ACC DAR Adapting to Climate Change in Coastal Dar es Salaam

Assessment of Land Cover Change Using Remote Sensing: Objectives, Methods and Results

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1 Introduction

This paper describes the study undertaken during Activity 2.1 of the ACC DAR project regarding the use of remote sensing techniques for monitoring Land Cover (LC) and it's changes (Land Cover Change – LCC).
The purpose of the study is to understand the relationship between land cover change in the peri-urban areas of Dar es Salaam (Tanzania) and the effects of Climate Change (CC).
Dar has undergone rapid urban expansion in recent decades, particularly along the main thoroughfares. This has led to urban sprawl in peri-urban areas and densification in central areas. Land cover monitoring is therefore fundamental to understanding the consequences of this unplanned urban development and defining actions that lead to negative impacts on the population and the environment.
In the present study, urban sprawl is considered a dynamic territorial phenomenon that creates rapid, low-density (characterized by a mix of uses), and discontinuous (urban areas interspersed with agricultural areas) urban development, particularly in the vicinity of transportation routes (i.e. the main connections between the periphery and the centre).
The purpose of this study is to develop a methodology for monitoring LC that allows for observation of the urban sprawl phenomenon and can be adapted to the needs of the Municipality in Dar. More specifically, the monitoring technique must be:

- economical, in order to guarantee practicability for the Dar Municipality;
- simple, in order to allow for regular updating of land use information;
- quick to execute, in order to reveal the land cover changes in a very dynamic area.

In order to reach such an objective, remote sensing was selected as the main instrument for obtaining data (satellite images), according to which LC and LCC could be classified and compared with the past. Remote sensing is understood as the measurement of electromagnetic energy, reflected by the surface of the land, through sensors that record such information in the form of images. Sprawl has consequences for land use (e.g. soil sealing, low settlement density), and can therefore be monitored through LC remote sensing techniques.
This study used a semi-automatic classification method that identifies materials present in the soil, classifying the base elements of the remote sensing image (i.e. pixels) according to their spectral signatures. This technique can be used to produce LC maps in a manner that is economical (satellite images are provided free by certain space agencies), simple (image processing is mostly automatic) and rapid (few inputs are necessary, i.e. the definition of the "training areas" that constitute the LC classes to be identified). It is important to note that these maps can only be used to determine LC, and not land use. For example, the map does not allow one to determine whether an area classified as "built-up" is residential or industrial; further spatial analyses and cross-referencing with other levels of information would be necessary to determine land use.
The accuracy of a semi-automatic classification can be calculated by comparing it with the reality on the ground through the use of error matrices. The level of accuracy is influenced by the reliability of input data (i.e. the correct definition of the "training area"), and by seasonal factors, such as phenological variations of vegetation.
The main constraint for this type of classification is the resolution (spatial, spectral and radiometric) of the remote sensing images, since they determine the level of spatial detail and the variety of materials that can be identified. At the moment, high-resolution images are relatively costly, and thus do not meet the affordability requirement of the project. For this reason, multispectral Landsat images (provided for free by the United States Geological Survey) and SPOT images (provided for free by the European Space Agency), were used in this study, with spatial resolutions of 30m and 10m respectively. At this level of spatial resolution, pixels are defined as "mixed", meaning that a variety of materials are located within the area defined by a pixel. The greatest difficulty when classifying these images is therefore identifying elements with dimensions that are smaller than those of the pixel, which is the case as regards the scattered buildings that characterize areas of sprawl.
This study has demonstrated that the developed methodology, which uses medium spatial resolution multispectral images, is adequate for monitoring land cover changes in the peri-urban areas of Dar es Salaam. LC maps for the years 2002, 2004, 2007, 2009 and 2011 were produced using Landsat images. An LC map for 2011 was also developed using SPOT images (the images from previous

years were not classified because they were obscured by a high level of cloud cover). The accuracy assessment confirmed the reliability of the maps produced.
LC classifications allowed for the identification of two urbanized classes: a “continuously built-up” area, and a “discontinuously built-up” area. The LC maps demonstrate the rapid increase of built-up surfaces from 2002 to 2011, and the expansion of “discontinuously built-up” surfaces along main thoroughfares. In 2011, the impervious surface was estimated to be between 8% and 16% of the total surface of Dar es Salaam.

2 The Phenomenon of Urban Sprawl

Urban sprawl takes on different forms in the various cities of the world in which it occurs, but it is generally caused when population growth and the physical expansion of a city are misaligned (UN-Habitat, 2010).
In the case of Dar es Salaam, population growth in the last 30 years has been considerable: from 1.36 million inhabitants in 1988, to about 2.5 million in 2002 (Kironde, 2006), to 3.4 million in 2010 (from DESA, World Urbanization Prospects: The 2011 Revision, http://esa.un.org/unpd/wup). Such demographic growth has combined with rapid urban expansion, the majority of which has been unplanned.
The phenomenon of sprawl in Dar has developed in many areas of the city, independently of whether areas were planned or not, and this has been mostly due to the inadequacy of the current land tenure regime, which slows down the purchase and sale of land (Kironde, 2006). Such areas are characterized by a lack of infrastructure and services.
The dynamism of sprawl can be understood as an expansion, through time, of low-density areas, and a densification of the more central areas. Areas that were rural at time t0 become low-density built-up areas at t1, and at t2 the same areas densify while in other areas, which were rural at t1, sprawl begins (see Figure 13, p.17).
The sprawl phenomenon has been observed and studied in many of the world’s cities, even though characteristics and development modalities differ between continents. Consequently, there are multiple definitions of sprawl that depend on the perspective of the researcher (Bhatta et al., 2010).
In the United States, this model of discontinuous expansion in the periphery has been criticized since the post WWII era for its inefficiency, lack of aesthetics, waste of space, and the attendant land speculation (Clawson, 1962). In the American context, many definitions of sprawl exist that refer alternatively or simultaneously to the following elements: models of land use, processes of urban expansion, particular behaviour with respect to land use, and the consequences of that behaviour (Galster, et al., 2001).
In Europe, sprawl is defined as unplanned urban development in peri-urban areas that generates certain market conditions, and is characterized by general low-density discontinuity of the urban fabric interspersed with agricultural areas, and the simultaneous presence of different land uses (EEA, 2006).
The main problems related to sprawl in the Western world include social and spatial segregation, low habitation density, and a lack of services, particularly public transportation (Couch & Karecha, 2006). Moreover, urban sprawl increases consumption of land, which is a limited and non-renewable resource (except perhaps in a very long-term sense), thus compromising agricultural use.
In developing countries, sprawl is a form of urbanization caused mainly by land speculation and phenomena of internal and external migration, which in turn are influenced by a variety of socio-economic motives. In particular, internal migration pushes people to move outside the city, towards periphery zones that are more affordable and are characterized by lower habitation density, which causes an expansion of urbanized surfaces and the fragmentation of physical and social spaces. In addition to people’s desire to live in periphery areas, these movements are caused by a lack of planning, a lack of enforceable legal frameworks and land control, and inadequate services (UN-HABITAT, 2010).
This phenomenon has also been observed in Dar es Salaam, and the urban-rural characteristics of the areas in which sprawl occurs offer the poorest of the population the possibility of compensating for such structural deficiencies through the cultivation of available land. Nevertheless, the improper management of resources and of refuse generates negative externalities in terms of human health and the environment, particularly as regards the land-water system (Simon, 2008).

3 Classification of Land Cover Through Remote Sensing

Land Cover is defined as the description of the physical material at the surface of the Earth. Examples of Land Cover (LC) include grass, asphalt, soil and water. In addition to LC, Land Use is defined as the manner in which people use the territory. Examples of Land Use (LU) include residential, agricultural, and sporting (Fisher, et al, 2005).

