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Application of GIS and Remote Sensing in Monitoring Effects of Urban Sprawl in Urban Kenya:

A case study of Eldoret Municipality

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Abstract

Urban sprawl is defined as unsustainable and uncoordinated growth. This study aims at detecting land use and land cover changes within Eldoret municipality over 25 years using Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper Plus (ETM+) imagery of 30m spatial resolution at 7-year intervals. GIS and remote sensing-based methodology has been adopted in supervised classification of satellite images into four classes; Built up, Bare land, Vegetation and farmlands. Post classification; Change detection analysis determined quantity and tendency of transition from one land cover class to another. The results were subjected to zonal statistics to determine nature, and extent of sprawl. The change analysis revealed general trend of increasing built-up areas from 5.382Km² in 1995 and 27.57 Km² in 2017. Depletion of green spaces is demonstrated by decrease in vegetation from 9.72% coverage in 1995 to 2.66% coverage in 2017. Eldoret municipality experienced negative growth in built environment in 2002-2009 transition due to Post Election Violence (PEV) and speculation of further unrest while there was great shrinkage of green spaces in 2009-2017 contributed by better political environment in 2013 as well as devolution. Zonal statistics analysis revealed uncoordinated development in defined land use zones. This study concludes that urban sprawl is a phenomenon that will persist in Eldoret town if left unchecked. As a result, this study recommends that; enforcement of policy framework on 0.5Acres minimum land holding size within municipality, restriction of change of user, set standard road width to 9m on residential and 15m on agricultural zones. Development of municipality's strategic plans and follow up to implementation. This study greatly highlights efficiency of Geographic Information Science (GIS) and Remote Sensing in detecting, monitoring and modelling urban expansion or sprawl and its drivers.

Keywords: Eldoret, urban sprawl, GIS, remote sensing, landsat, zonal statistics

INTRODUCTION

Sprawl can be defined as rapid expansion of the built-up area into suburbs in a discontinuous low-density and uneven pattern causing inefficient use of land resources and encroachment into agricultural land and natural covers (Antalyn and Weerasinghe, 2020).

Over the last three decades, there has been drastic global population movement from rural to urban areas and is projected that the up-to 61% of world's population will move to urban areas by the year 2050 making population growth one of the most important driving force of change in any urban setting.

According to 2017's UNECA report, East Africa is the least urbanized region in the Africa's Sub-Sahara consequently with fastest urban growth. Rapid urban growth in Sub-Sahara brings setbacks in attainment of the Sustainable Development Goal 11 on developing sustainable urban communities and affordable housing for the public.

Rapid urban growth has rendered most cities, small and medium towns unable to meet the growing demand of the social, economic and environmental population needs. UN-HABITAT 2014 report, indicate that despite significant overall growth, most cities in Africa continue to suffer under very rapid urban growth accompanied by massive urban poverty and many other social problems.

Major cities and towns in Kenya face serious problems as a result of urban sprawl majorly exhibited in land use occasioned by public and

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private land use conflicts, inappropriate mixed land use, traffic jams due to inadequate capacity of road network, traffic control during peak hours, solid and liquid waste management and sighting of waste management facilities and disaster management as far as drainage during floods and fire outbreaks are concerned (Njiru, 2016).

Eldoret town is facing serious planning and administrative problem which this study brings contemporary and advanced Remote Sensing technologies in monitoring this changes and effects that come with. Modelling the effect as well as forecasting the future pattern for purposes of formulating a working action plan that will see that sustainable development takes place in Eldoret.

Urban sprawl is a phenomenon that needs immediate address to achieve the global goal of sustainable cities as well as Kenya's vision 2030. Integrated mechanism that involves every stakeholder in decision making and planning guided by scientific facts and statistics from GIS-based analysis ensures that every decision and policy formulation is sufficiently informed and guided.

Problem Statement

Eldoret town is the largest town in the country after elevation of Nakuru town to city status which puts it on line as the next city. This projection requires that the town grow into being a city without inheriting town problems which negative sprawl is part of. Eldoret Municipality currently lacks an approved spatial development master plan to guide development and govern decision making on land use and management. This has led to development approvals on need basis in disregard of physical planning requirements as provided for in the Constitution 2010, physical land use and planning act of 2019 and county government act of 2012. For years now, there has not been any formal change of user for purposes of development in those areas whose use over time has changed through assimilation into the municipality leading to serious conflict between land use and the adopted town plan. Rapid conversion of land from agricultural to residential and commercial use has led to peri-urban areas becoming part of municipality organically without any formulated development plan. Sprawl along the major road networks especially Uganda road has led to ribbon development which is very uneconomical for the authorities to plan and manage. Additionally, clusters of informal settlement within municipality have been on the rise due to population increase and low employment supply coupled up with high living standards leading to search for relatively lower cost of living as explained by the bid-rent theory by Von-Thunen 1826 and Hurd 1903. Lack of political goodwill, financial and expatriate investment and urban management policy guide in steering sustainable urban growth from both national and county government has led to delayed implementation of respective master plans. Budgetary allocation for monitoring and development of prediction models for urban growth, either by government or the department is minimal making it less a priority. This has led to use of older techniques of measuring urban growth which do not give account to previous and current status as well as projected growth for mitigating the future expected negative impacts of sprawl. Slow or partial adoption of new scientific techniques such as GIS and remote sensing in the government and private sector has also become a hindrance towards realization of a better planning and management of development. The responsible departments have stuck on the old techniques which over time have become unproductive and inefficient in monitoring contemporary development and sustainable growth needs or expansion of Eldoret municipality.

Research Objectives

This study was guided by the following objectives;

1. To analyse land use and land cover change between 1995 and 2017 at 7 Years interval and project 2021.
2. To assess the rate of sprawl and conversion of other land use forms to built-up.
3. To propose measures for dealing with urban sprawl in Eldoret Municipality.

