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Hidden Diversity in an Urban/Rural Dichotomy: a Case Study for Dar es Salaam, Tanzania

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Abstract:

The diversity not captured by a dichotomous urban/rural classification plays an important role in the outcome of human events. For example, urbanization is crucial for studying malaria transmission in Africa, since incidence rates are low in highly urbanized areas, intense in rural settings, and transitory from in peri-urban zones. This paper aims to highlight differences in the level of urbanization in Dar es Salaam, Tanzania. Semi-variograms will be applied to aerial photographs of the city. Evaluation of the semivariogram components and functional form should facilitate the characterization of different patterns of urban development across the city. Moreover, those patterns should reveal a wide diversity in malaria transmission across Dar es Salaam. Those results should shed light on critical areas to be targeted for malaria control in Dar es Salaam, and facilitate the selection of the best combination of interventions that should be put into place in each area.

1. Introduction

Despite its broad usage, the word ‘urban’ has an amazingly varied set of definitions, depending upon ecological and cultural context (Phillips, 1993). The usefulness of the dichotomous classification (urban x rural) in the analysis of social phenomena has been heavily debated over the past 30 years. It has also been a concern for the United Nations, who recognizes the challenges in trying to establish uniform criteria to define urban areas (UN, 2001). The International Union for the Scientific Studies of Population (IUSSP) has established two committees to discuss the topic. The first in 1971, named *Committee on Urbanization and Population Redistribution*, and the second in 2000, entitled *Working Group on Urbanization* (Hugo, Champion and Lattes, 2002). Additionally, the National Research Council formed the *Panel on Urban Population Dynamics* in 1999 (Montgomery et al., 2003).

Critical points of discussion include the basic geographic unit to be considered, and if the definition should be based on ecological, occupational, socio-cultural, demographic, or economic dimensions (Lang, 1986; Dax, 1996). These issues become even more critical in areas experiencing rapid rates of urbanization, such as Africa. Although the continent was the least urbanized in 2000 (37.2%), it is expected to be the area with the highest urban population growth between 2000 and 2030 (3.27%), with 52.9% of the inhabitants likely to live in urban areas in 2030 (UN, 2002). In this setting, the traditional dichotomous classification hides major differences in both the level and pace of urbanization across the area, which may have important implications for urban planning and public policy.

One particular problem that is likely to occur in those areas is health related: the resurgence, aggravation, and spread of diseases. In fact there is a chain of events that contribute to health problems. Fast urbanization in poor areas may result in lack of sanitation and drinking water, precarious housing, lack of basic services, inefficient or inexistent waste collection, etc. These problems may grow to be more complex in settings where urban areas comprise practices and social behavior usually associated with rural areas, such as agriculture and livestock, which facilitate the spread of certain diseases.

In the case of malaria, for example, the level of urbanization is a crucial concept for understanding transmission of the disease in most countries of sub-Saharan Africa. Malaria is particularly severe in rural areas, where population density is low and individuals live in proximity to a large number of potential mosquito breeding sites. In contrast, malaria transmission occurs at significantly lower levels in urban areas, where population density is high, and the number of breeding sites is reduced (Trape et al., 2002; Robert et al., 2003). However, areas of recent urban expansion (usually called peri-urban areas) are transition zones between high and low malaria transmission. Two recent reviews of studies published after 1980 show that *Plasmodium falciparum* entomological inoculation rates - EIR (defined as the number of infective bites per person per year) in urban settings vary between 0.1 and 33.0, with an average of 7.1 in city centers and 45.8 in peri-urban areas, while the observed range for rural areas was 0.1 to 884.2, with an average of 167.7 (Hay et al., 2000; Robert et al., 2003).

Consequently, the use a dichotomous variable in any analysis of malaria risk will not be able to capture the true relationship between disease transmission and levels of urbanization. In addition, different configurations of urban structure, associated with malaria rates, should facilitate the identification of critical areas to be targeted for control programs, and improve the selection of the best combination of interventions that might be put into place in each area.

This paper aims to highlight the differences in the level of urbanization in a major urban center in Africa where malaria is considered to be a serious disease. Geostatistical analysis (semi-variogram) is applied to digital aerial photographs. Close evaluation of the semi-variogram components and of its functional form, is expected to provide information on the ideal spatial resolution required for the analysis of different urban patterns, the proportion of the area covered by objects in the ground, and the size, area, and variance of those objects (Curran, 1988; Woodcock, Strahler and Jupp, 1988b; Carr, 2000; Brivio and Zilioli, 2001). Therefore, these patterns do not include any type of socio-economic variables. They strictly reflect the way the space is organized as a result of the expansion of the city limits.

The African urban center chosen as a case study is Dar es Salaam, in Tanzania. It became the most densely populated area in the country, and the city with the most rapid population growth in east Africa. The latest Population and Housing Census reveals that Dar es Salaam moved from 356 thousand inhabitants in 1967 to 2.5 million in 2002. Population density in 2002 was 1,793 people per km^2, by far the largest human agglomeration in the country (Mwanza ranks second in Tanzania, but with only 150 people per km^2)[1]. Such growth, however, was not driven mainly by natural population increase. Since 1965, it is estimated that approximately 69% of the population growth was caused by rural-urban migration (Sommers, 2001), with a large fraction of migrants keeping their rural practices.

2. Urban expansion in Dar es Salaam

According to the city administrative specification, Dar es Salaam has an area of 1,393km^2, although a large fraction is not urbanized. Based on the work done by Briggs and Mwamfupe (2000), and by Mike Shand (http://mshand.geog.gla.ac.uk/DAR/tanzania.htm), it is estimated that the urban area in Dar es Salaam was approximately 25 km^2 in 1945, 40 km^2 in 1967, 93km^2 in 1978, 259km^2 in 1992, and 418km^2 in 1997. Recent estimates presented by Masanja (2002) show that the built-up area in 2001 was on the order of approximately 572 km^2. However, the intense urban development that

[1] For more information regarding the results of the 2002 Census in Tanzania check the tables released by the National Bureau of Statistics at http://www.tanzania.go.tz/census/tables.htm.

took place after 1978 was not homogeneous across the city. It was mainly driven by the hydrological characteristics of Dar es Salaam, and by the available public transportation system (Briggs and Mwamfupe, 2000).

Dar es Salaam has a complex creek system, with Msimbazi Creek and Mzinga Creek playing an important role in the spatial expansion of urbanization. Most of the development in the past was concentrated north of the creeks, while expansion to the south was constrained mainly by Mzinga Creek (Briggs and Mwamfupe, 2000). The marshy characteristic of the soil near the creeks left many areas unsuitable for housing construction, unless drainage was put in place.

The transportation system limited the expansion of urbanization even more. Until the late 1980s, the transportation network was precarious, and private vehicle ownership was limited. People needed to live in areas where access to and from the main city centre would be guaranteed by public transportation. As a result, urban expansion took place basically along the major roads, as shown in Figure 1. During the 1990s, the transportation system was dramatically improved, and different types of vehicles became available for the population. Access was provided not only to major roads, but also to feeder and dirt roads. Consequently, urban expansion started to become more intense in interstitial areas between the main roads (Briggs and Mwamfupe, 2000).

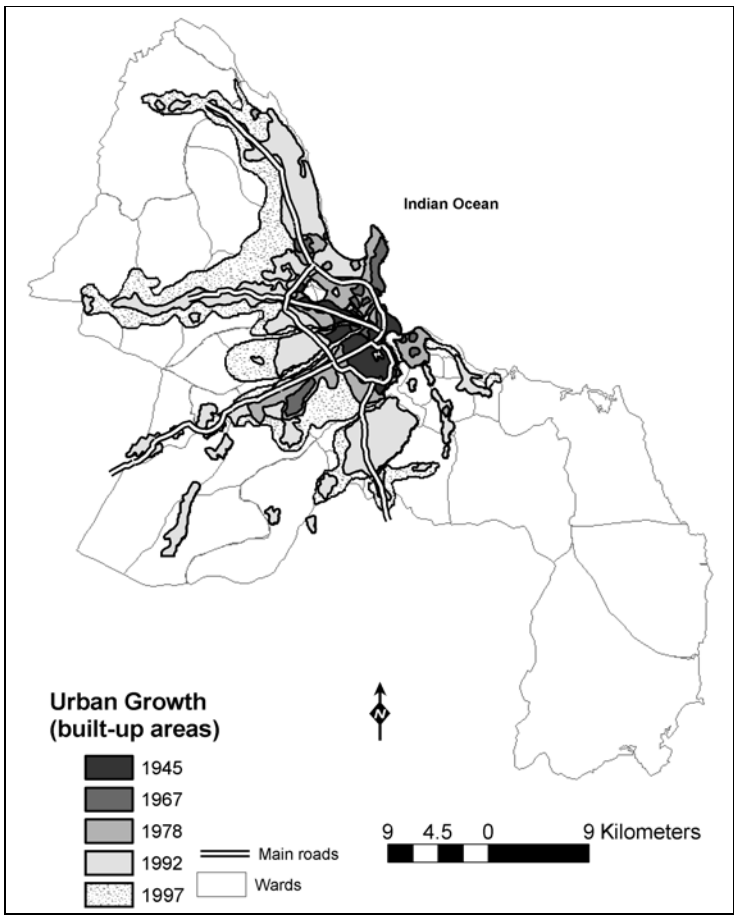


Figure 1 – Urban expansion in Dar es Salaam, 1945/97

Another important feature of the urbanization process in Dar es Salaam is the role played by agriculture in both the urban and peri-urban zones. As mentioned before, a large amount of the urban expansion observed in the city was not a result of natural population growth, but driven by rural-urban migratory movements. Moreover, migrants keep their traditional rural practices, such as raising livestock (mainly chicken and cattle), farming crops, and storing water. Knudsen and Slooff (Knudsen and Slooff, 1992) name this phenomenon 'ruralization' of cities. In Dar es Salaam urban agriculture is the second largest source of employment, and 74% of the farmers raise livestock. Crops raised in *matuta*[2], without adequate drainage, provide ideal conditions for mosquito breeding, and result in serious health problems (Mlozi, 1997; Dongus, 2000).

