SUSTAINING CRITICAL TRANSPORT INFRASTRUCTURE SPACE IN MEGACITIES: MULTIMODAL ASSESSMENT OF RAILWAY AND ROAD SYSTEMS IN KANO & LAGOS — NIGERIA

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Abstract

Globalisation has the most tremendous negative effects on the changing landscapes of many cities because of the roles of cities as the de facto economy and haven of liveable socioeconomic advantages. As the urban population grows, particularly in developing countries' mega-cities where transport development faces the most complex challenges, a more sophisticated framework of assessment of critical transportation infrastructure and transportation planning is required. This research aims to investigate transport effects of the complex web of interactions of urban chain processes to bring about a more sustainable (and resilient) transport infrastructure development of mega-cities. The interdisciplinary research concepts which incorporate the development of scenario-based applications and prediction techniques involving qualitative and quantitative frameworks were applied to the two Nigerians most populous cities (Lagos and Kano). The framework includes the analysis of spatial-temporal relationship of transport space and urban land use change, congestion and accessibility, sustainability paradigm and themes and ordering of priorities of the intervention policies based on transportation demand management objectives. Data sources include Landsat images, traffic and demographic data, transportation infrastructure inventories, and collaborative engagement with stakeholders and policymakers via questionnaires, interviews, and checklists. First, spatial-temporal analysis was carried out using remote sensing GIS software for land use classification and CA-Markov model implemented in IDRISI SELVA for temporal prediction and its suitability quality. Next is the assessment of accessibility and congestion pattern of the two cities using a surrogate multi-layer feed-forward and back-propagation model involving input-output and curve fitting (NFTOOL) implemented in artificial neural network wizard of MATLAB. Also, the sustainable paradigm and themes were carried using questionnaire and interview instruments and analysed respectively using SPSS and NVivo softwares. Finally, the priorities of intervention policy decision and quality of infrastructure and services were analysed using hybrid SERVQUAL-AHP models. The spatial-temporal analysis of the two cities produced patterns of rising trends for transport and built-up areas while the other land use classes are receding. For example, Kano transport space had grown from 137km^2 in 1984 to 290km^2 in 2019 while that Lagos grew from 337km^2 to 535km^2 in the same period. The dynamics model predicts spatial land requirement of Kano city for transport to reach 410km^2 in 2050 while Lagos will be needing 692km^2 in the same period. Future prediction of the two cities will be highly unsustainable for transport infrastructure. The congestion profile results put the two cities within congestion indices ranging from 7.5 to 10 on a maximum scale of 10, indicating extreme traffic congestion regimes and inaccessibility in the two cities. The sustainability paradigm comprising

literacy, sustainable choices and indicators of sustainable transport are below average exposing poor development in the area. Also, the thematic analysis revealed the preponderance of more negative sentiments from the interview over statements of optimism and progress and it corroborates the findings of sustainability paradigm. Finally, satisfaction quality assessment produced low quality scores of 48% and 49% for Kano and Lagos cities respectively. AHP equally allocated more weight to tangibility which defines infrastructure and service qualities. These values are suggestive of the necessity to infrastructure, public transit systems and management of transport demand in the decision policy making. To deal with rising urbanization trends in Nigerian cities and maintain liveable and accessible urban environments, aggressive push—and—pull policies that improve and increase transport infrastructure quality and drive sustainable transport, promote modal split, reduced motorization, and access control is recommended.

Declaration

I hereby declare that this thesis entitled “Sustaining critical transport infrastructure space in mega-cities: multimodal assessment of railway and road systems in Kano & Lagos — Nigeria” is the product of my research work and has not been presented anywhere for any degree. All sources of literature information are duly acknowledged in both the text and the reference section.

1st October 2021

Signature: ………… [redacted] …. Date: ………………………….

Suleiman Hassan Otuoze (ID No.: [redacted])

Dedication

I am dedicating the thesis to these venerable souls: first, to the beautiful and infallible souls of Prophet Muhammad (SAWA) and his *Ahlulbeit* (RA) who inspire the most examples in knowledge, wisdom, illumination of human minds, and devotion to Godly ways.

Also, I am dedicating the success to my late father, Alhaji Suleiman Otuoze Ege, whose virtuous life, moral rectitude, and spiritual devotion I am guided. I will forever stay true to your ethos of persevering with the pride of hard work, sincerity, and kindness to all. I promise, I shall continue to etch your memory in gold and bring honour to your good name.

Last but not the least; to my bosom late friend, Engr. Ahmed Hadi Ashara — a tribute to his short pious life, dedicated to hard work and full of devotion to his faith and service to humanity. You all are always remembered!

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Research Summary and Publications

A. Research Summary

Chapter one discussed the accessibility issues that growing urbanization pace has presented for mobility, liveability, and unsustainable urban development in developing countries. It highlighted worrisome areas of gaps and deficits in basic critical infrastructure deficits and how life cycle and maintenance problems and low investment portfolio in transport infrastructure, urban sprawls, population, and migration surges have beset the cities. Chapter one also detailed previous research efforts which left many gaps and inefficacies in terms of scientific knowledge of the problem and methodological approaches applied. The current research explored a variety of differing quantitative and qualitative methods from multidisciplinary knowledge domains of science and engineering to address the problem. Chapter two provides overview of the literature background relevant to the objectives, recent developments in finding solutions to urban chains and mobility connections, critiques and the gaps identified as well as the justification for the research.

Chapters 3–7 are the technical chapters. Instead of using the traditional urban chain analysis model, which lumps all infrastructures into the built environment without regard to their various need assessments and developmental paces, Chapter 3 utilized disaggregated spatial-temporal transition analysis, which decoupled transport infrastructure spaces as a specific land use class. The analytical techniques for model calibration, prediction, and analysis of spatial connections between urban chains and transportation infrastructure spaces involved remote sensing, GIS for land use classification and IDRISI SELVA for predicting temporal transitions. The spatial-temporal model in Chapter 3 provides a spatially explicit tool for predicting land use transition changes and to evaluate the suitability of the urban chain process.

The spatial-temporal analysis in Chapter 3 is consistent with previous scientific evidence pointing to a preponderance of potentially unstable, unsuitable, and unsustainable urban development in many Sub-Saharan African countries plagued persistently by the problems of inaccessibility, congestion, and decrepit infrastructure portfolios. Chapter 4 examined the relationship between urban chains and accessibility in relation to the causal roles of transportation infrastructure, demography, traffic volume and motorisation rates. The methodology of the congestion profile prediction model developed for the two major Nigerian cities involves multi-layer feedback propagation using input and curve fitting model implemented in artificial neural network wizard of MATLAB software. The study found a potential evidence of the negative consequences of transportation infrastructure problem, urban agglomeration, traffic, and motorisation rise contribute to extreme traffic regimes plaguing the urban landscapes of Nigeria.

In Chapter 5, broad-based questionnaire survey was undertaken to gauge sustainability thinking, awareness, and travel choices of a wide spectrum of urban stakeholders which defined Nigeria's transportation sustainability model, goals, and policies. The inferential statistical analysis of the survey response data was carried out using SPPS software. The study revealed low levels of performances both in terms of awareness and measures that promote sustainable transportation development. This implies that urban transportation policy, mobility management, infrastructure, and public transportation facilities are not keeping pace with agglomeration rate and requires a refocus on sustainable transportation policies.

Furthermore, Chapter 6 provides sustainability thematic analysis of Nigerian urban transport development policies was evaluated from the perspectives of policymakers who play leading roles in policy decisions. The surveys were conducted using interview protocol containing semi-structure questions and were analysed using NVIVO software to quantify the thematic references of transport sustainability. The findings support the unsustainable transportation development discussed in Chapter 5 and point to the importance of prioritizing transportation infrastructure and policy decisions to achieve the goals of more resilient, liveable, and accessible cities.

Lastly, in Chapter 7, travel demand management (TDM) objectives were employed to model policy decision and to evaluate the quality and priorities for optimal allocation, use and management of transportation resources. SERV-QUAL model was developed to characterize the five generic characteristics of service quality and satisfaction, namely tangibility, reliability, responsibility, safety-assurance, and empathy, based on a total of 136 respondents surveyed in Kano and Lagos cities. Also, Analytic Hierarchy Process (AHP) was used as a comprehensive framework, rational decision formulating tool, quantifying elements, and connecting them to overarching goals, and assessing potential solutions to the decision problems. The greatest decision priority in both cities is tangibility, which included TDM elements relevant to transportation infrastructures. The findings establish a framework for comparing identifiable standards in transportation services, management decision, and the importance of quality infrastructure in ensuring resilient and sustainable urban mobility.

Urban infrastructure modelling lays the foundation that could be used for scenario analyse and provides the platform for future prediction. Most research efforts on urban development can be understood as a series of alternative approaches to analysing with the inherent approximations that come with dealing with the real complexities of urban areas. While many developed countries, particularly in Europe, America, Canada, Japan, and Australia have approached the terminal phase of the urban transition, so, the single model theory may be applicable. Countries in the SSA are in the active phase of urban and demographic transitions; with huge infrastructure deficits, planning and management problems, political instability, corruption, and insecurity.

The dynamics of the urban system change constantly and become more and more complex in SSA, so most attempts to implement a single urban chain model cannot deliver precise long-term projections. It is feasible to evaluate emergent challenges in a multi-techniques and multi-disciplinary systematic framework, which can potentially facilitate their analysis and integration. The trans-disciplinary methodological approaches used in the research, including network analysis, GIS spatial analysis, cellular automata, micro-simulation, analytic hierarchy process and other agent-based models have provided both qualitative and quantitative depths to structural dynamics, spatial interactions, and scenario prediction. This trans-disciplinary approach can be seen as a pilot study to mitigate the complex multi-dimensional urban transport problem of Nigeria and other SSA countries.

B. **Journal Publications & Conference Presentations: Status of Technical Chapters**

Chapters 3 to 7 of the theses were presented into alternative paper formats. There are six journal manuscripts produced, three have been published in journals while the remaining three are undergoing reviews for transmission into journal papers. The reviews and data analysis of Chapters 4 and 6 have been presented in International Conferences. The citations of the technical chapters and their status of publication are as follows:

1) **Chapter 3:** This chapter explores the spatial-temporal analysis of land use dynamics and the connections between urban chains and transportation infrastructure space. Here, the two respective papers for urban chains and transportation infrastructure scenarios of Kano and Lagos cities have been published in peer-reviewed journal and the citations are:
   a) Otuoze S.H., Hunt D.V.L. and Jefferson I. (2021). Predictive Modelling of Transport Infrastructure Space for Urban Growth Phenomena in Developing Countries' Cities: A Case Study of Kano-Nigeria. Sustainability; 13(1):308. https://doi.org/10.3390/su13010308 **(published as journal article)**
   b) Otuoze S.H., Dexter V.L. Hunt and Jefferson I. (2021). Monitoring Spatial-Temporal Transition Dynamics of Transport Infrastructure Space in Urban Growth Phenomena: A Case Study of Lagos-Nigeria. Frontiers in Future Transport*ation* 2: 673110. https://doi.org/10.3389/ffutr.2021.673110 **(published as journal article)**

2) **Chapter 4:** Chapter provides predictive models for congestion and accessibility profiles of the main Metropolitan Statistical Areas of the two states. A review of transportation system resilience was carried out and presented at an International Conference while the manuscript of the technical chapter was published in a peer-reviewed journal. The citations of the journal and the conference are shown below:
   a) Suleiman H. Otuoze, Dexter V.L. Hunt and Ian Jefferson (2020). Review of trends in system resilience for sustainable future transport in megacities. 5th Annual International Conference on Engineering, 25-28 June 2018, Athens, Greece; Pg. 44 of Book of Abstract. The conference book of abstract is available from: https://www.atiner.gr/abstracts/2018ABST-ENG.pdf. **(Presented as Conference paper)**
   b) Otuoze S.H., Hunt D.V.L. & Jefferson I. (2021). Neural Network Approach to Modelling Transport System Resilience for Major Cities: Case Studies of Lagos and Kano (Nigeria). Sustainability; 13(3):1371. https://doi.org/10.3390/su13031371 **(Published as journal article)**
3) **Chapter 5:** The chapter dealt with assessment and modeling sustainability literacy and travel behaviors of the urban populace of the two cities. Below is the prepared paper draft title, which is undergoing review for publication in peer-reviewed journal:
   a) Otuoze S.H., Hunt D.V.L., Jefferson I. (2021). Sustainability Paradigm of Transportation Infrastructure in the Developing Countries: Case study of Nigerian Major Cities (Lagos and Kano). **(Undergoing review for journal publication)**
4) **Chapter 6:** This chapter analyzed the thematic references of transport sustainability from the perspectives of policymakers to assess the evolution of urban transport development policies of the two cities. An initial draft of this chapter was presented in poster format at an International conference in the USA while the upgraded version cited below is under review for journal publication.
   a) Suleiman H. Otuoze, Dexter V.L. Hunt and Ian Jefferson (2020). Institutional policy framework and perspectives on transport sustainability in the emerging Nigerian megacities: Case study of Lagos and Kano. 1st NVIVO International Conference, 23-24 September 2020. NVivo Community, QSR International, Massachusset, USA. https://vconf_materials.s3.amazonaws.com/boothmaterials/NVIVOposterpdf4_2oetnwq2r7.pdf. **(Presented as conference paper)**
   b) Otuoze S.H., Hunt D.V.L., Jefferson I. (2021). Thematic Analysis of Transport Sustainability Paradigm and Perspectives of Stakeholders of Major Nigerian Cities. (**Undergoing review for journal publication).**

5) **Chapter 7:** The chapter is focused on developing decision-making model which evaluates the quality of transportation services and prioritize the hierarchy of intervention strategies. The draft of the paper cited below has been submitted for review for journal publication.
   a) Otuoze S.H., Hunt D.V.L., Jefferson I. (2021). Measuring transport demand management compliance using AHP and SERVQUAL models: Case study of Nigerian cities. (**Undergoing review for journal publication).**

CHAPTER ONE: INTRODUCTION

CHAPTER ONE
INTRODUCTION

1.1 Preamble

While demographic statistics generally indicate an increasingly growing world population with the peaks of these growth figures in the developing countries[1] of Asia, Africa and Latin America, the number and size of cities are also rising. Fast urbanization[2] due to rising population growth and the frenzy of rural to urban migration has evolved emerging African cities into 'accidental' mega-cities (cities with more than 10 million people) (Amekudzi, et al., 2007). Cities in Sub-Sahara Africa (SSA), the world's poorest region, exhibit the worst urban development prospects, with many plagued by a mosaic of urban slums, ageing infrastructure and creeping urban mobility facilities (Aerts, et al., 2014; Sietchiping et al., 2012; Njoh, 2003).

Rapid urban development has been a major challenge to vital infrastructure in many fast-growing cities in both the developed and developing worlds in recent decades. Phenomenal rapid growth in urban population has been propelled by socioeconomic factors, poverty, insecurity, and favourable development policies in favour of cities (Aljoufie et al., 2013). Spatial-temporal dynamics of cities impacts not just the socioeconomic well-being of the urban population but relates to complex and multi-scale dimensions of physical planning and urban infrastructure development (Han et al., 2009).

Urbanization is not just an antithetical to equity, environment, and economic and land resources management, but it also impacts spatial distribution and social wellbeing of people. While urbanization is a catalyst of socioeconomic development in the developed countries, countries in SSA, like many other developing nations lacks capacities in supporting infrastructure, frameworks, and policies to leverage the transition towards optimal gains in sustainable development.

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[1]In the current research, the contextual definition of "*developing countries*" applies to urbanization paces and urban development stages based on countries experiencing an accelerated transition in the evolutionary phase. According to Farrell (2018), countries in the terminal phase of urbanization and population transition could be classified as "**developed countries*" (for examples, many European and North American countries, Australia, Japan). With expanding population and urban agglomeration, Sub-Saharan African (SSA) countries are still in an accelerated or active stage of urban transition.

*In terms of economic development, the United Nations defines a developing country as one with a weak economy typified by a low GDP per capita, low industrialisation, and poor performance on the Human Development Index (HDI) scale as compared to other countries (O'Sullivan & Sheffrin, 2003). HDI compares life expectancy, literacy, education, poverty, and other indicators across countries.

[2] The term "urbanization" refers to the movement of people from rural to urban settings, whereas the term "urbanization rate" refers to the proportion of people who live in cities relative to the overall population of the country (United Nations, 2014).

Urbanization exerts pressure on the changing urban landscape, including the Geo-spatial form, physical planning, infrastructure and with enormous ramifications on social and economic wellbeing of its dwellers. The main drivers of the sustained patterns of uncontrolled urbanism across SSA are population growth and migration. Gabon, for instance, leads the pack of 54 urbanizing SSA countries with 89.74 percent urban population, while Nigeria, Africa's most populous country, has agglomerated to 51.16 percent, with the potential to soar to 70% in 2050 due to increased population growth (2.58%) and the urbanization rate (4.23%) correspondingly (O'Neill, 2021).

Elsewhere in Rwanda, a country once ravaged by from the 1994 civil war genocide of 1994 and has emerged strongly a model example of a modern " sustainable city" in Kigali, urbanization has been shaped by good socioeconomic policies, sustainable development plan and setting the right targets and benchmarks for urban vision. Although, natural population growth of Rwanda compares to other countries across SSA subcontinent, it has maintained a distinctive trajectory of keeping urbanization low through policies that reduce migration and increases rural *reclassification*[3] (Baffoe et al., 2020). This success was achieved through well-coordinated policies in agriculture and subsidies, increased productivity and technology innovations, sustainable environmental policy and by spurning local economy through the celebrated socio-economic model called *Umuganda*[4].

Nigeria's urban management strategies and development policies have yet to provide a viable answer to the country's clear urbanization problem. Physical planning, land use change, critical infrastructure and transportation facilities are the most vital components of urban growth phenomenon that influence its transition and morphology. Urbanization is a multi-dimensional problem but bears its burden on economy, socio-demographic accomplishments, productivity, business and critical infrastructure. Provision of critical infrastructures and amenities are necessary for the city to thrive and function.

According to Ellis et al. (1997), Critical infrastructures are "a network of independent, large-scale, man-made systems (set of hard and soft structures) that function collaboratively and

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[3] Rural reclassification occurs where previous rural territories are reclassified through the permeation of socioeconomic densification, cultural and physical characteristics normally associated with urban centers (Wineman et al., 2020)

[4] "*Umuganda*" literally means people coming together for a common purpose. The idea is to foster a spirit of collective responsibility and civil pride by working hand-in-hand on practical local schemes. Repurposing the concept (coined from genocide era mobilization and drum-beat of war) is helping to undo the legacy of social division and motivate citizens to offer mutual assistance and get involved in collective actions that promote unity and a sense of belonging" (Turok, 2019; pg. 223)

synergistically to produce a continuous flow of essential goods and services". They are cyber-physical assets which makes society to flourish and function, absence or its disruption may impact negatively on normal life, safety, security, health, social-economic wellbeing of that society (Rinaldi et al., 2001; Lee et al., 2013; Neirotti et al., 2014).

Critical infrastructures (government services, banking, communication and information technologies, finance, food, health, water, energy, security, emergency services and transportation) are complementary, interrelated, and interdependent. The various areas of applications of critical infrastructures are shown in Figure 1.1. The complex webs of interrelationships are crucial synergy for political administration, economic viability, social wellbeing and in terms of security of an area.

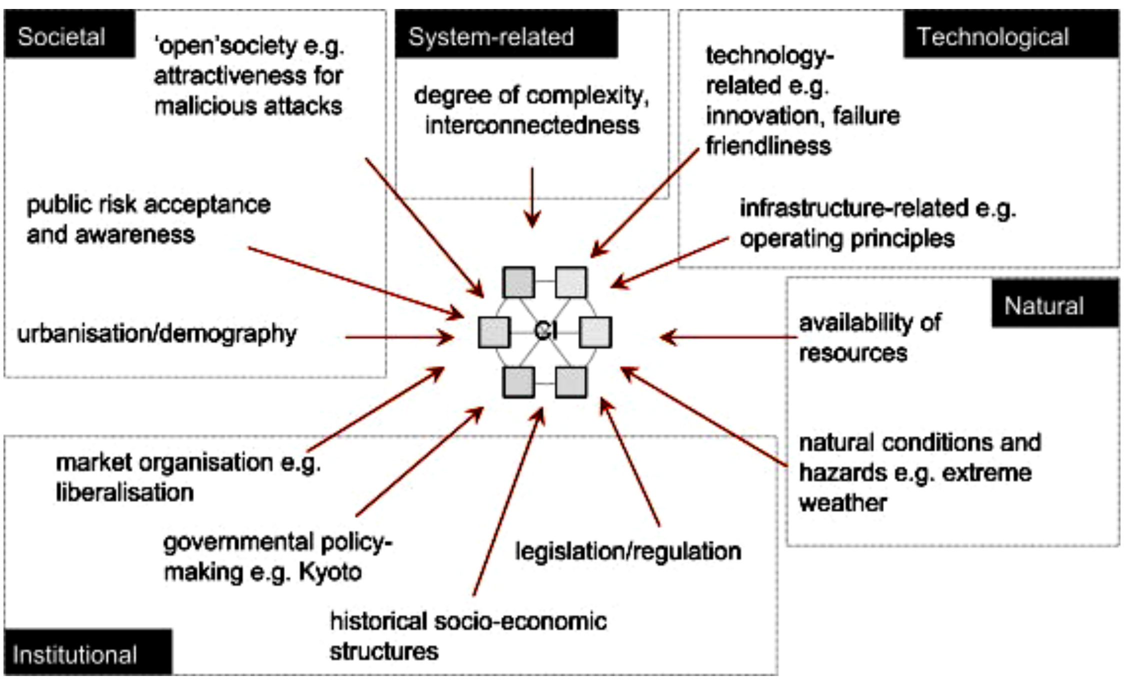

Figure 1.1: Problems and risk factors affecting critical infrastructures (IRGC, 2007)

Infrastructure systems, including transportation and communication, play significant roles in sustaining economic growth, social development and maintaining spatial services of cities and countries. Recently, the travel limitations imposed by COVID-19 pandemic have increased the deployment of digital computer platforms, information, and communication technologies as alternatives to physical travel (e.g., virtual learning, remote working, telecommuting, teleconferencing, and teleshopping etc.).

While telecommuting complements physical navigation and contributes beneficially to shaping the future of mobility by reducing congestion and carbon footprints, the limitations of working conditions, physical work relations and social interaction have increased the debate. According to researchers, the complementary role of remote virtual space is well recognized but cannot substitute physical travel, workplace, and spatial environment (Bin et al., 2021; Moranddini et al., 2020; Mäntymäki et al., 2019; Suel & Polak, 2018).

Literacy, digital skills, and infrastructure deficits pose impediments to societal integration and potentially aggravate the existing far-flung socioeconomic disparities. According to a 2019 report of the Digital Economy and Society Index (DESI), over 40% of European population lack the “basic digital” skills to navigate the new world of information and communication technology (ICT), e-commerce and e-government (European Commission, 2019). Transportation infrastructure continues to dominate the academic discourse as facilitator of accessibility, mobility and travel as facilities, assets and physical systems which underpin a functional society. While the education and literacy rates in Africa have increased, Sub-Sahara Africa is below par compared to the rest of the sub-regions and the world. For example, Sub-Saharan Africa the least literacy rate in the world – the population of children that have no reading proficiency or skills have reached 88 percent compared to 14 percent in Europe and North America (U.N., 2021).

In practically every metric of infrastructural performance, Sub-Saharan Africa (SSA) ranks poorest among all developing countries. Adding to the plethora of problems of SSA, there is a link between between infrastructure and socioeconomic development that makes it the poorest region. The World Bank estimated that electricity access is only available to 15 percent of the rural Africa and 35 percent of its urban settings (World Bank, 2021). Trotter et al. (2017) estimated that over 630 million inhabitants of the subregion are without electricity.

In 2010, Global infrastructure Index ranking of Nigeria is rated poorly at number 121st position out of 140 countries (Donaubauer et al., 2016). Similarly, Nigeria’s transport infrastructure index of 2.60 on a weighted scale of 5 ranks 117th out of 136 countries considered by the World Economic Forum in 2016, is grossly short of capacity to support 200 million population (WEF, 2016). In Nigeria, hard and soft infrastructures such as information, telecommunication and power systems that could complement the transportation infrastructure and provide an alternative to physical mobility have not functioned optimally due to a persistent lack of capacity and neglect. This research evaluates the effectiveness of combined measures of infrastructure (i.e., Geo-spatial transition analysis) and access control (i.e., congestion prediction, sustainability and travel demand management) to mitigate major transportation problems of Nigerian cities.

1.2 Transport infrastructure

Transportation is the developmental cornerstone of cities as society, people, businesses, industries, and administration of governance depend on interaction and accessibility. Transportation infrastructure is considered as one of the most important critical infrastructure elements because of its vitality to land use, societal linkages, productivity, commerce, and socioeconomic activities of people (Keeling, 2010; Achour and Belloumi, 2016).

Transport infrastructures of developing countries are unsuitable to contain its fast urbanization pace and the inadvertent sprawls. The developed nations have almost completed their transition phase, but are however, grappling with extreme climatic factors and end of life or life cycle problems (Rahman et al., 2009; Aradau, 2010; Miao et al., 2013). In many developing countries, urbanization have its potential economic and productivity impetuses. The negative consequences of fast agglomeration have led to uncontrolled sprawl in the economically disadvantaged urban fringes with perennial traffic congestion, pollution, dysfunctional development planning and land use alteration (Zhang et al., 2011; Mas et al., 2014). Several other contemporary empirical research findings have rated urban transport infrastructure as a facilitator of political stability, social development and a significant contributor to national productivity and economic growth (Yu et al., 2012; Solé-Ollé et al., 2012; Gwilliam, 2013; Agbigbe, 2016).

Transportation infrastructures are urban growth catalysts which impart on economic viability, land-use changes, and spatial expansion (Reilly et al., 2009; Müller et al., 2010; Chen et al., 2016). Globally, urbanization continues to challenge infrastructure development and poses various complex transport issues, primarily on traffic congestion, infrastructure deficit, pollution, and ecology of the cities (Bhatta et al., 2010; Aljoufie et al., 2016). Kiel et al. (2016) recorded that the audacious taxonomic trail in rapidly growing mega cities portends extreme weather problems that threaten urban connectivity and mobility.

Urbanization has an inherently strong, but a complex reciprocal relationship with transportation systems and is usually influenced by several socio-economic and physical components. The physical component of this relationship includes land use interaction, spatial transition dynamics, physical planning, and transport infrastructure, whilst the socioeconomic component includes travel demand, demography, economic agglomeration, and employment creation.

Urban planning is linked to improvements in land use, urban ecology, and the transport system. It is necessary to track spatial and temporal relationships of the development dynamics and demand response of transport infrastructure. In the spatial-temporal context of urban growth, population agglomeration increases demand for all services, the crucial roles of connectivity and socioeconomic impacts places transport at the core priority of urban infrastructure development (Al-Ahmadi et al., 2009; Funderburg et al., 2010).

Both the Physical and socioeconomic development of Nigerian urbanization are characteristically weak, making the relationship between urban growth and growth and transportation far more complex. Nigeria has Africa's largest population of over 200 million people, the demographic boom is projected to reach a milestone of over 410 million people in 2050 (UNDESA-DP, 2017). Natural population growth and migration tides have burgeoning effects on the urban chain process. Nigeria's rising urban agglomerations have produced many urban and peri-urban[5] sprawls – there are currently 36 cities (including one mega-city) expected to exceed population count of 500,000 people in 2020 (Aliyu and Amadu, 2017).

Transport infrastructure is the driving wheel of the urban growth phenomenon. In many Nigerian cities, soaring population growth and migration have triggered uncontrolled urban chains, leaving the cities with huge transport infrastructure gaps and increased travel demand, motorization and congestion besetting the urban environments. According to Lowitt (2006), motorization and private vehicle ownership have risen to a record high of over 70% in the leading SSA countries, including Nigeria, due to deteriorating and fragmented transportation infrastructure, urbanization, policy misfits towards public transportation systems, and access restriction. Nigeria's erratic power and electricity supply, poor information and telecommunication infrastructures have together imposed a limit on the capacity for the deployment of telecommuting hard and soft infrastructures which would have complemented physical mobility. The rampant insecurity across the country, as well as the fragmented urban planning layouts, has increased the challenges of telecommuting. The choices of Lagos and Kano cities as a case study is informed by the leading demography and urban agglomeration in Nigeria.

1.3 The Study Area

Nigeria currently ranks the world seventh most populous country with a population of about 190 million in 2017 and a growth rate of around 3% owing to its high fertility rate (Hilderink et al., 2012). The population figures were projected to be more than 400millions in year 2050 when it will become the world third most populous country (Anoba, 2019; Cummins; 2019; Olowe, 2020). Infrastructure is largely inadequate and dilapidated, the demographic reality of rural-

[5] "Peri-urbanization is the process by which urbanization draws into the orbit of urban cores even distant hinterlands so that they assume ever more physical, economic, social, and cultural characteristics normally associated with cities" (Phadke, 2020). Urbanisation is loosely defined as rural-to-urban transition involving a widening scale of spatial extents, land use change and conversion facilitated by population growth, economic agglomeration and increasing social and cultural activities.

urban migration in the country is expected to climb from 58 to 70 percent by 2050 (UNDES-DP, 2015). Amidst overpopulation and fast urban transition, the global index of transportation infrastructure which rated Nigeria as 117th out of 136 countries further emphasized the severity of the country's acute infrastructure problem (WEF, 2016)

Nigeria is in the spotlight of global population and urbanization, albeit economic resources to cater for infrastructures are declining. While the predictions by drivers of economic growth and development which includes population, labour, technology innovation, and industrial growth are favourable. But there is a downward turn in the country's economy, with the GDP steadily shrinking partly due to political scenario and the crunch of global economic recession (Anyaehie and Areji, 2015; Yapicioglu et al., 2017).

Most cities in Nigeria are beset by low accomplishment in quality of life, closely related to defective developmental policies, poor planning, inadequate infrastructure, and skewed modal choice in favour of road transport (Filani, 2003; Solanke, 2013). Weak governance, bureaucratic corruption, low literacy, chronic poverty, political instability, and insecurity are some of the problems affecting the country's socioeconomic growth and infrastructure development (Basorun and Rotowa, 2012).

Road transport is the dominant transport system playing a crucial role in the Nigerian economy, where there are poor developments of railway, inland water, and air transport. The modal share of the country's 195,000-kilometer road transport network, which accounts for 95 percent of all transportation systems, remains the most critical element in both urban and rural transportation (Campbell, 2009; Effiom & Ubi, 2016). The railway transport network comprising 3,505 km narrow gauge and 669km standard gauge reflects the dismal state of decay of the country's transport infrastructure.

Road networks have been shared based on ownership by responsibility and jurisdiction among the three tiers of government – federal, state, and local council authorities respectively. It includes 33,000-km falling under federal jurisdiction and 50,000-km represents state roads while the remaining 112,000 km feeder roads largely in disrepair state belong to the local government authorities that have the least financial resources (Road Sector Development Team, 2020).

Lagos and Kano are the two most populous cities of Nigeria. The fast-expanding spatial extents, as well as the deteriorating infrastructures make it difficult to cope with the massive influx of people into the two cities, rendering the system congested and difficult to navigate the urban terrains.

Kano City is located on 12°00′N 8°31′E and is the second most urbanized city in Nigeria. The city represents the economic capital of northern Nigeria and has a current population estimate of about 4.5 million (Demograghia, 2021). The main metropolis is an urban conurbation of only 8 out of 44 Local Government Areas in Kano State and it covers a land area of 499 km-square and population density of 14, 100 persons/km-square (Brinkhoff, 2021a). The city is connected by 3,113 km of road with a road density of 22,722 meters per square-km (Ibrahim & Mohammed, 2016).

Lagos, on the other hand, is one of the fastest growing cities in the world with a population estimate of over 20 million people (Fajemila et al., 2020). The demographic nature of the only Nigerian city that has agglomerated to the status of a mega-city revealed a densely populated cityscape of about 14,469 persons/km-square and a total land area of 3577.28km-square (coordinates: 6°27'N & 3°24'E). The main metropolis is located within 1,171.28 km-square area, comprising urban conurbations of 16 out of 20 Local Government Areas bounded by rivers, Lagoons, and Atlantic Ocean (Brinkhoff, 2021b). Lagos City has about 4,400 km total road networks, only 2,600 km of these congested roads were paved to varying degree of quality and service condition for over 2 million registered vehicles plying the chaotic road networks daily. Although the Bus Rapid Transit (BRT) Scheme, which operates on physically segregated 22km lanes has a current capacity of 200,000 passengers per day using the 220 BRT buses has eased traffic congestion along the corridor, the 'traffic jam' situation continues unabated in many parts of the city (Arimah, 2017).

While the onslaught of urbanization, sprawls and informal developments continues to rise in major Nigerian cities, transportation infrastructure, safety, cleanliness, social harmony, and sustainability are declining. Inadequate public transport and pedestrian facilities, heavy motorization as well as poor traffic management have exacerbated the grim and unfriendly realities of commuting in many cities.

Lagos city, for instance, ranks lowest of fifty cities in the Global Urban Mobility Readiness Index survey based on five core criteria: (1) infrastructure (public transit & pedestrian facilities), (2) transport system efficiency and traffic management, (3) economic attractiveness and shared mobility competitiveness, (4) social impact and equity and (5) technology innovation including eco-drive share and digital services (Wyman, 2020). Also, Kano's urban inaccessibility and congestion reflect Nigeria's overall decrepit transportation infrastructure, fast motorization, and inadequate traffic management problems (Ibrahim & Mohammed, 2016).

Proactive ought to be taken to retrofit infrastructure, manage traffic and increase the public transit share and to mitigate the precarious current and future mobility situation of these cities. Hence, the work is motivated as a technical blueprint to espouse the existing gaps, including the extreme traffic regime and infrastructure resilience problem, continuous tracking of land use transition, transport demand management and sustainable pathways to cater for accelerated population and urbanization of the next decades. To address the seemingly expanding transportation infrastructure deficit in Nigeria, this study investigates the causal effect and interaction between urban chain process and transportation systems of cities (i.e., Lagos and Kano).

1.4 Research gap

Globally, academics and policy makers are increasingly focusing on the dynamics of urban development and the transportation difficulties, as population growth and migration generate rapid urban infrastructure challenges. The relationship between urban landscape evolution and transport demands is difficult due to the complex variables of population growth, land use and planning policies, socioeconomic indicators, motorization rate and public transport policies (Aljoufie et al., 2013).

Transportation systems enhance accessibility and mobility of people and goods and influences socio-economic activities of the city. The spectrum of sustainability and resilience is threatened by uncontrolled urbanization which increased transport demand, infrastructure burden, traffic congestion, safety risk and environmental pollution. The neglected problem of transport infrastructure in most Nigerian cities has sprouted mosaics of urban sprawls that have dotted the fringes of the cities.

Urban chain process has a strong causal relationship with transport infrastructure development of cities but understanding the nature and extent of these mutual interactions are vital to urban planners, environmental researchers, transport scientists and policy makers. Although, many researchers have analysed urbanization in diverse contexts (Phadke, 2020; Turok, 2019; Farrell, 2018; Zhao et al., 2017; Mas et al., 2014; Kityuttachai et al., 2013; Thapa and Murayama, 2011; Bhatta et al., 2010).

While a few other researchers have also embedded transport development into planning and general urban landscape ecology (Geurs et al., 2006; Thapa & Murayama, 2011; Kityuttachai et al., 2013; Boori et al., 2015; Zhao et al., 2017). Other previous attempts at analysing the "causes and impacts" of freight on urban mobility (de-Jong et al., 2004; de-Jong and Ben-Akiva, 2007; Zhao et al., 2011) lacked focus on the mutual interactions between urban chains and transport developments, spatial analysis, demand responses of transport and the appropriate intervening policies. None of these researchers have thoroughly examined the linkage, causal relationships, and mutual interactions between urban chain processes and transport infrastructure especially in the foremost SSA urbanizing countries' cities.

Nigeria’s prospects of sustainable cities continue to decline due to urbanization surge incapable of coping with the lowly rated transport infrastructure and management profiles. Urbanization has worsened land use instability and put strain on inadequate transportation infrastructure, diminishing the resilience and capacity of the poor transportation systems and fail to develop with sustainable worldviews. The spectrum of sustainability and resilience is threatened by speedy urbanization which increased transport demand, infrastructure burden, traffic congestion, safety risk and environmental pollution. However, a variety of problems have plagued the roadways as with other transport modes, the most prominent among them are bad maintenance culture and the competing forces of infrastructure investment portfolios to whom transport sector is lumped with.

Although, Nigeria operates a federal system of government, the political economy is one of the monolithic oil dependent nature, which concentrates all powers and major political and developmental decisions at the centre (Khan, 1995; Ndimele, 2017; Adewuyi et al., 2020). A “top-down” hierarchy of distribution of resources and devolution of power from the federal government to state government and finally, to local authorities further lengthened the chains of bureaucratic process involved in urban and transport development (Hathaway, 1993).

The traditional aggregate coupling infrastructure development model adopted in Nigeria hardly differentiates the needs assessments of any infrastructures (transport, communication, water, housing, electricity, health, etc.). Application of coupled aggregate development model for urban chain process presents unsuitable challenges to urban chains due to a plethora of problems including Geo-spatial particularities, political interference, lack of development control and monitoring, rapid population, and urbanization agglomeration (Farrell, 2018).

This lumping of infrastructures has resulted in major gaps in terms of quantity and quality of infrastructure allocated to the sector and increased inequity in the investment portfolio allocation, bloated bureaucratic control, and political interference. Many large cities have become inaccessible with perennial traffic congestion and pollution being part of urban reality due to the country's current urban transition fraught with urban sprawl, fragmented infrastructures, segregated settlement and planning disharmonies, and development policy mismatch. Dynamic modelling of the reciprocal relationship of urban chain process with transportation systems could be beneficial to urban development analysis, scenario prediction and policy decision. To tackle the widening gap in transportation infrastructure in keeping with the rapid pace of urban transition in Nigeria, the research examines the causal effects of urban chain dynamics on transport facility as a means of sustaining urban spaces of the two biggest cities (i.e., Lagos and Kano).

1.5 Aim and objectives of study

The research is aimed at determining executable analytical metrics for assessing the causal impacts of urban chain dynamics on transportation facilities as a measure of preserving urban space in Nigerian cities (i.e., Lagos and Kano). The specific objectives that contribute to the overall aim are divided into four categories:

Objective 1: To provide analytical modelling techniques for predicting spatial-temporal dynamics of urban growth phenomena in relation to transport infrastructure space. The investigation of spatial and temporal scales of urban growth lies at the heart of urban development dynamics and integrated mixed land use/transport planning. This spatial analysis employs a disaggregate urban development model based on urban land use transition dynamics to track, model, and predict the spatial-temporal requirements of urban chains, as well as the expected transformation of transportation infrastructure spaces in Nigeria's two most populous cities.

Objective 2: To evaluate the role of transport infrastructure systems on urban resilience, its coping capacity and reliability against impacts of motorization and congestion. The analysis combined traffic characteristics, demographic data, and transport infrastructure to create a model based on input-output algorithm implemented in artificial neural network for real-time traffic analysis and prediction of congestion profiles of main metropolitan statistical areas.

Objective 3a: To assess the sustainability awareness, involvement, and sustainable travel behaviour of urban stakeholders. The assessment involves surveying and quantifying the level of sustainability literacy, community participation and to evaluate how much the existing mix land uses and available public transport system stimulates sustainable travel choices amongst a broad spectrum of stakeholders. The community of stakeholders surveyed includes academia (lecturers and students), transport operators[6], managers[7], policy makers and users who are city residents.

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[6] Transport operators in Nigerian context are private investors and concession companies operating transport assets. Nigerian Union of Road Transport Workers (NURTW) Co-operative, Primera TSL company running Lagos BRT fleets and Lekki Concession Company (LCC) handling Lekki Toll Gate are examples of operators.

[7] Transport managers are a coalition of state agencies and private partners involved with project development and management consultancy services, data collection and coordinating transport policies and programs. They are also vested with the responsibilities of planning, regulating, implementing policies, and franchising the operation of public transport infrastructure and services. Examples are Lagos Metropolitan Area Transport Authority (LAMATA) and Kano State Transport Authority (KASTA).

Objective 3b: To examine the institutional policy framework including the vision, targets and benchmarks and transport sustainability thinking of *policymakers*[8] using the themes of sustainability. The survey involves interacting with Heads of Transport in their capacity as policymakers at the behest of their state governments to assess the institutional capacity and policies, including infrastructure, urban development policies, public transportation, and non-motorized commuting facilities, among others driving sustainable transport policies.

Objective 4: To quantify transport infrastructure and service quality satisfaction using transportation demand management strategies, sustainable transportation development intervention decision-making. It involves prioritizing TDM objectives for decision support and assigning strategic management portfolios for the two cities, according to the needs of infrastructure and service satisfaction.

Figure 1.2 shows the structural flow, coherence, and sequence of relationships amongst the various objectives pursuant of the aim of the research topic. To maximize the benefits of the transportation infrastructure system, including effective, safe, and timely travel, accessibility, and services, an integrated approach to land use planning is required. Exploring the potential of integrated mixed land use/transport planning help to revitalize a community sense of neighbourhood planning and promote sustainable transportation development by increasing the use of public transportation, biking, and walking. Objective 1 provides the spatial-temporal analysis of transport infrastructure space and other land use changes in relation to urban growth phenomena.

While the Geo-spatial dimensions of land-use and transportation policies influence the essential criteria for sustainable urban transportation (reduction of travel distances and time), urbanization has increased competition for navigational access or right-of-way on the network of transportation facilities. Congestion has increased the frustration of urban dwelling due to the increasing share of private car ownership, motorization, access control problem and inefficient public transportation system. To understand the effects of transport infrastructure gaps on accessibility and urban linkage, Objective 2 examines the urban traffic regimes and congestion pattern of Lagos and Kano the two Nigerian cities to expose areas of improvement.

A multi-pronged approach that includes infrastructure efficiency, access control, sustainable travel behaviours and public transport system paves the way for a thriving land-use integration and sustainable urban transportation planning policy. Based on surveys of the various themes

[8] Policymakers are members of government departments and politicians involved with policy formulation and decision making e.g., Permanent Secretary and Directors in the Ministry of Transport, Commissioner of Transport acting for Governor and State House of Assembly Transport Committee Members.

and measures that promotes transport sustainability, the study in Objectives 3a & 3b could provide assessments of transportation policy frameworks, awareness and thinking and the contributions of various actors to the policies.

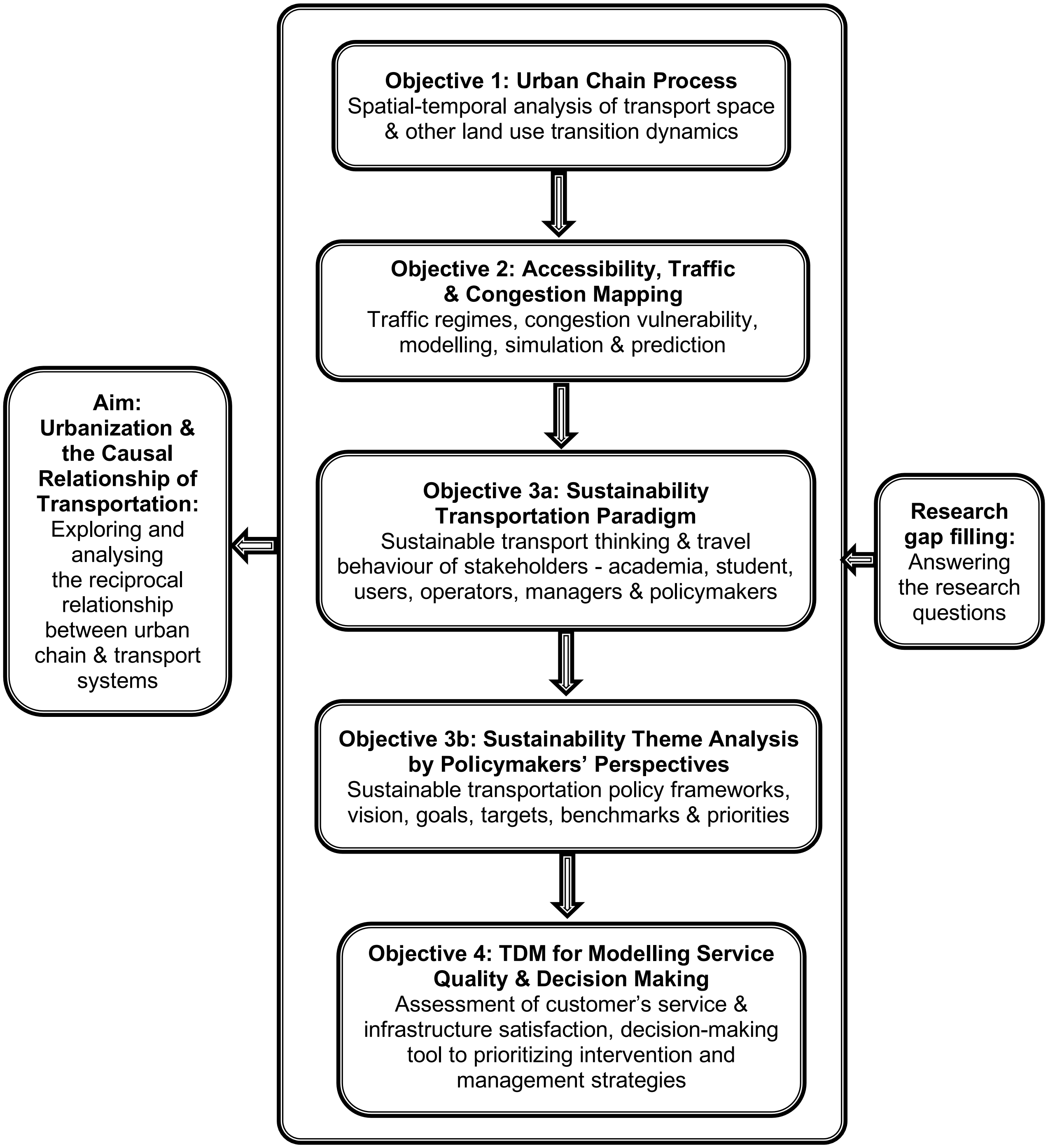

Figure 1.2: Flow diagram showing the sequence of coherence & linkage of aim/objectives of the research

Transport sustainability is linked to a land use spatiality and comprehensive transportation infrastructure planning but determining the development priorities to achieve the sustainability goal necessitates the use of transport demand models as a tool for policy decision. When complicated problems are well-structured and multiple criteria analysis are properly considered, more rationally informed decision are made. Using inputs of land use, demographic, socioeconomic data, transport demand models could predict the performances of transportation system (traffic and congestion profiles) under various policies, infrastructure, and service scenarios. Objective 4 investigates users and policymakers' satisfaction as well as preferences by applying travel demand management as a 'filtering down' process of decision making.

Nigeria is Africa's most populous country, with a population of around 214 million people[9]. Lagos and Kano are two largest cities – they represent the urban cum commercial hubs of Southern and Northern Nigeria respectively. The megapolis of Lagos ranks the most in terms of Africa's worst traffic congestion and time in traffic indices while Kano Metropolis, Nigeria's second most populous city is also rated among SSA countries' worst traffic congestion regimes[10]. The two most urbanized cities have been plagued by a gamut of other urban transport problems: infrastructure gap, inefficient public transport system, congestion, fragment land use and urban planning problems.

Despite the low transport infrastructure rating of 117th out of 136 country survey by the World Economic Forum (WEF, 2016), the continuing grip of heavy motorization with about 12 million registered vehicles majorly concentrated in urban areas (WHO, 2016); forms part of ubiquitous challenges confronting Nigerian cities. With these cities embodying most of the problems, it leaves much doubt that the transportation systems will be able to cope with the predicted population rise that will propel Nigeria into the third most populous country in the world in 2050 (UNDESA-PD, 2017). This study investigates the interaction of urban growth with the transportation system and proposes sustainable pathways to addressing the cities' transportation problems.

1.6 Research Methodology

The research methodologies were structured to address the study objectives and the methodological approaches include the following:

Method 1: First is the analysis of land use and transportation infrastructure reciprocal interactions to examine spatial transition dynamics. The methodological approach of

[9]IndexMundi: Nigeria Demographic Profile (https://www.indexmundi.com/nigeria/demographics_profile.html; accessed on 14/06/2021)

[10]Numbeo: (https://www.numbeo.com/traffic/region_rankings.jsp?title=2021&region=002; accessed on 15/05/2021)

disaggregate land use classification and modelling of Landsat imageries using Geographic Information System (GIS) remote sensing software and a further prediction of temporal time series using Cellular Automata-Markov (CA-Markov) was adopted. [11]Photogrammetry predates GIS in remote sensing but limited in range, speed, volume and type of data processing and model quality. Examples of photogrammetric applications are Photosynth, IMAGINE and PCI *Geomatica*. GIS is well suited to handle large volume of data involved in this research and the necessities of speed of analysis and spatially explicit analysis and prediction. Its spatial model calibration method classifies the functional relationships relevant to spatial changes and estimate model parameters using observed flow data and standard estimation techniques such as maximum likelihood classifier or ordinary least squares (Akgun et al., 2012). Hence, GIS has become prevalent and veritable tool for land use modelling because of its speed, robustness, quality, and spatial extents (Bettinger et al., 2017).

CA-Markov modelling establishes a set of framework spatial transition defined by grid cells and specifies rules that determine a cell's state based on the states of its neighbours (Ghosh et al., 2017). CA–Markov module fitted in IDRISI SELVA incorporates the functions of CA filter and the transition in Markov process which apply conversion tables and conditional probability of the conversion map to predict land use change states. Computer methods such as artificial neural networks (ANN) could also be used to quantify and predict spatial transition outcomes with some technical difficulties earlier highlighted (Liu et al., 2017). In spatial or temporal dynamic analysis, CA–Markov model is a robust approach for modelling and predicting land use changes because geographical information systems (GIS) can be integrated efficiently.

Method 2: In this study, artificial neural network was used as an adaptive artificial intelligence tool to investigate the complex domains of traffic congestion vulnerability and transport system resilience in Nigerian cities (Kano and Lagos). The methodology involves training the three algorithms Levenberg–Marquardt (LM), Bayesian Regularization (BR), and Scaled Conjugate Gradient (SCG) of multi-layer feed-forward back-propagation with input–output and curve fitting (NFTOOL) simulation model implemented in MATLAB R2019b software wizard to predict traffic congestion. The demographic cluster population of Metropolitan Statistical Areas (MSA), traffic characteristics, and infrastructure inventories are among the model input variables used for training target congestion elements (traffic volume, saturation degree, and congestion indices). Developing appropriate models for longer predictions by a time series, i.e., nonlinear

[11] *Photogrammetry is* the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena (Aber et al., 2010).

autoregressive exogenous model (NARX[12]) (Mane & Pulugurtha, 2018) and autoregressive integrated moving average (ARIMA[13]) (Wang et al., 2019) require a large pool of historical data and deep network training. Due to the paucity of data, multi-layer feed-forward back-propagation using input–output and curve fitting (NFTOOL) model lays the foundation for temporal time series prediction of urban traffic and discrete congestion profiling of the fast-evolving Nigerian cities.

Method 3a: In the process of integrating sustainability into the decision-making for transport infrastructure portfolio allocation, several tools, and methodological frameworks such as checklists, agent-based models (ABM[14]), rating systems, frameworks and traditional questionnaire surveys have been used (Giabbanelli & Crutzen, 2017). In the absence of socioeconomic data required by many of the listed models, the psychological feelings of stakeholders were assessed using questionnaire surveys to gauge the evolution of sustainability policies, conceptual knowledge and understanding of the benefits of sustainable travel behaviour. Inferential statistical analysis was carried out using SPSS software to bring qualitative and quantitative dimensions to the decision making and accord priority where necessary.

Method 3b: Questionnaire surveys were used to assess sustainability literacy and transportation sustainability themes. To bring psychological and phenomenological understanding to light in policy decision driving transport sustainability and further remove abstraction from claims of progress in the sector, interviews are used to uncover the meanings of the central themes of the sustainability subjects from the point of view of policy makers (Savin-Baden & Howell-Major, 2013). Focus group discussion, on the other hand, obtains responses from a group of participants and observes the ensuing discussions among the anonymous interviewees, whose response choices are limited to a set of predetermined answers (Adler et al., 2019). Interviewing method, in this research, provides a far greater depth of qualitative analysis than focus group discussion because of the details interviewees could give by the virtue of their positions as the topmost policy decision makers at the behest of their

[12] NARX is a dynamic network with recurring feedback connections containing several network layers used to forecast time series and multi - step predictions ((Mane & Pulugurtha, 2018).

[13] ARIMA model utilizes lagged average movement data to smoothen time series and predicts future values based on previous values using a "filter," which tries to separate network signal from noise, and then extrapolates signal to future predictions (Wang *et al*., 2019).

[14] Agent-based models simulate multi-agent simultaneous operations and interactions to replicate and predict the appearance of complex decision support systems (Gustafsson & Sternad, 2010).

governments. The qualitative thematic analysis was carried out using NVIVO software to assess their policy strength and weakness and visions of sustainable worldview.

Method 4: Transport demand management decision framework was developed to assess transport infrastructure quality and service satisfaction using SERVQUAL and AHP models. SERVQUAL model, an acronym for 'Service Quality' is a psychology-based qualitative research which assesses people's perception and expectation of quality service and the outcome of which helps shape policy decisions. Otherwise called Customer Satisfaction Index (CSI), it is used to priorities and close the gap between satisfaction and quality service delivery based on the five functional dimensions of quality (i.e., perception, reliability, responsibility, safety, and empathy) measured by questionnaire which collects the opinions of stakeholders and policymakers (Kansal et al., 2017).

Among several competing multiple-criteria decisions that either requires policy shifts, service and facility improvements or infrastructure investment portfolios, there is a need to structure problems and prioritize alternatives for more informed preferences and better decisions. Researchers have applied several multiple-criteria decision analysis (MCDA) tools[15] to aid decision making including Grey system, Fuzzy-set theory, Brown-Gibson model, Goal Programming Process, Rough Set Approach, and Analytic Hierarchy Process (AHP). Many of these models are either too data driven or involves complicated mathematical computations.

The use of AHP as MCDA tool has been growing in prominence because of a variety of commercially available softwares that has made the computation and interpretation easier (Vargas, 2010). AHP is used to break-down the decision problem into a hierarchy of subproblems, after which pairwise comparison is used to assess the relative importance of its various factors. The evaluation is converted into numerical values in term of weights of priorities to compute every alternative's score and consistency index of responses from decision makers (Saaty, 2005). The methodology of this research involves applying hybrid AHP-SERVQUAL model of TDM framework to evaluate the generic dimensions of quality satisfaction, assign strategic management portfolios and generate priorities on the consistency of decision-making choices.

1.7 Thesis Overview and Outline

The thesis consists of eight chapters: Chapters 1 and 2 are the introduction and literature review respectively, Chapters 2 to 7 are the core technical section which addressed the research objectives and are presented in alternative paper formats. While Chapter 8 forms the concluding

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[15] https://en.wikipedia.org/wiki/Multiple-criteria_decision_analysis

part of the research findings and some recommended areas of further research to increase knowledge and resolve the endless challenges of urban mobility and infrastructure problems in many developing countries.

The core technical section produced six publication papers in all, three of whom have been published in peer-reviewed, high impact journals and the remaining three are undergoing review for publication in highly rated journals. The literature review of Chapter three was presented in Annual International Conference on Engineering which held on 25-28 June 2018 in Athens, Greece.[16] The list of well referenced Appendices relevant to Chapter 5 is also included for the purpose of clarity. Figure 1.3 shows the relationship and coherence of chapter summaries.

Chapter one provides an overview, and scope of the research. It contains a general introduction, brief overview of current development, existing gaps, and motivations for the research. It also highlighted the study objectives pursuant of research aim, the methodology, study areas and thesis outline are introduced.

Chapter two presents the general literature background which relates issues highlighted in chapter one. It provides an in-depth critique, discussions, and gaps in the literature review, and analyses the rationale for appraising the nexus between urban chain process and the development of transportation system in the current research.

Chapter three, which was published in two journal papers involves modelling of spatial and temporal transition dynamics of urban chains in relation to existing and future transportation space requirements and was carried out to monitor urban land use evolution in the two cities (Kano and Lagos respectively). It involves classifying and quantifying urban chain process and transport characteristics by analysing Landsat images using remote sensing Geographic Information System (GIS) and hybrid Cellular Automata-Markov (CA-Markov) transition prediction model fitted in IDIRIS SELVA softwares. The published versions of the manuscripts shed light on spatial transition analysis of the causal link between urban land-use change and transport infrastructure and is presented in two separate sub-chapters (i.e., chapter 3a representing analysis for Kano Metropolis[17] and chapter 3b for Lagos City[18] respectively).

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[16] Suleiman H. Otuoze, Dexter V.L. Hunt and Ian Jefferson (2020). Review of trends in system resilience for sustainable future transport in megacities. 5th Annual International Conference on Engineering, 25-28 June 2018, Athens, Greece; Pg. 44 of Book of Abstract. The conference book of abstract is available from: https://www.atiner.gr/abstracts/2018ABST-ENG.pdf.

[17] Otuoze SH, Hunt DVL, Jefferson I. (2021). Predictive Modelling of Transport Infrastructure Space for Urban Growth Phenomena in Developing Countries' Cities: A Case Study of Kano — Nigeria. *Sustainability*; 13(1):308. https://doi.org/10.3390/su13010308

[18] Otuoze SH, Hunt DV and Jefferson I (2021) Monitoring Spatial-Temporal Transition Dynamics of Transport Infrastructure Space in Urban Growth Phenomena: A Case Study of Lagos—Nigeria. *Front. Future Transp.* 2:673110. https://doi.org/10.3389/ffutr.2021.673110

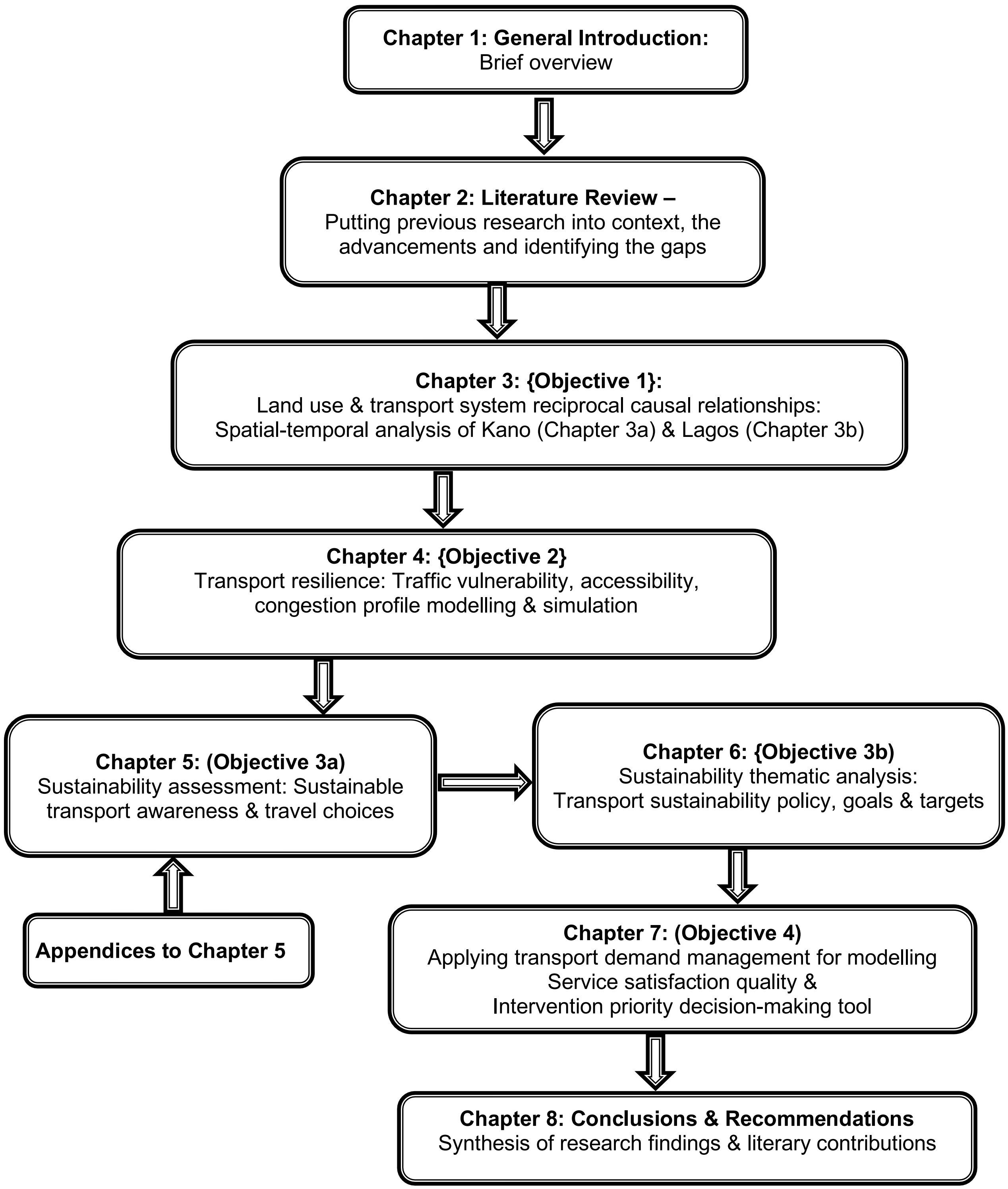

Figure 1.3: Relationship and coherence of chapter summaries

Chapter four provides models for predicting urban traffic congestion profiles based on demographic changes, traffic data, and transportation infrastructure inventories. This is necessary because of the analysis of spatial-temporal dynamics in chapter three, which delineates many unsuitable land use patterns as well as worrisome potential ramifications of increasing inaccessibility and transport problems of the two cities. The methodological approach involves Artificial Neural Network (ANN) model prediction used to optimize traffic network performances and congestion profiles. It employed a multi-layer feedback propagation with input and curve fitting ("NFTOOL") training algorithms based on some heuristic and numerical optimization methods. The three training algorithms used for modelling and prediction are Levenberg–Marquardt (LM), Bayesian regularization (BR) and Scaled conjugate gradient (SCG). The outcome of traffic congestion modelling in chapter four has been published in a peer reviewed journal.[19]

Chapter five examined transportation sustainability and development policies, as well as the degree to which the community of urban stakeholders is aware of sustainable travel choices and willing to embrace public transit systems as a low carbon footprint alternative to improve transportation system resilience and urban ecology. The questionnaire survey instrument was administered among academia, student, users, operators, managers, and policymakers and analysed using SPSS software. Appendices A to H are sampling table, questionnaire & consent, and extracts of the results of analysis of Chapter 5. The manuscript of chapter five has been submitted for publication in a peer review journal and is undergoing review.

