

A Geo-Information Approach for Urban Land Use Planning in Kampala

Shuaib LWASA, Uganda

Key words: Urban planning, residential housing, suitability analysis, GIS

SUMMARY

Like other developing countries, the nature and character of spatial developments in Kampala does not only pose a daunting and challenging task of improving the lives of the urban dwellers but also searching for optimum solutions to the haphazard spatial developments and inadequate infrastructure within settlements. The kind of living environment created by haphazard development has led to a deplorable living environment for an estimated 60% of Kampala's population. Although planning has been undertaken only 20% of the settlements are properly planned and serviced while for the big proportion of settlements the gap between the planning outputs and the actual developments in the city is widening further. Besides the existence and extension of this planning gap, the current planning procedures involve methods which are time and resource demanding activities and often far behind the speed of development of settlements. The Kampala structure plan 1994 which has just been extended by the City Council has not been evaluated to establish how much of the developments on the ground correspond to the plan. This is because development control has either failed to be implemented or been challenged by issues of precise information and location. Review of the plan is overdue given an annual growth rate of 5.6% for the city. In the face of these challenges, alternative planning approaches are necessary for timely provision of accurate information and planning outputs to support their implementation. Basing on findings of a of suitability assessment of land for housing, this paper attests to an alternative approach of GIS based model for urban land use planning by highlighting a procedure to identify factors for assessment, classify land based on the criteria, generate a suitability model and evaluate existing, potential and proposed areas for housing using the suitability model. The paper also highlights the usefulness of land allocation beyond suitability analysis in which GIS based allocation models have a potential in urban land use planning. Sensitivity of the GIS based models is also briefly explained before outlining some limitations. The paper concludes with a note that GIS based models offer the much needed powerful tools for enhancement of urban land use planning.

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1. INTRODUCTION

The analysis of land characteristics in identification of land suitable for development can play an essential part in the planning process (Hopkins 1977). Among the many concerns of urban planners, in guiding the spatial arrangement of activities is the optimum utilization of land for the benefit society. This involves making choices between available alternatives and as such it requires a procedure for the analysis of available alternatives. Alternatives for development usually start though not necessarily with consideration for buildable land. That is land on which if developments are installed would not detrimental or have adverse effects to the development. The process of identifying such land is the assessment of the fitness of tracks of land for development. Land suitability analysis requires integration of several data sets to model land use requirements and the characteristics of the land for the alternatives. In this respect, geographical information systems provide a tool in integrating and analyzing of land resources to determine the suitability for a land use or several land uses (Jankowski and Richard 1994).

Such modeling however needs a procedure for structuring steps in evaluation for different land uses. This paper presents results of a study that focused on the development of a model for assessing the suitability of land for residential housing development in Kampala. Geographical Information System is used and integrated with Multi-criteria Evaluation techniques to develop a model and analyze land with a potential for residential development in Kampala.

2. THE NEED FOR GEO-INFORMATION

Urban planning in the contemporary world has experienced a genesis in terms of methods and approaches to the analysis and identification of solutions to spatial development problems. In general most urban planning issues including housing, sanitation, circulation (transportation) and infrastructure for waste management are not only spatial in nature but also required characterization and analysis in the spatial sense. Modeling of space has traditionally been achieved through mapping utilizing cartographic techniques but such techniques are not only time-resource demanding, but also often provide information that is not up to date. Additionally in the urban planning context is the need to precisely relate a planned activity to the actual location on ground. To this end, the challenge is to provide both accurate information but also enhanced methods of spatial analysis for urban planning. Therefore Geo-Information and Geo-Information systems are required to provide a basis for spatial analysis of urban planning issues in the search for optimum solutions to urban development problems. Three important issues define the need for Geo-information and it follows that;

- The concern of planning is guiding the spatial arrangement of urban uses is to maximize utilization of space while sustaining the environment on which such uses largely depend.
- Spatial arrangement of activities is a decision making process between available alternatives and as such requires a procedure for the analysis of available alternatives.

- Land suitability analysis requires integration of several data sets to model land use requirements and the characteristics of the land for the alternatives

GIS's potential in the planning process is through the development and application of relevant models to support spatial decision making. Since suitability analysis deals with analysis of several data sets, GIS effectively relates the characteristics of land for land use allocation. It therefore emerges that geographical information systems are needed because they provide the tools for analyzing of land resource to determine the suitability for a land use or several land uses in the urban context.

3. THE STUDY ISSUE

Of all urban land uses, residential use demands for more land than any other and thus its is the most significant land use in the context of space needs. For example it requires probably 1000 sq m to accommodate 50 workers in an industry for production, but it requires it may require several times more land to house such workers. It is therefore imperative that suitable land for residential use has to be identified to maximize space utilization and limit environmental degradation. The suitability of urban land use is largely the strategic nature of a tract of land that would enable economically and socially feasible utilization of such land. Thus bio-physical factors, spatial economic factors (such as land values), social factors (such as preferences on distances to travel) are all important in the assessment of the fitness of land for urban development. But due to availability of data, the study focused on the housing suitability factors of soils, drainage conditions, existing land use, slope and accessibility to transport network. Evaluation was done for both existing residential areas and areas for future development. The essential element was to determine the suitability of land based on the limitations of the physical characteristics as well as accessibility to transport network in order to design a suitability model for residential development.

