

Application of GIS to monitor infrastructural development in Mombasa County, Kenya

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Abstract

The Government of Kenya, under its Vision 2030 Agenda, highlighted the need for decent and high-quality livelihoods for its citizens, by ensuring that sustainable provision be made for the necessary infrastructure required to meet their socio-economic needs. Thus, the government invested in an Electronic Development Application Management System (e-DAMS). It allows the Built Environment professionals to register and apply for planning certificates, construction permits, building inspection permits, and occupation permits. However, this system can only regulate and monitor the existing infrastructure projects in the database and has to exclude unauthorised developments. This GIS approach, which was built upon the recording and tracking of several types of electricity applications made by customers, could also be used to monitor new and existing infrastructure developments. Data were sourced from multiple government agencies in Mombasa County. A comparative analysis approach was subsequently employed to investigate the relationship between the trends in electricity supply applications, the respective types of urban land-use development, and the permits issued in approving the respective types of construction in Mombasa County. A direct relationship was found between the permits used to approve the respective types of construction and the Urban Development Master Plan. Also, a direct relationship was found between the applications for the respective types of electricity that were being made and the issuing of construction approval permits. The conclusion was reached that the applications for the prevailing types of electricity supply could be used as a proxy for identifying and assessing infrastructural development in Mombasa County. This GIS approach could provide the authorities with insights into unauthorised construction initiatives.

Keywords GIS, Infrastructure planning, infrastructure development, infrastructure monitoring

1. Introduction

According to the Global Competitiveness Report, with a score of 2.91 out of a possible highest score of seven, Sub-Saharan Africa ranks lowest among all the developing regions in terms

of infrastructure development and performance (Calderon *et al*, 2018). Over the last decade, Kenya has experienced rapid urbanization, with counties, secondary cities, and towns expanding at a remarkably high rate of 3.99% per annum (UN-Habitat, 2018). In particular, it was noted that at the time of their establishment it was mainly the counties that lacked urban management institutions and urban development plans. As such, they tended to grapple with unplanned developments, informal settlements, and uncoordinated and unplanned land-use developments. This situation has led to the development of e-DAMS, an online platform supporting applications for construction permits, reviews, approvals, and the monitoring of proposed developments. However, the system only supports the monitoring and evaluation of those new developments and totally neglects unauthorized developments. Furthermore, given that the counties lack the capacity to conduct inspections, most cases of unauthorized development go unnoticed, which hinders proper development planning, monitoring, and evaluations in respect of the infrastructure.

The study in this paper is an off-shoot from our web-based GIS system that was developed separately and focuses on optimizing the electricity application process in Mombasa County. This study presents a unique application of GIS to monitor and track urban development more rigorously. It sought to identify the correlation between the electricity supply requirements of customers and the type of infrastructure development taking place within the county. Datasets from multi-agency systems were integrated into one database for cost-effective resource use and rigorous monitoring of the urban development process. This study demonstrates that a data-driven GIS approach can be used both remotely and cost-effectively to monitor the development of the urban infrastructure.

1.1. GIS for infrastructure development

Despite the fact that infrastructure development in Kenya has made some impressive achievements over the years, there is still a huge gap in the implementation of GIS as a support tool. In fact, there are siloed GIS systems within individual stakeholder organizations which make it difficult to effectively and efficiently collaborate, plan, monitor, and evaluate projects. This impacts on urban planning that relies extensively on geographic information. GIS, as an urban and regional planning tool, provides a decision-support framework for solving engineering problems in infrastructural studies (Masser & Ottens, 2019). Despite the successful implementation of GIS for the purpose of monitoring environmental issues associated with agriculture, fishing, tourism, and forestry in Africa, its contribution to infrastructural management has been neglected (Shingai, 2020). If well incorporated into the GIS realm, GIS offers the following benefits to developers and stakeholders.