Chapter six further examines how much the institutional policy frameworks, urban infrastructure and planning developments are geared towards sustainable urban growth. It was carried through qualitative assessment of sustainability themes, visions, targets, benchmarks, and achievements expressed by policymakers who are the policymakers and purveyors of transportation policy decisions at the behest of government. The methodology for this chapter involves interviewing sessions with the Head of Ministry of Transport of Kano and Lagos States respectively. Ten (10) generic semi-structured questions relevant to transport sustainability were formulated for the interviews. The thematic analysis of the interview transcripts was carried out using NVIVO qualitative analysis software to assess how transport sustainability policy drives

[19]Otuoze SH, Hunt DVL, Jefferson I. (2021). Neural Network Approach to Modelling Transport System Resilience for Major Cities: Case Studies of Lagos and Kano (Nigeria). *Sustainability*; 13(3):1371. https://doi.org/10.3390/su13031371.

are evolving and the achievements. The manuscript draft of this chapter was submitted for NVIVO International Conference 2020[20] and is now being peer-reviewed for journal publication.

Chapter seven focuses on applying transport demand management model to survey and elicited satisfaction responses from urban stakeholders based on some generic dimensions of transport infrastructure and service satisfaction qualities. The analytical methodology involves a qualitative assessment of people's perception and expectation of quality service using a combined approach of hybrid SERVQUAL—AHP and the outcomes will help guide decisions and priorities for improvement. Chapter seven has been sent to a peer review journal as a manuscript for publication and is under review.

Chapter eight provides synthesis and summaries of research findings, reflections, discussions of the achievements of the specific objectives and contributions to knowledge. It also includes some recommendations of areas of identifiable further research to broaden the scope of knowledge and understanding of the problem.

APPENDICES SECTION

Appendices section is the supplementary part of chapter five, the details of Appendices Section is as follows:

- **Appendix A (Sampling Population):** Appendix A1 is for small population sampling with 5% and 10% margins of error by Glenn (1992). While Appendix A2 is a large population sampling with 5% and 10% margins of error also by Glenn (1992).
- **Appendix B1 (Transport Sustainability Questionnaire):** Appendix B1 contains 20 generic questions in the questionnaire for transportation sustainability and literacy survey.
- **Appendix B2 (Consent Form for Questionnaire and Interview Protocol):** This is the consent and confidentiality vouchsafe protocol for participants in the questionnaire and interview surveys.
- **Appendix B3 (Ethical Approval Certification):** The ethical approval certificate was issued by University of Birmingham Ethical Committee to carry out the research based on the "Declaration of Helsinki Protocol" which ensures that participants have enough details, well informed and made autonomous decisions.

[20] Suleiman H. Otuoze, Dexter V.L. Hunt and Ian Jefferson (2020). Institutional policy framework and perspectives on transport sustainability in the emerging Nigerian megacities: Case study of Lagos and Kano. 1st NVIVO International Conference, 23-24 September 2020. NVivo Community, QSR International, 35 Corporate Drive Burlington 01803 MA, USA. https://vconf_materials.s3.amazonaws.com/boothmaterials/NVIVOposterpdf4_2oetnwq2r7.pdf

- **Appendices C1-C2 (Population Estimates & Sampling for Kano and Lagos Cities):** These are the extracts of population samplings for Kano and Lagos Cities. They were estimated based on the demographics of the cluster population in Metropolitan Statistical Area (MSA) which removed the main metropolitan population where the research is carried out from the rest of the state.
- **Appendices D1-D2 (Sustainability Literacy Test Results for Kano and Lagos):** These are the results of sustainability literacy test conducted to measure awareness and knowledge of sustainability problems in the two cities.
- **Appendices E1-E2 (Response Counts to Question 10 – Suitable Sustainability Model for Kano & Lagos):** The sustainability model is based on questionnaire survey which elicited responses from the respondents regarding their choices of the model best suited for their city development based on social, economic, environmental and Geo-spatial peculiarities.
- **Appendix F1 (Chi-Square Distribution Table by Nielsen & Slatkin, 2013):** This is the table of the critical values of Chi-square distribution with the degrees of freedom based on the probability of exceeding the critical values.
- **Appendices F2-F17 (Chi-squared Contingency Tables for Kano and Lagos):** These tables are analysis extracts of aspects of sustainability based on 'yes or no' decision rule. The aspects of sustainability considered in the survey are mobility/transport, carbon reduction, resource use, water, energy, biodiversity, and waste/pollution control
- **Appendix G1-G8 (Counts of Ratings of Sustainability Pillars for the Two Cities):** The extracts are the analysis of the results of "how much the pillars of sustainability - economic, social, environment and multi-dimensional problems" have been supported by the two cities.
- **Appendices H1-H16** (**Measures Promoting Transport Sustainability for the Two Cities):** These survey analyses are measures promoting transportation sustainability in the two cities. They are public transport, synergy between, transport systems & economy, environmental stewardship & energy use, promoting alternatives to physical mobility, promoting non-motorized transport, security and safety measures, measures reducing motorization and private car use and social benefits and equity

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CHAPTER TWO: GENERAL LITERATURE BACKGROUND

CHAPTER TWO

GENERAL LITERATURE BACKGROUND

This is an interdisciplinary study; the general literature background establishes the context of the research. It explains how several fields are related and what parts of each discipline will be researched. The term “general literature background” is a stylistic choice of literature overviews covering only the central themes and objectives of the research. The literature review criteria provide contexts to the transportation system and infrastructures, issues and perceptions relating to research objectives but do not include methodologies which have been treated in detail in the technical chapters.

Section 2.1 introduced the various contexts of urban accessibility and definitions of the transportation system to complex chains of urbanization process in Sub-Sahara Africa. Section 2.2 which is relevant to Objective 1, analysed the effects of urban development models and intervening policies vis-à-vis the spatial-temporal scales of interaction between urban land use and transportation infrastructure. Section 2.3 presents the perspective of Objective 2 that explains the vitality and roles of transportation infrastructure on accessibility, traffic Congestion and urban system resilience.

Section 2.4 provides perspective analysis to Objective 3 assessing the various dimensions and indicators of sustainable transport policies and exposed the challenges, strength, and weakness of the evolution of SSA cities. Section 2.5 relates to Objective 4: it analysed the strategies and policies that drive sustainable transportation in the leading SSA cities, as well as how to scale up policies to keep up with Nigeria's rising momentum of the urban chain process. Finally, Section 2.6 is the synthesis and summary of the key reviews, perspectives, critiques, coherence and highlights of current and future developments, existing gaps, and deductive reason justifying the study.

2.1 Transportation System

Man has been boundless and limitless in his desire to conquer his environment, the evolution of transportation has been very crucial as a veritable tool for changing demands for mobility (Dvořák et al., 2017). Transportation provides the means of mobility, linkages and the physical interaction of man and land use components. It is one of the cornerstones of human civilization pushing boundaries for space, time as well as growth and socioeconomic development of a country. Security and political administration of an area cannot be guaranteed without an efficient and effective system of transport (Yang and Zhang, 2017).

The socioeconomic impetuses of accessible and connected cities are very crucial to the complex web of human interactions and endless choices. A well-functioning urban transportation system not only fosters senses of community in a globalized world, but it also acts as a potent force driving economic growth, sustainable development and environmental footprints of cities.

Transportation is an essential part of human life that helps man to conquer spatial and temporal boundaries. Due to its importance to virtually all spheres of human endeavours, there are multi-disciplinary discourses and several domains of knowledge to enhance understanding of transportation problems. They include engineering and technology, planning, health and safety, economics, political science, operational research, psychology, management, and law, among other disciplines.

A transportation system is defined as the set of interconnected elements, sub-systems and their interactions that result in a demand for travel within a specific area and a supply of transport services to meet that need (Cascetta, 2001). The functional elements are the travel ways, vehicles, control systems and the terminal facilities whereas the subsystems are alternate systems or modes of transportation that supplement the network (i.e., road, rail, air, and water transport systems). Transportation systems can be categorised based on these components and their relationships to broader economic, social, and physical systems in which they occur, whether they are currently used or planned for future use.

Nigeria's transportation systems are underperforming due to unbalanced and unsustainable development policy, with the road serving as the primary mode of transportation not only because of its inherent flexibility, but also because transportation development has prioritized the road over all other modes in the country's development (Onokala & Olajide, 2020). In terms of institutional policy coordination, urban transportation developments in the country were characterised by management proliferation, which results in conflicts and overlaps in the provision of infrastructure and management of services, as well as the regulations and enforcement of traffic laws.

The aggregate-level study utilized by most urban chain analysts is too broad to address a wide range of issues relating to transport infrastructure, unequal access to services, deprivation, congestion, management problems, socioeconomic variables, and environmental factors. The study envisioned a disaggregate analysis model that would be able to moderate these measurement discrepancies of more traditional urban chain models. Farrell (2018) has examined the nature and causes of a speedy urban shift in Nigeria and found a potential urban policy misalignment with the pressures of contemporary urban transition.

Nigeria's fragmented transport infrastructure and regional disparities have become a national burden. Many researchers have provided compelling evidence of degenerating transport problems, including unsustainable infrastructure (Soyinka et al., 2016), land use interference (Agarana et al., 2019), heavy motorisation and chaotic traffic congestion (Uzondu et al., 2019), accidents and safety (Odeleye, 2000), energy and emission (Maduekwe et al., 2020), and parking crisis (Owota & Aprioku, 2018). None of the scholars offered any empirical evidence on the influence of urban chains on Nigeria's transportation infrastructure crisis. This research provides the framework for enduring urban transportation development planning, tracking of mobility services and to understand the connection of urban chains for improved accessibility and socio-economic wellbeing of urban communities.

2.1.1 Functions of Transportation or Mobility to Man

The various benefits and vitality of transportation to liveability and sustenance of mankind are:

a) It contributes both time and place utilities to movement, goods, and services.
b) In urban areas, it provides useful links between dwelling places and employment centers relating human population to its land use.
c) It serves as a coordinating and integrating factor for industrialization.
d) It facilitates political administration of an area.
e) It also enhances the defense capability of a nation.

2.1.2 Transportation and the changing world

In a rapidly evolving environment, there are strong evolutionary interrelationships and interdependencies between the four critical dimensions of transport systems and services based on the findings of Tom (2006):

a) Changing demand: It involves changes in income, population, and land-use pattern affects change in demand both in the spatial distribution, quality, and the quantity of that demand.
b) Changing technology: With technology at our disposal, alternatives and choice related issues in transport are expanding. For instance, bus transit, taxis, trains, trams, metro rail transits (MRTS) and cable transport services are among the available alternatives for urban transport.
c) Changing operational policy: These are varieties of operational policies designed to improve affordability, safety, and efficiency, such as incentive for road tolls, bus fare, car-pooling, etc.

d) Changing public values: Public values are considered in transport policies who are themselves beneficiaries of the same monolithic system.

2.1.3 Transportation Infrastructure

The term infrastructure is constantly evolving with increasingly changing human needs. Currently, the contextual meaning of infrastructure has become broad and ambiguous, but aptly suited by the term “cyber-physical” facilities, installation and services required for a society to function (Smith et al., 2003; Romp and Haan, 2007; Fisher and Norman, 2010). They are key assets of public importance to a section or generality of the country which catalyses economic potentialities, productivity, and security of the area. It is vital for its economic and social importance, the absence of which has serious consequences for the wellbeing of the country’s populace.

United Kingdom government defined critical national infrastructure as “those infrastructure assets (physical or electronic) that are vital to the continued delivery and integrity of the essential services upon which the UK relies, the loss or compromise of which would lead to severe economic or social consequences or leads to loss of life” (Cabinet Office, 2010). EU defined the concept as “physical and information technology facilities, networks, services and assets which, if disrupted or destroyed, have a serious impact on the health, safety, security or economic well-being of citizens or the effective functioning of governments or economy” (OECD, 2008).

Safety hazards, disruptions and interference risks are typical system challenges and vary in terms of their relative nature, complexity, and size, as are systems' criticality levels. There are several internal or external system stressors which can lead to disruption just as the congestion of motorized cities with infrastructure issues has become an inevitable fact. It is there necessary to imbue resistance other called resistance in the modern infrastructure system of critical importance as a means of keeping serenity and functional state and to mitigate unforeseen scenarios without cascading into further disruption (Chen, 2008; Theoharidou et al., 2010).

Critical structures cannot presume full protection, but vulnerability of the assets should be minimal, and be mitigable. The means to recovery of critical infrastructure, otherwise known as resilience, has been defined by UK Cabinet Office (2013) as the “ability of assets and networks to anticipate, absorb, adapt to and recover from disruption”. Table 2.1 shows typical critical infrastructure sectors and their lead resilience departments by UK Cabinet Office (2013).

Table 2.1: UK critical infrastructure & lead resilience departments (Cabinet office, 2013)

Sector	Sub-sector	Sector resilience lead
Communications	Broadcast	Department for Culture, Media, and Sport
	Postal	Department for Business, Innovation and Skills
	Telecomms	Department for Business, Innovation and Skills
Emergency Services	Ambulance	Department of Health
	Coast Guard	Department for Transport
	Fire and Rescue	Department for Communities and Local Government
	Police	Home Office
Energy	Electricity	Department for Energy and Climate Change
	Gas	Department for Energy and
	Oil	Department for Energy and Climate Change
Finance		HM Treasury
Food		Department for Environment, Food and Rural Affairs
Government		Cabinet Office
Hazardous Sites		Department for Business, Innovation and Skills
Health		Department of Health
Nuclear		Department of Energy and Climate Change
Transport	Aviation	Department for Transport
	Ports	Department for Transport
	Rail	Department for Transport
	Road	Department for Transport
Water		Department for Environment, Food and Rural Affairs

Infrastructure is critical for both social and economic development of any country. They are critical to the application and distribution network of geospatial services such as transportation and communication. Cities' accelerated demographic and spatial growth has long-term ramifications for urban space in terms of inclusive socioeconomic development, environmental and ecological footprints. Urban process, particularly in emerging nations, spawns land-use competition, which poses a burden to equitable and harmonious use of urban space (Angel et al., 2012).

These issues are mostly the result of a lack of adequate urban governance, infrastructure neglect, poor Geo-spatial cum urban planning regimes incapable to manage growth and long-term sustainability. Increased urbanisation will further exacerbate the severity of these difficulties in developing countries' cities, especially those in Sub-Saharan Africa, unless efficient urban governance and spatial planning measures are established (Baffour et al., 2014).

Uncontrolled Urbanization in Sub-Saharan Africa has resulted in land resource spatial expansion, infrastructure problems, rising demand for basic services including transport, environmental degradation, insecurity, vulnerability of assets to risks and widening socioeconomic disparities, particularly in sprawling communities on the urban fringes (Parnell & Walawege, 2011; Dodman et al., 2017; Titz & Chiotha, 2019).

Fast urbanization, infrastructure deficits, ineffective public transport facilities, dysfunctional planning policies, incoherent management, and coordination as well as other negative externalities of urban chains, appears to be the underlying problems of non-performing urban transportation systems in Nigeria. From 1981 to 1998, the budget share of Transport Sector Planned Public Sector Expenditure by National Budget and Rolling Plans fluctuated from 8.6 to 15.2 percent, while population and urbanization peaked around the same time (Onokala & Olajide, 2020).

Urbanization triggered congestion in metropolitan areas and has eclipsed infrastructure development and transportation network functional efficiency. Traffic congestion and inaccessibility continues to hinder economic prosperities and social harmonies of major cities of Nigeria, like many SSA countries (Odufuwa, 2006). To improve accessibility and journey times in these cities, the research provides an empirical analysis of the connection between urban chains and the transport infrastructure based on four critical elements (spatial analysis, congestion resilience, sustainable commuting, and travel demand management).

2.2 Urban growth and land use spatial transition dynamics

The world population reaches a 7.5 billion mark in 2017, with an approximate annual increment of 83 million and projections from demographic transitions have revealed that the world population will reach its numerical milestones of 9.7 billion in the year 2050 and perhaps, more than 11.2 billion in the year in 2100 (Lutz, 2010; Gerland et al., 2014; Kowal et al., 2016).

Based on the same projection token, the global annual population increment is figured to be 83 million people, the highest variety of the figures in favour of Africa and Asia because of their high fertility rates (Rafter et al., 2012; Fosdick & Raftery, 2014). United Nation World Urbanization Prospects (UN, 2014) projections show higher growth of cities in these two continents, even as their resources are among the lowest. This is shown in Figure 1.1 below.

In developing countries, demographic and socioeconomic indicators are causes for concern, while infrastructures are either inadequate or challenged by unsafe life-cycle problems (Decker et al., 2002; Decker et al., 2007). Civilization ushered in changes in lifestyle, needs, and urban forms, triggering increases in demands for infrastructure vital to everyday life. The demand for the basic needs of man - food, housing, health care, energy, communication, mobility, and materials/utilities supporting life geometrically increase leaving huge trails of socioeconomic, environmental, and ecological footprints behind (Wackernagel et al., 2006; Eaton et al., 2007; O'Regan et al., 2009; Scotti et al., 2009; Holden, 2012; Chambers et al., 2014).

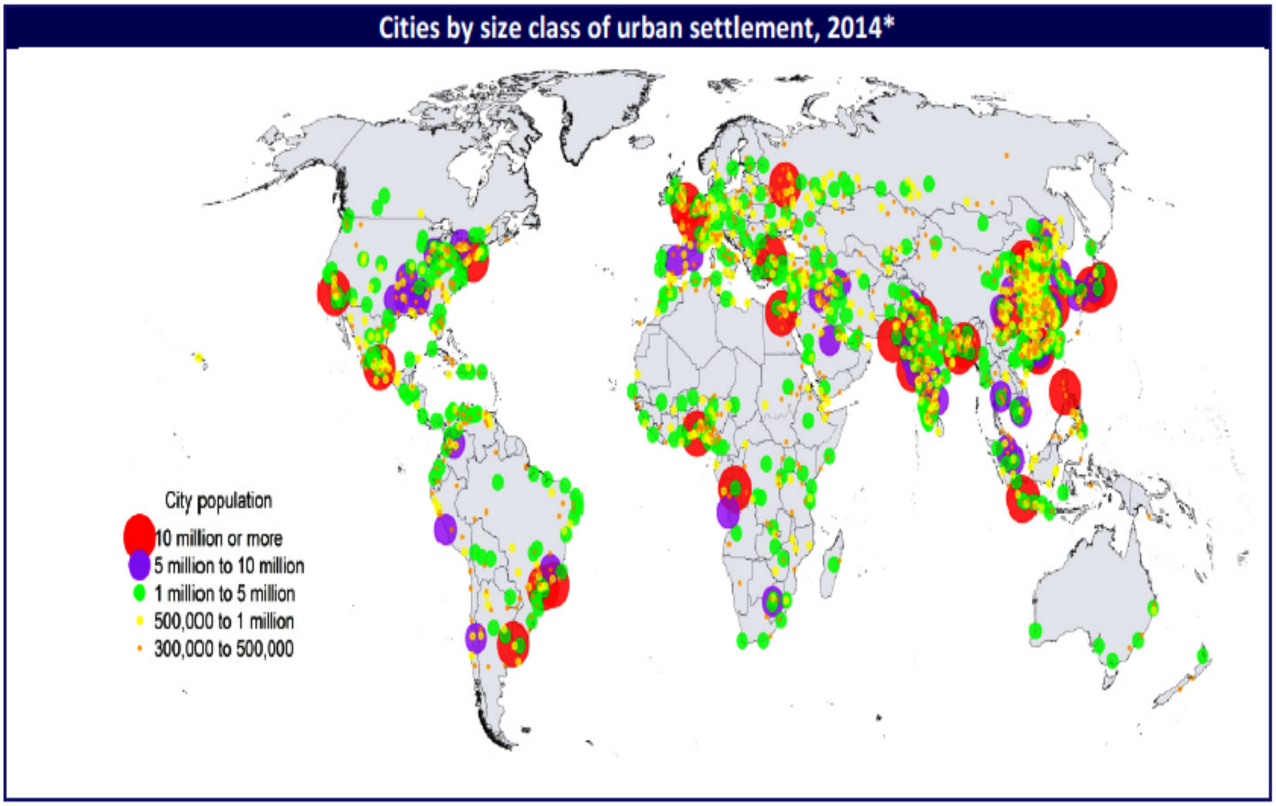

Figure 2.1: Geographical spread of major cities across the world (UN-DESA, 2014)

Many developed countries have almost completed the transition phase of urban evolution with practical steps being taken towards sustainable development, environmental harmony, risk mitigation, planning control and resilient infrastructure. Due to the progress achieved in the developed countries, their sustainable transport paradigm concentrates on green transport and ecologically friendly mobility. Developing countries have active phases of urban transition and having to contend with low income, population growth, corruption, insecurity, low productivity, migration, and huge infrastructure gaps (Decker et al., 2007). In either case, an integrated and sustainable strategy that tracks the developments is needed to meet current and future demands.

The main cause of Nigeria's current poor urban system is an unguided rate of rural-urban migration caused by a lack of rural development. Rural communities lack essential facilities, infrastructure and social amenities, the dismal conditions of these facilities act as a push factor driving rural-urban migration (Kessides, 2006). Migration and natural population growth have morphed the congested city environments into urban sprawls. The demand for transportation services in Nigerian cities has risen over time, while transportation infrastructure quality and supply of services have dropped significantly due to infrastructure gap, poor maintenance, and management problems. Urban agglomeration spins intensity of land use activities, demand and conversion of land resources and exerts same spatial transition chains and pressure on transportation infrastructure (Handy, 2005).

The goal of urban transportation is to meet the transport demands generated by a diverse range of urban activities in a wide range of urban contexts. The difficulty of connecting a specific mode of transportation with certain land use patterns and its socioeconomic impact is a paradox. The extent, form, origins, and destinations of commuting passengers and cargo freight in terrains relates transportation system attributes to land use factors. Economic and social-demographic factors influence the amount of spatial accumulation of activities and the amount of mobility requirements generated and attracted (Levine et al., 2019).

The complex relationship between transportation and land use patterns involves not just modal shift, but more of public transit systems in higher density commercial and residential areas while highways are associated with lower density activities and industrial areas (Rodrigue et al., 2016). Accessibility provision and safe throughput for freight services enhances liveability. Therefore, land use dynamics are generally determined by the development structure of urban governance, planning regulation, zoning restrictions, nature, and density of activities within a city or region.

Table 2.2 showed some key perspectives of urban dynamics that impact transport development. Most research in the SSA always fails to capture the onerous burden imposed by the spatial transition monitoring as the dominant driving force connecting land use to transportation infrastructure. Lack of effective development control, poor regulations, and the legal lacuna in the traditional *land tenure system*[21] have generated disputes over acquisition, reclamation and compensation and getting in the way of urban infrastructure development (Oluwatayo et al., 2019).

From the analysis of the review so far, spatial disparity or inequity is one of the most serious issues in urban planning and transportation infrastructure in developing countries cities. The concept of spatial equity in the context of the geographic requirement of urban facilities assists

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[21] Nigeria Land Tenure Law (1962) based on the precolonial customary law patrimonial right of ownership of families, natives and communities allowed the indigenous people of the various regions unfettered access to parcels of land in their localities and in some instances tacitly ceded control to the natives. Even while the law had been repealed by Land Use Act of 1978 which gives total control to state authorities, the local communities and private citizens continue to exercise some forms of control to the detriment of the urban policies and development planning (Oluwatayo et al., 2019).

urban planners in evaluating the impacts of current and future urban facility and service allocation strategies. Uncoordinated planning, lack of effective regulation and development control policies as well as urban sprawl contributed to Nigerian cities being riddled with portfolios of many abandoned construction projects, owing to land disputes, demolition, buffer encroachment and devolution crisis, litigation, and compensation costs.

Table 2.2: Review perspectives on urban transportation & change in land-use patterns in Sub Sahara Africa (SSA)

S/No.	Research perspective of land use influence on transportation systems	Research findings	Reference
1	ecological impacts of transportation infrastructure based on reconnaissance study of railway system in Kenya	The railway system deteriorates ecosystem by increasing deforestation, river sedimentation, flooding, soil erosion and destruction of biodiversity	Nyumba et al., 2021
2	Integer programming (IP) Optimization of the elements responsible for transportation problems in Lagos	Demographic checks and land use distribution were prioritized as the most significant factors	Agarana et al., 2019
3	African seaports and spatial development of hinterlands	Seaports are enablers of urban spatial growth and facilitators of economies of scale for the host communities in terms of commerce and production	Olakoju, 2020
4	Impact of road infrastructure development on Peri-Urban areas of Kisumu-Kenya and Accra-Ghana	There were improved accessibility, navigability, and transport services in the route corridors. But sadly, the neighbourhoods undergo gentrification and displaced the poor residents	Khanani, et al., 2021
5	Impact of railway on agriculture and urban development in Ghana	Railway systems transformed economic fortunes of cocoa-producing areas and enhanced spatial growth of the cities.	Jedwab & Moradi, 2012
6	Land Use Change and Traffic Impact Analysis in Planned Urban Areas in Dar es Salaam, Tanzania	inclusion of traffic impact analysis report in the portfolios of urban development proposals because of extreme traffic congestion scenarios in urbanising areas	Kazaura & Burra, 2017
7	Road expansion & the fate of Africa's Tropical Forests	Superhighway in Cross River-Nigeria has diminished biodiversity including 'flora and fauna' of forest and wildlife populations	Laurance et al., 2017

To achieve a sustainable framework in allocation of urban amenities, facilities and infrastructures; urban planners, environmentalists, and transport scientists must plan for spatial equity in the allocation of urban facilities to increase accessibility and liveability. Chapter 3 analyses the spatial-temporal interactions between urban growth phenomena and transportation development in Nigerian major cities. By attempting to address the interactions behind the transition of the urban spatial structure, the scientific knowledge of urban dynamics has broadened the scope of traditional land use models, which seemed until recently to be descriptive. The hybrid *CA-Markov* and *IDRISI SELVA* methodological approach provides a high level of spatially explicit resolutions and detailed realism, as well as the connection between the simulation and visual outputs on the urban spatial structure.

2.3 Transportation Infrastructure Resilience and Traffic Congestion Mapping

In the early 1970, resilience evolved in the field of ecological studies when it was thought that adaptation, survival, and growth in the face of adversities were identified as key resources of perpetuity otherwise called evolution (Folke, 2006). The term resiliency was adopted within the context of engineering, technology, architecture, construction, operation, and administration of urban infrastructure according to sustainable culture occasioned by population and urbanization rise, security risk, weather, and environmental problems (Mardani et al., 2016; Hosseini et al., 2016; Juan-García et al., 2017).

UK Cabinet Office (2013) defines infrastructure resilience as “Infrastructure resilience is the ability of assets and networks to anticipate, absorb, adapt to and recover from disruption”. Where issues still exist, systems properties should not be decimated, it should tolerable, proportionate, manageable, and able to minimize interruptions and with the capacity to retain functionality and return normality (Blockley et al., 2012; Jung et al., 2014). In any stable and efficient system rebound from difficult incidents, the main components of asset infrastructure resilience can be called the "4Rs" of resilience as shown in Figure 2.2. They are resistance, reliability, redundancy, response, and recovery. The definitions of 4Rs are dependent on the nature of the problem, institutional framework and intervention strategies and were defined by Schoen et al. (2015) as follows:

a) **Resistance:** These are measures that can give physical protection or fortification to the asset against threats. Examples are flood barriers; wind and fire shield in tall buildings, wind Velodrome, flood diversion gates in dams, anti-missiles, embankment, flood drain cum metro in Malaysia etc.

b) **Reliability:** It is the system's ability to preserve its functionality or operations under adverse conditions. Examples include route vending for congestion management and anti-freeze transport system heating.

c) **Redundancy:** This ensures that an asset backup alternative system will adjust to increase the stability of essential infrastructures, e.g., availability of alternative transport routes and modes.

d) **Response and Recovery:** This is a mobilized action plan of agencies, organization, authority, or government to respond and recover quickly from attacks, problem or disruption and bring normalcy to the system. For instance, the promptness of response and recovery plan from computer crash by British Airways in 2017.

Figure 2.2: Principal components of infrastructure resilience (Cabinet Office, 2013)

Congestion is a term used in the field of urban research to describe the slowing down of urban mobility—car movement in the city—and hence inherently indicates mismanagement, transportation infrastructure deficit, inefficient public transport system and heavy motorisation of traffic. The term has evolved to designate the most immediately apparent of urban mobility decelerations, reducing the phenomena of urban flows to a traffic management problem—often resulting in more automobile gridlocks, sprawling roadways, noise pollution and emission problems.

Efficiency of transport can be seen from the standpoint of minimizing delay, alternative modal choices, carbon footprint and resilience in downtime or any disruptive occurrences. Delay may be termed as any event that hampers steady flow of traffic and throughput thereby increasing journey time. Integrated modal share and provision of infrastructures ranging from aerospace to surface and sub-surface (underground) infrastructures are meant to diversify access and give margin of resilience to transport network. Provision of infrastructure can also be beneficial in stimulating economic growth, reducing maintenance costs, mitigating delay, or congestion and greenhouse emissions (Duranton et al., 2014).

On the basis of the above, researchers hold a two-way unique solution to congestion problems - infrastructure and access control; especially in developing countries where road transport is the basic means of mobility (Duranton & Turner, 2011; Duncan & Graham, 2013). Transport facilities without access control is a temporary congestion relief, which makes the problem more complex due to the natural attraction of commuters to good road without control and the inevitable congestion recurring decimal. The UK Department for Transport (DfT) studied congestion in London and concluded the same dilemma that reflects the maxim — '*you can't build your way out of congestion*' (Metz, 2018). Table 2.3 shows examples of land use interventions, transport and planning policies that improve accessibility and resilience, accelerate travel, and relieve traffic congestion (Vassallo & Bueno, 2019).

The complex link between human activities and biophysical processes is revealed in urban transport science. Sub-Saharan Africa has the world's greatest urban growth rate, but many cities are vulnerable due to ineffective urban policies, infrastructural deficits, and the general failure in incorporating sustainability and system resilience into urban transport development and land-use policy (Dodman et al., 2017). Many SSA cities and governments are yet to embrace the basic precepts of sustainable worldview and resilient urban transport policy. SSA countries' cities are outgrowing their infrastructure carrying capacities and congestion derives its negative associations, revealing crippling traffic regimes, overcrowding and the plethora of uncontrolled urbanization problems.

Among other factors, Nigeria and indeed, many SSA cities are rated highly "unliveable" and "inaccessible" because of extreme congestion and traffic regimes and safety problems (EIU, 2021). According to Ashik et al. (2020) accessibility is defined by the measurement of relative proximity between the origin and destination of trip or two geopolitical points. It has two basic dimensions – spatial and aspatial dimensions. The spatial dimension and its causal influence on urban transport landform is treated in Chapter 3. While aspatial accessibility combines socioeconomic, population density and demographic factors, quality/quantities of transport infrastructure, level of motorization and the degree of access control to maintain optimum traffic flow.

In the face of the huge gap in physical infrastructure, dwindling financial resources and management problems, it is important to ensure that urbanization goes in tandem with transport development. This study finds the nexus between urban congestion resilience, the capacity of transport infrastructure and traffic movements. Chapter 4 examines the state of Nigerian major cities through the prism and perspective of urban congestion, which reveals the intertwined layers of unsustainable development history and present urbanization trends, as well as the conflict between urban morphology, transport infrastructure and grinding urban inaccessibility. This traffic congestion modelling technique is intended to reveal the complicated and intricate interplay between the Nigerian cities' decades of the chaotic history of urban expansion and its inconsistencies with declining transport infrastructure and the environmental pictures.

Table 2.3: Urban development & resilient transport policies for mitigating congestion & inaccessibility (Source: Vassallo & Bueno, 2019)

Intervention policy	Definition
Mobility planning	Comprehensive management frameworks intended at meeting people's & businesses' mobility needs while adhering to sustainable standards
Mixed land-use	The arrangement of mutually beneficial and correlated land uses within a specific geographical location
Contingency planning	These are backup action plans meant to maintain functionality at downtimes or system failure
Compactness	Densification policy that centralizes urban activities to control urban sprawl
Push measures	Road tax, parking restriction policy, restriction on petrol/diesel vehicles, modal shift
Pull measures	Comprehensive framework for subsidized public transport, walking & cycling facilities, operator subsidy for decarbonization, subsidized transit fares for employees
Infrastructure improvements	Investing in sustainable and cos-effective infrastructure e.g., underground, metro, bike lane & pedestrian walkways
Service improvements	A variety of measures to enhance the quality, reliability, efficiency of transportation services e.g., transit usage & personal vehicle reduction, harmonizing mode & fare
Harmonizing policies & institutional synergy	Unifying transport policies & authorities, fiscal value regulation
Enforcement of safety rules & standards	Policy framework guiding safety standards, rules, law, and order
Remote working strategies for reducing physical travel	Alternatives to physical travel e.g., teleworking, distant learning, teleshopping
Digital infrastructure & services	Policies for monitoring and managing travel demand, flexible mobility, digital ticketing based on smart technologies and internet of things

2.4 Contextualizing transport infrastructure for sustainable urban development

The concept of sustainability may be succinctly described as 'ceaseless continuum capacity' describing goals and impacts of man's activities (Litman, 2003; Litman & Burwell, 2006). Sustainable transportation is a broad term that refers to transportation development that reaches beyond the immediate needs but long-term economic, social, environmental, and climate consequences. The key indicators of the three pillars of sustainable economic, social and environment developments are in Figure 2.3.

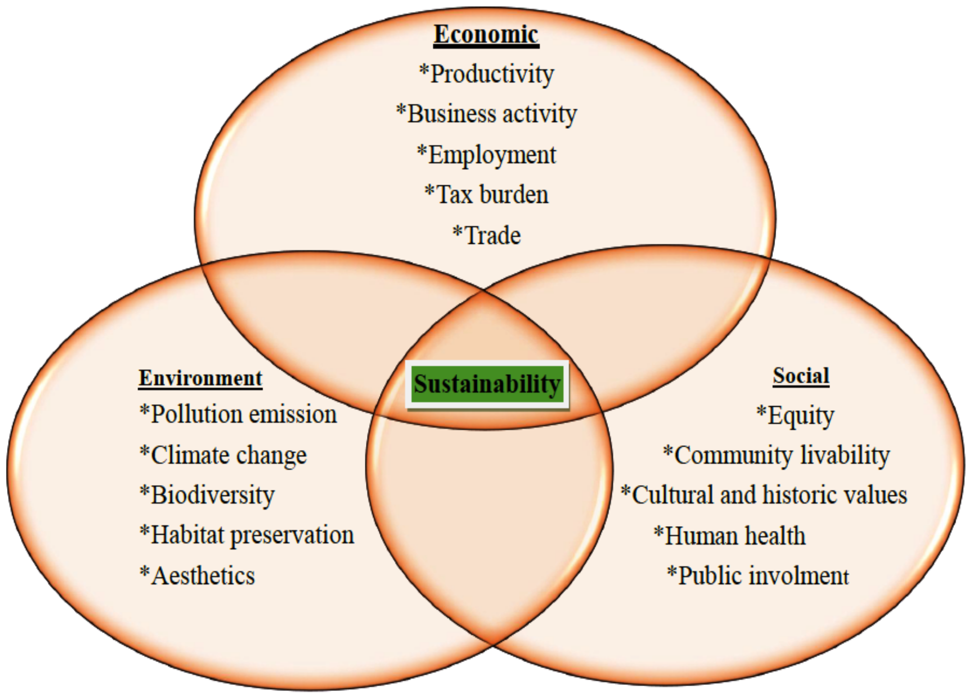

Figure 2.3: Issues in development sustainability (Litman & Burwell, 2006)

In recent decades, there have been many proposals for sustainable mobility development strategies in mega-cities to meet the rising spatial demand and to cope with uncontrolled urban sprawl, socioeconomic disparities, resilience, and environmental considerations. Compactness, an innovative and intelligent development strategy including mixed land use, simple facility, accessibility, green mobility and public mobility have been identified as drivers of sustainable transport (Zhao, et al., 2014; Clark et al., 2016; Song et al., 2017).

In terms of development pace and phase of transformation, mega—cities are rated in terms of their developmental transitions — low, medium, or high transition maturities. The main indicators of transition maturity differentiating developing and developed countries' mega-cities were detailed in Table 2.4. Some of the indicators of transition maturity are smart systems, infrastructure, sustainability indicators, safety, resilience, and disaster preparedness (Anneroth et al., 2012). Urban growth dynamics of over 6% annual agglomeration rise in African and Asian cities have placed them in the lower rung of the transition maturation with the challenges of poor infrastructure, life cycle and unsustainable development (UN-DESA, 2011).

Table 2.4: Development phases & characteristics of Megacities (Anneroth et al., 2013)

	Dhaka	Shanghai	London
Maturity Level	Low **Examples:** Dhaka, Kinshasa, Lagos	Medium **Examples:** Shanghai, Mexico City, Rio de Janeiro	High **Examples:** London, New York, Tokyo
Characteristics	High growth rate Young population Unplanned slums Limited mass transit Fragmented governance Weak energy, health, education infrastructure	Continuing growth Signs of aging population Urban planning evident Expanded mass transit Coordinated governance Improved energy, health, education infrastructure	Flat or negative growth Aging population Coordinated urban planning Embedded mass transit Centralized governance Established energy, health, education infrastructure
Challenges & Risks	Extreme poverty Extreme social segregation Inadequate housing Transport congestion Chronic air, water pollution Poor health outcomes Low education & skills Weak governance, corruption & crime High disaster risk	Pockets of poverty Chronic social segregation Unequal access to basic services & infrastructure Inefficient urban sprawl Chronic air pollution & congestion Vulnerable to natural & climate-related disasters	Widening inequalities Aging infrastructure requiring low-carbon, smart alternatives Aging mass transit requiring upgrading, expansion Air pollution requiring traffic controls Energy- inefficient housing Value concentration risks

Transport networks in urban processes, and with a growing population and spatial extents, depends on economic indicators to sustain urban life. Currently, urban mobility accounts for more than 60 per cent of all kilometre journey worldwide and therefore constitutes the largest sources of emission and pollution (Rode et al., 2017). The next decade's problematic mega-cities were predicted to emerge from the developing countries of Africa and Asia, where the population growth rate ranges from 3-5% and with insufficient transport facilities (Cracknell, 2000; Hendricks, 2008).

The population boom in the developing country has resulted in the emergence of 'accidental mega-cities' with a huge crisis of sustainable infrastructure, mismanagement, and lack of urban resilience. Both private car ownership and travel distance are increasing due to fragmented land use, sprawl and spatial expansion leading to perennial congestion, unattractive public transport systems, frequent accidents, and pollution problems (Walker et al., 2010; Vishwanath et al., 2015). Transport development has become like resource commodity that requires careful organization, coordination, evaluation and directing policy decisions that affect the sector (Ahmed et al., 2008). The approach should also incorporate supportive land-use practices, infrastructure, sustainable travel options and the use of innovative technology to ensure an environment of efficient and safer travel. Table 2.5 shows the dimensions and indicators of sustainable urban transportation.

Table 2.5: Sustainability component & challenge (Source: Bongardt et al., 2011)

Transport sustainable indicator/dimension	Definition of goal	Pillar type
Transport infrastructure and integration of land use	Coordinating a mutually beneficial infrastructure and services to integrate transport system and land use environment	Environment
Competitive & cost-effective business	A healthy and free market to encourage the use of effective public transportation.	Economic
Investment portfolios financing & funding	Creating the frameworks to acquire the financial resources required to meet investment, maintenance, and operational costs	Economic
Equity & Affordable transport expenditure	Beneficial schemes for children, students, old, challenged people and affordable household transport cost	Social & Economic
Emission & carbon reduction & fuel tax	Reducing the contribution of transportation to greenhouse emissions.	Environment & Economic
Modal share of public transit & non-motorized transport	Investment in shared infrastructure, spaces and facilities that keeps accessibility and carbon footprint	Environment
Resilience & reliability	To maintain fluid and congestion free transport network capable of retaining service functionality or recover from any disruption	Environment
Security and safety	Safety of staff, operational crew and users as well as functional resiliency in downtime or any challenging event	Social
Governance	Efficient government structures that allow participatory planning, benchmarking goals, & sustaining transportation policies & initiatives	Social
Comfortability & seamless navigation	Provision of smooth, comfortable, and seamless navigation across the transport network	Social

Empirical evidence from contemporary transport researchers have found that transport infrastructure is a *sine qua non* to economic development and productivity (Cox, 2010; Keho and Echui, 2011; Ojo et al., 2018). Calderon and Serven (2010) reported that a unit factor increase in the stock of transport infrastructure index has economic impetus of 0.68 in overall growth and could increase income per capita by 2.9 percent. Thus, the maxim “no roads, no transport, no trade, no specialization, and no economy of scale, no productivity progress and no development" captures the vitality of transport infrastructure to socioeconomic growth and development (Prud'homme, 2005).

Positive linkage has been found between high indices of transport system quality and minimum travel time, low transport cost and per capita average gross domestic product (GDP). A suitable road and rail network will considerably boost regional and international connectivity, trade, and economy. Thomas (2013), in the study of South Africa High-Speed Rail dubbed the "Gautrain", reported the positive impacts of the railway system which has eased road traffic congestion, improved commercial activities, created employment opportunities and attractive socioeconomic developments in the South Africa smallest province of Gauteng. This is because transport investments lead to increased quality of life, population vitality, reduced cost of production, business creation and urban-rural interactions.

According to United Nations Development Program (2009), low investment in transportation infrastructure in Nigeria has rendered the country among the world's worst in terms of accident black spot and congestion leading to the decline in economic and production performances. Monolithic road dependence, as the primary means of transport, weak infrastructure, and congestion, are the major sources of Nigerian transport problems, presenting a significant yearly economic loss of 2.4% (Iarossi and Clarke, 2011).

African cities continued to be unsettled by rapid urbanization thereby creating huge infrastructure problems. In terms of transport development and accessibility policies, none of the cities are within the safe threshold of affordable, inclusive, safe, resilient, and sustainable transport development. Based on the report of Stucki (2015), Rwanda operates a moderate green economy - the country is among the world's lowest in terms of per capita carbon dioxide emission (approximated at 0.65 tons CO_2/person). The transport sustainability pillar of the country promotes policies on public transport, integrated transportation planning and infrastructure upgrade, pedestrian and biking facilities, vehicle emission and importation age limits, electric bike, and effective regulations.

Nigeria, Africa's most populous country, continues to dwarf sustainable transport development policy achievements of both Rwanda and South Africa due to lack of synergy and disharmony in institutional policy strategies, bureaucratic bottlenecks, inadequate funding, and planning problems (Onolememen, 2015; Onatere et al., 2014). The cities require sustainable and integrated transportation system that covers entirely or a significant spatial extent of the urban territory and avails users of public transit alternative modes of transportation services that work in tandem through coordinated and harmonised validation system of infrastructure, fares, and management schemes. Also, the transport policy must incorporate schemes that motivate nonmotorised travel (biking and walking) and alternative to physical transport to pare congestion and carbon footprint.

This study is focused on analysing the barriers to sustainable transport development and how transportation infrastructure and management policies can strengthen the capacity for sustainable growth in emerging Nigerian mega-cities. Chapter 5 provides an assessment on perspectives, thinking and choices of various communities of urban stakeholders about sustainable transport development in Kano and Lagos cities. While Chapter 6 is a sustainability thematic analysis of transport policy frameworks based on semi-structured interview sessions with Heads of Transport Units of the two cities to expose the gaps in their policies.

2.5 Transport policy and travel demand management strategies in Nigeria and SSA

TDM is predicated on the commuters' motivation and intervention policies to embrace modal shifts, sustainable travel and shared public transport as well as creating awareness about shared responsibilities towards minimising carbon footprint and protecting the environment. According to Rotaris and Danielis (2015), the cumulative impact of TDM alternatives cannot be fully evaluated without looking at their feasibility and gauging users' acceptance. Transportation policy is the framework for transportation control, management, enforcement, and regulation frameworks provided by government authorities to guide the provision of sustainable, resilient, affordable, safe, comfortable, hitch and congestion free transportation system.

In many industrialized and advanced countries, high investment portfolios in transport infrastructure and technological improvement have reflected in a steady decrease in transportation costs, lowered production costs and stimulated economic growth and development. Poor investments in transport in Africa and Asia have remained the worst globalisation foe undercutting structural transformation, economic growth, industrial development, productivity, agriculture, trade and commerce, international and regional cooperation (Berg et al., 2017). According to Buys et al. (2010), upgrading transportation infrastructure has significant influence on SSA's economic performance - improving the main road infrastructure linking urban centres would boost productivity and commerce by $250 billion within 5 years. Transportation infrastructure investments have a huge potential to enhance the socioeconomic well-being and living conditions of the rural poor by improving their access to markets and social amenities.

The average cost of transportation from Doula, Cameroon to N'Djamena, Chad is 11 US cents per ton-kilometre, compared to $0.05 per ton-kilometre in France and $0.04 per ton-kilometre in the United States (Teravaninthorn & Raballand, 2009). The average cost of logistic and freight within Nigeria is also high – transport cost from Apapa-Lagos to the Nigerian second largest city in the north, Kano, is estimated at $0.09 per ton-kilometre (Mercier, 2018). Although the study focuses on spatial mismatch and dysfunctional transportation development in Nigerian case studies, it is clearly applicable to many sprawling cities in developing countries, where transportation infrastructure deficits have impacted socioeconomics, productivity, environment, trade, employment, and businesses. Apart from the economic losses induced by transportation infrastructure difficulties, various negative externalities such as congestion, accident, carbon emissions, and epidemics of pollution-related public health impose social and environmental costs.

On the global stage, many African metropolises are mostly isolated, with inadequate infrastructure, dearth of social amenities, facilities and other services, housing problem, sprawl, traffic congestion, slum, poverty, and insecurity (Titz & Chiotha, 2019). Fast urbanization, constrained transportation investment, poor management, and misaligned governance policies have stifled the potential for sustainable growth and equitable socio-economic development in developing nations, particularly in Nigeria and many SSA countries. The SSA sub - region remains the world poorest albeit home to the most urbanising cities and global highest natural population growth rate (Sietchiping et al., 2012).

From both research and policy standpoints, urbanisation processes in SSA appears to be complex and complicated as urban development pathways of the countries differ significantly from the rest of the world. Prioritizing the strategic use of limited resources should be based on a comprehensive knowledge of how transportation policy can spur economic growth and minimize social costs. Sustainable transport development policies are generally designed pliable and nuanced with impacts because of the competing demands of investment portfolios, need assessments, benefit-cost, policy options, legal and regulatory frameworks. Chapter 7 analysed and prioritized the various policy options based on AHP-SERVQUAL model of urban residents' responses to transport demand management (TDM) objectives-based infrastructure and service quality surveys.

2.6 Review summary

The literature reviews so far point to the preponderance of evidence of poorly managed and unsustainable urban chains across many SSA cities. Structural changes involving transport infrastructure systems play a pivotal role in fostering sustainability, resilience, improve mobility and accessibility and reduce economic losses due perennial traffic congestion. Although, huge infrastructure gaps and the question of inclusivity and equity still exist within the disconnected lower social rungs and sprawling communities on the urban fringes of SSA. Retrospective *ex-post* assessment of sustainable development efforts in some cities especially with regards to transportation infrastructure, TDM strategies and policy shift shown in Table 2.6 have revealed remarkable effects on the socioeconomic development and environmental footprints of these countries.

Urban form or morphology of many SSA cities does not have an enduring presence of liveable human geography and the capacity to cope with anticipated future urban agglomeration. Providing sustainable transport networks that improve infrastructure resilience beyond the temporal 2050 urbanisation milestones would necessitate a robust systemic framework guided by a thorough understanding of users' or stakeholders' needs, regulatory framework, budgetary allocation, financial resources, and environmental impact assessments. The review also suggests improvement in the development of urban transport infrastructure and a redefined shift in policy towards sustainability worldview.

Transport or mobility is germane to the daily lives of over 200 million Nigerians, but there are insufficient transportation portfolios to deliver far-reaching roadmaps on infrastructure development, and to strengthen multi-modal network interconnections because of ineffective policy, institutional and legal frameworks. The Nigeria National Transport policy Draft Report (1993) stated that: "At present, the Nigerian transport system functions in a crisis situation and one of the principal causes identified was a major imbalance between the needs of Nigerian society and economy for adequate transport facilities and the ability of the transport sector to meet such demand" (FGN, 1993). Despite the implementation of National Transport Policy (1993) and successive reforms, the transport infrastructure portfolios are deficient as annual budgetary allocation appears to have little impact on the quality of infrastructure delivery resulting in negative ramification for rising poverty and socioeconomic wellbeing for low-income earners (Oyesiku et al., 2020).

The enhancement of optimum performance, inclusivity, equity, affordability, economic impetus, environmental stewardships, and maximum social benefits are the key priorities of sustainable transportation and planning policy. Across many Nigerian cities, a considerable proportion of the urban population is reliant on the uncoordinated informal transportation service providers due to lack of investment in developing an efficient and integrated public transit system.

Table 2.6: Summary of key transport policy and benefits to some SSA cities

Transport policy	Example of city	Benefits	References
Modal share: Development of *"Gautrain" high-speed train*[22]	Gauteng, South-Africa	*Gautrain* has generated 92,900 job opportunities, conveys trip capacity of 120,000 passengers/day, alleviated 20% of traffic congestion in Gauteng province including Johannesburg and Pretoria	Thomas (2013)
Modal share: BRT public transport system	*"Rea Vaya"* (Johannesburg); "*MyCiTi"* (Cape Town); "*A re yeng*" (Pretoria); and "*Go George"* (George Town) BRT systems all in South Africa	The BRTs ushered "Corridors of Freedom, a spatial intervention to stimulate urban development along corridors BRT networks. BRTs reduced transport costs, carbon emission & traffic congestion. It has greater efficiency of journey time & increased safety from crime along the BRT corridors	Robinson et al. (2020); Bartels et al. (2016); Li (2019); Aboo & Robertson (2016)
Modal share: BRT public transport system	Lagos BRT, Lagos-Nigeria	The BRT carries 220,000 passengers per day. It reduced congestion, travel time, carbon emission and household travel cost	Gauthier & Weinstock (2010)
Modal share: BRT & light rail systems	Dar Rapid Transit (DART) & *Treni ya Mwakyembe* commuter rail system, Tanzania	BRT reduced traffic congestion & 50% of average journey time reduction. Light rail serves 30,000 passengers per day with fast ridership. Affordable BRT & rail fares and carbon reduction	Nkurunziza et al. (2012); Lifuliro et al. (2018)
Modal share: Light rail system	Addis Ababa Light Rail, Ethiopia	It has 150,000 passengers per day ridership, with affordable fares. It also reduced journey time, traffic congestion and carbon footprint.	Deyas & Woldeamanuel (2020)
Green transport policy: technology innovation, low carbon transport, restriction,	Policies on drone services, protected bike lane, BRT & bus network expansion, parking meters, vehicle import age restriction and electric motor bikes in Kigali-Rwanda	Application of medical service drones has reduced time and cost of delivering life-saving medical supplies. Safe and affordable bus and taxi services, congestion, and journey time reduction, greening and low carbon footprint, sustainable city	McCall (2019); Sudmant et al. (2017)
Modal share: Railway & BRT systems	Kumasi Railway[23] & Greater Accra BRT systems, Ghana	Some of the benefits includes congestion & travel time reduction, affordable fares and minimizing carbon emission	Jedwab & Moradi (2012); Brookins (2019)

[22] Gauteng train dubbed "*Gautrain*" is Africa's first high-speed rapid train and has made the city economic and industrial hub of South Africa. *Gauteng*, the smallest and most populous of South Africa's nine provinces has accounted for 33.9% of the country's GDP and 10% of Africa's total GDP (Thomas, 2013).

[23]Railway systems for mining purpose triggered structural transformation whereby subsistence farmers became commercial cocoa farmers, increasing income & GDP of the country (Jedwab & Moradi, 2012).

The situation in Kano replicates that of Lagos that has been rated the world second least liveable city in 2021 by the Economist Intelligence Unit (EIU, 2021), despite the acclaim of Bus Rapid Transit (BRP) initiative in 2008. Among many contending transportation policy issues competing for attention, transport infrastructure, the leading cause of congestion, increased journey time and harsh traffic regimes, is hardly accorded the seriousness it deserves in urban and transport policy portfolios.

Temporal data sets are required for the research and understanding of long-term implications and causal interaction of infrastructure investments as evidenced by a number of articles based on scenarios of other cities previously analysed. The strongest evidence against incompatible land use and transportation policy problems in the Nigerian cities are extreme traffic and congestion scenarios, delay, and high accident rate. In Nigeria, there seems to be scant comparative research and knowledge of different transport investment alternatives to help determine the best optimal priority and ordering of sequences of strategic decisions.

This work adopted a trans-disciplinary science and social-demographic approaches to analyse the interaction between urban chains and the transportation development and espoused the pathways to sustain critical transport infrastructure in major Nigerian cities. Understanding the existence of diverse elements in the working structures, priorities, internal mechanisms, and *modus operandi* of the statutory institutions (i.e., Department of Transport and urban governance) are necessary requirements and direct transfer of research findings is cautioned. The research will serve as technical cues to policymakers and broaden the literary knowledge and understanding of urban transport infrastructure, spatial and non-spatial accessibility pathways for emerging Nigerian mega-cities and for developing countries. The technical chapters (Chapters 3 to 7) of this research thesis have been presented in alternative paper format and their publication status indicated.

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CHAPTER THREE

SPATIAL TEMPORAL ANALYSIS OF URBAN LAND USE AND TRANSPORT INFRASTRUCTURE SPACE

CHAPTER THREE

TRACKING THE DYNAMIC TRANSITION OF TRANSPORT INFRASTRUCTURE SPACE AND LAND USE INTERACTION IN URBAN GROWTH PHENOMENA

This chapter has been developed in two separate paper manuscripts for publication ease - one manuscript for Kano metropolis and the other for Lagos Metropolis.

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CHAPTER THREE (A): SPATIAL TEMPORAL ANALYSIS OF TRANSPORT INFRASTRUCTURE SPACE AND URBAN LAND USE FOR KANO CITY

CHAPTER THEE (A)
(Published version of the manuscript)

Article

Predictive Modeling of Transport Infrastructure Space for Urban Growth Phenomena in Developing Countries' Cities: A Case Study of Kano—Nigeria

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Abstract: Global urbanization has the most tremendous negative effects on the changing landscapes in many developing countries' cities. It is necessary to develop appropriate monitoring techniques for tracking transport space evolution. The work explores the impacts of urban growth dynamics of transport space over the past decades as a basis for predicting future space demands in Kano, Nigeria. Three epochs of Landsat images from 1984, 2013 and 2019 were processed, classified and analyzed. Spatial classifications of land-use/land-cover (LULC) types in Kano include transport space, built-up areas, vegetation, farmland, bare land and water. The data analysis involves model calibration, validation and prediction using areas using the hybrid modeling techniques—cellular automata-Markov (CA-Markov) in IDIRISI SELVA 17.0 and remote-sensing ARC-GIS 10.7 softwares. The result finds significant expansion of transport and built-up areas while other LULC receded throughout the entire study period. Predictive modeling of transport infrastructure shows spatial expansion by 345 km^2 (3.9%) and 410 km^2 (11.7%) in 2030 and 2050 respectively. Kappa reliability indices of agreement (K_{IA}) classified images and ground maps were 85%, 86% and 88%, respectively, for 1984, 2013 and 2019 time series. The calibration quality met the 80% minimum suggested in literature for the spatial-temporal track and prediction of urban growth phenomena.

Keywords: transport; mobility infrastructures; land use land cover change; urban growth dynamics; spatial and temporal modeling; sustainable cities

1. Introduction

Urbanization has produced a variety of endemic structural changes in land-use/land-cover (LULC) characteristics. LULC highlights the causal relationships between spatial transformations involving land conversion and adverse environmental ramifications. Globally, urban agglomerations inches closer to worrisome milestones, as cities assume new roles of de facto national economies of many countries [1]. With globalization, the cities have become increasingly attractive to all strata of human society because of their strategic economic and political advantages, employment opportunities and availability of relevant infrastructures and facilities. Urbanization exerts a chain anthropogenic process on the natural environment and is arguably the major contributor to global land-use transition. LULC change is a complex mechanism that transforms natural landscapes, climate conditions and a major source of threat to environmental biology, ecological ‘flora and fauna’ and deterioration of biodiversity.

Fast LULC change has caused many catastrophic weather and environmental events due to rising tides of natural and anthropogenic forcing elements such as solar radiation, flooding, temperature, wind and seismic effects [2]. Whilst the evolutionary phases of the developed nations have reached their prime, their counterparts in the developing world are in the worst phase of uncontrolled urbanization. Whilst the developed nations' developmental stages have entered their primes, their counterparts in the developing countries are in the worst period of unchecked urbanization.

Manifest variants of crumbled infrastructure, poverty, insecurity, instability, and social-economic inequalities have increased the trend and scale of rural to urban migration, defining rural settings of Africa, Asia and South America compared to cities. In low- and middle-income countries, the marked population-cum-urbanization chains have had a tremendous impact on LULC transition and urban development planning. Equally, many cities are plagued by population waves, urban sprawls, and gaps in infrastructure, which currently occupy many domains of knowledge and discourses by policy makers and academia. Land Use Land Cover (LULC) expansion is among the major contributors to climatic change [3], not least the impact of the transport sector, which contributes a significant share of about 27% to global greenhouse gas (GHG) emission [4].

