THE APPLICATION OF A BI-LEVEL GEOGRAPHIC INFORMATION SYSTEMS DATABASE MODEL TO ENCOURAGE THE DISSEMINATION, USE AND PRODUCTION OF GEOINFORMATION IN DEVELOPING COUNTRIES.

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ABTRACT

A major characteristic of cities in developing countries is a fragmented cadastre. Martinez (1999) has developed a two-tier system, termed the Bi-level model to deal with this by incorporating informal areas (that have no cadastral framework) with formal areas. This paper presents an application of the Bi-level model for the Cape Town Metropolitan Region (CMR). This application illustrates how the model can be beneficial for monitoring large-scale urban growth at a metropolitan-level, which is predominantly informal in nature, and therefore difficult to manage with conventional planning tools. The model provides this support in several ways. Firstly, it enables the detection of new informal settlements and key areas of growth. Secondly, it enables settlement density and growth rate calculations as well as a qualitative settlement pattern study. Thirdly, it enables the analysis and means of optimizing the informal settlement relocation process. Furthermore, the CMR experience has shown how the model may be useful for guiding informal settlement upgrading initiatives at a local-level. By creating linkages to sectoral database models, the applicability of the Bi-level model can be extended across a range of disciplines (see Martinez and Abbott 2000). In addition, the data capturing capabilities of the low-end GIS platform enables the end-user to contribute to the database building process. Finally, the bi-directionality of the linkages ensures that while the geoinformation is produceable by all it also remains accessible by all.

1 INTRODUCTION

Existing Urban GIS models are faced with several limitations. Firstly, these models tend to be single-scale in nature. They are usually designed to operate at either metropolitan- or at the local-level. Secondly, they are generally designed to cater only for the needs of the formal and environmental sectors of the city system. These models do not cater for the "gaps" of data that exist in digital cadastres throughout the world. In the developed countries, these gaps correspond to areas of physical decay or economic decline. In the developing countries, they correspond to informal settlement areas. In view of these limitations, a new two-scale urban GIS database model, termed the "Bi-level model" has recently been proposed (Martinez 1999, pp. 135-144, Martinez and Abbott submitted). The Bi-level model is a GIS database design that has been developed to enable GIS to be used for informal settlement upgrading applications. The full details of the conceptual model are discussed elsewhere. In this paper, a brief background to the model is first given. This is followed by discussions that illustrate how the metropolitan-level of the model may be used to monitor the growth and aid the upgrading of informal settlements in the Cape Town Metropolitan Region (CMR) in South Africa.

2 BACKGROUND

2.1 THE BI-LEVEL MODEL

The conceptual framework of the Bi-level model has been discussed in detail elsewhere (Martinez and Abbott in press). In figure 1 the Bi-level model is shown in the context of other urban database models which may exist for a city in a developing country. These models could include a metropolitan-level formal settlement database, a formal city digital cadastre and sectoral database models (Martinez 1999, p 140). If a formal city digital cadastre exists, it would serve as the spatial reference framework for the Bi-level model. At the centre of the Bi-level model (on the right hand portion of the diagram) is a metropolitan-level database. Attached to this basic reference framework are a series of local-level databases. To this two-tier system, other databases may be attached to extend the applicability of the model. These extensional databases are referred to here as “potential sectoral models” attached to the Bi-level model. These databases are inter-linked through bi-directional database warehouse connections. While the model requires internet-connectivity to achieve its full potential across a metropolitan region, it recognizes the need for community participation-based methods at a local-level. Members of the community are actually involved in capturing and entering informal settlement data into the local-level database. Furthermore, the model is applicable not only in the developing countries with informal settlements, but also more generally in any country that is faced with gaps in the digital cadastre.

