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# Analysis of the Impact of New Road Infrastructure Development on Urban Sprawl and Modelling Using Remote Sensing-Thika Road superhighway and Eastern bypass of the Nairobi Metropolitan, Kenya)

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***Abstract:*** *The construction of new roads, continuous rise in population and rural urban migration, has given rise to urban sprawl in cities, and such has happened to the Nairobi Metropolitan. This urban sprawl follows areas where there is a good communication network, among other factors, leading to the conversion of the initial land uses to settlement in the outskirts of urban centers where land is available. The same scenario obtains in this area of interest. Remote Sensing techniques and geographic information systems (GIS), were used in this study to track various land use changes over a period of fourteen years. This was done using Landsat 7 ETM+ images for year 2000 and 2009 and Landsat 8 OLIS-TIRS for year 2016. Supervised classification with maximum likelihood classifier was used to quantify and model land use along the Eastern bypass and Thika superhighway of Nairobi metropolis in Kenya. Post classification analysis was used for change detection, field samples were conducted for accuracy assessment using Erdas imagine software. The results were maps that shows the past as well as the current land uses. IDRISI 17.0 was used in the prediction of the Land use expected for the year 2025. The results shows that the grassland and cropland gradually decline; giving way to settlement. It further shows that the settlement is not necessarily linear as could have been expected and this research will help policy makers to design a proper framework to enable proper and sustainable development.*

***Keywords:*** *Change Detection; Land Use and Land Cover Change; Urban sprawl; CBD*

## I. Introduction

The development of transport infrastructure and relevant road furniture has an in influence on the level of development along the route and areas in proximity to it. Construction of roads brings about accelerated development especially towards areas where land is still available and open for development. It was observed that road transport network development has significant total impact on land use patterns [1]. Transportation and land use are very closely interconnected as everything that happens to land use has transportation implications and every transportation action affects land use [2]. Urban growth pushes cities outwards from the Central business district (CBD) where they were initially located to stretch towards the periphery where there is land available and hence less concentration of settlement, giving rise to urban sprawl [3]. It has been observed that in human settlements, transportation is closely related to the structure and density of settlement and the use of land, and that transport route generates different land uses on areas in close proximity to the roads [4]. Good transport infrastructures attract investors, developers and many land speculators and this leads to conversion of land use mostly from agriculture and ranches to residential and industrial use.

The expansion of cities prompts upgrading of transportation lines to cater for the flux of the volume of traffic both human and material. A city’s growth in most cases results to the growth of other centers around it eventually merging to form a metropolis [5]. Nairobi metropolis has grown has a result of this, and has grown from Nairobi City to the adjacent counties of Machakos, Kiambu, and Kajiado. When the infrastructures are good people are able to use less time in travelling between various destinations. People tend to settle in areas abutting the roads so as to enjoy accessibility benefits. In the pursuit of improving the lives of its citizens, the Government of Kenya (GOK) has a commitment to the development of infrastructure and more so the road network. This has been achieved through the construction of bypasses, widening of roads and building the missing links. The roads under study are a component of these roads and are intended to channel traffic away from the city center. Eastern bypass is approximately 35 kilometers long while Thika superhighway is 40 kilometers long.

There are several studies which have been done in trying to understand the link between development and road infrastructure. In a study in Iowa and Wisconsin it was realized that highways are key tool for development and have been integrated as development policy tools [6] [7]. A similar study in California covering four major metropolitan regions of San Francisco Bay area covering nine counties, Sacramento covering six counties, Los Angeles-Long Bay covering three counties and one county in San Diego over a period spanning three decades in a transportation corridor, came to the same conclusion that highway development greatly influences the location of commercial, residential and industrial facilities and hence influencing direction of growth.

Highway improvements and the consequent user benefits can create conditions conducive to increased commercial activity in the area of the project. Transportation investments can stimulate business growth via expansion of existing businesses or attraction of new businesses in the corridor, reduction of costs in moving goods and materials and increased inter-regional traffic. There have been numerous studies on the effects of transportation improvements on real estate values. The expansion of cities prompts upgrading of transportation lines to cater for the flux of the volume of traffic both human and material. A city's growth in most cases results to the growth of other centres around it, eventually merging to form a metropolis.

