

Geospatial Technologies and Their Contribution to Cadastral Survey and Spatial Planning of Urban Expansion: A Case of Chuka Municipality, Tharaka Nithi County, Kenya

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Abstract

Urban expansion has become an unstoppable trend in many areas that fail to update their cadastral maps and land use plans, leading to unplanned, unsurveyed urban sprawl. This study uses Chuka municipality as a case to investigate the application of the cadastral system as a tool for urban regularization. Specifically, the study aims to examine current spatio-temporal urban changes and land-use trends; identify the key challenges and impacts arising from unplanned urban expansion; analyze the underlying drivers of urban expansion, including challenges and gaps in historical cadastral surveying; and finally propose geospatial technology-based strategies for sustainable urban redevelopment. Using a mixed-methods approach that combined quantitative and qualitative data, the study employed geospatial technologies to achieve its objectives. Using Sentinel-2 Land-Use Land-Cover data, the study found that the built-up area of Chuka Municipality increased by approximately 16.85% between 2017 and 2024, while cropland and tree cover decreased by 10.21% and 2.47%, respectively. Challenges associated with the boundary expansion included infrastructure and service overloads, informal settlements and tenure insecurity, and environmental degradation and risk amplification. The study also found that linear development along major roads, the rise of educational and social facilities (Chuka University and Kirubia Stadium, respectively), institutional and policy gaps in land administration, and technical limitations in cadastral frameworks were drivers of urban expansion. Finally, the study proposed geospatial technology-based strategies to address urban expansion, including multicriteria decision analysis for land suitability and participatory planning. The study covers the old Chuka Municipality and its expansion to the Ndagani neighborhood (Chuka University). The study excludes the rest of the municipality.

Keywords: Urban Expansion Challenges, GIS, MCDA, cadastral surveying, planning

1. Introduction

1.1 Study Background

All over the globe, cities are growing faster than the original land-use plans that were intended to accommodate them. Mahendra et al. (2020) highlight that less developed cities account for 90% of the expansion of built-up areas that were not planned for future needs. This condition creates unequal access to services, and by 2050, an estimated 2.5 billion people will likely lack adequate water and sanitation (Mahendra et al., 2019). Old cadastres and land registries are unable to curb this spread, which stretches to about 20-30% of farmland and flood-prone areas.

Extending infrastructure, such as roads and pipelines, to these ill-scattered areas costs about 50% more due to inefficiencies (Jaeger et al., 2012). Old historical-based land surveys are known to work well in the old era but fail to deal with the always-rising urban population, which is projected to expand to up to 68% in the year 2050, contributing to wasted land resources and outdated infrastructure that fail to serve the growing population (Friedmann & Douglass, 1978). Cities in Africa keep expanding without updated land and cadastral records and consume as much as 40% of the best farmland each year, while straining the infrastructure, as 90% of future urban growth is taking place where there is weak planning, leading to 60% of the city's peripheral residents lacking the most basic services (Lwasa & Kinuthia-Njenga, 2012). In 70-80% of the development just outside urban areas, it is entirely informal due to the absence of spatial and land-use planning frameworks. This inhibits organized land improvement and increases flood risk by about 25-50% due to unplanned development (Gasore, 2019).

Rapid growth along highways triples energy needs while reducing green space by about 35%. This is because the original plans did not account for population densities exceeding 10,000 people per square kilometer (Lwasa & Kinuthia-Njenga, 2012; Gasore, 2019; UN-Habitat, 2020). Urban property records are relics from colonial times and are therefore antiquated. Only 27 percent of these Kenyans, who live in urban areas with a population of about 13.8 million (Kenya, 2019), have piped water, and fewer than 25 percent are connected to sewers.

Conclusions from boundary assessments made in 1960 hold today, and urbanization projections indicate about 33.4% in 2030 (UN-Habitat, 2018; Cira et al., 2016). Proper land registration took place after independence in only 40% of towns. This has led to informal settlements where 50% of the urban poor live and has resulted in more than 200% traffic on roads in expanding areas (Nabutola, 2011; Cira et al., 2016). Furthermore, land records from before 1963 do not account for population growth rates of 8% to 40%, leading to infrastructure deficits of 70% and further widening social and spatial divides (Government of Kenya, 2015; Nabutola, 2011).

This outlines how, from global inequality to informal growth in Africa and service deficiencies in Kenya, the old land registries generate almost all urban problems. It has thus become critical

to update land information using modern geospatial tools to support sustainable growth management.

1.2 Problem Statement

Urban areas drive 80% of global GDP and national development through economic hubs and infrastructure, yet rapid population growth demands adaptive planning and subsequent cadastral surveying. Nevertheless, initial land use planning and cadastral frameworks, designed without provisions for future expansion, lead to uncontrolled sprawl, informal settlements, and strained Infrastructure services such as roads and water. This study uses Chuka Municipality in Tharaka-Nithi County, Kenya, as a case to illustrate these dynamics.

1.2.1 Significance of the Study

This study examines geospatial technologies as tools to address challenges of urban boundary expansion, using the case of Chuka Municipality, focusing on cadastral resurveying, aerial mapping, GIS-based land-use analysis, and remote sensing to support updated planning. By mapping spatio-temporal changes and proposing strategies such as MCDA zoning, it offers practical solutions for sustainable infrastructure, tenure security, and outward growth management, benefiting planners, policymakers, and similar towns.

1.2.2 Study Objectives

1. To examine the current urban spatial-temporal changes and land use trends in Chuka Municipality
2. To identify the key challenges and impacts arising from unplanned urban expansion in Chuka Municipality
3. To analyze the underlying drivers of urban expansion challenges and gaps in historical cadastral surveying in Chuka Municipality.
4. To propose geospatial technology-based strategies for sustainable urban growth and development

1.2.3 Research Assumptions

1. Spatial-temporal changes and land use trends have not been systematically planned and surveyed in Chuka Municipality
2. Geospatial technologies can promote sustainable urban growth and development

1.3 Relevant Scholarship

1.3.1 Theoretical Background

1.3.1.1 Concentric Zone Theory

Ernest Burgess developed the Concentric Zone Theory of urban land use in 1925. According to this theory, urban land develops by expansion in circles from the central business district (CBD),

with different zones for industry, working-class housing, middle-class residences, and commuter suburbs, while assuming the land to be flat and uniform invasion succession processes (Burgess, 1925; Park & Burgess, 1925). The theory points to many urban problems, such as density gradients that place infrastructure under great pressure and zoning conflicts when expansion encroaches on agricultural fringes without cadastral updates, as rings fail to predict irregular sprawl (Aliaga et al., 2013).

The greatest strengths of the theory are its simplicity that allows the visualization of socio, economic segregation and the historical fit for industrial cities like Chicago, where it predicted 20, 30% land value drops per ring; however, the weaknesses of the theory include oversimplification that ignores topography, transportation, and modern polycentric growth, which makes it inadequate for 68% global urbanization projections by 2050 (Burgess, 1925; Park & Burgess, 1925; Aliaga et al., 2013).

The theory can be linked to urban challenges by showing the cadastral inflexibility of fixed zones, which is good for initial planning but is not robust to changes in land subdivisions due to a population surge, and it has been criticized for ignoring peripheral informal encroachments (Harris & Ullman, 1945).

1.3.1.2 Sector Theory

In 1939, Homer Hoyt put forward the Sector Theory as an adaptation of the Concentric Zone idea. He argued that urban growth sectors take the form of wedges along transportation corridors leading from the CBD, so that the high-rent areas are linearly extended by rail/road access, while the low-income zones fill the leftover spaces.

It is one of the solutions that sprawl along highways, where sector intensification exacerbates infrastructure strain, e.g., a 25% rise in vehicles per kilometre in linear developments due to land-use segregation without boundary resurveys (Aliaga et al., 2013). They are tasked with incorporating the role of the transport to explain 40% of Chicago's radial patterns and among their strengths is the subdivision planning for efficient services made possible by transport; on the other hand, the overemphasis on socio, economics, the disregard of multiple nuclei or topography, and the restrictions that come with applying the theory to non-western cities with 70% informal sectors are some of the flaws (Gasore, 2019).

This model can support cadastral relevance by advocating linear parcel alignment; however, it cannot anticipate further expansions as sectors become rigid in the face of polycentric problems, such as peri-urban voids.

1.3.1.3 Multiple Nuclei Theory (Proponent Theory)

Chauncy Harris and Edward Ullman are credited with introducing the Multiple Nuclei Theory in 1945, in which they improved previous models by showing that cities grew around several nodes

(e.g., airports, universities) rather than a single central business district. This development was influenced by the terrain, agglomeration economies, and land-use compatibility, thereby allowing for decentralized subdivisions. The theory helps to understand urban problems like sprawl through nodal cadastre, where nuclei contribute 50- 60% to the outward growth; thus, links suffer without geospatial updates; however, it still averts the transition of land uses through remote sensing (Harris & Ullman, 1945)

Their strengths lie in the depiction of modern cities' reality, thus accounting for about 80% of the world's cities exhibiting polycentric patterns, the capacity to adapt to topography, and the merging of the cadastre for multi, nodal surveying which, to a great extent, overweigh the vulnerabilities such as the lack of clarity in the formation of the nodes or the failure to consider slums which, however, are taken care by the use of modern geospatial tools (Harris & Ullman, 1945).

As the main theory, it stands out by placing geospatial technologies for cadastral renewal within the context of expansion, as, compared to the rigid predecessors, it has fewer flaws in a dynamic context.

1.3.2 Empirical Literature

1.3.2.1 Urban spatial-temporal changes and land use trends in Urban Areas

Globally, Taubenbck et al. (2021), who conducted a study on the impact of urban sprawl on sustainable development in Asian megacities, found that 15-20% of the area was urbanized from 2000 to 2020 through a time series analysis of Landsat images; their work cannot be faulted for multi, year precision (85, 92%) but the 30m low resolution can be a disadvantage behind going without micro-subdivisions (Taubenbck et al., 2021).

Rawat and Kumar (2015), who made urban sprawl maps for Hyderabad, India, found using LISS, IV images that a 28% area of agriculture had been converted to urban areas which agrees with the Mahendra et al. (2019)'s research on upward/outward city expansion in the Global South that found 90% of low, income population growth via the use of Sentinel data. The two studies have contributed to the change-detection literature, and their work has been reviewed by Jaeger et al. (2012), who addressed urban sprawl issues and criticized the studies for ignoring cadastral integration and overemphasizing metrics. The studies support the idea that LULC changes have far exceeded local development. However, they differ on the issue of fragmentation: Rawat and Kumar (2015) underestimated the next-door city pattern by 10% relative to Taubenböck et al. (2021).

In Africa, Shah Heydari et al. (2024), who examined urban change hotspots in Ethiopia, Nigeria, and South Africa, detected 1.5% growth using Sentinel-2/Landsat (2016, 2020), achieving 90% pixel-to-person accuracy but struggling with spectral confusion for "red blob" classes. Gasore (2019), researching the role of cadastral data in peri-urban planning in Kigali, reported that about

70% of Land Use Land Cover (LULC) changes were remapped using a hybrid GIS, thus agreeing with Mabin et al. (2013), who analyzed Polokwane rangeland-to-urban changes based on a 40% agricultural conversion. Both were field-validated but limited to 5-year spans, thus ignoring cadastre obsolescence; by contrast, Heinrigs (2020) studied African agglomerations and argued that, without VHR data, 20-30% trend inflation is possible.

Among the Kenyan studies is Ndengu (2001), who studied technology for urban decision-making in Nairobi and used GIS to analyze LULC of 1990 and 2010, showing 35% built, an increase through matrix modeling technique; it has strong ecological services (ES) quantification but weak in pre-2010 data gap (Ndengu, 2001). Ouma et al. (2025), working on spatio-temporal LULC in drylands, attained 92% accuracy, which agreed with Mwaura (2023) who reported Nakuru UPA urban sprawl of 25% through Rapid Eye, both were validated but according to Nabutola (2011) who studied urbanization management after the Constitution of Kenya (2010) lacks overlaying of cadastral amidst 8-40% of population, driven trends which are contradictory to UN, Habitat (2018) analysis of informality voids.

These empirical studies agree on the use of geospatial technologies for tracking gender; however, they also reveal the lack of integration between cadastral and longitudinal data, which needs to be addressed by projection hybrids.

