An expanded assessment of risks from flooding in Luanda

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John Mendelsohn, Stephie Mendelsohn & Ndapewa Nakanyete

Introduction

Although Luanda has a relatively dry climate with average annual rainfalls of about 360 millimetres, occasional heavy falls of rain lead to flooding and fast flows of water down river courses and steep slopes. The flooding typically results in the inundation of homes and commercial properties, roads being closed to traffic for extended periods and an increase in disease associated with contaminated water, such as cholera, gastro-intestinal infestations and malaria. Torrents of water cause erosion which undermines the foundations of houses, as well as damaging roads, sewage and storm water drainage infrastructure.

An earlier assessment of the effects and risk of flooding focused on part of Luanda, notably the municípios of Cacuaco, Cazenga and Sambizanga. The results of that work, which was down in 2007 are presented in Appendix 1. The information in this new study expands the assessment to cover the whole of Luanda. In addition, cognizance is taken of the different types of housing in the city, since levels of risk and damage are much greater to poor communities that people living in homes that are more structurally sound and in areas where infrastructure is available to drain storm water.

Methods

The broader assessment of structural damage, risk of flooding and malaria was based on the following sets of data.

1. A digital terrain model of Luanda, obtained from *Shuttle Radar Topography Mission* (SRTM) data, used to highlight zones of steep terrain were high rainfall and surface runoff might lead to erosion and structural damage to buildings and other structures. The original data were obtained as an XYZ ascii file with 90 metres horizontal resolution. Using Global Mapper (version 12) these data were interpolated and used to extract three categories of slope:
   - Less 3 degrees, i.e. relatively flat
   - Slight slope between 3 and 10 degrees
   - Steep slopes of more than 10 degrees.

   The three slope categories were then converted into tif images, then ArcView grid files and finally ArcView shape files.

2. All streams and rivers and their adjacent floodplains was digitized to identify areas that are potentially inundated after heavy rain. The mapping was done from Quickbird satellite images taken in 2007 and 2008. Other areas susceptible to flooding were mapped off the same images and classified as isolated pools, borrow pits or lakes and marshes. The identification of pools was aided by an aerial survey conducted over part of Luanda in 2007, as described in Appendix 1.

   Isolated pools mapped as points which were then categorised into small, medium and large sizes. Buffer areas were then produced to reflect their relative expanses: 15 metre radii around small pools, 30 metres for medium ones and 60 metre radii around large pools. The borrow pits, lakes and marshes were mapped out as polygons.

3. A final set of the data were produced by combining all the stream and river, pools, borrow pits and lakes and marshes into one set of polygons around which a buffer area of 300 metres was mapped. This broad surrounding zone was used to as an approximate area in which malaria may be most prevalent since these areas are relatively close to the breeding sites of *Anopheles gambiae,*[1] the major vector of malaria in Luanda.

Areas of steeper slope, potential inundation and standing water as shown in (Figure x) were then analysed in relation to a set of data on population density. These density data are described in Appendix 2, and allow estimates to be made of the number of people living within risk areas. Estimates were also produced of the number of people within various risk areas living in different types of housing.

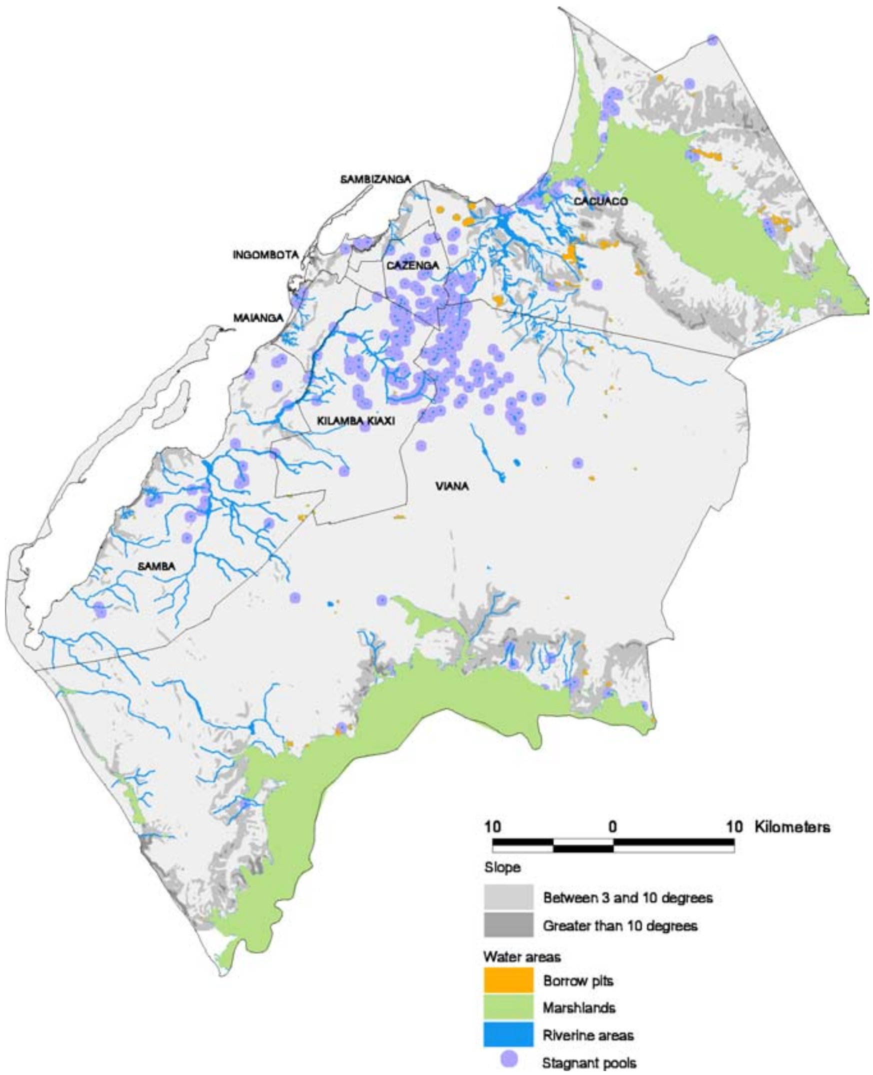


Figure 1. Areas of risk associated with flooding, slope and standing water in Luanda

[1] Areas of high mosquito abundance and mosquito distribution in urban areas have been shown to correlate with breeding sites this strongly effects the risk of malaria infection (Gimnig J.E., Hightower A.W., Hawley W.A., 2006. Application of geographic information systems to the study of the ecology of mosquitos and mosquito-borne diseases. *Wageningen UR Frontis Series, 9,* 27-39.

Results
The main results are provided in the following table, which shows the number of people estimated to live in each type of risk area in relation to the type of housing concerned.

Type of housing	Potential 'flood area'	Potential 'malaria area'	Slope more than 10^o	Slope 3 -10^o
Rural	10,600	66,000	2,000	26,300
Owner-built on planned sites	9,800	184,000	0	4000
Bairro Popular	100	11,300	0	0
Social housing zones	1,300	19,500	0	2,400
Old urban centre	100	2,700	1,600	24600
New suburbs and condominiums	2,900	53,500	500	8500
Zona Industrial	0	300	0	0
Old musseques	*53,000*	*901,000*	*23,000*	*282,000*
Transitional musseques	*5,500*	*190,000*	*1,100*	*16,500*
Organized musseques	*4,800*	*159,000*	*500*	*16,700*
Peripheral musseques	*43,100*	*613,000*	*3,700*	*196,000*
TOTAL	**131,200**	**2,200,300**	**32,400**	**577,000**
Total in musseques	*106,400*	*1,863,000*	*28,300*	*511,200*

A total population of about 131,200 people was estimated to live within potential flood risk areas surrounding rivers, pools and borrow pits, mainly within Cazenga, Cacuaco and Kilamba Kiaxi (Figure 2). Of these people, approximately 106,400 live in musseque housing which is characterized by its informal nature and high population density, flimsy building construction and general absence of services, such as safe water, sanitation and refuse removal.

