URBAN LANDUSE SUITABILITY ASSESSMENT USING GEOINFORMATION TECHNIQUES FOR KISUMU MUNICIPALITY IN KENYA

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ABSTRACT

The present land use situation in Kisumu municipality portrays a state of mixed and conflicting land uses. This has been attributed to improper land use allocation strategies, lack of appropriate spatial decision support systems coupled with ever competing land use needs.This study aimed at assessing the suitability of urban land use allocation in the municipality through generation of GIS-based land use suitability maps that will enhance land use allocation in the municipality. The process considers multiple land use objectives, determines the amount of land required by each together with their environmental requirements. This was in view of the fact that the practice of urban land use allocation has all along been begged on economic factors devoid of environmental concerns which play a vital role for sustainable urban development. Both spatial and non-spatial data was analysed systematically through criteria formulation, multi-criteria evaluation and multi-objective land allocation processes to generate the land use allocation model from which land use suitability maps were derived. The decision-making tools incorporated within the spatial decision support system (SDSS) modules of ArcGIS and IDRISI for Windows were used.

Keywords: *Suitability analysis, Decision support systems, Multi-criteria evaluation, Multi-objective land allocation.*

1. INTRODUCTION

Urban planning is the process of influencing, controlling or directing changes in the use of land overtime and space in an urban area (Healey, 1992). It therefore involves plan preparation and development control. To achieve this, a concept of sustainable development must be addressed to remedy social inequities and environmental damage, while maintaining a sound economic base (Harris, 2000). The sustainable development or best use of the land will be carried out by assigning the land use zones on the basis of capability, compatibility, use of proper technology and measures to protect environmental degradability (NEMA 2004). In the past planners and developers were increasingly ignoring the natural environment and causing damage to it (Arthur and Nalle, 1997). Planning was dominated by an emphasis on physical building and re-development which ignored social issues and environmental concerns. The aspiration now is to move towards more organic planning rather than the imposed approach of the 1950s to 1970s, but also a strengthened role for planning compared to the 1980s and 1990s (Nijkamp, 1990). Among the aims are to tackle urban decline, reduce the use of greenfield land, and limit urban sprawl and to improve the quality of design of the built environment (UN-Habitat, 2005).

Increased urbanization in Kisumu municipality has placed tremendous pressure on urban environment and thus there is need to improve land use planning strategies (NEMA, 2009). With an annual growth rate estimated at 2.8% and densities of 828 persons per sq. km, Kisumu municipality has one of the highest urban population densities in the country, bringing with it the associated complexities in urban planning (UN-Habitat, 2005). The municipality faces systematic challenges and threats among the urban community ranging from poor urban physical planning and infrastructure services, degraded urban environment, loss of biodiversity and therefore increased urban poverty. The Municipality's improper land use allocation, including land for industrial development, commercial, residential, social infrastructure, utilities, and transport points at the lack of land use zoning maps to guide the municipality's activities. According to UNEP, UN-Habitat, UNESCO and Kisumu County Council (2005) the existing land use plan date back to the 1970's and is outdated and was developed based on urban land use planning theories which

apparently focused on market forces of demand and supply chain. In the development of these plans environmental concerns were therefore not entrenched in the land use planning and zoning of the municipality.
In this study a land use allocation model was developed utilizing four dominant urban land uses namely industrial, residential, commercial and recreational/open areas. The model based on Multi-Objective Land Allocation procedures looks at the influence of both physical and environmental characteristics and solves for competing land use categories and allocates land to a particular land use with regard to its suitability criteria. From the model land use suitability maps are derived that will help re-affirm land use areas that are suitably allocated, re-allocate areas that are in conflict with environmental planning considerations, conserve fragile ecosystems and protect public open spaces for recreation. A suitability analysis is then carried out by comparing the current land use situation and the ideal/suitable land use allocations from the model through map algebra.

2. METHODOLOGY

2.1. Study Area

This research was carried out in Kisumu municipality. The municipality lies within Kisumu district in the western part of Kenya and covers an estimated area of 295.8 km² of which 35% is water. It is situated approximately 0° 00' to 0° 13' south of the Equator and 34° 35'to 34° 53'east of Greenwich. . It lies between Lake Victoria with an altitude of 1160m above sea level and the Nyando escarpment to the north. The area within the town boundary rises gradually from the lakeshore to the foot of the escarpment, a level of approximately 1259m. Kisumu municipality has sub-humid and semi-humid tropical climate with high mean temperatures ranging from 27.7°C to 30.8°C and rainfall that varies with altitude. The mean annual rainfall varies from 1100mm in the south to 1500mm in the north and potential evaporation of 2200mm and 1900mm respectively.