1.3.2.2 Challenges and impacts arising from unplanned urban expansion

Informal Settlements

Jaeger et al. (2012), who analyzed urban sprawl planning challenges globally, quantified 50-60% of the urban poor in 30% of fringe encroachments, without using tenure surveys (Jaeger et al., 2012). Gasore (2019), studying Kigali peri-urban cadastral gaps linked to 70% informality, amplified exclusion, per Shah Heydari et al. (2024)'s African hotspots research. UN-Habitat (2018), focusing on Kenyan urban planning, reported that 56% of Nairobi slum dwellers were from areas outside the 1963 boundaries.

Environmental Effects

Taubenböck et al. (2021), examining Asian megacity sprawl, found a 20-35% loss of green space, raising flood risks by 25-50% in the absence of LULC baselines. Shah Heydari et al. (2024) and Mabin et al. (2013), studying African urban hotspots and shifts in Polokwane, noted that 40% of arable land is eroded, worsening the climate. Ouma et al. (2025) found that in Kenyan drylands, less than 25% of sewerage was linked to river pollution.

Infrastructure Strains

Mahendra et al. (2019), researching Global South expansion, showed 50% cost hikes overloading services for 2.5B by 2050. Gasore (2019) highlighted 90% African peri-urban gaps.

Cira et al. (2016), studying Kenyan plan barriers, and Nabutola (2011) noted 70% deficits with 200% road overload.

Security and Social Insecurity

Friedmann and Douglass (1978), analyzing city sprawl management, linked 30-50% fringes to crime zoning. Lwasa and Kinuthia-Njenga (2012) linked greater than 10,000/km² densities to gang recruitment in East Africa. UN-Habitat (2018) also detailed Kenya's 50% segregation of the urban poor.

1.3.2.3 Drivers of urban expansion challenges and gaps in historical cadastral surveying

Globally, numerous scholars have studied on the drivers of urban expansion, for example, Li et al. (2022), who examined the driving forces of urban land expansion in Mentougou, China through the use of Google Earth Engine, firstly by random forest modeling figured out that elevation, collapse risk, and fiscal expenditure are the main influence factors, which allowed them to attain a very fine non-linear detection (85% accuracy).

However, this study is somewhat limited by its disregard for socio-political aspects of tenure gaps in cadastral legacies (Li et al., 2022). Arsanjani et al. (2013), who only dealt with global urban growth patterns using cellular automata in their study, discovered that population density and accessibility explained about 40% urban sprawl, which is consistent with the study of Seto et al. (2012) who determined the main drivers of urban expansion worldwide to be GDP and neighborhood effects, both studies scoring high in terms of predictive potential but being criticized by Jaeger et al. (2012) who looked at the problematic nature of urban sprawl for not taking into account the historical rigidity of cadastral that can increase costs by 50% (Arsanjani et al., 2013; Seto et al., 2012; Jaeger et al., 2012).

All the studies agree on the biological, physical, and economic drivers, but differ in their views on governments' roles. Li et al. (2022) estimated the impact of migration on urban expansion to be 15-20% lower than that reported by Seto et al. (2012).

On the African continent, Adjei Mensah et al. (2024), who studied the effect of urban expansion on changing agricultural practices in Hawassa, Ethiopia using GIS, identified human population growth and the closeness to the highways as two factors contributing to 60% of the total variation, the results are grounded in historical and future simulations but not very strong in terms of the integration of the cadastral system given the existence of historical voids (Adjei Mensah et al., 2024).

Using logistic regression, Cofie et al. (2023), exploring land cover changes and urban drivers in Wa, Ghana, discovered that topography and GDP were the main factors that led to 35% expansion, which is in agreement with Mabin et al. (2013)'s Polokwane rangeland shifts based on economic priorities, both of which are field, validated but limited by short, term data that do

not account for colonial cadaster gaps unlike Gasore (2019), who looked at Kigali peri, urban cadastral roles and maintained that 70% informality was due to outdated surveys. (Cofie et al., 2023; Mabin et al., 2013; Gasore, 2019). These places have agro-conversion (40%) at the center, but are at odds with Heinrigs (2020), which undercounts agglomeration by 25%.

Kenyan studies include Siriba et al. (2011), which examines cadastral changes after independence and, using archival sources, reveals that adjudication gaps allowed peri-urban areas to expand by 30-40%. This study is strong in historical depth but lacks geospatial quantification (Siriba et al., 2011). Based on the constitution, Nabutola (2011) observed how changes in urbanization management has featured migration and tenure reforms linked to the overloading of infrastructures, which agrees with the Cira et al. (2016) study that identified the barriers to urban plans as including mainly fiscal and policy drivers accounting for 70% deficits, both being policy, oriented but, according to Ndengu (2001), they lack LULC overlays to explain an 8, 40% population growth (Nabutola, 2011; Cira et al., 2016; Ndengu, 2001). The study stresses post-1963 gaps but differs from UN-Habitat (2018) on informal drivers.

The empirical results reveal that population and economic factors are the main drivers of cadastral obsolescence; therefore, policy should incorporate thorough historical and geospatial evaluations.

1.3.2.4 Geospatial technology-based strategies for sustainable urban development.

Globally, a study conducted by Taubenbck et al. (2021) on urban sprawl mitigation in Asian megacities using multi-temporal Landsat and Sentinel-2 data revealed that an integrated remote sensing strategy can allow 92% accurate LULC forecasting aimed at curbing 15- 20% expansion rates, a strength of scalability, but cloud interference in monsoonal areas has weakened this capability (Taubenbck et al., 2021). Li et al. (2022), at the same time, are working on the cadastral renewal for land expansion control in Mentougou,

China, through Google Earth Engine and random forest, suggested parcel dynamic mapping that could reduce risks by 85%, which is in line with Arsanjani et al. (2013)s cellular automata modeling for global urban simulation achieving predictive precision, however, both of them have been criticized by Jaeger et al. (2012), who examined sprawl planning tools, for lack of legal integration that results in 50% implementation cost inflation (Li et al., 2022; Arsanjani et al., 2013; Jaeger et al., 2012). These researchers are unanimous in their view of the effectiveness of geospatial hybrids for zoning. However, they differ in their prioritization of biophysical versus socio-economic aspects, with the work of Taubenbck et al. (2021) insufficient to address the tenure gaps that are evident in Li et al. (2022).

In the African context, Gasore (2019) investigated cadastral and GIS strategies for peri-urban sustainability in Kigali, Rwanda, and found that drone-based surveying significantly increased tenure security to 80% against historical voids, was robust in field validation, but was limited by high costs for scaling (Gasore, 2019). Adjei Mensah et al. (2024), with a focus on predictive

modeling for the urban, agro balance in Hawassa, Ethiopia, utilizing GIS, cellular automata, presented scenario planning that would save 60% of the farmland, which is in agreement with Cofie et al. (2023)'s logistic regression study for Wa, Ghana which projected 35% controlled growth, both very much focused on the future while according to Mabin et al. (2013), who studied South African urban dynamics.

These two are limited in their multi-stakeholder integration, as they overlook about 40% of informal conversations (Adjei Mensah et al., 2024; Cofie et al., 2023; Mabin et al., 2013). They agree on the use of remote sensing for sprawl regulation but disagree on the weighting of the economic drivers, with Gasore (2019) prioritizing cadastre over Cofie et al. (2023)'s focus on topography.

In Kenya, Ndengu (2001) maintained that GIS and matrix modeling can support 35% LULC trend management for sustainable zoning by excelling at ES assessment. However, they are limited by pre-2010 data (Ndengu, 2001). Ouma et al. (2025) came up with monitoring measures that can be implemented with 92% accuracy for the control of expansion, thus in line with Nabutola (2011)'s post-Constitution planning tools that propose aerial surveys for 70% infrastructure alignment, both tried and tested. However, UN-Habitat (2018), which reviewed urban planning frameworks, criticized them for relying on small-sample studies of urban centers and thereby ignoring national cadastre reforms (Ouma et al., 2025; Nabutola, 2011; UN-Habitat, 2018). These agree on GIS for Kenyan sprawl but conflict with Siriba et al. (2011) on historical cadastral emphasis, as Ndengu (2001) underplays post-1963 gaps (Siriba et al., 2011).

Across scales, empirical studies endorse geospatial strategies such as GIS-cadastral hybrids to curb expansion, reporting 80-92% accuracy gains, yet disagree on the socio-legal versus biophysical foci; major gaps persist in affordable, integrated models for developing contexts, underscoring the need for MCDA-enhanced approaches that bridge historical surveys with predictive zoning.

Tools

GIS and Remote Sensing for LULC Monitoring

Taubenbck et al. (2021) pointed out the advantage of multi-temporal scalability in reducing planning errors by 20%, but also the disadvantage of cloud, which is prone to data gaps in tropical areas (Taubenbck et al., 2021). Shah Heydari et al. (2024), on the other hand, commended the pixel-to-people GIS for 90% accurate hotspot delineation, thus agreeing with Rawat and Kumar (2015)'s mapping of Hyderabad. However, they were criticized by Gasore (2019) for requiring cadastral layers to limit peri-urban voids to 70% (Shah Heydari et al., 2024; Rawat & Kumar, 2015; Gasore, 2019).

All these methods are very good at detecting trends; however, they cannot do so without ground-truthing. Thus, Ouma et al. (2025) facilitated Kenyan drylands with RapidEye hybrids (Ouma et al., 2025).

Cadastral Resurveying and Drone/Aerial Mapping

To address accuracy issues in Kigali peri-urban cadastres, Gasore (2019) suggested comprehensive GIS and drone resurveys to maintain a tenure accuracy level of 80%, which should be the minimum required to address all scenarios adequately. One can interpret that such an approach would be highly resistant to historical gaps. However, at the same time, there will always be the problem of high cost, especially in low-resource settings, according to Siriba et al. (2011) (Gasore, 2019; Siriba et al., 2011).

On a global scale, the work of Li et al. (2022) integrates GEE to dynamically update parcels, which aligns with Ndengu (2001), who proposed the use of technology in Nairobi. The two studies are strong in non-linear modeling but weak in integrating the law. As Jaeger et al. (2012) showed, there was a 50% cost overrun in the absence of proper policies (Li et al., 2022; Ndengu, 2001). In Kenya, Nabutola (2011) argued that aerial photographs were the best way to conduct zoning after the Constitution, mainly because surveys were experiencing significant static challenges (Nabutola, 2011).

MCDA and Predictive Modeling for Zoning

Mahendra et al. (2019), while studying Global South urban expansion, suggested using MCDA and GIS for equitable zoning and predicted that, if their proposal were implemented, growth would be reduced by 90%. They pointed out that MCDA offers the attractive feature of flexibility across multiple criteria, but the main problem, according to Arsanjani et al. (2013), is data scarcity, which hinders progress (Mahendra et al., 2019; Arsanjani et al., 2013).

Adjei Mensah et al. (2024), in their application of cellular automata to visualize the developmental futures of Hawassa, are therefore in agreement with Cofie et al. (2023), who interpreted the situation in Ghana as one of good logistics. At the same time, they were identified by Mabin et al. (2013) as overly optimistic, as they ignored 40% of agro-loss (Adjei Mensah et al., 2024; Cofie et al., 2023; Mabin et al., 2013). In Kenya, UN-Habitat (2018) used predictive GIS to achieve 70% deficit closure, with minimal flaws in validated scenarios (UN-Habitat, 2018).

These geospatial strategies demonstrate superior adaptability compared to traditional methods, converging on a hybrid cadaster-modeling approach for sustainability.

2. Research Methodology

2.1 Research Design

This research follows a mixed-methods design, with a study framework for explanatory purposes. The choice of a mixed-methods study design is well justified because it allows exploration of multiple methods. Qualitative, quantitative, and spatial data have been collected. Thus, the design provides a rich, multifaceted investigation of the urban expansion issues affecting Chuka Municipality. The mixed-methods feature is that quantitative geospatial data and qualitative contextual data are collected and analyzed simultaneously but separately; the interpretation and triangulation of the combined results help create a holistic understanding.