Nairobi metropolis has grown has a result of this and has grown to the adjacent counties of Machakos, Kiambu, and Kajiado. When the infrastructure are good and they support less travel time, they influence the expansion of a town or city in that direction as people tend to settle in areas proximity to the roads to enjoy accessibility benefits. According to a research by real estate firms; the area around Thika superhighway which enjoys good accessibility attracts high returns several times over as areas in Kitengela, Mlolongo and Rongai due to heavy traffic congestion in those areas. In the pursuit of improving the lives of its citizens, the Government of Kenya (GOK) has a commitment to develop of infrastructure and specifically, the road network. This has been achieved through the construction of bypasses, widening of roads and building the missing links. The roads under study are a component of these roads and are intended to channel traffic away from the city centre. The continuous demand for people to settle in these areas and the presence of traffic snarl ups during peak hours have prompted the conducting of this research.

Other highway critics have also argued that constructing new roads or expansion of the existing ones by widening it to improve accessibility or relieve traffic congestion is a futile exercise especially in the long run; as improved roads spur additional travel or divert trips from adjacent alternative roads or parallel routes, quickly returning a facility to its original congested condition in the long run [8]. In the long term, structural changes can be expected. Notably, people and firms locate to exploit the accessibility benefits created when freeways are upgraded. The consequences would be various uses; shopping malls, petrol stations, fast food restaurants, warehouse would cluster or align themselves around interchanges, along road frontage and along connecting arterials [9]. This phenomenon can be observed in the roads under study especially peak hours.

A close look at Thika superhighway will reveal the coming up of malls for example Thika Road Mall (TRM) at Roysambu, Mountain Mall at Roasters area, the Garden City at formerly Kenya Breweries grounds, uni-city at Kenyatta university, Juja mall and Spurrs mall. Along Eastern bypass there are many warehouses and eateries lining the route and others coming up. However, the local authorities have not kept pace with this fast growth. This may be a result of limited resources or having no proper and current spatial growth situation, hence the reason for this study to give the correct situation to aid in planning.

The main objective of this study is to determine the effect of the construction of the roads and bypasses on land use with special reference to the study area corridor by establishing what has happened in the past and model the projected future changes with the aim of making recommendations on appropriate land use management framework. Land uses will be quantified pre and post the construction period and this previous and current status will be used to model the expected future changes. This is to help the stakeholders to come up with relevant policies to guide the relevant planning of service provision and development approval. The study has been achieved by using change detection process of identifying differences in the state of a phenomenon by using multi temporal datasets. With advance in computer capability and technology remote sensing (RS) and geographic information systems (GIS) have become effective tools for detecting phenomena change. GIS is a useful tool for measuring the change between different epochs and with the ability to incorporate varied sources such as classified images, topographical maps, and hydrological of data into a change detection platform. Also, GIS can analyze the changing trend by modeling the available past data and using statistical and analytical functions to come up with the likely future trends; this has been conducted using supervised classification for the Landsat satellite imagery of 2002, 2009 and 2016. Modelling has been done using the images of 2002 and 2009 to predict 2016 and the classified images of 2016 used as a validation dataset. Further, the data set of 2009 and 2016 is used with the modelling validating parameters obtained incorporated to predict the projected land uses in 2025. This will help in having proper intervention measures to assist in development. The various land use transition areas are determined so that proper and effective are designed to enable sustainable development and timely social amenities provided.

## II. Study Area

The area of study falls in Kenya, under Nairobi and Kiambu counties, traversed by the roads under study. It covers a buffer belt of five kilometres from the centerline of these roads which intersects and crosses at Ruiru. It runs from $1^{0}00^{'}$ to $1^{0}20^{'}$ South and $36^{0}50^{'}$to $37^{0}05^{'}$ East.

