

DETECTION OF CITY GROWTH AREAS USING SPOT IMAGE INTERPRETATION

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Invited Paper

1. INTRODUCTION

For twenty years ITC-Urban Survey staff have been teaching the use of airphoto interpretation techniques as a method for quickly, efficiently and economically collecting data, to be used in the administration and management of large and medium sized cities. The students taught are mid-career town planners, most of them from cities in developing countries.

Satellite remote sensing in the form of LANDSAT did not broaden the possibilities. The terrain resolution of 70 m was so much less than the .5 m resolution of airphotos 1:10,000, which are the usual tool for townplanners, that no practical application of the images could be developed.(1)

With the arrival on the market of SPOT images the situation underwent a change. Although a terrain resolution of 20 m for the colour images and 10 m for the black & white images is still much less than .5 m (that is to say, 20 to 40 times less), it is conceivable that these images may be included in the array of tools available for collecting data on fast-growing cities.

With this in mind we started research on SPOT images in August 1986. First we used images from Almelo in The Netherlands and then we continued with images from Bandung in Indonesia. The research on Bandung was made possible by a grant from the BCRS (Dutch Government Policy Commission Remote Sensing). The report of that research is now being prepared for printing and will probably be available by August 1988.(2) Preliminary results of the research were reported in Jakarta at the Asian Remote Sensing Conference October 1987.(3)

The attention in this paper will mainly be directed towards an experiment in the delineation of the urban area of Bandung on SPOT FCC (false colour composite) enlarged to a scale of 1:50,000. The interpreters were 17 town planners, who were attending an Urban Survey course at ITC.

A first group of town planners had interpreted the images in 1987. The results were not encouraging. Interpreters included large areas which were suspected to be non-urban. However, ground truth was at that time not available. After elaborate preparations the experiment was repeated in January 1988, and now with results which can be considered useful.

Research on the potentials of SPOT black & white images is still in an early stage and will be reported later. But see for preliminary results the BCRS report (forthcoming).(2)

2. AN EXPERIMENT ON DELINEATION OF THE URBAN AREA.

Cities in developing countries grow fast. Population growth rates of 5% per year are very common. This means a doubling of the population of a city in 14 years. But already 4-5 years after a map revision, 25% of the urban area will not be indicated on the map.

Local governments have only limited numbers of qualified staff in their planning and management departments. It is difficult for these departments to keep information on land use in the city fringe up-to-date. Usually information on city development is scattered throughout the administration. A synoptic data source, with which map revision could be done reliably and quickly by personnel with a limited training, would be a welcome tool.

As SPOT images are such a synoptic data source with the metric qualities of a 1:50,000 map we decided to do an experiment in the delineation of the urban area.(6) The research question was: "With what accuracy can an interpreter delineate the urban area on a SPOT image?". To answer this question we basically used the same methodology as used earlier with small format oblique photography for monitoring newly built-up areas of cities.(4)

2.1 THE PROFILE OF THE INTERPRETERS DOING THE TEST.

We asked participants of the Urban Survey post graduate course to make a delineation of the urban area of Bandung. See figure 1.

These course participants are mid-career architects, civil engineers and town planners, most of them from cities in developing countries. At the moment of the test they had finished a large series of exercises in airphoto interpretation. They made an interpretation of a SPOT FCC at scale 1:50,000 from a city in The Netherlands (Almelo), to familiarize themselves with this new remote sensing tool.(3)

They also made an urban-change-monitoring exercise of the southern fringe of Bandung, with aerial photographs 1:5,000 black & white from 1979 and small format aerial photographs 1:20,000 colour from 1987, and thus had obtained some knowledge of the local forms of urban development at the city fringe.

