MONITORING THE TREND OF UNPLANNED DEVELOPMENTS IN AN URBAN AREA

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ABSTRACT

Although remotely sensed data has been used extensively for urban studies, additional collateral information is usually a pre-requisite for the correct automatic identification and localization of objects found within a particular scene. Hence the ability to categorize an urban area into informational classes namely formal or informal developments requires information about the town model which has in principle some legal backing. In this study, remotely sensed data is used as a source for current information. Specifically, spatially enhanced 1998 SPOT XS (10m) resolution for Dar-esalaam, Tanzania is automatically interpreted and the classes aggregated into developed (built) and reserved (non-built). The 1992 land use map is used to mask out the newly developed areas. Weighted indicators based on compatibility of land uses, infrastructure network, and hydrological sources are used to establish their relationship on the new developed areas. Results show that existing land uses influence highly new developed areas. A combination of the weighted indicators is also employed to constrain the new developed areas thus resulting in a stratification of the new areas into fuzzy blocks ranging from those which are likely extensions of unplanned developments to those which are unlikely. Such information could facilitate planners in prioritizing areas that require urgent reaction planning.

INTRODUCTION

According to recent reports, African cities are among those experiencing highest population growth in addition to other social challenges e.g. environmental degradation, lack of urban services, deterioration of existing infrastructure, lack of access to land, economic crises and shelter [8]. This growth has been attributed to natural population growth as well as rural-urban influx. Unfortunately majority of the urban population live in inadequate housing, mainly slums and squatter settlements, with an estimated one billion people in the whole world. Such developments are characterized by densely built up structures with a separation of within 2-3m which poses a risk in the event of fire outbreak or contagious diseases, diverse construction materials e.g. plastic, tin and asbestos sheeting, wood and cartons, single storied with flat and near horizontal roofs, minimum size of 4 x 4m with roof heights of 2-2.5m having simple geometry of 4-sided shapes, isolated and random as opposed to compact and systematic physical location which results in ineffective use of land [5],[6] and [3]. It is also worth noting that these does not only occur in the areas designated as Extended Metropolitan Regions (EMRs) but also within the jurisdiction of an urban area.

The fractal city paradigm [1] perceives the morphology of cities as complex entities which undergo changes according to the local rules and prevailing conditions as opposed to the conventional approach of simple, ordered structures which can be expressed by lines and shapes. However, abstraction is normally employed for purposes of modeling and understanding how urban forms evolve as well as their spatial organizations. The capability of modeling techniques are limited in describing reality because not all factors that influence land development patterns are incorporated. Furthermore, land use models are constrained by data available. In general there are four categories of planning models namely land use, transportation, economic, and environmental impact [9]. The difficulties in modeling phenomena such as informal developments using existing theories could lead to lose of subtle information which could otherwise be vital to planners, because they are developed with constraints to facilitate ease of manipulation. However, they can be employed for strategic and long term planning which is also one of the roles of urban planning departments.

In most developing countries, use of land is complicated by complex and ambiguous law systems which results in ownership and occupation conflicts e.g. some unplanned developments take place on already allocated land. The ability to effectively address the problem has been curtailed by lack of information and suitable techniques. There is therefore need for real time indicators that can be used to localize and thereby monitor their trends thus forming a platform for subsequent negotiations.

