Enhanced geographic information system application using IRS-1C data – Potential for urban utility mapping and modelling

K. Radhakrishnan, S. Adiga, Geeta Varadan and P. G. Diwakar

ISRO Headquarters, Antariksha Bhavan, Bangalore 560 094, India

The tools of geographic information system (GIS) which can be used in a variety of ways to address the local problems of rapid urbanization have been discussed. With the availability of high spatial resolution data of IRS-1C many new ways of looking at urban utilities and environment have been illustrated. The new GIS models which can be adopted on an operational basis by developing and linking data bases in spatial and non-spatial form down to cadastral level have been explored. Day-to-day problems of the urban dwellings, i.e., traffic and transportation, greenery, solid waste disposal, pollution, location of new layout for urban growth, road alignments, etc., have been given a new look under the GIS environment with possibilities arising from the high resolution colour images of IRS-1C satellite.

MORE than 25 per cent of India's population lives in urban areas and consists of about 3500 towns of varying sizes. Over the last four decades, the urban population has more than quadrupled. Nearly one-third of the urban population, i.e., about 70 million Indians live in 23 metropolitan cities, with the major concentration in Bombay, Calcutta, Delhi, Madras, Hyderabad and Bangalore. Most of the urban centres started as trading towns centred in agricultural areas and grew with the pace of industrial development. In the process, some of the best agricultural lands were consumed for urbanization. According to an estimate, nearly 10 million hectares of productive agricultural land will be lost in the country by the year 2001 due to unplanned growth of the urban centres. This poses problems of housing, sanitation, supply of power and water, disposal of waste and environmental pollution. Hence, comes the need for integrated urban planning, which calls for information on the spatial distribution and extent of land and other natural resources in and around the urban centres and their dynamics. We specially look for urban sprawl or the pattern of growth, urban landuse, urban transportation and urban zoning based on environmental considerations, demography and developmental needs.

Remote sensing and geographic information system (GIS) addresses the problems related to urban planning and management. GIS can be defined as a set of tools for collecting, storing, retrieving, transforming and displaying geographically referenced spatial data with its corresponding attribute information to meet a specific requirement. The distinguishing feature that separates GIS from other information storage and retrieval systems is the use of the location of features in a co-ordinate space as the fundamental referencing principle and as important variables in quantitative analysis. There are essentially two kinds of data bases: one, the specific characteristics of a location called as spatial data (e.g., its slope, soil type, etc.) and the other attribute data (statistics or written text, tables, etc.). New maps can be generated precisely by easily integrating innumerable layers of data. Thus a GIS has a data base of multiple information layers that can be manipulated to evaluate relationships among the chosen elements in the different layers under consideration. The data analysis in GIS is supported by computer-aided mapping and data base management[1]. In the present study high spatial resolution data, i.e. PAN and LISS-III data have been used together effectively to bring out various potential areas of urban studies under GIS environment.

The earlier work on growth of Bangalore city based on maps and satellite imagery[2] has addressed the urban sprawl and growth of Bangalore city using the Landsat Thematic Mapper imagery. The study has also demonstrated the use of remote sensing data for updating and monitoring of urban landuse/landcover change. Here we look into the localized problems and new developments of urbanization. A major goal of most local Government GIS efforts is to implement a multipurpose integrated system that will serve the needs of a variety of users[3]. Local Governments also depend on the information on ownership of landholdings which can be provided with the cadastral overlays on PAN + LISS-III kind of product of IRS-1C satellite. In the pre-digital period, the ownership record was ignored due to technical limitations that will not apply under the new technology[4]. Large scale satellite pictures and GIS techniques allow development of land information system at the level of land ownership. In view of urban environmental problems and related issues, a variety of approaches by which solutions can be achieved have been discussed in the present study. Initial results of the study using IRS-1C have been presented with illustrations to demonstrate the potential of high resolution PAN and multispectral data for addressing various problems of urban planning and management and their solutions.

Objectives

The objective of the present study is to use IRS-1C high spatial resolution data for utility mapping and modelling. Some of the direct and conjunctive applications are:

Direct applications

- Detailed urban landuse mapping (1 : 10,000 scale)
- Urban sprawl mapping
- Transportation network mapping
- Water pollution and greenery monitoring
- Settlement pattern mapping updating for census purpose
- Solid waste disposal sites identification.

Conjunctive applications

- Suitability assessment
- Environmental assessment
- Growth profile analysis
- Transportation zones.

Conjunctive applications use remote sensing data layer and urban development data layers in a GIS environment. After performing integration of the layers the same can be used for various types of modelling purposes.