In the field, scholars such as Taubenbck et al. (2021) and Gasore (2019) have been personally employing mixed geospatial analyses to diagnose urban sprawl in specific cities. In their studies, they have combined satellite image interpretation with ground observation. This work not only follows but also significantly broadens this method by incorporating a professionally generated and preserved cadastral dataset from the 2020 Chuka Municipality mapping project. Thus, the study adds an action research perspective. Pragmatically, the design aims at producing not just diagnostic knowledge but also prescriptive, technology-based planning solutions.

2.2 Study Area

Chuka Municipality in Tharaka-Nithi County, Kenya, is used as the primary case for the research. The town boundary has since been expanded to encompass the now-Chuka Municipality. The town was recently upgraded to a municipality; the primary focus of this study remains the old town area and its immediate environs of Ndagani. It is a typical secondary town that is rapidly expanding and unplanned, with the expansion beyond its boundaries into agricultural zones.

The town is located on a major transportation route (Class A9 Road) that, according to Sector Theory (Hoyt, 1939), places it on a path of linear development that, most of the time, outgrows the town's formal planning frameworks. The way it is expanding from a well-defined Central Business District (CBD) to include agricultural and residential areas on the periphery is a perfect example of what the study on the dissonance between old cadastral maps and new urban dynamics is all about.

The researcher chose Chuka Municipality deliberately because he was deeply involved in a large geospatial mapping project for the town in 2020, which gives him a unique, high-resolution baseline dataset. This prior involvement made it possible to conduct a study, not merely seeing the town as a subject of investigation but as an active ground on which cadastral surveying and land-use planning strategies can be put into practice and critically assessed.

The town of Chuka, as per the local physical development plan (L.P.D.P.) that was approved in 1988, has an area of about 462 hectares. However, the county team determined the survey area,

shown in Figure 1. The project area is approximately 39 percent of the entire town area. The project area includes the area between Chuka Girls (west), Kathituni Primary, and Chuka Hospital, with Chuka Hospital being furthest to the East. Chuka Boys' High School is situated in the South of the project area. North is where Chuka University is, which is slightly isolated due to the many valleys between the two locations. Figure 1 gives the breakdown of the surveyed area as a percentage of the total town area.

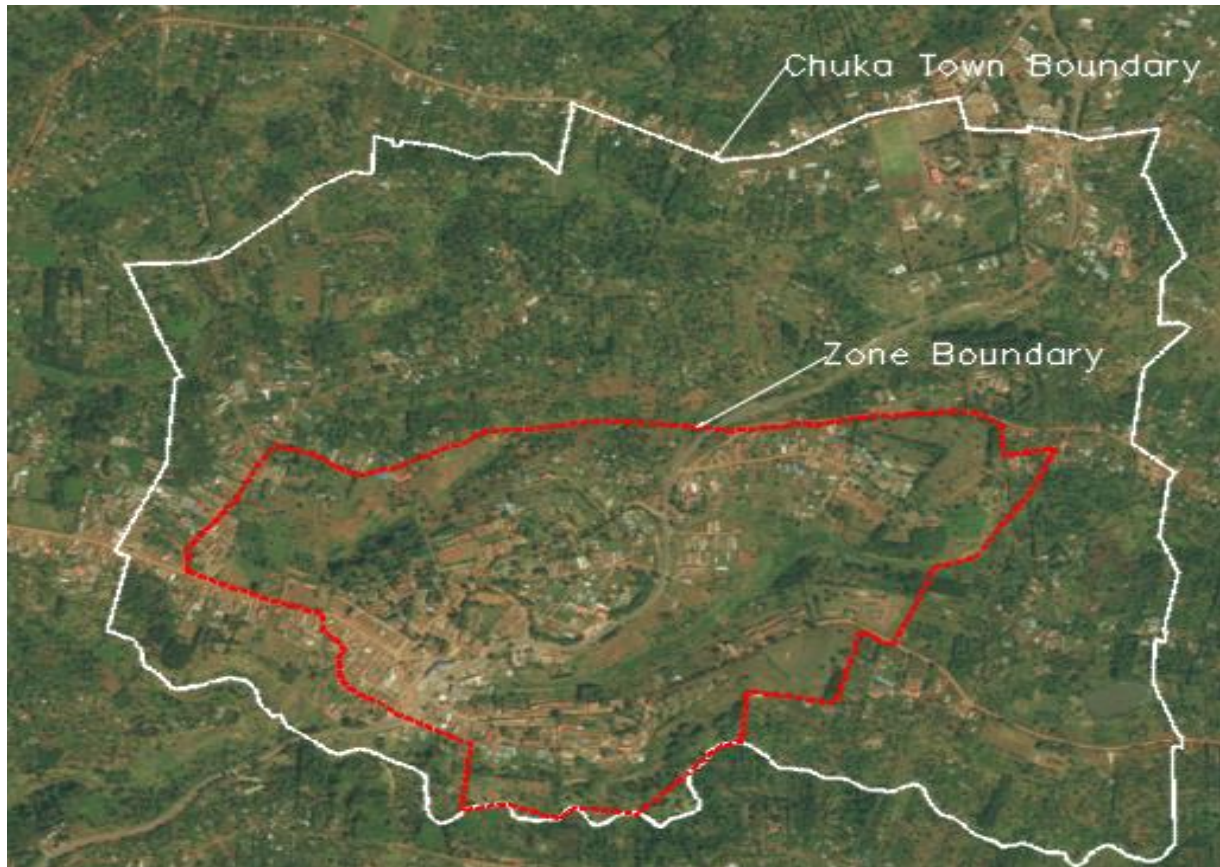


Figure 1: Study Area

Population

The population of the study area, estimated at 10,922 by the Kenya National Bureau of Statistics (Kenya, 2019), is projected to grow steadily at an annual rate of 2% over the next 15 years, reaching 13,565 in 2034.

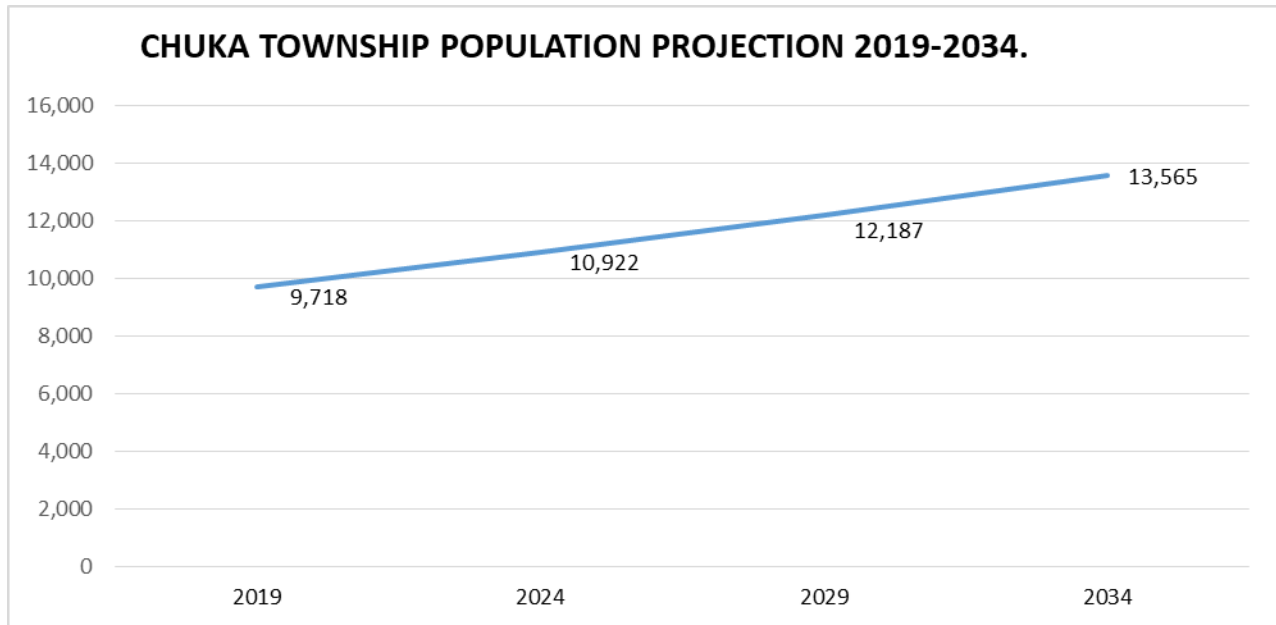


Chart 1 Population of The Study Area

Source: KNBS, 2019

2.3 Population and Sampling

Population

The reason for choosing Chuka Municipalityship is that the land is owned by the county government of Tharaka Nithi and leased to various individuals. Thus, it becomes a revenue source for the county. On the contrary, little is gained in this area due to the lack of land tenure security. Most of the residents have leases issued by the defunct county council. The lending financial institutions do not recognize the leases. The study covers all land parcels, structures, developments, utilities, and natural features within the township.

Sampling techniques

The study area, in terms of its geographical boundary, was clearly defined through a joint technical process. A collaborative effort among surveyors from the county and national governments, county planners, and a team from the University of Nairobi (researcher belongs here) was responsible for this delineation. The researcher led the team. The area was officially registered as land previously owned by the county council, but the Tharaka Nithi County Government now owns it.

A multi-stage sampling strategy was used within this defined spatial population to collect primary data. For the geospatial analysis, the entire delineated township area was treated as the

complete spatial census for change detection and cadastral analysis, ensuring full coverage. A purposive sampling technique was employed to identify key informants for the qualitative data collection. National and County government officers were selected for the study.

This sample comprised county government officials from the Departments of Lands, Physical Planning, and Environment who were either involved in or had knowledge of the 2020 project and planning activities, as well as local community leaders and landowners from identified high-change or conflict zones (e.g., informal settlement areas, agricultural conversion frontiers). This sample was intended to provide a deep understanding of the institutional, political, and social factors driving expansion, as well as the practical difficulties of implementing geospatial plans.

2.4 Methods of Data Collection

2.4.1 Secondary Data

Existing boundaries were first surveyed and then accurately matched to the georeferenced registry index maps (RIMs) via overlay to verify consistency and extract boundary data. The town had two types of boundaries: fixed and general. The general boundaries did not provide precise locations because the maps are only approximate. On such a map, physical evidence on the ground always takes precedence in legal matters; therefore, it was preferable to use existing boundaries. Where the maps and the ground differed, discrepancies were identified.

Secondary datasets were the primary spatial and temporal framework for the study. It consisted of several key datasets. At first, historical cadastral records were obtained from the Survey of Kenya; these included the Registry Index Maps (RIMs) for Chuka Municipality and several cadastral survey plans (Folio/Register numbers), many of which were from the colonial and early post-independence periods. Secondly, land use/land cover classification was performed using supervised classification of Sentinel-2 satellite imagery in ArcGIS Pro for 2017, 2020, and 2024. Spatial and attribute data from a 2020 drone survey were also used.

After classification, the pixel counts for each LULC class were extracted using the Tabulate Area tool. Percentages were calculated by dividing each class count by the total number of pixels, then multiplying by 100. This provided the proportions of each land cover type for temporal comparison across the three study years. The three years were chosen because the Esri Sentinel 2 Land Cover Explorer website provided 10 m resolution data.

The 2020 Baseline Project Dataset, produced under the researcher's coordination, was the main secondary data source. The data consisted of drone imagery, digitized and geo-referenced cadastral layers, coordinates for established ground control points, and a digital topographic cadastral plan with parcel and infrastructure attribution details. These data are comparable to the geospatial databases used by Ndengu (2001) and Ouma et al. (2025) in their urban studies in Kenya. The study also examined documentary evidence, such as development plans and policy documents, and parts development plans (PDPs) to understand the planning frameworks.