REMOTE SENSING FOR MONITORING URBAN AREAS

With the proliferation of remotely sensed data sources, gaps in information continue to be filled particularly for applications requiring frequent monitoring e.g. urban sprawls, deforestation, disaster management, etc. The ability to extract useful information from remotely sensed data depends among other things on the object themselves and the algorithms employed for the reconstruction purposes. Manual interpretation techniques synergistically incorporate context, edges, texture and tonal variations in the detection, identification and labeling of objects from remotely sensed imagery. Conversely, classical automatic image interpretation systems are based on tonal information which has been found to be inadequate, specifically for applications characterized by heterogeneous patterns. A more robust image interpretation scheme is one that incorporates human interpreters knowledge in the automatic identification of objects. Several knowledge representation schemes exist of which the most commonly employed include the production rules, semantic nets, frames, predicate logic [2]. In the context of dynamic urban environments in developing countries which are predominantly characterized by informal structures, the fundamental requirement is in the identification and monitoring their trends. In general existing detection and identification techniques range from the simple combination and comparison of two images taken at two different epochs supported by ancillary information [6] , whereas monitoring trends involve either short-term or long-term modeling [9]. In order to support reaction planning, short term as opposed to long term modeling would be useful. This is due to the fact that this phenomena is difficult to model due to its rapid and haphazard nature. On the other hand, the spatial complexity and heterogeneity of the objects as well as the cost associated with the current available high resolution data sets in the 1-5m domain necessitates trading off between spatial resolution and costs without compromising the set out objectives. This has led to techniques that make use of sub-pixel classifier [4] on relatively low resolution data sets as well as enhancing low multispectral resolution data with high panchromatic data or in general integration of low resolution multispectral data with collateral information at a certain level of data fusion namely pixel, feature or information.

AIM AND CONCEPT OF THE STUDY

In areas prone to spontaneous developments, e.g. in developing countries new illegal developments are predominantly characterized by informal settlements. This study focuses on the trend of these illegal or informal developments. In this regard, developed and reserved areas are generated through the automatic interpretation of current remotely sensed image based on spectral, object and structural feature information. Trend modeling is based on three assumptions:-

- Compatibility of land uses, which implies that existing land uses do influence new land uses, in this case further growth will tend to weave out based on its origin of growth.
- Ease of communication, i.e. nearness to main transport routes.
- Nearness to hydrological features, i.e. proximity to existing sources rivers.

Proximity search based on these indicators is tested using different Euclidean distances to establish their degree of influence on the new developed areas. Verification of whether these are truly extensions of unplanned developments is subject to confirmation against a town model map or physical survey. Figure 1-1 shows the overview of the methodology. Details are given in the following sections.

INPUTS

The study site for this project is Dar-esalaam, Tanzania which is among the fastest growing cities confronted with spontaneous developments. It has an estimated population of 3.0million with 70% living in informal settlements.
The data sets included:

a) Raster-based data

- SPOT multispectral 1998 (20m resolution)
- SPOT panchromatic 1998 (10m resolution)
- Enhanced SPOT multispectral 1998 (10m resolution, figure 1-3)

b) Vector-based data

- Land use 1992 coverage showing among other information the location of unplanned developments prior to 1992 (figure 1-4)
- Main roads coverage as of 1992 (figure 1-5)
- Main rivers coverage (figure 1-6)

