

SPOT DATA FOR URBAN LAND-COVER MAPPING AND ROAD MAP REVISION

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ABSTRACT:

Urban managers in the developing world, where cities face rapid population growth and expansion in area, urgently need updated maps that can be produced quickly and economically. The potential of SPOT data for mapping and revision of road and land-cover information was tested for a study area in Manila, Philippines. Large-scale maps complemented with field work were used as reference to evaluate the accuracy of maps produced at 1:25 000 scale. Visual interpretation of panchromatic data produced the best results. The revised roads had an overall accuracy of 87%, which is comparable to the existing base-maps produced from aerial photos. 13 land-cover types were separated with an overall accuracy of 92%. Areas under construction and varying degrees of completion covered 23% of the urbanized area.

KEY WORDS: Urban land-cover, Map revision, Developing country, SPOT

INTRODUCTION

It is not uncommon for cities in the developing world to face annual population growth of up to 10 percent, and an expansion in area by 50 to 100 percent every 10 years. When having to respond to these development pressures, the urban managers often have no up-to-date base-maps and systematic information on the extent of settlements, land-use patterns, environmental problems, and infrastructure facilities.

New solutions need to be found that meet the urgent requirements for updated and well maintained information bases. Traditional techniques, such as ground surveying and conventional aerial photogrammetric methods are frequently too costly for the municipal budget. Because of the time required for production, the resulting maps are repeatedly out of date and need revision on delivery.

With this background, a pilot project was initiated within the framework of the UNDP/UNCHS(Habitat)/World Bank Urban Management Programme. The project seeks to advise the urban manager on the utility of satellite remote sensing as a source of information in developing countries (Paulsson, 1992). The pilot project is undertaken in collaboration with the GRID centre at UNEP in Nairobi.

This paper presents findings from a case-study in Manila, Philippines, regarding the potential for urban land-cover mapping and road map revision.

URBAN LAND-COVER MAPPING

The nature of urban land-use and land-cover makes computer-based methodologies like classification difficult to use. The primary obstacle is that materials such as concrete maintain their reflectance characteristics as measured by the satellite also when they are configured by man to accommodate a diverse array of land-uses. The proportion of vegetation can help the computer; *e.g.*, to discriminate commercial zones from single-family and multiple family residential. But the importance of size, shape and texture/pattern for separating urban features cannot be overemphasized.

Computer-based analysis has been used in developing country environments to produce fast mapping with the limited scope of mapping the extent of urbanized area; *e.g.*, Brouwer *et al.* (1990). 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 are, however, not yet operational. Often, a final delineation through visual interpretation is needed to improve the results (Gastellu-Etchegorry, 1990). In the latter study, standard visual interpretation of panchromatic SPOT prints was also done and produced significantly better results.

When the satellite data is supplemented in the analysis by field verifications, air photos, old maps, and general familiarity with the area, visual interpretation can produce more detailed

mapping. Examples include Thibault *et al.* (1991) who delineated 15 urban land-cover types; and Gamba (1990) who created a typology comprising 38 zones based on structure, density, land-use, and vegetation type.

For operational applications, visual interpretation would therefore be the obvious choice. This paper examines the utility of SPOT data interpreted with limited access to reference data.

URBAN ROAD MAPS

As for urban land-cover mapping, methodologies for automated road delineation from high-resolution satellite data have started to be developed (Van Cleynenbreugel *et al.*, 1990; Møller-Jensen, 1990), but the results do not yet match those achieved by visual interpretation.

Through visual techniques, major roads and railways are readily detectable, while minor roads and tracks cannot be reliably mapped (Salgé and Roos-Josserand, 1988; Manning and Evans, 1988). Primary reasons for non-detection are tree canopy closure or weak contrast between surface material and the surrounding. Alleys in very high density urban areas, which are common in developing country cities, are also difficult to distinguish (Bertaud, 1989).

The higher contrast of recently constructed roads suggests that satellite imagery would be valuable for revision of urban road maps. A test of this application is reported here.

STUDY AREA AND DATA SOURCES

An area of rather flat terrain covering 8 by 8 km on the southern edge of Metropolitan Manila, Philippines, was selected for the study. This displays a variety of land-uses, and contains both older areas and significant recent growth in urban development (Figure 1).

Three digital SPOT images were used in the study; two panchromatic from 21 February 1987 and 12 February 1990, and one multispectral dated 18 February 1989. The 1990 image was geometrically corrected by resampling to UTM projection on 1:25 000 urban base-maps. The RMS error was less than one pixel. The other two images were resampled to the corrected image with an error of less than one half of a pixel.