1.1.1. Asset management

The question as to which resources are needed, where they occur, and how they can be located, exploited and made accessible is pertinent to every project discussion. A GIS framework provides answers to these questions by facilitating holistic evaluations of where infrastructure upgrades may be needed and where new infrastructures need to be developed, along with timeframes for each project, thus promoting proper resource allocation and exploitation (Shingai, 2020; ESRI, 2002).

1.1.2. Infrastructure planning

A GIS framework provides a great tool for planners by supporting their relevant planning and decision-making strategies (Yaakup *et al*, 2002; Jain & Subbaiah, 2007; Geospatial World, 2013; Chang *et al*, 2012). To avert the potential confusion caused by a lack of vital data, city officials in Addis Ababa, Ethiopia, have leveraged GIS to its well-deserved status position by developing a geodatabase that reflects the socioeconomic and housing status of its residents. This geodatabase provides key information to various stakeholders within the city and has led to the collection of increased revenues by the finance department; an increase in the issuing of title deeds to property owners, and the increased use of geospatial data by the urban planning departments in the city (ESRI, 2002).

1.1.3. Monitoring and evaluation

Monitoring forms part of an integral part of the urban planning process as it allows for the reviewing and updating of policies and strategic plans (Yaakup *et al*, 2002). It provides early warnings to stakeholders and points out any sources of friction, imbalances, shortfalls, and failures within the planning and management process (Yaakup *et al*, 1997).

1.2. Comparative analysis

A comparative approach is a methodology that analyses phenomena by putting them together to establish points of similarity and difference between them (Shahrokh & Miri, 2019). This technique is used to describe and explain relationships between two or among more phenomena by providing credible reasons among large-scale social units such as regions, nations, societies, and cultures (Adiyai & Ashton, 2017). The methodology employs both qualitative (descriptive) and quantitative (statistical) analytical skills. In fact, this technique has been employed extensively in the field of urban planning and the built environment. In France, for instance, this method was employed to conduct an analysis of the infrastructure and development of the transport sector (Maimunah, 2012). Also, this method has been employed in a study of the effect of infrastructure development on economic growth in developing countries (Suh, 2017).

2. Methodology

The study area was confined to Mombasa County, which is located along the coastal region of Kenya. It covers a land area of 229.86 km² and a water area of 65 km². The county hosts six constituencies, namely, Changamwe, Jomvu, Kisauni, Nyali, Likoni, and Mvita. For the purposes of infrastructure development and this study, the county was divided into four geographical zones, namely, Mainland North, Mainland West, Island, and Mainland South (Figure 1).