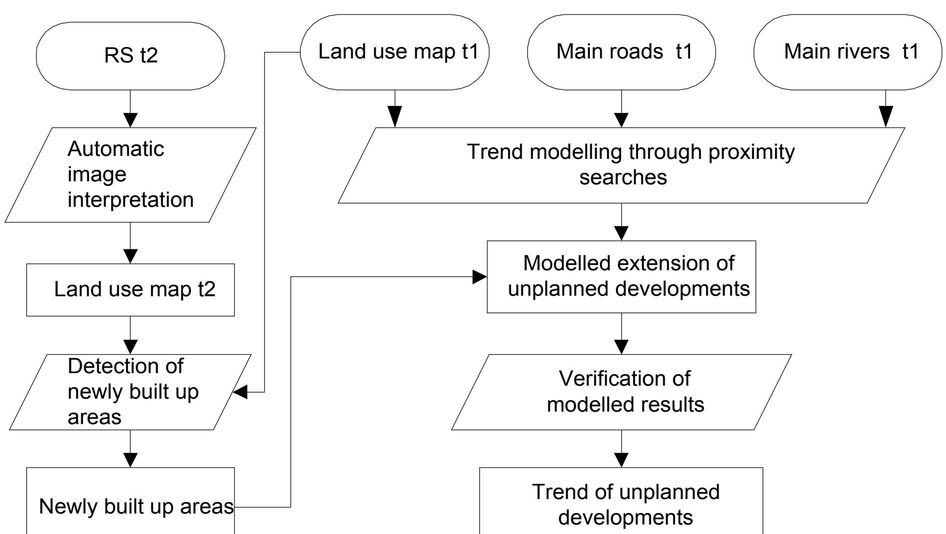

Fig. 1-1 Trend Modelling

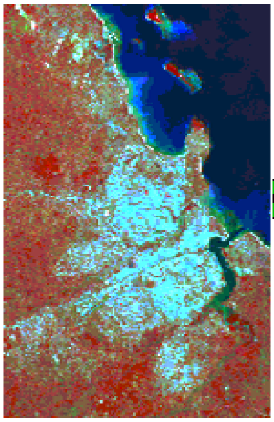

Fig. 1-3: XS SPOT, 1998

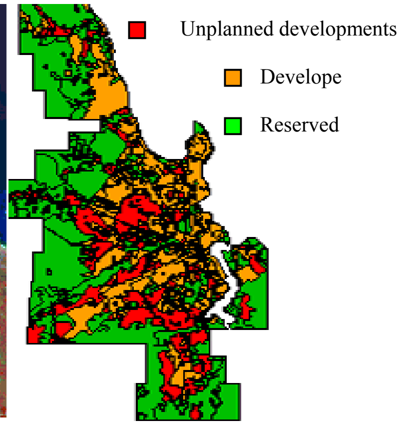

Fig. 1-4: Land use, 1992

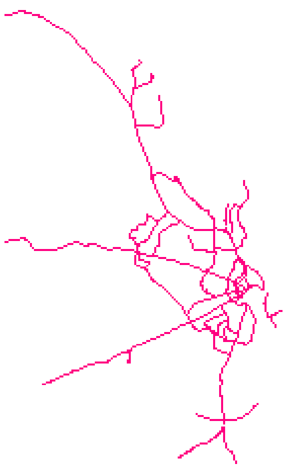

Fig. 1-5: Main road coverage

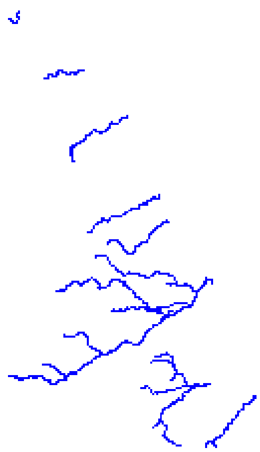

Fig. 1-6: River coverage

METHODS

Automatic Image interpretation

Different pattern recognition techniques namely statistical, grammatical, structural and descriptive, use different search and matching strategy which in turn depend on the data and the specific application. The ultimate goal in all the interpretation techniques is the identification of objects and their description within a scene. In this regard the knowledge of photo-interpreters is very vital and is normally exploited and incorporated in image interpretation systems particularly for complex aerial and very high resolution satellite images. The ability to explicitly code and represent such knowledge, thus making it repeatable and portable leads to robust image interpretation systems. In principle, a rule-based image interpretation system, essentially entails, the identification, extraction and classification or labeling of features for the particular application, and their subsequent representation..

Feature extraction involves, segmentation based on local properties (i.e. neighborhood operators and uniformity of gray level). In general algorithms include texture, shape analysis, region growing, boundary detection, histogram thresholding, probabilistic relaxation and multispectral classification. The choice of the segmentation method depends on the problem under investigation.

The labeling of edges and regions resulting from the segmentation processes is also application dependent. The idea is to assign regions or edges to meaningful classes and also useful for the application. For instance, in this study thresholding aims at discriminating between developed and reserved areas. This basically entails selecting a suitable threshold say g such that,

$$MinGray <= g <= MaxGray.$$

Which results in regions corresponding to this condition. Although, this method is very easily implemented, its success depends on the separability of the gray level bands as well as the spatial distribution of the gray levels [7]. Two scenarios can be identified here namely, a straight forward case in which the clusters can be distinctly separated and a complex case whereby either the gray levels occur with the same frequency or they are distinct but do not correspond to meaningful classes. This necessitates stepwise thresholding incorporating domain knowledge about the scene. Consequently in order to be able to label features specifically for complex and heterogeneous applications e.g. urban studies both automatic histogram and interactive thresholding are employed.

In this study, Normalized Vegetation Index (NDVI), high density image, texture image, and a clustered image, with additional information from the multispectral channels and principal components were used as inputs in the image interpretation.

