Application of GIS in urban utility mapping using image processing techniques

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Growing cities are creating an alarming situation in all countries of the world. It has led to serious land use problems such as loss of agricultural land, unauthorized urban sprawl, high land values, speculation in land, and other related problems. In this emerging scenario, it is essential to have updated information on urban growth patterns and their impact on the living environment. Growth and development of these cities are likely to continue and therefore there will be a need for proper planning and managing or improving the existing infrastructure facilities. This study demonstrates image fusion of LISS-IV MX and Cartosat-1 satellite data to create detailed town planning and utility mapping for amenity patterns and facilities available in Karaikal city, India. Road patterns within the city are analyzed and a road network map is generated. A proximity analysis was carried out to understand the availability of institutions, hospitals, and industries for effective disaster management. Karaikal has grown rapidly in all directions especially in north, northwest and west parts. A big question for planners is the provision of proper amenities. Using geographic information system and remote sensing, city administrators can now evolve an expert decision support system aimed at various decision-making processes.

Keywords: high-resolution satellite data; proximity analysis; utility mapping

1. Introduction

India’s fast economic growth during the 1990s and rapid urbanization during the same period are interlinked. The contribution of urban areas to the gross domestic product was 50–60% though the overall level of urbanization was just 28% in 2001. In the twenty-first century, the majority of the world’s populations are living in urban areas for the first time in the history (1). Urbanization is an index of transformation from a traditional rural economy to a modern industrial one. It is the progressive concentration of population in urban units.

Urbanization can be defined as a concentration of people in a geographic area who support themselves from the city’s economic activities on a fairly permanent basis. The city can be a center of industry, exchange, education, government, religious activity, tourism, or involve all these activities. These diverse areas of opportunity attract people from rural areas/smaller towns/other cities to the cities where the opportunities and life style quality match their aspirations. Predominantly, urban growth has meant the enlargement of existing towns at every level and significantly, not the addition of new towns. One distinctive feature of India’s urbanization is increasing metropolitanization.

The Ministry of Urban development, Govt of India launched a National urban information system with the objective to generate a multiscale hierarchical urban geospatial database including thematic data for various levels of urban planning. Economic growth was thus seen to be highly dependent on the fortunes of the urban areas and their ability to attract investment and increase productivity. Urban households across India, particularly the poor and the disenfranchised, continue to have limited access to potable water, sanitation, drainage, and solid waste disposal facilities. Urban transport is a key element of urban infrastructure. An effective urban transportation network not only enhances productivity and facilitates high growth of the economy, but also empowers the poor by increasing employment opportunities. Analysis of the best path between two points (3), the location of a new service center (school and power substation) and assignment of the areas of influence of a center are facilitated. Maps derived from geographic information system (GIS) analysis showing maintenance occurrence, impact of breaks or leaks (4), and impact of future development can assist with infrastructure management. Public transport is energy efficient and less polluting and helps in maximizing urban–rural linkage with improved access for the peripheral population to city centers without proliferation of slums in and around cities. Urban areas have many obvious faults insofar as their services to people are concerned. They can be overcrowded, contain large amounts of substandard housing, be polluted (air, noise, and environmental), be
centers of unemployment, and have vested interest groups. However, with all of these faults, urban areas are here to stay. The charge to planners, at all levels, public and private, is to find ways of making these essential elements in our social system work better, more efficiently, and thus make our cities better places to live in.

In order to prepare urban development plans, planners need detailed information on the distribution of land and its use in city and surrounding areas (5). For example, the city planners and engineers are required to plan optimum routes for transportation and construction of better utilities. For planning these utilities in better way, the availability of total information spatially assumes importance. High-resolution satellite data have great potential for providing cost-effective and up-to-date information on cities in developing countries (6). The current/near high-resolution satellite data from Cartosat-1, 2, Cartosat-3, RISAT, ASTER, and Landsat ETM in optical will begin to meet urban needs. Every day planners use GIS technologies to research, develop, implement, and monitor the progress of their plans. Urban planners and decision-makers have to be more sensitive in the decision-making process and by analyzing qualified data, to make the best decisions.