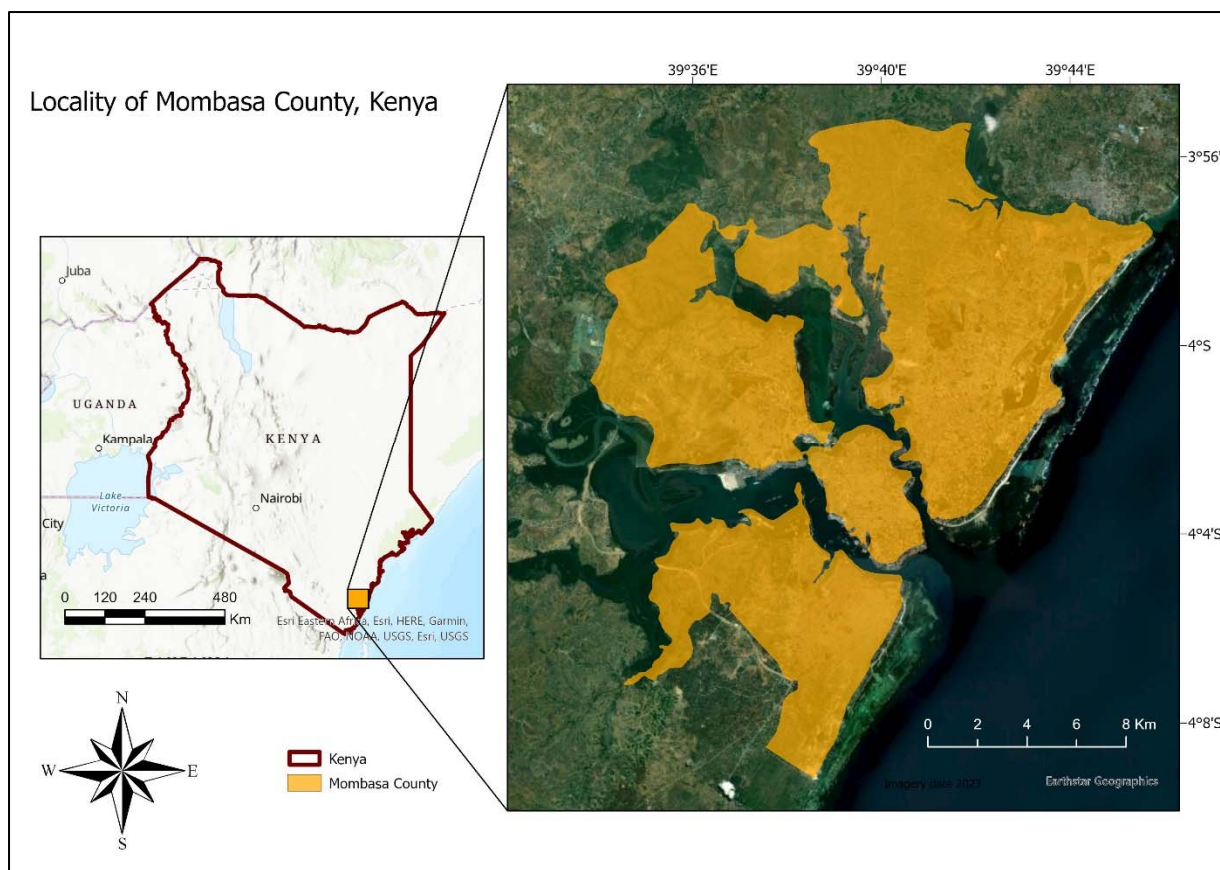


Figure 1. Mombasa County, Kenya.

This study leverages the foundational functionality of our web-based GIS to track diverse types of applications for new electricity connections in Mombasa County, Kenya. The development of the web-based GIS follows the waterfall system's developmental methodology, a linear and sequential approach where each stage progresses only after the completion and testing of the preceding stage. Building upon this foundation, we initiated the process of collecting and organising new datasets within a desktop GIS specifically developed for this study. The following datasets were included in the study:

- i. Statistics in respect of customers' electricity applications over the last three years - ,these including their applications for the various types of electricity connections that were being made within this period.
- ii. The Mombasa County Urban Development Master Plan that has been used as the benchmark against which progress in infrastructural development can be measured.
- iii. Approved construction permit data for Mombasa County which were used to identify the actual type of infrastructural development taking place within the study area.

Owing to the restriction on the data available at the time of the study, comparative analysis was the only feasible method of research to pursue. This method employed a qualitative approach to study the proposed Urban Development Master Plan as the basis of comparison. A quantitative approach was subsequently applied to assess both the electricity application types and the construction permit approval data. The categories within the separate datasets were restructured into corresponding groups (Table 1).

Table 1: Corresponding categories for each component of the infrastructure map.

TYPE OF ZONE	TYPE OF CONSTRUCTION PERMIT	TYPE OF ELECTRICITY APPLICATION
Commercial (business/tourism-oriented) Industry/logistics Transport	Commercial development Mixed development	Corporate applications
Residential (low, low-medium, medium, medium-high, high density)	Residential development	Individual applications Group applications
Commercial and Residential	Modification of a current development	Additional load Meter separation

This table facilitated comparison across multiple datasets and an analysis of the relationships between the relevant variables. A comparison was then made to establish the similarities and differences between the proposed infrastructure developments on the master plan and thereafter, the statistics pertaining to the approved construction permits. A comparison between the statistics relating to the approved construction permits and the application trends for new electricity connections was then carried out.

