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Application of Satellite Image-Mapping for Stratification of the Kumasi Peri-Urban Interface

Development of methods of peri-urban natural resource information collection, storage, access and management
DFiD Project R6880

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DFiD Project R6680 Report

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RNRRS Programme	**RNRRS Production System**
NRSP	Peri-urban interface
Project Title	
Development of Methods of Peri-Urban Natural Resource Information Collection, Storage, Access and Management	
Relates to Project Output	
2. Stratification of area for village level RRA and detailed image data collection	

Application of Satellite Image-Mapping for Stratification of the Kumasi Peri-Urban Interface

Introduction

Context of this work within Project R6880

This work contributes to Output 2 - Stratification of area for village level RRA and detailed image data collection. Originally, in Output 3, we aimed to carry out RRA on the basis of the stratification derived here. Subsequently, Output 3 has been modified to take account of RRA activities and a Village Characterisation Survey undertaken by the Kumasi Lead Research team (KLRT).

Unfortunately, it was not feasible to synchronise the activities of this work with those of the KLRT in order to assist the design of the Village Characterisation Survey as was originally envisaged. We have therefore concentrated on the development of transportable methodology for stratification of village level surveys in the Kumasi peri-urban interface using satellite imagery and have related our results to the survey that was actually carried out.

Context of stratification in natural resource and socio-economic surveys

Stratification forms part of the statistical design of a sample survey. It improves the precision of the survey results when the sample observations are extrapolated to give information applicable to the whole of the universe being sampled - the peri-urban interface in the current work.

The first step in survey design is the identification of the population or universe for which particular information is required. In natural resource surveys, the universe is usually the geographical extent of the study area. In socio-economic surveys the universe is typically the people within a specific grouping e.g. farmers.

The second step is to define the sample unit, which is the entity on which the observation is made. In natural resource surveys this is typically a small area of land, in socio-economic surveys this is a person or household etc. The sampling frame defines all the possible units from which the sample is to be selected. In natural resources surveys this will be all the small sample areas which make up the area of interest - an area frame. In socio-economic surveys it is a list containing all the individuals - a list frame.

The process of stratification aims to put the sample units into sub-groups within which all the sample units are similar, and to calculate a weighting for each group usually according to its size. The sample is selected randomly within each stratum and statistical estimators are calculated. Stratification increases the efficiency of survey by increasing the precision of the result for the same sample size. Conversely, it allows the number of sample measurements to be reduced for the same overall precision. As sampling is usually one of the main costs of a survey this considerably improves the economic efficiency.

Context for integration of natural resource and socio-economic data

In the current work we have the geographical universe which is the study area - peri-urban Kumasi for which a GIS called KUMINFO has been created to hold and enable analysis of data with geographical co-ordinates. There is an increasing desire to explore the integration of socio-economic data sets in the GIS and thus to develop a participatory element to the GIS.

In this work, we link the list frame to the geographical frame and this will allow integrated interpretation of natural resource and socio-economic information. The method enables sampling units for socio-economic surveys to be selected by objective random sampling, instead of in an *ad hoc* manner, to facilitate up-scaling. It also enables the selection of sample locations for collection of additional data through high resolution aerial digital photography (ADP).

Definition of the Geographical Universe -Co-ordinate systems and implications for field work with the GPS

The geographical universe is defined by a series of mathematical equations that enable the positions of features on the curved surface of the earth to be transformed onto the flat surface of a map. The utility of this approach is that it enables us to quantify many things directly from the map (e.g. distances between villages and Kumasi markets, areas covered by plantations or fields). Thus maps are indispensable for natural resource surveying.

The advent of the Global Positioning System (GPS) has opened up the possibility for collecting additional data for specialised surveys which have geographical co-ordinates and can thus be used within the GIS. However, there are two main complications that must be overcome.

The first is that the co-ordinate systems used by the GPS and available maps are usually different. This is because mapping requires that we approximate the irregularly curved shape of the earth (the geoid) with a regular shape of known dimensions (the spheroid). Unfortunately, no single spheroid provides the best approximation to use in a given location. The GPS uses a spheroid that best approximates the earth as a whole (WGS 84). Locally produced maps used spheroids which are of different shapes and different positions relative to WGS 84 (War Office with Accra and Clarke 1880 with Leigon Datums in Ghana).

The positions of objects on the spheroid are defined in terms of the Latitude (angle from the equator) and Longitude (angle from the Greenwich Meridian). The use of two spheroids offset from each other means that the same point will have different co-ordinates in each system. Latitude and Longitude co-ordinates are transformed to map co-ordinates using mapping equations that define the map projection. This is done automatically within the GIS. However, the result of collecting data with two systems (spheroids) means that they will be offset from each other typically by as much as 250 m depending on circumstances. This frequently causes problems for analysis in the GIS and nearly always it causes problems for data collection with GPS.

In the GIS it is possible to calculate the difference between one system and another and to re-project all the layers to the same co-ordinate system so long as the mathematical definitions of the different systems are known and the relationship between them is known. Several methods can be used to undertake datum transformations although the most frequently applied is the Abridged Molodensky formula.

Unfortunately, the GPS receivers normally used only have limited capability to be programmed for local co-ordinate systems. So, for field work, it is desirable to use a world wide system known as Universal Transverse Mercator (UTM) with the WGS 84 datum. Unfortunately this brings difficulty with the use of available maps for navigation and fieldwork because of the offset caused by the different datums (the spheroid dimension and its position with respect to the geoid) and the different origins of the map co-ordinates.

It is usually very difficult to obtain sufficient description of local mapping systems in developing countries as the information is often classified as a military secret. This makes the application of GIS and GPS difficult. In this work and in later reports we demonstrate transportable methodology to solve the problem with sufficient accuracy for natural resource applications.

The second problem of working with the GPS is the deliberate introduction by the US Department of Defence of a random error, which changes with time, to prevent military use by potential enemies. This increases the positioning error of the hand held systems from a potential precision of ~10m to around ~100m. The error is introduced by the GPS satellites and is therefore the same for all receivers in the locality at the same time. Thus if a second receiver is positioned in a known stationary location. The system allows the calculation of the error. Co-ordinates can thus be corrected by post survey processing using this so-called Differential GPS (DGPS) set-up. This does not increase ability to locate features accurately in the field unless the error is communicated to the field receiver in real time. In the developed world such systems are available but are very expensive and can be unreliable. We demonstrate in future reports, extension of the application of satellite mapping in conjunction with the use of low cost non differential GPS systems which enables this problem to also be overcome.

The Geographical Universe for the Kumasi Peri-Urban Interface

Topographic Maps

The study area is covered by a series of 1:50 000 topographic maps. The maps represent the first edition published by Survey of Ghana and are based on aerial photography collected in April 1972 and February 1973. The Ghana national mapping system is based upon the Transverse Mercator projection, with a co-ordinate system in Imperial units (feet). The parameters of the mapping system are presented in Table 1. The 1972/3 map sheets use the Accra datum. In 1977 a new datum, the Ghana mapping system was made metric and a new spheroid (Clarke 1880) and datum (Leigon) was adopted.

Satellite Imagery

A single SPOT-3 HRV-2 panchromatic scene (56-336/7) was available for the work. The image was acquired on 17 December 1994 at 10:51 am and covers most of the Kumasi peri-urban interface. The principal benefits of the use of satellite systems for the collection of natural resources data by remote sensing is the large area coverage provided by individual scenes, the low cost relative to conventional methods and the currency of the data afforded by the repeated satellite coverage. In an operational survey additional imagery would be acquired to ensure the whole of the desired area is covered. For the purposes of this research and demonstration of methodology, we adopted the part of peri urban Kumasi covered by this image as our study area.