LC and LU describe different aspects of the reality at the surface of the Earth, and their identification necessitates a variety of data. Production of an LC map requires information regarding exclusively the materials present at the surface. Remote sensing can therefore be used to measure reflected electromagnetic radiation (defined as radiance), with which the relationship between reflected energy and incident energy (i.e. the reflectance, a physical property that is characteristic of every material) can be deduced, allowing for identification of the LC type.

On the other hand, production of an LU map requires information regarding the use that people make of a certain territory, which can only be partially obtained through the use of remote sensing and interpretation of images of the territory. In this case, the main limit of remote sensing consists in the difficulty of recognizing the use of a certain surface (for example, it is not always possible to determine through photo interpretation whether a green area is a public park or a private garden, or whether a building is for residential or commercial use). As such, LU mapping requires integration of remote sensing data with other information, such as regulatory plans, cadastral data, and field surveys to classify unplanned areas (not identified in official documents).

In the specific case of Dar es Salaam, the rapidity of urbanization processes underway, and the dearth of data on land use (which is partly due to the considerable informal growth of the city) render the development of an LU map relatively problematic. Given that the objective of the present study is to develop a methodology for describing the evolution of urbanization in Dar es Salaam that is adapted to the needs and resources of local Administrations, the decision was made to classify only LC, since it requires exclusively remote sensing data, which has economic and temporal advantages (further data is not required) as compared with the classification of LU.

There are a variety of methods for developing LC maps, including manual (like photo interpretation), automatic, and semi-automatic. In this study a semi-automatic method of classification was used, based on the subdivision of pixels from remote sensing images according to the spectral properties of the materials on the ground (the so-called spectral signature, i.e. the reflectance values at various wave lengths) (Richards & Jia, 2006). Unlike automatic models, this type of classification requires establishment of the image classification algorithm (in this case, the Maximum Likelihood algorithm), acquired through a "training area" (a sample area of pixels representing the LC classes noted above) and is a much faster method than photo interpretation.

Semi-automatic classification methods can be applied to many types of remote sensing images acquired through sensors that are usually installed on satellites (satellite remote sensing) or on board airplanes (aerial remote sensing).

On the basis of the sensor use, remote sensing images are characterized by:

- Spatial (or geometric) resolution, which defines the dimensions of the pixels ("picture element"), thus characterizing the level of detail in an image (Figure 1);
- Spectral resolution, which defines the number and the width of the spectral bands recorded in an image – these are necessary in order to reconstruct the spectral signature of various materials, and therefore they allow for the identification of such materials;
- Radiometric resolution, which defines the number of grey tones that characterize each pixel, and is attributable to the sensitivity of the sensor recording variations in energy.

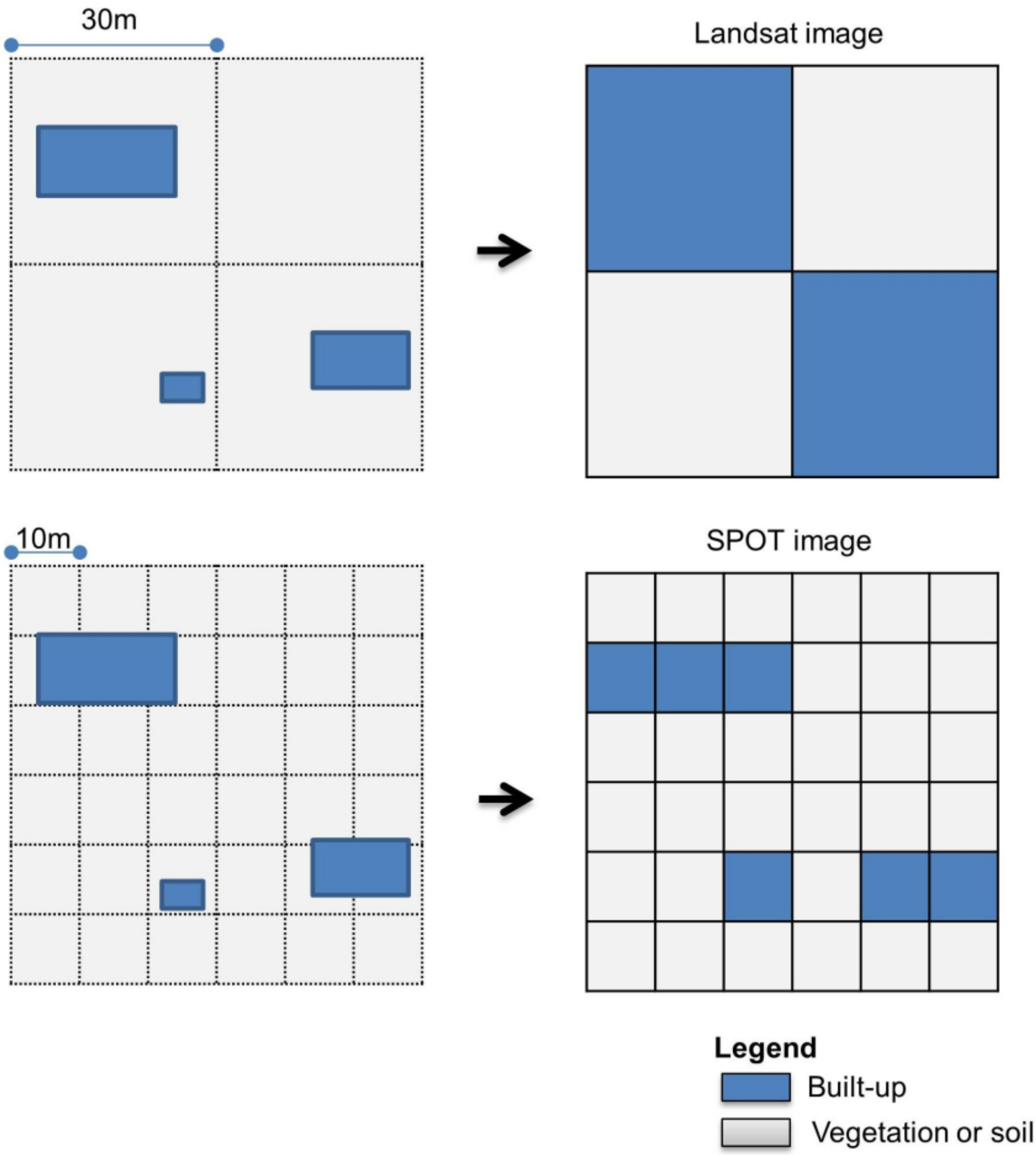

Figure 1: Example of different spatial resolution for the same area

Images can be subdivided as high resolution (less than 4m) or medium resolution (from 4m to 30m), and as multispectral (with a maximum of 12 spectral bands) or hyperspectral (with dozens or hundreds of spectral bands).

Even though hyperspectral remote sensing images and those taken from planes have become more economical thanks to technological developments in the field of remote sensing, satellite images are even more affordable (if the same surface is acquired), especially considering that certain space agencies provide their images free of charge for research purposes. Moreover, the superficial extension of satellite images is usually wider than those obtained from airplanes, rendering the former more appropriate for studying the entire region of Dar es Salaam (the aerial images require more acquisition tracks and therefore more flights).

In the present study, multispectral Landsat satellite images (provided free by the United States Geological Survey) and SPOT satellite images (provided free by the European Space Agency) were used.

The two types of images have different spatial and spectral characteristics. In particular, Landsat images have lower spatial resolution than SPOT images, but have better spectral resolution (see Tables 1 and 2).

