A COMPARISON OF A VISUAL INTERPRETATION AND A TWO STAGE APPROACH FOR CLASSIFYING URBAN DEVELOPMENT USING SPOT.

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ABSTRACT

The growth of Dar es Salaam, Tanzania's largest city, occurs predominantly through unplanned development. Given population growth rates that are estimated to be currently above 5% and the lack of resources to provide affordable housing to the burgeoning population, informal development will continue to be the major source of shelter. Information on the growth process is sorely needed to guide policy development and direct strategic interventions.
Generally, visual interpretation is found to be the most effective means to extract information on urban development from SPOT images. Automated classification using standard classification algorithms for generating information on urban land use is problematic. Pixel classifiers do not consider the composite landcover characteristics of many land uses and the pixel size is not well suited to the level of generalisation actually required. For this research, a method was developed and tested for urban land use classification based upon land cover probabilities in various land use classes. It incorporates a degree of spatial aggregation equivalent to that applied in an existing data set of 1992 land use and in a visual interpretation with the same image data. Comparison between the land use sample set and the classified image show an overall similarity of 90%, though considerable variation exists in certain classes. Both the visual interpretation and the two stage classification procedure provide evidence of significant expansion of the urban area.

1 URBANISATION AND THE DATA CRISIS IN DAR ES SALAAM

Tanzania's largest city, Dar es Salaam, is estimated to have a population of around 3.0 million persons, with 70% estimated to be living in unplanned or self regulated settlements (Sawio, 1998). Several of these settlements date back as far as the 1950s but it has been the post-independence period that has seen substantial expansion of urban development and self-regulated residential areas. Monitoring of such settlements with the aid of aerial photographs reveals that consolidation process resulting in increasing housing densities continue to this day in even the oldest settlements.

The lack of information and understanding of the nature of these complex processes of settlement formation and consolidation is a barrier to effective policy formulation, though certainly not the only problem to be confronted. The urban management capacity has been severely depleted by a plethora of problems, not the least of which was the period of economic stagnation and decline that characterised the 1980's. In the 1990's, however, several projects have commenced that are designed to address the many problems being faced by the national and local agencies responsible for the planning and management of the city (Sliuzas, 1993). Components to improve the information base for planning and management have led, amongst other things, to the production of a digital topographic database of the year 1992, at scale 1:2500 covering a large part of the urban area. However, since then urban expansion and consolidation has proceeded and no definite decision has yet been taken to update the maps.

Several local studies and planning agencies have produced generalised maps of the urban area via extensive fieldwork. However, such work is difficult to verify and is not easily repeated. SPOT imagery may in this sense provide a useful ancillary source of data that could be used in between regular aerial surveys. Such images would enhance and expedite the fieldwork required for the interpretation and delineation process. The use of ERS data for urban monitoring, and the extraction of terrain information from stereo SPOT and ERS, which was undertaken as part of the same project, is described elsewhere in these proceedings (Dekker, 2000, Sliuzas and Brussel, 2000).

1.1 Use of SPOT for urban monitoring

Various characteristics of urban environments can be extracted from remote sensing. Typical categories of data extractable from systems with a variety of temporal, spectral and spatial resolutions are well described by (Cowen and Jensen, 1998). They acknowledge a preference for higher resolutions of less than 1 metre for many urban applications, but also state that systems with spatial resolutions of 5-20 metres can be used for land cover/land use investigations. While their work refers primarily to studies of western cities, many studies have also been made of non-western urban areas in various regions (see for example: (Pollé, 1988) for a general description of opportunities; (Pollé and Van den Boogaard, 1996) for a study of Bandung, Indonesia; (Yeh *et al.*, 1996) for a study of the Pearl River Delta, China; (van Deursen *et al.*, 1999) for a study of Ougadougou, Burkina Faso).

Some caution is necessary in the transfer of apparently successful techniques from one context to another. Ground feature characteristics such as size, materials/cover, settlement structure, and density etc. are likely to influence the ability to both interpret and classify terrain features and attributes. A study of visual interpretations of 3 urban land use classes from imagery of Denver, Colorado, with a 1.5 metre spatial resolution, found classification accuracy to be dependent upon contextual information. An interpretation window of 60m x 60m produced near optimal accuracy for the classes residential and transportation while slightly poorer results where obtained for commercial land use (Hodgson, 1998) (pg. 804). Similar results may not be achievable in a city with a high proportion of mixed land uses and extensive informal development. Further, it is also clear that the use of imagery with higher spatial resolutions will have a direct influence on classification accuracy. The limited budgets of urban development agencies in many developing countries will however be a major barrier to the widespread, regular use of very high-resolution imagery.

