Prospective Slum Policies: Conceptualization and Implementation of a Proposed Informal Settlement Growth Model

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Abstract:

This paper provides an improved methodology for analyzing the dynamics of slums in Developing Countries (DC). In particular, it demonstrates how Geographic Information Systems (GIS) and Cellular Automata (CA) can be integrated to model, simulate, predict and dynamically visualize the growth of slums, and thus will improve future planning practices in DC. The paper first examines factors that contribute to the existence and spread of informal settlements (IS). It then assesses past and current slum policies to conclude that they are failing to contain the rapid expansion of slums. It is argued that weaknesses of these policies include on the one hand, planning instruments that are often rigid, inappropriate and outdated, inherited from former colonial powers. On the other hand, urban planners often overlook future spatial extension of slum areas.

This paper also explains how factors underpinning emergence and growth of slums are accommodated within an Informal Settlement Growth Model (ISGM) that loosely couples a GIS with a CA model. In this way it is demonstrated how a *VISUAL BASIC* macro can be linked with GIS to design a flexible and generic modeling environment. Here, the ISGM is applied to simulate and predict the growth of IS in Yaoundé, Cameroon with slum allocation accuracy of up to 73%. In doing so, the model tests various mechanisms that motivate slums' growth, such as proximity to roads, rivers, market places, existing informal settlements, cultural and ethnic groups. By integrating physical, socio-cultural and economic factors that underpin slums growth, the ISGM provides a much stronger practical framework to achieve slum reduction.

Finally, the paper demonstrates how such spatio-temporal simulation and visualization of urban dynamics are critical for the appraisal of the past, present and probable future location of slums. Moreover, it is argued that dynamic visualization via *movies* can provide new insight into the emergence and growth of IS. The ISGM is also evaluated in terms of sensitivity, reliability, validity and usability, for which it generally scores highly. The paper concludes that the proposed model can potentially enhance decision-making processes in urban planning, informed prospective slum policies and help predict the likelihood of slum emergence and growth, which will eventually improve the quality of life within developing countries' urban areas.

Keywords: Urban growth; Slum policies; Urban planning; Modeling and simulation; Trends and prediction; Developing Countries; Yaoundé.

Introduction

Recent surveys indicate that between 40-70% of urban dwellers in Developing Countries (DC) now live in slums and the trend does not show any sign of slowing down (UN-Habitat, 2003; Davis, 2004). There is growing evidence that the *informalization* process of urban centers in DC will persist and that existing policies and programs will do little to curb the expansion of slums. This paper assesses and highlights the weaknesses and achievements of past and current informal settlement policies and programs in DC since the 1950s. One of the key lessons of this assessment is that past and current slum policies act and react on existing slums and fail to capture and incorporate preventative and proactive measures that could reduce the spread of future slum growth and ultimately mitigate the effects of unplanned settlements on the majority of urban dwellers in DC. It is now well established that the proliferation of slums associated with the lack of security of tenure is changing not only the urban form and structure, but also (and more importantly) is exacerbating poverty, housing problems, inequality and social exclusion in most cities in DC. In the meantime, urban and slum policies have reached a 'deadlock' situation whereby innovative and effective measures to properly address the challenge of slum growth barely exist.

This paper therefore argues that to improve current practices and their cost-effectiveness, future slum policies and programs should be *proactive* in their design and implementation, that is, oriented to address future growth and associated issues before they occur. Such forward thinking strategies and slum prevention policies would go a long way in achieving the long-term reduction and management of slums. To implement such a paradigm shift, this paper proposes that one way to reduce slum occurrence should be an integrated conceptual framework based on spatial technologies such as Geographic Information Systems (GIS), and a modeling approach such as Cellular Automata (CA). The paper will then present a methodological framework of an *Informal Settlement Growth Model (ISGM)*, which can predict the emergence and growth of informal settlement patterns. The model is built around the theories of slums growth and factors pertaining to their emergence and growth. Such factors (physical, economic and socio-cultural) include topography, transportation network, existing pockets of slums, source of income (informal economic sector), places of worship, and cultural and ethnic groups.

The application of the slum prediction model to Yaoundé (Cameroon in Western Africa) shows a slum allocation accuracy of up to 73%. This strongly indicates that the model has the potential to inform future urban policies and assist urban planners and other slums stakeholders in their quest to improve the management of the informalization of cities in DC. Urban planning policies and programs also stand to gain by using such a modeling tool to proactively address the long-term and the potential problems of slums. This is in contrast to the *quick-fix* measures that are often adopted in DC. The result is encouraging and challenges the view that slums are 'spontaneous' and cannot be predicted and 'planned'. More importantly, the dynamic visualization outputs of the model adds another insight into the slum emergence and growth and thus indicates that urban and slum stakeholders (such as public, private, financial institutions, practitioners and NGOs), could have an improved knowledge of the location of new and future informal settlements and therefore could take proactive measures for the 'planning' and provision (or at least facilitate the provision) of decent infrastructure and services for the potential and future slum/urban dwellers. However, the proposed slum framework will require fine tuning to make it more 'user friendly' to a larger audience (for instance by upgrading the programme to a menu driven software). Nevertheless, the model constitutes a slum growth benchmark that will benefit from further tests on other cities in DC.

This paper first discusses the factors that underpin the emergence and growth of informal settlements along with various slum policies initiatives. Secondly, it elaborates on the usefulness of simulation and modeling in informing the design of future slums policies. Thirdly, the paper presents a simulation, modeling and dynamic visualization approach that was developed using a GIS/CA programming framework. Finally, the paper demonstrates how the proposed slum simulation model is implemented in Yaoundé, Cameroon, and it then evaluates its strengths and weaknesses when it comes to informing future urban policies.

1. Informal Settlements: Why, How and Where?

The UN-Habitat (2003) estimates that 78.2% of city dwellers within Developing Countries (DC) live in slums[1]. These slums are often described by their low-standard housing, overcrowding, acute shortage of basic physical and social services and infrastructure, high environment and health threat, non-compliance to planning regulations, insecurity of tenure, faulty alignment of streets, social composition (especially in relation to migration) and unfavorable socio-economic and living conditions. This section first presents the spatial dynamics and the importance of slums in the DC context, and it then discusses the factors that often trigger the emergence and growth of slums.

1.1 Informal Settlement in Developing Countries: An Implosion

Since the 1950s, the number of urban population living in slums has continued to grow in most DC cities. An earlier pilot survey of 14 cities in DC by the UNCHS (1982) reported that IS housed between 32% and 85% of the urban population. The UNCHS (1996) and Jenkins (2001) report that slums make up as much as 32% of Sao Paulo, 33% of Lima, 34% of Caracas, and 59% of Bogota in South America, and 44% in Maputo, 60% in Dar-es-Salaam, 70% in Luanda, and 85% in Addis Ababa in Africa. In some countries, slums now constitute the essential characteristic of the urban landscape. For instance, the Global Urban Observatory (2003, p.81) reports the case of Ethiopia (99.4%), Chad (99.1%), Afghanistan (98.5%) and Haiti (85.7%). Also, Pugh (2000) estimates that slums grow at a rate of 30-70% of the housing stock in most cities in DC.

One of the explanations for such increase of slum dwellers is that the urbanization in DC was initially perceived as a mechanism for improving living conditions and the environment, especially for city dwellers with greater access to income. A corollary effect, however, was to induce significant migration from the rural areas to the city context where housing was not available or affordable to cope with the significant influx of people and thus contributing to the expansion of IS. Coupled with the high natural population increase in urban areas and the continuous decrease and depreciation of competitive opportunities in rural areas, rural populations have continued to move to urban areas (Rempel, 1996; Kengne & Sietchiping, 2000, Davis, 2004). It is worth noticing that recent slum expansion in DC is largely controlled by four additional factors: intra-urban migration, natural population increase, reclassification and annexation (UN-Habitat, 2004)

In DC, cities have since grown at such high and uncontrolled rates that a combination of factors now explain why IS are the dominant land use pattern in most urban areas (Obudho, 1992). For instance, insufficient urban infrastructure (especially housing) and services, the poor vision of city planners, the inconsistency of urban land use management, inadequate planning scheme, clashes of land rights, and economic crisis (e.g., structural adjustment and unemployment) are all further contributing to the slum expansion. It is now a well-documented fact that, since the 1980s, international *neo-liberal* policies such as Structural Adjustment Programmes and globalization have and will lead to rapid proliferation of informal settlements, increase of social inequalities, and spread of poverty in DC (Balogun, 1995; Portes & Hoffman, 2003; UN-Habitat, 2003; Davis, 2004; Shatkin, 2004).

The impoverishment of city dweller, in particular, reflects on the inadequate and decaying quality of housing. The low standard of housing (which can be translated at the citywide scale as informal settlement) is important to study because the quality of dwellings is one of the spatial and visible expressions of the deterioration of living conditions in cities in DC. The problem facing the IS dwellers can be so acute that for them, the informal land and housing markets are considered the only plausible answer. A complicating factor is that the degradation of residential urban land use is now so severe that from the poverty perspective, there is enough evidence to support the argument that poverty is becoming more prevalent in urban areas than in most rural areas in DC (Pugh, 1997; Satterthwaite, 2001).

Such rapid and continuous deterioration of living conditions in urban centers highlights the need for more innovative responses to the slums issues (Pugh, 1997; UN-Habitat, 2003). Without innovative and proactive measures, the amalgamation of shelters outside the official building schemes and regulations, will continue to develop into slums, underlining the prevalence of unplanned developments as the new form of urban extension.