Research Questions

The following research questions guided the study:

1. What is the past and current general land use land cover trend in Eldoret municipality?
2. What causes urban sprawl in Eldoret municipality?
3. What is amount of built-up area in every land use zone within Eldoret municipality?
4. Which zones are mostly affected by sprawl and the level of fragmentation?
5. How can urban sprawl within Eldoret town be addressed?

Study Area

Eldoret town about 312km North West of Kenya's capital city Nairobi on the main Kenya – Uganda Railway Line and along Africa's Great North Road (Cairo to Cape Town). Eldoret Municipality covers approximately 148 km2. Eldoret is a home to more than 500,000 people. Eldoret Town grew as an agricultural centre due to high agricultural potential area of the larger Uasin Gishu County in Rift Valley Province. Eldoret is a high-altitude region with high rainfall, with annual average of 1223mm. Temperatures are relatively low due to the high altitude around the town ranging between a minimum of 8˚c and a maximum 27˚c.

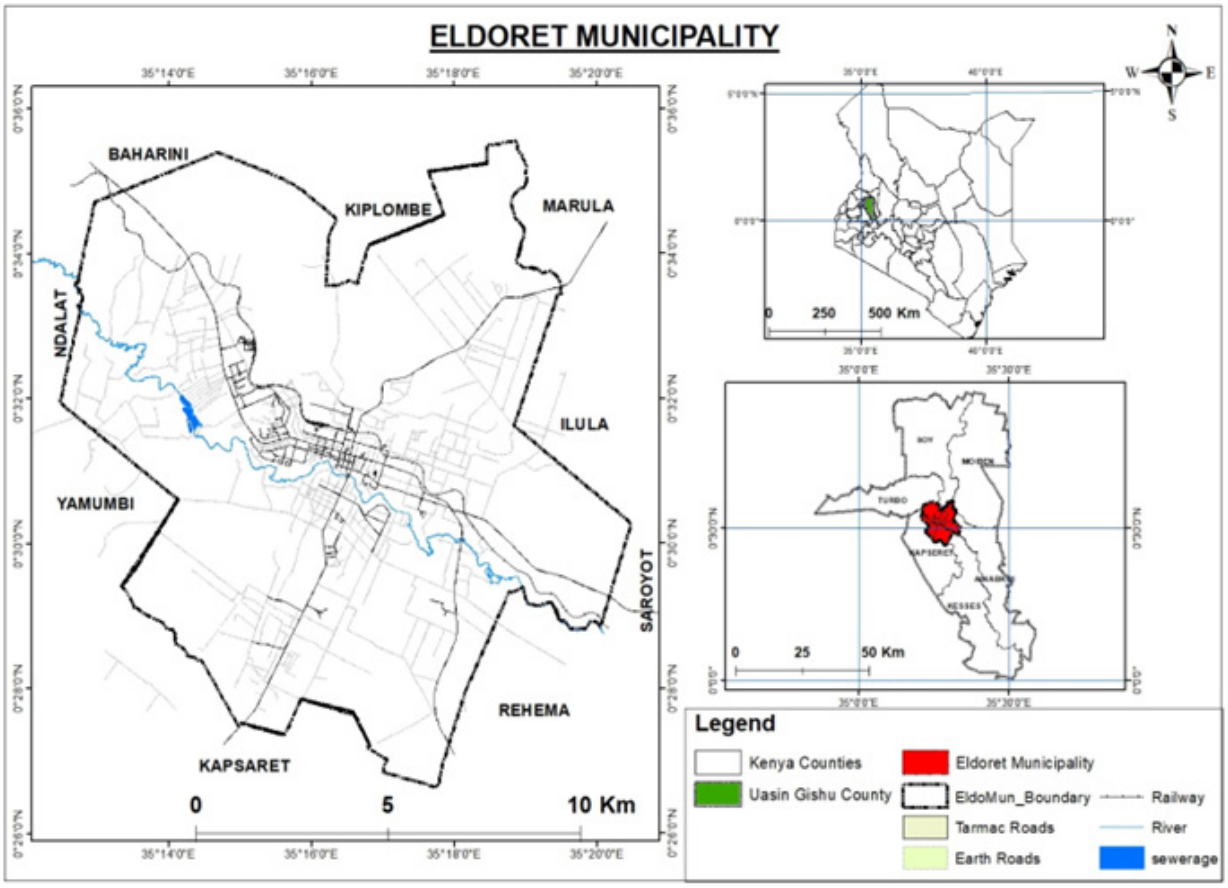

FIGURE 1
Study area map
Source: Author, 2022

Understanding the concept of urban sprawl.

Urban sprawl can be described based on density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity of the urban built-up environment within and around town or a city (Ujoh et al., 2010). Positive urban sprawl can be regarded as urbanization since it allows migration of a population living in an urban centre towards rural areas adjacent to the town.

Urban sprawl pattern and trends.

Urban sprawl is characterized by aspects such as unplanned and unnecessary land consumption, Low average population densities as compared to the older urban centres, Fragmented open space, wide gaps between development and a scattered appearance, Lack of public spaces and community centres (Chen et al., 2018).

In attempts have been made to show spatially and analytically the various changes in land cover over a period of time by indicating inter-class land cover change. This is to an extent an improvement on the work (Butt et al., 2015; Afify 2011).

Urban sprawl takes different forms as, radial in the fringes of city or town, linear along transport

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lines, clustered around a social amenity and leapfrogging forms of urban sprawl.

Causes and effects of urban sprawl.

Urban sprawl does not take same form everywhere as the dominant factor causing it vary with the urban set up, level of country's development or structure of society maintain that driving forces and causes of urban sprawl are interrelated and can be used interchangeably (Bhatta, 2010; Al Jarah et al., 2019).

Strategies for dealing with urban sprawl.

Constant monitoring of demographics and distribution pattern helps in pointing out the direction of sprawl (Wassmer, 2002). Major and primary means of monitoring urban sprawl is by doing temporal analysis of land use and land cover which is aided by remote sensing classification of temporal multi-spectral images (Bhatta, 2010).