A total population of 577,000 people was estimated to live in the gradient zone between 3 and 10 degrees while only 32,400 people were estimated to live in steep gradient zones of greater than 10 degrees. The majority people in both slope categories live in Old Musseques; 282,000 and 23,000 respectively in areas of moderate and steep slope. Areas most affected by slope with high densities of people are in Sambizanga and Mainga (Figure 3).

The broad and approximate area where inhabitants may be more susceptible to malaria was estimated to house about 2,200,300 people, of which about 1,863,000 are inhabitants of informal low-income musseque areas. These figures are of course rough estimates, but the concentration of high densities of people in certain areas (Figure 4) could be used to target activities to reduce the risk of malaria infection.

Since these broad areas are also within reasonable proximity of flood and standing water, they may also be used to focus on places where other water-borne diseases may be prevalent.

Figures 2, 3 and 4 focus on the most densely populated areas of the city and where low-income housing with poor services is concentrated. However, the same data on population density housing types and risks from flowing are available for the whole province and other areas can therefore be examined in detail.

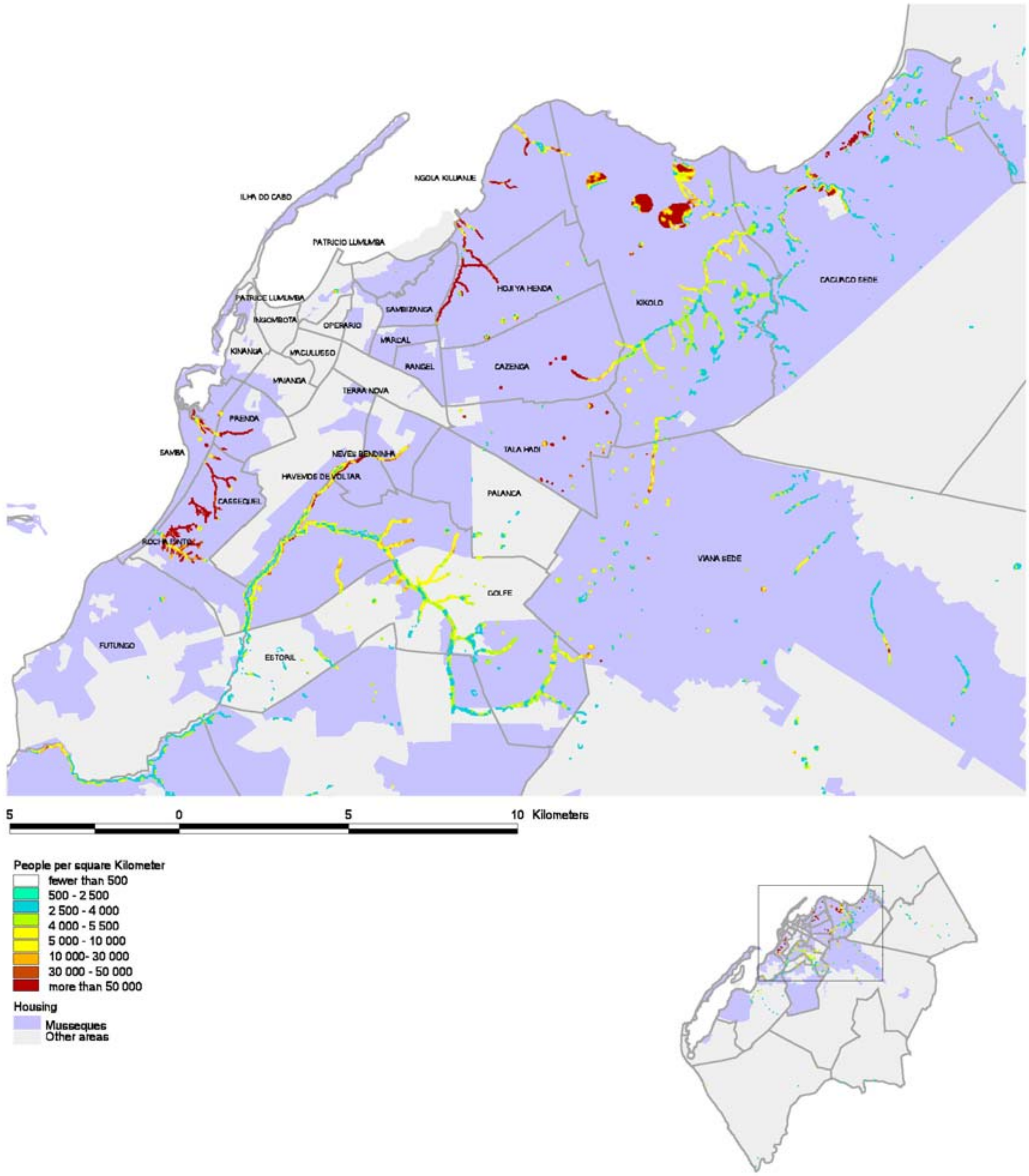


Figure 2. Densities of people in areas most likely to be flooded after heavy rain, which are around permanent pools of water, borrow pits, river flood plains and lakes and marshlands. The map focuses on the most densely populated areas, outside of which problems of flooding affect relatively few people.

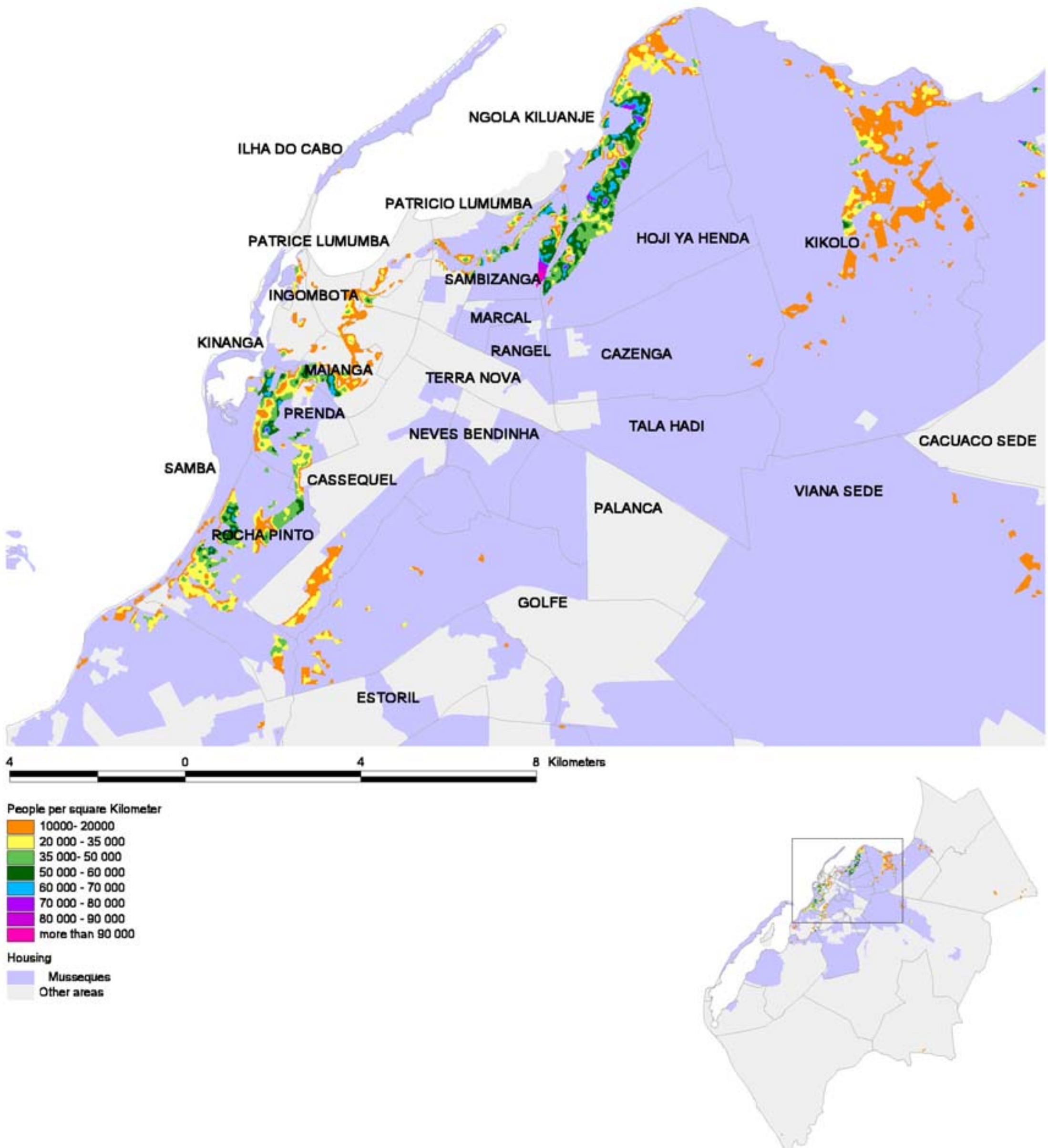


Figure 3. Densities of people in areas where the slope is greater than 3 degrees.