1.2 How and Where Informal Settlements Emerge and Expand?

Various reasons are often put forward to explain the emergence and growth of slums in DC. For instance, research shows that slums excel in marginal or less valuable urban land such as riverbanks, steep slopes, dumping grounds, abandoned or unexploited plots, along transportation networks, near industrial areas and market places, and in low lying areas or wetlands (Blight & Mbande, 1998; Global Urban Observatory, 2003).

Other work suggests that slums seem to be mutually attracted, at least in part, by spiritual or religious activities (Berg-Schlosser & Kersting, 2003; Davis, 2004). Such correlation is also well documented for new urban migrants who prefer to settle in neighborhoods that share similar socio-cultural backgrounds (Malpezzi & Sa-Adu, 1996). It could therefore be argued that the knowledge of dominant ethnic, cultural and religious groups in existing neighborhoods or slums could provide useful clues for exploring future expansion and location of slums. Such knowledge is valuable for the spatial prediction of slum growth, especially in cities where ethnic, cultural and religious differences highly influence the location choice of the urban dwellers.

Moreover, there is now sufficient evidence to argue that IS dwellers tend to have been born in cities and previously lived in informal settlement (probably nearby) or they are planning to move to a future informal settlement and preferably in the peri-urban areas (UN-Habitat, 2003).

This suggests that established slums can duplicate themselves and serve as a stepping-stone for the emergence of future settlements on the nearest available land.

Another important factor is the close correlation between the informal economy and IS (Kengne, 2000). This is because knowledge, skills and experience are not often pre-requisites for accessing the informal job market, as it is the case within the formal or public sector (Happe & Sperberg, 2003). Migrants to the urban areas have long fuelled the informal economic sector (often represented by popular market places), which employs more than 70% of the labor force, and contributes an average of 40% of the GDP of developing cities (Kengne, 2000). Another important factor that helps to explain the proliferation of slums is the rigidity of urban planning regulations associated with other factors such as poor governance, corruption and nepotism, which all lead to a severe shortage of land and urban housing, squatting, and infringements of building regulations (Fekade, 2000).

The end result of all these factors is rapid, unstructured and unplanned expansion, conflicting land tenure and property rights, poor quality dwellings, decay of the physical environment, unhealthy living environment, severe social problems, and low socio-economic status for IS occupants that all constitute the common characteristic of IS. Various measures have constantly been undertaken to improve the conditions of slums in DC, but their effectiveness are often questionable.

2. Slum policies in Developing Countries: A Review

Slums are often conceived and portrayed as institutional failures in housing policy, housing finance, public utilities, local governance and secure tenure. Thus, measures to address their existence and appearance have evolved around such thinking. During the postcolonial period, particularly in the 1950s and 1960s, the issue of slum in Developing Countries (DC) emerged as an important area for urban research and policies (Pugh, 1997). As a result, various slum strategies were implemented to (at least) mitigate the socio-economic, physical and health wellbeing of slums and their residents. This section discusses governmental attitudes, responses and policies towards slum since the 1950s. These changes can be categorized into three main approaches: centralized control of housing, neo-liberal approach and the emerging *preventative* approach. For the purpose of this paper, these three approaches are discussed following five major chronological categories: *laissez -faire* attitudes in the 1950s and 1960s; *site and service* programs in the 1970s, slum upgrading in the 1980s, enabling strategies and security of tenure in the 1990s, and *Cities Without Slums* action plan in the 2000s. The following analysis will first invoke the instruments various DC have used to implement each policy. The successes and shortcomings of each policy and program will then be highlighted in regards to the experience of each country. Finally, I demonstrate how this succession of policies and programs has done little to secure a sustainable long-term response to the shortage of shelter and contain the expansion of slums in DC.

2.1 *Laissez-faire* Attitude: 1950s-1960s

During the *tolerance period* in the 1950s and 1960s, urban authorities in DC turned a 'blind eye' to slum and focused on public housing (Farvacque & McAuslan, 1992; Rakodi, 2001). Slums were considered 'relics of traditional villages' and in the process of being absorbed by the new urban planning scheme inherited from Western societies— with little consideration of local and cultural realities (Gaskell, 1990; Njoh, 2003). However, many urban dwellers, especially new migrants in the low-income category, could only afford shelter in marginal and unsuitable land around these new 'planned settlements'. In fact, policy-makers and urban planners regarded the existing slums as a temporary situation, and thus a minor threat to long-term urban development. The perceived 'low-income' shelter strategy was to develop public housing projects.

Unfortunately, these projects were implemented in a discriminatory fashion, largely because the 'indigenous' political rulers, who replaced the colonial power, perpetuated the existing social and class divisions as the previous 'master' (Fanon, 1963). In fact, the main beneficiaries of formal public and planned housing schemes were civil servants and middle and upper-income earners (Fekade, 2000). Moreover, nepotism, corrupt practices, poor governance and incompetence significantly and rapidly contributed to the expansion of slums, and widened the gap between those who were in positions of power or had some sort of 'connections' and the rest of the urban population (Global Urban Observatory, 2003).

Overall, it appears that between 1950 and 1960, most urban authorities in DC adopted a *laissez-faire* attitude towards burgeoning slums. The alternative choice, public housing schemes, performed poorly in terms of meeting housing demands in many cities in DC. For example, Hope (1999) reports that public housing schemes across Africa as a whole provided less than 5% of housing needs. The failure of public housing can also be attributed to factors such as cost, socio-economic discrimination, and inappropriate design (Malpezzi & Sa-Adu, 1996; Hope, 1999). Thus, such public housing schemes were unable to supply sufficient dwellings. Instead, the approach marginalized the majority of urban dwellers and ignored low-income urban dwellers and rural urban migrants who settled there generating more slums. Furthermore, it is now clear that urban effort and resources directed towards providing public housing have ended up serving a small portion of urban dwellers and usually those that were largely better resourced than the majority (Adeagbo, 2000).

2.2 Site and Service Scheme: 1970s

In the 1970s, most governments in DC opted for a direct and centralized (State) intervention, executed through World Bank's instigated programs such as the *site and service* scheme. This particular scheme advocated the clearance of centrally located slums and their relocation to newly serviced plots often outside the existing urbanized areas. This policy was driven by affordability and cost-recovery strategies (van der Linden, 1986).

Site and service schemes are credited with enabling shared responsibilities between slum dwellers and government. On the one hand, the program emphasized the participation and the contribution of the beneficiaries to the resettlement process. Similarly, the programs acknowledged and capitalized on the ability of low-income dwellers to mobilize informal resources. On the other hand, local governments were no longer acting as 'providers' but as 'facilitators', which saved them some resources (Pugh, 2001).

The implementation of site and service scheme was heavily criticized especially its demolition and eviction components. In some cases evicted slum dwellers were relocated to other parts of the city (for example chirambahuyo in Harare). In many other instances, slum dwellers were left in 'limbo' without alternative housing and land arrangements or compensation (Butcher, 1986). The demolition without adequate relocation process actually aggravated the housing shortage partly because there were not sufficient plots available to relocate those whose houses had been demolished.

Other shortfalls of the scheme included the relatively low number of beneficiaries, the lack of understanding and clarity around the role of the private sector, the lack of planning around the location of new serviced plots, low or non-existent standards, and the failure to achieve cost recovery (Pugh, 2001). For instance when assessing the number beneficiaries, Hope (1999) found that less than 6% of intended beneficiaries in Kenya, Zambia and Zimbabwe actually benefited from the scheme for the paradoxical reason of affordability. This was so because the transitional period between the demolition and the new establishment was not always well negotiated (lack of slum dwellers' participation). Moreover, several evicted slum dwellers had difficulties accessing or being qualified for new serviced parcels due to lack of land titles and rights (the majority could not legally claim and prove their tenure right), illiteracy (most documents were written and they needed to fill out applications), corruption and bureaucratic hurdles (Malpezzi & Sa-Adu, 1996).

Overall, the implementation of site and service schemes failed to address slum management issues and there was often no provision made for preventing or reducing the future expansion of slum. The magnitude of the negative impacts and shortcomings easily offset the positive aspects to a point where new strategies had to be introduced with the hope of curbing the rapid and continuous degradation of slum areas.

2.3 Upgrading Strategies: 1980s

In the 1980s, the upgrading strategies emphasized the improvement of communal infrastructure and services within the established slums (Banes *et al.*, 2000). In particular, the upgrading projects targeted the improvement of basic services (e.g., sewage, water, sanitary, garbage collection, electricity) and infrastructure (e.g., road, market, healthcare and education centers) that were lacking or decaying in slum areas (Pugh, 2000). Upgrading projects were to be implemented with lesser intervention of government than in site and service schemes. Local upgrading strategy was appealing because it avoided (unnecessary) demolition, was cheaper per unit than site and service approach, and preserved social and economical networks. The upgrading program aimed to achieve three main goals: affordability, cost recovery and replicability.

In terms of affordability for instance, there were some instances of success. Earlier assessments of onsite upgrading projects were encouraging (World Bank, 1994). For instance, in his evaluation of Visakhapatnam (India), slum upgrading, Abelson (1996) reported that the beneficiaries' income rose by 50% and their land value and assets improved by 82%. In other instance, the San Martin Pores (Manila) upgrading project was praised for the community participation and legal and institutional planning outcomes (Santiago, 1987; Kessides, 1997). The importance and success of grassroots participation in various Word Bank funded upgrading schemes have been reported for projects in Indonesia (especially the Kampung Improvement Program) and other projects in South America countries such as Bolivia, Brazil, Mexico, Costa Rica and Peru (World Bank, 1995; 2003).