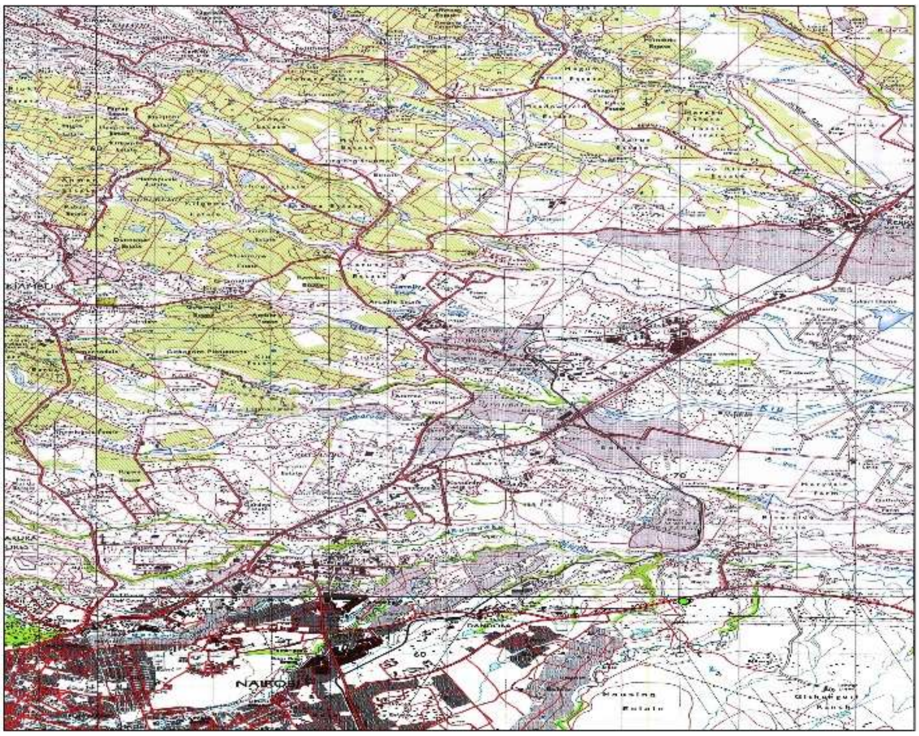

**Figure1.** Map of part of study area. (Source: Survey of Kenya

## III. Methodology

Erdas imagine software was used for classification and Idriss Kilimanjaro used for modelling. Supervised classification approach was adopted for the purpose of this research, that is, to compare classification a posteriori, for the reason that the available data for use were acquired in different seasons by different sensors. The research was carried out as depicted by the flow chart in figure 2.

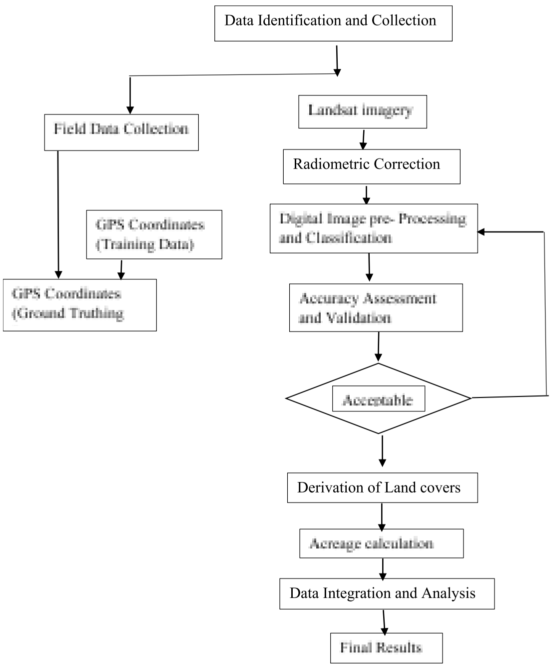


**Figure 2:** Flow diagram

The research process comprised image pre-processing, the design of classification scheme, image classification, accuracy assessment, and analysis of the land use/cover changes and dynamics of urban growth. A total of five land use/cover classes were derived with some of the factors considered during the design of classification scheme being: the dominant land use/cover categories within the area of interest, the need to consistently discriminate land use/cover classes irrespective of the seasonal differences and the need to clearly distinguish and conveniently discern and map the changes.

Information extraction on land use land cover was done using supervised classification. In supervised classification, spectral signatures were developed from specified locations in the image, given the generic name 'training sites' and were user defined. Generally a vector layer was digitized over the raster scene creating training samples. The vector layer comprises various polygons overlaying different land use types. The areas with known land cover were digitized, and then the image processing software computed the spectral signatures that were used to classify all the pixels in the scene to represent the land cover types. The training areas were established by viewing portions of full scene in an enlarged format on an interactive color display device. Training sites were developed for the five land use/ land cover classes based on Google earth, familiarity with the study area and ground sample points.

The land use categories of interest in this study were settlement, wetland, cropland, open grassland, and forest. Multiple polygons were created for each land use category to help ensure that the classifier had sufficient information to create the spectral signatures. The more polygons accurately delineated the more the spectral signatures and the better for the results obtained. Settlement consists of buildings, roads, built up areas, parking, run way and bare open surface. Wetland includes, rivers, natural and man-made dams and bonds. Cropland includes fruit trees, bananas, coffee, maize, beans and any food trees. Open grasslands includes savanna grass and shrubs, grass and any green open areas. And forest consists of natural or many made planted mixture of trees. The classification results were recorded in a confusion matrix with category codes representing the various classes.