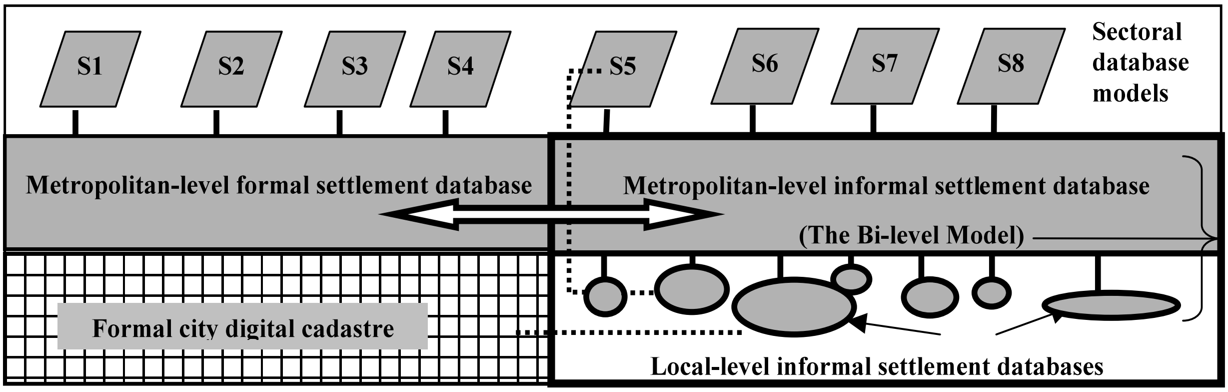

Figure 1. The conceptual framework of the Bi-level model. Here the Bi-level model is shown in the context of the formal city digital cadastre and sectoral (S1-S4) model databases. (Source: Martinez and Abbott submitted, figure 5).

2.2 APPLYING THE BI-LEVEL MODEL FOR THE DISSEMINATION OF GEOINFORMATION

The manner in which the Bi-level model can be used as a mechanism for data diffusion has already been discussed (Martinez 1999, pp.148-149, Martinez and Abbott in press, pp.13-14, figure 6). Figure 2 illustrates further, in the context of the linkage accessibility environment (LAE) diagram (Martinez and Abbott 2000, figure 7), how a database network based on the Bi-level model can facilitate the dissemination of information. At the center of the diagram in the intranet environment (I) lies the metropolitan-level database. The local-level and potential sectoral model databases are distributed throughout the intranet and all three internet environments (IE1-IE3) (defined in Martinez and Abbott 2000, section 7). The quadrangular arrow in figure 2 indicates that data can effectively be distributed through unidirectional linkages from the metropolitan-level database to sites in all four database-connectivity environments.

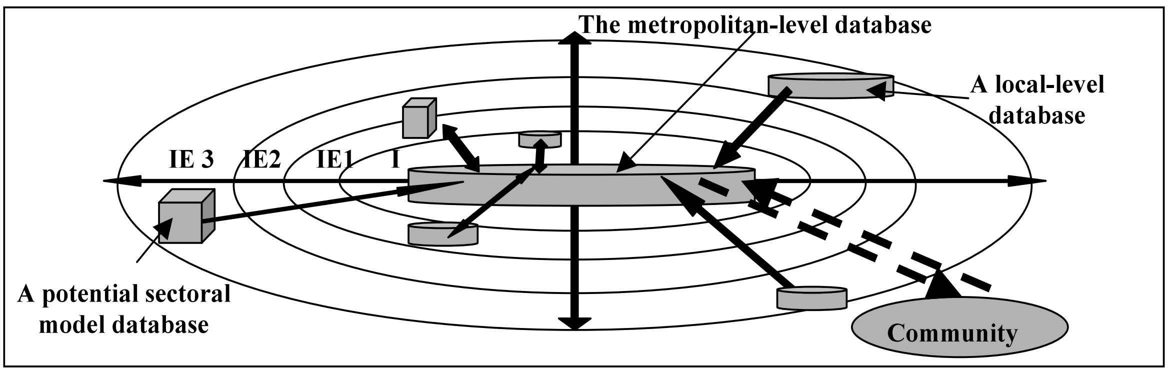

Figure 2. Linkages of the Bi-level model on an LAE diagram. (Source: Martinez and Abbott 2000, figure 8)