2.2. Data and Data Processing

The data collected for this study were scanned and georeferenced topographic maps at a scale of 1:50,000 covering Kisumu municipality, soil maps, geological formations , hydrological data including rivers, streams, wetlands, lakes and ponds, land cover maps, satellite imagery consisting of Aster satellite imagery and quickbird satellite imagery and infrastructure data including roads and railway network covering the municipality area. The raw data obtained was in different projections and different coordinate systems. This was transformed to WGS 1984 Universal Transverse Mercator (UTM) projection using zone 36 south for Kisumu municipality. Constraint and factor maps were generated from this data and criteria identified that formed the basis for multi-criteria analysis.

2.2.1. Evaluation criteria

Tables of evaluation criteria were generated based on topography, infrastructure (roads and railways), soils, geology and constraint maps. A summary of these criteria, indicators and classifications for industrial, residential, commercial and recreational land uses are given below in tables 1- 4 respectively. Measurement indicators as used in the tables refer to the factor of consideration used in modelling while the scale ranges are specific intervals for units of measurement.

Table 1. Evaluation criteria for Industrial land use

Criteria	**Measurement indicator**	**Scale range**	**Classification**
Topography	Slope	0% - 37%	0-6% - Very suitable 7 - 13% Suitable 14% and above - Not suitable
Railway infrastructure	Euclidean distance	200m – 10800m	Within 200m – Suitable Beyond 200m - Decreasing suitability
Road infrastructure	Euclidean distance	300m – 11400m	Within 300m - Suitable Beyond 300m - Decreasing suitability
Soils	Depth to bearing layer	500cm -1500cm	Below1m – weak stability 1m – 1.5m – Suitable stability Beyond 1.5m – Not suitable
Geology	Bearing strength	80 - 200 kn/m^2	Above 150 – stable Below 150 – unstable
Constraints/Buffers	Buffer distance	20m – 60m	Suitable beyond buffer zone

Table 2. Evaluation criteria for Residential land use

Criteria	**Measurement indicator**	**Scale range**	**Classification**
Topography	Slope	0% - 37%	0-3% - Not suitable 4-25% - Suitable 25% and above - Not suitable
Road infrastructure	Sound level - Euclidean distance	200m – 11400m	Within 200m - Not suitable Beyond 200m - Increasing suitability
Soils	Depth to bearing layer	500cm -1500cm	0.5 - 1m – Suitable 1m -1.2m – Moderately suitable Beyond 1.2m – Not suitable
Geology	Bearing strength	80 - 200 kn/m^2	Above 80 – stable, suitable Below 80 – Unstable, Not suitable
Constraints/Buffers	Buffer distance	20m – 60m	Suitable beyond buffer zone

Table 3. Evaluation criteria for Commercial land use

Criteria	**Measurement indicator**	**Scale range**	**Classification**
Topography	Slope	0% - 37%	0-10% - Very suitable 10 – 20% Suitable 20% and above – Not suitable
Road infrastructure	Sound level - Euclidean distance	200m – 11400m	Within 300m – Suitable Beyond 300m –Decreasing suitability
Soils	Depth to bearing layer	500cm -1500cm	0.5 – 1.0m – Suitable 1m – 1.5m – Moderately suitable Beyond 1.5m – Not suitable
Geology	Bearing strength	80 - 200 kn/m^2	Above 80 – stable, suitable Below 80 – Unstable, Not suitable
Constraints/Buffers	Buffer distance	20m – 60m	Suitable beyond buffer zone

Table 4. Evaluation criteria for Recreational land use

Criteria	**Measurement indicator**	**Scale range**	**Classification**
Topography	Slope	0% - 37%	0-25% - Not reserved 25% and above – Reserved
Land cover	Land use type	1 – 10 levels	Swamps, Forested Hills, Plantation, Open low shrubs, conservation areas – Suitable and reserved Others –Decreasing suitability
Soils	Depth to bearing layer	500cm -1500cm	0.5m – 1.5m - Unsuitable Beyond 1.5m - Increasing suitability
Constraints/Buffers	Buffer distance	20m – 60m	Within buffer zone- Reserved