Study area

Bangalore city of Karnataka has been identified for the present study. The city corporation limits are enclosed within 12°50′ to 13°10′ north latitudes and 77°30′ to 77°45′E longitudes. The area falls in two Survey of India (SOI) toposheets (57 G/12 and 57 H/9) on 1 : 50,000 scale.

Physiographically the study area forms a part of south interior maidan region of Karnataka. The southern part of the area forms an uneven landscape with intermingling hills and valleys. The physiographic features in the north western and western parts are barren rocky hills. The northern portion forms a hilly terrain, while the eastern part forms plains and uplands. The central portion is by and large an urban area.

Bangalore has been classified as seasonally dry tropical savanna climate with four seasons. Average rainfall in the area is 860 mm. Major portion of rainfall is received during April to June and thunder storms during September to October. April is usually the hottest month with mean daily maximum temperature of 33.4°C and mean daily minimum at 21.2°C. The mean monthly relative humidity is lowest in March (44%) and high during June to October (80%). The area forming part of Deccan plateau is comprised of gneisses, granites, basaltic dykes and laterites.

Data used

Both spatial and non-spatial data are used for the study. Mainly the panchromatic and multispectral data from the IRS-1C satellite are used. The details are given below:

(i) IRS-1C LISS-III data of path 100 and row 64 of 20 January 1996.
(ii) IRS-1C PAN data of path 100 and row 64 of 20 January 1996.

IRS-1C panchromatic camera has a spatial resolution of 6.25 m and spectral range of 0.50–0.75 μm. The spectral range of first three bands of LISS-III camera with 23 m spatial resolution are 0.52–0.59 μm, 0.62–0.68 μm and 0.77–0.86 μm. While the fourth band in middle infrared region has 70 m spatial resolution.

Besides the SOI toposheets covering the city on 1 : 50,000 scale, SOI city guide map on 1 : 20,000 scale (surveyed 1979–80) and Bangalore District Statistical Hand Book (1993–94) and Bangalore Census (1991) books are also used for the study.

Image processing

The remotely sensed data from the satellite are analysed for extracting information on surface features and for deducing their properties for identifying objects on the earth, based on the observations made on the reflected/scattered energy from the earth on different spectral channels. Digital image processing is a means by which the manipulation and interpretation are performed on the images in the digital form with the aid of computers. Digital data are treated with various algorithms for enhancing the features for better interpretability and analysis[5].

IRS-1C PAN and LISS-III data are used together in order to extract information at high spatial resolution. As the PAN camera has a high spatial resolution of 6.25 m and LISS-III contains rich information in the multispectral mode at a relatively high spatial resolution of 23 m, the two data sets were combined for optimum information. On the basis of the above, an attempt has been made to generate false colour composite (FCC) by merging PAN and LISS-III data for value addition.

As the PAN data for Bangalore and surroundings have been covered in 4 sub-images, a mosaicing of these sub-images has been done to generate a single image of PAN sensor. LISS-III has been referenced and registered with PAN data by considering well-spread GCPs in the entire image. Sub-pixel accuracy was achieved in the image referencing which is very important in deriving good merged product of PAN and LISS-III. Subsequently the FCC of PAN + LISS-III was generated.

Bangalore City Corporation boundary was overlayed on the PAN + LISS-III product and an image pertaining to corporation area was studied. The final image was used to demonstrate the possibilities of extracting a variety of information for use under the GIS environment (Figure 1).

Development of urban GIS

The various types of data available for the study of urban environment have to be integrated. The information may be of the spatial or non-spatial type. The spatial data consist of a string of geodetic control points and provides the geographic reference for the data in terms of (x,y) co-ordinate system. The base map needs to be created in the spatial domain using 1 : 50,000 SOI topographic maps which serve as a reference for the rest of the thematic layers for natural resources. For the study of detailed urban environment and related problems it is essential to create a data base of cadastral maps which will serve as a reference for extracting and analysing information with respect to survey numbers/ownership of the land parcels. Also, a link mechanism needs to be established in such a way that natural resources layers can be overlayed with cadastral boundaries in the form of graphics for any developmental analysis. Hence, a one-to-one correspondence is required