Study by Rubiera-Morollón and Garrido-Yserte (2020) elaborates that the element that can most restrain the urban sprawl trend is having a very strong, dynamic and attractive centre. A centre that provides for all the human needs sufficiently attracts people and prevents outward dispersion of population.

Different causes of urban sprawl have been classified and summarized in **Table 1.**

TABLE 1
Causes of urban sprawl

Macro-economic factors	Economic growth, Influence by satellite towns and market centres.
Micro-economic factors	Rising living standards at the town centre.
	Availability of cheap agricultural land outside but around municipality.
Demographic factors	Population growth pressure in town leading to increase in housing needs.
Housing preferences	Availability of more space per person and housing preference outside the town centre
Central municipality problems	Poor air quality and noise pollution make town centre not liveable.
	Unsafe environments and lack of green open space within town while the urban fringes provide for good green space and safety.
Transportation	Poor public transport and rise in private car ownership.
	Inhomogeneous fare tariffs to destinations within same distance range from the town centre.
Policy and Regulatory frameworks	Weak land use planning policy and control.
	Political influence and hindrance on development and control
	Lack of deployment of contemporary planning skills and techniques.

Sources: Adapted from Karakayaci, 2016

Policy, technology, legal and institutional framework of urban sprawl

The major shortcoming of remote sensing monitoring is that it is only based on the quantitative analysis of the land cover change without any qualitative approach of monitoring and modelling sprawl.

Work of Chen et al. (2018) gives detailed application of GIS in analytical classification, monitoring and modelling of urban sprawl. However, Brunner, 2012 found that solutions to urban sprawl that prove to be successful in one location may not

endure in others. According to Herold, Goldstein, and Clarke (2003), land use change models should incorporate both human and natural systems for effective and conclusive action plans.

Al Mashagbah, Al-Adamat, and Al-Amoush (2012) affirms that Remote sensing is an excellent data source for monitoring the urban land use change while GIS has strong spatial and statistical analysis capabilities.

RESEARCH METHODS

Analysis of land use and land cover change between 1995 and 2017 at 7 Years interval and prediction of 2021 LULC. All the image scenes have been selected to fall on the same season to reduce preprocessing needs and effect of cloud cover in varying seasons.

Data acquisition

Primary data derived as satellite images in Geotiff format from USGSS, from same sensor (Landsat) were used for land use land cover classification in ERDAS IMAGINE and ArcMap 10.5 software. Landsat has been chosen over other satellites due to its availability and workability in spatial analysis. Xie, Sha, and Yu (2008).

Data preprocessing

Landsat images of between 1995, 2002, 2009 and 2017 were acquired, layer stacked and Subset using Eldoret municipality boundary Shapefile as the AOI.

Image classification

Supervised classification was performed on the subsets using Maximum likelihood classifier by selecting the training sites evenly representing the four chosen classes within the image subset which were; Built-Up areas, Vegetation, Farm land, bare land using Google Earth (Norovsuren et al., 2019).

Accuracy assessment

Confusion matrix was used for accuracy assessment on classification output to determine quality and confidence (Foody, 2002).

Change detection

Post classification change detection technique according to Lu et al. (2004) is the most preferred as it allows determination of amount, location and direction of change. It also makes it unnecessary to perform the radiometric and geometric correction. Change detection was done on TerrSet Land change modeller for this study because of its guaranteed compatibility with ArcMap classified image output as opposed to other software **(Figure2).**

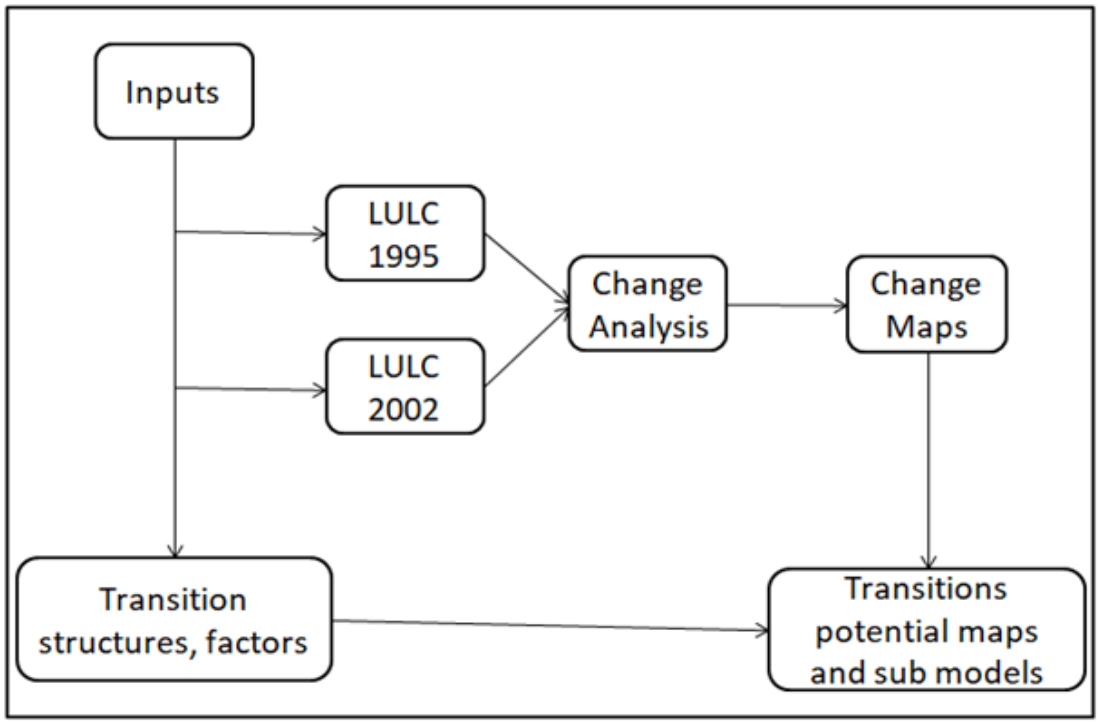

FIGURE 2
Flow chart for land change modeller analysis.
Source: Author, 2022

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Zonal Statistics

Proposed land use map from Uasin Gishu county government physical planning offices, road network, rivers and water points, schools and health facilities were acquired as secondary data for subsequent analysis of sprawl in this study.