Land covers include physical and human landscapes (e.g., vegetation, rocks, water bodies, arable land, and transport infrastructures). Land use, on the other hand, involves human activities on the ground including farming, mining, commercial and industrial developments etc. Empirical studies by researchers have established many diverse fields of applications of LULC including geology and mining [5,6], hydrology and water catchments [7], agriculture [8], forestry and wildlife [9,10], urban evolution and regional geography [11], climate change and environmental ecology [12]. The traditional urban growth of Nigeria has always merged all infrastructure development together, including transport, without recourse to their differing critical needs and priorities.

The rapid global urbanization pace is undercut by epic challenges of meeting the greater demands for housing, health and educational facilities, good transport systems, employment and other basic services, especially for the poor urban communities. The key impetus of a sustainable urban planning regime optimizes development for socioeconomic and environmental inclusion for all, with compatible land use and resilient infrastructure. Urban planning developments in developed countries have long been discernibly planned and coordinated with sustainable outlooks [13]. The developing countries' cities, on the other hand, have concentrated development at the center, while the periphery is littered with a scattered mosaic of urban sprawl and slums neglected by the political authorities [14,15].

Segregated socioeconomic structure of Nigerian society, together with the menacing atmosphere of Boko-haram Islamist insurgency and other violent crimes has heightened the plague of urbanization in Kano—the second most populous city in the country [16–18]. The underlying population increase in Kano metropolis combined with massive transport infrastructure deficits has brought mobility, pollution, motorization, safety and urban transport problems to a head [19,20]. The spatial, socioeconomic and environmental impacts of loosely planned cities can be devastating, especially for the city which has experienced remarkable urban growth over a short period of time [21].

Efficient, accessible and resilient transport infrastructure and services bore the hallmark of livable sustainable cities. While Kano city authorities are attempting to cover up for the seemingly wide gap in transport infrastructure, sufficient attention has not been paid to the changing physical and spatial-temporal scales of the urban landscape and its compatibility with a sustainable paradigm.

In theory, all past events could influence our forecasts for the next experiment when sequences of stochastic events are observed. Satellite imaging has been widely used with remote-sensing technology to locate, inventory, map or classify landscape ecology [22,23]. Like a Markov chain, a Markov process can be considered a directed graph of a system's states [24]. Thus, a Markov continuous process could be adapted to model dynamic changes in transport infrastructure and urban landscape ecology by two-time states to forecast potential distribution areas.

In order to make informed decisions, there is a need for comprehensive documentation of LULC transition, and the causal effects of transport planning and policy interventions. The research is motivated to examine the relationship between city growth, the demand of transport infrastructure and transition chains in landscape ecology with the goal of predicting future land-use changes scenarios in Kano metropolis. In this research, we apply three Landsat images (from Thematic Mapper (TM) of July 1984, Enhanced Thematic Mapper Plus (ETM+) of March 2013 and Operational Land Imager (OLI) of October 2019) for remote sensing transport landscape mapping.

Geographic information systems (GIS) are remote-sensing tools for tracking geographic and spatial changes, LULC simulation and scenario prediction. It is commonly used to study LULC changes and prediction based on past knowledge with a validation model to measure the accuracy of prediction [25]. Continuous Landsat imagery data offer useful information which can be used as a prediction reference. Landsat has remained the most widely used satellite remote-sensing data, and its continuous long-term dependability, cost-effectiveness, and timeliness have made it a useful resource for tracking LULC transition.

Many developed countries have largely reached the terminal stage of urban transition; the climax of future urban growth potential of 2030 to 2050 will take place in African and Asian cities where most of the world-leading mega-cities will emerge [26]. Mega-cities, cities with at least ten million inhabitants, are sprouting in Africa without the critical aspect of infrastructure development. Needless to say that the Nigerian city of Lagos became the world 14th largest mega-city with an urban population of more than 15 million in 2013 [27]. Kano metropolis, the second largest city of 4million inhabitants, is exhibiting similar growth potentials to join in the pack. The cycle of urbanization coupled with defective and poorly oriented policies is negatively impacting the most basic infrastructure [28].

We retrospectively tracked urbanization in Nigeria from two important temporal milestones (1984 and 2013) to when the research data were taken in 2019. The country returned to civil rule in 1983 blossomed economy, an impetus triggering the high urbanization wave in 1984 with many cities almost tripling in size within a few years [29]. At 2013, demographic indices for the first time reached a pinnacle of 58.3% urbanization level, putting more Nigerians in cities than rural settings [16].

The trajectories of future potential population and urban growths are higher—urbanization level is estimated at about 67.1%, creating more than 295 million city dwellers out of about 450million projected total population in 2050 [27]. Even as urbanization is often related to higher wages, improved productivity and overall living standards improvements, the speed and size of the new urban paradigm in developed countries do not assure these improvements. In the United Nations Human Development Index, Nigeria is ranked 152 out of 178 countries among the group of “low human development” [30].

Furthermore, we developed a Markov probability transition matrix implemented in IDRISI SELVA 17 to forecast likely future scenarios of transport infrastructure and land-use ecology to Kano city’s urban form in 2030 to 2050 temporal periods after model validation. Population and urbanization growth indicators speak to the strategic importance of these time scales to planning and development control—Nigerian population forecast could climb 450 million milestone in 2050, with urban agglomeration spikes of about 70% in 2030 [30]. The cellular automata-Markov (CA-Markov) model fitted in IDIRIS SELVA software could be used to establish a spatial weighting of a specific area roughly the same as existing land use, making it very accurate in spatial-temporal dynamics and quantitative estimation of LULC change modeling [31]. Finally, a scientific framework is developed for tracking urban spatial-temporal dynamics and as a decision-making tool for ecological conservation and optimal resource allocation for Nigerian cities.

2. Materials and Methods

The methodology involves using hybrid GIS and CA-Markov for assessing and examining LULC modeling and predicting transport system infrastructure demand in Kano metropolis. Before implementing algorithms for LULC change detection, a series of pre-processing measures were carried out for Landsat images, including radiometry and atmospheric correction, cloud and atmosphere recognition, and stacking of images [32,33]. The methodological algorithm of the hybrid model is shown Figure 1.

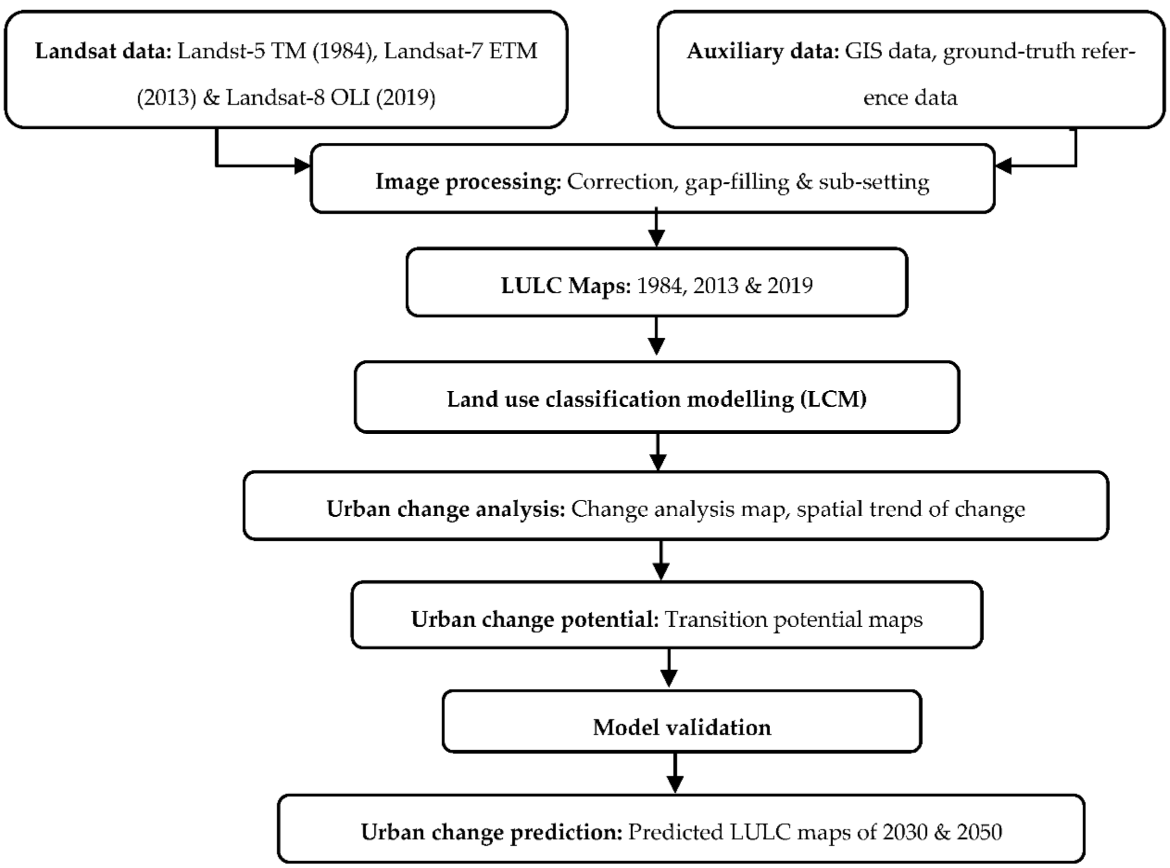

Figure 1. Methodology of land-use/land-cover (LULC) change modeling.

2.1. The Study Area

Kano city is an urban conurbation of eight (8) Local Government Areas (LGAs) (Dala, Fagge, Gwale, Kano Municipal, Nassarawa, Tarauni, Ungogo and Kumbotso), located between latitudes 11°25′ N to 12°47’ N and longitude 8°22′ E to 8°39′ E on 472 m above sea level in the Sahel desert. It is the commerce nerve center of the northern country due to its long flourishing marketing (and dominant economic) activities. Nevertheless, agriculture is a second means of employment on the savannah vegetation with Jakara and Challawa rivers being the main water bodies draining the city catchment area [34]. Figure 2 shows the location map of the city metropolitan study area and Figure 3 is the digitized map of major transport infrastructure.

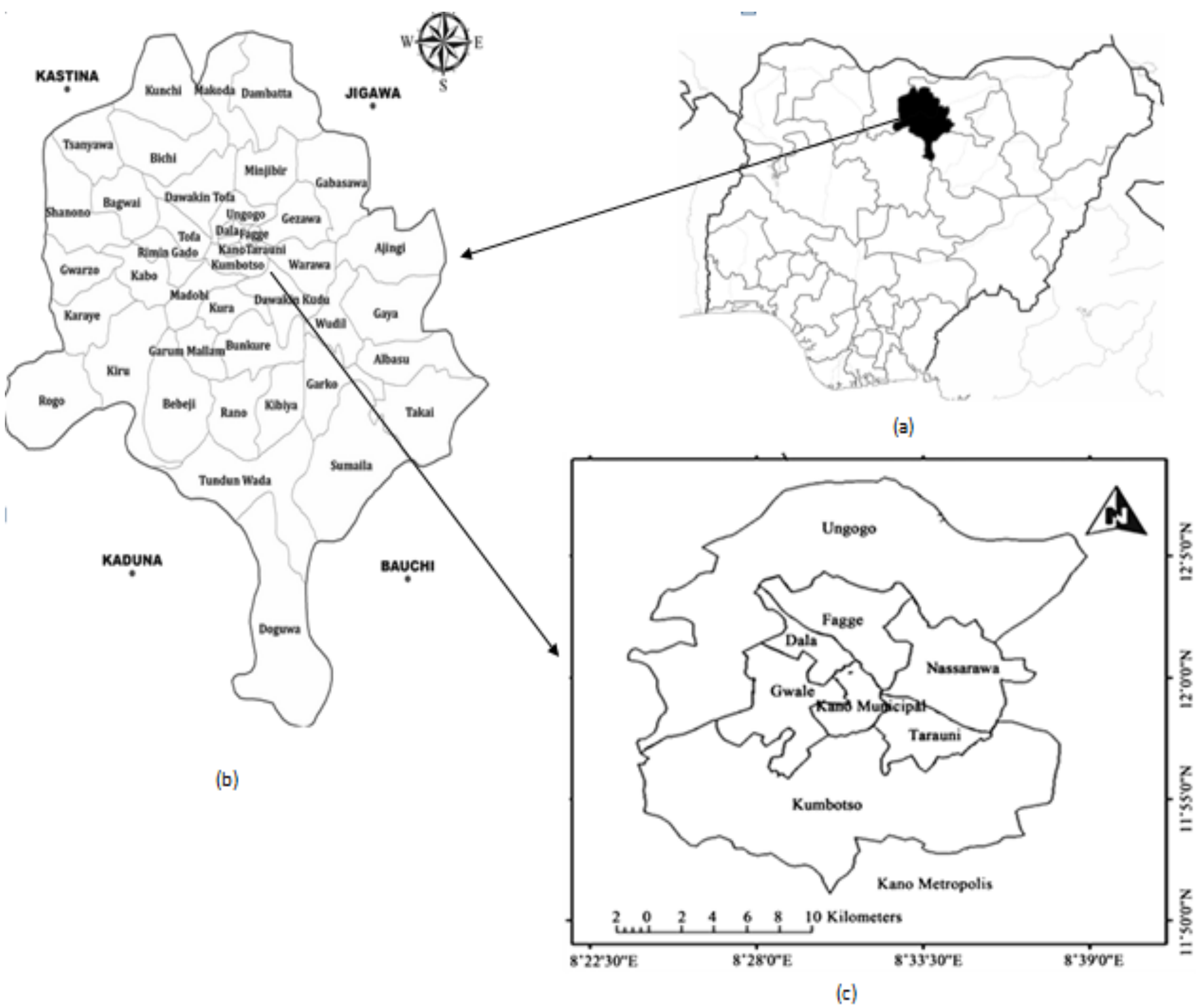

Figure 2. Map of Kano State showing the study area: (a) Nigeria (b) Kano State (c) Kano city.

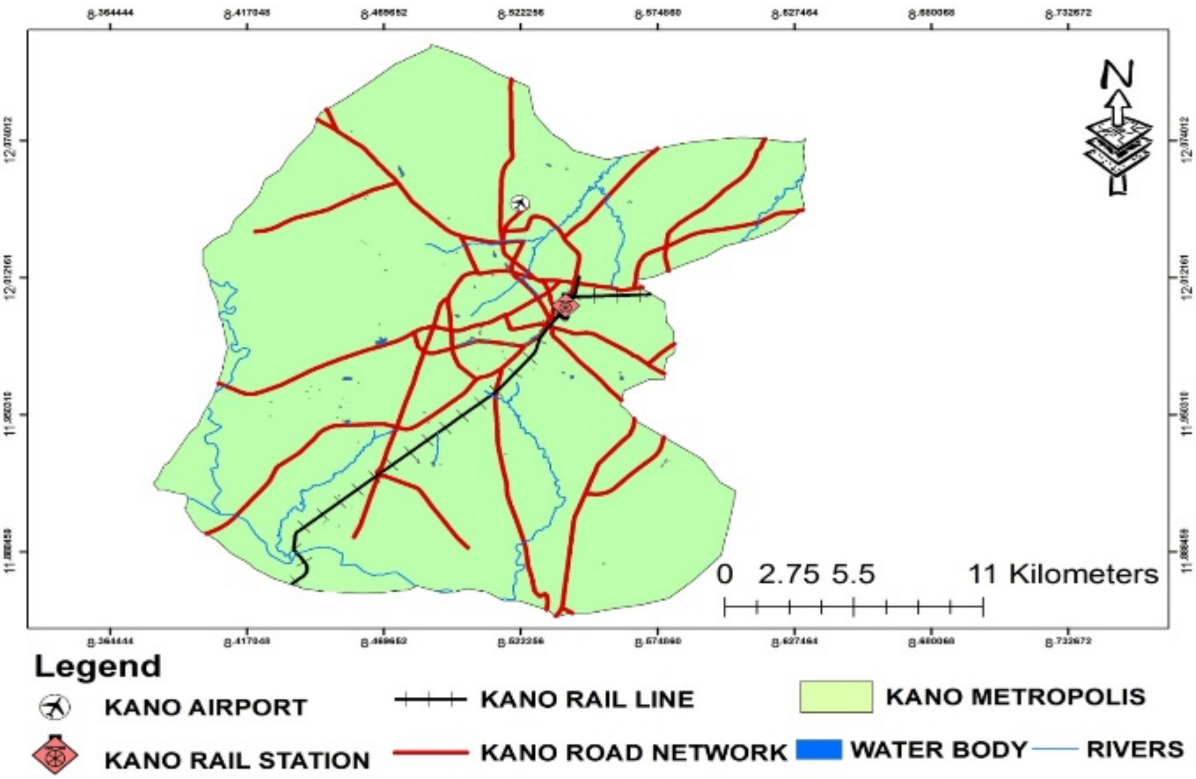

Figure 3. Digitized map of major transport infrastructure in Kano metropolis [35].

2.2. Sources of Data and Image Processing

The geo-referenced data used are the United States Geological Survey (USGS) Landsat (https://earthexplorer.usgs.gov/) imageries—thematic mapper TM (Landst-5 TM), enhanced thematic mapper ETM (Landsat-7 ETM) and operational land imager OLI (Landsat-8 OLI) respectively for 1984, 2013 and 2019 temporal milestones. Also, other ancillary data obtained are land use maps obtained from the Nigerian National Space Research and Development Agency (NASRDA (https://nasrda.gov.ng)), high resolution Google Earth photos and physical landmarks from knowledge of the area for verifying and delineating major transport infrastructure including roads, airports, and railway lines. Table 1 provides detailed attributes of the Landsat data used LULC transition analysis.

Table 1. Description of Landsat data for analysis of Kano LULC change.

Imagery Date	Sensor	Satellite	Path	Rows	Spatial Resolution (m)	Spectra Bands
25/07/1984	TM	Landsat 5	191	055, 056	30	7
15/03/2013	ETM+	Landsat 7	191	055, 056	30	7
02/10/2019	OLI	Landsat 8	191	055, 056	30	8

Data files in tagged image file (TIF) format was downloaded with less than 10 percent cloud cover and imported as raster using ERDAS IMAGINE 2014 software. The raster format is registered image-to-image based on similar projection system and re-sampled to a spatial resolution of 30 × 30 m. The sequence of digital image processing includes correction of the atmosphere, radiometry error and the geometry, as well as image gap filling, area of interest sub-setting and band selection.

The digital elevation model (DEM) data collection of the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) repository at the USGS website was used for the land areas in 30 m spatial resolution posting for the surface elevation and topography extraction. Cloud constitutes a very critical barrier to remote sensing and optical quality, especially in some humid tropical environments, thus, cloud cover effect is a key requirement for land cover dynamics. To guarantee the accuracy of atmospheric correction, level 2 atmospherics with geometric and radiometric pre-corrected Landsat imageries were obtained from USGS Earth Explorer and with delineated conversion scale factor into surface reflectance.

In May 2003, a scan line corrector (SLC) compensating for the satellite forward motion of Landsat 7 Enhanced Thematic Mapper Plus (ETM+) failed, thereby imposing a state of “fill-no-data” otherwise called data “gap” on image scenes especially in heterogeneous landscapes. From the date henceforth, gap filling processing for Landsat 7 ETM+ SLC-off became necessary. In the current research, the gap filling software approach involves Interactive Data Language (IDL 7.0) (https://glovis.usgs.gov/). Therefore, three further images were required to fill the “no-data” areas: (1) an anchor fill in the image (2) an image obtained before May 2003 (3) an image obtained post anchor.

Spatial transformation was carried out by manual image registration adopted to match images of the same scene from the different satellite imageries using Landsat 5TM (for 1984) as master control points. With these control points, the alignment of image scenes also involves stacking other satellite imageries (Landsat 7 ETM and Landsat 8 OLI) and compared with referenced auxiliary data. The transformation matched points yielded error average (root mean squared error (RMSE) = 0.12 pixels) at a resolution of 30m is a good match iteration being less than the suggested literature threshold of RMSE <0.5 pixel [36,37].

Predictive modelling of LULC change is an increasingly growing research field due to its significance in identifying the anthropogenic and ecological impact of human activities. LULC change has a direct impact on global change, including biodiversity, water and biological cycles and ecological systems. These changes are typically triggered by human activities (e.g., urbanization, deforestation, mining, overgrazing and agriculture intensification), and other natural causes relating to cosmic radiation and climate change. In view of the strategic importance, scientists have formed an international LULC organization linked to the International Geosphere Biosphere Program (IGBP) and the International Human Dimensions of Global Change Program (IHDGCP) both founded in 1987 [38].

In the study of LULC transition, several different modelling techniques have been implemented, land use conversion and its drivers have dominated the discourse. The models provide a probabilistic estimate of where the changes might potentially occur by understanding the factors driving them [39,40]. Several methods have been developed involving computer implemented algorithms for accuracy, speed, and ease of handling big data in land use modelling and prediction. Prediction models have been categorized into four groups—dynamic (process-based), optimization, stochastic and empirical–statistical based techniques [41].

Cellular automata (CA) are one of the modelling algorithms which is a time and space based discrete dynamic system that obeys specific rules on a uniform space grid. Due to its ability to depict a complex system using a series of small collection of rules and states for detecting spatial-temporal behavior, it is particularly selected for LULC modelling. Markov chain analysis involves a stochastic modelling for the study of the dynamic transition process of land use at various spatial and temporal scales based on the assumption that the physical state can be determined if an earlier state is known. CA incorporates transformation rules that are used to describe a certain cell's state. CA-Markov was compiled as one of the powerful models in IDRISI SELVA software for spatial interaction and modelling simulation [42].

2.3. Image Classification and Accuracy

The quantitative aspects of LULC transition monitoring and analysis are precision driven, as the quality of various LULC mapping application algorithms are vital to the potential dynamic change modeler. Application of different classification algorithms, namely—maximum likelihood classifier (MLC), support vector machine (SVM), random forest (RF), decision tree (DT), Mahalanobis distance (MD), artificial neural networks, spectral angle mapper (SAM), Fuzzy logic adaptive resonance theory-multi-agent process (Fuzzy ART—MAP) and genetic algorithms produced satisfactory accuracies (i.e., Kappa value > 84%) [43,44].

In order to appropriately classify the individual Landsat images, a widely adopted method of supervised maximum likelihood classifier (MLC) was used to generate the relevant land-use classes and to evaluate urban expansion including transport spatial evolution. MLC is commonly adopted because of its ease of parametric convergence as many of the other classifiers usually take time to optimize.

The algorithm also assumes that the data is normally distributed and predicts a high probability that a certain pixel is placed into the right class. Additionally, it has a high probability of quantifying minority groups within the appropriate pixel spectral class without being mis-classified into the larger LULC classes during model training. Landsat image classification was carried out using ARC-GIS 10.7 based on supervised classification of maximum likelihood where each pixel was classified into one of the following land use classes: transport infrastructure, built-up areas, farmland, vegetation, bare land, and water. The distribution maps were classified into the six LULC categories including its spatial extent, based on the characteristics displayed directly in remote-sensing images (e.g., size, form, texture and hue etc.). Post-classification change detection was implemented in IDRISI Selva 17 pro version software, which requires two classified images to be compared with details on pixel-based transition [45].

Since there are uncertainties embedded in every stochastic process, a confusion matrix was created to check for classification and transition change detection accuracies. For instance, while the software user accuracy describes the likelihood that a pixel is actually a particular land-use class or landmark on the ground image, product accuracy defines the probability that a pixel (or raster) is correctly categorized. A complete pixel-by-pixel ‘ground truth’ map is not feasible; it is important to provide a sufficient selection or sampling pixels to ensure robust accuracy assessment of a classification. An appropriate sampling methodology must be employed that satisfies statistical needs. The amount of reference pixels needed for accuracy evaluation depends on the minimum accuracy level required—e.g., 80% to 85% minimum accuracy is recommended by Jensen (1986) [46].

We computed the optimal number of pixel sample points for overall classification accuracy evaluation at 85% minimum accuracy level. The number of appropriate sample points decreased as acceptable error increased. Using stratified random sampling, the total sample (204-pixel points in Equation (1)) was further delineated by thematic classification into at least 30 pixels per LULC class to avoid any form of bias. Van Genderen and Lock (1977) recommended a minimum of 20 observation pixels per referenced LULC class for 85% classification accuracy and 30% minimum pixel points per land-use class for 90% observed accuracy.

$$\mathrm{N} = \frac{\mathrm{Z}^2 * \mathrm{p} * \mathrm{q}^{\sim}}{\varepsilon^2} = \frac{2^2 * 85 * 15}{5^2} = 204 \qquad (1)$$

where N = Total number of sampled pixel points; p = Expected accuracy (%); $\mathrm{q}^{\sim} = 100 - \mathrm{p}$; z = 2 (standard normal deviate of 1.96 for 95% confidence level); ε = allowable error (usually 5 to 10%)

To check for model reliability, we estimate the value for Cohen's Kappa Index of Agreement ($\mathrm{K_{IA}}$) given by Equation (5). The approximate minimum value of 80% is a substantial agreement between simulated and actual data and an indication that the prediction model fits well [47].

$$\mathrm{K_{IA}} = \frac{\mathrm{P_o} - \mathrm{P_e}}{1 - \mathrm{P_e}} \tag{2}$$

where $\mathrm{P_o}$ is the number of times there are relative agreements among the layers of raters; $\mathrm{P_e}$ is the hypothetical probability of agreement by chance.

Out of 204 selected training sites identified based on image recognition keys as ground-truthing points, 122-pixel points (60%) were used for training. Validation by Kappa reliability assessment checks was carried out based on 82-pixel points (40% ground reference). The general LULC map trends showed a variable rate of change between different LULC classes in the area of study.

2.4. Transition by Markov Chain Process

A Markov chain process could be defined as a process with changing sets of states, $S = S_0, S_1, S_2, S_3, \ldots, S_t$. The process changes from one state to another by scales called steps. We may scale the measure of state transition based on temporal time scales (t), whereby the current state (S_t) changes to another state (S_{t+1}) by likelihood transition probability (P_{ij}). If the case is otherwise, where the system remains in a stationary state (S_o), then, the probability of that state is given by (P_{ii}).

The probability of a shift or conversion of land use from one state to another is dependent only in a set of discrete-time steps if the times are sequentially arranged such that the transition probability matrix is given by:

$$S_{t+1} = P_{ij} * S_t \tag{3}$$

$$\begin{bmatrix} \mathrm{P_{11}} & \mathrm{P_{12}} & \cdots & \cdots & \mathrm{P_{1m}} \\ \mathrm{P_{21}} & \mathrm{P_{22}} & \cdots & \cdots & \mathrm{P_{2m}} \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ \mathrm{P_{m1}} & \mathrm{P_{m2}} & \cdots & \cdots & \mathrm{P_{mm}} \end{bmatrix} \tag{4}$$

Empirical findings by researchers [48,49], suggested three basic conditions necessary for Equation (3) to converge: firstly, $P_{ij} = \sum p_{ij} = 1$, such that $(0(p_{ij} \leq 1)$. Second, the assumption should hold that the transition probabilities remain unchanging. Thirdly, the Markov chains are regarded as a model of first order, which only makes the situation of the transient system contingent on the former. If we denote the transient phase time series as $T + 1$ and the initial period as T, Markov stochastic process theory may be used to calculate the state transition probabilities given from the initial state to the n^{th} state, as well as a stable state. Thus, Markov transition probability for n^{th} is given by the relationship:

$$P_{ij}^{(n)} = \sum_{k}^{m-1} P_{ik}^{(n-1)} P_{kj}^{(n-1)} \quad (5)$$

where m = number of columns or rows and the transition probability matrix at n^{th} stage is equal to the n^{th} power of the first-stage transition probability matrix.

2.5. Cellular Automata-Markov (CA-Markov) Prediction

The CA-Markov specifically uses the transition script in the Markov chain output analysis to apply a contiguity filter which allows creation of land-use characteristics from time-to-time. Based on initial state matrix (S_0) and n^{th} stage transition probability $(P(n))$, we can estimate transport infrastructure land area and indeed, other land-use transition in Kano metropolis by applying a Markov simulation model $S(n)$ in Equation (6):

$$S(n) = S(n-1) \times P^{(1)} = S(0)qP^{(n)} \quad (6)$$

3. Results

3.1. Land-Use/Land-Cover (LULC) Mapping

The LULC transition retrospective trend is shown in Figure 4 by the spatial-temporal shifts from 1984 to 2019. Table 2 provides remote-sensing data on Kano land-use and spatial patterns for 1984, 2013 and 2019 respectively. During 1984 to 2013, urbanization had gathered momentum as evident in transport and built-up areas which recorded noticeable spatial growth of 97 km^2 (70.8%) and 57 km^2 (196.6%), respectively. In the same 29-year period, other land use classes had suffered spatial losses and receded in sizes—farmland (—81 km^2), bare land (—56 km^2), vegetation (—1.5 km^2) and water (—12.9 km^2) respectively. In these four land-use classes, the bulk of the spatial reductions is mainly attributed to significant gains in both transport and built-up areas.

Table 2. Land use area distribution in Kano metropolis.

Year LULC Types	1984		2013		2019	
	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent
Transport infrastructure	137	17.6	234	31.0	290	34.9
Built up areas	29	3.7	86	11.1	111	16.3
Farmland	355	45.3	274	36.3	261	31.3
Bare land	210	26.7	154	20.4	150	18.0
Vegetation	17	2.3	15.5	2.1	14	1.7
Water	34	4.3	21.1	2.7	09	1.0
Total	782	100	784.6	100	835	100

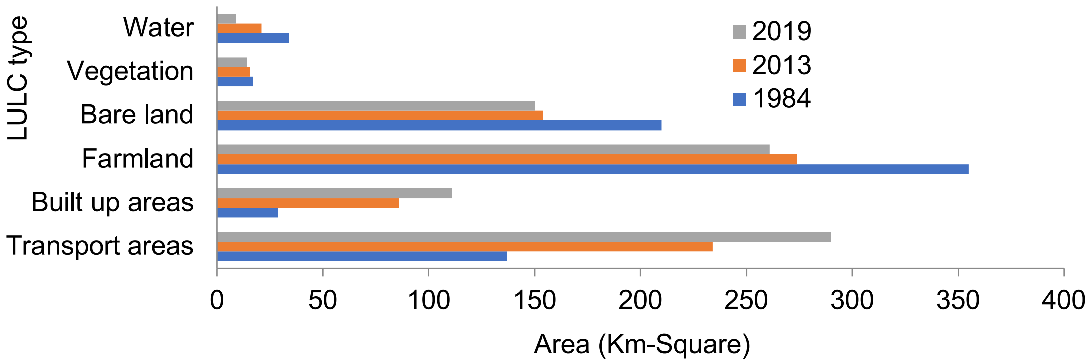

Figure 4. LULC temporal changes from 1984–2019.

It can be argued to a reasonable degree that vegetation and water losses are not only due to urbanization alone. The effects of the Sahel Savannah Africa's severe climatic conditions (drought, desert encroachment, etc.) and other anthropogenic activities - erosion, mining, bush burning, and pastoral farming have been stressed for the changing landscape and loss of flora and fauna in the region [50-52]. Similar patterns of spatial transition gains and losses occurred in 2013 to 2019. Transport and built-up areas recorded transition gains of 56 km^2 (23.9%) and 25 km^2 (29.1%) respectively, while other LULC classes (farmland, bare-land, vegetation and water) receded by −25 km^2 (−29.1%), −5 km^2 (−2.6%), −1.5 km^2 (−9.7%), and −12.1 km^2 (−57.4%), respectively.

3.2. Model Validation

An appropriate precision assessment technique is needed to ensure that remotely sensed data are useful and efficient. Accuracy evaluation could be defined as a comparison between a map produced by remotely sensed data and another referenced source map. We used the Cohen's Kappa coefficient estimate to check for the agreement or otherwise. The visual change agreements in terms of geospatial and temporal transformations between classified land use and referenced ground maps were assessed using the following four dimensions of accuracy checks—producer accuracy, user accuracy, overall accuracy, and Kappa index of agreement.

- The producer accuracy (PA) of software manufacture is the ratio of samples correctly classified LULC pixels in the same class to the row total of pixel samples in that class. It is an omission error between observed features in the ground reference missing in classified image, i.e., PA = (100 — error of omission) %.
- The user accuracy (UA) is the ratio of samples correctly classified LULC pixels in the same class to the column total of pixel samples in that class. It is a commission error of the wrong classification types between classified and ground images, i.e., UA = (100%—error of commission) %.
- Overall accuracy (OA) is the total pixel of correctly classified samples in the diagonal cell diagonal matrix divided by the overall pixel total sample.
- Kappa index of agreement (K_{IA}) provides check for accuracy of classification between remote sensing classified images and referenced ground maps.

In this study, the classification model was validated in terms of its ability to simulate spatial transition patterns of land use and land cover changes in Kano city using the classified transition base map in the temporal series—1984, 2013 and 2019. The level of agreement between actual and simulated landscape areas of the base map is a test of the reliability upon which Markov chain transition probability matrix scalability in the future LULC prediction of Kano metropolis is dependent.

The validation involves cross-tabulation of the error or confusion matrix for checking the reliability of agreement between classified LULC and ground reference. A confusion matrix calculates the identifiable land-use areas on the classified maps as row matrix, the ground reference images as column matrix and the pixel samples in the cells of a diagonal matrix are the correctly categorized LULC classes.

We evaluated how close the two LULC maps are to the degree that the VALIDATE module created a Kappa coefficient to test the model's goodness. The results in Table 3 indicate a satisfactory prediction for the three temporal time series of classified images.

The observed spatial data and the classified maps compare reasonably well producing the following Kappa indices of agreement—($K_{IA} = 85\%, 86\% \ \& \ 88\%$) for the three-temporal series: 1984, 2013 and 2019, respectively. The values are higher than the 80% minimum suggested in the literature [53], and we can pre-judge that the calibration model is a good predictor of future LULC transition analysis (e.g., 2030 and 2050).

Table 3. Accuracy checks for classified LULC maps.

Land Use Types	1984		2013		2019	
	UA (%)	PA (%)	UA (%)	UA (%)	PA (%)	UA (%)
Transport land	89	88	86	84	88	93
Built-up areas	84	78	76	81	89	82
Farmland	78	82	84	82	85	86
Vegetation	89	84	86	83	84	90
Bare land	88	92	94	92	96	94
Water	87	79	84	86	87	95
Overall accuracy (%)	86		89		90	
Kappa coefficient (%)	85		86		88	

3.3. Model Application

3.3.1. The Initial State

Based on 1984 spatial areas of LULC classes—transport infrastructure, built-up areas, farmland, vegetation, bare land and water, the initial state matrix given by $[S\,(0)]$ can be built into mutually evolving land use areas depicted by Equation (7). The land-use areas' initial state transition matrix for the first-time step, 1984 to 2013, is shown in Table 4.

$$\mathrm{S}(0)=\begin{bmatrix}\text{Transport areas}\\ \text{Builtup areas}\\ \text{Farmland}\\ \text{Bareland}\\ \text{Vegetation}\\ \text{Water}\end{bmatrix}=\begin{bmatrix}137\\29\\355\\210\\17\\34\end{bmatrix}(\text{unit: km}^2) \quad (7)$$

Table 4. Areas of initial state transition matrix for 29 years—1984 to 2013 (km^2).

From 1984:	To 2013: Transport Land	Built-Up Area	Farmland	Bare Land	Vegetation	Water	Area Total
Transport land	83.5837	17.1113	11.9738	18.4813	5.8499	0.0000	137
Built-up areas	6.8382	22.1618	0.0000	0.0000	0.0000	0.0000	29
Farmland	56.1965	0.0000	272.4270	16.3655	0.0000	10.0110	355
Bare land	44.3520	42.8400	35.5740	87.2340	0.0000	0.0000	210
Vegetation	3.1637	5.1527	0.0000	0.0000	8.6836	0.0000	17
Water	0.0000	0.0000	8.7244	7.2794	0.2176	17.7786	34

3.3.2. The Transition State Probability Matrix

The transition probability matrix is determined using LULC landscape classes from 1984 and 2013 as base map. We superposed the raster maps of the landscape and extracted the respective properties in the overlay database using ArcGIS software application. Thus, the initial state transition probability matrix (P_{ij}), was calculated between 1991–1999 (Table 5) and then, further into the current year (2013–2019) as shown by the result in Table 6.

Table 5. Initial transition probability matrix from 1984 to 2013.

From 1984:	To 2013:					
	Transport Land	Built-Up Area	Farmland	Bare Land	Vegetation	Water
Transport land	0.6101	0.1249	0.0874	0.1349	0.0427	0.0000
Built up areas	0.2358	0.7642	0.0000	0.0000	0.0000	0.0000
Farmland	0.1583	0.0000	0.7674	0.0461	0.0000	0.0282
Bare land	0.2112	0.2040	0.1694	0.4154	0.0000	0.0000
Vegetation	0.1861	0.3031	0.0000	0.0000	0.5108	0.0000
Water	0.0000	0.0000	0.2566	0.2141	0.0064	0.5229

Table 6. Transition probability matrix from 2013 to 2019.

From 2013:	To 2019:					
	Transport Land	Built-Up Area	Farmland	Bare Land	Vegetation	Water
Transport land	0.6504	0.1543	0.0151	0.0332	0.0336	0.1134
Built up areas	0.1732	0.8268	0.0000	0.0000	0.0000	0.0000
Farmland	0.2025	0.0000	0.6897	0.0698	0.0097	0.0283
Bare land	0.2477	0.0164	0.2137	0.5222	0.0000	0.0000
Vegetation	0.1439	0.2412	0.0000	0.0000	0.6049	0.0000
Water	0.0138	0.0335	0.2714	0.0016	0.0000	0.6797

The prediction model results in Table 7 displayed transport infrastructure and built-up areas as the sole gainers of LULC dynamic transition, other land classes (farmland, bare-land, vegetation, and water) are expected to recede significantly. A spatial land-use expansion of 55 km^2 (19%) is expected for transport infrastructure from 2019 to 2030 and a further 65 km^2 (18.8%) in 2050. Similarly, built-up area is predicted to grow by 29 km^2 (26.0%) in 2030 and 15 km^2 (10.7%) in 2050.

Table 7. Markov chains predicted areas for 2030 and 2050 (km^2).

Land Use Types	2030		2050		Change: 2019–2030		Change: 2030–2050	
	Area	(%)	Area	(%)	Area	(%)	Area	(%)
Transport land	345	38.6	410	42.4	55	3.90	120	11.7
Built-up area	140	15.6	155	16.0	29	2.40	44	2.8
Farmland	250	27.9	248	25.7	–11	–3.30	–13	–5.5
Bare land	139	15.5	135	14	–20	–2.40	–24	–3.9
Vegetation	13	1.5	12	1.2	–1	–0.17	–2	−0.5
Water	8	0.89	7	0.72	–1	0.11	–2	–0.3
Total	895	100	967	100	–	–	–	–

4. Discussion

4.1. LULC Maps

Land-use classification maps for 1984, 2013 and 2019 time series in Kano metropolitan respectively are shown in Figures 5–7. Evidence of increasing of urbanization is apparent in continuously increasing agglomeration within Kano as shown in the LULC spatial expansion and transition gains in transport infrastructure and built-up areas in the two-time series (1984–2013 and 2013–2019), respectively. The spatial and temporal changes in the urban landscape are likely to be attributed to high indices of population and migration—the main factor for the emergence of the scattered mosaic of many urban slums especially on the fringes of Kano metropolis.

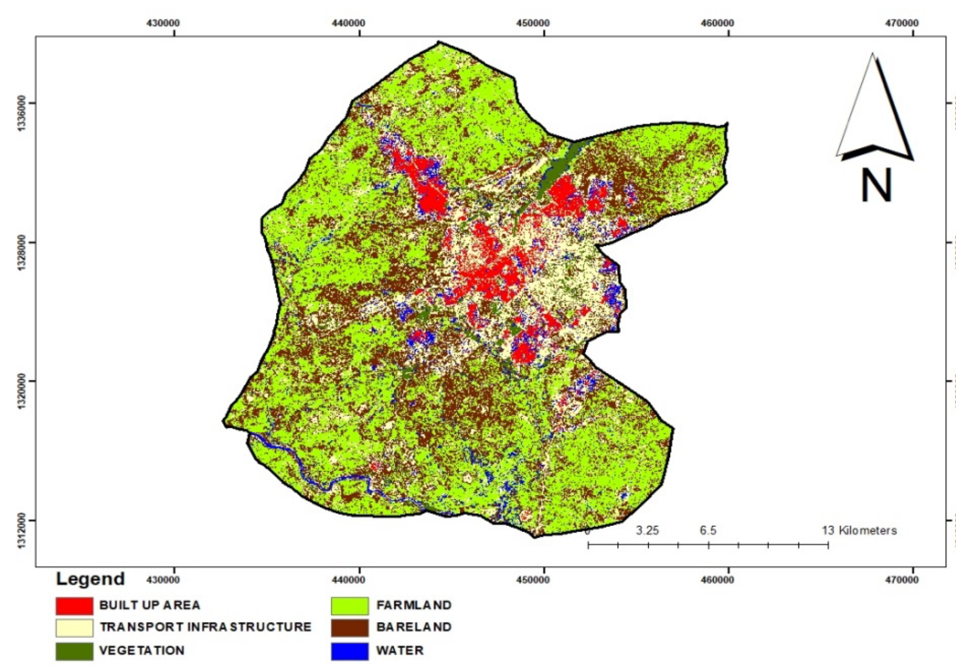

Figure 5. Kano city classified LULC map of 1984.

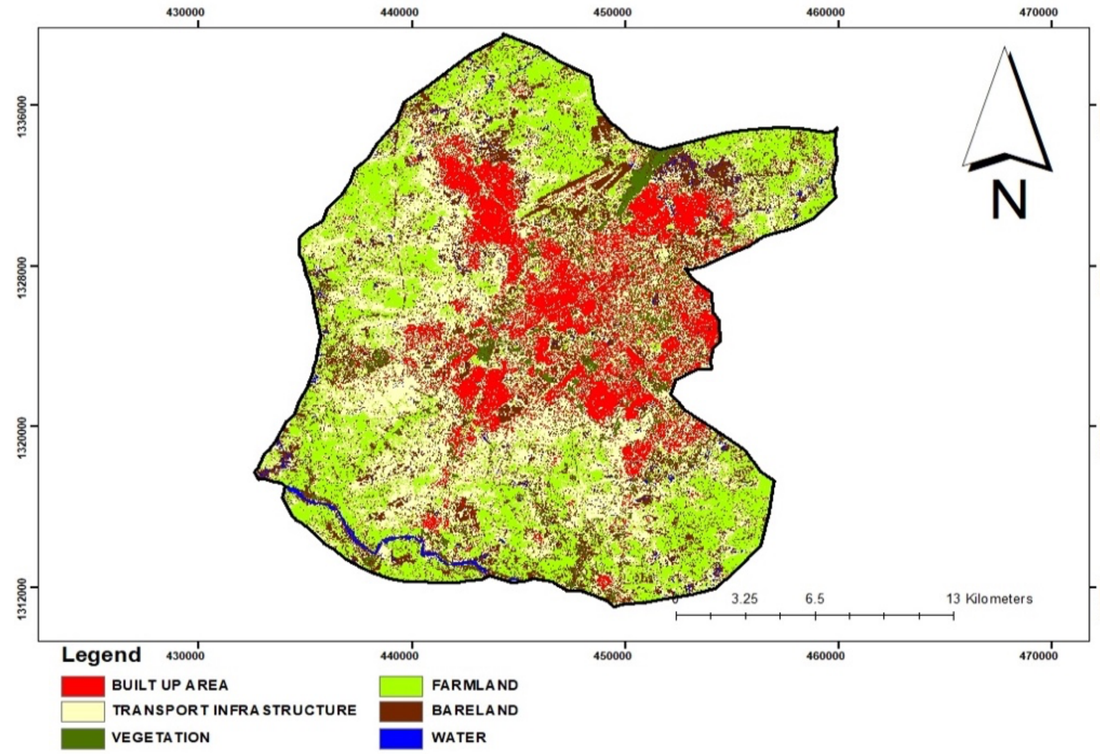

Figure 6. Kano city classified LULC map of 2013.

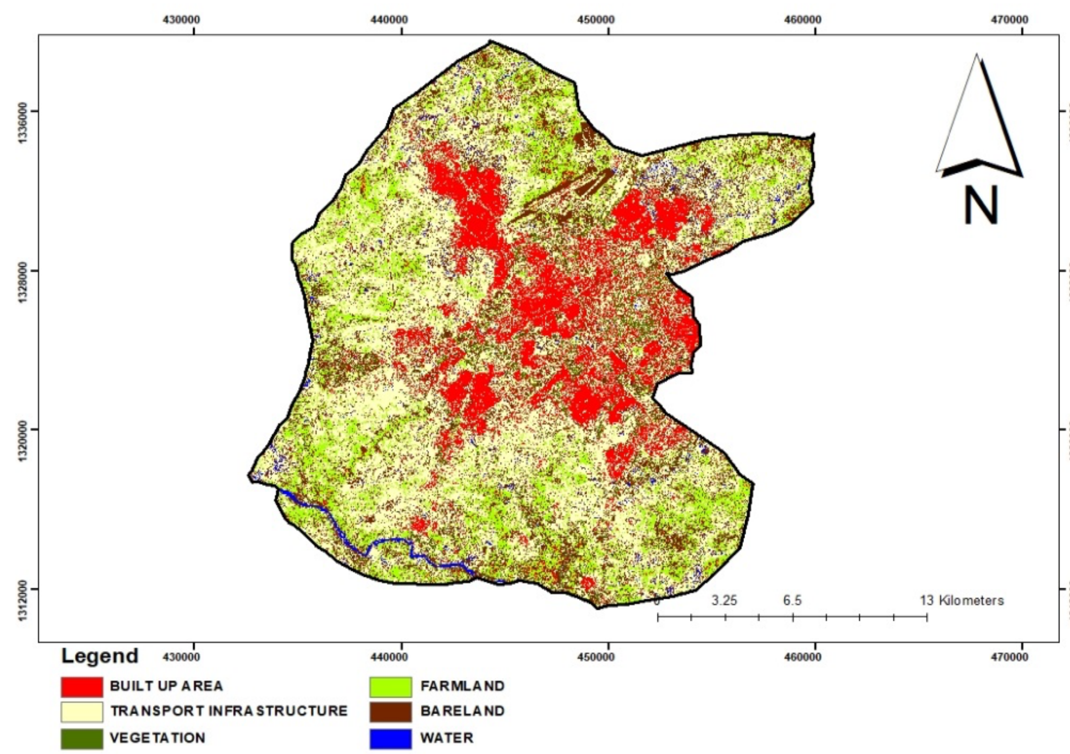

Figure 7. Kano city classified LULC map of 2019.

Many researchers have found a similar link between high urbanization rates with economic growth to provide basic infrastructure development in many cities in Sub-Saharan Africa [16,54,55]. This inequitable expansion continues to pose serious commuting challenges to the urban population who have to navigate through exhaustive daily congestion experience in the city's dilapidated and inadequate infrastructures of the single road transport mode, predominantly cars.

4.2. Markov Land-Use Prediction

The model is used in the forecasting of future growth of the land dynamics and is called Markov land-use prediction (MLP) after calibration and validation. The steps include defining, standardizing, and aggregating defined criteria in the decision wizard module of IDRISI Selva 17.0 to area maps for LULC transition changes. To predict future urban land-use distribution at discrete time scales, we substitute inputs of initial state matrix areas (Equation (7)) and initial state transition matrix (Table 4) into a Markov simulation model in Equation (6). Transition distribution maps in Figures 8 and 9 are the outcomes of the Markov chain prediction of urban landscape evolving trends in the Kano metropolitan environment for 2030 and 2050, respectively.

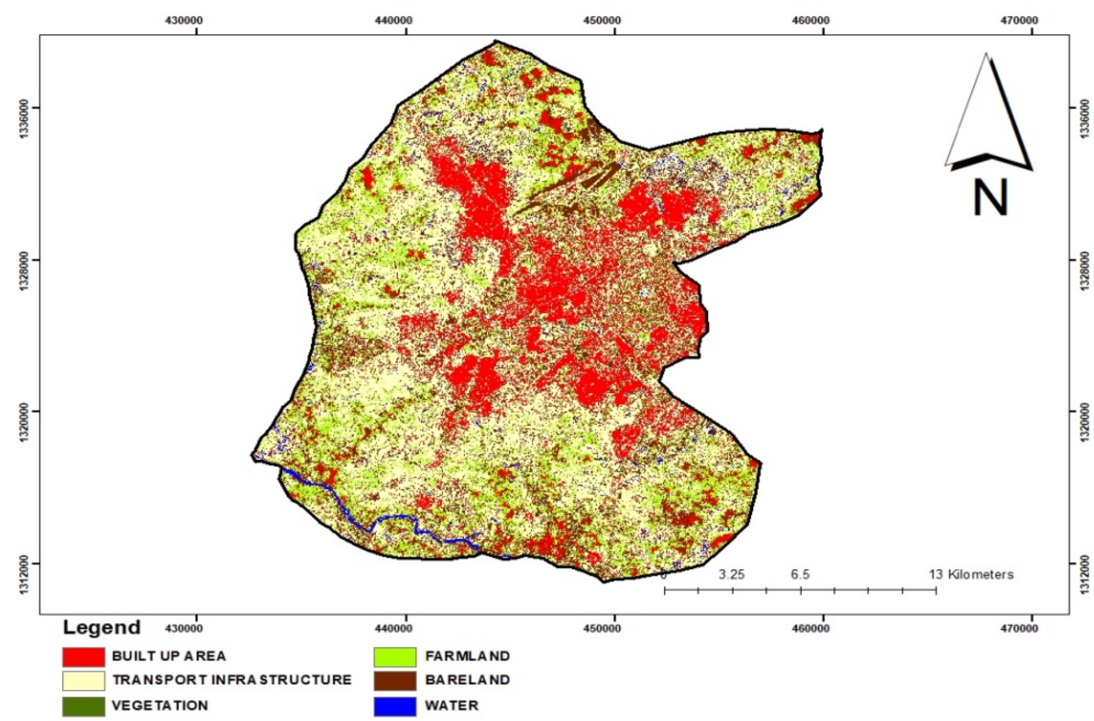

Figure 8. Predicted LULC map of 2030.

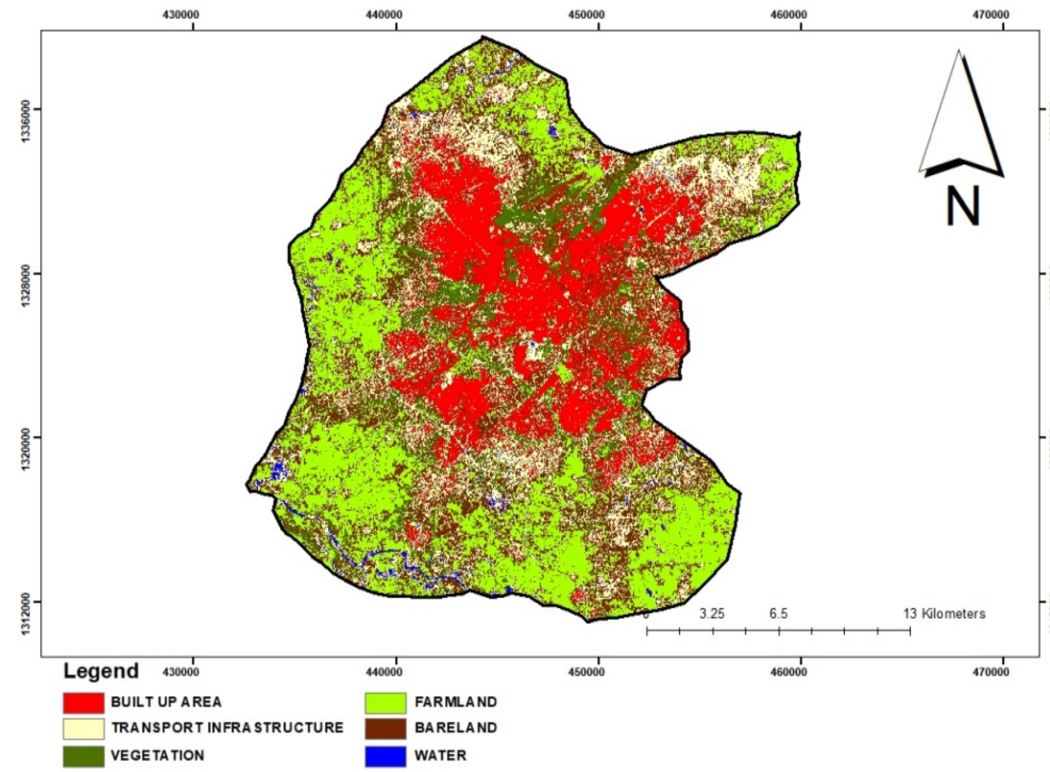

Figure 9. Predicted LULC map of 2050.

Future prospects of these spatial-temporal growth indicators may be more realistic for built-up areas than transport infrastructure. The developments in the Nigerian built environment could be guaranteed as traditional land title holders, estate developers, businessmen and other private interests are the main purveyors of the sector. Huge infrastructure gaps were created by the legally binding roles of municipal governments representing various government levels (federal, state and local authorities), often with complex relationships in terms of planning visions, priorities, interests, resources and jurisdictions as the sole provider of urban infrastructures [34]. Nigeria's dilapidated transport infrastructures—roads, airports and railway system—are the worst affected by multi-level public infrastructure decays due to politics, bureaucracies, and institutional corruption [56].

4.3. Transition Suitability Maps

ArcGIS was used to prepare images taking note of some important factors and constraints. It was further processed by importing into IDRISI were in the form of suitability maps, the CA-Markov chain analysis using multi-criteria evaluation (MCE) to produce decision rules. MCE involves a predictive decision technique that introduces an aspect of spatial contiguity and distribution of transition analysis in the Markov chain process. It involves using Boolean overlays to reduce criteria to suitability logical statements and combining statements by logical operators, i.e., union (OR) and intersection (AND). The modules incorporate factors (criteria) and trade-offs for creating suitability maps and to address the multi-objective decisions. The various factors (rules) and constraints were used to create a single evaluation index [57]. The factors display the level of suitability of the conversion area while constraints are depicted in the form of standardized Boolean maps where zero (0) values were the less acceptable regions and values close to one (1) were the most suitable LULC projected conversion areas [53,58].

The study considered a set of factors that impact LULC transition rule, including transport facilities, demography, settlement, forest, urbanization, market, vegetation and agriculture etc. Infrastructure construction and water bodies were set as constraints and a Fuzzy function was used to process the standard factors in combination with the weighted linear combination (WLC) at different functions and control points. Using the WLC method, factors or criteria are standardized into similar numeric range, and combined by weighted average. In the WLC module, the weights of the factors were extracted from the analytic hierarchy process (AHP) function. The MCE module used the constraints, factors, and weights to extract a suitability map of land-use types while IDRISI Collection Editor derives suitability atlas. Transition potential suitability maps in Figures 10 and 11 for 2030 and 2050 have parameters closer to zero, an indicator of a general lack of acceptable or suitable future change.

These images are evidence of some inequalities in spatial-temporal developments, unsustainable locations and susceptible LULC shifts requiring policy reorientation and focused attention on sustainable development of the city. Urban spaces are continuously littered with portfolios of poor quality, and decayed and abandoned transport infrastructure investments due to under-funding and bureaucratic corruption [55,59]. A more holistic approach to solving Kano city’s perennial transport problems is recommended, one that will include improving both the quality and quantity of transportation infrastructure, regional cooperation, transport demand management (TDM) and resiliently engineered and sustainable planning developments.

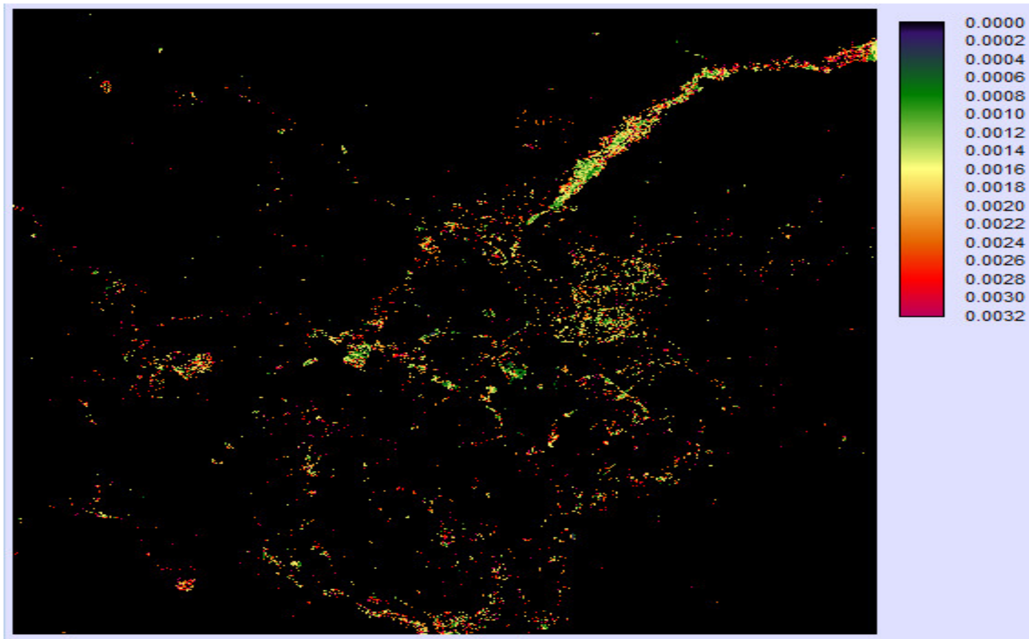

Figure 10. Transition potential suitability map for 2030.

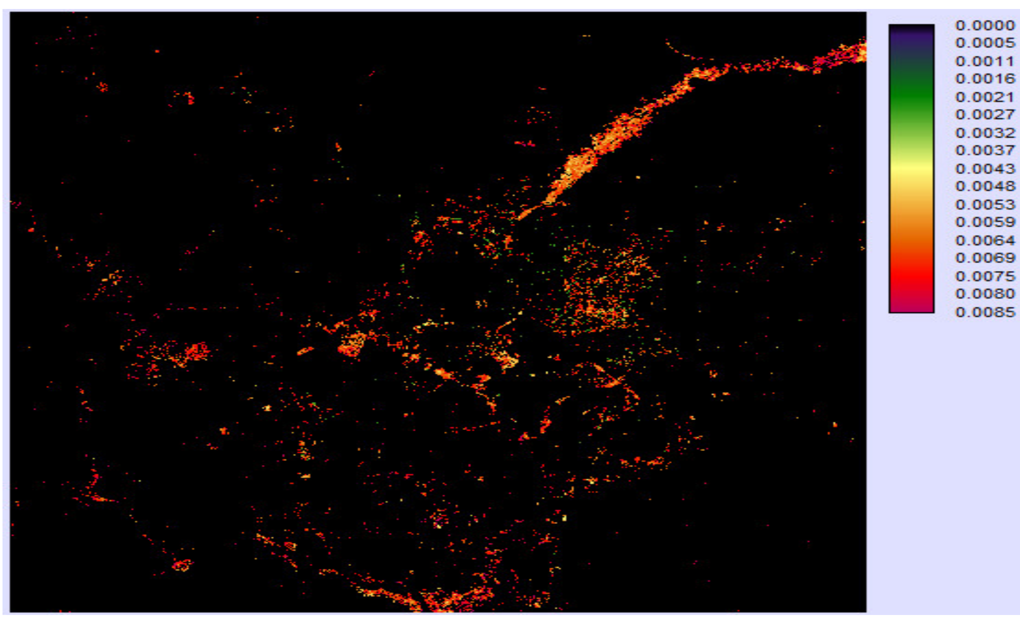

Figure 11. Transition potential suitability map for 2050.

5. Conclusions

The findings from the research revealed the following:

The research has shown that future LULC transition and transport infrastructure spatial demand can be easily predicted using GIS and CA-Markov. Knowledge of the factors driving

LULC shift is very critical for precise future outcomes and weighted suitability maps of the MCE process. During the past decades from 1984–2019, urbanization has increased unsuitable LULC changes by exerting demands that aided the spatial transformation of the transport area and built environment, and depleted other land uses. The results of Kappa classification accuracies ranging from 85% to 88% are within the range of 80–85% suggested in the literature.