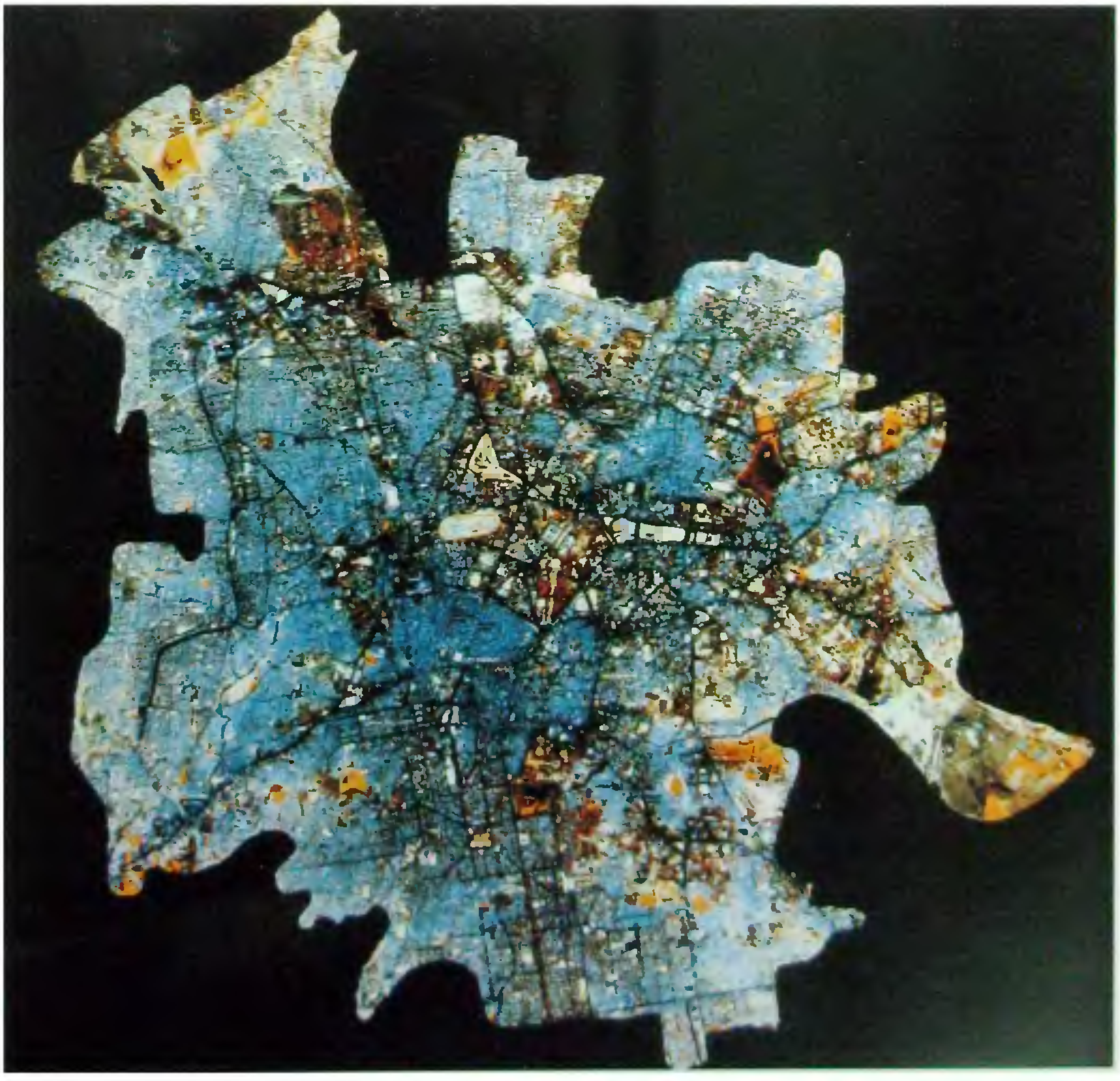

Figure 1.

to be built amongst cadastral overlays and resources map and finally in turn with the base map of the GIS. The non-spatial information creates a relational data base comprising of information on fiscal reports, administrative records, natural resources information and various other land records. All the non-spatial data should have a total linkage with the spatial data layers for queries or integrated analysis.

An attempt has been made in the present study to bring out various aspects of GIS development for Bangalore city using ARC/INFO capabilities at the Regional Remote Sensing Service Centre of ISRO at Bangalore. The high potential of using PAN + LISS-III data of IRS-1C has also been demonstrated by highlighting a few sample illustrations of possibilities to directly use remote sensing inputs for GIS development. Various new areas in which the remote sensing data can drive the GIS techniques have been explored. Especially for the formation of new layouts with prior analysis based on cadastre, a new perspective with better solution for traffic congestion, new ring road alignments to ease the traffic flow into the city limits from the national high ways, heat islands and the relationship with concrete built up areas and emphasis on heat-sink elements for better environment are discussed. Yet another new possibility is in the area of infrastructure development for urban corridors. This is done by deriving accurate terrain height information from stereo coverage of IRS-1C PAN. This is also useful in deriving accurate slope and aspect information which can be used in an integrated way with other thematic layers for better developmental activities. All these ideas towards enhanced GIS capabilities have been elucidated in the following chapters.