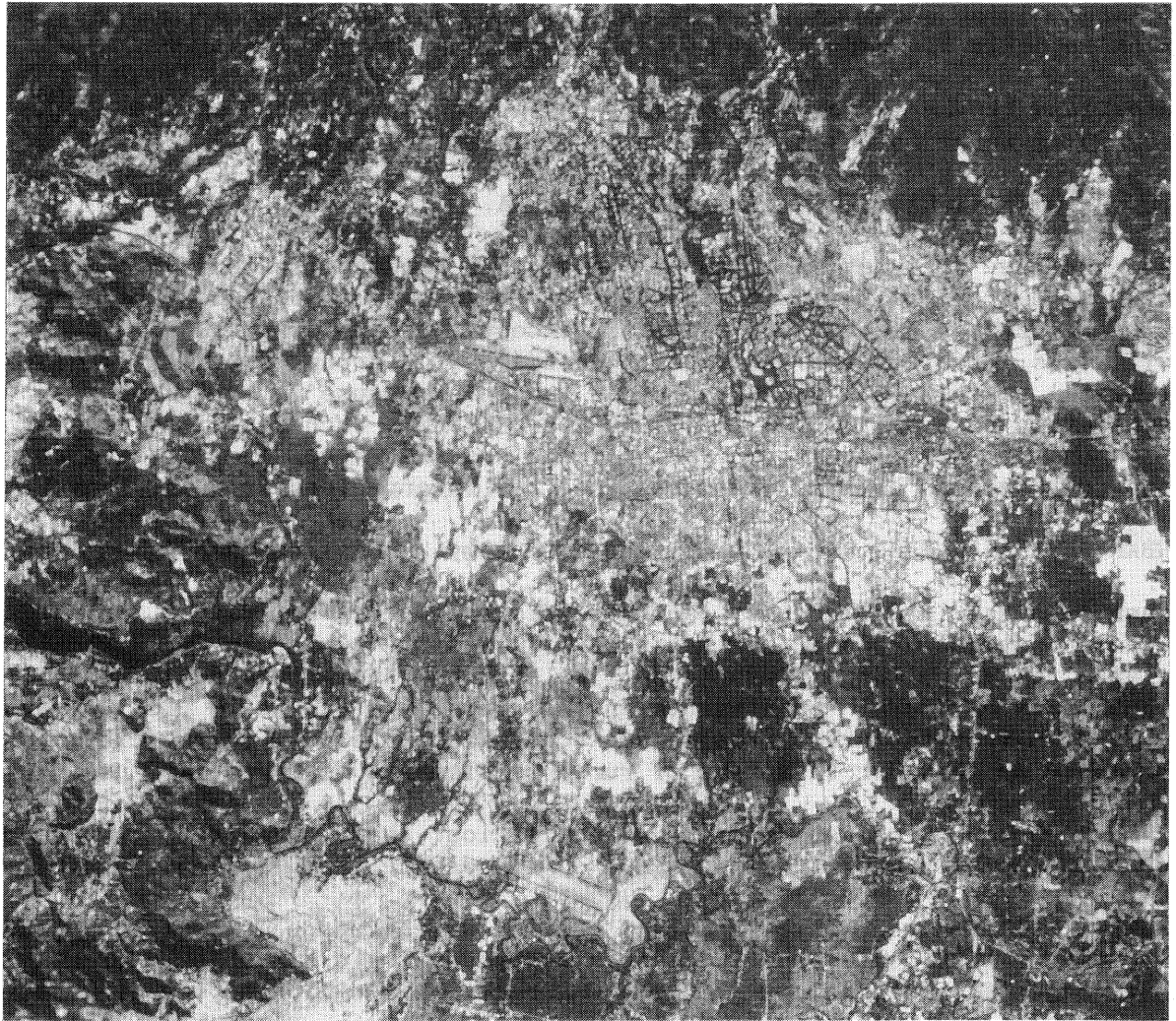


Figure 1. Greater Bandung conurbation, Indonesia, 6 July 1986. Black & white reproduction of the SPOT FCC. Scale 1:125,000. The conurbation includes the small town of Cimahi to the west along the main road to Jakarta. The study area is limited to the area north of the river Citarum.

2.2 THE INSTRUCTIONS FOR INTERPRETATION.

In two sessions the methodology of the delineation of the urban area on remote sensing images was discussed. During these sessions slides were shown of the SPOT FCC image of Bandung, oblique aerial photographs of selected urban developments and ground photographs in order to further familiarize the interpreters with the area. Attention was given to the special problem

of large bluish areas on the SPOT image which were not urban areas but rural areas recently flooded in a period of excessive monsoon rains.

We decided on the definitions of the concepts to be used and on the procedures to be followed, as described (partially) below.