Table 2 provides information on the area coverage, spectral and spatial resolution and data storage requirements for the SPOT and Landsat satellite systems. For such systems the scene area coverage and spatial resolution characteristics are fixed. In general, for studies that encompass the peri-urban interface the collection, storage and interpretation of satellite data does not present undue technical difficulties or resource requirements.

Satellite mapping of villages in the peri-urban environment of Kumasi

The raw satellite imagery has to be converted into image-maps for practical application. This involves visual enhancement to improve the representation of features to the eye, and geometric correction of the image to bring it to a known scale and map projection. This thus creates an important data set for direct use within the GIS and the potential for low cost production of image-maps for field data collection.

The panchromatic image supplied for use in this work contained significant areas of very dark features, including water and forest, in addition to the generally bright features of the built environment. Consequently the contrast of the image was enhanced using a bi-linear function. Prior to the geometric correction of the image, a series of tests were performed using different filters on the raw SPOT scene. The aim was to enhance the degree of visual separation of the villages in the peri-urban region around Kumasi. A 5 x 5 edge enhancement filter was selected and applied prior to the geometric correction.

The procedure for geometric correction of the satellite image is to correlate a series of control points with known geographical co-ordinates with the same points identified on the image in order to determine mathematical transform equations. This is frequently done using maps to define the control points.

A preferred map scale for geometric correction of a SPOT PAN image is 1:10 000, allowing a positional accuracy equivalent to the pixel size of the image (10m). However, the only source of control in this instance was the 1:50 000 topographic maps. The geometric correction of the image used ground control points and a first order linear transform. The output pixel size was selected to be 20 feet, with cubic convolution re-sampling. The map co-ordinates of the ground control points were digitised from the map sheets. Nine separate map sheets were required to cover the area of the SPOT scene. Each map sheet required an individual calibration of the corner map grid co-ordinates with the digitising grid. In general the calibration error in reproducing the map grid was of the order of 50-60 feet.

A total of 32 GCP points were identified and map and pixel co-ordinates extracted. The overall RMS error for all 32 points was 5.11, equivalent to over 100 feet. With 29 control points the RMS error was reduced to 3.13, equivalent to approximately 60 feet and consistent with the digitising error. The resultant geo-corrected image is shown as Figure 1.

Stratification and Sample Village selection of the Kumasi Peri-Urban Environment

Stratification based on distance to market

Stratification was attempted for the village characterisation survey commissioned in the Kumasi peri-urban area as part of NRSP-PUI Project R6799. A stratified random sampling scheme was devised for village selection. Stratification was undertaken on the basis of access to the city. The underlying assumption is that all villages with the same ease of access will have the similar characteristics. The strata consisted of 5 concentric zones based on distance from the centre of Kumasi and 6 sectors, each of 60° arc. A total of 66 villages were subsequently randomly selected from the strata based on three criteria: (a) on-road (no more than 2km from a main road; (b) off-road (more than 2 km from main roads as shown on 1:50000 map); (c) within 5 km of the city centre main market. Further details of the procedure are available in the relevant R6799 documentation.

However, it is not possible to up-scale these results because the method did not define the population of villages within each of the strata, therefore observations cannot be correctly weighted. It is also not clear if all villages in each stratum had an equal chance of being selected; therefore the sample may not be random.

Stratification based on degree of village growth

We present a stratification that can be up-scaled, based on village growth and size. The underlying hypothesis is that villages of similar size and growth rate will have similar development characteristics. The stratification makes use of the area estimates for each village derived at two dates, from the topographic maps (1972/73) and the processed satellite image (1994) as described in Appendix 1. The population of villages was defined by giving all the villages in the study area a unique number and establishing the geographical co-ordinates. Village names are not unique. Figure 2 shows a summary of the estimates of absolute area in 1972/3 and the subsequent degree of growth up to 1994 for all the villages in the study area. These two variables were divided into four classes, based on an approximately equal number of villages in each class. To illustrate the procedure of village selection, a single village from the mid-point of each category was selected for each of 16 categories (Table 3). Figure 3 shows the absolute size in 1972/3 and 1994 for two of the villages in the sample. These villages would form the basis for the targeting of an ADP and socio-economic survey. A random sample of villages can be drawn using the village identification number.

The relative growth characteristics of the 66 VCS villages are shown in Figure 4. Comparison with Figure 2 suggests that the village selection method applied by the lead research team has resulted in a sample of villages which covers the range of growth and size classes, although there are clearly categories of growth that are under represented. The availability of the % growth in area for the population of villages provides a sound basis on which appropriate weighting can be applied to the results of the village characterisation survey. Also there may be interesting links that can be established between village size and growth and the access criteria used in the original survey. This should be explored further, project resources permitting.

Potential Application of Stratification to the Targeting of ADP Surveys

The spatial resolution of satellite systems may be limiting with respect to some natural resources information requirements and consequently airborne digital photography systems (ADP) have been developed. These systems are capable of ultra-high spatial resolution (20 cm to 1m), with typically fewer wavebands (2-4) and with small area coverage for individual scenes, although the scene area coverage and spatial resolution characteristics can be selected within limits by adjustment of the flying height of the aircraft.

To date ADP systems have been used mainly to collect remote sensing data for relatively limited area coverage, for example individual agricultural fields or small towns. For studies related to the peri-urban interface the area of study may exceed 1600 km^2. While it is technically feasible to undertake an ADP survey to provide complete scene coverage of such an area, the data volumes generated are typically larger than can be efficiently managed. Table 2 compares the digital data storage requirements per km^2 of the Landsat and SPOT satellite systems with two ADP systems. Clearly even for moderately sized study areas with spatial resolutions approaching 20 cm the data storage, processing and interpretation requirements of an ADP survey are likely to present technical difficulties.

These factors suggest that in many instances a cost-effective strategy for the implementation of ADP surveys for studies in the peri-urban interface will be through targeting of scene acquisition at a sample of locations rather than by undertaking complete area coverage. A number of methods of targeting could be envisaged, including for example a simple systematic survey design. In many situations it may be preferable to apply some form of stratification over the area, prior to the application of a sampling strategy. Various factors may be suitable for the development of a geographical stratification, including maps of land use/cover, soils, landscape suitability and topography. Alternatively, stratification may be based upon interpretation of available high resolution satellite imagery.

The stratification method based on village growth could be a basis for the targeting of ADP surveys for natural resources linked to villages. It is hypothesised that the exploitation of the natural resource base can be linked to the distribution, area and growth characteristics of the villages. Having randomly selected the sample of villages, these would also be flown using the ADP. Additionally, the availability of a geo-corrected satellite image provides an efficient basis for undertaking geo-referencing of ADP data collected as part of such a survey. Figure 5 provides an example of ADP data geo-referenced to a satellite image base.

Conclusions and Recommendations

Satellite image-mapping provides a low-cost, way of defining large geographical regions with known properties (e.g. UTM) for use in the development of both area and list frame surveys and linking them. The method is highly transportable because of the global coverage of satellites and the ready availability of imagery.

Satellite image-mapping also provides a way of producing navigation documents for visiting sample units when maps are unavailable or out-of-date. The photographic quality of the image-map can be of particular importance in areas with few features. These also provide a framework for using GPS for field work as both can be produced with the same co-ordinate systems, thus overcoming the problem of obscure mapping systems used by many countries and allowing the consistent entry of data collected with the aid of the GPS.