Despite these specific successes, upgrading programs also had many shortcomings and overall, failed to meet their expectations. Generally, they were criticized at four main levels: failed financial commitment, negative socio-economic impacts, insecurity of tenure and the nonreplicability of 'best practices'. First, the program was implemented and financed by foreign agencies, which over time gradually reduced their financial support to the various projects. For instance, the relative importance of the upgrading budget of the World Bank went from 42 % in the late 1970s to less than 8 % in the late 1980s (Brennan, 1993). Similarly, local government could not sustain the financial cost of upgrading. As the funding dried out, many programs were suspended, and the lack of income meant that infrastructure and services could not be created, completed, sustained or maintained.

Second, upgrading programs did not produce the socio-economic impacts projected. For instance, in his review of the upgrading programs in Indian cities, Amis (2001) indicated that the program had no contribution to poverty reduction or problems related to unemployment and land security, which the program had aimed to achieve. Ironically, improving infrastructure and services had led to an increase in real estate value, thus encouraging land speculation. Low-income dwellers were, therefore, shifted out of the upgraded areas for the benefit of middle and high-class urban dwellers. The UN-Habitat (1999) illustrates this problem with the example of Dandora, a slum in Nairobi, where in the 1980s, the World Bank financed an upgrading program. A survey in the area 10 years after the completion of the program revealed that more than half of the current inhabitants were middle or high-income city dwellers, and were not resident at the commencement of the program.

Third, upgrading programs did not often integrate security of tenure with employment or income-enhancing activities. There was no evidence from any of the upgrading programs to support the argument that such a project could be duplicated elsewhere, nor sustained in the long term (Durand-Lasserve, 1996). Sehgal (1998) indicated that instead, many associated negative factors jeopardized the sustainability and the success of upgrading programs: local politics, corruption, conditions attached to foreign aid, the value of real estate and the location of a particular slum or squatter settlement.

Fourth, upgrading programs only reached a small portion of slums and did not develop into an ambitious project that could address the shortage of shelter on a citywide scale. The upgrading of communal infrastructure and services did not improve individual dwellings. Therefore, on many occasions, the socio-economic and physical environment within the upgraded areas continued to deteriorate (Werlin, 1999). The insecurity of tenure deterred slum dwellers' ambition to undertake housing improvements or upgrade individual shelter. The lack of security of tenure also inhibited the efforts of public and private service providers (such as electricity, water and telephone companies) to invest in unplanned areas. Moreover, the upgrading model did not address the issue of emerging slums, nor did it provide a proactive approach towards the creation of future slums.

2.4 Security of Tenure and Enabling Approach to Slums: 1990s

One of the major ways in which urban planning strategies have been approached to improve the slum conditions has been the development of practical mechanisms to consolidate and secure land tenure. The security of tenure campaign is closely associated with the *enabling approach* (World Bank, 1993). The enabling approach advocated seven major points: development of housing financing systems, targeting of subsidies, encouraging property rights (including security of tenure), improving infrastructure, auditing and removing barriers, restructuring building industries and reforming institutions (Pugh, 2001). The enabling approach is understood as advocating that legal, administrative, economic, political, urban stakeholders and financial institutions should facilitate and secure the shelter and tenure to the most vulnerable portion of urban dwellers. In the 1990s, the enabling approach was implemented through security of tenure strategies largely supported by international agencies, namely UN-Habitat and the World Bank, as a contingent measure to limit the eviction and demolition threat in slums (Jenkins, 2001). The assumption was that although slum settlers do not necessarily have the legal title over the land, they could undertake improvement on their properties without fear of eviction. The enabling approach, via its emphasis on security of tenure, also postulated that the availability of and the accessibility to urban land provide a sense of 'belonging' and brings stability to an urban area (Kombe & Kreibich, 2000).

The security of tenure approach derives from the assumption that when the residents have the sense of appropriation, they also have the confidence, motivation and will to invest, upgrade or improve their environment. The capability of slum dwellers to significantly improve the quality of their environment can be illustrated with a project in Dar-es-Salaam in Africa whereby through securing the land, residents had the incentive and the motivation to clean up the neighborhood (Durand-Lasserve & Royston, 2002). The regularization of this informal environment will help address the problem of tenure insecurity in already established slums, which otherwise would translate into a vicious cycle of construction, destruction, eviction and reconstruction. In contemporary Africa for instance, South Africa is leading the land regulation campaign by providing secure tenure with basic services to displaced squatter dwellers. Before destroying a slum, the government in South Africa allocates new plots with basic functional services such as roads, water and sewage (Masland, 2002).

The security of land policy, however, has two major limitations. First, this policy advantages land grabbers and informal 'conquistadors', rather than those who reside there. So, when regulation does occur, the *slumlords* (who do not necessarily live in the settlement) will resell or rent the land to city dwellers, eventually at a higher price because the land value has increased with the security (Payne, 2004). Therefore, slum settlers who failed to claim their land rights, or who were renting, will seek another site to develop or create slum-like settlements (Fernandes, 1999). It is also fair to query how the security of tenure intends to address the availability of urban land (especially access of low-income dweller to planned settlements) and removal of artificial land shortages. Second, the implementation of security of tenure does not guarantee any long-term solution to the expansion of emerging and future slums. This is an important gap that the security of tenure policy has failed to address.

2.5 Cities Without Slums Action Plan: Post-2000s

The new century has called for new strategies and plan for slum. In 1999, the World Bank and the UN-Habitat initiated the *Cities Without Slums* (CWS) action plan, which constitutes a part of the United Nations Millennium Declaration Goals and Targets. Specifically, the action plan aims at improving the living condition of at least 100 million slum dwellers by the year 2020 (UN-Habitat, 2003). The main innovation in this policy is to move from the physical eradication or upgrading of slums adopted by past policies, to start to address one of the fundamental reasons why slums exist in the first place: poverty. The action plan recognizes that slums are largely a physical manifestation of urban poverty, and to deal with them effectively, future actions and policies should also associate urban and slum stakeholders in the poverty reduction or eradication campaign.

This extended approach of CWS action plan is encouraging, but raises four important concerns. Firstly, poverty is just one of the components of the incidence of slum (Shatkin, 2004). The CWS is not comprehensive enough to determine other variables that also account for slum incidence. Such variables could include (at the macro and cross-country levels) debt burden, health issues, social and political instabilities and natural disasters. Secondly, the number targeted is far too modest to significantly change the number of slum dwellers by the year 2020. In 2000, it was estimated that 850 million people live in slums and it is projected that by 2020 the number will reach 1.8 billion (UN-Habitat, 2003). It is clear that this target will do too little too late to effectively improve the living conditions of more than 1.7 billion slum dwellers. Thirdly, there is no clearly defined variable to measure the 'improvement of living conditions' of 100 million slum dwellers. One can reasonably query how it will be possible to differentiate between 'improved living conditions' driven by CWS –in different cities, realities and contexts– and other city development strategies. Such uncertainty suggests that the operational and methodological components of the CWS action plan are yet to be defined or fine-tuned. Finally, the CWS action plan does not articulate what measures should be taken or formulated to curb the emergence of new slum. Similarly, there is no provision or indication as to what actions various urban 'stakeholders' at all levels (local, national and international) should undertake to reduce, if not stop, the mushrooming of new slums. Unless these concerns are properly taken on board, the ambitious 'City Without Slums' action plan remains a slogan.

2.6 Where Do We GO From Here?

The review clearly shows that despite a few 'best practices' recorded in implementing slum policies, slums have continued to dominate the urban landscape of most cities in DC. Some of the weaknesses of past slum policies are that conditions pertaining to the incidence of slums were not taken into account. Such conditions include the negative impact of international interventions (e.g., Structural Adjustment Programs), the impacts of neoliberal policies (e.g., liberalization and globalization), urban poverty (or income gaps), poor governance, socio-economic and political instabilities, rapid urban growth rate, inadequate planning regulations, poor housing financing (especially for the low-income earners), and limited access to sustainable source of income (Shatkin, 2004). Moreover, all the five major approaches towards slum point to lack short-term and 'quick-fix' measures rather than a long-term vision of the prospects of slum incidences (Jacobsen *et al.,* 2002).

The literature also indicates that past and existing slum policies and programs have been largely counterproductive because, at the end of the operation, the poor are not the main beneficiaries, instead, middle and high-income earners take over improved dwellings (Jacobsen *et al.*; 2002; Davis, 2004). It is not, therefore, surprising that "what is happening in most cases is the reverse: piecemeal, undirected or impractical policies that cannot be implemented or which, in practice, benefit only those in power" (UN-Habitat, 2003, p. 5).

This situation raises three issues. Firstly, that housing in urban areas is not the sole problem of low-income people, but an urban crisis that needs to be tackled irrespectively of the income level. Because of the shortage of planned development, it is clear that high, medium and low income urban dwellers are actively involved in informal land and housing provision (Smart, 1986). Secondly, the outcome of these policies indicates that housing schemes or urban planning that target a specific population group is not viable. Notwithstanding, designing urban planning for the poor is discriminatory. Finally, such repetitive failures are a clear indication that *fractional* slum policies and programs, which have aimed to address one or a few aspects of slum thus ignoring other components, could only perpetuate the existence and expansion of slums. To start reversing this way of thinking, future slum policies should engage in a more holistic and comprehensive approach that will not only integrate factors of emergence and growth of slums, but will also co-operate with various national and international urban slum stakeholders.

