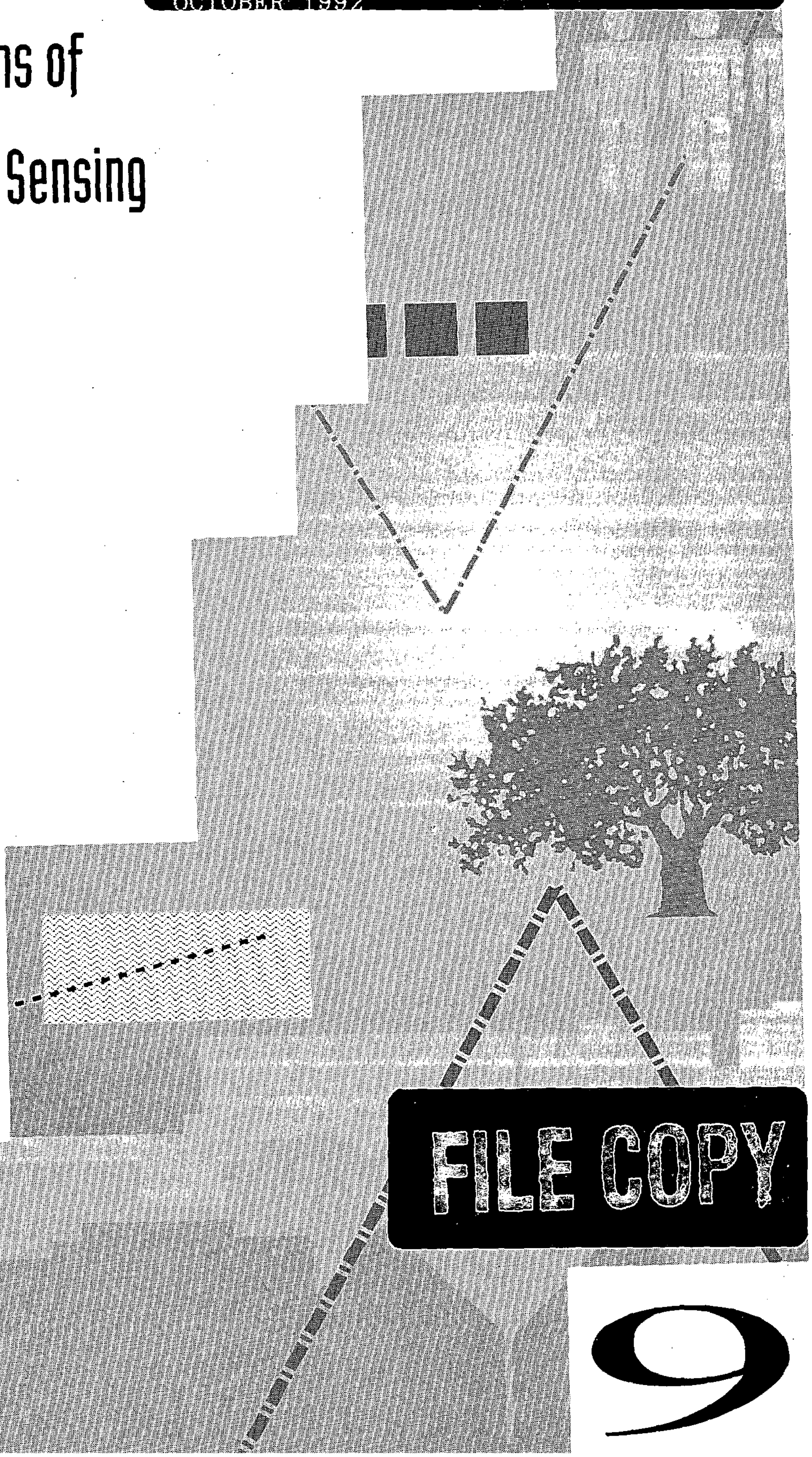
Urban Management Programme

Urban Applications of Satellite Remote Sensing and GIS Analysis

Bengt Paulsson



URBAN MANAGEMENT PROGRAMME DISCUSSION PAPER

9

Urban Management Program

Urban Management and the Environment

Urban Applications of Satellite Remote Sensing and GIS Analysis

Bengt Paulsson

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The Urban Management Program (UMP) represents a major approach by the United Nations family of organizations, together with external support agencies (ESAs), to strengthen the contribution that cities and towns in developing countries make towards economic growth, social development, and the alleviation of poverty. The program seeks to develop and promote appropriate policies and tools for municipal finance and administration, land management, infrastructure management, and evnironmental management. Through a capacity building component, the UMP plans to establish an effective partnership with national, regional, and global networks and ESAs in applied research, dissemination of information, and experiences of best practices and promising options.

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FOREWORD

This paper has been prepared for the environment component of the Urban Management Programme (UMP), a joint undertaking of the United Nations Development Programme (UNDP), United Nations Centre for Human Settlements (UNCHS), and the World Bank. The UMP represents a major effort by the United Nations family of organizations, together with external support agencies (ESAs), to strengthen the contribution that cities and towns in developing countries make toward economic growth, social development, and the alleviation of poverty. In addition to its environmental focus, the program seeks to develop and promote appropriate policies and tools for land management, infrastructure management, urban poverty reduction, and municipal finance and administration. Through capacity-building, the UMP is establishing an effective partnership with national, regional and global networks, and ESAs in applied research, information dissemination, and experience exchanges regarding best practices and options.

The paper is part of a series of management tools produced by the UMP. It has been prepared in collaboration with the Global Resource Information Database (GRID) Center at the United Nations Environment Programme (UNEP) and the Sustainable Cities Programme launched by UNCHS (Habitat). It was made possible by financial assistance from the Government of Sweden. The techniques studied will also be applied in the new City Data Programme established by Habitat. The information derived from the series will be used in preparing detailed operational guidelines to help policy makers and technical staff in developing countries carry out appropriate urban development policies and techniques, especially at the city and municipal level of government.

The range of reports from the environment component of UMP covers urban waste management and pollution control, regulatory and economic instruments for pollution control, local management of wastes from small-scale and cottage industries, land degradation, energy-environment linkages in the urban sector, the urban environmental planning and management process, the health impact of urban environmental problems, the economic spillover effects of urban environmental problems, and urban environmental data collection. All of these reports will contribute to an overall report on environmental strategies for cities.

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EXECUTIVE SUMMARY

1. Throughout the world, urban managers and policy makers make strategic decisions on environmental protection, infrastructure development and maintenance, land development, and land administration and taxation. In many cities in developing countries they also have to respond to specific pressures, such as rapid population growth and an expansion in urban areas. Yet rarely do they have access to up-to-date base-maps and systematic information on the extent of settlements, land-use patterns, environmental problems, and infrastructure facilities.

2. A reliable information base is essential for successful urban management and strategic decision making. Lack of information contributes to problems such as ineffective urban development programs and activities; un-economical and badly planned investment projects; poor functioning of land markets; property tax and transport and utility systems; and disregard of the environmental impact of development on the population.

3. One promising new source of information for urban management is high-resolution satellite data. Satellite remote sensing is increasingly being used for timely and cost-effective development of information in a wide number of applications. At the same time, computer-based geographic information systems (GIS) are being used more and more by urban agencies to improve the management and use of information. There is currently a strong trend toward more closely integrating these two technologies.

4. This report serves as a practical guide to show how satellite remote sensing can be a useful source of urban management information and to demonstrate the benefits of geographical analysis of available data. It focuses on operational applications in cities in developing countries, based on a comprehensive review of recent reports and illustrated by experience from case studies and operational projects. It does not attempt to cover all possible urban applications of GIS technology or serve as a detailed manual for all possible applications of satellite remote sensing. Rather, it offers an introduction to the technologies, available range of products, and various methods of analysis offered by satellite remote sensing.

Major areas of application

5. Satellite remote sensing can be used to gather strategic planning information pertaining to a district or a whole city. For the last twenty years, the system has been used to collect data that is used mainly for regional planning and at small scales (typically 1:25,000). However, new developments have considerably increased the potential use of satellite images for urban applications.

- Satellite images now have higher resolution, which means that more detailed maps at larger scales can be produced.

- Microcomputer technology is becoming widespread and therefore more accessible and affordable.

- Computer-aided mapping and information management is rapidly increasing, both in industrialized and in developing countries.

- The number of staff trained and experienced in satellite remote sensing has increased in many developing countries.

- National and regional remote sensing centers for education, training, and application have been established.

6. Satellite remote sensing, however, should never be evaluated and applied in isolation, without comparison to other mapping techniques and sources of information. Other remote sensing techniques—such as traditional aerial photographs and small-format air photography, or sample surveys—have unique and complementing advantages.

7. Satellite data is particularly useful for detecting major changes in urban land-cover and land-use because of frequent coverage, low cost, and the possibility of overlaying images from different dates exactly on top of each other. The number and types of land-cover and land-use categories identified will depend on where and why the map was produced. Panchromatic (black and white) images are generally best for urban land-cover types because they have better resolution (that is, a more defined picture). Multispecteral (color infrared) images give more information on vegetation.

8. Road networks can also be rapidly and readily updated from satellite images. Old roads are more difficult to distinguish, particularly small streets in high density areas. Land-cover information from satellites is used together with data from other sources, such as identifying hazard-prone areas. Satellite data can also be used indirectly as a sampling frame for collection and analysis of socioeconomic data such as population density, distribution, and growth. When information from satellite images can be combined with other sources, it can be used for GIS analysis in evaluating construction costs and environmental impact of alternative routes for utility and highway corridors; identifying population groups at risk from environmental pollution hazards; or ranking areas where human intervention is most needed to limit and prevent natural hazards, such as flooding.

Technology issues

9. Useful sources of satellite data for urban applications are the U.S. Landsat, Thematic Mapping (TM) series and the mainly French, Satellite for Terrestrial Observation (SPOT) series, although other sources exist. Various products are offered either in the form of digital data for computer-based processing or as photographic images. The costs for the products vary according to the amount of processing from US\$0.37/km^2 for a Landsat TM image at 1:100,000 scale, to US\$10/km^2 for an enhanced SPOT image at 1:25,000.

10. The main constraint on the availability of satellite images is the frequency of cloudy and hazing conditions in a city. Some areas have guaranteed cloud-free conditions for a large part

of the year. However, some tropical areas with rainforest conditions have an almost perpetual cloudcover; in these areas, realistic planning offers the only way to overcome this obstacle. Useful images will be obtained only during the seasons, however short, that offer cloud-free conditions.

11. All analysis of remote sensing images must be based on reference data, which is essential to identifying the features in the images and to verifying the reliability of the interpretation. It is usually necessary to do field work, but other useful reference data can be obtained from maps, reports, and aerial photographs that need not be entirely up-to-date. The estimated accuracy of a map should be clearly stated.

12. In a GIS this is even more crucial, since many layers of information of varying quality can be used together in the analysis.

Institutional Issues

13. Urban information management technology can only be successfully applied after institutional, procedural, and information quality issues have been addressed. There must be a management policy dealing with such matters as institutional mandates and linkages, technology strategies, human skills development, and financial management.

14. The first series of steps to improve information management include defining the information needs, setting priorities, and then comparing these with the state of existing information and the capabilities of data producers and users. The major costs of improvement are in data acquisition, institutional improvement, and education and training. Equipment represents less than 20 percent of the costs. In fact, the greatest cost involved in developing and managing a GIS is usually the effort it takes to build and maintain the computerized database.

15. One successful institutional model is to set up a network of information sharing agencies. Agencies retain responsibility for their own information and agree to share parts that are of interest to others. A separate municipal information agency can handle inquiries for data and act as a coordinator and catalyst in the network.

16. Education and training at all levels should be an integral part of the information improvement strategy. The amount and type of training needed depends, in part, on the level of technology to be used. Besides training hands-on users in the new technology, there is also a need to educate managers about concepts so they can make wise decisions on its use.

17. A high level of technology does not necessarily produce better results from remote sensing images. It takes little effort to create the institutional structure, or reach the basic level of technology needed to start applying remote sensing with good results.

Conclusions

18. High-resolution satellite data have great potential for providing cost-effective and up-to-date information on cities in developing countries. The data allow it to be possible to gather strategic planning information on a district or whole city basis, and this can be used to complement information from other sources. Because satellite remote sensing also can be successfully applied with varying degrees of technological sophistication, a system can be set up incrementally allowing for cost and manpower considerations. Provided an institutional function is established to support a broad spectrum of urban management information concerns, satellite remote sensing can be an effective technology for use by urban managers.

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I. INTRODUCTION

The need for urban management information

1.1 A broad and reliable information base is essential if cities are to be managed effectively. Lack of information contributes to problems such as ineffective urban development programs and activities; un-economical and badly planned investment projects; poor functioning of land markets, property tax and transport and utility systems; and disregard of the environmental impact of development on the population.

1.2 Throughout the world, urban managers and policy makers make strategic decisions on environmental protection, infrastructure development and maintenance, land development, and land administration and taxation. In many cities in developing countries they also have to respond to specific pressures such as annual population growth of up to 10 percent and an expansion in urban area from 50 percent to 100 percent every ten years. Yet rarely do they have access to up-to-date base-maps and systematic information on the extent of settlements, land-use patterns, environmental problems, and infrastructure facilities.

1.3 Traditional techniques such as the plane table survey for mapping and the ground survey technique of visiting every plot to check occupancy and use are time-consuming, costly, and cumbersome. Often, conventional methods of aerial photography are too costly for limited municipal budgets, and by the time the maps are finally produced they are frequently out of date and need to be revised as soon as they are printed. In many countries security regulations also restrict, or make impossible, the use of aerial photography.

1.4 The need for new solutions to update, and improve the management of, information is increasingly being recognized. The tools and technologies to do this must be cost-effective and easily adaptable to the conditions of developing countries. One promising new approach for gathering information on urban areas is to use satellite remote sensing. At the same time, computer-based geographic information systems (GIS) are being used to improve the management and use of information.

The satellite remote sensing approach

1.5 For the last twenty years, satellite remote sensing has been used to collect data that is used mainly for regional planning and at small scales (typically 1:250,000). However, new developments have considerably increased the potential use of satellite images for urban applications.

- Satellite images now have higher resolution (that is, a more clearly defined picture), which means that more detailed maps at larger scales can be produced.

- Microcomputer technology is becoming more widespread and therefore more accessible and affordable.

- Computer-aided mapping and information management is rapidly increasing, both in industrialized and in developing countries.

- The number of staff trained and experienced in satellite remote sensing has increased in many developing countries.

- National and regional remote sensing centers for education, training and application have been established.

1.6 In the industrialized world, the move from experimenting with satellite data to using it for practical purposes has encouraged the establishment of private companies offering customized products and services.

1.7 Because of these new developments, satellite remote sensing can be applied for the regular updating and cost-effective development of information on themes such as land-use, environmental issues, infrastructure facilities and for compiling up-to-date base-maps.

Relations to other information sources

1.8 Satellite remote sensing should never be evaluated and applied in isolation, without comparison to other mapping techniques and sources of information. Other remote sensing techniques—such as traditional aerial photos and small-format air photography, or sample surveys—have unique and complementing advantages.

1.9 A main criterion in choosing a mapping technique should be the scale of presentation. Satellite remote sensing is normally used only for scales between 1:25,000 and 1:250,000.[1] Satellite imagery cannot provide the same sort of detailed information that is available with aerial photography and ground surveys at larger scales. For this reason it is mainly used in data collection for planning purposes. Table 1–1 summarizes some advantages and disadvantages of the available sources of data for mapping.