The result of the stratification undertaken for this project provides an objective basis for assessing the results of the Village Characterisation Survey. It is recommended that additional work be undertaken to investigate the relation of the VCS results to absolute village size and the degree of growth. In addition, the potential for up-scaling the results of the VCS should also be determined.

It is also recommended that further investigation is made of the use of geo-corrected satellite imagery as a basis for designing ADP surveys within a geographical framework and for the geo-referencing of ADP data for the production of large-scale false colour map documents.

Table 1. Parameters of the Ghana National Mapping System

Projection	Spheroid	Semi-Major Axis (a) m	Flattening (1/f)	Origin of grid	False Northing	False Easting	Scale factor
Pre-1977 Datum: Accra							
TM	War Office 1924	6378300	296.0	N 04° 40′ W 01° 00′	0.0 feet	900000 feet	0.99975
Post-1977: Datum Leigon							
TM	Clarke 1880	6378249.145	293.465	N 04° 40′ W 01° 00′	0.0 feet	900000 feet	0.99975

Table 2. Comparison of Sensor Specifications for Satellite and ADP Systems

Sensor	Scene coverage (km)	Spatial resolution (m)	Scene pixel dimensions (pixels)	Pixels/band (10^6)	Bands	Total pixels (10^6)	Storage (mb/km^2)
Landsat							
MSS	185 x 185	~80	3548 x 2953	10.58	4	42	0.001
TM	185 x 185	30 & 120^3	6967 x 5965	41.56	7	291	0.009
SPOT							
Multi-spectral	60 x 60	20	3000 x 3000	9.0	3	27	0.008
Panchromatic	60 x 60	10	6000 x 6000	36.0	1	36	0.01
ADP							
Kodak DCS420	0.35 x 0.23 - 1.5 x 1.0	0.23 - 1	1524 x 1012	1.54	2	3	37 - 2
Kodak DCS460	0.70 x 0.47 - 3 x 2	0.23 - 1	3060 x 2036	6.23	3	18	54 - 3

Table 3 Example stratification and sample village selection for the peri-urban environment of Kumasi, Ghana

	Growth Criteria			
Village Size	Negligible (~0%)	Moderate (100%)	Medium (200%)	Large (400%)
Very Small	SISKURO	KANAGIO	KAPRO	SWEDRU
Small	FREBOYE No 1	ASEMPANEYE	ABONU	AHWIAA
Medium	DOTOM	YABI	KWASI-PANIN	YAASE
Large	SAWIA	TRABUOM	DWAASI	FUMISUA
Very Large	ADWUMAKAS EKESE	OYOKO	KOFORIDUA	NKAWIEKUMA

Figure 1 SPOT Panchromatic image of Kumasi, Ghana

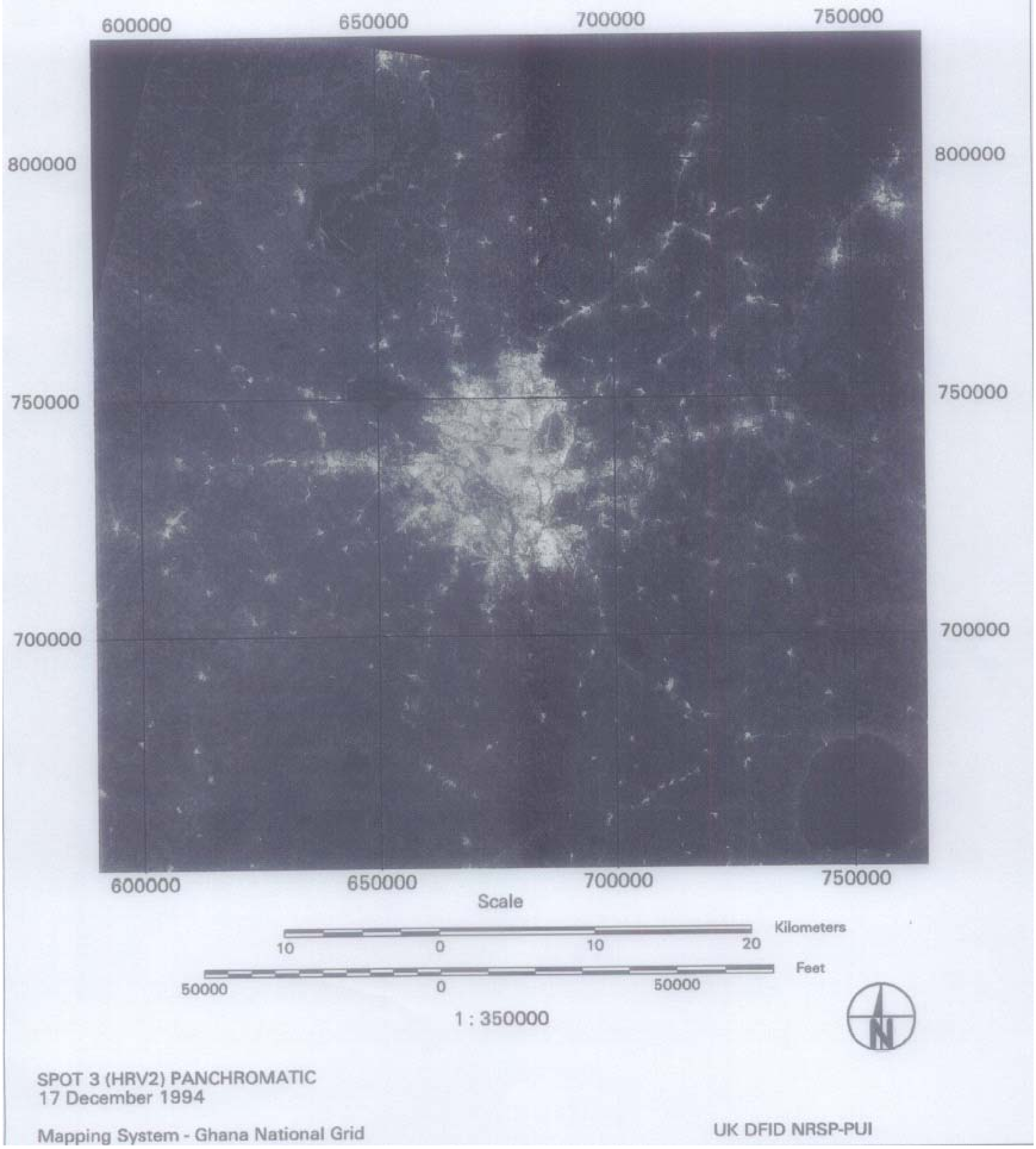
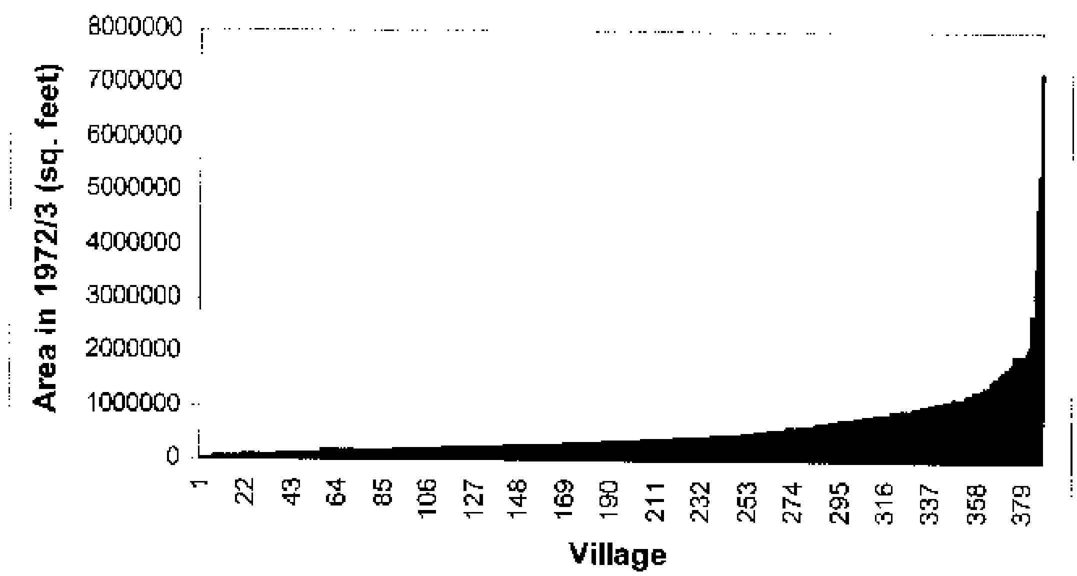