2.3 AN OPERATIONAL DEFINITION OF URBAN AREA.

The exercise "delineation of the urban area of Bandung" is done on a SPOT false colour composite scale 1:50,000. On these images urban objects cannot be recognized by their SHAPE and SIZE, except for some large ones: airport, golf links, stadiums etc. We have to decide that a group of pixels (picture elements) represents a group of "urban" objects because of a typical combination of TONE, COLOUR and TEXTURE or PATTERN. Such decisions can be based on experience with the type of image and some knowledge of the city at hand, obtained in earlier exercises (see the interpreters' profile above).

URBAN AREA is a land use class in the dichotomy: urban land/non-urban land.

Urban land use is defined as: land use related to city activities. In the rural or natural areas it is that type of "land use" which is not directly related to agricultural production (like farmland and farmsteads). Many inhabitants of "rural" settlements in the vicinity of the city (let us say up to 6 km from the urban fringe) are economically related to the city. Therefore we consider this type of rural settlements as urban land use.

We have chosen to use an "exclusive" definition: that means that, in case of doubt on the nature of the land use, we will decide that it is non-urban.

What we will consider as a "group of pixels" which can be delineated depends not only on the identity of the pixels (representing urban objects or non-urban objects), but also on the size and relative location of the group of pixels. (5)

We have chosen the following size rules to limit the amount of detail:

- minimum curtilage 5 mm x 5 mm (terrain: 250 m x 250 m or 6.25 ha)
- minimum width 2.5 mm (terrain: 125 m).

The fringe of the urban area is a zone with areas of rural land use mixed with areas of urban land use: scattered individual buildings (individual plots having become urban), ribbon developments along roads leading to other settlements and isolated large scale developments for housing and industry. In order to guide the delineation in such complex areas we have to use rules for GENERALIZATION, IDEALIZATION and AGGLOMERATION.

GENERALIZATION

The minimum curtilage and the minimum width give the standard for the minimum area to be delineated. This standard should also be followed for the generalization of the delineation. The line should not follow the outline of every small plot or narrow plot, but should be generalized along important boundaries of urban land or along the "average" boundary of urban land. (Figure 2.)

TEMPLATE minimum curtilage and minimum width

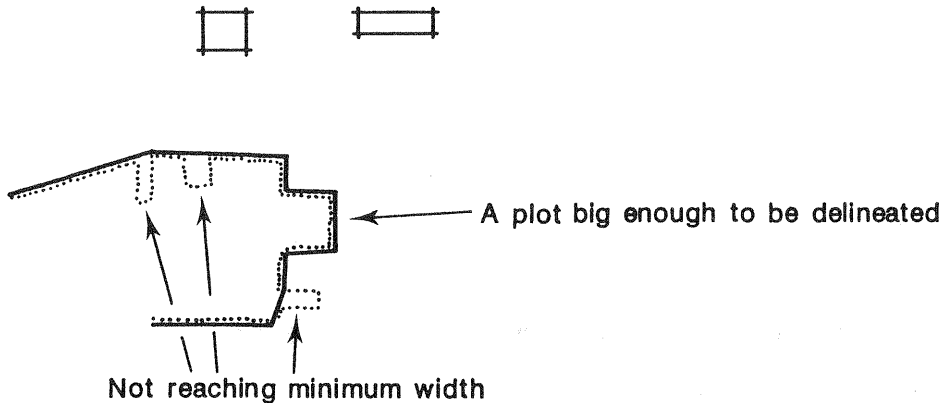


Figure 2. Generalization of the outline of the urban area.

IDEALIZATION

The interpretation technique of idealization is used to make a boundary between the two map entities "urban land use" and "non-urban land use" where in reality only a diminishing density of urban land use can be observed (actually: larger distances between pockets of development). (Figure 3.) How to make the concept IDEALIZATION operational is further described under the concept AGGLOMERATION.

AGGLOMERATION

A small urban area (smaller than the minimum curtilage) will be combined with a nearby urban area, if the distance to that area is less than twice the diameter of the small urban area (measured in the direction of that other urban area). The process may be repeated. The final delineation must fulfill the conditions of the minimum curtilage and the minimum width. The area delineated in this way should not contain areas of non-urban land

larger than the minimum curtilage. The technique of agglomeration should only be applied to urban land. (Figure 4.)