Spatial analyst extension in ArcMap has zonal statistics tools that include tabulate area, zonal statistics as table which were adopted in this study (Ko Lwin, 2009).

Research studies as Soysal et al. (2012) has employed use of zonal statistic tool for spatial analysis and proved efficient. Input zone data that is provisional land use zone map that defines the size, shape, and location of each zone.

An input value raster containing the values used in the evaluations within the zones of the input zone data. Classified built up area map was used in this study (Florance & Gale, 2018).

RESULTS AND DISCUSSION

Presentation of the classification, reclassification, temporal analysis, transition analysis, spatial statistics and the zonal statistics results. Results discussions have been supported with maps, tables, illustrative and trend graphs.

Image Classification

The four land use maps obtained with four different classes i.e. Built-Up, vegetation, farmland and bare land have been represented in the classification maps for respective years of study **(Figure 3).**

They were derived through supervised classification. Quantitative interpretation shows general trend of increasing built-up areas over the years of study. This analysis of the area coverage has been represented in a graph **(Figure 4).**

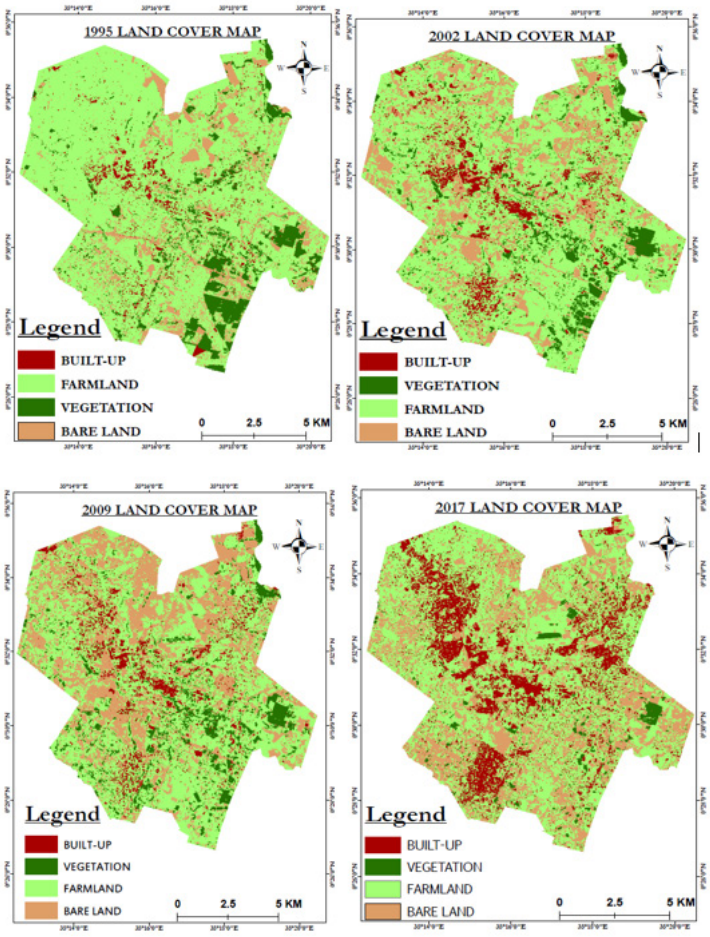

FIGURE 3
Results of image classification.
Source: Author, 2022

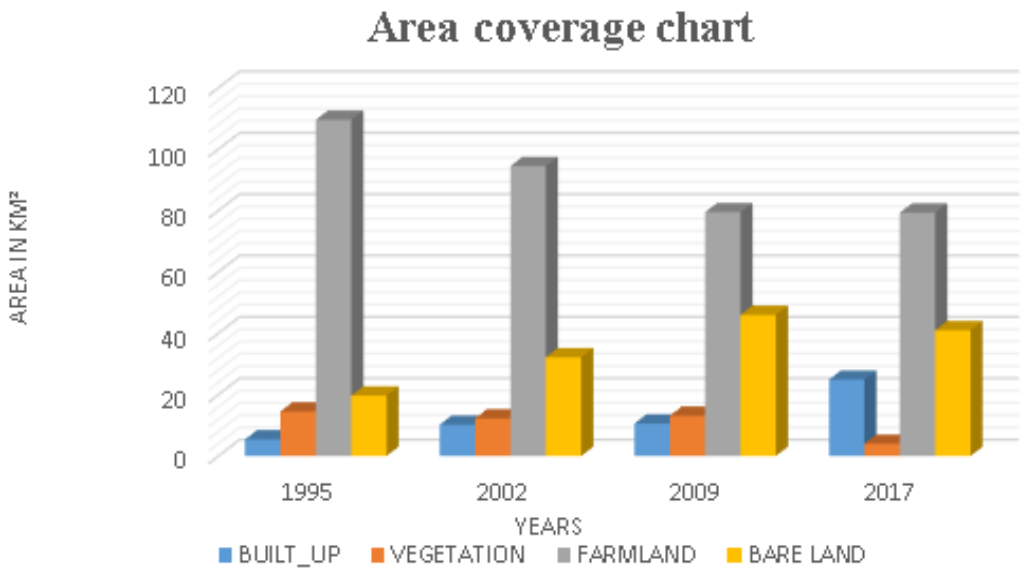

FIGURE 4
Graphs of Land use and land cover area coverage analysis.
Source: Author, 2022

Accuracy Assessment

Evenly distributed samples of an average of 200 polygons were randomly selected from each epoch classification output to assess accuracy. Error matrices as of the mapped class against the reference class were used to derive overall accuracy, producer's and user's accuracies and the Kappa statistics. All the accuracies were above 85% which according to Herold, Goldstein, and Clarke (2003) are considered of good remote sensing analysis standards **(Table 2).**

TABLE 2
Results of accuracy assessment

Sensor	Acquisition date	Classified image	Overall accuracy %	Kappa Statistics
Landsat TM	28/2/1995	1995 LCM	85.52	0.73
Landsat ETM+	21/2/2002	2002 LCM	87.48	0.75
Landsat TM	31/1/2009	2009LCM	88.31	0.78
Landsat TM	12/2/2017	2017 LCM	90.56	0.82

Sources: Prepared from Google Earth, 2022

Change Detection.