2. Methodology

2.1. Study area

The Karaikal region is embedded in the Nagappattinam and Tiruvarur Districts of Tamil Nadu State. The study area lies between 10° 49’ and 11° 01’ northern latitude about 150 km and lies between 79° 43’ and 79°52’ eastern longitude about 150 km. It has an area of 161 km² and a population of 170,640 as per the 2001 census. Karaikal is located at an average altitude of 4 m from mean sea level and is surrounded by plain and coastal areas. Karaikal has an annual average rainfall of about 126 cm.

The step-by-step procedure for master plan preparation of Karaikal town and its utility mapping are shown in Figure 1.

2.2. Geo-Referencing

Georeferencing and Image rectification involve the removal of random and systematic errors in the image and then transforming the image to UTM projection and the WGS 84 datum. About 4–5 well-distributed-ground control points (GCPs) for each scene are used for georeferencing. The image is rectified using GCPs using a first-order polynomial transformation with RMS xy accuracy better than one pixel at each check point. The Erdas Imagine 8.6 image processing software was used for this operation.

2.3. Data fusion

Image fusion was carried to fuse the LISS-IV Multispectral and Cartosat-1 panchromatic (PAN) in order to obtain high spectral and spectral resolutions of the imaging system (7). Fusion is an image processing technique that merges the co-registered high-spatial resolution PAN image with low-spatial resolution multispectral image to produce a multispectral image with high resolution. Further image fusion helps to enhance the information content and improves interpretation of the fused or hybrid images by taking advantage of complete information in both the multispectral and PAN images.

2.4. Administrative layers

The sharpened Georeferenced Cartosat-1 (PAN) and IRS LISS-IV (MX) fused satellite imagery were used to coregister the georeferenced area of interest (AOI) from the administrative boundaries shapefiles following the spatial reference framework. The AOI shows the city core boundary (municipal/corporation limits), village boundary, and settlement name.

2.5. Preparation of urban land use/land cover

Urban land use is central to the Master plan/Development Plan preparation and the main theme of the thematic mapping component. The urban land use classification was delineated from Cartosat-1 and LISS-IV MX fused data up to level-IV at 1:10,000. Each level contains information of increasing content and specificity. The built-up area comprises residential, institutional, commercial and industrial, road areas, and religious and cultural places. The land cover comprises crop land, fallow, vegetated area, scrub land, aquaculture, and water bodies. These were interpreted using on screen digitization with the help of key elements. For urban planning, the maps made in this manner can be used as:

(1) identification of vacant land for acquisition;
(2) updating of base maps; and
(3) alignment of major roads and railways.

2.6. Utility planning

The quality of life in urban areas largely depends on the availability of infrastructure (such as water supply, waste
disposal, road rail infrastructure, communication facility, house types, and availability of various other basic services, health, and education). Here, the study takes into account major facilities like educational facilities, hospitals, and industry. GIS can quickly analyze and display a route from a station or global positioning system (GPS) location to an emergency call. This route (depending on the sophistication of the street file) may be the shortest path (distance) or the quickest path (depending on time of day and traffic patterns). With the help of remote sensing, GPS, and GIS, one can update facility locations easily. Further, site suitability for various services, needed for planning purposes, can be carried out easily. The physical accessibility of various services can be determined in a GIS by using road network, buffer, and connectivity analysis within any specified number of km/m. Results will also show how much area and population a service covers. One can create buffers of various distances, a feature in many GIS packages, like ArcGIS. City planners can calculate service demands for public facilities, such as schools and hospitals. Spatial connectivity analysis can be done easily (using the roadmap to locate which is the nearest facility in case of emergency).

Network analysis can be carried out to see which facility is most linked as well as the points of least connectivity.