1.10 Reference data (sometimes the term "ground truth" is used) are always needed to some extent in the analysis of remote sensing images. These reference data can be in the form of maps, air photos or air reconnaissance, although normally some field work on the ground is also necessary. The two main uses are to help identify the features shown in the image and to verify the reliability of interpretations. To a large extent, the amount and kind of reference data needed depend on the experience and background of the interpreter.

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1. Even scales such as 1:10,000 are possible, but the information content in the images does not increase with this increase in scale.

Table 1–1. Sources of data available for mapping

Source	Advantage	Disadvantage
Aerial photography	High resolution/accuracy Well established technology Simplicity of processing	High costs and delays Security restrictions Heavy logistics Need for ground control[1]
Small-format aerial photography	High resolution Low costs Low complexity	Not well known Need for ground control[1] Limited to small surveys
Airborne radar	No cloud problems Fast coverage	Low resolution High costs and complexity Not operational
Satellite imagery	Low costs and fast production No security restrictions Low ground control/logistics Time series possible	Low to medium resolution Small details not visible Not well known

1. Ground control refers to measurements needed for geometric corrections. It does not mean reference data for the analysis.

Source: Modified from Gastellu-Etchegorry (1990b).

Integration of GIS and remote sensing

1.11 Computer-based geographic information systems (GIS) increasingly are being used to collect, store, analyze and display maps and other spatial information. A GIS can help to improve the management and use of this information at all levels of an organization. One of the most important advantages of a GIS is the possibility of combining data from different sources and of exchanging information between organizations.

1.12 There is currently a strong trend toward integrating GIS and remote sensing more closely. New information can be developed through remote sensing techniques and existing information can be regularly updated so that it is still useful. By using a computerized GIS it is possible to improve the interpretation and analysis of remote sensing images by combining reference data from several sources.

Objectives of the report

1.13 This report has been written for policy makers, urban managers, professional planners and advisers, and officials responsible for production and maintenance of urban management information in the fields of application covered, among others. It aims to answer questions such as:

> What type of information can satellite remote sensing give? How does it complement other available techniques? What types of products are available and how are they analyzed? What capacities are required to use the technique in our city?

1.14 It is intended as a practical guide to show how satellite remote sensing can be a useful source of urban management information and to demonstrate the benefits of geographical analysis of available data. It does not aim to cover all possible urban applications of GIS technology or to serve as a detailed manual for all possible applications of satellite remote sensing. Rather, it provides an overview of operational applications in cities in developing countries, based on a comprehensive review of recent reports and illustrated by experience from case-studies and operational projects. Promising research fields and methodological studies are also mentioned. The report offers an introduction to the technologies, available range of products, and various methods of analysis offered by satellite remote sensing. It also addresses important institutional issues.

II. SATELLITE REMOTE SENSING AND GIS TECHNIQUES

Sources of satellite data

2.1 Among the primary satellite data relevant to urban applications are the American Landsat series and the predominantly French SPOT.

2.2 Landsat has produced multispectral (infrared color) data since 1972 with its MSS instrument and since 1984 with its TM instrument. TM provides 30 meters resolution compared to 80 meters for MSS, and it also records thermal data. The first SPOT satellite was launched in 1986 supplying panchromatic (black and white) data with 10 meters resolution and multispectral data with 20 meters. The term "high-resolution satellite data" normally refers to TM and SPOT imagery. In the 1990s, data from satellites with enhanced capabilities will become more widely available. A new Landsat satellite, scheduled for launch in 1992, will have the additional capacity of panchromatic data with 15 meters resolution.

2.3 Both systems have a worldwide network of distributors, central archiving and customer-service facilities in the United States and France/Sweden respectively, and additional receiving stations in more than ten countries worldwide.

2.4 The satellites orbit the Earth from North to South. The revisit frequency to any point on the globe is sixteen days for Landsat and twenty-six days for SPOT.[2] Imagery is not continuously recorded over all areas, but often in response to customer requests. The SPOT satellites have two pointable instruments, as illustrated in Figure 2–1. This means that the same area can be covered at least weekly if demanded, and that imagery from two dates with different viewing angles can be used as a stereo-pair. In practical terms, however, the possibility of acquiring usable data is governed by the frequency of cloud-free conditions at a particular location.

2.5 Each satellite image covers a large area, 60km x 60km for SPOT and 185km x 170km for Landsat. Numerical values of the surface reflectance are recorded for squares on the ground, for example 10m x 10m, defining the geometrical resolution of the imagery. The data are acquired by ground receiving stations, evaluated regarding cloud-cover, and then archived. A database is kept that can be searched for all available imagery.

2.6 Satellite data are provided either in digital form for computer processing or converted to photographic media. A large number of products are available differing in scale and type of enhancement applied. Of special importance are geometric corrections and improvements in interpretability. This is discussed in more detail in Chapter IV: Technology Issues and in Annex A: Procuring Satellite Data Products.

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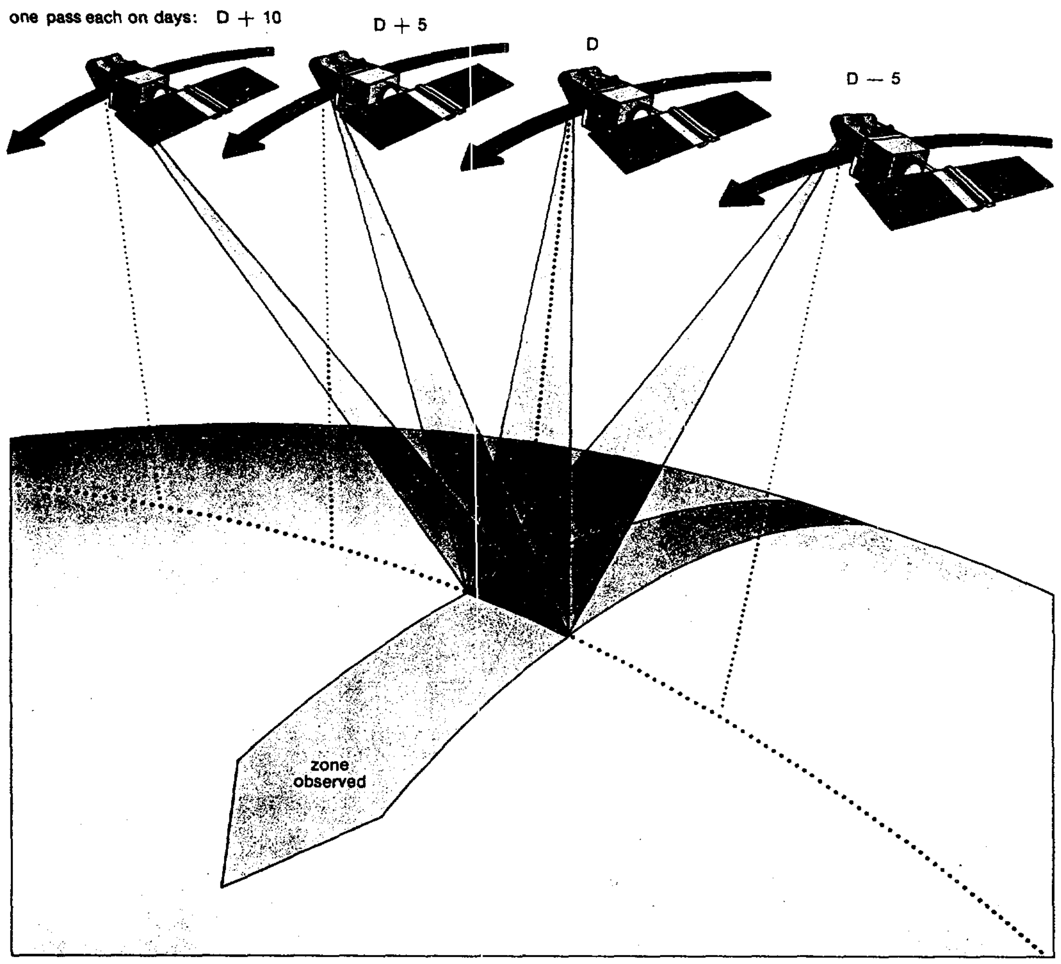
2. The satellite orbits are sun-synchronous. This has the effect that all images are recorded in the late morning, around 10:00 to 11:00 a.m., local sun time.

Figure 2–1. Pointable instruments on SPOT satellites



If the instruments could only point vertically down, twenty-six days would pass between each possible attempt to acquire an image of a certain location. With the pointable instruments, any area can be covered at least weekly, if desired.

Source: Spot Image

Analysis techniques

2.7 Remote sensing analysis techniques can be grouped into two categories: computer-based processing and visual interpretation.

2.8 **Computer-based processing.** The digital nature of satellite data means that it can readily be manipulated and analyzed with computer-based techniques. The different levels of products offered are all produced through digital processing. This includes geometrical correction, scale transformations, contrast enhancements, and mosaicking. Several images or other kinds of spatial data in digital form can be analyzed simultaneously.

2.9 Statistical analysis, such as regression, can be used on the image data together with any variable having a valid relationship with the reflectance recorded by the satellites. Automatic classification algorithms are frequently used for assigning each area in an image to a category such as forest, land-use, or soil type. Even though the processing is automated, the quality of the results depends on the skill and attention of the human operators.

2.10 The performance of the computer-based analysis can be improved through incorporation of additional information such as texture and context. Knowledge-based systems of classification, which are able to include cartographic experience and additional information, are being developed to improve the performance of the automatic processing. This advanced type of analysis, however, has not yet been proved operational.

2.11 Output from computer-based analysis can be in the form of hard-copy photographs and maps, as statistics, or as a new image or map layer in the computer.

2.12 **Visual interpretation.** The human brain automatically takes into account texture, structure, context, experience, and "common sense" in the analysis of the reflectance data. Other advantages of visual interpretation are that expensive equipment like computers are not necessary; it is not as sensitive to poor atmospheric conditions like haze and smoke; and the amount of training required is considerably lower. The interpretation can be facilitated if the imagery has been enhanced through computer processing and customized for a certain application.

2.13 Mapping can be done on a transparent overlay, on a photographic print, or in a photogrammetric instrument. An integrated computer-mapping/image-processing system can also be used for visual interpretation directly on a monitor. This allows for interactive image enhancements, zooming, and simultaneous display of related map information during the analysis. The resulting map is also produced in computerized format.

2.14 Any method of analysis requires reference data for calibration, verification, and completion. The amount and type needed depends on the particular application. The skill of the analysts and their level of familiarity with the area also are very important factors.

2.15 Although an overwhelming majority of the research efforts in this field have been devoted to computer-based methods, visual interpretation is commonly used for practical applications.

GIS and computerized mapping

2.16 **Definitions.** Map production and handling are increasingly being computerized. This allows dynamic and flexible handling of map information in a manner comparable to the way word-processing systems deal with written information. There are many computer software systems available to handle maps and other spatial data. Among the various terms used to characterize the different types, one is geographic information system (GIS). A wide diversity of definitions are given for the terms (Parker, 1988; Cowen, 1988; Fisher and Lindberg, 1989).

2.17 Spatial data have physical dimensions, such as a lake, a road, or a standpipe. The dimensions tell *where* the objects are. But geographical objects also have nonspatial attributes like ownership, surface material, and age, and these tell us *what* the objects are. In a GIS both kinds of information, together with information on the relationships between them, are used to analyze the data, model future scenarios, make predictions, and reach conclusions. An unlimited number of maps can be stored and analyzed together through overlaying. Thus complex questions, such as the following one, can be answered: Which land parcels are at least two hectares large, in a commercial zone, vacant for sale, not subject to flooding, not more than a kilometer from a heavy-duty road, and have no slope over 10 percent?

2.18 The overlaying technique was developed using manual methods and traditional maps (McHarg, 1969; Steinitz, 1976). It of course can still be done manually, but a computer-based system greatly enhances the capabilities and flexibility. The overlaying operations include compositing of maps, applying mathematical expressions and Boolean logic, performing proximity searches, analyzing topography, clustering, and aggregating.

2.19 If these kinds of analyses are not needed, cheaper software like computer-aided design or drafting (CAD) can be used for mapping and visualization.[3] These are purely graphic systems, but can be linked to database management software.

2.20 Other computer mapping terms used in an urban context are automated mapping/facilities management (AM/FM) and land information system (LIS). AM/FM is the term generally applied to systems using computerized graphics to assist utility companies in managing their facilities (Thorpe and Gilbert, 1987). LIS refers to systems having land parcels as their basic unit of information or being land administration based.

2.21 **Applications of GIS.** According to reliable estimates, 70 percent to 80 percent of the information and activities concerning local governments are location related (Somers, 1987). A GIS can provide support to the management and use of this information on all levels, including

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3. The reader should be aware that the term GIS is sometimes wrongly used as to include any computer system that can handle map information.

operational, managerial, and decision and policy making. Applications include property management; property assessment and taxation; land-use planning and development; environmental protection; planning and management of services such as police, transportation, and utilities; facility management; inspections; and mapping.

2.22 Many of these functions rely upon the same basic data. These can originate from maps, surveys, charts, text, tables, or remotely sensed imagery. The sources frequently differ in scale, accuracy, coordinate system, and areal coverage. A GIS can offer tools for integration of such heterogeneous data sets.

2.23 One of the most important benefits of GIS is this possibility to integrate data from different sources and exchange information between organizations. Duplication of efforts in costly data-collection can be reduced, and discrepancies in the information can be eliminated. This can help reduce expensive damages to infrastructure facilities and the environment. The broader information base and easier access for the user can be vital factors in enhancing the efficiency and effectiveness of decision making.

III. REVIEW OF MAJOR AREAS OF APPLICATION

Base-mapping

3.1 In the urban context, the term base-maps is normally applied to large-scale maps in the range of 1:500 to 1:2,500. Mapping at these scales can be achieved only by aerial photography or terrestrial surveying. Development/thematic maps, the scales of which range from 1:10,000 to 1:50,000, are used in local governments for planning purposes. In these cases satellite imagery can be considered for creating or updating base-maps. This is especially true when security restrictions, costs, and time requirements prohibit or hamper the use of aerial photography.

3.2 Numerous studies have assessed the applicability of satellite data for topographic mapping after SPOT data with stereo capability became available in 1986. Although those studies do not specifically address the urban environment, they assess the quality of the data regarding geometric accuracy and elevation mapping, and give general guidance on the information content.

Geometric quality

3.3 The geometric quality of satellite data depends on the level of processing. The accuracy achieved depends on how well the geometry of the unprocessed data was modelled, as well as on the quality of control points measured in the image and on the ground or on a reference map. The geometric quality is especially important when overlaying several images or maps as done in a GIS.

3.4 To use satellite imagery for accurate mapping, or for mosaicking and overlaying, it must be rectified to fit a map projection. This is done through geometric precision correction. Through this, SPOT panchromatic data can yield an accuracy of up to 3 meters (Westin et al., 1988), which meets standards for 1:5,000 scale maps.[4] For SPOT multispectral data the figure is approximately doubled, and for Landsat TM data, around 15 meters.

3.5 The geometry of precision corrected SPOT data thus can be better than is normally found in thematic maps at scales of 1:25,000 and can be used to correct errors in these. The quality depends, of course, on the accuracy of the control points used. If these are taken from a map of poor quality, the corrected satellite data will be correspondingly inaccurate. An advantage compared to aerial photography is that very few control points are needed, e.g. less than ten for an area of 3,600 square kilometers for a SPOT image and 32,400 km^2 for Landsat.