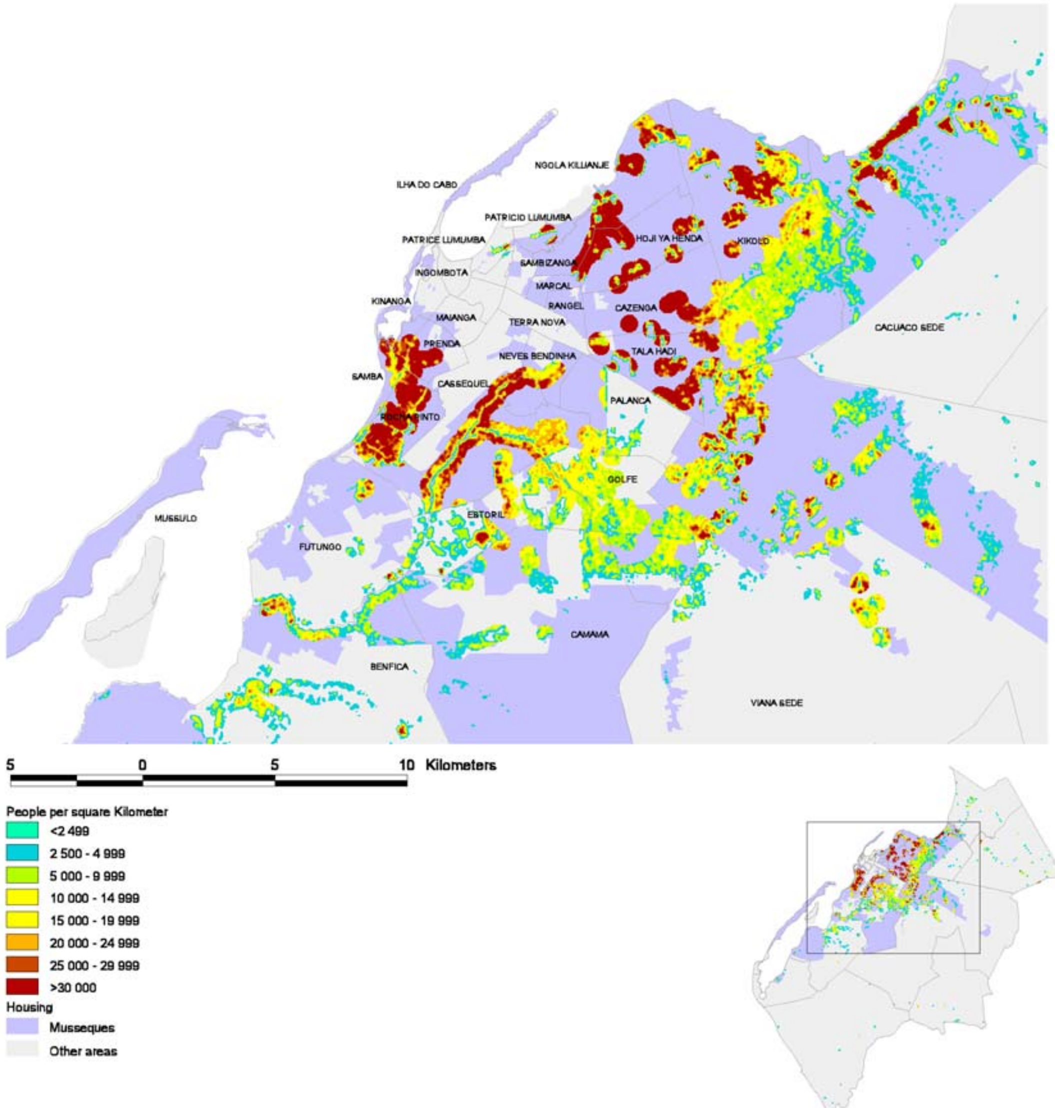


Figure 4. Densities of people in areas within 300 metres of standing water in pools, along rivers and in marshes and lakes.

Appendix 1:

An assessment of flooding in Luanda: risks and damage

2007 report

Introduction

Exceptional rains during the first few months of 2007 prompted the need to assess the consequences that residents of Luanda face as a result of flooding, largely as damage to housing, road blockages and increased disease. This report addresses these aspects in three ways:

1. From an overall assessment of the extent and risk of flooding in an area of 520 square kilometres covering most of the city.
2. Through a more detailed assessment of flood damage in relation to population density in the *municipios* (municipalities) of Cazenga, Cacuaco and Sambizanga.
3. From information collected in a survey of 2,227 households located in or close to areas that had suffered the immediate consequence of flood waters in Cazenga, Cacuaco and Sambizanga.

The areas covered by the three sets of data and assessments are shown in Figure 1.

Methods

Overall appraisal of flooding across Luanda

The broader assessment of damage and the risk of flooding was based on the following sets of data.

1. A digital terrain model of Luanda, obtained from Alvarion in Israel, which was used to highlight zones of steep terrain where high rainfall and water flow might lead to severe erosion and the collapse of buildings and other structures. The original data were obtained as an XYZ ascii file with a 50 metre horizontal resolution, which was the converted into ArcView grid and vector files. The Neighbourhood Statistics (Range variable within 250 metres) function of ArcView's Spatial Analyst was used to classify zones of differing slope.
2. A map of drainage lines digitized by Development Workshop (DW) staff was also used to indicate areas where erosion can be expected, and where flat areas adjacent to rivers and streams might be inundated by high water. The rivers were categorized into broad and narrow drainage lines, so that indicative buffer zones of 100 and 25 metres, respectively, could be mapped on either side of the centre lines of the rivers.
3. Areas where flood waters remain visible. There were partially compiled during an aerial survey over part of the city on the 7th of March 2007. The survey followed a pre-planned survey route and was conducted by five observers in a helicopter. Two observers photographed areas of flooding while the other observers helped scout for signs of flooding, navigate along the route, and record positions where photographs were taken. The positions of the photographs were later plotted in an ArcView shape file, and each photograph was classified as showing pools or sheets of standing water, road damage, or water in floodplains along drainage lines. All the pre-planned flight lines across the city could not be covered as a result of budget limits and restrictions imposed by civil aviation authorities (see Figure 1).

   However, photographs taken during the survey were further helpful in identifying other areas of standing water that were visible in Ikonos and QuickBird satellite images purchased by DW and in those available from Google Earth. About 132 such patches of standing water were thus mapped off the satellite images, in addition to about 150 separate areas of standing water that were photographed during the helicopter survey. Finally, areas of flood damage were identified and mapped by the team of enumerators that did the household survey (see below).

Examples of flood areas identified from the aerial survey (top) and those to be seen in satellite images provided by Google Earth. Note the abandoned houses with no roofs in both images.