However, the likelihood of a bi-directional linkage decreases as one moves towards the outermost connectivity environment Furthermore, particularly with applications involving data flows to and from user groups without access to the internet, there may be other “human-based” (ie. non-internet-based) information flows between communities and the developers of local-level databases. Without the database network shown in figure 2, a multitude of potential GIS user groups would constantly be requesting data updates from the original database sources. Through the database warehouse connections required by the model, the latest data can always be accessed. The bi-directionality of the connections facilitates a return flow of processed data. This is a critical aspect of the model if the local-level platform is to be used for negotiating upgrading proposals (see Martinez and Abbott 2000, Martinez 1999, p 228). Finally by placing and maintaining community-based data on one site in such a network, the users of the remaining inter-connected sites have access to this data. This does away with the need for several user groups to approach communities directly for the same sets of data.

2.3 APPLYING THE BI-LEVEL MODEL FOR THE PRODUCTION OF GEOINFORMATION

The manner in which the Bi-level model may be used for the production of metropolitan- and local-level data on informal settlements has been discussed in detail elsewhere (Martinez and Abbott 2000, Abbott, Martinez and Douglas in press). One of the tools developed to aid the attribute data capturing process was a customized Access database interface. This interface enabled community members to capture the attribute data for local-level databases. However, the primary manner in which the model contributes to the data production process is by providing a mechanism for accelerating the data transfer process between user groups with different data capturing and processing capabilities. The bi-directionality of the linkages employed in the model implies that both the metropolitan and local-level database users can contribute to the database development process. Data can be captured at the local-level, processed at the metropolitan-level and returned for analysis and attribute data population at the local-level. This enables special procedures such as image processing, linework cleaning and centroid placing, which may only be possible on a high-end GIS platform, to be carried out on the data captured at the local-level. The ease with which data may be transferred between the various user groups also reduces duplication in the data capturing process.

3 APPLYING THE METROPOLITAN-LEVEL OF THE BI-LEVEL MODEL TO MONITOR THE GROWTH OF INFORMAL SETTLEMENTS IN THE CAPE TOWN METROPOLITAN REGION (CMR)

3.1 Introduction

The Bi-level model described in the preceding sections was used to develop a database of informal settlements in the Cape Town Metropolitan Region (CMR) based on 1996 aerial imagery. The technical aspects of how this database was constructed is discussed in detail in Martinez and Abbott (2000). The database was developed initially with two primary aims. The first was to obtain a more up to date shack count for the CMR. The second was to model the growth of informal settlements in the CMR. The results and the methodology of the 1996 count have been discussed in detail in Martinez 1999 (pp. 229-264). In summary, a total 65 freestanding shack informal settlement areas (consisting of a total of 59 868 freestanding shacks) were mapped over an area of 873.83 ha. In the following sections a synopsis of the observations that arose by comparing the results of this work with previous studies and vector data sets is presented. Particular emphasis has been placed on settlements in Ikapa and Khayelitsha which are the key informal settlement bearing areas in the CMR (see figure 3). This is followed by a discussion on how this data can be used to obtain indicators of the growth rate and spatial distribution in order to optimize the process of upgrading these informal settlements.

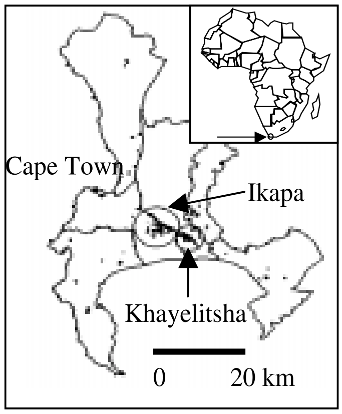

Figure 3. Location map.

3.2 New Settlements

The result of a series of comparative vector-image data overlays with previous studies (see Martinez 1991, pp. 231-236) carried out at the metropolitan-level suggested that at least 7 new settlements were detected by the 1996 survey. The list of the minimum number of newly detected settlements included the following areas: Airport (369 shacks), Eastern Khayelitsha (53 shacks), Ottery (49 (shacks), Witsand (312 shacks), Heinz Park (207 shacks), Hangberg (203 shacks) and the Palm Tree Settlement (49 shacks). The remaining areas listed here had not been listed by previous informal settlement studies.

