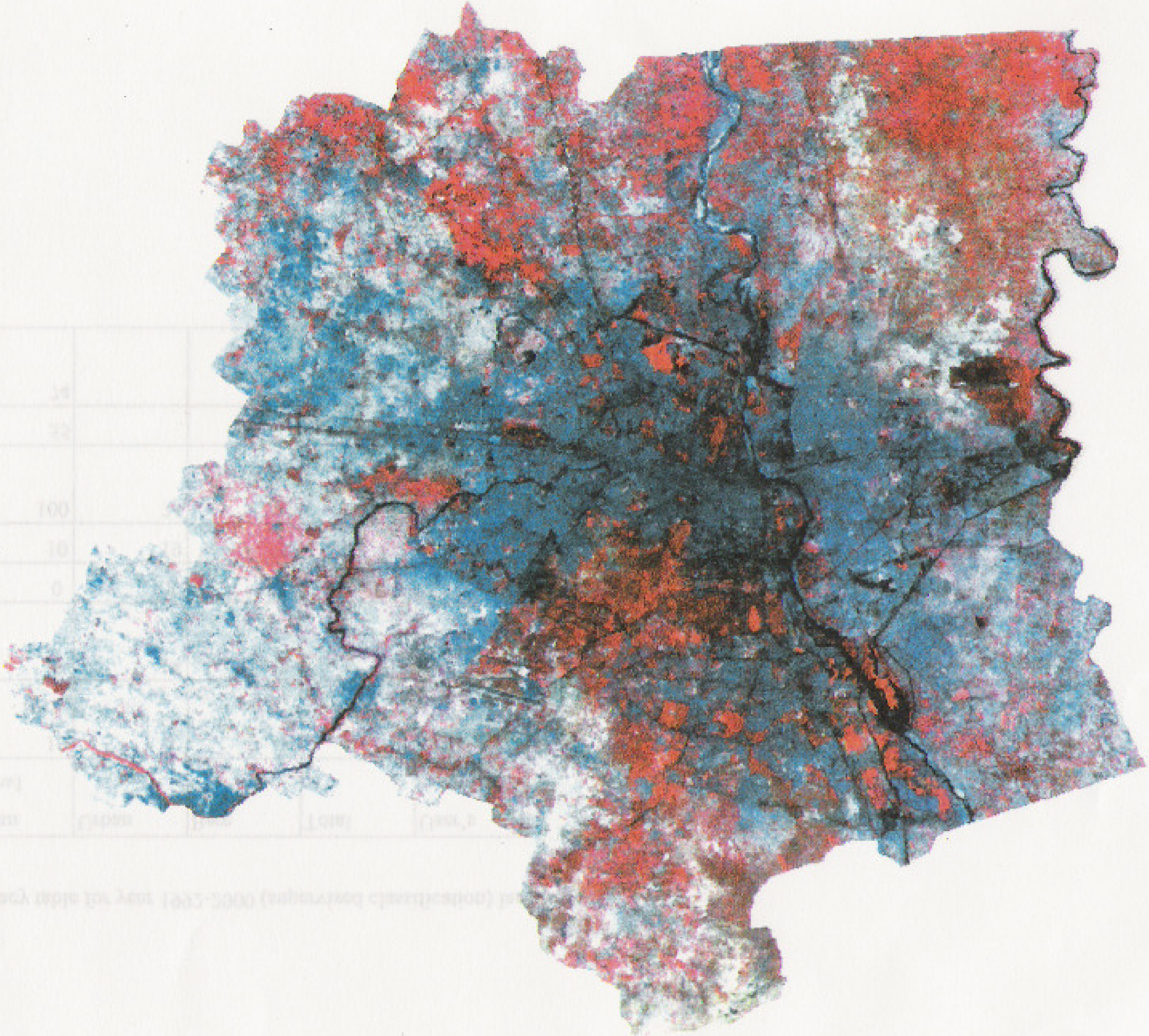

Fig. 6.1 False Colour Composite (FCC) of IRS LISS I data of October, 1992

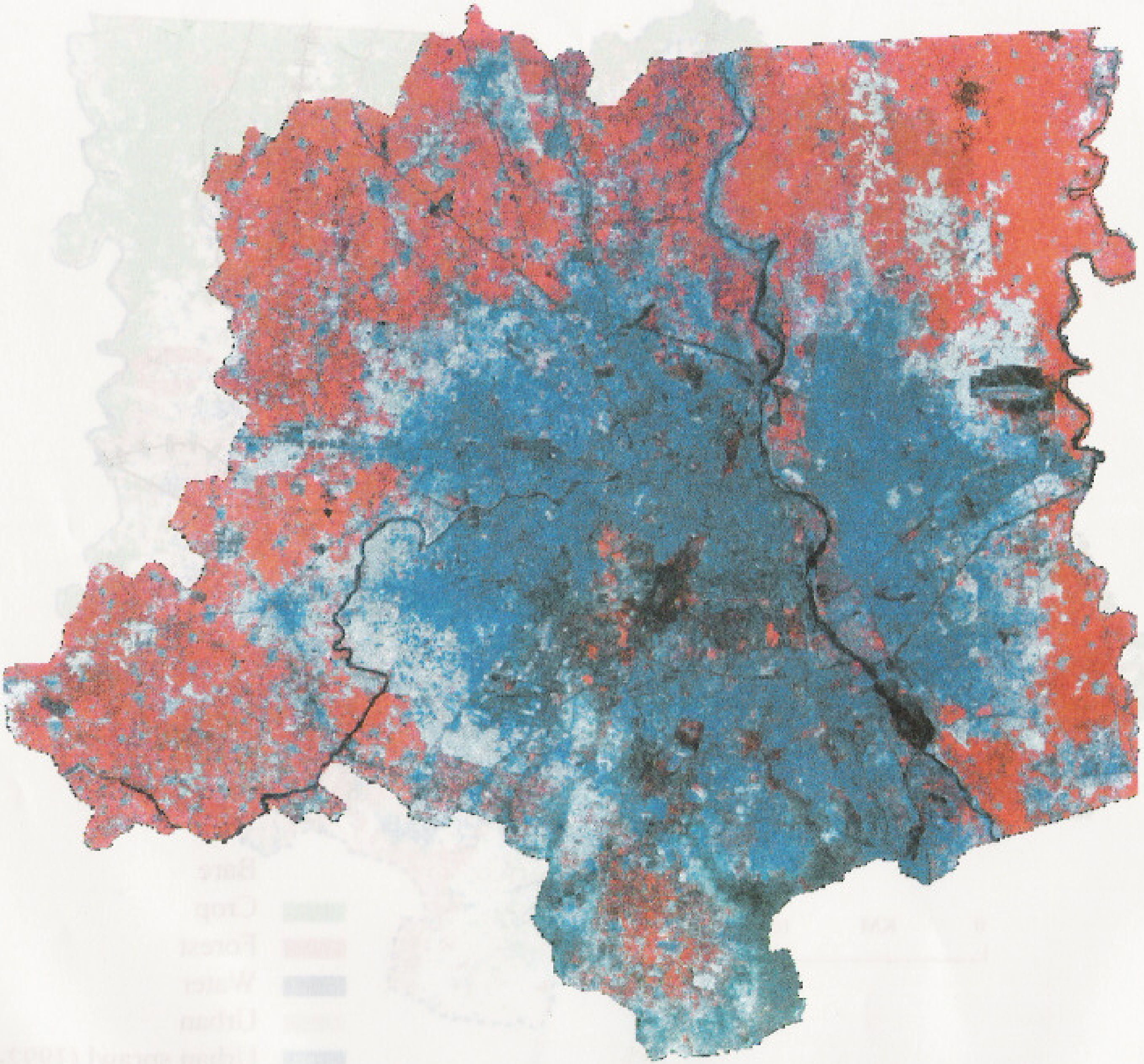

Fig. 6.2 False Colour Composite (FCC) of IRS LISS III data of March, 2000

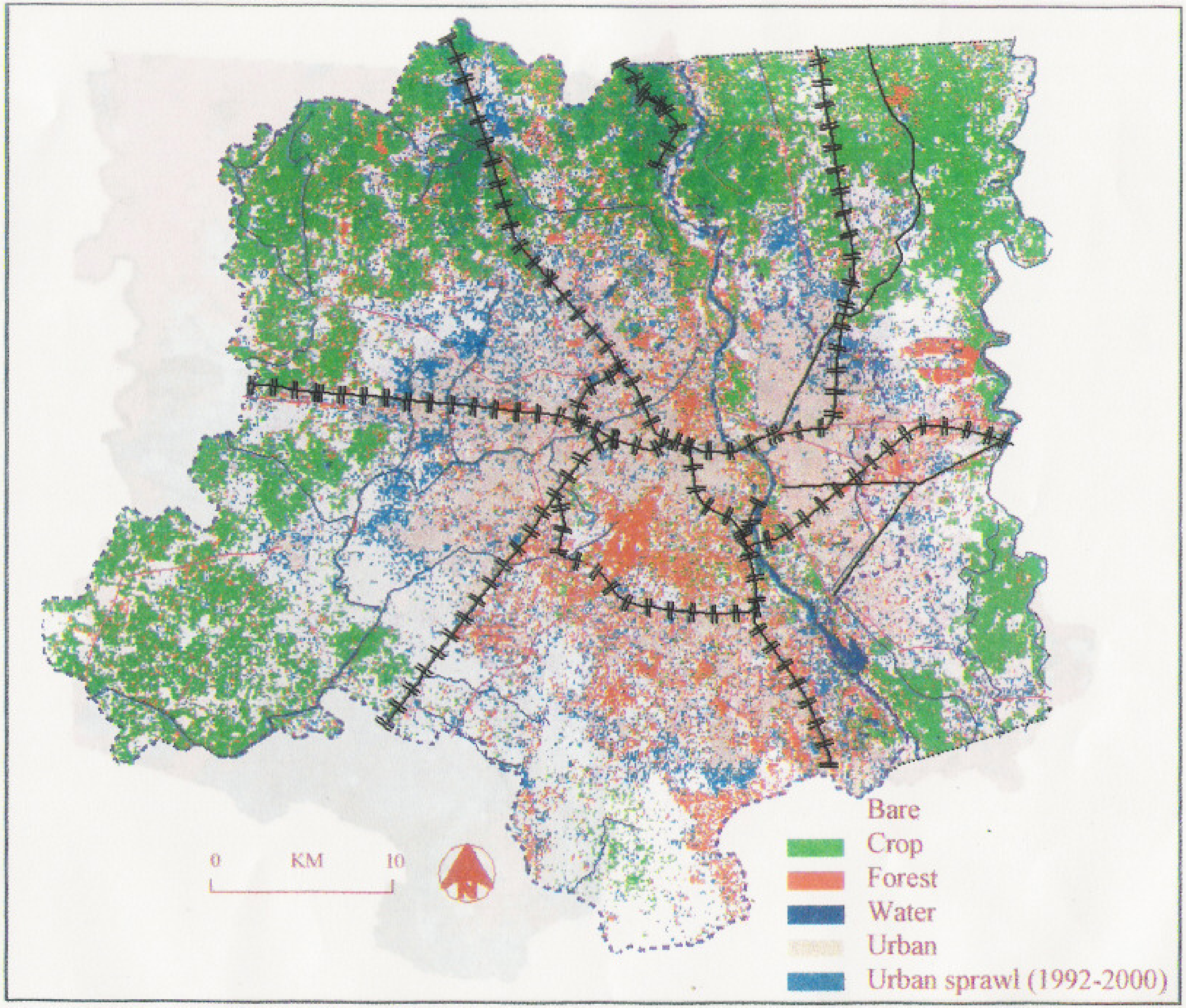

Fig. 6.3 Land use classification (1992-2000)

7.0 CONCLUSIONS

1. A good level-1 land use map, in terms of accuracy of classification, is obtained from digital image processing of the satellite data of an urban area.
2. It is suggested that for accuracy estimation for land use change map, the map used for generation of stratified random samples be post processed. The post processing eliminates the possibility of selecting marginal points where it is very difficult to establish the land use change class. Apart from ease in noting the reference class, the samples generated are also more representative.
3. In nearly a decade, the urban sprawl has been nearly 50% in Delhi. Considering the omission and commission errors in the urban and urban sprawl classes, the sprawl is nearly 33%. This is a large sprawl and it will necessitate improvement in the urban infrastructure. The discharge from the area will increase and the estimation of the design discharge will be required from the areas with changed catchment hydrological characteristics.
4. The supervised classification map is superior to the unsupervised classification map for the urban sprawl class. This result is also reported in literature and is in line with the principles of digital image processing.
5. The supervised classification map with good accuracy cannot be generated in single iteration. The class designation change can be prompted in the accuracy checking exercise. The overall visual inspection of the result will also prompt the image analyst to include more training sites.
6. In past, the runoff estimation has been successfully done using SCS curve number technique by using average CN from level-1 land use map. Thus, the map generated here can be used for study in the impact of urbanization on runoff.
7. In the error estimation, the samples are drawn from overlay map from unsupervised classification of 1992 and 2000. Samples are also drawn from overlay map of unmodified supervised classification of 1992 and unsupervised classification of 2000. Thus, the accuracy estimation will be biased with respect to the sprawl area derived in these two overlay maps.

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