Land cover quantification, trends and analysis over the period of study is captured in this section. Change detection was done through a multi-date post-classification comparison to derive changes in land cover in the study intervals (Nong et al. , 2018). Determination of loss and gain in every land cover over the transition period was done to determine the net change of the land cover. A negative net change implies that the land cover class converted to another land cover through the land use change while positive net change implies that the particular land cover class benefited from loss of another land cover class.

Change detection result analysis shows that in 1995-2002 transition, built up and bare land area increased in coverage by 99.6% and 63.89% respectively while vegetation and farmland reduced by 15.55% and 13.76% respectively. That is an indication of destruction of forest vegetation as built-up environment grew to take agricultural land.

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The transition period 2002-2009, the built-up environment declined for reasons of slow urban growth or poor environment to grow the municipality. One of the reasons attributed to this is the 2007-2008 Post-election violence that affected Eldoret. Forested vegetation has seen grew while farmland mostly remain bare due to drought or other unfavourable reasons.

In 2009-2017 transition, there is clear rise in built up environment coverage. This has been attributed majorly to devolution and key projects that were commissioned around this period like the Eldoret Southern bypass and other improved roads. High rate of subdivision of agricultural land gave people residential homes. The green spaces eventually reduced (**Figures 5, 6 and 7**).

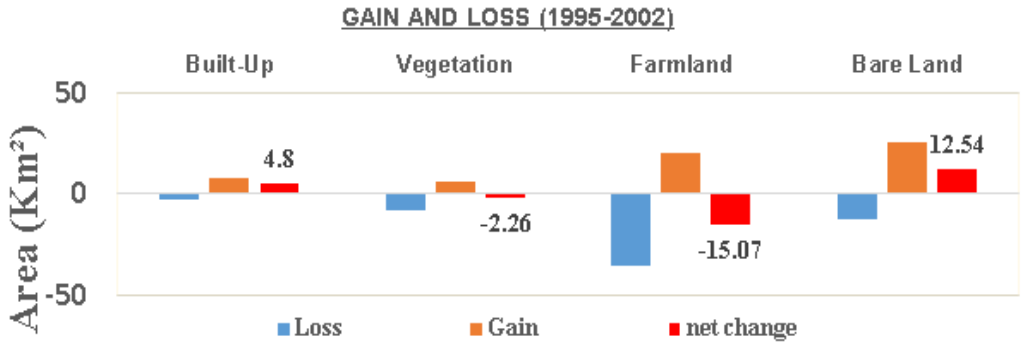

FIGURE 5
Gain and loss analysis 1995-2002
Source: Prepared from TerrSet modeler, 2022

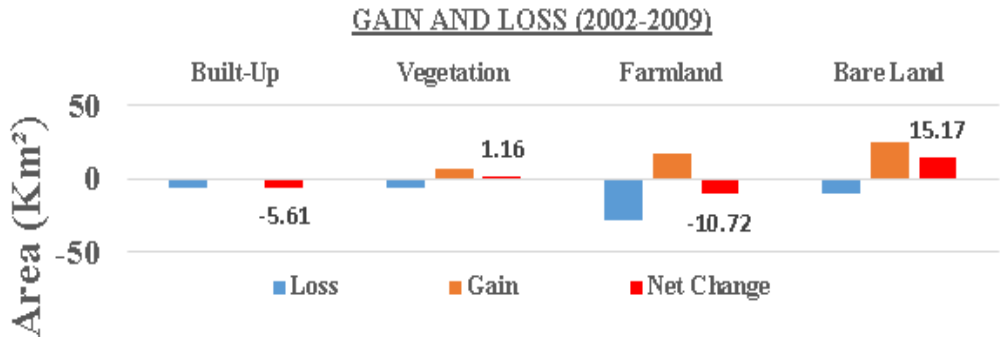

FIGURE 6
Gain and loss analysis 2002-2009.
Source: Prepared from TerrSet modeler, 2022

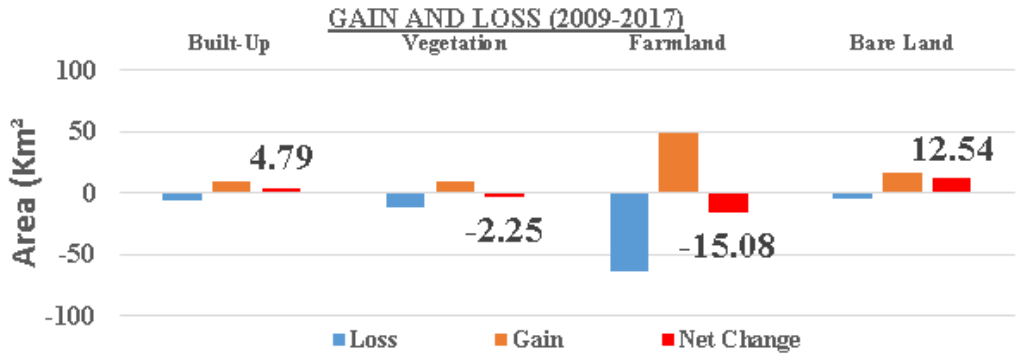

FIGURE 7
Gain and loss analysis 2009-2017.
Source: Prepared from TerrSet modeler, 2022

Built-up Area Sprawl Analysis

This section covers analysis of the built-up area coverage, change and transition of other land use forms to built-up through the epochs of study.