3.6 When the side-looking capabilities of the SPOT satellites, as described in Chapter II, are used to capture images, the oblique viewing angle will cause relief displacement between higher and lower altitudes in an image. This is important in mountainous regions. With the maximum

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4. As an example of accuracy standards for mapping, the national regulations in the United States have the following specifications regarding horizontal accuracy: For scales larger than 1:20,000, not more than 10 percent of clearly identifiable points tested shall be in error by more than 1/30 inch (0.85 mm) measured on the map. For scales of 1:20,000 or smaller, the limit is 1/50 inch (0.5 mm) (ACSM-ASPRS, 1989). This equals 12.5 meters on the ground at 1:25,000 scale and 8.5 meters at 1:10,000.

angle of 27 degrees and an altitude difference of 200 meters, the displacement of a hill-crest is 2.0 millimeters in an image on a scale of 1:25,000, and 5.1 mm at 1:10,000 scale. In a vertical SPOT image these displacements are negligible. At the edges of the larger Landsat images, the displacement would amount to half the values in the example above.[5]

3.7 Most image-processing systems have some kind of geometric correction functions that enable the advanced user to rectify standard products in digital form to a map projection. Normally these functions rely on polynomials for the rectification instead of a model of the geometry of the unprocessed data. The high accuracy cited above cannot be reached with the polynomial method. If such geometric quality is needed, precision corrected data have to be procured from a supplier.

Elevation mapping

3.8 As SPOT data have stereo capabilities, elevation mapping can be done. This is either made in a photogrammetric instrument using film products, or using digital data and automatic generation of digital elevation models in a computer. The accuracy of the mapping depends mainly on the geometric quality of the data, the difference in viewing angles and the type of land-cover. The time lapsed between the capture of the two images in a stereo-pair should not be too long, as the appearance of the terrain can change considerably. Taking these factors into account, several studies state accuracies in elevation mapping in the range of 4 meters to 10 meters using both film products (Kratky, 1988; Veillet, 1988) and digital data (Leclerc, 1988; Westin et al., 1988). This is sufficient for contours at an interval of 20 meters, which means that normally it is not satisfactory for urban mapping.

Information content

3.9 It is impossible to describe the information content of an image type with one unambiguous measure. The resolution of the data such as 20 meters (for SPOT multispectral) gives an indication, but this does not mean that all objects 25 meters wide and no objects 15 meters wide can be identified. Interpretability depends to a large extent on an object's contrast to its surroundings, shape, and complexity. Different settings create different conditions. The considerable divergence in the figures given below are to a large extent dependent on such site-specific factors. The skill of the analysts and their familiarity with the area are other important factors. Figure 3–1 illustrates the information content in SPOT panchromatic data.

3.10 The conclusions regarding topographic mapping from SPOT data at 1:25,000 to 1:50,000 scale in a number of studies on several continents can be summarized as follows (Dowman and

5. The relief displacement can be eliminated if a digital elevation model is used during the precision correction. The result is an orthoimage, equivalent to an orthophoto derived from air photos. As this extra processing will add to the costs, and as digital elevation models are not yet easily available in developing countries, the best way to avoid these distortions would be to avoid images taken at extreme viewing angles.

Figure 3–1. SPOT panchromatic image
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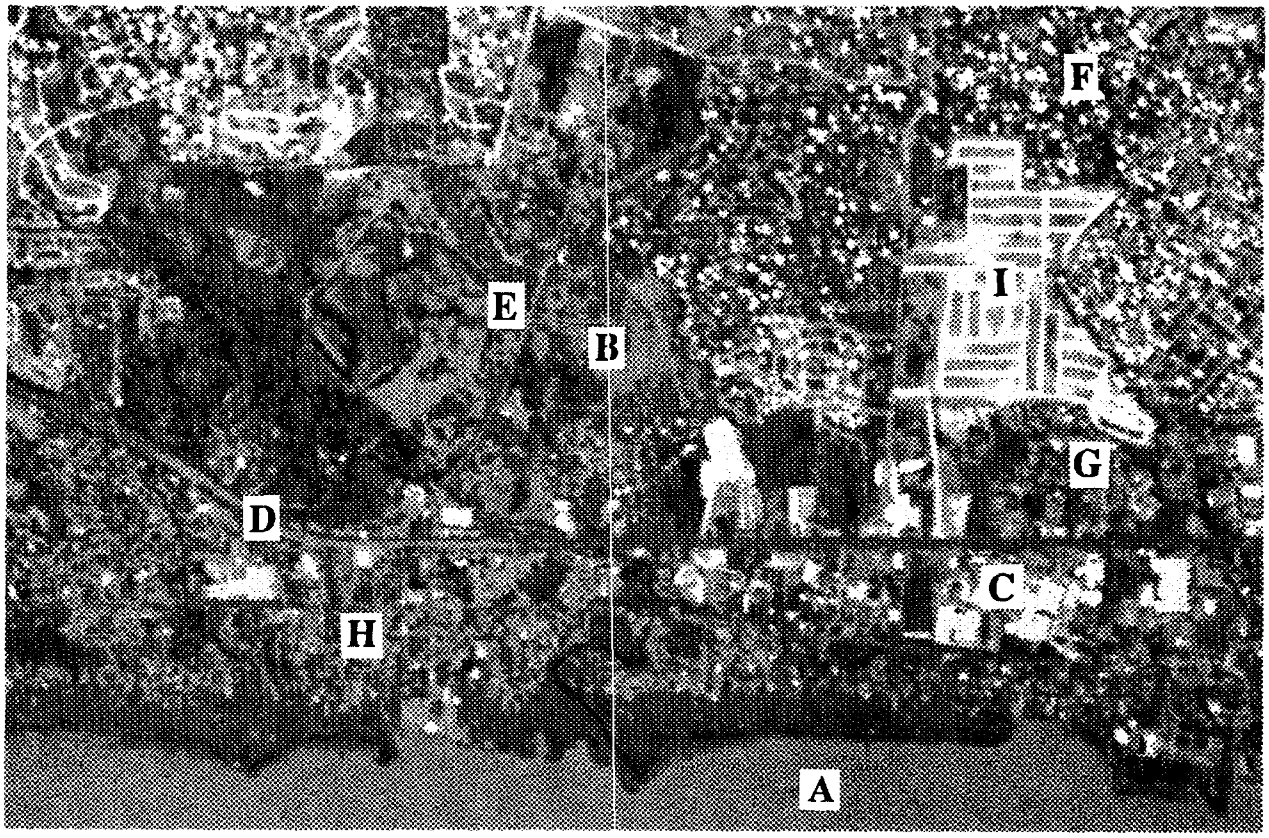


Part of southern metro Manila, Philippines. Scale: 1:28,000.
A = lake; B = green open space; C = industries; D = highway; E = major arterial road.
Residential areas: F = low density; G = medium density; H = high density; I = under construction.

Note: This is an example of low-cost output produced on a laser printer. The reproduction does not disclose the normal quality of photographic prints.

Peacegood, 1988; Manning and Evans, 1988; Priebbenow and Clerici, 1988; Salgé and Roos-Josserand, 1988; Thirlwall et al., 1988):

> Wide linear objects such as roads and large rivers were successfully delineated, but the majority of minor roads, tracks, and streams cannot be detected. The percentage figures for the former were above 90, but for the latter the range was from 19 percent to 55 percent.
>
> Point objects cannot be accurately mapped. For buildings the percentage ranges from 21 to 67. When built-up areas were delineated instead, the accuracy was more than 80

percent. Manning and Evans (1988) summarized the results by stating that 70 percent of the linear objects and 36 percent of point objects could be mapped with SPOT panchromatic data at 1:50,000 scale. Panchromatic data yield better results than multispectral, but the latter is better for hydrography and vegetation. The number of mapped objects increased by 20 percent when a complementing interpretation was done with multispectral data. Landsat TM data had considerably lower information content than SPOT.

3.11 All the studies relied on visual interpretation in some form. Dowman and Peacegood (1988), who compared data in digital and photographic form, preferred to work with digital imagery because of their higher information content and the possibility to enhance the image interactively. In most circumstances, however, the higher costs and complexities associated with the use of computers would outweigh these benefits.

3.12 Not all objects normally found in a topographic map at 1:25,000 to 1:50,000 scale can be mapped directly from the satellite images. Complementing field work or help from other available sources such as old maps and air photos is needed. On the other hand, most areal and larger linear objects can be mapped. This is often the most important information to update. Recently developed areas also tend to be more easily interpreted due to their higher contrast.

3.13 A geometrically correct satellite image is often a good and inexpensive base-map when existing maps are obsolete or unavailable. The image can be used as a photomap at scales up to maximum 1:10,000 although the information content does not match the scale. From the image it is possible to produce quickly maps with major areal and linear objects updated. Additional detail can later be filled in as information derived from other techniques become available, depending on demand, priorities, and resources allocated.

Land-use and land-cover

3.14 Land-use and land-cover mapping are two of the most common applications for satellite remote sensing. The nature of urban land-use, however, does make computer-based methodologies like classification difficult to employ. The primary obstacle is that materials such as concrete are configured to accommodate a diverse array of land-uses but maintain uniform reflectance characteristics as measured by the satellite. The proportion of vegetation can help the computer discriminate between commercial, single-family, and multiple-family residential zones. But the importance of size, shape, and texture/pattern for separating urban features cannot be overemphasized (Colwell, 1983).

3.15 The structure of urban land-use in developing countries further complicates adaptation of methods originating from developed country environments. Residential, commercial, and industrial land-use frequently are not separated. The structure of urban land-use is typically more dense, which requires higher resolution data for discrimination. A statement by Welch (1982) that a resolution of 5 to 10 meters is needed in Asian cities is often cited. For detection of change, a lower resolution is sufficient.

Box 1. Base-map from satellite data

In Dar es Salaam, Tanzania, a panchromatic SPOT image in map sheet format at 1:50,000 scale was used to quickly collect information on the growth of the city. The primary objective was to produce an up-to-date base-map, to be used together with the image map for strategic environmental planning. The present extent of built-up areas and roads also provide vital information for the initial planning of major infrastructure rehabilitation.

The maps were produced by visual interpretation of the photographic prints and traced on easily reproducible transparent overlays. The first overlay contained features for location, including coast line, trunk roads, railways, major drainage channels, and the extent of built-up areas. Another contained only road delineations. A number of such overlays on different themes will be produced where information from the image, available maps, and other sources are compiled in a common format. In this way, a "manual GIS" is developed for the analysis of environmental issues. When capacities for computer processing become available in the future, a large part of the costly database development will already be in place.

3.16 Factors mentioned earlier should be taken into account when defining the categories to be mapped. Nomenclatures developed using other mapping techniques, or in other settings, may have to be modified to agree with categories that can be identified in the satellite data.

3.17 The limitations of computer-based classification based only on reflectance data have prompted research into methods that include texture and context information and knowledge-based processing (Gong and Howarth, 1990; Møller-Jensen, 1990). These methodologies, however, are not yet operational.

3.18 Another alternative is to use classified multispectral data as an input and aid for visual analysis that takes into account texture, context and shape. Ehlers et al. (1990) used computer-based classification to derive rural land-use/land-cover, and visual interpretation to map the urban areas. Gastellu-Etchegorry (1990a) used classification results together with original multispectral image data as inputs to a final delineation using visual interpretation.

3.19 In the latter study, standard visual interpretation of SPOT panchromatic data was also conducted and produced significantly better accuracy than the combined method. Both methods proved much faster and more convenient than interpretation (without stereo-plotting) of infrared-color aerial photographs at 1:30,000 scale. Trolier and Philipson (1986) concluded that possibly twice as many categories could be derived through visual analysis as compared to computer-based classification.

3.20 To conclude, SPOT panchromatic is the best type of data to use for urban land-use/land-cover mapping. Multispectral data are of great value for separation of vegetation types and hence for mapping the peri-urban environment. They may also better separate high density areas from vegetation. These are easily confused in the panchromatic data because of similar greyshades and because the structure in the high-density areas is not discernible in the satellite image.

3.21 Visual interpretation performs better than operational computer-based classification methods, but can be aided by output from them. The main reason is that the human brain can interpret the urban structure better than the computer; for example, the size, layout, and position of buildings give clues to their use.

3.22 Computer-based methods typically separate only urban/non-urban land-use, or produce three urban density types. They can also be used to derive special land-cover information, such as amount of vegetation, or to establish a regression model giving the building densities.

3.23 The number and types of classes mapped with visual interpretation depends on the particular pattern of the urban land-use and aim of the studies. In Pakistan, Bertaud (1989) could separate categories: high, medium, and low density; spontaneous settlements; industries; developed land; defense; and the class service/utilities/government/institutional. In Cairo, Thibault et al. (1991) produced a land-cover map with five network types (canals, roads, and railways) and twenty-two cover types, of which fifteen cover types were urban in nature. The SPOT data were supplemented in the analysis by field verifications, air photos, old maps, and general familiarity with the area.

Box 2. Urban land-cover map

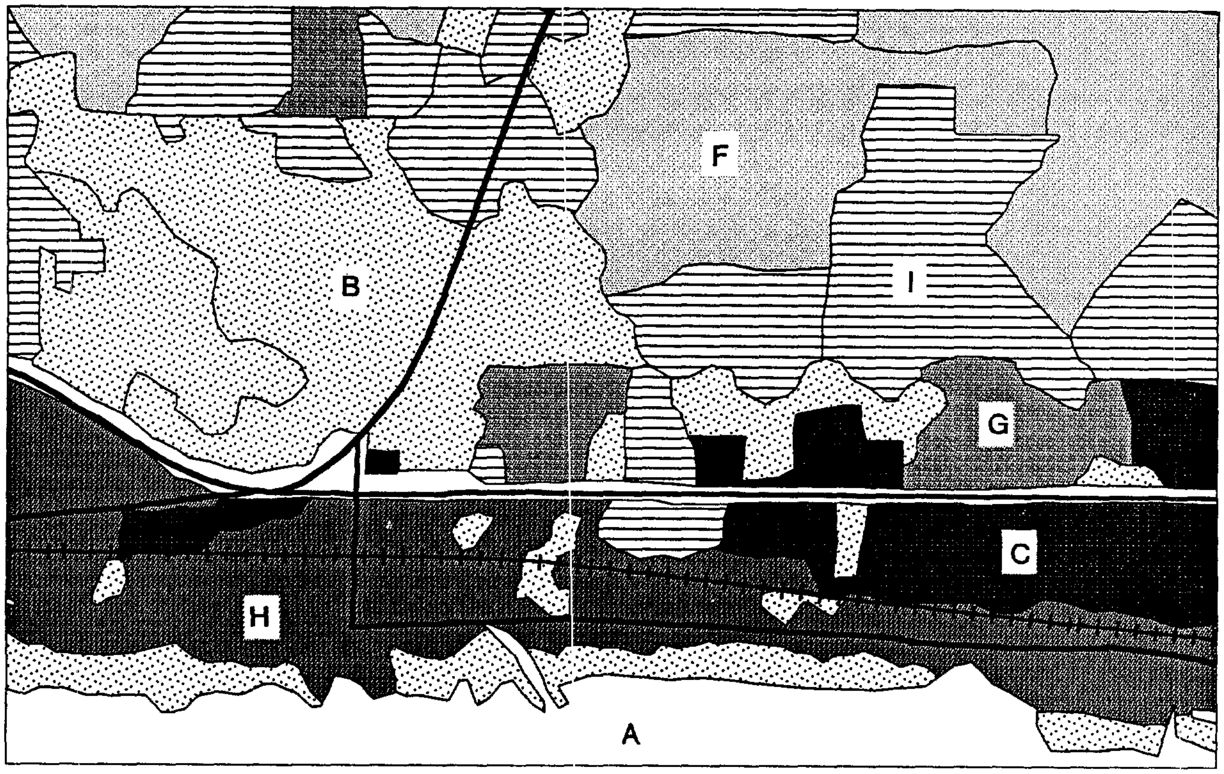
Over a pilot area in Manila, the Philippines, a land-cover map at 1:25,000 scale was produced through visual interpretation directly on the monitor in a combined image processing/GIS system (Paulsson, 1992). With only rudimentary reference data—an old road map—and scant familiarity with the area, it was possible to separate 13 cover types with an overall accuracy of 92 percent. Residential areas were separated according to density, but the labelling of these had to be done from subsequent field work. Special emphasis was put on dynamic classes; four classes described areas under construction depending on type and degree of completion. Seventeen percent of the land area, and 23 percent of the urban area belonged to these types.