Accuracy assessment is an important part of classified supervision process as it provides the means of assessing the quality of the results obtained, that is, how well or how faithfully the classified pixels represent the desired information classes and categorize and relate to the actual features on the ground. This helps users to evaluate whether the accuracy of the map suits their objectives or not and make an informed choice. Accuracy assessment was conducted for the 2002, 2009 and 2016 land use/cover maps using Google earth, topographical maps, ground point and local knowledge. Ground truthing points collected using a handheld GPS were used to assess the accuracy of classified image for the year 2016. In the other scenes for years 2002 and 2009, points were picked from the original image where land cover could be easily interpreted using false and natural color composites together with previous topographical maps. These points were later used to assess the accuracy of the classified images.

The classified images together with the digitized layers were integrated into a geodatabase and manipulated in Arc map 10.2.1. The suite of GIS capabilities allowed the post-classification comparisons, facilitating qualitative assessment of the factors influencing urban expansion and enabled modeling of future urban trends using Markov chains. The transitions between 2002 and 2016 were modeled using Land Change Modeler to produce a predicted map of 2016. The 2002 images were used together with the 2009 images to come up with the 2016 predicted images. In an attempt to validate the model, the predicted map obtained was compared to the map of the same year 2016 classified as derived from the satellite images. It was crucial to validate the model so that it is easy to determine the validity of the map that is being used to predict or model the future situation. Once validated, the model was used with the same prediction time difference using the 2009 and 2016 land use land cover maps to predict the land use land cover map for 2025. LCM embedded in IDRISI 17.0 was used in the prediction of the LULC map in 2025 as follows: In the change analysis step, the changes between 2002 and 2016 were assessed. These changes do represent transitions from one class to another, which were important in identification of the dominant transitions to urban thus enabling us to target them for modeling. Transition potential modeling and driving forces determination step was responsible for determining the location of the change and results in a number of transition potential maps equal to the significant transitions to urban, considered in the change analysis step. These transition potential maps represent the suitability of a pixel to turn into urban one in each transition, based on a group of factors - driving forces - that are used to model the historical change process. The driving force in this case was taken as proximity to roads. In the change prediction step, LCM used the change rates determined from the first step (change analysis), as well as the transition potential maps produced from the second step (transition potential modeling), to predict a future scenario for 2016. This step was responsible for determining the quantity of change to urban areas in each transition in 2016. There are two basic types of predictions: hard and soft predictions. Hard prediction yields a projected map of 2016, where each pixel is assigned one land cover class; the class that it is most likely to become. Soft prediction, however, is different, as it produces a vulnerability map in which each pixel is assigned a value from 0.0 to 1.0, indicating the probability of the pixel to become urban in 2016.

The validation process aimed to determine the quality of 2016's predicted map relative to 2016's LULC map (the map of what exists in reality). Taking the classified image of 2016 as reference, sample points were digitized and assigned classification codes for comparison with the classification codes generated based on the predicted results.

## IV. Results And Discussion

By examining the classified maps a trend was revealed of how the classes change over the period. Visually looking at the 2002 map and 2009 map, it can be deduced that forest land rapidly diminishes and gives way to cropland and settlement. This was attributed to the fact that the super-highway and the by-pass open up the inaccessible areas, allowing more settlement in the form of economic activities, and these in turn lead to urbanization as can be seen from the maps.