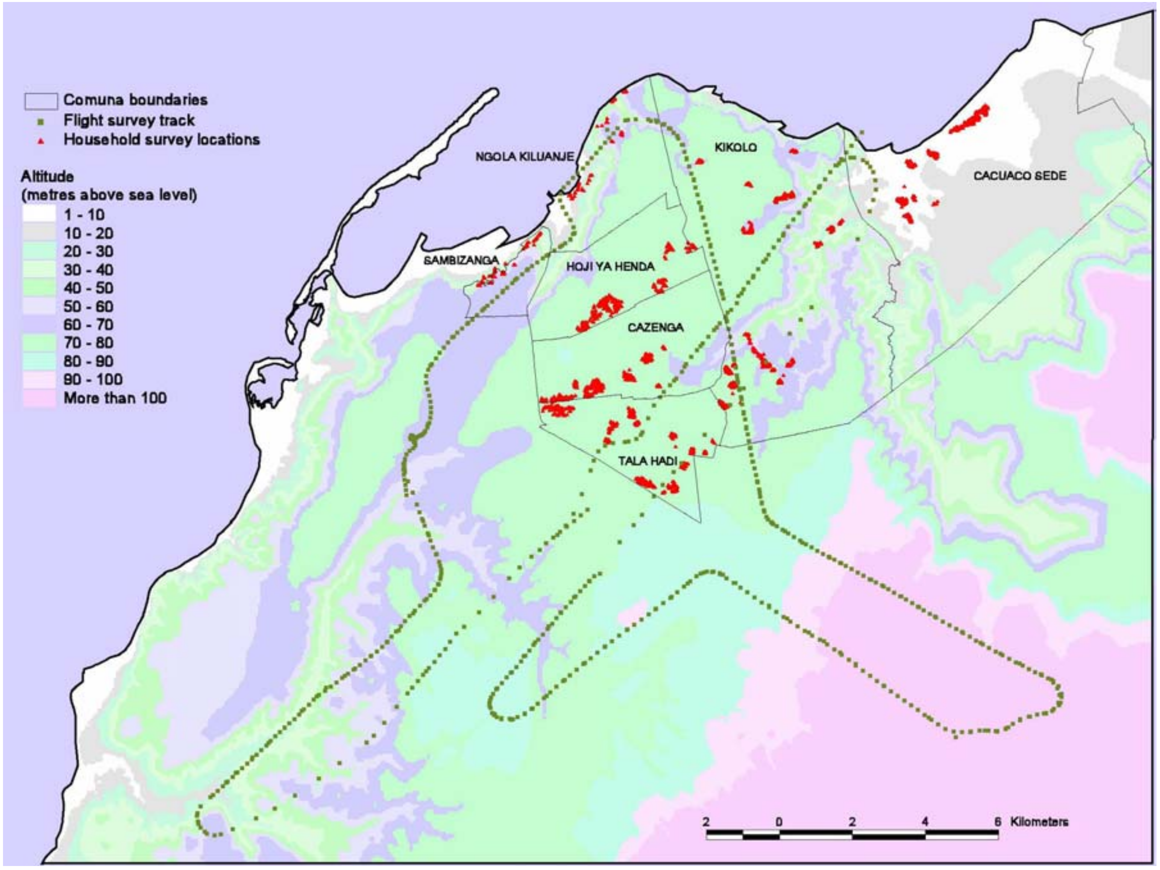


Figure 1. The area on which this assessment of flooding focused, the course flown during the aerial survey on 7 March 2007, the boundaries of comunas *in the* municipios *of Sambizanga, Cacuaco and Cazenga and the locations of the household survey.*

Household survey
A total of 2,227 households were surveyed between May and September, 2007. This was several months after the main flooding in January, February and March of 2007. The households were all within the *municipios* of Cacuaco, Cazenga and Sambizanga and were distributed among six *comunas* as follows:

Table 1. Number of households surveyed in each *comuna* in the *municipios* of Cacuaco, Cazenga and Sambizanga

Municipio	***Comuna***	**Number of households surveyed**
Cacuaco	Cacuaco Sede	403
	Kikolo	334
Cazenga	Cazenga	389
	Hoji Ya Henda	315
	Tala Hadi	639
Sambizanga	Ngola Kiluange	74
	Sambizanga	73
Total		2,227

The survey aimed to collect information from households that were likely to have been affected by flooding. The enumerators therefore selected areas where damage was known to have occurred, and also selected homes that appeared to have suffered from flood damage. As a result of the selections much of the survey data is **not** representative of households within the broader areas covered by the *comunas*. For variables reflecting structural damage, the survey results are also **not** representative of all households close to areas of flooding because houses that had visible signs of damage were selected. The biased nature of sampling must therefore be borne in mind.

Cacuaco, Cazenga and Sambizanga
The area covered by this work in the three *municipios* comprises 127.6 square kilometres. About 2.08 million people live in the area, a figure derived from the estimation of population densities. Almost all these people reside in informal or low income housing. Over and above the large number of people prone to the direct effects of heavy rain, the consequences of flooding merit special attention because large pools of water accumulate and remain stagnant in shallow depressions in which there are also substantial accumulations of domestic rubbish and other waste. Furthermore, several major arterial roads transect the three *municipios*, with the result that flood waters disrupt the movement of both residents and people living elsewhere.

Information was derived from the aerial survey, the use of satellite images and household survey (as described above), and discussions with administrative officials and other local informants. In addition, population densities and the number of people most affected by local flooding were estimated by digitizing and calculating the areas of all roofing visible in QuickBird images. A figure of 6.6 square metres of roof per person was then used to estimate the number of residents in each home. The figure of 6.6 square metres was obtained from data collected by the survey team at 482 homes where both the number of residents and roof area (in square metres) was reported.[2] Using the estimated number of people living 'under' each area of roofing, estimates of population density across the whole of Cazenga were derived through the use of the Density function in ArcView's Spatial Analyst; using a distance of 50 metres and the simple method for estimating densities.

RESULTS

Overall assessment of flooding in Luanda

Four main kinds of direct damage were identified.

- Flooding of homes and commercial premises. Floodwaters generally disappeared from flatter areas of sheet flooding after several days or a few weeks, whereas homes close to depressions, often filled with stagnant water, remained flooded for much longer.
- Structural damage (in Portuguese *desabamento*) to buildings. While comparatively few homes were affected, the costs of repairing or replacing those that were largely destroyed or damaged were substantial.
- Road blockages, most of which lasted a few weeks but caused severe disruption both locally and to the broader flow of traffic in the city.
- Increased incidence of diseases, mainly malaria, cholera and gastro-intestinal infections. Some immediate deaths were reported, but the debilitating effects of these diseases are likely to have lasted many months after the heavy rains.

[2] In fact, there was an average of 8.5 square metres of roof area per resident in the 482 homes. However, the figures were skewed by a small number of homes that had few residents living within large houses with extensive roofing. For this reason, the median figure of 6.6 square meters of roofing per person was adopted as providing a more reasonable estimate.

The remnants of sheet flooding as pools of water lying in roads. The houses around these roads would have been flooded after the heaviest rains.

A typical stagnant pool surrounded by massive accumulations of rubbish and growths of algae on the water surface

Many houses built along steep slopes in Sambizanga suffered structural damage

Blockages along drainage lines led to surges of water causing severe erosion which undermined the foundations of nearby homes.

The main results of this work for the greater part of the city are depicted in Figure 2, which shows that the majority of ponds of standing, stagnant water images (shown as dots in the map) are in the flatter areas away from the coast in the *município* of Cazenga and further south in Viana and Kilamba Kiaxi. Clay soils predominate in these flat areas, whereas sandy soils through which water drains more rapidly occur closer to the coast. It is in these flat, clay areas that most roads were flooded and where most disease attributable to standing water was to be expected. In addition to the standing water found during the aerial survey or on satellite images, other kinds of inundation are reflected on the map as places identified as sheet flooding, structural damage, and areas where there was a combination of structural damage and sheet flooding, and borrow pits (locally called *buraco*). These old excavations, from which building sand had been removed years previously, are now often inhabited and pools of water lie at the bottom of pits. Many of the borrow pits have steep walls, immediately above or below which homes have been built.