To produce the map covering a 60 km^2 area, one week was used for development of the classification system and image interpretation. One day was spent on field work, one day on corrections and final labelling, and one day on analysis of the accuracy.

During interpretation, the road map was superimposed on the image and the pattern of roads offered important clues for the analysis. Areas of similar structure and tones were delineated and given preliminary labels. At the field visit, boundaries and labels were checked and adjusted.

Although the possibilities of zooming and enhancement of the digital data in the image processing system did help the interpretation, it is not impossible to produce a similar map through photographic products. SPOT panchromatic was the most useful dataset, but multispectral data proved better for identification of water bodies and vegetation types, and for separation of high density areas from vegetation.

Figure 3–2. Land-cover map produced from SPOT satellite data



This is a simplified version of the map described in Box 2, and covers the same part of the pilot area in metro Manila as Figure 3–1.
Scale: 1:28,000.
A = lake; B = green areas; C = industries.
Residential areas: F = low density; G = medium density; H = high density; I = under construction.

Change mapping and updating

3.24 Satellite data are suitable for mapping of change and updating because of its frequent coverage, low cost, and the lower resolution requirements for change detection. Urban land-use frequently has a rapid rate of change. Even in developed countries, it is too expensive to update maps often enough to keep up with the pace of development if traditional techniques are used.

3.25 Change detection can have the limited scope of identifying change to target for detailed mapping or for revision of urbanized area boundary. In a study by Martin and Howarth (1989) using SPOT multispectral data, visual comparison of two images, interpretation of a multidate image, and classification of a multidate image all produced accuracies over 90 percent for change/no change. The results are consistent with those obtained by Landsat MSS data (Martin, 1989), but SPOT enables more detailed delineations. For this application, automated methods can be justified because of the speedy coverage of large areas.

3.26 Identifying the type of change is more difficult, and the accuracies achieved are accordingly lower. As with ordinary land-use/land-cover mapping, visual interpretation normally performs better than computer-based classification. Computerized maps can be interactively updated through digitizing on a monitor displaying the old map over satellite data. Updating can yield more detailed delineations than initial mapping because of the help in interpretation given by the old map.

3.27 Ehlers et al. (1990) reported an accuracy of 87 percent when classifying urban change in the north-eastern United States into single-family residential growth or other growth by comparing SPOT data with old aerial photographs. Stow et al. (1990) compared different sets of satellite data to update an urban land-use map in the southwestern United States at 1:24,000 scale having nineteen classes. At least 80 percent of the land-use parcels that had changed were detected, and at least 70 percent of them were correctly identified. For operational use they suggest the use of a multidate SPOT panchromatic image for detection and interpretation of change and further interpretation using an image with merged SPOT panchromatic and Landsat multispectral data. For areas displaying extensive change, color aerial photos should be acquired and the interpreted change delineated based on the SPOT data.

Box 3. Detecting Changed Areas

Two SPOT panchromatic images over metro Manila from 1987 and 1990 were analyzed in an image-processing system to detect areas with major land-cover changes. The map output highlights areas of major construction, including new roads, residential areas, commercial centers, and industries. Also individual large residential houses were detected, whereas small houses, particularly in dense areas, could not be seen.

The two images were corrected to fit exactly on top of each other, and one image subtracted from the other. The resulting difference image showed areas where the surface reflectance had increased or decreased between the two points in time, such as construction sites. Selected areas in it were studied in detail to determine thresholds for change/no change. These were used to produce a map of change covering the whole city.

This type of mapping is useful for fast detection of major land-cover changes. In addition to differences in the built-up area, major change in vegetation, such as clear-cutting, is distinguished. The time required for the analysis is one or two days. The output would guide further analysis that is needed to identify the types of change and produce more detailed mapping.

3.28 Lo and Shipman (1990) have demonstrated how a GIS approach can facilitate quantitative analysis of change dynamics and assessment of the environmental impact of planning measures and related land-use change. Land-use data with a time difference of ten years were integrated with topographic and geologic data. Among other things, the analysis could assess the encroachment of urban development on steep slopes susceptible to soil erosion and the success of a reforestation program in controlling the spread of severely eroded badlands.

Infrastructure

3.29 A number of studies have shown that major roads and railways are readily detectable in high-resolution satellite images. Accuracies between 90 percent and 100 percent were reported by Salgé and Roos-Josserand (1988), and Manning and Evans (1988). Minor roads and tracks are not always visible; accuracy figures range from 23 percent to 64 percent depending on categorization. Primary reasons for nondetection are tree canopy closure or weak contrast between surface material and the background. Alleys in very high density urban areas are also difficult to distinguish. Recently constructed features, especially in wooded areas, are normally easier to map and update because of high contrast.

3.30 The best results are produced with SPOT panchromatic data and visual interpretation. Methodologies for automated road delineation from high-resolution satellite data have begun to be developed (Van Cleynenbreugel et al., 1990; Møller-Jensen, 1990), but the results do not yet match those achieved by visual interpretation.

Box 4. Updating a road map using SPOT data

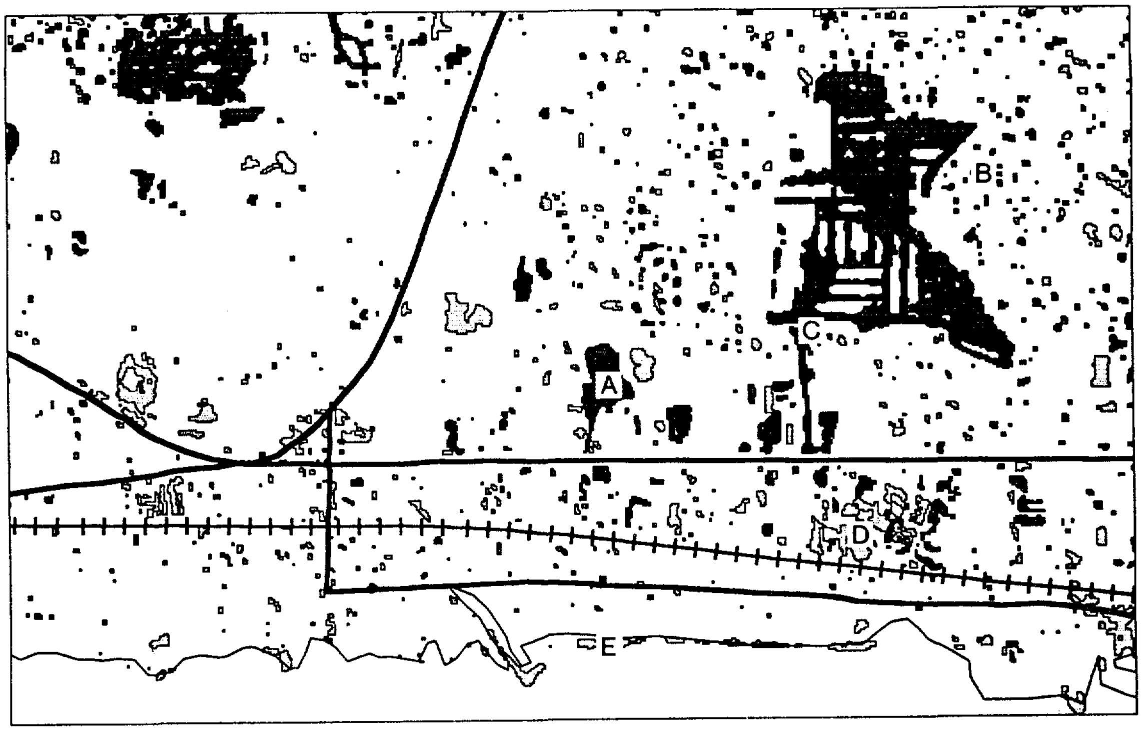
A road map at 1:25,000 scale was updated using SPOT data for an area in Manila (Paulsson, 1992). The existing map was digitized and superimposed on the imagery in an image processing/GIS system. New roads were added through interactive digitizing on the monitor with an overall accuracy of 87 percent of the total road length. Although the interpretation was done without any reference data or knowledge of the area, field work revealed that the accuracy was comparable to that of the existing map, which had been produced from aerial photography, and better than an "updated" road map available to the public.

Field completion is necessary to achieve a completely accurate map, but during the analysis the roads that needed checking could be reliably identified. In areas under construction at the time of image acquisition, and in areas with a very dense road network, the exact delineation of the roads proved difficult.

SPOT multispectral data was considerably less valuable than panchromatic data. The delineation of new roads required one day for the 60 km^2 area, whereas the digitizing of the old map took one week. One day was spent on field checking, and one day on completion in the office. The advantages of using a completely computerized system included interactive zooming and contrast enhancements. Disadvantages were the somewhat slow progress, difficulties in getting good hard-copy images for field checking, and the high cost of equipment, training, and service.

To create a completely new road map only from the satellite data was considered impossible. Old neighborhood roads were to a large extent impossible to distinguish where the road network was dense and vegetation obscured the ground.

Figure 3–3. Land-cover change map produced from satellite data

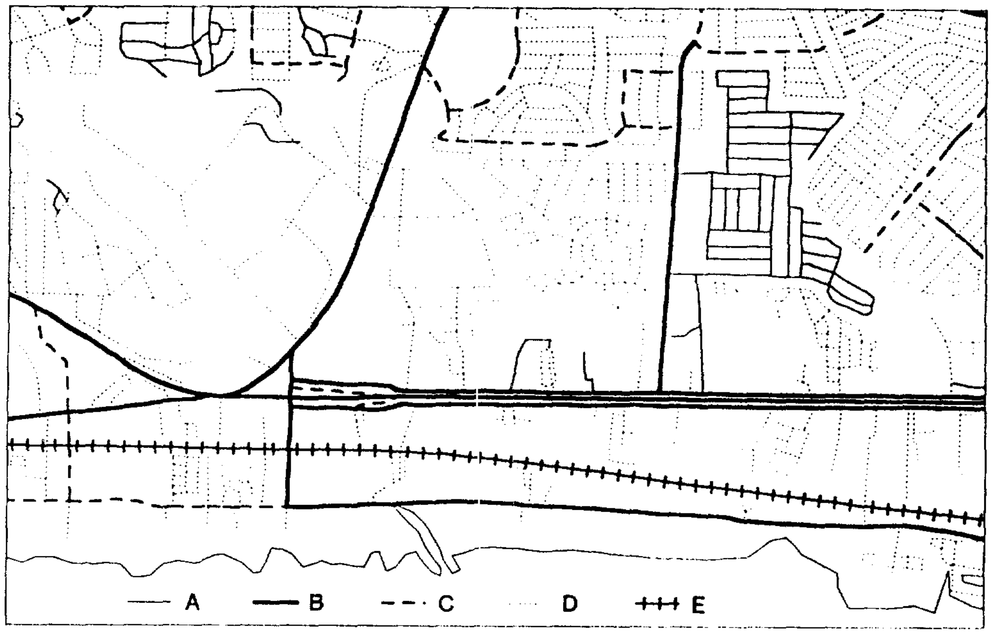


Same area of metro Manila as Figure 3–1 and 3–2.
Scale: 1:28,000. Analysis described in Box 3.
Brighter areas: A = construction site; B = new houses in low density area; C = new roads.
Areas of decreased brightness: D = construction in older image; E = increased water level.

3.31 A special application is described by Philipson et al. (1988), who used SPOT panchromatic data to monitor land-cover changes for an inventory of active and inactive waste storage and disposal sites in the northeastern United States. Changes were categorized and delineated with an accuracy of 95 percent using the image and old topographic maps. A related example is the method suggested by Nascimento Brito et al. (1990) where Landsat TM data were used to monitor the extension of sand pits in an environmentally sensitive area in Brazil.

3.32 Information on land-cover and infrastructure derived from satellite data can be used for geographic analysis in the planning of infrastructure development. One type of application is routing and siting of new facilities. Spotlight (1990) describes how land-cover information from satellite imagery was combined with land ownership, soil type, slope and visibility indicators in a GIS to evaluate alternative sites for a power transmission line. The selected route combined economic and political acceptability with minimized disturbance of environment, geology, and land-use. This technique is useful to assess the environmental impact and costs for construction and land acquisition when selecting routes for utility and highway corridors (Ehlers et al., 1990).

Figure 3–4. Road map updated from satellite data



Same area of metro Manila as Figure 3–1, 3–2, and 3–3.
Scale: 1:28,000. Production described in Box 4.
A = new roads.
Roads present in old map: B = arterial roads; C = distributor roads; D = neighborhood roads;
E = railway.

3.33 Another type of use is the zoning or stratification of a city according to physical and socio-economic properties for infrastructure planning. This is described later in the section on housing typology. Zones with different characteristics may be suitable for different approaches for waste collection or sanitation. With estimates of areas and densities, it may be possible to approximate the number of users and calculate system costs and waste quantities.

3.34 With infrastructure networks and attribute data stored in a GIS, valuable information for maintenance and investments can be derived. Lupien et al. (1987) have shown how analysis of the best path between two points, the location of a new service center (school, power substation), and assignment of areas of influence of a center is facilitated. Cowden (1990) described how maps derived from GIS analysis showing maintenance occurrence, impact of breaks or leaks, and impact of future development can assist the infrastructure management.

Population

3.35 Two techniques for fast population estimates that were developed using aerial photography, but are relevant to satellite remote sensing, are described by Colwell (1983). It has not, however, been possible to find an evaluation of the accuracy achievable with high-resolution satellite data.

3.36 The land-use/area density technique is based on measurement of various types of residential land-uses through remote sensing. The resulting areas are multiplied by average population densities for each type. This can be established from census data or field sampling. A limitation is that the technique requires detailed land-use information for accurate estimations. The method can also be used for calculation of population increase by using areas derived from change mapping techniques. In this case, one has to be aware that the population can increase significantly through densification, without new areas being built-up. Bruijn (1987) describes such a case in spontaneous settlements in Dar es Salaam. (See the section on housing typology later in the paper.)