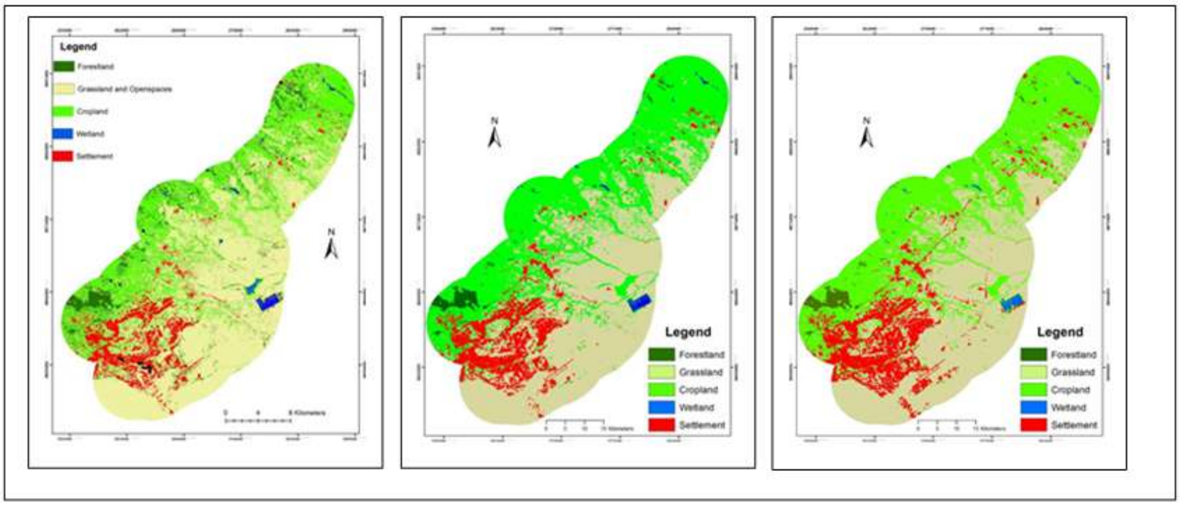


**Figure 3:** Land Use Land Cover Maps – 2002, 2009 and 2016

The accuracy assessment was conducted for all images under consideration namely and all had an overall accuracy greater than 75%. This implied that the classification results were in agreement with the ground truth data and thus implied that we could have confidence in subsequent processing using results from the classification. The results of 2016 have been provided here for illustration.

**Table 1:** Accuracy Assessment for the year 2016

| | | **Ground Classes** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Forestland | Grassland | Cropland | Wetland | Settlement | Total | **User Accuracy** |
| **Map Classes** | Forestland | 55 | 2 | 4 | 1 | 1 | 63 | 87.30% |
| | Open Land | 4 | 61 | 6 | 2 | 1 | 74 | 95.31% |
| | Cropland | 5 | 3 | 58 | 3 | 2 | 71 | 81.69% |
| | Wetland | 2 | 2 | 1 | 26 | 2 | 33 | 78.79% |
| | Settlement | 1 | 1 | 2 | 3 | 22 | 29 | 75.86% |
| | Total | 67 | 69 | 71 | 35 | 28 | 270 | |
| | **Producer Accuracy** | 82.09% | 88.41% | 81.69% | 74.29% | 78.57% | | |

Post-classification change detection revealed in 2002, forest land was covering 2396.43 hectares but reduced to 1901.6 in 2009, a cumulative decrease of about 494.83 hectares representing a decrease of 20.65 per cent. We can also deduce that the area under settlement was 3607.56 hectares in the year 2002 and changed to 4641.45 hectares increasing by 1033.89 hectares which is an increase of 28.66 per cent. We can also deduce that the area under wetland was 3311.91 hectares in the year 2002 and changed to 3235.42 hectares which is a decrease of 2.31 per cent equivalent to 76.49 hectares. Furthermore, the results show that in 2009, forest land was covering 1901.6 hectares while it increased to 1978.38 hectares in 2016 giving a rise of 76.78 hectares equivalent to 4.04 per cent. We can also deduce that the area under settlement was 4641.45 hectares in the year 2009 increasing by 4899 hectares to 9540.45 hectares equivalent to 105.55 per cent. It can be reported that forestland and wetland are not being affected so much possibly due to environmental awareness and intervention measures by relevant bodies. Table 2 summarizes the areas as analyzed in change detection.

**Table 2:** Analysis of Land Use Areas

| | 2002 | 2009 | 2016 |
|---|---|---|---|
| **Land Use** | **Area (ha)** | **Area (ha)** | **Area (ha)** |
| Forestland | 2396.43 | 1901.6 | 1978.38 |
| Grassland | 43375.4 | 42583.9 | 32606.9 |
| Cropland | 32109 | 32167.5 | 29252.6 |
| Wetland | 3311.91 | 3235.42 | 3251.62 |
| Settlement | 3607.56 | 4641.45 | 9540.45 |

Analysis of the overall changes from the year 2002 to the year 2016 showed the transition that has taken place. For example it shows that in 2002, forest land was covering 2396.43 hectares while it reduced to 1978.38 hectares in 2016 giving a reduction of 418.05 hectares equivalent to 17.44 per cent. We can also deduce that the area under settlement was 3607.56 hectares in the year 2002 increasing by 4632.89 hectares to 9240.45 hectares equivalent to 156.41 per cent. Grassland, therefore, is the class that has changed so much giving way to settlement. This can be demonstrated graphically as per figure 4.