Vectorizing Cadastral Plans, R.I.M.s, and P.I.D.s

Given the differences in available data across the plans and the unique challenges, a tailored approach to vectorizing boundary data was adopted. The process followed for vectorization was as follows:

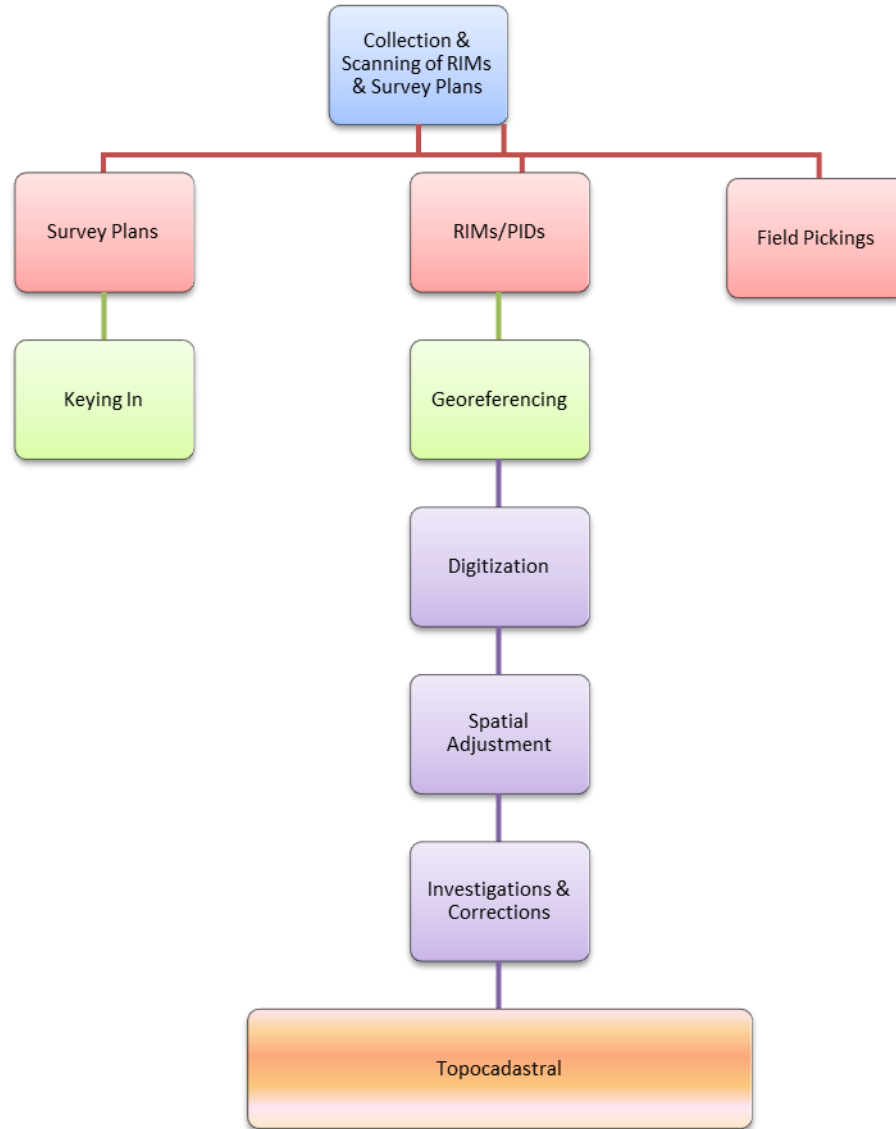


Figure 2 Vectorization Process

2.4.2 Primary Data Collection

Primary data collection was intended to serve several purposes, such as verifying secondary data, identifying data gaps, and gaining a qualitative understanding of the data firsthand. Two activities mainly formed the primary data collection. One follow-up field validation was an

assessment to check for changes that have occurred in the urban areas since the last time. GPS units were used to record the exact locations of new buildings, and drone imagery was used to confirm land-cover changes in the sample areas. Ground truthing using this method is the most common practice, including by Rawat and Kumar (2015) and Shah Heydari et al. (2024).

Later, semi-structured key informant interviews (KIIs) were conducted with officials and community leaders. Interview guides tried to elicit the respondents' views; hence, the focus was on themes like perceptions of growth challenges and the usefulness of geospatial plans, thus helping to answer the qualitative explanatory data questions, as evidenced by Cira et al. (2016) and Nabutola (2011), about the importance of such data for a better understanding of planning implementation barriers.

2.5 Research Instrument

The main research instruments were the researcher-developed protocols for geospatial analysis and the semi-structured interview guides. The geospatial protocol was implemented within Geographic Information System (GIS) software such as ArcGIS 10.5, Google Earth Engine, ArcGIS Pro, and Google Earth Pro that offered a standardized, reproducible workflow for processing all raster and vector data, like the methods reported by Li et al. (2022) and Arsanjani et al. (2013). The semi-structured interview guides consisted of open-ended questions arranged by theme, providing space for interviewees to elaborate on their answers while ensuring that the core topics were covered. The interview guides were pre-tested, and the geospatial classification schemes were cross-validated with the highly accurate 2020 field survey points to ensure validity.

2.6 Data Analysis

Data analysis took place through two parallel, converging modes. To analyze explanatory geospatial quantitative data, several procedures were used. First, a supervised maximum-likelihood classification was applied to satellite imagery to produce LULC maps at each time point. This is one of the most efficient methods for detecting changes quickly (Taubenböck et al., 2021; Rawat & Kumar, 2015). Next, post-classification change detection was performed to obtain a change matrix showing land conversion. Both the historical and 2020 cadastral data were checked for spatial accuracy and completeness by overlaying the digitized parcels onto modern basemaps, thereby revealing discrepancies, following an approach similar to that of Gasore (2019) in his cadastral study.

Subsequently, Multi-Criteria Decision Analysis (MCDA) was conducted, combining factors such as slope and proximity to roads to identify the area most suitable for future urban growth. Hence, Mahendra et al. (2019) recommended such a technique to planners. Thematic analysis was conducted on qualitative interview data. Thematic analysis is a method of identifying, analyzing, and reporting patterns (themes) within data. It entails a series of steps, viz, data familiarization, initial coding creation, theme(s) generation, and lastly theme definition. The results were

integrated at the level of interpretation, where the quantitative sprawl patterns were elucidated and enriched by the qualitative themes.

2.7 Data Presentation Methods

Findings are explained through a combination of visuals and text to both clarify and maintain academic rigor. Spatial findings, such as LULC change maps, cadastral discrepancy maps, and urban suitability maps, are displayed as high-resolution, fully annotated, professional cartographic figures. Tables and graphs depict quantitative trends. Qualitative data have been summarized in a narrative format centered on the theme's points, with anonymized participant quotations that closely align with it. In the discussion chapter, these modes of presentation are brought together, with maps and tables used to illustrate and support the interpretive arguments.

2.8 Limitations

This study recognizes several limitations in its research design. Firstly, although the 2020 dataset offers an excellent baseline, the longitudinal window for evaluating how those mapping outputs influence actual planning outcomes is limited to the period from 2020 to the completion of this study. The long-term effects might not have been fully visible yet. Secondly, the precision of the historical LULC assessment depends on the resolution and quality of the archival satellite images, which are lower for earlier years (e.g., 2000, 2010).

Thirdly, purposive sampling for qualitative interviews, while very informative, cannot be generalized to the entire population of Chuka Municipality. Nevertheless, the aim is to generalize analytically to theory rather than to the population. Lastly, the researcher's positionality as a former project coordinator and current analyst may introduce bias. However, this is controlled by being transparent about methods, triangulating data sources, and maintaining a reflexive study that records analytical decisions; thereby, the research remains unbiased and objective while being deeply contextual.

3. Results and Discussions

3.1 Urban spatial-temporal changes and land use trends in Chuka Municipality.

This part of the study presents the results for the first objective, based on an integrated analysis of multi-temporal satellite imagery (2017, 2020, and 2024) and primary data collected during the 2020 cadastral survey and planning project. Using a mixed-methods approach, changes can be measured quantitatively, while qualitative aspects help explain underlying trends.

3.1.1 Urban Spatial-Temporal Changes

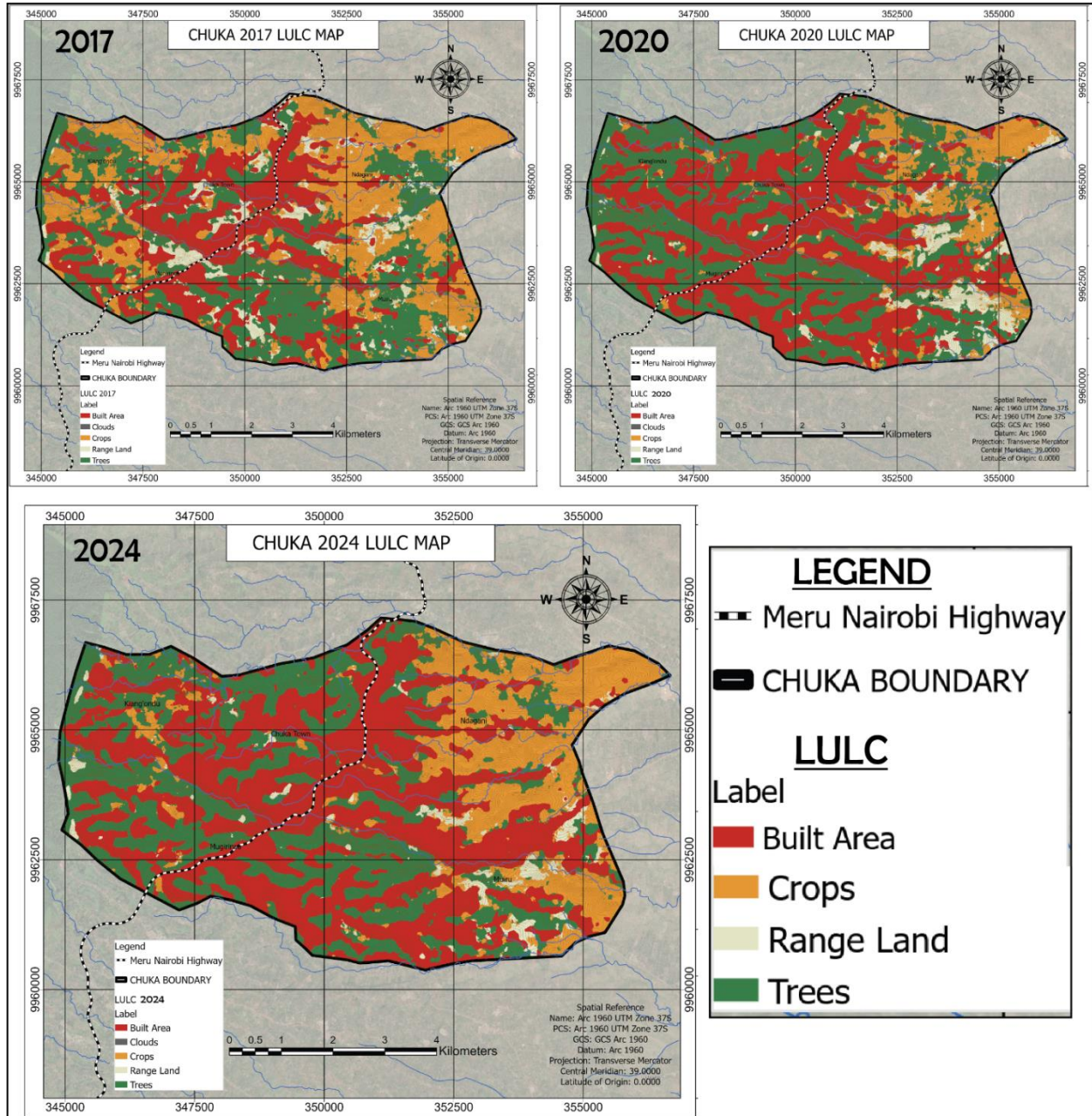


Figure 3 Land Use Land Cover Map of Chuka

To obtain the Land Use/Land Cover Change, Esri's Sentinel 2 data were processed in ArcGIS, and the results show a significant, rapidly increasing conversion of natural and agricultural lands into urban areas (see Figure 3). As depicted in Table 1, the built-up area saw a striking net

increase of 16.85 percentage points, going from 29.78% of the study area in 2017 to 46.63% in 2024. This growth was not steady but was notably more intense between 2017 and 2020, when the built-up area increased by 12.22 percentage points.

The period of the fastest increase coincides with the 2020 ground survey, which recorded a development boom, with the newest units being bedsitters and high-rise apartments mainly for the university population. In terms of location, this growth followed a straight-line pattern, like a ribbon along the Nairobi-Meru highway (A9) and the Chuka-Kathwana road (C93), a pattern supported by the 2020 field report.