Table 1: Characteristics of Landsat 7 Images (NASA, 2011)

Bands		Spectral range [µm]	Pixel size [m]
Band 1	Blue-Green	0.45-0.52	30
Band 2	Green	0.52-0.60	30
Band 3	Red	0.63-0.69	30
Band 4	Near IR	0.77-0.90	30
Band 5	Mid-IR	1.55-1.75	30
Band 6	Thermal IR	10.40-12.50	60
Band 7	Mid-IR	2.09-2.35	30

Table 2: Characteristics of SPOT 5 images (HRG sensor) (from http://earth.esa.int/pub/ESA_DOC/SPOT/Annex-5-1-2SPOTtechnicaldata.pdf)

Bands	Spectral range [µm]	Pixel size [m]
B1 : Green	10	0.50 – 0.59
B2 : Red	10	0.61 – 0.68
B3 : Near-Infrared (NIR)	10	0.78 – 0.89
B4 : Short-Wave Infrared (SWIR)	20	1.58 – 1.75

The developed classification methodology consisted of the following phases:

- image selection, with as little cloud cover as possible;
- preprocessing, in which the images are prepared for the actual classification through georeferencing; conversion of pixels from DN to reflectance; masking of clouds, and mosaicking of images;
- processing, the phase of data elaboration through semi-automatic classification processes.

Considering the objective of Activity 2.1, the developed methodology has concentrated on recognizing and classifying urbanized classes. For example, mosaicking of images acquired during different seasons was introduced in the preprocessing phase in order to fill in the image gaps created during the cloud masking phase. Although, on the one hand, this led to an increase in the surfaces that could be recognized as urbanized, on the other, it also increased the spectral variability of the image, particularly with respect to vegetation (the phenological state of vegetated areas, which changes over the course of the year, can differ notably within a mosaicked image, according to the acquisition dates of constituent images). An example of variability in the phenological state of vegetation is illustrated in Figure 2.


Figure 2: Example of seasonal variation of vegetated surfaces; left: a Google Earth image obtained on 11/06/2010, right: a Google Earth image obtained on 05/02/2011

To avoid classification errors in urbanized classes, it is useful to consider several other classes that are present at the surface (such as vegetation and bare soil) that therefore complete the LC. In particular, several vegetation indexes (i.e. NDVI) were calculated and used in the classification phase in order to improve the identification of vegetation.
The following LC classes were therefore defined:

- "Continuously Built-up", a densely developed class (see example in Figure 8), whose pixels are characterized by homogeneity of urban cover
- "Discontinuously Built-up", an urbanized class with low-density development (see example in Figure 9), whose mixed pixels are characterized by a variety of land cover types, including urbanized, vegetation and bare soil
- "Full Vegetation", a class of very green and abundant vegetation (mainly trees and forests), whose pixels have a high NDVI value
- "Mostly Vegetation", a class of vegetation that is less green than "Full Vegetation" (typically grass and brush), whose pixels have a medium NDVI value
- "Soil", a class that represents bare soil, or sparse vegetation (including dry grass)
- "Water"

The classifications produced conserve the spatial resolution of the original images (i.e. 30m for Landsat classifications and 10m for SPOT classifications).
An important constraint in this type of classification is the pixel resolution, since it determines the level of detail with which materials on the ground can be identified. The second constraint, linked to the first, is the dimension of smaller objects that the classification seeks to capture. In particular, urban sprawl is characterized by low-density development, and therefore the objects to be identified in this classification are single buildings with distance between them. Such buildings are often smaller than the dimensions of the pixel (for example, a Landsat pixel is 900 m^2), which will therefore be mixed in such areas (i.e. composed by a mix of impervious materials, vegetation and soil).
Figure 3 displays the dimensions of a Landsat pixel (30x30m), superimposed on Quickbird images in areas classified as "Discontinuously Built-up" and "Continuously Built-up". In the "Discontinuously Built-up" area, a pixel includes single buildings as well as the surrounding soil and vegetation.

Figure 3: Superimposition of the dimensions of a Landsat pixel (30x30m) on a Quickbird image for the classes "Discontinuously Built-up" (left) and "Continuously Built-up" (right)

Semi-automatic classification allows for identification of LC classes on the basis of spectral response variations of the pixel and the composition of materials on the surface. The value of the pixel is based on the average of electromagnetic energy reflected by the materials on the surface and received by a sensor. As such, an object with a small surface but high reflectance situated among materials with low reflectance can considerably influence the value of the pixel. In Landsat images, this type of situation arises with roads. In fact, despite the fact that a Landsat pixel (30x30m) is much wider than roads (usually between 4m and 10m), roads have higher reflectance (due to the asphalt) than surrounding materials (especially where there is vegetation) and are therefore easy to identify in the image, even if it is only 2 or 3 pixels wide (see example in Figure 4). This type of phenomenon occurs frequently in the peri-urban context, where the roofs of buildings are brighter than the surrounding vegetated surfaces.

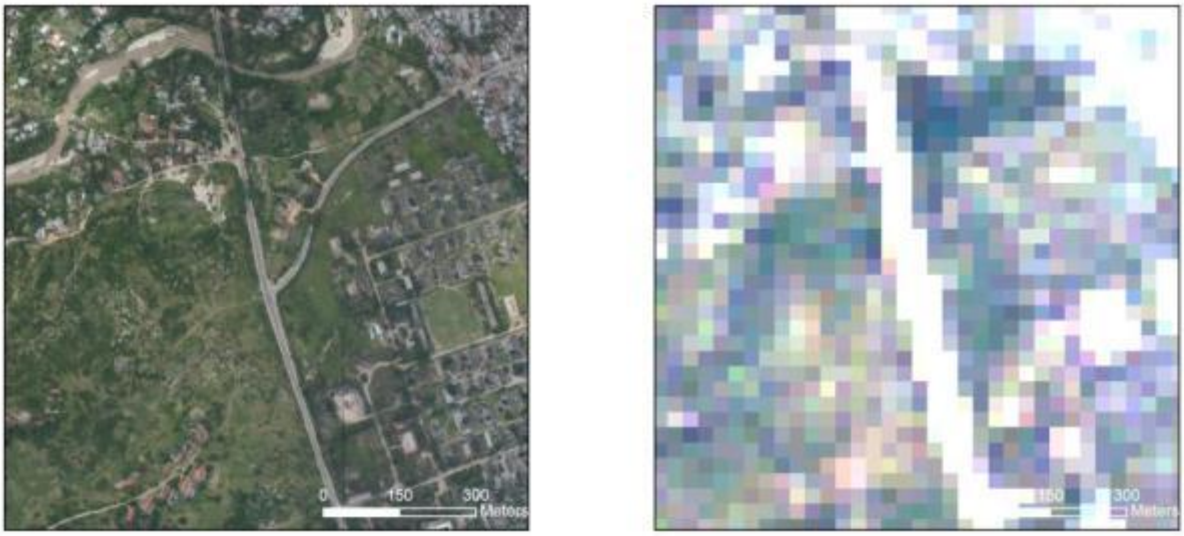

Figure 4: Comparison of a street captured by the Quickbird (left) and Landsat (right) satellites, in which the greater width of the road due to higher reflectance of the asphalt is evident

3.1 Verifying the Accuracy of Classification

After producing the LC classifications they must be validated through verification of their accuracy (i.e. the level of concurrence between the map and the reality on the ground. Validation was conducted

using an approach similar to the one developed for accuracy analysis of the Corine Land Cover 2000 (APAT, 2005) by ISPRA (ex-APAT, now the Italian National Institute for Environmental Protection and Research). In particular, analysis was based on photo interpretation of high-resolution images in randomly selected sample units.
Through a comparison of photo interpretation and classifications, error matrices were developed that allowed for calculation of the overall accuracy of the classification, as well as the producer's accuracy and the user's accuracy for various classes. Field study also proved useful in verifying the correctness of photo interpretation in sample areas.
In the mosaicked images, certain land covers, including vegetation and bare soil, are considerably influenced by seasonal variations, and it is therefore probable that the accuracy of these classes is relatively low. Vegetated areas in an image acquired in a humid season may have become bare soil if verification is conducted during the dry season, and vice versa. Nevertheless, for this study such classes are not the main objects of classification, and it is therefore acceptable that their accuracy be lower.