The main objective of the study was to develop a model for assessing land suitable for residential development in Kampala. This specifically focused on; identification of factors which are important in evaluation of land for residential development; classify land basing on criteria including soils, slope, drainage transport network accessibility in relation to the requirements for housing development; generate a suitability map for Kampala that combines these criteria, showing levels of suitability for residential use; evaluate the suitability of existing, proposed and potential residential areas; and utilize GIS outputs to estimate future land requirements for residential purposes.

4. A GIS BASED APPROACH

Various methods for analysis of land suitability exist including the Gestalt, factor combination method, ordinal combination method and linear combination method. But most of these methods are mathematical in nature and facilitate the assessment of a piece of land on the basis of various factors for its suitability. Similarly, GIS methods of analysis offer possibilities of combining different layers using mathematical functions for various purposes including suitability assessment. Each of this method however has limitations of application in the GIS environment but this study employed the weighted linear combination method which offered better opportunities for analysis of land for urban development, appendix 1. GIS and weighted linear combination method were integrated with multi-criteria analysis

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techniques to identify factors and scoring or weighing of such factors. The procedure for the GIS analysis is shown in flow chart of figure 1 describing the steps and data combination. The GIS based procedure utilized is as follows;

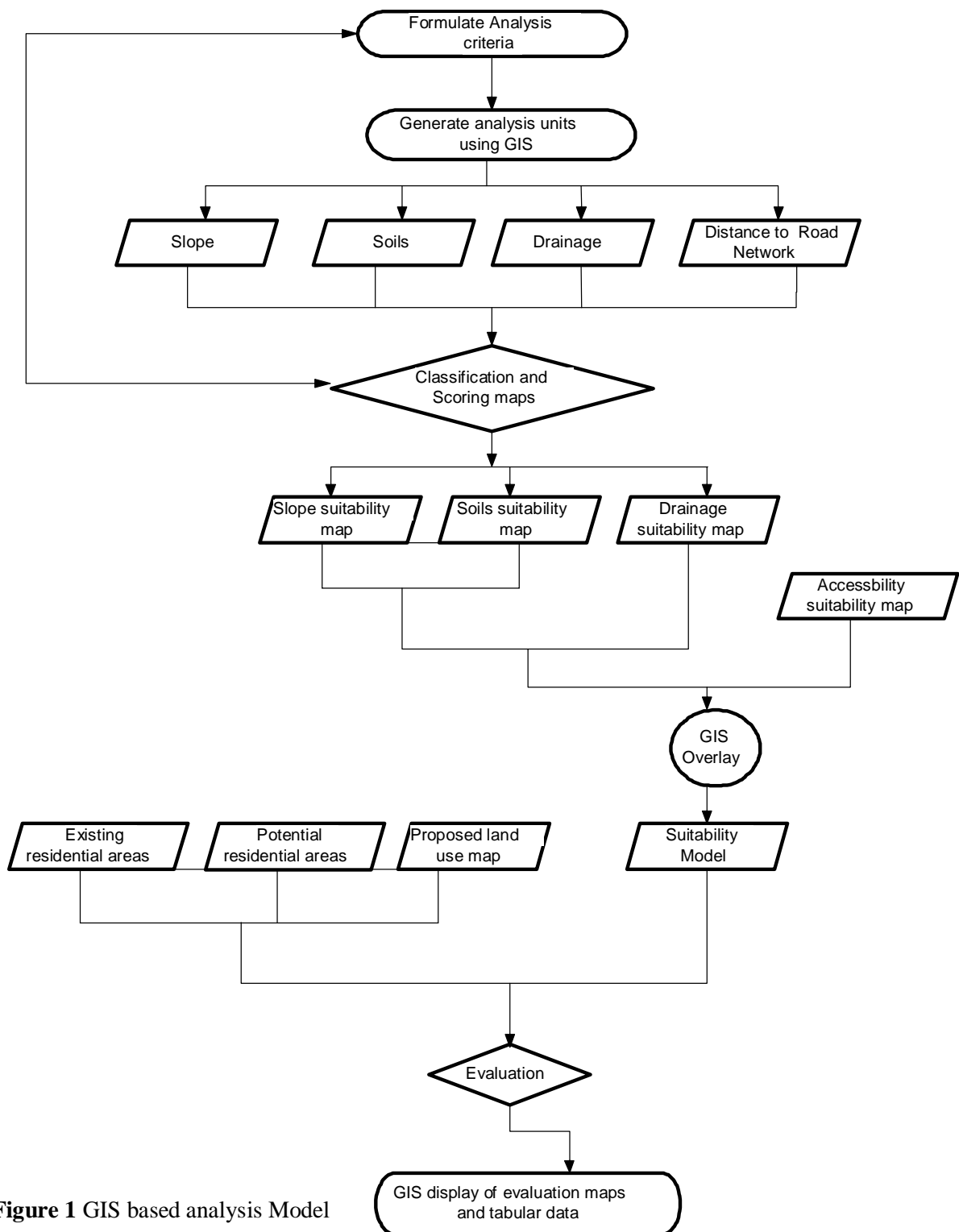


Figure 1 GIS based analysis Model

4.1. Suitability Analysis Model design

Determining Criteria

The definition of evaluation criteria usually depends on the type of problem and availability of data to support the analysis criteria. In this study deriving criteria was based on the deductive approach Voogd, (1983) from general to specific criteria. Knowledge of a functional relationship between a land use and its optimal site as well as a description and measurement of the properties of the potential site, so that they may be matched in relation to the requirements are important in definition of criteria. The specific analysis criteria were identified from the following general broad criteria

- Physical criteria including physical factors such as slope, soils, drainage conditions
- Environmental criteria, which refers to the suitability of the site from the conservation and ecological point of view
- Socio-economic criteria, including land prices, distance from the site to employment area and proximity of the area to the existing infrastructure.

Suitability Scores

For each criterion, a suitability score was applied using a seven-point scale to determine the qualitative rankings of the suitability on each criterion. The rankings range from 1 (Not suitable) to seven (Highly suitable). This “positive direction” Voogd, (1983) is chosen to keep the scores understandable since the higher the score, the more suitable the site is. Suitability classes are given as below:

- Not Suitable (1): This is attributed to sites with characteristics imposing certain constraints, which can not be overcome or technically excluded for development eg ecological areas.
- Least Suitable (3): A level for sites with characteristics imposing constraints, which can be overcome, but by massive investment.
- Moderately Suitable (5): This is for factors with many criterion indicators. It denotes sites with constraints but where the investment is higher than in the suitable class.
- Suitable (6): Sites with characteristics, which can be overcome by moderate investment.
- Highly Suitable (7): Areas with characteristics imposing no significant constraints for development.

Criteria used in the analysis

Based on availability of data criteria used included slope, soils, drainage, accessibility to transportation network. At the time of the study, data on other criteria were not available. Weights were assigned since not all aspects have an equal importance in the evaluation. Therefore slope was given weight 7, drainage 9, soil type 5 and accessibility 3. The criteria maps as shown in figure 2 below;