According to the predictive models of transport infrastructure and metropolitan built-up areas will respectively experience spatial expansion by $345\,\mathrm{km}^2$ and $410\,\mathrm{km}^2$ from 2019 to 2030. Following the same trend, the prediction estimated a further $140\,\mathrm{km}^2$ land area conversion for transport infrastructure and $155\,\mathrm{km}^2$ for built-up areas in 2050. These spatial figures established a strong connection between LULC changes and unsuitable urbanization growth, especially in transport systems and built-up areas. LULC losses of farmland, bare land, vegetation, and water LULC dynamic transition over the temporal time series pose a significant threat to biodiversity, the climate and environmental disharmony in Kano City.

The Arc-GIS CA-Markov hybrid model is spatially explicit and well-integrated as a means of isolating transport spatial, temporal development of other infrastructure and provides alternative pathways for quantitative tracking of evolution of urban process. Over the last three decades (1984–2019) under study, the developmental practices adopted have culminated in fragmented land use in Nigerian cities. The research will serve as a guide for spatial-temporal monitoring and to explore a sustainable approach to improving the relationship between land use and demand for urban transport facilities in many cities.

Although, the forecast of increasing transportation infrastructure could improve urban mobility frustration, congestion, and quality of life; sustained urbanization and population growths are likely to exacerbate the problem. While it is evident that Kano's population and urbanization booms will continue to grow, exploring the various dimensions of integrated urban planning, sustainable transportation, transport demand management and inter-regional development cooperation could stem down urbanization and improve the wellbeing of urban society.

It is proposed that these future research studies use more comprehensive socioeconomic and environmental variables to enhance understanding of the causes, patterns, and regional demographic influences to effectively guide transport and urban planning. Further studies may also attempt to determine possible changes in the intensification of land use resulting from changes in management of land-use resources.

Author Contributions: The authorship contribution CRediT taxonomy are "Conceptualization, S.H.O., D.V.L.H., and I.J.; methodology, S.H.O.; software, S.H.O.; validation, S.H.O.; formal analysis, S.H.O.; investigation, S.H.O.; resources, S.H.O., D.V.L.H., and I.J.; data curation, S.H.O., D.V.L.H., and I.J.; writing—original draft preparation, S.H.O.; writing—review and editing, D.V.L.H., and I.J.; visualization, S.H.O.; supervision, D.V.L.H., and I.J.; project administration, S.H.O., D.V.L.H., and I.J.; funding acquisition, S.H.O., D.V.L.H., and I.J. All authors have read and agreed to the published version of the manuscript.

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CHAPTER THREE (B)

SPATIAL TEMPORAL ANALYSIS OF TRANSPORT INFRASTRUCTURE SPACE AND URBAN LAND USE FOR LAGOS CITY

CHAPTER THEE (B)
(Published version of the manuscript)

Monitoring spatial-temporal transition dynamics of transport infrastructure space in urban growth phenomena: A case study of Lagos—Nigeria

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Abstract: Lagos is one of the fastest growing world mega-cities with a huge urban mobility crisis, the traditional aggregate city's development model could not provide reliable scientific solutions to monitor the competing demands of various land-use components and the urbanization's effects on transport infrastructure space. This study uses a disaggregated predictive spatial modelling approach to investigate the evolutionary dynamics of transportation infrastructure space to address the fragmented urban chain process. The methodology involves analysis and modelling of the land-use spatial transition changes that have occurred over the past three decades using three Landsat imagery epochs (1984, 2013 and 2019) in remote sensing ARC-GIS 10.7. Furthermore, the prediction of the two-temporal milestones (2030 and 2050) using hybrid cellular automata-Markov (CA-Markov) implemented in IDIRISI SELVA 17.0 software when the tides of social-demographic factors were expected to bring about significant urban spatial transformation. The forecast results are expected to increase the area for transport infrastructure spaces by 93km^2 (7.3%) in 2030 and 157 km^2 (12.4%) in 2050. The model's kappa reliability coefficient estimates for the three temporal scales $(k_{1984} = 85\%;\ k_{2013} = 88\%\ \&\ k_{2019} = 89\%)$ are higher than the 80% minimum adjudged strong agreement between the ground truth and prediction classified images in literature. The model provides efficient tool in urban development planning and sustainable transport decisions.

Keywords: transport infrastructures; land-use land cover change; urban growth phenomena; dynamic transition modeling; sustainable mobility

1 Introduction

Globalization has not only brought about the transformation of human activities through the alignment of the economy, trade, investment, employment, industry and technology beyond regions, countries and continents. However, it has also triggered uncontrolled migration and urbanization because of the attraction offered by the aforementioned activities. Many cities in the developing countries are currently facing an uncertain future due to high urbanization rates and poor infrastructure. The most critical aspect of local, regional and global relations is transportation, and the poorly rated and dysfunctional state of infrastructure in developing countries has aggravated many social, economic and environmental issues about the viability of the fast-agglomerating urban centers of Africa and Asia (Goryakin et al., 2015; Njoh, 2008). Urbanization includes regular land surfaces being changed over into different land use/land cover (LULC) (i.e., Houses, transport, built areas, parks and other impermeable surfaces) which results in dramatic transition in the consistency of the urban landscape with its toll on human habitation and urban areas (Cai et al., 2019). Rapid urbanization, population growth and economic developments are the main causes of LULC change with numerous consequences on urban settings, not least in terms of ecological processes and increased environmental footprints (Wang et al., 2018).

Urban chain process is thought to usher in positive improvements in living quality, the advancement of human civilization and economic accomplishment in developed countries. Many African cities are hybrid urban and peri-urban slums inundated by the massive influx of people hardly able to cope with its inadequate and fragmented infrastructure and planning developments (Xu et al., 2019). Reckoning with some of the recent pressures and disruptions in cities caused by increasing urbanization, lack of timely and credible information on urban spatial-temporal transition in developing countries has constantly been a strong barrier to the deployment and implementation of suitable planning policies for city management.

In the last centuries, societies continued to exploit and transform the environment leading to tremendous improvements (and dis-improvements) to landscape and land Geo-morphology. This dramatic alteration has had a profound effect on the natural environment, sometimes, leading to abuse, over-exploitation and disruption over time (Adhikari & de Beurs, 2017). When reflecting on the direct consequences of over-exploitation and related human activities on land resources, some researchers have stressed that the biophysical properties of the land are over-exploited and the purpose on which it is based or the reason for which the land is used (land-use) must be moderated and made sustainable (Ojima et al., 2005; Peters et al., 2016; Turner et al., 2001).

There is no stop button to urban growth, development, and complex spatial-temporal transformation, not least when the economic prospects remain the strongest impetus. Therefore, keeping tabs on the transition through modelling, simulating and forecasting the future city growth and scenarios would be beneficial as an effective planning tool for grasp the interactions between the natural environment and the anthropogenic challenges of rapid urbanization. Accordingly, the estimation of LULC transitions is a necessary step to gain holistic and ethical insights needed for management of natural resource and sustainable development tracking (Cobbinah & Aboagye, 2017).

The extent of spatial-temporal land use change varies with time, geographic area and most significantly, the land cover nature. Land cover is the bio-physical areas observed from the earth, which includes vegetation, bare lands, soils, rock outcrops and water catchments (Panagos et al., 2015). Information on LULC cannot easily be obtained without the aid of applied remote sensing technologies and techniques. For example, geographic information systems (GIS) and remote sensing (RS) are powerful tools for capturing reliable and timely information on the spatial distribution of LULC changes across large areas. In addition, GIS provides a versatile framework to track changes for digital data collection, storage, display and analysis (Dragicevic et al., 2001).

Remote sensing imagery and GIS have proven to be useful tools in determining LULC changes, for geodetic probing and interpretation of geophysical changes of the earth's surface. The application of GIS-RS in urban and environmental planning has resulted in the tremendous development of spatial modeling methods, not least when used in decision and planning support modeling tools such as Markov chain (MC) (Jokar Arsanjani et al., 2013) and hybrid Cellular Automata-Markov (CA-Markov) (Basse et al., 2014). Other decision support tools are Logistical Regression (LR) (Hu & Lo, 2007), Artificial Neural Network (ANN) (Pijanowski et al., 2002) and the dynamic *Conversion* of *Land* Use and *its Effects* (*CLUE*) models. Also, many studies have shown that integrated multilayer perception-Markov chain analysis approach with GIS could be effectively used for measuring and modelling changes in spatial-temporal LULC changes (Mishra & Rai, 2016).

These models have proven their ability to provide a quantitative approach to tackle multi-dimensional problems of cities and as an environmental planning decision-making technique. Therein, it can be used to assess land suitability for development – both crucial and necessary for effective management of large cities. Similarly, researchers have regularly highlighted the shortcomings of these types of individual models (Basse et al., 2014; Guan et al., 2008). To overcome the perceived shortcomings, hybridized integrated modelling approaches are commonly used for simulating and projecting LULC - see for example, (Triantakonstantis & Mountrakis, 2012).

In the last decades, remote sensing (RS) and geographic information systems (GIS) have been successfully used for land and other natural resources management and for updating spatial data. It is effective both in terms of offering a much lower cost than conventional ground survey methods and the efficacy of rapid routine LULC data acquisition (Araya & Cabral, 2010). Understanding the growth, shape and pattern of complex dynamics require robust RS techniques and tools including GIS and CA-Markov for decision modelling (Barredo et al., 2004).

Since 1972, satellite data and images from the Landsat Multispectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) have been widely used because of their rich spectral resolutions in land cover studies in many diverse agricultural, forestry and built environment fields (Reis, 2008). Landsat is one of the most widely used remote sensing data for satellites, and its continuous long-term availability, cost-effectiveness and timeliness have made it an invaluable resource for monitoring LULC change. Vast literature has provided general technical information on Landsat data (Chander et al., 2009; Markham & Helder, 2012; Roy et al., 2014).

Tracking the change process is necessary to identify land use properties of interest between two or more temporal dates on digital images. Most common techniques described in the literature involve comparison and classification of key components based on temporal images at various referenced dates. Some of the familiar methods include traditional image distinction, image regression, post-classification-comparison, image ratio, and change on-screen manual digitization by a review of key components and classification of multi-date images. Research Synopsis have proven that the post-classification-comparison (pixel-by-pixel) analysis is the most reliable approach and has the benefit of evidence the magnitude of the changes (Jat et al., 2017; Leao et al., 2001).

In the current study, the main objective is to simulate LULC changes using RS-GIS and hybrid transition CA-Markov techniques which are applied to satellite imagery to monitor past development dynamics and to predict future scenarios affecting urban mobility and supporting infrastructure space in the most evolving Nigerian mega-city of Lagos. In this study, urbanization is monitored in Nigeria from two significant time-steps (1984 and 2013) to the current research year in 2019. In 1983, the country’s return to civil rule returned activated economic growth, which immediately birthed the era of high urbanization due to the attractiveness of the city in 1984 (Blei et al., 2018). For the first time in 2013, population indices hit an urban population of 58.3 per cent, bringing more Nigerians in cities than in rural areas (Farrell, 2018). Furthermore, likely scenarios for 2030 and 2050 milestones, decades of worst population booms were predicted to better understand the roles of land-use processes and necessity of sustainable development in terms of planning and policy implementation.

2 Methodology

The methodology of this study is focused on LULC potential change modeling and prediction of transport infrastructures in the main Lagos are using arc-GIS 10.7 and hybrid cellular automata-Markov (CA-Markov) in IDIRISI SELVA 17.0. A number of pre-processing steps were performed on Landsat imageries before applying LULC change detection algorithms, including, image registration, geometric rectification, atmospheric, radiometric and topographic corrections, introduction of confusion matrix for change detection analysis and evaluation of accuracies (Gašparović et al., 2019; Phiri et al., 2020). The methodological steps involved in LULC modelling are shown figure 1.

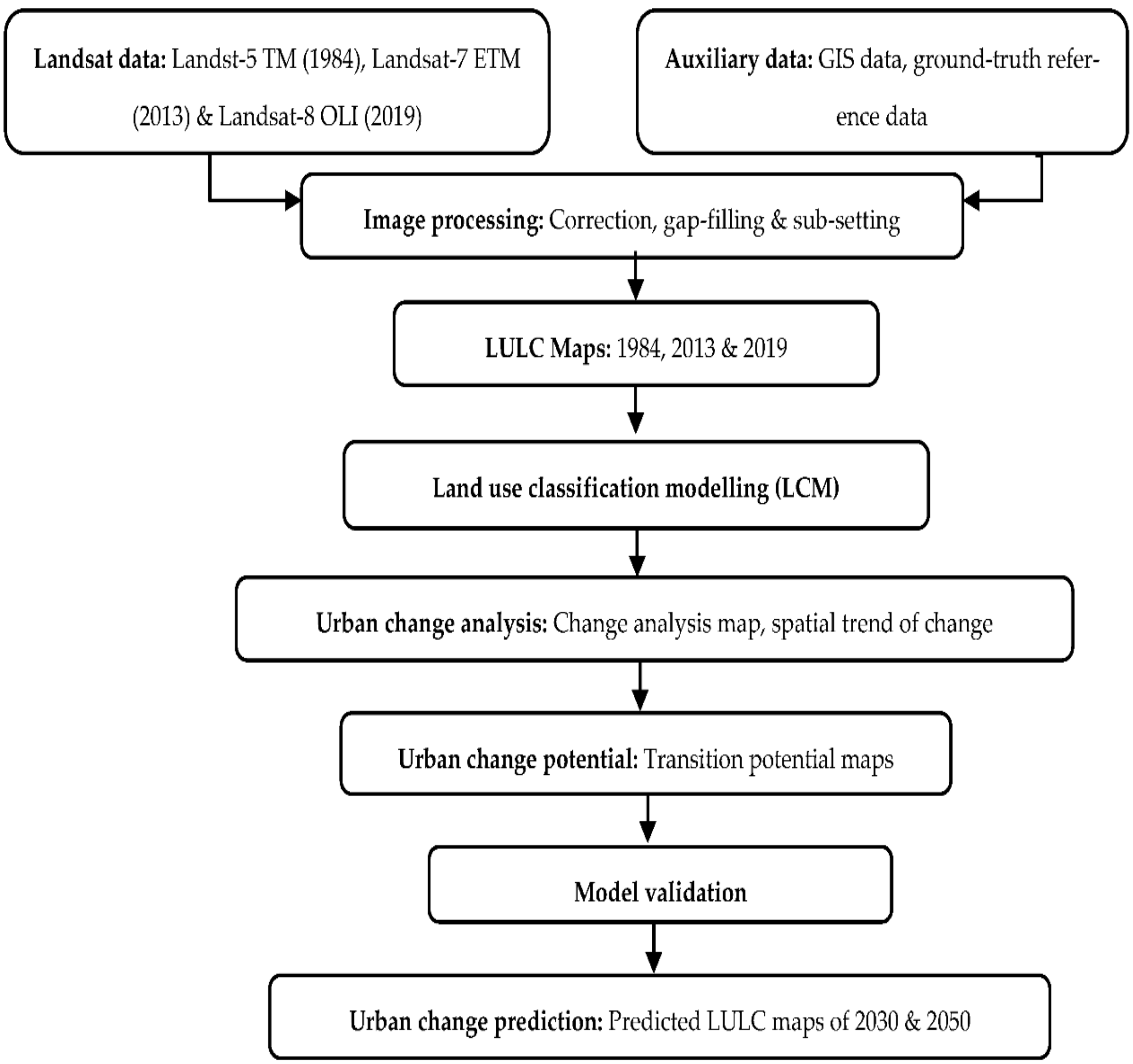

Figure 1: Methodology of simulation of urban LULC change modelling

2.1 The Study Area

Lagos is situated approximately at latitude 6 ° 27'N and longitude 3 ° 24'E in the south-west of Nigeria. It is both Nigerian commercial and industrial headquarters. Lagos state covers an area of about 3577. 28km-square, but the main Metropolitan Lagos is about 1,171.28 km-square comprises 16 out of 20 Local Government Areas (LGAs) as shown in (Figure 2). The current estimated population is about 13.9million and the urban agglomeration density is about 6,871 residents per km-square (UNDESA-PD, 2019). It is the most populous city in sub-Saharan Africa (SSA) and currently ranking sixteenth largest city in the world with the pinnacle of urban growth rate of about 5.8 percent (Aliyu & Amadu, 2017).

Lagos is experiencing one of the fastest paces of urbanization because of its economic and industrial importance spinning high demand and devolution of land with resultant rapid LULC changes over the past decades. The city is plagued by perennial traffic congestion, safety issues and mobility frustration due to the nexus of problems of heavy motorization and continuing traffic of people to the city from all parts of Nigeria as well as neighboring countries, high population density and inadequate infrastructure (Olajide et al., 2018). Figure 3 shows the major transport infrastructure map of the study area.

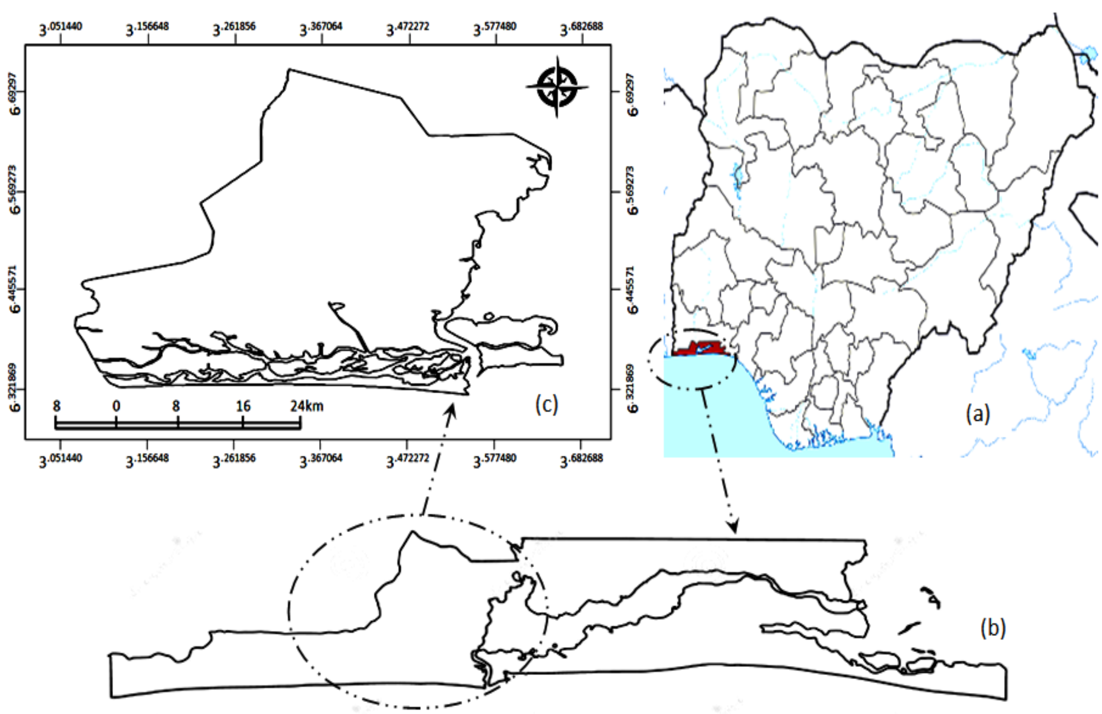

Figure 2: Location map showing: (a) Nigeria (b) Lagos State (c) Metropolitan study area

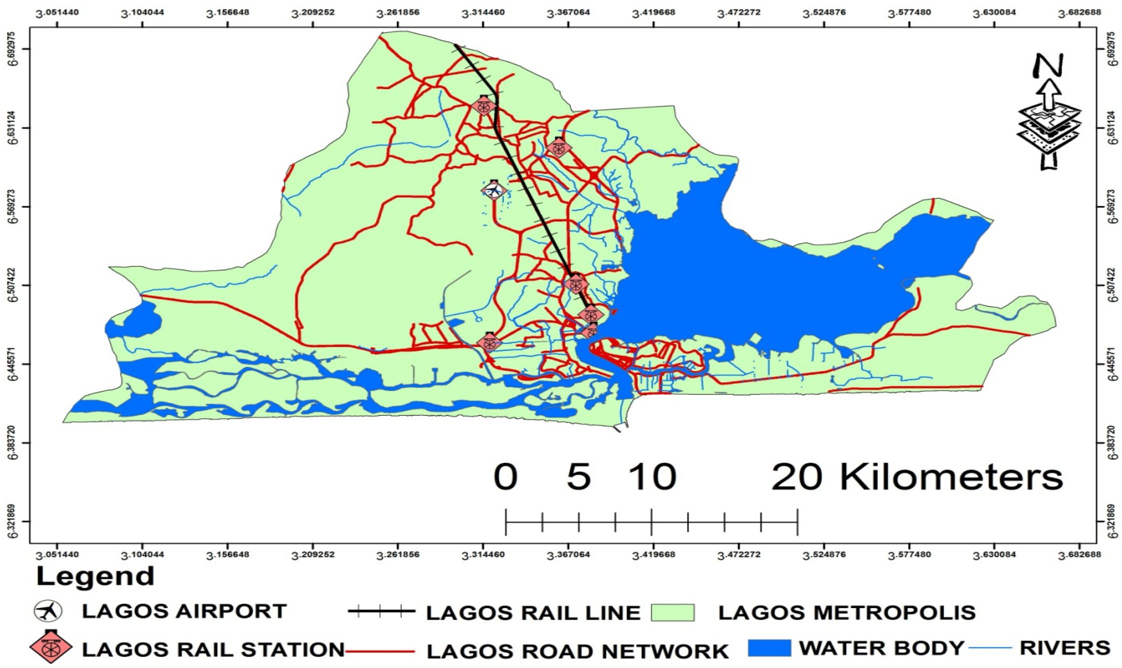

Figure 3: Major transport network map in Lagos

2.2 Data Source and Processing of Image

The US Geological Society Landsat[24] image data – Thematic Mapper (Landsat—5 TM), Enhanced Thematic Mapper (Landsat—7 ETM) and Operational Land Imager (Landsat—8 OLI) used for the study was obtained respectively for 1984, 2013 and 2019. Other ancillary data and infrastructures used for verifying accuracy and referencing are the major maps for roads, airports, rail lines obtained from Nigerian National Space Research and Development Agency (NASRDA)[25], high—resolution Google Earth images and the coordinates of physical landmarks based on field experience. Specific attributes and descriptions of Landsat RS data resources used for Lagos metropolis LULC change are listed in Table 1.

Table 1 - Description of Landsat data resources used for analysis in Lagos metropolis

Imagery date	Sensor	Satellite	Path	Rows	Spatial resolution (m)	Spectra bands
25/07/1984	TM	Landsat 5	191	055, 056	30	7
15/03/2013	ETM+	Landsat 7	191	055, 056	30	7
02/10/2019	OLI	Landsat 8	191	055, 056	30	8

24 https://earthexplorer.usgs.gov/
25 https://nasrda.gov.ng

A series of pre-processing steps, including atmospheric correction, atmosphere and cloud shadow identification and composite/fusion /metrics techniques were performed on Landsat images prior to implementation of algorithms for change detection (Chander et al., 2009). Data files were extracted with less than 10 percent cloud coverage in tagged image file format and imported to ERDAS IMAGINE 2014 as raster imageries. The image is registered picture-to-picture and re-samples at 30 x 30metres spatial resolution based on a similar projection method. Processing of digital images involves the atmospheric correction, radiometry error, geometry, image gap filling, the sub-setting field and band selection.

Cloud is a crucial obstacle for optical remote sensing in land use dynamics, particularly in certain humid tropical areas. In order to ensure the accuracy of cloud effects, geometric and radiometric pre-corrected Landsat imagery from the USGS Earth explorer with a linear factor for conversion to surface reflectance is obtained at level 2 atmosphere. The Global Digital elevation model (DEM) dataset of land areas at 30-m spatial resolution postings used in elevation surface and topography analysis were obtained from Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) repository at the USGS website (http://earthexplorer.usgs.gov/).

In May 2003, scan line corrector (SLC) in Landsat—7 ETM satellite completely failed to compensate for the forward motion of the satellite, creating image scenes data gap scenario or "fill-no-data" status particularly in heterogeneous scenes. Henceforth, it is appropriate to fill gaps for Landsat 7 ETM+ SLC-off. For this study, dynamic data language IDL 7.0 gap-filling software was used (https://glovis.usgs.gov/). Consequently, the "non-data" areas needed three additional pictures: (1) an image anchor fills (2) an image taken prior to May 2003 and (3) the post-anchor image.

An image manual registration that used Landsat 5TM (1984) as master control points to synchronize images from various satellite images from the same scene was carried out as a spatial transition. The matching of image scene involving stacking the control points with other satellite pictures (Landsat-7 ETM and Landsat-OLI) is compared with referenced auxiliary data. The average error of transformation-matched points (RMSE = 0.18 pixels) at 30 m resolution produced a good iteration as it satisfied RMSE < 0.5 pixels in literature (Sheng et al., 2008).

Due to its importance in identifying the anthropogenic and ecological effects of human activities, predictive modelling of LULC change is an increasingly growing research area. The factors transforming LULC changes, including urbanization, water and biological cycles, biodiversity, anthropogenic and ecological processes, exert significant effects on global change. The ecological footprint of human over-exploitation and over-dependence on the earth's resources is increasing due to increasing anthropogenic influences, including urbanization, oil and mineral explorations, deforestation, industrialization, intensive agriculture, and overgrazing.

The contribution of natural phenomena, including extreme climate events, earthquakes and tsunamis, solar and cosmic radiations to changes in global and LULC transformations is also prominent. Scientists have established an international LULC organization linked to the International Geosphere Biosphere Program (IGBP) and the International Human Dimensions of Global Change Program (IHDGCP), both formed in 1987, in view of the strategic significance of global change (Halmy et al., 2015).

Several different modelling techniques were applied in the study of LULC transformation, land use conversion and the debates were dominated by the stochastic assessment of where potential changes might occur by understanding the factors driving them (Halmy et al., 2015; Srivastava et al., 2012). Predictive LULC modelling techniques are computer implemented algorithms for ease of speed, accuracy and handling large data and are classified into optimization, stochastic, empirical–statistical and dynamic or process-based techniques (Lambin et al., 2000). Cellular automata (CA) features within the category of discrete time and space dynamic system-based algorithm which obeys the specific rules of the uniformly spaced grids.

In particular, CA is most preferred for LULC modelling because of its illustrative capability to depict a complex system based on a collection of sets of rules and states used for dynamic transition prediction and detection of both spatial- temporal dimensions. For the study of the various complex phases of land use transition problems at different spatial and temporal multi-scales, Markov chain analysis (MCA) is applicable as a stochastic modelling technique based on the premise that if an earlier physical state is known, the next state can be calculated. Since neither of the two models can fulfil the need for effective prediction, a hybrid CA-Markov algorithm was compiled and implemented in IDRISI SELVA software as a veritable tool for spatial modelling, simulation and prediction with visual qualitative and quantitative scales (Aburas et al., 2016).

2.3 LULC classification

The reliability of different LULC mapping implementation algorithms is important to the dynamic change prediction modeler as LULC transformation tracking is precision-driven in both qualitative and quantitative dimensions. Researchers have applied the following land use classification algorithms — artificial neural networks (AAN), genetic algorithms, support vector machine (SVM), decision tree (DT), random forest (RF), FUZZY ART-MAP, Mahalanobis distance (MD) and maximum likelihood classifier (MLC) with Kappa accuracies greater than

84% (Talukdar et al., 2020). MLC is commonly adopted due to its fast parametric convergence as many other classifiers require time to optimize (Keuchel et al., 2003). MLC presupposes that the data are normally distributed and estimates a high probability that a certain pixel belongs to the correct category it is classified into. Also, the algorithm has been chosen because of its higher likelihood to quantify minority classes into their specific category of pixel spectral, without being overfilled or subsumed by major classes during sampling image training.

The distribution maps have been grouped into the four LULC groups, including their spatial area, based on the features specifically seen in the remote sensing imageries (e.g., shape, size, hue, and texture etc.). A well-established approach of supervised maximum likelihood classification (MLC) was employed to produce the respective land use groups and to assess the urban spatial expansion, including transport evolution. The classification of the Landsat imagery was performed using ARC-GIS 10.7 software based on supervised classification of maximum likelihood where each pixel was categorized into one of the following classes: transport infrastructure, built-up areas, vegetation, and water respectively. To carry spatial and temporal shift predictions, a post-classification, transformation detection was carried out using IDRISI Selva 17 pro software. The process involves 'from-to' perception details of two classified images to arrive at pixel-based change information comparison (Otuoze et al., 2021b). Here, classified images of two different time-shifts (i.e., 1984-2013) using cross-tabulation to assess the spatial quantitative dimensions are assessed.

2.4 Accuracy Assessment

To assess the overall accuracy of the classification, a confusion matrix was created, and accuracy assessment consists of accuracy of the producer, user, overall accuracy, and kappa value. Cohen's Kappa value is a measure of agreement of two raters which gives a comparison between the predefined ratings of the producer and that of the user. Some researchers have emphasized the necessity to perform accuracy assessments for individual classification if the data set is to be used for the study of change detection and for classification accuracy as the test will account for all ambiguity matrix elements including diagonal elements (Halmy et al., 2015). According to (Weng, 2010) and (Yusuf et al., 2014), the minimum level of accuracy assessment acceptable should be at least 85 percent when defining LULC categories in remote sensing results while model reliability checks with Kappa values of 80% minimum is adjudged to be reasonably good.

A full 'ground truth' pixel by pixel map is not feasible; it is critical that adequate selection or sampling pixels are given to ensure that a classification is robustly assessed. Suitable methodology of sampling must be used to respond to statistical reliability. According to (Jensen & Lulla, 1987), the optimum amount of reference pixel necessary for the precision assessment depends on the required minimum level of accuracy; for example, moderate to good accuracy requires 80 to 85% Kappa index of agreement (K_{IA}). It was ensured that least 204-pixel points taken based on stratified random sampling method (e.g., Equation 1) were considered to increase the percentage of accuracy assessment (Abd El-Kawy et al., 2011).

$$N = \frac{z^2 * p * q^*}{\varepsilon^2} = \frac{4 * p * q^{\sim}}{\varepsilon^2} = \frac{2^2 * 85 * 15}{5^2} = 204 \qquad (1)$$

where N = Total number of sampled pixel points; p = Expected accuracy (%); $\mathrm{q}^* = 100 - \mathrm{p}$; z = 2 (standard normal deviate of 1.96 for 95% confidence level); ε = allowable error (usually 5-10%).

The total sample was further delineated by thematic classification into at least 30 pixels per LULC class in order to prevent any form of bias. To attain a minimum 85% accuracy; 20 minimum pixel points per land-use class and 20 pixels per referenced LULC class for 90% accuracy of classification were recommended (Van Genderen & Lock, 1977). Out of the 204 sample sites chosen, 122-pixel points (60 percent) were used for training based on the key image recognition and validated on a basis of 82-pixel points (40% reference points) with Kappa reliability assessments. The general patterns in LULC maps showed an evolving rate of various LULC classes within the period of analysis.

As previously described, four categories of LULC classes which includes transport Infrastructure, built-up areas, vegetation and water could be delineated perhaps, due to the geography and climate of the area. Whilst user accuracy describes the probability that a pixel will actually represent a class on the ground on the image, product accuracy defines the likelihood that a pixel or region is classified correctly (Pontius Jr & Millones, 2011). The empirical definition of Kappa statistics is given in Equation 2, a value above 0.8 indicates a strong-to-perfect agreement or precision between two maps (Liping et al., 2018). The Kappa tests were for1984, 2013, and 2019 images were estimated to determine the predictive quality of input data.

$$K = \frac{P_o - P_e}{1 - P_e} \qquad (2)$$

where $P_o$is the is the number of times that the rating thresholds have relative agreements

P_e is the hypothetical probability of agreement by chance

2.5 Markov Chain Transition Analysis

Markov chain model (MCM) was developed by (Ulam, 1962) for solving stochastic processes and land use modelling. MCM has also been used for LULC modelling and simulation changes and patterns. Researchers have applied MCM in dynamic systems for predicting LULC future state based on the preceding state (Jianping et al., 2005; Li et al., 2018). The Markov chain process could be defined as a systematic process of changing state sets, $S = s_0, s_1, s_2, s_3, \ldots, s_t$. The transition potential likelihood of land use conversion from one state to another depends on a sequential discrete time scale such that transition probability matrix into a particular state is given by Equation 3.

$$S_{t+1} = P_{ij} * S_t \quad (3)$$

$$P_{ij} = \begin{bmatrix} P_{11} & P_{12} & \cdots & \cdots & P_{1m} \\ P_{21} & P_{22} & \cdots & \cdots & P_{2m} \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ P_{m1} & P_{m2} & \cdots & \cdots & P_{mm} \end{bmatrix} \quad (4)$$

where S_t and S_{t+1} denote state of land use at time steps t and $t+1$ respectively, P_{ij} is the transition probability matrix for change state i to j.

According to Guan et al., (2008), Equation (4) can converge under three conditions: (1) first, that $\sum P_{ij} = 1;\ and\ 0 \leq P_{ij} \leq 1$. (2) Secondly, the hypothesis that the probabilities for the transition should remain unchanged. (3) The third condition is the valid assumption that Markov chain is a transient system under a first order model where the latter state is consequent upon the former. In the current study, temporal state probability (P_n) implemented in IDRISI Selva version 17 in the current study involves solution to primary matrix ($P_{(0)}$) and transition matrix (P_{ij}). In this case, maps of the Markov chain model for 1984 and 2013 were used to generate changes in the transition matrix for the duration of 29 years. Furthermore, the process is repeated on the 2013 and 2019 map for potential land use to extract changes in the transition matrix following Equation (5).

$$P_n = P_{(n-1)} P_{ij} = P_{(0)} P_{ij}^n \quad (5)$$

Markov stochastic process theory can be used to measure the state transition probabilities from initial state to n^{th} state, as well as a stable state based on the transient phase time series as T+1 and the initial duration as T. Therefore, the relationship provides Markov's transition probability for n^{th} state in Equation 6.

$$P_{ij}^{(n)} = \sum_{k}^{m-1} P_{ik}^{(n-1)} P_{kj}^{(n-1)} \qquad (6)$$

2.6 CA-Markov Chain Model and Prediction

Cellular Automata (CA) has many conceptual applications to land use modifications, spatial modelling and land use prediction. It is demonstrated by a grid space called raster that characterizes or describes the cell neighbourhood structure. As a function of the location and sequent time stages of the neighbouring cells, it's a number of transition policies to determine the state transitions for each cell space at the same time to adjust its structure and configuration. This fundamental property of CA implies that LULC changes can be clarified by the current state and changes in adjacent cells for any area (cells) (Mishra & Rai, 2016).

Although, a Markov chain model might have good categorical transfer probabilities, but there is a lack of spatially referred overall performance and distribution parameters for land use application (Arsanjani et al., 2013). The addition of CA to a Markov model results in the possibility of spatial transitions taking place over a period of time in a specific location. In different terms, Geo-referenced and spatial changes from the Markov Chain model are then made by using cellular automata giving rise to the hybrid model — CA-Markov model (Parsaie, 2016). The CA-Markov model implemented in IDIRIS SELVA is equipped to develop a spatial weighting on specific areas that are roughly the same as existing land use, making it very reliable in spatial-temporal dynamics and quantitative estimation of LULC change modelling (Wang et al., 2018).

The outputs of Markov chain analysis (MCA) are used by the CA-Markov model, specifically the transition area file, to apply a contiguity filter or matrix that enables other land-use characteristics to be created from time to time (Basse et al., 2014). The transport infrastructure areas and other land use transition in Lagos can be estimated using the Markov simulation model S(n) in Equation 7 based on the initial state matrix (S_0) and n^{th} phase transition probability (P(n).

$$S(n) = S(n-1) \times \mathrm{P}^{(1)} = \mathrm{S}(0) \times \mathrm{P}^{(\mathrm{n})} \qquad (7)$$

3 Results

3.1 LULC transition maps

The retrospective pattern of the LULC transition is shown by the spatial-temporal changes from 1984 to 2019 in Figure 4. Table 2 shows LULC change the city recorded in the respective time steps (1984-2013 and 2013-2019). The margins of LULC transition gains from 1984-2013 showed increments of 103km-square (8.1%) and 106 km-square (8.3%) for transport infrastructure and built-up area respectively marked the momentous land conversion birthed economic growth within the period. By the same time period, vegetation and water recorded losses of −115km-square (−9.1%) and −93 km-square (−7.3%) respectively. The next time step of 2013-2019 recorded that transport infrastructure and built-up area had another increment of 95km-square (7.5%) and 70km-square (5.5%) respectively, while vegetation and water suffered a further LULC regression of −103km-square (−8.1%) and −62km-square (−4.9%) respectively.

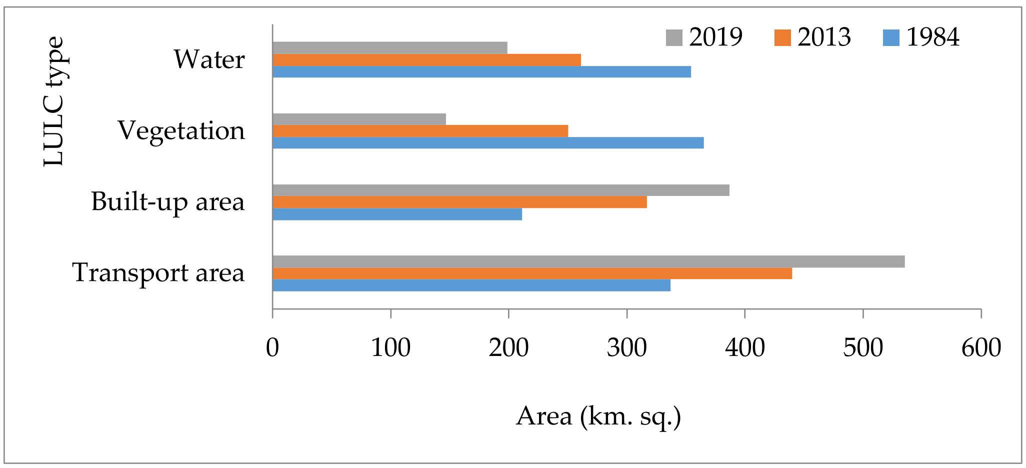

Figure 4: Spatial-temporal changes of LULC classes from 1984–2019.

Table 2: Statistics of LULC areas in Lagos from 1984 to 2019

Year	1984		2013		2019	
LULC class	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent
Transport infrastructure	337	26.6	440	34.7	535	42.2
Built up areas	211	16.7	317	25.0	387	30.5
Vegetation	365	28.8	250	19.7	147	11.6
Water	354	27.9	261	20.6	199	15.7
Total	1,267	100	1,268	100	1,268	100

3.2 Validating Model Accuracy

Validation involves checking the reliability of agreement between the actual and predicted LULC classified image maps using the Kappa Index of Agreement (K_{IA}). Models generated in 1984 and 2013 were validated by the predicted and actual 2019 analysis period using VALIDATE module in the analysis tools. For the current study, the spatial-temporal and visual analysis of the Landsat data and a visual analysis accomplished satisfactory accuracy in the four dimensions considered — producer, user, overall and Kappa accuracies.

- Producer accuracy (PA) is the ratio of the pixels correctly classified samples in a particular delineated class category to the row total number of referenced pixel samples in the class. Alternatively, it estimates the number of the ground image observed features omitted on the predicted classified maps. That is, $\mathrm{PA} = (100 - \mathrm{omission\ error})\ \%$.
- User accuracy (UA) removes commission error from classification by measuring the ratio of the pixels correctly classified samples in a particular delineated class category to the column total number of referenced pixel samples in that class. Alternatively, the UA is a measure of the margin of the wrong classification between the referenced ground images and the predicted images, otherwise called commission error. That is, $\mathrm{UA} = (100 - \mathrm{commission\ error})\ \%$.
- Overall accuracy (OA) is the ratio of the total number of correctly classified pixel samples in the main cells of diagonal matrix to the total number of pixel samples
- Kappa statistics (KS) check the classification accuracy by measuring the level of agreement remote sensed data and reference ground truth imageries.

On the correctly classified LULC map, a confusion matrix measures the recognizable land-use areas simulated as a row matrix, the field reference images being the column matrix, and the pixel sample points as the diagonal matrix cells. Table 3 shows that the various accuracy assessments for the Landsat images of the three temporal times series. The classification attained overall accuracies ranging from 87% (1984) to 92% (2019) respectively, while Kappa indices of agreement values of 85% (1984) to 89% (2019) respectively indicated satisfactory validation for the classified LULC imageries.

The degree of agreement between the simulated areas and the ground reference map is a measure of reliability on which both the qualitative and quantitative dimensions of the estimation of the Markov chain transition probability of future scenarios in Lagos could be scaled. The values guarantee that minimal errors were encountered, thus, the prediction model could give accurately specify location and quantity. The Kappa statistics for 1984, 2013 and 2019 are evidence of good to perfect calibration model for conducting transition analysis for 2030 to 2050 and agrees with 80% minimum recommended in literature sources (Liping et al., 2018; Weng, 2010).

Table 3: LULC maps for accuracy assessment

	1984		2013		2019	
Land use type	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)
Transport infrastructure	84	82	88	90	89	95
Built-up areas	79	83	91	88	94	92
Vegetation	87	85	89	87	91	89
Water	83	89	82	90	93	96
Overall accuracy	87		90		92	
Kappa coefficient	85		88		89	

3.3 Application of CA-Markov chain model

3.3.1 Initial State

MCA is a probability experiment which estimates and transfers probability matrix of the expected LULC changes. The second aspect is the conditional probability images of the predicted time series (2030 and 2050) respectively. Table 4 shows the initial original state matrix [S (0)] which is integrated into mutually changing land use areas defined by Equation 8 based on 1984 LULC classes — transport infrastructure, built-up area, vegetation and water respectively

$$S(0) = \begin{bmatrix} \text{transport infrastructure} \\ \text{built} - \text{up area} \\ \text{vegetation} \\ \text{water} \end{bmatrix} = \begin{bmatrix} 337 \\ 211 \\ 365 \\ 354 \end{bmatrix} (\text{unit: km}^2) \qquad (8)$$

Table 4: Areas of initial state transition matrix for 29years —1984 to 2013 $(\mathbf{km^2})$

	To 2013:				
From 1984:	Transport land	Built-up area	Vegetation	Water	Area total
Transport land	175.5096	110.9741	38.2495	12.2668	337
Built-up areas	60.7469	141.3278	8.9253	0.0000	211
Vegetation	128.3340	116.1795	120.4865	0.0000	365
Water	28.3908	22.1250	0.0000	303.4842	354

3.3.2 The transition state probability matrix

Tables 5 and 6 display the summaries of the various likelihood of LULC transition probability matrices for the time steps - (1984 to 2013) and (2013 to 2019) respectively. For examples, the probabilities for transport infrastructure in 1984 remaining transport infrastructure in 2013 is 52.08%, while vegetation in 1984 becoming transport infrastructure in 2013 is 35.16%. In the second period (2013-2019), Markov transition probabilities of changes from vegetation in 2013 to transport infrastructures and the built-up area in 2019 are 19.00% and 24.35% respectively. Other land-use classes' probabilities are lower and have less likelihood in the transition dynamics.

Not only is the efficiency of the visible change and shifting faces of the transport region week, but the rapid urbanization and population growth cannot keep pace with it. Nigerian cities are dependent on road transport with menacingly poor life cycle and maintenance issues besetting many urban transport facilities (Ojo et al., 2018; Otuoze et al., 2021b). The study has established the major constraint posed by transport infrastructure problems to competitiveness, growth and development of the Nigerian cities. Implementation of land-use integration, modeling, calibration and spatial statistics could allow piloting of a comparative system for evaluating good practice, quality and commitment to good ethics in the development and management of transport infrastructure.

Table 5: Transition probability matrix of LULC changes from 1984 to 2013

From 1984: LULC class change	To 2013: Transport Infrastructure	Built-up Area	Vegetation	Water
Transport Infrastructure	0.5208	0.3293	0.1135	0.0364
Built-up Area	0.2879	0.6698	0.0423	0.0000
Vegetation	0.3516	0.3183	0.3301	0.0000
Water	0.0802	0.0625	0.0000	0.8573

Table 6: Transition probability matrix of LULC changes from 2013 to 2019

From 2013: LULC class change	To 2019: Transport Infrastructure	Built-up Area	Vegetation	Water
Transport Infrastructure	0.5017	0.3331	0.0448	0.0364
Built-up Area	0.3012	0.6330	0.0567	0.0091
Vegetation	0.1900	0.2435	0.5666	0.0000
Water	0.1083	0.0226	0.0756	0.7935

3.4 Markov Land-use Prediction (MLP)

Table 7 shows the various area statistics showing changes in LULC based on 2030 and 2050 predictions. The transition area for LULC changes in Table 7 shows that transport infrastructure space will increase from 535km^2 in 2019 to 628km^2 in 2030 and to 692km^2 in 2050. Also, built-up area will grow from 387km^2 in 2019 to 501km^2 in 2030 and then, to

535km^2 in 2050. Based on the analysis of spatial trends, land use conversion trends are expected to deplete vegetation and water catchment to recede from 147km^2 and 199km^2 in 2019 respectively to 15km^2 and 25km^2 in 2050 due to over-exploitation triggered by demand and could exacerbate the unsustainable urban situation of the city.

Table 7: Transition area statistics of predicted LULC areas in 2030 and 2050

LULUC Class	2019		2030		2050		Change 2019–2030		Change 2019–2050	
	Area (km^2)	(%)	Area (km^2)	(%)	Area (km^2)	(%)	Area (km^2)	(%)	Area (km^2)	(%)
Transport area	535	42.2	628.0	49.5	692.0	54.6	93	7.3	157	12.4
Built-up area	387	30.5	501.0	39.5	535.0	42.2	144	9.0	148	11.7
Vegetation	147	11.6	55.00	4.3	15.0	1.2	−92	−7.3	−132	−10.4
Water	199	15.7	85.00	6.7	25.0	2.0	−114	—9	−174	−13.7
Total	1,268	100	1,269	100	1,267	100	–	–	–	–

4 Discussion

4.1 Classified LULC Imageries

Figures 5-7 display land-use classification maps generated for the 1984, 2013 and 2019 time series in Lagos respectively. The continuously growing urban agglomeration in Lagos spatially transformed the transport and urban landscapes as evident in the land area gains in the respective time series. Transport growth and influence of rapid urban chain increased the significant gains in the two land use classes 1984 to 2019 and are largely the transition gainers of receding green vegetation and water catchments.

It can be observed that LULC gain in both transport infrastructure and built-up area are evidence of increasing urbanization trend as new ventures into land reclamation, sand filling of lagoons, floating islands and other water bodies were triggered by increasing land demand and conversion. For example, the most prominent case of urban chain projects triggered by dire land demand in Lagos is the ambitious Victoria Garden City (VGC), built entirely on the reclaimed sea and lagoon land, rendering the city vulnerable to constant weather events and the pre-eminence of existential flooding threats.

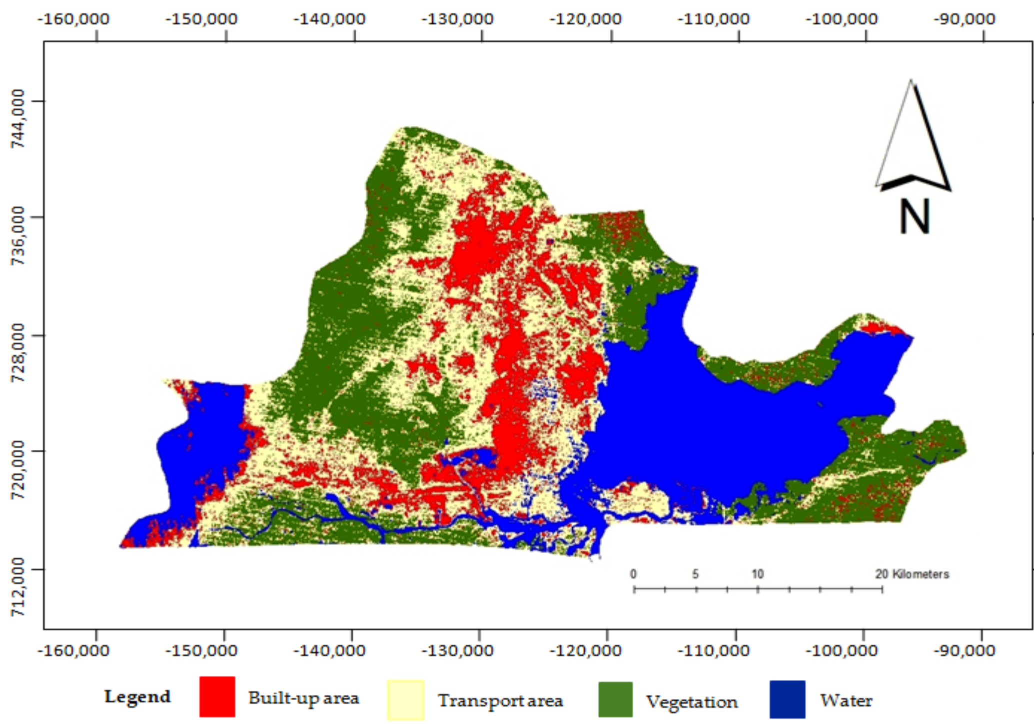

Figure 5: Classified LULC map of Lagos Metropolis in 1984

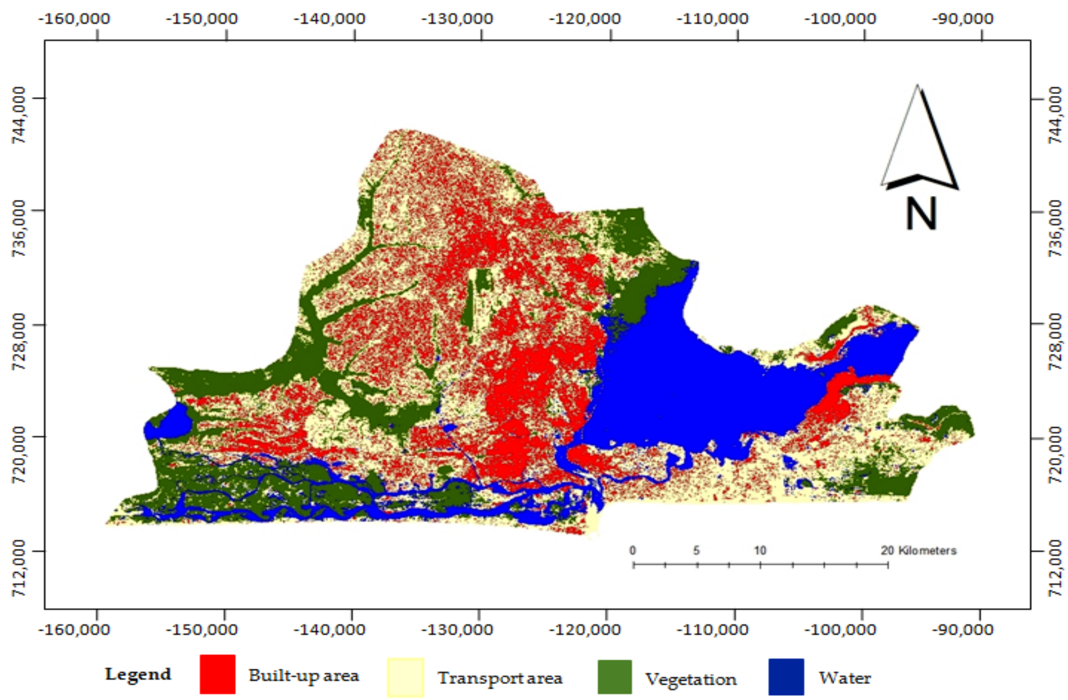

Figure 6: Classified LULC map of Lagos Metropolis in 2013

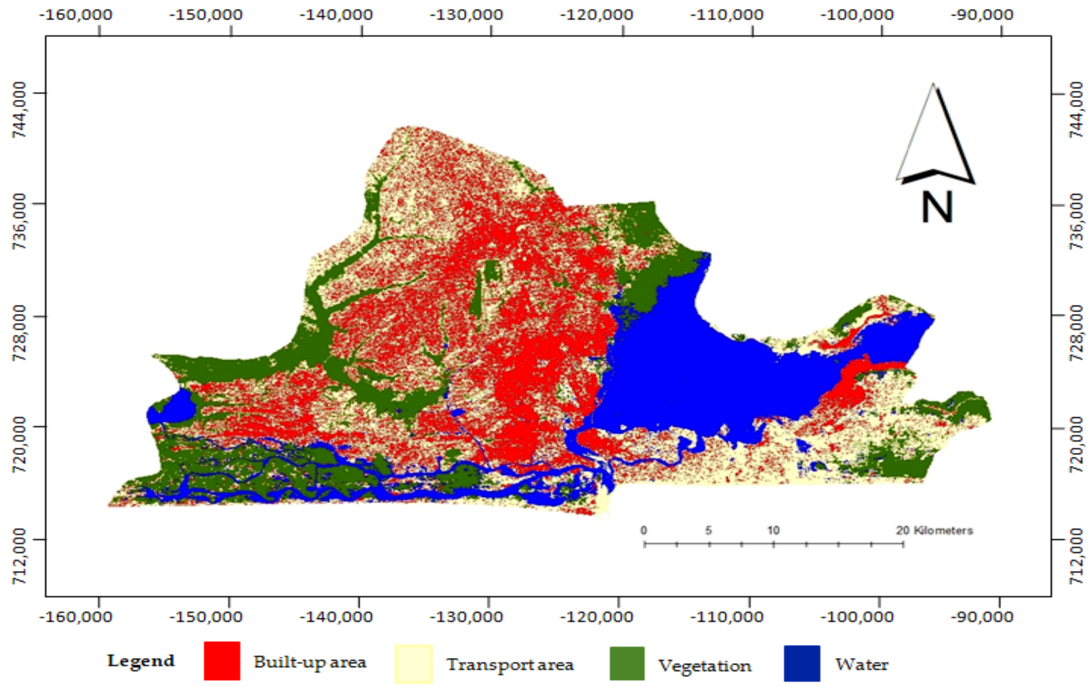

Figure 7: Classified LULC map of Lagos Metropolis in 2019

The spatial-temporal changes in the urban environment are due to higher natural population growth factors (i.e., higher fertility and low mortality rates), migration and the city's regional economic and industrial strategic influences. The magnitude of these individual factors' contributions is debatable; however, among researchers, there is a preponderance of views in favour of natural population as the dominant driver of urban spatial evolution (Bloch et al., 2015; Ojo & Ojewale, 2019). As Nigeria began the early-accelerated phase of urban transition, natural population and urban migration accounting for 48% and 37% respectively, are the major contributors to the evolutionary phase of urban demographic statistics while 15% of rural areas are reclassified into towns and urban centers (Fox et al., 2018).

Nigeria has regional dimensions to its demography and urban process – the conurbations of northern countries show higher fertility rates and lower rural-urban migration propensity, while the southern states exhibit the reverse. Farrell (2018) concluded that urban natural population growth factors represent about 60% of the exponentially rising share of the overall urban agglomeration in the developing countries, whereas rural-urban drift and reclassification represent the remainder.

While favourable natural demographic statistics are the driving force behind urbanization, there is also a strong causal relationship between the recent migration surge and the long-running insurgency war and other security crises. Nigeria is currently beset by instability, including Boko Haram and ISWAP Islamist insurgencies, banditry, and the herders-farmers crisis, all of which have worsened the country's segregated socioeconomic structure, increased poverty and has offset the dynamics of urban migration chains. According to Farrell (2018, p. 288), "increasing insecurity in the northeast due to the emergence of Boko Haram has also been linked to the recent intensification of rural to urban migration". The number of internally displaced people (IDPs) in war-torn Northern Nigeria has risen to 3.3 million (Olanrewaju et al., 2019).

The International Organization for Migration (IOM) documented 1,491,706 internally displaced persons (IDPs) living in critical conditions in displacement camps across the affected state's urban fringes and the remaining swelling urbanization (Itumo and Nwefuru, 2016). Insecurity has hampered rural reclassification which would have stemmed down urbanization migration tides based on equitable share of socioeconomic development and infrastructure allocation. Critical infrastructure and social amenities have been lost to the insurgency and many rural communities within the restive northern regions of Nigeria have been uprooted.

The cities continue to be the facto economy even as the country's indigenous economies are underperforming or rather tanking in some sectors due to low productivity, industrial decline, infrastructure failure, unemployment, inequitable growth and development, and a lack of social inclusion. The economic viability of the city amidst this chaos creates an attraction for urban migration, the annual population rise of Lagos stands at about 5.8% (Aliyu & Amadu, 2017). Over the last few decades, Nigeria's urban population and spatial expansion have steadily increased, while socio-demographic, economic, and security indicators in rural settings have dwindled. A similar correlation between high urbanization rates and economic growth has been identified by researchers to be responsible for gaps in urban planning and basic infrastructures including transport facilities in many Sub-Saharan African cities (Njoh, 2008; Otuoze et al., 2021a). This inequitable development continues to cause a significant threat to the urban dwellers who navigate the daily traffic congestion and crumbling transport infrastructure.

Urban development continues to produce a manifest poor relationship between transport, land use and travel habits that cause mobility and congestion problems within and outside Lagos metropolitan areas. There is a causal connection between unsustainable urban growth and the problem of accessibility in Lagos due to the leading role of the city as national economic and industrial hub. Also, post-colonial Land Use Act (1978) minimized government authority and lent local lease holders, private individuals and informal players unhinged power of influence, the variables that resulted in weak land management, sub-optimal development planning, and mosaics of urban sprawls and slums with persistent mobility issues (Kanyepe et al., 2021; Oluwatayo et al., 2019).

4.2 Land-Use Prediction by Markov chain

The previous Kappa statistics validation enables another soft prediction to classify the grid cell level position and growth of future LULC potential changes further from 2019 to 2030 and 2050 respectively (Figures 8 and 9). After calibration and validation, Markov land-use prediction (MLP) is used to forecast future growth and evolution of land use dynamics. The measures after calibration and validation include the so-called Markov land-use prediction (MLP). The steps include the definition, standardization and aggregation of specified criteria in IDRISI Selva 17.0 decision wizard module map the LULC transition shifts.