Figure 2 Absolute area (top) and relative growth (bottom) for the 387 villages



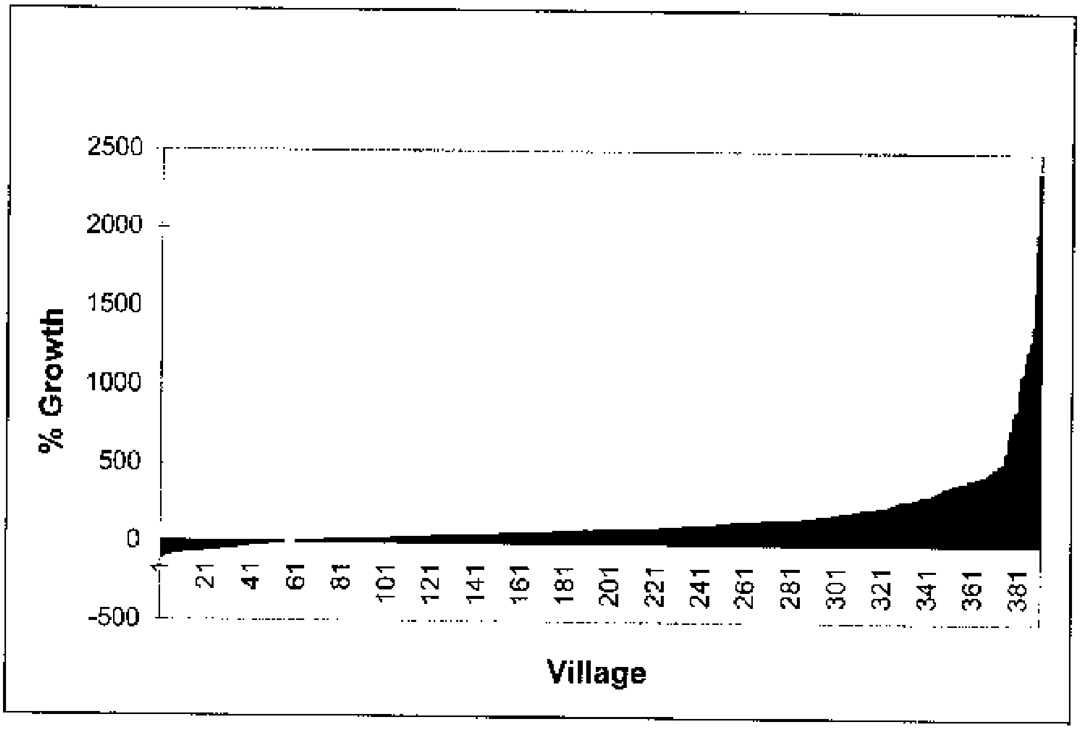
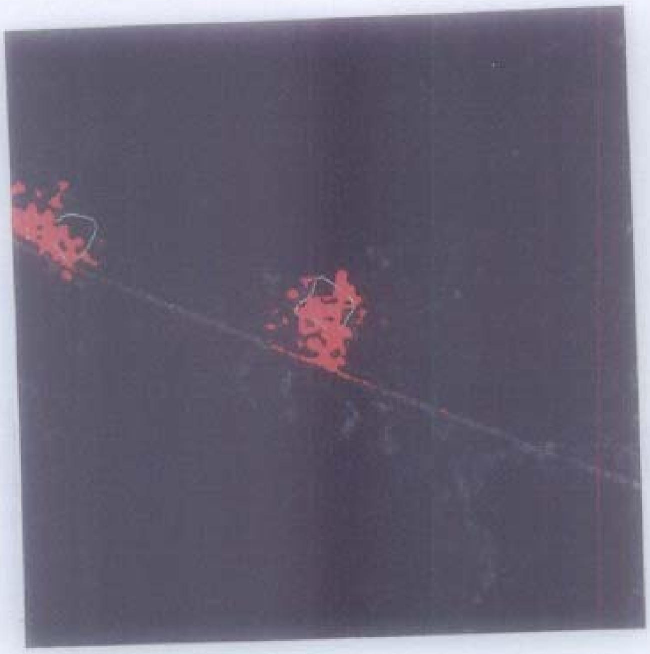


Figure 3 The map interpreted area (white polygon) and the classified SPOT Panchromatic image for two sample villages



Asempaneye
Size category - small   Growth category - moderate

Nkawiekuma
Size category - very large   Growth category - large

Figure 4 Relative village growth for the VCS villages

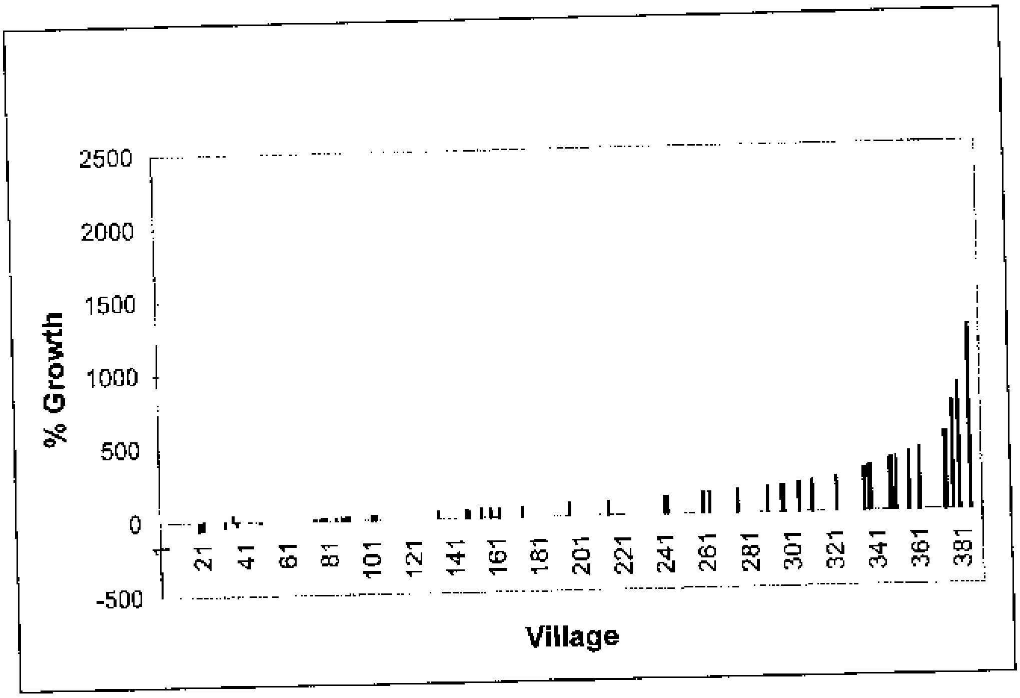


Figure 5 Example of geographical referencing of ADP data using geo-corrected satellite image

ADP at 1.5 feet resolution

SPOT Pan at

20 feet resolution

Appendix 1
A Methodology for the Estimation of Village Growth Statistics

Overview

The methodology applied to the estimation of village growth statistics is presented in Figure A1 and involved deriving estimates of the area of all the villages in the peri-urban environment of Kumasi for 1972/3 and 1994. The data source for 1972/3 were a series of 1:50,000 topographic maps from which the areas of the villages were manually digitised. The data source available for 1994 was a single SPOT panchromatic scene that required digital classification to identify the built environment as detailed in the following section. From these estimates of absolute area, the degree of village growth over the period was derived.

