Monitoring spatio-temporal compliance of urban development plans using GIS and remote sensing in Nairobi City County, Kenya

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Abstract

Development control aims to provide an urban environment with quality service delivery, optimal use of available resources, conservation, and reduction of haphazard urban growth. At the core of development control is the compliance assessment process, which ensures adherence to regulatory policies. The City of Nairobi compliance assessment process lacks considerable enforcement capacity and this has led to uncontrolled development. This study uses GIS and remote sensing to assess the spatio-temporal compliance of development plan(s) in Nairobi City County. Land use/cover of Nairobi City County from 1976 to 2019 were obtained from classified Landsat images at a nearly 10-year interval of six epochs (1976, 1984, 1993, 2002, 2010 and 2019). The zoning plan maps were digitised and superimposed on the classified images to determine compliance, taking subsequent reviews of spatial development plans into account. The non-compliance rates for residential, commercial, and industrial activities varied at 57~84%, 63~81% and 65~92%, respectively, during the study period (1976–2019). A comparison between the planned and non-compliant areas showed that residential, commercial, and industrial activities occurred mostly outside planned areas from 1976 to 2019. The analysis showed a considerably less increase in non-compliance on commercial land use. This is so because of the review done on the zoning plan for Nairobi City in 2005. The industrial land use non-compliance was constantly increasing over the study period, an indicator of the ever-rising rate of urbanisation in the Nairobi metropolitan area. This study illustrates the power of rapid spatial mapping in monitoring compliance of urban development plans for informed decision making.

Keywords: remote sensing; development control; development compliance assessment; geographic information systems; spatio-temporal analysis

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Introduction

Remote sensing is the science of obtaining information about the Earth surface or objects on the Earth surface without direct contact with the objects (Aggarwal, 2004). Urban remote sensing is rapidly becoming popular in urban management since it is driven by technological advancement. The high-resolution imagery has demonstrated the ability to apply remote sensing technology in all socio-economic sectors (Melesse et al., 2007). The remote sensing technology was already widely applied over the last two decades in urban land use/cover analysis due to improved accuracy of about 80% (Tiwary, 2005). In this case, leveraging on this processing power and the quality of satellite data, fine details on land development can be obtained, analysed, and used for policy decision making.

On the other hand, geographic information systems (GIS) have developed from automated mapping to sophisticated modelling and spatial analysis, a key element in decision support (Zerger et al., 2002). The most crucial component in the anatomy of GIS is the network, which enables the rapid sharing of digital information. In the past, GIS was used as stand-alone software, but the internet has increasingly been integrated into many aspects of GIS use (Longley et al., 2005). The systems' performance is based on good management of the GIS activities and procedures, which entirely rely on people who design the software, maintain it, supply it with data and interpret results (Longley et al., 2005). The aspect that relies on human influence is fundamental in interpreting the computational results of the analysis.

The focus of this paper is the Nairobi City County (NCC) which is the biggest city and the capital of Kenya. Nairobi is an important economic hub in the east and central Africa region. The city lies between 1600 and 1850 m above the mean sea level, giving it a temperate climate. Two rivers cross it (Mathare and Nairobi), Karura forest lies on the north and to the south is the Nairobi National Park (Otiso, 2012). Figure 1 shows the location of Nairobi City County.

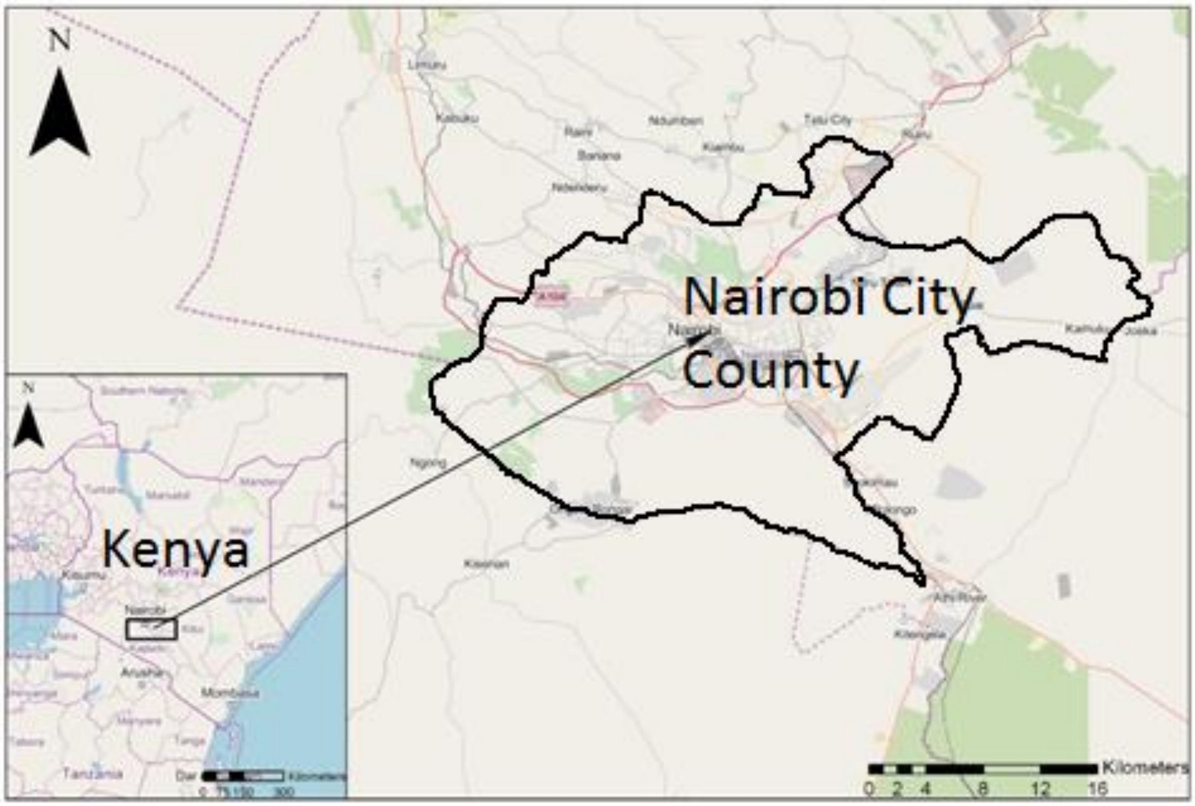


Figure 1: Study area - Nairobi City County (Adopted and Modified from Google maps, 2019)

Development control is a tool used to regulate the urban environment to achieve quality and efficient delivery of services, optimal land use, and a quality environment (Iddrisu Abu, 2015). Development control processes in Nairobi City County were adopted from the old British planning systems, characterised by human-based processes. These development control processes involved stages in which development plans had to be submitted to the local authorities for evaluation (Booth, 1999). One key aspect that is evaluated is the alignment of the development plans with existing zoning ordinances.