Analysis and interpretation

The PAN + LISS-III value added product has been derived at 6.25 m resolution. Besides the detailed information equivalent to aerial photographs, the quality of information was of high standard. This kind of data open out a lot of new challenging applications, especially in the area of urban utility-oriented information extraction.

Effective traffic management

The transportation network of Bangalore city, having road widths of hundred feet, sixty feet and forty feet are clearly visible using IRS-1C PAN data. Road update for better traffic management (especially where regular traffic congestion is observed in the peak hours of the day) can be done straight away using these data. Information of new traffic signal spots can also be suggested based on the analysis of the data. Even street level information is possible with such data. Such a map can even be used by Bangalore Transport Services (BTS) in the city limits to optimize the routes and improve the bus services.

From the image map it can be seen that a large number of vehicles get into/get out of the city at a few major points. With the ring road implementation nearing completion, suggestion on optimum traffic management can be thought of. For example, during peak hours all incoming vehicles could be diverted to the ring road so as to reduce the congestion within the city limits. Many such alternative transport/traffic management can be thought of under GIS environment. Using GIS it is also possible to come out with optimum routes for the citizen in the time of emergency by locating all the major hospitals and dispensaries and the best route to reach each one of them from any point in the city. This could serve as a very good utility for the people of Bangalore.

New road alignments

The Bangalore city has extended beyond the present municipal limits and BDA limits. The kind of new facilities that can be thought of for future growth of Bangalore can be brought out in detail using IRS-1C data.

The fine spatial resolution can help in satisfying some of the criteria for new road alignments on similar lines to ring road alignment of Bangalore. They are: detailed landuse/landcover map (1 : 10,000 scale), avoidance of some dense settlement, potential agricultural plantations, industrial and religious places along the alignment; to follow the topography as easily as possible in order to balance the earth work (here the stereo-pair images of PAN will come in handy); to keep the curves and drainage cuttings at the minimum; to suit further development and to avoid weaker zones like unearthed zones, erosion-prone areas and environmentally fragile areas, quarries, etc. The stereo-pair images from PAN camera would be further useful in determining the contours at an interval better than those available from the SOI maps and thus aid in construction of roads. The Department of Space played a significant role in the alignment of ring road, now in its final stages of completion. Figure 2 indicates the existing ring road clearly and also shows the new settlements that have developed along this route. Thus IRS-1C data will not only be helpful in aligning any future road alignment but also can be a convenient tool for monitoring the urban sprawl along the newly laid out peripheral roads (Figure 2).

Cadastral overlay

For an efficient urban land information system it is essential to have a total data base of the landuse and land holdings in spatial form, substantiated with textual information in the data base. Basic conceptual model for GIS in such cases is to have a multipurpose cadastre. This model is based on the land parcel as the central entity in the GIS. The ownership parcel, or cadastre, is the entity with which most local Government operations and applications are concerned[3]. The model proposed by Rebecca Somers may be adopted for deriving and managing the cadastral level information. The model components are:

- A spatial reference framework
- A large scale base map
- A cadastral overlay
- Linkage mechanism
- Land-related data.

IRS-1C PAN + LISS-III data at scale 1 : 10,000 can be used in conjunction with basemap and cadastral map to build a total data base on land holdings for operational use.

For urban infrastructure development mode like outer ring road construction, airport site selection/acquisition, a quick idea about the existing land utilization survey, numberwise, is of paramount importance. For this, remote sensing satellite data can be utilized for preparing the land utilization maps. Overlay of the cadastral map on satellite data will clearly indicate the land utilization with respect to survey number and the ownership of the land.

Census mapping

The primary objective of census operation is to maintain and update the census results decennially and disseminate the results to other user agencies who are involved in the planning process. Though the census provides retrospective synchronous demographic and other infrastructural details, the spatial/geographical dimension is lacking or absent.

The combined approach of satellite data interpretation and GIS will provide an opportunity for urban planners to frequently update the perspective plans of growing cities/towns which gives a quick appraisal of environmental status, urban encroachments, infrastructural gaps and developmental needs, health and sanitary facility requirement, etc. The method also helps in identifying various problems encountered by growing cities and tackling them on a scientific basis. The large scale satellite images of IRS-1C facilitate frequent updation of master plans of cities/towns in a cost effective manner as compared to the conventional approach and air-photo interpretation techniques.

Figure 2.