According to the administrative structure of Dar es Salaam the city is divided in districts, wards, and sub-wards (also called Mtaa). There are three districts, namely Ilala, Kinondoni, and Temeke, which have 22, 27, and 24 wards, respectively. The Tanzania National Bureau of Statistics (NBS) classified each ward into urban, rural, or mixed, although the criterion is not strict or extremely precise. Overall, urban wards typically have a nuclear center, and provide basic infrastructure and social services. Rural wards are mostly areas dominated by agriculture. Finally, mixed areas have both urban and rural characteristics.

Table 1 – Percentage of wards categorized as urban, rural, and mixed, according to the National Bureau of Statistics

District	Urban	Mixed	Rural
Ilala	72.8%	13.6%	13.6%
Temeke	62.5%	8.3%	29.2%
Kinondoni	77.8%	14.8%	7.4%

Source: http://www.tanzania.go.tz/census/census/regions.htm

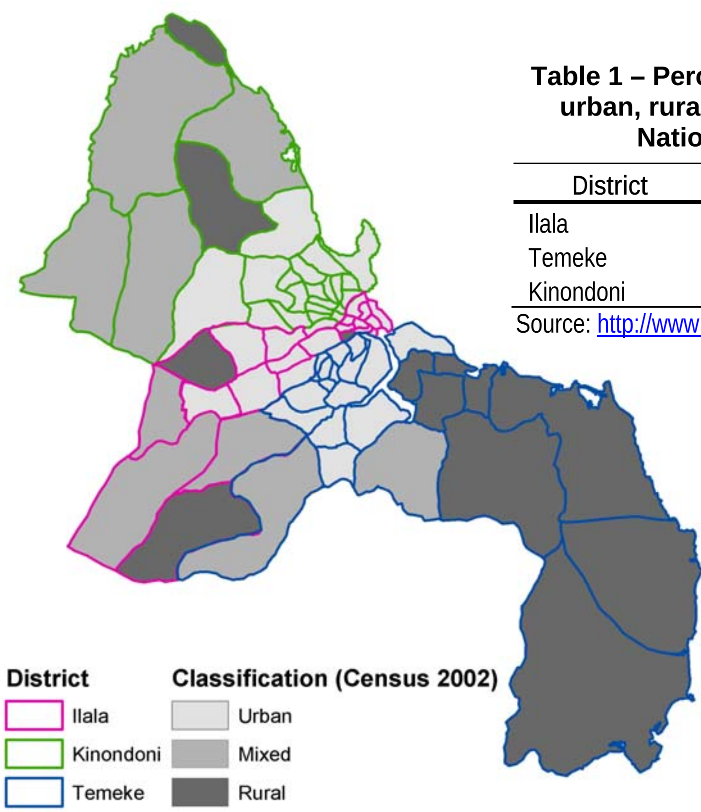


Figure 2 – Classification of wards in Dar es Salaam according to the National Bureau of Statistics

[2] In Swahili, *tuta* means raised planting beds. *Matuta* is the plural form of the word, and means ridges for planting often made on grounds with high water table.

The classification was used in the Census 2002, and is summarized in Table 1. Temeke is the least urbanized district, as shown in Figure 2. Kinondoni, located north of the creeks, and with a good transportation network, is the most urbanized. The district also concentrates most of the upper scale housing in the city.

3. Geostatistical analysis of aerial photographs

The application of geostatistical models to remotely sensed imagery can have multiple purposes. They may be used to estimate the values of pixels not observed or those that could not be used due to errors of the sensor. Also, they may facilitate the description of the spatial structure of the landscape, and semi-variogram models have been particularly useful for that matter.(Curran, 1988; Woodcock, Strahler and Jupp, 1988b; Woodcock, Strahler and Jupp, 1988a; Carr, 2000; Brivio and Zilioli, 2001; Longley, 2002).

In this paper, semi-variogram models are used to describe and contrast urban scenes of dare s Salaam, Tanzania. Although the city is considered to be the most urbanized area in the country, it presents major contrasts across the landscape, with developed and upper scale areas located meters apart from unplanned housing and urban agricultural fields. Semi-variograms of those different areas should reveal significant dissimilarities.

The source for this analysis is a set of digital aerial photographs taken from Dar es Salaam in May 2002, covering all urbanized areas of the city. Three wards considered as rural (located in Temeke) were not covered in the images, and six wards with mixed classification were only partially represented. The images were taken at an average altitude of 950m, using a Nikon D1X still camera. The spectral resolution covers only the visible channels – RGB (red, green, and blue), and The ground resolution (pixel size) is approximately 0.5m. The images were captured and processed by GeoSpace International (www.geospace.co.za), and released as a georeferenced and orthorectified mosaic. In Dar es Salaam, the mosaic can be acquired through the Tanzania Survey & Mapping Division of the Ministry of Lands.

3.1. *The model: semi-variogram*

Consider subsets of the aerial photographs, where $Z(s)$ is the measurement of brightness associated to pixel s, and $s = 1, 2, \dots$ n. The spatial dependence observed among those pixels is expected to conform to the First Law of Geography, which says that "*everything is related to everything else, but near things are more related than distant things*" (Tobler, 1979). Under that assumption, it is possible to model the spatial structure in the data by the use of the semi-variogram, which relates the semi-variance observed in the data to the distance at which they are calculated.

Assuming that the data is intrinsically stationary, the difference between two pixels at a distance *h* depends only on the distance *h*. In other words, both the mean and the variance of the difference between any two pixels separated by distance *h* are constant (Cressie, 1993). That is:

$$E\left(Z(s+h)-Z(s)\right)=0\text{, and }\operatorname{var}\left(Z(s+h)-Z(s)\right)=2\gamma(h)\text{,}$$

where the quantity $2\gamma(h)$ is called the variogram and $\gamma(h)$ the semi-variogram. The semi-variogram can be invariant under rotation (isotropic) or it may show directional effects (anisotropy). In the latter case, the spatial correlation assumes different magnitudes depending on the direction.

The semi-variogram is composed of three parameters: nugget effect, sill, and range, as shown in Figure 3. A careful analysis of those parameters provide useful information regarding the spatial resolution, the presence of processes that operate at multiple scales, and the size, area, shape and density of objects in the scene (Curran, 1988; Woodcock, Strahler and Jupp, 1988b).

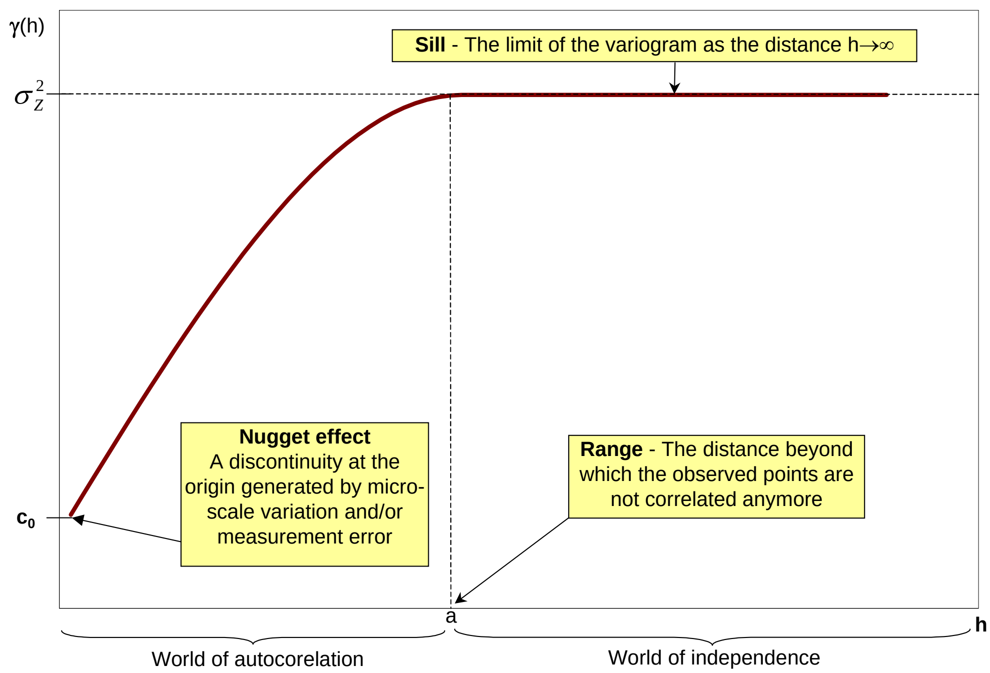


Figure 3 – Graphical representation of the classical semi-variogram

The nugget effect occurs when there is discontinuity at the origin. Ideally, $\gamma(0) = 0$, but if a discontinuity is observed, $\gamma(h) \to c_0 > 0$ as $h \to 0$, and c_0 is called the nugget effect. It is caused by measurement errors and microscale variance in the data. In applications of semi-variograms to remotely sensed images the nugget effect can be originated by errors in the sensor, for example (Woodcock, Strahler and Jupp, 1988b; Brivio and Zilioli, 2001).