In terms of development control and planning, the city follows zoning plans that have evolved under different planning regimes. The initial master plan for Nairobi City was developed in 1926 and subsequent revisions/updates in 1948, 1973 (Booth, 1999) and 2012 spatial plan (Otiso, 2012). The most recent Master Plan is the Nairobi integrated urban development master plan of 2014 (NIUPLAN, 2014). The NIUPLAN has called a lot of attention to sustainability and achieving the millennium development goals (Nairobi City County, 2014). Moreover, the plan was made in line with Vision 2030 goals, which are anchored on the social, economic, and political pillars of development (Nairobi City County, 2014). These policies give a holistic approach to development control processes.

Development control in Nairobi largely focuses on approving and rejecting development applications based on the zoning scheme. The Nairobi County Government use development control guidelines from the physical planning handbook, physical planning act, and building code (Cirolia & Berrisford, 2017). However, due to the overwhelming need for development and political interference, the development control guidelines are not adhered to precisely. At the same time, most developers do not apply for development permissions, and when submitted, what is implemented eventually does not fit with the approved documents (Cirolia & Berrisford, 2017). This process should be monitored through several site visits. The process has been reviewed over the years, and various attempts to improve the process of monitoring development approval using technology and online plan submission portals for compliance checks have been created. However, continuous monitoring of development activities in Nairobi City County is still a problem.

In Nairobi, non-compliance has manifested in many ways, from illegal constructions to encroachment of the conservation areas. This has greatly reduced the quality of life characterised by low standard housing facilities and insecure buildings that collapse in adverse weather conditions (Mugo et al., 2014). The ripple effect of non-compliance is the development of slums over time and reduced quality of life because of environmental pollution (Kuffer & Barrosb, 2011). These scenarios manifest due to a weak development monitoring and evaluation process.

The process of monitoring the adherence of development plans in Nairobi City County is still experiencing challenges since compliance assessment is not in real-time, and only small sections are monitored due to limited resources. Unapproved developments can still go unnoticed for a while before action is taken. The main goal of this research is to carry out a compliance assessment of zoning plans for Nairobi City County over 43 years (1976–2019) using remote sensing and geographic information systems. The power of rapid mapping through remote sensing technique is utilised for a county-wide compliance assessment at six epochs (1976, 1984, 1993, 2002, 2010 and 2019).

Methodology

Research design

The study reviewed original zoning plans for the study area. It analysed the changes that occurred in different periods in the zoning ordinances and the effectiveness of ensuring compliance. Both quantitative and qualitative research methods were employed.

Data

The data used in this study included remotely sensed satellite images and zoning/development plans. Land use/cover was obtained from Landsat for the years 1973 to 2019 in at least 10-year intervals (1976, 1984, 1993, 2002, 2010 and 2019), to aid in assessing the spatio-temporal adherence of zoning ordinances. Table 1 shows Landsat sensors and related data specifications.

Table 1: Description of Landsat images used in this study

Sensor	Spatial resolution (m)	Reference system	UTM Zoning
1976 Landsat 1-3MSS	60	WGS84	37S
1984 Landsat 5 TM	30	WGS84	37S
1993 Landsat 5 TM	30	WGS84	37S
2002 Landsat 5 ETM+	30	WGS84	37S
2010 Landsat 5 ETM+	30	WGS84	37S
2019 Landsat 8 OLI	30	WGS84	37S

Satellite Image processing

The choice of the image processing technique was based on the level of accuracy required, the amount of time and the resources available. A supervised maximum likelihood classification technique was adopted in this study. The object-oriented classification was also used for the Landsat 8 images, with higher spectral and radiometric resolutions. Maximum likelihood is used in this classification because it is relatively fast and achieves higher classification accuracy than other supervised classification techniques. Training samples were collected to ensure there were no overlaps during classification. Selection of the training samples for the land use/cover classification included water bodies, forest, grassland/savannah/bare land, commercial, residential, and industrial.

Zoning plans processing

The land use and zoning plans were acquired from the 1978 zoning ordinances of Nairobi City. The plans were reviewed in the year 2005, and some zones were changed to mixed development. The boundaries from the plans were used in the analysis to overlay the classified maps to demonstrate the level of adherence to the zoning ordinances. Figure 2 shows the digitised zoning plan for the 1978-79 rezoning strategy.

The subsequent plan includes the 2005 zoning review document touched mainly 4 zones; Westlands, Kileleshwa, Parklands, and Loresho, which were made mixed-use, changing from the earlier residential zones. Essentially, this review took effect and was incorporated into the development control process. The 2014 plan has not yet taken effect; therefore, it was not used in this study.