Classified images were reclassified to only two classes shown as class 1 for built up areas and 0 for non-built-up areas. The Built up areas and the non-built-up areas. The interclass transition was then determined through image differencing to develop change maps which displayed pairs of results, 1 to 0 and 0 to 1 confirms there is interclass transition while 1 to 1 and 0 to 0 are areas of no change.

The transition potential for non-built land cover land cover to built-up environment and vice versa over the period of study was determined to estimate and show the trend of urban built environment growth. The ability of built up area not to change over the period of study is described as built-up areas' persistence to change from previous year of study and change from other land cover contributing to its growth. Areas of no change are not significantly no change but it is so in reference to built-up areas. Changes taking place in this area do not affect the built-up area and therefore considered as areas of no change.

This section also shows the transition from all land cover classes to built-up that was quantified to find how much area is contributed by all the other land covers to the built-up area. The analysis show that the most significant land cover contributor to built-up environment growth is the farmlands. This proves that agricultural land has majorly been converted to other uses as residential and commercial use and therefore, urban sprawl **(Figures 8, 9, 10 and 11).**

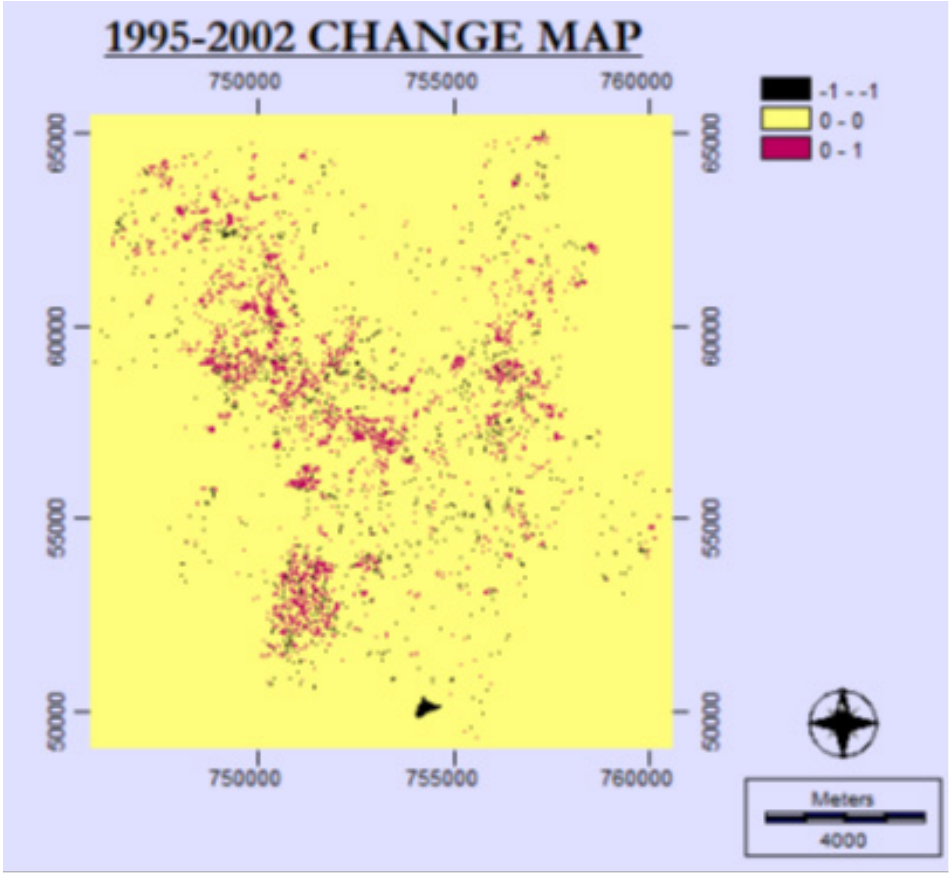

FIGURE 8
Results for Land use land cover transition potential map
Source: Prepared from TerrSet modeler, 2022

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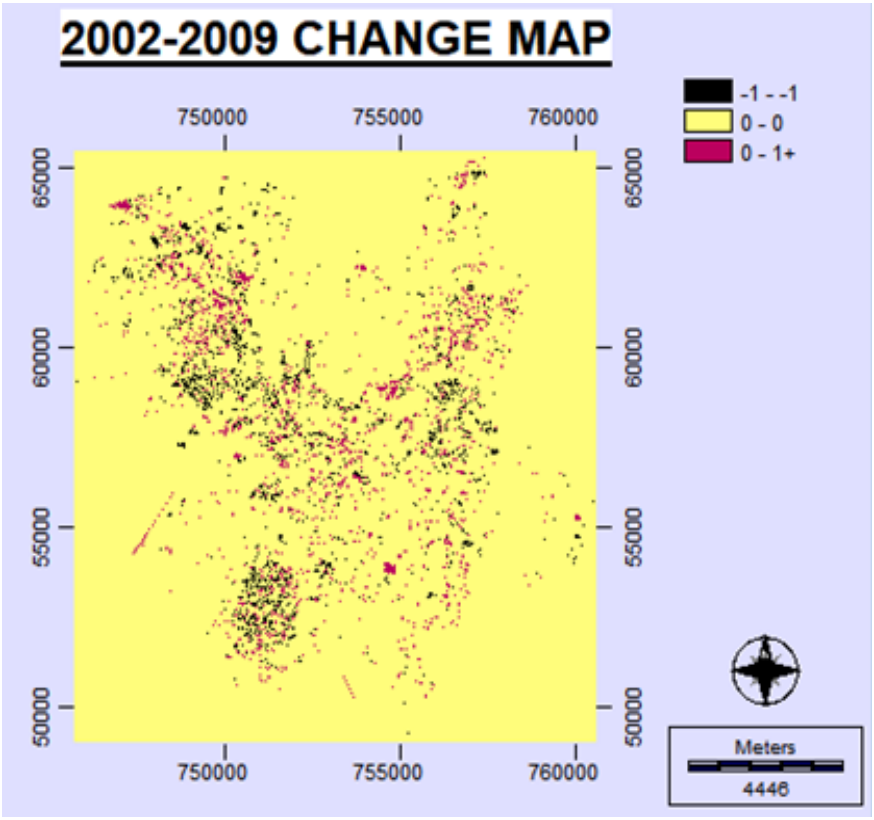