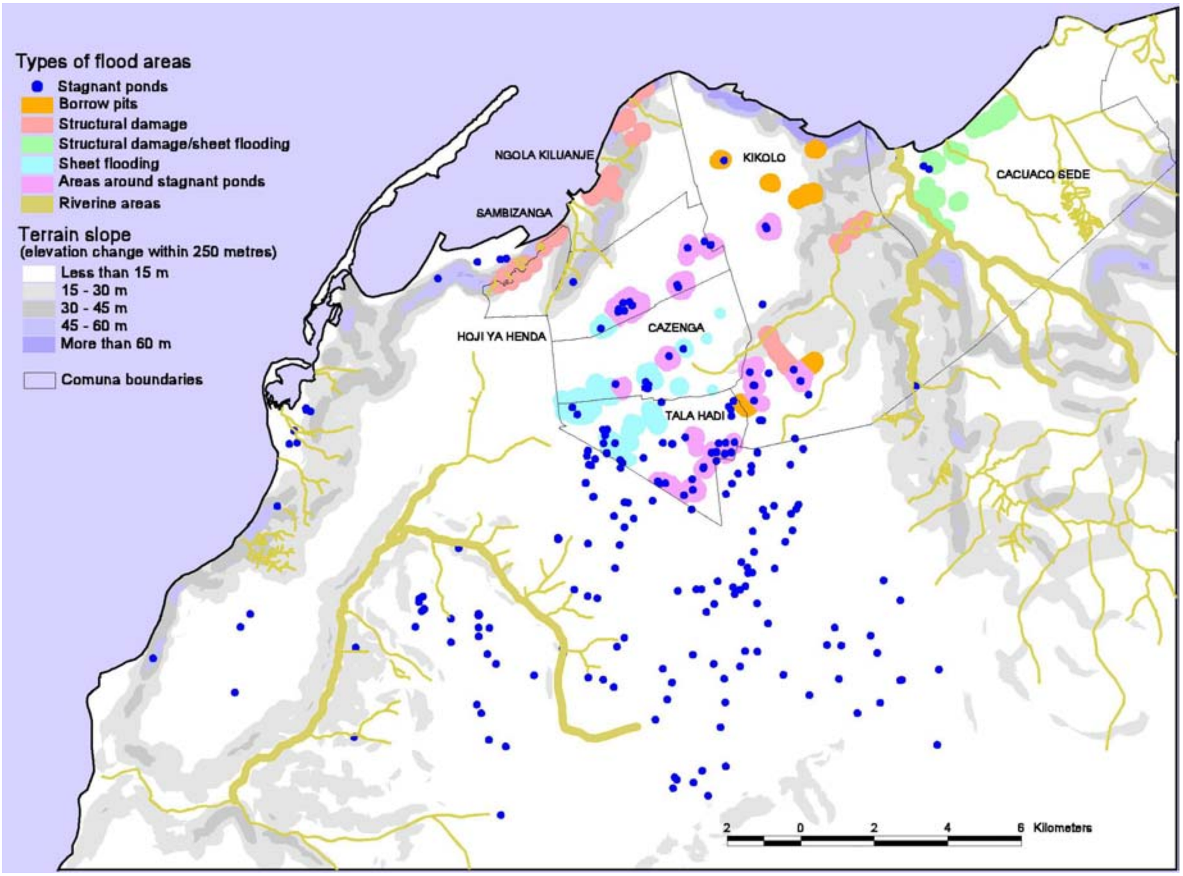


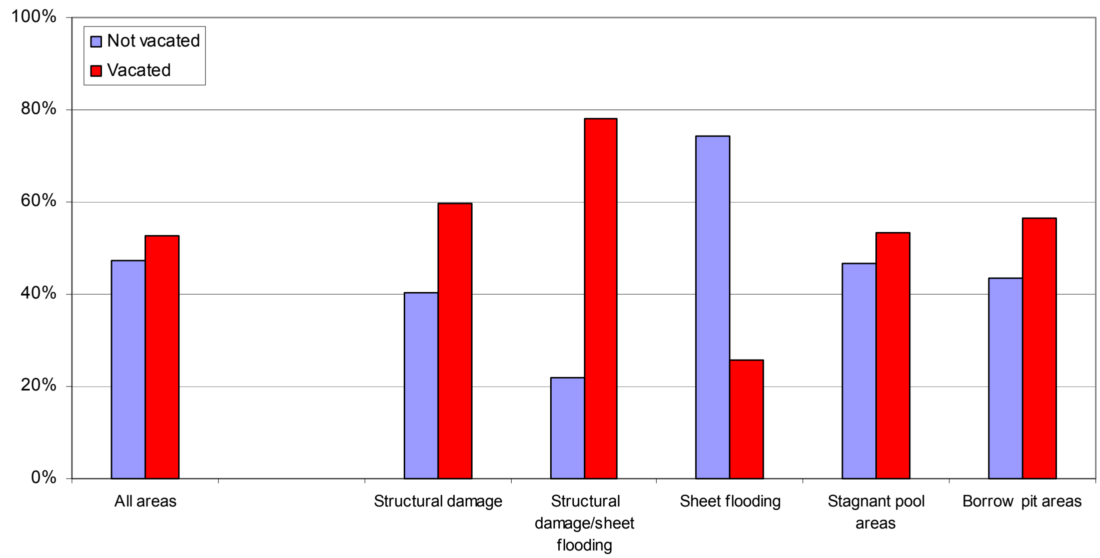
Figure 2. An overall assessment of the locations where flood damage occurred early in 2007, and where flooding is likely to be most hazardous.

Structural damage mainly occurred in places of steep relief, as in Sambizanga, or where homes had been built close to rivers or man-made drainage canals, especially where the drainage lines had been blocked by garbage. This caused water to dam up and then surge down hill once the blockages gave way to the pressure of accumulated water. As would be expected, most homes that were physically damaged were ones with rudimentary foundations and flimsy walls. A combination of sheet flooding and structural damage was observed in Cacuaco where some homes were flooded in low-lying flat land near the coast. Other structural damage occurred to houses lining the many small drainage lines that transect the coastal plain.

It would appear that relatively few homes have been built (and were thus flooded) in the broader river valleys in Luanda. Most damage from flooding along the many rivers and streams in the eastern and south-western areas of the city were likely to be structural as a result of erosion of the banks of the drainage lines.

Household survey results
Each household survey area was classified according to the kind of flooding to which it had been exposed (see Figure 2), and the analyses that follow are based largely on that classification and comparisons between the *municípios*.

More houses were vacated as a result of flooding than those that remained occupied (Figure 3). This was true for all types of flood areas except for sheet flooding, presumably because water levels were lower than elsewhere and these homes suffered less structural damage (Figure 4). Of those houses that were vacated, 17% were left for less than 5 days, 19% for between 5 and 15 days, 12% for 15 to 30 days, and more than half (53%) for more than a month. These percentages did not vary significantly between *municipios* or types of flood areas.



.Figure 3. Percentages of surveyed homes that were vacated or that remained occupied after flooding.

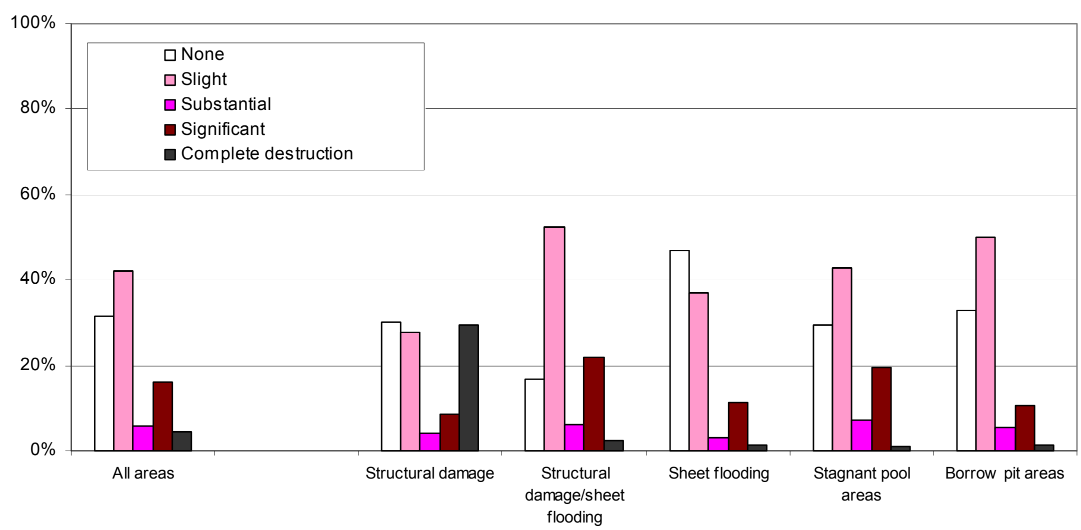


Figure 4. Percentages of surveyed homes that reported different degrees of damage to their property as a result of flooding.