Moreover, one of the most intriguing outcomes of past and current slum policies and strategies relates to their lack of long-term perspective in relation to housing needs in urban areas. Significantly, urban authorities do not always have the means to appreciate the social and spatial scope of slums, nor do they have the adequate land management instruments and appropriate appraisal tools (Brennan, 1993; Jenkins, 2001).

3. Can Simulation and Modeling Help Slum Policies?

As discussed above, it is now well established that there are common factors that can explain the incidence of slums in DC (even for variables that might have been overlooked in previous and current slums policies). Such knowledge constitutes an advantage modeling method could use to grasp a better understanding of the contribution of each variable in the emergence and growth of slum. Although all factors pertaining to the emergence and growth of slum are difficult to be realistically captured and modeled within or with help of GIS, there is still a range of keys IS variables that could be accounted for in IS dynamic modeling and simulation. These factors include topography, markets, places of worship, vacant land, transportation networks, river systems, and other land uses. It will be demonstrated how such key selected spatial and temporal variables could be used to simulate the growth of informal settlements. Whilst a model of incidence of slum will not be able to account for all the factors that explain the emergence and expansion of slum, a slum growth model can for instance help inform the decision making process for preventive slum expansion.

Developing a model is one strategy that could help improve urban land use management in many DC. It is clear that a slum or informal settlement model would not intend to address all the issues raised in this paper in regard to why responses to the expansion of IS have failed. For example, it is very difficult for a spatio-temporal model to account for other issues of slum growth such as lack of political will, legal and policy impediments and funding issues. However, an informal settlement model, which outlines the context and spatial dimensions of emergence and growth, could provide critical information to a range of key stakeholders for an improved understanding and response to these complex urban dynamics processes that define many cities in DC.

One of the underlining assumptions of the proposed model is that the scope of the slums could be appraised from historical trends to give a future perspective using socio-economic and physical data in GIS and modeling frameworks. Such a model could also use the factors that contribute to the emergence and growth of slums as discussed above. Knowledge about the long-term expansion of slums can be achieved using an approach that would clearly demonstrate the historical trends while at the same time, project the possible location of future slums patterns (Abbot, 2002). Specifically, what this paper suggests is that a long-term perspective and proactive approach is required to predict where new unplanned settlements will occur and therefore act accordingly. This new proactive approach entails a good knowledge of contributing factors to the emergence of and growth of IS (Abbot & Douglas, 2003). These factors include transportation networks, sources and places of income and employment (e.g., market places), worship places, existing slums areas, and topography (e.g., slope gradient).

A computerized GIS, a spatial technique, can greatly contribute in this IS representation process, especially helping with the organization of data, for instance using an overlaying method, and establish correlations between physical factors and the location of IS (UN-Habitat, 2003). Simulation of the historical expansion of IS could provide clues as to where future settlements will occur. Moreover, the simulation and modeling techniques can be used to obtain new insights into the process and intrinsic correlation between the factors underpinning the expansion of IS and their future location.

One of the advantages of adopting the simulation and modeling approaches is their capacity to incorporate the dynamic behavior of IS and visually represent their expansion. The proposed IS model would seek to add dynamic visualization component to the human and geographical dimensions of unplanned developments, in order to gain better insights into the prospects of future distribution and tendency of slums. The capacity to map and visualize IS expansion will help in designing a better and more efficient decision-support system and policies for managing slums in DC cities (Sietchiping *et al.*, 2004). This model could also assist in the development of contingency plans to make land and housing available for and accessible to all urban dwellers.

Compared to other approaches (such as static mapping), the dynamic modeling and simulation approach will result in better-informed policies and facilitate the decision support process. The main challenge is, however, in relation to how to conceive, design and implement a model of IS emergence and growth. One question for instance is: can the dynamic representation and modeling of IS be achieved within GIS technology, in parallel with another technique, or through an integration framework between a spatial technique and simulation and modeling techniques? The next section will evaluate how the spatial techniques such as GIS can be used in combination with modeling and simulation techniques, namely cellular automata, to investigate the dynamic behavior of slums in DC.

4. Modeling Informal Settlement: Methodology

This section discusses how the key factors pertaining to the emergence and growth of slums, can be used to develop a dynamic Informal Settlement Growth Model (ISGM). The model is developed around two main approaches: Geographic Information Systems (GIS) and Cellular Automata (CA).

4.1 Geographic Information Systems and Urban Dynamics

In the context of urban modeling, Geographic Information Systems (GIS) can be primarily considered as a tool for capturing, storing, displaying, manipulating and analyzing spatial data. It has been demonstrated that GIS does not have modeling capabilities *per se* and its integration with other approaches is usually suggested as a possibility to address this weakness (Yates & Bishop, 1998; Batty & Jiang, 1999). Yet, GIS is useful because it helps prepare input data (from various sources) and it can support the display and the visualization of models' output.

One of the main criticisms of using GIS as a modeling tool is that modeling within GIS is static, whereas all geographic phenomena are dynamic. Modeling within GIS is also selective and restrictive (separating growth from location). In other words, existing GIS-based urban models lack the temporal and predictive dimensions (Batty & Xie, 1994a and 1994b; Clarke *et al.,* 2002; Batty, 2003). Consequently, there is now a growing interest in incorporating a predictive, modeling dimension within GIS software (Raines *et al.,* 2000; Couclelis, 2002).

4.2 Cellular Automata and Urban Dynamics

Cellular automata (CA) are best described as mathematical models where space is dynamically expressed by means of discrete time increments and processes. Any CA consists of regular *grids of cells*; which can adopt any one of a finite number of *k possible states*, the latter being updated synchronously in discrete time steps according to a local interaction *rule*. That is, the state of any cell is determined by its previous state and the states of a surrounding *neighborhood* of cells (Batty & Longley, 1994).

Whereas GIS reproduces static urban forms and structures, CA is suitable for simulating the complexity of dynamic urban forces and their resulting features. Theoretical studies have lay the foundation for various applications of CA models of urban growth within hypothetical or real cities of developed countries (Cecchini, 1996; Phipps & Langlois, 1997; Wu & Webster, 1998). Moreover, a strong body of urban dynamics research supports the introduction of CA into urban studies (Batty & Longley, 1994; Wegener, 1994; White & Engelen, 1997; Batty, 2003).

4.3 Integrating GIS and CA for Urban Dynamics

Researchers have soon realized that in order to build a more realistic dynamic model able to mimic and forecast real urban situations, there is a significant need to combine and complement the capacities of GIS data with the CA model. For example, Wagner (1997) compared GIS and CA and pointed out that they are both space-time models of their universe are both based on a two-dimensional plane. Moreover Wagner showed that GIS and CA are similar, and complementary in many other ways. For instance, GIS provides a good environment for retrospective analysis of data and their visualization capacity has significantly improved the realistic simulation of urban patterns when a CA approach is used.

Additionally, Couclelis (1997) provided a generic framework for the exploration of the common features within the GIS and CA environments, in order to develop better computer models of real urban dynamics and structures. A good illustration is the Clarke's Urban Growth Model (UGM), which has been tested in different cities such as San Francisco Bay, Buffalo, Baltimore in the US, and Lisbon and Porto in Portugal (Clarke & Gaydos, 1998; Silva & Clarke, 2002). The UGM has also been adapted to model the expansion of urban areas within developing cities (Leao, 2002; Sietchiping, 2003b). Accordingly, the proposed ISGM draws its origins from the concept, theory and technologies of both CA and GIS.

5. Designing an Informal Settlement Growth Model

This section presents the background of the proposed Informal Settlement Growth Model (ISGM). First, the conceptual framework of the model is outlined, followed by the description of its technical and operational configurations.

5.1 Conceptual Framework of the ISGM

The proposed ISGM draws from existing urban dynamics models, which are based upon the integration of GIS and CA, such as those developed by Clarke and Gaydos (1998), Batty *et al*. (1999), and Yeh and Xie (2001). Following similar principles developed by these models, the ISGM loosely couples GIS and CA technologies to predict the emergence and growth of IS patterns. That is, the ISGM is conceived on CA principles whereby pixels or cell-based grid squares change one by one. Their multiple states are synchronously updated in discrete time steps according to generic rules. In other words, the previous states of neighboring cells determine the state of each cell at any given iteration. The ISGM uses various forms of the *Moore extended neighborhood*, and it can accommodate an unlimited number of user-defined rules. It is worth noting that the cellular automata developed within the ISGM is extremely flexible due to its ability to incorporate functions such as *thresholds*, *constraints*, *probability factors*, *attraction* variables and *edge shaping* factors. Moreover, general assumptions of IS growth can be fine-tuned to suit the local conditions in this model whilst still maintaining the general conditions pertaining to the emergence and growth of IS. Such assumptions are drawn from the factors behind IS emergence and growth (as discussed above) to design the proposed model.

5.2 Technical Specifications of the ISGM

The technical specifications of the ISGM are as follows:

(a) the model's space is made up of a two-dimensional matrix of square, equal size cells;

(b) it accommodates an unlimited amount of input data with the same format and properties;

(c) each layer consists of at least two states (e.g., road and non-road);

(d) each layer is in raster format and each cell has a unique identification number (ID) because changes operates at a cell level (bottom-up approach);

(e) changes operates only on vacant or available land[2] on the defined matrix of 4 x 4 extendable Moore neighborhood;

(f) cells change according to predefined and homogeneous rules;

(g) each layer has a unique identification number (ID) (e.g., water: 20, vacant land: 1). This allows the macro program to read and convert the value of each land use category into *ascii* format, as well as set up the spatial neighborhood filters in a logical way; and,

(h) the selection of any one cell is random.