2.2.2. Criteria weights and criteria standardization

Criteria weights were adopted from a study report on 'Kisumu City Environmental Profile on Sustainable Urban Mobility' by UNEP et al. (2005), whose values were based on the analytical hierarchy process. The assigned weights translated to approximately 10% for geological influence, 10% for environmental constraints, 20% for soils, 25% for infrastructure influence and 35% for topographical influence. These percentages were used as weights in the computation of the final appraisal matrix used in the weighted module of ArcGIS during multi-criteria evaluation process. However the criterion scores as shown in the criteria tables above were determined on different scales. These scores were transformed into one common dimensionless unit through standardization by quantitative ratio scale according to Ruiter and Sanders (1998) using the formula:

$$Standardizedscore_i = \frac{(Raw\ score_i - Min\ 'raw'\ score)}{(Max\ 'raw'\ score - Min\ 'raw'\ score)} \times 10 \qquad (1)$$

Where the standardized score is the new criterion score standardized, the raw score is the criterion score before standardization and the row maximum is the maximum criterion score by the same row while the row minimum is the minimum criterion score by the same row.

2.3. Data Analysis

2.3.1. Land Use suitability analysis

Suitability analysis is the process that involves use of criteria maps in combination with the standardized criteria weights and subjecting them to various processing modules in ArcGIS to obtain ranked land use suitability maps. Use is made of the model builder tool embedded in the ArcGIS software. The process involves sieve analysis and multi-criteria evaluation procedures that were used in combination. Reclassification was used to categorize the factor values to tally with the measurement scale and ease allocation of the score values in the same module. The entire process was structured in the model builder as shown in Figure 1 below. The final process in the multi-criteria analysis was the use of the weighted overlay module. Several raster maps were overlaid using a common measurement scale of values weighted according to their importance to create an integrated analysis. An evaluation scale was selected and the raster maps added. The cell values of each input raster were assigned values from the evaluation scale and assigned a percentage of influence based on the criteria weights. The cell values were multiplied by the raster's weight and added to produce the final output raster. For suitability modeling, higher values of the output raster indicate that a location is more suitable and lower values indicate less suitable regions. The results of this modeling are a set of ranked suitability maps for industrial, residential, commercial and recreational land use categories.

2.3.2. Land allocation using MOLA

Land use allocation corresponding to each land use objective was accomplished using the Multi-Objective Land Allocation (MOLA) analysis procedures in Idrisi Remote Sensing and GIS software. Since each objective competes for the same land within the municipality, to overcome this problem it is necessary to evaluate the objectives using a multi-objective decision making process. Based on the information from a set of suitability maps from the MCE process-one for each objective, the relative weights to assign to objectives, and the amount of area to be assigned to each, MOLA determines a compromise solution that attempts to maximize the suitability of lands for each objective given the weights assigned. For input, MOLA requires a set of ranked suitability maps for each objective.

The ranked suitability maps from the MCE procedure above were converted to the byte range (0-255) using the fuzzy module and standardized using the RANK command. For ranking the images in a multi-objective decision making process, descending ranks were used for primary images and ascending for the secondary ordering of ties. This helps maintain consistency with the logic of MOLA whereby areas best for a particular objective will be those that are most suitable for that objective and least suitable for others (Janssen 1992). Equal weights of 0.25 were given to the four objectives and areal requirements specified in terms of cells. During the iterative process, MOLA displays a variety of data concerning its progress and when the areal requirements are satisfied within the accepted tolerance level a final raster image showing the compromise solution was generated. For subsequent analysis, the final image was exported to ArcGIS where land use suitability maps were derived.

2.4. Landuse Suitability Assessment

The current land use allocation in the municipality was derived from a combination of quicbird satellite imagery and aster satellite imagery. Using the generated land use allocation model from the study and the current situation, a comparison of the two land use models was done through map algebra in ArcGIS software. This was to determine the variations in land use zones based on the derived land use allocation model and the current land use situation.