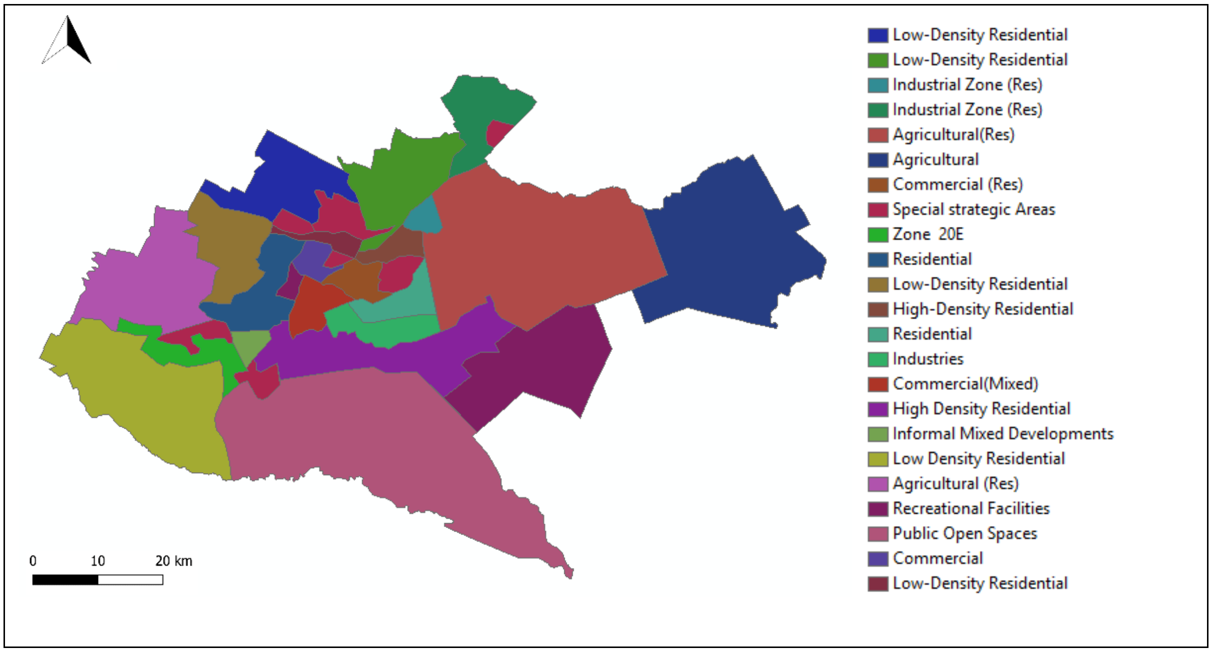
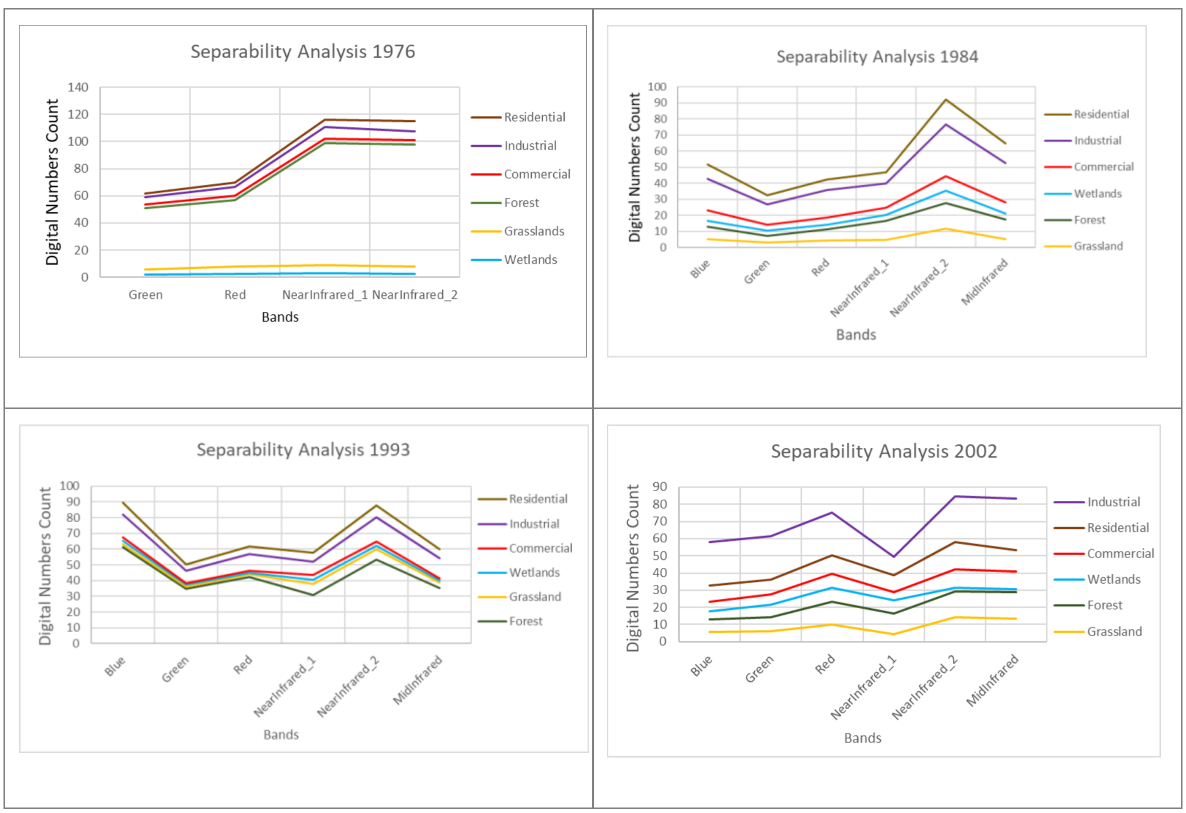


Figure 2: Digitized Zoning plan for 1978 (Source: Adopted and modified from Nairobi zoning strategy for 1978**)**

Spectral separability was performed to evaluate the ability of different images to discriminate between land use/cover (residential, industrial, commercial, forest, grassland, and wetland) in Nairobi City County. Moreover, it was used to assess the quality of the classification of the training data samples. In carrying out this study, the inspection was done using two approaches: the first approach involved analysing the visual brightness of the histograms of the areas where the training samples had been created. Secondly, a quantitative evaluation was done on the separability. Figure 3 shows a plot of spectral separability for the residential, industrial, commercial, forest, grassland, and wetland in Nairobi City County.