FIGURE 9
Results for Land use land cover transition potential map.
Source: Prepared from TerrSet modeler, 2022

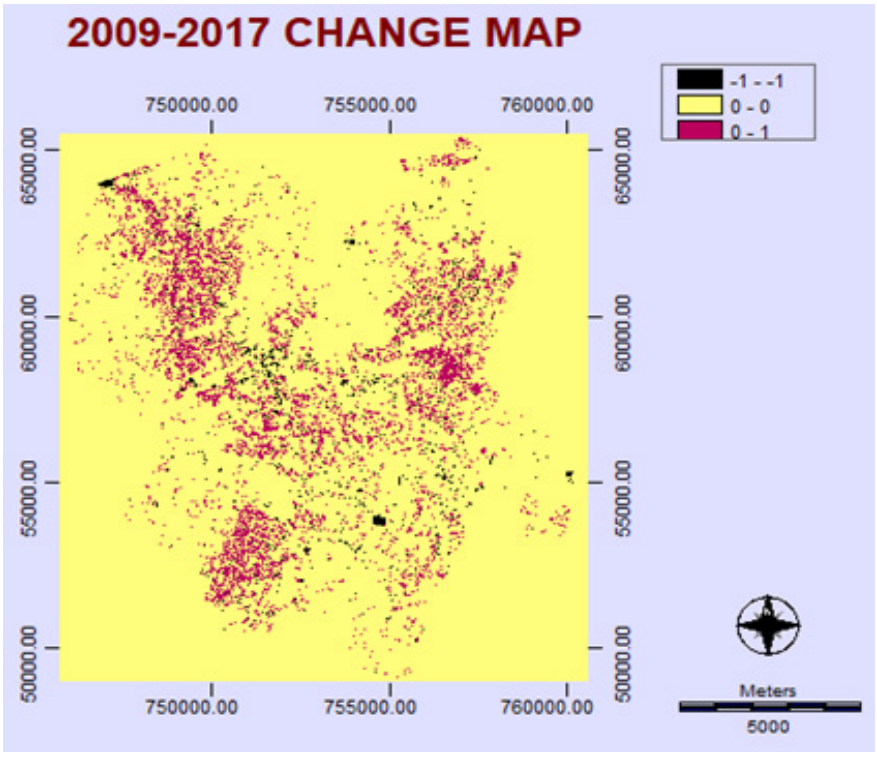

FIGURE10
Results for Land use land cover transition potential map
Source: Prepared from TerrSet modeler, 2022

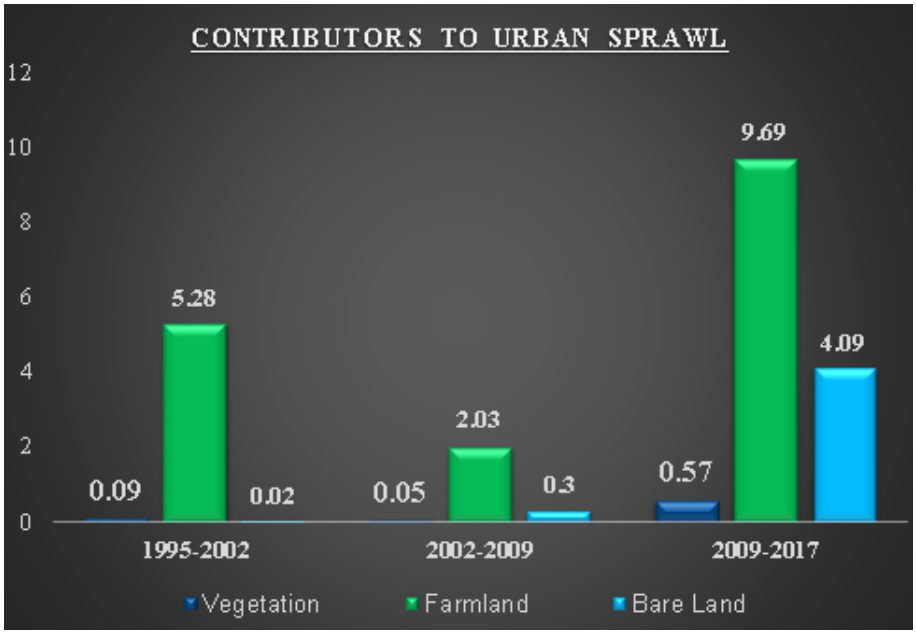

FIGURE 11
Graph of LULC contribution potential to built-up.
Source: Prepared from TerrSet modeler, 2022

Zonal Statistics.

Development of the overlay image of 2017 built-up area land cover map, land use zonal map and major transport network shapefiles. This determined the proximity of built areas to the major roads and so assess influence of the road network on sprawl. According to Khajavigodellou, Alesheikh, Hakimpour & Chapi (2015) there is strong correlation between the road network and urban sprawl in areas where sprawl takes the linear form which this study upholds.

The overlay images show the relationship between the set-up municipality's master development zoning plan with the built-up area distribution map.