The sill can be understood as the limit of the semi-variogram, when this limit exists. In a classical semi-variogram, such as the one shown in Figure 3, the sill describes the maximum semi-variance in the data, which approximates the global variance (σ_Z^2). However, there are spatial processes that do not conform to a classical semi-variogram. The process may have an infinite variance, in which case the semi-variogram has no sill or it can rise above the global variance (theoretical sill). Additionally, it can show a cyclic pattern, oscillating around the theoretical sill, being usually called “hole effect” semi-variograms (Pyrcz and Deutsch, 2003).

The cases when the observed semi-variogram rises above the sill can be better understood by using the statistical concepts of covariance (*C*) and correlation (*ρ*). The mathematical relationship between those measures and the semi-variance is (Bailey and Gatrell, 1995)

$$\rho(h) = \frac{C(h)}{\sigma_Z^2} \text{ and } \gamma(h) = \sigma_Z^2 - C(h)$$

At distance *h* = 0, the covariance equals the global variance, therefore

$$\gamma(h) = C(0) - C(h) = C(0) * (1 - \rho(h))$$

The relationship shows that in the particular cases when the observed semi-variogram exceeds the sill, the correlation between two spatial locations separated by a certain distance *h* is negative (Pyrcz and Deutsch, 2003).

The range describes the distance *h* at which the sill occurs. It is the distance beyond which *Z*(*s*) and *Z*(*s*+*h*) are not correlated anymore. The intuition is that, according to the First Law of Geography (Tobler, 1979) the semi-variance may increase as distance increases. This behavior is observed up to a certain point (range), after which the data is not correlated anymore, and the semi-variogram will stabilize. The value of the semi-variogram at this point is the sill, and it will eventually equal the global variance.

3.2. *Selected areas*

Subsets of the Dar es Salaam aerial photographs were selected so that the spatial structure of different landscapes could be analyzed. Each subset covers an area of 100x160 meters, which corresponds to images of approximately 200x320 pixels in size. All subsets from the digital images were created using Erdas Imagine© version 8.5.

Initially, 24 subsets were selected, and 17 were chosen for the present analysis. The subsets were grouped in 8 categories of landscape configuration: (i) upper scale housing with paved roads, (ii) ocean housing, (iii) urban expansion (peri-urban), (iv) middle scale housing with unpaved roads, (v) unplanned housing development, (vi) saltpans, (vii) housing with *matuta* fields (urban agriculture), and (viii) agricultural fields. These categories portray the most common scenes in urban Dar es Salaam, and are spread throughout the three districts. Additionally, a subset scene of an agricultural field located in a ward classified as rural by the NBS was selected. The purpose is to compare the spatial structure of similar landscape types located at urban and rural areas.

3.3. *Spatial pattern of different landscapes*

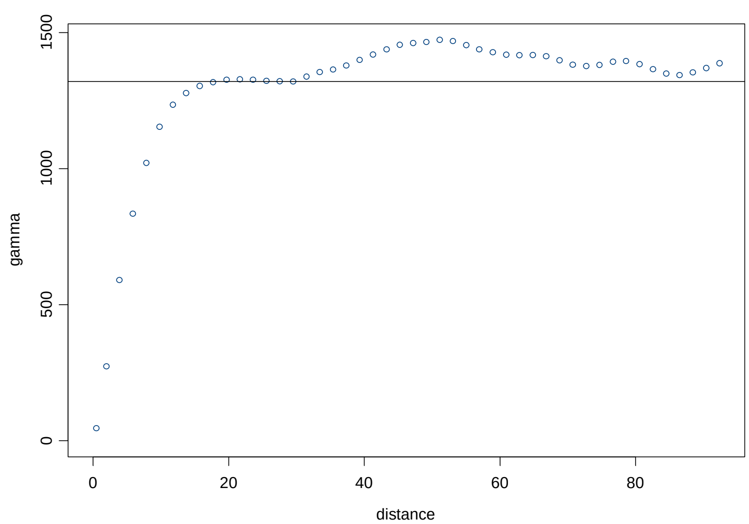
The spatial structure of all 17 subsets was appraised by the use of semi-variograms. All calculations were done in S-Plus© 6 for Windows, using the spatial statistics module. Based on the size of the subsets the total number of lags considered for the semi-variogram computations was 48, which results in a lag size of approximately 2 meters or 4 pixels.

No attempt was made to model the semi-variograms, since the primary goal of this analysis is to understand the spatial structure of the data, and not to generate spatial estimations. Additionally, no correction for anisotropy was done. Instead, omni-directional and directional semi-variograms were calculated, and directional effects evaluated. Directional variograms were calculated for rotations of 0^o (N-S), 45^o (NE-SW), 90^o (E-W), and 135^o (NW-SE).

<u>(i) Upper scale housing with paved roads</u>

The subset image in this category is located in Msasani ward, Kinondoni, considered by the NBS as an urban ward. The global variance of the scene is 1,320.4, and the observed semi-variogram reaches that sill at approximately 16 meters, as shown in Figure 4. However, after 32 meters it goes above the theoretical sill (represented by a solid line in Figure 4), revealing a negative correlation between pixels above that distance. This is a consequence of the spatial structure of the scene: large lots contain multiple and varied sized houses, open fields, and trees. The directional semi-variograms for this subset showed evidence of slight directional effects.

Figure 4 – Subset scene and semi-variogram: upper scale housing with paved roads - Msasani



(ii) Ocean housing

A typical upper scale house in the ocean shore is represented by a subset scene from Kivukoni ward, Ilala (an urban ward according to the NBS). The observed global variance is 1,200.3. The omni-directional semi-variogram shown in Figure 5 clearly reveals the presence of two different spatial processes in the scene. In fact, the directional semi-variogram highlights two distinct patterns. The first, observed in the E-W and NW-SE directions, shows an almost linear unbounded pattern, representing a process with a significant trend in the data. The second, observed in the N-S and NE-SW directions, can be called a multi-frequency semi-variogram (Curran, 1988), and is a result of the presence of repetitive spatial patterns in the scene.

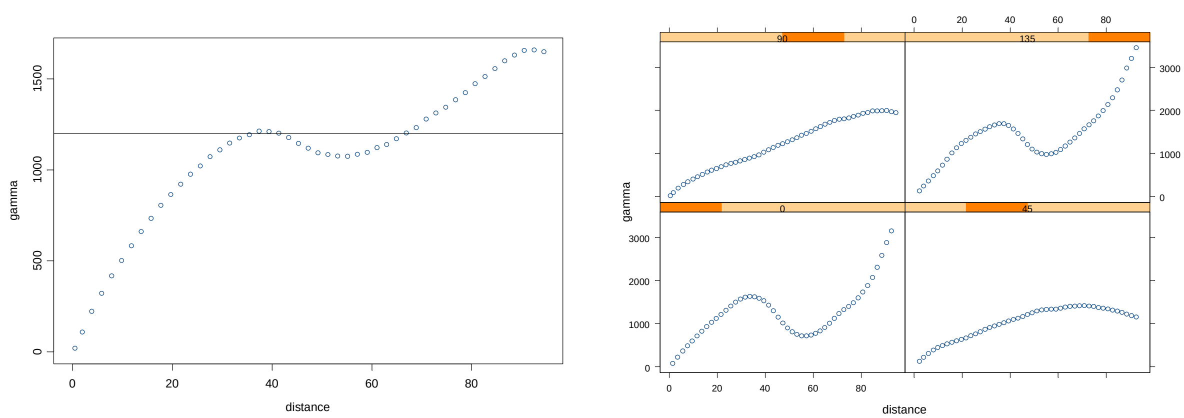


Figure 5 – Omni-directional and directional semi-variograms: ocean housing - Kivukoni

It is likely that the two processes reproduce the different levels of greenness observed in the two open fields in front of the houses. The gradual slope of the semi-variogram reflects the higher variance in the size of objects in the scene at shorter distances.