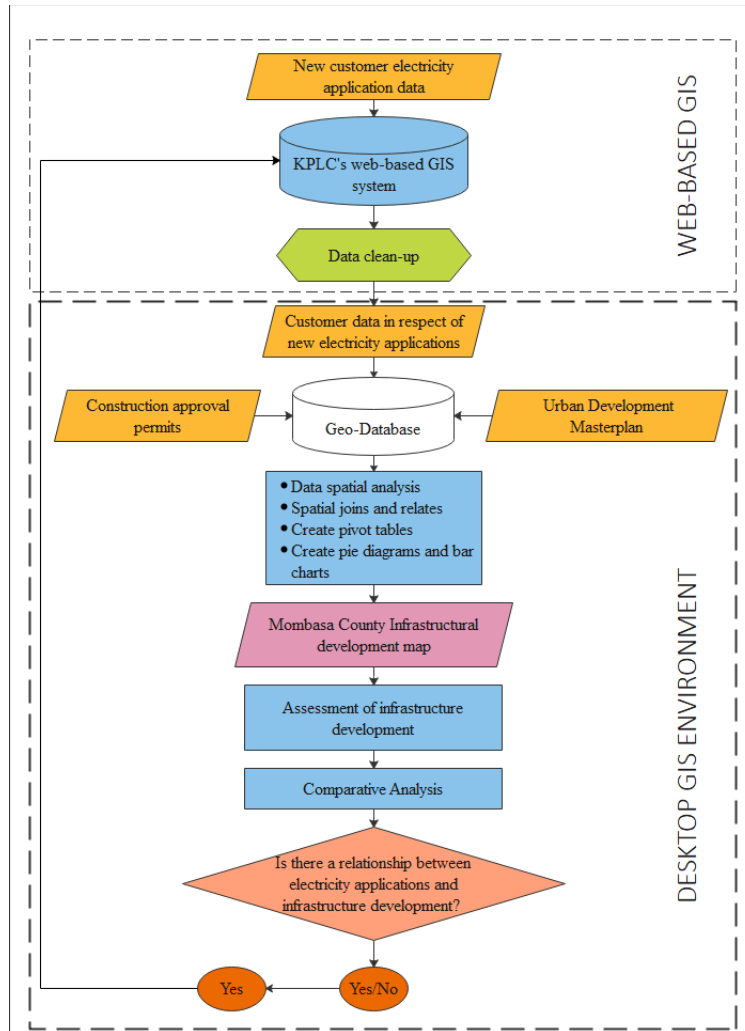


Figure 2. Methodology flow

Figure 2 shows the methodological framework that integrates the different components of the study to establish the relationship between applications for new electricity connection types and permit approvals in respect of the respective types of construction. This framework sought to clarify whether applications for new electricity connection types could be used as a proxy for asset management, and for planning, monitoring, and evaluating infrastructure development in Mombasa County.

3. Results

The comparison between Mombasa County's proposed 2015-2035 Urban Development Master Plan, the distribution ratio per geographic zone of the approved construction permits, and the trends in several types of electricity applications within the county are outlined below. Construction permits were categorized into four sub-sets, namely, residential development,

commercial development, mixed development, and modifications to existing developments (Table 2). The distribution ratio for each sub-set per geographical zone was then used to plot pie charts per zone (Figure 3).

Several applications for new electricity connection types were identified. They were based on the unique reference number normally generated when a customer submits an application documents. These references were grouped into categories indicating the probable type of construction development taking place in an area (Table 3). These categories were then used to plot bar graphs per geographic zone.

Each of these data category layers was visualized in order to examine the distribution of each development category. Furthermore, the results were displayed side-by-side to give a better view of the comparative analysis of the infrastructure development patterns in the county. Figure 3 displays the distribution ratio per geographic zone for the approved construction permit types compared to the defined urban development structure, as prescribed in the Urban Development Master Plan. Figure 4 displays trends in several types of electricity applications compared to the distribution ratio per geographic zone for the approved construction permits.

Table 2: Types of construction permit approvals.