Box 5. Analyzing urban growth

Satellite data complemented household surveys in a shelter sector analysis for Brazzaville and Pointe-Noire, Congo. The interpretation of SPOT panchromatic images at 1:25,000 scale and air photos showed an average yearly increase in urban area of around 10 percent during the 1980s. From the figures on the total urbanized area, the total number of plots was estimated from relations established in other sources. The results of the analysis included a falling percentage of plots occupied (45 percent) while the older residential areas had densified. Part of the explanation to these contrasting trends are the relative affordability of new plots and a serious lack of infrastructure in the peripheral areas that discouraged development.

The extent of urban areas in 1992 and 1991 respectively, were interpreted from photographic prints of the satellite images mounted on light tables and traced on transparent overlays. The extent of the urban areas in 1983/1981 were interpreted from aerial photographs and plotted on the satellite images. The resulting areas were measured on the overlays with a planimeter.

The results did show the great value that satellite images have as all other available geographic data were rendered obsolete by the rapid urban growth. Unfortunately, mistakes in the survey design prevented the imagery from being used for stratification of the samples and development of a housing typology as intended.

The advantage of using satellite data in the form of enhanced photographs at large scales, requiring only basic cartographic equipment for the analysis, was confirmed. At the national Congolese Center for Geographical Studies, it was possible to find staff with the basic training and equipment needed to produce good results within less than one week.

3.37 The built-up area technique is based on the relationship between the total built-up area of a settlement and its population. Lo and Welch (1977) applied this approach to cities in China using Landsat MSS data and reported good results. Because of the small scale of this imagery, the technique was considered to be limited to cities of at least 500,000 population.

3.38 Forster (1990) suggests the use of remote sensing to enhance census data. By analyzing which parts of a census district are built upon, a better estimate of the population distribution is provided, particularly at the rural-urban fringe.

3.39 Dureau et al. (1989) have developed an area sampling methodology for sociodemographic surveys of urban areas, where high-resolution satellite imagery is used to optimize the area sampling plan. The advantages of this approach are an accuracy at least equivalent to simple random sampling, no reliance on any other sampling frame than the satellite data, and lower costs. The degree of use of satellite data will depend on availability of other types of remote sensing and map data. The urban boundary (sampling frame) is identified through visual interpretation, possibly aided by computer-based classification. For stratification, a relationship between field-observed density of built-up areas and reflectance data is established and used for classification. The methodology was first applied on a migration study in Quito, Ecuador, and a detailed handbook was published.

Housing typology

3.40 Bertaud (1989) described a methodology for developing a housing typology in Karachi, Pakistan, using satellite data and aerial photography. She defines housing typology as "a classification of different residential patterns of development or urban fabrics that have the same physical and socio-economic characteristics." Housing types are selected according to plot and building sizes, construction type, and density. The typology is used to structure and complement data collected from censuses and sample surveys by disaggregating it spatially.

3.41 Visual interpretation of panchromatic SPOT data should ideally be combined with aerial photos or small-format aerial photography. The photos enable more detailed analysis while the satellite data provide an up-to-date mapping base covering the whole area. In compact areas, it is not possible to evaluate densities from the satellite data. In the study just mentioned, four different types were identified in photographic prints at 1:24,000 scale. Using aerial photographs, one additional type was differentiated, and two types were reclassified into two subtypes each. Field surveys are required to calibrate the typology and to collect supplementary physical and socioeconomic data.

3.42 In Buenos Aires, Argentina, Gamba (1990) created a detailed typology from field data and available maps. This was based on a categorization of the structure and density of the built-up area, building types, construction material, land-use, and type of vegetation. Based on this typology, thirty-eight types of homogeneous zones were identified through visual interpretation of multispectral SPOT and Landsat data.

3.43 The zoning of a city based on a housing typology can be used as a base for geographic analysis of urban development in various applications. The theme would depend on the type of complementing data collected from censuses and sample surveys. Examples include projection of land requirements according to housing type; assessment of trends in the housing market regarding supply and demand of each type related to the income structure; population estimation based on densities and household sizes; and evaluation of the demand for, and capacity to pay for, infrastructural services such as electricity, waste disposal, and water supply.

Hazard-prone areas

3.44 The following is based on a comprehensive review of remote sensing literature applicable to natural hazard preparedness and emergency response planning that is presented in Kreimer and Zador (1989). Here, only applications related to development of baseline information on vulnerability to natural hazards are mentioned.

3.45 In potentially flood-prone areas, satellite imagery has been used successfully to determine baseline norms, such as maximum flooding levels, and to monitor river fluctuations. It has also been used to support the development of coastal area management plans, to monitor land-use changes in flood-prone areas, and to model coastal dynamics.

3.46 Through mapping of land-use, geology and geomorphology using satellite remote sensing, landscape stability maps can be derived that identify landslide-prone areas. Mapping and assessing of landslides after they have occurred, which is a common application, is of great value in defining potential risk areas.

3.47 Satellite imagery is commonly used for geologic structural mapping. By mapping of surface features associated with active seismic zones, areas with a high risk for earthquakes can be identified.

3.48 Satellite data have also been used for wildfire risk prediction and modelling. Image analysis can provide an assessment of fuel load and other spatial information related to fire behavior. Historical data showing areas destroyed by fire and where fires originated can be derived. Satellite remote sensing can also contribute to the development of fire management planning operations.

3.49 As an example relating to volcanic eruptions, less hazard-prone areas in the vicinity of active volcanoes can be identified by combining topography with data on land-use and vegetation derived from remote sensing.

Watershed analysis

3.50 The watershed is the natural geographic unit for the study of hydrology. In urban areas, the operation of drainage networks and the design of new infrastructure requires estimations and modelling of potential run-off. Information on watershed topography, soils, land-use, groundwater table position, and rainfall patterns are used. The quality, quantity, and timing of run-off and floods are strongly dependent on land-use and land-cover.

3.51 Satellite remote sensing can contribute with land-use/land-cover information relevant to run-off studies. Trolier and Philipson (1986) identified an ideal list of classes relevant both for quantity and quality of run-off, eleven of them rural and eleven urban. Using visual interpretation of Landsat TM data, it was possible to recognize all but six. The errors, however, were not considered serious, as the confused classes have similar effects.

3.52 An alternative approach was described by Pierre and Pedron (1989). The ratio of impervious surface over the total watershed area was calculated by computer-based classification of SPOT multispectral data, which was then used for computation of rain-water in-flow to drainage networks.

3.53 Johnson (1989) describes how a digital map-based hydrologic modelling system was applied to an urban watershed. It was shown that models not taking into account spatial variations within the watershed can introduce substantial errors.

3.54 An application for large river basins is reported by Meijerink et al. (1988). A watershed in Indonesia was studied, where flooding and waterlogging have increased and caused severe damage. Much of the problem can be attributed to deforestation. Satellite data and aerial photography were used to investigate changes in land-use and river regime, as well as the damage caused. Trends were established by using old maps and imagery. Through GIS modelling, possible trends for each section of the watershed were identified, and recommendations for remedial measures given.

Multisectoral studies, GIS modelling

3.55 It is far beyond the scope of this report to make an exhaustive inventory of possible urban applications of GIS analysis that have reference to satellite remote sensing. In the preceding sections, examples are offered that relate to specific applications covered. Below are a few additional examples of how information derived from satellite data and other sources have been used.

3.56 Bertaud and Young (1990) have shown that it is possible to identify urban population groups at risk from environmental pollution by relating physical data disaggregated geographically with population and environmental health data in a simple geographical database. Using health indicators like lung cancer mortality, a distinctive geographical pattern was detected in Tianjin, China. It was not possible, within the scope of the study, to establish causality relationships between diseases and environmental conditions. To be able to relate health indicators to residential conditions, land-use and housing quality data are needed. Satellite imagery was used in the study to update and complete a land-use map, and it is proposed that it should also be used for the development of a housing typology.

3.57 An internal World Bank report has integrated data derived from remote sensing and other sources in a GIS for geographical analysis of growth pressures and environmental impact in an urban fringe area of Mexico City. Historical land-use data were analyzed to study the past and present trends in land-use patterns and urban expansion. Future scenarios were analyzed for a number of issues: growth accommodation capacity of newly expanded areas and vacant land within the urban area, the impact of growth scenarios on local hydrological conditions, and the environmental implications of changes in nonurban land-use patterns induced by urban growth.

3.58 Meaille and Wald (1990) described the initial development of a methodology for numerical simulation of regional urban growth. GIS and remote sensing information were used to calibrate and constrain the simple model of diffusion describing the growth. Only physical environmental properties were used in the model, although it was recognized that social and economical factors should be included. Data on land-use, urban delineations, and fire hazards derived from satellite imagery were used together with GIS information on topography, population, infrastructure and administrative boundaries. The scope of the study was methodological and the results obtained were not readily applicable, but it provides an insight into the potential value of numerical simulation models combined with GIS and remote sensing, and of the type of difficulties and limitations likely to be encountered.

3.59 Bender and Bello (1990) reported on the use of GIS as a major tool for natural hazards management in Latin America and the Caribbean at national, regional, and local levels. Information on natural hazards, natural resources, population, and infrastructure has been gathered, organized, and analyzed. As an example, areas with landslide hazards were identified through combining thematic maps of slope, geology, and hydrology into a composite map. By adding a landslide occurrence map, it was possible to detect which combinations of factors were associated with landslides and to classify those areas according to degree of risk. When information on population and infrastructure in areas of severe hazards were added, priority areas for preventive activities could be identified.

IV. TECHNOLOGY ISSUES

Satellite data products

4.1 Starting in the 1980's, there has been a move from experimental to operational applications as the remote sensing technology was commercialized. With the rapid expansion of the market, and the emergence of a value-added industry, the suppliers are trying to develop products that are more adapted to the needs of the user. The idea is that through further processing by the supplier, the user would need to invest less in specialized skills and equipment before being able to use the information. This section is intended as a brief guide to the range of available satellite data products. See also Annex A: Procuring Satellite Data Products for more details on the products and some cost indications.

4.2 **Product media.** Products based on satellite data are available as digital data, as master films, or as photographic enlargements. Digital data are used in computer-based image processing, or as a backdrop image in a computerized mapping system. Master films are used for analysis in photogrammetric instruments, or to produce photographic enlargements for visual interpretation.

4.3 **Standard products.** Satellite data products are usually classified into standard and value-added. Standard products are produced highly automatically with little operator intervention and with no external information added in the processing. They are therefore also less costly. The sole suppliers are the operators of the satellite systems and receiving stations.

4.4 The basic image format in which satellite data are provided is called a scene. The size of it—60 x 60km for SPOT and 185 x 170km for Landsat—is determined by how wide a strip on the ground the satellite instruments cover when passing from North to South. The data are then cut off in the direction of the movement to form a rectangular image, a scene. Also smaller portions, the most common being quarter scenes, are sold. The standard scales of photographic products are given in Table 4–1 below.

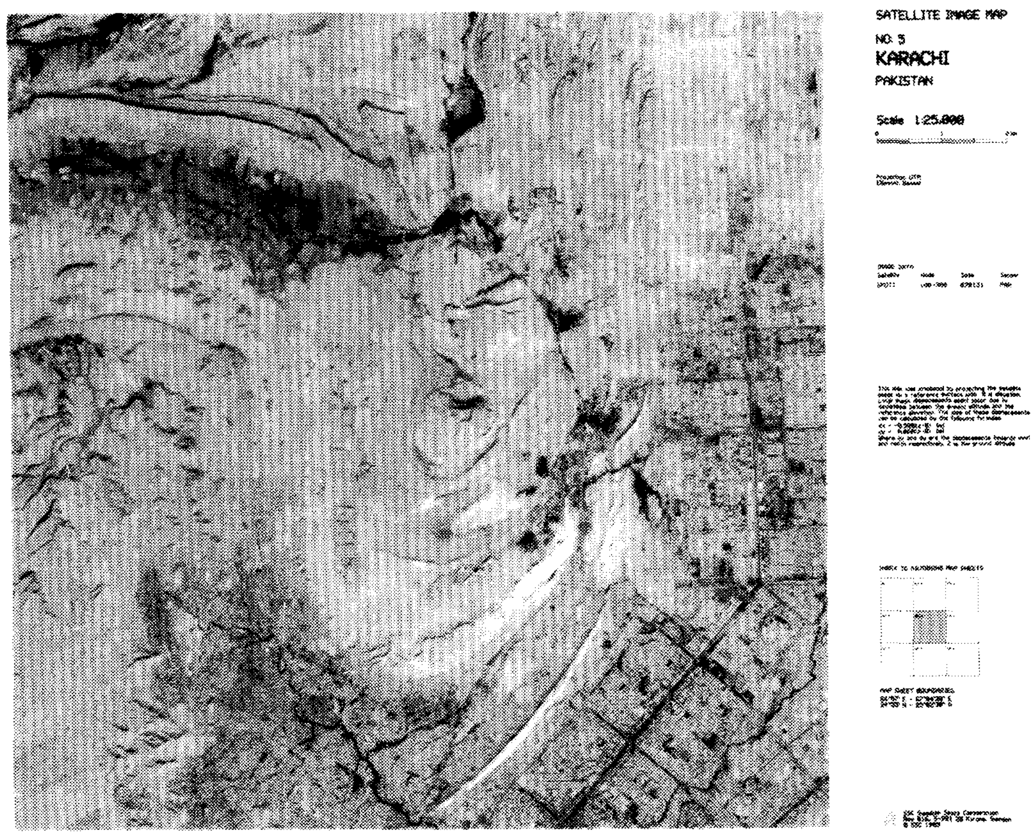
Table 4–1. Scales for standard photographic products

Type of product			Film	Print
Landsat TM,	1/1 scene,	185 x 170km	1:1000,000	1:250,000
Landsat TM,	1/4 scene,	92.5 x 85km	1: 500,000	1:100,000
SPOT,	1/1 scene,	60 x 60km	1: 400,000	1:100,000
SPOT,	1/4 scene,	30 x 30km	1: 200,000	1: 50,000

4.5 **Value-added products.** This term is used when the satellite data have been further processed with external information added, such as ground control points. Value-added products can be ordered from both the suppliers of standard products and specialized "value-added" companies. They are not bound to the scene format as the standard products.

4.6 Most value-added products are geometrically precision corrected with the help of ground control points to fit a base-map. The geometric quality is especially important when several images or maps are to be used in the analysis, as done in a GIS. Figure 4–1 gives an example of such a product in map sheet format.

Figure 4–1. Satellite image in map sheet format



Part of Karachi, Pakistan. The image was produced from SPOT panchromatic data. It is reduced here to 1:100,000 scale.

4.7 Image enhancement techniques can be applied which improve the contrast and definition in the image and facilitate the interpretation. This also means that the products can be reproduced at larger scales; the maximum scales are approximately 1:50,000 for Landsat TM, 1:30,000 for SPOT multispectral, and 1:20,000 for SPOT panchromatic. Even larger scales are possible, such as 1:10,000 for SPOT panchromatic. The information content does not increase with this increase in scale, but it can be convenient to have the images at the standard mapping scales used. As applications in the urban built-up environment often require the resolution restrictions of the data to be stretched to the limit, image enhancement can significantly improve the utility of the data.

Technical availability and constraints

4.8 The basic technical availability of satellite data was described in Chapter II above. Landsat TM data are available from 1984, and SPOT data from 1986. Acquisitions of imagery from Landsat MSS started in 1972, but these data are not as useful for urban applications.