The essence of the ISGM is its defining of CA-like conditions under which any matrix cell should behave at each time step. It can accommodate an unlimited number of rules, however, and the following were declared to express the general conditions under which IS are thought to emerge in the test city:

1. Existing, formal land use classes are not changing. This is so because IS resulting from the decaying of planned developments is marginal and therefore, beyond the scope of the proposed ISGM. That is, all new IS occur on vacant land. However, using a framework similar to the ISGM, Wyatt *et al.* (2002) demonstrate that it is quite possible for an ISGM to take into account the conversion of planned developments into IS.
2. No cell 'dies' after emerging. That is, it evolves and maintains its state. This condition suggests that an IS cell cannot return to it previous state or mutate to another land use type once it is created. This rule is in line with the emergence and expansion of IS patterns observed within cities where unplanned developments prevail.
3. If a cell does not contain at least one IS cell in its defined neighborhood, a new IS cell cannot emerge[3]. This condition prevents IS emerging in an isolated area, and also performs the consolidation of IS patterns. The specific rule also mimics the emergence and expansion of IS in the peri-urban areas.
4. Any new IS cell is generated with a user-defined probability. The probability depends on two conditions: the stages of growth the model is in, and the properties of the surrounding cells (land uses). There is, however, an exception: if a vacant cell is located on a high slope, then its probability of becoming an IS cell at the next iteration decreases (the *bust* factor).
5. If a vacant cell is located close to IS[4] (e.g., less than four extended neighbors away from IS cell) emergence factors such as a road, river, market place, worship place or low slope cell, then its probability to become an IS cell increases by a user-defined value (*boost* factor). Moreover, if a vacant cell is close to railway and road, its probability of becoming an IS cell becomes even greater.

Additionally, the general probability of IS emerging on vacant land is either *boosted* or *inhibited* by the type of dominant cultural and ethnic group located within its neighborhood.

The model provides possibilities to fine-tune its rules in order to adapt to a specific condition and to improve its accuracy. Accordingly, the model underwent several instances of refinement and modification to increase its simulation capacity and test the validity of its underlying assumptions. This is because the ISGM is written using the *Excel®* macro, from the same family as *Microsoft VISUAL BASIC (VB)*. *VISUAL BASIC macro* language was chosen because it is reasonably easy to learn, write and modify. More importantly, the CA-like behavior can be written in VB and then linked to a GIS environment. Moreover, unlike other GIS programs that have specific languages, *VB macro* is a cross-platform language that is appropriate for prototyping and which can be supported by almost any GIS environment.

In comparison then, to other CA models, the ISGM is *transparent* in the sense that one can access and modify its source commands, record new macros, manipulate the model's spreadsheet and so directly check its consistency. The macro language code for ISGM is a standalone programme that utilizes a GIS interface to identify the input files and display the results of the application. For this application, *Idrisi*®GIS software is used as the display interface, because of its ability to preserve the properties of input and output files. Similarly, Idrisi® offers the possibility of calibrating, validating and statistically comparing the output of the simulation.

The proposed ISGM can be divided into five sequential modules: setting up, calibration, looping, application of rules, and display as follows:

- First, in the dimension module the user states the general condition of the macro and lists all the files to be used for the calibration.

- Second, in the calibration module the user states the *base_year*, the *final_year*. This automatically generates the number of iterations (annual changes for the calibration), the *nett_pixel_gain* (which is the amount of space (cell) to be converted into informal settlement) and the *annual_target* (which is a constant that divides the expected number of new IS cells by the number of iterations). The annual target can be formally expressed as (equation1):

$$\Delta_t(X,Y) = \left| N_{pixel}(Y,t) - N_{pixel}(X,t) \right| \quad (1)$$

where:

- $\Delta_t(X,Y)$ = Net gain pixel of land use *t* from year *Y* to year *X*

- $N_{pixel}(X, t)$ = Number of pixel characterizing a land use of type *t* for a year *X*

- Third, in the looping module, five loops are automatically set: (1) the *iterations loop* that checks the user-defined number of iterations at different temporal growth stages; (2) the *annual change loop* that resets the changes to zero; (3) the *random cell loop* that continuously checks the map to locate a random cell; (4) when a random cell is not found, the *non-changing cell loop* sends the operation back to the random cell loop; (5) otherwise, the macro proceeds to *search for the cells* at the edge (neighborhood) of the existing IS cell.

- Fourth, the transition rules module executes the conditions (using *If Statements*) and the probabilities (local and general) under which a vacant cell can change to an IS cell. This will be effective only if all the stated conditions are satisfied, and the specified quota (*annual_target*) has been reached. The macro can then record the new (update) value of each cell into the output file.

- Finally, the display module sets the parameters for automatic display of the calibration results based upon the user-defined, GIS environment, image format, size, and color palette.

Figure 1 summarizes a step-by-step procedure to successfully execute the five modules of the proposed model.

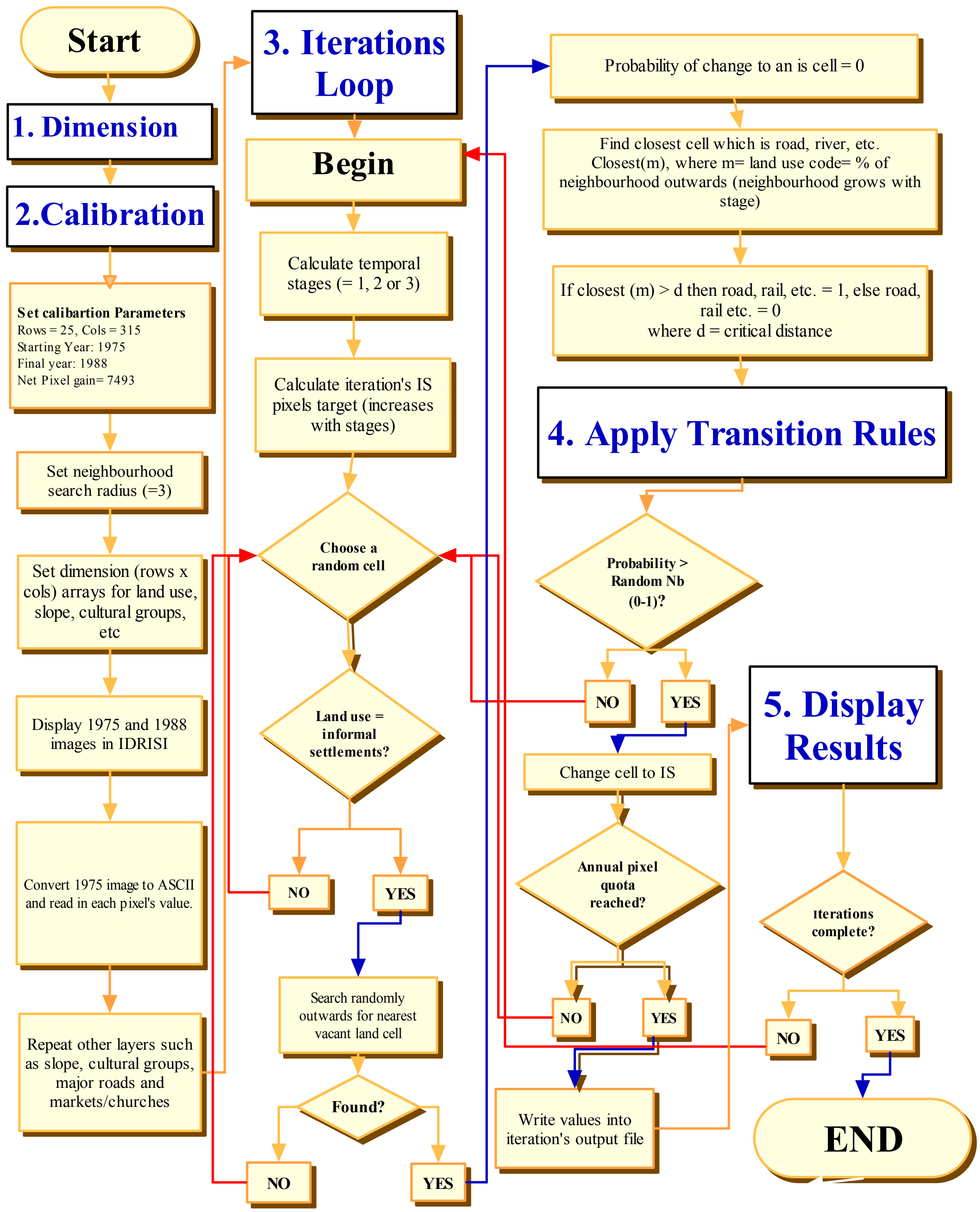


Figure 1. Sequence of operations and flowchart of the Informal Settlement Growth Model execution

6. Implementation of the Proposed ISGM to Yaoundé

This section briefly introduces urban growth experienced in Yaoundé, the capital city of Cameroon in Central Africa, and presents how the data are prepared and used within the proposed ISGM.

6.1 An Overview of Yaoundé Urban Informal Settlement Growth

Yaoundé is the second largest city (after Douala) and also the capital city of Cameroon in Central Africa (figure 2). It has been selected for testing the ISGM because of its rapid urban population growth and the extent of its unplanned development. The urban area of Yaoundé has grown by almost tenfold in less than five decades. Specifically, with an urban area of about 1,500 ha in 1956, Yaoundé covered 5,300 ha in 1980 and about 14,000 ha in 2000 (Sietchiping, 2003a). Research shows that 80% of settlements in Yaoundé are informal (against 30% in 1960s) and accommodate about 85% of city dwellers (Franqueville, 1984; Pettang *et al.*, 1995). Similarly, the informal market represents more than 80% of housing stock and Yaoundé last had a planning document in 1982 (Pettang, 1998; Bopda, 2003).