The representation includes a knowledge base which comprises of data (objects, facts, goals) and rules (condition, action) and an inference engine whose role is to assemble rule instantiations in a conflict set from where one or more rules are selected based on some criteria e.g. best first or specificity. The relationships are represented using the condition-action pairs, thus

IF (condition)
THEN (action)

Whereas the association between relationships are realized through the two logical relationships namely AND and OR.

This entailed pre-processing, image interpretation, growth trend modeling and evaluation of the results.

Detection of newly built up areas

The ability of remotely sensed data to continuously provide a synoptic view of the actual situation on the ground is one of the benefits being exploited for dynamic studies e.g. urban growth, deforestation, agriculture, disaster monitoring, etc.

Within the framework of urban environments undergoing rapid changes in terms of growth, the location and extent of the new developments are vital indicators for subsequent planning. Specifically, in situations where unplanned developments are prevalent, it is of paramount importance to be able to localize and monitor their trends. In trend monitoring, this involves first, the detection of newly built up areas. Specifically, the integration of remotely sensed data with previously interpreted information depicting among other things the existence of these unplanned developments can be used to mask new developed areas from the new remotely sensed image. This will form the basis for establishing whether part of the new developed areas are extensions of the unplanned developments.

Trend modeling

Modeling aims at generating alternative scenarios of possible developments based on some reasonable rationale. Social, environmental, economical, etc indicators influence the rate of urban dynamic. The incorporation of these indicators in assessing growth facilitate the planners in weighting their influences accordingly. There are two types of influences that should be distinguished namely independent and combined, whereby independent refers to each indicator in isolation whereas combined is the effect of all the indicators. In this study three environmental indicators have been tested namely existing unplanned developments, communication network and hydrological information.

Verification of modeled results

The prediction of the extent of growth of unplanned developments depends on two main factors the accuracy of the interpreted image and the viability and rationale of the modeling criteria used. Ideally, physical survey or current aerial photographs could be used to check the interpreted and the modeled results thereby giving an indication of the feasibility and the practicability of the technique.

Experiment

For the interpretation of the SPOT XS image, figure 1-3, the following features were generated; a 3 x 3 window was used together with the variance operator for the texture generation and this is shown in figure 1-7. A high pass filtered image highlighting high density features is depicted in figure 1-8. Figure 1-9 is the normalized vegetation index layer that enhances principally sealed and non-sealed areas. A total of 100 clusters were generated using the ISODATA algorithm which were then aggregated into 10 clusters as shown in figure 1-10. It is evident that, separability of classes based on spectral aspects alone is not feasible as indicated by the areas marked A, B, and C. Other additional features incorporated in the classification include multispectral channels namely bands 2 and 3, as well as the principal components.

Fig.1-7: Texture image

Fig.1-8: High edge density image

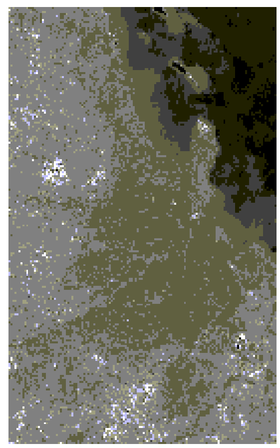

Fig.1-9: NDVI image

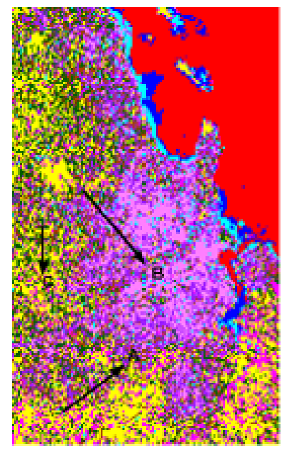

Fig.1-10: Unsupervised layer

The hypotheses, rules and conditions applied in the automatic interpretation of the image in this study are shown in table 1-1.