The base-maps at 1:25 000 scale were used as reference data in the analysis. They were produced from aerial photos dated 1986 and contained information on roads, rivers and administrative boundaries. For evaluation of the results, land-use maps at 1:10 000 scale were used. These were produced from aerial photos dated 1983 and 1986, but were published only in 1989/90. Although of good quality, they had to be supplemented by field work to incorporate changes, and are therefore a good example of urban maps that are outdated already when published.

IMAGE ANALYSIS

The panchromatic image from 1990 was used for the land-cover mapping. With only one analyst, it was not considered possible to do an unbiased interpretation of both panchromatic, multispectral, and multitemporal imagery for comparison of the information content in the data. Instead, the most promising data were chosen for the mapping. The multispectral image was compared to the panchromatic after the interpretation was completed to decide relative advantages.

The digital imagery was interpreted on the monitor in an integrated image processing/GIS system. The digitized road information in the base-map from 1986 was overlaid on the imagery to help the analysis. While the scale of the map was to be 1:25 000, interpretation was done at 1:12 000 and 1:6000 scale.

Areas judged to be homogeneous regarding land-cover were delineated and interactively digitized. As little reference data was available, the polygons were only given tentative labels for checking in the subsequent field work. The interpretation of land-cover relied mainly on the size and layout of buildings, image texture, context, and the structure of the area. Special emphasis was put on separating types of residential areas and dynamic classes describing the on-going developments. The latter would be important to enhance and maintain the usefulness of this type of map in a fast developing area.

For updating of roads, all the three SPOT images were used sequentially. The road network according to the digitized base-map from 1986 was superimposed on each image separately, and new roads delineated and digitized directly on the monitor in the combined image processing/GIS system.

ACCURACY ASSESSMENT

The accuracy of the land-cover mapping was assessed by comparing it to the reference land-use map at 1:10 000 scale. A regular grid was used to select the sample points. First, the classes in the reference map had to be converted to agree with the nomenclature in the land-cover map. As the sources for the reference map were from 1983 and 1986, the code for areas that had changed were adjusted according to field work findings. Densities of the residential areas were derived from the building outlines present in the reference map.

The accuracy of the road map had to be checked through field work. Around 60% of the roads delineated from the satellite images were visited. Roads missing in the map were recorded when encountered. A systematic search for missing roads was not feasible for the whole area, but it can be assumed that most new roads would be close to areas of new development, and therefore that most missing roads were found in the parts covered by the field visit.

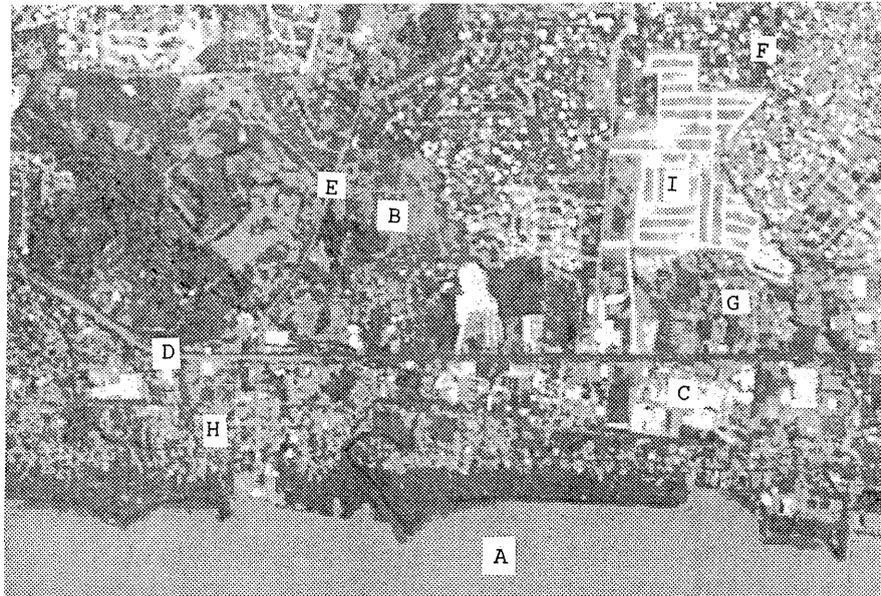


Figure 1. SPOT panchromatic image, © CNES 1990, over part (4.4 x 2.6 km) of the study area in southern Metro Manila, Philippines.
 A = Lake, B = Green open space, C = Industries, D = Highway, E = Major arterial road;
 Residential areas: F = Low density, G = Medium density, H = High density, I = Under construction.