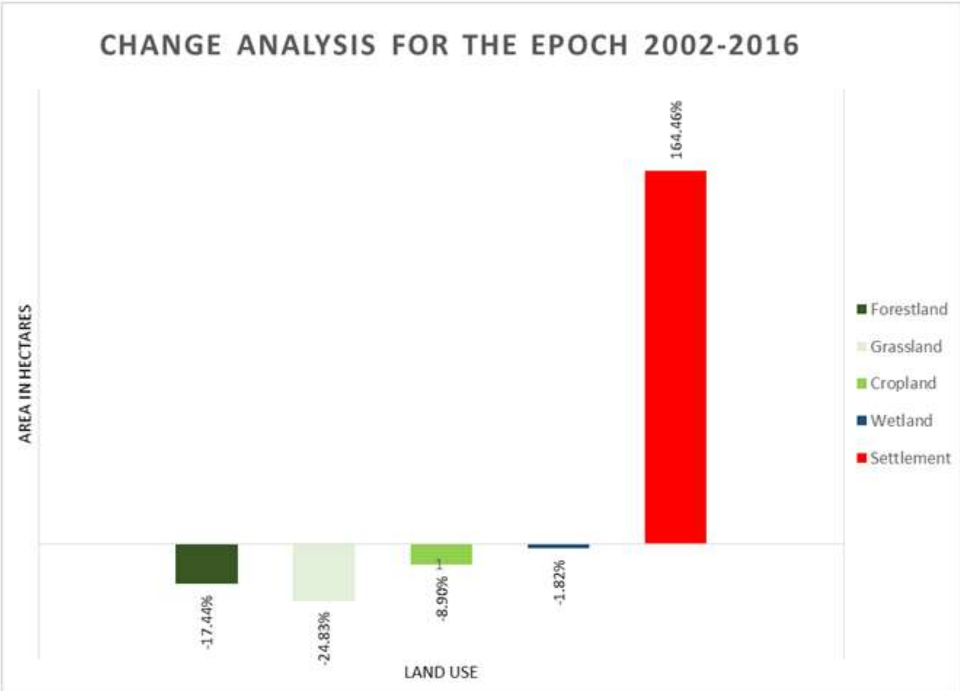


**Figure 4:** Land Use Change Analysis for epoch 2002 - 2016

Markov chain analysis in Idrisi Selva software was used to compute the transition probability matrices for the epoch 2002 – 2009. The transition probability matrix indicates the probability of transition between the various land use classes into other classes. To predict the transition probability matrix of land use change for 2016, land use maps for 2002 and 2009 were used in the modeling. Table below shows results of the transition probability matrix.

**Table 3:** Transition Probability Matrix

| | | 2009 | | | | |
|---|---|---|---|---|---|---|
| | | Forestland | Settlement | Wetland | Cropland | Grassland |
| **2002** | Forestland | 0.5011 | 0.4451 | 0.0088 | 0.0205 | 0.0245 |
| | Settlement | 0.2082 | 0.677 | 0.0039 | 0.0996 | 0.0112 |
| | Wetland | 0.115 | 0.5803 | 0.2485 | 0.0489 | 0.0073 |
| | Cropland | 0.0346 | 0.5612 | 0.0029 | 0.3809 | 0.0204 |
| | Grassland | 0.5107 | 0.1742 | 0.0049 | 0.0404 | 0.2697 |

The transition probabilities matrix records the probability that each land cover category will change to every other category. This matrix is the result of cross tabulation of the two images adjusted by the proportional error. As can be seen from the matrix, the probability of pixels, in 2002, transitioning to settlement in 2009 is significantly higher than the probability of transition to other classes and as such we can feel confident that there will be a further urbanization in the 7 year epoch.

In addition to the transition probability matrix, the Markovian module also generates a transition areas matrix. This transition areas matrix records the number of pixels that are expected to change from each land cover type to each other land cover type over the next time period (2002 – 2009). This matrix is produced by multiplication of each column in the transition probability matrix by the number of cells of corresponding land use in the later images. In both of these files, the rows represent the older land cover categories and the columns represent the newer categories.