3.3 Key areas of growth

3.3.1 Introduction. In addition to the comparisons carried out at the metropolitan-level, vector-vector overlay comparisons were carried out at a smaller scale for the major informal settlement areas in the CMR (the Ikapa/Crossroads and Khayelitsha districts). For this the 1996 data of this study and a vector data set acquired for 1995 from the Cape Town City Council was utilized. Given the problems facing the quantification of the 1995 vector data (due to the format of the vector data, it was decided to simply overlay the two georeferenced data sets and thereby use the data to highlight areas of growth in a qualitative manner. Quantitative comparisons with previous studies were also carried out and the numbers of shacks listed in brackets below represent the net growth over a period of 17 months (December 1994 – May 1996).

3.3.2 The Ikapa/Crossroads district of Cape Town. The limits of this district are shown in the left-hand box of figure 4, together with all of the informal settlements that have been identified within the boundaries of the district. The right-hand box then illustrates four examples of settlements from within this group. The results of the comparisons indicated that the total number of shacks increased significantly from 1995 to 1996 in Brown's Farm (831 new shacks), Crossroads (1616 new shacks), Lower Crossroads (153 new shacks) and Nyanga (397 new shacks). The comparative vector overlays clearly illustrate the influx of informal settlement dwellers in the northern section of Ikapa (Guguletu). A selection of these overlays (see Martinez 1999, figures 9.4 to 9.9) is presented in figure 4 (right-hand box). The settlement growth areas extending beyond the 1995 settlement boundaries have been crosshatched. In Guguletu, the overlays suggest that most of the growth has occurred along the northern and eastern margins of Kanana (449 new shacks), New Rest (144 new shacks) and Barcelona (705 new shacks) (see figure 4). In Brown's Farm, the growth has occurred in an interspersed manner over 39 small localities within the settlement. This settlement provides an example of growth by settlement densification as opposed to marginal growth process occurring in Guguletu. West of Brown's Farm, a marginal growth process is suggested for Sweet Home (279 new shacks). While both the marginal growth and densification processes are visible in Crossroads and Boy's Town. Net increases in the number of shacks were also detected immediately south of Crossroads in the Samora Machel (75 new shacks) and Sweet Home (279 new shacks) settlements.

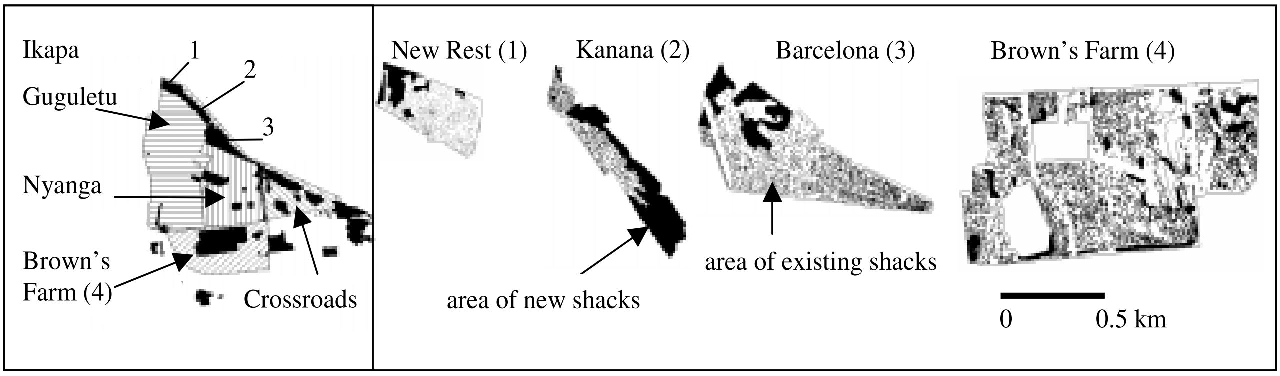

Figure 4. Vector overlays of 1996 (this study) and 1995 data illustrating the areas of informal settlement growth in the Ikapa/Crossroads district. The insert shows the relative position of these settlements in the Ikapa/Crossroads district.