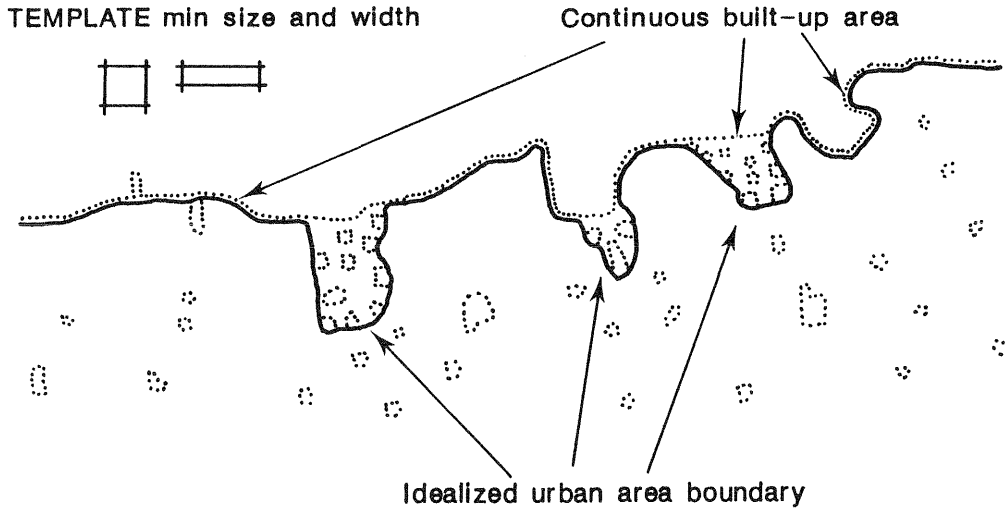


Figure 3. Idealization of the boundary of the urban area.

TEMPLATE minimum curtilage 5 mm x 5 mm; minimum width 2.5 mm

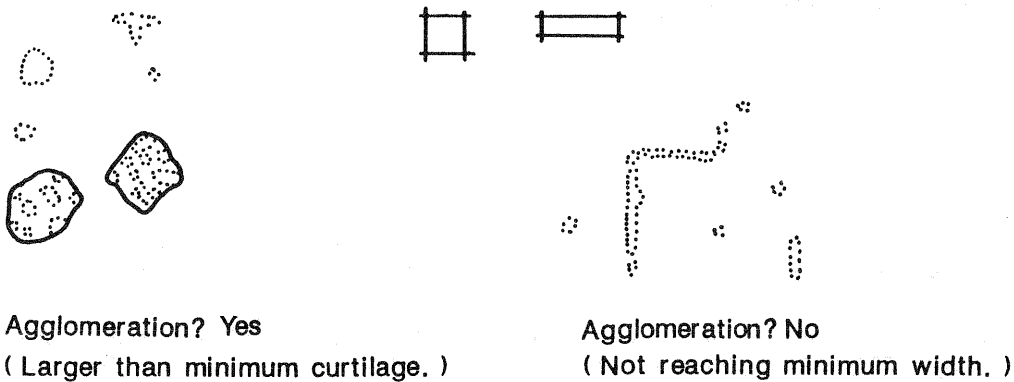


Figure 4. Agglomeration, minimum curtilage and minimum width.

The rules given above have served as a guideline during interpretation. There was no drill on the correct application of these rules. This reflects the normal situation in a town planning office, where remote sensing interpretation is mostly an occasional activity, unlike the situation in any institute where map production is the main activity.

2.4 THE FIRST RESULTS OF THE TEST ON DELINEATION OF URBAN AREA

The maps produced by the 17 interpreters differ greatly in a large number of details. In order to obtain an overview of the magnitude of these differences the maps were compared by an overlay technique in the ITC geo-information system on grid basis USEMAP. The results can be found in table 1.