Processing of SPOT Panchromatic Image

The SPOT image was visually enhanced and geometrically corrected prior to digital classification as described in the main text. An initial 8 classes were extracted from the image using the IDODATA algorithm in ERDAS Imagine™ 8.2. The signatures of these classes were used in a Maximum Likelihood classification of the SPOT Pan image. The resultant classes were displayed sequentially and compared with the SPOT Pan image for a selection of villages located systematically across the complete image. Figure A2 shows the results for two villages only, Swedru located approximately 15 km to the north of Kumasi and Manso Nkwanata located approximately 40 km to the south west of Kumasi. Of the 8 classes generated, classes 6, 7 and 8 provided an approximate discrimination of the built environment, although a visual inspection of the SPOT image indicated that the amalgamation of these 3 classes generally over estimated the area of built environment. This was especially apparent in the south west quadrant of the image, as revealed by the results for Manso Nkwanta (Figure A3). Visual inspection of the image confirmed the presence of haze in this part of the image. Reducing the number of classes from 3 to 2 resulted in an under representation of the size of many of the villages in the northern section of the image.

Prior to any further processing all blocks of contiguous pixels smaller than 605 pixels were eliminated from the 3 class aggregated image. This represented an area approximately equivalent to the smallest discrete urban feature identified on the 1:50000 topographic maps. The resultant built environment class was used as a mask with the SPOT image to generate a new image. This image had all the non-built areas set a digital number value of 0, but leaving the original SPOT Pan digital numbers for areas defined as built environment within the mask image. A 2nd ISODATA clustering was performed on this image. Once again 8 classes were chosen and used in a supervised Maximum Likelihood classification. The results of this classification were compared with the SPOT image and a selection of two classes was determined by visual inspection to most adequately represent the built environment across the image. Finally, a 5x5 low pass filter was applied to the image. The resultant classification is shown in Figure A4 for the two example villages. Comparison between Figure A4 and Figure A3 shows that the influence of haze on the classification has been reduced considerably. The final result for the Kumasi area is shown in Figure A5.

Estimation and evaluation of the village areas for 1972/3 and 1994

A total of 387 villages were identified in the peri-urban environment of Kumasi by classification of the SPOT image. Villages such as Abuakwa which were on the fringes of Kumasi City in 1972/3 (Figure A6) but which have subsequently been overtaken by the growth of Kumasi were excluded from the analysis due to the difficulty of objectively defining the village bounds appropriate to the 1994 imagery. The areas of the villages for 1994 were determined by a count of pixels from the digital map. The areas of the 387 villages appropriate to 1972/3 were obtained by manual digitisation of the urban class from the 1:50 000 map sheets. A number of the villages were represented in the topographic maps by dots. An approximate area equivalent for a single dot was determined by equating the village with the largest number of dots with the smallest area explicitly displayed on the maps.

Clearly the bases and precision of the two methods of area estimation are different and requires some investigation. Figure A7 top shows the 1:50 000 topographic map interpreted area (red polygon) together with a scanned aerial photograph for the village of Nyameani. The aerial photography dates from the mid-1960s and has a scale of 1:45 000. As is normal cartographic practice, the boundary of the village area has been generalised for representation at the 1:50 000 scale. The bottom of Figure A7 shows the digital classification of the village area. It is apparent that the village of Nyameani has experienced relatively minor growth between the dates of imagery. It is evident from Figure A7, that for a village of the same dimensions the digital classification method is likely to underestimate village area compared to a method based on visual interpretation of aerial photography and subsequent cartographic generalisation. The reason for this is that the digital classification discriminates principally the buildings, areas of bare ground, tracks and roads as village, but not areas that are vegetated, such as gardens and fallow areas which in the peri-urban environment of Kumasi typically occur within the village confines. A visual interpretation of the village boundary is unlikely to separate out such areas from within a generalised interpretation of the boundary of the village and will therefore typically result in a larger area. It is also evident from Figure A7 that the extension of the built environment class away from the village boundary along the road network will add to the village area compared to the interpretation of the aerial photography.

A preliminary evaluation of the accuracy of the built environment class was undertaken by analysis of a sample of 34 villages that encompassed the typical range of village sizes. The area of each village was visually interpreted and digitised from the geo-corrected SPOT image. These estimates were compared against the pixel count from the built environment map. The results of the comparison are shown in Figure A8 and confirm the already noted general tendency for the digital count method to underestimate the village area.

Estimation and evaluation of the village growth for 1972/3 and 1994

The estimates of village area for 1972/3 and 1994 were used to derive the degree of village growth over the period. An analysis of the data revealed 56 villages had negative growth. The associated villages were all relatively small in terms of absolute area in 1972/3. Further investigation revealed that such villages had in fact remained static in terms of area during the period, and the indication of village area contraction was due to the difference in precision of the two methods as indicated previously.

Although there is a general tendency for the digital count method to underestimate the village area compared to visual interpretation, there are some indications of overestimation of village area. Within the peri-urban area of Kumasi sand winning is an important activity. Such areas are sufficiently bright to be classified by the digital method as built environment. In many villages it would appear that the areas affected are sufficiently small to remain undetermined within the precision levels of the general methodology. However, at least for the village of Kurofoforom the area of sand winning appears sufficiently large to lead to an erroneous indication of village growth. This indicates the importance of undertaking a visual assessment of any selected villages prior to inclusion in any form of survey.