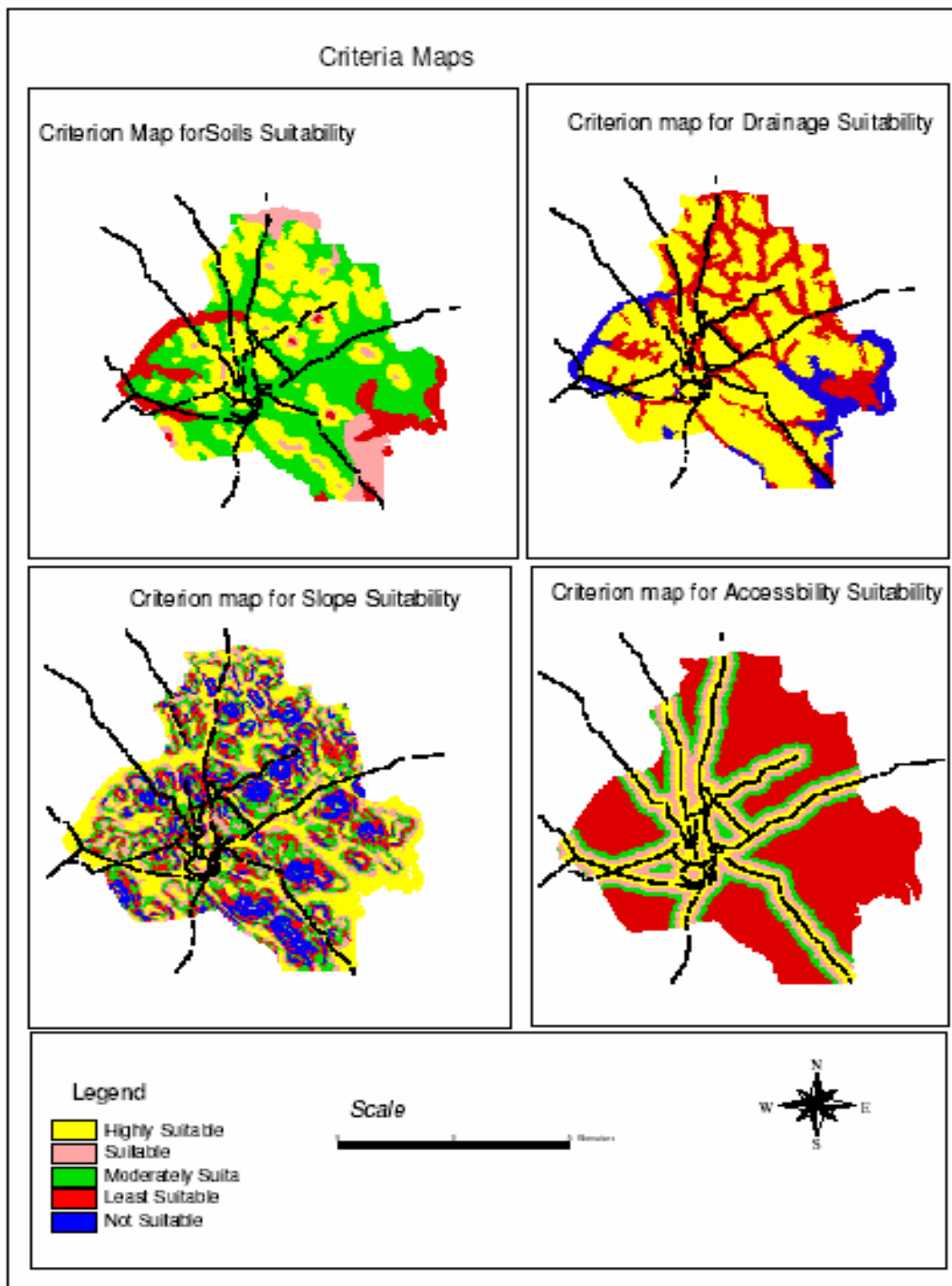


Figure 2 Criteria maps

In the GIS environment the weighted linear combination method was applied on all the criteria maps to generate a composite suitability map. Using this final composite suitability map analysis of suitability zones was undertaken. Areas not suitable and least suitable occupying 8,935 ha representing 50% of the total study area as shown in table 1.