**Table 4:** Transition Areas Matrix

| | | **2009** | | | | |
|---|---|---|---|---|---|---|
| | | Forestland | Settlement | Wetland | Cropland | Grassland |
| **2002** | Forestland | 688255 | 611411 | 12115 | 28109 | 33611 |
| | Settlement | 1023979 | 3328820 | 19250 | 489810 | 55298 |
| | Wetland | 6959 | 35113 | 15040 | 2957 | 444 |
| | Cropland | 14522 | 235723 | 1226 | 159966 | 8562 |
| | Grassland | 48368 | 16501 | 466 | 3826 | 25539 |

As can be seen from the transition areas matrix, the number of pixels (and hence the area) expected to transition from other classes to urban class is the highest relative to the transition to other classes. This further re-enforces the notion that we shall see a further urbanization trend moving forward. Moreover, Markov also outputs a set of conditional probability images. Taken from the transition probability matrix, the images report the probability that each land cover type would be found at each location, in the next future phase, as a projection from the later of the two land cover images. These can be used as direct input for predicting the land use for the specified period, 2016. Examples of conditional probability images for transition to settlement, grassland and forestland are as shown in figure 5.

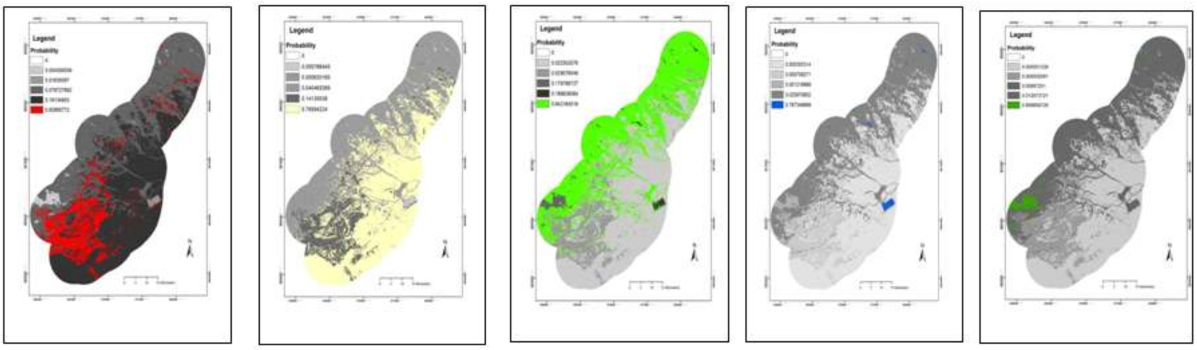

**Figure 5:** Conditional Probability Images

A raster data model is applied in GIS to model continuous data in space. The model partitions the study area into grid cells or pixels, with each grid cell being filled with the measured attribute values in a matrix, and cell values are written in rows and columns. CA-Markov models represent an urban area in form of a lattice of cells, each of which exists in one of a finite set of states. The progression of time is modeled as a series of discrete steps with future patterns determined by transition rules (as developed from Markovian analysis), which specify the behavior of cells over time.

As an example, a cell transits from undeveloped urban area (other land use type) to developed urban area, based on a set of conditions at each cell and its neighboring cells at each time step. The pixel value of the raster data model in classified images and the simulated images from CA-Markov represents each land use type with the cell size determining the smallest unit or object that can be identified. Consistent with the above theory, CA_Markov in Land Change Modeler (IDRISI) to predict the land use in 2016 was implemented. This was done so as to be able to conduct accuracy assessment/validation for the prediction model. In this case, the prediction was done by comparing the classified image of 2016 as the reference against the predicted land use class for 2016. This was achieved through the usual confusion matrix and the results of the same are presented in the figure 6.