Figure A1 Methodology for estimation of village area and growth characteristics

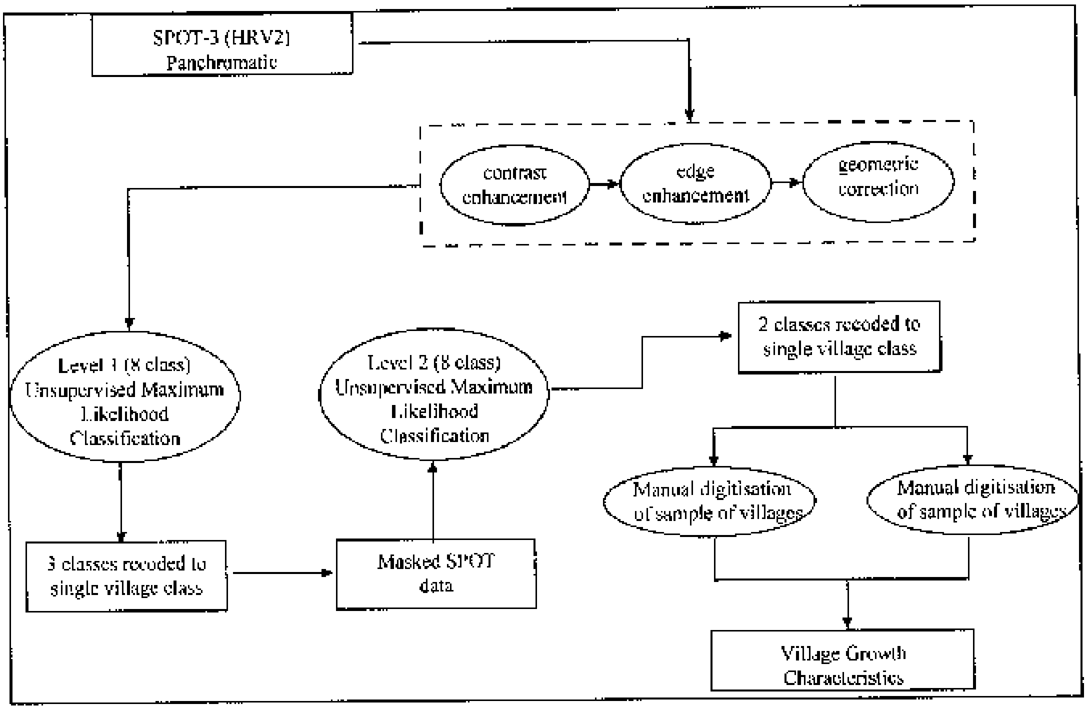
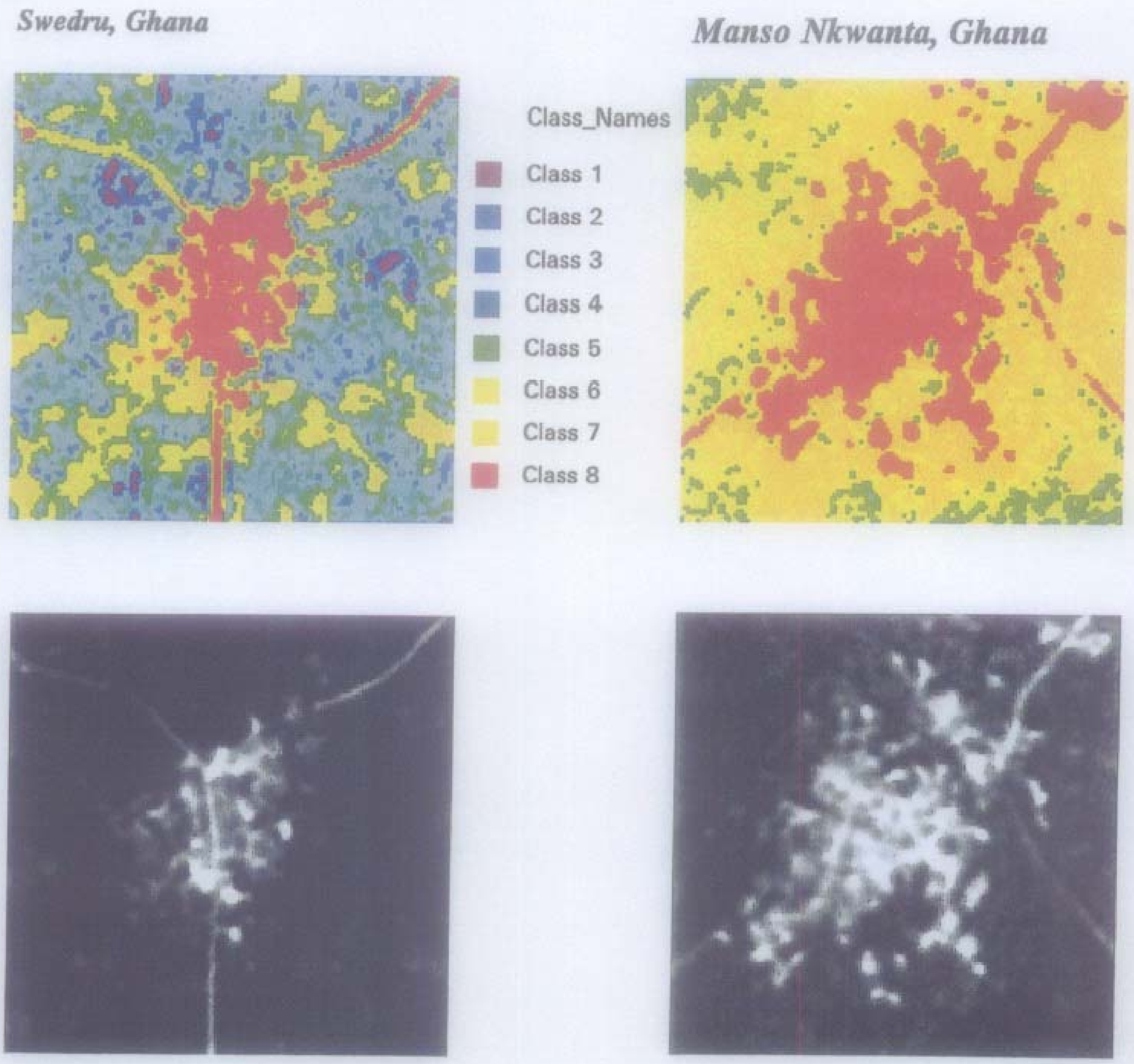


Figure A2 1st Level Classification (top) of SPOT Panchromatic Image (bottom) for two villages