4 Results of LC Classification

This section summarizes the results of the methodology applied to Landsat and SPOT images, which allowed for the production of LC maps.

4.1 Landsat Classifications

For Landsat images, the classification algorithms were established on the basis of the following training areas:

- the "Continuously Built-up" class contained at least 60-70% developed surfaces;
- the "Discontinuously Built-up" class contained at least 20-30% and no more than 50-60% developed surfaces (in general, isolated buildings with dimensions no greater than 220 m^2 were not identified).

Such values are indicative because, as described above, the value of each pixel is the result of the reflectance of the materials on the ground. Therefore, the surface area of a particular type of cover is not the only determinant of the resulting reflectance value of the pixel.
The elaboration of Landsat satellite images allowed for rapid and low-cost production of LC maps of Dar es Salaam for various years (2002, 2004, 2007, 2009, 2011). The classification for 2011 is reported in Figure 5.

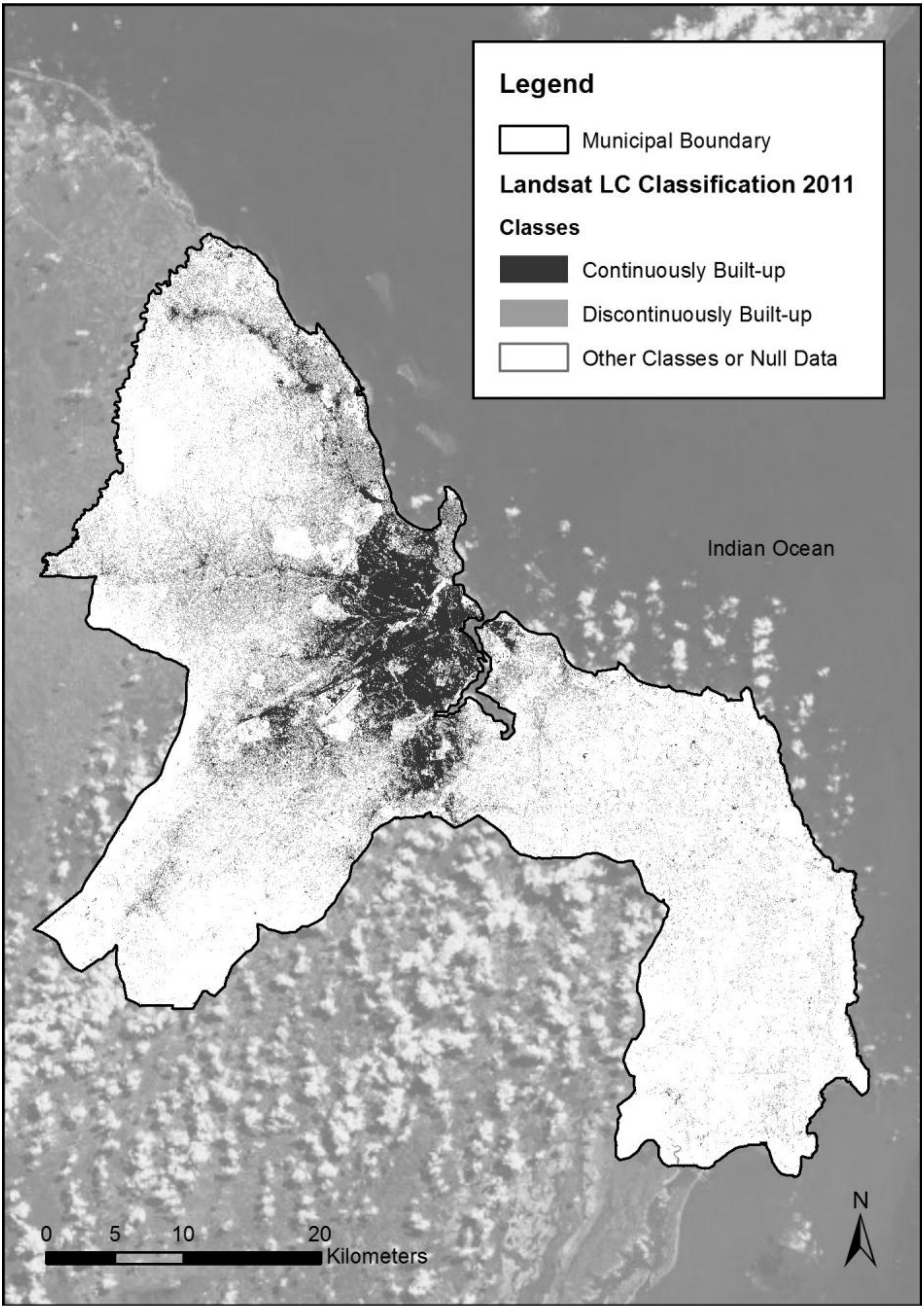

Figure 5: LC classification obtained from Landsat images for 2011

The bar graph in Figure 6 demonstrates the evolution of LC from 2002 to 2011 in the “Continuously Built-up” and “Discontinuously Built-up” classes, based on Landsat classifications. The rapid growth of developed surfaces is notable, particularly from 2007 on.

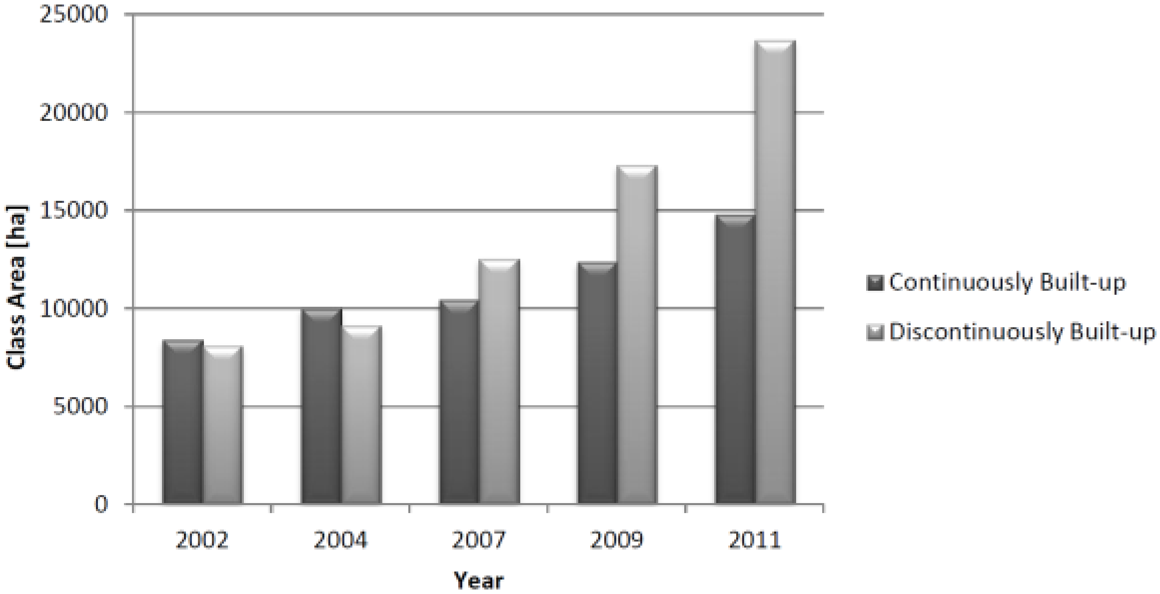

Figure 6: Evolution of LC in the “Continuously Built-up” and “Discontinuously Built-up” classes

The line graph in Figure 7 represents the evolution of “Continuously Built-up” and “Discontinuously Built-up” classes as compared with the demographic growth of Dar. Demographic data was obtained from the 2002 census and subsequent projections (United_Republic_of_Tanzania, 2006).
The built-up classes have grown considerably more than the population. In particular, the “Discontinuously Built-up” class reflects a non-linear relationship with the population, which confirms the definition of urban sprawl provided by UN.HABITAT (2010) (i.e. that population growth and the physical expansion of the city are misaligned).