Deaths were reported in 49 (4%) of all houses surveyed, but there was no discernible trend to indicate that more deaths occurred in association with certain kinds of flooding. In response to the question of whether members of households fell ill as a consequence of the floods, about 65% reported yes, and 35% said no. The highest percentages of disease were reported in homes around pools of stagnant water (74%) while the lowest was in areas affected by structural damage (48%). This may be due to the fact that most structural damage was in Sambizanga, where only 41% of households reported flood-relate disease compared to 62% and 69% in Cacuaco and Cazenga, respectively (Figure 5).

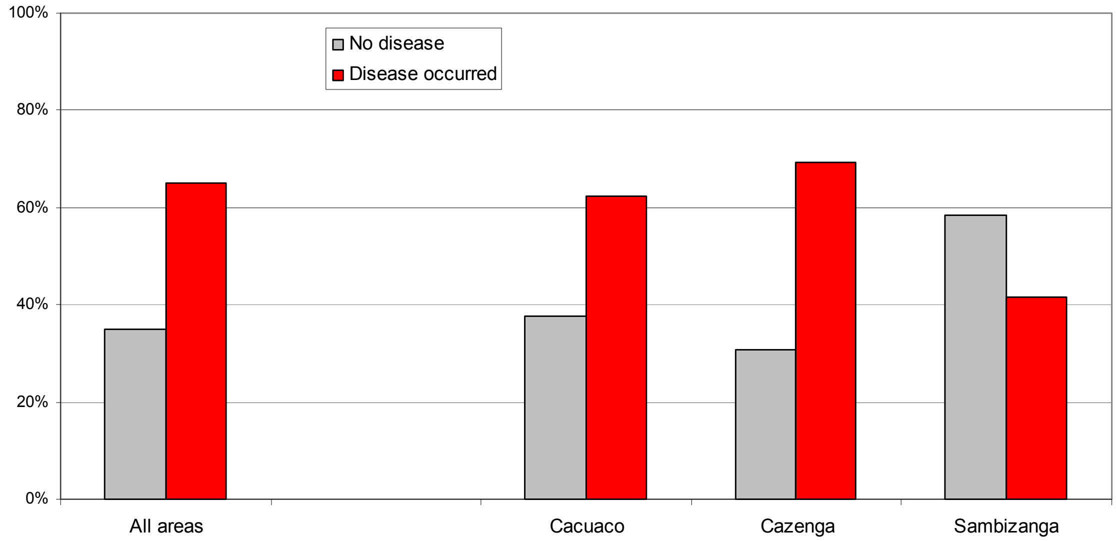


Figure 5. Percentages of households reporting disease due to flooding.

Three main illnesses were reported: malaria (69%), cholera (16%) and diarrhea (in 17% of all homes) (Figure 6). In addition, 31% of households said that people had suffered from other diseases, such as respiratory problems, flu and colds and skin diseases. The greatest difference in occurrence between the *municipios* was for malaria, which was reported in 48% of homes in Cazenga, 43% in Cacuaco and only 25% in Sambizanga. This suggests that it was the difference in malaria affections that caused the lower overall incidence of disease in Sambizanga. It is also probable that mosquitoes carrying malaria are more abundant in Cazenga and Cacuaco where there are many more pools of stagnant water (Figure 2).

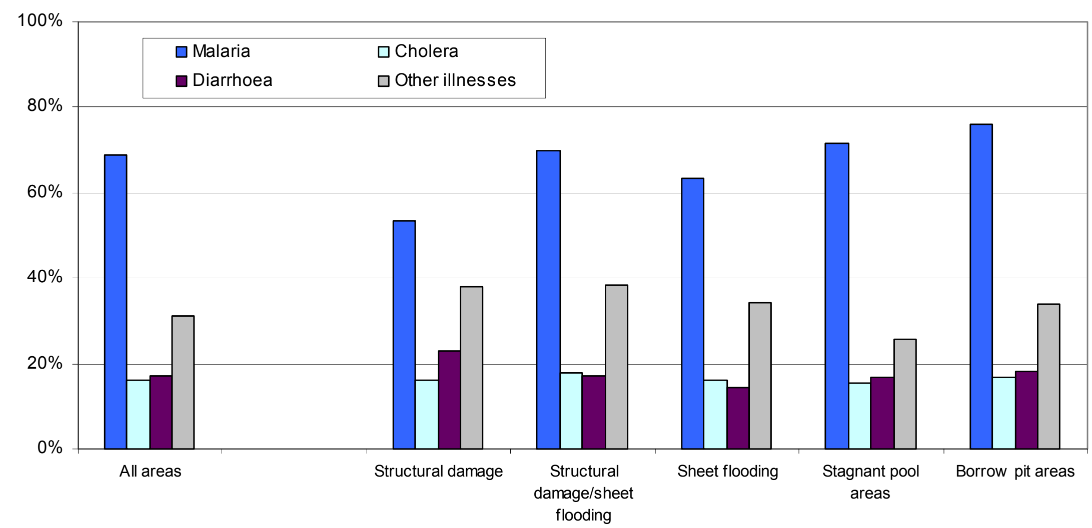


Figure 6. Percentages of households reporting the occurrence of malaria, cholera, diarrhea and other diseases as a result of flooding.

While excessive amounts of flood water were obviously a problem, the consequences of flooding are aggravated by (a) the volume of garbage in the city and (b) poor sanitation, especially in the informal *musseque* settlements. As mentioned above, massive volumes of refuse clog drainage lines, and the large and amounts of organic waste in stagnant pools must contribute to these pools of water being reservoirs of disease. This includes faecal material, since 22% of all households were noted as not having any toilet facility. People in these homes are reported to normally defaecate in plastic bags which are discarded with other domestic waste, which is normally placed on the street (Figure 7).

For example, 86% of households had no rubbish removal system, and of those having no system for removal: 57% and 39%, respectively, either placed their rubbish in the street or burnt it in the street. The remaining 4% of homes deposited their refuse in containers.

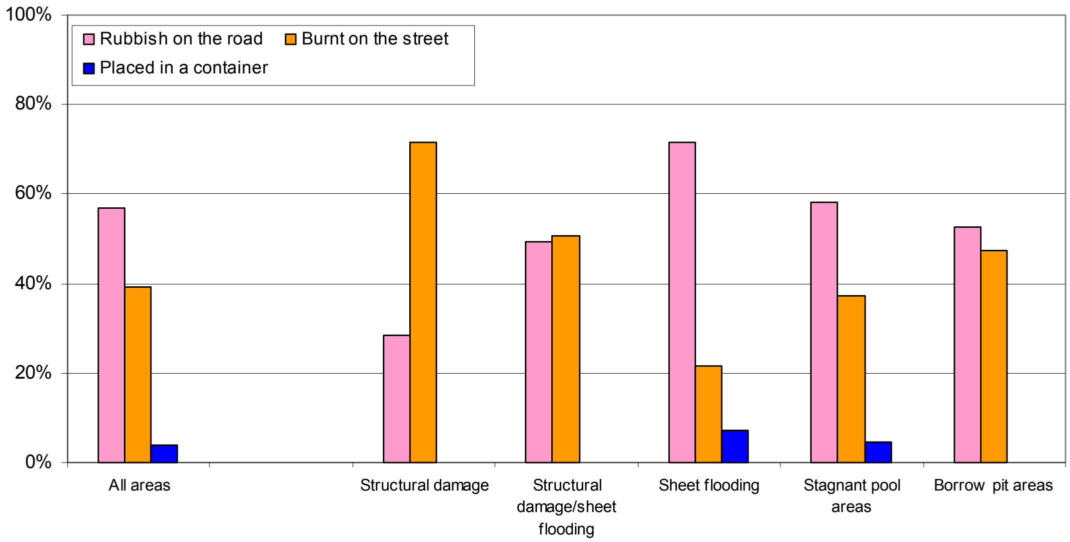


Figure 7. The percentages of households associated with different types of flooding depositing their household rubbish on the street, in a container or burning it on the street.

Mounds of rubbish being burnt along a road, a method used to dispose of domestic waste by 39% of the homes surveyed.

Returning to the small number of households that do have a rubbish removal system, all of these were in Cazenga, which is the only *município* where a few homes were recorded as having toilets linked to a piped sewage system. A small number of households in Cazenga were also the only ones that reported having their own water supply system, all other homes obtaining their water from public taps or tanks owned by water vendors.