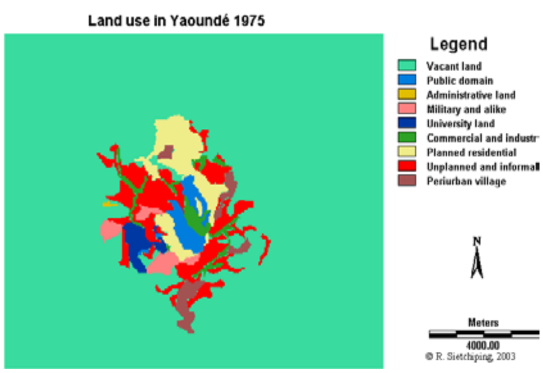
Figure 2: Location of the study area, Yaoundé, Cameroon in Central Africa

Credit: http://www.map.freegk.com/cameroon/cameroon.php

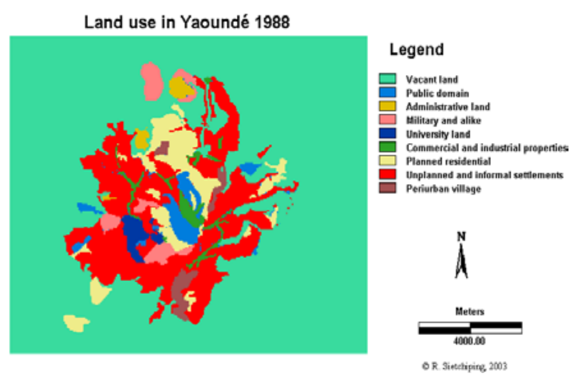
6.2 Data Preparation and Use for the ISGM

Various Geographic Information Systems (GIS) software (*ArcINFO®, ArcView®* and *Idrisi32®)* are used to prepare a series of layers. As demonstrated in section 1.2, these layers were selected because they constitute key factors for the emergence of slums. Maps[5] considered include transportation networks (railway, major roads, other roads and proposed ring road), land use classes (base and final years), river systems, places of worship, market places, topography, and ethnic and cultural groups[6]. As will be shown later, only lines and areas features will be sensitive to the model.

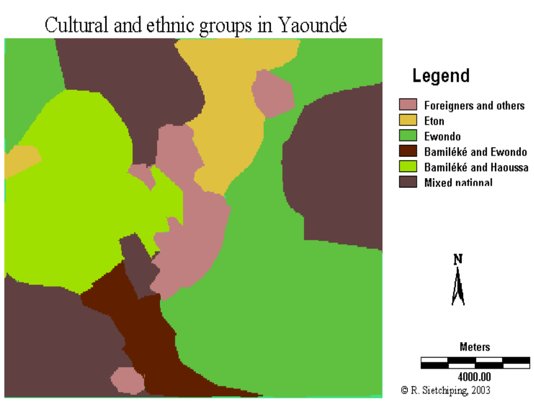
It is worth mentioning that the attempt to use markets and places of worship as points to determine the expansion of IS was not satisfactory. In fact the spatial insignificance of these point features will render them inadequate to trigger change, even if their probabilities were significantly greater than those for the other factors. This problem could only be corrected by representing market and worship places as polygons (areas). Some of these layers are used individually (figs. 4b, 4c, and 4d) and others are merged (figs. 4a, 4e and 4f) to improve the model performance. Figure 3 shows the final layers used in the calibration of ISGM on Yaoundé, Cameroon.



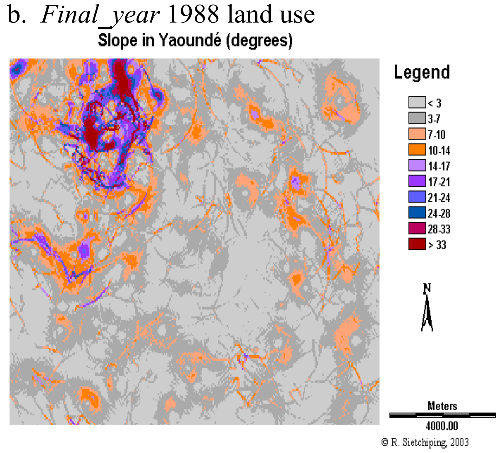
a. *Base_year* 1975 land use



b. *Final_year* 1988 land use



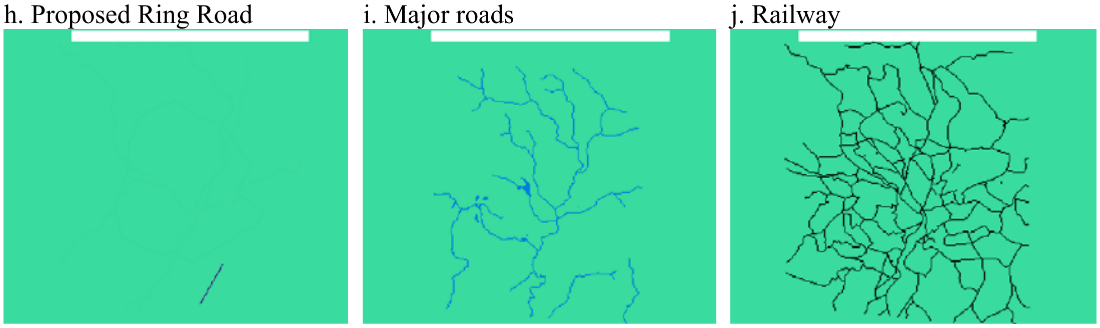
c. Ethnic and cultural groups



d. Slope in degrees

e. Excluded areas (White) f. Market areas g. Worship places

h. Proposed Ring Road i. Major roads j. Railway



k. Airport Runway l. Water m. Road network

Figure 3. Final maps layers used for the calibration of ISGM on Yaoundé, Cameroon

7. Calibration Results of the ISGM

The ISGM underwent a series of modifications to optimize the output. To statistically validate the model, the VALIDATE module in *Idrisi*^{TM} (Release 2) was used to assess the level of accuracy of the model's outputs. To achieve such statistical validation, the *reality map* (1988) and the *simulated map* (1988) of each version were converted into two classes: informal settlement and non-informal settlement. The *Validate* function then returned a series of *kappa* and other statistics about the quantity and location accuracy of the simulation outputs (Pontius, 2000). Overall, the quantity scores of the simulated maps perfectly agreed (100%) with the reality map, because in the ISGM, the user predefines the quantity of simulated IS cell before the calibration. In contrast, the locational scores varied largely between simulations.

This section describes some of the modifications introduced into the ISGM and the subsequent results, which indicate how the model is sensitive to different input parameters. Selected samples of calibration results based upon the IS growth criteria are presented in figure 4 (for clarity and space, the map scale and legends for the simulated maps are purposely omitted). These results are displayed with their kappa location score (*V* as the percentage of location accuracy, that is the number of times the location of IS cells on the simulated map exactly matches the location of the cells on the reality map).

