Monitoring of Urban Growth of Informal Settlements (IS) and Population Estimation from Aerial Photography and Satellite Imaging

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Urban growth and informal settlements

In the last 50 years the shape of cities has changed dramatically. People have started to migrate from rural areas, attracted by the opportunities created by a more dynamic economy and by the apparent easier life within the cities. This trend has been observed in Europe during the whole 20th century, but has now considerably slowed down, to the benefit of smaller urban centres, which have grown around larger ones.

In the least developed world, this trend has slowed down too but the growth rate is still high. In most of the countries the majority of the population now lives in urban centers and the proportion of people looking for better lives in cities is alarming. According to UN sources[4], at the beginning of the 21st century, almost 50% of the world's total population will be living in urban areas.

In Africa, but also in other continents, urban growth has reached situations close to anarchy, enhanced by civil wars and internal disturbances. The result of this very rapid and unplanned urban growth is that 30% to 60% of residents of most large cities in developing countries live in informal settlements[5].

Available data barely accounts for the reality, as in most cases, they are based on figures extrapolated from old census, carried out in the '70s or, if recent, obtained with poor accuracy, as informal settlements (or slums, shacks) are difficult to monitor. Slums or informal settlements are without any doubt a reality and their rapid growth is one of the major challenges that authorities in charge of providing essential services have or will have to face in the near future.

This reality has appeared while the world economy has shown a global decline, leaving most of the least developed countries with fewer and fewer resources available to cope with the exponential growth of the population, unable to address their needs for basic infrastructures, like potable water, waste evacuation, energy, education and health care facilities.

A new paradigm (how we do things) will have to be found to address the problems created by the urban poor, if our goal is to avoid the "tragedy of the commons"[6] and eventually, if our ambitions are set quite high, to "eradicate" poverty, as many international organizations aim to do.

If the trend in urban growth has been quite difficult to manage and regulate, more can now be done to monitor the extent of this problem. Basically, one will have to answer these questions: where are these settlements and how many exist; at what pace have they grown; and, finally, how many people will need basic services.

Paradoxically, some of these answers can now be found using new methodologies, derived from sophisticated technologies, developed to study the earth from the sky, from aerial photographs to satellite imagery, in combination with local competences and more accessible software and hardware, presently available and used throughout the world.

Aerial or remote sensing imagery now has the capacity to provide planners and decision-makers with information previously restricted to specialized units, at competitive costs, opening new ways to monitor the dynamics of fast growing settlements.

One of the first applications of this useful technology is to provide maps to those who are in charge for the planning of the necessary infrastructures for these forgotten areas.

Spatial representation of a town

The need for a spatial representation of a city, a country, or a continent has evolved in a fascinating way from the antiquity to the present era of remote sensing, where precise images can be obtained from satellites, laser beams or aerial digital imagery. From very simple maps showing only a few indications like rivers, roads, buildings, etc. the problem with the evolution of the technology and with the precision of the observation means was always to reduce the number of objects which could be identified to easily recognise symbols, covering a wide diversity of themes in every observed field.

If in the early evolution of the cartography the problem was to obtain a more precise description of the

1 Data Exchange Platform for the Horn of Africa (DEPHA), UNEP Nairobi, Kenya
2 Geneva Foundation, Geneva, Switzerland
3 University of Nairobi, Master in Public Health, presently with ICRC
4 An Urbanizing World, Global Report on Human Settlements, UNCHS (Habitat), 1996
5 UNHCS, 1997. Indicators Programme, United Nations Centre for Human Settlements (Habitat) at http://www.unchs.org/20 September 1997
6 K.Spielmann, ENCOP, From environmental change to environmental conflict, p.4, Environment and Conflicts Project, Center for Security Studies and Confict Research, Swiss Federal Institute of Technology, at http://www.fsk.ethz.ch/fsk/encop/encop.html

landscape, the problem has now shifted to produce maps which illustrate specific topics, with selected signs and symbols allowing users to understand the spatial distribution of only a few objects. An example of an attempt to create a readable map is shown in figure 1, where minimum information can be recognized.

The map of the same city, cropped from a 1:100,000 map of the concerned area of Somalia (figure 2) shows how difficult it is to obtain a readable (and correctly oriented) spatial representation of a city. This requires a given level of abstraction and space representation. It has been observed that very often, people with a relatively low level of instruction, orient themselves easier when using an aerial photograph than when using a map.

Fortunately, development of technology has now put different kinds of images at the disposal of the general user. However, the problem of how to generate maps from these images will arise, as maps are still necessary for a simplified symbolic representation of the specific thematic issues to be discussed and eventually implemented.

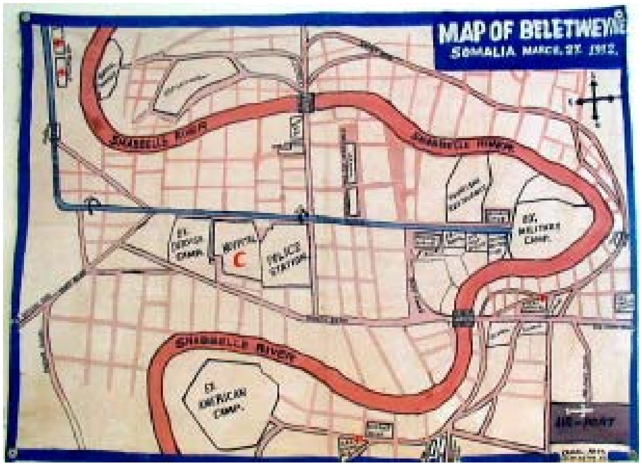


Figure 1 *Makeshift map of BeletWeyne (Somalia*)

Figure 2 *1.100,000 of Belet Weyne Shabelle Valley (Somalia)*

Geographical Information Systems (GIS)[7] and spatial analysis of an urban environment

Geographical information packages are now so common that nobody can ignore them. Digestion of rapid information is essential in order to master the rapid evolution of society and has made GIS products fashionable. At the same time, these packages have become more accessible and user-friendly and are easy to purchase. They do require, nevertheless, some methodology and are still quite restricted to people with specific training, but their use is constantly growing in any sector of society.

A GIS system is without a doubt “the method” to draw, edit, and modify an urban map and to insert, in an interactive way, any kind of data linked with specific objects represented on it. GIS is a system combining a computer, software, geographical information and operators which can accept, handle, analyse and visualise in an efficient way any kind of spatial data with a geographical reference. Data is represented on a map and any represented object may contain information which can be analysed, from which models can be built and visualised and, at the end, if necessary, produced in a printed copy.

Maps, geographical data, operators and computers

The availability of maps is not equal around the world. In the developed world it is quite easy to obtain a map of a town at a suitable scale and to get access to a lot of data like road networks, topographic readings, main buildings, census data, satellite images, aerial images and also, hardcopy maps. Recent technological developments in the field of remote sensing have resulted in increased access to an incredible number of data, even if their coverage, scales and geographic projections are not always compatible.

In the least developed countries and, for sure in countries affected by internal conflicts or by a civil war, this information is scarce. Maps of scales lower than 1:100,000 are difficult to find or are not accessible, for state security reasons. Available data is of poor quality and *metadata*[8] is of poor definition.

Computers are presently being used to provide many technical services as they have become accessible even to poorly funded municipal utilities, or are put to their disposal by NGOs or other international agencies. It is now possible to scan existing maps on A0 scanners, geo-reference them and train operators to use the necessary software to add new features and to start

7 *Geographical Information System and Computer Cartography*, Christopher B. Jones, Longman Ltd. 1997

8 ***Metadata*** are data accompanying data and describing their quality, i.e. accuracy, precision, spatial resolution, scale, errors, coordinate systems, data exchange format, etc., ibid ref. 5

manipulating databases[9]. However, working with a GIS system is still not so simple and it takes time to gain the necessary experience to be able to operate and analyse data.

Mapping of a town

As far as town maps are concerned, the quality is generally poor, and they are rarely available in electronic formats. Most of them have been prepared during colonial times or during a particular project when an agency undertook to rebuild the road grid, the drainage or the water supply network. The date of the map refers to that specific time and recent developments have not been included. Monitoring or planning are not possible without a map. Whatever may be done to understand the evolution of an urban environment, the first step is to find one at a suitable scale, according to the problem you are faced with. But this may not be easy. In several situations, the authors had access to the unique map of a city and enormous precautions had to be taken to make copies.