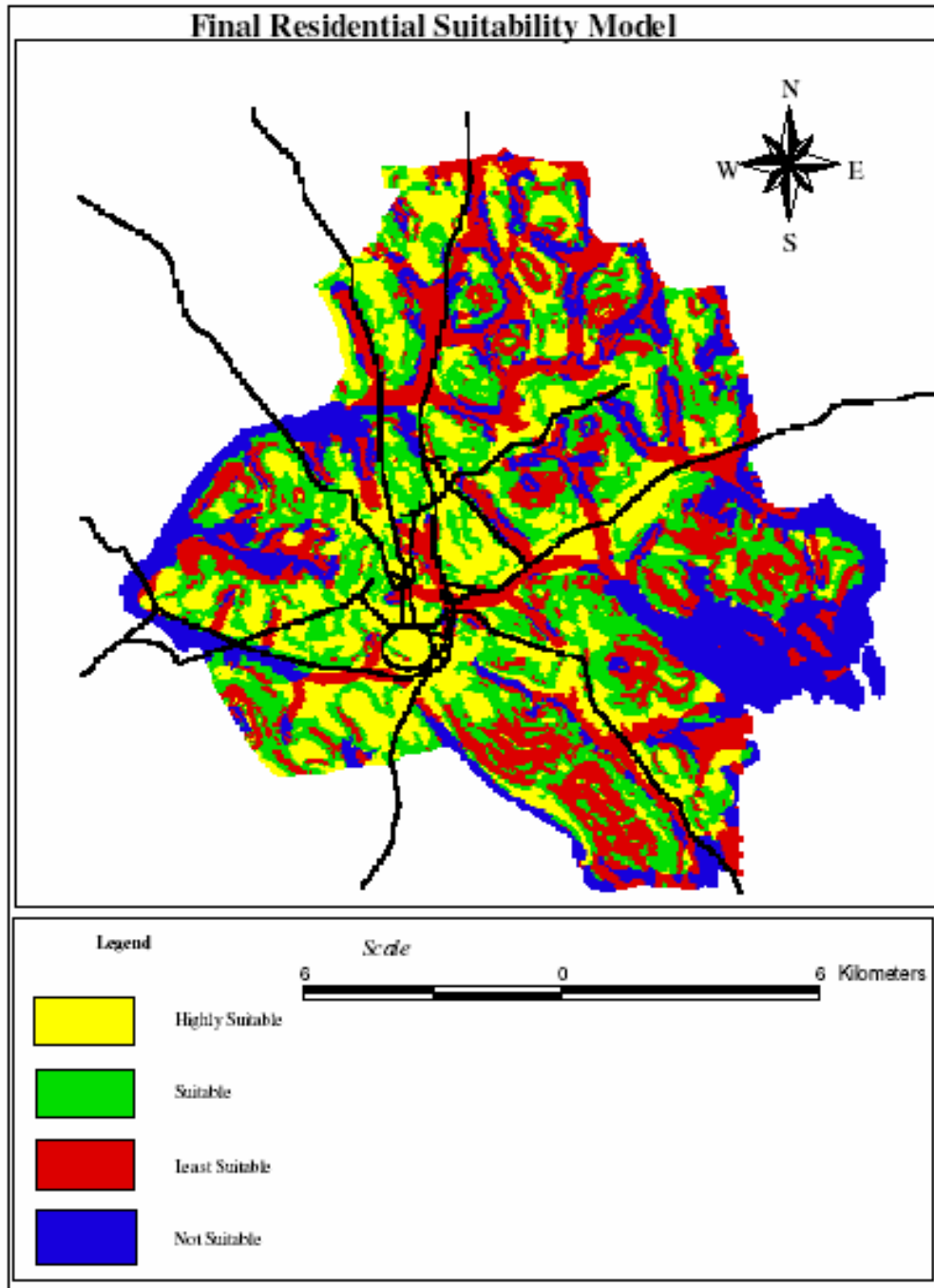


Figure 3 Composite Residential Suitability map

5. EVALUATION OF THE EXISTING, POTENTIAL AND PROPOSED RESIDENTIAL AREAS

An evaluation of the existing residential areas was done to determine the level of development in Kampala on suitable or unsuitable land. An overlay of the residential areas and the suitability map showed that most areas 62% are located on highly suitable and suitable land while 38% of the residential areas are located on either least suitable or not suitable land. Table 1 shows the area of residential development in relation to the suitability map and illustrated in figure 3. The existing land uses give an indication of the extent of available land for development. Potential land for development included land under agriculture, bush land and grassland basing on the 1996 land use map. While other land cover classes including wetlands, forests were excluded in evaluation of potential land for their ecological importance. The results of the analysis were used to estimate the future land available for development in Kampala as shown in table 2. Since the structure plan for 1994 was available, an evaluation