1.2 Research objectives

This paper describes two aspects of a recent research project using and comparing various remote sensing products (Sliuzas *et al.*, 1999). The component described here aimed at producing updated information on the extent of Dar es Salaams urban area in a manner compatible with existing data of 1992 landuse derived from aerial photography. It was intended to use the results to improve some of the locally produced maps of urban growth which had been created through fieldwork. The general feeling of the team was that the extent of actual development was being considerably exaggerated in some areas.

Although it was expected that visual interpretation would provide the best results, some recent work carried out by (Gorte, 1998) using a two stage classification approach suggested that some opportunities may exist for applying semi-automated classification tools within an urban environment. His approach was tested in a rural part of The Netherlands and was primarily focussed on classifying agricultural fields. The Dar es Salaam environment is very different and may provide insights into the wider applicability of the method. Also, the availability of existing data sets of the study area raise the possibility for incorporating existing knowledge into the process, thereby improving reliability and consistency with earlier data. Cities for which no prior knowledge exists on the status of development do not exist. It is therefore important that products derived from remote sensing are compatible with existing data. Utilisation of existing data and knowledge can improve the quality of data derived from remote sensing and thereby enable more effective use to be made of this data source.

1.3 Description of the base data of 1992

The original 1992 land use data was derived by visual interpretation of panchromatic stereo aerial photographs, scale 1:12500, of the core part of the city covering approximately 340 square kilometres (Hakuyu, 1995). A subsequent researcher expanded this to a total area of 950 square kilometres, by including fringe areas with the aid of panchromatic, mono aerial photographs at scale 1:25,000, enlarged from the original 1:54,000 photographs (Atikah, 1999). The classification included 9 main land use classes and land uses with a minimum size of approximately 1 Ha. were delineated. This data provided the reference frame for comparison purposes with the maps derived from SPOT.

2 VISUAL INTERPRETATION METHOD

For visual interpretation a 10 metre resolution fused PAN-XS image of 28 May, 1998 was created. The interpretation of urban land use relies on a combination of image clues and local knowledge. The interpreter worked without prior knowledge of the area but had access to all previous data and some recent small format aerial photography that included parts of the urban fringe. Evidence for classification may be obtained via clues related spectral reflectance and to the structure and texture of the image (Hodgson, 1998). The latter are determined by the various types of buildings, other structures and infrastructure (roads etc.), their size, construction materials and their proximity to one another. After working in a training area, an interpretation was made of that part of the image coinciding with the 1992 data.

A distinction has been made between one urban and three non-urban classes (water, forest and agriculture/other). A procedure was developed and tested for on-screen digitising with 1992 land use boundaries displayed over the image. Although this has not allowed for an independent classification it does improve the consistency between the 2 data sets which would otherwise likely suffer because of variation between interpreters. Difficulties in maintaining classification consistency in longitudinal studies can often be substantial, making temporal analysis unreliable, if not impossible (Sliuzas, 1988). The combined use of SPOT and SFAP was found to be very useful; the SPOT images provide a geometrically controlled overview of the study area while the SFAP provides useful details in some difficult to interpret locations. The very low