RESULTS AND DISCUSSION

Land-Cover Map

The final land-cover map contains 13 categories after the tentative interpretation classes were grouped based on the field work experience (Figure 2). The categories are listed in Table 1 and an accuracy matrix given in Table 2.

Urban Land-Cover Types	
10	Transportation
20	Industrial/Commercial
Residential Areas	
31	Under Construction
32	Empty
33	In-Filling
34	Low Density
35	Medium Density
36	High Density
Non-Urban Land-Cover Types	
40	Lake
51	Seasonal Swamp
52	Wooded Areas
53	Green Open Space
54	Golf Course

Table 1. Land-cover classes.

The three classes describing residential areas under development may require some explanation. 'In-Filling' means that the road network is finished and plots are started to be built upon and occupied. The 'Empty' class contains areas where the road network is completed, often before 1986, without signs that the plots are being developed. Large parts of the area belong to this type of idle land: 9% of the total area with residential land-cover. The criteria for separating these three classes may seem subjective, but the differences seen in the image were confirmed by reference data, although some errors of commission occurred. The classes are also an important clue to the dynamics of urban growth in the area; 23% of the urbanized area belonged to these three classes.

In the interpretation, it was also attempted to separate construction in Industrial/ Commercial areas, but the field work revealed a low accuracy. These areas were therefore not separated in the final map. The difficulties are due to that high reflection from existing industrial buildings was misinterpreted as recent construction, and that new buildings were added to already developed industrial estates.

The class Industrial/Commercial has the lowest accuracy; 77% regarding errors of commission and 72% for errors of omission. These occurred where smaller industries were located in residential areas, and similarly where small residential areas lay in industrial/commercial zones. It should be noted that separation of small-scale commerce and industry that is commonly intermixed in the residential areas of medium and high density was not attempted. These cannot be separated.

Interpretation	Reference Data													
	10	20	31	32	33	34	35	36	40	51	52	53	54	Total
10 Transportation	21													21
20 Ind./Comm.		23	1		1	1						4		30
31 Res. Constr.			33											33
32 Res. Empty		1		18								4		23
33 Res. In-Fill		3			33	1	3							40
34 Res. Low Dens.						108								108
35 Res. Mid Dens.		2	1	1	2	4	96	7						113
36 Res. High Dens		1						40		2		1		44
40 Lake									23					23
51 Swamps										18				18
52 Wooded											8	1		9
53 Green Open Sp.		2		1		1					1	103		108
54 Golf Course													13	13
Total	21	32	35	20	36	115	99	47	23	20	9	113	13	583

Table 2. Accuracy matrix of land-cover map. Overall accuracy: $537/583=92\%$

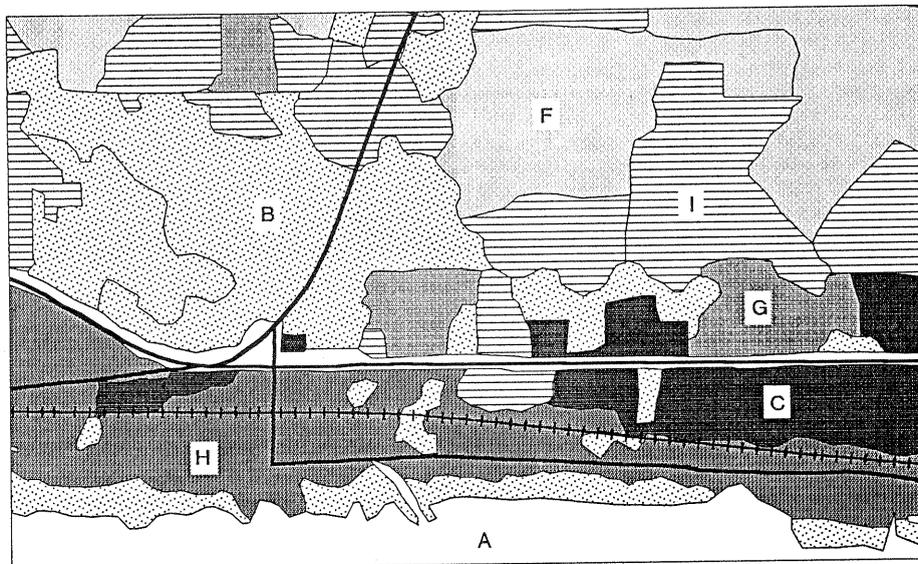


Figure 2. Land-cover map. Simplified version of the map described in the text. The figure covers the same part of the study area as Figure 1, (4.4 x 2.6 km). A = Lake, B = Green areas (classes 51-54), C = Industrial/Commercial; Residential areas: F = Low density, G = Medium density, H = High density, I = Under construction, Empty, or In-Filling.