In the 1976 image, the separability could not be achieved entirely in this classification; the separability patterns in the graph show that commercial and residential land use are closely stacked together in terms of digital numbers. The line graph for the commercial land use closely assumes the shape of the forest graph across all the bands. This can be attributed to the sensor design properties at that time. Looking at 2002, 2010 and 2019 images, the classification would better separate the training samples. All the NIR- bands in the composite images demonstrate a better separability than the other bands in some training samples. This informs the selection of samples and the available band that would be essential in discriminating different features in the images.



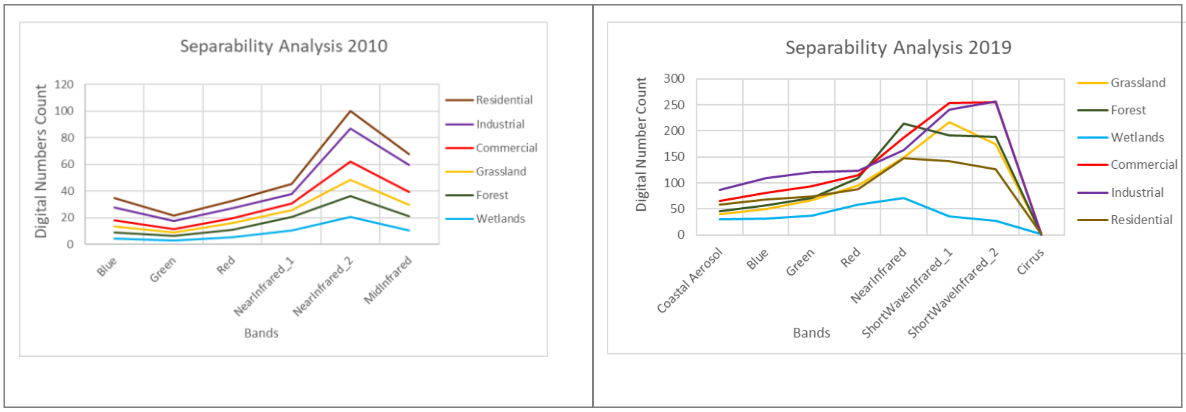
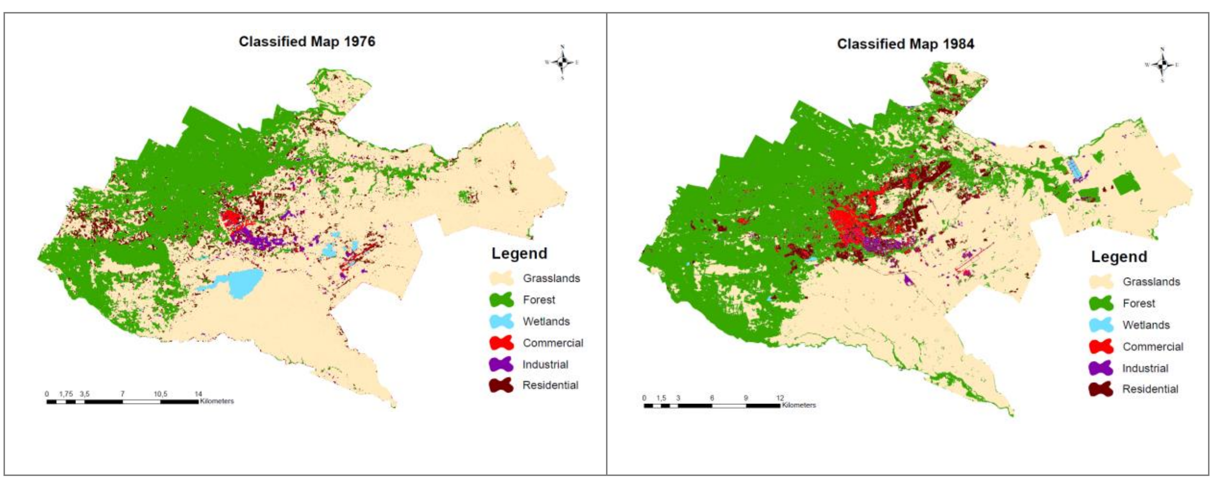


Figure 3: Spectral separability for the residential, industrial, commercial, forest, grassland and wetland in Nairobi City County

Results and discussion

Land use/cover

A lot of processing power is needed in the implementation of the classifier's tasks. This process was aided by the google earth engine, which greatly reduced the processing time. Subsequent processing of the images on Arc Map required the subsets of the study area. The subset was made using the current administrative boundary of Nairobi City County (NCC). Figure 4 shows the spatial distribution of land use/cover over NCC from 1976 to 2019.