of the proposed residential areas was done in relation to the suitability map. This evaluation is important to analyze the land use policies related to residential development.

Class	Existing Residential Areas		Potential Residential Area		Proposed Residential Areas	
	Area_Ha	%	Area_Ha	%	Area_Ha	%
Highly Suitable	1,564	31	1,438	18	953	16
Suitable	1,601	31	2,029	25	1,634	28
Least Suitable	1,369	27	2,750	34	1,989	34
Not Suitable	588	11	1,892	23	1,352	23
Total	5,122	100	8,109	100	5,928	100

Table 1 Tabulated results of existing, proposed and potential residential areas

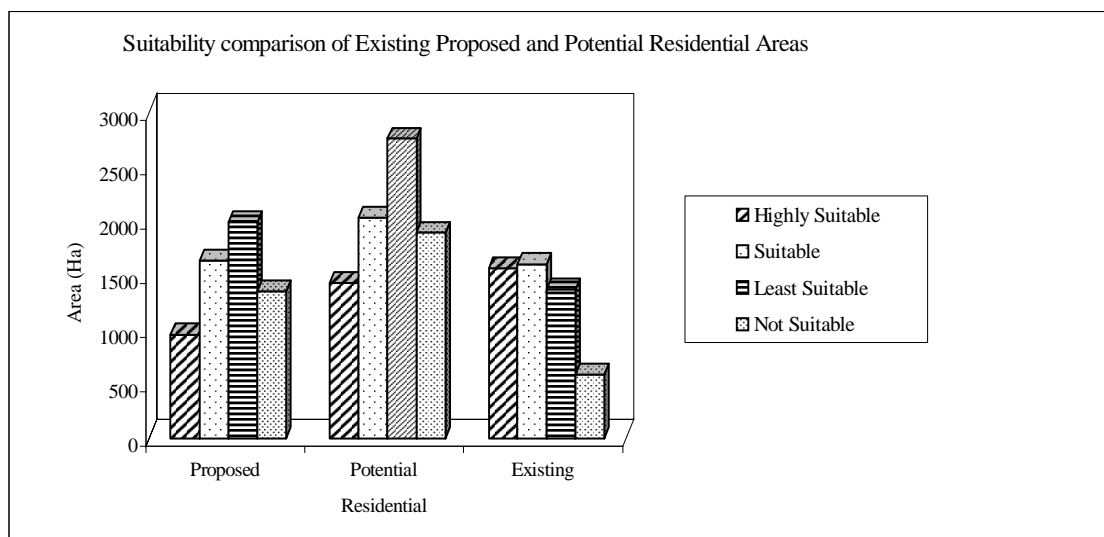


Chart 1 Suitability comparison of existing, proposed and potential residential areas

Evaluation of the proposed land use plan to analyze other land uses indicated that 25.8% of the least suitable or not suitable land is designated as environmental, (*see map 3.13*), while 54.21% is designated for residential use. 5% is for industrial use, 3.84% for commercial, 3.05% open green areas, 2.92% institutional, 0.84 for utility while 3.95% is reserved for future industrial use. 66.77% of the highly suitable or suitable land is designated for residential purposes.