The shape of this area is strong evidence for Hoyt's (1939) Sector Theory, in which transport routes are the main axes of urban growth. At the same time, the clusters around Chuka University and the Ndagani market Centre show a newly forming polycentric structure, thus fitting well the patterns of city development predicted by Harris and Ullman (1945) in their Multiple Nuclei model. The scale of this transformation underscores that Chuka Municipality is undergoing a fundamental spatial restructuring at a pace far outstripping historical planning frameworks.

Table 1 Land Use Land Cover Change of 2017, 2020, and 2024

Land Cover Class	2017 (%)	2020 (%)	2024 (%)	Change (2017-2024)
Trees	33.85%	40.47%	31.38%	-2.47%
Crops	29.50%	12.00%	19.29%	-10.21%
Built Area	29.78%	42.00%	46.63%	+16.85%
Range Land	6.86%	5.51%	2.70%	-4.16%
Clouds/Water	0.01%	0.02%	0.00%	-0.01%

Land Cover Class	2017 (%)	Area (ha)	2020 (%)	Area (ha)	2024 (%)	Area (ha)	Change (2017-2024)
Trees	33.85%	1,907 ha	40.47%	2,281 ha	31.38%	1,768 ha	-2.47%
Crops	29.52%	1,663 ha	12.00%	676 ha	19.30%	1,088 ha	-10.22%
Built Area	29.78%	1,678 ha	42.00%	2,367 ha	46.63%	2,628 ha	+16.85%
Range Land	6.86%	387 ha	5.51%	311 ha	2.70%	152 ha	-4.16%
Clouds	0.01%	0.7 ha	0.02%	1.3 ha	0.00%	0.0 ha	-0.01%
TOTAL	100.00 %	5,636 ha	100.00%	5,636 ha	100.00%	5,636 ha	0.00%

3.1.2 Dominant Land Use and Land Cover (LULC) Trends

In the Sentinel-2 LULC map, the transition is characterized by the straightforward and extensive replacement of agricultural and vegetated land with urban fabric (Fig. 3). The most significant loss was to cropland, which dropped by 10.21 percentage points, from 29.50% in 2017 to

19.29% in 2024. This is equivalent to losing more than one-third of the cropland of 2017. The deterioration was most severe between 2017 and 2020 (17.50 points), coinciding with the maximum BUA expansion phase and evidence of farmland being converted into residential and commercial plots, as a 2020 field report explained.

Moreover, tree cover was not healthy, with a net loss of 2.47 percentage points despite a temporary uplift in 2020. This net loss results from the clearing of trees for urban development and from urban encroachment into biologically fragile valley areas, as documented in a 2020 fieldwork finding that identified settlements and farming within ecologically fragile valleys. Rangeland also declined by 4.16 percentage points, thus further restricting the availability of local livestock grazing and ecosystem services.

The combined loss of Crops, Trees, and Rangeland (16.84 points) is almost a mirror image of the increase in Built Area (+16.85 points), indicating nearly one-to-one land conversion (Table 1). This systematic erosion of productive and ecological land for urban use aligns with the global challenges highlighted by Mahendra et al. (2019). It reflects the specific threats to food systems and biodiversity noted in East African urban studies by Lwasa and Kinuthia-Njenga (2012).

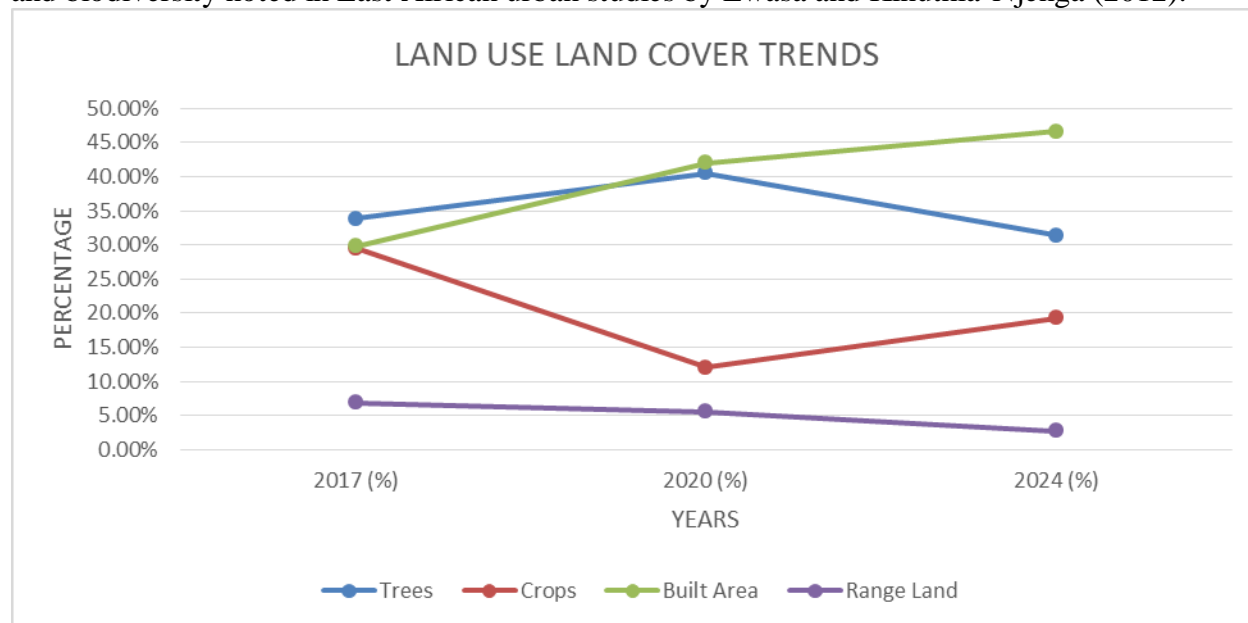
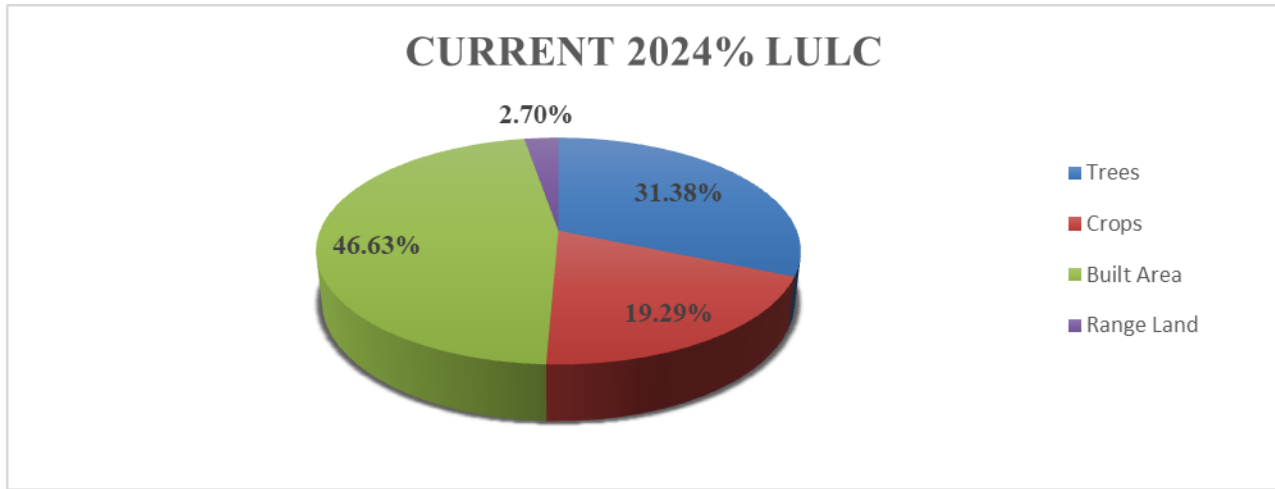


Figure 4 LULC Trend

According to recent findings, the most dominant LULC in 2024 is the built-up area, accounting for 46.63%. This shows that the built-up area is dominating other land uses to become the main Land use. It shows how people are encroaching on agricultural land, reducing its size, which can lead to lower agricultural production because the land is used for other purposes. This finding aligns with Taubenböck et al. (2021), who also found an increase in built-up areas using Landsat Time series.



3.1.3 Cadastral Informality and Spatial Fragmentation

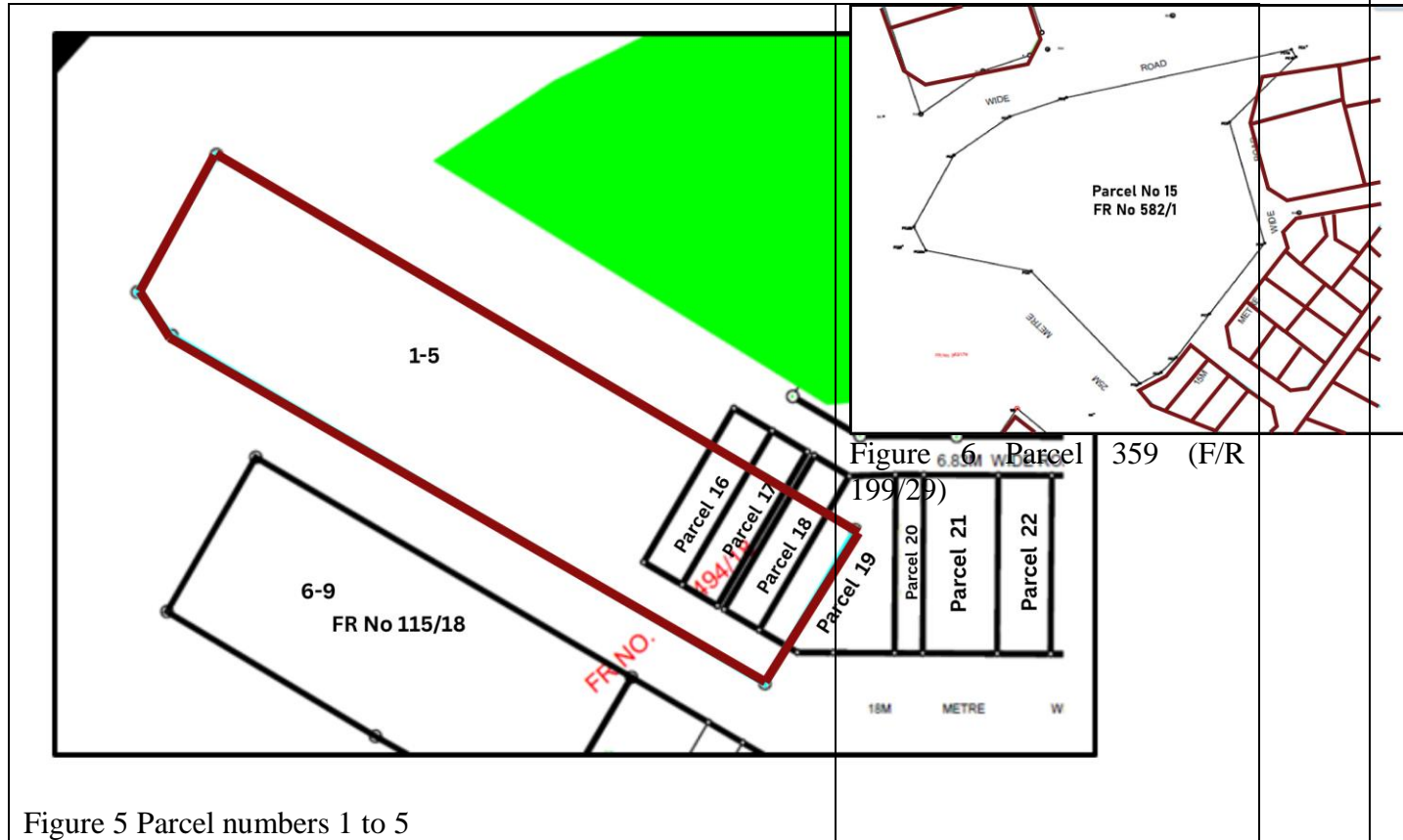
A fundamental finding was the severe disconnect between the dynamic urban landscape and the obsolete cadastral framework intended to manage it. The 2020 survey provided definitive evidence of widespread cadastral informality. The fieldwork found that, under the 2013 scheme plan, only 271 of 1,327 parcels (20.4%) had been surveyed, leaving 1,065 (80.0%) unsurveyed.