4.9 The availability also has to do with how operational a satellite system is from the customer's point of view. It should be easy to find out what data and products are available, and the delivery has to be reliable. The Landsat and SPOT systems meet these requirements, although some of the local receiving stations are not entirely operational. Standard products are normally produced and shipped within one month after order; value-added products take another one or two months.

4.10 Landsat and SPOT distributors will both provide, free of charge, lists of all images available in the archives over a specific site.[6]

4.11 Notably, space photographs from the Soviet Cosmos satellite series have the best resolution (5 meters) of all data on the civilian market. However, although they were made available internationally towards the end of the 1980's, very few organizations have used them. Data from Indian and Japanese remote sensing satellites are also available.

4.12 The fact that there are normally no security restrictions on satellite data is a major advantage when comparing the availability of satellite data with aerial photography. Anybody can in principle buy data over any part of the Earth.

4.13 The main limiting factor for acquiring satellite data is climatic constraints. This is dealt with under a separate heading below. Radar satellite data that are not affected by this are becoming available from the European ERS-1 and the Canadian RADARSAT during the first half of the 1990's. The utility of this data for urban applications remains to be tested. When operational satellite radar systems are in place, this may become an interesting alternative where cloud-cover make other forms of remote sensing impractical.

6. Please refer to Annex B: Procuring Satellite Data Products on how to request this information.

4.14 A serious constraint is the information content in satellite data. Many of the urban mapping requirements, such as cadastral mapping, cannot be met. Even if satellite images are available at scales like 1:25,000, they do not contain the same amount of information as aerial photos at the same scale. This is further discussed in the section on base-mapping.

4.15 Copyright regulations prohibit a customer to resell or share the satellite data with others. The respective satellite operator holds the copyright to standard products, whereas for value-added products it belongs to the producer. Unless otherwise agreed, the products can only be used for the buyer's own purpose, and even internally only a limited number of copies are allowed. Maps and other output produced by the customer through analysis of satellite data are not covered by these copyright restrictions.

4.16 Another limiting factor for many developing countries is that foreign exchange reserves have to be used to purchase the data. One effect is that support from institutions in industrialized countries is frequently needed.

Climatic constraints

4.17 The most important constraint for acquiring satellite data is the frequency of clouds and haze, as the instruments on Landsat and SPOT cannot see through them.[7] This is illustrated by the fact that only around 20 per cent of the images held in the global archives are estimated to be useful judging by the cloud-cover. Some tropical areas with rainforest climates have an almost perpetual cloud-cover, and the probability of getting useful data is equivalently low. Other areas have guaranteed cloud-free conditions for a large part of the year.

4.18 The only way to deal with this constraint is through realistic planning. Most areas have at least one dry season per year when the probability for completely cloud-free conditions is high.[8] This should be taken into account when ordering new acquisitions. In very cloudy areas, the user may have to accept that the data are older than would be optimal, rather than waiting for an unknown period of time before new cloud-free data can be acquired.

4.19 It should also be pointed out that, because of the large area covered by satellite images, even when the cloud cover is relatively high (30-40 per cent) the site of interest may be cloud-free in the image.

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7. Infrared light can better penetrate haze, smog and thin clouds. Color combinations using only infrared light from spectral bands 4, 5 and 7 are available from Landsat data. These can be useful in hazy areas for applications such as general vegetation mapping.

8. One source of information on cloud-cover patterns is the lists of archived satellite data, mentioned in the section above.

4.20 One way around the problem may be to purchase images from two or more dates. Together these may give a cloud-free coverage of the area of interest. Through computer-based processing, the supplier (or an advanced user) can produce a cloud-free mosaic from the images.

4.21 The analysis methodology selected also has an influence on the climatic constraints. Analysis which requires two images, such as stereoplotting and automatic change detection, are more vulnerable as both images have to be cloud-free. Computer-based methods are generally more sensitive, whereas a human analyst can more easily identify and take into account the effects of poor atmospheric conditions. For the parts of the image that are completely obscured, the lacking information has to be supplemented with more field work and other reference data.

Reference data

4.22 All analyses of remote sensing imagery need reference data to help identify the features in the imagery and to verify the reliability of the output. Sometimes the term "ground truth" is used. But although it is normally necessary to gather some information through field visits, large parts of the reference data can consist of available maps and reports, conventional aerial photographs, and oblique photographs taken by a conventional camera from a light aircraft during reconnaissance flights. This material can be very useful even if it is not entirely up-to-date.[9]

4.23 Analysis of satellite data is sometimes utilized to produce borders between areas of different patterns, although what makes out the patterns cannot be directly determined from the image. An example is delineation of residential areas according to density. A pattern related to the density can be distinguished, although the individual houses cannot be counted or measured in the image. In this case the reference data are used to measure the density and label the areas delineated in the satellite image.

4.24 In computer-based automatic processing, reference data are used to identify "training areas" with known characteristics. Statistical measures calculated from the image data for these are then used for statistical analysis and labelling of the entire image.

4.25 Working within a GIS environment can be a way to relate reference data to remote sensing data. The integration of data from several sources can facilitate and improve the analysis, both when computer-based processing and visual interpretation are used.

4.26 The amount of reference data needed is to a large extent determined by the familiarity of the interpreter with the area covered. Different applications also have very different needs for reference data. Mapping of general land-use and land-cover can be done with access only to old maps, whereas socio-demographic surveys need several staff-months of sample interviews. Other factors to take into account are the size of the area and the precision needed.

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9. See Annex B: Reference Data and Quality Control for discussion on the collection of reference data.

Quality control

4.27 It is important to be aware of the errors that are present in any map. In a GIS it is even more crucial, as many layers of information can be used together in the analysis. Data from sources of varying quality can be integrated in the system. These can have different original formats, dates, scales, and inconsistencies in definitions and delineations. Unless the GIS user is aware of the reliability, the final product—though the design could make it look very convincing—can be impaired with errors, and even misleading. One rule of thumb is that the final output will only be as accurate as the least accurate input layer utilized.

4.28 Annex B: Reference Data and Quality Control, contains more details on potential sources of error and techniques for accuracy assessment.

4.29 As noted above, a statement of the reliability of maps is essential for the proper use of the data. In remote sensing, it is a normal procedure to give a quantitative assessment of the mapping accuracy. A criterion established by Anderson et al. (1976) for land-use and land-cover maps is widely used. This requires a level of accuracy of at least 85 per cent, and that the accuracy should be approximately equal for most categories in the map. One important result from the trend towards integration of GIS and remote sensing may be an increased awareness in the GIS community of the importance of accuracy assessment. This should become part of other data collection processes.

V. INSTITUTIONAL ISSUES

5.1 It is now widely recognized that urban information management technology can only be successfully applied after institutional, organizational, procedural, and information quality issues have been addressed. There must be a management policy dealing with such matters as institutional mandates and linkages, technology strategies, human skills development, and financial management. A recent UMP study deals with these issues in detail.

5.2 New technology is only a tool for information management, not a solution in itself. Without good quality data, and organizations and routines with a capacity to maintain the data sets, the information systems will fail, irrespective of the technology used.

5.3 The first series of steps to improve information management include defining the information needs, setting priorities, and then comparing these with the state of existing information and the capabilities of data producers and users. The major costs of improvement are in data acquisition, institutional improvement, and education and training. Equipment represents less than 20 percent of the costs. In fact, the greatest cost involved in developing and managing a GIS is usually the effort it takes to build and maintain the computerized database.

5.4 The main obstacles to successful GIS implementation are connected with organizational structure and management, rather than technical issues (Croswell, 1991). The biggest problems are coordination and communication difficulties within and between the organizations involved, followed by lack of management commitment and high-level support. Croswell's report also offers some guidelines for successful development of GIS.

5.5 High-level support, policies and commitment from management are essential since the real benefits of GIS technology lie in the integration of resources within and between organizations. This also calls for involvement and support from the users when a GIS system is being developed. User committees and regular progress reports sent to all those involved in development of the system are one way to gather and maintain support.

5.6 One successful institutional model is to set up a network of information sharing agencies. Agencies retain responsibility for their own information but agree to share parts that are of interest to others. A separate municipal information agency can handle inquiries for data and act as a coordinator and catalyst in the network.

5.7 Data sharing is enhanced by GIS techniques. However, to make full use of the potential, it is important to evaluate data exchange capabilities when choosing equipment. The content, quality, format, and way data are encoded are important technical factors that must be taken into consideration and for which conventions and standards must be set. But it is even more important to be aware of, and take account of, the institutional barriers that make many agencies reluctant to share information. These are often the main obstacles to data exchange and integration.

Box 6. The Singapore land data hub

In Singapore, a national land data bank has been created through a network of information sharing agencies. Twelve government agencies are participating in this effort to integrate and share common land-related data in digital format. Financial and technical assistance was provided by UNDP and Habitat. Information held by the Land Data Hub include cadastral boundaries and textual data; building outlines; sewerage, drainage, and telephone networks; and information from topographic maps.

Now it is much easier to integrate standardized common data with local data maintained by each agency. Substantial cost savings result from avoiding work duplication and data inconsistencies. As an example, Singapore Telecom can now import 70 percent of the data for its base-maps from the Hub. Through a one-stop center that supplies data from several sources, the information is easier to access for users in both the public and private sectors.

The twelve agencies are responsible for the continuous supply and updating of data to a support unit located in a central ministry. This unit harmonizes data from the different sources. A high-level committee of representatives from the participating agencies provides policy direction and is important in ensuring the implementation of agreed policies and procedures. A subcommittee with middle management or operational level representatives meets monthly to define and review data exchange requirements, standards, and procedures. Within three years, the system moved concept utilization to initial implementation with 50 percent of the data imported by the support unit.

5.8 Education and training at all levels should be an integral part of the information improvement strategy. The amount and type of training needed depends, in part, on the level of technology to be used. Besides training hands-on users in the new technology, there is also a need to educate managers about concepts so they can make wise decisions on its use.

5.9 In the analysis by Croswell (1991), problems and deficiencies in training, education, and recruitment were more important obstacles to GIS implementation than factors related to technical issues. The problems experienced included exaggerated "user-friendliness" of computer software, and training programs that were not sufficient to enable users to reach an operational status.

Options for applying satellite remote sensing

5.10 It is possible to build up an organization's satellite remote sensing capacity step by step. This is important for many urban managers of cities in developing countries who may be faced with irregular funding.

5.11 Satellite remote sensing can be applied with varying degrees of technological sophistication. Three levels of technology are described below. Each places different demands on staffing, equipment, technical support, and institutional development.

5.12 A higher level of technology does not necessarily mean that better results will be produced. On the contrary, in most cases visual interpretation of satellite images is better than computer-based processing for urban applications. Because of this, it takes little effort to build up the basic capacity and level of technology needed in an organization so that it can begin using satellite remote sensing with good results.

5.13 Experience has shown that, once trained, people who are knowledgeable in a field of application and are familiar with the locality quickly learn to produce accurate results through visual interpretation of satellite images. Staff trained in remote sensing can often be found working in environmental and natural resource management. Many countries also have government agencies or research institutions that employ remote sensing techniques. Although these people may not be familiar with urban applications, it can be fruitful to collaborate with them and exchange expertise in order to explore the usefulness of satellite remote sensing for urban development.

5.14 There are numerous ways in which information derived from satellite remote sensing can be applied in the urban context. Because of this diverse potential, it is important to have a good administrative structure for the remote sensing capacity within an urban government. One promising option is to establish a small (two- to four-person) team as part of a planning or operations department. This team should be authorized to meet all government requests for analysis, interpretation support, and information products based on remote sensing. This approach would provide continuity of personnel and skill that would enhance the quality and type of information extracted from the imagery. The current trend for short-term, project-oriented approaches to remote sensing are not cost-effective and do not make optimum use of the information content of the data, the equipment, or the personnel.

5.15 As with GIS, the real benefits of satellite remote sensing are realized through collaborative efforts between urban agencies. Institutional barriers may hinder cooperation initially, but remote sensing provides an excellent vehicle to stimulate cooperative activities.

5.16 A high level of technology is not necessary for remote sensing to produce good and useful results. The move from basic to intermediate and high levels of technology (described earlier) can therefore follow from the general development and improvement of urban information management. Once maps are available in digital format and the necessary institutional and technical requirements for information-sharing have been established, remote sensing applications can be used to their full potential within a computerized GIS system.

5.17 It may be that urban applications alone do not justify the investments needed to create a fully-integrated, high-level system for computer-based image processing using currently available technology. The team of analysts for such a system should be familiar with the application, basic photo-interpretation, satellite remote sensing, and possess computer skills and knowledge of applied statistics. Similarly, a fundamental knowledge of traditional thematic cartography is required as a basis for digital cartography and GIS.

Technological options

5.18 **Basic level.** Photographic prints from satellite data are visually interpreted with the help of reference data. Maps are manually traced from the prints using basic cartographic equipment and skills. The interpretation may be improved through the use of photographic prints or transparencies mounted on light tables and interpreted using macroscopes. If the satellite images are corrected to the map projection, accurate maps can be produced with a minimum of processing. Maps can be updated by overlaying transparencies of the old map on top of the image. Changes over time can be analyzed by systematically comparing old and new images of the same area. Map overlay analysis is also done manually.

5.19 When an investment in manpower development and basic computer equipment and software to a cost of minimum US$5,000 is justified, the information produced can be processed in spreadsheet and database management software systems on microcomputers. The tabular data can be linked to the maps by recording map coordinates and assigning unique identification numbers for each map feature.

5.20 **Intermediate level.** Image processing is carried out as per the basic level, but map handling is computerized. Maps produced by visual interpretation are digitized directly from the satellite image prints. Digitized maps that were originally of different scales can be plotted to the scale of the image and superimposed to improve the analysis.

5.21 The basic requirements for a complete microcomputer installation with computer-based mapping capability would cost at least US$10,000.

5.22 **High level.** Both map handling and image processing is computerized. In an elementary computer system of this kind, the satellite image is only used as a backdrop for digitizing maps on the monitor. A fully integrated system offers interactive image enhancement and computer-based image analysis integrating the map information and other data including satellite data, scanned aerial photos and video recordings.

5.23 Maps can be produced through interactive digitizing from the monitor, directly from the digital image processing results, or digitized as in the intermediate level. With the currently available systems it is cumbersome to digitize an entire map from the monitor; this method is more suited for updating, completion, and adjustments.

5.24 The cost of the most basic system at this level is not less than US$20,000. For a system intended for basic operational use, a more realistic figure is US$40,000.

5.25 A more detailed description of options and costs and some general guidelines to consider when selecting computer hardware and software are offered in Annex C: Equipment requirements.

VI. CONCLUSIONS

6.1 High-resolution satellite data have great potential for providing cost-effective and up-to-date information on cities in developing countries. However, satellite remote sensing does not replace other, more well-known, information-gathering techniques. It is possible to gather strategic planning information on a district or whole city basis and this can be used to complement information from other sources. An amount of field work and other kinds of reference data are usually necessary for the analysis.

6.2 Satellite images can provide a suitable map base to which information from other sources can be added. Images can be used at scales up to a maximum of 1:10,000 although, even at these larger scales, the information content is at best comparable to aerial photographs at 1:25,000 scale which limits their usefulness.

6.3 Satellite data are useful for fast and inexpensive mapping and updating of urban land-use/land-cover and road networks. Land-cover information can also be used together with data from other sources in other applications, such as the identification of hazard-prone areas. Satellite data are particularly useful for analyzing changes over time by comparing images of the same area taken on different dates. The images can also be used indirectly, for example for spatial analysis and collection of data on population density, distribution and growth.