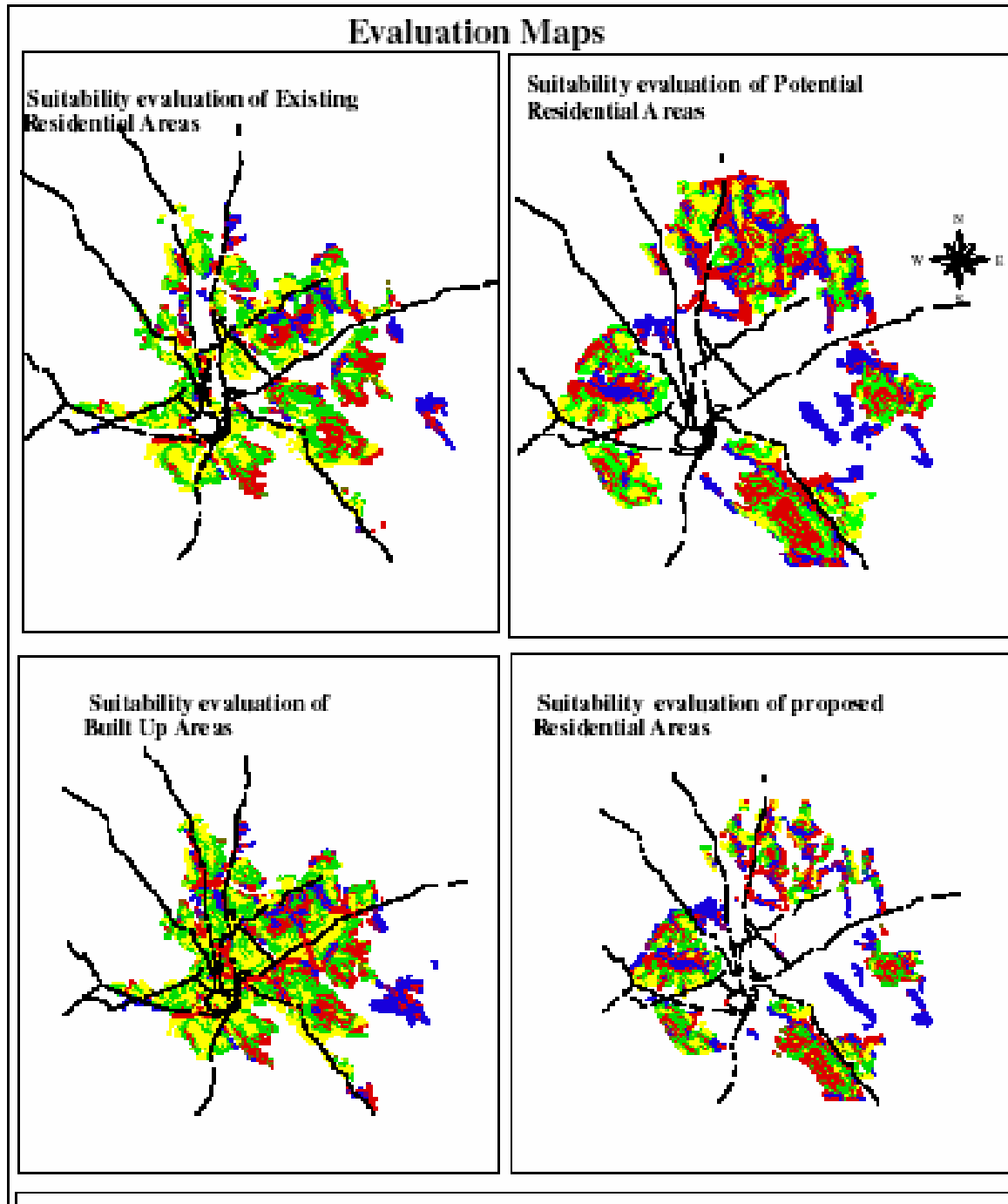


Figure 4 Evaluation maps

6. ESTIMATING LAND REQUIREMENTS

Land suitability maps provide information only about the supply of land at various levels of suitability for a use or different uses. Suitability maps can be used in allocation of land uses, but this needs to look at the relative demand of land for a use or various uses. Therefore, after establishing the qualitative characteristics of sites for residential development in Kampala, and where it can be conveniently placed, an estimate of land requirements through time was quantified. This was done on the basis of population projection reflecting the demand side in relation to land available for development. To achieve budgeting for land, areas, which are highly suitable and suitable were considered as suitable land for future development denoted as class **A**, while least suitable and not suitable are considered to be unsuitable land denoted as class **B**. Therefore available land is highly suitable + Suitable land of potential land. Area – population density in terms of number of Households (HH) per hectare was used together with the minimum plot size of 200 m² as set out in the structure plan of Kampala 1994. Land requirements through time were estimated up to year 2009 assuming the base year at 1999. This was done basing on two assumptions:

- In projecting population, the annual growth rate is assumed to remain at 4.76% for the next ten years.
- Household size is assumed to remain at 4.0 for the next ten years and that every plot, is occupied by one household.