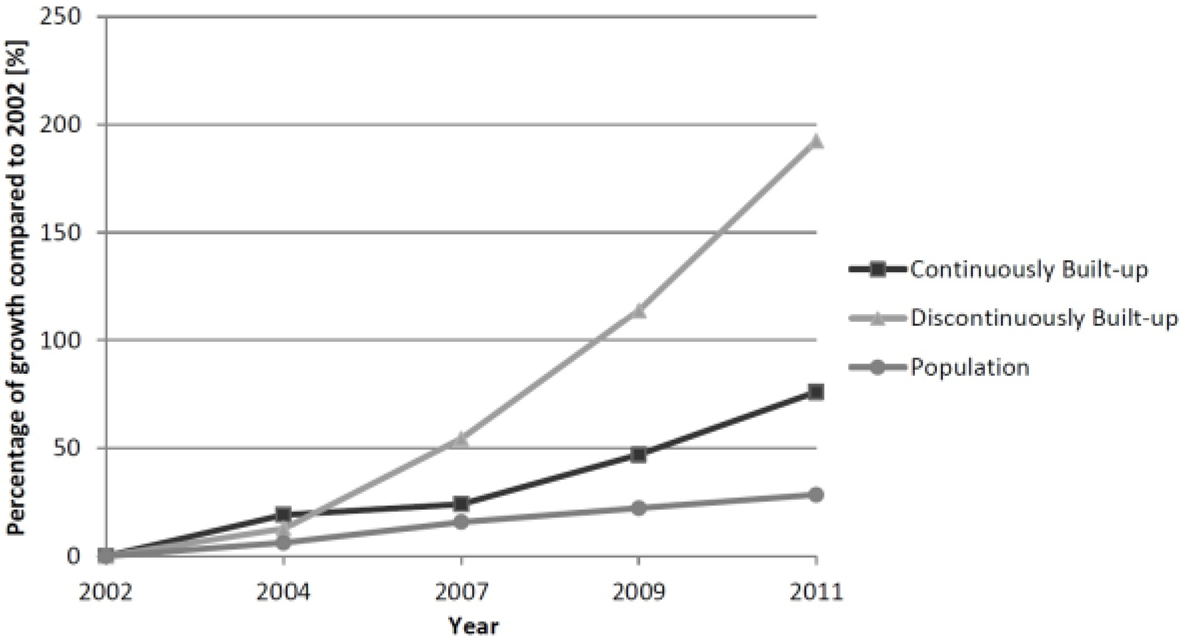

Figure 7: Evolution of LC compared with demographic growth

Figures 8 and 9 contain two profiles produced during the LC validation, and demonstrate the different densities of development between the “Continuously Built-up” and “Discontinuously Built-up” classes.

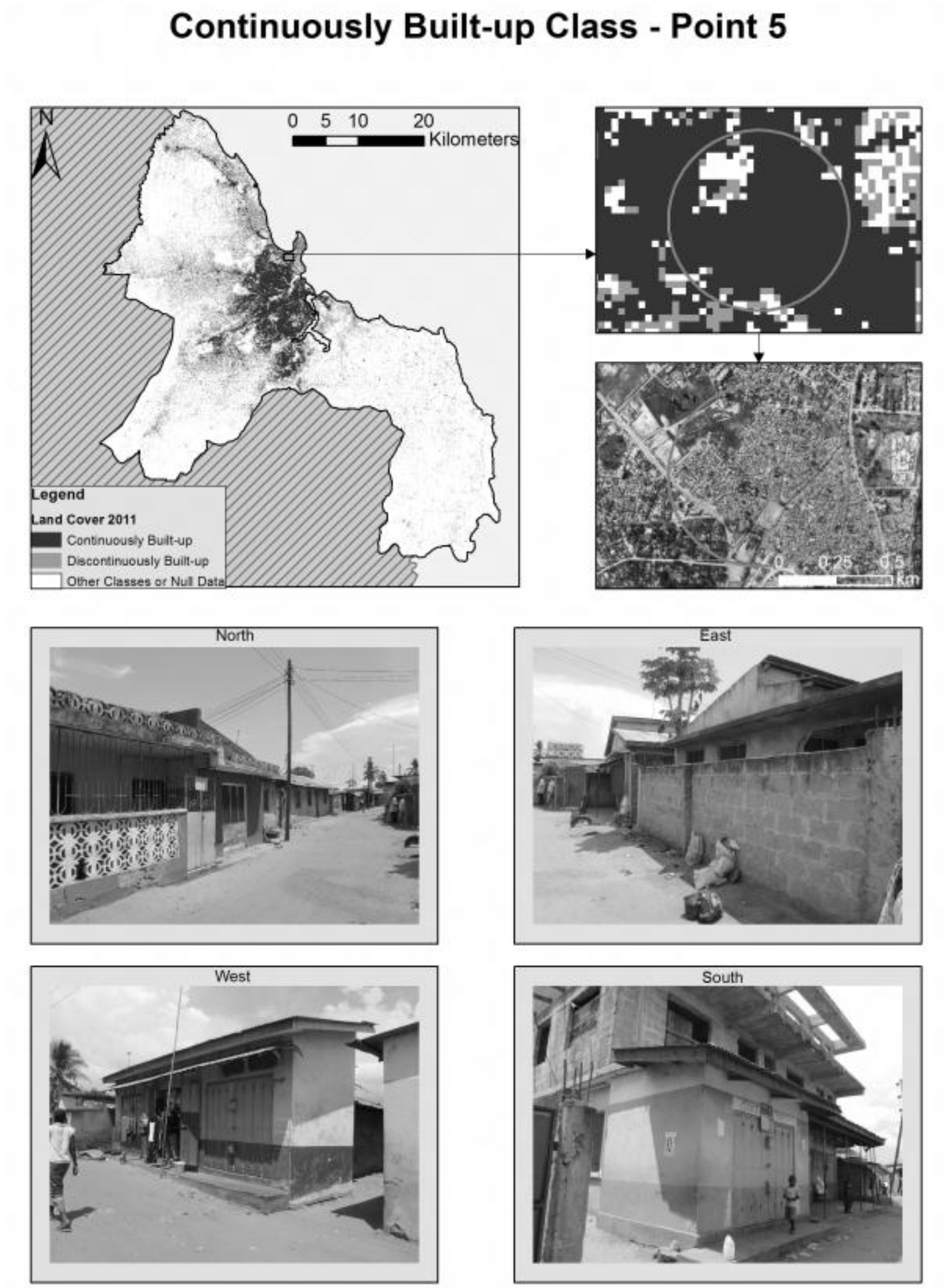

Figure 8: Example profile of an area classified as "Continuously Built-up", produced during the LC validation activity