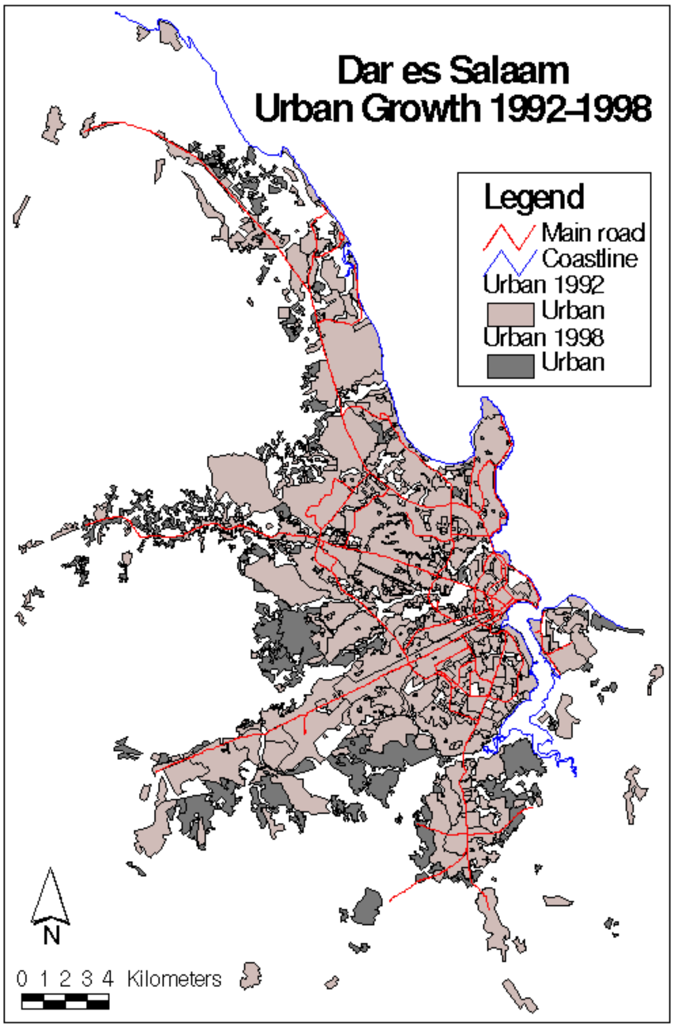

Figure 1: Comparison of 1992 urban area from aerial survey with visual interpretation of the 1998 urban area from fused SPOT imagery (adapted from Atikah, 1999).

building densities in many newly developing areas tend to frustrate interpretation and delineation. While high density developments and large industrial complexes are quite easily identified, corrugated iron roofs and the sandy soils found along much of the coastal plain share similar reflectance characteristics. On several occasions misclassifications were corrected with the aid of SFAP.

2.1 Visual interpretation: urban growth 1992 - 1998

The observed growth follows the same general pattern that was visible in the period 1982-1992 (Figure 1). Main characteristics are: 1) extension areas are almost exclusively informal settlements; 2) most growth occurs in the southern part of the city; 3) ribbon-like settlements are developing along the ridges in the hills to the west of the city, much of this development appears to be associated with higher income groups than that found in the south; 4) relatively little expansion occurs to the north of the city and to the east across the harbour. The image clearly shows that some locally produced maps had significantly exaggerated development, particularly in the eastern regions, which are still very much dominated by small rural village communities and agriculture.

The city's growth, from 215 sq. Km. in 1992 to 262 sq. km. in 1998, is almost exclusively occurring without formal approval of the local authority and therefore concerns unplanned or informal development. This being the case, the unplanned residential areas have expanded by approximately 58% from 8100 Ha. in 1992 to 12,900 Ha. in 1998. This amounts to an effective annual growth rate of approximately 8% which is more than double that found in an earlier study of 1982-1992 (Hakuyu, 1995).

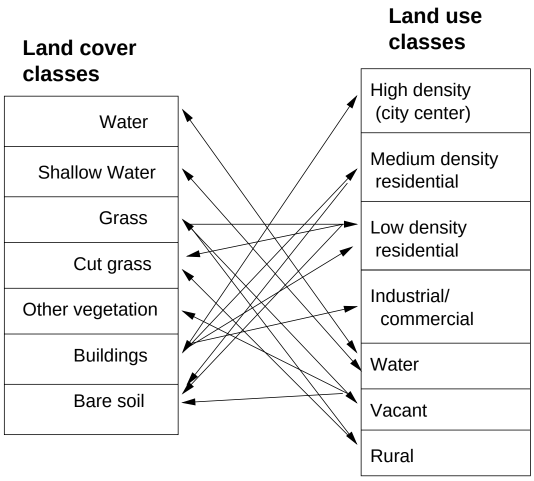

Figure 2: Many-to-many relationship between land cover and land use classes.

3 TWO-STAGE CLASSIFICATION

This section explores the difference between land cover and land use classification of image data, with emphasis on the dependency of land use (as opposed to land cover) on scale and resolution. We introduce a land use classification approach based on land cover densities.

3.1 Land cover and reflection

Reflection measurements, stored in an image, are indicative for land cover in the terrain. Land cover is a local property of the earth surface. Its values are from a nominal domain: the names of materials covering the earth surface. To a certain extent the domain depends on the observation point and on the mapping scale. In case of earth observation using air-borne and space-borne sensors it contains classes like grass, bare soil, maize, water, concrete, roof tiles, woods and heather.