On the basis of these assumptions, an estimate of future land requirements is quantified as described in table 3 for all the divisions in the district.

Division	Suitable land Available (Ha)	1999 - 2004			Year 2004 - 2009		
		New.HH	Available	RLand	New.HH	Available	RLand
Central	146	12,658	- 101	253	13,507	- 354	270
Nakawa	762	15,324	426	307	16,352	67	328
Makindye	905	20,984	494	420	22,400	74	448
Rubaga	752	20,121	358	403	21,481	155	430
Kawempe	771	17,803	423	356	19,001	- 45	380
Total	3,336	74,232	1,636	1,486	79,234	-103	1,586

Table 3 Estimated land requirements for future development

The estimates indicate that the central division, which is occupied mostly by the CBD, has limited highly suitable and suitable land for development. Where as this may hold, the figures do not reflect the actual situation. This is because land use data for 1996 classifies most of the division as built up areas. Generally the results indicate that there is not enough highly suitable and suitable land to accommodate future growth between 2004 -2009. This implies that land, which is least suitable and not suitable, is likely to be intensively built up if the development patterns continue as it is.

7. BEYOND SUITABILITY ANALYSIS

The analysis of land suitability is only indicative of land that would be available for development but does not provide a method for allocation of uses in the planning process. Land allocation is a process which depends on the demand and supply of land. Where as land suitability yields information on supply, demand needs to be assessed for final allocation. Important in allocation is the need to consider the competition between uses for similar pieces of land. Allocation models are in this context useful for integration into the GIS based approach for urban land use planning. Such allocation models would involve comparison between demand, supply and competition. Therefore rules would have to be formulated for the allocation to enable a systems allocation process.

8. SENSITIVITY ANALYSIS

The steps undertake in the design of the model as well as the analysis that follows have uncertainties in their application. It is necessary to look at these uncertainties by testing the sensitivity of the analysis results. A sensitivity analysis is useful not only to bring out the uncertainties but also offer an opportunity to determine the criteria and scores more realistically. Thus sensitivity was taken to be the response to the final suitability score with a change in criterion score or weight. Two approaches were used in testing sensitivity of the model including changes in weights and the scores on a parameter.

The first approach involved a change in a parameter or criterion which is accessibility to the transport network. This was considered bound to change when new roads are constructed in the district or existing roads are upgraded from gravel to asphalt roads. Therefore a road segment was added to the network used in the first model in the part of the district where accessibility is poor but the existing trunk road can be upgraded to link the eastern and northeastern parts of the district. The new accessibility map was included in the model and the results compared with the zones of the new suitability map to the zones of the first suitability map. The result indicated a change in the suitability levels but not as significant.

The second approach involved changes in weights of the different criteria. In many evaluation problems, scores and priorities are uncertain while evaluation methods involve different assumptions. Since the aim of the evaluation was to provide the decision-maker with a ranking of alternatives, the uncertainty is important in relation to its impact on the rankings. Weights can be changed either for all or a few criteria to reflect the different opinions and views of evaluators. This implies that there can be many possible alterations of the weights depending on the different evaluators including policy makers, technical team members and the public. In testing the model using this procedure, the weight of the slope factor was changed because of the nature of the study area's topography and the need to avoid very steep slope that are of environmental importance. The results indicate that all suitability levels changed in terms of area coverage with the least suitable changing by 6.43%. But compared to the effect of accessibility, change in weights came out as significant and sensitive to the model results as shown in figure 5 below. The importance of this sensitivity analysis points to

a need for a consensus on the weighting especially in a situation where there are many evaluators of different interests.

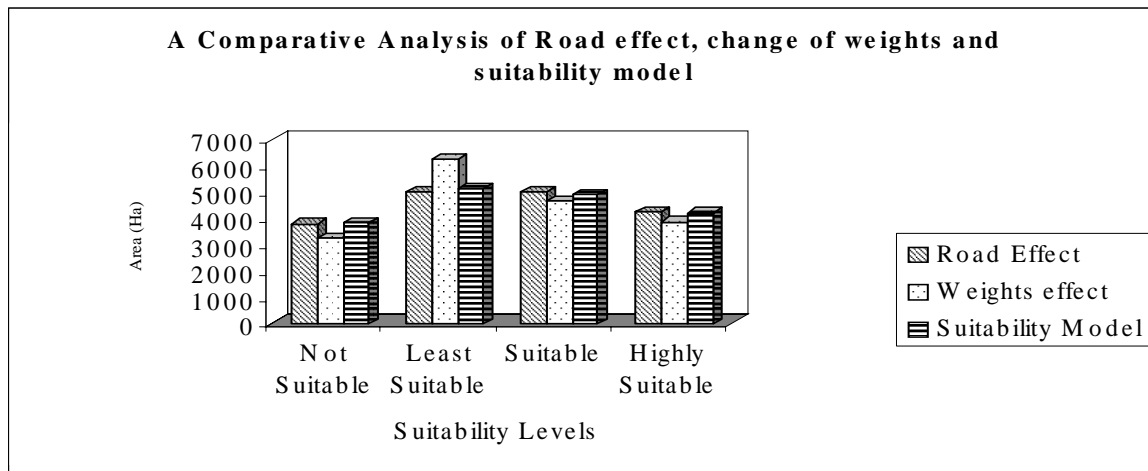


Figure A comparative analysis of road effect, change in weights and the suitability