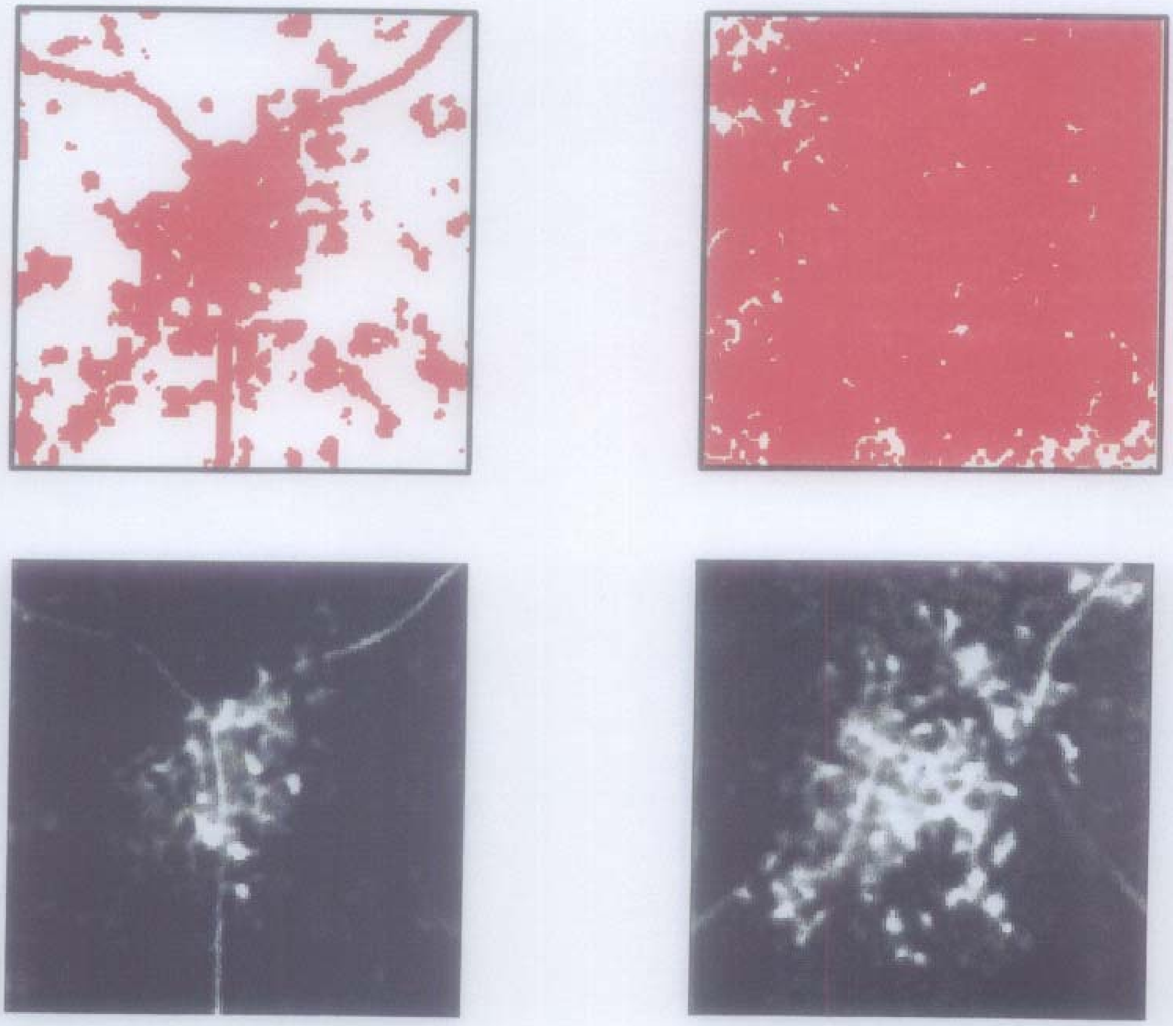


SPOT-3 HRV-2
December, 1994

UK DFID NRSP-PUI

Figure A3 1st level built environment class (top) and SPOT Panchromatic image (bottom) for two villages

Swedru, Ghana *Manso Nkwanta, Ghana*

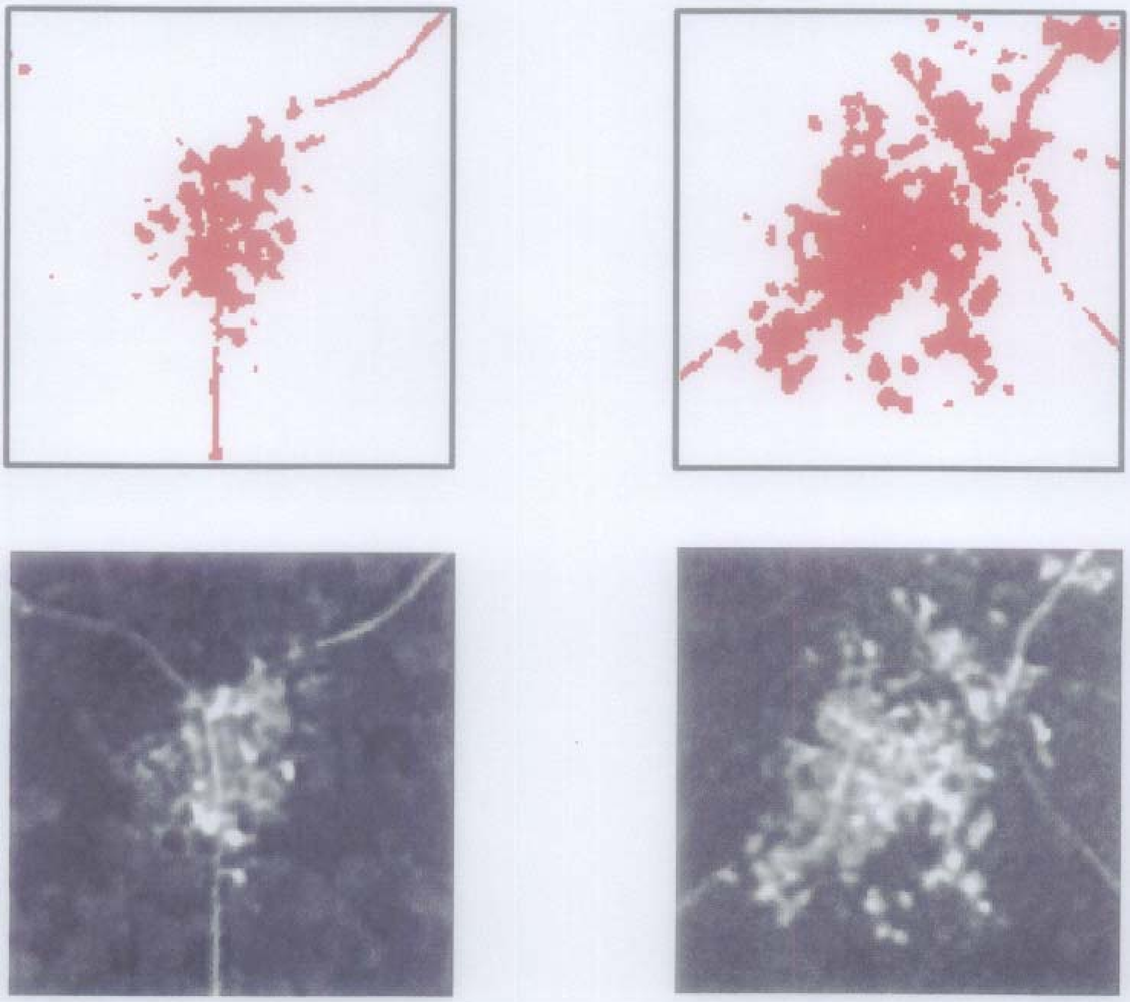


SPOT-3 HRV-2
December, 1994

UK DFID NRSP-PUI

Figure A4 Final classification of built environment class (top) and SPOT Panchromatic image (bottom) for two villages