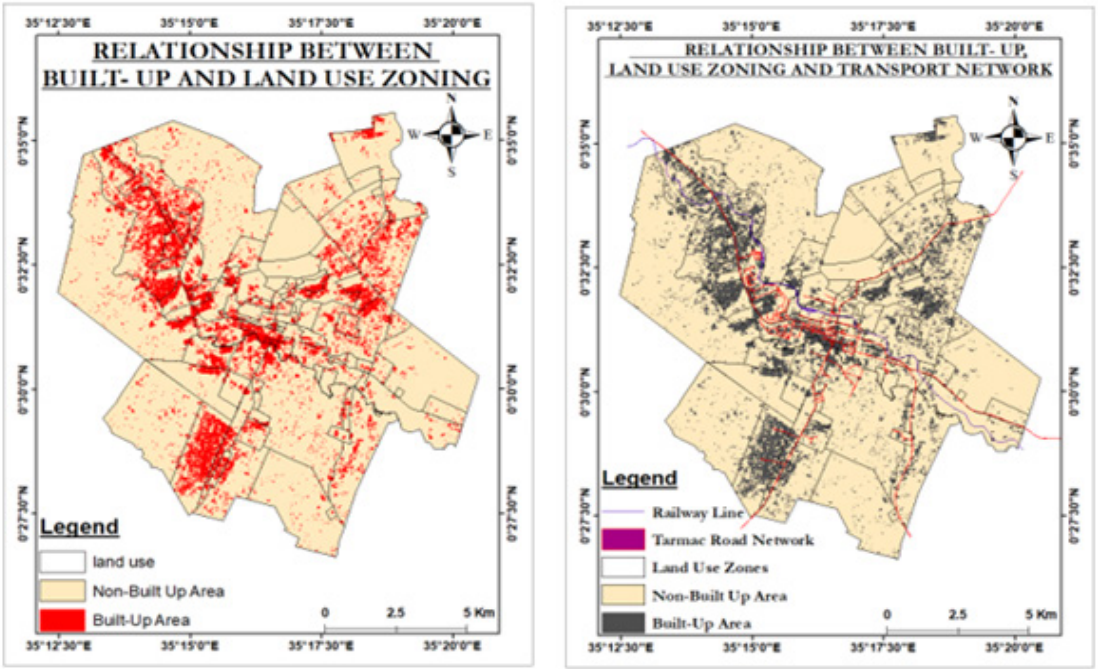

FIGURE 12
Built-up distribution and land use map overlay for zonal statistics Analysis
Source: Author, 2022

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CONCLUSION AND RECOMMENDATIONS

The results give a clear indicator that Sprawl in Eldoret municipality has occurred majorly through existence of the Nairobi-Uganda Road. Other roads like Eldoret-Kisumu, Eldoret-Kaptagat and Kitale-Cherangani roads have influenced urban sprawl. This has contributed to the linear sprawl.

Much development and urban set up came after the post-election violence in 2007/2008 and also greatly after inception of the county governments under the new constitution 2010 through devolution which made Eldoret town grow rapidly as a result of increased financial allocation and revenue collection by the county government of Uasin Gishu.

There exists serious land use conflicts and urban gaps within town centre and at the fringes of the municipality due existence of informal settlements such as Langas, Munyaka, Kamukunji, Huruma and Shauri yako.

Municipality boundaries have involuntarily been expanded to accommodate nearby areas deemed to have grown to become part of the town with or without change of user.

Increase in land market prices within the municipality has forced people to buy and develop land in the nearby areas where they can still access town centre easily. This increase, coupled with low financial and economic potential resulted in fragmentation of agricultural land into small portions which people can afford for commercial cum residential use.

Difference in traffic congestion and inconsistent tariffs towards different destinations outside the town has also made people live and develop in direction where transport tariffs have for long time been considered lower and consistent. The result is increased in housing development in those areas. Preference of salient environment outside the town has resulted in several clusters of low density residential spaces far from the central business district. Case, (Kipkorgot, Hillside, Kapsaret and Kimumu) have eventually resulted in urban gaps

Growth of neighbouring centres (Maili nne, Kapsaret) which eventually become part of the municipality is also major player in urban sprawl. Development of Eldoret southern bypass has greatly influenced growth towards Kapsaret.

This study strongly recommends GIS& RS as powerful tools and better technologies in monitoring effects of urban sprawl and inform spatial growth in a systematic manner through planning.

Eldoret town has good prospects of becoming a city. Serious and tough decisions however have to be made so that it grows as a model city for the rest. Several studies as (Al Jarah et al. 2019) has put forward recommendations that can also be adopted for Eldoret Municipality.

This study also recommends the following;

i. Adoption of GIS as well as setting up a fully-fledged GIS lab for monitoring, managing and addressing urban sprawl.
ii. Setting up a GIS department or sub department in every county departmental office to enable development of systems and databases that will inform spatial and non-spatial decision making that affect Eldoret town.
iii. Physical master plan be prepared covering the new municipality extents, approved and be implemented however implication it will have but achieve streamlined and organized town plan.
iv. Fast growth of informal settlement be addressed at early stage so that moving forward, issues of mushrooming slums is avoided. Affordable housing should be adopted as a remedy to the un-organized informal settlement.
v. Land ownership be addressed through concerted effort between county and national government so that allotment be done and that idle and land under informal settlement be put under proper affordable housing program.
vi. The county government to oversee implementation of both national and county government policies on housing and infrastructure to ensure growth is not skewed, leap frogging or unidirectional.
vii. Full funding of the urban development agenda by both governments and or with other collaborators will see the town grow with minimal sprawl thus controlling the negative effects brought by sprawl
viii. Development of sustainable and cohesive

transport system. Development of transport network that accommodate, cars, riders and pedestrians. Tying proper drainage with transport allows control and alleviation of effects of floods.

ix. Satellite towns be planned and some key government Agencies, Ministries and departments be moved to those areas to reduce the pressure in the CBD. Adopt the nodal planning system.

x. Where development cannot be avoided, a buffer zone should be made for natural and protected resources be preserved.

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