There are of course classical ways to produce maps, using a team of surveyors equipped with appropriate instruments. But this is not always possible, as the process is time consuming, costly and sometimes difficult to carry out due to logistical constraints and, in volatile situations, due to poor security, particularly if the work has to be performed in an area at risk, where crime is fairly common. In such situations the easiest approach is to rely on remote sensing techniques.

In the following, we will describe what can be done with the different techniques available; what kind of results can be expected and at what costs. We will describe some results obtained on several informal settlements of Nairobi and the potential for such techniques to monitor the evolution of an urban environment.

Nairobi is not exactly a town in a war situation but the situation of some areas may resemble some of the informal settlements observed in countries at war when the security situation around the town is poor and when people start to gather into the towns to seek better security, settling where it is possible in an unorganised way. Nairobi is also a town where access to modern technology and relatively stable services is easy and where the competences required for such an approach are available. Classical aerial photography, aerial digital imagery and several types of images obtained from different satellites will be compared and commented upon. Their potential to estimate the population of informal settlements will also be presented.

Nairobi and its evolution

Nairobi was founded in 1901 along the Mombasa-Kampala railway (Kenya Uganda Railway). It grew in an organized way, like almost all the colonial cities, until the second world war, reaching a population of 118,000 in 1946. The present spatial distribution of the population reflects the patterns laid by the British rather than the traditional African ones[10]. Characterised by large avenues and well planned, it was considered one of the most modern cities of Africa. Like many other cities of the continent, its population has grown quickly, reaching more than two million in less than 50 years due to in-migration and natural increase.

In recent times, large areas of the city, where access to land was easier, have literally been “occupied” by low-income migrants. The in-migrants had no choice other than to organise themselves in an informal way to cope with the lack of infrastructures. Everything had a tendency to become informal - accommodation, employment, transport and even industrial activities. In these areas of the town and also in Nairobi, the informal population growth has resulted in environmental degradation, overcrowding, poor housing, limited access to water and poor sanitation.

Although national development plans often state an interest in improving the physical and social environment of low-income urban areas, few countries have actually initiated improvement programmes. Little has been done to provide the homes and neighbourhoods with the services essential for a healthy and decent life, also because the policy toward these settlements has never been clearly defined. In these informal areas, a minimum of services have been implemented mainly by local associations or NGOs, but the lack of effective and coordinated programs to meet the needs of the residents is evident and only recently, through the initiative of the World Bank, UNDP and the Nairobi City Council, has a more comprehensive approach been observed.

Urban areas

Several extensions of the boundaries of the city took place before 1963 when the actual boundaries were fixed to 690km^2. Since then all the settlements leading to the increase of the population took place within this area. The present eight sub-administrative areas are shown in the next figure. The boundaries have been vectorized using four 1:50,000 topographic maps of the interesting area, and matched with the road network and the river’s course. A total surface of 704km^2 can be computed, slightly higher than the previous figure quoted. The difference is probably due to the difficulty to digitise the eastern boundaries of Kasarani, obtained from the

9 For minimum requirements see: Giorgio Sartori, *Appropriate Technologies for Remote Sensing in Developing Countries*, Ph.D. thesis, to be published

10 R.A. Obudho, in “...” Chpt. 9, Nairobi, National Capital and Regional Hub, http://www.unu.edu/unupress/unupbooks/uu26ue/uu26ue0o.htm

circumscriptions' ones and to some slight modifications in the shapes of this particular administrative area in the area south-east of the Jomo Kenyatta International Airport.

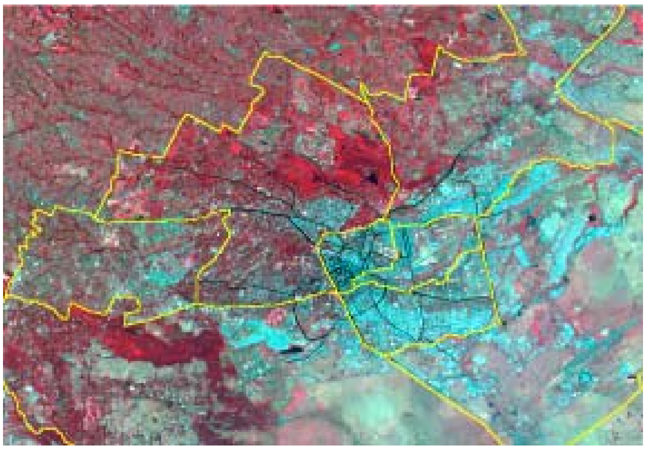


Figure 3 *Administrative areas of the town and Landsat 96 subset*

Table 1 *Administrative areas as computed from the shapefiles digitised from the 1:50,000 topographic maps of Kenya*

ID	ADMIN3	AREA square meters	PERIMETER meters	AREA hectares
1	Kasarani	74,326,055.45	51,382.33	7,432.61
2	Embakasi	241,887,765.39	97,371.83	24,188.78
3	Pumwani	11,249,656.21	17,605.15	1,124.97
4	Makadara	20,350,262.96	22,310.74	2,035.03
5	Langata	222,020,184.77	94,157.83	22,202.02
7	Central	7,850,553.77	12,191.93	785.06
6	Parklands	88,821,745.96	51,887.42	8,882.18
8	Dagoretti	38,196,269.57	34,235.42	12,701.80
	Total	**704,702,494.00**		**704.70**

The respective areas computed directly in hectares from GIS are presented in the next table.

At the time of Kenya's independence in 1963, the population of Nairobi was about 342,764. Since then the figures have increased at an annual rate which has decreased from 6% to about 5%, totalling to 2,143,254 at the end of 1999[11] living in an area of 696.1km^2. The official figures of the population have always been questionable as it was never clear if the population of the informal settlements was included in the statistics.

During the recent national census, the population of the largest informal settlement, Kibera, totalled to 276,000, significantly less than the admitted figure of half a million, raising a question mark on the possibility to carry out a census in such difficult situations.

11 *1999 Population and Housing Census*, Volume 1, Republic of Kenya, Central Bureau of Statistics, January 2001

Informal Settlements (IS)

Policies toward informal settlements

Informal settlements have existed within the town for a long time. Until the late 1970s the policy has been to demolish them, followed by a period where they were tacitly accepted. In the last 10 years only three - Muoroto, Kibagare, and the Bellevue at Wilson airport - have been demolished.

The stated Government position on informal settlements is that squatters should be offered an alternative resettlement before being evicted. Beyond that, there seem to be no Government policies dealing specifically with informal settlements. In the absence of such policies, the full range of legislative measures such as the Public Health Act (PHA) apply to informal settlements. The evolution of the different policies is outlined in the following table.

Governmental policy	Comments
Kenya's official housing policyin the late 1960s	Demolition of informal settlements has continued in line with the PHA which mandates the Local Authority to maintain "sanitary conditions" and to keep the City free of "nuisances", including poorly constructed dwellings, overcrowding and unsanitary conditions.
Building Code, planning regulations and Grade I by-laws	Aiming at facilitating the development (for the wealthy white settlers) of affordable low-cost housing has greatly contributed to the mushrooming of informal settlements in Kenya, by ruling out the construction of affordable housing for low-income earners. It forced the poor households to seek affordable housing in informal settlements.
Grade II by-laws, 1980	Aimed at formulating more realistic building standards for low-cost housing (have been adopted only in a few secondary cities (e.g. Nyeri). It allowed for the construction of semi-permanent dwellings and pit latrines.
Low-income Housing By-law review in 1985	Approved by the Government the same year. However, they have not yet been implemented. A committee has been set-up (around 1994-96) to draw a plan of action for the 1985 by-law review and general revision of the National Building Code. By mid-1999, the process was still ongoing.
Nairobi City Council	
Responsible for the urban development, management and provision of services Role in regulating the growth and upgrading of informal settlements	As an arm of the Government, the NCC role is to enforce the Local Government, Public Health and other relevant Acts. However, the NCC is legally restrained from operating in unplanned and unauthorized areas. An outbreak of cholera in 1972, led to the construction of 2km main to ensure minimum access to potable water. Currently, the NCC is responsible for formulating policies within the frame of different Governmental Acts.

No major demolitions have occurred since the last one, in 1993. Beginning in the 1990s, internal and external pressures made things move faster since:

- It was more and more difficult to "ignore" a segment of the population which accounted for more than 50% of the total population of Nairobi
- The informal settlement's population could increase the risk of social and political unrest
- The worsening of environmental problems would increase the risk of and outbreak of an epidemic (cholera, plague, meningitis, diarrhoeal diseases, etc.)
- Donor pressure

In 1996, with the support of the NCC, the Informal Settlements Co-ordination Committee (ISCC) was established. It has been formed to co-ordinate the efforts of the Central Government, NCC, NGOs, CBOs (Community Based Organizations) and the private sector in developing Nairobi's informal settlements. It is chaired by the Provincial Commissioner.