(iii) Urban expansion (peri-urban)

Two subsets were selected to represent landscapes of urban expansion, usually called peri-urban areas. In those settings, it is common to find unfinished constructions, where just the initial foundation of houses is on the ground. In some cases the building process is undergoing. In others, however, the foundations may be abandoned, which provides ideal conditions for mosquito breeding, and may facilitate the spread of diseases such as malaria. This is better represented in scene B, where three of those foundations can be easily recognized in Figure 6.

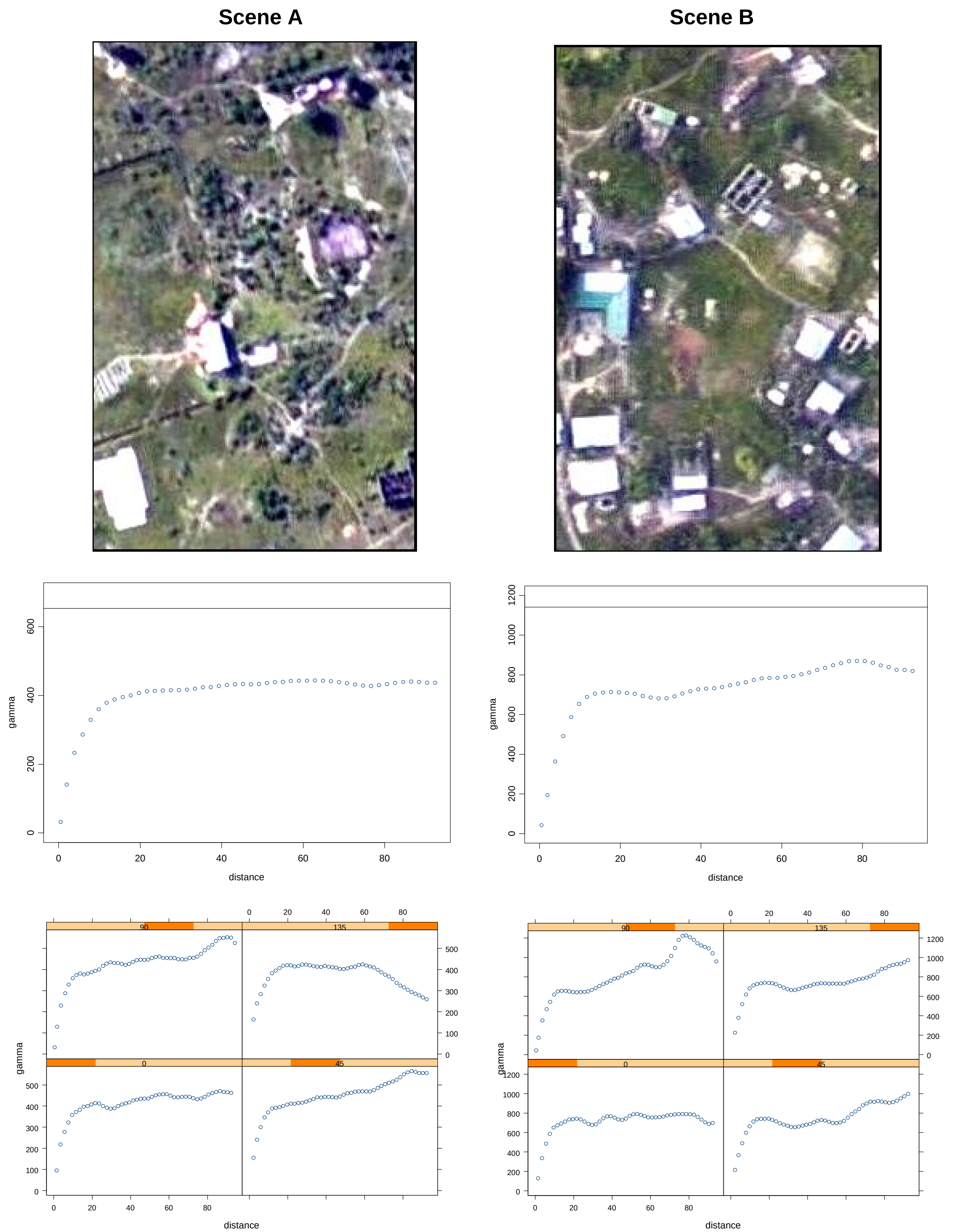


Figure 6 – Subset scenes and semi-variograms: urban expansion in Kunduchi and Vingunguti

The two scenes present different levels of urban expansion, reflected in the amount of man-made transformation observed in the landscape. Therefore, it is likely that scene A is a younger expansion than scene B (not by coincidence, scene A is located in a ward considered to be a transition between urban and rural, while scene B is in an urban ward). This is reflected in the global variance of the scenes, as shown in Table 2. Scene B, with more intense expansion (characterized by irregularly located houses), has a much higher variance than scene A. The semi-variograms observed in both scenes never reach their theoretical sill, which shows evidence for the presence of large homogeneous areas in the scenes. This same pattern was observed by Woodcok, Strahler and Jupp (Woodcock, Strahler and Jupp, 1988b) when analyzing an image from Canoga Park, CA.

Table 2 - Selected subsets – urban expansion: global variance and location

Scene	Global Variance	District	Ward	Type of area (Census)
A	653.4	Kinondoni	Kunduchi	Mixed
B	1,141.5	Ilala	Vingunguti	Urban

Additionally, the range in both scenes is approximately 12 meters, which somehow reflects the size of houses. This is a much smaller range when compared to the upper scale housing scene shown before, emphasizing the effect of the size of the objects present in the landscape on the observed range. Finally, the directional semi-variograms show evidence of the presence of directional effects in both scenes, which can be caused by the way the houses are being built (concentration of houses in one particular area can reduce the variance in that direction).

(iv) Middle scale housing with unpaved roads

This category portrays a very common scene in the most urbanized areas of Dar es Salaam, where middle scale houses are arranged on a quasi-regular grid, with unpaved roads. The chosen subset is located in Mikocheni, Kinondoni. Although the streets are unpaved, this is a very organized urban scene, and the observed global variance is 883.4, lower than the theoretical sill associated to the upper scale housing scene.

The directional semi-variogram, shown in Figure 7, reveals the presence of anisotropy. The directional effect in residential scenes such as this one may result from the road network and the shape of houses along the streets (Woodcock, Strahler and Jupp, 1988b). In fact, in this particular subset the streets run in only one direction, possibly introducing a trend in the process.

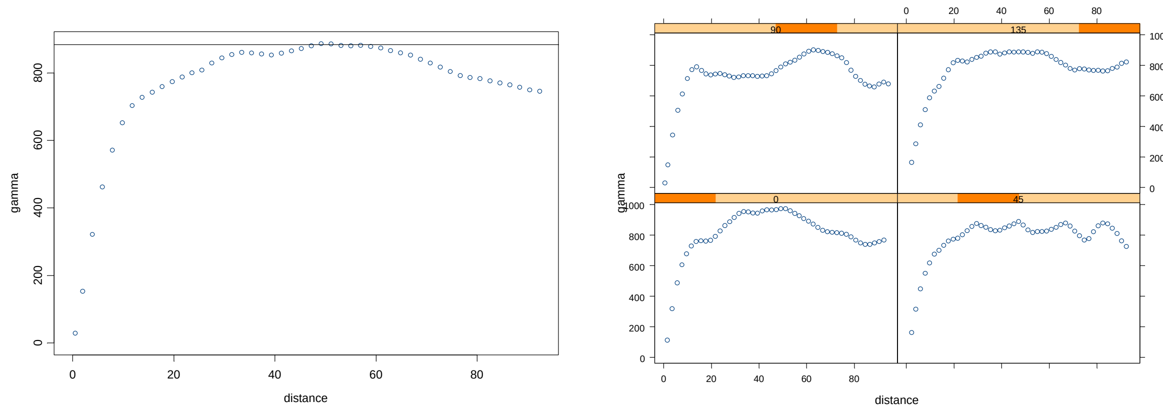


Figure 7 – Omni-directional and directional semi-variograms: middle scale housing in Mikocheni

<u>(v) Unplanned housing development</u>

Two subsets were chosen to represent this category, which is a very common scene not only in Dar es Salaam, but in major urban areas in expansion in third world countries. Houses are built on irregular grids, on lots of varied size, with unpaved roads and only a few trees, as shown in Figure 8.

In both scenes A and B the houses are the most common element, which has a major impact in the range of the semi-variogram. Both omni-directional semi-variograms shown in Figure 8 have a range of approximately 10 to 12 meters, and the size of the houses varies between 8 and 12 meters. Streets are not distributed in an organized network. In fact, most of the houses are not accessible by a well defined street suitable for motorized transportation.