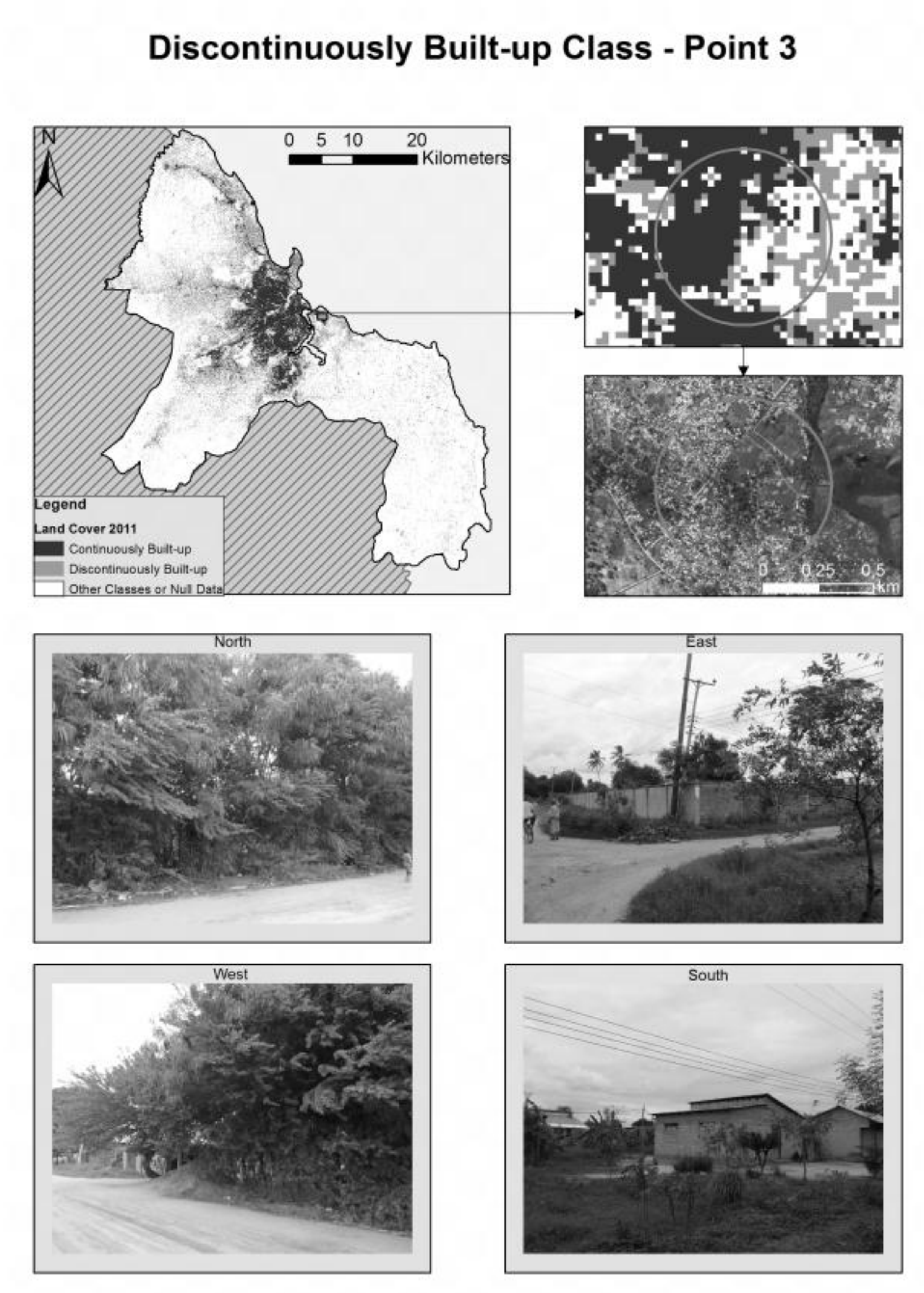

Figure 9: Example profile of an area classified as “Discontinuously Built-up”, produced during the LC validation activity

The main challenges encountered during LC classification and confirmed during the accuracy analysis were as follows:

- high cloud cover over Dar es Salaam during most of the year, which considerably limited the number and frequency of satellite images acquired, necessitated image mosaicking and increased the time required for classification and the spectral variability of images;
- spectral similarity between bare soil and artificial white surfaces often resulted in confusion during the classification process;
- because it is subject to seasonal variations in vegetation, the “Discontinuously Built-up” class was constituted by mixed pixels and was thus more effected by the spectral variability that results from image mosaicking;
- the rate of growth in Dar es Salaam and the rapid evolution of the territory (see example in Figure 10) rendered the collection of training areas difficult, since areas must remain stable over time in order to be used as a point of reference in multiple periods.

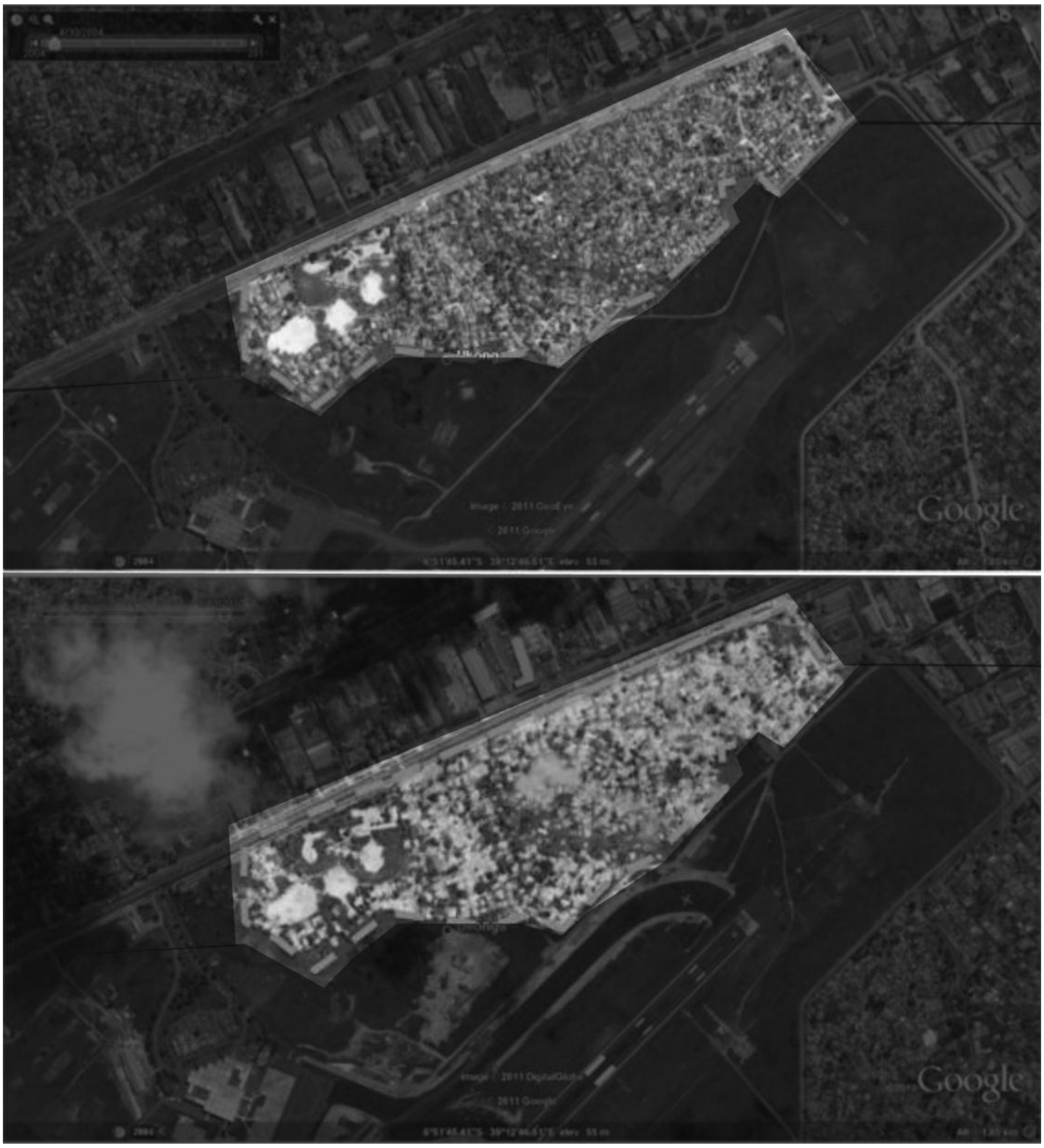

Figure 10: Example of settlement dynamism in Dar es Salaam. Google Earth images show a settled area in proximity to the airport, present in 2004 (top: highlighted) but demolished in 2010 (bottom: highlighted)