Plan 2013	No. of Parcels	%
Surveyed Plots	271	20.4%
Unsurveyed Plots	1065	80.0%
Total No. of Plots	1336	

Table 2 Unsurveyed Plots

Source: Chuka Municipality LPDP and cadastral survey records, 2020

This land administrative gap directly facilitates spatial informality. The study documented numerous technical discrepancies, including overlapping plots, parcels missing from Registry Index Maps (RIMs), and un-demarcated fixed boundaries (See Figures 5 and 6). In another instance, many parcels were identified as having fixed boundaries in survey plans but no ground demarcations (See Table 3). This absence of a clear, updated, and authoritative spatial record results in highly fragmented and irregular subdivision patterns, as development proceeds without reference to a coherent cadastral layout.



Source: Authors Fieldwork, 2020

Table 3 Undemarcated Plots

	F/R No.	Parcel N0
1	294/41	263,264,265,266
2	230/91	83,84,85,90,91,92,93,94,95,97,98,99,121,122,123,124,125,126,111,112,113
3	223/90	163,169,170,171

Source: Authors Fieldwork,2020

The consequence is profound tenure insecurity, with the report noting that only 89 title deeds were identified among the 300 surveyed plots. This empirical condition of cadastral obsolescence and the resulting spatial fragmentation directly support the arguments of scholars such as Gasore (2019) and Siriba et al. (2011). It also demonstrates the inapplicability of Burgess's (1925) Concentric Zone Theory, which presupposes a stable and orderly cadastral

system for its zonal succession, a condition wholly absent in the rapidly transforming periphery of Chuka Municipality.

3.2 Challenges and impacts arising from unplanned urban expansion in Chuka Municipality

This part of the study addresses the second objective and presents the results of the various challenges and negative effects arising from uncontrolled urban sprawl, as illustrated in Section 3.1. The 2020 survey and planning report is a direct source of empirical evidence for these consequences.

3.2.1 Infrastructure Overload and Service Deficits

The research established that unplanned growth has substantially contributed to the deterioration of physical infrastructure and urban services. The 2020 field survey revealed that encroachment into road reserves was widespread, with businesses such as Magunas Supermarket, a local garage, and Kenya Power occupying road space (See Figures 7 and 8). This encroachment, combined with the absence of planned road truncations, leads to traffic congestion and accidents.

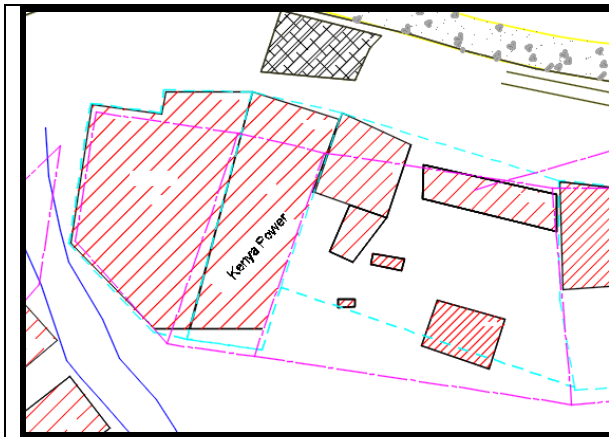


Figure 7: Kenya Power Structure Road Encroachment

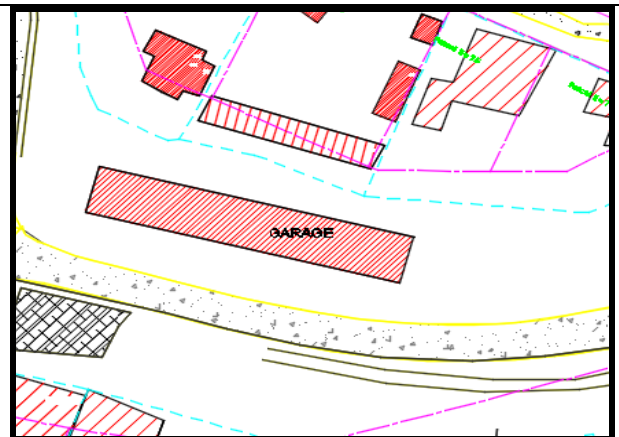


Figure 8: Garage Road Encroachment

Source Authors Field Work, 2020

The study also pointed out that planned critical infrastructures, such as an 8.35-hectare airstrip in the 1988 plan, which by 2013 had been completely subdivided for residential purposes, and a bus park that has never been built, do not exist (See Table 4 and Figure 9). Problems with sanitation are severe; the report shows that the 1988 plan had only one sewage treatment plant, which was later subdivided. Observation of the ground revealed that in informal settlements, people use shallow, temporary pit latrines within 5 meters of the River Nkenye, violating public health regulations and polluting the water.

Table 4 Proposed Vs Existing Airstrip

	Area in m ²
Proposed Airstrip in 1988	83,520.01
Airstrip Surveyed in 2020	9,947.37

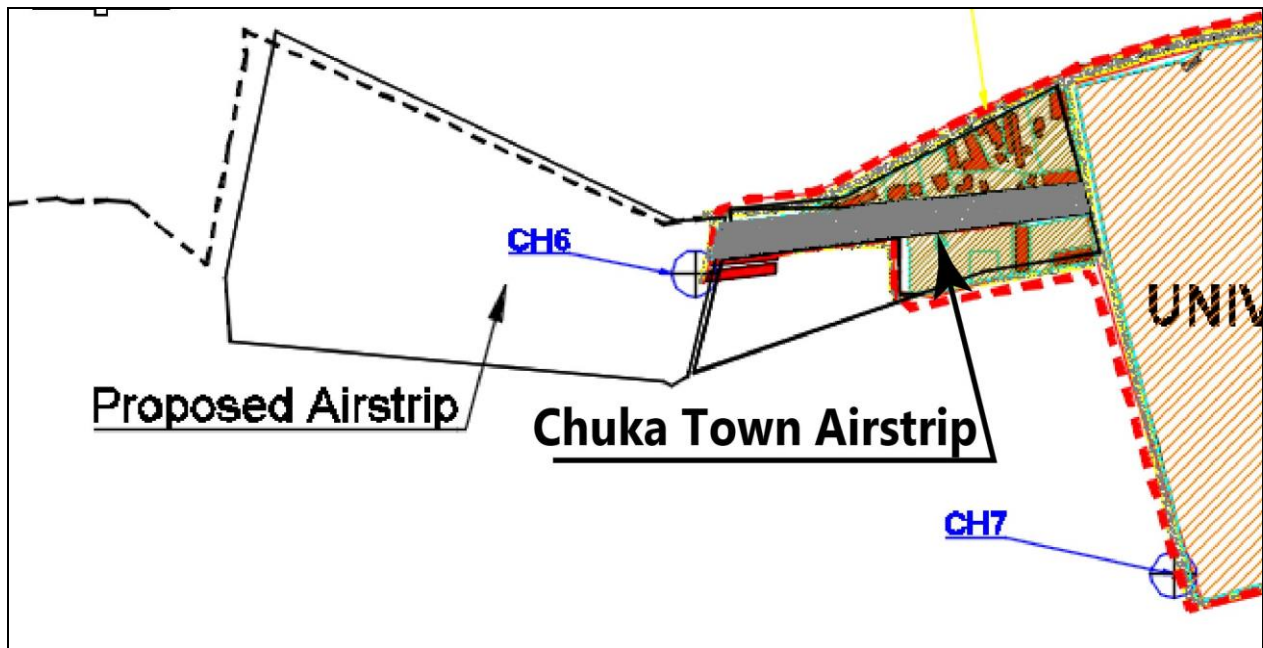


Figure 9 Proposed and Picked Airstrip

Source Fieldwork (2020).



Figure 10 Temporary Pit Latrine Located 5 Metres from River

This systemic failure to align infrastructure provision with urban growth is consistent with the findings of Cira et al. (2016) and Nabutola (2011) on the 70% infrastructure deficit in expanding Kenyan towns. It also illustrates the global cost inefficiencies identified by Jaeger et al. (2012), in which running development in a scattered manner can cost up to 50% more.

3.2.2 Informal Settlements and Tenure Insecurity.

A major and direct impact of unplanned growth is the proliferation of informal settlements and, consequently, the insecurity of tenure of their residents. The fieldwork clearly indicated an increase in informal settlements in Jombas and around the mosque, among other areas, with these settlements mainly located within ecologically sensitive riparian zones (*Figure 11*).

Besides, these places are among the most deprived/excluded in almost everything: field surveys confirmed that they have only semi-permanent structures, no piped water or electricity, and poor sanitation facilities. The underlying problem is closely related to the cadastral deficiencies discussed in Section 3.1.3. Most of the plots (80%) in the 2013 plan have not been surveyed, and only 29% of the surveyed plots hold title deeds (*See Table 2*). Therefore, most residents cannot legally own their properties.



Figure 11 Informal Settlements

Source: Authors Fieldwork, 2020

The study established that the lack of secure land tenure has "limited the rate of urban development" as residents are "sensitive to the fact that anytime the rightful owner could claim the land". This finding provides a concrete local case for the global analysis of Jaeger et al. (2012), who link the absence of tenure surveys to 50-60% of the urban poor living in fringe encroachments and aligns with UN-Habitat (2018) reports on informal settlements in Kenyan cities.

3.2.3 Environmental Degradation and Risk Amplification

Plots with Boundaries at the Centerline of the River

The encroachment of development into ecologically fragile areas has led to significant environmental degradation and increased community risk. The 2020 analysis found 167 plots with boundaries at the centerline of River Nkenye, and field surveys confirmed agricultural and settlement encroachment into the riparian reserve.

The study found that, under the 2013 Plan, 167 plots border the riverbank. However, it is not possible to determine from the plans or imagery the type of land use, housing density, or quality of housing materials. Some of these factors adversely affect the river ecosystem. Of these, 11% are agricultural, 23% are commercial, and 57% are residential.