The cartographic data base, a part of urban GIS created by bringing notional maps available at Corporation, Ward, Charge and Enumerator Block level to proper scale by referencing with geographic co-ordinates and in turn with IRS-1C data enables the following:

(i) A means for standardizing the geocoding of controlling boundaries (like exact fitting of actual enumerator block, etc.).

(ii) Flexibility to frequently change geocoding due to increase in population density or due to administrative changes.

(iii) Better way of maintaining previous census results and better means to compare the census data collected during different census periods.

(iv) Compatibility and inter-changeability of information between different types of maps, scales forms a base for standardization.

(v) Quick measure of disseminating data and reduce the time required for printing and publication of maps, utilization of scaled maps during subsequent census and surveys, etc.

(vi) Generation of information in specific formats (both cartographic and attribute information) and a user-friendly query system.

The urban GIS helps to derive varieties of information, viz. area statistics, infrastructural facility-gaps and deficiencies, forecasting of demographic data, derivation of data for taking crucial decisions on urban problems through planning models (Figure 3).

Image-map generation

For any urban-related study it is necessary for one to have a high spatial resolution image depicting typical utility-oriented details like good road network, prominent places of interest, places of recreation and parks, places of tourism, etc. Image maps are documents where the conventional planimetric information is replaced by satellite image. Taking advantage of high spatial resolution of IRS-1C PAN (6.25 m) and optimized spectral resolution of LISS-III (23 m) a synergistic fusion of the data

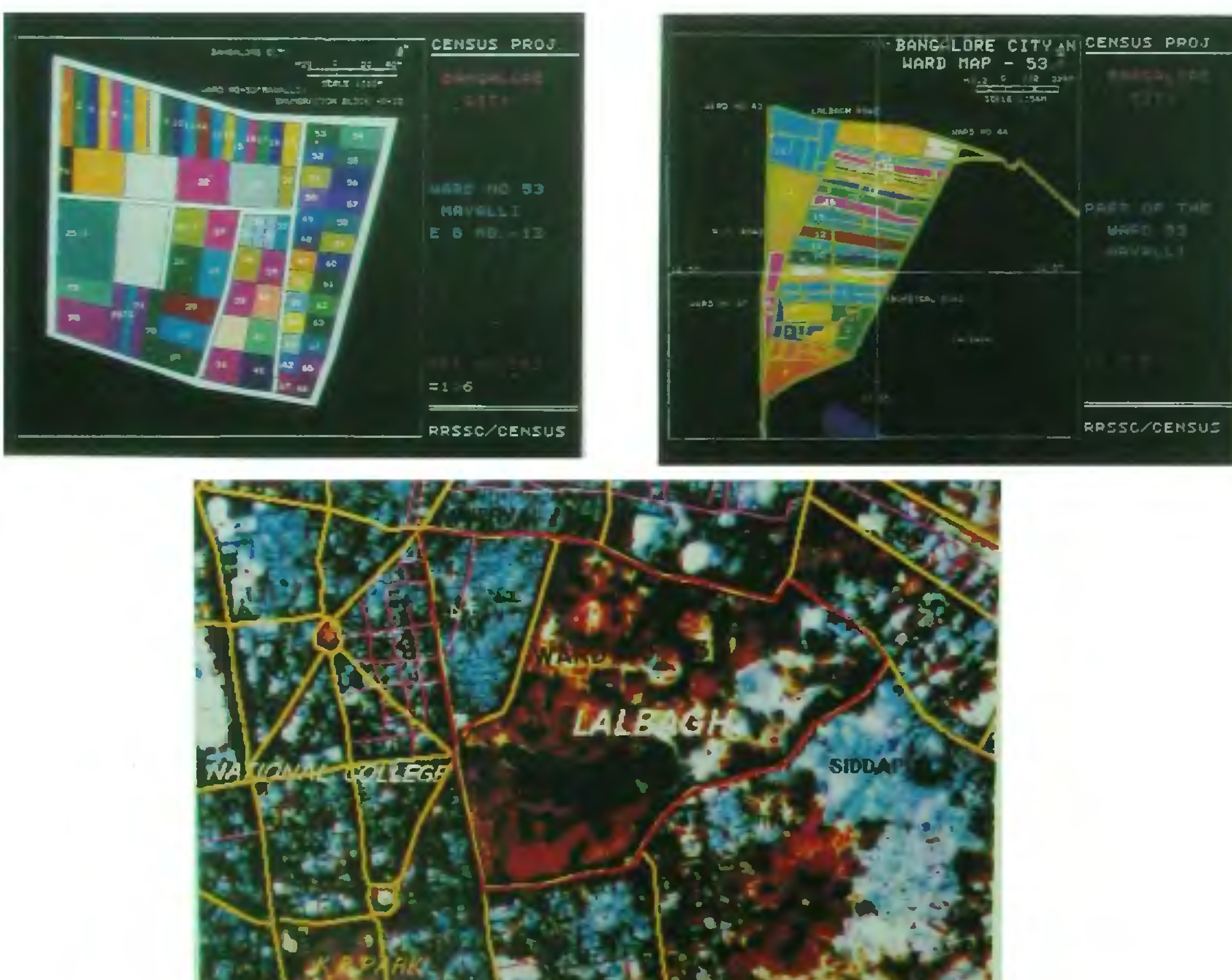

Figure 3.