Table 1. Agreement on the interpretation of urban land on a SPOT FCC 1:50,000 of Bandung July 1986 between 17 town planner-interpreters.

	km2	% of total map
1. full agreement		
NON-URBAN Land Use	216	59
URBAN Land Use	54	15
2. no full agreement		
URBAN Land Use by:		
12 - 16 interpreters	28	8
6 - 11 interpreters	24	6
1 - 5 interpreters	45	12
1 - 16 interpreters	97	26
3. Sum URBAN Land Use	151	41
Total map	367	100

The agreement between interpretations is low (full agreement on 74% of the map). While in total 151 km² (41% of the map) has been indicated by one or more interpreters as urban, only on 54 km² (15% of the map) is there full agreement between the interpreters. To understand better the causes of the differences between the interpreters we decided to make a standard interpretation.

2.5 COMPARISON WITH A STANDARD INTERPRETATION

The author has acquired considerable local knowledge of Bandung, obtained in the period 1976-1980, which knowledge was refreshed during a systematic reconnaissance survey in July 1987, with the SPOT FCC 1:50,000 as field document. In addition, small format aerial colour photography at scale 1:20,000 was obtained in three missions covering the major part of Bandung's urban fringe. These photographs have served as detailed "ground truth" for the interpretation of the SPOT FCC.

The 17 interpretations were individually compared with the standard interpretation using ITC-USEMAP. The following classification was used for the assessment of the individual interpretation:

- CORRECT URBAN : the gridcell (1 ha) is classified on both maps as urban;
- MISSED URBAN : the gridcell is classified in the standard interpretation as urban, by the second interpreter as non-urban;
- WRONG URBAN : the gridcell is classified by the interpreter as urban, but as non-urban in the standard interpretation.

One of the interpreters had obviously not grasped the problem of the bluish areas indicating flooded land, and had made an interpretation comparable to the ones made a year earlier, when we were not yet aware of that problem. For the remainder of the analysis his interpretation was left out as being too deviant from the group's work.

Visual comparison of the individual maps with the standard interpretation readily reveals two types of differences:

- small differences in the placement of the boundary lines;
- small and large areas of wrong interpretation not in the vicinity of the boundary line of the standard interpretation.

These differences do not in practice have the same meaning. The first type is less interesting, because it does not help to understand the difficulties of interpretation.

In order to separate the two types of error we decided to define a "boundary zone" around the perimeter of the delineated urban area of the standard interpretation. The remaining areas of the map are "core areas", either urban or non-urban. As core areas, all those gridcells have been considered which had no neighbouring cells of the opposite land use (concentration index 9 in USEMAP). These cells are at least 100 m away from the boundary line. The boundary zone is mostly two gridcells (200 m) wide.

The perimeter of the urban area of Bandung is very long (300 km ?), one because of the fragmented urban development, and two because several areas with rural land use, larger than the minimum curtilage, can still be found inside the main urban area. Therefore the boundary zone is as large as 60 km². Of this 60 km², 30 km² is located in the urban area (27% of the total urban area) and 30 km² is in the non-urban area. The remaining core-urban area is 84 km².

Table 2 gives the subdivision of the differences over the different zones.

Table 2. Average result of the comparison of 16 individual interpretations of the urban area of Bandung with the standard interpretation.

	WHOLE MAP		CORE ZONES		BOUNDARY ZONE	
	km2	%	km2	%	km2	%
Standard URBAN	114	100	84	100	30	100
Average CORRECT URBAN	89	78	73	87	16	53
Average MISSED URBAN	25	22	11	13	14	47
In the non-urban zone:						
Average WRONG URBAN	8	7	2	3	6	20

The concentration of errors in the boundary zone can be read in the table. The proportion "correct urban" is higher in the core zones (87%) than in the whole map (78%). The missed urban is higher in the boundary zone (14 km2) than in the core zones (11 km2). Of the area wrongly classified as urban the major part (6 km2 of the 8 km2) falls within the boundary zone.

Figure 5 demonstrates the relative sizes of the different types of errors.