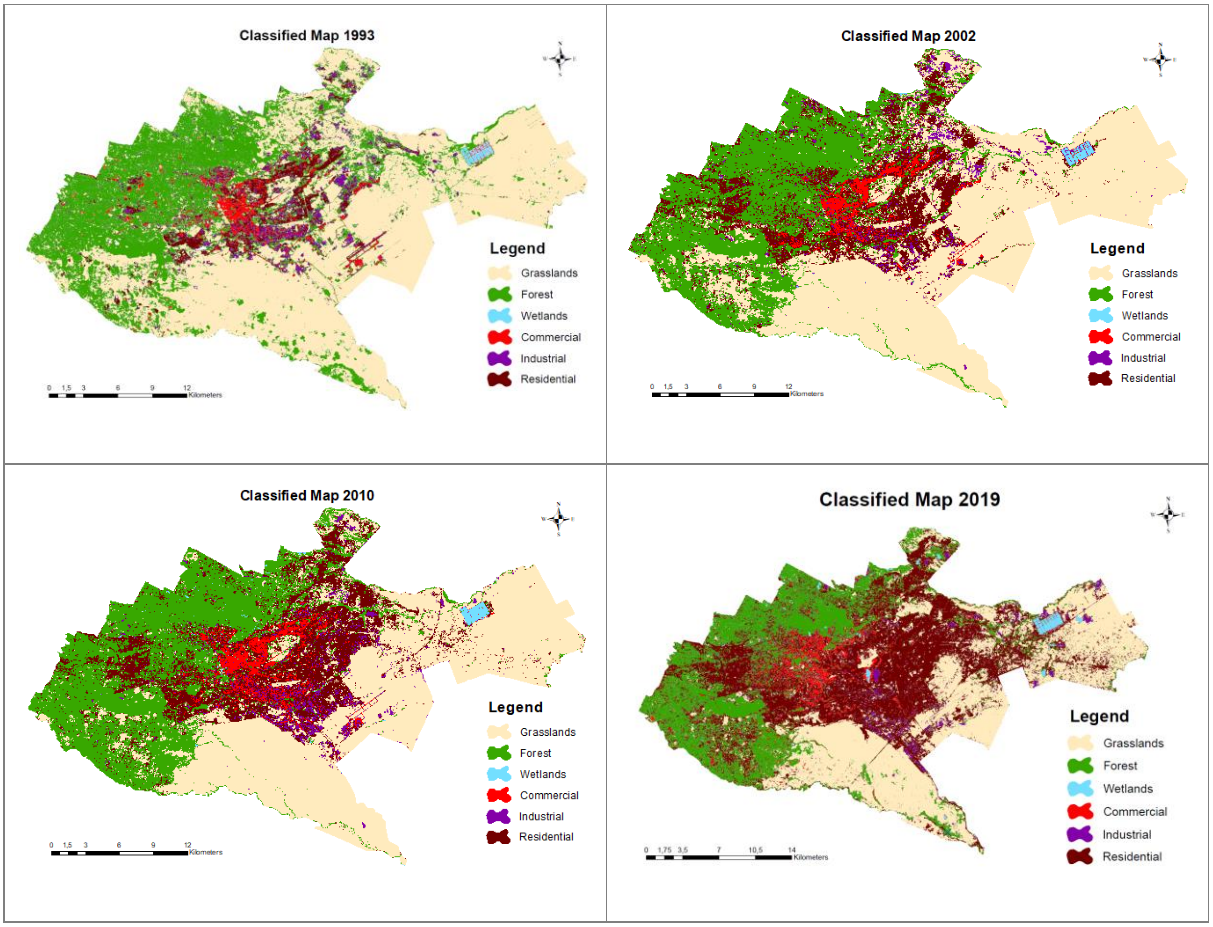


Figure 4: Spatial distribution of land use/cover over Nairobi City County from 1976 to 2019

A general trend of increasing growth in industrial, commercial, and residential activities over the last 43 years is displayed in Figures 4 and 5. The highest growth occurred in residential land use followed by commercial and industrial land use in that order. The land areas covered by forest and grass (grassland) have consistently decreased since 1976. The wetland has reduced over the years, though not plottable in Figure 5 due to relatively small areas. The accuracy of classification ranged from 65 to 85%.

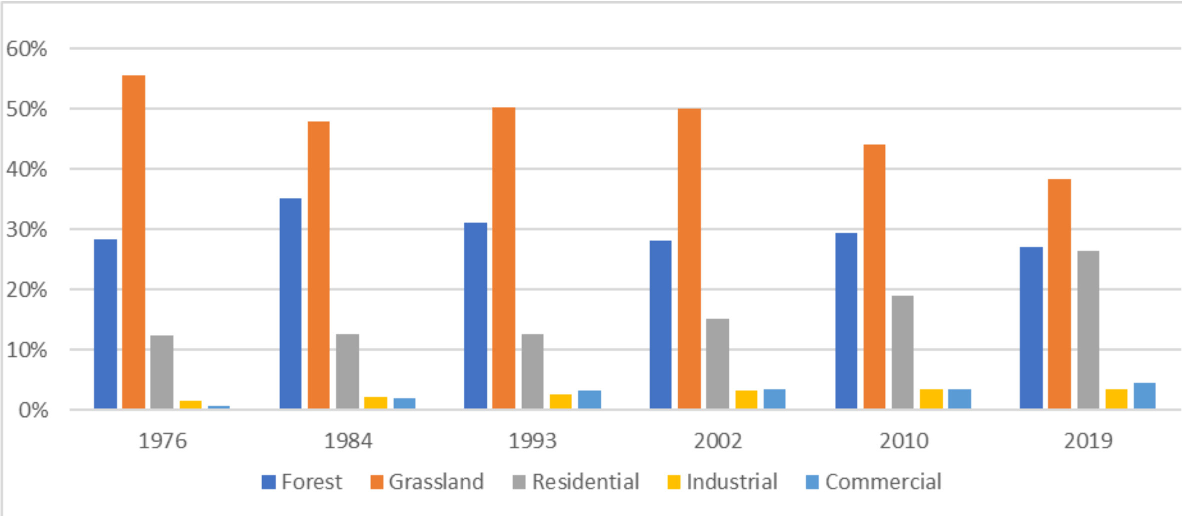


Figure 5: Percentage land use/cover over Nairobi City County from 1976 to 2019

Compliance Analysis

The compliance assessment in this study is limited to commercial, residential, and industrial land uses. These uses often encroached onto areas covered by forest, grass, and water bodies. The compliance assessment was done by extracting and superimposing development/zoning polygon onto the three classified land uses (commercial, residential, and industrial). The classified area that fell outside the zoned area was termed non-compliance, while the classified area within the zoned area was termed compliance. The percentages of non-compliance have been analysed and tabulated in the next sub-sections.

Commercial compliance

As shown earlier in the classification results, there was a general trend of increasing industrial, commercial, and residential activities over the last 43 years. It is important to note that the commercial activities zone increased after 2002 as a response to the pressure on limited space for commercial activities. Figure 6 shows the spatial correlation between planned and actual commercial activities over NCC from 1976 to 2019.