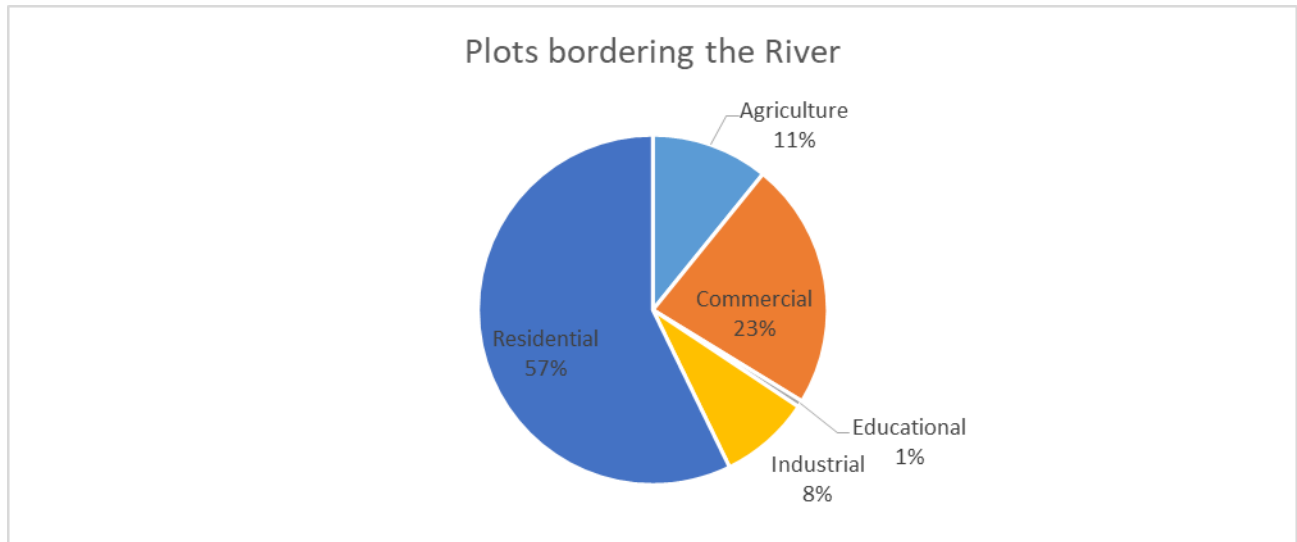


Figure 12 Plots boundaries at the centerline of the river

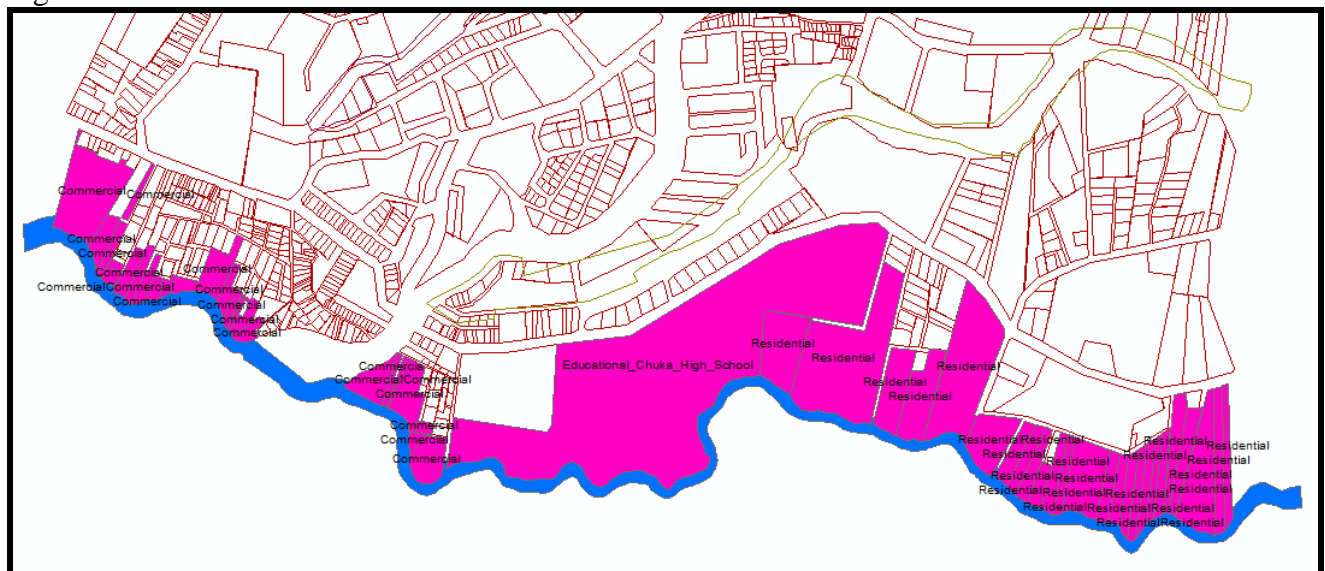


Figure 13 Plots with Boundaries at the centre of the river

Source: Field Survey, 2020

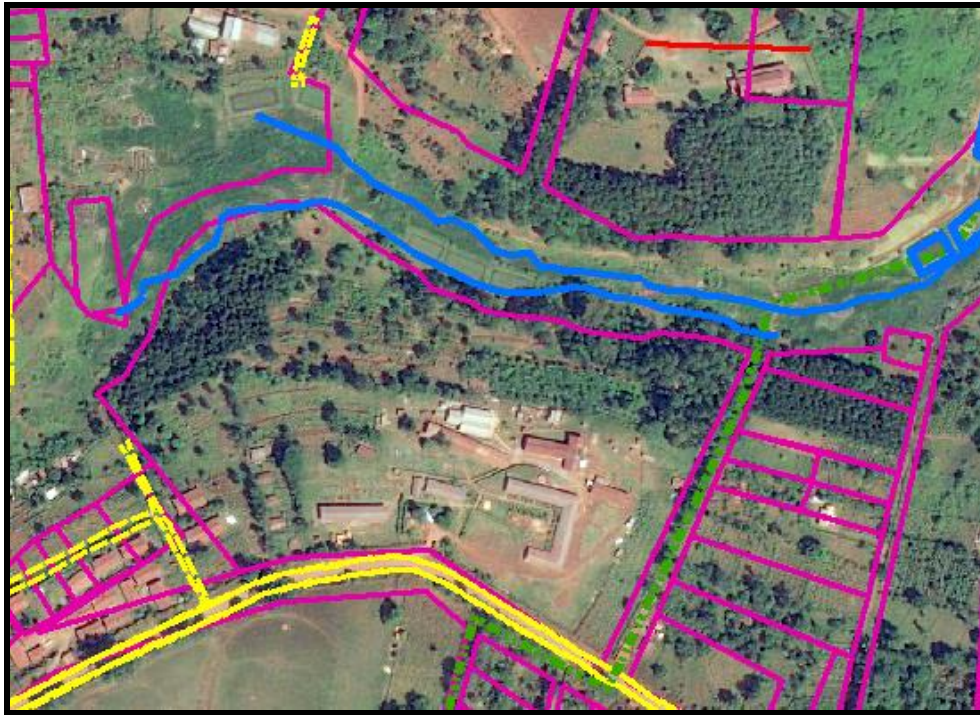


Figure 14 Plots near the Nkenye River

The destruction of natural buffers, together with the indiscriminate dumping of solid waste in valleys and open drains, as shown in Figures 15 and 16, greatly worsens the risk of flooding and contaminates water sources. The study further noted that soil erosion was occurring on the steep, bare slopes and that open burning of biomedical waste was taking place at Chuka Referral Hospital (Figures 17 and 18). These actions cause air and soil pollution, thus weakening the community's capacity to cope with such changes.

These effects correspond to the environmental consequences of sprawl that Taubenbck et al. (2021) observed, reporting a 20-35% loss of green spaces and a 25-50% increase in flood risk in Asian megacities. They also reflect issues related to the loss of arable land and pollution, as highlighted in African urban studies by Mabin et al. (2013) and Ouma et al. (2025).



Figure 15 Solid Waste near Open Drain 1



Figure 16 Solid Waste near Open Drain 2



Figure 17 Solid Waste Dumping 1



Figure 18 Solid Waste Dumping 2

Source: Author's fieldwork, 2020

3.3 Drivers of urban expansion challenges and gaps in historical cadastral surveying in Chuka Municipality.

This section addresses the third objective by analyzing the underlying forces driving unplanned urban expansion and the specific failures within the historical land administration system that have exacerbated these challenges. The analysis synthesizes spatial data with the institutional and socio-economic insights from the 2020 fieldwork survey.

3.3.1 Primary Socio-Economic and Infrastructural Drivers

The growth of Chuka Municipality is mainly due to a combination of demographic and economic factors operating within a well-defined infrastructural geography.

Proximity to Transportation Corridors

The proximity and good links provided by the main transport lines, especially the Nairobi-Meru Highway (A9) and the Chuka-Kathwana road (C93), were the primary spatial drivers. In fact, site investigations conducted from 2020 onwards found that the commercial and residential developments were largely along these two roads, confirming their role as the main axes of growth, as outlined by Hoyt's (1939) theory.



Figure 19 Linear Developments near Road Networks

Source: Author's Construct from Google Earth, accessed in 2026

Rise of Education Facilities

A crucial demand, a secondary driver, is the significant expansion in the number of students and service providers at Chuka University. The study reported a shortage of student hostel accommodation, which drove the visible trend of private landlords converting their houses into bed sitters, and the university itself was building a 17-story block. Within a 1km radius of Chuka University, the area is densely built up (see Figure 20). Hence, a single, powerful nodal institution can energize real estate markets and drive suburban expansion, as discussed in Harris and Ullman's (1945) Multiple Nuclei Theory. Besides, the economic transformation from agriculture to trade and real estate is underway.

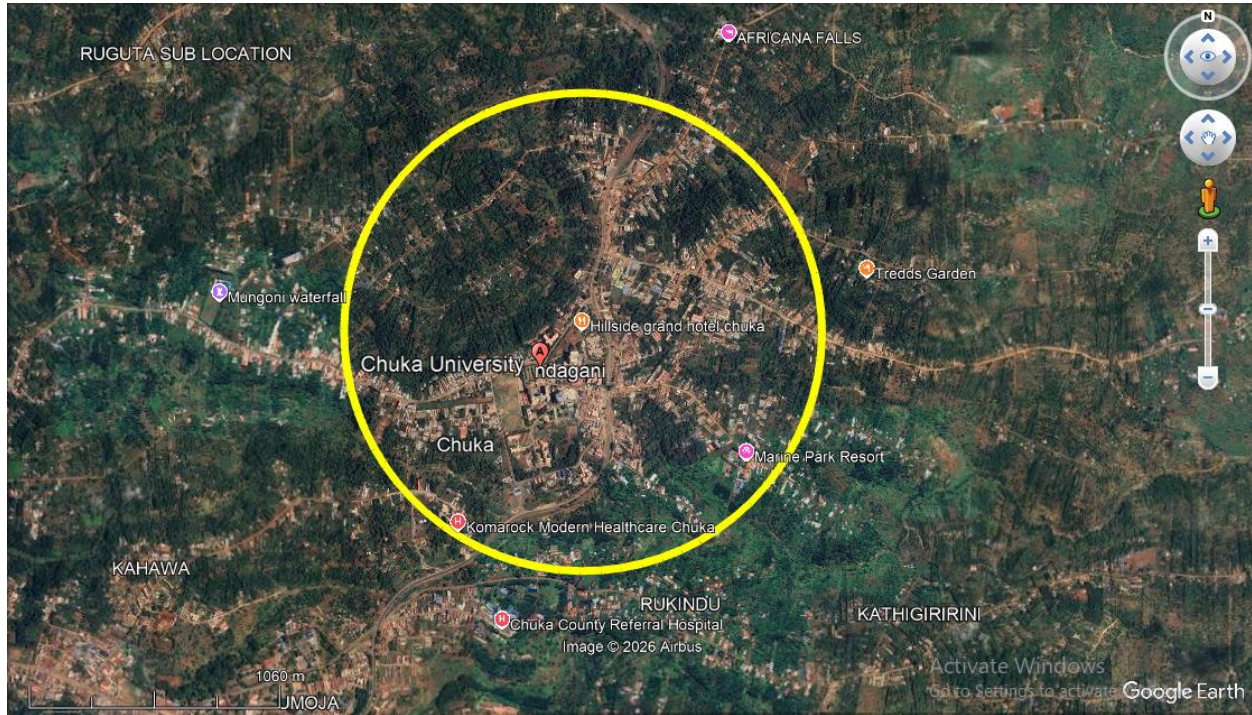


Figure 20 1km radius of the built-up area around Chuka University, 2020

Land values

The study found that land prices vary with a parcel's proximity to the main transport corridor and its terrain. (up to KES 4.5M for 0.115 acres) Moreover, the conversion of farmland and reserved land into residential plots (See Table 5). Table 5 tabulates various land values as per the time of the Integrated Strategic Urban Development Plan (Chuka ISUDP, 2020). These land values could attract investors who buy land for real estate development to maximize their profits.

Table 5 Land Values

S/No	Neighbourhood	Size (acres)	Price in Millions (Kenya Shilling)
1.	Kangoro	0.25	1.3
2.	Kirege	0.25	1.6
3.	Gituaka	0.25	3
4.	Kimbumbu Junction	25	2.8
5.	Ndagani	0.25	2.5
6.	Kiereni Kiunguni junction	0.20	1.3
7.	Mariani	2	2
8.	Jombas	0.115	2.3
9.	Kathituni Primary	0.26	3.2
10.	Mungoni	0.10	1

11.	Chuka Municipality	0.115	4.5
12.	Nembure near Kivue	1	3

Source: Field Work, 2020

3.3.2 Institutional and Policy Gaps in Land Administration

The problems of urban expansion have become more severe because the institutions and policies governing land administration have not functioned efficiently. The biggest factor driving people to live informally is that cadastral surveying and land registration are far behind planning and market activities. The fieldwork has shown, without a doubt, that the 2013 plan included 1,327 parcels, but only 271 were surveyed, and only 89 titles were registered (*see Table 2*).

This situation provided the informal sectors with a significant opportunity to engage in transactions and development outside the legal window. The findings link this to post-independence adjudication, noting that land registration was carried out in only about 40% of towns, resulting in a tenure legacy of uncertainty. On top of that, this institutional gap has been compounded by the lack of strong development control and plan enforcement, as shown by the fact that most of the developments on the ground have not conformed to the 1988 and 2013 plans and the issuing of Part Development Plans (PDPs), which are in contradiction with the main plan (*See figure 21*).