In January 1997, the Kibera Urban Environmental Sanitation Pilot (KUESP) was formed to address the possible environmental aggravation due to additional water brought into the settlement by another ongoing project, the Kibera Water Infilling (20km of additional mains from the Water and Sewerage Department).

Following a visit by the President to Kibera in March 1997, the environmental sanitation problems in Kibera (and other informal settlements) have been brought into focus. The Kibera Infrastructure Project (KIP) was thereafter established to address priority access routes and environmental sanitation problems. A special decree and financial allocation was made available by the NCC to facilitate basic improvements.

Informal settlements of Nairobi

A lot of information exists concerning the informal settlements of Nairobi (see Obudho[12], Olima[13]). The first detailed study of the informal settlements of Nairobi was carried out by Matrix consultants in 1993,[14] followed in 1995 by Ngau with a baseline study of all the informal settlements of the NGOs and CBOs working within these informal settlements[15].

A definition of Informal Settlements (Matrix) is given in the following table:

Definition of an informal settlement (Matrix Development Consultant)
• "owners" of structures have either a quasi-legal right of occupation or no rights at all • structures (houses) are constructed largely of temporary materials and do not conform to minimum standards • majority of the structures are let to on a "room-by-room" basis and the majority of households occupy a single room or part of a room • density is high, typically 250 units per hectare, compared to 25 per hectare in middle income areas and to 15 per hectare in high income areas • physical layouts are relatively haphazard making it difficult to introduce roads, pathways, drainage, water and sanitation • majority of the inhabitants have low or very low incomes • urban services such as water and sanitation are non-existent or minimal; morbidity and mortality rates caused by diseases due to poor environmental conditions are significantly higher than in other areas of the city (owing to poor sanitation, lack of potable water, poor drainage, uncollected refuse and overcrowding

12 Obudho, R.A. ibid 1
13 Olima, W.H.A. *The Dynamics and Implications of Sustaining Urban Spatial Segregation in Kenya, Experience from Nairobi Metropolis*, International Seminar on Segregation in the city, Lincoln Institute of Land Policy, Cambridge, MA, July 2001
14 Matrix Development Consultants, Nairobi, Kenya, *Nairobi's Informal Settlements: an inventory*, March 1993, USAID
15 Ngau, P.M. (1995) *Informal Settlements in Nairobi, A baseline survey of slums and Informal Settlements and Inventory og NGOs and CBOs activity*, Technical Report No.2

Informal settlements were mapped using aerial imagery and their population estimated using ground surveys to monitor space occupancy in the dwelling's units, the number of the dwelling's units per structure and the number of structures per hectare. These studies are still considered as a benchmark and, in the following, we will refer to them as the Matrix study and as the Ngau study. In the Matrix study, 29 areas were identified as informal. The Ngau study identified a total of 133 informal settlements, distributed over seven divisions, with an estimated 77,600 structures.

The data of this last study are listed in table 2. The number of people per dwelling unit is in this last study quite high, between four and six and the population estimation, close to 1,900,000, largely depends on the accuracy of this parameter. If we admit that the mean surface of a dwelling unit is $9m^2$, this occupancy rate would result in a surface occupancy of four to six people per $9m^2$, e.g. 0.44 to 0.66 people/m^2, which is quite a high value, bringing the population estimate for Langata to about 900,000 people alone.

Table 2 *Informal settlements in Nairobi) per administrative division (from Ngau 1995).*

Division	No. of villages	No. of structures	Approx. No. of rooms	Av. No. of persons per room	Estimated population
Makadara	7	5,013	11,496	6	68,976
Pumwani	11	3,136	10,418	5	52,090
Embakasi	14	3,865	14,865	3	44,595
Kasarani	43	26,530	97,715	4	390,860
Parklands	7	2,190	9,310	4	37,240
Dagoretti	34	15,240	97,320	4	389,280
Langata	17	21,615	180,625	5	903,125
Total	**133**	**77,589**	**421,749**		**1,886,116**

It is known that the main informal settlement of Langata is Kibera and that would mean that its population is close to that value, which needs to be confirmed. Other sectoral studies were then undertaken, mainly of Kibera, the largest informal settlement, commissioned jointly by the UNDP/World Bank Regional Water and Sanitation Group for East and Southern Africa (ESA) as part of technical assistance to the Nairobi City Council's Water and Sewerage Department[16]. Since then, data are mainly focused on Kibera.

In 1998, the UNDP/World Bank commissioned a new study on Kibera with the aim to support the preparation and implementation of the Kibera Water Distribution Infilling Component (KWDIC), a component of the Third Nairobi Water Supply Project (TNWSP), aimed at developing and testing community-based options for improving water supply in Kibera. Four aerial images were obtained and used to produce a map of all the structures of the informal settlement. The map would then be used to allow the ground survey teams to orient themselves in the maze of the settlement and to randomly or completely select the structures where data would have to be gathered. Without such a map it is impossible for a team to carry out ground survey work.

16 *The Water Kiosks of Kibera and Water and Environmental Needs of Kibera*, Field Notes, UNDP/WB, May 1997

What has been done for Kibera is still lacking for almost all the other informal settlements. Population figures are inconsistent, data are related to different periods as field surveys may be more difficult to carry out due to security reasons. For example, even for Kibera, during the recent visit of the US Secretary of State Colin Powell many articles were published in the press[17] quoting population figures varying from 1,000,000 to 260,000 people only for this settlement, considered as one of the easier ones to study.

If anything has to be undertaken in any rational planning of these informal settlements, a pre-requisite is the availability of useful and accurate information and data. If this issue may now partially be solved for Kibera, it remains unchallenged for the other settlements, where information provided by "classical methods" of data collection, such as national census or sampling surveys may be questioned, where the sources of errors are numerous (coverage, misreporting, under-reporting) and where accessibility and acceptability may be problematic.

In many of these informal settlements the total population growth is high and has been estimated to be close to 12%. A natural increase may account for 4-5%/year and the remaining is due to in-migration (or in-filling[18]), which may be limited by physical constraints, if there is no more land to allow for expansion. But the increase of the density of the dwellings per hectare has its own limits and new informal settlements will have to be created in new areas.

In the following we will describe the combined use of modern remote sensing techniques and Geographical Information Systems (GIS) to monitor the evolution of the surfaces of the informal settlements of Nairobi and their potential, if combined with limited ground surveys, to estimate their population.

Available data and material

The following data were used:

Available Data and Material

- Population estimate from surveys (table)
- Sketches of slums (to be geo-referenced) at different scales (1993)
- Map of Kibera with dwelling units (PHOTOMAP LTD aerial survey 1998)
- Map of IS located in the south-eastern part of Nairobi (Acquisition date: 7 September 2000 from IKONOS Space Imaging INC. archives)
- Geo-referenced maps of Nairobi (street map and 1:50,000 geo-referenced, 19??-19??)
- Aerial images of Kibera (mosaic of registered images)
- Digital Elevation Model of Kibera
- LANDSAT 5 (6 bands) 1990, LANDSAT 5 (bands 4-3-2-) 1996 and LANDSAT 7 (7 bands) 2001

17 192 Entries on Kibera, Nairobi, Slums in www.google.com
18 Jun Li and Heinz Ruther, IS-Modeler: *A Low Cost Image-Based Tool for Informal Settlement Planning, Geoinformatics and Socioinformatics*, the Proceedings of Geoinformatics '99 Conference, Ann Arbor, 19-21 June, 1999, pp 1-19

Remote sensing, GIS and field data

The paper uses three types of data: remote sensing, GIS and data from the field. Each type comes from different sources and has its proper peculiarities. We may summarize that as follows:

Type	Source	Advantages	Constraints	Quality/Resolution
remote sensing	aerial survey	provides 3d view/model, fast acquisition	expensive, covers small areas, registration/ ortho-rectification is difficult/time consuming	extremely good resolution (1:10k) and registration (1-5m if properly processed)
	satellite imagery	covers large areas, uses multi-band sensors, fast acquisition, shows changes over time, relatively cheap	cheapest images are coarse, analysis require expensive software/skills	from coarse (25m) to good (1m), reasonable registration (50-100m)
	digital camera	very cheap, fast acquisition	only appropriate hardware/software can support registration/mosaicing	varies
GIS	large scale maps	may accommodate historical data, integrates different sources	time consuming	depending on source
	remote sensing	can perform spatial analysis, integrates data over time	time consuming if not automated,	depending on source
field data	surveys	accurate socio-economic data	expensive, time consuming	depending on methodology
	population census	accurate data, historical trends	difficult to get (in developing countries)	depending on desegregation level
	historical data	goes back in time	difficult to link to space	difficult to judge

As a matter of fact each type of data has its own strength and limitations that make it unique and indispensable. Only a good mix of the different techniques can provide the appropriate tools to investigate the issue of urban growth in a flexible and comprehensive manner.