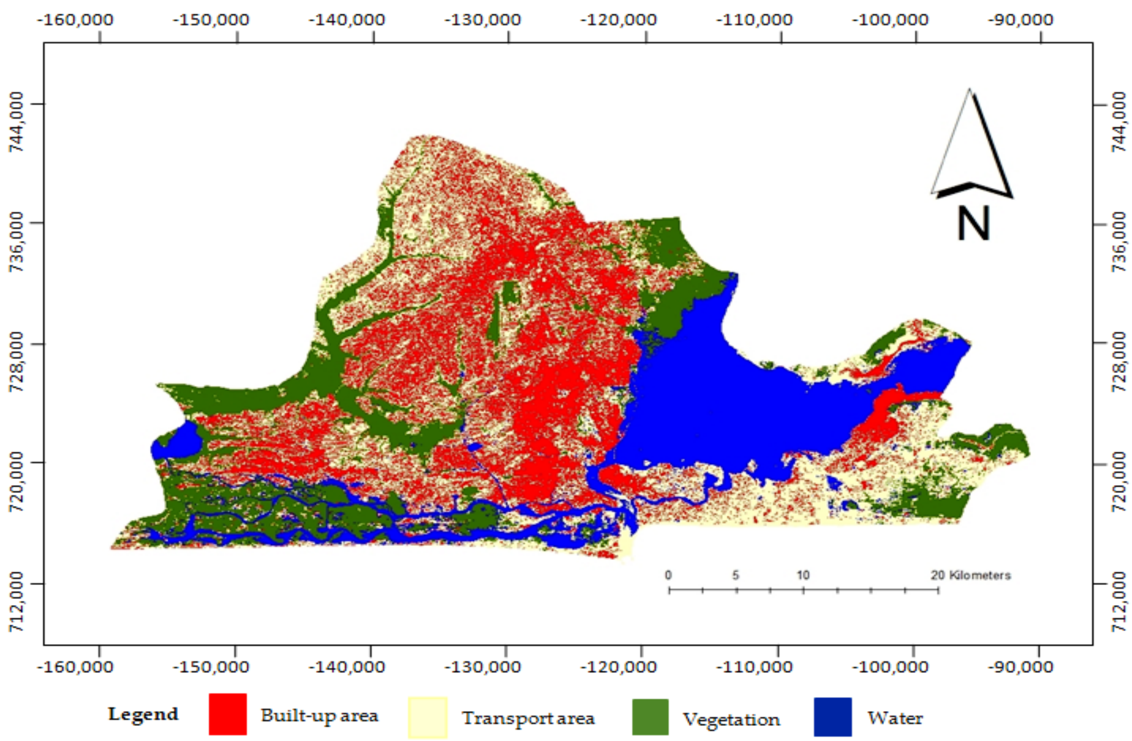

Figure 8: Predicted LULC map in 2030

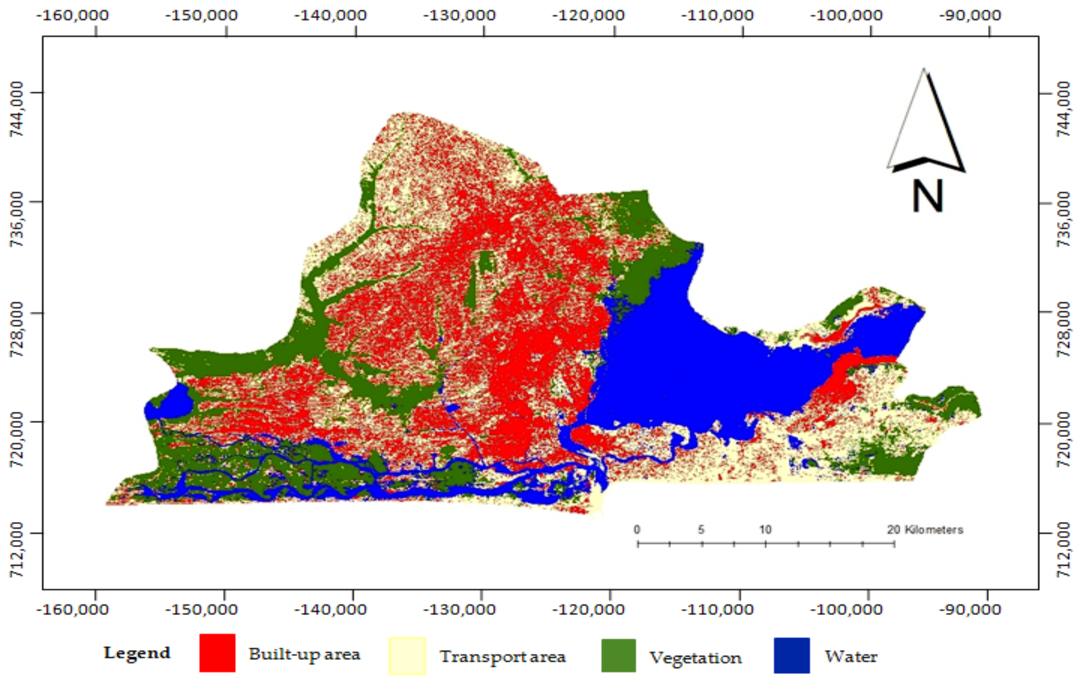

Figure 9: Predicted LULC map in 2050

These increasing trends of urbanization and the transport infrastructure area will exert proportional demand for the transport system, expanding including roads, railways, bridges, jetties, airfields, parking place and other terminal facilities, sustainable travel corridors and recreational parks. The various classes of LULC transition gains and losses encountered by different land use changes were analysed and the gains and losses as well as the net changes are shown in Figure 10. The predict demands in land area for transport will rise from 535km^2 in 2019 to 698km^2 in 2050 while built environment would have from 387km^2in 2019 to 535km^2 in 2050. Land consumption being the main factor of urban growth chains has shown evidence that vegetation and reclamation from lagoons are the main sources of these land conversions. For example, vegetation lands would have been depleted from 147km^2 in 2019 to 15km^2 in 2050.

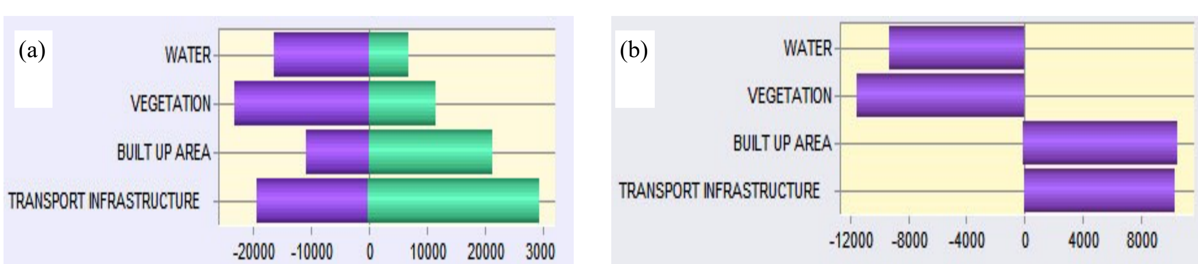

Figure 10: (a) Gain and loss chart (b) net change chart

By the same token, water catchments would have been devolved or reduced from 199km^2 in 2019 to 25km^2 in 2050. The pre-eminence of extreme weather-related events — flooding, hurricane, and inundation on critical infrastructure in coastal cities including Lagos are sad realities of land reclamation. The scale of urban transport resilience and the strength of resistance are constantly shifting in the past decades due to disruptions and must be adequately planned (Douglas et al., 2008). Although, transport infrastructure and built-up areas are the two predicted LULC change modelling winners, while other LULC classes are expected to retreat; the prospect of delivering quality transportation is doubtful as many Nigerian cities have been beset by dilapidated and inadequate infrastructure. A more holistic approach to solving the city's ongoing transportation problems will include a vision for improving both the quality and quantity of transportation infrastructure, efficiency, traffic demand management (TDM) and resilient thinking for future urban challenges.

The future prospect of a possible spatial-temporal growth measure for built-up areas may be more promising than for transport networks, as government, with little to no private involvement, is the sector's key policy maker. In terms of planning, visions, aspirations, priorities, jurisdictions and management techniques, the legally binding roles of various municipal authorities representing different jurisdictional interests- federal, state and local authorities wholly morphed into urban government - have created complex bureaucratic bottlenecks (Atufu & Holt, 2018). Nigeria's poor transport systems —roads, bridges, airports and railway infrastructure continued to decline due to the non-aligning policies of the various levels of government, political whims and multi-level corruption (Ojo et al., 2018).

The traditional infrastructure policy of Nigerian cities hardly differentiated the needs assessments of any infrastructures (transport, communication, water, housing, electricity, health, etc.), leaving gaps in the development of some critical infrastructure. Bureaucratic bottleneck, planning problems and defective spatial analysis have remained part of the investment portfolios and management of the transport sector, which was a unit of the Lagos State Ministry of Works and Housing till 2019 when the section attained a full ministry status. Communities around Lagos and the government are locked in a constant fight for compensation for any damaged assets along the route corridors of new transportation infrastructure projects due to policy misalignment and a lack of genuine spatial evaluation. Lagos' current "aggregate" development policy ignores the long-term consequences of spatial change patterns in land resources, as well as how to accommodate future transportation infrastructure spatial allocation. This research is intended to contribute to the analysis of spatial transformation characteristics and future planning analysis in a developing country urbanism.

A new frontier of knowledge of the urban growth phenomenon involving "disaggregate" spatial transition potential change model has been applied to analyze spatial-temporal demand of transport infrastructure, oppose to the current lump-up "all-in aggregate" model used. Although the research model is spatially explicit for predicting current and future transport and LULC change scenarios, the scope of the study is only limited to the extent of Lagos imagery data and the ground truth references collected for analysis. Due to a lack of data and knowledge, the roles of sprawling communities in the urban, peri-urban, and rural fringes in terms of connectivity, accessibility and mobility, as well as the impacts of other regional states, could not be captured. It is hoped that future research will also highlight the impacts of urban sprawl and regional effects in transport spatial transition study.

4.3 Suitability Quality of Transition Maps

ArcGIS applied to develop LULC classified images took account of the urban peculiarities including important factors and constraints driving the evolution. Further analysis was carried out by importing into IDRISI wherein the CA-Markov chain analysis uses Multi-Criteria Evaluation (MCE) to generate decision rules in the form of suitability maps for determining the feasibility and viability qualities of prediction. MCE provides a predictive decision methodology that incorporates an element of spatial contiguity, transition analysis and distribution in the processing of the Markov chain. It is a multi-criteria evaluation (MCE) and pre-requisite for prediction based on an aggregation of various decision constraints into a single evaluation index (Mishra & Rai, 2016).

The various constraints are criteria which limit LULC appropriate expansion are expressed in Boolean maps where suitable transition areas were set at one (1) while unsuitable areas have their visual indicators set at zero (0). Boolean overlays are used to minimize requirements for logical statements of suitability and combine statements by logical operators, i.e., union (OR) and intersection (AND). Factors (criteria) and trade-offs are integrated into the modules to construct suitability maps and to resolve multi-objective decisions. In order to create a single evaluation index, different factors (rules) and constraints were used (El-Hallaq & Habboub, 2014). The steps involve developing identified criteria, standards and aggregation. And finally, the decision wizard module in IDRISI Selva 17.0 generates the suitability maps. The closer a value is to zero, the less suitable the area and vice-versa (Liping et al., 2018).

The research took cognizance of the range of variables or criteria, including transportation networks, population density, settlement, forest, urbanization, marketplace, economic and business agglomerations, industries and agriculture etc., affecting the LULC transition rule. Construction of infrastructure including transport and buildings and water bodies is set as constraints and the Fuzzy function was applied to evaluate the standard factors at various functions and control levels combined with Weighted Linear Combination (WLC). Factors or parameters are standardized into identical numerical sets by means of weighted mean and are generated from the AHP function in the WLC module. In order to extract a suitability map of land use forms, the MCE module used factors, constraints and weights, while suitability atlas was generated by IDRISI Collection Editor. The suitability maps in Figures 11 and 12 displayed the feasibility of CA-Markov transition prediction. Furthermore, transition potential maps of 2030 and 2050 have transition area indicators visibly far from one (1), which is evident that LULC changes are generally unsuitable and unsustainable.

Whilst it is obvious that Lagos city, like many cities in the developing countries will experience future population and urbanization booms, the imperative of improving transport infrastructure, public transit services and non-motorized commuting could reduce land conversion and rapid LULC change. Urban areas in Lagos, as with many Nigerian cities are constantly dotted with low-quality construction portfolios, deteriorated, and uncompleted transport infrastructure projects due to inadequate funding, corruption, and governmental bureaucratic bottlenecks (Ojo et al., 2018; Olajide et al., 2018). The study finds the imperative of holistic and multi-level sustainable transport policy to reduce transport infrastructure gaps and planning synergy for modal shift and provision of smart and resilient infrastructure to make the city more liveable, accessible, economically viable and to bring the traffic congestion to the barest minimum.

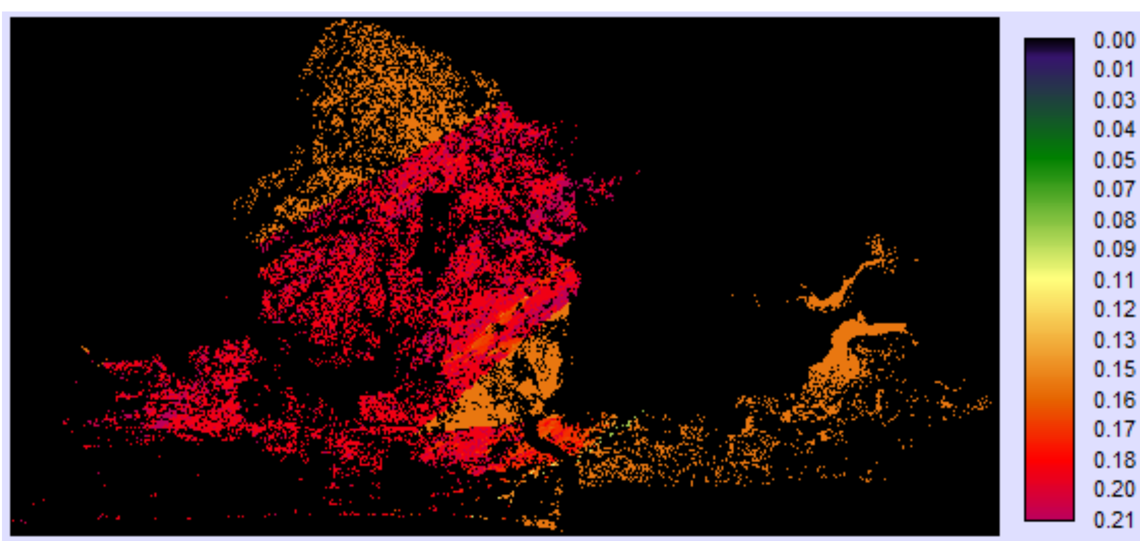

Figure 11: Transition potential suitability map for 2030

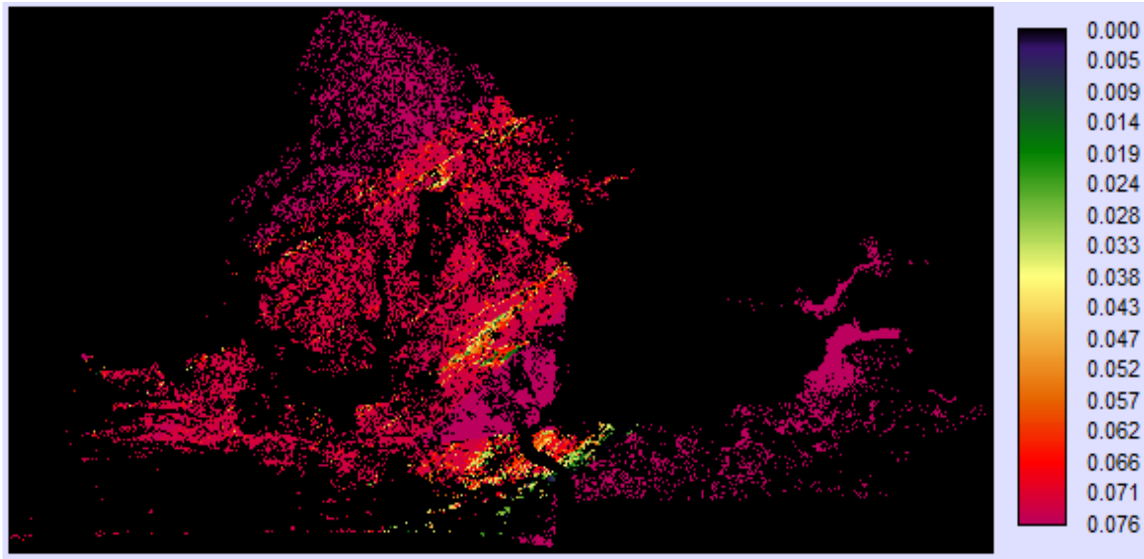

Figure 12: Transition potential suitability map for 2050

5 Conclusion

The following deductions were made from the research:

The study has isolated the transition dynamics of urban transport facility demand from the traditional aggregate urban planning model which slowed the development of many critical infrastructure and established a lack of congruence between urban chain and declining transport systems in Lagos metropolis. First, with combined approaches of remote sensing, GIS and CA-Markov with Landsat TM/ETM+/OLI satellite images, this study recorded growth in transport infrastructure and built-up land use classes while LULC classes for vegetation cover and water receded in 1984—2013—2019 time series. For predicted future LULC changes in the city, repeated trends of increasing gains in land use areas were recorded for both transport and built-up areas while vegetation and water reduced in the order of time steps from 1984—2013—2019.

The results of LULC classification produced Cohen's Kappa agreement statistics ranging from 85% — 89%, which are greater than the minimum of 80% suggested in literature. The analysis shows a clear picture of spatial-temporal growth disparities and unsustainable location and quantitative LULC changes which require policy reorientation and planning to handle urban growth. The study forecasted that transport infrastructure demand and land conversion will increase by 93km^2 (7.3%) in 2030 and 157 km^2 (12.4%) in 2050. Similarly, built-up areas will increase by 144 km^2 (9.0%) and 148 km^2 (11.7%) respectively in the two prediction periods with increasing socio-demographics, urban and peri-urban slums, and frustration.

In the globalized world, the strategic socio-economic offered in terms job opportunities, social amenities and critical infrastructure have increased the attractiveness of cities to all sections of human society. Urbanization imposes anthropogenic chains on the natural world and is arguably the key driver to the transformation of global land use. LULC change shapes the dynamic process that changes natural ecology, climate, and environmental conditions, and is a major challenge to biodiversity, water cycle and 'flora and fauna' of ecological environment. Poverty, lack of infrastructure and economic opportunities and insecurity as a result of the insurgency, banditry and kidnapping in rural Nigeria have increased the scale of urban migration (Abbass, 2012; Bulus et al., 2020).

The nexus of socioeconomic variables, climatic and ecological constraints and security problems in the rural areas have constituted "push-and-pull" factors motivating urban migration. The drifts and sprees of migrants into the main Nigeria urban hubs have not only impacted the economy but have increased security and infrastructure problems. According to the World-Bank (2016, p. 3), "Stagnating agricultural productivity and substantial conflict, particularly in the north, have spurred (urban) migration, not urban jobs or services".

Although, the forecast on increasing transport infrastructure could ameliorate mobility frustration, congestion, and quality of life in the city; a sustained increase in urbanization rate is likely to worsen the problem. Lagos being a low-lying coastal city is facing a pre-eminence of serious anthropogenic and ecological problems including flooding if the current spate of land reclamation continues unabated. The study contributes to the evolutionary dynamics of transport space and offers a means of tracking spatial and temporal dimensions in order to reinforce the relationships between change in land use, smart resilient cities and sustainable delivery of transport services. It is suggested that the future may explore the variables, causes, impacts and contributions made to the evolutionary chains of urban transport space by socio-demographic, economic and environmental factors to achieve the goals of sustainable and accessible Lagos city.

The disaggregate model applied for the analysis of urban transport chain process and the prediction is spatially explicit and reliable for forecasting current and future urban scenarios. However, due to a lack of continuous data on various rural and urban demographics, as well as discrepancies in the history of spatial transformation, the available choice involves an estimation of urban growth indicators using national population and urbanization indices. The urban population estimates in this study's time series (1984, 2013 and 3019) were either back calculated or extrapolated using data for Nigeria's three (3) national census results from 1963, 1991 and 2006 respectively.

Due to chains of estimations and disaggregate into urban growth components, it is difficult to completely vouchsafe the accuracy of the estimates due to uncertainties in urban chain trajectories, human factors and the likelihood of over-estimation or under-estimation of the figures of the predicted time series. The current indicators and projected outcomes point to challenging future realities, the simulated spatial transformation has negative consequences and repercussions for urban environments, demographics, and the vast population of city dwellers. The growth indicators will create pressure in the economy, housing, employment, poverty reduction strives, transport and other infrastructure, land resources, security, crime and violence. It is expected that future study will push the discourse and explore means to further resolve these underlining problems.

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CHAPTER FOUR: NEURAL NETWORK MODELLING OF TRANSPORT SYSTEM RESILIENCE

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CHAPTER FOUR

(Published version of manuscript)

Article

Neural Network Approach to Modelling Transport System Resilience for Major Cities: Case Studies of Lagos and Kano (Nigeria)

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Abstract: Congestion has become part of everyday urban life, and resilience is very crucial to traffic vulnerability and sustainable urban mobility. This research employed a neural network as an adaptive artificially intelligent application to study the complex domains of traffic vulnerability and the resilience of the transport system in Nigerian cities (Kano and Lagos). The input criteria to train and check the models for the neural network are the demographic variables, the geospatial data, traffic parameters, and infrastructure inventories. The training targets were set as congestion elements (traffic volume, saturation degree and congestion indices), which are in line with the relevant design standards obtained from the literature. A multi-layer feed-forward and back-propagation model involving input–output and curve fitting (nftool) in the MATLAB R2019b software wizard was used. Three algorithms—including Levenberg–Marquardt (LM), Bayesian Regularization (BR), and a Scaled Conjugate Gradient (SCG)—were selected for the simulation. LM converged easily with the Mean Squared Error (MSE) (2.675×10^{-3}) and regression coefficient (R) (1.0) for the city of Lagos. Furthermore, the LM algorithm provided a better fit for the model training and for the overall validation of the Kano network analysis with MSE (4.424×10^{-1}) and R (1.0). The model offers a modern method for the simulation of urban traffic and discrete congestion prediction.

Keywords: traffic congestion; critical infrastructure; urbanization; resilience; sustainability transport; modelling; artificial neural network

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1. Introduction

The network of the transport system facilitates people's mobility, enhances their social interaction, and improves their quality of life. Globally, man-made and natural disasters pose increasing vulnerability challenges to transport infrastructure networks in many cities. The capacity of transport networks to recover from challenges and cope with competing users' demands is important. In addition to threat and vulnerability, the resilience concept has an incorporated cost, planning, management and adaptive strategy to cope with pressure and uncertainties [1]. In the early 1970s, ecological research showed that resilience is essential to our lifespan, or else survival, as academics realized the essential nature of their capacity to adapt, to survive, and to evolve in the face of adversity [2]. Due to urban vulnerabilities and the congestion impediment—an increasing concern in the development of transport resilience—various debates and discussions among scholars, analysts, industry, experts and public officials were ignited [3,4].

The world population surpassed the 7.5 billion mark in 2017, with projections to reach its numerical milestone of 9.7 billion in the year 2050 [5]. The rising urban population seriously confounds the ease of mobility of urban dwellers, and more importantly the socioeconomic accomplishment of the city. Congestion has become part of everyday life of the more urban population in cities and towns. The causes, regulations and modulation of road traffic congestion have been analyzed by various models, algorithms, statistical methods and prediction models. The inputs into the congestion forecast models may include the traffic volume, speed, occupancy, quality of infrastructure, and demographic parameters [6,7].

Naturally, every system has its problems, as the notion of perfection—not least in the field of transport planning—is hardly achievable. Like every system, the pressures on critical infrastructure come in the form of turbulence, disruption, or damage, but the overall concept that really defines resilience is the capacity to recover, rebound, or withstand the problem and maintain the functionality without further truncation [8]. Where adversity arises, structures or properties must not be fragile, decimated, or impaired, but should be resilient, tolerable, safe and mitigable, with a capacity to return to normality and functionality [9]. In keeping pace with sustainable culture due to the demand of a growing urban population, migration, security risk, natural occurrences, weather problems and environmental pollution, the resilience concept has been reshaped and adopted into the engineering, technology, planning, design, construction, operation and management of urban infrastructures [10].

In the last decades, urban commuting and freighting has become a serious challenge for infrastructure, in part because of rapid urban growth and socioeconomic developments in many fast-growing cities of both developed and developing countries. These phenomenal growths in the populations of cities have been attributed to population growth, combined with migration or population drift, socioeconomic reasons, and the biased disposition of policies in favour of cities [11]. The spatial–temporal transformations and growth of cities is highly complex, with transport infrastructure at the heart of physical planning and socioeconomic development [12]. Urbanization and population growth are two phenomena that are linked to the emergence of many mega-cities (urban demographics of more than 10 million people), with the deepening complexity of urban interaction, and inadequate transport infrastructure and services leading to a declining transport quality index in the developing countries [13].

With the rising multi-scale challenges to transport infrastructures and mobility in most cities, resilience thinking remains a key underpinning component of the achievement of functional environments that are both fit-for-purpose and fit-for-future. Transport resilience highlights the pathways for cities' survival against growing scenarios of congestion, delays, and socioeconomic losses due to natural and artificially induced challenges (e.g., climate change, environmental pollution, earth tremors, deforestation, erosion, and degradation from mining activities). A number of resilience analytical tools—e.g., artificial intelligence and agent-based modelling techniques, including artificial neural networks (ANN) [14], fuzzy systems (FS) [15], adaptive network-based inference systems (ANFIS) [16] and genetic algorithms [17]—have been deployed for the analysis and prediction of complex system resilience.

Based on the demographic information, inventory of transport infrastructure and mobility data available, resilient models may be fitted with artificial neural networks (ANN) to forecast the resilience of transport services in the Nigerian cities (Kano and Lagos as a case study). Figures 1 and 2 are the digitized maps of the main statistical areas constituting the urban conurbations of Kano and Lagos, respectively.

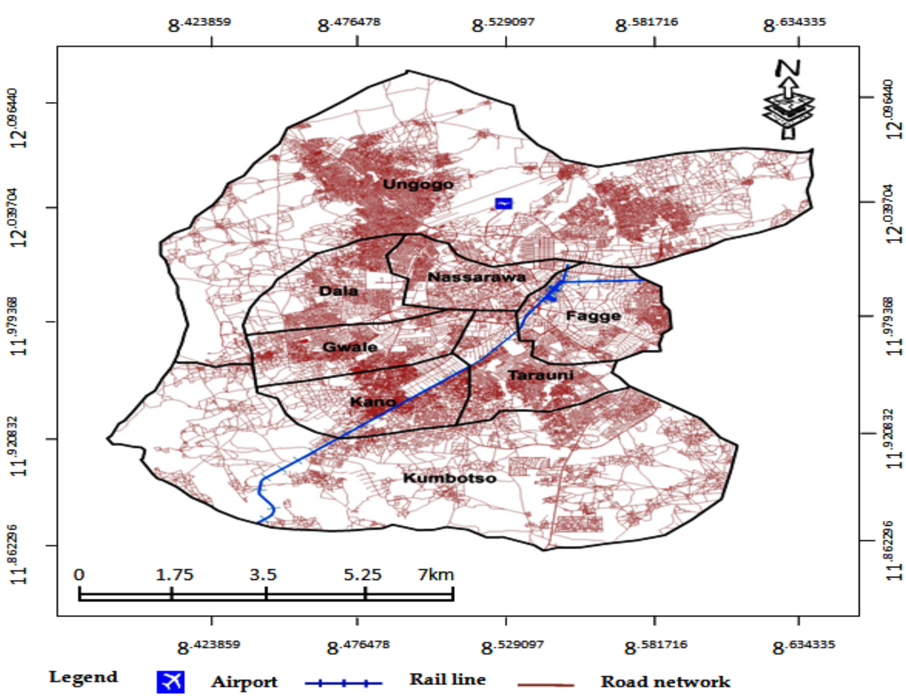


Figure 1. Digitized map of the transport infrastructure of Kano metropolis.

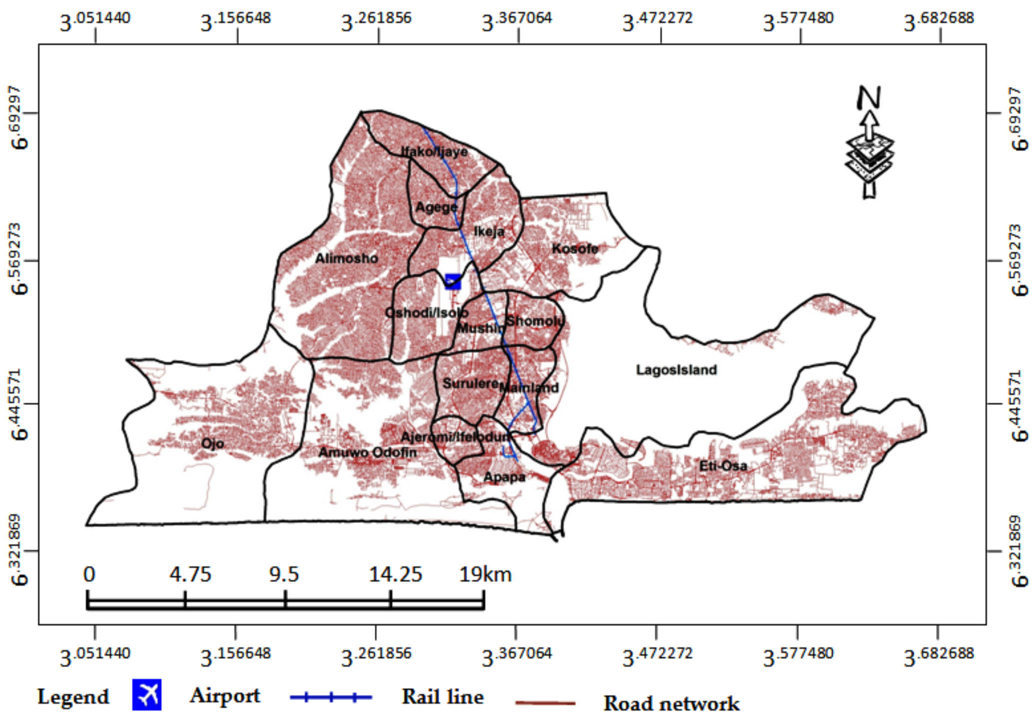


Figure 2. Digitized map of the transport infrastructure of Lagos metropolis.

1.1 Traffic Congestion and Resilience Mapping of Nigerian Cities

The hallmark of sustainable, livable cities lies in the effectiveness, efficiency and resilience of their transport infrastructure and services. Whilst most cities in developed countries are in the terminal phase of urban transition, African and Asian cities will be the culmination of future urban growth potential from 2030 to 2050, when most of the world's leading mega-cities (cities with a population of over 10 million people) will arise. The rapid pace of urban growth in Africa has sprouted several 'accidental' mega-cities, leaving gaps in the development of critical infrastructure. The Nigerian city of Lagos became the 14th largest mega-city in the world, with an urban population of more than 15 million in 2013. Kano Metropolis is the regional commercial capital of Northern Nigeria, and is second to Lagos, with a population of 4 million [12]. The rising trajectories of urbanization/population potentials have compounded the infrastructure problem, with about 67.1% of the predicted 450 million population in 2050 becoming urbanized [18]

According to the World Economic Forum 2016–2017 report, Nigeria's poorly-rated physical infrastructure ranks 132nd amongst a cohort of 138 countries surveyed; this huge deficit accounts for the greatest drag to economic, human and social developments [19]. While the infrastructure deficits have increased congestion, and impeded connectivity and socioeconomic growth, the mobility problem of the two cities has also been exacerbated by heavy motorization and the drag on the development of the railway transport system. Traffic congestion is one of the major stressors of the urban ecological environment, albeit that weather factors, security, and safety have expanded the scale and dimension of what constitutes urban transport resilience. Congestion is defined as a situation in which “the demand exceeds the capacity of the road” [20]. Not only has congestion increased emissions, fuel consumption and travel costs, it also has a direct impact on speed, travel time delays and service quality.

Congestion imposes pressure on and vulnerability of infrastructure due to the asymmetry between the rising demand for services and the infrastructures that are available to cater for commuters’ needs. The nature of the transport system in Nigeria is largely road-biased, assessing its scale, attributes, topology, and resilience a much more complex phenomenon. Lagos and Kano are Northern and Southern Nigeria’s respective regional geopolitical, commercial, and industrial strategic hubs. Urban transport in many developing countries is becoming increasingly complex due to the fewer modal options available for the multitude of rounds of origin and destination trips produced and the volume of traffic involved [21].

Lagos is estimated to generate 7–10 million daily passenger and freight trips, with the share of these road transport modes (private cars, taxis, buses, trucks, motorized and non-motorized bikes) accounting for approximately 95% of all trips [22]. Farah [23] reported the generally poor state of transport infrastructure in Kano metropolis, which was struggling to cope with the exponentially-growing passengers and freight trips brought on by urban agglomeration spikes. Out of more than 7,600,000 vehicles registered in 2008, about 10% were different categories of haulage trucks exerting irrecoverable maximum fatigue damages on the 193,200 km total road length in the country. An average of 5000 daily single trips was recorded in wet tanker trailer haulage services moving petroleum products [24].

The perennial congestion in many port cities has also been linked to the extended dwelling times of ships due to port disruptions, berth scheduling issues, higher numbers of mega ships, and insufficient infrastructure to increase the demand for cargo handling [25,26]. These reasons perhaps explain why road clusters around Apapa, where the Port Authority of Nigeria is located, experience worse traffic congestion than the rest of the development areas in the city of Lagos. In both emerging and industrialized economies, Albayrak et al. [27] describe the closely-related determinants of air traffic volume, i.e., population, proximity to other transport networks, economy, tourism, distance to alternative airports, tourism, leading cities, urbanization, and migration.

A transition to a resilient and sustainable ‘shared mobility’ framework has been proposed by researchers in order to mitigate urban congestion problems [28]. The context of traffic congestion and urban mobility resilience are complex in a sector such as passenger and freight transport, in which significant socioeconomic, environmental, behavioral and technological inputs are considered in a sound predictive methodology. Therefore, the problem is now more related to which primary performance metrics need to be used and how the data can be collected, aggregated, formulated, and analyzed in order to predict vulnerability and extreme congestion scenarios in the emerging developing countries' mega-cities.

Vulnerability is a common feature of poor and inadequate infrastructures, and defective policies in terms of planning, regulation, and management. Vulnerability, according to Knoop et al. [29], is negatively related to resilience, and is defined as the "reduction of system performance as a consequence of dynamic factors, including flow length, free flow and congestion density which pressure the system". Equation (1) shows that transient loss of resilience (TLR) determines the level of vulnerability, and is related to functionality within the system; that is:

$$TRL = \int_{t_0}^{t_1}[100 - Q(t)dt \qquad (1)$$

where $Q(t)$ is the quality of functionality under the pressure time step t_0 to t_1.

The index of resilience in Equation (2) is a normalized metric ranging from 0 and 1, and is determined from the recovery curve of functionality [30].

$$R = \frac{\int_{t_0}^{t_h} Q(t)dt}{t_h - t_0} \qquad (2)$$

According to Aftabuzzaman [31], it is possible to relate resilience to the congestion index of a travel corridor or an area based on the assessment criteria of speed, flow, and other related data. The assessment metric of the congestion threshold and index development are related to population, travel infrastructure, traffic, and motorization indices. The scope of resilience is currently not domiciled in the traditional field of ecology, but rather has spurned burgeoning research interests in engineering and technological innovation, environmental studies, economic solutions, business, and institutional cooperation. The definition of vulnerability in the transport system may be related to reduced accessibility and connectivity, likely due to natural causes and the exogenous impacts of human activities that are harmful to the urban environment [30].

In this context, a resilient evaluation is an integrated way of evaluating the causal effects of various factors and occurrences affecting functionality and the transport system's spatial diversities. The measure(s) of resilience in a system are numerous, but the three overarching concepts enumerated by Holling [32] include vulnerability, resource available, and the degree of internal controllability, in addition to interdependency (i.e., between the various components of the transport system). Travel time is a very significant factor affecting commuters' choice of travel, which could be used as an appropriate indicator of a transport system's reliability and quality.

The relevant aspects that impact transport resilience are: the network capacity [3]; economy, pricing and financing [33]; and logistics and freight [34]. Due to the widening scale and necessity of system survival, transport resilience research has also been extended to transport communication and information [35], community resilience [36], transport demand management [37], and natural disasters and exogenous impacts [38]. The problem of the undifferentiated lumping of critical infrastructure development in Nigeria has perhaps created many gaps in terms of the quantity and quality of infrastructure allocation to the transport sector and remains the biggest challenge to the ease of mobility and interaction in many cities. This study provides a framework for the assessment of the transport resilience of the two major cities through indices of congestion and accessibility, and the critical position of physical transport infrastructure stock, using an Artificial Neural Network (ANN).

2. Materials and Methods

In order to alleviate complex infrastructure problems, innovative solutions are required to address the range of challenges. This requires a global approach using implicit surrogate estimators of resilience models and repeated evaluations over time. ANN can be applied for prediction even where the detailed characteristics of the system are not available. It is a machine learning algorithm that is capable of solving complex problems using random function approximation combined with the application of nonlinear statistical models that display the input–outputs of complex relationships in order to develop a model solution [39]. By means of model calibration, validation, and forecasting, ANN may learn from example data set(s) and provide answers to many problems, including machine translation, pattern recognition, fault detection, prediction, and decision processes (Silva et al., 2017). Structurally, ANN models consist of three components: inputs, hidden layer(s), and outputs (Figure 3). The input layers are the information receiver of the example data set. The numerical computation and pattern recognition are carried out by the hidden layer(s), and the output layers display the results.

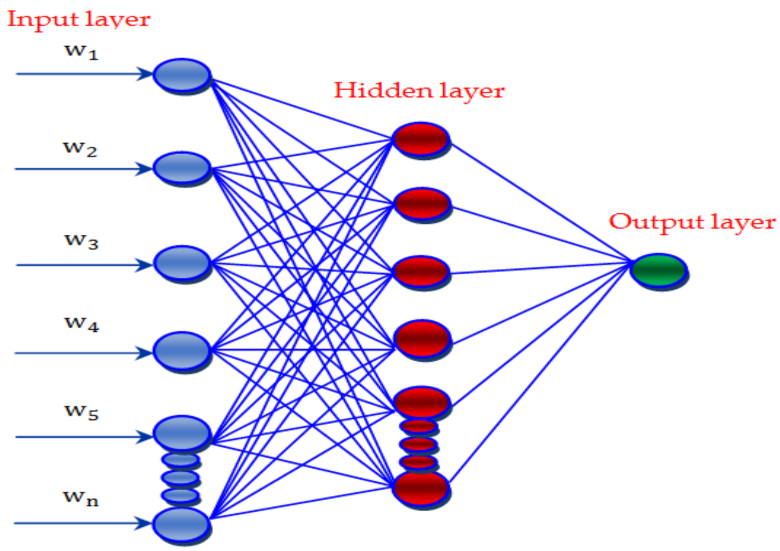


Figure 3. Structure of the ANN model.

The parameters that affect the output are the learning rate, batch size, weights, biases, optimizer, epoch, width, and depth. Every node within the network allocates some weights, and the weighted sum of the inputs and the bias is determined using a transfer function. Then, the activation function which obtains the output result releases the most acceptable result from the node based on the received data [40]. Some of the commonly used activation functions in ANN include Sigmoid, RELU, Softmax, and Tanh, etc. Figure 4 shows the architecture that accompanies the typical ANN model previously shown in Figure 3.

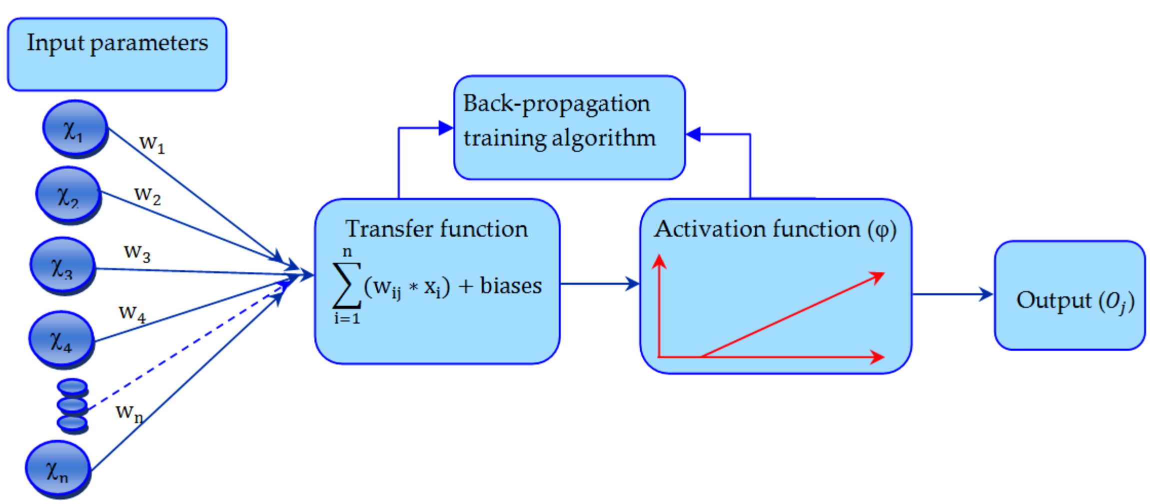


Figure 4. Typical architecture of the ANN model.

Feed-forward and feed-backward loops can be adopted by ANNs. Feed-forward typically uses a unidirectional loop for supervised learning, in which data, such as facial recognition, are sequential. Feed-backward, or back-propagation, has a feedback loop suited for memory retention in sequential or time-dependent data sets [41]. Depending on the network type, it is possible to measure the differences between the expected output and the resulting output with error functions, and then to modify the weights of the NN through the back-propagation process.

Unfortunately, benchmarked cases of transport resilience for the management of the complex systems are not available in many developing countries. As such, this research aims to assess the efficacy of an Artificial Neural Network (ANN) surrogate model to determine the resilience of transport system networks in the cities of Nigeria. Based on literature knowledge, the preliminary testing was undertaken with some arbitrarily-defined network architecture with a 'trial and error' approach in order to select the optimal parameters for the most reliable predictions (see, for example Abduljabbar et al. [42]; Mattsson and Jenelius [43]). Tables 1 and 2 were extracted for further study from the traffic and demographic data and the inventories of transport infrastructure.

Table 1. Demography, traffic parameters and transport infrastructure inventory of Kano city.

Cluster Identity	MSA Council Area	${}^{1}\mathrm{N}_{\mathrm{npc,2006}}$	${}^{2}\mathrm{N}_{\mathrm{est,2018}}$	${}^{3}\mathrm{Z}_{\mathrm{area}}$ (km^2)	${}^{4}\mathrm{N}_{\mathrm{road}}$	${}^{5}\mathrm{L}_{\mathrm{road\ est.}}$ (km)	${}^{6}\mathrm{L}_{\mathrm{rail\ est}}$ (km)	[7]Typical Route Traffic Vol. (Veh/hr)
KN1	Dala	418,777	613,346	19	296	221.42	0.00	3505
KN2	Fagge	198,828	293,037	21	209	218.80	21.35	4937
KN3	Gwale	362,059	524,055	18	353	252.62	0.00	2931
KN4	Kano municipal	365,525	543,746	17	461	284.22	6.59	3820
KN5	Kumbotso	295,979	431,185	158	541	594.61	7.19	3563
KN6	Nasarawa	596,669	873,531	34	223	188.82	0.30	3355
KN7	Tarauni	221,367	324,942	28	399	249.86	2.88	4535
KN8	Ungogo	369,657	535,638	204	1213	1052.79	0.00	2751
	Total	2,828,861	4,139,480	499	3695	3063	38	—

*Metropolitan Statistical Area (MSA) constituting Kano city = 8 LGA's; ${}^{1}\mathrm{N}_{\mathrm{npc2006}}$: cluster population demography of Kano metropolitan city based on the National Population Census (NPC [44]); ${}^{2}\mathrm{N}_{\mathrm{est.2018}}$.: cluster population, 2018, estimate of Kano metropolitan city based on NPC, 2006 (Author, 2018); ${}^{3}\mathrm{Z}_{\mathrm{area}}$: land area courtesy of Kano State Ministry of Land and Physical Planning (KNSMLPP [45]); ${}^{4}\mathrm{N}_{\mathrm{road}}$: cluster total number of roads (KNSMLPP [45]); ${}^{5}\mathrm{L}_{\mathrm{road\ est.}}$: estimated total length of all roads within the cluster (KNSMLPP [45]); ${}^{6}\mathrm{L}_{\mathrm{rail\ est.}}$: estimated total length of all rail within the cluster (KNSMLPP [45]);[7] traffic volume (KNSMLPP [45]).

Table 2. Demography, traffic parameters, & transport infrastructure inventory of Kano city.

Cluster Identity	* MSA Council Area	$^1N_{npc,2006}$	$^2N_{est,2018}$	$^3Z_{area}$ (km^2)	$^4N_{road}$	$^5L_{road\ est.}$ (km)	$^6L_{rail\ est}$ (km)	[7]Typical Route Traffic vol. (Veh/hr)
LA1	Agege	459,939	669,574	17.0	1096	310.35	2.51	4604
LA2	Ajeromi-Ifelodun	684,105	996,621	13.9	471	161.19	0.00	3388
L A3	Alimosho	1,277,714	1,913,429	137.8	893	523.80	0.00	3952
LA 4	Amuwo-Odofin	318,166	476,988	179.1	120	302.87	0.00	3518
LA 5	Apapa	217,362	323,362	38.5	202	129.81	0.00	4495
LA 6	Eti-osa	287,785	411,495	299.1	291	187.51	0.00	2685
LA 7	Ifako-Ijaye	427,878	620,190	43.0	133	148.12	6.73	3929
LA 8	Ikeja	313,196	460,562	49.92	430	316.46	0.00	4513
LA 9	Kosofe	665,393	990,093	84.4	188	210.41	1.04	3953
LA10	Lagos Island	209,437	308,410	9.3	311	208.35	0.86	3170
LA11	Lagos Mainland	317,720	473,724	19.2	324	207.59	10.91	4255
LA12	Mushin	633,009	916,176	14.1	938	351.60	3.89	3174
LA13	Ojo	598,071	883,324	182.0	242	383.58	0.00	4115
LA14	Oshodi-Isolo	621,509	912,174	42.0	1056	362.33	1.65	3496
LA15	Shomolu	402,673	585,232	14.6	1077	386.26	0.84	3820
LA16	Surulere	503,975	729,171	27.1	507	199.84	5.16	5275
	Total	9,013,534	11,670,525	1171.02	8279	4390.07	33.59	—

* Metropolitan Statistical Area (MSA) constituting Lagos city = 16 LGA's; $^1N_{npc.2006}$: cluster population demography of Lagos metropolitan city based on the National Population Census (NPC [44]); $^2N_{est.2018}$: cluster population, 2018, estimate of Lagos metropolitan city based on NPC, 2006 (Author, 2018); $^3Z_{area}$: land area courtesy of Lagos State Ministry of Transport (LASMT [46]); $^4N_{road}$: cluster total number of roads (LASMT [46]); $^5L_{road\ est.}$: estimated total length of all roads within the cluster (LASMT [46]); $^6L_{road\ est.}$: estimated total length of all roads within the cluster (LASMT [46]); [7] traffic volume (LASMT [46]).

The methodological scheme for the ANN model prediction is shown in Figure 5. Importantly, the optimization of the performance of neural networks requires the exploration of many variants of the traditional back-propagation training algorithm on the basis of some heuristic and numerical optimization methods. The algorithms for multi-layer feedback propagation with input and curve fitting ("nftool"), are defined as follows:

(a) Levenberg–Marquardt (LM) algorithm (trainlm): this is the speediest training algorithm for a moderately-sized network; when the training set is large, it has memory reduction function to use.
(b) Bayesian regularization (BR) algorithm (trainbr): this is a mathematical method which transforms a nonlinear regression in the manner of a peak regression into a 'well-posed' statistical problem.

(c) Scaled conjugate gradient (SCG) algorithm (trainscg): this is the only algorithm with a conjugate gradient that needs no line search, which is excellent for general-purpose algorithm training.

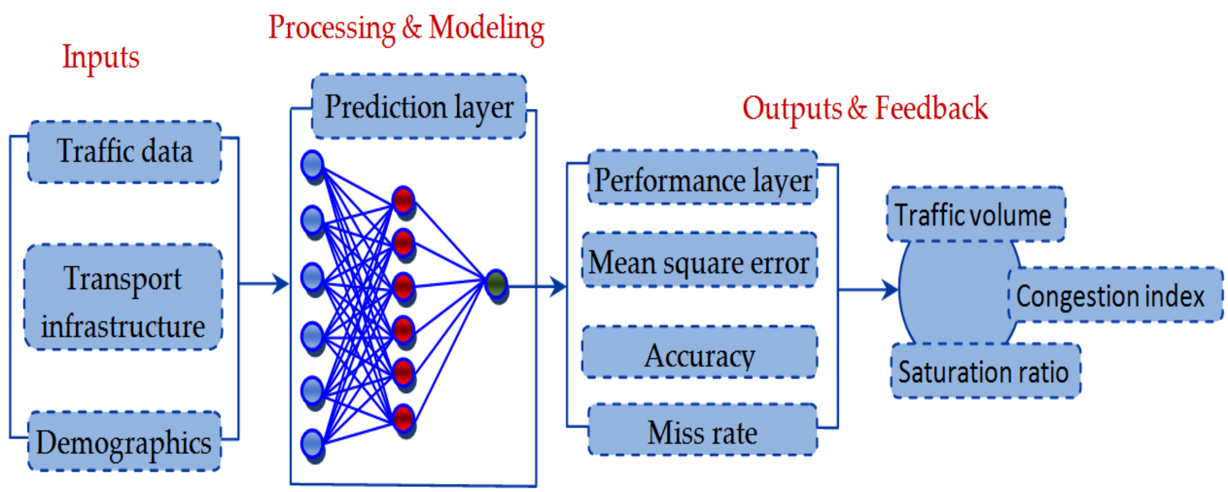


Figure 5. Methodological scheme of traffic and congestion prediction.

In order to determine the vehicular traffic spatial variance and congestion pattern, representative development area congestion level measurements using the traffic saturation degree on some selected main road corridors could be deployed in order to measure congestion patterns in Kano and Lagos. Based on the evaluation, the average degree of saturation and level of service of urban roads can be obtained. The saturation degree compares the actual field traffic volume in a particular period to the designed traffic capacity in a typically designed roadway.

For a two- or three-lane highway in Nigeria, a standardized capacity volume of 2000 cars per hour, a typical-design hourly factor of 10%, and a directional split factor of 60% are recommended by the Highway Capacity Manual (HCM [47]), and are usually adopted for design purposes. Based on the respective acceptable traffic parameters—an urban speed limit of 40 km per hour and a minimum speed of 10 km per hour—typically used for Nigerian road design ([48]), the value of the congestion index measurement (x) on a scale ranging from 2 to 10 could be estimated using Equation (3) (as proposed by Wang et al.) [49].

$$C_{index} = \begin{cases} \frac{x}{0.4} * 2;\ x \le 0.4 \\ \left\{\left(\frac{x-0.4}{0.2}\right) * 2\right\} + 2;\ 0.4 \le x \le 0.6 \\ \left\{\left(\frac{x-0.6}{0.15}\right) * 2\right\} + 4;\ 0.6 \le x \le 0.75 \\ \left\{\left(\frac{x-0.75}{0.15}\right) * 2\right\} + 6;\ 0.75 \le x \le 0.9 \\ \left\{\left(\frac{x-0.9}{0.2}\right) * 2\right\} + 8;\ 0.9 \le x \le 1.0 \\ 10;\ x > 1.0 \end{cases} \quad (3)$$

3. Results

3.1. Congestion Pattern

Lagos and Kano have 16 and 8 development area councils, respectively, representing the number of MSA clusters of the two cities. Equation (3) was applied to each cluster in order to provide some scalar representations for congestion rating with the traffic volume and the degree of traffic saturation. Tables 3 and 4 contain the relevant prediction input data, including the transport infrastructure, demographics, and traffic congestion indices. The results of the congestion indices for Lagos and Kano cities, using Equation (3) (Wang et al. [49]) showed that the two cities currently face extreme traffic regimes. This is, perhaps, due to the combined factors of mono-modal transport development tilted in favor of the road mode, the poor quality of the transport infrastructure, and disjointed transport policies.

Table 3. Input and target data for the neural network analysis based on the traffic characteristics of Kano city.

Cluster No	x_1	x_2	x_3	x_4	x_5	x_6	$x = x_7$	$(C_{index}) = x_8$	Congestion Level Based on [49]
KN1	613,346	221.42	32,281	0.3610	296	2103	1.05	10	Extreme
KN2	293,037	218.80	13,954	0.7467	209	2962	1.48	10	Extreme
KN3	524,055	252.62	29,114	0.4820	353	1759	0.88	7.7	Moderate
KN4	543,746	284.22	31,985	0.5227	461	2292	1.15	10	Extreme
KN5	431,185	594.61	2729	1.3790	541	2138	1.07	10	Extreme
KN6	873,531	188.82	25,692	0.2162	223	2013	1.01	10	Extreme
KN7	324,942	249.86	11,605	0.7689	399	2721	1.36	10	Extreme
KN8	535,638	1052.79	2626	1.9655	1213	1651	0.83	7.1	Moderate

x_1 = population estimate for 2018; x_2 = total road length (km.); x_3 = population density (persons/sq.km.); x_4 = road per population (km./1000persons); x_5 = number of roads; x_6 = traffic volume (veh./hr.); x_7 = saturation degree x (ratio); x_8 = congestion index (C_{index}).

Table 4. Input and target data for the neural network analysis based on the traffic characteristics of Lagos-city.

Cluster No	x_1	x_2	x_3	x_4	x_5	x_6	$x = x_7$	$(C_{index}) = x_8$	Congestion Level Based on [49]
LA1	669,574	310.35	39,387	0.4635	1096	4604	2.30	10	Extreme
LA2	996,621	161.19	71,700	0.1617	471	3388	1.69	10	Extreme
L A3	1,913,429	523.80	13,886	0.2737	893	3952	1.98	10	Extreme
LA 4	476,988	302.87	2664	0.635	120	3518	1.76	10	Extreme
LA 5	323,362	129.81	8400	0.4014	202	4495	2.25	10	Extreme
LA 6	411,495	187.51	1376	0.4557	291	2685	1.34	10	Extreme
LA 7	620,190	148.12	14,424	0.2388	133	3929	1.96	10	Extreme
LA 8	460,562	316.46	9227	0.6871	430	4513	2.26	10	Extreme
LA 9	990,093	210.41	11,731	0.2125	188	3953	1.98	10	Extreme
LA10	308,410	208.35	33,163	0.6756	311	3170	1.58	10	Extreme
LA11	473,724	207.59	24,674	0.4382	324	4255	2.13	10	Extreme
LA12	916,176	351.60	64,978	0.3838	938	3174	1.59	10	Extreme
LA13	883,324	383.58	4854	0.4342	242	4115	2.06	10	Extreme
LA14	912,174	362.33	21,719	0.3972	1056	3496	1.75	10	Extreme
LA15	585,232	386.26	40,085	0.66	1077	4604	1.91	10	Extreme
LA16	729,171	199.84	26,907	0.2741	507	3388	2.64	10	Extreme

$\boldsymbol{x_1}$ = population estimate for 2018; $\boldsymbol{x_2}$ = total road length (km.); $\boldsymbol{x_3}$ = population density (persons/sq.km.); $\boldsymbol{x_4}$ = road per population (km./1000persons); $\boldsymbol{x_5}$ = number of roads; $\boldsymbol{x_6}$ = traffic volume (veh./hr.); $\boldsymbol{x_7}$ = saturation degree x (ratio); $\boldsymbol{x_8}$ = congestion index ($\boldsymbol{C_{index}}$).

According to the congestion index (C_{index}), most Lagos road networks are experiencing traffic bottlenecks, which is otherwise called a 'jam' situation. The same dire situation is endured in all but two local development areas in Kano, which includes chronic traffic dilemmas and accessibility disruptions across the city. Currently, the reprehensible traffic congestion situations in Lagos and Kano have cascaded beyond the maximum design thresholds. The results of the traffic and congestion indices for Kano and Lagos exceeded the 2000 vehicles per hour adopted for the design capacity [47], and the values for tolerable or 'moderate' congestion profiles ($C_{index} = 6 - 9$) recommended by Wang et al. [49]. The most common 'extreme' congestion situations ($C_{index} = 10$) in the Metropolitan Statistical Areas (MSA) have over-stretched supporting infrastructures and are constant sources of mobility dilemmas across the cities.

3.2. Modeling Traffic Resilience Using a Neural Network

In this study, the MATLAB R2019b software wizard was adopted in order to integrate the training model—a multi-layer feed-forward back-propagation involving an input–output and curve fitting (nftool). The model fitting tool is a versatile mapping facility applied between the numeric input and target data sets for the assessment of the compatibility of a prediction in which Nonlinear Autoregressive Network with Exogenous Input Neural Network (NARX-NN) inputs are not available [50]. Unfortunately, the authorities of the two cities have not been keeping adequate track of the temporal and spatial data of the elements contributing to the perennial traffic congestion problems in the two cities. In the current analysis, NARX-NN could not be considered as predictor of the dynamic or recurrent time series because of the dearth of the input time-step traffic data pool for the predictive modeling. NARX is a recurrent neural network (RNN) model analysis tool for the prediction and forecasting of chaotic time series dynamic systems [51].

The $nftool$ model proposed could provide a real-time input–output network quality scenario analysis that is useful for congestion management, vehicle scheduling, and routing systems. By developing scripts and using a graphical user interface on a case-by-case basis, and by providing training to solve problems of approximation, a quality predictor can be created for spatial and temporal predictions of problems of urban environments [52,53]. As the model is populated with more data, future research may incorporate the model (multi-layer feed-forward back-propagation) into a genetic algorithm or other optimization algorithms in order to better improve the transport service and prediction qualities.

In the MATLAB R2019b platform, the most suitable algorithms were used to train the best possible solutions within the ANN's $nntool$ or $nnstart$ command window, and to further predict outcomes. In order to create the *nftool* fitting model, three algorithms (i.e., Levenberg-Marquardt (LM), Bayesian Regularization (BR) and Scaled Conjugate Gradient (SCG)) were trained to compare the best network outputs. Based on the results, the algorithm that produced the best output metrics was selected. Within this process, it was necessary to look for the algorithm which minimized the mean-standard-error (MSE) and maximized regression (R) between the network outputs and the target in order to enhance the generalization of the chosen network topology [54]. The input data ($x_1\ to\ x_8$) in Tables 3 and 4 define the traffic characteristics which impact on the congestion indices of the cluster population of the metropolitan areas in the two cities. Table 5 is the network training target characteristics data ($t_1, t_2\ \&\ t_3$), i.e., arrays of random numbers generated from the recommended standards. Table 5 shows an example of the random numbers used as the target training for the traffic saturation degree generated by the command prompt in the MATLAB command window. The results (Tables 6 and 7) are shown and discussed in detail in Section 3.3.

Table 5. Target data to train the desired network output (Kano and Lagos).

Training Targets	Range of Values
Moderate congestion profile (C_{index}) (Wang et al. [49])	t_1: $6.0 \leq C_{index} \leq 10.0$)
Moderate saturation index (x) (Wang et al. [49]):	t_2: ($0.75 \leq x \leq 1.0$)
Moderated traffic volume (v) (Highway Capacity Manual [47])	t_3): ($1200 \leq v \leq 2000\ veh/hr$)
Example of random number generator command prompt for Lagos traffic	
Saturation degree (x); ($n = \text{Number of MSA} = 16\ (Lagos)\ \&\ 8\ (Kano\ )$	
>> $xmin = 0.75$	
>> $xmax = 1.00$	
>> $n = 16$	
>> $x = xmin + rand(1, n) * (xmax - xmin)$	

Table 6. Performance evaluation of the NN Resilience model for Kano.

Algorithm	MSE	R	Forecasting Equation
Levenberg-Marquardt (LM)	4.424×10^{-1}	1.000	$Ouput = 1.0 * Target + 0.47$
Bayesian Regularization (BR)	8.253×10^{-1}	0.932	$Ouput = 0.99 * Target + 0.02$
Scaled Conjugate Gradient (SCG)	5.337×10^{-1}	0.928	$Ouput = 1.1 * Target - 0.35$

Table 7. Performance evaluation of the NN Resilience model for Lagos.

Algorithm	MSE	R	Forecasting Equation
Levenberg-Marquardt (LM)	2.675×10^{-3}	1.000	$Ouput = 1.0 * Target + 0.022$
Bayesian Regularization (BR)	6.473×10^{-3}	0.9312	$Ouput = 0.98 * Target + 0.078$
Scaled Conjugate Gradient (SCG)	4.582×10^{-3}	0.9085	$Ouput = 0.99 * Target + 0.027$

3.3. Model Simulation and Validation

The proposed model testing and simulation requires correlation and the use of the mean squared error (MSE), representing the error calculated from the network output and the targets for the assessment of the performance function of the network. The MSE is the performance function that measures the accuracy of the model's prediction error, and it can control the extent of the correlation between the real and the forecast values, which is otherwise known as the Pearson Correlation Coefficient. In order to mitigate model over-fitting, a widely-used approach during the training of models of NN was adopted, in which the data are randomly split into three phases: training, validation and testing [55]. As such, the data were randomly divided into 70%, 15%, and 15% sets for the training, testing and validation, respectively, with a maximum of 1000 epochs. Figure 6 shows a custom view of the *nftool* fitting model adopted. Tables 7 and 8 are the *MSE, R* and forecasting equations for the various algorithms used for the prediction. Figures 6 and 7 show the accuracy of the regression plots for the Levenberg–Marquardt (LM) model, which fits better than other the algorithms, i.e., Bayesian Regularization (BR) and the Scaled Conjugate Gradient (SCG).

Table 8. NN summary of the measured targets and the predicted output (Kano city).