3. Result

3.1. Urban land-use mapping with IRS P6 LISS IV

The Karaikal region was mapped using Cartosat-1 and IRS-P6 LISS IV data. An urban land use map was prepared and mapped at 1:10,000 scales. Level-IV mapping of the urban land use was successfully executed. IRS LISS IV data was found that it has high-information content and shows the enhanced capabilities of the sensor. Earlier, with this resolution, only level-III mapping of urban land use was possible, but here it provides more information on urban features.

A total of 32 classes were mapped, among which 25 are urban land-use classes. An analysis of all the mapped classes shows that the major land uses in the study area are forest, built-up area and agriculture, respectively. Almost 50% of the study area comes under the category of fallow land, which is due to large amount of single crop area around the city. With the influx of population over the last few years, the city is growing rapidly along

![Urban land use map](image-url)
the transport corridors. The next major land-use category is the built-up area, which consists of Karaikal region urban area inside the city. In this study area, there is a good amount of agricultural activity, which consists almost 28% of land area. All categories of water bodies form more than 20% of the total study area. Most of the water bodies in the study area are in the form of rivers, majority being seasonal rivers. In urban land-use classes, almost 50% of the urban area comes under residential/commercial activity. The city has a spread development, as almost 50% of residential land use has high density. The high-density residential area in the city forms the central business district, where administration is carried out. The next major urban land-use category is institutional, showing the educational character of the city. The city has a good amount of vacant land as part of the low-density residential area and public/semipublic institutional buildings. A significant finding is that more than 16% of built-up area comes under urban sprawl category, demonstrating rapid urbanization around Karaikal city. Karaikal is one of the fast growing cities and emerging as the major service, commercial, and institutional center in its region. Figure 2 shows the urban land use map for the Karaikal town.

3.2. Application

These results can be achieved by queries in GIS design and application:

- determination for future town planning;
- determination of accessibility of schools;
- determination of the shortest distance between the selected places; and
- determination of important and necessary places for tourism.

The quality of life in the urban area largely depends on the availability of infrastructure such as water supply, waste disposal, road rail infrastructure, communication facility, house types, and availability of various other basic services, health, and education (8). Queries can be made on institutions concerning their accessibility from the nearest distance and mode of transport. Services provided at each site can be obtained from the tables. By clicking on several points in each site, information on the geology, planning and zoning, utility infrastructure, and other information can be obtained. In this study, two major facilities like educational facilities and hospitals were taken into account. In case of institution, the shortest route for the Vinayaka mission medical college and for the particular street address was used. The resulting map shows the shortest route. The ability of GIS to identify the geographic extent of a health facility catchment area (9), which corresponds to the area containing the population utilizing this facility, in case of Australia, Switzerland, and Canada.

By using GIS, with the help of road network, buffer analysis and connectivity analysis, i.e. within 100 m how much area it covers, was carried out. Network analysis was carried out to find out which are the points of least connectivity as shown in Figure 4. Similarly, Figure 3 shows closest hospital facility for the particular village Melsakukudi in Karaikal to Kovilpattu town, which fulfills specified criterion.

4. Conclusion

In this study, optimum planning for site management decisions and geographical data query were carried out to obtain both visual and detailed information and network analysis applications. However, this study on GIS design and application for cultural heritage sites and network analysis reveals important considerations to help users make decisions for future town planning. The advantage for making decisions based on the overall data from this system could provide spur economic revitalization, enhanced city planning, economic development,
and preserve important cultural and heritage sites and buildings. Moreover, users appear to save time via GIS design and enhanced decision-making. The applicability of the GIS database has far-reaching potential in making effective decisions in town planning.

The GIS is served in this study as an “intelligent” database. GIS is used to provide a compact space where all sorts of data relevant to Karaikal Town area can be stored in digital format, including images, maps, documents, and photographs. Data have been already arranged so that it can be incorporated into displays like maps, charts, and tables, and queried in the service of sophisticated analytical procedures. Future analyses will be the basis for future planning, design, and site management decisions. The list of queries is endless, and unique to every potential user. A successful plan and implementation will provide an opportunity to local decision-makers to provide a synoptic and detailed planning of the town.

Notes on contributors

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