Unfortunately, it is quite difficult to get this type of data on cities in developing countries and any attempt made should consider using what is available, merging it with low cost new data. The easiest way to acquire new data is from remote sensing that, unfortunately, visualises only roofs and other types of objects, not understanding how they are linked with day to day living.

This understanding comes from the field surveys that are time consuming and very difficult to carry out. Both, remote sensing and field surveys need a spatial tool to allow or expand spatial analysis capacity: the integrating factor is GIS, which needs data sources to provide fuel to its engine.

Each source has limitations which are an intrinsic part of the technique that we may recall just for those who are not very familiar with them. At the same time we will mention facts about their application in the study area.

Remote sensing: for studying small things use magnifying glass

Dwelling units in informal settlements are difficult to be isolated. Only structures can be recognized in the maze of the settlement. They are one storey, iron tin made barracks. The morphology changes according to the age of the IS. At the beginning, the units are composed of single structures which are isolated and not iso-oriented. With time evolution and density increase, the structure's units merge into multiple units that lose their initial shape (see frequency of area of the units in relatively new and mature IS). Therefore, the roofs provide information on the surface of units, not on the number of dwellings and, therefore, on families. The roofs are almost all made with tin sheets, which are quite easy to detect on a multi-band image, but more difficult on a panchromatic or false true colour one.

For this study we got LANDSAT 5 TM (25m resolution), IKONOS false colors (1m) and panchromatic aerial survey (equivalent to …). The LANDSAT 1990 image has the six bands and comprehends a large area surrounding the city. The cloud coverage, although is not heavy, poses some problems whenever the image is used to detect differences with other images acquired in different years.

The LANDSAT 1996 is cloud free, but it is a small window with only bands 4-3-2. These bands are good to detect vegetation (the assumption roofs = no vegetation works to a certain extent) but do not help much in differentiating iron from other man-made surfaces; for this purpose the near to infrared bands are better. If we assume that the signature of a pixel is unambiguous whenever the surface of the object is uniform for a total surface that is double the pixel size, we need objects not smaller than 2,500m^2. Therefore, LANDSAT images are not suitable to study peculiarities of IS, and we will discuss their use in identifying IS later.

High resolution images

To describe the morphology of IS, very high resolution images are needed either from aerial surveys or from 1-2m satellite imagery. IKONOS allowed the identification of the IS also at their first initial stage and their vectorizing. Through the 1m image it has been possible to spot out the growing areas and the differences related to densities between historical data and the present IS (see box). Aerial images may provide a stereoscopic view and may extract such information generating very high accuracy topographic maps at a scale of 1:5,000. The intermediate step between the feature extraction and the map composition provides AUTOCAD files that can easily be translated into a GIS format. This way it is possible to generate very high-resolution 3D models that facilitate spatial analysis. Panchromatic images are subject to the difference of reflection of the iron sheets due to their orientation in relation to the position of the sun and the rust. This makes it very difficult to isolate units without three-dimensional views, while natural colors minimize the problem.

In our study the Kibera black and white images have been scanned at 500dpi, rubber-sheeted and registered against the large scale topographic map to create a unique mosaic. Such an image, overlays to the 3D model and provides an additional tool to understand the dynamics of IS. However, it is clear that only very high resolution images can provide a tool to understand the structure and morphology of IS.

Macro analysis

Although very high resolution images are the best way to study IS, lower resolution images may be used to get a macro picture of the phenomenon and its change over time. LANDSAT TM new images are nowadays very cheap. It is also easy to get images from the archive that go back to the early ‘70s in its previous incarnation, the MSS (Multi-Spectral Scanner). Image classification, both unsupervised and supervised, is becoming a routine task that is made easy by new software generation. Land use classification is quite straightforward in non-urban areas. It becomes difficult whenever it is meant to differentiate various components of the urban structures. What mostly influences the spectral reflectance are to a large extent the presence of vegetation and, all together, the material of the hand-made surfaces.

Application to Nairobi’s Informal Settlements

At its inception, Nairobi was divided into areas for Europeans, Asians, Africans, administration, industries and parks[19]. Although this division has been abolished since independence, it is still possible to recognize the original patterns which are now reflected into the land value and houses/population density. The original private estate and European only areas are now high cost low density residential areas characterized by huge gardens rich in plants and trees. The Asian areas are now mostly middle income and medium density areas and are still characterized by the presence of plants and green areas surrounding the structure units. The central business district, the recent low cost quarters and industrial areas are marked by the virtual absence of vegetation and, therefore, the main difference is among tarmac, soil, tiled and tin roofs.

Here is one of the key issues. Tin roofs are very common in Africa since they provide a fast and cheap way to cover barracks, industrial buildings and small residential houses. We attempt to generate a supervised classification of the Nairobi land use according to the following classes:

19 See Obudho nte no.3

Type of land use	Features	Population density	People/ hectare	People/ km^2	People/pixel (25m x 25m) 625 m^2 LANDSAT
informal settlement	50-60% tin roofs and soil	very high	1500-2500	Up to 200'000	125
very densely built residential	cement, tile and tin roofs and soil	high	400	40'000	25
very densely built commercial and barracks	cement and tarmac, lower percentage of tin roofs	medium	224	22'400	14
medium income residential areas	vegetation mixed with tin roofs	low	80	8'000	5
high income residential areas	trees and gardens with little roofs surface	very low	16	1'600	1
industrial areas	tin roofs and soil	minimal	0.16	16	0.01
open space i.e. urban agriculture, grazing	grass, open bush	none	0	0	0
trees, forest	vigorous vegetation	none	0	0	0

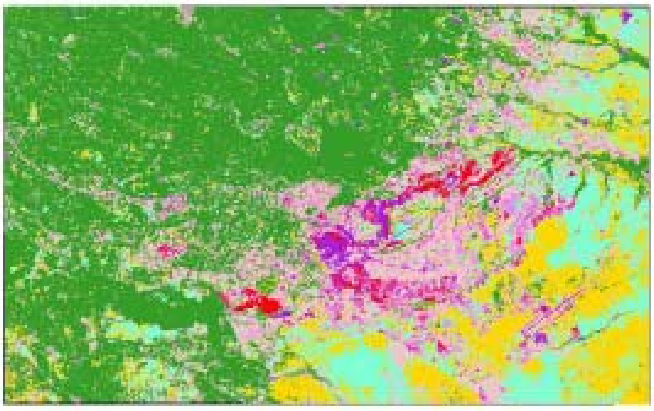


Figure 5 *Subset of the same image submitted to a guided classification.*

Each class has been identified by at least two areas of interest[20] (AOI) that were known to belong to the concerning class. The aim of the exercise is to generate a land use map that may be translated into a population density one. This provides an easy to use tool to extract actual population figures for any given area. Applying the same methodology to an image acquired in a different period it is also possible to compare population changes at a glance.

Results and limits of the use of LANDSAT images

The image below shows the results, using the image acquired in 1996, bands 4-3-2. Informal settlements are shown in red, open space areas in yellow, forests in green, downtown and high storey building areas in magenta and industrial areas in pink.

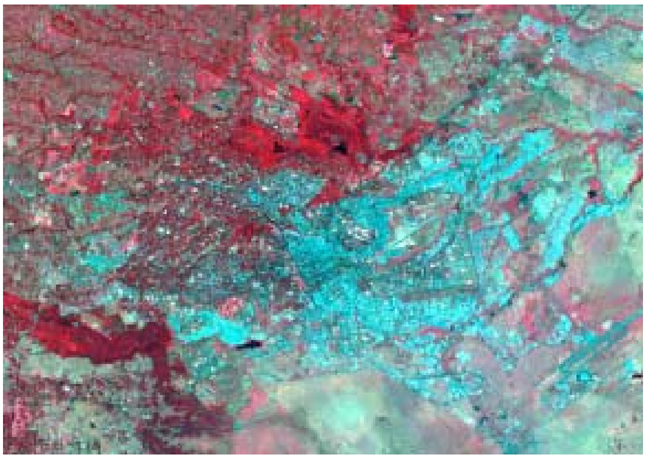


Figure 4 *Subset of a 1996 LANDSAT image, bands 4-3-2*

While the overall pattern is clearly correct and the main areas are clearly discriminated, problems have been encountered in recognizing the informal settlements from the industrial areas. This is mainly due to the fact that both show the same building materials and the spectral reflectance is almost identical. Both areas are constituted by tin roofs and soil, with little presence of vegetation in the industrial areas.