Cluster Number	Traffic Volume			Traffic Saturation Degree			Congestion Index		
	Target (Veh/hr)	Output (Veh/hr)	Error (%)	Target	Output	Error (%)	Target	Output	Error (%)
1	1243.4	1313.2	5.32	0.8668	0.7997	−8.39	6.7104	6.7303	0.30
2	1341.7	1960.5	31.56	0.9120	0.9320	2.15	7.5944	8.3271	8.80
3	1730.2	1786.4	3.15	0.7563	0.7821	3.30	6.5357	6.4308	−1.63
4	1464.7	1430.9	−2.36	0.9606	0.8361	−14.89	6.1236	6.8253	10.28
5	1918.8	1917.8	−0.05	0.8898	0.8551	−4.06	9.7566	8.6291	−13.07
6	1294.5	1330.2	2.68	0.9635	0.7874	−22.36	7.2052	6.4732	−11.31
7	1990.7	1982.9	−0.39	0.8370	0.9179	8.81	7.1821	7.5128	4.40
8	1632.0	1632.8	0.05	0.8615	0.7568	−13.83	7.3317	6.5056	−12.70

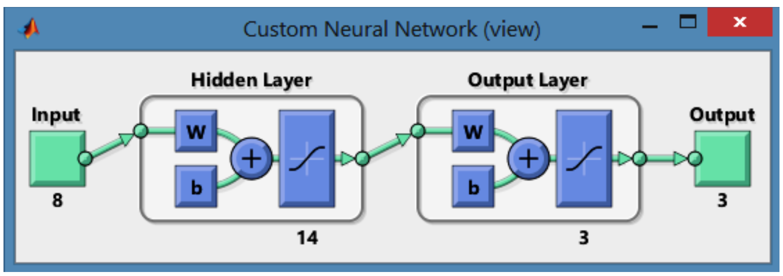
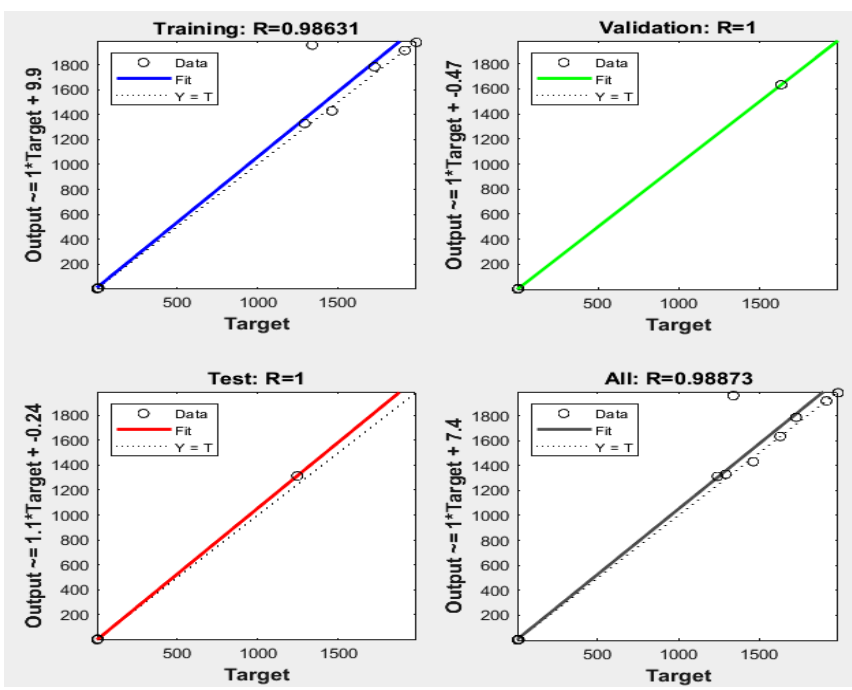
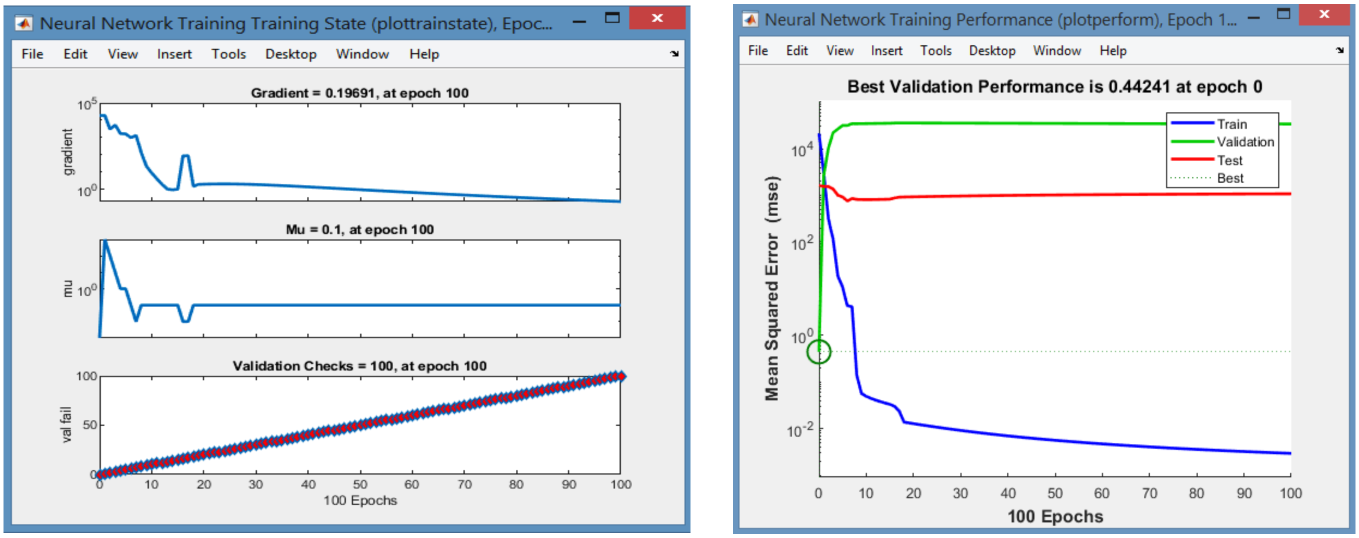


Figure 6. Custom view of the *nftool* fitting model.



(a) Regression analysis.



(b) Network training state

(c) MSE for performance accuracy

Figure 7. NN parameters for the LM algorithm for the Kano network.

4. Discussion

The relationship between one or more predictor (input) variables and a response (output) variable is compared by regression models. The most widely-used evaluation metrics for this comparison are Pearson's correlation coefficient and the mean squared error (MSE) [56]. The simulated output points of the experiment may or may not likely match the real ones due to the confounding random and calculation errors or selection biases. The MSE quantifies the square error equivalent to the prediction sums of the variances and square biases existing between the observed experimental data and the ground truth, as shown in Equation (4):

$$\mathrm{MSE} = \frac{1}{n}\sum_{f=1}^{n}\left(\hat{\theta}(f) - \theta(f)\right)^2 = \sigma_{\hat{\theta}}^2 - \mathrm{E}\left(\left[\hat{\theta} - \theta\right]\right)^2 = (\mathrm{RMSE})^2 \qquad (4)$$

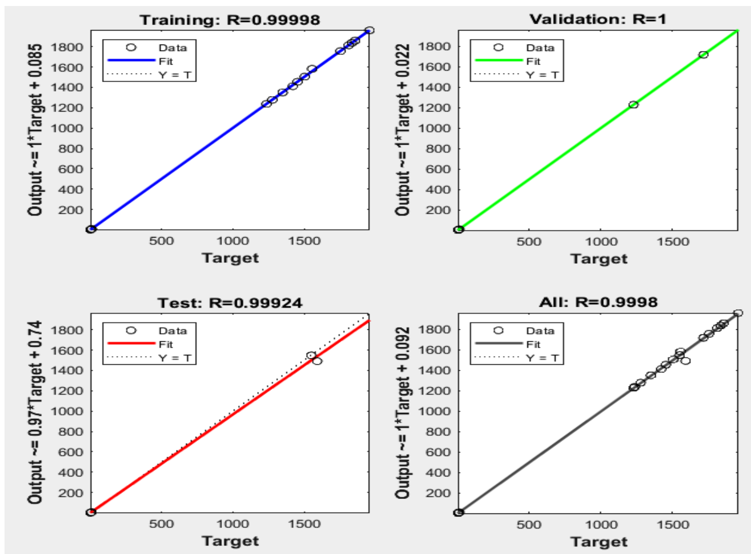
where $\hat{\theta}$ symbolizes the experimental prediction data, θ is the reference ground truth, RMSE is the acronym for root mean squared error, and *E* is the operator of the expected value.

The statistical reliability is determined by Pearson's correlation coefficient (COR or R), which compensates for the agreement between the ground truth and the prediction defined in Equation (5). The correlation coefficient measures how well a model correlates by minimizing the error between the experimental observation and model's predicted data; the value ranges between 0 (no goodness of fit) and 1 (perfect agreement) [57].

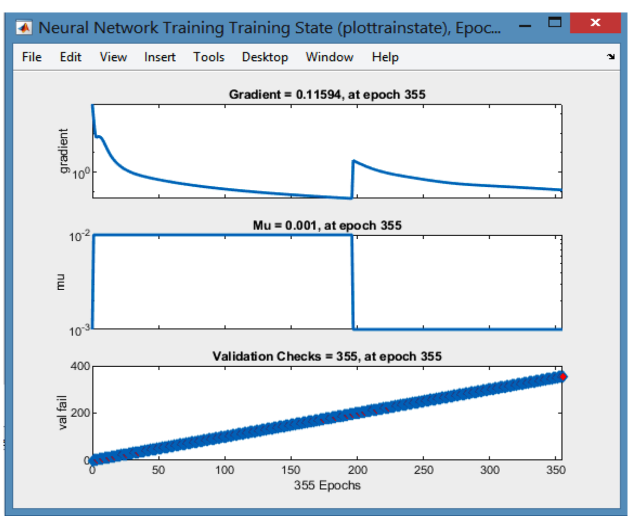
$$\mathrm{COR}\left(\hat{\theta}, \theta\right) \frac{\mathrm{COV}\{\hat{\theta}, \theta\}}{\sigma_{\hat{\theta}} * \sigma_{\theta}} = \frac{\mathrm{E}[(\sigma_{\hat{\theta}} - \mu_{\hat{\theta}}) * (\sigma_{\theta} - \mu_{\theta})]}{\sigma_{\hat{\theta}} * \sigma_{\theta}} \qquad (5)$$

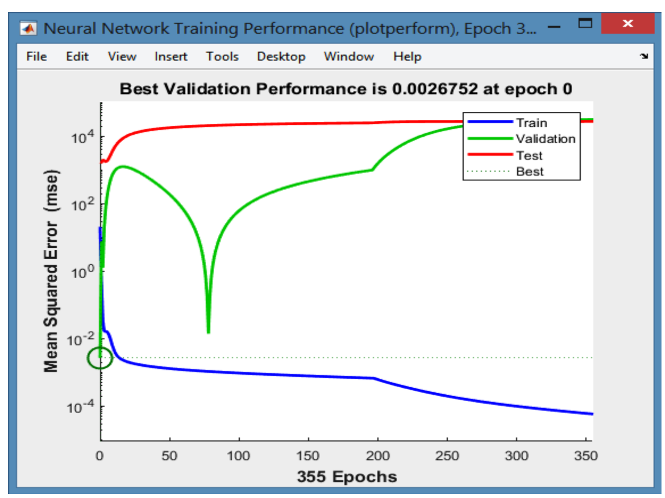
where *COV* is the covariance, σ represents the standard deviation, and μ stands for the expected value (mean).

Tables 6 and 7 are evidence that LM provides a better approximation compared to the other two algorithms. Tables 8 and 9 are the summaries of the NN output simulation with the normalized target forecast. Figures 8 and 9 provide a comparison of the target network and the predicted output values of the traffic volume, saturation degree and congestion indices. The high regression values for the LM for the two cities ($R = 1.000$) shows the suitability of the model and the better performance of LM ahead of BR and SCG [58].



(a) Regression analysis.

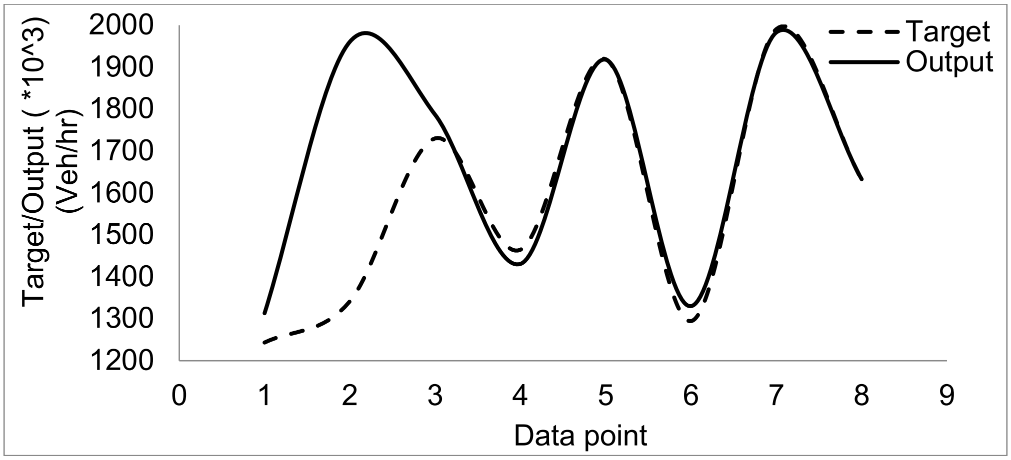




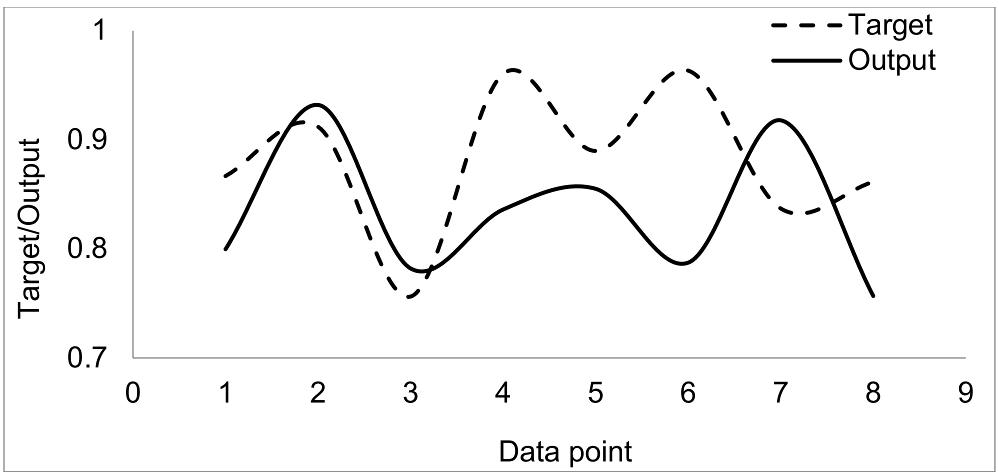
(b) Network training state

(c) MSE for performance accuracy

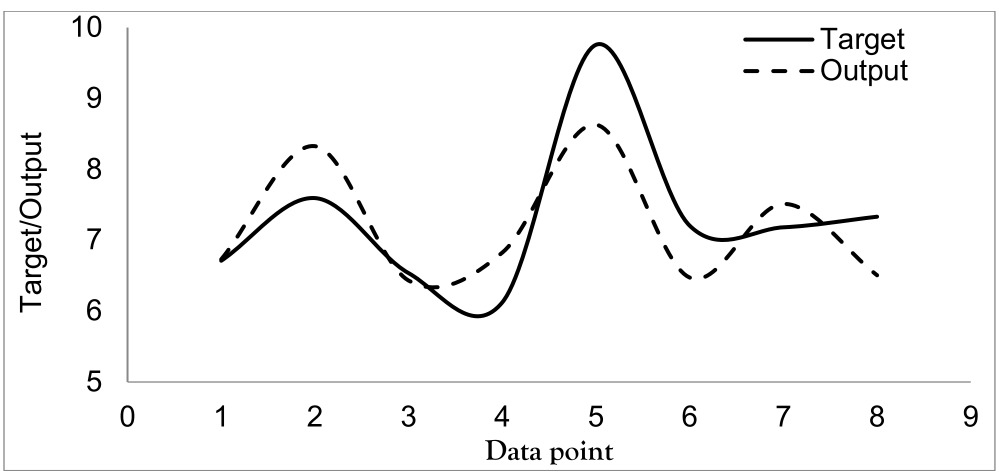
Figure 8. NN parameters for the LM algorithm for the Lagos network



(a) Traffic volume



(b) Saturation degree



(c) Congestion index.

Figure 9. Comparison of the measured target and the output traffic parameters for Kano city.

Out of three algorithms for the (NFTOOL) fitting model used, LM performed better than BR and SCG both in terms of MSE and R. The high regression values for LM for the two cities ($R = 1.000$) adjudges the suitability of the model and the better performance of LM ahead of BR and SCG. For instance, the model fitting for Kano produced LM's MSE = 4.424×10^{-1} and R = 1.000, while a similar result was replicated in the modelling of the data collected from Lagos (LM's MSE = 2.675×10^{-3} and R = 1.000). Furthermore, BR produced equally minimal MSE values of 8.253×10^{-1} and 6.473×10^{-3} for Kano and Lagos, respectively; their various regressions are also within the range adjudged as a perfect model in the literature (R = 0.932 for Kano and 0.9312 for Lagos). Thirdly, the SCG algorithm fits the same way as the two previous algorithms; the MSEs for Kano and Lagos are 5.337×10^{-1} and 4.582×10^{-3}, while their R values are 0.928 and 0.909, respectively.

The regression analysis lent towards the empirical scalar response and supported the optimization process for the prediction of the variables. For instance, the target moderate congestion was set at $C_{index} = 6$ out of 10, in order to guarantee that the traffic facilities will function optimally during the model simulation (Wang et al., 2018). The LM algorithm forecasting equation for the congestion indices of Kano and Lagos cities are $(Ouput = 1.0 * Target + 0.47)$ and $(Ouput = 1.0 * Target + 0.022)$, respectively. These equations are conditional upon good input parameters (i.e., to maximize the input from transport infrastructure, and to minimize both the traffic and demography) in order to deliver on the long-term goals of sustainability and resilience.

In this study, the COR or R values revealed a good assessment of the comparison between the prediction and the ground reference, indicating that the data exhibited linear structural prediction patterns. The visualization trends of the traffic and congestion simulations showed some random variations, which may depend on the cluster's trip generation, infrastructure quality, and temporal dimensions. Although the three NN algorithms—LM, BR and SCG—are good congestion predictors, [59] argued that traffic congestion will continue to beset the developing countries' cities due to poor investment in infrastructure. The economic losses and escalating environmental problems are major sources of worry.

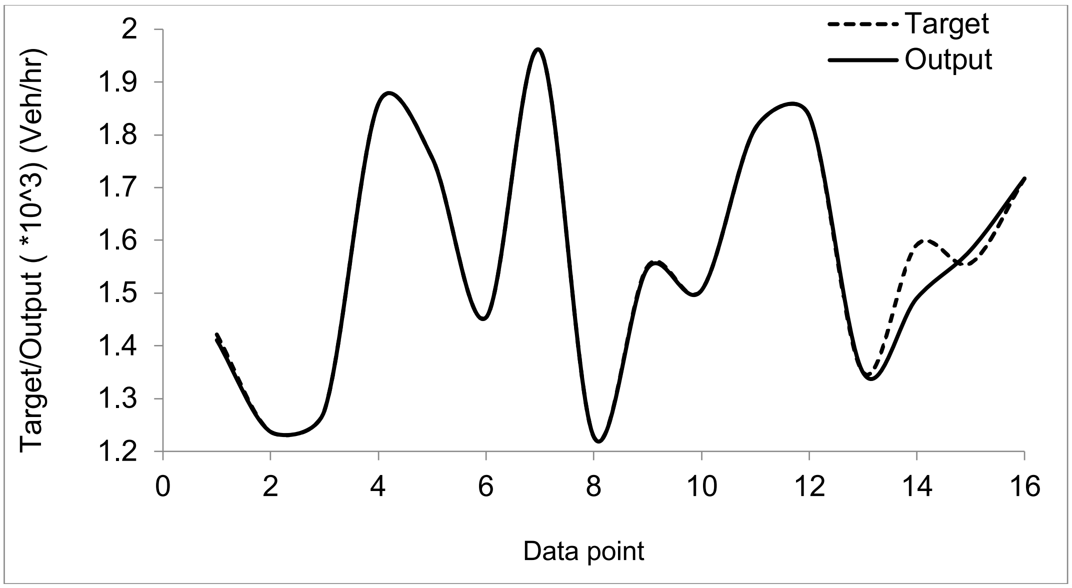
The provision of infrastructure is arguably a temporary congestion relief, and often time will lead to a complicated result, as drivers are inevitably drawn to unregulated good road facilities and may exacerbate congestion issues instead of ameliorating them. Researchers have questioned the factual assumptions underpinning infrastructure without a sustainable transport outlook [60,61]. As such, the maxim "You can't build your way out of congestion" revealed a paradigm shift from the dilemma towards a two-way (infrastructure-cum-access control) congestion mitigation approach [62].

In order to attain the role of the de facto economy which is currently the hallmark of sustainable cities, a holistic policy on transport infrastructure investment and sustainable transport development must include public transport. Although Lagos, Abuja and Kano have pioneered Bus Rapid Transport (BRT) to a lesser extent, development policy needs to focus more on public transport facilities and services, and to prioritize non-motorized transport in order to resolve the current difficult situation.

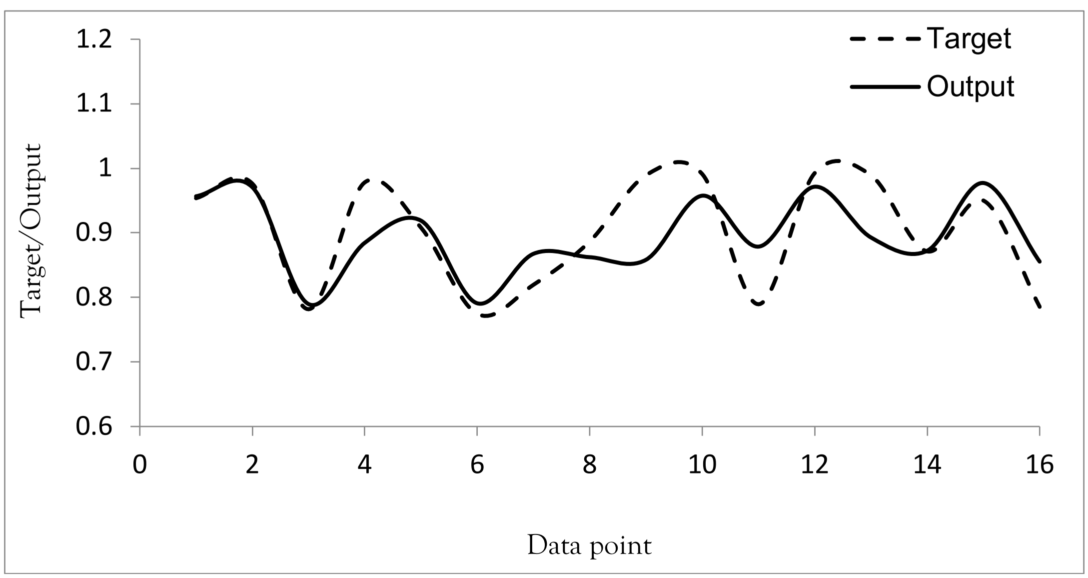
Table 9. NN summary of the measured targets and the predicted output (Lagos city).

Cluster Number	Traffic Volume			Traffic Saturation Degree			Congestion Index		
	Target (Veh/hr)	Output (Veh/hr)	Error (%)	Target	Output	Error (%)	Target	Output	Error (%)
1	1421.5	1410.8	−0.76	0.9537	0.9567	0.31	7.6870	9.0132	14.71
2	1236.9	1236.9	0.00	0.9764	0.9708	−0.58	9.6629	9.3970	−2.83
3	1277.7	1277.6	−0.01	0.7817	0.7897	1.01	9.1688	9.1756	0.07
4	1858.8	1858.7	−0.01	0.9783	0.8846	−10.59	9.8380	9.5884	−2.60
5	1755.9	1755.9	0.00	0.9081	0.9189	1.18	8.6230	8.5991	−0.28
6	1453.7	1453.8	0.01	0.7744	0.7909	2.09	6.1428	6.2208	1.25
7	1960.2	1960.1	−0.01	0.8196	0.8676	5.53	9.3965	9.5614	1.72
8	1227.6	1227.7	0.01	0.8867	0.8623	−2.83	9.736	9.6918	−0.46
9	1551.0	1547.2	−0.25	0.9894	0.8583	−15.27	8.7149	7.8775	−10.63
10	1505.2	1505.0	−0.01	0.9912	0.9576	−3.51	9.0310	9.5435	5.37
11	1812.4	1812.4	0.00	0.7894	0.8787	10.16	8.9725	8.9573	−0.17
12	1836.2	1836.2	0.00	0.9926	0.9715	−2.17	7.5689	7.5706	0.02
13	1349.5	1349.5	0.00	0.9893	0.8929	−10.80	8.6219	8.6430	0.24
14	1591.8	1490.5	−6.80	0.8713	0.8723	0.11	6.6847	8.7901	23.95
15	1556.5	1581.6	1.59	0.9501	0.9773	2.78	8.8242	9.7559	9.55
16	1717.1	1717.1	0.00	0.7855	0.8555	8.18	6.1273	6.2060	1.27

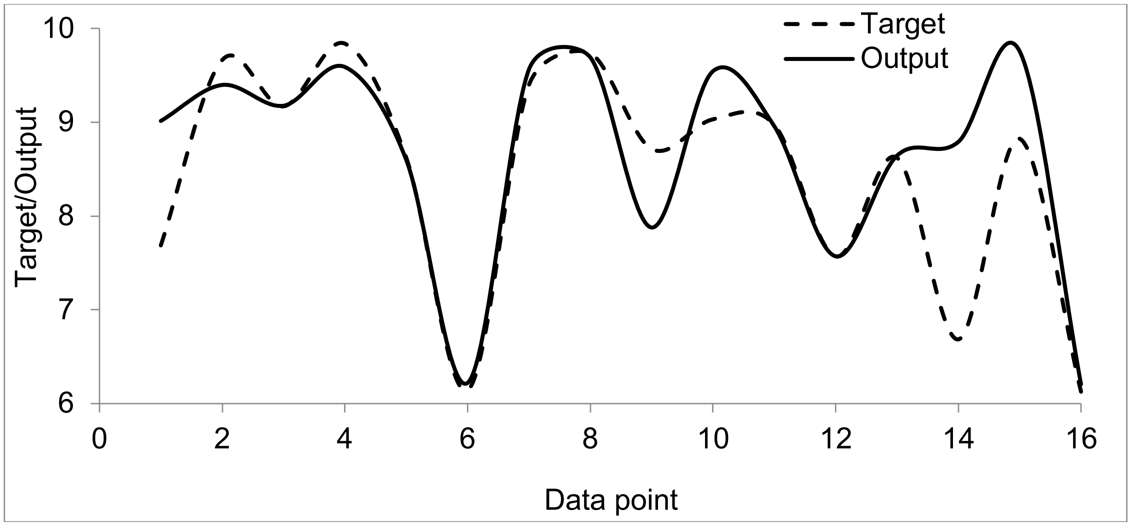
In Figures 9 and 10, the predicted values are moderately close to the target values and could represent accurate predictions for the monitoring of the persistent congestion of the road traffic in Nigerian cities. The figures show that the model is very accurate in terms of calibration and prediction accuracy because the relative errors are small. The prediction, as demonstrated, is very useful for neural networks, such that a preprocessing of the real data is applied in order to predict the congestion rating as an indicator of transport service and infrastructure qualities. In both cities, the poorly defined and complex areas of mobility resilience reveal substantial deficiencies in the complementary role of urban spatial dynamics, policy targets and benchmarks, traffic demand, public transit strategy, and low sustainability. In their various synoptic applications of ANN, researchers have observed that a multi-layer feed-forward back-propagation model provides a better fitting quality for traffic congestion, but lacks the capacity for a time series forecast in which a large pool of data is not available [63,64].



(a) Traffic volume



(b) Saturation degree.



(c) Congestion index.

Figure 10. Comparison of the measured target and output traffic parameters for Lagos city.

5. Conclusions

The research findings can be summarized as follows. The prediction model implemented in the input–output and curve fitting (NFTOOL) model of the neural network has successfully connected the congestion profiles of the two cities to their infrastructure, urban traffic regimes, and demography. The present work has applied novel deep-learning modeling techniques for transport resilience forecasting. The methodology has provided a 'smart' means for traffic and transport-related analytics and prediction. The model offers novel approach to the prediction of the traffic and congestion profiles of cities in real-time, and with quality and precision. The model, above all, provides a persistent learning process by constantly upgrading the input variables, thus providing a larger database to properly train and test the ANNs so that accurate predictions can be created in the future.

In the survey of the two most populous Nigerian cities (Kano and Lagos), the congestion indices are higher than the threshold for 'moderate' congestion ($C_{index} = 6$) suggested in the literature (Table 5). The capacities of the road facilities are overstretched by the 'extreme' traffic situations with target and output counts greater than 2000 vehicles per hour, as suggested in the design manual from which the roads were constructed. These results are evidence of many multifaceted and multi-dimensional cycles of failures. Nigerian cities, like many developing countries, are riddled with incomplete transport infrastructures, low quality portfolios of construction, unsafe urban sprawls, and a lack of effective planning and control policies. Other issues include political interference, financial corruption, and bureaucratic bottlenecks.

Whilst most cities are assuming the role of the de facto country's economy, urban transport, especially in the generation of the rapidly evolving mega-cities of developing countries, require smart transport systems for effective mobility and congestion control. This is necessary, especially in the face of the prevalent public health and safety risks, environmental pollution, and socioeconomic losses due to congestion problems. The implementation of the intelligent technology and deep learning techniques carried out in this research would contribute to the academic discourse on urban transport resilience and, importantly, ensure that urbanization goes in tandem with equity, social and economic inclusion, and environmental stewardship.

Transport systems and their associated infrastructures are vital to both the growth and prosperity of modern societies. Risk, uncertainties, and perturbations have cascaded the capacity and boundaries of the resilience and survival of transport systems in developing countries due to population growth, urbanization, and sprawling settlements, not least around urban fringes. An increased emphasis on network throughput and resilience would not only reduce the economic maladies of congestion, but would also boost safety, accessibility, and critical cyber-physical asset protection.

The consequences of urban growth and spatial inequality have resulted in several unbelievable and 'unsustainable' cities with little capacity to muffle or resist any known and unknown systemic problems. In order to address current and future challenges, this study recommends a policy reorientation through the enhancement of public transport facilities and the strengthening of the drive for sustainable transport development. In addition to this, future studies need to explore the temporal and economic dimensions of traffic congestion with inputs that aggregate big data for predictive real-time analytics and retrospective insights.

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CHAPTER FIVE

Sustainability Paradigm of Transport Infrastructure in the Developing Countries: Case study of Nigerian Major Cities

CHAPTER FIVE

(Undergoing publication review)

Sustainability Paradigm of Transport Infrastructure in the Developing Countries: Case study of Nigerian Major Cities (Lagos and Kano)

By

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Abstract

Globally, the burgeoning urban population in the last decades has led to unprecedented spatial transition of cities and the emergence of many urban sprawls especially in lower income countries where urban evolution is not adequately supported with infrastructure development. While Nigerian cities, like their counterparts in the developing countries, have been projected to be among the highest of future demographic and urbanization indices, increased problems of infrastructure, congestion and pollution have plagued the cities liveability and prosperity. Mobility, the means of interaction of any population and its land, is prominent among the myriad of cities' problems due to incoherent planning policies, poor management, and unmitigated infrastructure gaps. This study assesses the pathways of modal sustainability approach to surmounting the seemingly challenging transport infrastructure problems in the Nigerian major cities (Lagos and Kano). The methodological approach for data collection involved questionnaires administered among different communities of city dwellers otherwise called stakeholders to assess their knowledge of sustainability, perceptions, ratings of accomplishments and travel choices that promotes transport sustainability in the cities. For the purpose of data collection, two thousand questionnaire samples on the various aspects of transport sustainability were administered in each of Lagos and Kano cities whereby 509 and 505 were retrieved in the respective cities. The data were analysed using IBM SPSS analytical software. A gap in the knowledge and literacy of the subject is evident in the low average sustainability literacy test scores of 37.5 and 45.2% respectively for Kano and Lagos surveys. In the two states, the results also showed weak accomplishment levels for the sectors with most of the measures and indicators of transport sustainability falling below 50 percent benchmark in literature. The synopsis will serve as a blueprint and policy guide for the affirmative course of action in sustainability worldview and a contribution to literary discourse on developing approaches to mitigate the complex interplay of mobility and infrastructure problems in the cities of developing countries.

Keywords: Transportation, infrastructures, megacities, urbanization, sustainability

1 Introduction

Transportation provides a means of mobility, linkages and physical interactions between citizens and the environment. Beyond movement, transportation is one of the cornerstones of human civilization pushing the boundary for space, time as well as growth and socio-economic development of a country (Jeon and Amekudzi, 2005). Security and political administration of an area cannot be guaranteed without an efficient and effective system of transport (Jackson and LaTourette, 2015, Yang and Zhang, 2017).

Complex interplays have characterized the concept of sustainability in terms of definition, indicators, metrics of assessment, targets and the benchmarks since its conceptualization for ecological studies in 1713 by Hans Carl von Carlowitz (Wang *et al*., 2015). Sustainability has been defined as a *'ceaseless continuum capacity*' describing the goals and impacts of human's activities (Litman and Burwell, 2006).

The United Nations commissioned report of Brundtlands (1987) defined *"Sustainable development as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* The concept has three broad intrinsically complex dimensions – environmental, social and economic indicators.

Individual and collective cognitive orientations posed by the developed countries are beyond satisfying immediate human needs and aspirations but galvanizing sustainable world view of technologies and engineering infrastructures to cope with complex and unpredictable future (Allenby, 2007). Indicators of sustainable development, such as the current Sustainable Development Goals (SDG's: https://sdgs.un.org/goals) have shown slow pace of evolution in Africa as with many developing countries (Akeel *et al*., 2019). The most probable reasons for the slow development, *inter alia* are reflective of post-colonial problems, infrastructure gap(s), low income and poverty that culminate to make sustainable choices difficult (Thakran, 2004).

Whilst the future built environments may not be solely hinged on robust urban infrastructure, pre-eminence of existential weather threats, risk and life cycle have increased the complexity of the debate for achieving sustainability. Starting with the developing countries to the most developed counterparts, urban and metropolitan centers are becoming increasingly vulnerable due to climate change, increasing human demography, rapid urbanization and scarcity of resources. Urban governance demand and capacities are already overstretched in terms of hazardous events, security risk, environment, technical and financial resources which are increasingly overwhelming critical infrastructures (Yigitcanlar *et al*., 2008).

There is no known novel high-tech incubation to effectively rid the transport infrastructure and service demand problems, not least when an increasing human population, migration and weather problems continually push the boundaries of risk and uncertainty management (Kahn-Ribeiro *et al*., 2007). Perspectives have been shifted to management and recycling of resources, increasing political will, economic viability, social, and environmental assessment as the new focus of future sustainable development (Seto *et al.*, 2012).

Currently, global financial agglomeration, economic growth and human development indices of cities have been rated as the *de facto* governments. The economic accomplishment of the urban metropolis, according to the McKinsey Global Institute (2012) will be the new drivers of economic growth and development with higher than two-third of global GDP will come from the economic accomplishment of six hundred (600) future cities as from the year 2025.

Organization for Economic Co-operation and Development (OECD) estimated that global infrastructure investment demand to contain rapid urbanization in 2030 will be more than US$ 53 trillion (OECD, 2012). By the same token, climate change and environmental footprint have been envisioned to increase (Howden *et al*., 2007). Studies on climate change vulnerability have shown that many coastal cities will vanish in the coming decades due to rising sea level (Balica *et al*., 2012). An UK's Independent Newspaper report on climate change predicted that climate-related events will cost the world economy more than £1.5 trillion by 2030 (Johnston, 2016).

In the developing countries, deficient policies, changing political will, regulations, poor job execution, low income and poor financing; apart from extreme weather events further reduce the capacity for infrastructure delivery and increases the spate of vulnerability (Campbell-Lendrum and Corvalán, 2007). Unsupported slums and a scattered urban mosaic of Africa, Asia, Island countries and other low-lying cities are thought to be most vulnerable to extreme events (Bello *et al*., 2012). Inadequate infrastructure in the urban slums exposed the terrain to weather elements and challenging mobility problems.

The transportation sector, especially surface or on-road transportation (ORT) is amongst the highest emission contributor, accounting for the largest modal share (i.e., >50%) in developing countries (Unger et al., 2009). Thoughtful developments, holistic views and the pathways of sustainable mobility can de-risk vulnerable urban and metropolitan areas. Surmounting social and economic dilemmas through strategies, capacities and management of urban governance (Wang *et al*., 2015); and avoiding the creation of rural to urban dependency paths which leads to migration, sprawls and unlivable urban fringes are vital ingredients (Grober, 2013). This research aims to measure the level of compliance to sustainability world view and transport sustainability paradigm of Nigerian major cities: A case study of Lagos and Kano.

1.2 Mobility issues and necessity of sustainability in Nigerian cities

In 2017, Nigeria ranked seventh in the world's most populous countries with a population of over 190 million. Figure 1 shows the population projection trends using a growth rate of about 3%, with projections of circa 400 million by 2050 (United Nation Department of Economic and Social

Affairs-Population Division, UNDESA: https://population.un.org/wpp/DataQuery/). According to the same demographic reality checks, about 50% of the populations are currently urban dwellers with higher expectation of 70% in the year 2050.

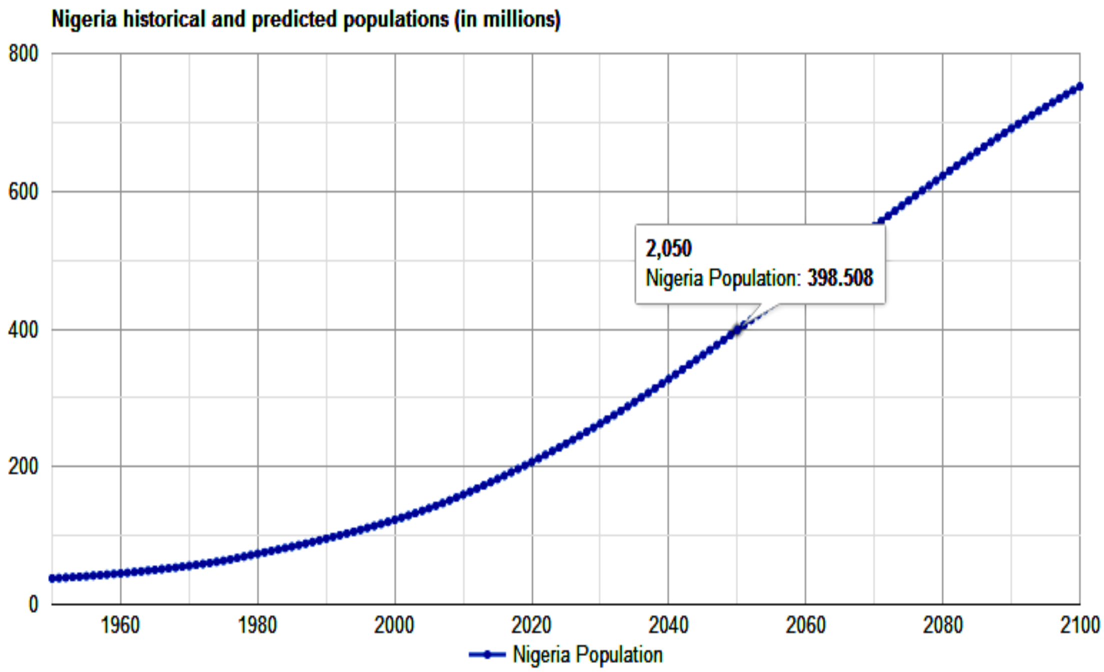


Figure 1: Nigerian population projection (UN-DESA, 2015)

Nigeria has about 194,394 km of roads; the surfaced roads account for 108,000 km, out of which only about 36,600 km is paved (to a varying degree of condition). These are shared among the three jurisdiction ownerships of the local council, states and federal government authorities (Filani, 2003). In 2016, the World Economic Forum WEF (2016) considered Nigeria as a country with a huge transport infrastructure deficit with a global ranking of 117th out of 136, with transport infrastructure index of 2.60 on a weighted scale of 5. Like many developing African countries, it has a low GDP which gives rise to poor infrastructures. The country is heavily motorized, relying mainly on the road transport modal choice for mobility. Researchers have reported a staggering proportion of about 90% of all transport movements in Nigeria are by road, leading to high accident casualty rate, pollution and ecological problems in ever more congested cities (Campbell, 2009).

Due to the over dependencies on road, life cycle issues, and low return on investment have beset the transport infrastructures. The quality of life in most cities is generally poor, which is closely related to the defective planning and development policies skewed in favor of road mode

(Basorun and Rotowa, 2012). The structure of geographic spatial disposition and the ailing infrastructure could not cope with the frenzy of urban migration and population rise so that liveability and sustainability become difficult.

1.3 Statistical test and Data analysis

The most vital aspect of any data analysis is selecting the most appropriate statistical test to adopt. In this study, the research instrument for data collection is by questionnaire which consisting of nominal and ordinal scaled questions. As such, both descriptive and inferential statistical tests are applicable for analysis. Descriptive statistics adopt measures of central tendency (such as mean, median, standard deviation) and measures the spread or variability of a set of data. This does not present any inference on the sample population properties. Inferential statistics, however, involve making a valid deduction and prediction from a small representative sample data generalized for the entire larger population from which the sample was drawn. For the purpose of the current analysis, frequency (or the equivalence in percent), mean and standard deviation are adopted.

In addition, the use of inferential statistics in the study is applied. This involves cross-tabulation of frequencies or percentages and the Pearson's chi-square test to infer. The vital aspect of inferential statistics is the use of probability theory for inferring (or deducing) attributes of a population-based on the properties of the sample drawn from the population. The deduction or inference is based on the reliability and precision of the level of evidence of the properties of the population.

A Chi-square test, otherwise called *"goodness of fit"* test is a probability of independence of a distribution and is useful for analysing categorical data with a view to detecting any significant differences among the variable data sets (McCormick *et al*., 2015). The Chi-square value so obtained is the likelihood that the null hypothesis is accepted to be right. And the conventional "cutoff" point for a p-value of 0.05 was used for testing the null hypothesis that the variables in the data set are independent or unrelated. Whilst probability values lower than the "cut-off" point mean a weak probability; the probability values high than the "cut-off" is a high probability. We justify the use of Chi-square test of level of significance due to large sample sizes (505 for Kano and 509 for Lagos) collected for the study areas and the assumption of unrelatedness of stakeholders sampled.

2 Research methodology

This chapter comprises the research design, target population, sample size and sampling procedures, research instruments, the validity of the instruments, reliability of the instruments, data collection procedure, and data analysis techniques. In order to adequately assess the performance of transport indicators, targets, benchmark and to galvanize among the dwellers of major Nigerian cities, the use of questionnaire was employed to carry out sustainability literacy test (SLT) among the stakeholders (government, academia, operators or managers and public users).

A sustainability literate person, according to Parkin *et al*., (2004), is described by his or her aptitude *"to recognize and reward other people's decisions and actions that favour sustainable development"*. The same definition goes with the assessment of responsibility of the government or responsible authority of an area who is the forerunner and purveyor of sustainable development and culture. Such aptitude is related to knowledge, skills and understanding required to fashion a more sustainable development future (Vare and Blewitt, 2010).

The questionnaire (Appendix A1) contains stakeholders' demographics, sustainability literacy test (SLT), paradigms and ratings of sustainability pillars based on respondents' understanding of the concept. Most importantly, the questionnaire contains an assessment of travel choices, the needs, indicators and ratings of sustainable transport infrastructures in the Nigerian cities. Two thousand (2,000) samples of the questionnaire were administered in each of the two Nigerian most populous cities.

Also, reflective assessments of the drivers, targets and possibly any benchmarks of policies towards transport sustainability bordering on achievements, existing scenarios, and policies towards a sustainable transport future of the cities were carried out in the two cities. For questionnaire analysis, many types of statistical software, including SAS, STATA, SPSS, and R with varying degrees of accuracies are applicable. Analysis of questionnaire data was done using Minitab18 for modelling and IBM Statistics SPSS 20 software. IBM SPSS 20 for the questionnaire data analysis was used because of its adaptability, friendliness, and availability.

2.1 Research design and sampling method

A research design usually provides for the academic and research community a margin of confidence that the outcome of the findings is valid, reliable and reflects the reality of the situation addressed by the research (Cooper and Schindler, 2008). In the absence of population census data since 2006, the revised urban population agglomeration by UNDESA—PD (2019) estimated that Lagos and Kano metropolitan population were around 15 million and 4 million people respectively in 2018. Lagos state currently has 57 local council development areas while Kano has 44.

A *priori* judgment of the demography may be necessary because of the large population involved and to guarantee optimal sample size. Although larger sample size reduces error and increases statistical power and vice-versa; it will be more economical in terms of labour cost, resources, effort and time to keep an optimal sample size (Creswell, 2009). The population of the two states will be sampled by dividing individual states into geographic units representing a heterogeneous population subset called *"clusters"* (Tate *et al*., 2007; Nafiu *et al.*, 2012 and 2013).

In this study, the number of local development areas which are part of Metropolitan Statistical Areas (city boundary) in each state forms the basis for clusters – KN* and LA* respectively for Kano and Lagos. For population estimates for the two states in 2018, the following were used: Nigerian census figures by National Population Commission NPC (2006), the projected population figures by the National Bureau of Statistics NBS (2016) and a growth of 2.58% approved by UN population division's World population prospect, (UN, 2017). In addition, United Nation (2015) population estimate by projection or back-calculation was used as shown in Equation 1:

$$P = P_0 * e^{rt} \qquad (1)$$

Where P is the projected population; P_0 is the current population; e is the natural logarithm base equivalent to 2.71828; r is the population growth rate (%), and t is the time (years)

For large population sampling, equation of Slovin (1960) is given by Equation 2:

$$n_o = \frac{z^2 * p(1-p)}{e^2} = \frac{z^2 * pq}{e^2} \qquad (2)$$

Where z is the standard normal variate of confidence level (z = 1.28, 1.44, 1.65, 1.96 and 2.58 respectively for C.L of 80, 85, 90, 95, 99%); p is the standard of deviation or probability based on prevalence; e = margin of error differentiating two samples (usually assumes value of 5% but can be set 0- 10%).

Cochran (1977) developed a similar formula in Equation 3 for sampling a large finite population based on Slovin (1960)

$$n = \frac{n_o}{1 + \frac{n_0}{N}} \qquad (3)$$

where n_o is sampling based on Slovin (1960) and N is the total population, Setting Slovin equation at 95% confidence level with Z = 1.96 approximated to 2.0 and maximum variate of $p = q = 0.5$; then, Equation 2 becomes:

$$n_o = \frac{2^2 * 0.5 * 0.5}{e^2} = \frac{1}{e^2} \quad (4)$$

Substituting Equation 4 into 3 gives rise to Equation 5:

$$n = \frac{\frac{1}{e^2}}{1 + \frac{\frac{1}{e^2}}{N}} = \frac{N}{1 + (Ne^2)} \quad (5)$$

Both Slovin (1960) and Cochran (1977) sampling methods are very close for large population estimation. For a small finite population, correction equivalence in Equation 6 may be applied. Wider range of sampling choices for finite population was developed by Glenn (1992) shown in Appendices B1 and B2.

$$n = \frac{n_0}{\{1 + [\frac{n_0 - 1}{N}]\}} \quad (6)$$

In the sampling demography, children aged 0-15years who constitutes 45% of the population in Nigeria are not part of the target population and will not be included in the survey. This is largely due to requirements of informed consent of parents or guardians and age limitation in understanding the problems.

Questionnaires were to be administered at public places, including, transport stations, schools, offices, markets, parks, etc., because of physical planning problems whereby identifying housing location may prove difficult. Sample sizes for Lagos and Kano states were based on Slovin (1960) formula.

$$n_o = \frac{z^2 * pq}{e^2} = \frac{1.96^2 * 0.55 * 0.45}{0.05^2} = 381$$

Also, using Cochran (1977) formula, samples for Lagos and Kano states are close to Slovin (1960), thus:

$$n_{lagos} = \frac{N}{1 + (Ne^2)} = \frac{11{,}670{,}526}{1 + (11{,}670{,}526 * 0.05^2)} = 400$$

$$n_{kano} = \frac{N}{1 + (Ne^2)} = \frac{4{,}139{,}480}{1 + (4{,}139{,}480 * 0.05^2)} = 400$$

Using an expected response rate of 20% for the proportion of the questionnaire that will be returned, the total sample size for each of Lagos and Kano states is 2000. Appendices C1 & C2 are the sample sizes-based distribution of population for the respective development areas. Figures 2 & 3 show the geographic maps of Lagos and Kano states where the Metropolitan Statistical Area (MSA) which are boldly indicated in red.

$$n_{total} = {}^{400}/_{0.2} = 2{,}000 \text{ samples}$$

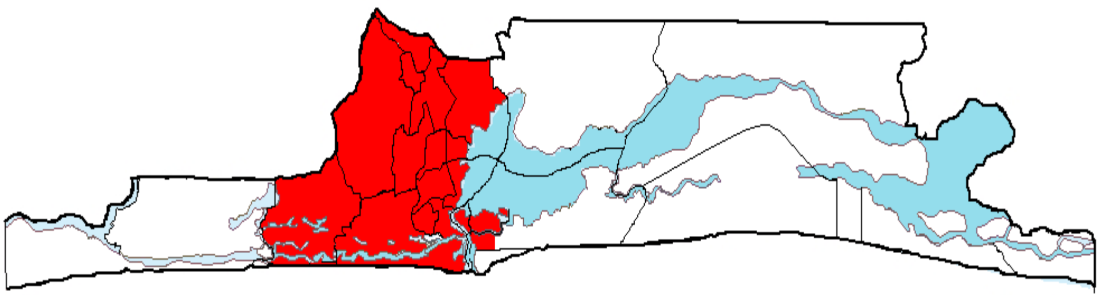


Figure 2: Map of Lagos State showing the metropolitan agglomeration (in red colour) (https://en.wikipedia.org/wiki/Lagos, assessed on 12th July, 2018)

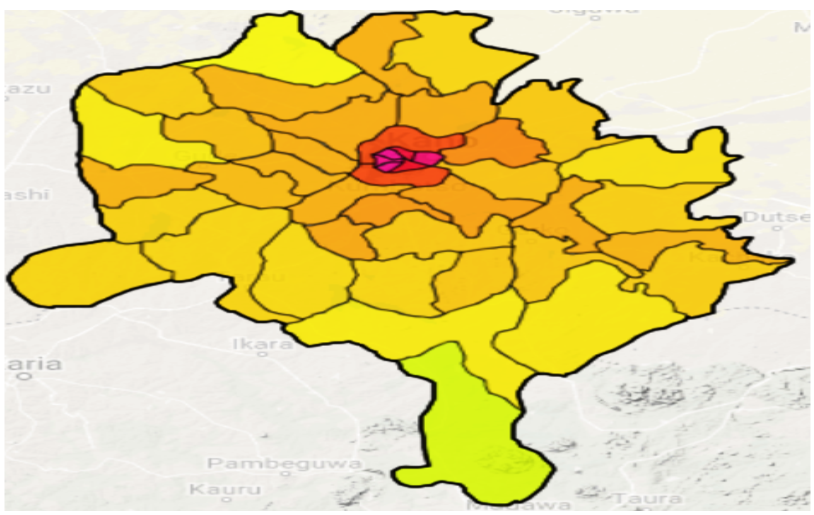


Figure 3: Map of Kano State showing the metropolitan agglomeration (red color)
Source: (https://www.citypopulation.de, assessed on 12th July, 2018)

Based on the distribution of the city development council area (CDCA) in the two states, the development areas in Appendices C1 & C2 provide the bases for sample size estimation of MSA covered by the cities as proportions of the CDCA making up the respective MSA of the two cities. MSA population estimates were carried out using census population data of 2006 obtained from the Nigerian population commission (NPC, 2006). Further population extrapolations were carried out to cover some important milestones relevant to the research using population figures from the Nigerian Bureau of Statistics (NBS, 2016).

2.2 Questionnaire structure and data collection

The questionnaire survey involves dual methods of web and paper-based means of administering questionnaires to the sample population. The dual approach was considered because of the plethora of foreseeable problems, including defective internet facilities, erratic power supply, low level of education, logistical and security problems in many developing countries (Akeel *et al*., 2019).

The three key components of the questionnaire are (1) demographics, (2) sustainability literacy test (SLT), (3) awareness and rating of sustainability pillars. Most importantly, the questionnaire contains elements to understudy the needs, indicator, perception and expectation ratings of achievements of transport sustainability based on the assessments of the all-inclusive urban stakeholders. While the paper-based questionnaire provides the means to physically distribute and retrieve from the respondents, the web type questionnaire was designed on Google drive and made available via online survey platforms. Both web-based and Paper-based surveys were tailored towards the maximum time duration of 20minutes.

In either case, the survey was prefaced with an introduction, research statement, confidentiality, the invocation of consent, right of voluntary participation, safety and non-transmission of data and means of communicating with the researchers. Twenty questions were administered to assess the overall knowledge base of transport sustainability in the two Nigerian cities. Questions Q1 to Q5 (Section 3.1) were framed to gauge demographic inputs of respondents, whilst Q6, Q7, Q8, Q9, Q11 & Q12 (Section 3.2) were tests of respondents' knowledge of sustainability subject matter as refreshers two pillars of sustainability Questions Q10, Q13 & Q14 (Section 3.3).

Furthermore, respondents were required to answer Questions Q15, Q16 and Q17 (Section 3.4) which provides insights on mobility choices, needs, indicators, ratings and policy assessment of transport sustainability of the two cities. Finally, Questions Q18, Q19 and Q20 (Section 3.1) were included to determine the best means of effective means of communicating transport sustainability, and how the respondents wished to receive feedback on the research outcomes.

2.3 Ethical consideration

The questionnaire specimen and interview protocols were submitted to Science, Technology, Engineering and Mathematics Ethical Review Committee of the University of Birmingham, United Kingdom. The researcher vouchsafes strict adherence to standard ethical procedures in every step of the research. All conventional ethical standard procedures bordering on voluntary consent, withdrawal right, confidentiality and data handling were addressed in the consent form

(Appendix A2). Without any outstanding potential ethically important concerns raised, the ethical approval registered Ethical Review ERN_18—1248 was issued for the study (Appendix A3).

3 Results and Discussion

3.1 Demographic data

This section reveals cross-tabulations and test of association between the demographics of the respondents and their rating of transport sustainability in Nigerian mega-cities. Table 1 and 2 are the summaries of respondents' demographic and the count's details their biodata in the two states surveyed.

The gender distribution of Kano respondents had 69.9% male participants while the proportion of female participants is 30.1%. Also, the proportion of gender distribution in Lagos State is 53.8% for male and 46% accounts for female. It has been observed that there are more female respondents in Lagos than Kano, a factor attributed to low-quality education and socio-cultural factors, including customs, traditions and religion which places sexist barriers and minimal interaction between male and female genders in the predominantly Muslim northern city of Kano (Aminat, 2016; Abdullahi *et al.*, 2015; Zivkovic, 2014).

Other than the randomness in the data collection, there are no specific deductions that can be ascribable to the differences in respondents' counts with respect to age, type of involvement, qualification and job rank in both Kano and Lagos surveys.

Table 1: Demographic counts of respondents in Kano State

S/No	Demographics	Respondents' distribution: Frequency count (%)	Total count (%)
Q1	Sex	Male: 353 (69.9); Female: 152 (30.1)	505 (100)
Q2	Age grouping	16-25yrs: 166 (32.9); 25-40yrs: 179 (35.4); 40-65yrs: 91 (18.0); Above 65yrs: 69 (13.7)	505 (100)
Q3	Respondents' involvement	Students: 87 (17.2); Lecturers: 53 (10.5); Govt officials: 58 (11.5); Private operator/Managers: 86 (17.0); Users: 221 (43.8)	505 (100)
Q4	Respondents' qualification	Other or non: 10 (2.0); Primary Sch Cert.: 67 (13.3); O'level: 100 (19.8); Diploma/NCE: 187 (37.0); Bachelor/HND: 106 (21.0); Master degree: 28 (5.6), PhD: 11 (2.2)	505 (100)
Q5	Respondents' rank	Unemployed: 90 (17.8); Junior level - 1-6: 177 (35.0); Mid cardre - 7 to 12: 150 (29.7); Management cadre - above 12: 88 (17.4)	505 (100)

Table 2: Demographic counts of respondents in Lagos State

S/No	Demographics	Respondents' distribution: Frequency count (%)	Total count (%)
Q1	Sex	Male: 274 (53.8); Female: 235 (46.2)	509 (100)
Q2	Age grouping	16-25yrs: 131 (25.7); 25-40yrs: 171 (33.6); 40-65yrs: 93 (18.3); Above 65yrs: 114 (22.4)	509 (100)
Q3	Respondents' involvement	Students: 98 (19.3), Lecturers: 58 (11.4); Govt officials: 83 (16.3); Private operators/Managers: 106 (20.8); Users:164 (32.2)	509 (100)
Q4	Respondents' qualification	Other or non: 23 (4.5); Primary Sch Cert.: 116 (22.8); O'level: 125 (24.6); Diploma/NCE: 142 (27.9); Bachelor/HND: 53 (10.4); Master degree: 33 (6.5); PhD: 13 (2.6)	509 (100)
Q5	Respondents' rank	Unemployed: 102(20.0); Junior level - 1-6: 93 (18.3); Mid cardre - 7 to 12: 204 (40.1); Management cadre - above 12: 110 (21.6)	509 (100)

3.1.1 Regression modelling for prediction of the quality of sustainability

The nature demographics of the population may impact on the outcomes of the quality of sustainability data collected. The poison regression model may be useful for the assessment and prediction of the quality of sustainability data (Q) based on demographic information of respondents. Poisson regression features prominently in the regression analysis of modeling count data and contingency tables where a generalized linear model is required (Long and Freese, 2006; Greene, 2008). According to Jones *et al*., (2013), the assumption of the Poisson distribution is that Q response variable having linear combined inputs of unknown parameters is equivalent to the logarithm of the expected value to fulfil equal dispersion property ($E[X] = Var[X]$). While the quality of sustainability data, Q, is the dependent variable, the demographic information constitutes the inputs of independent variables. The demographic inputs used are:

1) Sex ($\text{male: S}_1, \text{ female: S}_2$),
2) Age group ($16-25\text{yrs: AG}_1,\ 25-40\text{yrs: AG}_2,\ 40-65\text{yrs: AG}_3,\ :\text{Above 65yrs: AG}_4$),
3) Level of education ($\text{Other or non: LE}_1,\ \text{Primary Sch Cert: LE}_2,\ \text{O'level: LE}_3,\ \text{Diploma \& NCE: LE}_4,\ \text{Bachelor \& HND: LE}_5,\ \text{Master degree: LE}_6,\ \text{PhD: LE}_7$),
4) Type of involvement ($\text{Students: TI}_1,\ \text{Lecturers: TI}_2,\ \text{Govt officials: TI}_3,\ \text{Private operator \& managers: TI}_4,\ \text{Users: TI}_5$)
5) Rank in the job (Unemployed: RJ_0; Junior level: RJ_1, Mid-cadre: RJ_2, Management cadre: RJ_3).

The model fitting was carried out using Minitab 18. Tables 3 and 4 showed summaries of the model. The Spearman's rank correlation coefficient was calculated to be 0.302 which shows a weak positive relationship between the respondents' ratings of aspects of sustainability and their importance to the sustainability paradigm in both Lagos and Kano. Also, the analysis of demographic data of Lagos and Kano respondents shows that all the variables are significant as all the p-values computed are all greater than alpha (α = 0.05) justifying the existence of a relationship between the demographics and predicted sustainability responses.