The observed range also provides crucial information regarding the most appropriate scale for analysis of urban scenes similar to those shown here (Curran, 1988). For the purposes of classifying the image into different categories, which facilitates the understanding of patterns of land use, the location of high risk areas for certain diseases, the quality of roads, and the demands for drain repair, among other issues, the range suggests the maximum spatial resolution that could be used. Above that range, the spatial structure of the urban scene would be smoothed and less informative.

Table 3 - Selected subsets – unplanned housing development: global variance and location

Scene	Global Variance	District	Ward	Type of area (Census)
A	2,175.1	Kinondoni	Msasani	Urban
B	1,980.0	Kinondoni	Tandale	Urban

As shown in Table 3, the global variance of both scenes is extremely high, in fact, the highest among all 17 scenes studied in this paper. It reflects the fact that unplanned housing developments are highly disorganized spatial processes. In both scenes A and B the observed omni-directional semi-variogram sill exceeds the theoretical sill. In scene A negative correlation between pixels are expected to occur at distances above 10 meters, when different elements are most likely to be compared (houses, trees, shadows, unpaved street, bare soil, and agricultural fields).

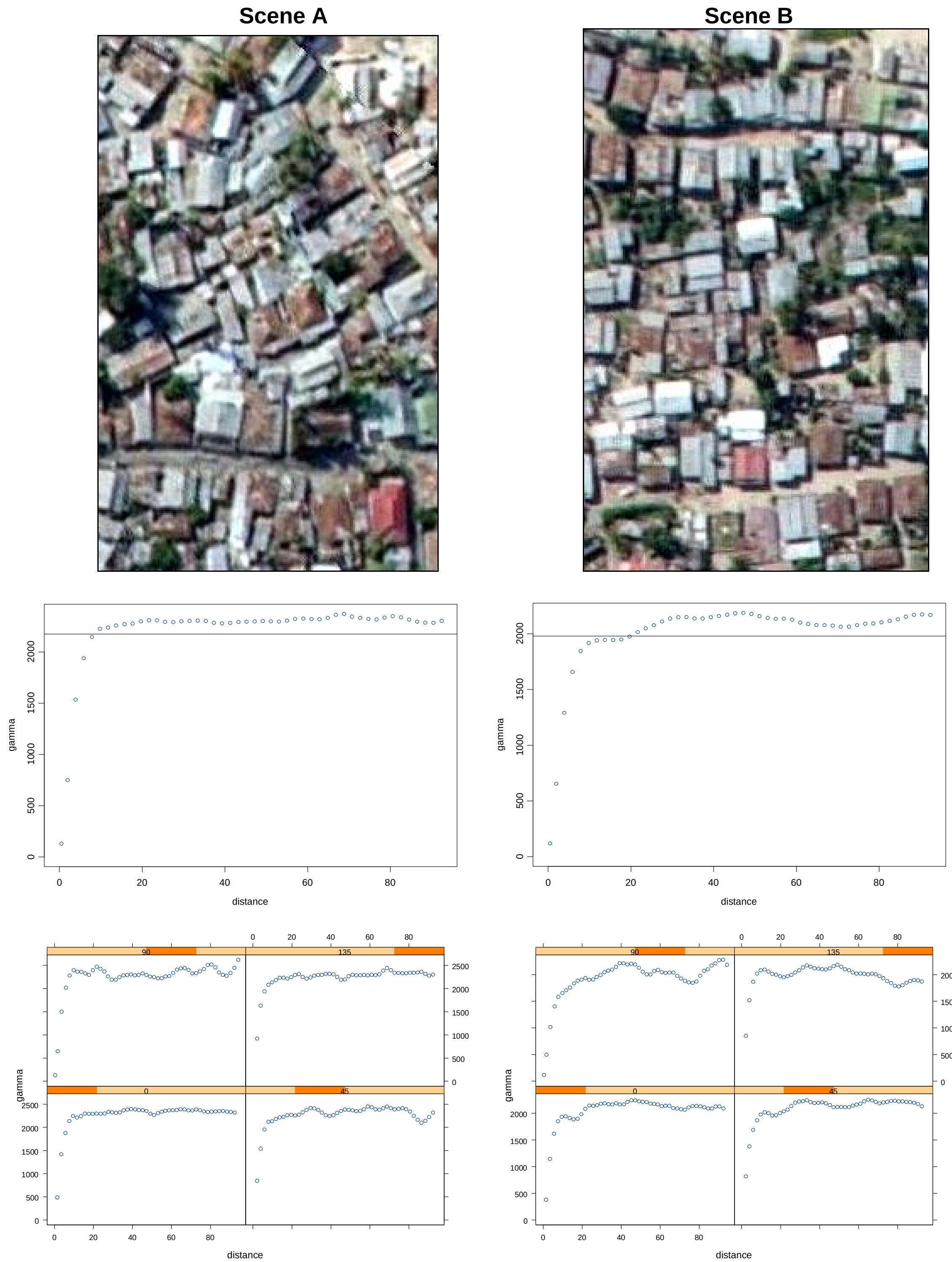
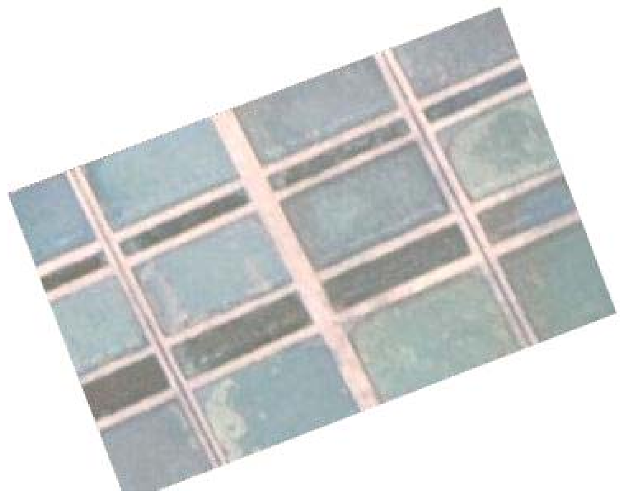


Figure 8 – Subset scenes and semi-variograms: unplanned housing development in Msasani and Tandale

(vi) Saltpans

Since Dar es Salaam is situated along the Indian Ocean, the presence of salt mines is very common in wards close to the sea. To describe the spatial structure of areas with saltpans a subset situated in Kunduchi, Kinondoni was chosen. According to the NBS this ward is considered to be a mix between urban and rural types. The global variance is 870.6, and the shape of the observed omni-directional semi-variogram can be classified as multi-frequency (analogous to the scene for an ocean house). The rectangles are the main pattern in the scene, and they occur in a repetitive and fairly homogeneous way. The pans separating the rectangles have the same effects as roads on a residential scene, and introduce a trend in the data. This is reflected in the directional semi-variograms shown in Figure 9. In the N-S direction (0^o) the semi-variogram alternates the pattern roughly every 20 meters, which is approximately the height of the rectangles in the subset.



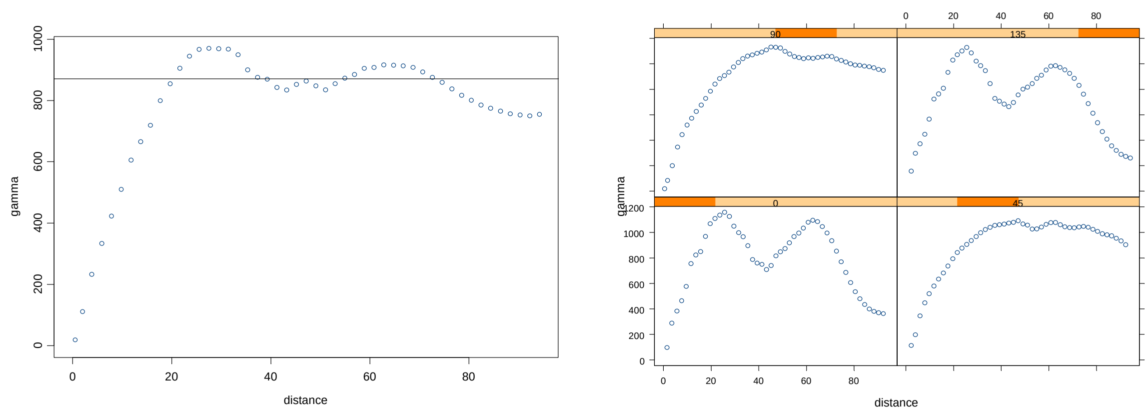


Figure 9 – Subset scene and semi-variogram: saltpans in Kunduchi

(vii) Housing with *matuta* fields (urban agriculture)

Three different subsets were elected to represent urban agriculture practices, specifically the development of crops in *matuta*. Scenes A and B, shown in Figure 10, are located in a residence complex, Tazara Quarters, measuring approximately 140,000 m^2, with 20% of this area occupied by buildings with similar size and disposed on a quasi-regular grid. It is an area with a high water table, favoring agricultural practices, especially *matuta*. In the early 1990s this area presented a very high risk for malaria transmission. Based on samples of breeding sites analyzed in the area, almost 2 million *Anopheles* mosquitoes could be expected to breed in this residence complex (Castro et al., 2004).