9. LIMITATIONS OF THE GIS BASED MODEL

It is imperative for any methodological approach to highlight its limitations or areas in which questions can still be raised. The GIS based model presented in this paper has a number of limitations and these can be categorized under the methodological limitations and limitations related to criteria. Under the methodological limitations, the methods used in the evaluation are considered. The weighted summation technique has a limitation of the compensatory problem Lewis (1977). This means that a cell with a low score on one criterion may gain from other criteria on which it scores highly. For example permanently wet areas will have a low score on the drainage criterion while it scores highly on the slope criterion. Thus the result score after the weighted summation technique may be exaggerated. This could yield a score which places such an area in medium suitability level yet permanent wetness can be very disadvantageous to housing.

The second category of limitation is related to criteria used in the analysis. Considering the aspects of residential development, there are several factors including proximity to employment, social services, land availability and prices. These factors were not included in the design of the suitability model, yet they are important. This was due to non-availability of data on these factors. Additionally, areas that are suitable for agriculture are considered in suitability analysis for urban uses, such that they are kept out of the analysis. In this paper, this factor was not considered because of two reasons; the first one is that areas suitable for agriculture are in most cases generally suitable for residential uses. The second reason is that, in Kampala, there is urban agriculture usually done on spaces between houses, open land and undeveloped parts of plots. It is generally assumed that areas suitable for residential use are also suitable for agriculture thus it does not hinder urban agriculture since residents of the area engage in the activity.

10. CONCLUSIONS

In the context of application, the analysis indicates that housing has been developed in unsuitable areas especially low income housing. Likewise 23% of the proposed areas for housing were also unsuitable for development. This implies that development in Kampala is proceeding in a haphazard manner with potential impacts on environment as well as future costs of dealing with the problems of unguided spatial development. It is also observed that in any suitability analysis, identification of criteria, their scoring and weighting is important in obtaining usable results. The capabilities of GIS based models demonstrated in this study indicate that they can provide a powerful tool in planning of Kampala. But data availability is important in such GIS based models. The results indicate that improved results can be obtained if data are available. Additionally to effectively utilize GIS in suitability analysis, it needs to be integrated with other techniques in order to obtain acceptable results. GIS based models can yield suitability evaluations if criteria identification, their scoring and techniques for determining suitability are available and used. The significance of the model use indicates a shortfall in alternative and appropriate approaches for urban land use planning but the potential use of GIS based models can help greatly in closing the gap created by inappropriate approaches. It is therefore necessary that urban land use planning models based on GIS be developed for appropriate and better allocation of land for urban development. Planning in Kampala can be enhanced and spatial information properly integrated in the planning activities in the city of Kampala. This would improve the standards of planning and delivery of services to the residents of the district.

In general GIS based models offer a powerful tool for suitability analysis due its capability to process and analyze different layers of spatial data. The grid processing is suitable for this kind of analysis due its ease in modeling, by working with value maps. GIS models offer an opportunity to enhance planning in Kampala and provide the much required information in planning. The current manual methods for planning are unable to cope with the fast developments and growth of the city calling for more robust, accurate and timely procedure for planning. Coupled with high resolution satellite imagery which can provide up to date data, GIS based models of urban land use planning will become important methodologies in urban land use planning.

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APPENDIX 1

$$S_i = \frac{W_s r_s + W_d r_d + W_{ac} r_{ac}}{W_s + W_d + W_{ac}}$$

Figure 1 Weighted Linear Combination Method

Where S_i is the score for a pixel i

W is the weight of a factor

R is the score of a factor type

s , d and ac represent the factors soil condition, slope, drainage and accessibility to road network

BIOGRAPHICAL NOTES

Graduate in Geography (1996) at Makerere University, acquired Masters in GIS for Urban Management, ITC 1998, Masters in Regional development and Planning, Makerere University 2000, A PhD candidate in Makerere University. I have worked for Kampala City Council since 2003 and a part-time lecturer in Makerere University. Also worked on several projects in Uganda as GIS consultant. A member of EIS Africa Network and African Association of Remote Sensing of the Environment. I have published on Urban Housing, GIS as a communication tool and participated as a speaker in several conferences on GIS, Remote sensing and Urban Development. I was also a panelist on the recent cyber seminar on Health Implications of Urban Expansion hosted by PERN and CIESIN.

CONTACTS

Mr. Shuaib Lwasa
Department of Geography Makerere University
P.O Box 7062
Kampala
UGANDA
Tel. +256 41 531261
Fax + 256 41 542265
Email: lwasa_s@arts.mak.ac.ug