The estimated Poisson model has 62.3% Adj. R-Square and 74.8% R-Square (Tables 3 and 4) respectively, indicating sufficiency of the eight independent variables in the Table for predicting quality of sustainability. The remaining 25.2% R-Square is attributed to other factors, not covered by the study and the error term. For Lagos, the Regression Equation (Q_{Lagos}) is estimated as:

$$\begin{aligned} Q_{Lagos} = {} & 1.403 + 0.0\, S_1 + 0.0003S_2 + 0.0\, AG_1 + 0.0200\, AG_2 + 0.0605\, AG_3 + 0.0276\, AG_4 \\ & + 0.0\, TI_1 - 0.074\, TI_2 - 0.008\, TI_3 - 0.0361\, TI_4 - 0.0203\, TI_5 + 0.0\, LE_1 \\ & + 0.058LE_2 - 0.008\, LE_3 + 0.012\, LE_4 + 0.025\, LE_5 - 0.041\, LE_6 - 0.028\, LE_7 \\ & + 0.0\, RJ_0 - 0.0491\, RJ_1 - 0.0040\, RJ_2 + 0.0155\, RJ_3 \end{aligned}$$

Removing all the zero coefficients parameter from the model, gives the revised fitting regression model as:

$$\begin{aligned} Q_{Lagos} = {} & 1.403 + 0.0003S_2 + 0.0200\, AG_2 + 0.0605\, AG_3 + 0.0276\, AG_4 - 0.074\, TI_2 - 0.008\, TI_3 \\ & - 0.0361\, TI_4 - 0.0203\, TI_5 + 0.058LE_2 - 0.008\, LE_3 + 0.012\, LE_4 + 0.025\, LE_5 \\ & - 0.041\, LE_6 - 0.028\, LE_7 - 0.0491\, RJ_1 - 0.0040\, RJ_2 + 0.0155\, RJ_3 \end{aligned}$$

On the other hand, Kano data have fitted an estimated Poisson model with 75.7% Adj. R-Square and 81.44% R-Square respectively. The Regression Equation for Kano (Q_{Kano}) is given by:

$$\begin{aligned} Q_{Kano} = {} & 1.390 + 0.0\, S_1 - 0.0025\, S_2 + 0.0\, AG_1 - 0.0169\, AG_2 - 0.0324\, AG_3 - 0.0257\, AG_4 \\ & + 0.0\, TI_1 + 0.074\, TI_2 + 0.016\, TI_3 + 0.053\, TI_4 + 0.051\, TI_5 + 0.0\, LE_1 \\ & + 0.012\, LE_2 + 0.008\, LE_3 + 0.035\, LE_4 + 0.031\, LE_5 - 0.007\, LE_6 - 0.057\, LE_7 \\ & + 0.0\, RJ_0 - 0.038\, RJ_1 - 0.058\, RJ_2 - 0.055\, RJ_3 \end{aligned}$$

A further simplification by removing variables with zero co-efficient gives:

$$\begin{aligned} Q_{Kano} = {} & 1.390 - 0.0025\, S_2 - 0.0169\, AG_2 - 0.0324\, AG_3 - 0.0257\, AG_4 + 0.074\, TI_2 + 0.016\, TI_3 \\ & + 0.053\, TI_4 + 0.051\, TI_5 + 0.012\, LE_2 + 0.008\, LE_3 + 0.035\, LE_4 + 0.031\, LE_5 \\ & - 0.007\, LE_6 - 0.057\, LE_7 - 0.038\, RJ_1 - 0.058\, RJ_2 - 0.055\, RJ_3 \end{aligned}$$

The model summaries in Tables 3 and 4 indicate that they are good predictors of sustainability qualities, Q, producing high regression values (R-Square values being 0.748 and 0.8144 respectively for Kano and Lagos responses) are reliable indicators of the data quality.

Table 3: Model summary for bio-data and demographics of Lagos respondents

S/N	Source	DF	Chi-Square	P-Value
1	Regression	17	2.73	1.000
2	Sex	1	0.00	0.994
3	Age Group	3	0.62	0.891
4	Type of Involvement	4	0.78	0.941
5	Level of Education	6	1.10	0.982
6	Ranking in the Job	3	0.51	0.916
7	Error	491		
8	Total	508		
Model summary: R-Sq.= 0.748; R-Sq. (Adj.) = 0.623; AIC = 2797.21				

Table 4: Model summary for bio-data and demographics of Kano respondents

S/N	Source	DF	Chi-Square	P-Value
1	Regression	17	1.47	1.00
2	Sex	1	0.00	0.960
3	Age Group	3	0.28	0.963
4	Type of Involvement	4	0.58	0.965
5	Level of Education	6	0.55	0.997
6	Ranking in the Job	3	0.26	0.967
7	Error	487		
8	Total	504		
Model summary: R-Sq. = 0.8144; R-Sq. (Adj.) = 0.757; AIC = 2643.60				

3.2 General sustainability literacy test (SLT)

Sustainability Literacy Test (SLT) is an assessment tool for evaluating the knowledge of baseline concepts, fundamentals fundaments, and responsible actions relating to the various themes and aspects of sustainable development. In order to deepen the knowledge and awareness of core sustainability literacy, UN (2012) in Rio +20 agenda advised nations to "ensure all learners acquire knowledge and skills needed to promote sustainable development."

In what became the forerunner among previous efforts at evaluating sustainability knowledge and awareness, an acclaimed web-based SLT evaluator dubbed *Sulitest* (2016) became the choice of many researchers (Akeel *et al*., 2019; Cezarino *et al*., 2018; Moon *et al*., 2018). The aspect of contextual relevance being emphasized by Sulitest (2016) was considered in formulating general modular SLT and those on the specifics of Nigeria.

The ultimate goal of carrying the SLT is to enable the ranking of the participating stakeholders as "*literate or otherwise*" by taking them through multiple choice and multi-choice questions covering the problems and evolving trends on the subject matter. Herein, the survey is premised on the minimum of 50% SLT pass score recommended in the literature as a basis for distinguishing the knowledge and awareness levels of the various communities of participating stakeholders (Storey (2013).

SLT involves six literacy questions — Q6, Q7, Q8, Q9, Q11 and Q12 to tests respondents' knowledge of sustainability subject and their response scores are disaggregated with respect to their stakes or involvement. Multiple choice questions with answer options A to E were asked to test SLT knowledge of respondents. Some multi-choice questions (where more than one option might answer the question) were included and hints provided not to constraint respondents to a single option where that applies. SLT questions were formulated from the core sustainability pillars and crosscutting domain areas in the general sustainability concept.

Details of SLT assessment and the scores are detailed in Appendices D1 and D2. SLT gross average per Kano city is 37.5%, while the mean score for the various stakeholders who passed the test are in the order — Students (40.0%), Lecturers (54.7%), Govt. Officials (44.8%), Private operators & managers (33.5%) and Users (33.2%) respectively. In Lagos, the gross SLT average pass for the city is 45.2% and the stakeholders' corresponding mean performances are Students (35.6%), Lecturers (63.5%), Govt. Officials (46.6%), Private operators & managers (49.7%) and Users (41.2%) respectively as shown in Figure 3.

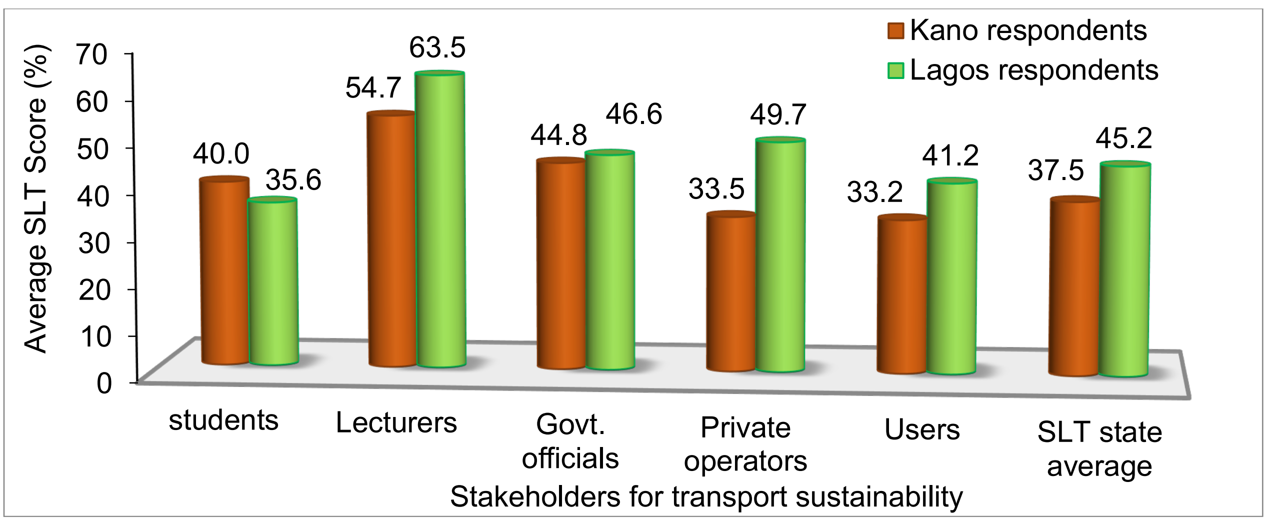


Figure 3: SLT performance scores of survey stakeholders

Higher average scores amongst lecturers and government officers are evidences of the over-arching and positive impacts of education since these two stakeholders are the most educated amongst the cohort. This view of positive impact and congruence between education and higher SLT was supported by researchers in different sustainability areas (Akeel *et a*l., 2017; Omisore *et al*., 2017; Nashash, 2013, Connolly, *et al*., 2008).

Relatively, most communities of stakeholders except lecturers can be adjudged "SLT illiterates", when compared to the minimum threshold of 50% recommended by Storey (2013) to adjudge a survey population as “SLT literate”. This is a further credence to congruence and the positive impact of education to SLT awareness. The outcomes are corroborative of former surveys which rated sustainability awareness of Africa as low with Nigeria and Ethiopia being rated 34% and 30% respectively in terms of sustainability literacy and awareness (Omisore *et al*., 2017; Globescan, 2016).

Many reasons were adduced to slow pace of embracing sustainability in the region, including post-colonial poverty challenges (Abdulgafar *et al*., 2013), lack of education curriculum for sustainability teaching in both lower and higher institutions (Akeel *et al*., 2019, Leal and Pace, 2016). Other probable causes are the defective pedagogical practice and lack of sustainability of target and benchmarks (Kolenick, 2018; Noguchi, 2017), bad leadership and lack of institutional synergy (Akintoye and Opeyemi, 2014; Ogbodo, 2010). UN-DESD Final Report 2014 concluded that sustainable development is still an “emerging interest amongst African countries” (UNESCO, 2014).

The demographic imbalance in education between the northern and southern regions of Nigeria might have been responsible for relatively higher SLT scores among Lagos respondents compared to their Kano counterparts. A plethora of regional peculiarities — urbanization rate, economic and industry agglomeration, population density and the pre-eminence of extreme weather event in the coastal southern cities may be responsible for greater SLT knowledge and awareness among Lagos respondents than the rest of the country (Okunlola, 2012).

3.3 Measure of aspects and pillars of sustainable development

The responses to questions Q10, Q13 and Q14 provide insights into the priorities, thoughts and model(s) that are better suited to sustainability pillars (environment, social and economy) in the two most populous Nigerian cities. The questions and responses are based on the perceptions of the respondents of the Nigerian city dweller towards sustainable behaviour. The survey prompts question Q10 provides alternatives amongst the five most popular sustainability models without any ordinal scales and the responses were elicited from respondents’ perception and priorities of the various aspects of sustainability pillars.

Q10: *Reckoning with the priorities of governments, geo-political factors, economic gaps, social-cultural diversity, inequalities in resources, which of these models would you perceive to be best suited for sustainability pillars in Nigeria?:*

a) *‘Mickey mouse’ model where environment and society are subsidiary to the pivotal role of economy*
b) *‘Bullseye’ embedded model of hierarchy – the relationship pecking order starts from economy to society down to environment*

c) *'Triple bottom line' model where equal interactions and relationships occur among environment, economic and societal pillars*
d) *'Bullseye' embedded model of hierarchy – the relationship pecking order starts from environment to society down to economy*
e) *'Bullseye' embedded model of hierarchy – the relationship pecking order starts from economy to society down to environment*

Responses to Q10 shows that the stakeholders are in favour of all-inclusive triple bottom line model (Option C), which accords equal priorities to the developments of environmental, economic and societal pillars were preferred by respondents of the two cities. The proportions of the population supporting the choice of the all-inclusive triple bottom line model are 65.6% and 69.8% respectively for Kano and Lagos cities. The details of the results of the survey questions are presented in Appendices E1 and E2.

Researchers have argued for the harmony of urban development, especially in the developing countries due to rampant socio-economic problems, infrastructure gaps, environmental challenges and the emergence of urban slums trailing high urbanization (Zhang *et al*., 2017; Hammer and Pivo, 2017; Roberts and Cohen, 2002; Basiago, 1999).

For the rating of aspects of sustainability, the survey prompts Question Q13 addresses the order of relevance accorded the aspects by respondents and the frequency counts, means and rankings are in Tables 3 and 4. The results support that higher priority of mobility or transport above other aspects of sustainability in the two cities as shown by the means score ranking.

Survey prompt Q13: Please, rate how important are the following aspects are to sustainability paradigm of your country? (5 = highly important, 4 = important, 3 = undecided, 2 = unimportant, 1 = highly unimportant)

Table 3: Respondents' rating of aspects of sustainability & paradigm for Kano Survey

	Response Counts (n=505)						
Aspects of sustainability	5	4	3	2	1	Mean	Ranking
Mobility/transport	386	78	4	33	4	4.602	1
Carbon reduction	329	93	20	35	28	4.307	4
Resource use	300	131	34	13	27	4.315	3
Water	247	182	26	14	36	4.168	6
Energy	300	132	38	21	14	4.352	2
Biodiversity	224	191	56	7	27	4.145	7
Waste & pollution control	292	129	37	35	12	4.295	5

Table 4: Respondents' rating of aspects of sustainability & paradigm for Lagos survey

Aspects of sustainability	Response Counts (n=509)						
	5	4	3	2	1	Mean	Ranking
Mobility/transport	434	50	21	4	0	4.796	1
Carbon reduction	263	198	33	11	4	4.385	2
Resource use	245	142	69	49	4	4.130	5
Water	198	225	47	15	24	4.096	6
Energy	255	154	39	43	18	4.149	4
Biodiversity	198	220	19	58	14	4.041	7
Waste & pollution control	210	212	53	22	12	4.151	3

Furthermore, the chi-squared (χ^2) test of significance was used to use to test the hypothesis that the rating of sustainability aspects and types of responding stakeholders are independent or without relationship. Chi-square has useful application for testing discrete ordinal variable counts having at least three response options and for non-parametric tests as *a priori* case in hypothesis testing (Bagdonavicius & Nikulin, 2011).

In using the test, it is possible to determine both the observed and expected frequencies of data collected in the survey question and the checks of whether a significant difference exists per chance. Corder and Foreman (2014) raised the caveat of checking that the expected frequency is equal to or greater than 5 for there to be the appropriateness of testing. The chi-squared P-value ($\boldsymbol{\chi^2_{cal}}$) may be calculated using the formula:

$$\chi^2_{cal} = \sum_{i}^{n} \frac{(O_i - E_i)^2}{E_i} \qquad (1)$$

Where $O_{i,}$ = observed value; E_i = expected value, $\mathrm{E_i} = (\text{Row total} * \text{Column total})/\text{Grand total}$

The categories or groups considered for analysis are based on the decision rules such that Likerts 5 and 4 grouped as "yes" affirmative responses; while those rated 2 and 1 were grouped as "no" category. The neutral or undecided category (Likert 3) was not considered as they exert little to no influence on the test of hypothesis.

Hypothesis testing: The testing of null hypothesis $(\mathrm{H_0})$ and alternative $(\mathrm{H_a})$ and the significance level are:

- $\mathrm{H_0}$: Aspect of sustainability & stakeholders' responses are independent or without relationship
- $\mathrm{H_a}$: $\mathrm{H_0}$ is false (Aspects of sustainability and stakeholders are related or dependent)

Decision rule: H_0 is rejected if the Chi-squared value calculated called P-value (χ^2_{cal}) ≤ Chi-squared value from table (χ^2_{tab}) in Appendix F1 at α and df; otherwise, we fail to reject the null hypothesis.

Degrees of freedom, $df = (r-1)(k-1)$ where r is the number of rows, k is the number of columns

$$r = 2 \text{ rows of responses}; k = 5 \text{ columns ofstakeholders}, \quad df = (2-1)(5-1) = 4$$

The tabulated chi-squared value (χ^2_{tab}) = 9.488 at α = 0.05 and $df = 4$. Summaries of the test are shown in Tables 5 and 6, with details of the analysis being presented in Appendices F2 to F17.

Table 5: Summary of Chi-squared test of sustainability aspects for Kano respondents

Aspects of sustainability	Chi-squared calculated (χ^2_{cal})	Chi-squared table (χ^2_{tab})	Decision rule / inference
Mobility/transport	3.00	9.488	$\chi^2_{cal} < \chi^2_{tab}$; H_0 is rejected
Carbon reduction	11.463	9.488	$\chi^2_{cal} > \chi^2_{tab}$; we fail to reject H_0
Resource use	6.392	9.488	$\chi^2_{cal} < \chi^2_{tab}$; H_0 is rejected
Water	13.925	9.488	$\chi^2_{cal} > \chi^2_{tab}$; we fail to reject H_0
Energy	3.205	9.488	$\chi^2_{cal} < \chi^2_{tab}$; H_0 is rejected
Biodiversity	14.097	9.488	$\chi^2_{cal} > \chi^2_{tab}$; we fail to reject H_0
Waste & pollution control	7.736	9.488	$\chi^2_{cal} < \chi^2_{tab}$; H_0 is rejected

Table 6: Summary of Chi-squared test of sustainability aspects for Lagos respondents

Aspects of sustainability	Chi-squared calculated (χ^2_{cal})	Chi-squared table (χ^2_{tab})	Decision rule / inference
Mobility/transport	1.764	9.488	$\chi^2_{cal} < \chi^2_{tab}$; H_0 is rejected
Carbon reduction	6.630	9.488	$\chi^2_{cal} < \chi^2_{tab}$; H_0 is rejected
Resource use	7.262	9.488	$\chi^2_{cal} < \chi^2_{tab}$; H_0 is rejected
Water	9.553	9.488	$\chi^2_{cal} > \chi^2_{tab}$; we fail to reject H_0
Energy	8.127	9.488	$\chi^2_{cal} < \chi^2_{tab}$; H_0 is rejected
Biodiversity	18.258	9.488	$\chi^2_{cal} > \chi^2_{tab}$; we fail to reject H_0
Waste & pollution control	8.619	9.488	$\chi^2_{cal} < \chi^2_{tab}$; H_0 is rejected

Statistical inference: For the respondents from Kano, the observed relationship between the two categories of stakeholders' responses - 'yes'(affirmative positive responses) and 'no' (negative responses) are statistically significant for mobility/transport, resource use, energy, waste and pollution control aspects of sustainability since $\chi^2_{cal} < \chi^2_{tab}$. Therefore, the null hypothesis is rejected, and the alternative is chosen — which indicates that the respondents believe that only the listed aspects of sustainability are of priority importance to their city's sustainability paradigm. Other aspects of sustainability – carbon reduction, water and biodiversity are not accorded priority.

However, Lagos respondents accorded mobility/transport, carbon reduction, resource use, energy, waste and pollution control as important aspects of sustainability while water and biodiversity are not considered important. Mobility/transport took the highest number of priority rankings in the two cities with positive response counts being — Kano = 464 ($\chi^2 = 3.000$; $\rho < 0.05$), and Lagos = 484 ($\chi^2 = 1.764$; $\rho < 0.05$). Mobility is, perhaps, accorded the highest order of priority because of the daily frustration of commuting in a highly congested city and the difficulty of navigating many disjointed urban slums with huge infrastructure problems that have beset many unliveable Nigerian cities (Adedayo *et al*., 2014).

In Question Q14, respondents' authorities of urban governance were requested to rate the level of compliance to the vision of how sustainable the cities are with respect to the sustainability pillars of economy, social and environment. This includes multidimensional issues such as: poverty, corruption and bureaucratic bottlenecks that pervade governments of many developing countries. The impacts of the four sustainability indicators on the wellbeing of the populace and the infrastructures were assessed using the following question in the survey prompt.

Q14: *Please, rate how much do the following sustainability pillars have been addressed by your city infrastructural development? (5=very strongly addressed, 4=strongly addressed, 3=moderately addressed, 2=poorly addressed, 1=not addressed)*

The mean scores of the pillars of environment, economy, social and multidimensional sustainability for Kano city 2.46 (49.2%), 2.53 (50.6%), 2.52 (50.4%) and 2.28 (45.6%) respectively, while a Lagos mean score of sustainability pillars are 2.58 (51.8%), 2.61 (52.2%), 2.64 (52.8%) and 2.50 (50.0%) respectively in the same order. Details of the response counts of the various communities of stakeholders are in the Appendices G1 to G8. The results in Figure 4 depict consistency in low achievements in the four dimensions considered — social, economy, environment and multi-dimensional indicators.

In order to deliver on sustainable development goals, proactive measures are necessary to achieve the legitimate objectives in the developing countries (UN—DESA, 2013). Based on the results, Nigeria cities could be seen as stark examples among burgeoning yet vulnerable mega-cities with many trails of unsustainable development indicators. In the absence of adequate mitigation, the effect of climate change and socio-economic backlash threatens to increase this trend.

Integrated sustainable management of natural resources and habitats needs to be encouraged and steps to minimize and adapt to the concept of shared albeit diversified responsibilities embraced. In the absence of adequate mitigation, the effect of climate change and socio-economic backlash threatens to increase unabated in Nigeria. Integrated sustainable management of natural resources and habitats needs to be encouraged and steps to minimize and adapt to the concept of shared albeit diversified responsibilities being embraced.

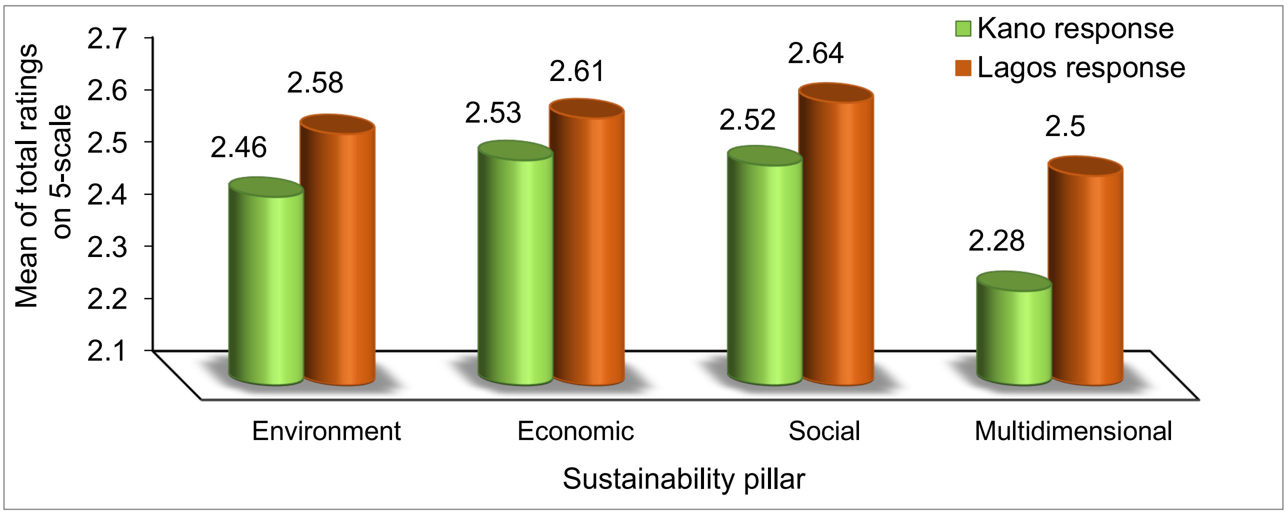


Figure 4: Mean rating of sustainability concepts in the Nigerian cities

3.4 Indicators of transport sustainability by travel choices

In this survey, transport sustainability in Q15 was used to assess the respondents' frequent travel choices for the various journey types among the dwellers of the two cities as and results are presented in Tables 5 and 6:

Q15: Base on the list of available mobility/travel choices; choose your most frequent transport method(s) to commute the following journeys?

Table 5: Survey of most frequently used mobility choices for various journeys in Kano State

Journey purpose	Walk	Bicycle	Train	Bus	Taxi/car-hire	Motorbike	Personal car	Total
Workplace/school	52	33	0	35	95	23	267	505
Shopping	62	23	0	32	74	20	294	505
Recreation/Leisure	141	59	0	43	16	22	224	505
Religious centres	150	40	0	36	58	22	199	505
Other……………	141	21	11	25	49	22	236	505
Total	546	176	11	171	292	109	1220	2525
Percentage	21.6	7.0	0.4	6.8	11.6	4.3	48.3	100

Table 6: Survey of most frequently used mobility choices for various journeys in Lagos State

Journey purpose	Walk	Bicycle	Train	Bus	Taxi/car-hire	Motorbike	Personal car	Total
Workplace/school	56	18	3	102	78	40	212	509
Shopping	77	13	0	98	58	32	231	509
Recreation/Leisure	99	14	5	100	64	65	162	509
Religious centres	124	22	7	85	56	71	144	509
Other……………	87	38	12	99	81	100	92	509
Total	443	105	27	484	337	308	841	2545
Percentage	17.4	4.1	1.1	19.0	13.2	12.1	33.0	100

Figures 5 and 6 are plots of commuting choices for most journeys of the two Nigerian cities. This shows that the surveyed respondents are more favorably disposed towards personal cars — 48.3% in Kano and 33.0% in Lagos respectively. By the same estimates, motorized travel share accounts for 71.4% of journeys in Kano and 78.4% in Lagos respectively. The current findings are consistent with Lowitt (2006) who opined that motorization could be higher than 77% in emerging Sub-Saharan African cites because of rising population and urbanization rates. The synoptic findings revealed that the low living condition is exacerbated by high urban motorization rate in Nigeria estimated to be about 69%.

Lagos city has over 1.2 million registered vehicles traversing the decayed transport infrastructure, making the city one of the most congested in the world. Residents spend about 14 per cent of their household budget on transport alone compared to 6.5% in South African cities (Kumar and Bartett, 2007). To stem the tide of motorization, promoting public transportation and non-motorized commuting is the vital keys. Urban infrastructures are the most crucial elements underpinning sustainable transport policies and the most vital enablers of sustainable choices (Silva *et al*., 2014).

For the current study, the proportions of public transport modal shares (bus + taxis + train) are respectively 19.0% and 33.3% in Kano and Lagos as indicated in Figures 5 and 6. It is obvious that the public transport modal shares of the two states are largely weighted on buses and taxis, with little or no local train services (0.4% and 1.1% respectively in Kano and Lagos) to compliment in the public transport system.

Although, Lagos public transit has marginally improved due to the positive impact of the new bus rapid transport (BRT) pilot services; congestion is still a perennial problem of the city. The findings of this research are consistent with the survey of United Nations Human Settlements Program GRHS 2013 Report, which estimated between 35- 45% of a public transport share in most Anglophone Sub-Sahara Africa, ranking them among the lowest in the continent (Pirie, 2013). The efficiency of Lagos BRT services has been listed in World Bank (2017) — 9% traffic reduction, 13.5% CO_2 emission reduction, travel time reduction, 48% reduction in average monthly travel cost and 31% accident reduction in the pilot travel corridor. Albeit traffic flow profile as well as indicators of transport sustainability of the entire city's non-BRT routes are getting worse due to increased motorization in the city.

In addition, low public transport services were observed in Kano with the government of Kano yet to commence the proposed BRT and Lite-Rail services across the congested major route corridors (Economic Confidential, 2020). Transport services are currently disorganized as they are handled by multiple private transport interests as the *de facto* managers. The myriad of problems, not least the defective policies, dilapidated infrastructure coupled with the interplay of uncontrolled urbanization and disintegrated land use planning are the major constraints against pathways for adopting more sustainable urban commuting choices in the two Nigerian cities (Figueroa *et al*., 2013). The phenomenal trends of urban growth in the two main Nigerian cities are not only troubling upsets in transport sustainability, but also signals of more extreme traffic congestion, emissions, accident rates, low economic efficiency, socioeconomic disharmony and gaps in vital transport infrastructure.

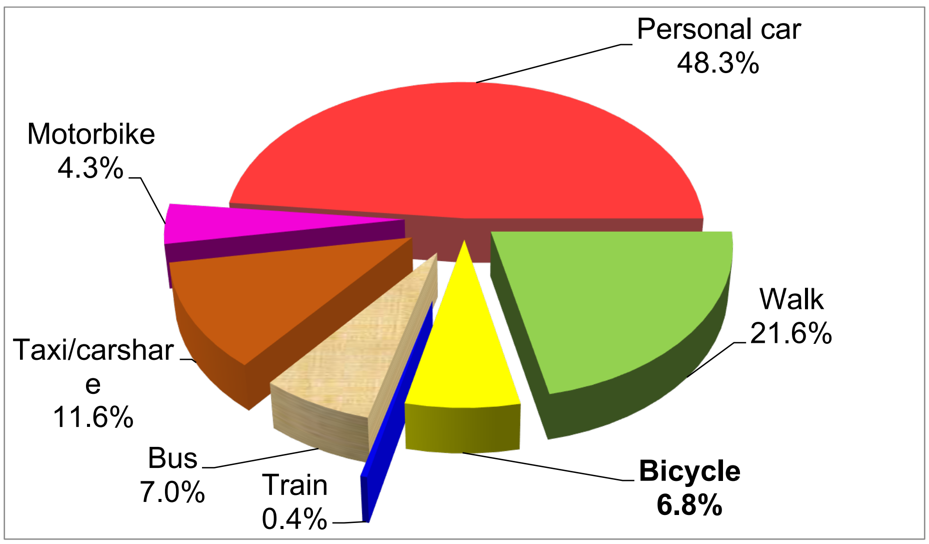
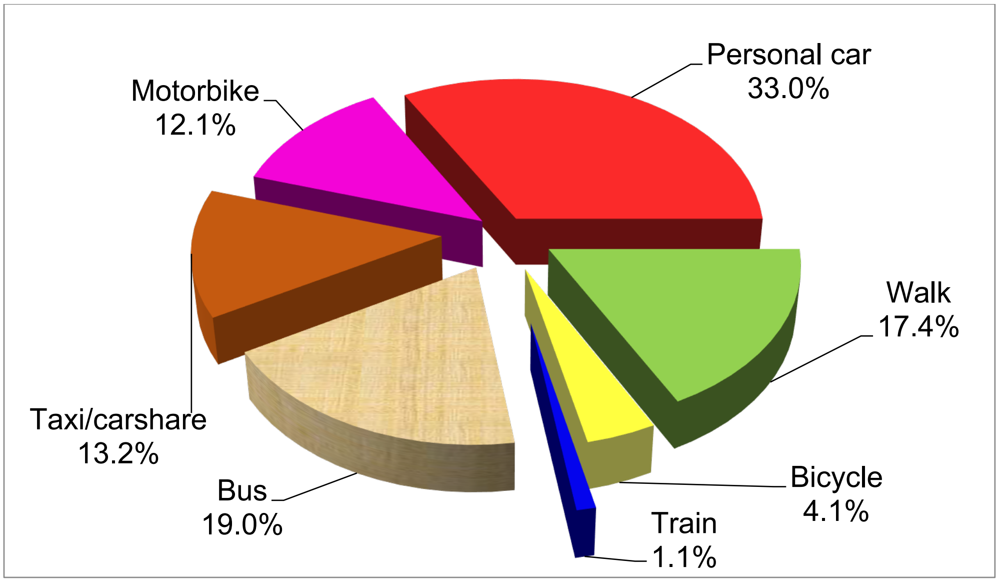


Figure 5: Modal share for journeys in the city of Kano



Figures 6: Modal share for journeys in the city of Lagos

In question Q16 survey prompts, responses were collected on how policy decisions on urban infrastructures and services are reflective of prospects and measures of attainment of sustainable travel in the two cities. The mean scores and standard deviations of various indicators of transport sustainability are in Table 7 and the details of response count results are in Appendices H1 to H16.

Q16. Please, rate your city's transport sustainability by how much the following performance indicators policy and initiatives have been addressed? (5=very strongly addressed, 4=strongly addressed, 3=moderately addressed, 2=poorly addressed, 1=Not addressed)

Table 7: Mean scores and standard deviations of transport sustainability indicators

Indicator needs	Kano (n=505)		Lagos (509)	
	Mean	Standard deviation	Mean	Standard deviation
Public transport	2.245	1.037	2.443	1.032
Synergy between transport systems & economy	2.144	0.990	2.482	1.033
Environmental stewardship & energy use	1.828	0.983	2.490	1.048
Promoting alternatives to physical mobility	2.056	1.007	2.682	1.083
Non-motorized transport	1.767	0.891	2.550	1.031
Security & safety measures	2.133	0.898	2.574	1.004
Reducing motorization & private car use	1.785	0.904	2.567	1.009
Social benefits & equity	1.808	0.862	2.523	0.957

The mean response scores of Lagos survey are relatively higher than Kano counterparts with regards to transport sustainability indicators measured; albeit indicators mean scores of the two cities are very low, with many below average. Urban population contends with inadequate infrastructure, the number of cars on Lagos' roads is increasing, causing heavy jams and gridlock (Mogaji, 2020). Rising sprawl and demography accentuated the gaps in infrastructure need, which leads to perennial traffic problems (Uzondu et al., 2019). The same pattern is replicated with insufficient numbers of public transit vehicles and dilapidated road networks, which, however, pose major commuting problems (Madugu, 2018).

Rather than the usual persuasive rhetoric, the narrative should focus on addressing critical gaps in infrastructure, land use planning, provision of public transit services and creating awareness of sustainable travel behaviour. Sustainable travel goes with access control, akin to the metaphorical statement — *"carrot-and-stick"* and with the right equity struck between social, economic and environmental dimensions for efforts at greening the cities' infrastructure and transport services to succeed.

The final question on transport sustainability section is the survey question gauging how respondents felt about effectiveness of the measures and indicators of transport sustainability in bringing about the desired improvements to the paradigm of sustainable mobility. The last question of the transport sustainability segment is the test on how respondents feel about the efficacy of transport sustainability measures and metrics to achieve the desired changes to the sustainable mobility paradigm.

> *Q17: Rate by summing up your perception on how effective the implementation of needs indicators and policy initiatives in Question 16 above could motivate sustainable transport delivery in your city?" (Very effective=5; 4=effective; 3=medium; 2=ineffective; very ineffective=1).*

The mean scores in Table 8 show that the measures were rated to be at least 80% effective across the wide spectrum of stakeholders. Based on the results in Figure 7, 96.7% and 97.6% of respective respondents in Kano and Lagos rated the measures of transport sustainability from moderately effective to be very effective. The Chi-square test conducted based on cutoff condition (P0.05) and degrees of freedom, DF =16 shows that there is also no significant difference, indicating lack of relationships between ratings and the stakeholders' type at $(\chi^2 = 6.888;\ \rho = 0.549)$ and $(\chi^2 = 15.364;\ \rho = 0.498)$ for Kano and Lagos respectively.

Despite the unanimous agreement on the efficacy of the measures indicated by the means, trends such as an obvious increase in the use of cars and social change as demonstrated by the "sharing economy" have been proposed as a window of opportunity to transform the transportation system in a way that is sustainable. The productive economy is transportation dependent, the enduring vision of effective urban planning, transport infrastructure and management policies are equity-based where progressively a sense of mobility and access to opportunities are recognized (e.g., employments, services, goods, healthcare delivery and education).

Climate policy has affected transport policy priorities as the sustainable transport goals are hindered by targets on low carbon emission travel. These have been echoed with priority areas to expedite action by many countries (Geerlings *et al*., 2016). The European Environment Agency (EEA) recorded that transport alone accounted for 27% of total emission in 2016 with the road sector accounting for 72% of the share (EEA, 2018). The Transport White Paper of European Commission laid down targets of 20% greenhouse gas (GHG) emission reductions from 2008—2030 and 60% reductions by 2050 setting agendas, pathways and milestones for eco-vehicle adoption, motorization reduction and green mobility.

The real paradigm shift depends on the deployment of outlining measures which radically lower emissions. Otherwise, carbon emission figures are likely to be significantly higher by 2030 and 2050 in Nigeria — a country where more 90% of current motorized transport is by road (Odeleye, 2000). This is accompanied with use of vehicles with poor environmental and safety credentials (Uchenna, 2020). Efforts must be channelled to keep the binding Paris Agreement stipulating global temperature increases are limited at pre-industrial levels of 1.5—2°C, and 40% minimum emission cut by 55 countries with 55% shared of global greenhouse emission, this includes Nigeria as signatory (UNFCCC, 2015). The currently ratified Accord of UN Environment Program (UNEP, 2019) stipulated annual global emission cut by 7.6% to achieve the 1.5°C targets of the Paris Agreement by 2030.

Table 8: Effectiveness of implementation of transport sustainability measures for Kano responses

Stakeholder type	Frequency counts, mean & S.D. (n=505)						Mean	Standard deviation
	1	2	3	4	5	Total		
Student	0	2	20	34	34	87	4.115	0.836
Lecturer	0	0	12	14	27	53	4.283	0.900
Government official	0	0	10	22	26	58	4.276	0.738
Private operator	1	4	21	26	34	86	4.023	0.964
User	1	9	60	66	85	221	4.018	0.927
Total	2	15	127	161	200	505	4.143	0.117
Percent	0.4	2.9	25.0	31.8	39.1	100	—	—

Table 9: Effectiveness of implementation of transport sustainability measures for Lagos responses

Stakeholder type	Frequency counts, mean & S.D. (n=505)							Standard
	1	2	3	4	5	Total	Mean	deviation
Student	1	2	7	43	45	98	4.316	0.777
Lecturer	0	0	11	20	27	58	4.276	0.761
Government official	0	1	10	31	41	83	4.349	0.735
Private operator	1	2	25	36	42	106	4.094	0.885
User	1	4	27	48	84	164	4.000	0.911
Total	3	9	80	178	239	509	4.207	0.136
Percent	0.6	1.8	15.7	35.0	47.0	100	—	—

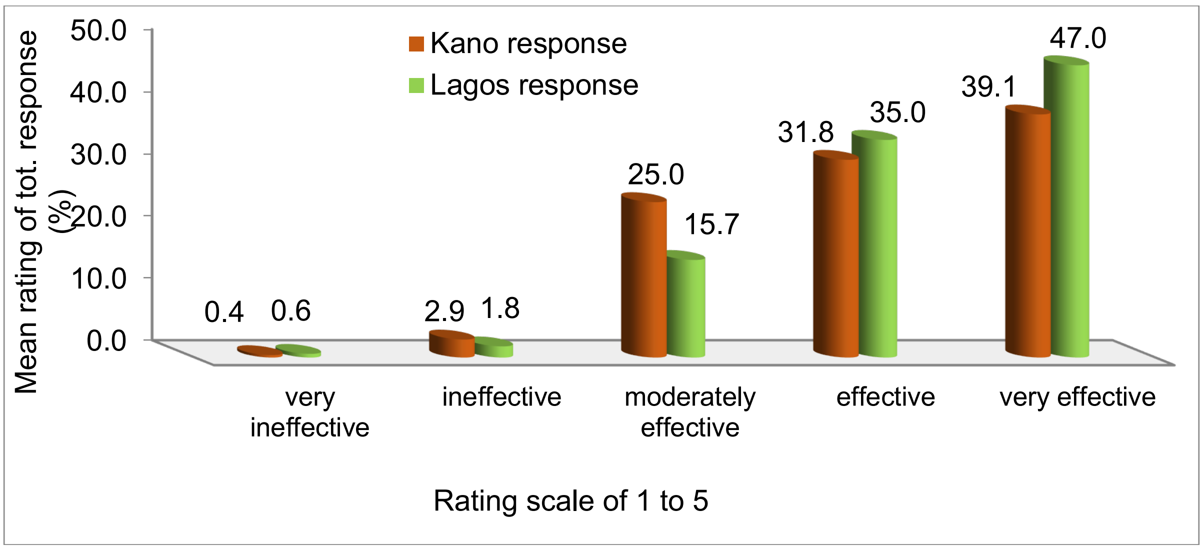


Figure 7: Rating of effectiveness of transport sustainability measures

3.5 Sustainability awareness communication

Questions Q18 was included to determine the best means of effective means of communicating transport sustainability. The results for Kano and Lagos are shown in Tables 10 and 11. Figure 8 shows the relationship between stakeholders' rating and effectiveness of communication. The results showed that 88.8% and 91.8% of respondents in Kano and Lagos respective have positive feelings ranging from moderate to very effective that the various means of communication will increase awareness of transport sustainability. Also, the Chi-square test result with a cutoff (P0.05) and degrees of freedom (DF=16) shows that there is no significant difference, an indication of independent views between ratings of means of communication and the stakeholders' type for Kano and Lagos respectively.

Survey prompt Q18: Rate how effective could the following communication/information channels increase awareness of transport sustainability? (5 = very effective, 4 = effective, 3 = neutral, 2 = ineffective 1 = very ineffective)

Table 10: Effectiveness of means of communication of transport sustainability by Kano respondents

Means of communication	Crosstabs: Rating count						Chi-square test df = 16		
	1	2	3	4	5	Total	mean	χ^2	Sig.
Billboard and posters	10	30	156	152	157	505	3.8	9.335	0.674
Fliers and leaflets	50	47	119	139	150	505	3.6	15.829	0.465
Print media like newspapers, magazines	16	43	100	186	160	505	3.9	21.064	0.176
Electronic media like television, radio	11	21	138	142	193	505	4.0	8.807	0.921
Internet and Social media	22	49	95	138	201	505	3.9	15.225	0.508
Incorporating sustainability into the teaching core and curriculum of education	12	40	147	151	155	505	3.8	18.120	0.317
Total	121	230	755	908	1016	3030	3.8	-	-
Percent (%)	4.0	7.6	24.9	30.0	32.5	100	-	-	-

Table 11: Effectiveness of means of communication of transport sustainability by Lagos respondents

Means of communication	Crosstabs: Rating count						Chi-square test df = 16		
	1	2	3	4	5	Total	mean	χ^2	Sig.
Billboard and posters	5	25	98	183	198	509	4.1	15.608	0.210
Fliers and leaflets	17	30	150	154	158	509	3.8	17.373	0.136
Print media like newspapers, magazines	8	26	112	163	200	509	4.0	23.257	0.107
Electronic media like television, radio	11	23	136	157	182	509	3.9	18.251	0.294
Internet and Social media	11	31	138	155	174	509	3.9	24.970	0.070
Incorporating sustainability into the teaching core and curriculum of education	32	30	109	173	165	509	3.8	12.563	0.704
Total	84	165	743	985	1077	3054	3.9	-	-
Percent (%)	2.8	5.4	24.3	32.3	35.3	100.0	-	-	-

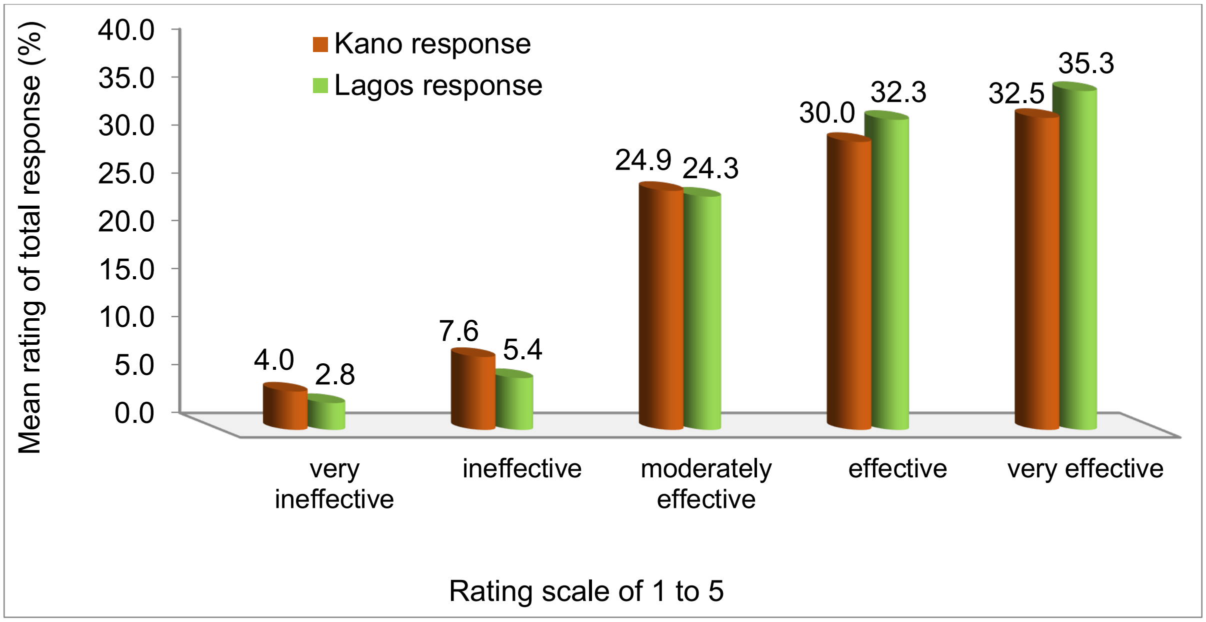


Figure 8: Rating of effectiveness of communication of transport sustainability

Finally, survey Q19 assesses how respondents rated themselves on their knowledge of transport sustainability and Q20 provides the means of communicating research feedback to respondents if desired. The result of the respondents' self-rating of sustainability literacy in the two cities is in Tables 12 and 13 (also plotted in Figure 9). Based on the results, 49.1% of Kano respondents rated their knowledge and awareness higher than average SLT scores while 57.6% of Lagos dweller believed they are moderate 'SLT literate" (i.e., minimum 50% threshold for an 'SLT literate person" proposed by Storey (2013).

The slow progress of changes to transport infrastructure and services in the previous chapters may not support self-appraisals of their knowledge of the sustainability problems. Similarly, Akeel et al. (2017), in sustainability pedagogical research on Higher Engineering education curriculum, blamed the over-rated SLT self-assessment on the over-inflated view of how much they actually know the concept and on their low education. The Chi-square test result shows that there is also no significant difference, indicating lack of relationships between the ratings and the nature of stakeholders involved ($\chi^2 = 10.325;\ \rho = 0.849$) and ($\chi^2 = 17.786;\ \rho = 0.337$) for Kano & Lagos respectively. The ratings of respondents are higher than SLT average score.

Table 8: Kano respondents' self—rating of sustainability knowledge

Stakeholder type	Cross-tabulation: Rating counts (n=505)					Total
	1	2	3	4	5	
Student	24	28	13	10	12	87
Lecturer	11	13	10	6	13	53
Government official	13	11	13	12	9	58
Private operator/manager	21	28	17	18	22	86
User	57	51	34	41	38	221
Total	126	131	87	87	94	505
Percent (%)	25.0	25.9	17.2	17.2	18.6	100.0

Table 9: Lagos respondents' self—rating of sustainability knowledge

Stakeholder type	Cross-tabulation: Rating counts (n=509)					Total
	1	2	3	4	5	
Student	22	24	19	16	17	98
Lecturer	12	13	11	12	10	58
Government official	12	16	23	16	16	83
Private operator/manager	21	22	29	17	17	106
User	35	39	31	32	27	164
Total	102	114	113	93	87	509
Percent (%)	20.0	22.4	22.2	18.3	17.1	100.0

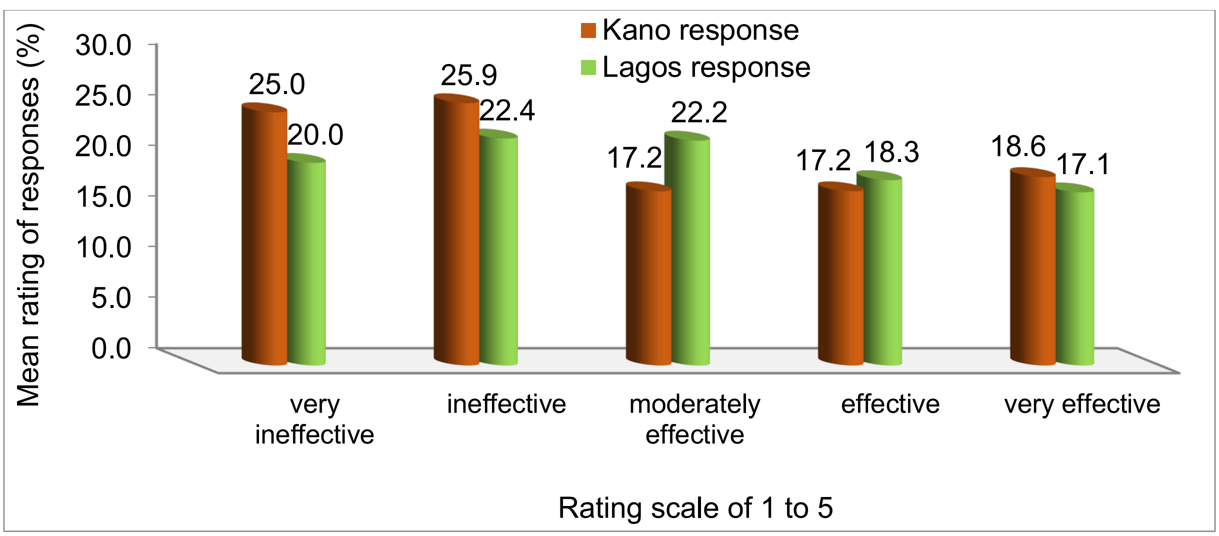


Figure 9: Respondents' self-assessment of sustainability awareness & knowledge

4 Conclusion

The summary of findings can be succinctly presented as follows:

- The low average literacy test scores of 37.5% and 45.2%, respectively, of Kano and Lagos, are indicative of a knowledge gap and low literacy on the subject of transport sustainability.

The results showed weak accomplishment levels for the sectors with most of the measures and indicators of transport sustainability falling below 50% threshold in the literature (Storey, 2013). Researchers have attributed low SLT scores to lack of awareness, low literacy, institutional bureaucracy, defective laws, low income, and corruption among the plethora of problems militating against the successes of sustainable development in Nigeria and many African countries (Thakran, 2004; Akeel *et al*., (2017).

- When respondents rated by how much the various pillars exert its effects on the sector, the effects of environmental, economic, social, and multi-dimensional pillars on sustainable transport development respectively are rated as 49.2%, 50.6%, 50.4% and 45.6% for Kano city, whilst for Lagos, they are 51.8%, 52.8%, 52.8% and 50%.
- The study findings support the view of a need for greater awareness and education regarding sustainable travel behaviors, as all transport sustainability indicators were rated 50% and below, revealing inadequate performance of the sector.
- Consistent with the findings in diverse areas of research, achievements in many aspects of sustainable developments of the country are rated average and below; possibly because of lack of priority and awareness, lack of equity in socioeconomic development and leadership problems (Akee*l et al*., 2017; Ajik*e et al*., 2015; Ima*m et al*., 2008). The research outcomes will serve as a blueprint for the affirmative course of action through a worldview of sustainable development in transport and a literary contribution for the interplay of mobility, services and infrastructure problems in the urban dynamics of developing countries' cities.

6 Disclosure of conflict of interests

The authors declare no potential conflict of interest.

7 Acknowledgement

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CHAPTER SIX: Thematic Analysis of Transport Sustainability Paradigm and Perspectives of Stakeholders of Major Nigerian Cities

CHAPTER SIX

(Undergoing journal review)

Thematic Analysis of Transport Sustainability Paradigm and Perspectives of Stakeholders of Major Nigerian Cities

By

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Abstract

Rising population cum urbanization trends and their ramifications of mobility problems are crucial for urban-dwelling, infrastructures, economy, environment, and morphology of the cities. In many developing countries, keeping harmony between the fast urbanization pace and umpteen challenges of urban mobility has become difficult. This study assesses the institutional policy frameworks and perspectives of transport sustainability in the two of Nigeria's most populous cities (Lagos and Kano). The interview protocol adopted involves semi-structured model questions formulated to reflect the relevant indicators and themes of transport sustainability and were conducted with the various Unit Heads of Transport Departments of the two states. The data collected were transcribed and analysed using NVivo12 Pro software. Although, the interviewees expressed strong optimism of capacity to meet infrastructure and service demands in some of the IN-Vivo statements, the response counts of transport sustainability themes showed lower bars of capacity as more negative sentiments critical of the current and future situations were expressed. The findings' determined that scaling-up the key policy and interventions by authorities and stakeholders will enable the cities to cope with the challenging scenarios of the next decades.

Keywords: Urbanization, motorization, sustainable transport, infrastructure, traffic behaviour stakeholders

1.0 Introduction

Globally, cities have assumed the roles of the de facto government due to the ramification of high urbanization rates. The fallout of World War II came with phenomenal global urbanization growth due to pressure of reconstruction and economic recovery. United Nation Habitat Report on world cities presented evidence of increasing urbanization and grossly 'unsustainable' scenarios of accelerated urban sprawl in many developing countries (UN, 2010). Effective mobility systems are the mainstay of the economy, means of social interaction, liveability and quality of life of the dwelling population.

Empirical evidence has shown unprecedented trends of population agglomeration in Nigerian cities, with some reviews indicating between 5 to 10 percent annual growth rates (Filani *et al*., 2002; Aliyu and Amadu, 2017). Defective policy drives and ineffective planning have led to the rapid expansion of Nigerian cities with scattered mosaic of urban slums beset by infrastructure problems, ineffective public transport systems, traffic congestion, pollution and other environmental problems, housing shortage, insecurity, and social disharmonies.

Urban transportation systems are the very sinews of land use interactions. Therein sustainable transport is one of the core aspects of *'green environment'* and in line with the global yearning for responsible action towards "*balance between current and future needs*" (Marsden and Docherty, 2013; WCED, 1987). According to Rode *et al*, (2017), *"the patterns of development in cities are associated with the growth of urban transport and mobility allowing access for people and goods".*

The positive effect on sustainable transport outlook of a city has been illustrated by research on different aspects of transport systems. It comprises economic development, employment, property values and enhanced quality of life, promoted by mixed land use, improved air quality (due to emissions and/or carbon reduction), congestion reduction, flexibility and reduced modal travel time (Fernández-Isabel & Fuentes-Fernández, 2019; Delatte *et al*., 2018; Alotaibi and Potoglou, 2018; Litman, 2015; Amin *et al.*, 2014; Amin *et al*., 2014; El-Geneidy *et al*., 2013).

In Nigeria, transport policy decisions are predominantly at the behest of non-profit actors representing multi-level *urban governance*[26] including federal, state, and local governments. The relationships which endure a lot of complex and sometimes turbulent political will have led to many policy failures and misdirection. Inconsistent public transport policy and lack of civic education have increased motorization thereby making congestion part of chaotic scenes of everyday city life in Nigerian cities shown in (Figures 1a-d).

Evidence of these problems could be seen in dilapidated transport infrastructures, unsafe transport systems and road transport, which represent staggering 95% of modal share in Nigeria. Compared to *urban regimes* [27]of developing Europe countries and the United States of America, the strength of public-private coalition has greatly been deployed. Rather than flexing the traditional power of central authority in developing countries, the *urban governance* advocates equitable devolution of power and control on issues that affect their wellbeing; a reflection of the maxim that:

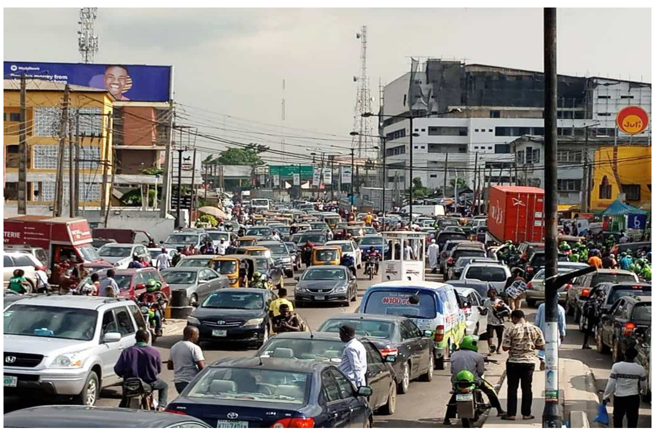
[26] Urban governance includes partial "destabilization of policy making, deinstitutionalization of policy making and challenge to democratic system which requires diversified complex decision-making alliance" (Chuang, 2019).

[27]Urban regime is the analysis of relationships between public-private urban coalition" (Giersig, 2008)

“the question is no longer what autonomy actually is for local authority within state, but capacity territories have to become collective actors” (Le Galès, 2002; Le Galès and Therborn, 2010).

Public authorities as government employees are the sole policy purveyors, mediators, and influencers of transport sustainability in many developing countries. They are vested with the authority to manage, make key decisions and steer the overall direction of government policies (Sloman *et al*., 2010). DeHart-Davis and Guensler (2005) reported the existence of meddlesome bureaucratic pressures of urban governance on vital management decisions deployed overtly or covertly by experts working at the behest of urban government:

“Given the dwindling government resources and waning political will to impose direct control over individual behaviour, policy-makers may increasingly attempt to persuade employers to mediate society’s most pressing and intractable problems, such as individual driving behaviour”.



(a)

(b)

(c)

(d)

Figures 1(a) & (b): Typical traffic congestion Ikeja-Lagos (Source: Author, 2019) Figures 1(c) & (d): Typical traffic situation in Kano metropolis (Source: Author, 2019)

The present work involves thematic assessment of the institutional policy framework and perspective of transport sustainability using interview instruments conducted by experts who are representative of governments of the two most populous Nigerian cities. According to Cresswell (2012), an *interview* is a "*face-to-face conversation typically between a researcher and a participant involving a transfer of information to the interviewe*r".

In this work, the interview is intended to provide a critical assessment of the extent of achievements in measures that are reflective of the drive towards sustainable commuting in the Nigerian most congested cities - Lagos and Kano. Through interview survey, we focus on the sentiment assessments (positive and negative) and the priorities of the various authorities relating to transport policies, institutional frameworks, benchmarked targets, travel behaviours and the measures being taken to align with the developmental goals and visions of sustainability worldview. The survey outcome is envisioned to answer or abstract the survey prompt question:

> "*How are the city's transport systems and infrastructures structured to deliver the current and future goals of sustainable commuting?*"

2.0 Materials and Methods

The research involved interviews of experts who are stakeholders representing authorities and governments of the two cities to steer the discourse on transport sustainability paradigm of the countries. Ten (10) model questions were formulated based on indicators and themes of transport sustainability as shown in the interview protocol (Appendix 1A). They include measures promoting public transport, synergy between transport systems and economy, environmental stewardship, and energy use. Others are measures promoting alternatives to physical mobility, non-motorized transport modes, security/safety, reducing motorization as well as social benefits and equity. The procedural guide involves an interview protocol, which is a semi-structural open-ended subject related probe with tease out questions to elicit thematic responses by words, phrases, or sentences that reflects the research questions in face-to-face interaction. The questions are:

Q1. Sustainable mobility is a measure to encourage public transport, reducing motorization, eco-vehicles, provision of sustainable travel choices and pollution reduction, what strategies have been adopted to achieve the objectives in your state.

Q2. Transport infrastructures are both physical and cyberspace assets which can impact positively on sustainability drives and pathways, what are the existing realities and strategic vision for the future of your state in terms of transport infrastructure?

Q3. In year 2030 to 2050, cities of the developing countries (including your own) have been projected to top the charts in terms of urban population, congestion, and pollution. And reckoning with the maxims that "you cannot build your way out of congestion", what policy drives and strategic planning have been in transport demand management?

Q4. As part of sustainable development goals (SDGs), built environment, including transport infrastructure must be resilient to unforeseen events (extreme weather events, risk, and security) to ensure their resistance or survival, what strategies are in place in your city to guarantee the resilience of transport infrastructures and mobility?

Q5. Infrastructure investments are complementary to economic growth and development, what impact(s) does transportation infrastructure investment rendered to the city's economic growth and development?