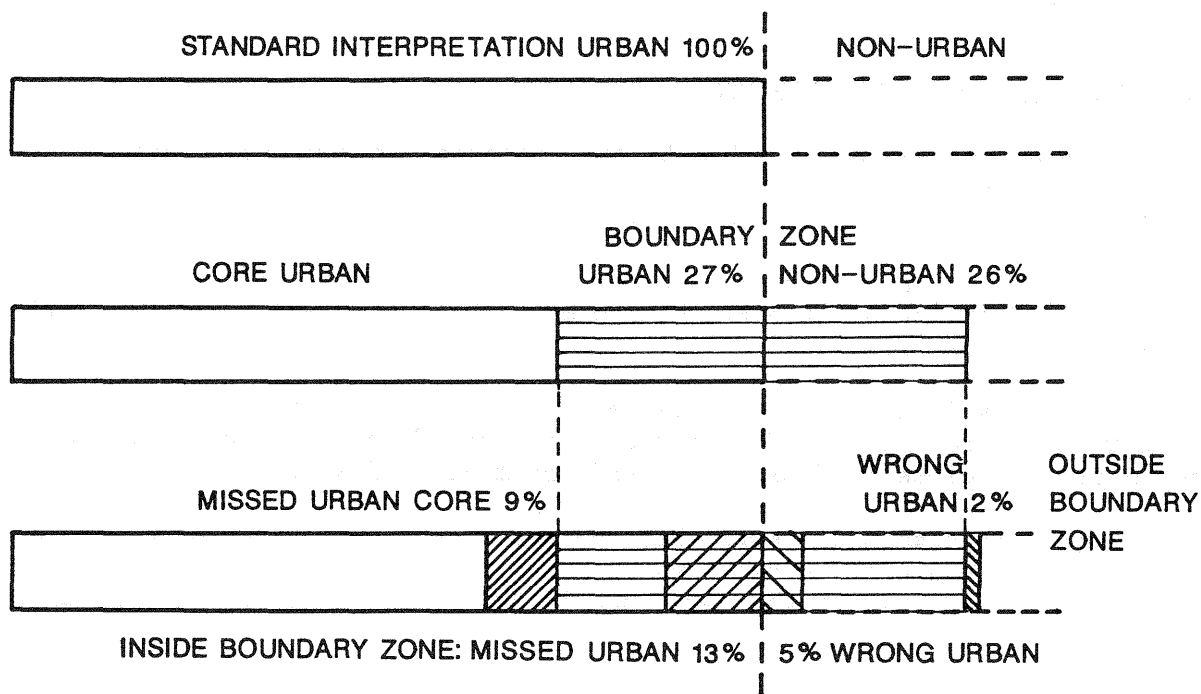


Figure 5. Average result of the comparison of 16 individual interpretations of the urban area of Bandung with the standard interpretation.

The two most important error classes are, in our opinion, "missed urban core" (9%) and "wrong urban outside the boundary zone" (2%). The missed urban (13%) and the wrong urban (5%) inside the boundary zone are, although not wholly symmetrical, at least partially caused by inaccuracies of boundary drawing, digitizing and sampling (in order to convert the digitized polygons into gridcells). Furthermore, the role of the processes of generalization, idealization and agglomeration, where judgement of sizes and feeling for shapes are more important than the interpretation urban/non-urban, has to be taken into consideration.

The first one of the more important errors, missed urban core, can be explained, at least partly, by the fact that the standard urban area is larger than any of the individual interpretations has made it out. The rule "in case of doubt, classify as non-urban" tends to make the delineated urban area smaller when the interpreter is more often in doubt. When making the standard interpretation, with the help of much more local knowledge and the availability of airphotos, this interpreter could be surer about his decisions, especially in areas of scattered urban development.

The second important error is caused by the fact that interpreters occasionally mistook the bluish area (flooded, but not urban) for urban land. But quantitatively this is of some significance only in individual interpretations.

2.6 VARIATION AMONG INTERPRETERS

The total area delineated as urban by the different interpreters varied considerably. The minimum value obtained was 83 km² and the maximum 111 km². The average was 95 km² with a coefficient of variation of 8%.

The amount of core urban area missed was on the average 11 km² (13%), with a coefficient of variation of 34%. The minimum area missed was 5 km² (4%) and the maximum 18 km² (16%).

The area wrongly interpreted as urban area in the non-urban core area was only somewhat more than 2 km² with a coefficient of variation of 48%. The minimum wrongly classified was 1 km² and the maximum 5 km².

Two interpreters combined a more than average missed core urban area with a more than average wrongly classified as urban in the non-urban core area. And even these had only 15 km² (10%) and 17 km² (12%) respectively core area misclassified.