TYPE OF PERMIT	DESCRIPTION
Residential development construction permits	Any construction permit application made for the development of bungalows, maisonettes, and apartments. Any application on the construction permits file, with a narration suggesting the construction of any of the mentioned constructions, was categorized under this type of construction for permit approval.
Commercial development construction permits	Any construction permit application for the construction of warehouses, container freights, and office spaces. Any narration suggesting the construction of any of the mentioned facilities on the permits file for the approval of construction was categorized under this class.
Mixed development construction permits	Any application made for the approval of any type of construction for the development of both commercial and residential units. Any narration suggesting such developments on the permits file for construction approval was categorized as such.
Modification of development permits	Any application made for the approval of any type of construction for conducting extensions to or alterations on an existing development. This type of development applies to any development, be it residential, commercial, or mixed. Any narration on the permits file for construction approval suggesting any of these types of extensions or modifications on an existing development was categorized under this class.

Table 3: Description of each type of electricity application

APPLICATION TYPE	DESCRIPTION
Additional load applications	These are applications for additional supplies of electricity by corporate/individual customers upgrading their electricity usage.
Corporate applications	These are applications for a new supply of electricity by commercial entities whose electricity consumption exceeds 3KV _a .
Group applications	These are applications for a new supply of electricity by a group of individuals residing in one locality.
Individual applications	These are applications for the supply of electricity by individual applicants whose electricity consumption is below 3KV _a .
Meter separation applications	These are applications for the installation of additional meters for either individual or corporate applicants.

4. Discussion

The main objective of this study was to ascertain whether application trends for new electricity connections can be used as a proxy for identifying and assessing the current level of development of the infrastructure. To achieve this, a comparison was carried out between the trends in the approval of construction permits *versus* the Urban Development Master Plan. Along with this, another comparison was carried out between the trends in construction permit approvals *versus* the trends in the applications for new electricity connections within the county.

i. Trends in construction permit approvals and in the Urban Development Master Plan

From Figure 3, it is evident that construction approvals are evaluated against the proposed development plan and structures, and only those applicants that comply with these requirements are approved and issued with a permit. Thus, there must be a 1:1 relationship between the approval for the respective types of construction permit and the proposed urban development zones on the master plan.

ii. Trends in approved construction permits and trends in new electricity applications

From Figure 4, it can be observed that the percentages in respect of the applications for the respective types of electricity correspond with the approval ratios within the

geographical zones of the county for the respective types of construction permits. Thus, the type of electricity application corresponds with and indicates the type of development taking place in an area.

These results have demonstrated that this GIS approach can help in remotely monitoring urban development, whether the developments be new or existing, authorized or unauthorized, cost-effective or not, and in a passive manner to reduce use of limited resources.

Discrepancies between the type of permit and the application for a specific type of electricity connection can also be an indicator highlighting non-conformity in respect of the approved development type in an area. This would help in the inspection of areas remotely and avert future non-compliance with laid-out development proposals and plans. Future studies could focus on a web-based GIS integration of this type of application, with other existing information systems, and incorporate data from different agencies within Mombasa County. This would allow for approved construction permits to be overlaid with the new electricity connection data to identify areas with gaps or spaces symbolizing unauthorized developments.

A hindrance to the study was that the data pertaining to construction approval permits were not date stamped and did not include the relevant geographical coordinates. Therefore, it was not feasible to conduct a least square regression analysis to establish a statistical relationship between construction permits and electricity application trends over time. Furthermore, some of the electricity application data were incomplete and did not contain any information pertaining to geographical coordinates. A change in data policy could allow for the capturing of date, time, and location metadata, based on the cadastral demarcation. This would facilitate credible data correlations in future studies.