The relation between land cover and reflection is complex. Due to influences caused by soil, moisture, plant variations, building materials, age etc., a single land cover class can have many different reflectances. Moreover, reflection, as measured by the sensor in a satellite, depends not only on earth surface reflectance, but also on illumination (which can vary in within a single image because of terrain relief) and on atmospheric conditions. Finally, the measurements are influenced by sensor noise.

As a result, for each class a wide variety of reflections is measured. Most supervised classification methods handle this situation by associating a statistical distribution of reflections with each class. The distribution parameters are estimated from training data, i.e. examples of pixels that the user provides to the classifier, selected on the basis of available ground truth or image interpretation. Conversely, for certain reflections that occur in the image it is not clear what class should be associated. The distributions of different classes may overlap, which means that a single reflection occurs in pixels of different classes. Then a classifier cannot decide for sure to which class a pixel with such a reflection belongs. It will select the class C_i with the highest probability (say P_i) of being correct — and accept probability $1-\mathrm{P}_i$ that this selection is the wrong one. An additional problem are mixed pixels, containing a mixture of classes. This happens when objects are small or narrow compared to the image resolution, as well as at the boundaries between larger objects.

3.2 Land use

To monitor urban development, land use is more relevant than land cover. Land use describes human activities taking place on the earth surface. Like land cover, land use is a nominal property, with classes such as agricultural, industrial, residential, commercial, forestry and recreation.

Land use and land cover are related, but the relationship is many-to-many. A certain land use may consist of a composite of various covers and, conversely, a single land cover can occur in a diversity of land uses (Fig. 2).

3.3 Scale and resolution

Land cover can be considered point information, describing the material that is present at a certain point on the surface. Land cover is scale-independent in a rather wide range of scales. Land use, on the other hand, is related to application and to scale. At a national scale, for example, regions with predominantly industrial activities can be distinguished from