Cacuaco, Cazenga and Sambizanga
As mentioned earlier, six *comunas* in these *municipios* were selected for additional study because so many people live there: over two million. Most homes belong to people who are not well off, with the result that they may not have ready access to services and facilities that would protect them from disease and other effects of flooding. In addition, the flat landscape covering much of Cazenga *municipio* and Kikolo *comuna* results in extensive sheet flooding and the accumulation of water standing in stagnant poolsfor long periods. For example, many of these pools still contained substantial amounts of water in October 2007, which was at the end of the dry season and many months after the heavy rains earlier in the year.

Figures 8 and 9 present the main assessments of risk in relation to population density for areas prone to sheet flooding and for areas that surround stagnant pools, respectively. Estimates are given on the maps for the number of people that live within those areas, thus making it possible to identify places where more people are at risk than others. An estimated 237,000 people live within all the areas of sheet flooding in Figure 8.

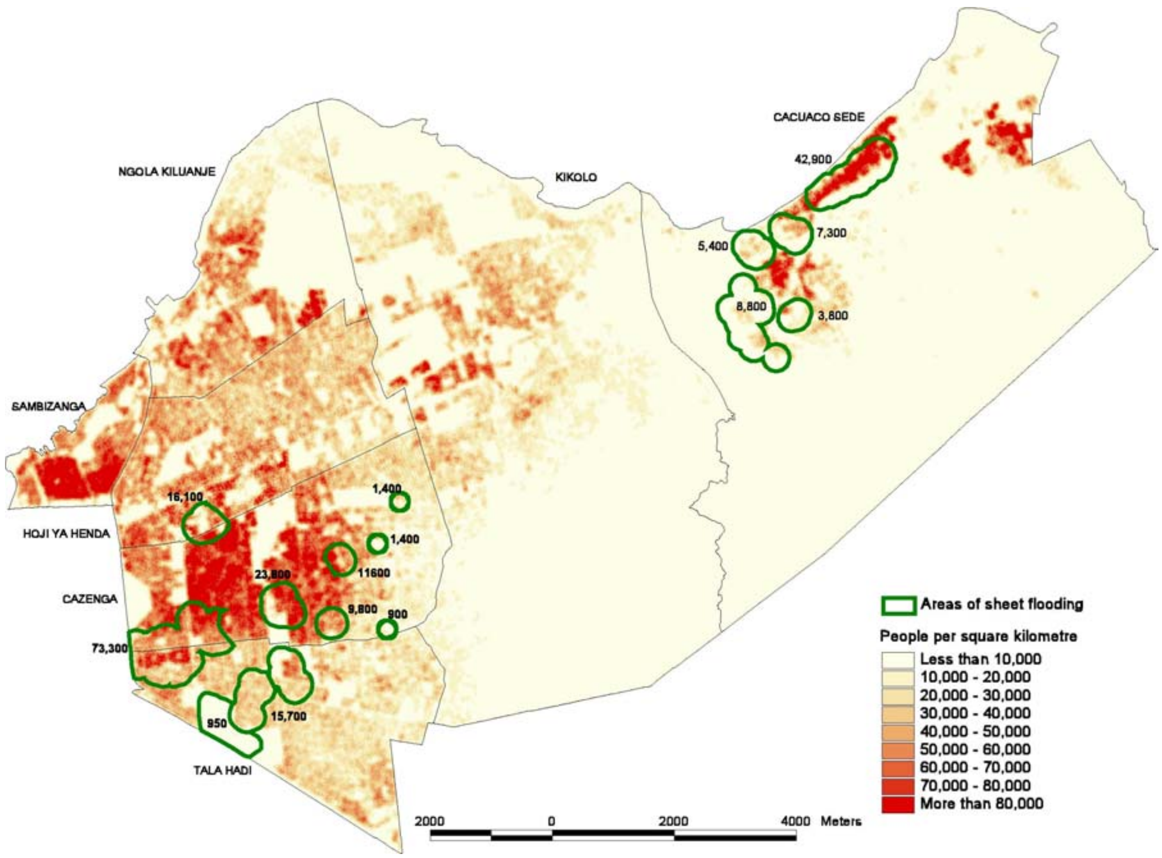


Figure 8. Population densities, the boundaries of comunas *and estimates of the number of people living within each area of sheet flooding.*

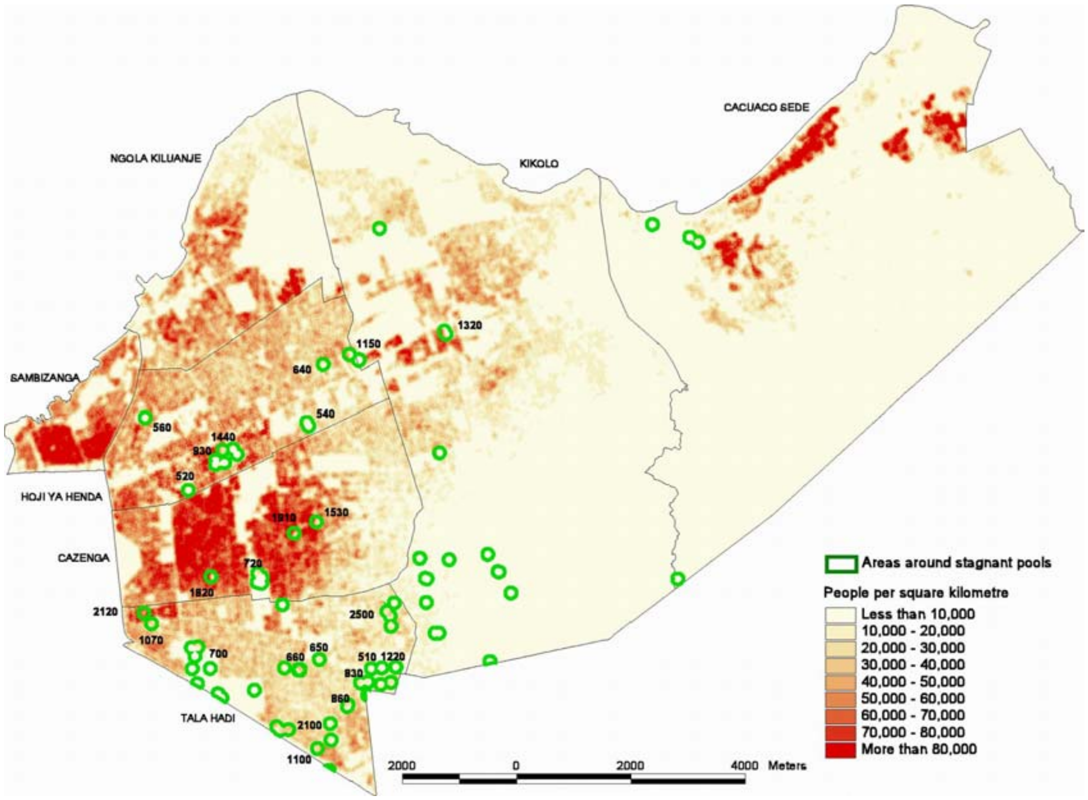


Figure 9. Population densities, the boundaries of comunas *and estimates of the number of people living within 100 metres of pools of stagnant water.*

A total of about 33,600 people live within the surrounds of stagnant pools shown in Figure 9, which only shows population estimates for those areas where there are more than 500 people. While it may be more difficult to diminish the effects of extensive sheet flooding, impacts to people living in areas close to stagnant pools would be easier to reduce, and the information given in Figure 9 could be used to prioritize pools for immediate remedial action. For example, more than 20,000 people would benefit if measures were taken to fill-in the 13 pools which are each surrounded by more than 1,000 people.

Finally, Figure 10 provides a comparison of population density and areas close to river drainage lines and those with steep gradients where structural damage is most prevalent. The only area where large numbers of people live in steep areas is Sambizanga.