sets has resulted in a product which has high quality of value addition. Such hybrid data are amenable for image map generation even up to 1 : 10,000 scale providing details with high accuracy. Using these data an attempt is made to produce an image map with details of major and minor road networks and important land marks in the heart of the city.

Satellite data-based maps are a multi-disciplinary management tool for local and regional studies. They are easy to produce and provide a base product for all developmental projects, particularly in regions for which existing survey maps are not up-to-date. They facilitate ground surveys and controls and serve as the plotting basis for thematic maps when updating or assessing natural resources. This type of maps produced for urban areas can be conveniently used for updation of city guide maps, generation of urban atlases for inclusion in the educational curriculum, etc. (Figure 4).

Heat island mapping

The causes of the urban heat island are complex; generally its appearance can be attributed to the effects of urbanization. Although direct heat release to the atmosphere as a result of human activity constitutes an important contribution to local urban heating under some conditions, the urban heat island is more directly a result of the redistribution of the solar energy reaching the ground than a result of anthropogenic heating. Urbanized areas are generally characterized by a substitution of artificial materials such as concrete, brick, glass and steel for natural vegetation. Changes in landuse, occurring as a result of human activity, are reflected in surface temperature patterns, which are now resolvable in great detail by infrared radiometry from space.

With growing number of vehicles in the city, increase in the high raised structures leading to concrete jungles, reduction in the tree-clad areas, rapid industrialization all around the city, there is general warming and changes in weather conditions over a period of time with urban growth. To understand this dynamics of heat sink, an attempt has been made to generate heat island map by using satellite images with thermal sensors over Bangalore. Both day and night thermal data have been used followed by ground calibration. Contours of hot spots have been derived and overlayed on the Bangalore area shown with greenery. On interpretation it is clear that thick urban development and built-up areas emit high temperature. Hence, these areas need development of vegetation with lot of biomass to act like a heat sink and bring down the emitted temperature considerably (Figure 5).