6.4 Image analysis can be improved and data bases be expanded and kept up-to-date more easily when remote sensing is used together with a computerized GIS. Applications for this integrated system include the evaluation of urban growth scenarios, the planning of new transport routes and sites of infrastructure facilities, environmental zonation, and planning to mitigate natural hazards, such as flooding.

6.5 Panchromatic (black and white) data from SPOT satellites are generally considered the most useful single data set for urban applications because they have a higher resolution (*i.e.*, a more defined picture). A combination with Landsat TM or SPOT multispectral (infra-red color) data will often improve the interpretation, especially for vegetated areas.

6.6 Satellite images over urban areas are better analyzed visually rather than by using automated computer-based methods. This means that only basic cartographic equipment is needed to reach good results. Experience has also shown that, when given adequate training, a person familiar with the locality and the field of application can quickly learn to produce interpretations of good quality. Consequently, satellite remote sensing applications should not necessarily be considered "high-tech" tools requiring heavy investments in training and equipment. Reference data and the analyst's experience and familiarity with the area are the most important factors that translate remote sensing images into a meaningful management tool.

6.7 Satellite remote sensing can be successfully applied with varying degrees of technological sophistication which can be built up, step by step. The integration with GIS can be developed as the general capacity for managing information develops. A project-by-project approach is usually too expensive and does not make optimum use of the personnel, equipment, and the information contained in the data. Because of this, and the wide number of potential

applications, a promising option is to set up an institutional function to support a broad spectrum of urban management information concerns.

ANNEX A: PROCURING SATELLITE DATA PRODUCTS

A1.1 Satellite data products covering any part of the Earth are supplied by sales representatives networks covering the developed countries, and by some agents in developing countries. The SPOT system has a strict policy where agents and distributors of standard products must follow the same price policy and only sell to customers within their designated marketing area. For Landsat data, this is less rigorous. Operators of Landsat receiving stations normally sell data to any customer, and considerable price differences occur. Value-added products from both types of data are marketed and priced by any producer without restrictions. Therefore it can be well worth comparing quotations.

A1.2 The normal steps when ordering satellite data are the following:

- Customer requests the supplier to search for available data in the archive.
- Customer evaluates the archived data to determine whether it satisfies the demands.
- Ordering of specified products. Or—if no satisfactory data are available—request for acquisitions to be made; that is, specified products will be delivered as soon as suitable data are acquired.

A1.3 The information needed to search the archives are:

- Name of country and city (or other area);
- Latitude and longitude coordinates for corner points of the area;
- Type of data required (panchromatic, multispectral), or type of product needed;
- Preferred dates, for example, certain season, maximum age of data; and
- Maximum acceptable cloud-cover.

A1.4 The archive search returns a list of available data specifying the date, the exact coverage, and an estimated percentage of cloud-cover. From this information, the customer can select the most suitable data and ascertain that the whole area of interest is covered.

A1.5 For detailed evaluation of the listed data regarding coverage and the position of clouds, so-called quick-look images can normally be provided. These are small overview images where the location of clouds can be determined in relation to conspicuous landmarks such as shorelines and rivers. Quick-look images are normally provided free of charge and delivered within one month.

A1.6 Products are ordered by specifying the data that should be used, the type of product, and the media.

A1.7 For geometrically precision corrected products, the required map projection and Earth ellipsoid have to be specified. (Normally the same as for the existing base maps.) When ground control points are used to correct the geometry of the data, the normal conditions of delivery are that the purchaser provide maps for the control point measurements. The accuracy achieved in the geometric corrections is to a large extent determined by the quality of the maps provided. This entails that the maps used should be at as large a scale as possible, and preferably not smaller than 1:100,000. The maps do not need to cover the entire area of interest. Ground control points can also be supplied from field measurements, for example, using a ground positioning system (GPS).

A1.8 The total time normally needed from first contacts until the products are delivered is at least six to eight weeks. This does depend, naturally, to a large extent on the available means of communication, the type of products ordered, and the type of shipment selected.

A1.9 On the side of the sales representatives, the time required for the steps involved are as follows: An archive search is done within one or two weeks; standard products are normally produced and shipped within one month after order while value-added products may take another one or two months. Quick-look images are normally produced in less than three weeks. New acquisitions can start two to four weeks after the receipt of a request, whereas the time needed before the satellites can acquire usable data is primarily determined by the cloud conditions.

Points of contact

A1.10 The primary distributors of data from the Landsat, SPOT, Indian, and Japanese satellites are listed below. From these, it is possible to get information on their respective sales representatives network and data receiving stations. They also provide selective lists of enterprises providing value-added products and services.

EOSAT, 4300 Forbes Boulevard, Lanham, Maryland, U.S.A. 20706-9954
Tel.: 1-(301) 552-0571, Fax: 1-(301) 552-3762, Telex: 277685 LSAT UR

SPOT IMAGE, Cedex 16 bis, av. Edouard Belin, 31030 Toulouse, France
Tel.: 33-61 53 99 76, Fax: 33-61 28 18 59, Telex: 532079

National Remote Sensing Agency (NRSA)
Department of Space, Balanagar, Hyderabad - 500 037, Andhra Pradesh, India
Tel.: 262572, Telex: 4256555 SITA IN

Remote Sensing Technology Center of Japan (RESTEC)
Uni-Roppongi Bldg., 7-15-17 Roppongi, Minato-Ku, Tokyo 106, Japan
Tel.: 3-403-1761, Telex: 2426780 RESTC J

Range of products available

A1.11 An overview of satellite data products is included in Chapter IV. Below, some further details and clarifications are offered. For both Landsat and SPOT, user handbooks are available that provide detailed technical data on the satellite systems (USGS, 1984; Spot Image, 1987).

A1.12 **Product media.** Digital data are normally provided on 9-track tapes, with tape cartridges becoming an option. Some suppliers also provide sample products on diskettes for personal computers, but this is not an alternative for operational use as the data storage capacity is too limited on these.

A1.13 Master films are produced from digital data using film recorders. The common format is 24 x 24 cm. Black and white films can be either positive or negative, whereas color films are positive. Color satellite images are normally composed through representing the light from the near infrared part of the spectrum in red colors, the light from the red part in green, and the green light in blue colors in the image. (The Landsat TM instrument records light from 7 different spectral bands. Many alternative combinations are thus possible.) In this composition—which is the same as for infrared aerial photos—lush vegetation has red tones, built-up areas have green or blue tones, turbid water is green, whereas clear water is black.

A1.14 Photographic enlargements from master films are available as prints or transparencies on material of good dimension stability. To preserve the quality of the data, the enlargement should be maximum six times compared to the master film.

A1.15 **Standard products** are normally provided in scene format, as explained in Chapter IV. System correction is the term used for the computer processing needed to transform the stream of signals transmitted from the satellite into standard product images. This includes calibration of the reflectance values recorded by the instruments to a uniform standard, comparable to exposure adjustment for a camera. The geometry of the data is further corrected to produce images with as small distortions as possible. But the images are not corrected according to a map projection, which means that a map that is overlayed will not fit exactly.

A1.16 SPOT has two kinds of standard corrections called Level 1B and Level 2A. Level 2A involves more processing, has a better geometric quality, and is accordingly more expensive. The images are further produced according to a given map projection. A map can therefore be overlayed, but the exact location of the image relative to the map coordinate system may have to be adjusted in the order of some hundred meters.

A1.17 **Value-added products** are not bound to the scene format as standard products are, and they are often geometrically precision corrected to fit a base-map. Several scenes can be mosaicked together and the products cut out according to map sheets, district boundaries, drainage basins, etc. Some suppliers offer images in map sheet format at standardized unit prices. This means that the supplier takes the risk that the number of scenes needed to cover an area varies depending on the location.

A1.18 Products where data from different instruments are merged into one image are also available. Through this the color information from SPOT or Landsat multispectral data can be combined with the better geometric resolution of SPOT panchromatic, allowing color images at larger scales. Some analysts prefer, however, to use the products from the different instruments separately in the analysis.

A1.19 Data from two dates can also be merged to form a "multidate" or "change image." In this, areas where the land cover has changed between the two dates will stand out in specific color tones. These images are used for change analysis and map updating. Digital elevation models (DEM) produced from SPOT data are other examples of value-added products; these are further described in the section on base-mapping.

Price indications

A1.20 Indications of 1992 prices in US dollars are given below for a selected number of products. Satellite data products in scene format are largely standardized regarding specifications and prices. Some products in map sheet format are starting to become standardized, but prices and specifications still vary considerably between suppliers. Other value-added products and services are still evolving and often targeted to markets in industrialized countries. It is therefore impossible to include these in this brief overview.

A1.21 One fundamental issue regarding prices is that the bulk of the cost is for the data itself—this covers the costs for operation of the satellites, facilities on the ground to receive and process data, and the management of the system. In what form the data are provided does not make so much difference. Several products from the same original data, such as digital data and a master film, can be obtained for a comparatively minor extra cost. Likewise, extra copies of photographic products and several enlargements from the same master film cost less than US$200 for color products, and less than US$100 for black and white.

Table A-1. SPOT products in scene format
(1992 cost in US$)

Type of data	Level 1B	Level 2A	Level 2B
SPOT panchromatic (b/w), 10m	2,500	3,100	3,800
SPOT multispectral (color), 20m	2,000	2,500	3,250

Note 1: The levels referred to are, according to SPOT terminology: 1B—system correction, 2A—in map projection without use of ground control points, 2B—precision corrected with ground control points.

Note 2: The same price applies irrespective of the media, i.e., digital tape, film or photographic print. The prices are further identical for a full scene (60 x 60 km) or a quarter scene (30 x 30 km), but the scales of the photographic products differ:

Full scene: Film 1:400,000, print 1:100,000; Quarter scene: Film 1:200,000, print 1: 50,000

Table A-2. Landsat TM products in scene format
(1992 cost in US$)

Size of scene	System corrected			Precision corrected Digital
	Digital	Film	Print	
Quarter scene (92.5 x 85 km)	3,100	2,700	2,900	4,200
Full scene (185 x 170 km)	4,400	2,700	2,900	5,500

Note: All products are multispectral (color) with 30m resolution. Standard scales for the photographic products are:

Full scene: Film 1:1,000,000, print 1:250,000
Quarter scene: Film 1: 500,000, print 1:100,000

Table A-3. SPOT products in map sheet format, precision corrected
(1992 cost in US$)

Scale and type of data	1 sheet	4 sheets	8 sheets
1:50,000, panchromatic OR multispectral	7,600-9,200	18,000-20,000	28,500-36,500
1:25,000, panchromatic OR multispectral	6,400-6,600	11,500-15,000	17,400-26,900
1:25,000, merged pan-chromatic AND multispectral	7,800-12,700	20,700-20,800	30,700-37,900

Note 1: Products in map sheet format supplied at standardized prices is a relatively new phenomenon. The prices differ widely between producers, primarily depending on product specifications and the volume discounts given. Accordingly, only approximate price ranges depending on the number of sheets ordered are indicated.

Note 2: Map sheets are normally cut according to latitude and longitude grid; 15'x15' for 1:50,000 and 7.5'x7.5' for 1:25,000. The approximate maximum area is 800 and 200 km^2 respectively.

Note 3: Some suppliers have special, and considerably lower, prices if data from only one scene are used. Approximate prices for panchromatic OR multispectral data are US$4,200, US$6,500 and US$9,500 for 1, 4 and 8 sheets respectively at 1:25,000 scale.

Cost comparison with aerial photography

A1.22 Mapping at medium scales based on satellite data is normally less expensive and faster than conventional mapping using aerial photos. Exact figures are impossible to give on a general level, as the costs depend largely on the location and the type of mapping. Salaries, productivity, techniques used, equipment costs, and project timetables are major factors. A few examples of cost comparisons are given below.

A1.23 The cost for data acquisition is less for satellite data than for aerial photography. A comparison must take into account the factors that cause considerable variation in costs for photo coverage, such as scale, size of the area, aircraft operating and staffing costs, field logistics, and climatic restrictions. Color or infrared photography can increase basic costs by 30 to 60 percent. As an example, for the mapping done at 1:25,000 scale in Manila under this project (in 1991), the cost for conventional air photos at 1:32,000 scale would be roughly US$30/km^2, 8 map sheets of geometrically precision corrected SPOT data at 1:25,000 would cost US$11/km^2 (or 5.9 if produced from one scene only), and a system corrected panchromatic SPOT scene would be US$0.7/km^2.

A1.24 For photographs taken from light aircraft with a hand-held camera, the only major cost is aeroplane rental. The cost for this is in the range of US$100-200 per hour.

A1.25 Data acquisition is only one of the steps in map preparation. Cost comparisons should preferably consider the whole process. Canada is one of the countries where the use of SPOT data for topographical mapping has been studied most extensively. Some figures on cost comparisons for topographical mapping in the Canadian context were summarized in Gastellu-Etchegorry (1990b), and are cited in the tables below. For map revision, and when time is a critical factor, the use of satellite imagery was proved particularly cost effective. The reader should bear in mind the limitations to interpretability in SPOT data, as mentioned in the section on base-mapping.

Table A–4. Costs for digital topographical mapping at 1:50,000 scale in Canada (US$/km^2)

Steps	SPOT data		Conventional mapping	
Acquisition of images/photos	2.5		4.0	
Ground control	10.0		14.0	
Production of digital map	29.0		52.0	
Field verification	10.0		10.0	
Drawing and editing	17.0		17.0	
TOTAL (Percentage)	69.0	(71)	97.0	(100)

Table A-5. Costs for analog map revision at 1:50,000 scale in Canada
(US$/km2)

Steps	SPOT data		Conventional mapping	
Acquisition of images/photos	0.5		4.0	
Ground control	0.0		0.0	
Production of analog map	2.5		15.0	
Field verification	6.0		6.0	
Drawing and editing	5.0		5.0	
TOTAL (Percentage)	14.0	(47)	30.0	(100)

A1.26 A cost comparison for mapping of a coastal zone in Polynesia at 1:50,000 scale is cited in Bertaud (1989). The study was conducted by the French Hydrographic and Oceanographic Survey in 1987. This can have relevance to costs for urban applications because of the small area covered, 500 km^2. The total cost was US$285/$km^2$ for conventional mapping using aerial photos and involving 24 person/months, compared to US$160/$km^2$ using SPOT data and 3 person/months. The costs for image acquisition were US$170/$km^2$ and US$45/$km^2$ respectively.

ANNEX B: REFERENCE DATA AND QUALITY CONTROL

Collection of reference data

B1.1 For mapping, reference data are typically collected in the following steps:

- Inventory of existing material such as maps, reports, and aerial photographs.
- Initial overview field reconnaissance for familiarization with the area and the theme of mapping.
- After preliminary interpretation, main gathering of new reference data in the field.
- Accuracy estimation of end product.

B1.2 The collection of field reference data can be very expensive and time consuming. Constraints on budget and time often dictate that all new reference data have to be collected in one field visit. In this case it is important that a preliminary interpretation be done relying on the available reference data and the local knowledge of the interpretation team. The data collection can then be optimized according to the aims of the mapping, and the work can be targeted on objects that could not be identified directly in the preliminary analysis. For subsequent accuracy assessment, an appropriate amount of field data should also be withheld from use during the interpretation.