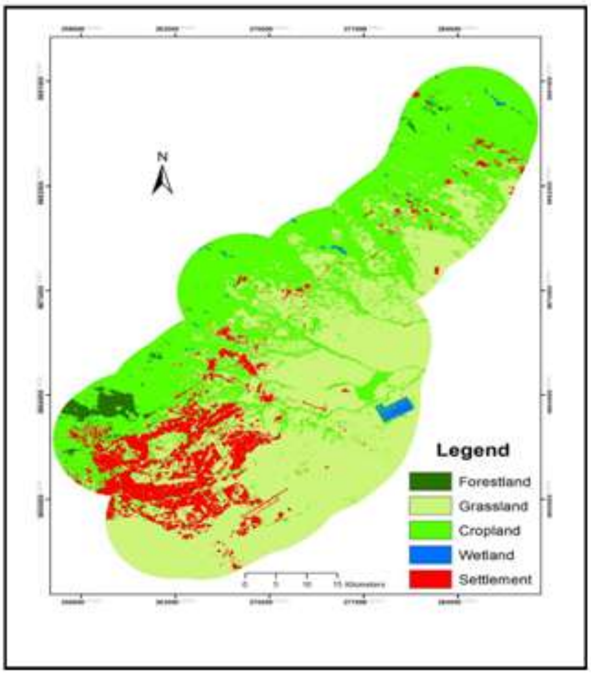


**Figure 6:** Predicted Image for 2016

The accuracy assessment results comparing the classified image of 2016 against the predicted classified image of the same year are presented in the table above. The overall accuracy was determined to be 67.23% which was found to be within acceptable limits. This gave confidence in the prediction model and which was subsequently adopted to predict the classified image of 2025. Markov was used to derive the transition probability matrix, the transition probability areas and the set of conditional probability images which were then incorporated into Markov CA to predict the classified image of 2025. The predicted image is as shown in figure7.

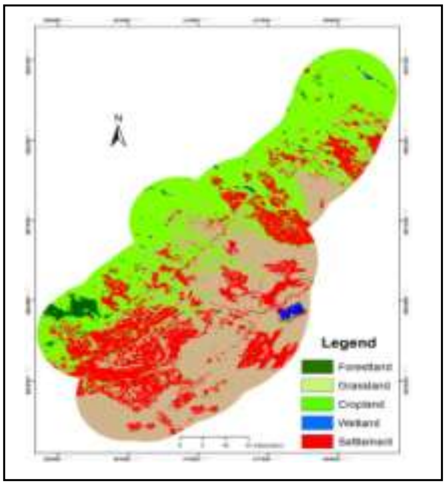


**Figure 7:** Predicted Image for 2025

The study brings out the fact that grassland is the use that is fast giving room to settlement more or less in equal measure, which is the area being converted from grassland to settlement is nearly equivalent and counterbalances each other. This could be explained by the fact that when clearance has been done of say the cropland, the period before construction starts the area transits to a grassland albeit temporarily.

The area under cropland has relatively remained the same over the years from 2002-2016 with minor changes. This could be the fact that most croplands are the permanent type of crops which has not gone through cutting. This is especially the coffee plantations which have remained untouched, this is more so for farms under cooperatives and large farms. But this is likely to change making an inference from the model has it shows that more cropland areas are going to transit to settlement. Also it shows that there is a higher rate tendency of linear settlement close to the roads, with pockets of gaps in areas which does not show much change linearly as could have been expected, this is especially so where the land ownership is institutional or by a government agency or department. This was more so in areas where institutions owned large track of land; for example starting from Muthaiga golf club, Utalii college, Kenyatta university and police and military barracks on both roads which prohibit or control urban sprawl in that direction hence the roads not realizing their full potential. Also some large parcels are under company and cooperative schemes and since majority like Mboi-Kamiti, Githunguri and Tatu city just naming a few are having ownership disputes and wrangles hence slowing subdivisions and development and consequently the expected urban sprawl following the roads. The implications of this, therefore is that there shall be uncontrolled development if policies are not put in place to check development in these areas.

## V. Conclusion

Decision-maker both in national and county government needs proper and real information about the current spatial situation for making informed future planning decision. A cross tabulation of land use images for 2009 and 2016 revealed that there was significant changes experienced in that epoch, and particularly as it relates to urban growth. This was used the projection of the urban growth patterns and trends for the future. For purposes of validating the prediction model, an accuracy assessment was conducted between the predicted image and the classified image and the results showed an overall accuracy of 75% which was deemed acceptable.

The study has shown that grassland and cropland areas are giving way to more settlements in the area of study and as such there is need to develop social amenities and infrastructure to take care of the upcoming settlements. Appropriate policies should be put in place to facilitate controlled development in these areas. If development policies and zoning regulations are not set and enforced at the start, it becomes difficult later; because the first developments to arise set the stage for future growth patterns as new developers follow and improve on the current developments. The study is important as it will point out to the decision makers the current development levels and projected levels for planning purposes making an assumption that other factors influencing sprawl were to be held constant in the near future. Further it was realized that although development was linear in some places it is not exactly linear as would have been expected that it will follow the roads and a study may be necessary to understand this scenario.

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