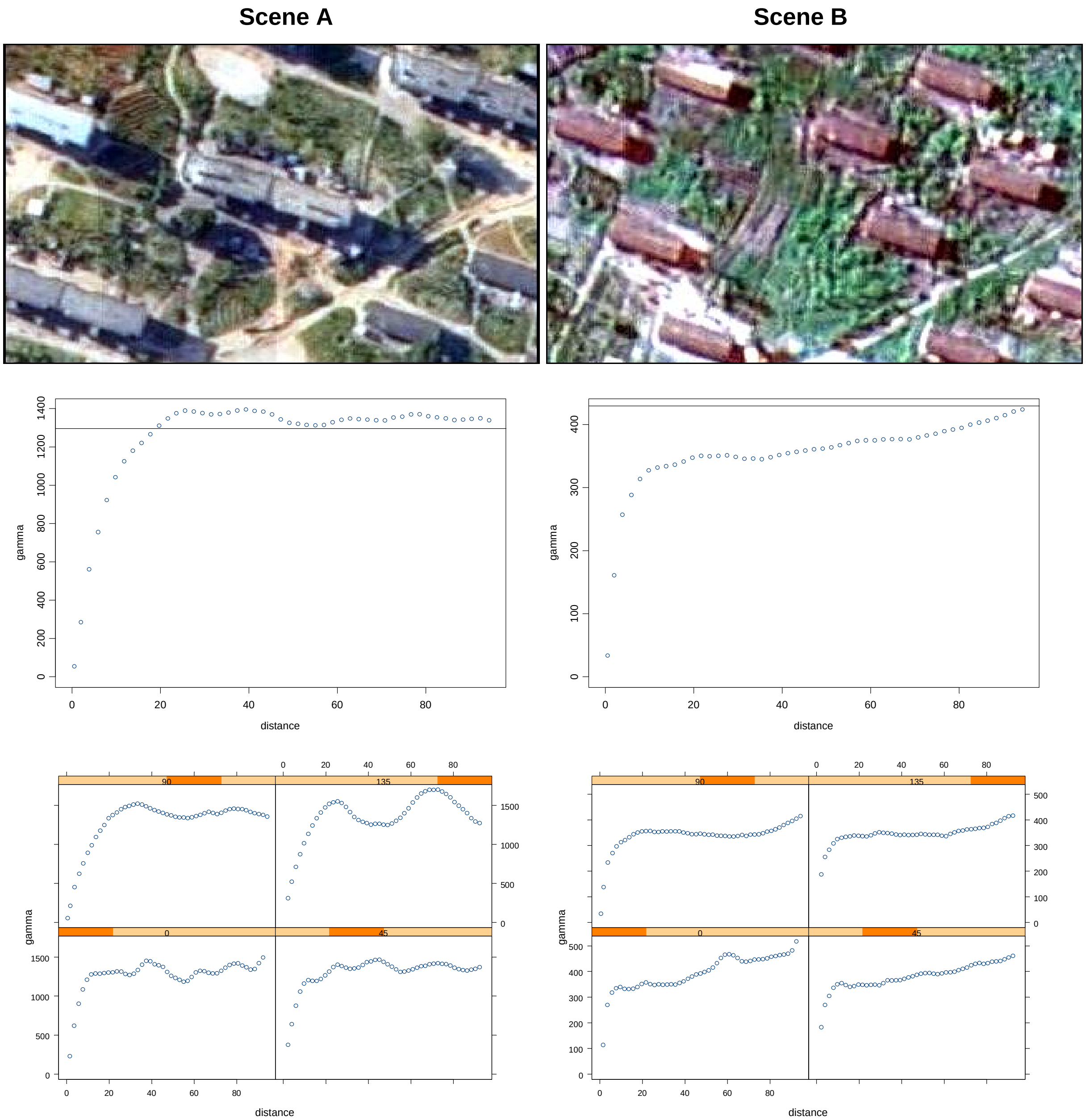


Figure 10 – Subset scenes and semi-variograms: urban agriculture in Tazara Quarters

Scene C, presented in Figure 11, depicts a slight different residential arrangement. Buildings vary in size, and are irregularly distributed in space. Additionally, while in scenes A and B agriculture practices surround all buildings, in this scene *matuta* fields are heavily concentrated in one spot, while houses tend to be built together.

Among the three subsets, scene B presents the most organized spatial structure, and therefore the smallest global variance, as shown in Table 4. As a planned residential complex, all houses measure approximately 10x23 meters, and that affects the magnitude of the observed range of the omni-directional semi-variogram. Scene A is strongly impacted by shadows, since the buildings are taller. Moreover, the *matuta* fields are less homogeneous than those in scene B, and there is a network of alleys which are likely to introduce a trend in the data. This is corroborated by the directional semi-variograms shown in Figure 10.

Table 4 - Selected subsets – housing & urban agriculture: global variance and location

Scene	Global Variance	District	Ward	Type of area (Census)
A	1,296.4	Temeke	Azimio/Chan'gombe	Urban
B	429.5	Temeke	Chan'gombe	Urban
C	1,174.1	Temeke	Tandika	Urban

Scene C shows a different spatial structure, as expected based on the organization of the objects across the area. The semi-variogram never reaches the theoretical sill, and it stabilizes at approximately 39 meters. Between 10 and 39 meters the semi-variogram shows a linear increase, resembling an unbounded pattern. One of the explanations could be, again, the size of the houses and matuta fields. Houses in the scene have a size ranging from 8-16, approximately. Additionally, the directional semi-variograms highlight the presence of trend in the data, a result from the clustering of houses and matuta fields across space.

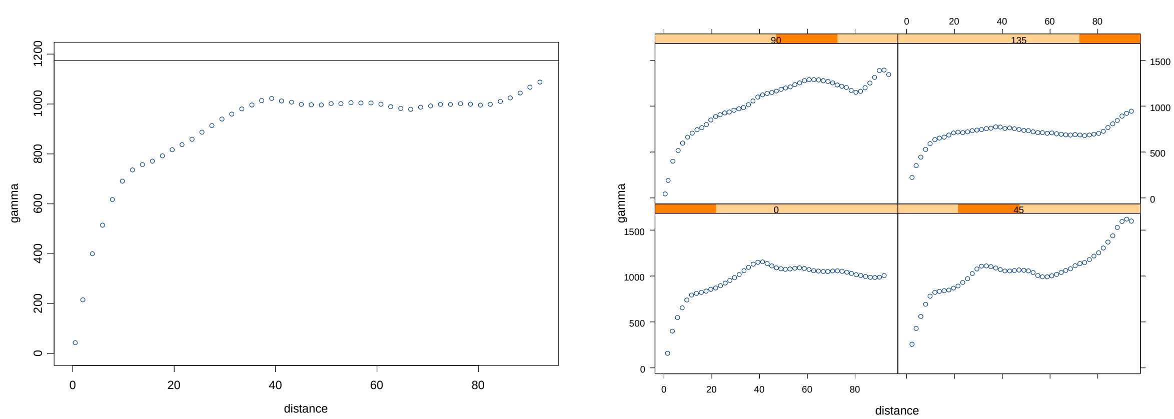


Figure 11 – Subset scene and semi-variogram: urban agriculture in Tandika

(viii) Agricultural fields

Four scenes were selected to represent different types of agricultural fields, including one located in a rural ward (scene A), as shown in Figures 12a and 12b.