3.3.3. The Khayelitsha district of Cape Town. In the Khayelitsha district, a net growth in the number of freestanding shacks was detected in the Bongwani – Ikwezi Park (628 new shacks), Greenpoint (100 new shacks), Silvertown (769 new shacks) and Town 1 Village 1 (307 new shacks) areas. The vector overlays for the Khayelitsha district (see figure 5) clearly indicate that a marginal growth process has taken place in Silvertown, Greenpoint and Town 1 Village 1 areas. In addition, a new settlement consisting of 53 shacks was detected to this east of Khayelitsha and has been referred to as Eastern Khayelitsha. The data for Khayelitsha suggests that the existing relocation policy is resulting in a natural shift of the population towards the margins of the informal settlement area centres.

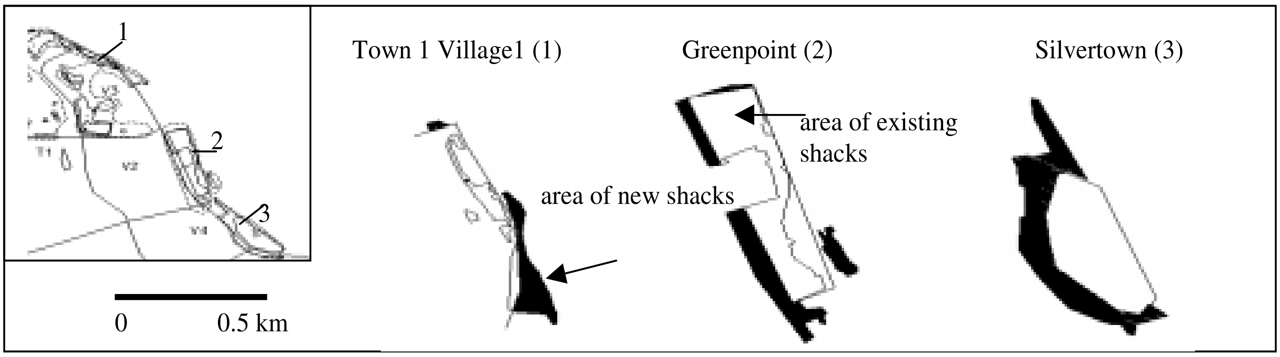

Figure 5. Vector overlays of the 1996 data and 1995 data illustrating the growth of informal settlements in the Khayelitsha district. The inset shows the location of the settlements in Khayelitsha.

4 SETTLEMENT DENSITY CALCULATIONS

The results of the shack count data discussed above were also utilized to determine the average settlement density (ρ) for each of the informal settlement areas in the CMR (Martinez 1999, p 249). This parameter was calculated as a function of the total shack count for the settlement (X), the shack count for the nth sub-settlement of a settlement consisting of n sub-settlements (χ_n) and the density (shacks / hectare) of sub-settlement n (ρ_n):

$$\rho = [(\rho_1\chi_1+\rho_2\chi_2+\rho_3\chi_3+\ldots\ldots\rho_n\chi_n)] \quad / \quad X \qquad (1)$$

The density distribution calculated using this relation ranged from 3 du/ha to 247 du/ha and averaged at 99 du / ha ± 60 (n=65). The density values calculated in this study were significantly higher than the densities calculated in previous studies as they were calculated exclusively for freestanding shack areas (ie. the open spaces within the individual settlements were mapped out and the areas were subtracted from the settlement area). Using these average settlement densities, a density-based classification was devised for informal settlements in the CMR. The following density ranges were used in the classification scheme: 200 - 250 du / ha (dwelling units per hectare), 150 - 199 du / ha, 100 - 149 du / ha, 50 - 99 du / ha and 0 - 49 du / ha. The results of the study indicated that the majority of the settlements (43 %) lie in the 50 - 99 du / ha category. An approximately equal number of settlements lie in the 0 - 49 du / ha (22 %) and 100 - 149 du / ha categories (19 %), and less than 13 % of the settlements lie in the 150 - 199 du / ha (11 %) and 200 - 250 du / ha (1 %) density categories. A thematic map based on the density classification scheme (Martinez 1999, p 251, figure 9.11) showed that in Ikapa, the highest density settlements are situated in Nyanga (Mpetha, Mpinga and Mpuku). The lowest density settlements are situated north of Guguletu (Kanana) and east of Crossroads (Klipfontein Glebe). In Khayelitsha, the highest density settlements occur towards the centre of the area (Trevor Vilakazi, Victoria Mxenge and Victoria Mxenge South).