Accuracy analysis of LC classifications demonstrated their reliability, particularly as regards urbanized classes. The error matrix calculated for 2011 Landsat classifications (Figure 5) indicated that the "Continuously Built-up" class was recognized with a high level of accuracy (producer's accuracy 93.1%, user's accuracy 98.0%), and the "Discontinuously Built-up" class was classified with a medium-high level of accuracy (producer's accuracy 71.9%, user's accuracy 96.7%).

4.2 SPOT Classification

The availability of SPOT images allowed for the generation of classifications for 2011 (Figure 12), but with the exclusion of the Temeke area (due to excessive cloud cover). The distribution of LC classes is illustrated in Figure 11.

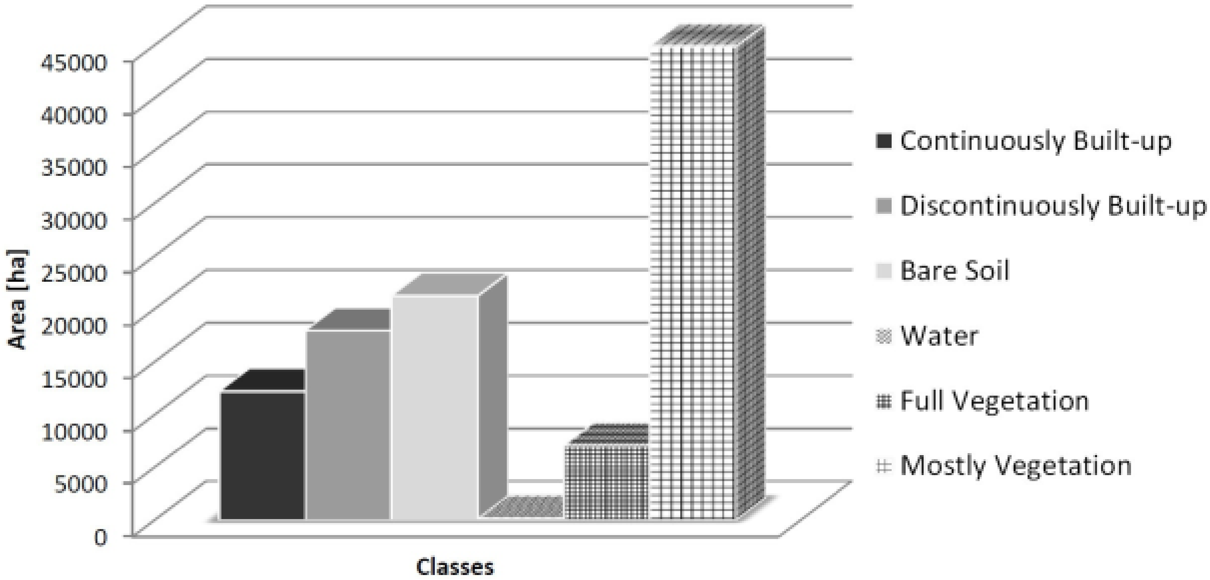

Figure 11: SPOT classification distribution

The classification algorithm was established on the basis of the following training areas:

- the "Continuously Built-up" class contained at least 70-80% developed surfaces;
- the "Discontinuously Built-up" class contained at least 40-50% and no more than 70-80% developed surfaces.

The coverage percentages are different than those reported by the Landsat classification, as the spatial resolution of SPOT images is greater (i.e. 10m) and allows for the identification of smaller elements on the ground. The above comments regarding the fact that the reflectance value of pixels does not depend exclusively on the surface area of a land cover apply again here.
The SPOT classification, despite its lower spectral resolution, obtained good accuracy results for the "Continuously Built-up" class (producer's accuracy 88.8%, user's accuracy 100.0%) and for the "Discontinuously Built-up" class (producer's accuracy 69.4%, user's accuracy 88.1%).