Increased Subdivision in the 2013 plan has led to greater urbanization of Chuka Municipality and Ndagani Area. As a result of poor land administration, land is being subdivided into “Points” In Ndagani next to the university. Ten points means a plot of 10 metres by 10 metres (100 square metres). This indicates inadequate housing.

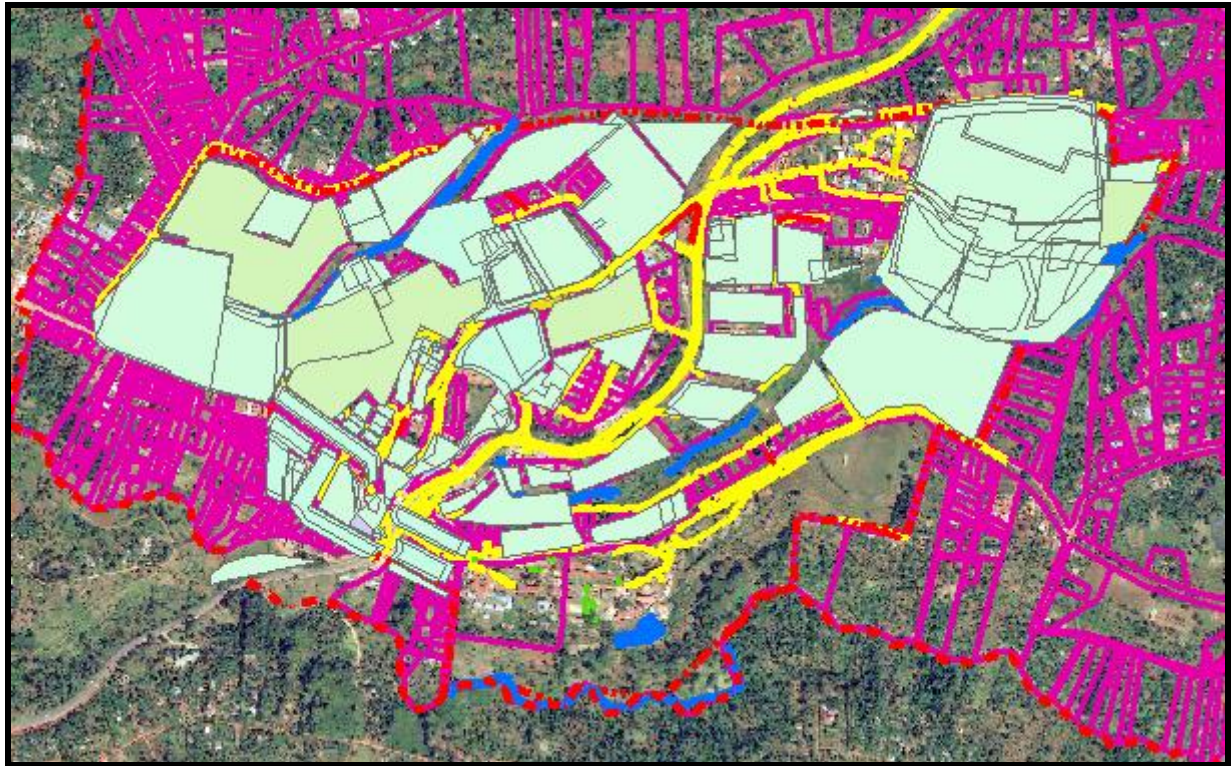


Figure 21 Increased Subdivision from the main Plan

Source Field work, 2020

The inability to prevent encroachment on road reserves and water bodies is a direct consequence of this enforcement vacuum. These results thereby provide the empirical basis for the positions of Siriba et al. (2011) and Nabutola (2011) that the post-1963 cadastral gaps have facilitated 30-40% of peri-urban sprawl in Kenya. These findings also align with Cira et al. (2016), who identified policy and fiscal drivers as root causes of 70% infrastructure deficits.

3.3.3 Technical Limitations of Historical Cadastral Frameworks

The physical and technical shortcomings of the old cadastral system alone are another cause of the planning issues that are faced in the study area. The study encountered historical survey data that was inaccurate, incompatible, and incomplete. This affected the Registry Index Maps (RIMs), which were characterized by "shifts, warps, and distortions" due to drawing errors and coordinate-system transformations from the native Cassini system, and the cadastral plans (F/Rs), which were overlapping or contained unsurveyed plots (See Figures 22 and 23).

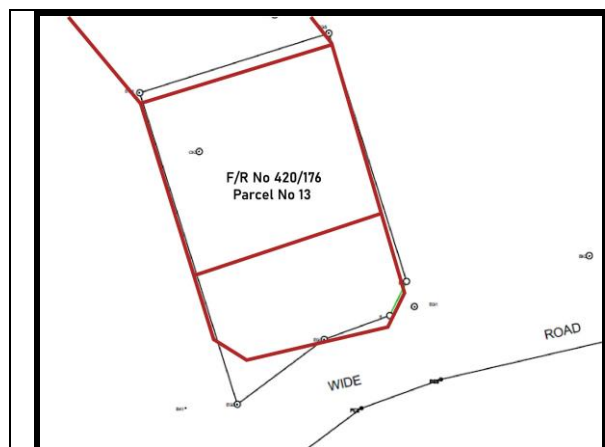


Figure 22: Technical Errors between 2 Survey Plans

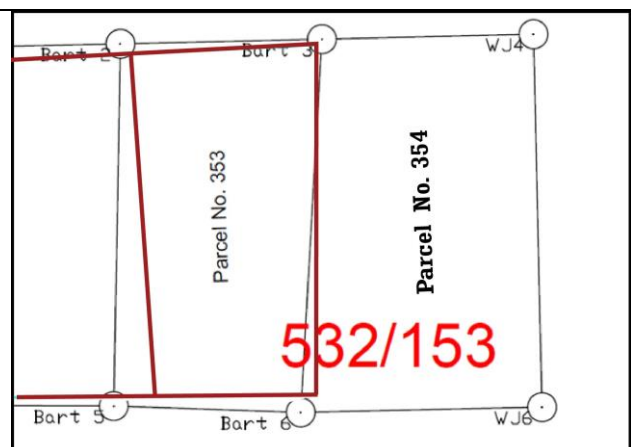


Figure 23: Technical Errors between 2 Survey Plans

Source: Author, 2020

At the heart of it was a system designed for static general boundary surveys that are legally "only approximate," where "evidence on the ground takes precedence over the map." The whole concept is totally at odds with the needs of a rapidly subdividing urban area, which requires dynamic, high-precision management, hence the discrepancies and conflicts documented in this paper.

On top of that, the inflexible, zoning-based approach of historical plans (such as the 1988 plan) ignored topographical constraints and changing market forces. A case in point is the plan, which designated land for an airstrip and industrial purposes in locations that were topographically unsuitable or economically unviable. As a result, they were converted, a process that the plans could not adaptively handle. This technical inflexibility is a criticism of theoretical models like Burgess's (1925) Concentric Zone Theory when applied to modern, irregular urban growth, as highlighted by Aliaga et al. (2013).

3.4 Geospatial technology-based strategies for sustainable urban development in Chuka Municipality.

This part of the study discusses the last (fourth) objective of the research. It presents a set of integrated geospatial strategies to address the identified challenges and provide a path to sustainable urban development in Chuka Municipality. The strategies are based on the interpretative results of the present study, learning from the 2020 initiative, and the literature.

3.4.1 An Integrated Cadastral-GIS Database as a Foundational Planning Tool

The first and most pressing strategy is to create a live, interoperable cadastral GIS database to address the critical data gaps underlying the current study's findings. The study has laid the groundwork for this through the digitization of RIMs, the rectification of cadastral plans, and the incorporation of drone imagery, GPS, and surveyed ground truth (See Figure 2 on the *Vectorization Process*). This work should be formalized and extended to a perpetual cadastral updating mechanism.

This strategy uses high-resolution satellite imagery (e.g., from Planet or Airbus) and drone photogrammetry to regularly monitor and document new subdivisions and construction, primarily in fast-growing areas such as the corridors to Kathwana and Ndagani. These updates will be verified through the approved Part Development Plans (PDPs) and land transaction records at the county registry. This thus forms a "single source of truth" which planners, surveyors, and the land registry can collaboratively maintain.

An integrated system of this kind is a direct solution to the problem of cadastral informality and overlapping plots, as illustrated in Sections 3.1.3 and 3.3.2. This is consistent with the framework presented by Gasore (2019) for Kigali, in which GIS and drone resurveys were planned to increase tenure security, and it also aligns with the appeal by Siriba et al. (2011) to modernize Kenya's cadastral systems. Carrying out this first step is pivotal to ending the "Cycle of Cadastral Obsolescence."

3.4.2 MCDA-Based Suitability Zoning and Growth Scenarios

To prevent future encroachment into ecologically sensitive areas and guide development to suitable locations, this study proposes a Multi-Criteria Decision Analysis (MCDA) model for land suitability and zoning. Building on the environmentally sensitive Areas mapped, the model would integrate critical thematic layers derived from geospatial data: slope (from a DEM), flood-prone zones (from hydrological modeling), soil type, existing agricultural value, proximity to existing road infrastructure, and distance from major nodes such as the University and CBD.

Stakeholder consultation with county planners and community leaders would determine the weighting of each factor. The result would be a suitability map that grades land for urban expansion into the categories "Most Suitable," "Moderately Suitable," "Unsuitable," "Restricted," and "Protected." The map would be central to revising the 2013 Local Physical Development Plan; therefore, it would provide a sound scientific justification for zoning decisions.

Additionally, the Cellular Automata (CA) method can be integrated into this MCDA structure to forecast urban growth scenarios for 2035: "Trend" (unplanned) and "Planned" (MCDA-guided). The idea of combining these two techniques is well covered in the literature, e.g., Mahendra et al. (2019), who advocated the use of MCDA and GIS for fair zoning in the Global South, and Adjei Mensah et al. (2024), who carried out a similar study in Hawassa, Ethiopia, using this kind of modeling.

4 Geospatial Tools for Participatory Planning and Infrastructure Optimization: A Conclusion

Geospatial technologies should be leveraged for participatory planning, land-use mapping, and infrastructure network optimization to address infrastructure gaps and support inclusive planning. The 2020 project used the KoboCollect toolbox to collect field data, which serves as a good example of how to crowdsource data on service gaps, such as the locations of solid waste dumps, nonworking streetlights, or blocked drains. Such data may be presented on a public participatory GIS (PPGIS) portal, through which residents can not only submit reports but also view planning proposals.

5. Recommendations

The study examined the current urban spatial-temporal changes and land-use trends in Chuka Tharaka Nithi County, which follow a linear pattern along the major roads. This is because the town is located in a rugged terrain that inhibits development in very steep areas. Organically, the town has emerged with three nodes. The original CBD, the university node, and the new stadium. It is recommended that the nodes be properly planned, surveyed, and issued with title deeds. This will revitalize residents and help them develop the town.

The study has identified the main challenges facing the unplanned town. A holistic plan and survey of the town and its neighborhood are the only sure way to address infrastructure and services. Issues of very narrow roads and poor waste disposal all contribute to the problem. Identify the key challenges and impacts arising from unplanned urban expansion in Chuka Municipality.

The underlying drivers of urban expansion, including population growth, have been identified. To address the challenges, then, new techniques and approaches must be embraced. The two-dimensional growth has clearly created urban sprawl. Vertical growth in suitable areas is critical. The GIS-MCDA can identify such areas. To analyze the underlying drivers of urban expansion challenges and gaps in historical cadastral surveying in Chuka Municipality.

When planning infrastructure, one can use GIS-based network analysis to determine where new public facilities, such as bus parks, fire stations, and health clinics, would have the greatest impact based on population and travel time. For example, studying the catchment area of a planned but unbuilt bus park (2013 plan) may identify a more suitable, centrally accessible location that could help ease CBD congestion.

Also, the least-cost path methodology can be applied to the design of new roads connecting the growth areas identified in the MCDA suitability map, thereby improving accessibility without encouraging ribbon development. Thus, the practical, cost-effective GIS planning approach is

demonstrated in Ndengu's (2001) work in Nairobi and is also advocated in the city leaders' UN-Habitat (2018) guides.

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