Table 1-1: Hypotheses, Rules and Conditions for the interpretation of the image

HYPOTHESES	RULES BASED ON CONDITIONS	
Developed	Texture	heterogeneous
	Spectral Class	Clusters 3,8,9,10
	Edge energy	high
	NDVI value	low
Reserved	Texture	homogeneous
	Spectral Class	clusters 1,2,4,5,6,7
	Edge energy	low
	NDVI value	high

The 1998 interpreted image was used in combination with the 1992 land use map to extract newly developed areas. Specifically, the 1992 land use map was used to mask previous developed areas thus leaving only new developed areas.

This information was then used as an input together with infrastructure and hydrology information to model the likelihood of the newly developed of being an extension of the existing unplanned developments. First, independent influence was assessed to establish the amount of new developed areas falling within the proximity of already unplanned developments, roads and rivers based on different proximity distances, specifically 20m, 60m, 80m, 100m, and 200m. Secondly, a combined effect is evaluated whereby the proximity to the rivers is made as large as possible due to risk of flooding, road proximity is also assumed reasonably due to the non-uniform distribution of the communication network and the two are kept constant (i.e. 300m and 80m were assumed respectively) and what is varied is the information pertaining to the nearness to the already existing unplanned developments (i.e. 60m, 80m and 100m were tested). The rules and conditions used to model these scenarios are contained in table 1-2:-

Table 1-2: Hypotheses, Rules and Conditions for trend monitoring

HYPOTHESES	New Status	Compatibility (m)	Communication (m)	Hydrology (m)
Very likely	Built	60	80	300
Likely	Built	80	80	300
Maybe unlikely	Built	100	80	300
Unlikely	Built	>200	80	300

RESULTS

Figure 1-13, shows the interpreted image with the two aggregated classes namely developed and reserved whereas figure 1-14 shows the newly developed areas. An analysis of the effect of influence of existing rivers, roads and unplanned developments is highlighted in figure 1-15a, b, and c respectively, whereas figure 1-16 is the corresponding statistical summary. Figure 1-17 shows the weighted new developed areas on the basis of proximity to the already existing unplanned developments (60m, 80m, 100m and >200m), communication network (80m), and hydrology (300m).

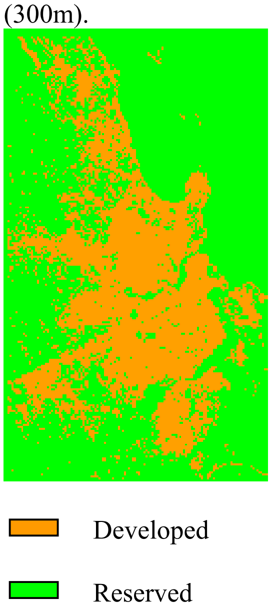

Figure 1-13: 1998 Interpreted Image

Figure1-14:1998, New developed areas

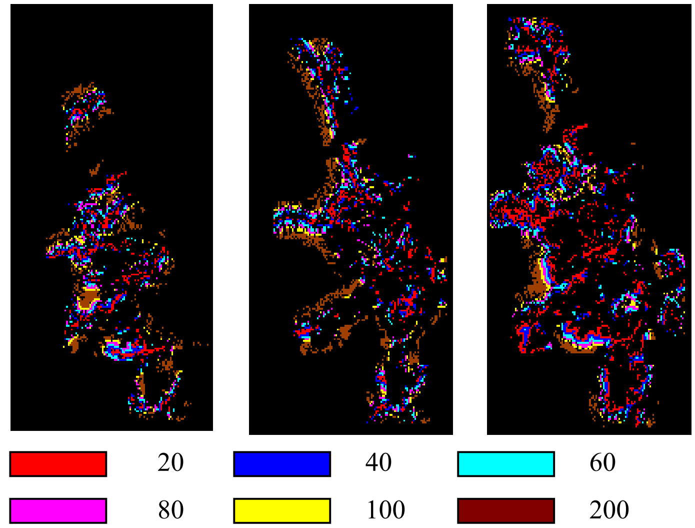

Fig. 1-15a:River Buffer Fig. 1-15b: Road Buffer Fig.1-15c:Unplanned Buffer

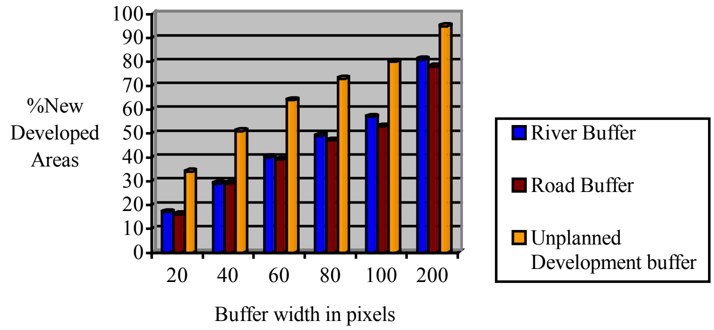

Figure 1-16: Comparison of new developed areas based on river, road and unplanned developments.