It is noticeably the fact that the classification confuses very high and high classes in the most famous slum, Kibera, while it easily recognizes other lower density informal settlements like those in the Dagoretti area. The supervised classification leads to a total number of pixels per given class. Using only this approach and because of the distinction problems outlined above, it is not possible to compute any consistent estimation of the population of the different classes and, therefore, of the town.

However, it is possible to distinguish between at least several land uses using an automatic classification. All the classes obtained which are considered as open spaces or forests are grouped into a unique class, named open space. The remaining class, referred to as the High Reflectance Anthropogenic built-up (HRA) area,

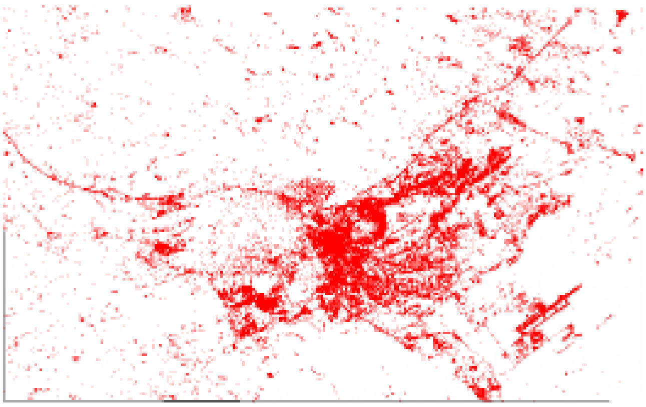


Figure 6 *High reflectance anthropogenic built-up area. Automatic classification of a subset of LANDSAT 1996 image (bands 4-3-2) using 6 classes and colour grouping.*

20 An AOI is a surface with homogenous characteristics

gives us the high density built-up areas. The results of this automatic classification using six classes is given in the next figure, where the HRA built-up area of the town's LANDSAT subset are shown.

The open space area represent areas where any further expansion of the town may take place or has already taken place, as this classification is reflecting the land available for expansion in 1996. Since then the town has expanded as many areas have been used either in a planified or in an informal way. But where and how exactly these areas have grown cannot be detected using LANDSAT images, the magnifying glass is not powerful enough.

Use of HRA built-up area from LANDSAT images

We have seen that the supervised classification does not allow to differentiate between the roofs of informal settlements and those of other structures. This will lead to a high proportion of the number of pixels of the very high density class. Moreover it includes roads, airports, and all other built-up areas. However, it must be pointed out that the very high density class does not consider areas where the vegetation cover is important, like in Muthaiga or Loresho, where the density of habitation is low but not negligible.

Table 3 Automatic classification of 1996 LANDSAT *image (Arcview Image analysis or ERDAS Imagine 8.1). 6 classes. Total number of pixels 844 x 1371 = 1'157'124*
Total area of the subset: 723.20 km2.

Classes	No. of pixels
Unclassified	12'658
1	**97'279**
2	301'701
3	180'538
4	242'784
5	179'310
6	142'854
Total	**1'157'124**

The only result we may obtain from this method is the proportion of the HRA built-up area, which represents 8.4% of the total surface of the subset, that means 6,079 hectares. If we use the figure of 1,015 hectares, quoted in the Matrix study, for the total surface of the informal settlements in 1993 the proportion of the urbanised area used by the IS is about 16.7% and probably lower as class one (HRA built-up area) takes also roads, etc into account, which are not areas where people live, in principle. This is quite consistent with the results of the literature and means that a large proportion of the population of the town, close to 50%, lives in informal settlements on a surface which represents less than 18% of the inhabited areas of the town.

Use of data from a well-studied informal settlement: Kibera (Nairobi)

Kibera is the largest informal settlement of Nairobi and most probably of all of sub-Saharan Africa. With a given total surface of 229 hectares (Matrix) it hosts an estimated population of about 500,000 people or more. Kibera is located very close to the city centre and to the industrial area and, therefore, attracts many people due to low transport costs to areas where daily cheap manpower may be needed. A number of studies have been carried out on this informal settlement but only a few have reliable information based on field surveys. In 1993, the total surface was estimated at 229 hectares with a population of 248,160 estimated with the use of aerial images. The number of inhabitants per hectare was close to 1,100 with a mean surface per dwelling unit of $9m^2$.

The last census[21], carried out in 1999 gives a total surface of 223.4 hectares and a population of 286,739. As stated above, in 1997 the UNDP/World Bank together with the Nairobi City Council commissioned a local company, PHOTOMAP Ltd., to conduct an aerial survey to map this informal settlement, with the aim of paving the ground for improving the living conditions of its inhabitants.

Figure 7 *1998 Aerial images of Kibera (courthesy of World Bank RWSG for Eastern and southern Africa)*

From the images at a scale of 1:10,000 it was possible to map all the structures' units and major features like contours, drainage, roads and pathways, fences, water tanks and pipes were vectorized.

21 See footnote 2 supra

3D models

Using Arcview 3D analyst and the elevation data (contours) a 3D terrain model of Kibera can be obtained. Over it, a 3D representation of the one-storey structures can be overlaid, attributing an arbitrary value to the height of the structures, assumed to be 3m in this informal settlement. In this particular case the 3D view is not of great help as all the buildings have approximately the same height but would be of great interest if, in any reshaping of this informal settlement, the construction of multi-storey structures would be considered. The 3D view is shown in the next figure.

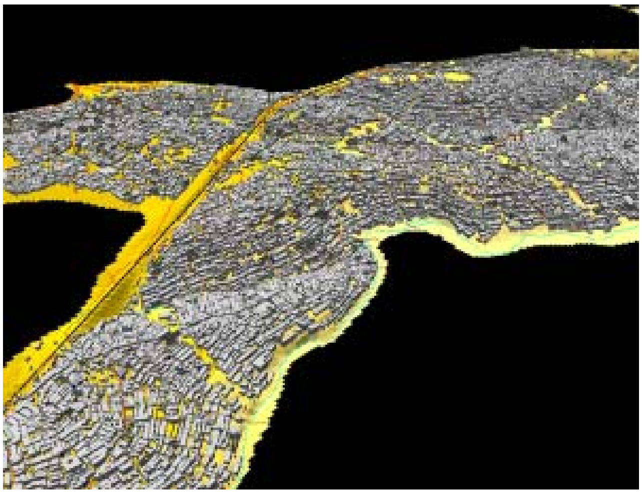


Figure 8 *3D view of Kibera, built from elevation contours.*

GIS software packages allow to compute cross section profiles from elevation contours. In the particular case of Kibera, they may be used to plan the layout of any water or waste-water pipeline and could be of great help for planners. Beside queries on the attributes of a specific shape-file, GIS packages also perform other functions, which can be used by physical planners, such as the proximity analysis function or the buffer function. Their use will not be discussed here.

Use of the map with GIS software

The map was obtained using a stereo-plotter allowing to discriminate the height of any object. However, the complexity of the roofs of the units and their vicinity did not allow to discriminate the dwelling units and could only provide the shapes of the habitative structures. It was impossible to get definite information on the dwelling units which host the family or household unit and therefore to translate the results into population figures.