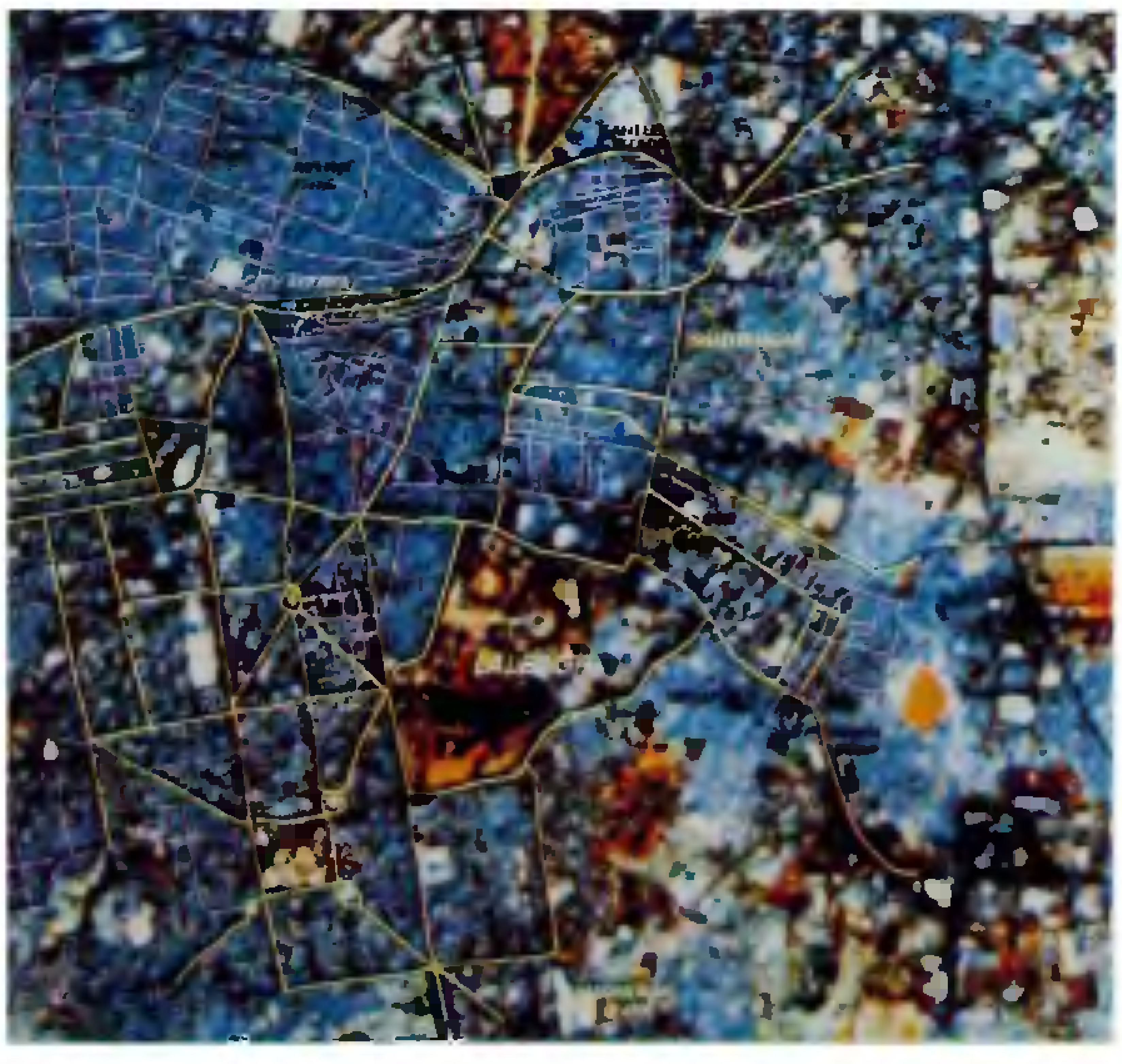

Figure 4. Image – Map out put.

Polluted lakes around Bangalore

Many of the naturally formed tanks around Bangalore area are heavily polluted either with weeds, water hyacinth or other pollutants. The IRS-1C data of 1996 depict either the relicts of quite a few of such tanks or much reduced sizes of the tanks seen earlier with information on choked up drainages and tanks full of water hyacinth, algae, etc. Among the major tanks, except for Lalbagh lake and Sankey tank all remaining water bodies are found to be highly polluted. Action plans, on reviving some of the old tanks and making them pollution free, can be attempted by analysing temporal satellite data using GIS techniques (Figure 6).

Solid waste management

In Bangalore there is a need for immediate action for a systematic assessment of the hazardous waste and its indiscriminate disposal. Under solid waste management, attention should be focused mainly on two issues, viz., (i) identification of suitable sanitary land filling to isolate waste from human society and the eco-system, and (ii) monitoring the existing land fill sites for environmental impact assessment. Settlement of a land fill cover caused by decomposition and consolidation of wastes can initiate cracking, irregularities and depressions in the cover which can allow water to infiltrate into the waste and can lead to groundwater contamination. Generally the following criteria are adopted to select favourable garbage disposal sites:

(i) it should be a land depression and is water tight.
(ii) the depth of the groundwater level should be more.

Figure 5. Bangalore city and surroundings with isothermal contours.

(iii) it should be an isolated depression without much rain water collection
(iv) it should be away from a water source and human interaction
(v) it should not be in the direction of urban growth.

IRS-1C data can aid in identification and location of such dumping sites and in evaluation of historical changes in landuse within and near hazardous waste and sanitary landfills. The data can also be used to characterize solid waste landfills and hazardous waste sites in the following ways:
(i) the high resolution stereo pair images facilitate to compute digital elevation models of the landfill which can result in more accurate prediction of surface water runoff and performance of volumetric measurements.
(ii) the improved high resolution data including the SWIR band data enable to map chemical compositional differences that are environmentally significant by monitoring the landcover changes and identifying the stressed vegetation, etc.