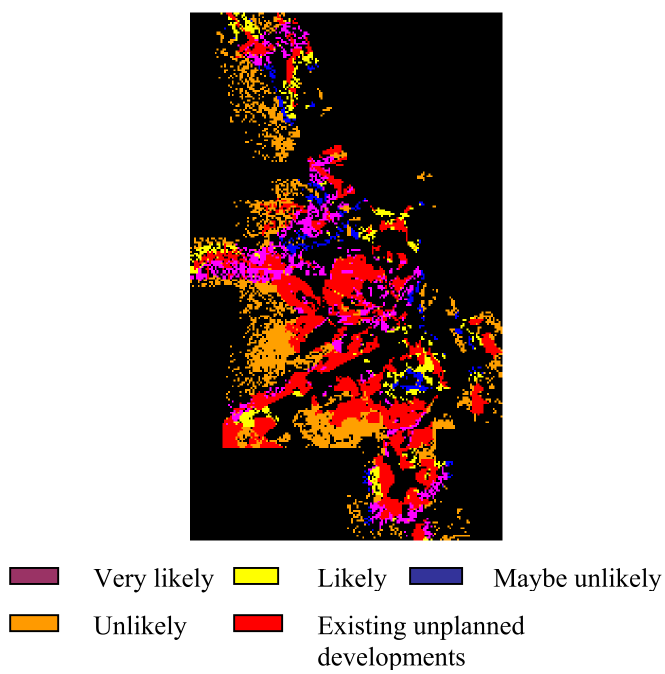

Figure 1-17: Modeled scenarios of possible extensions of unplanned developments

DISCUSSION

The existing unplanned developments tend to have more influence on newly developed areas in comparison to the other weighting parameters namely proximity to main communication network, and hydrology as seen from figure 1-16. This could be an indicator of the extension of unplanned developments. As a rule of thumb, new developments tend to occur in areas compatible with existing land uses. The initial low influence by the existing hydrological sources can be attributed to the fact that the terrain is relatively flat and there are risks of flooding in the event of heavy rains and therefore few developments are likely to take place very close to the rivers, on the other hand ease of communication parameter indicates the need to extend and fairly distribute the network in order to cater for the diverse land uses particularly residential areas. An attempt to prioritize new developed areas based on these weighted indicators on a fuzzy scale, namely very likely, likely , moderately likely, and unlikely could assist planners in strategizing their reaction planning processes in the situations whereby there is dynamic growth characterized by unplanned developments.

CONCLUSION

Remote sensing data is useful at all levels of urban planning as it provides the spatial component required in the planning processes. It can be used to show the existing ground situation before any strategic and projections of further land uses are made. In the event change has occurred two images taken within this time frame could be used to detect this change and finally it can be used together with town model information to quickly identify unplanned developed areas thus facilitating the necessary reaction planning as in the case of informal settlements. From the practicability point of view, there will always be a trade off between cost and the resolution of the data, which further depends on the phenomenological characteristics of the objects. For instance, in the case of unplanned developments there is need to understand the trend which would eventually enable the necessary measures to be taken thus avoiding unnecessary expenditure and turn around time in the provision of the necessary infrastructure.
To adequately address the problem of unplanned developments, consistent and update information is required. This will enable planners assess the pattern and therefore invoke the necessary measures. The advantage of frequency of coverage of earth features by remotely sensed imagery could be exploited in combination with town model information. The degree to which this problem can be addressed will depend on among other things the gravity of the problem and the techniques used to interpret the image which in turn determine the quality and content of information derived.

Acknowledgements

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