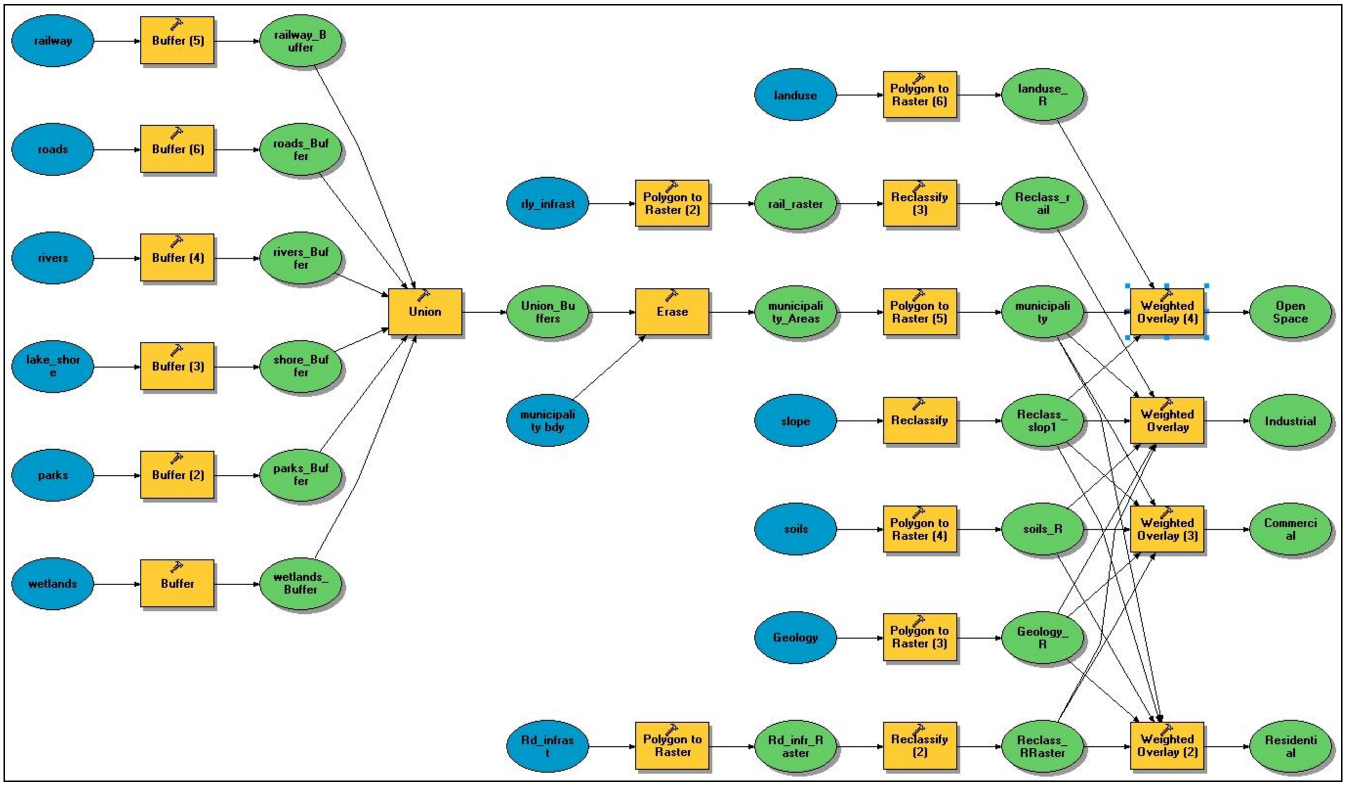

Figure 1. Built processes in the model builder

3. RESULTS AND DISCUSSION

3.1. Ranked Suitability Maps

The ranked suitability maps presented in Figures 2, 3, 4 and 5 below show levels of spatial suitability within the municipality for each single land use objective. These levels which result from the MCE process are a cell by cell evaluation of the raster by use of the appraisal matrix. Level 10 shows the best suitability for a location for the particular land use. The levels reduce gradually with declining suitability upto level 0 which is an indicator of total exclusion meaning that the location is not suitable at all for the given land use.