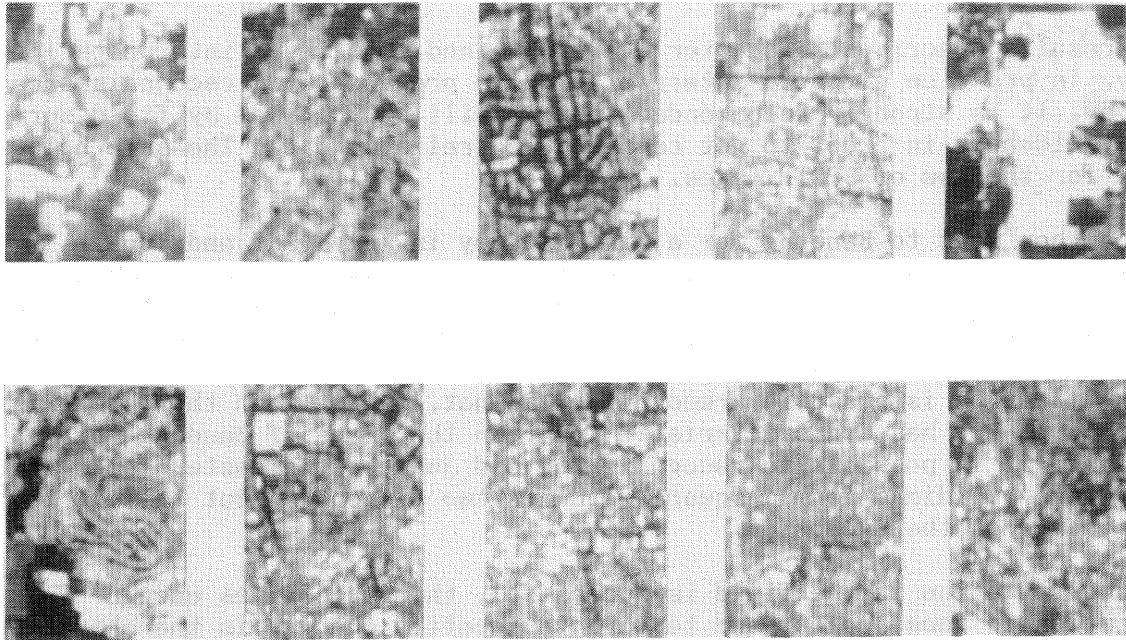


Figure 6. Samples of tone and texture combinations on the SPOT FCC image of Bandung, which can be used in interpretation, both in the office and during fieldwork. The original was in colour, but not "sharper". Scale 1:50,000.

Legend: A B C D E
F G H I J

A. A new industrial area, with buildings big enough to be identified individually in the field. B. A small town (Cimahi) near Bandung, developing into a suburban growth town. C. A high income residential area with the characteristic streets lined by big trees. D. Recent extensions of the city, mainly middle class housing areas. E. A middle class housing project outside the city in the rural area. F. Golf links (grass strips lined with trees); at the southern side high and middle income housing projects. G. An institutional area; a stadium can be recognized. H. The city centre with many large modern buildings, surrounded by old low and middle income housing. I. Low and middle income housing areas mixed with small scale commercial and workshops, west of the city centre. J. An area with scattered urban development (isolated developed plots); this area gives problems of idealization: the southern part is predominantly urban, the northern part predominantly rural.

3. FIELDCHECK AS NECESSARY COMPLEMENT OF IMAGE INTERPRETATION

The results described in chapter 2 are obtained from image interpretation only. In practice airphoto interpretation is preceded by a reconnaissance survey. It is strongly recommended that it will be followed by field survey and fieldcheck in order to get complete and reliable data. The same holds true for the use of SPOT images.

The author went to Bandung for a field survey in July 1987 and found orientation in the field feasible, although not easy. The main problem has been that it is impossible to recognize individual buildings on the image. Only when a building is strongly contrasting with its environment and has a large enough size, then it may be possible to identify it on the image. Identification is possible, recognition is not, except when the object is very large and has a characteristic form. On the image of Bandung for example, it is possible to recognize the old jail on the eastern side of the city: the buildings form a square with its two diagonals. But this is to be considered as the exception.