Figure 3. Road map updated from satellite data. Same part of study area as Figure 1, 2 and 3 (4.4 x 2.6 km).
 A = New roads; Present in old map: B = Arterial roads, C = Distributor roads, D = Neighbourhood roads, E = Railway.

Separation of high density residential areas from vegetation was considered difficult during the interpretation, although this is not evident from the accuracy assessment. The grey shades are similar, and the structure evident in the image for the less dense classes is not pronounced in the high density areas. The road map was valuable to help in this delineation.

The labelling of the residential areas had to be guided by field work in the study. It is expected that aerial photos and old land-use maps would have been very useful for this task, had they been available. It was shown that delineation of land-cover zones is possible in satellite images even with little reference data and familiarity with the area. When this ancillary information is added in the analysis - as would be the case in operational applications - better results are expected, both regarding accuracy and the number of classes possible to separate.

The multispectral image was, as expected, better for identifying and delineating non-urban land-cover types. It was also better for separating high density areas from vegetation due to the contrasting colour shades. As it was judged to be considerably less useful for the urban land-cover classes, the panchromatic data would be the best single data source for this type of mapping.

Revised Road Map

Field-checking of the new roads in the revised map at 1:25 000 scale (Figure 3) gave an accuracy of 87% according to road length (Table 3). The errors of commission are most common. These include walls built around estates (40%), temporary tracks, and small drainage canals. New roads that were detected but had mistakes in the delineation are listed separately in the table.

	Length (m)	%
Correct	34760	87
Delineation wrong	710	2
Commission error	3880	10
Omission error	730	2
Total	40080	

Table 3. Field-check of new roads.

The results must be regarded as good, considering that the interpretation was done without any reference data or knowledge of the area. The accuracy was comparable to that of the existing 1:25 000 scale base-maps that had been produced from aerial photography with limited field checks. It was better than an "up-to-date" road map that was being offered to the general public in book-shops.

Difficulties were experienced in areas still under completion where the road network was very dense. In parts where also houses were under construction the exact delineation was hard to determine from the image. Field completion of the map should therefore be necessary for accurate mapping. It was found that during the analysis, the roads that needed checking could be reliably identified. This would be an important means to improve the efficiency of the field work.

From the experience in the study, it was not considered possible to create a completely new road map only from the satellite data. The small neighbourhood roads were to a large extent impossible to distinguish in older areas where the road network is dense and vegetation obscure the ground.

Satellite data are suitable for revision of road information because of the high contrast of new roads. In the study area, this higher contrast was still noticeable in five year old roads. If the map to be revised is too old, the contrast of the roads to be added may already have faded and the vegetation cover may preclude detection.

The multispectral image was considerably less valuable than the panchromatic data. It was possible to detect the new roads, but difficult to determine the delineation where the road network was dense.

As during the land-cover interpretation, the possibilities of map overlaying, interactive zooming, and contrast enhancement in the image processing/GIS system were useful for the analysis. Disadvantages included the somewhat slow progress when interpreting and digitizing directly on the monitor, difficulties in getting good hard-copy images for field work, and the high cost of equipment, training and service. As it should not be impossible to produce similar maps using images in photographic form, the disadvantages of computer-based processing may outweigh the advantages for many operational users.

CONCLUSIONS

SPOT data proved to be valuable for accurate mapping and revision of roads and land-cover information at 1:25 000 scale. Zones of similar pattern, such as residential areas of different densities, can be delineated in the image. It is often not possible to identify the type of land-cover in detail directly from the image. For this, familiarity with the area and reference data in the form of field work, aerial photography, and maps are needed.

Road information was updated with good results. Field completion is necessary to achieve a completely accurate map, but the roads that needed checking could be reliably identified during the analysis.

As very little reference data was available and as the interpreter was not familiar with the area, the study could be taken as a measure of the amount of information possible to readily extract from the imagery with the help of limited field work. In operational applications, the addition of more reference data should make possible more detailed and accurate mapping and revision.

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