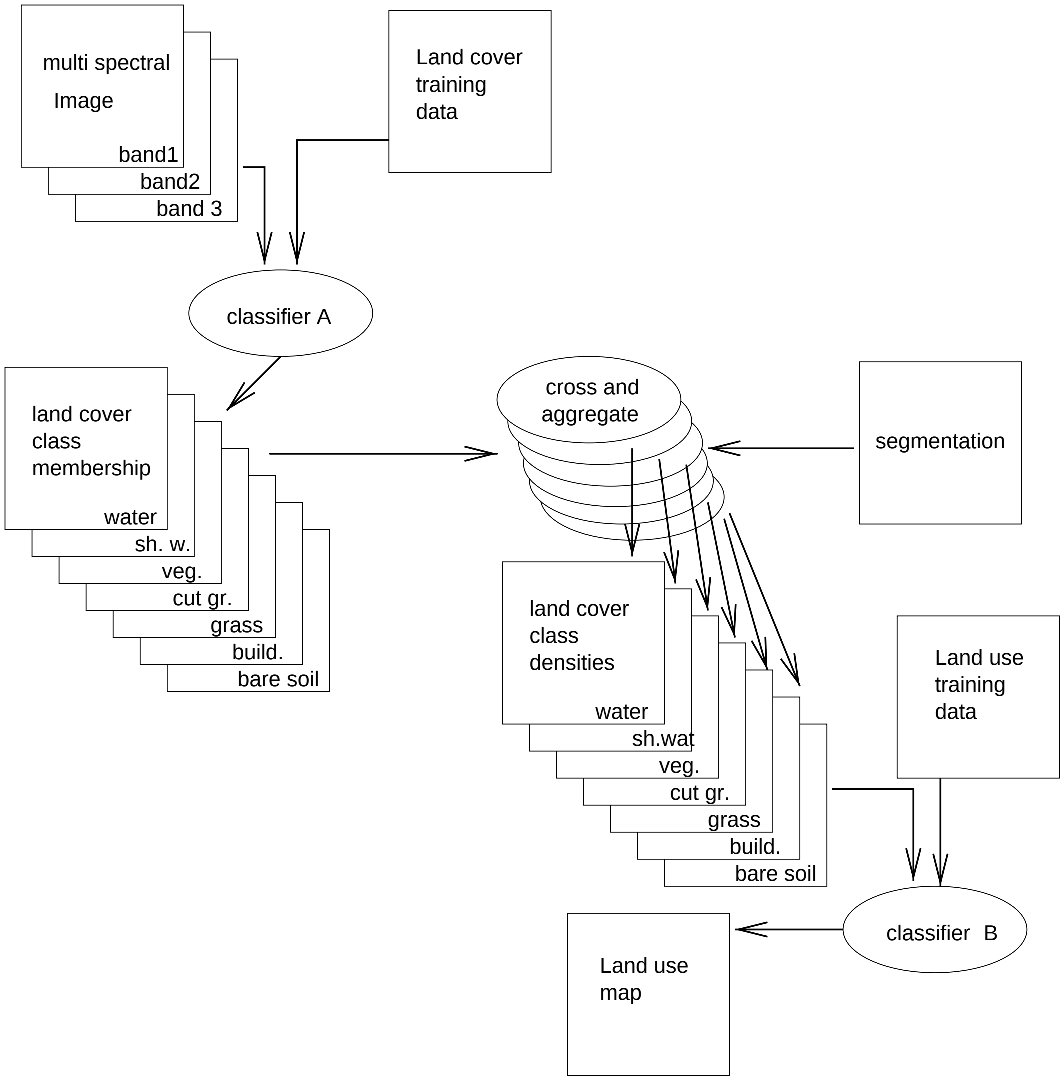

Figure 3: Two-stage classification flow diagram

rural ones. At a regional scale a distinction may exist between urban, agricultural and ‘natural’ areas. At an urban scale, the relevant distinction may be between residential, commercial, industrial and recreational areas (Molenaar, 1998).

Concerning data acquisition, land use can often not be established by looking at single points, but requires to investigate areas. Often, a land use class is characterized by a rather specific mixture of land covers. For example, in suburban residential areas (in a particular cultural setting), a mixture of roads, houses and gardens can be expected with more or less fixed proportions.

Land use classes that are composed of several cover classes often have indeterminate (fuzzy) boundaries. When the land use classes two adjacent areas have a cover class in common, the boundary between the areas may be difficult to localize.

At the resolutions of nowadays satellites, such as Landsat Thematic Mapper (30×30 m) or SPOT XS (20×20 m), some land-use classes are quite heterogeneous, since each pixel’s reflection depends on the (predominant) land cover inside it. The resulting urban spectral signature spreads out over a large part of the feature space and cannot be modeled adequately by a multi-variate Normal distribution, as applied by Maximum Likelihood classifiers. It will have a large spectral overlap with other land use classes that contain the same cover types.

3.4 Method

We present a land use classification method that takes the above considerations into account. It consists of three stages, indicated the by ellipses in Figure 3.