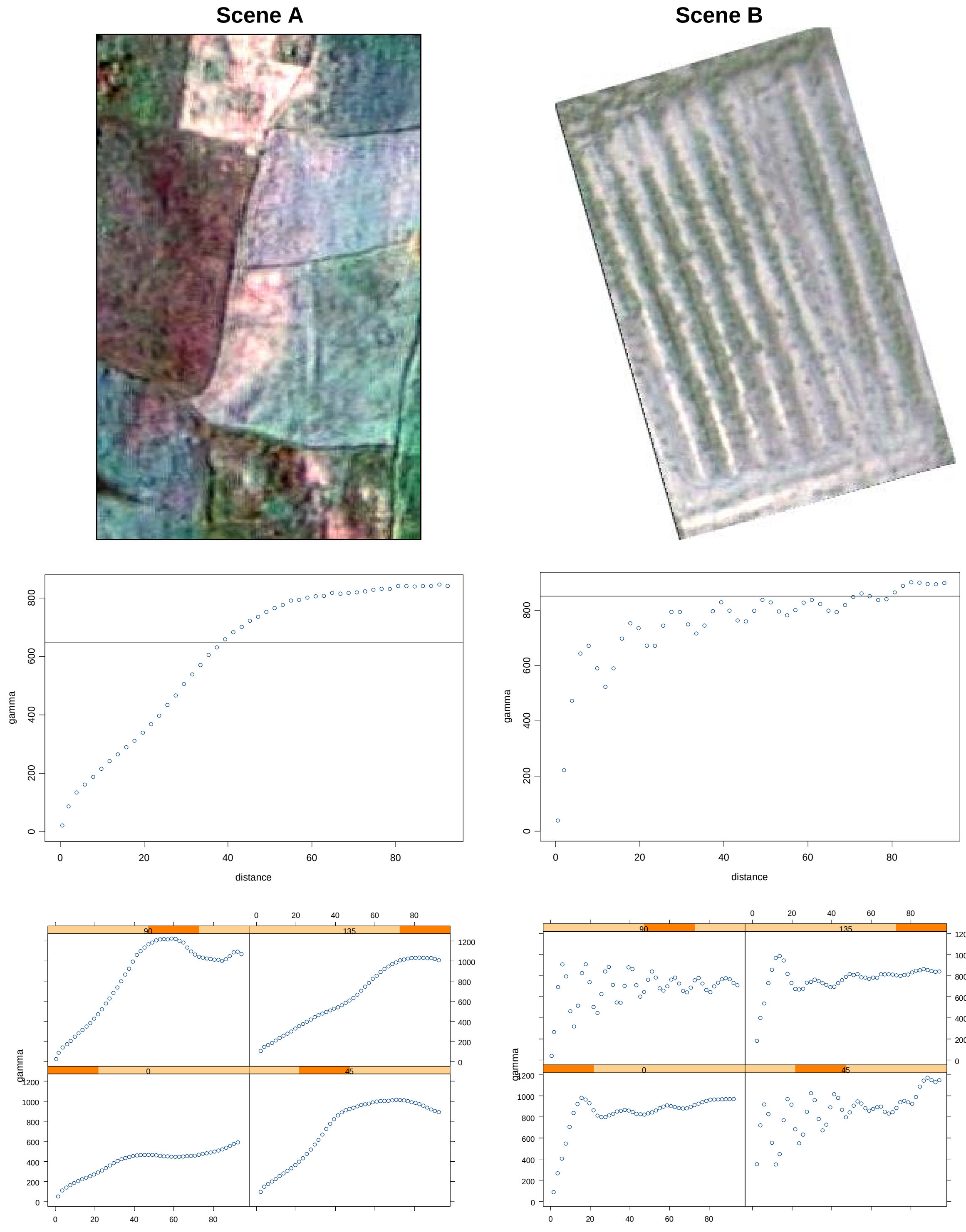


Figure 12a – Subset scenes and semi-variograms: agricultural fields

Scene A is characterized by crops being produced in large portions of land. That may be more likely to occur in rural areas, since the population density is lower, and bigger parcels can be dedicated to one single household and one produce. The distribution of different crops in the fields results in significant directional effects. In fact, the directional semi-variograms observed for scene A presented in Figure 12a reveal different spatial structures in all four directions evaluated. The omni-directional semi-variogram has a gradual sloping, indicating a high variance in the size of elements in the scene.

Scene B is a classical example of a hole-effect semi-variogram. It shows an oscillating pattern at an interval of approximately 6 meters, which is the average size of the ridges in the agricultural field. The dominance of those ridges in the scene is reflected on the directional semi-variograms. The cyclic pattern is stronger in the E-W and NW-SE directions, and more subtle in the N-S and NE-SW directions.

Table 5 - Selected subsets – agricultural fields: global variance and location

Scene	Global Variance	District	Ward	Type of area (Census)
A	646.617	Temeke	Mjimwema	Rural
B	851.630	Kinondoni	Kunduchi	Mixed
C	394.421	Kinondoni	Mikocheni/Kawe	Urban
D	507.998	Kinondoni	Kunduchi	Mixed

Scene C has the smallest variance among the four subsets in the category of agricultural fields, as shown in Table 5. Elements in this scene include different crops, trees, distinct agricultural practice (matuta x others), and the amount of bare soil. The distribution of those elements in the area might introduce a trend in the data, captured by the directional semi-variograms shown in Figure 12b. A very similar spatial structure is observed in scene D, although with a higher global variance. Cultivated *matuta*, shallow *matuta*, and trees compose this scene. The spatial structure is distinct from that shown in Figures 10 and 11, where *matuta* and housing were combined in one single scene. The directional semi-variograms of scenes C and D show that for some directions the semi-variogram in unbounded and never reaches a sill.

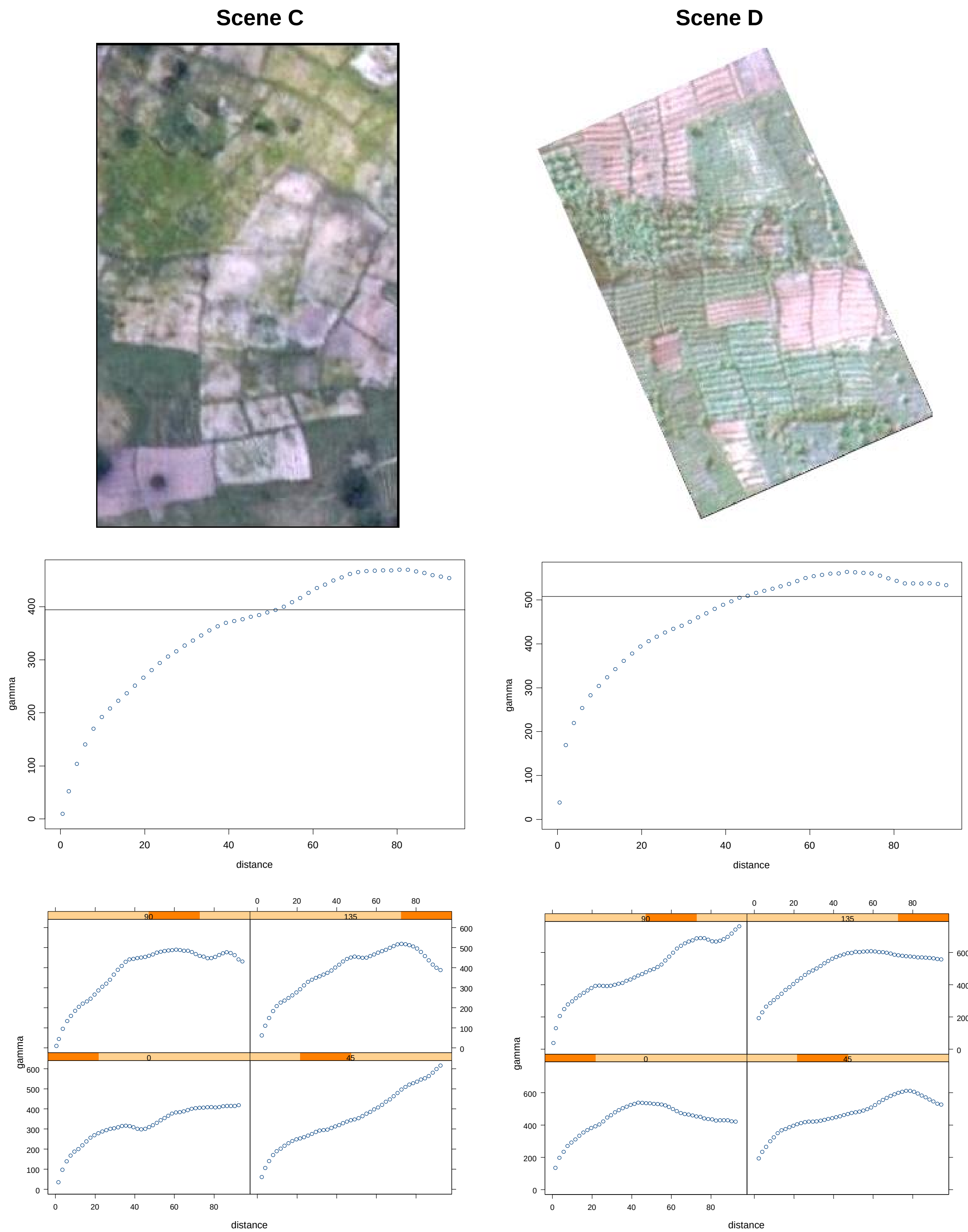


Figure 12b – Subset scenes and semi-variograms: agricultural fields

3.4. *Contrasting patterns of urban structure*

The analysis of individual types of urban landscapes highlighted unique features that characterize their spatial structure. Mostly important, however, is the comparison between the observed patterns, with special attention to differences in the global variance and the range, which suggests the most appropriate spatial resolution for the analysis of each scene.

Figure 13 compares the omni-directional semi-variograms for 5 types of residential areas in Dar es Salaam. The highest sill is observed for the unplanned housing developments, which is an area with little spatial organization (houses are not placed on a regular grid, and their orientation, shape and size may vary). In contrast, the lower sill is associated to the peri-urban scene with earlier expansion (line ⑤ in Figure 13), and therefore less man-made transformation to the landscape, resulting in small variability across the scene. As the expansion process intensifies the variance is expected to increase. In fact, the other peri-urban scene, expected to have an older expansion process (line ④ in Figure 13), has a spatial structure that approximates the pattern observed for a middle scale housing landscape. Eventually, if the urban expansion turns into a disorganized housing setting, the theoretical and observed sill should increase to the levels observed for the unplanned housing development scene analyzed here.