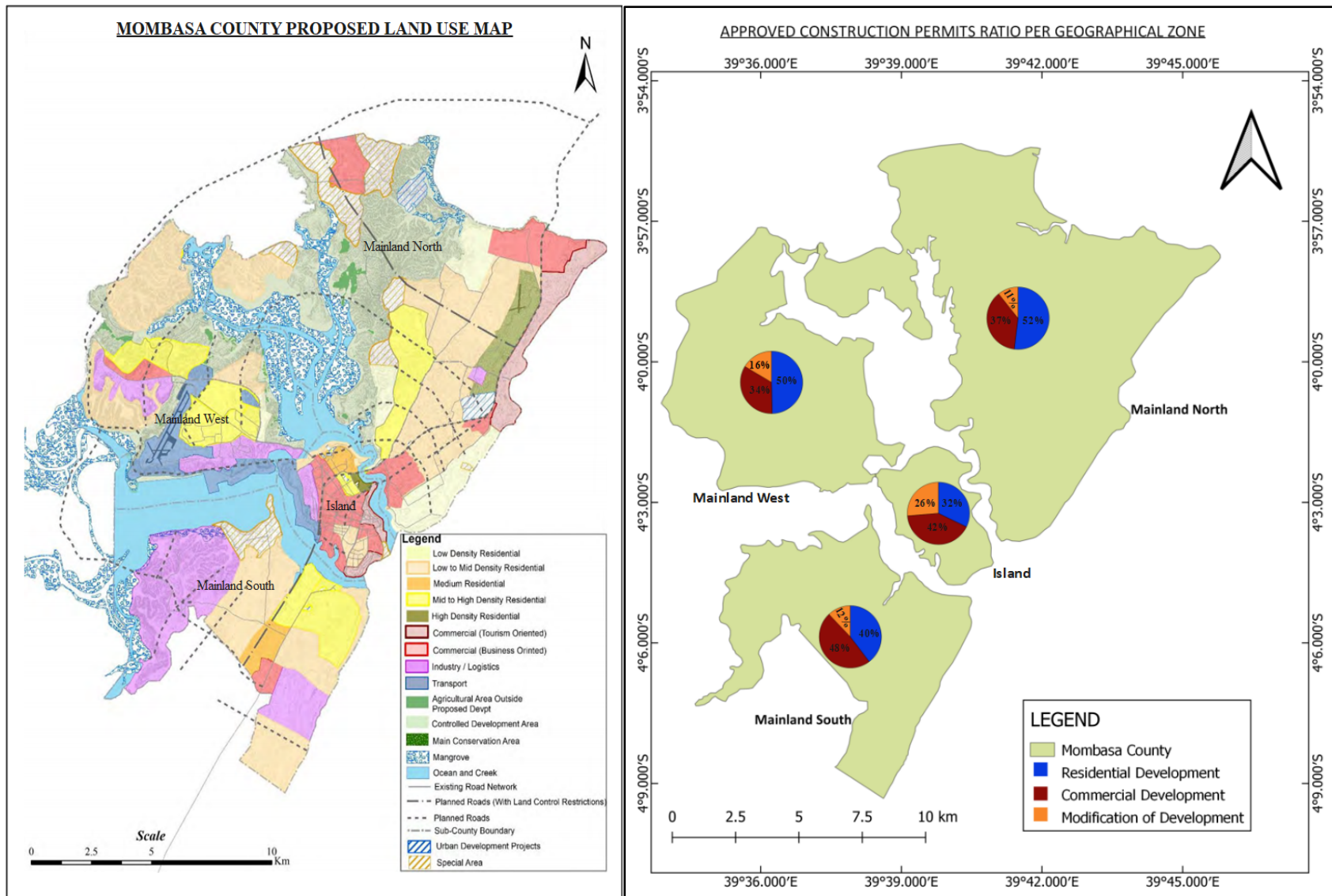


Figure 3. Proposed land use map (JICA, 2018) and approved construction permit ratio.