1. Compute land cover class memberships (classifier A).

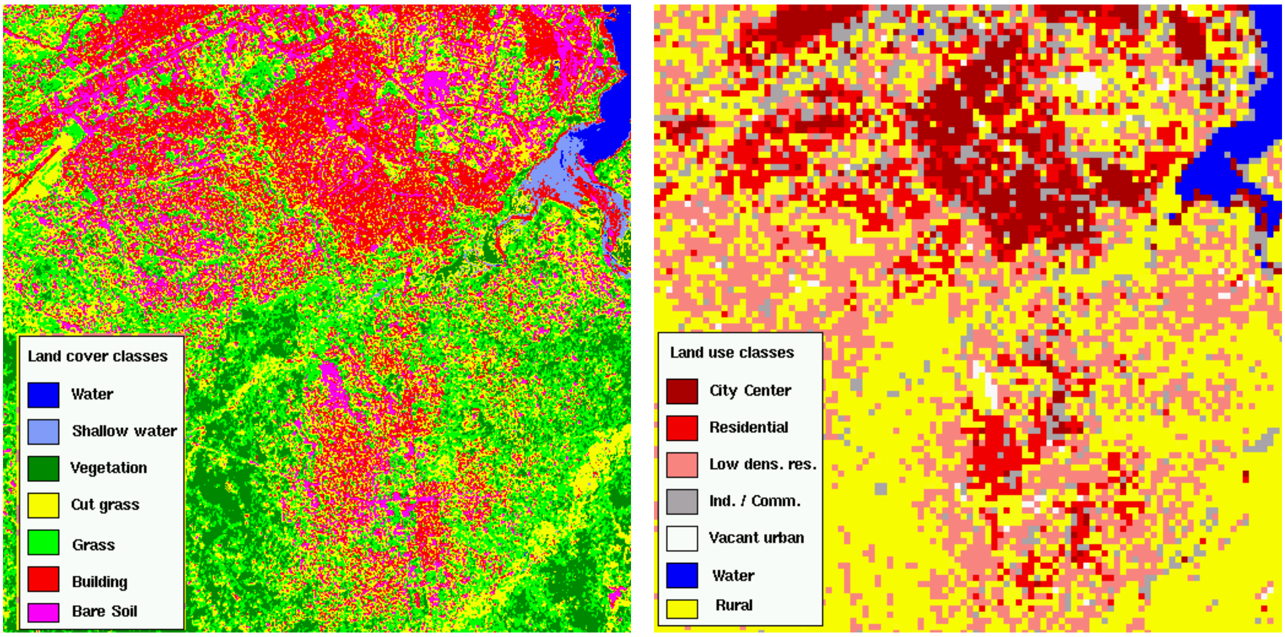

Figure 4: Two-stage classification: land cover(left) and land use, derived from land cover densities in 5×5 cells (right).

2. Aggregate these into land cover class densities in spatial units (Cross and Aggregate).
3. Perform land use classification in the feature space of land cover class densities (Classifier B).

Training samples are collected for seven land cover classes: Water, shallow water, grass, cut grass, other vegetation, building and bare soil. As usual in maximum likelihood classification, multi-variate normal distributions are assumed for the reflections in each class. The resulting land cover classification is shown in the left side of Fig. 4. Land cover densities are obtained by aggregating land cover class probabilities over (small) image regions. In the experiment, 5 $\times$ 5 pixel regions were used, corresponding to 1 Ha. in the terrain. Using the seven density layers thus obtained, a new 7-dimensional feature space is set up, and trained with samples for seven land use classes: High density residential (city center), medium density, low density, industrial/commercial, vacant, rural and water. With this configuration a straightforward maximum likelihood classification is executed (Fig. 4 - right).

4 COMPARISON OF RESULTS

Assuming that the visual interpretation of the urban area gives the best results it is therefore useful to compare it to the results of the two stage method. Table 1 shows that the two-stage classifier performs rather well for the medium-density and high-density urban classes. The results of the classifier also concur with the visual interpretation of the eastern part of the study area. The rural nature of most of this area has also been confirmed through fieldwork in June, 1999.

The classifier's performance for low-density areas is very unreliable, with much confusion apparent with riverbeds in the hills to the west of the city and some sand mining areas. As this class is expected to include the early stages of informal settlements, it is extremely important for monitoring purposes and more work is needed to ascertain the principal factors contributing to misclassification.

Future work will compare sample areas for which building density is known with the classifier in order to assess its reliability for certain density classes. Improvements may well be achieved through the use of additional rules either during or following the classification procedure. Such rules may include aspects such as terrain conditions and relative proximity to infrastructure, which has been shown to have an important influence on the location choices of settlers in informal development (Hakuyu, 1995). Information concerning informal land transactions, which can be obtained through local community leaders, could also provide useful indications of development pressure and impending construction.

Another prominent source of classification differences is the result of large open spaces in many of the institutions such as the Dar es Salaam University and several large military camps. They are a classic example of the difference between land cover and land use. In the 1992 land use map, knowledge of the boundaries of these institutions has been used to classify all land owned by them as Institutional, and later as urban land. Much of their sites is non-built, and may be in use as sport fields, gardens, or be idle. Given the size of such green spaces, the classifier identifies them as agriculture/vegetation.

Table 1: Comparison of areas in visual interpretation classes with classes from the improved maximum likelihood classification. (source: Sliuzas et al., 1999)

Class from 2-stage maximum likelihood	**Visual interpretation class** Urban (Ha.)	Non-Urban (Ha.)	Total (Ha.)	**Agreement (%)**
Low density	12033	12871	24904	48
Medium density	6893	485	7378	93
High density	3780	343	4123	91
Agriculture/Veg.	4396	53922	58318	92
Bare soil	469	93	562	17
Total (Ha.)	**27571**	**67714**	**95285**	

5 CONCLUSIONS

This study has shown that SPOT images can be used for monitoring the growth of fast growing cities such as Dar es Salaam, providing more reliable data than is possible through fieldwork alone. However, it must be appreciated that the use of satellite systems by local organisations is limited by the prevailing weather conditions, which generally allow a very limited time-window for data acquisition, and a lack of resources to allow images to be regularly acquired. In order to refine the classification of urban areas it is advisable that the interpreter has a thorough knowledge of the local situation.

The two stage classifier is able to produce comparable results for the more densely developed urban areas, but performs inadequately for low density areas in particular. Further work is required to address issues related to calibration of density classes and improving the reliability of the classifier with low-density urban development.

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