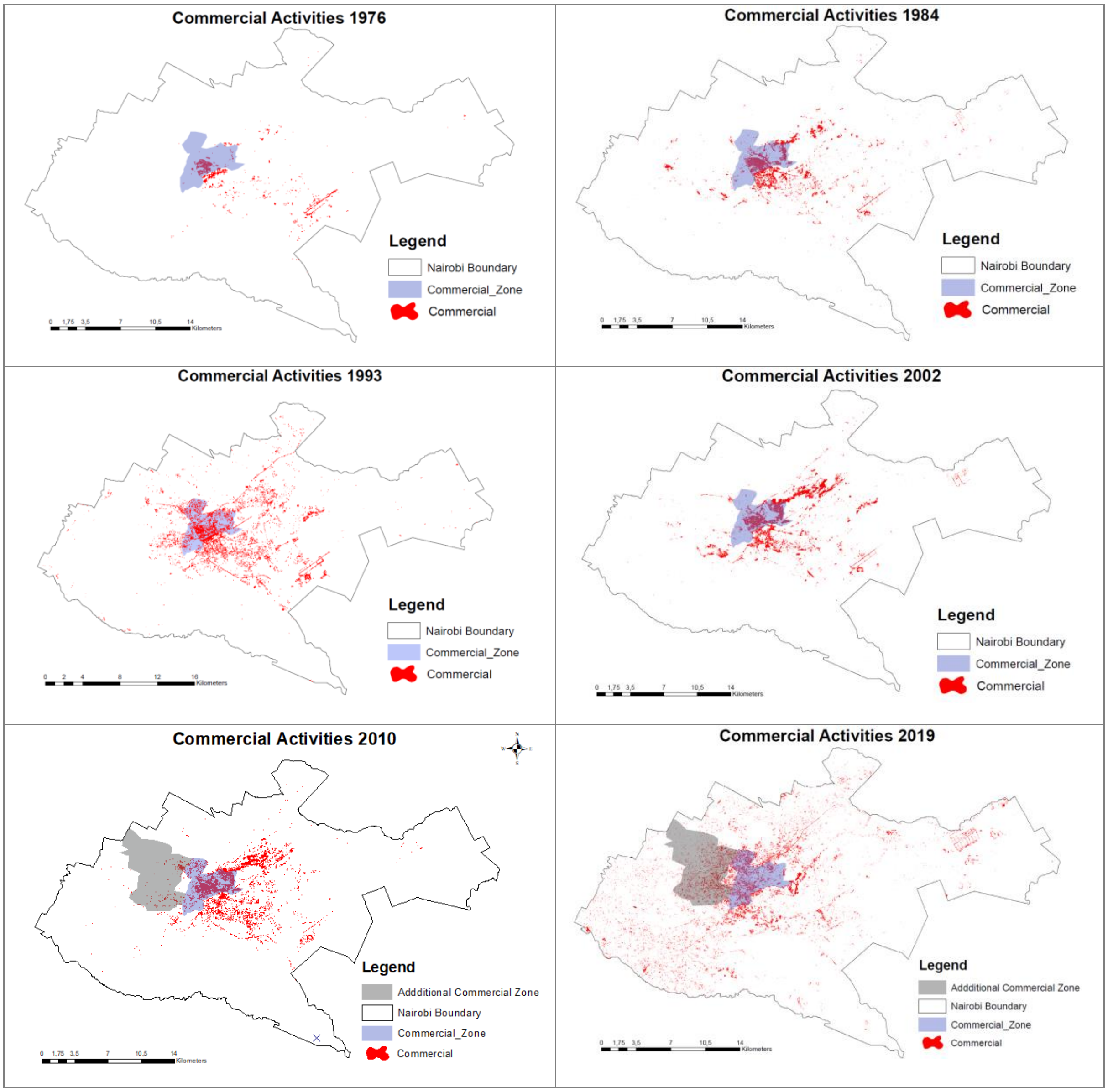


Figure 6: Spatial correlation of planned and actual Commercial activities in NCC from 1976 to 2019

There is a general increase in commercial activities outside the zone from the maps of 1976-2002. The maps for 2010 and 2019 show the additional zone which was made mixed land use in response to the pressure within the central business district. Table 2 shows non-compliance in commercial activities in NCC over the last 43 years.

Table 2: Non-compliance in commercial activities over NCC from 1976 to 2019

Year	Existing (Ha)	Compliance (Ha)	Non-compliance (Ha)	% Non-compliance
1976	495	135.06	359.94	73
1984	1394.62	471.23	923.39	66
1993	2330.01	521.53	1808.48	78
2002	2389.14	551.77	1837.37	77
2010	2448.27	896.24	1552.03	63
2019	3252.69	607.81	2644.88	81

The commercial non-compliance increased but remained relatively constant, ranging from 63 to 81%, with the highest non-compliance occurring in 2019. These statistics were not enough to assess the zoned area against the incompliant areas; thus, a comparison was made between the area planned and the incompliant area to assess the actual availability of land for commercial activities.

Residential compliance

The patterns in the residential also show a lot of non-compliant activities from the year 1976 to 2019. This can easily be explained by the growth of the informal settlements in the 70s, 80s and 90s, and since then, they have been increasing. The areas zoned for residential activities are relatively expensive, and only the middle-upper class and the upper class could afford to stay in the zoned areas. Even as late as 2019, the zone on the southwest i.e., Karen is still sparsely populated because of the high land and rent values. Figure 7 shows the spatial correlation between planned and actual residential activities over NCC from 1976 to 2019.