5 NET GROWTH RATE CALCULATIONS

5.1 The Ikapa/Crossroads and Khayelitsha districts of Cape Town.

Annual growth rates were calculated for each of the settlements mapped and are expressed here as the percentage increase in number of shacks per year (Martinez 1999, p 250). This data was used to highlight the key areas of growth in Ikapa/Crossroads and Khayelitsha (see figure 6). From figure 6 it can be seen that significant positive growth rates were observed along the north-eastern margin of Guguletu for the following settlements: Kanana (75 %), Barcelona (35 %), Phola Park (14 %) and New Rest (7 %). Towards the centre of the Ikapa, Nyanga displays a mixture of static (less than 2 % per year), increasing and decreasing freestanding shack area growth rates. Settlements that appear to have a static growth rate are: Mpinga Square (1 %), KTC informal (1%), Black City (2 %) and Mpetha Square (2 %). The high densities for these areas suggest that they have not experienced any significant growth recently simply due to a lack of space. Settlements that appear to have grown significantly in Nyanga are Miller's Camp (24 %) and Mkonto Square (10 %). Positive growth rates were also observed in the southern parts of Ikapa/Crossroads for the Crossroads (34 %) and Brown's Farm (14 %)

settlements. In the central areas of Khayelitsha no positive net growth was observed, however significant positive growth rates were observed for the following settlements in the marginal areas: Bongweni - Ikwezi Park (49 %), Silvertown (40 %) and Green Point (5 %) settlements.

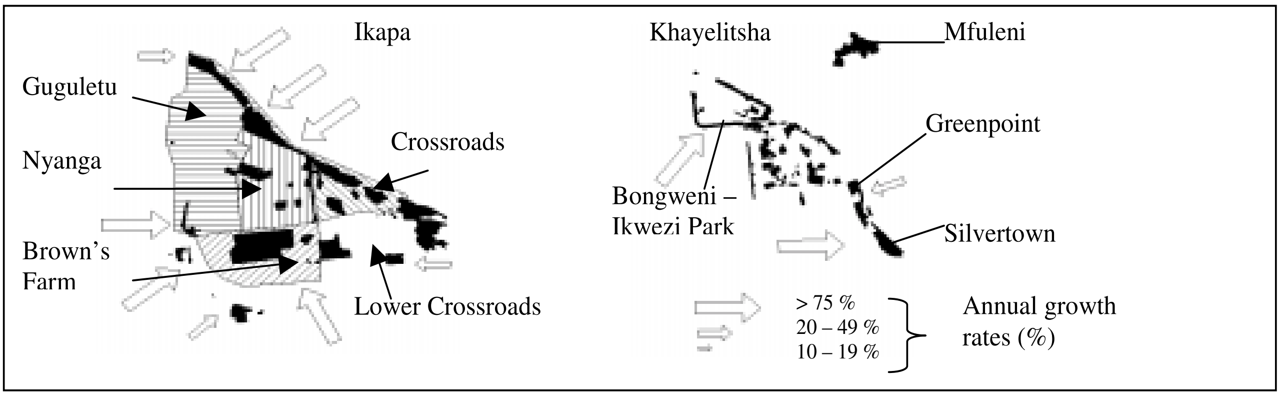

Figure 6. Key areas of informal settlement growth in Ikapa/Crossroads and Khayelitsha districts.