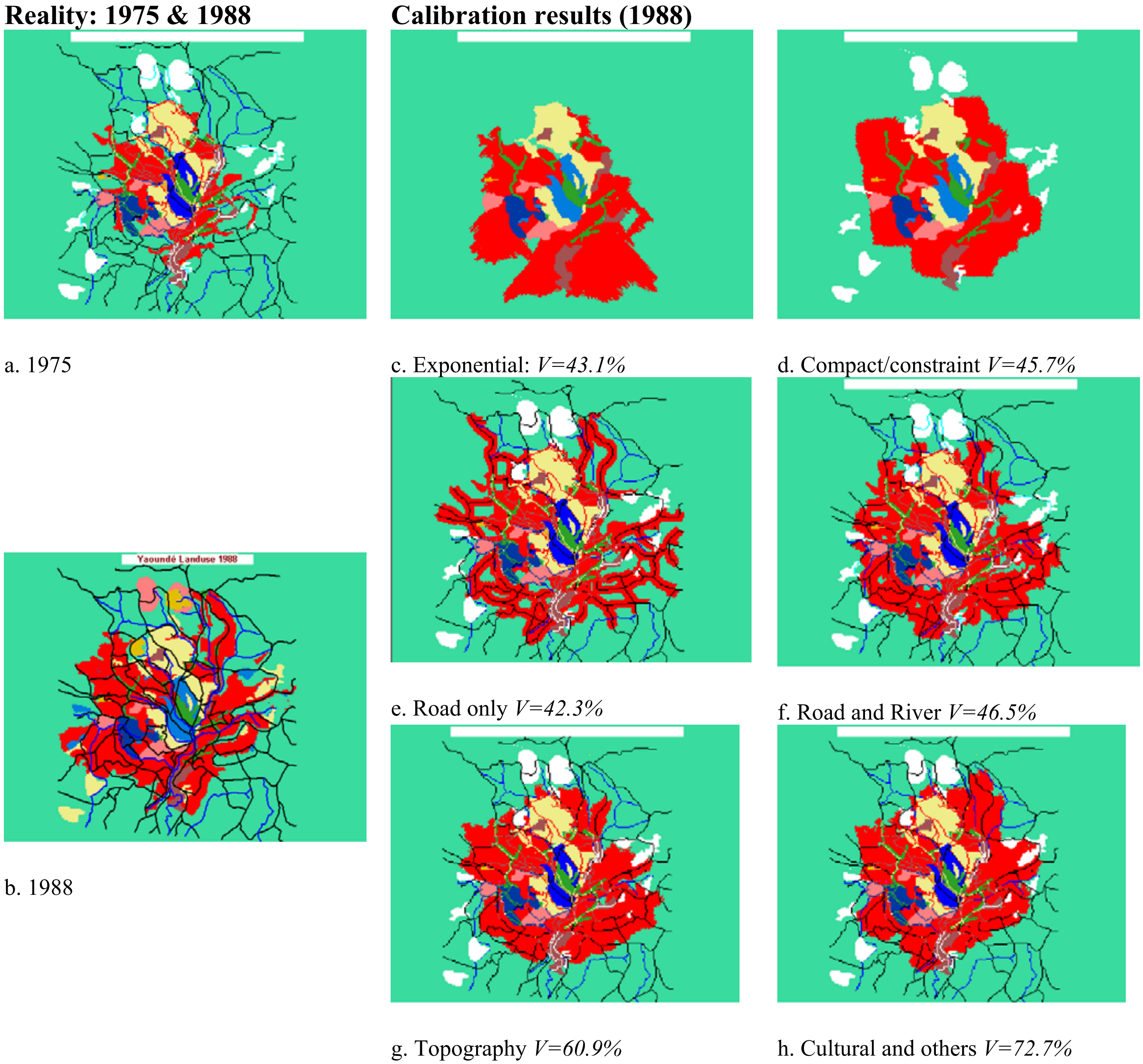


Figure 4. Sample of the calibration of ISGM in Yaoundé

Figure 4 presents six different calibration results that were obtained by changing different input parameters and by fine-tuning the ISGM. Each simulation result would be compared with the pattern in the base year (fig. 4a) and the actual configuration of IS in the target year (fig. 4b). The exponential growth (fig. 4c) tests the ISGM when it runs without any constraints and returns a location accuracy of 43.1%. Informal settlement cells emerge at the proximity of existing IS cells with a probability of one. That is, only existing IS are considered and other slum growth factors such as roads, rivers and market places are not included). The result shows that this application does not capture the essence of IS growth mechanisms, especially the direction and spread of IS patterns.

The next calibration (fig. 4d), however, applies some basic constraints to the model that generates a more compact form of IS pattern. This was achieved by adding the 'excluded areas' file (see fig. 3e) and by increasing the probability of new IS cells (from 0.2 to 0.4) to emerge in the neighborhood of existing IS. This application produced 45.7% accuracy. The ISGM is then modified to test the sensitivity of the model to road layers (fig. 4e), with the probability of 0.8 for road and 0.2 for existing IS cells in the neighborhood. That is, other factors are ignored. This application recorded the lowest location accuracy, 42.3%. This was so because the main aim was to test how the model was sensitive to linear features, not necessary the location of informal settlements.

The linearity of the IS growth pattern is then further improved by combining the road and river systems with the existing IS patterns (fig. 4f), with their respective probability of 0.4, 0.3 and 0.3. The locational accuracy of 46.5% was obtained, but there are still some 'pockets of vacant cells' on the simulation outputs (figs. 4e and 4f). Slope factor is, therefore, added and major roads[7] are differentiated from other roads along with their respective probabilities: major road (0.3), other roads (0.1), gentle slope or lowland (0.2), existing IS cell (0.1), market and places of worship (0.2) and rivers (0.1) are factored in. This time, the accuracy was improved to 60.9%. This calibration generates the IS patterns shown in figure 4g. It is worth mentioning that this version of the model also more effectively accounts for socio-cultural factors like the location of market and worship places.

Finally, figure 4h shows the contribution of cultural and ethnic composition (along with other factors previously tested such as road, river, topography, markets and worship places) in the expansion and spatial distribution of IS patterns in Yaoundé. Table1 presents the probabilities of each factor at three different temporal stages as illustrated in figure 4h. It is worth mentioning that some factors (e.g., cultural groups) were self-exclusive and the threshold function of the model will redistribute the probabilities when the quota (100%) is reached. This version produced a location accuracy of 72.7%

Table 1: Input variables, probabilities and stages of ISGM for figure 4h

Add probabilities during the simulation stages as follows:			
Variables/Stages	**Stage 1**	**Stage 2**	**Stage 3**
Slope (Slope ≤ 10^0)	0.1	0.3	0.3
Market places	0.01	0.03	0.04
Worship places	0.01	0.01	0.01
River (> 0.66 neigh) and road	0.3	0.3	0.7 (road); 0.2 (not road)
River (> 0.33 neigh) and road	0.1	0.2	0.3 (road); -0.8 (not road)
River (< 0.33 neigh) and road	-0.5	-0.2	0.3 (road); -0.3 (not road)
All roads	0.01	0.02	0.03
Major roads	0.5	0.4	0.4
Proposed ring road	0.2	0.3	0.3
Railway lines	0.2	0.3	0.2
Airport Runway	0.3	-0.3	-0.4
Cultural group 1	-0.1	-0.2	-0.3
Cultural group 2	0.2	0.4	0.3
Cultural group 3	0	0.1	-0.1
Cultural group 4	0.1	0.3	0.3
Cultural group 5	0	0.03	0.01
Cultural group 6	0	-0.2	-0.1

Compared to previous calibrations, this version defines two factors of proximity: one for all the criteria considered in the model (equation 2) and the other, which makes exception of river cell (equation 3) as follows:

$$m+ = \frac{(neigh(n)+1)-a}{neigh(n)} \quad (2) \qquad m\_ = \frac{(outside(n)+1)-b}{outside(n)} \quad (3)$$

where:

m+ = positive growth towards the proximity to any variable considered except 'river'

m_ = negative growth towards any river cell in the neighborhood

neigh(n) = total number of neighbors of *m* within the radius range of n pixels.

a = closest vacant pixel in the neighborhood

outside (n) = total number of neighbors – *neigh(n)*

b = total number of vacant land in a radius *n – a*

It was necessary to redefine a function for cell at the proximity of rivers because it helps capture the essence of IS growth towards the river course, whereas in other cases, the growth occurs outwards, and possibly at different stages.

8. Dynamic Visualization of ISGM

One of the critical components of urban dynamic modeling in geography is to simplify the understanding of processes by facilitating their visual interpretation. An important part of such a dynamic visualization and representation is to ensure that the processes are not represented in a static manner. The ISGM implements the dynamic visualization through the time-series animation of the simulation output. The practical aim of developing the dynamic visualization of the ISGM output is to allow a quick and easy appraisal of the expansion of IS patterns over time. Time-series functionalities such as animation are not readily available in most GIS environments. By allowing the option of generating a simulation output according to a user-defined format, the ISGM provides the flexibility to export its multiple map outputs to the available animation medium to create either a movie or a simple map animation.

For this model, the IS macro generated the output in two different formats: *Idrisi*® format and *Bitmap* (*.BMP*). However, the user can define any other output format. It is important to recognize that the time-series algorithm in *Idrisi*®*Release Two* failed to support the creation of the visual animation of the output layers from Idrisi® format files (*.RST*). It is also worth noting that before the automatic format conversion was developed and incorporated into the model, each Idrisi® output format was manually converted into a desktop publishing format such as .BMP. The automation of the data conversion avoided the tedious task of manual conversion, hence facilitating the creation of a dynamic visualization.

To produce dynamic visualization of the output files, a desktop format, namely .BMP, was used, mostly because of the high quality of the visual contrast. Two different approaches were used: visual animation in *MS PowerPoint*®, and the creation of movie files using a trial version of a video editing freeware, *VideoMatch*®. When creating the animation in PowerPoint, files are individually imported into the program, and then the time and order of each simulation are set in the *custom animation* window. There are options to add text and comments to the images as they appear on the screen. This method is an effective way to display in detail, the growth of IS over time, and monitor trends in their expansion. Animation in MS PowerPoint® also has the advantage to display the features clearly and at the same level of detail as the simulated maps. One of the disadvantages of this method is the user requires a PowerPoint application to run the dynamic visualization.

When creating a video or movie using VideoMatch® (one of the various video software freely available on the internet), individual files are imported into the program. The sequence of appearance and the duration of each appearance are then set by the user. The number of input files and the duration of each appearance determine the size of the video. One of the drawbacks of this method is that the file can be large and take time to be converted into a movie format. Unlike PowerPoint®, the spatial resolution, and therefore the quality of the visual contrasts are reduced during the conversion from *.BMP* to a movie format. Nevertheless, the user has a range of options to visualize and transfer the data.

The actual animation of the model output was important to actively see the emergence and growth of IS patterns across different parts of the map. Without the animation of simulated maps of Yaoundé for instance, the model would have not identified the need to suggest the three-phases of development of IS to capture the change in IS growth at different periods. From the dynamic visualization of IS emergence and growth in Yaoundé, it was possible to identify sections of the city (e.g., southern and western) experiencing rapid expansion of slums. It was also useful to correlate and recognize the central role cultural and ethnic groups, road networks and topography play in the identification of IS growth mechanisms. This suggests that urban planners and policy-makers could incorporate the dynamic visualization of IS expansion in their quest to understand the *informalization* process.

9. Evaluation of the ISGM

A vital part of any model development is having a robust system of evaluation to provide some capacity to check its validity and usefulness. A key part of the work undertaken to develop the ISGM was therefore developing a framework to test its effectiveness and value at simulating IS growth and expansion in a 'real' context such as that of Yaoundé. This section outlines the evaluation criteria used to test the model. Four main criteria were used based on the work of Giudici (2002) to evaluate the ISGM performance. These criteria are sensitivity, validity, reliability, and efficiency and utility and are discussed below.