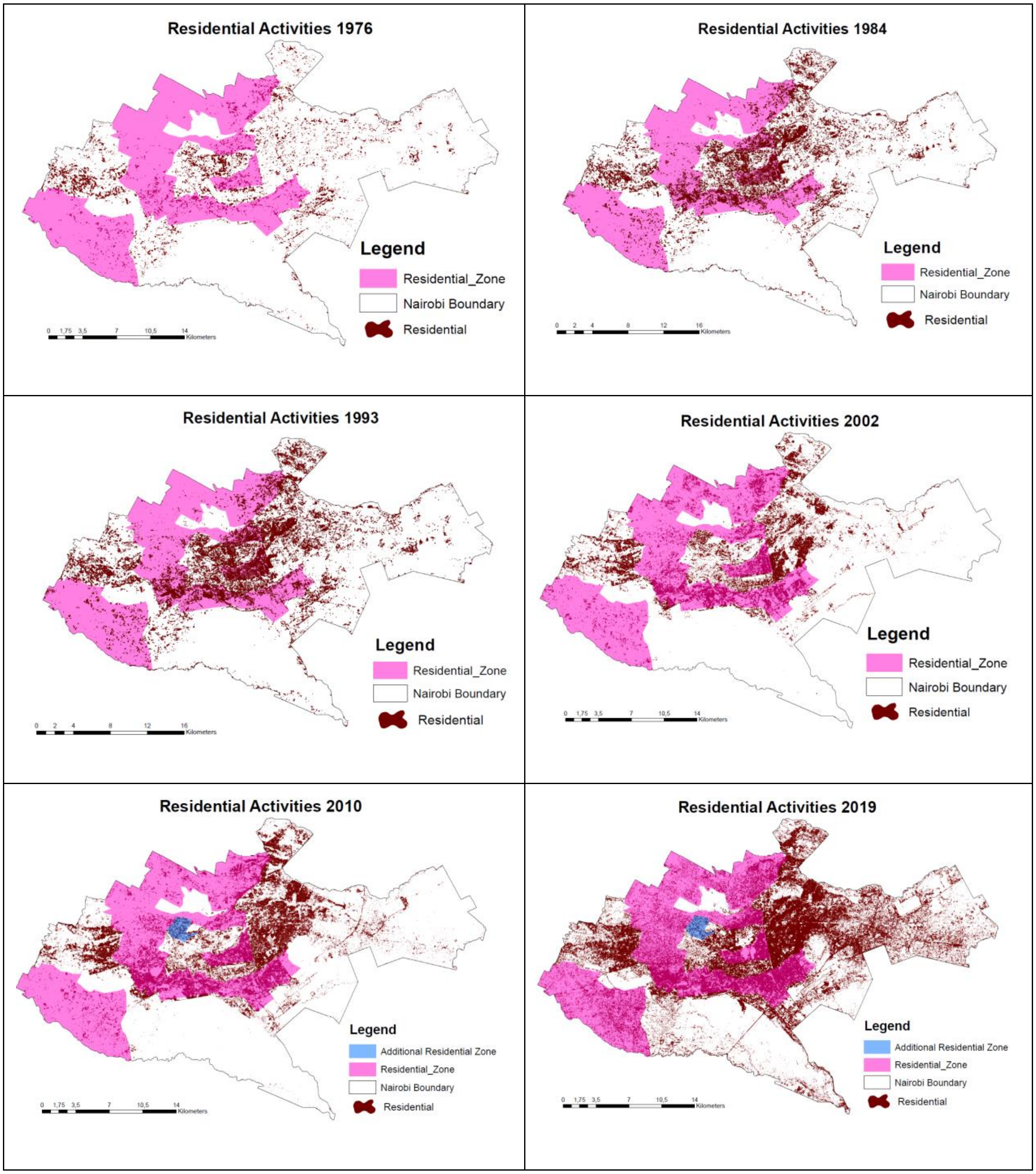


Figure 7: Spatial correlation of planned and actual residential activities in NCC from 1976 to 2019

The residential area demonstrated the highest non-compliance rate in 1993 (Figure 7 and Table 3) with 84% non-compliance. The patterns in the residential non-compliance cannot be explained by policy change, although the rate of non-compliance was already dropping between 1993 and

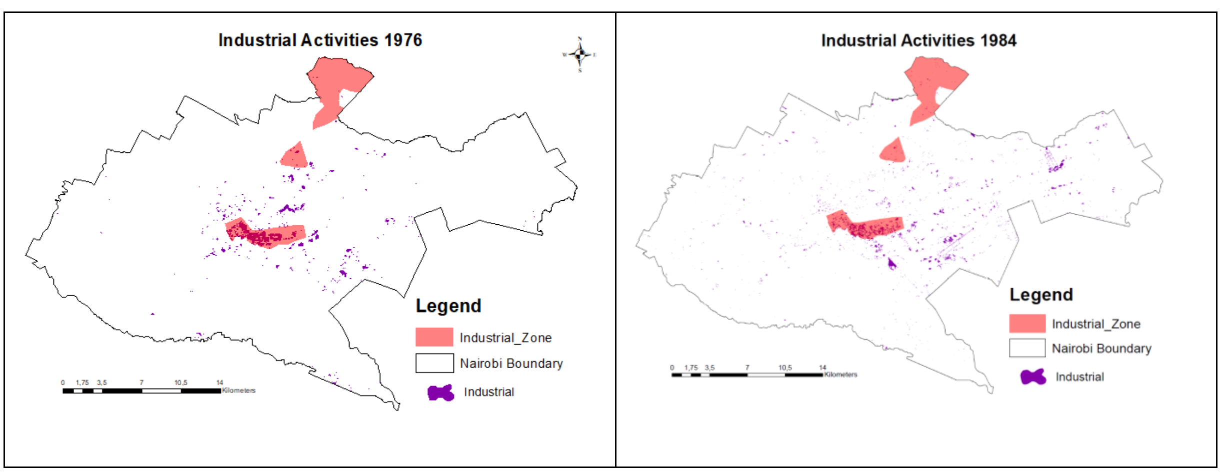
2002. The general reduction in non-compliance in residential land means that people are now more likely to live within the designated zones compared to the earlier years. However, it is important to note that residential area zoning was increased after 2002, hence the lower non-compliance rate compared to the previous years.

Table 3: Non-compliance in residential activities over NCC from 1976 to 2019

Year	Existing (Ha)	Compliant (Ha)	Non-compliance (Ha)	% Non-compliance
1976	8790.48	1908.07	6882.41	78
1984	8896.73	1585.61	7311.12	82
1993	8898.52	1380.42	7518.1	84
2002	10809.01	4664.71	6144.3	57
2010	13398.66	5614.52	7784.14	58
2019	18717.95	9217.05	16500.9	64

Industrial compliance

Similarly, the spatial trends in Nairobi's industrial activities show a consistent increase in industrial activities over the years (Figure 8). A lot of industrial activities seem to have been happening then and thereafter. The compliance level in industrial activities seems to have been relatively high in 1976.