5.2 Other areas.

Other areas in the CMR that experienced significant positive growth rates were Sweet Home (188 %), Lower Crossroads (15 %) and Samora Machel (5 %) and Vietnam (29.2 %). In the case of relatively small settlements, a growth rate factor was calculated by dividing the number of shacks in 1996 by the number of shacks in 1994. This factor was used as in some cases, "settlements" that were extremely small in 1994 (eg. comprised of only 1 shack) have increased by over an order of magnitude in size. Growth rates were calculated in this manner for Heinz Park (69), Ottery (49), Pelican Park (3.8), Vrygrond (2.1), Wallace Dean (1.4) and Mitchell's Plain (1.3). These growth rates illustrate the importance of mapping even the smallest settlements. In the case of Ottery, 1 shack was detected in 1994. By 1996, this location had grown to a settlement of 79 shacks. Other areas further away from the main informal settlement region in the CMR which have experienced a net growth are: Bloekombos (30 %), Marconi Beam (12 %) and Samora Machel (5 %).

5.3 Population estimates.

Despite of several factors which inhibit the calculation of population estimates (Martinez 1999, p 257), estimates were calculated for each settlement using average household size values from previous studies. The total population calculated for all the informal settlements in the CMR was 251799. Thus the results of this study indicated that by 1996, 8.8 % of the total CMR population (2.87 million) resided in informal settlement areas.

6 APPLYING A BALANCED RELOCATION POLICY

The current policy applied by local government in informal settlement areas in the CMR (Provincial Administration of the Western Cape, PA:WC) is one of relocation. The percentage of relocation planned for the majority of the settlements ranges from 50 % to 90 % with an average at 54 %. In some cases the entire settlement is planned for relocation. By using density-based indicators it is possible to reduce or optimize the amount of relocation required for each settlement. If one assumes that the settlements with a density of 60 - 110 du / ha have the potential for in situ upgrading (Martinez 1999, p 258), then the density classification scheme discussed above may be used to identify settlements that have the potential for upgrading (see table 1). Furthermore, the settlements in the lowest density categories: 0 - 49 du / ha, 50 - 99 du / ha and a number of

Settlement	Density (du / ha)	Settlement	Density (du / ha)	Settlement	Density (du / ha)
Barcelona	50	Joe Slovo	105	New Rest	77
Boy's Town	97	Kanana	45	Samora Machel	81
Gxa-Gxa	83	Lower Crossroads	81	Vietnam	65

Table 1. A selection of the informal settlements identified as having the potential for in situ upgrading.

the settlements in the 100 - 149 du / ha category "have the potential for in situ upgrading". In essence, 69 % of the informal settlements in the CMR should be investigated for in situ upgrading possibilities (Martinez 1999, p 258). Furthermore, a limited amount relocation can be applied to reduce the density of the remaining settlements in the higher density categories. In fact, it is possible to create a spreadsheet to minimize the amount of relocation to achieve the required planning densities. Martinez (1999, p 259) has shown that the total number shacks for relocation (S_r) from a settlement can be calculated as a function of number of shacks in the nth sub-settlement (S_n), the sub-settlement area for the nth sub-settlement (S_{an}) and the required average settlement density (D_r):

$$S_r = ([S_1 - (S_{a1}*D_r)] + [S_2 - (S_{a2}*D_r)] + ...+ [S_n - (S_{an}*D_r)]) \quad (2)$$

Using the individual sub-settlement components required for equation 2, one can easily determine the number of shacks that must be removed from each sub-settlement to attain the required planning densities. By following this approach one can begin to apply a true minimum relocation policy as opposed to the present relocation policy being implemented by local government in the CMR.