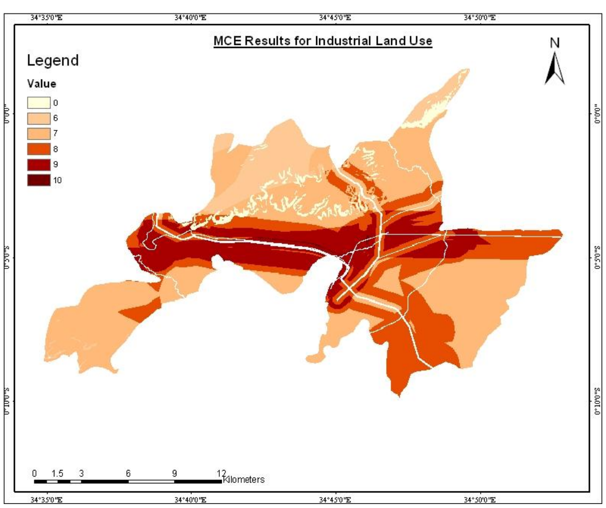

Figure 2. Map of ranked industrial land use

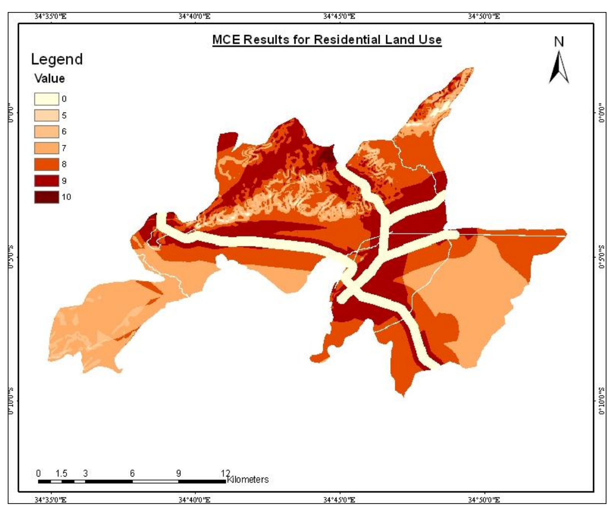

Figure 3. Map of ranked residential land use

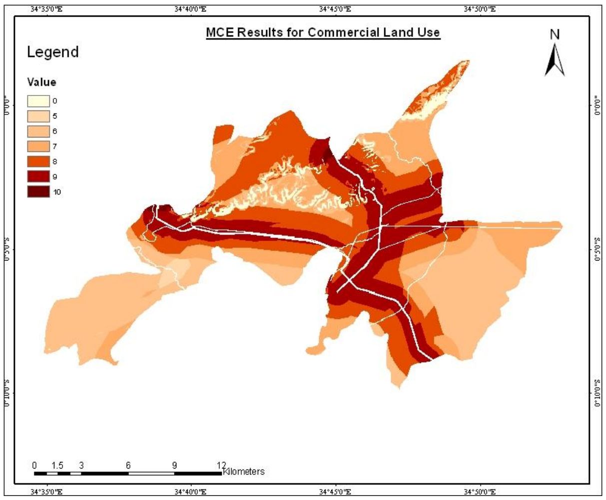

Figure 4. Map of ranked commercial land use

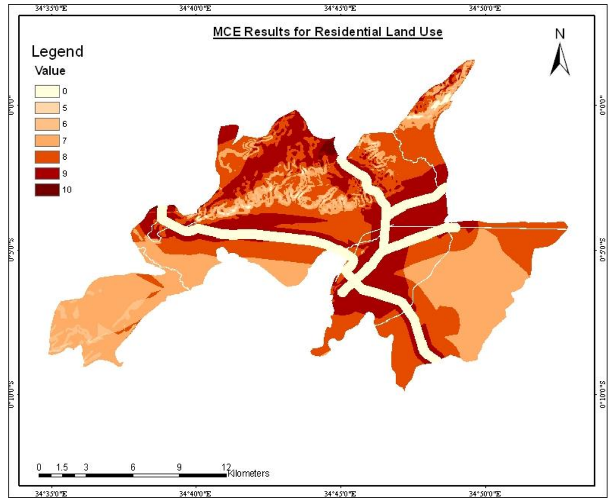

Figure 5. Map of ranked recreational land use

In Figure 2 above, slope and infrastructure especially the railway network play a greater role in ranking areas suitable for this land use objective. In the case of residential land use, slope, infrastructure and soil types had greater influence on the location of suitable areas. However favorable commercial land use locations seem to concentrate mainly along the road network as this had greater influence on the location of business enterprises. Recreational land use on the other hand rests with discriminated land from other land uses. Land use as a criterion had greater influence on the rankings for recreational land use. Conservation areas that were restricted from any other form of land development or areas already used for protective purposes like parks were highly rated for this particular land use.

3.2. The Land use Allocation model

The final land use allocation model resulting from the MOLA process indicating the four dominant land use types is shown in Figure 6 below.