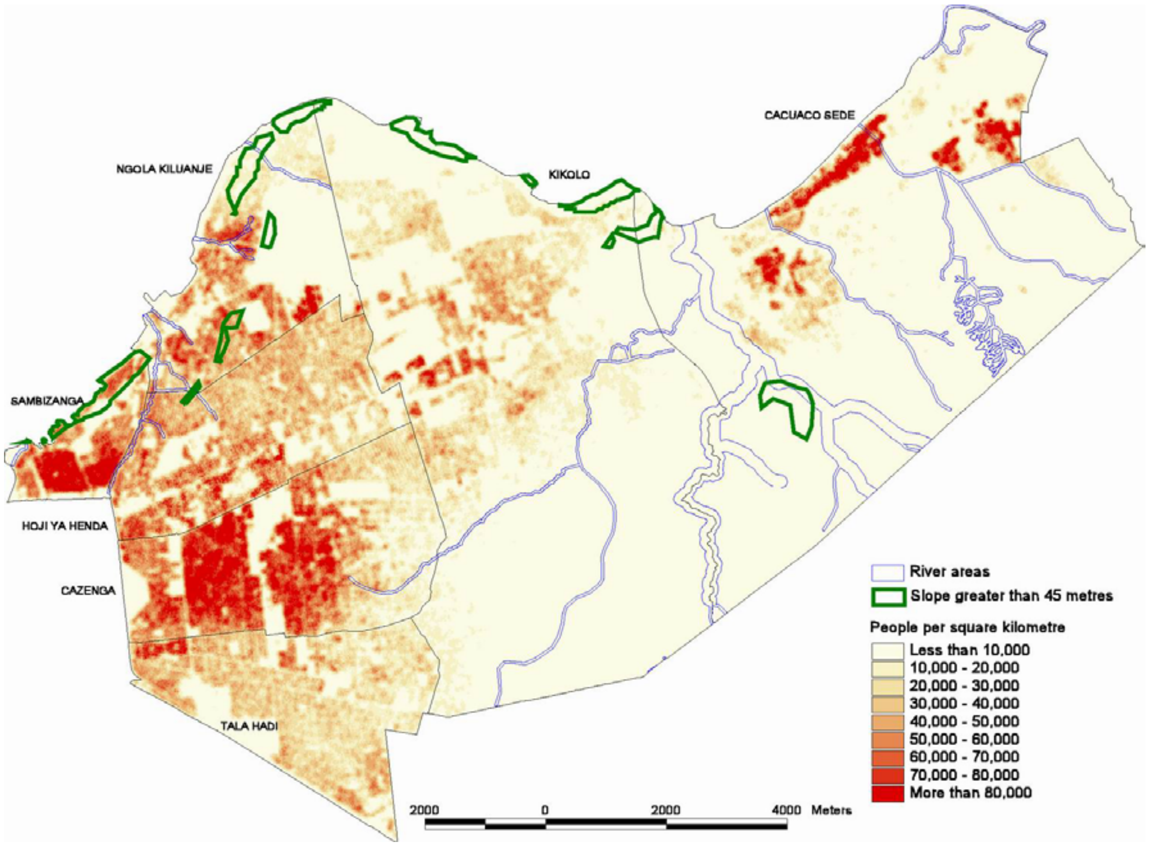


Figure 10. Population densities, boundaries of comunas*, areas surrounding rivers and streams and places where slopes change more than 45 metres within a distance of 250 metres.*

CONCLUSIONS

This study provides a first assessment of the impacts and risks of flooding in Luanda, especially within the *municipios* of Cazenga, Sambizanga and Cacuaco. However, much more information is needed for other areas of the city, and especially on the effects of road blockages. This was an aspect that could not be included in this study. While the heavy rains were unexpected and caused substantial damage of the kind described in this study, it seems obvious that the impacts of flooding were exacerbated by poor urban planning and poor maintenance. Indeed, it could be argued that it is really the effects of bad planning and maintenance – rather than flooding – that caused much of the damage.

For example, with better planning (and control) many informal and structurally weak houses would not have been built in places where they were vulnerable to flows of water or severe erosion. Likewise, better maintenance of drainage lines would have enabled much of the storm water to flow away rapidly. But more than anything else, it is probably the lack of sanitation and garbage removal that aggravated the impacts of flooding, particularly around the large stagnant pools. The cost of filling in these pools would seem to be low, but the benefits are likely to be considerable. The filthy nature of the pools is hard to describe, and it is also difficult to know the volumes of organic waste, faecal material and even inorganic poisons that have settled in these depressions. I hope the last photographs in this report give a better idea of their condition, and the circumstances under which nearby residents live.

Years of rubbish are piled up in this pond of stagnant water (top) while children use sheets of cloth to net tiny fish and shrimps from a pool that remains filled with water months after the heavy rains early in 2007.

Appendix 2:

House, population density and indicator mapping in Luanda:

Satellite images

New Quickbird images taken between 2007 and 2009 have been acquired for the whole province. Most of the images were taken in 2008. One small area of Kifangondo and Funda in Cacuaco has not been photographed, but we should get the new image for that area in the next 2 or 3 months. Few people live in that area and so it has little effect on our datasets now.

The georeferencing of the new images is not consistent, with the result that there are differences of 10-40 metres in some areas. This should be fixed at some stage, but is not a problem for current mapping purposes.

House mapping

Three approaches have been used to map houses and people in Luanda:

1. In areas of very high density of single-level houses, we mapped areas of roofing visible in the satellite images. This method was adopted because it is usually impossible to identify individual houses, the edges of the roof on one house often being right next to the edges of the roofs of its neighbours. The resulting sets of data are polygon shape files for each of roofing, and we have calculated the area (in square metres) of each mapped roof.
2. In areas where individual houses can be identified more clearly we have mapped each house as a dot, and so the resulting data sets consist of point shape files.
3. The boundaries of apartment blocks or predios were mapped as polygons, and the number of apartments in each predio has been estimated by multiplying the number of levels or floors with the number of apartments in each level. The number of levels and apartments was counted by enumerators who visited each apartment block.

Number of people per house

Two methods are being used to estimate the number of people mapped:

1. An estimate was obtained of the number of square metres of roofing per person from data collected at 482 homes where both the number of residents and roof area (in square metres) was reported. Processing of these figures gave a figure of 6.6 square metres of roof per person[3]. The homes were informal structures in Cazenga, Sambizanga and Cacuaco.
2. For houses mapped as points and for apartments, we used the following estimates of the number of people per household: 5 people per apartment, 6 people per house in urban housing types, and 7 people per house in all other housing types.

Typology

All areas of Luanda have been mapped into different zones. This was done from the satellite images and informants were then requested to identify and categorize the type of development. The zones focus largely on types of housing to reflect different socio-economic conditions that are associated with housing and zonation.

Files

Roof mapping, point and predio data are stored in the following files:

[3] In fact, there was an average of 8.5 square metres of roof area per resident in the 482 homes. However, the figures were skewed by a small number of homes that had few residents living within large houses with extensive roofing. For this reason, the median figure of 6.6 square meters of roofing per person was adopted as providing a more reasonable estimate.

File name	**Records**
Points1	89,874 points and 622,747 people
Points2	144,808 points and 1,004,051 people
Viana	151,706 points and 1,056,573 people
Kilamba Kiaxi	128,626 points and 892,287 people
Roof mapping1	104,911 polygon/points and 908,598 people
Roofmapping2	105,099 polygon/points and 1,206,169 people
Predios	1,627 predios, 27,945 apartments, 139,725 people
Commercial and other non-housing building points	13,445 points

Note that for purposes of creating density estimates the roof mapping polygons were converted into points (by calculating centroids).

The ArcView grid data set (*Luanda dens*) has a cell size of 10 x 10 metres, and the unit of density assigned to each cell is the number of people per square kilometre. For certain analyses, for example those where the values of cells are added up, the resulting figure must be divided by 10,000 (= 100 multiplied by 100 ten x ten metre cells). The ArcView Grid has the following metric co-ordinate system: Transverse Mercator, Central meridian 15 East, Base latitude 0^o, 500,000 m false easting and 10,000,000 m false northing, scale factor 0.9996, and WGS84 spheroid.

The densities were in the grid file were estimated using the Density function in ArcView's Spatial Analyst; using a distance of 50 metres and the 'simple' method for estimating densities. For predios a distance of 100 metres was used for the density estimates to 'spread' the population in each predio over a wider area.