Swedru, Ghana *Manso Nkwanta, Ghana*



SPOT-3 HRV-2
December, 1994

Figure A5 Built environment class derived from SPOT Panchromatic image

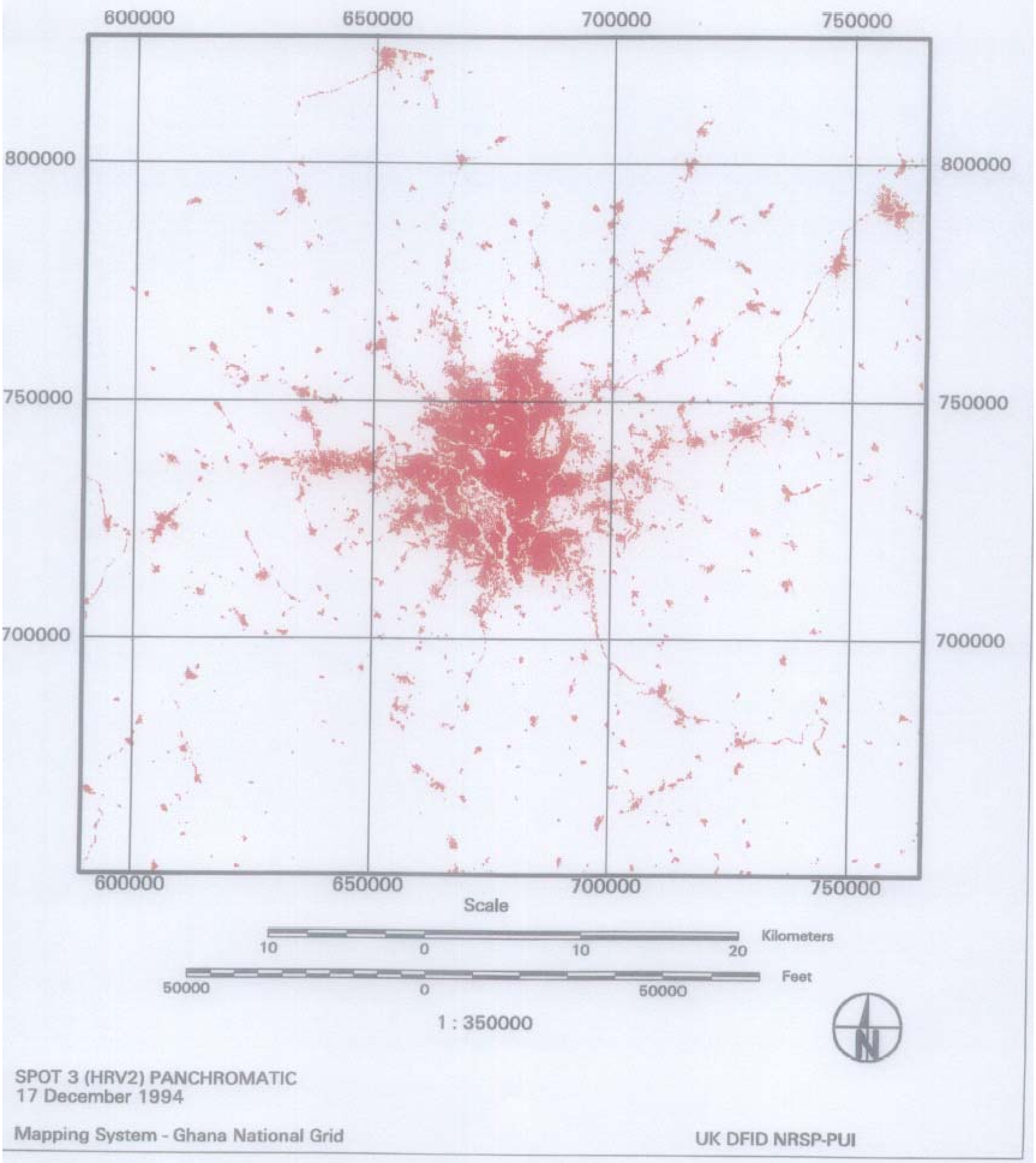
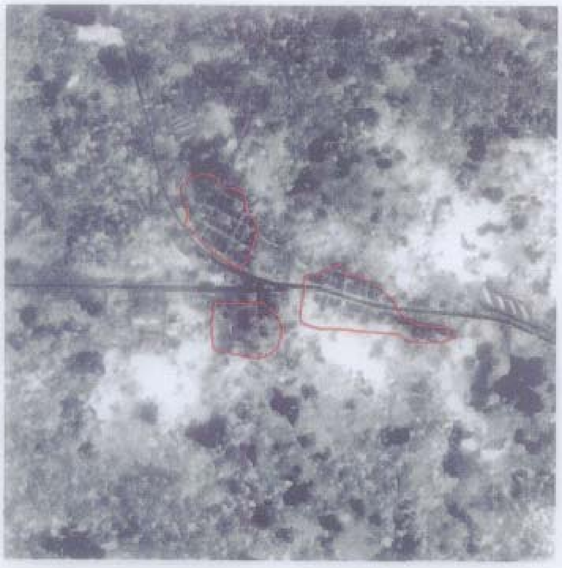
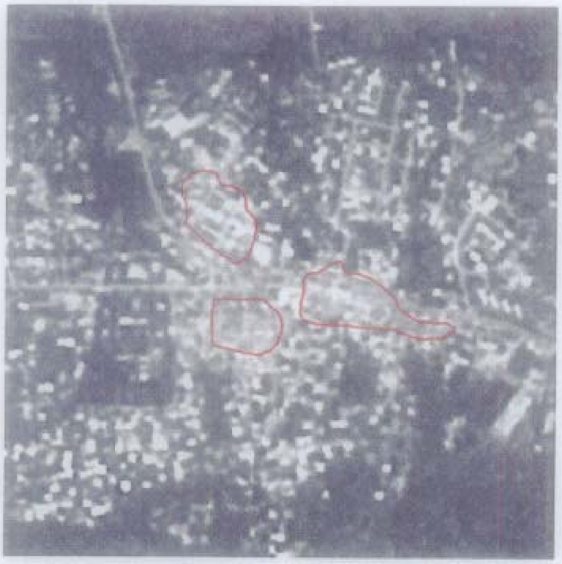


Figure A6 The map interpreted area of Abuakwa (red polygon) together with a 1960s aerial photograph (top) and SPOT Panchromatic image (bottom)

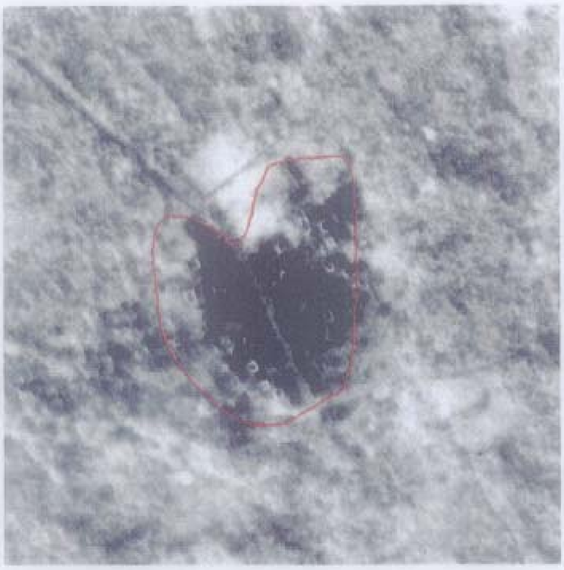


1:45 000 Panchromatic Air Photos - 1960s

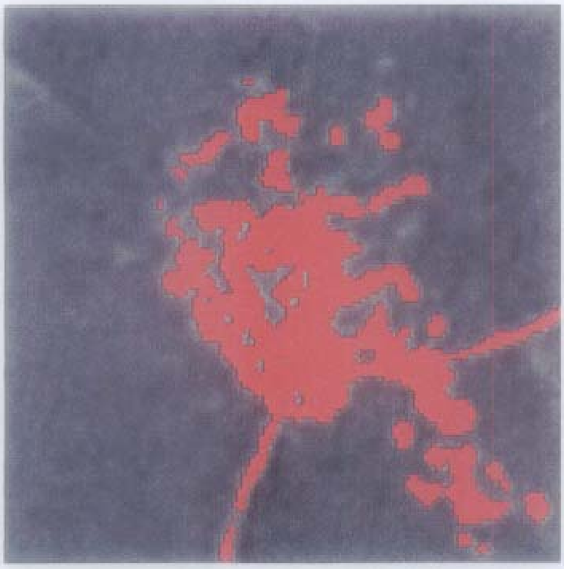


SPOT-3 (HRV-2) Panchromatic Image - December 1994

Figure A7 The map interpreted area ofNyameani (red polygon) together with a 1960s aerial photograph (top) and the classified SPOT Panchromatic image for 1994 (bottom)



1:45 000 Panchromatic Air Photos - 1960s



SPOT-3 (HRV-2) Panchromatic Image - December 1994

Figure A8 Comparison of screen digitised area and digital count area for 34 villages