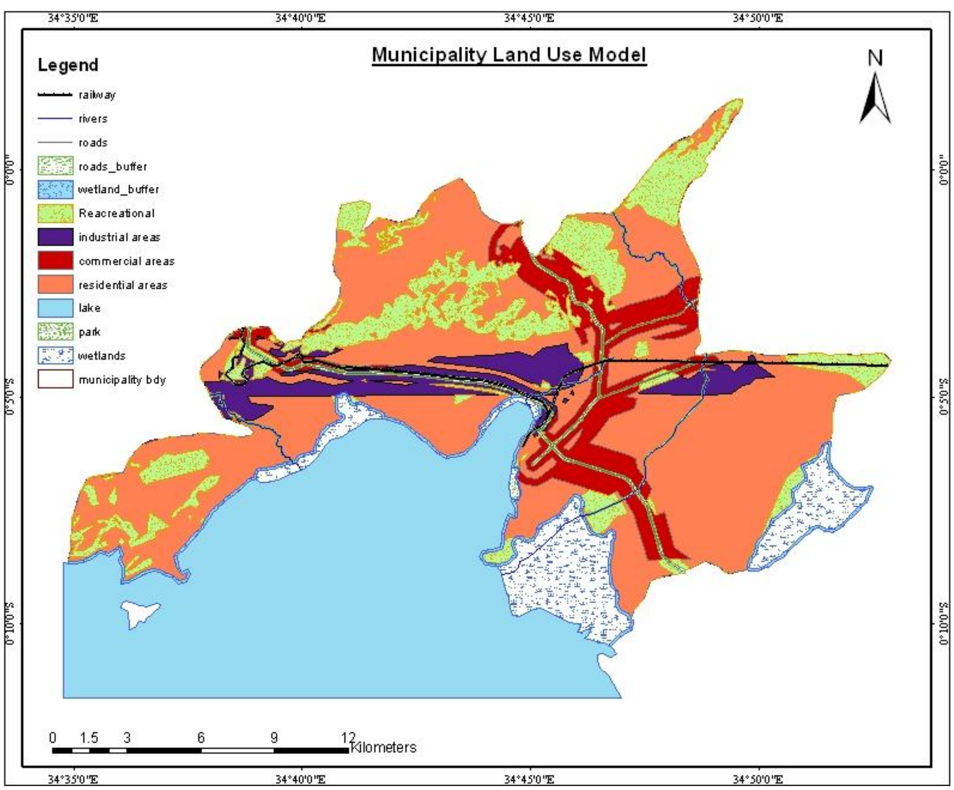

Figure 6. Land use allocation model

The Figure above shows the land use allocation model generated from the Multi-Objective Land Allocation process. The model comprises residential, commercial, industrial and recreational land uses. Embedded in the model to complete up the visual representation are other topographical features including the lake, wetland areas, rivers, parks, road and railway networks and open areas presented as buffer zones. The model shows a complete representation of the ideal land use allocation for Kisumu municipality.

3.3. Land Use Suitability Maps

Land use suitability maps shown in Figures 7, 8, 9 and 10 below were derived from the land use allocation model. These maps show the locations within the municipality where the four dominant land use types (residential, commercial, industrial and recreational) can be located with minimal conflict and minimal damage to the ecosystem when subjecting the land to such uses.