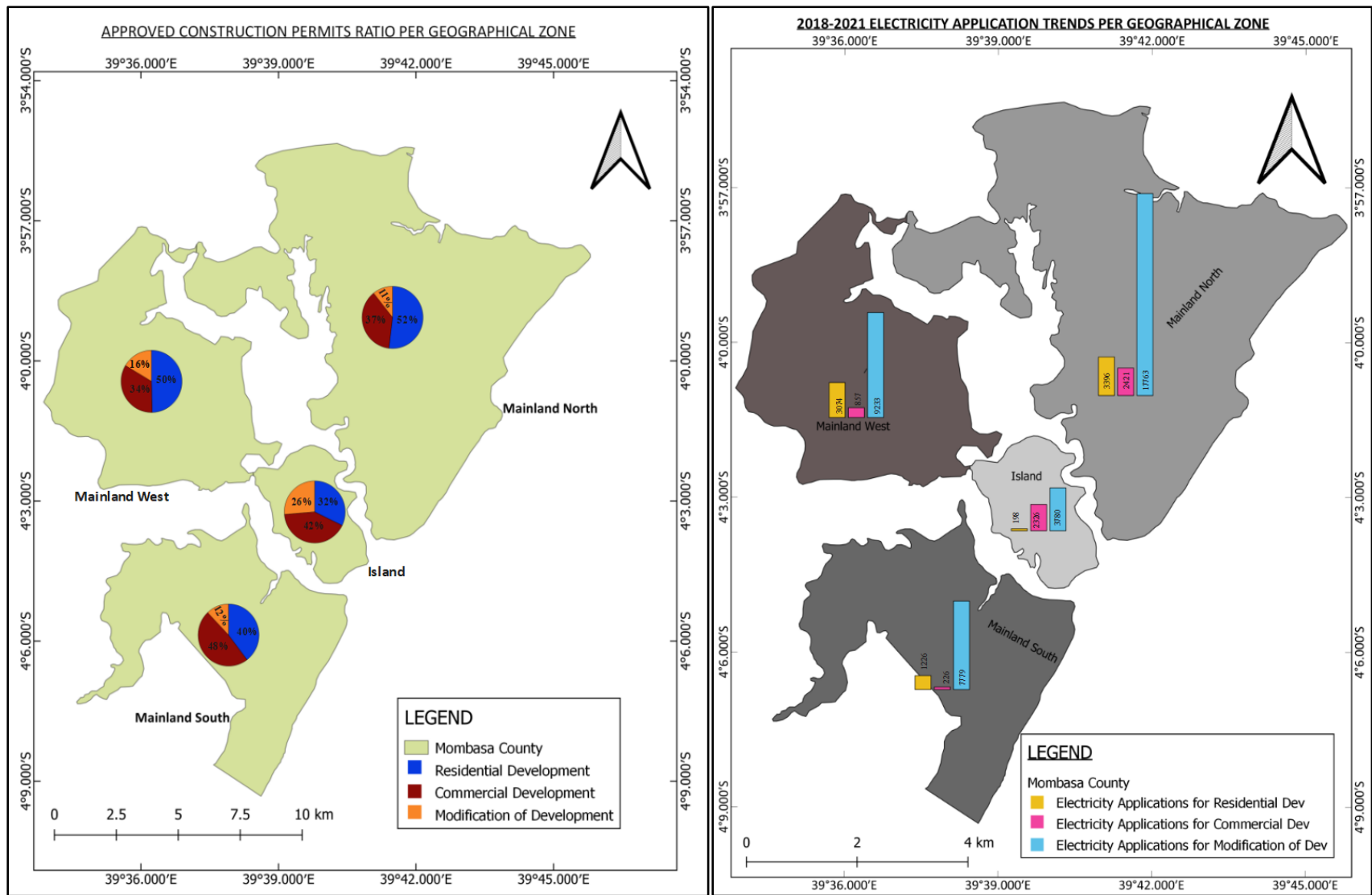


Figure 4. Approved construction permit ratio and the electricity connection trends.

5. Conclusion

This study has shown a direct relationship between the Urban Planning Master Plan, applications for the approval of construction permits and for the respective types of electricity connections. Together with the capabilities of a GIS, this knowledge can be leveraged to facilitate asset management and infrastructure planning, and also to monitor and evaluate infrastructure development in Mombasa County. This would be a cost-effective and resource-efficient manner of tracking the progress of ongoing infrastructure projects.

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