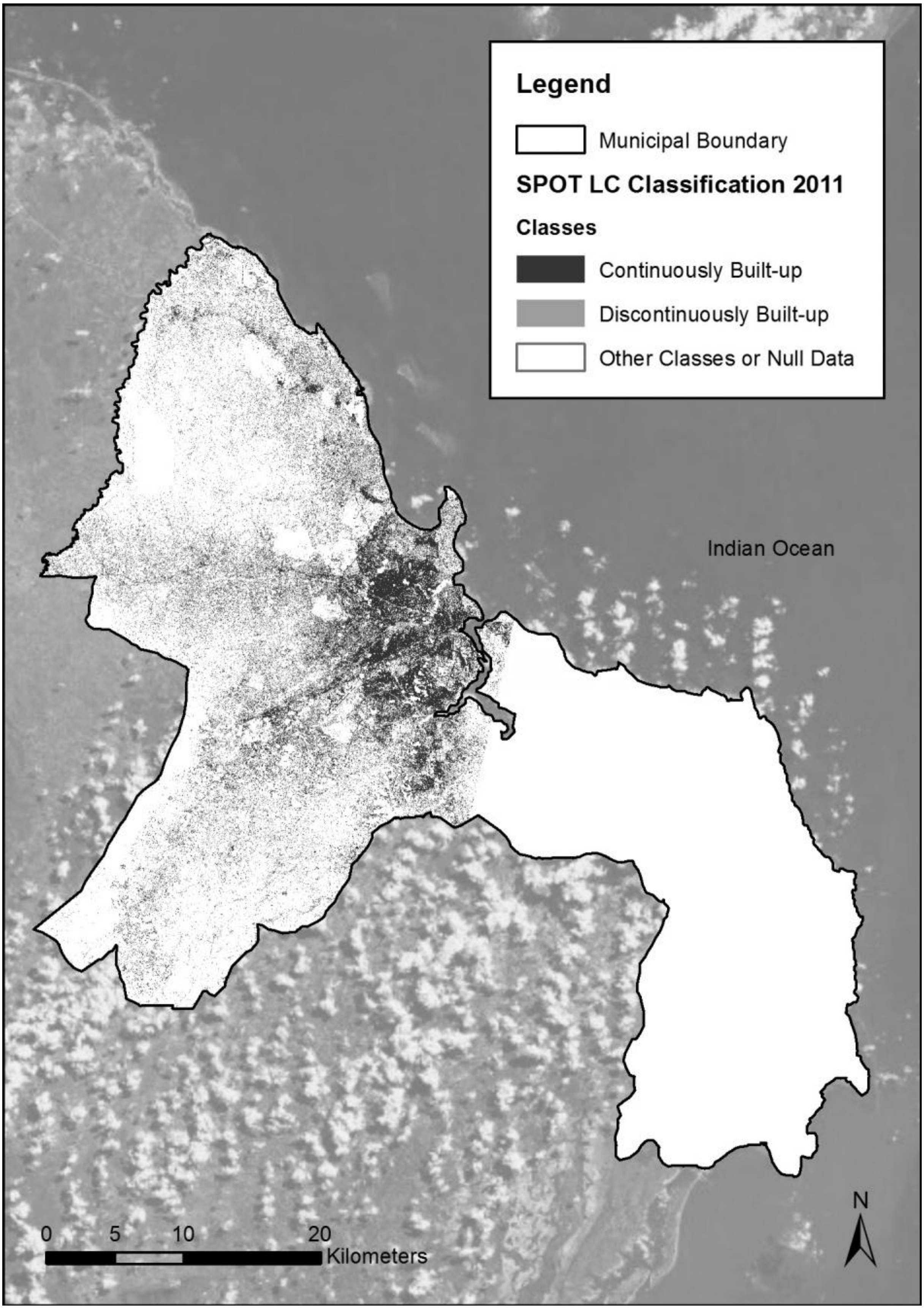

Figure 12: LC classification obtained from SPOT images for 2011

5 Conclusions

This study has developed a methodology for the classification of LC in Dar es Salaam through remote sensing.
The following classes of development have been identified on the basis of the classification of Landsat images:

- "Continuously Built-up", a densely developed class, whose pixels are characterized by homogeneity of urban cover (at least 60-70% of the pixel area);
- "Discontinuously Built-up", a class with low-density development, whose mixed pixels are characterized by a variety of land cover types (at least 20—30% and as much as 50-60% of the pixel area is developed).

The classifications of Landsat images in the 2002-2011 period has allowed for assessment of the evolution of urbanized areas. The maps produced indicate rapid expansion of developed surfaces, particularly in the "Discontinuously Built-up" class. Figure 13 demonstrates the expansion of this LC class along main thoroughfares and the gradual densification of central "Discontinuously Built-up" areas that have become "Continuously Built-up" areas.

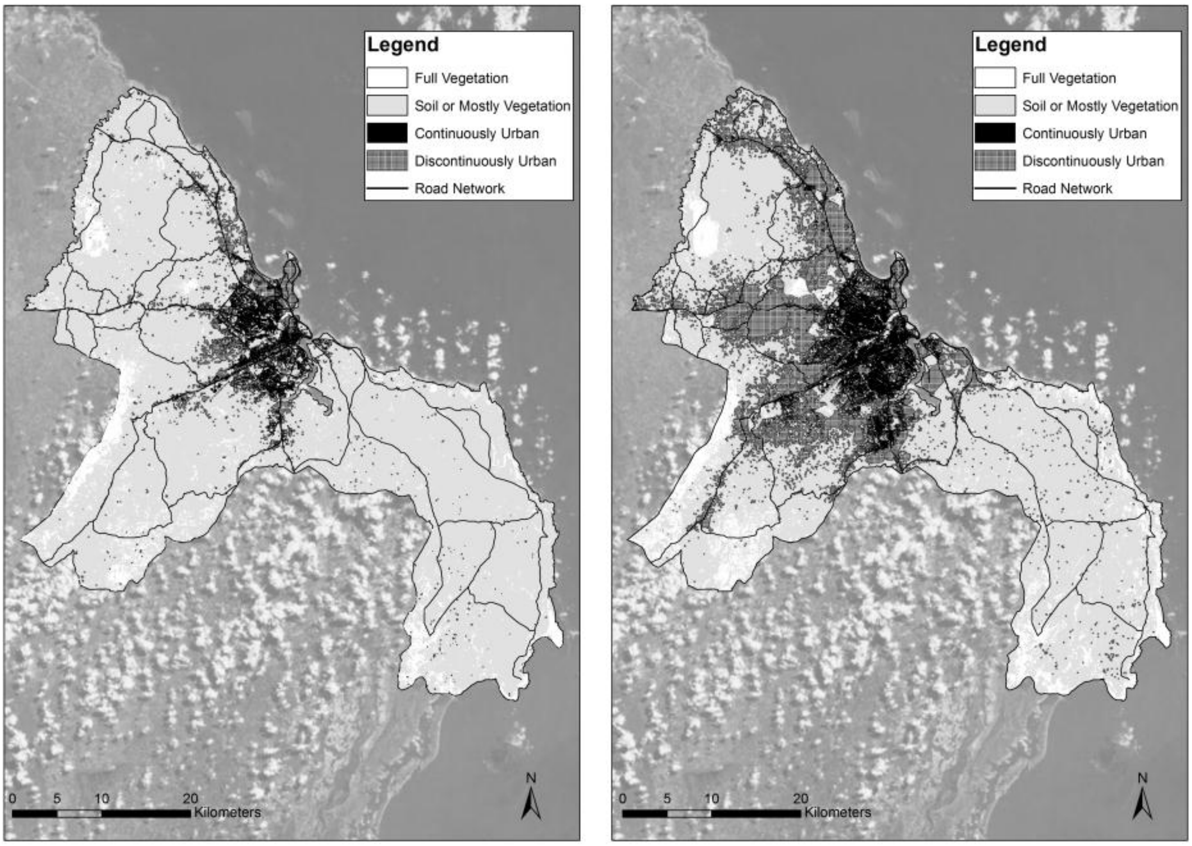

Figure 13: LC Classification for 2002 (left) compared with the classification for 2011 (right)

Accuracy analysis of these classifications has demonstrated their reliability. In particular, as regards the 2011 Landsat classification, the "Continuously Built-up" class was recognized with a high level of accuracy (producer's accuracy 93.1%, user's accuracy 98.0%), and the "Discontinuously Built-up" class was classified with a medium-high level of accuracy (producer's accuracy 71.9%, user's accuracy 96.7%).
The 2011 SPOT classification, despite its lower spectral resolution, obtained good accuracy results for the "Continuously Built-up" class (producer's accuracy 88.8%, user's accuracy 100.0%) and for the "Discontinuously Built-up" class (producer's accuracy 69.4%, user's accuracy 88.1%).
Given these results, and considering the greater availability of Landsat images as compared with SPOT images (and bearing in mind that 3 SPOT images are required for each LC classification in

Dar), one can conclude that the former are more adapted to the development of LC maps over multiple years, and thus are more appropriate for LCC analysis. On the other hand, SPOT images, given their greater spatial resolution, are more useful for detailed study of LC in limited areas.

It bears mentioning that the “Discontinuously Built-up” class does not necessarily represent areas of urban sprawl. For example, consolidated areas in the Msasani Peninsula are classified as “Discontinuously Built-up” due to their low-density settlements. However, such areas are more stable over time and occupy a smaller surface as compared with areas of sprawl, which develop along the main thoroughfares.

The identification of urban sprawl on the basis of the LC maps produced in the present study depends mainly on the spatial resolution of those maps. Landsat classifications, which achieved greater accuracy than those based on SPOT images, have a 30m resolution. Since the buildings that characterize urban sprawl are smaller than a Landsat pixel, it follows that the actual impervious surface for a pixel classified as “Discontinuously Built-up” is not $900m^2$, but rather a variable portion thereof, between 20% and 60% of the area of the pixel (for the reasons explained above in the definition of the classes). Similarly, the actual impervious surface for the “Continuously Built-up” class is between 60% and 100% of the pixel area.

Therefore, as regards the 2011 LC classification, the actual impervious surface in the “Discontinuously Built-up” class is estimated at between 5000ha and 14,000ha. The actual impervious surface in the “Continuously Built-up” class is estimated at between 9000ha and 15,000ha. Of Dar es Salaam’s total surface area of 180,000ha, an area of approximately 14,000ha to 29,000ha (i.e. between 8% and 16% of the total surface) is impervious.

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