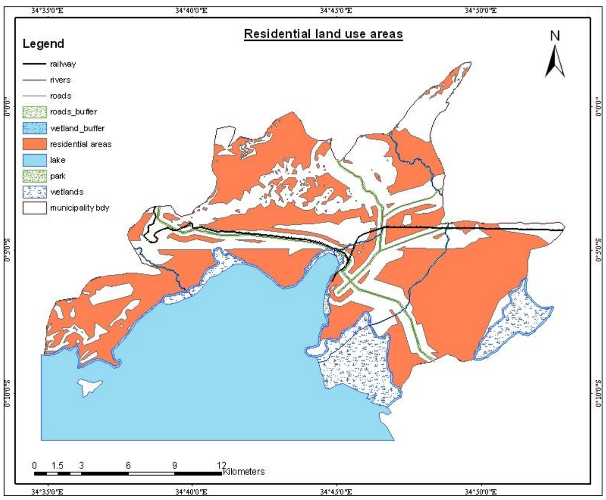

Figure 7. Map showing residential land use zones

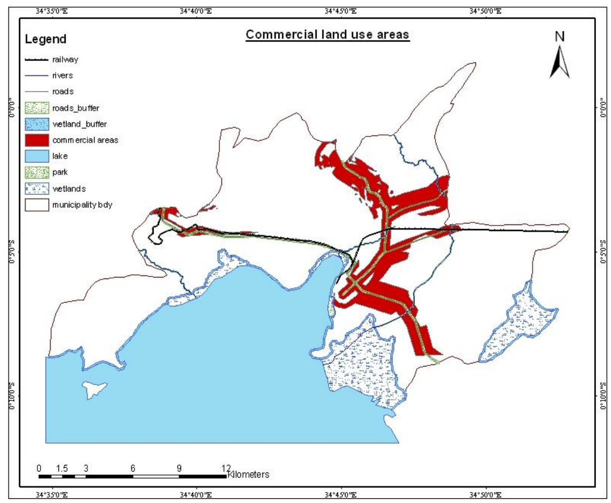

Figure 8. Map showing commercial land use zones

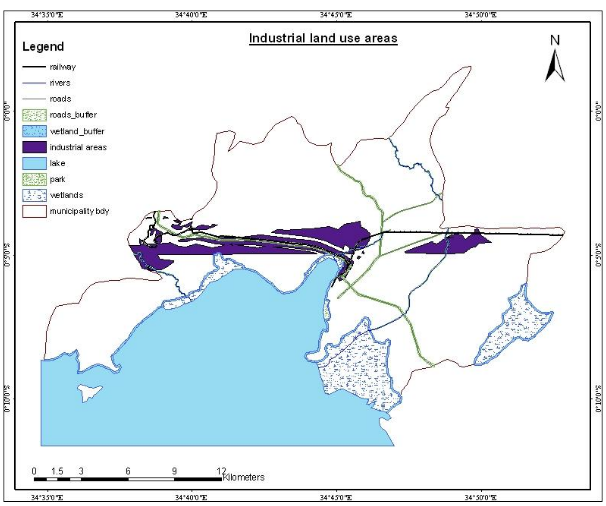

Figure 9. Map showing industrial land use zones

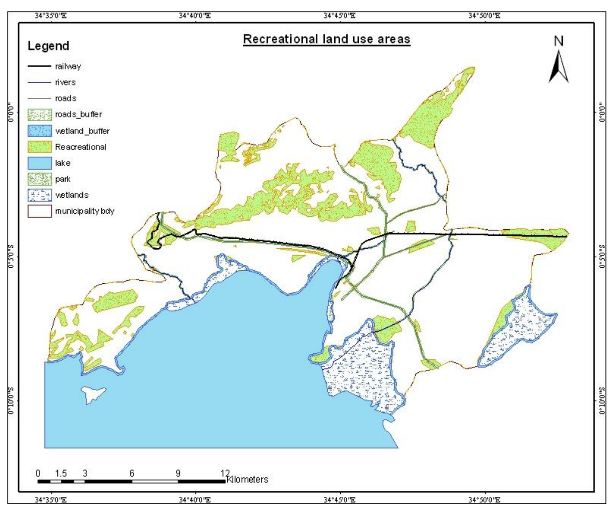

Figure 10. Map showing recreational land use zones

From Figure 7 above the total allocation for residential land use was about 51% (15140 ha) of the total municipality surface area and dominated most parts of the municipality. Figure 8 shows areas suitable for commercial land use planning depicted in brown colour. This constitutes about 10% or 3006 ha of the total municipality area. The commercial land use offer services that are used by the population of the town or urban area as a whole including the inhabitants of its hinterland and are concentrated primarily along the road networks. In Figure 9 is shown industrial land use zones shaded purple in colour. The percentage allocation amounts to about 7.5% (2160ha) of the total surface area within the municipality. It can be seen that most of the industrial land use distribution follows linearly along the railway transportation networks because of the inherent accessibility and reduced transport cost advantages. Figure 10 on the other hand shows zones suitable for recreational land use shaded in green and blue in colour. This comprises the categories of land classified as swamps, forested hills, open low shrubs, conservation areas, parks, lake and river riparian reserves, road and railway buffer zones and such other land found to be too steep for any form of development. The total allocation constitutes about 31.5% or 9271 ha of the total land surface area of the municipality.

3.4. Suitability Assessment

The quantitative analysis of land use in Kisumu municipality between the current situation vis-à-vis the derived land allocation is shown in tables 2 and 3 below.