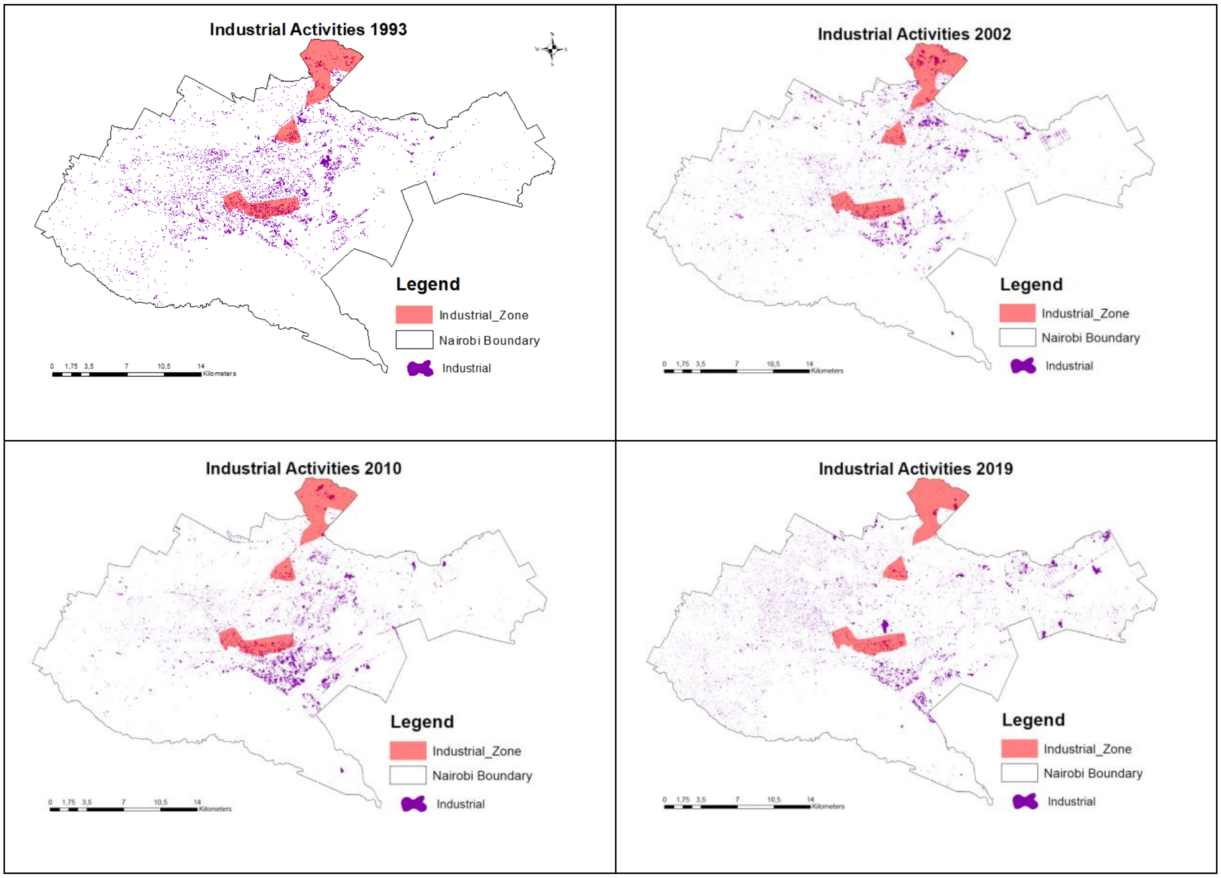


Figure 8: Spatial correlation of planned and actual industrial activities in NCC from 1976 to 2019

Table 4: Non-compliance in industrial activities over NCC from 1976 to 2019

Year	Existing (Ha)	Compliant (Ha)	Non-compliance (Ha)	% Non-compliance
1976	1097.28	379.8	717.48	65
1984	1588.95	220.75	1368.2	86
1993	1927.44	456.62	1470.82	76
2002	2265.93	394.28	1871.65	83
2010	2383.11	313.87	2069.24	87
2019	2493.99	196.42	2297.57	92

The industrial non-compliance experienced was slightly the same pattern as the commercial. Although the industrial zone remained unchanged, there was a reduction in pressure after the 2005 review. The non-compliance again went up, indicating more development and growth that could not be accommodated within the industrial zones in 2019. The non-compliance rate in

2019 was 92% which is the highest ever to be recorded. This means more factors are influencing the location of industrial activities outside the zoned areas.

Conclusion

This study aimed to assess the level of compliance of commercial, residential, and industrial development with zoning plans in Nairobi City County using remote sensing and GIS technologies. This was achieved by superimposing zoning plans on each land use (commercial, residential, and industrial) at six epochs (1976, 1984, 1993, 2002, 2010 and 2019). The choice of the epochs was based on the availability of clear satellite (Landsat) data and the desire to have a nearly 10-year interval (to enable change detection in an urban area).

The non-compliance rate for residential activities varied from 57 to 84%, while non-compliance rate for commercial activities varied from 63 to 81%, during the study period (1976–2019). The non-compliance rate for industrial activities was consistent over the years with population increase. Moving from 65% in 1976 to 92% in 2019, an indication of the steady growth in the industries within Nairobi City County. These results show that most residential, commercial and industrial activities take place outside the planned areas in Nairobi City County.

Despite the limitations mentioned earlier on the spatial resolution of the data, especially on the earlier satellite data, the GIS and remote sensing techniques effectively analyse spatial development compliance. Remote sensing technology can be integrated into the already existing online plans submission to ensure rapid compliance assessment on the master plans and zoning ordinances. This would reduce the cost of development control which is the most limiting factor to the consistency checks and enforcement of the zoning plans in Nairobi City County.

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