B1.3 Many textbooks recommend the use of theoretical sampling strategies where the data are collected at randomly distributed points. In practical applied remote sensing this may not be a fruitful approach, when many resources must be devoted to finding points that are difficult to access. The "equal distance sampling" is useful in such cases. This method is based on observations made at equal distances along routes traversing the area. Another way is to concentrate the field observations on sites easily identified in the images and on the ground, such as road junctions, railway crossings, bridges, etc. With the two latter approaches, you must be careful not to bias the data by excluding objects not found close to easily accessible routes. Rather than conducting all field sampling on the ground, it is advised to use a light aircraft.

Error sources

B1.4 The development and spread of GIS technology has increased awareness of the reliability of maps. This becomes critical when information from a variety of sources and of varying quality are integrated. There is accordingly a need to identify sources of error in the analysis, to document the accuracy of the source material and outputs, and to introduce procedures that improve the accuracy.

B1.5 One can differentiate between two sources of error: inherent and operational. Inherent error refers to the uncertainty present in the source materials. Operational error are uncertainties that are introduced during data input and processing in the GIS. The inherent errors are difficult to control for a map user. In some cases, as in vegetation maps where the boundaries are often gradual, any delineation is a simplification of reality and two interpreters would not put it at exactly the same position. Map producers are therefore normally advised to provide error statements and to clearly describe the mapping procedures. This allows for the user to assess the suitability of the data for a particular use.

B1.6 One important potential source of operational error is the data entry process. Campbell and Mortenson (1989) describe how errors can be controlled and documented by using formalized log sheets and continual feedback to the technicians. This includes checking of the consistency, completeness, and registration of the data sets before digitizing; controls during digitizing; and a thorough comparison of plots of the digitized data with the source maps. That the resulting operational error increases rapidly as the number of layers used in the analysis increases was demonstrated in a study using maps of topography, vegetation, and soils by Walsh et al. (1987). The conclusion to be drawn is that careful project planning, awareness of sources of error, and honest guidance of the final user is necessary to produce reliable findings.

Accuracy assessment

B1.7 The accuracy of a map is determined by comparing the category as derived from the remote sensing analysis to the known category for each sample point. A review of necessary considerations and available techniques for assessing the accuracy in remotely sensed data is provided in Congalton (1991).

B1.8 The sample points to use in the accuracy assessment should not be identical to the reference data used in the analysis. Neither should only points clearly belonging to a category be used; also points that are difficult to assign to a category must be included. These two types of bias would lead to overestimations of the accuracy. A general rule is that a minimum of 50 sample points for any category are needed to give meaningful results. As some categories are more prone to error than others, a smaller sample can suffice for "easy" categories such as water. The information from the assessment is normally displayed as an accuracy matrix.

Figure B–1. Example of an accuracy matrix

	Reference Data			
Map Data	Urban	Forest	Water	Total
Urban	53	12	2	67
Forest	20	35	8	63
Water	3	10	73	86
Total	73	57	83	216

Sum of the major diagonal = 161
Overall accuracy = 161/216 = 75%

B1.9 The accuracy matrix exemplified in Figure B–1 shows how each category sample was interpreted and where misinterpretations occur. On the major diagonal are the correctly classified values. The sum of these divided by the total number of sample points gives a figure on the overall accuracy of the map. This is the most widely used value for accuracy, but several other statistical measures can be calculated from the matrix. The figures outside the diagonal allows for analysis of the errors of omission and commission and the confusions that occur between categories. As an example, the matrix shows that the most frequent errors in the map are urban areas that were mapped as forest.

ANNEX C: EQUIPMENT REQUIREMENTS

C1.1 Questions regarding what computer equipment is needed to start a GIS or remote sensing facility are often asked by prospective users. Some general guidelines on how to select computer software and hardware and their approximate costs are given below. However, the major costs for improved information management are in data acquisition, institutional improvement, education, and training.

C1.2 Computer-based mapping and image processing place high demands on data storage and computational capacity. Specialized equipment, such as digitizers for map input, plotters for map output, and special hardware parts to increase computation speed, tend to be expensive compared to more general-purpose equipment that have a larger market.

C1.3 It is advisable to start small with an easy-to-use system. This would be used for a pilot phase, where the requirements are better identified, and for when the building of the database is initiated. Work on the database can begin even before the equipment has been installed, by checking of the consistency, completeness, and registration of the data sets.

C1.4 Experiences from the pilot phase will guide the investments, if justified, in a more expensive operational system. Considering the rapid development of the technology, a new product may meet the requirements better and at lower costs than during the pilot phase. It is important that the pilot investments in database building, training, and equipment can be transferred to the new system. To achieve this, the compatibility and possibilities of upgrading should be an important aspect when selecting the first system.

C1.5 The reliability of the hardware and software is an important consideration. This is especially true when service support and spare parts are not easily available. It is very common that the time and effort required for support of the computer installation is underestimated.

C1.6 How easy a system is to learn and use can be more important than the theoretical processing speed and capabilities. A tool that is regarded as too complicated to use will not be put into work. The cost of learning the system, and relearning functions that are not often used, should be compared to the cost of purchase.

C1.7 The compatibility with systems already in place in other organizations should be examined. This is important not only from the point of view of data exchange but also because the larger pool of experience gathered by the users will help overcome the many small stumbling blocks always present in computer processing.

Sample configurations

C1.8 Approximate prices in the United States for some sample computer configurations are given below in US dollars (1992). Local costs, which vary widely from country to country, can be considerably more after taxes and the like are added. The reader should bear in mind the rapid technological change in computer systems and the continuing price declines on the world market.

C1.9 There is a proliferation of products on the market, some 200 GIS software packages are offered for mainframe, minicomputers and microcomputers. The operational capacity and the costs of the products differ widely. GIS software range in price from US$300 to US$30,000, and remote sensing packages from US$300 to US$50,000. The potential buyer should seek experienced advice in selecting software or, as a minimum, insist on a demonstration that the software will perform the applications required.

C1.10 Because of the large number of products available, the rapid technology development, and a wish not to favor any particular supplier, no specific products are given here. The interested reader can find surveys of computer software, amongst others, in the *1991-92 International GIS Sourcebook* and through the Réseau A.D.O.C. Contact addresses for these two sources are included in the section on further readings. The report *Micro-computer based GIS 1991* (HS/261/91) is available free of charge from Habitat. The most common GIS software used for urban applications on microcomputers are evaluated in this publication.

I: A minimal system without computer-mapping capabilities:

386-based PC system with diskette drives, 2 Mb RAM, 80 Mb hard-disk, VGA display.	US$2,500
Matrix printer.	300
Spreadsheet software.	900
Statistical program.	300
Word-processing software.	300
Graphics presentation program.	300

II: A basic system with GIS or thematic mapping capability:

386-based PC system with diskette drives, 4 Mb RAM, 100 Mb hard-disk, super VGA display.	US$4,000
Digitizing tablet, A2 size.	3,000
Pen plotter, A3 size.	2,000
Matrix printer.	500
GIS program, low-end.	2,500
(Alt. Thematic mapping program.	1,000
Software as in configuration I.	1,800

III: A system with very basic image-processing capability:

386-based PC system with diskette drives, 4 Mb RAM, 100 Mb hard-disk, super VGA display.	US$4,000
Tape drive, 9-track tape, 6,250 bits per inch.	5,000
Color inkjet printer, A4 size.	1,000
Matrix printer.	500
Image processing program.	400

IV: A GIS and image processing system on micro-computer:

386-based PC system with diskette drives, 6 Mb RAM, 400 Mb hard-disk, super VGA display.	US$6,000
Digitizing tablet, A2 size.	3,000
Color inkjet printer, A3 size.	2,000
Pen plotter, A1 size.	5,000
Tape drive, 9-track tape, 6,250 bits per inch.	7,000
Image display card, 1024 x 1024 pixels, 24-bit.	4,000
Image display monitor.	1,500
Matrix printer.	500
GIS software, high-end.	7,000
Image-processing program, high-end.	7,000

V: A high-end GIS and image-processing system on workstation:

Workstation with 24 megabytes of memory, tape cartridge unit, and full color image display.	US$30,000
Digitizing tablet, A1 size.	4,000
Color inkjet printer, A3 size.	2,000
Pen plotter, A0 size.	7,000
Tape drive, 9-track tape, 6250 bits per inch.	7,000
GIS software.	30,000
Image-processing software.	30,000

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SUGGESTED READINGS

For the reader's basic information, the following two textbooks are suggested:

Lillesand, T.M., and R.W. Kiefer. 1987. *Remote Sensing and Image Interpretation*. Second Edition. Madison, Wisconsin: University of Wisconsin.

Aronoff, S., 1989. *Geographic Information Systems: A Management Perspective*. Ottawa, Ontario: W.D.L. Publications.

A reference work in GIS technology is the *1991-92 International GIS Sourcebook*. The contents include a survey of products and services, an industry directory, and articles on technology and application topics. The publisher is GIS World, Inc., P.O. Box 8090, Fort Collins, Colorado 80526, United States.

Many of the references in this report come from the journal *Photogrammetric Engineering and Remote Sensing*. This mainly carries research papers on remote sensing and related GIS applications. It is published by the American Society for Photogrammetry and Remote Sensing, 210 Little Falls St., Falls Church, Virginia 22046, United States.

Articles in the Urban and Regional Information Systems Association's *Proceedings* and *GIS/LIS Proceedings* document many GIS applications and problems that have been experienced in addressing them with GIS and remote sensing technology. URISA materials are available from: Secretariat, Urban and Regional Information Systems Association, 900 Second St. N.E., Suite 304, Washington, D.C. 20002, United States.

Two GIS magazines that carry articles and news items on applications and products are:

Geo Info Systems, 859 Willamette St., P.O. Box 10460, Eugene, Oregon, 97440-2460, U.S.A.
GIS World, GIS World, Inc., 2629 Redwing Road, Suite 280, Fort Collins, Colorado, 80526, U.S.A.

The francophone reader can contact the Réseau A.D.O.C. to obtain information on literature and products related to urban applications of GIS and remote sensing. A.D.O.C. stands for "Amélioration Des Outils de Connaissance pour la gestion urbaine dans les pays en développement," and the point of contact is: Christiane Weber, Unité associée 902—Institut de géographie, 12 rue Goethe, 67000 Strasbourg, France.

GLOSSARY

Attribute

Nongraphic information associated with a point, line, or area element in a GIS.

Base-maps

A base-map is a general purpose map upon which other more specific purpose maps are based. A base-map is usually made with reference to the national survey control network and plotted in terms of the national coordinate system. A base-map may be either a topographic or cadastral map.

Bits per inch (BPI)

The density of data, counted in bits, recorded on a magnetic tape. Common standards are 800, 1,600, and 6,250.

Cadastral map

A cadastral map shows the real property framework of an area. A cadastral map usually shows property boundaries, administrative boundaries, legal road corridors, and parcel identifiers. Some also delineate the area of each parcel, road names, and administrative area names.

Computer-aided design (CAD)

Computer software for design. Such applications are used in engineering, architectural, and planning agencies for technical designs and other drawings produced by such agencies.

Digital data

Data represented in a computer-compatible format.

Digital elevation model (DEM)

A matrix of numbers representing the altitude on a grid pattern.

Digital terrain model (DTM)

A matrix similar to DEM giving derived terrain values for parameters such as slope, terrain orientation, slope length, runoff direction, the portion of sky visible at each point, etc.

Environmental impact assessment (EIA)

An environmental impact assessment is an assessment of the likely impact of undertaking development or change upon land. It includes all aspects of land and people—physical, economic, social, and cultural. EIA is a 'show-cause' procedure that strives to balance economic, technical, and environmental factors and associated costs.

Geographic information system (GIS)

A geographic information system is a system for collecting, inputting, checking, processing, integrating, analyzing, modelling, and reporting on information relating to a land surface. They may be established and used for many functions, some of which are forecasting potential commercial areas, analyzing factors contributing to seismic hazard levels, determining high risk erosion areas, or assisting in the determination of optimum use of land.

Geometric correction

The removal of sensor, platform, or scene induced geometric errors such that the image data conform to a desired projection. This involves the creation of a new digital image by resampling the original image data.

Global positioning system (GPS)

A tool for geodetic positioning where small receiving instruments on the ground measure the position using signals sent from satellites in orbit.

Hard-copy

Computer output, such as maps and images, printed on paper, photographic material, or other permanent media.

Image enhancement

The manipulation of image density or image digital data to see more easily certain features of an image.

Infra-red

Pertaining to or designating the portion of the electromagnetic spectrum with wavelengths just beyond the red end of the visible spectrum, such as radiation emitted by a hot body.

Land information system (LIS)

The term land information system is applied to systems focused on land parcels as their unit of information or are land-administration based. A land information system is a series of operations used for strategic and operational management, information provision for day-to-day operations, which involves the collection, storage, maintenance, processing, analysis, and dissemination of land-related data including maps and records for land registration, land assessment and evaluation.

Monitor

Usually a TV screen used to display data, graphics, and images.

Mosaic

An assemblage of overlapping aerial or space photographs or images whose edges have been matched to form a continuous pictorial representation of a portion of the Earth's surface.

Multispectral

Generally used for acquisition of remote sensing data in two or more spectral bands.

Near-infrared

The preferred term for the shorter wave lengths in the infrared region extending from about 0.7 micrometers (visible red), to around 2 or 3 micrometers (varying with the author). The term really emphasizes the radiation reflected from plant materials, which peaks around 0.85 micrometers.

Panchromatic

Used for films that are sensitive to broad bands. Satellite image with only one band that scans images in black and white.

Photomap

A photomap is a map of the terrain, the map base of which are photo images from aerial photography. The various types of photomaps are: unrectified photomap, rectified photomap and orthophotomap. An enlarged approximately scaled aerial photograph (unrectified photomap) approximates a map, while an orthophotomap is an accurate map product.

Pixel

A contraction of a picture element. In satellite images, an integrated radiance mapping unit.

Preprocessing

Commonly used to describe corrections and processing done to image data before information extraction. Includes geometric and radiometric correction, mosaicking, resampling, and formatting.

Processing

The operation necessary to produce negatives, slides or prints from exposed film, plate, or papers. Also, the manipulation of digital data by means of a computer.

Reflectance

The ratio of radiant energy (such as visual or infrared light) reflected by a body to that incident upon it.

Remote sensing

Remote sensing is the discipline of data gathering, analysis, and presentation of data obtained remotely from the object under survey or analysis. Analysis may be by simple mirror stereoscope or by a sophisticated computer-assisted image processing and analysis system. Instruments used in data gathering include cameras and electro-optic scanners either hand-held, aircraft-mounted or satellite-mounted. Remote sensing is greatly improved by the additional data source of ground sampling being incorporated in the procedure. It is used for land use surveys, topographical mapping, and resource mapping in general.

Small format aerial photography

Low-cost aerial photography using cameras with small film formats and light aircraft; viable for surveys of limited areas (< 50 km^2).

Spectral band

An interval in the electromagnetic spectrum defined by two wave lengths, frequencies, or wave numbers.

Stereo-pair

A pair of photos (or satellite images) that overlap in area and are suitable for stereoscopic examination.

Thematic map

A thematic map is one with a theme (for example, a soil map, land-use map, a cadastral map). In general, the theme portrayed on the map may not be obvious upon an inspection on the ground (it may not be visible in the field).

Topographic map

A topographic map shows the physical features visible on a land surface, usually portrayed on a two-dimensional map. It shows both the natural and artificial features.

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