Table 5. Current Land use allocations

Land use type	Area in hectares	Percentage area
Residential	23,440.9	79.3 %
Commercial	1,168.6	4.0 %
Industrial	189.6	0.6 %
Recreational	4,779.7	16.1 %

Table 6. Land use allocations from the model

Land use type	Area in hectares	Percentage area
Residential	15,140.0	51.2 %
Commercial	3006.6	10.2 %
Industrial	2160.3	7.3 %
Recreational	9271.9	31.3 %

Based on the above two tables a matrix of comparison shown in table 7 below was derived through map algebra that showed areas of commission and omission for each land use type. This was to determine the suitability of the current land use against the expected ideal situation.

Table 3: Matrix of land use comparison

Existing Land use in Ha

Model Land use	Residential	Commercial	Industrial	Recreational
Residential	x	369.2 *(2.4%)*	62.0 *(0.4%)*	677.1 *(4.5%)*
Commercial	2451.0 *(81.5%)*	x	0 *(0.0%)*	94.9 *(3.2%)*
Industrial	1855.6 *(85.7%)*	79.7 *(3.6%)*	x	185.0 *(8.5%)*
Recreational	3314.2 *(35.7%)*	25.5 *(0.3%)*	11.1 *(0.1%)*	X

The matrix table contains rows which represent the total land in hectares that should belong to the correct land use according to the model but is currently occupied by a different land use according to the ground situation. The columns on the other hand indicate the existing land use to which the given values belong. Residential land use which currently occupies 79.3% of the municipality land preoccupies most of the other land use types. 81% of commercial land has been converted to residential use leaving defined strip land for commercial enterprises along major transportation routes and a round the central business district. 80% of land meant for industrial use is also under residential use and about 36% of recreational being utilized for residential as well. This is basically attributed to the rapid urbanization in Kisumu, particularly in the last decade coupled with low investment in infrastructure and basic service expansion that has resulted into enormous pressure on the urban environment with an annual growth rate estimated at 2.8% and densities of 828 persons per square kilometer (UN-habitat, 2004).

Commercial land use which currently stands at 4% from the expected 10.2% is situated in most of the designated areas. Only 2.4% of residential land went to commercial land use according to the land use allocation model while 3.6% of industrial land has been converted to commercial uses. However a small percentage of 0.3% of the areas meant for recreational purposes have been taken up by commercial activities. Generally it can be said that commercial land use is well sustained though the overall allocation is small. Commercial land use needs to be increased in designated areas to avoid land use conflict especially with residential areas.

Industrial land use is the minimal land use within the municipality currently estimated at 0.6% of the total land area. This is due to under exploitation of the town's potentials in terms of industrial development. Most of the industries are service industries with minimal manufacturing going on. Major industries in Kisumu such as Kisumu cotton Mills, Kenya Matches, the Fish processing and Agro-based industries closed down while some like Kenya breweries scaled down their operations. The desired recreational areas in the municipality remain unattainable to create an environmentally conducive surrounding. Out of the expected 31.3% of municipal land meant for open space and/or recreation, only half of it (16.1%) is under this land use. This includes areas occupied by wetlands, shrubs and bushes, road reserves, lake reserves, parks, ponds etc. 4.5% of the expected residential areas are currently left as open land with 3% of what could have been under commercial land use also being left as open land. 8.5% of the industrial land use allocation still remains unutilized and therefore classified as open space.

4. CONCLUSIONS

The current land use situation in Kisumu municipality presents a cross utilization of land in terms of location and quantity. There is improper land use allocation, including land for industrial development, residential settlement, commercial and recreational uses. This situation is exacerbated by the limitations posed by the inadequate strength of the planning department in the Council contributed by lack of a viable land use allocation model that would have seen improprieties in land use allocation solved. The non-existence of this model has posed a danger in land use allocations where policy and rules do not take center stage and environmental factors do not suffice in the municipality's land use planning schemes.

It can therefore be concluded that Decision support systems that are currently available have the capability to carry out land use suitability analysis and allocation and can handle multiple land use objectives with multiple data types needed to facilitate urban land use planning. These systems when used immensely reduce the time spent on manual drafting. The systems also infuse Information Technology into the planning process and make the planner become abreast with Geographical Information systems.

The Land use suitability maps should be generated based on hard data and scientifically reasoned out criteria. This is possible through the use of urban land use allocation models that are developed based on empirical evidence of the physical and environmental characteristics of the area under consideration. These maps show clearly the appropriate spatial location of each land use and this is what urban planners need most to begin their planning process. By adopting the Land use allocation model and the derived land use suitability maps, corrective measures can be taken to allocate land in the municipality according to capability and compatibility. This is especially possible in the informal settlements which are not yet fully developed.

5. REFERENCES

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