7 SPATIAL PATTERNS OF SETTLEMENTS

An alternative, less quantifiable indicator, that may be used to prioritize the upgrading process is the settlement pattern. Distinct settlement patterns such as dwelling unit clusters, clumps, central space patterns and ring street patterns have been recognized by other studies. The data captured for the present study, has facilitated the recognition of at least three, and possibly four, distinct shack cluster morphologies in the Ikapa/Crossroads district alone (Martinez 1999, pp. 260-262, figure 9.15). The first class is characterized by a very high shack density. The individual shacks are tightly clustered and represent areas that are highly inaccessible in terms of the provision of urban services. The second class is represented by a linear arrangement of shacks. The distribution of shacks in this area is expected to have a channeling effect on the overland storm water runoff. A third class may be recognized, which is characterized by a shack density that is lower than the first and second types. This class lacks the highly linear arrangement of the second class. The fourth class is characterized by an extremely low shack density, which indicates that these areas may be highly accessible for the development of urban service infrastructures. The third class is expected to represent the intermediate stage of a gradational transition from the fourth to the first class. Examples of the settlements in the Ikapa/Crossroads district that may be placed into each of these classes have been discussed in detail elsewhere.

8 USING THE METROPOLITAN TO LOCAL-LEVEL DATABASE LINKAGES TO GUIDE THE INFORMAL SETTLEMENT UPGRADING INITIATIVES

The relocation optimization methodology (discussed in section 6) is acceptable in principle. However, it needs to be done in conjunction with an upgrading implementation strategy that tests the maximum number of people that can be upgraded. It is here that the linkages between the metropolitan-level and the local-level databases in the Bi-level model (section 2) have a critical role to play. The metropolitan-level database is faced with the limitation that not all of the settlements have been sub-divided into clusters. This constrains the full potential utility of the density-based relocation approach. Furthermore, while the application of the density-based methodology can be used to identify upgradeable informal settlements (Martinez 1999, pp. 262-263), it still leaves many practical questions unanswered. Issues such as exactly how many shacks and which shacks should be removed remain unanswered. Some of these issues can be addressed through the creation of a metropolitan-level to local-level database linkage. An example of such a linkage (see figure 7) was created between the metropolitan-level of the Bi-level model for

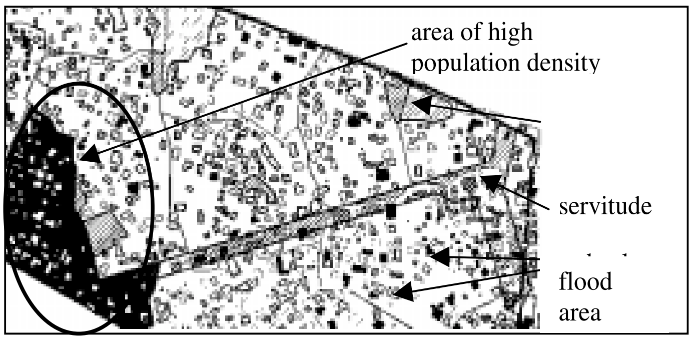

Figure 7. Utilizing the metropolitan- to local-level database linkage to view the density variation across a settlement.

Cape Town and a local-level database recently created for New Rest through the New Rest / Kanana Development Trust. Through this linkage it was possible to illustrate the density variation across the settlement. Furthermore, the linkage enables density-based relocation approach to be tested in the context of reality. The linkage enables this by giving the user of the metropolitan-level system access to information on the basic cadastre and detailed socio-economic data. However, perhaps the most import advantage, is that the metropolitan-local-level database connection opens the door towards community involvement in the decision making process. In the same way that the local-level data can be accessed by metropolitan-level planners, the upgrading proposals made by these planners can be viewed from the local-level platform (Martinez and Abbott 2000). This is a critical factor as the success of an upgrading proposal will inevitably rely on the long-term support of the community involved.

9 CONCLUSIONS

This paper has shown how the metropolitan-level of the Bi-level model may be used to analyse the growth of informal settlements across large urban areas. In the case of the CMR vector-vector data overlays have enabled the detection of new informal settlements and of existing settlements that have experienced marginal and interspersed growth processes. Furthermore it has illustrated how the metropolitan-level to local-level database linkage may be used to guide the application of a density-based minimum relocation approach to informal settlement upgrading. While the large-scale process analyses presented here apply primarily to the metropolitan-level, the model can also be applied for the analysis of processes at the global-level. For this, a global-level database linked to a series of metropolitan-level databases would have to be developed.

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