Conclusion

The field of geographic information system and its applications or adaptation for solving newer problems of urban utilities has been rapidly growing in the past few years. Now, with the launch of IRS-1C satellite a host of new application areas have emerged. In the present study, the IRS-1C PAN and LISS-III data have been optimally fused by employing image processing techniques so that the same can be used in a variety of ways to fit into GIS applications. Certain new areas like image-map generation, cadastral data base generation and modeling, etc. have been made possible with such a high resolution data. It is possible to prepare thematic maps to the scale 1 : 10,000 which are useful for various urban applications and infrastructure development. A new look at the type of data base generation and modelling at the cadastral level has been suggested which will help the government authorities in monitoring and planning with respect to survey numbers/ownership parcels. The requirements of census mapping, road align-

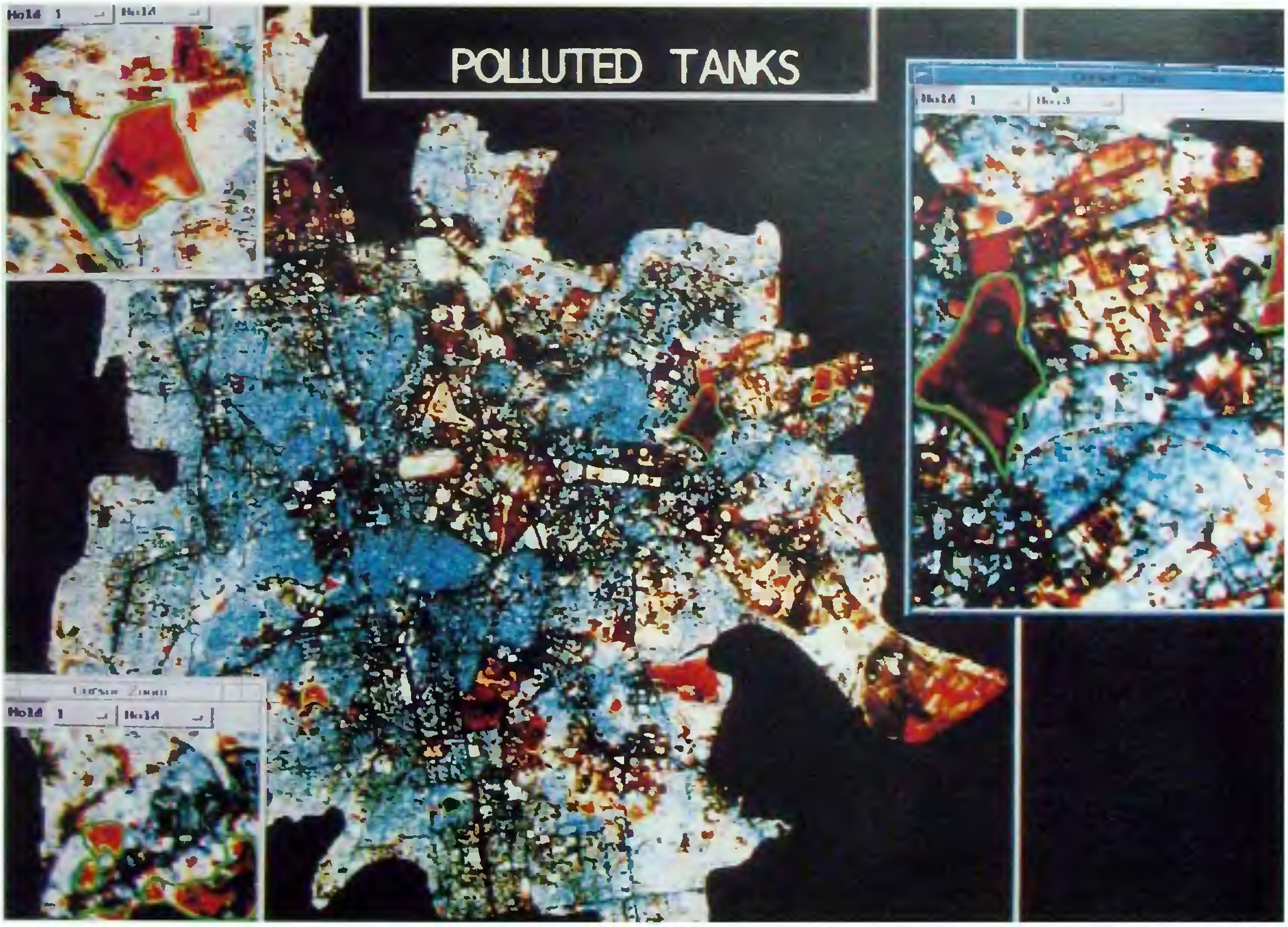

Figure 6.

ment and metropolitan development can be easily met with by using the proposed GIS development methods. Many other urban environment-related problems like identifying areas without greenery and taking up such areas for planting high biomass yielding trees, traffic management and re-routing problems with respect to local road networks and national highways, identification of heat islands using thermal infrared data and using the heat island contours as overlay on the high resolution data to pin point areas emitting/radiating high energy in urban pockets are addressed. Hence, conclusive evidences are drawn on the use of high resolution data driving the capabilities of GIS to solve problems of urban areas specially related to the utilities and environment.

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