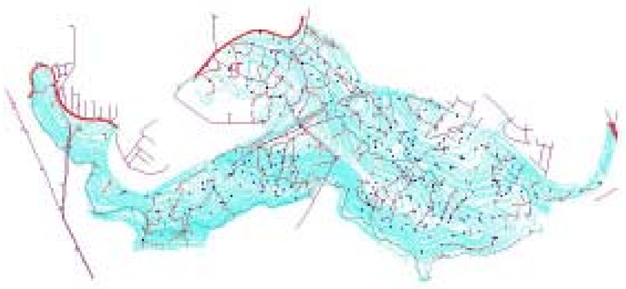


Figure 9 *Vectorized contours, roads, pipes, water tanks, etc. of Kibera obtained from the aerial image*

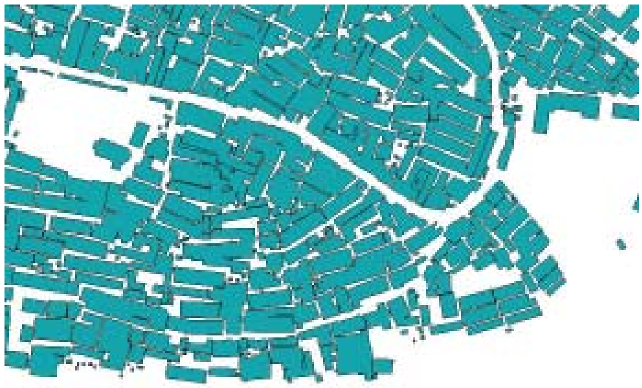


Figure 10 *Map of the structures obtained from the aerial image.*

GIS software allows to compute the surface of all the vectorized structures. A frequency analysis to count the surface's structures per given interval has been carried out to identify any possible organized trend in the construction size. An interval of 4m has been used up to a value of 200m^2, neglecting the larger ones, which represent a very small part of the 21,116 units used for the analysis.

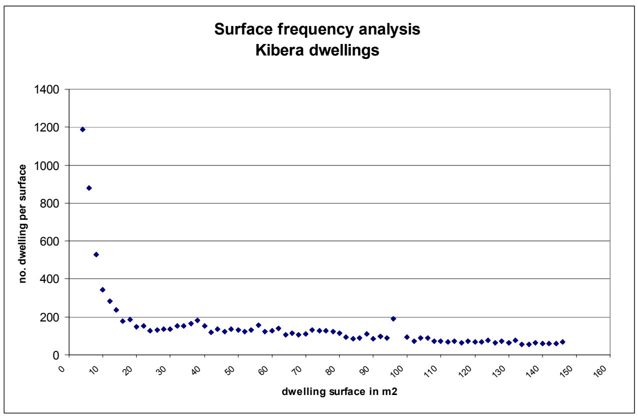


Figure 11 *Frequency analysis. Number of structures per interval*

While it is known from household surveys that the average dwelling unit has a size of $9m^2$ the study of the frequency of the areas of the vectorized polygons does not show any significant peak, thus ruling out the existence of a multiple of a module, which would allow to confirm that the area of every house would be a multiple of the a/m dwelling unit surface. Therefore, the only way to estimate the population is to gather the population density (number of people/m^2) and combine it with the information obtained from the GIS.

The lesson learnt is that GIS/remote sensing and ground surveys are unable to generate a population estimate on their own and therefore there is a need to combine the two approaches. GIS/remote sensing provides the surface of the units and the total surface of the IS, but also allows the ground survey teams to carry out the survey. The ground survey provides data of the size of the dwelling units and the number of occupants per surface unit.

The aerial mapping of 1998 enabled the teams of the Departments of Physical Planning of the Ministry of Land and Settlements to carry out this survey. Initial results obtained on about 40% of the structures gives the figure of **0.33 - 0.39 people/m^2 (or 3 - 3.5 people/ $9m^2$).** These results will be further refined as the survey proceeds.

Since Kibera is completely surrounded by well-defined residential boundaries, its expansion is not possible and the surface measured in 1993 and recently are very close. The total surface of the 21,116 structures can be easily computed and is close to 133,3834 hectares. Based on these figures the total population of Kibera is now estimated at **480,000,** if the mean value of 0.36 people/m^2 is used, and at 444,000 or 517,000 when the two extreme values of 0.333 or 0.388 are used (+/- 7.7%).

The ratio between the total surface and the built-up one is close to **0.6** and, more precisely, to 0.595 if the figure of 224 is used and 0.582 if the admitted surface of 229 is considered. In fact the total Kibera surface computed from the boundaries vectorized around the rubber-sheeted polygons structures, done to match perfectly the topographic map, is 205.33 hectares, quite significantly smaller than the 229 hectares figure quoted in the Matrix results. Unfortunately, what has been done for Kibera cannot be done for the other informal settlements, as precise data on the surface of the structures is not yet available. IKONOS images may provide only part of the answer for such areas covered.

Growth of informal settlements

Since 1993 the informal settlements have grown either in density per habitants per hectare and in size, with an estimated growth rate of 10% per year, with a city population growth rate decreasing from 7% in 1963 to less than 5% in 1989[22].

Here, we will consider the case of Kibera. As far as density is concerned, the data available is that of 1993 as well as data from the computed surface of the dwellings, obtained from aerial images combined with ground households surveys, carried out by the Physical Planning Department during 2001. A total of more than 40% of the dwellings have been surveyed and a mean value of 3 - 3.5 people/dwelling unit has been obtained. The mean surface of the dwelling unit is $9m^2$.

From the GIS data we can compute the total inhabited surface (sum of the individual surfaces of the dwellings). As the total surface is known, a ratio of 0.6 can be obtained, the inhabited surface therefore representing 60% of the total surface of the informal settlement.

Despite the fact that the area of the IS sketched in 1993 has the same surface than that drawn from the 1998 aerial survey, the density per hectare has more than doubled, increasing from 1,096 inhabitants/ha in 1993 to 2,333 in 2001 if the value of 3.5 people/$9m^2$, and to 2,000 if the value of 3 people/$9m^2$ is used.

IKONOS SpaceImaging Inc. image

A $100km^2$ image of an area was selected where the distinction between metallic sheets covering the dwellings and those covering industrial premises was difficult to distinguish. Basically, the area covers a large part of the eastern part of the city, where informal settlements have mushroomed in recent years. A similar image covering the western part of the town would have allowed to obtain a complete picture of the evolution of the informal settlements, but owing to the relatively high cost of coverage, it was decided to limit the study to the selected part of the city. A 2000 archive image was available, even if slightly shifted from the selected area. Cloud coverage was less than 5%. The following specifications were available:

Unit of measure: square kilometer	Imagery source: archive > 6 months
Processing level: Standard geometrically correction	Resample method: cubic convolution
Resolution: 1 meter	MTFC: yes
Data type: color	File format: Geo TIFF
Band combination: Natural B>B, R>R, G>G	Bits: 11 bit
Datum: WGS 1984	Output media: CD-ROM
Map projection: UTM	Quantity: 100
Zone: 37	Item price: 38.5 USD
Acquisition date: 7 sept 2000	

The difference in the pixel resolution between the LANDSAT image and the IKONOS one is clearly visible in the next figure where the two images have been superposed. On the right side, the high resolution of the IKONOS image allows to recognize the structures of the informal settlement, in this case Mukuru (Industrial area).

22 Source: *Census Data*: Government of Kenya

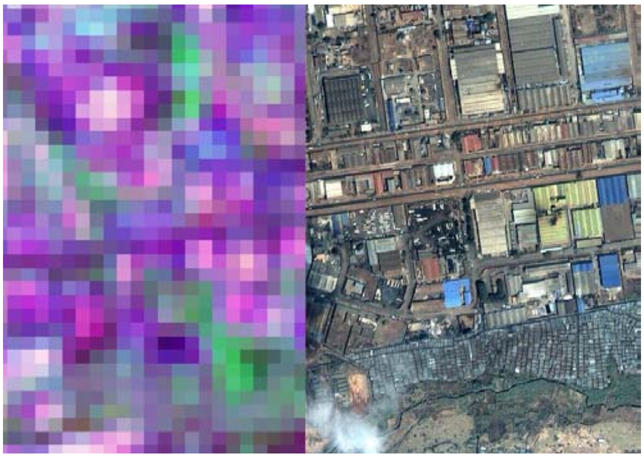


Figure 12 *Comparison between LANDSAT and IKONOS*

Using the IKONOS image, it is possible to vectorize the boundaries of the different informal settlements, which can be easily recognized in this area. On the same image the boundaries of the different settlements identified by the Matrix in 1993 were also positioned. The results are presented in the next figure.

Figure 13 *Evolution of the informal settlement's boundaries in the industrial areas from January 1993 to September 2000*

The main settlement has expanded in the northern area reaching its maximum in-filling possibilities. Other settlements have grown in the southern open space, but their surface occupancy ratio (R = total surface/ surface of the structures) is still lower than 0.5. In this area, the 1993 surface of 53.168 hectares has grown to 138.47 hectares, showing an increase of 260%, if all the areas are considered. Clearly at these soil occupancy levels, the ratio depends on how we consider the boundaries.