When orientation in the field is successful, the image gives enough variation in tone, colour and texture to identify changes in the character of the area, e.g. more trees, a different type of roof material, lower or higher density etc.. And certainly the change from urban to non-urban areas, although not always clear during office interpretation work. See the examples of tone and texture combination in the black & white reproduction of parts of the SPOT FCC in figure 6.

Major corrections of the map, based on office interpretation, can probably be made even in a fieldcheck of 2-3 days. However, detailed corrections would take considerably longer to be made.

But in practice the town planner will only be interested in removing the gross errors. Anyhow the image does not give not enough details for engineering mapping and maps for detailed planning.

The main uses of SPOT images will be the updating of small-scale city overview maps (e.g. scale 1:50,000), and the detection of important city extensions. These extension areas can be selected for aerial photographic missions e.g. small scale aerial photography of 1:20,000 with a resolution of 1 m or better. Subsequent enlargement to scale 1:2,000 can provide the necessary detailed maps.

4. CONCLUSIONS

- SPOT false colour composites enlarged to scale 1:50,000 can be used for monitoring urban growth. Delineation of the urban area on the image is possible with a minimum curtilage of 5 mm x 5 mm (6.25 ha), but additional field survey and field check is recommended.
- Delineation of the urban area in the office alone can be expected to have the following accuracy:
 - for the whole urban area: average correct 78% with a coefficient of variation of 8% ;
 - for a core urban area, i.e. without a boundary zone of at least 100 m: average correct 87% with a coefficient of variation of 5%.
- Delineation of the urban area without fieldcheck may include areas wrongly classified as urban area: the average wrong urban area is 3% with a coefficient of variation of 48%.
- Tone, colour and texture differences are sufficient for orientation in the field. It is possible to identify on the image areas with a specific combination of tone, colour and texture that can be identified in the field as urban or non-urban land use.
- Scattered urban development, i.e. only individual small plots are developed as urban land use, poses a problem in generalization and idealization during interpretation.
- SPOT FCC can be an additional tool for the town planner in developing countries, especially when no recent aerial photography can be obtained at short notice.

5. REFERENCES

1. See the example of Enschede, The Netherlands: Ir. C.A. de Bruijn, Delineating urban areas from Landsat images using digital processing; a comparison with grid-based photo interpretation, IN: Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment, Freiburg, 1978, International Archives of Photogrammetry Vol. XXII-7.
2. Drs. V.F.L. Pollé, Monitoring and measuring human settlement changes by remote sensing methods, A case study with SPOT images of Bandung, Indonesia; in cooperation with Prof. Dr. M. Juppenlatz and staff from ITB - Institute of Technology Bandung, Indonesia; BCRS (Beleids Commissie Remote Sensing) report, P.O.Box 5023, 2600 GA, Delft, The Netherlands, forthcoming.

3. V.F.L. Pollé, SPOT image interpretation for information on human settlement growth, IN: Proceedings of the Eighth Asian Conference on Remote Sensing (ACRS 1987), Oct. 22-27, 1987, Jakarta, Indonesia, p.Q-14-1.
4. Victor F.L. Pollé, Monitoring newly built-up areas in cities with oblique airphotos using a 35-mm camera, IN: Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment, Freiburg, 1978, International Archives of Photogrammetry Vol. XXII-7.
5. This is a larger curtilage than Forster (page 141) considers as the minimum for mapping at the scale of 1:50,000: 2 mm x 2 mm. See: B.C. Forster, An examination of some problems and solutions in monitoring urban areas from satellite platforms, IN: International Journal of Remote Sensing, 1985, VOL 6, no 1, 139-151.

Three reasons for choosing a minimum curtilage of 5 mm x 5 mm:

- delineating many areas of 2 mm x 2 mm in the urban fringe would take much more time than could be made available;
 - the minimum area delineated is large compared to the thickness of the pencil line, which makes comparison of interpretations easier;
 - experience has learned that interpretations usually differ so much that differences are readily visible even with a comparatively large minimum curtilage; in this experiment the differences are measured in km} while the minimum curtilage is 6.25 ha.
6. On SPOT images, processed level 1B, the average length measurement of distances of 10 km is better than 1%. See reference 2.