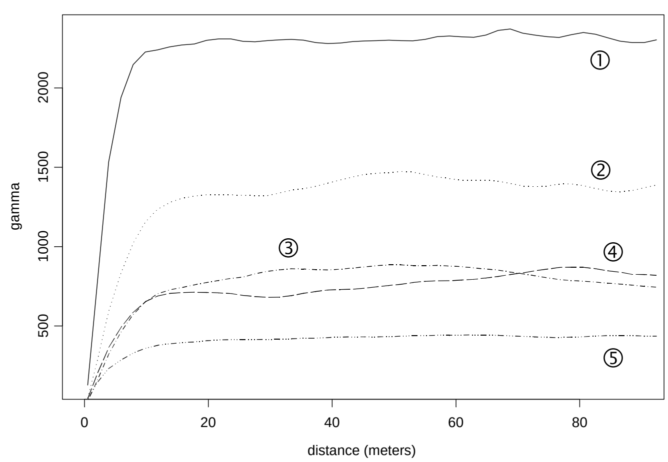


Figure 13 – Semi-variograms for different types of residential areas

① Unplanned housing development – scene A

② Upper scale housing

③ Middle scale housing

④ Peri-urban – scene B

⑤ Peri-urban – scene A

The observed height of the sill for the upper scale housing depends on the spatial organization of the houses in the scene. In this paper the selected scene shows a residential area with large plots that have multiple houses, and open spaces that can have varied uses (garden, cemented, etc). The more spatially organized these houses are, the smaller the height of the sill.

The range is roughly the same for all scenes, except for the upper scale housing subset, which can be explained by the larger sized of the houses in this scene. This finding suggests that the most appropriate spatial resolution for the purposes of classifying the scenes should be smaller than approximately 10 meters. Images with pixel size larger than that would not allow the distinction of the different objects in the scene. However, depending on the purpose of the classification, the resolution should be even finer. For example, if the goal is to associate objects in the ground to risk factors of disease transmission, a spatial resolution of 10 meters may be too coarse. As a result, although the range does give an idea of the spatial resolution, it is determined by the most dominant element in the scene, and therefore the final decision should be made based on the goals of the research.

Figure 14 shows the spatial structure of different residential areas with urban agriculture (specifically *matuta*), and facilitates the comparison of those landscapes with peri-urban areas and with scenes where matuta is the sole element.

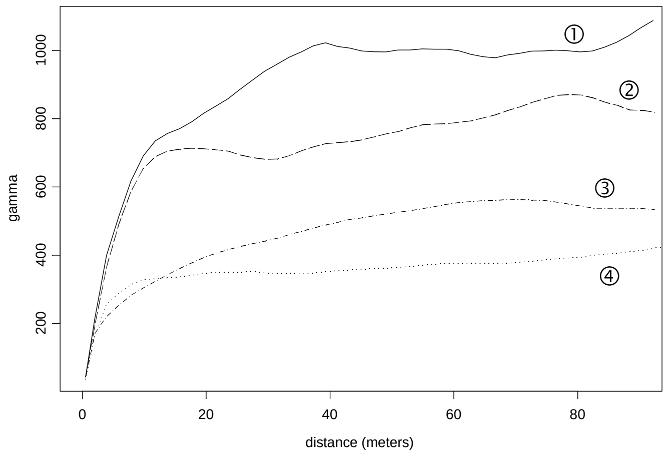


Figure 14 – Semi-variograms for different types of residential areas with urban agriculture

① Urban agriculture – scene C
② Peri-urban – scene B
③ Agricultural fields – scene D
④ Urban agriculture – scene B

The highest sill is observed for the urban agriculture scene in which *matuta* and houses are located in specific areas in the landscape. Moreover, houses vary in the direction they are built, in size and in shape. Such urban landscape configuration has a similar structure as a peri-urban scene, showing the complexity in characterizing an urban scene. On the other hand, the subset taken from the Tazara Quarters residential complex, portraying a well organized spatial structure, has the lowest global variance, and a pattern that resembles the semi-variogram observed for *matuta* fields. Therefore, depending on how dominant the houses are on the scene, the urban agriculture landscape can have a very similar spatial structure as a *matuta* field.

The omni-directional semi-variograms for different types of agricultural fields are presented in Figure 15. The highest sill is observed for the rural scene, which may indicate that agricultural fields in more urbanized areas are likely to be more organized across space. It is difficult to identify the most appropriate spatial resolution for analyzing those areas, since the semi-variograms do not quite stabilize at an upper limit. In fact, some of the directional semi-variograms observed for those scenes were unbounded, which means that the variance of the process goes to infinity.

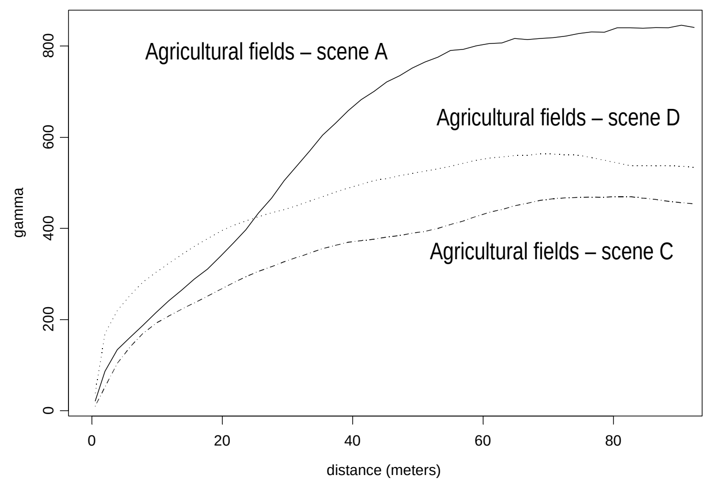


Figure 15 – Semi-variograms for different types of agricultural fields

4. Implications for malaria control

The role played by urbanization on malaria transmission is twofold. On the one hand, it reduces the number of places that could potentially become *Anopheles* breeding sites, since standing water tends to be more polluted, and there is considerable building construction and pavement of roads (Knudsen and Slooff, 1992). On the other hand, the initial process of urban expansion is accompanied by an increase in malaria rates at the periphery of the city. This is driven by the establishment of new shantytown zones with open sand pits and burrows, and by the dangerous encounter at the 'urban fringe' of a population with low malaria immunity coming into contact with parasite carriers migrating from rural areas. Therefore, as mentioned before, malaria transmission in the most urbanized areas is less intense than in peri-urban and rural areas.

As a consequence, it is reasonable to expect that the observed malaria rates in different areas of Dar es Salaam may have a relationship with the spatial structure of the area. In other words, the way in which the elements are organized in space may facilitate the transmission of the disease. The next step on this research will be to investigate if this relationship in fact is true. In March 2004 a project for integrated urban malaria control will be launched in Dar es Salaam. Larval, adult mosquito, and household surveys will be conducted during two years, and the impact of interventions for control evaluated. The sample frame of the project is the 10-cell unit, a spatial aggregation of 15-20 houses. The goal is to compare the observed malaria rates in each sampled 10-cell unit with the spatial structure described by the semi-variogram for that area. Rates will be compared with the parameters of the semi-variogram, and with the theoretical sill. If the expected relationship is significant, then the analysis of different areas (not sampled) could shed further light on the expected level of malaria transmission in the area, and indicate the need for control interventions.

5. Conclusion

The use of geostatistical models for the analysis of urban structures is no novelty. Previous studies have shown how these applications facilitate the understanding of the shape, size and variance of the elements found on the ground, as well as the most appropriate scale to study different scenes. The use of semi-variograms has highlighted the diversity in the organization of the urban space, especially through the analysis of its components (mainly the range and the sill).

In this study we replicate these applications for Dar es Salaam, Tanzania. Although the city is the main urban center in the country, the structure of the urban space is highly diverse, and very distinct of other main urban centers in most developed countries. Unplanned housing is present in many areas, recent expansion of the city has been accompanied by the establishment of squatter areas, urban agriculture is a constant presence, and livestock is also practiced. As a result, some areas are more likely to face health problems than others, although there are no distinct borders separating them. The health risk is a very local phenomenon, but the consequences usual spread beyond these local areas.

The purpose of this initial appraisal was to observe if, indeed, different patterns of spatial structure could be observed in Dar es Salaam, so that the link with malaria transmission could be pursued. The results do show that the city is extremely diverse regarding spatial organization. Therefore, the next step will investigate the relationship between malaria transmission and the spatial organization of the elements that compose an urban scene. Although detailed data on malaria cases is not available, a new Urban Malaria Control Program will be launched in Dar es Salaam in March, 2004, and will provide the necessary information to perform the analysis.

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