9.1 Sensitivity

Sensitivity assesses the behavior of the model whenever changes are made to its properties, structure and inputs. In the case of Yaoundé, the ISGM has clearly demonstrated that the modification of the configuration of the model reflects on its output. For instance, the output of a road-based ISGM (fig. 4e) was different from exponential growth (fig. 4c) and river-based simulation results. It was demonstrated that ISGM had the capacity to test various hypotheses of IS, especially when the key factors were progressively added to the model. In that respect, factors such as main roads, vacant land, cultural and ethnic groups, topography and markets places were shown to play an important role in the emergence and expansion of IS. Similarly, excluded areas (which consisted of enclosed and protected areas, such as military camps and airport) emerged as a serious deterrent to the exponential growth of IS.

9.2 Validity

Validity assesses how the output agrees with the conceptual framework of the model. The calibration results show that it is possible to combine the GIS and CA approaches to simulate and predict IS dynamics. One of the advantages of the loose coupling of a flexible CA (*VISUAL BASIC macro language*) and spatial GIS environment is that it facilitates building and maintaining models. With ISGM, it was shown that one could easily modify probabilities and explore what happens if the model mutates its structure due to new information, or due to spatial and temporal changes. The proposed model has also demonstrated what the main driving forces behind the expansion of IS are, as well as indicated the respective weights that each factor considered had at different stages or scenarios of urban development. Furthermore, the model's capacity to combine physical changes with socio-cultural aspects is significantly important in terms of capturing the depth and breadth of dimensions that represent IS expansion and therefore, increase our understanding of IS behavior and improve urban planning responses. This knowledge of the role of both physical and socio-cultural dimensions is particularly vital for urban planners and governments who can use the model to better anticipate the emergence of future IS.

Quantitative validation of the model involved using the *Validate* module in *Idrisi* to measure the level of precision of each simulation. It was shown in section 6 that the precision of the outputs increased with the sophistication of the model. For instance, the implementation of the ISGM on Yaoundé clearly demonstrated how accuracy of prediction improved from 43% (fig. 4c) to 72.7 % (fig.4h). Nevertheless, future development of the ISGM could well benefit from the incorporation and strengthening of the statistical analysis and evaluation built within the program itself. However, the results of the ISGM could not be compared with other models' results, only because such similar IS models do not exist.

9.3 Reliability

Reliability examines the quality and truth of the results provided by the model. In that regard, the proposed ISGM has performed properly and generated expected outputs based on the data input, the rules and the probabilities. The application of the proposed ISGM to Yaoundé has shown that the choice of key IS growth factors, the definition of rules and the application of sound probability estimates, significantly improve the calibration of the predicted output. The model does not, however, take into consideration other important factors of IS emergence and growth, such as urban policies, governance issues, corruption, impact of structural adjustment programmes, transparency of decision making process, which could have improved its performance if suitable data about them had been available. Despite this, the simulation of IS could allow planners and policy-makers to do a preliminary *What if?* analysis with the purpose of assessing the system's behavior under different conditions and evaluating which alternative policies should be adopted.

9.4 Efficiency, utility and generality

Efficiency refers to the model's precision given time, equipment and expertise limitations, whereas utility assesses the efficiency, usefulness of the model. Generality is the extent to which a method or model can be successfully applied, with minor modifications, to a wide range of situations (in this case cities). Compared to other urban dynamics models, the ISGM is a *low cost* model (Wyatt *et al.*, 2002) and can be obtained free of charge from the author. Moreover, the proposed ISGM is fast to run and quite flexible in data input. In terms of equipment, the ISGM is versatile and it can be implemented on a standard computing platform with a *VISUAL BASIC* application, and a nominated raster GIS environment. Furthermore, the testing of the ISGM within Yaoundé clearly showed that, with limited modifications, the model has the potential to be successfully used to explore the expansion of IS in other cities of DC. The model also provides multiple outputs, which can serve to create a *movie* of IS dynamics, thus gaining better insights into the dynamic of IS patterns. As the case study of Yaoundé indicated, ISGM allows the rapid development of different types of growth, which could greatly improve interaction amongst government and urban stakeholders. This is of paramount importance for proactive strategic planning that can anticipate the future location of IS and then act before they become widespread. Nevertheless, the viability of the proposed model would be even greater if the program were converted into menu driven software.

Concluding remarks

This paper has shown that GIS technology can be loosely coupled with the CA approach to simulate the behavior of IS dynamics in cities in DC. The *VISUAL BASIC* language used for designing the ISGM allows flexibility and provides full control (customization) over the modeling and simulation processes. In that regard, the proposed model can be considered as a 'white box' in opposition to other urban dynamics models that portray 'black-box' approach.

The proposed model is at its early stages and so, has room for further improvement, especially in the areas of fine-tuning the model, user-friendly, more rigorous calibration algorithm, development of a menu-driven interface, and adding other key variables such as level of governance, corruption and public participation in the planning process. Nevertheless, it was demonstrated that the ISGM embodies the logic of IS growth, thus sheds light on human settlement behavior in DC and in doing so, helps urban researchers to better understand processes of unplanned expansion in order to inform planning. Importantly, this study has shown that within certain boundaries, important human dimensions and characteristics can be incorporated into a modeling framework. The model adds to our capacity to plan because it is able to incorporate a larger range of variables and in particular, socio-cultural characteristics that are central to understanding human settlement behavior. In doing so, it could be argued that the ISGM begins to challenge the assumption that spatial models cannot be used effectively to better understand human behavior because they cannot handle spontaneous phenomena and human interactions such as slums. I therefore believe that this proposed ISGM represents an important contribution to the state-of-art of informal settlement modeling within DC.

Finally, this paper has demonstrated that the proposed model has also been developed within a robust evaluation framework based upon its sensitivity, reliability, validity and usability. This framework has indicated that the ISGM can potentially improve the urban planning and decision-making processes that would ultimately lead to the long-term improvement of the quality of life in developing cities. This outcome suggests that a key further step is the models' capacity to be useful in a 'real-world' planning context by governments and urban planners.

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[1] It is worth noticing that there is no commonly agreed definition of 'slum', because the term can vary extensively depending on a range of factors including the country or region, legal status or insecurity of tenure (squatting and land invasion/grabbing), location and size, compliance with planning regulations (informal settlement), poor socio-economic conditions of its inhabitants, lack or decay of services and infrastructure (slum). In this paper, and for the modelling purposes, 'slum' is used interchangeably with other expressions such as informal settlement, squatter settlement and unplanned settlement to indicate common characteristics in some urban areas in DC. They include poverty and overcrowding, poor or informal housing, inadequate access to safe water and sanitation, and insecurity of tenure (Davis, 2004; UN-Habitat, 2003).

[2] *Vacant land* refers to any cell, which does not belong to a built-up on the reality maps. Vacant land will therefore include peri-urban land and villages, 'unplanned' areas, land without clear tenure, non-protected areas and public land prone to squatting."

[3] For the purpose of this application of ISGM within Yaoundé and giving the marginal occurrence of isolated informal settlement patterns, the proximity (neighbourhood) approach within a cellular-like framework was applied. In some occasions, however, isolated patterns of informal settlements can emerge in areas, which might not satisfy the general conditions outlined in this paper. In such circumstances, the ISGM offers three options:

a. adding the subsequent factor that would account for the emergence of such dispersed distribution;
b. extending the neighbourhood to include the areas where potential slum could emerge. However, a large neighbourhood (8 or 16) could, however, slow down the program;
c. altering the general condition and/or probability to suit the specific need.

[4] It is important to note that this assumption is the proxy of the core characteristics of IS which include, poor services (e.g.; water, sewage, electricity and school), social insecurity, lack or decay of infrastructure, insecurity of tenure, densely built-up areas and poor socio-economic conditions of its inhabitants (mostly poverty).

[5] All data were sourced from official documents, except the worship and market places layers, which were derived from Bopda's work (Bopda, 2003). For instance, roads, rail line, airport area with runway and land use maps (scale of 1:12000) were derived from the official urban planning documents by the Ministry of Urban Planning (MINUH, 1990). Rivers, contours, spot heights, and other layers were compiled from two topographic maps of Yaoundé at a scale of 1:12000 obtained from the National Institute of Cartography of Cameroon. All these layers were digitized using *Arc Info*, then exported into *Arc View* for georeferencing, analysis and editing**."**

[6] It is worth noting that there are more than 200 cultural/ethnic groups in Cameroon and it is likely to find more than a dozen in cosmopolitan Yaoundé. Based on population census (1976 and 1997) and previous study (Bopda, 2003; Franqueville, 1984), this paper represents the four main ethnic/cultural groups that dominate the Yaoundé urban space: Ewondo, Eton, Bamiléké and Haoussa. The Ewondo (and Bané) are the indigenous population of Yaoundé whereas the Haoussa, Bamiléke, Eton and others are 'migrants'. The map of cultural and ethnic groups was obtained from the percentage (simple majority of ethnic/cultural origin in each neighborhood) of the origin of its inhabitants. The likelihood of each neighborhood influencing the emergence of new slums was a function of the historical slum trend in each neighborhood, the composition of its surroundings and the probability of other variables considered. The ethnic/cultural map was extrapolated to the entire area of study to so that the prediction module could account for the ethnic/cultural group. This was so because there is a strong link between cultural/ethnic background and prevalence of IS and an even stronger the relationship with land use.

[7] It is worth mentioning that after several calibrations and accuracy tests of ISGM within Yaoundé, it became evident that the importance of the road influenced the location of slums. The road layer was then divided into two categories: 'major' and 'minor' roads. Using various trials-and-errors operations, each category was finally assigned its respective probabilities.