To avoid gross bias, the surfaces of the structures can be digitized and clipped from a 1 hectare polygon and compared. If randomly selected their ratio will give an idea of the age of the settlement, particularly if the layout of the structures was not planned. At the very end of the evolution the in-filling process will occur up to ratios as high as 0.60 or even more, 0.7. At these ratios and if the mean surface per dwelling is similar to that measured in Kibera, the densities may reach 2,000 or even 2,500 people/hectare.

The automatic classification of the LANDSAT image may be of some use in these situations, as open spaces are easily recognized. Superposing the informal settlements' boundaries may provide a clue to identify where the settlements may expand. In the next figure the results of such an approach are shown, and the area where expansion has occurred in the recent years are quite clearly visible, with some not affected at all probably because the owners of that specific land had other projects in mind. A more precise analysis, involving the status of the soil ownership may provide an idea of any future trend in the evolution of any specific area.

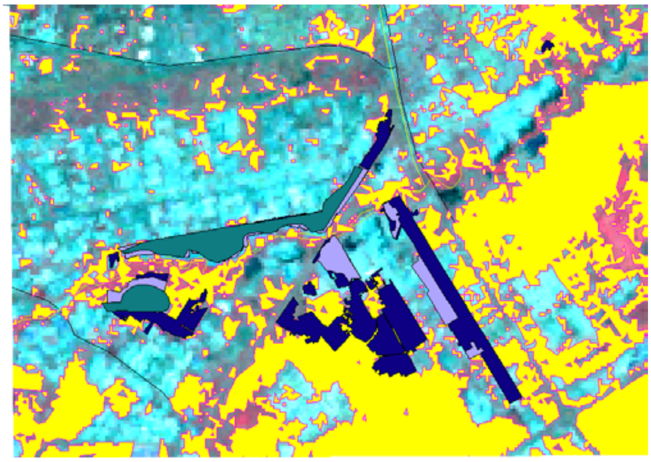


Figure 14 *Open space areas from an automatic classification of a LANDSAT image combined with vectorized boundaries of the main informal settlements of Mukuru (industrial area). LANDSAT image: 1996 and IKONOS image: 2000. Open spaces: yellow; informal settlements from 1993: purple; Nairobi topomap: grey; IKONOS 2000: dark blue.*

According to this expansion the population in the Mukuru area has increased from 65,280 in 1993 to almost 170,000 in 2000 if the 0.6 occupation factor and the same density/hectare than in Kibera are applied. This may be true for the "older settlements" but not for more recent ones, where the density is still quite low, close to 1,000 inh./ha.

Informal settlements' population dynamics: a calculated approach

Using population and surface data from the Matrix we can compute the density (people/hectare) for each informal settlement identified during that specific study. In Kibera, the surface has not changed significantly since 1993 and in 2001, but the density has changed. Using different growth rates, respectively 5%, 7.5% and 10% we can project the yearly increase of the population. In 2001, the estimates obtained from the ground surveys match the 10% growth rate per year. We can therefore assume that the population growth rate of the slums is close to **10%,** the value being the sum of the normal growth rate of the population (probably close to 4% per year) and the influence of the migration (in-filling).

A **densification** process is taking place. But there is a limit of this process and particularly in Kibera where the boundaries are fixed and no further expansion is possible. The density per hectare has doubled in Kibera in about 8 years, reaching what we consider the upper limit for a single-storey settlement, slightly higher than 2,000 people/hectare. Beyond this limit no further reasonable increase can be considered. At this density some services can be made available if the layout is carefully planned with roads, pathways, drainage and other essential services laid between the structures.

Having reached their maximum density the only other way to grow is by spatial expansion. Most probably, where land is available, both densification and spatial expansion may occur simultaneously. For instance the Makadara IS (Mukuru) have expanded by a factor of 200 to 260%, depending on how we consider these new settlements. But quite rapidly, and certainly in the oldest settlements, the densification has occured and has reached its maximum.

Fortunately, not all the settlements have had the same **starting density**. Many, and particularly those of the Dagoretti area, have had a computed density close to 400 in 1993 and will reach the 2,000 densification limit in 15 to 20 years. If we apply this growth rate to all the settlements, the entire population of the identified informal settlements can be projected, as is illustrated in the next figure:

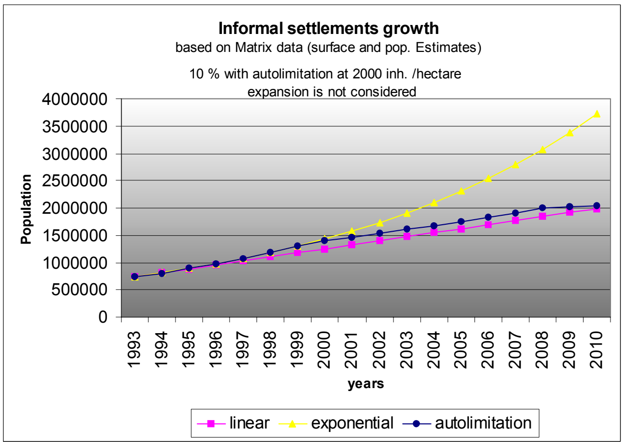


Figure 15 *Informal Settlement Growth based on Matrix Data (Surface and population estimates of 1993). Growth rate 10% with autolimitation at 2000 people per hectare. Expansion is not considered*

Using the surfaces of the Matrix and assuming that a densification process has taken place, the population of the slums of Nairobi is presently close to **1.5 million.** The total projected population figures are increasing but in **a linear** way and not exponentially.

The settlements that have reached their maximum densification will stop contributing to the growth of the population, like Kibera and Mukuru, but all others will continue. The phenomenon is visible when the settlements are considered separately as it shown in the next figure.

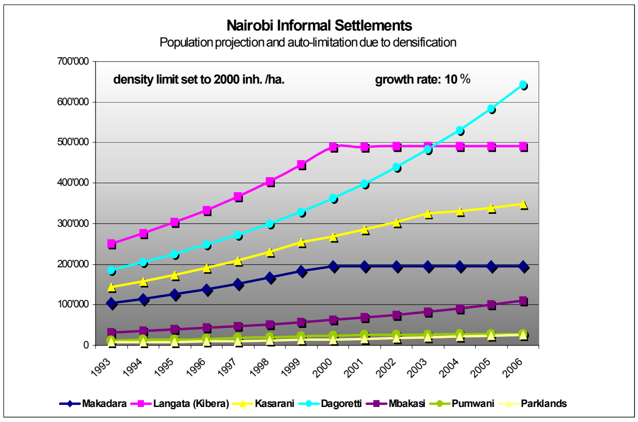


Figure 16 *Population projection by administrative divisions. Growth rate 10% with autolimitation at 2000 people per hectare. Expansion is not considered*

Unfortunately, the expansion factor can be considered only where precise images are available, that is where IKONOS images have been obtained.

Expansion

Where expansion has taken place and where the density is high, the 0.6 factor of occupancy can be applied. The population of the expanded area can be computed from the vectorized boundaries or from the total surface of the structures. In all the other areas, where the density is low, less than 0.6, all the structures must be vectorized as polygons. ARCVIEW allows to compute the total surface of the polygons and using the 0.36 people/m^2 occupancy rate (or future data obtained on each particular settlement from ground surveys), the population can be estimated, assuming that all the structures are used for habitat purposes.

This approach can be used for the informal settlements shown and vectorized in the IKONOS image and in other images of similar resolution. The results of the specific case of Kiambio, a new settlement close to the military airport are shown in the next figure. All the structures have been vectorized over the IKONOS image and their total surface computed using Arcview GIS software. The settlement shows that some sort of planning has been applied, particularly in the northern areas, followed by an in-filling unorganized densification process, visible in the central/lower part of the image, with structures less homogeneous than the majority.

Figure 17 *IKONOS image of the Kiambio informal settlement (Northeast of the military airport)*

Two methods can be used to compute the inhabited surface:

a) the global soil occupancy ratio (surface of the structures/total surface of the settlement) using several representative clips
b) the total surface of the vectorized structures

The result multiplied by the soil occupation density (number of people/surface) obtained from a ground survey, will give the total population estimate. One hectare polygon clips have been done on different parts of the settlement. The results are shown in the following figures.

Figure 18 a *Clips of the dwellings vectorized surface using 1 hectare polygons at two different locations for the Kiambio informal settlement (IKONOS image of 7 September 2000)*

Figure 18 b *Clips of the dwellings vectorized surface using 1 hectare polygons at two different locations for the Kiambio informal settlement (IKONOS image of 7 September 2000)*

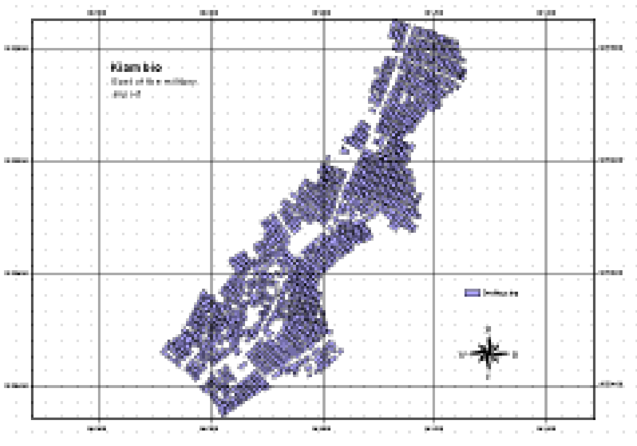


Figure 19 *Vectorized structures of the Kiambio informal settlement.*

From the first figure a total surface of 12.48 hectares has been computed from the boundaries. The two clips give a mean soil occupancy ratio of 0.52 (clip 1: 0.49 and clip 2: 0.57) and the inhabited surface calculated using this approach is 6.49 hectares.

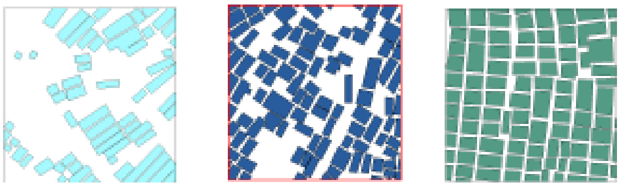
988 structures have been vectorized with a total built-up surface of 6.71 hectares. Assuming that the soil occupation density is the same as that obtained for Kibera, 0.36 people/m^2, the population estimate of this informal settlement was, at the date of the acquisition of the image, 23,369 and 24,169 respectively, with a density close to 1,925 inhabitants/hectare. The same operation can be carried out in all the informal settlements with the use of a high resolution image, either from IKONOS (without clouds) or using a low-cost mosaic of geo-referenced digital images, obtained by aerial survey[23].

23 See Sartori, supra ft.note 9

How informal settlements grow

A simple model of the growth of the slums can be outlined, depending on the density factor. If we clip a **one hectare polygon** in any area where settlements with the specific characteristics outlined previously can be monitored, the mean surface occupancy ratio can be easily computed from geo-referenced images.

Three different ratios are given below, with surface occupancy varying from 0.3 to 0.70. That means a population density varying from about 1,000 inhabitants/hectare to a maximum of 2,552. The last situation is probably quite exceptional. It is also possible that the size of the polygons may be slightly affected by the vectorization process, which may be particularly difficult in such areas, as we are working close to the limits of the resolution (1m).



R = 0.32
D = 1152 hab./ha

R = 0.50
D = 1800 hab./ha

R = 0.71
D = 2556 hab./ha

Figure 20 *Growth phases of an informal settlement. Clips from digitised polygons. IKONOS image - September 2000. Surface occupation 0.36 people per square metre*

An example of the evolution of an informal settlement can be simulated from an image of a layout of plots found in the eastern areas of Nairobi. Plots of land “planned” for construction can be identified on the IKONOS image, as is shown in the next figure. A tentative layout can be recognized but its shapes are poorly planned, leading in the near future to an unorganized informal settlement, when the in-filling and expansion processes have occurred.

Figure 21 *Plots of land ready for construction*

A simulation of such an evolution is given in the following figures where the building process of the structures changes with time, arbitrarily fixed, as we have not acquired the images. The initial planning intentions are quickly forgotten even if in some areas an organized layout can be observed. Areas like this are numerous and we do not know to what extent the concerned authorities have been involved in the planning process, how the necessary authorization for such major developments within the city boundaries have been obtained and if the essential services are part of the planning process.

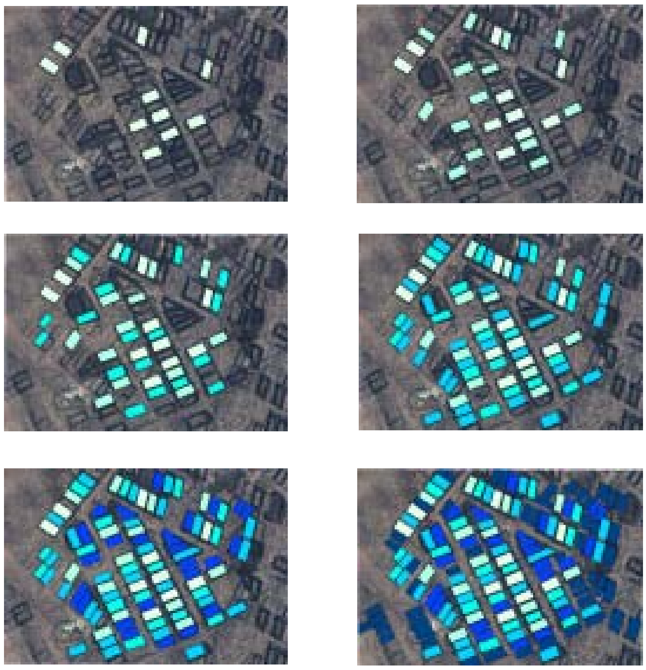


Figure 22 *Simulation of the evolution of a poorly planned area.*

What is clear is that there is an economic pressure to build houses, and they must be built at low costs. As indicated by many authors, the present legislation is not adapted to the prevailing situation of the city and neither to the country’s realities. A revision of the building legislation standards would be needed quickly, together with an acceptable soil occupation policy. The time left to reshape some of these informal settlements is short and soon the problems will reach levels beyond any control with epidemics, social unrest and crime at their highest values.

Data from displaced people or refugee camps clearly show that the mortality rate is directly related the soil occupancy rate. In crowded areas where the density of the people was close to 1 person/3m^2 of total available surface, the mortality rate increased from 1/10,000 people/day, considered as the upper acceptable limit before immediate intervention, to up to 2/10,000 people/day, where steps had to be taken to control the specific disease responsible for the epidemic pattern. Relocation to less crowded areas in a planned way had an immediate impact on the mortality rate.

The fast growth of the towns also mean an increase in the number of street children. They represent the visible part of poverty and have been born mainly in informal settlements. A study conducted in Eldoret on the health problems affecting different categories of children, show that those without proper shelter were also the most affected, implying that what has been outlined above is already a reality, with HIV, URTI (upper respiratory tract infections), gastro-enteric diseases, typhoid and skin diseases prevalence patterns much higher than the values of normal primary school children.[24, 25]

Conclusions

Remote sensing and particularly high-resolution satellite images (IKONOS 1m) are suitable for monitoring the shapes and growth of informal settlements, provided that cloud coverage does not interfere with the areas to be studied. The morphology and the surface of every structure can be computed after vectorization using GIS software, which provide essential information to understand how these informal settlements grow and can be used to assist planners in their task to organize the unorganized and to mould an acceptable shape for the new settlements. This is only possible if regular monitoring of the evolution can be performed. Satellite images may be too expensive to cover the total surface of a town in a regular way, but they pave the way for a comprehensive understanding of the importance of this phenomenon in the present trend of urbanization.

The population of informal settlements can be estimated from high-resolution images knowing the mean number of people per surface unit or per dwelling, at a relatively low cost. In such a densely populated and built-up environment, the collection of accurate information is only possible with the use of a suitable map, which can only be obtained with the combined use of GIS and remote sensing techniques.

If high resolution satellite images (IKONOS) provide precise information of the evolution of the very small, images with lower resolution (LANDSAT TM 25m) are still useful to monitor the yearly evolution of the built-up areas of large towns as they are also less costly. Unfortunately, the size of the pixel does not allow to distinguish between areas of similar reflectance. Furthermore, their use to monitor the growth of informal settlements is limited.

Examples of the possible use of such images are given for Nairobi, where the informal settlements host an estimated population of more than 1.5 million, representing more than half of the population of the town. The recent growth of some of the settlements of the eastern part of Nairobi could be monitored from an IKONOS 100km^2 image.

Like in other areas, the informal settlement population's density has increased from a mean 1,100 people/hectare to more than 2,000 people/hectare and even more, probably one of the highest ever observed in a human settlement, similar to those found in some displaced people's settlements or in unorganized refugee camps. High resolution remote sensing is now an affordable useful tool to monitor fast growing settlements, and its use will become increasingly popular.

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