Q6. In what ways does transport infrastructure investment impacts on mobility, linkage, and dynamics of social change within the state?

Q7. How do transportation systems in the state integrate communities with a focus on urban-rural integration, land use interactions and regional relationship?

Q8. What impact do transport infrastructures have on the political administration, security and safety, law, and order in the state?

Q9. Q9. How do you assess the overall measures, indicators and performances of sustainable transportation systems and infrastructures on the overall pace of development and future of the city?

Q10. Reckoning with the priorities of governments, geopolitical factors, economic gaps, social-cultural diversity, inequalities in the endowment of natural and human resources, what model hierarchy of sustainability pillars (environment, social and economic) will be best suited to your city's transport infrastructure?

Interview contents were first transcribed and analysed using qualitative data analysis (QDA) software called NVivo 12 Pro version[28]. Other useful qualitative analysis softwares that can be used are MAX QDA, LEXIMANCE ATLASTi (Palmer & Bolderston, 2006). In this study, unstructured and non-numerical data indexing, theming, and theorizing were adopted. The first step carried out was to juxtapose the relationships by querying the relevant themes in the interview transcripts in comparison to emerging broad-based transport sustainability identified in the literature.

The *thematic analysis*[29] followed the chronological inductive order of *coding*[30] and collating the *codes* into relevant themes as recommended by researchers (Braun and Clarke, 2006; Park and Chowdhury, 2006; Leech and Onwuegbuzie, 2011; Chatterjee *et al*., 2017; Barter and Chatterjee, 2019). Relevant sub-themes were categorized as a child *node*[31] under which they are related. Data reduction method follows the first coding method involving a mixed method of

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[28] https://www.qsrinternational.com

[29] Thematic analysis involves identification of impactful concepts reflecting the qualitative research data set in the analysis

[30] Coding means collecting words or phrases which captures the essence of various nodes

[31] Node means reference or code collection defining a theme

participants' narrative, emotion, and *In-Vivo coding*[32] following the pyramid scheme showing the step-by-step research modelling and abstraction shown in Figure 2.

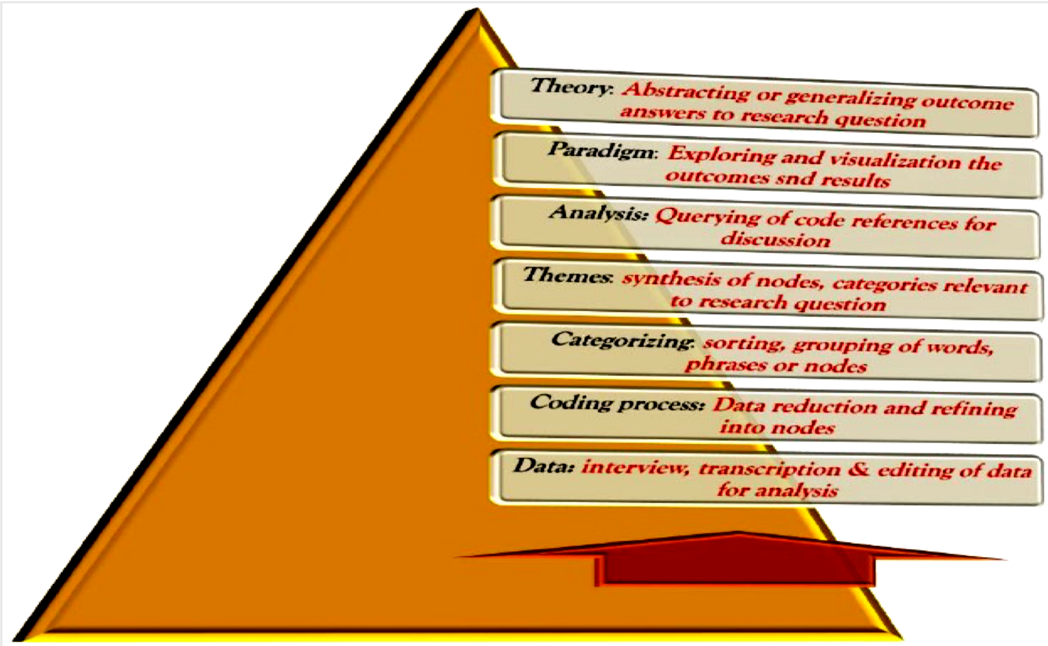

Figure 2: Research pyramid scheme (Source: Author, 2019)

2.1 Ethical consideration

The interview protocol was submitted to Science, Technology, Engineering and Mathematics Ethical Review Committee of the University of Birmingham, UK. The researcher vouchsafed strict adherence to standard ethical procedures in every step of the research. All conventional ethical procedure bordering on voluntary consent, withdrawal right, confidentiality and data handling were addressed in a consent form. There were no outstanding potential ethically important concerns raised and the ethical approval registered Ethical Review ERN_18-1248 was issued in the study.

3.0 Results

To research outcome explores meaningful similarities and compiles categories of subject themes for the study using inferential information or descriptive statistics by first, assigning thematic codes. The transcript of the interview was initially uploaded into NVivo 12 software for code—forming and the relevant themes on the various topics of transport sustainability topics - infrastructure, urban form, economic indicators, environmental aspects, and social outlooks to

[32] *In-Vivo* coding means coding by direct quotation of participant's response

be categorized. The necessities of robust and broad-based interventions to improve public transport systems with a focus on public transportation and non-motorized commuting to improve the quality of urban life were analysed.

The component inferential analysis considered sentiments as distinct vitality and if they are correlated with a particular emotion, distinct appraisals, different degrees of anticipation or different patterns of thought-action. Table 1a and 1b show the result of reference counts queried based on positive and negative sentiments expressed in respects of the various themes of transport sustainability for the two cities. Sentiment weights in the results are mere emotional cast of the consciousness and thinking of the subject of transport sustainability.

The finding highlights evidence in the responses supporting gaps between the current realities and future measures proposed to mitigate the seemingly perennial congestion frustration and the plethora of urbanization induced problems plaguing the two cities. Regrettably, the study displayed low performance of transport sustainability was highlighted by higher counts of negative sentiments over theme counts supporting the expression of positive optimism and emotions assuring future sustainable or ‘smart city’ laundered in the interview. Also, interview finds some corroboration between statements of intents and practical steps in the areas of critical infrastructure, planning policies, regulations, and management, albeit, with incommensurate strategies in keeping pace with the trends of urbanization and provision sustainable urban mobility.

Table 1a: Reference counts of transport sustainability themes by sentiments expressed in the interviews

Thematic categorization[33] by nodal collection	Descriptions	Kano: Counts			Lagos: Counts			Total	Weight (%)
		+ve	−ve	Sum	+ve	−ve	Sum		
Social Concept									
Transport infrastructure	Quality & quantity of cyber-space assets in the transport systems	8	20	28	19	30	49	77	9.7
Accessibility	proportion of Service availability & frequency	4	8	12	3	6	9	21	2.6
Congestion reduction	Reducing delay or travel time reduction	3	18	21	7	21	28	49	6.2
Sustainable mobility, biking & walking	Public transport & facilities for non-motorized means (biking & walking)	5	25	30	12	26	38	68	8.6
Information/communication	Awareness, education, news, information e.g., phone and internet services	0	2	2	0	4	4	6	0.8
Road network & Vehicles	Road network, linkage, nodes, intersection, and regional interaction	4	11	15	6	16	22	37	4.7
Reliability & efficiency	Travel length, shortest distance, fast routes-subways, metros, tubes, rails, all weather travel consideration & modal choice in worst traffic	0	2	2	2	6	8	10	1.3
Security & Safety	Identifying vulnerability, risks, crimes & negative externalities imposed on users	3	7	10	8	14	22	32	4.0
Flexibility, comfort & efficiency	Intermodal linkages, door-to-door services, coverage & reliability	0	3	3	4	12	14	17	2.1
Availability of disable service	Facilities and protection for disable e.g., ramp, lifts etc	0	2	2	3	4	7	9	1.1
Social equity & benefits	justice and fairness in share of impacts, development benefits, job creation	2	6	8	8	6	14	22	2.8
Modal share	proportion of commuters using different types of transportation modes rail, water, air, road, cycling and walking	0	5	5	7	11	18	23	2.9
Parking & terminal facilities	Availability of parking facilities including bus stops, lay-bys, stations as well as disincentives e.g., restrictions, regulation and parking toll	4	7	11	5	15	20	31	3.9
Transportation & public transport services	Means of commuting, measures reducing motorization including train services, car-sharing, BRT, Metros, trams, cable cars	3	10	13	13	20	33	46	5.8
Private car & motorization reduction	Measures of reducing car ownership, motorization reduction, non-motorized commuting	2	8	10	3	14	17	27	3.4

[33] Thematic categorization is the collection of relevant nodes for formation of the various transport sustainability themes

Table 1b: Reference counts of transport sustainability themes by sentiments expressed in the interviews (continued)

Thematic categorization by nodal collection	Descriptions	Kano: Counts			Lagos: Counts			Total	Weight (%)
		+ve	−ve	Sum	+ve	−ve	Sum		
Reduced land change & land use issues	Land consumption, land ownership, mixed land use neighbourhood planning, services, school & work trips	3	5	8	1	7	8	16	2.0
Telecommuting & tech-based services	All alternatives to physical commuting e.g., tele-shopping, open university, teleconferencing, courier services	0	1	1	1	3	4	5	0.6
Traffic management	Signalization, signs& signal, right of way & flow of traffic	2	7	9	4	11	15	24	3.0
Aesthetic & beauty	Beautification, facelift, and parks along travel corridors	3	4	7	4	7	11	18	2.3
Pedestrian crossings, flyovers& speed reduction	Speed reduction and traffic calming measures, bumps, shoulders & protective barriers for pedestrian protection	2	6	8	4	9	13	21	2.6
Public health & emergency response	Public health services, waste disposal, sanitation, emergency response & accident & casualty reduction	2	4	6	4	4	8	14	1.8
Accident reduction rates	Measures to reduce accident casualty, death, injuries & economic losses	2	6	8	2	9	11	19	2.4
Environment concepts									
Waste remediation schemes	Transport wastes recycling including automobile parts, tyres, used oils	3	3	6	3	6	9	15	1.9
Air quality, pollutant & noise reduction	Air quality, dust, noise pollutants and other control measures	0	6	6	5	9	14	20	2.5
Carbon & greenhouse gases reduction	Schemes for carbon footprints, targets, and benchmarks	0	3	3	4	6	10	13	1.6
Ecological footprint, resilience	Flooding, wind gust, heatwave & other extreme weather events	1	2	3	3	8	11	14	1.8
Economic concepts									
Road tax, finance & investment	Public funding, road tax, investment, and maintenance cost	2	2	4	5	9	14	18	2.3
Parking toll, congestion charging	Parking vending & tickets, dedicated routes & congestion disincentives	0	7	7	0	8	8	15	1.9
Average income & wages	Transport infrastructures enhancing business & produce	9	9	18	10	18	28	46	5.8
Mean transport cost	Reduced household transport expenditure	2	9	11	6	12	18	29	3.7
Economy, productivity & employment	Business, trade and job creation	6	8	14	6	7	13	27	3.4
Fuel reduction & clean energy	Vehicle driven by clean fuel & renewable energy sources	0	1	1	0	3	3	4	0.5
	Total	75	217	292	160	341	501	793	100

4.0 Analysis and Discussion

The thematic analysis implemented in the data classifications supports the stakeholders' knowledge of the requirement of transport sustainability for the two cities. Interviewees' perceptions show congruence and harmony between public transport users and positive effects of infrastructure, travel cost, convenience, comfort, reliability, security and safety. There is a serious infrastructure deficit with 95% modality in favour of road transport. Arguably, infrastructure approach alone is not enough inducement to public transport and non-motorized commuting, other soft measures, including incentives for public transport use and disincentives to private mode (e.g., low fares, road tax and parking toll) could also challenge sustainable commuting (Lidón *et al*., 2016; Zhang *et al*., 2015)**.**

The total numbers of transport sustainability thematic references are 292 and 501 respectively for Kano and Lagos. The figures show higher indication of awareness and sustainability thinking of authority of Lagos State than Kano State. Generally, negative sentiments abound more in the interviews corroborative of the existing gaps and realities of the two cities as in Table 1. There are 217 and 314 negative sentiment counts in Kano and Lagos interviews respectively, compared to the expression of positive optimism with counts of 75 and 160 for Kano and Lagos respectively.

As seen in Figure 3, Lagos has more sustainability indicators than Kano, but overall proof of the need to scale up key policies and initiatives to achieve sustainable urban mobility has been justified. Significant relative negative transport sustainability concerns over optimistic sentiments tacitly reveal the low policy and achievement bars and lack of preparedness for future population and urbanization booms that Africa is expected to rank higher (Bloch *et al*., 2015; Farrell, 2018).

In Lagos, it is important to provide a good public transport service for a resilient picture towards sustainable cities, to minimize the use of private cars and to increase non-motorized commuting. Lagos has an urban population of about 14million in 2019, but much is left to be done while a rather slow pace with many critical gaps visible in the target of becoming a '*smart city'*[34] are some of the upsets (Makinde *et al*., 2017).

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[34]The interviewee prominently expressed hope of Lagos becoming a "Smart city', defined by "a smart and sustainable city is an innovative city that uses information and communications technologies and other means to improve living standards, efficiency of urban management and urban services and competitiveness while meeting the needs of current and future generations in the sectors of the economy, society and the environment" (van den Buuse and Kolk, 2018).

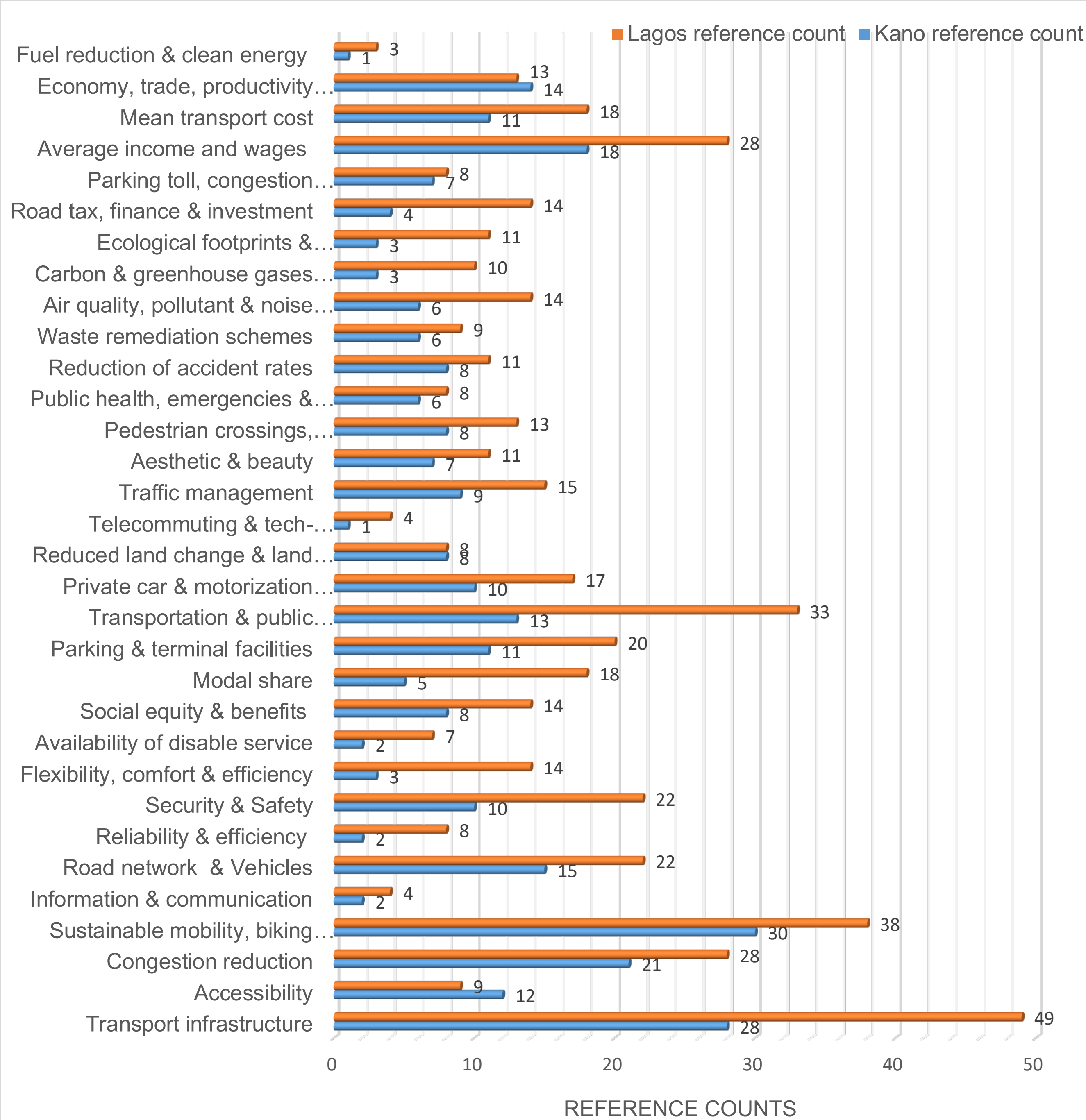

Figure 3: Transport sustainability themes reference counts

Even the most celebrated coalition of urban experts for transport management in Lagos State, *LAMATA*[35], seemed to have neglected the opportunity offered by cycling in the modal share of urban commuting in their Strategic Transport Master Plan for year 2032. The same uni-modal

[35] *Lagos Metropolitan Area Transport Authority* (*LAMATA*) is the agency vested with the responsibility of "planning, implementing, regulating and franchising public transport infrastructure and operations in Lagos State"(https://lamata-ng.com/, accessed , 05/11/2019)

policies tilted in favour of road infrastructures were replicated in Kano. Other critical gaps observed by researchers are infrastructure, financing, defective policies and regulations, security and safety (Mobereola, 2006; Duduta *et al.*, 2012). The interviewee, in his corroboration of the problems contended that:

> *"The imperative action calls of sustainable transport have been prioritized, as Lagos currently home to one-tenth of the Nigerian population in land area less than one percent of the country. Some of the problems include the crisis of authority between the state and federal government, infrastructure, finance, political will and enforcement of the law. Transport is everything to the city's survival and aggressive policy drives are currently being pursued not only to curb congestion but to make our vision of a smart city a reality"*
> *(**Assistant Director, Lagos Ministry of Transport**).*

Although, Kano state is favored by its huge land mass (*circa* 20,680 km^2), only eight of the 44 development area councils fall within the zone of the Kano Metropolis with most of land use and commercial activities concentrated with a congested nucleated zone of about 499km^2. According to the National Bureau of Statistics (NBS) figures, the Kano metropolitan city which had 900,000 residents in 1983 had grown to over 4million inhabitants in 2018 (Madugu, 2018).

The developmental trajectory of the shared public spaces, transport services and infrastructures for motorized and non-motorized transport are not in tandem with this booming urbanization rate. Perhaps, some reactive measures, including the introduction of one hundred Bus Rapid Transit (BRT) buses (without BRT routes) were both ineffective and inefficient. In addition, tacit expression of disenchantment and the dysfunctional and non-aligned policies towards public transportation and the sustainability paradigm are visible. This is evident in the interviewee's idiomatic analogy (quote below) referring to infrastructure gaps and fewer choices of modality.

> *"We must put the cart before the horse. Inadequate infrastructures have hampered the containment of traffic congestion problems"* ***(Director, Transport Unit, Kano State Ministry of Works, Housing and Transport).***

Also, another strong factor pushing the rate of motorization is the status definition and symbolism of social stratification of owning a personal car among the Nigerian populace. Lagos has its car culture etched in colonial history and since then, many residents have been acquiring cars not for the sake of necessity, but in keeping with their status prestige and social standing. In reality, Kano city is a historical horse and bicycle city. Similar views of disconnection between land use interaction and non-motorized commuting especial biking and walking were expressed in Kano.

> *“Our bike culture is gradually being lost to motorized vehicles. Nowadays, people are acquiring more and more personal cars to show their status in the society rather than need or convenience”* ***(Director, Transport Dept., Kano State Ministry of Works, Housing and Transport).***

The plague of status motorization has not spared people on the lowest rung of the social ladders. In the quest for a status boost for the poorest segment of the population and perhaps, because of perennial congestion in most cities, the stock of motorbikes rose in 2015 to about 31% of all registered automobiles in Nigeria (Onawumi *et al*., 2016). Also, motorbike accident(s) has become one of the leading causes of road traffic accident (RTA) casualty with an annual death rate of about 23-30% in Nigeria (Manasseh, 2013; Emiogun *et al*., 2016). *Global Status Report on Road Safety* reported that out of the annual global RTA deaths of 1.3million, Africa ranks the highest having fatality rate of about 26.6% per 100,000 population with its flash points in Sub-Sahara Africa (SSA) (WHO, 2015 & 2018).

According to the same report, Nigeria has RTA mortality, including biking and pedestrian-related accidents, accounting for annual mortality of 20.5% (35,621 deaths per 100,000 persons) making it one of the highest public health burdens in the country. While researchers have identified factors, including poor infrastructures, safety regulations, traffic management and other human factors, the menacing pace of heavy motorization has further complicated the problems of urban mobility in most Nigerian cities (Nantulya and Reich, 2002; Ohakwe *et al.*, 2011).

Figures 6 is the analysis word-cloud of thematic references emerging from the interview. From the word cloud, the higher the strength of word frequency queried in the analysis, the larger the displayed font size of the thematic words and is an interpretation of the importance of the reference to the conceptual discourse and subject of the interview. In this case, transport infrastructure and sustainability clearly ranked the most highlighted references to concepts of transport sustainability among the emerging concerns and thinking of local authorities of the two Nigerian cities. Figure 7 shows the relationship model tree for the query of thematic concepts in the analysis, which are categorized by close references into measures supporting a particular thematic concept.

Figure 6: Transport sustainability world cloud for Kano and Lagos

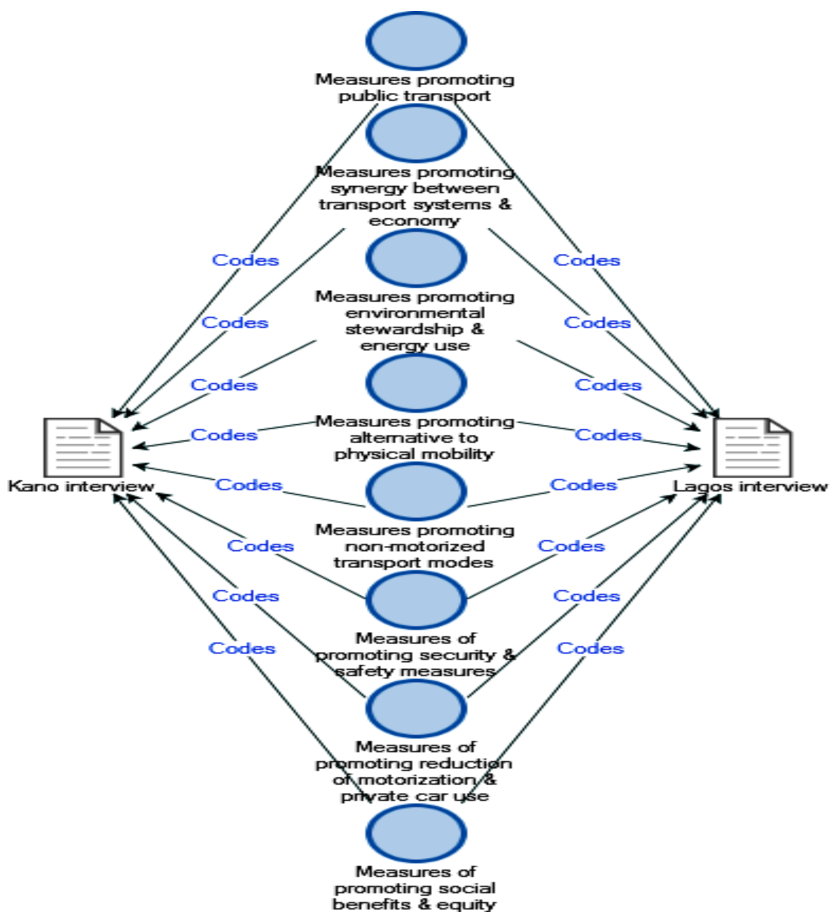

Figure 7: Analysis model tree for measures promoting transport sustainability

5.0 Conclusion

From the interview survey of the two Nigerian cities -Lagos and Kano, transportation has been identified as major contributors and driving force of spatial-temporal dynamics and morphologies of the urbanization. The research has provided some discernible evidence of convergence between transport infrastructure problems in the cities and non-alignment of public policy goals, mismanagement, and laissez-faire attitude towards public transportation sector. As a result of the neglect, socioeconomic impacts of sustainable transport measures were hardly quantified; thereby, leaving the problems unmitigated.

The results have shown the gaps even as the experts were optimistic about the future. According to some researchers, the extent to which employees of an organization can be interviewed on behalf of his employer exerts some caveat and corporate defense for the employer (Bartle and Chattterjee, 2019; Van Malderen *et al*., 2013; Lyon *et al*., 2009). Amidst interviewees' positive perceptions in some *IN-Vivo* responses, the sentiments of transport suitability themes, albeit speak for worsening mobility problems. Interviewees are employees of the city authorities who will perhaps; speak for positive images through the lens and collective corporate standpoint of their employers. Lyons *et al*. (2009) concluded that:

> "*There was difficulty in judging how and to what extent the individual responding to a survey on behalf of a business could reflect the corporate view"*.

There is a steady but progressive ebbing of the bar on habitability, flora, and fauna of urban environment due to dramatic urban change, population transition, motorization, and lack of proactive interventions in terms of planning, policy framework, management, and regulation of public transport. Lack of equity in terms of economic and social benefits has increased the number of urban slums across the fringes of the city landscape.

The contemporary urban challenges of urban commuting, linkage, connectivity, and land use interaction with anthropogenic factors of land change, carbon emission, pollution and flooding have exacerbated vulnerability and compromised resilience of the two cities against any difficult situations. Out and above any measures, infrastructure and mobility demand management is more critical which require prompt attention to salvage the difficult situation.

The study shows prevailing evidence that existing developments in the two cities in terms of urban mobility are unsustainable and unable to fulfil future demands. In the interim, hard measures such as access control might not bring the desired change for a developing economy like Nigeria due to gross infrastructure gaps and low-income situation. Soft measures of influencing travellers' attitudes and behavioural choices through mobility management could bring some positive impacts on traffic and congestion problems.

According to CIVITAS (2013), 'soft mobility demand measures' such as "marketing, information, communication, education, organization of services and coordination of activities" are better in terms of the impact the coercive and disincentive approaches. Also, urban landscape spatial disparities must be addressed with balances developments equitably shared in development areas and promoting rural-urban linkage as well as regional interactions. The findings are expected to serve as a blueprint for a policy maker to reinvent their wills and policies towards the challenges of the future and a technical contribution technical to academic discourse.

6.0 Disclosure of conflict of interests

The authors declare no potential conflict of interest.

7.0 Acknowledgments

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https://www.who.int/violence_injury_prevention/road_safety_status/2018/en/

APPENDIX A1: INTERVIEW APPOINTMENT AND PROTOCOL

LETTER OF INTERVIEW SCHEDULE APPOINTMENT & INTERVIEW PROTOCOL

Department of Civil Engineering,
University of Birmingham, U.K.
B15 2TT, Edgbaston, Birmingham, England.
Date

The Commissioner/Director,
Ministry of Transport,
Lagos/Kano States, Nigeria

Dear Sir/Madam,

REQUEST FOR INTERVIEW SCHEDULE APPOINTMENT

My name is **Suleiman Hassan Otuoze**. I am a Doctoral Researcher from the Department of Civil Engineering, University of Birmingham, U.K. I am working on a research topic entitled **"Critical Infrastructures for future transport in megacities"**. The survey is titled **"Awareness level of transport sustainability imperatives among stakeholders in Nigerian major cities"**, and is one of the research sub-themes or objectives to model sustainability awareness vis-à-vis the thinking among stakeholders (students, lecturers, government officials, private operators/ managers and public users) in the Nigerian transport sector. The study is focused on the Nigerian transport infrastructures and the future scenarios affecting the country's two most populous cities (Lagos and Kano).

I am writing to seek an appointment for a schedule of interview with you to respond to my research study question on one-on-one face-to-face interaction on issues bordering the transport infrastructures of your city. The interview session is anticipated to last for duration of approximately 45 to 60 minutes.

Appointment could be communicated to the researcher through following address and phone numbers: *Suleiman Hassan Otuoze, Dept of Civil Eng., University of Birmingham, B15 2TT, U.K. E-mail: HSO647@student.bham.ac.uk. Phone No:*

Looking forward to your kind response.

Best regards.

Yours faithfully,

Signature: ....

Suleiman Hassan Otuoze

INTERVIEW PROTOCOL

Date and time of interview: ....

Location/Address: ....

Interviewer: ....

Position of Interviewee: ....

Dear Sir/Madam,

Thank you for accepting my request to engage in this face-to-face stakeholder interview session of the doctoral research topic titled "Critical infrastructure for future transport in megacities: A case study of Nigeria".

Your participation in the interview session is voluntary and inputs, opinions, knowledge and perception from the session will be not be transmitted or used for any purpose other than the proposed research. All notes and recordings taken during the session as the identity of interviewee will be kept in the strictest confidentiality.

This survey aims to collect information/data from experts or stakeholder on transport system sustainability in the state. Recall that sustainability involves "the *development (measures) that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1983). With respect to transport sustainability, the following survey questions will provide bases for assessment of developments, vision, progress and gaps in city's transport sector:

1. Sustainable mobility are measures to encourage public transport, reducing motorization, eco-vehicles, provision of sustainable travel choices and pollution reduction, what strategies have been adopted to achieve the objectives in your state.
2. Transport infrastructures are both physical and cyberspace assets which can impact positively on sustainability drives and pathways, what are the existing realities and strategic vision for the future of your state in terms of transport infrastructure?
3. In year 2030 to 2050, cities from the developing countries (including your own) have been projected to top the charts in terms of urban population, congestion and pollution. And reckoning with the maxims that "you cannot build your way out of congestion", what policy drives and strategic planning have been for transport demand management?
4. As part of sustainable development goals (SDGs), built environment including transport infrastructure must be resilient to unforeseen events (extreme weather events, risk and security) to ensure their resistance or survival, what strategies are in place in your city to guarantee resilience of transport infrastructures and mobility?
5. Infrastructural investments are complimentary to economic growth and development, what impact(s) does transportation infrastructure investment rendered to city's economic growth and development?
6. In what ways does transport infrastructure investment impacts on mobility, linkage and dynamics of social change within the state?
7. How do transportation systems in the state integrate communities with focus on urban-rural integration, land use interactions and regional relationship?
8. What impact do transport infrastructures have on the political administration, security and safety, law and order in the state?
9. How do you assess the overall measures, indicators and performances of sustainability transport infrastructures on the overall pace of development and future of the city?
10. Reckoning with the priorities of governments, geo-political factors, economic gaps, social-cultural diversity, inequalities in the endowment of natural and human resources, what model hierarchy of sustainability pillars (environment, social and economic) will be best suited to your city's transport infrastructure?

****Thank you for your time and valuable contributions****

CHAPTER SEVEN
Measuring transport demand management compliance using AHP and SERVQUAL models: Case study of Nigerian cities

CHAPTER SEVEN
(Undergoing journal review)

Measuring transport demand management compliance using AHP and SERVQUAL models: Case study of Nigerian cities

by

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Abstract

Urbanization has continued to widen the gap between demand and resources available to provide resilient and sustainable transport service in many fast-growing developing countries cities. Transport demand management is a decision-based optimization concept for both benchmarking and ensuring efficient use of transport resources. This study assesses service quality of infrastructure and mobility services in the Nigerian cities of Kano and Lagos through five dimensions of quality (i.e., Tangibility, Reliability, Responsibility, Safety Assurance and Empathy). The methodology adopts a hybrid AHP-SERVQUAL model applied on questionnaire surveys to gauge the quality of satisfaction and the views of experts in the field. The consistency ratio (CR) test produced values of 0.0341 and 0.0373 for Kano and Lagos respectively. The pairwise parameters for the two cities meet the criterion of $\mathrm{CR} \leq 0.10$ for satisfactory multi-criteria decisions. The criteria wights (WC) from AHP analysis prioritize tangibility, which defines the state of transportation infrastructure and services, in terms of satisfaction qualities and intervention decision weights in the two cities. The results of SERVQUAL modelling recorded ‘unsatisfactory’ ratings of service quality in the two cities with CSI values of 48% and 49% for Kano and Lagos respectively. The satisfaction indices are identified as indicators of low performances of TDM measures and the necessity to re-order priorities and take proactive steps towards infrastructure. The findings pilot a new framework in urban transport science, providing multi-criteria decision tool for equitable portfolio allocation, intervention hierarchy and resource management to deliver future resilient city and sustainable mobility.

Keywords: Transport demand management, Decision support, Infrastructure, Service quality, Sustainable travel

1.0 Introduction

The roles of urban centres as the de facto economies of many countries are increasingly challenged by disruptions from social disharmony and a plethora of environmental problems arising from urbanization, population growth and transport problems. Transportation is the underpinning of urban accomplishment, providing linkage and interaction between the population and a means of carrying out land use activities. World Urbanization Prospects 2018 projected that 7 out of every 10 people by 2050 are going to be city dwellers with increased burden on resources, ecology, and infrastructure (*United Nation, 2020)*.

The torrent of urbanization globally has persistently troubled many cities in developing countries with mobility ranking high among complicated and complex challenges of urban dwelling. Authorities and governments in many cities of developing countries have rolled out a number of policies, strategies and programmes to engineer sustainability and resilience with little success – not least because of the pace of spatial expansion and population growth.

Spontaneous *urban sprawl*[36] *has* fragmented metropolitan areas of the developing countries with scattered mosaics of urban and peri-urban slums and large swathes of satellite villages in the urban fringes for people with low social rungs (James *et al*., 2013). Concerning mobility, unrestricted urban growth increases transportation infrastructure needs, travel costs and time, congestion, pollution, and social segregation in both the city and the countryside. Transportation infrastructure has spurred the pace of motorization and private car ownership because of fragmented planning, ineffective laws, poor safety, and security rather than ameliorating the problem (Angel *et al*., 2012). The consequences of unrestricted growth and development of cites are overwhelming frustrating urban life, in addition they have undercut social-economic and environmental viability of many cities.

The traditional infrastructure and access control solutions have exhausted its limit of efficacy. As such management is currently the unique solution to stem down the increasing tides of motorization and congestion in the fast-evolving cities (Metz, 2018; Transport for London TFL, 2014). Transport demand management provides the most persuasive and indirect approach that can foster social-economic and environmental cohesion through public transport, shared vehicles, non-motorized, and sustainable infrastructure coordinated at multi-level urban governance. The study provides an assessment of transport service quality and demand management objectives for Nigerian cities (Lagos and Kano) based on a hybrid *AHP—SERVQUAL* model.

2.0 Literature Review

Transport infrastructure and service demand are causal effects of urban evolution and population agglomeration and are closely linked to the complex interface of land use and

[36]Urban sprawl refers to "unrestricted growth (and development) in many urban areas of housing, commercial development, and roads over large expanses of land, with little concern for urban planning" (Fouberg, 2012).

planning policies.[37] Bringing socio-economic harmony and environmental stewardship to the rising pace of urbanization has led to mobility management otherwise called *Transport demand management (TDM).* It is a concept premised on the need to manage mobility as a resource commodity coordinated with interplays of demand, supply, quality, price**,** equity, the environment and reduced motorization **(**Lynch, 2000; Rose, 2007a; Ahmed *et al*., 2008**)**. Australian Transport Council ATC (2006) defined *TDM* as "*an intervention to modify travel decisions so that more desirable transport, social, economic and/or environmental objectives can be achieved, and the adverse impacts of travel can be reduced*".

Whilst Vakili *et al.,* (2008) argued that the complementary strategy for *TDM* solution should be reflected in transport planning, infrastructures and land use resources bespoke with sustainable urban growth and development. Rose (2007b) explained that TDM investment decisions and choices cannot be made without appraisal and evaluation to synergize infrastructure and non-infrastructure solutions. This involves organizing, coordinating, evaluating and directing policies and decisions that affect transportation objectives, infrastructure and environment.

Additionally, some researchers have considered TDM as a mobility intervention which incorporates the supportive land-use practice, sustainable travel options and application of cyberspace technologies to maintain efficient and sustainable travel in a safer environment (Orozco *and* Guerrero 2013). According to Gärling et al., (2002), reduced motorization and congestion are at the core of TDM whereby the widely suggested strategies include, but are not limited to the following:

- Car ownership and motorization reduction
- Public transport systems
- Cycling or pedestrian facilities
- Car-sharing
- Neighborhood planning for residential markets, shopping, offices, parks and
- Recreational facilities to minimize traveling

Transport Canada (2017) outlined some adaptive measures and strategies bordering on "*wide range of policies, programs, services and products that influence how, why, when and where people travel to make travel behaviours more sustainable*". It also included:

- Outreach

[37]Urbanization and transport relationship are "typical chicken and egg conundrum of what comes first: better transportation or population growth …" (Batty et al. 2003, p.1)

- Promotion
- Education
- Parking control
- Road tax
- Public transport incentives & automobile disincentives

In the evaluation process (Figure 1) all of these are complemented by planning policies, land use practices and alternative(s) to travel. Solutions to emerging questions (i.e., the why, when, where and how) are given an acronym '3WH'. Apart from the critical factors of demography, socioeconomic dimensions, planning and development of infrastructures, the key goals of TDM are congestion, pollution, and environmental impact reductions (Litman, 2003; Davis *et al*., 2005; Bamberg *et al*., 2011).

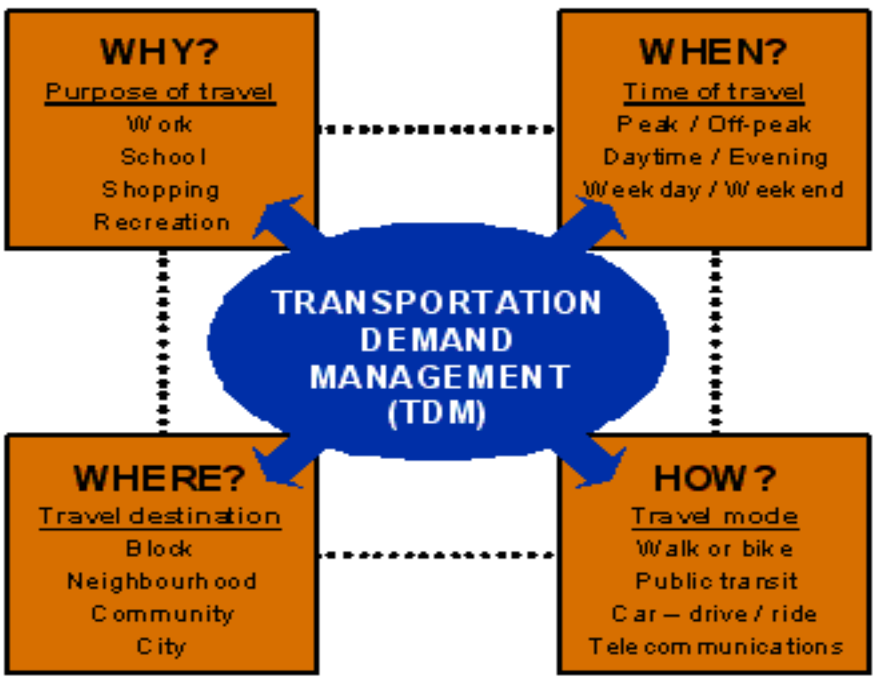

Figure 1: The '3WH' of TDM (Transport Canada, 2017)

Transportation as an economic service is demand and supply responsive, determined by price, service quality and growth in population. Litman (2017) contended that growth in population exerts corresponding effects on the general supportive land use and infrastructures. Figure 2 shows the connection between land use and transport system and the necessity of TDM policy for achieving urban equitable growth and sustainable development within emerging metropolitan cities.

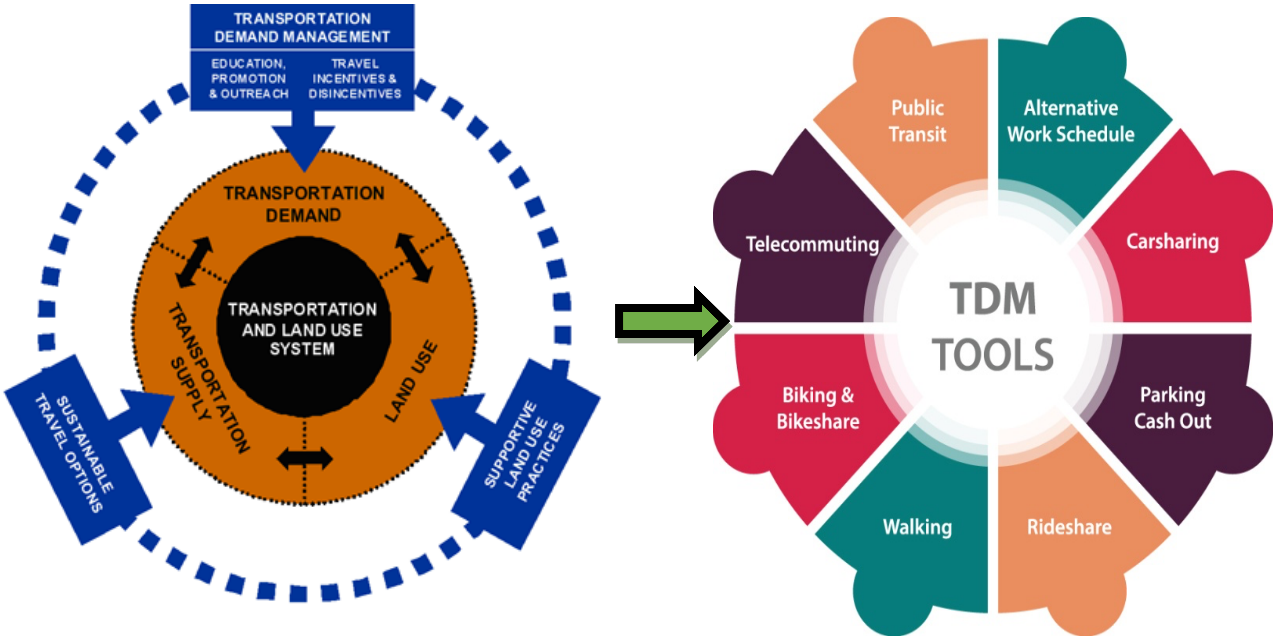

Figure 2: (a) Inter-relationship between transport & land use system (Transport Canada**,** 2017)
(b) Transport Demand Management (Tennessee State Dept of Transport *TNDoT*, 2017)

TDM promotes sustainable mobility initiatives in the form of:

- mass transit
- alternative routes and modal choices
- incentives and disincentives for peak hours
- parking toll
- congestion pricing
- car-sharing
- cycling
- walking and telecommuting

In general, TDM framework(s) are developed based on behavioural choices and travel patterns which are further defined by goals, rules, principles, and theories on which travel are based. It reflects the socioeconomic dynamics of convenience, cost, time, and inputs of sustainability in terms of energy, ecosystem, and environments (Loukopoulos *et al*., 2004).

Whilst the ranges of TDM objectives are broadly similar in nature, the evaluations and approaches to the problem may vary. The long-term aim of TDM is to tilt the dynamics of transport demand away from private car ownership in favour of public or mass transit - which involves evaluating the level of satisfaction about the choices available and taking responsible decisions based on the outcomes (Saelens *et al*., 2014).

Researchers have proposed a number of methodological tools for evaluating service quality, satisfaction and prioritizing improvement decisions of various urban facilities and services at various spatial and temporal perspectives, for example Multi-Criteria Decision Analysis (MCDA) using either (or both) of the following:

- Analytic Hierarchy Process (AHP) (Kumru and Kumru, 2014; Al-Atawi et al., 2016; Moslem and Duleba, 2018)
- Hybrid AHP models, which include
  - Interval Pair-wise Comparison Matrix (IPCM) (Feizizadeh and Ghorbanzadeh, 2017; Ghorbanzadeh et al., 2019)
  - Geographic Information Science modeling (GIS) (Malczewski and Rinner, 2015)
  - Fuzzy optimization modeling (Kahraman et al., 2006; Larimian et al., 2013) SERVQUAL—AHP (Zhu et al., 2011; Alam and Mondal, 2019) and Interpretive Structural Modeling (ISM) (Duleba et al., 2013; Ji et al., 2018)

In this paper and for a number of reasons (See Section 4.0) the use of the last option is adopted.

3.0 Study Areas

According to Kiel Institute for World Economic Index (Donaubauer *et al.*, 2014), Nigerian general infrastructure is ranked 95th on the global weighting scale; with global ratings of transport, energy, finance, information, and communication technology (ICT) being 60th, 108th, 118th and 104th respectively. The rating is highly reflective of the myriad of problems and dilemmas that exist therein, including (Olajide *et al*., 2018):

- Poor planning
- Slum and sprawl proliferation
- Corruption
- Resource problems
- Political interference
- Insecurity
- Jurisdictional coordination problems among regions and government.

Due to the gross asymmetry of declining resources and infrastructure gaps on one side and the geometric growth in population and urbanization on the other side requires a synergy in the approach. Unfortunately, TDM as 'push and pull' has been dire in its application to urban transport public policy strategy of the two most post populous Nigerian cities (Lagos and Kano). Although, some of the measures of TDM appear somewhat coercive and are highly motivated towards public financing, the subtle underpinning aspects of the overall TDM policy objectives are (or should be) equity, social inclusion and environmental harmonies which can be achieved through rational decision-making (Sandjoko, 2013; Boltze & Tuan, 2016; Haghshenas *et al*., 2015).

4.0 Methodology

In any decision-making situation when selecting the most appropriate alternatives without compromising strategic continuity, the process of aligning the right choices and objectives is most critical. For the purpose of this research, a combined approach of the hybrid *SERVQUAL—AHP* is used to evaluate the difference in the priorities of TDM with regard to transport infrastructure and services in Lagos and Kano cities.

Saaty (1977) proposed Analytic Hierarchy Process (AHP) as a mathematical decision-support tool involving pairwise comparison of different alternatives by prioritizing, weighting, ranking and simulating possible outcomes according to specific criteria. Since then, it has been widely used because of its unique simplicity in simulating outcomes and evaluating the consistency of decision-making choices and for assigning strategic management portfolios (Vargas, 2010).

To construct the logic hierarchy of AHP, three necessary assessment criteria are (i) comparison matrix, (ii) standardized matrix and (iii) weight consistencies.

i. Development of comparison matrix based on questionnaire outcomes polled from experts' opinions on a 1 — 9 absolute fundamental scale numbers suggested by (Saaty, 2005) shown in Table 1.
ii. Calculation of standardized matrix from weight factor given by the following Equations 1 to 2:

   Unnormalized parameter geometric mean value, $PU_i = \sqrt[n]{RMV} = \sqrt[n]{a * b * c * d * e}$ (1)

   Normalized parameter value, $PN_i = {PU_i}/{\sum_{i=1}^{n} PU_i}$ (2)

   Where n is the total inferential parameters and i^{th} is the reference parameter
iii. Calculating the weight consistencies of expert questionnaire judgments using Equations 3 to 4

Consistency index, $\mathrm{CI} = \frac{\lambda_{\max} - \mathrm{n}}{\mathrm{n} - 1}$ (3)

Consistency ratio, $\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$ (4)

Where is the $\lambda_{\max}$ pair-wise comparison maximum eigenvalue of the matrix; RI represents random consistency index based on assessment parameters (N). Table 2 shown the random inconsistency indices for $\mathrm{N} = \{\mathrm{n} = 1;\ 2;\ \dots\dots;\ 10\}$. The value of consistency ratio, $\mathrm{CR} \leq 0.1 \text{ or } 10\%$; otherwise, the pair-wise matrix may be termed inconsistent and indicator parameters must be re-evaluated (Saaty, 2005).

Table 1: AHP Priority Measurement Absolute Scale (Saaty, 2005)

Scale of importance	Definition of priority	Description of intensity rating	Reciprocal
1	Equal Importance	Two actions lead to the goal in equal measures	1
2	Equal to moderate	Values indicating intermediate importance	1/2
3	Moderate importance	Perception & decision slightly favours one factor over the other	1/3
4	Moderate to strong	Values indicating intermediate importance	1/4
5	Strong importance	Perception and decision strongly favour one factor dominating the other	1/5
6	Strong to very strong	Values indicating intermediate importance	1/6
7	Very strong importance	Perception and decision strongly favours one factor dominantly over the other	1/7
8	Very strong to extreme	Values indicating intermediate importance	1/8
9	Extreme importance	Evidence affirms highest possible dominance of perception & decision favouring one factor over another	1/9

Table 2: Random Consistency Indices (Saaty, 2005)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

SERVQUAL model, on the other hand, is an acronym for ‘Service Quality’ proposed by Parasuraman et al. (1985) for evaluating Customer Satisfaction Index (CSI) based on the five functional dimensions of perception and expectation satisfaction gaps — *“perception, reliability, responsibility, safety and empathy”.* Zeithaml *et al.* (1988) defined service quality as “a form of attitude, related but not equivalent to satisfaction, and results from a comparison of expectations with perceptions of performance”.

It is psychology-based qualitative research assessing people's perception and expectation of quality service and the outcome which helps inform decisions and priorities that can close the gap between satisfaction and quality service delivery. The survey evaluation is normally carried out using questionnaire checklist administered to assess participants' opinions about quality of service rendered to them (Kansal et al., 2017).

The SERVQUAL instrument was developed to evaluate the expectations and perceptions of participants from two major Nigerian cities regarding transport service quality using the transport demand management (TDM) objectives as the standard benchmark for the assessment. TDM tries to influence transportation demand by attempting to address element of travel choices or behavioural psychology (i.e., why, where, when, and how people travel) in order to improve the efficiency of the transportation system and meet desired specific planning goals. In this research, the five SERVQUAL generic dimensions of satisfaction quality adopted for TDM are as follows:

i. **Tangibility** is the perception of the physical appearance of infrastructure, facilities, equipment, and personnel rendering services. In this case, assessment and evaluation involves physical state of general infrastructure including travel ways (road, rail, etc.), vehicles, control systems, terminal facilities as well as the services.
ii. **Reliability** is the capacity to deliver the proposed service in a specific manner efficiently and reliably. It involves the maintenance of functional and dependable system without compromising quality.
iii. **Responsibility** is the measure of service provider's availability and promptness to support consumers and deliver services within a reasonable amount of time. It also involves the burden of accountability, responsibility, and control of actions on users and providers alike.
iv. **Safety assurance** is the critical dimension which requires integrity, competence, security, protection facilities and courtesy to inspire consumer's faith and confidence.
v. Empathy is the duty of care given by the service providers to the users or customers. Empathy for transport services includes information, communication, old and disabled services, societal equity, and participation.

The quality assessment is basically a satisfaction gap score (G) given by the difference between Expectation (E) and Perception (P). Zhu *et al*., (2011) contended that weighted ratio of perception (WP) to the weighted emotion (WE) gives a better estimator of CSI than the gap score (G). *Customer Satisfaction Index (CSI)* for all TDM measures (enumerated in five

SERVQUAL dimensions) was evaluated for the surveys of Kano and Lagos cities using Equation 5. The results are compared to the performance satisfaction rating benchmarks shown in Table 3 (Alam and Mondal, 2019).

$$CSI = \frac{\sum_i^n WP}{\sum_i^n WE} \times 100\% \qquad (5)$$

Table 3: Customer Satisfaction Index (CSI) and Quality of performance

(CSI) %	Weighted gap score	Satisfaction level
75 — 100	≥ *0*	Very high
65 — 75	—1 ≤ Gap < 0	Satisfactorily good
50 — 65	—2 ≤ Gap < 1	Moderate
Below 50	Gap ≤ —2	Low to unsatisfactory

Source: Alam and Mondal, 2019

4.1 Questionnaire Structure

The questionnaire checklist for SERV-QUAL assessment contains twenty-seven (27) attribute questions relevant to TDM performance indicators applicable to Lagos and Kano cities. There in the five critical SERV-QUAL dimensions are assessed as follows — *Tangibility (5 questions), Reliability (5 questions), Responsibility (5 questions), Safety-assurance (6 questions) and Empathy (6 questions)* respectively. Questions were structured to ensure linguistic clarity and responses, for example, in the question "*how much do you agree that the TDM measures have been addressed in your city*"? The standardized responses provided were rated over 5-point Likert scales —with 1 = *'strongly disagree';* 2 = *'disagree';* 3 = *'fairly agree';* 4 = *'agree'* and 5 = *'strongly agree'.*

4.2 Ethical consideration

A first draft of the questionnaire was submitted to Science, Technology, Engineering and Mathematics Ethical Review Committee at The University of Birmingham, UK. The researcher adhered to standard ethical procedures in every step of the research. All conventional ethical issues bordering on voluntary consent, withdrawal right, confidentiality and data handling were addressed within a consent form. There were no potentially important ethical concerns raised and the ethical approval registered Ethical Review ERN_18-1248 was issued for the study.

5.0 Results and Discussion

5.1 Service Quality Modelling

In total 136 questionnaire responses (58 for Kano and 83 for Lagos) were validated by comparing the questions with the strategic TDM objectives found within the literature wherein they corroborated well with the various cities' sustainable and workable solutions (Litman, 2017; TAC, 2011; Sloman *et al*., 2010; WSDOT, 1996). Furthermore, Kaiser-Meyer-Olkin's measure of sample adequacy were calculated to be 0.802 and 0.821 respectively, for Kano and Lagos, with the two values computed at (α=0.05).

For good internal consistencies of the questionnaire data, reliability evaluation was carried out giving rise to *Cronbach's alpha values,* $\propto_{Kano}= 87.6\%$ & $\propto_{Lagos}= 92.2\%$ respectively. The α— values are greater than the recommended 70% minimum for good statistical outcomes by researchers (Hair *et al*., 2006; Churchill, 1979). Table 4 shows the mean and standard deviation of *TDM* objectives classified under the five *SERVQUAL* dimensions and Appendices A1 and A2 are the frequency counts.

Table 4: Classified *TDM* objectives under the *SERVQUAL* dimensions

SERVQUAL Dimensions & TDM Objectives	Kano ($n = 58$)		Lagos ($n = 83$)	
	Mean	SD	Mean	SD
Tangibility	2.32	0.22	2.49	0.27
Transport infrastructures to enhance throughput and service quality, parking and terminal facilities	2.52	1.06	2.60	1.24
Bike and pedestrian infrastructures & recreation parks	2.00	1.17	2.13	1.05
Improved land use planning and transport facilities	2.55	1.30	2.70	1.25
Aesthetic along travel corridor	2.43	1.27	2.80	1.26
Metro facilities, subway, light rails to reduce congestion	2.12	1.11	2.22	1.16
Reliability	2.46	0.13	2.54	0.10
Efficient and resilient public transport services	2.53	1.13	2.51	1.11
Reducing delay or travel time	2.42	1.40	2.40	1.14
Flexibility, linkages and available of door-to-door services	2.67	1.24	2.62	1.21
Reliable and fast alternative transport modes	2.29	0.92	2.47	1.13
Transport infrastructure access control and right-of-way	2.41	1.09	2.68	1.24
Responsibility	2.40	0.30	2.43	0.16
Congestion reduction and charging on vulnerable routes	2.33	1.05	2.31	1.12
Road pricing, parking management and tolling	2.57	1.14	2.59	1.27
Improved public transport services and ridership share	2.88	1.26	2.65	1.13
Reduce motorization and private car ownership	2.02	0.96	2.36	1.25
Environment stewardship: Carbon reduction and renewable energy use	2.21	0.99	2.25	1.13
Safety assurance	2.50	0.20	2.44	0.19
Pedestrian crossing at busy intersection	2.78	1.03	2.74	1.24
Speed and traffic calming measures	2.68	1.15	2.55	1.18
Traffic signs and signal	2.60	1.21	2.54	1.24
Reducing crime and law violation	2.40	1.14	2.29	1.07
Traffic noise, pollution and waste reduction	2.29	1.06	2.22	1.25

Transport accident and improved rescue responses	2.24	0.96	2.29	1.05
Empathy	2.46	0.19	2.46	0.17
Cheaper transport fare	2.67	1.11	2.52	1.17
Social benefit (services for babies, students, disable and old people)	2.26	1.05	2.13	1.12
Duty of care for public health and sanitation services	2.76	1.07	2.63	1.13
Education, awareness & public involvement in policy decision	2.28	0.89	2.42	1.15
Disable public transport facilities and services	2.43	1.11	2.46	1.23
Alternative to physical travel: Teleshopping and teleconferencing	2.38	1.14	2.60	1.16

5.2 Analytic Hierarchy Process Approach to TDM Decision Making

The questionnaire survey of expert opinions based on the mean values of TDM objectives was used to develop a pairwise comparison matrix in Tables 5a and 5b.

Table 5a: AHP analysis for Kano transport survey based on geometric means of five dimensions

SERVQUAL Dimensions	Tangibility	Reliability	Responsibility	Safety assurance	Empathy	RMV	PU_i	*WC	**WSV	$\frac{WSV}{CW}$
Tangibility	1.00	2.03	2.08	2.00	2.03	17.21	1.7667	0.3294	1.6969	5.1507
Reliability	0.49	1.00	1.74	1.80	1.81	2.78	1.2269	0.2288	1.1752	5.1365
Responsibility	0.48	0.58	1.00	1.87	1.87	0.97	0.9939	0.1853	0.9543	5.1491
Safety assurance	0.50	0.56	0.54	1.00	1.92	0.29	0.7788	0.1452	0.7503	5.1662
Empathy	0.49	0.55	0.53	0.52	1.00	0.08	0.5963	0.1112	0.5740	5.1622
Total							5.3626	1.0000		25.7648

**WC = Weighted Criteria; **WSV = Weighted Sum Value*

$\lambda_{max} = 25.7648/5 = 5.1530;\ CI = 0.0382;\ RI = 1.12;\ CR = 0.0341$

Table 5b: AHP analysis for Lagos transport survey based on geometric means of five dimensions

SERVQUAL Dimensions	Tangibility	Reliability	Responsibility	Safety assurance	Empathy	RMV	PU_i	*WC	**WSV	$\frac{WSV}{CW}$
Tangibility	1.00	1.97	2.06	2.05	2.03	16.87	1.7596	0.3270	1.6917	5.1735
Reliability	0.51	1.00	0.53	1.82	1.90	0.93	0.9865	0.1833	0.9431	5.1447
Responsibility	0.49	1.89	1.00	1.96	1.92	3.46	1.2816	0.2382	1.2322	5.1738
Safety assurance	0.49	0.55	0.51	1.00	1.97	0.27	0.7688	0.1429	0.7384	5.1687
Empathy	0.49	0.53	0.52	0.51	1.00	0.07	0.5848	0.1087	0.5625	5.1756
Total							5.3813	1.0000		25.8363

**WC = Weighted Criteria; **WSV = Weighted Sum Value*

$\lambda_{max} = 25.8363/5 = 5.1673;\ CI = 0.0418;\ RI = 1.12;\ CR = 0.0373$

The geometric means of (yet to be normalized) data was carried out for TDM decision(s) using analytic hierarchy process (AHP). The consistency test produced consistency ratio, CR's of

0.0341 and 0.0373 for Kano and Lagos respectively. These two values meet the condition that $\text{CR} \leq 0.10\ (10\%)$ for the pairwise parameters to be satisfactory in the multi-criteria decision.
The subjective decisions of TDM solutions have been prioritized based on criteria weights and the pairwise relative qualitative judgment and consistency comparison from their eigenvalues. The TDM checklist result provided ordered rank and priority hierarchy based on the criteria weights (WC) for Kano survey which are as follows — *Tangibility (32.94%), Reliability (22.88%), Responsibility (18.53%), Safety-assurance (14.52%) and Empathy (11.12%)* respectively.
Likewise, TDM priorities accorded the following intervention order by criteria weights (WC) for the Lagos participants' responses as follows - Tangibility (32.70%), Reliability (18.33%), Responsibility (23.82%), Safety assured (14.29%) and Empathy (10.87%) respectively. Tangibility dimension comprising TDM elements relevant to transport infrastructures attracted the highest decision priorities in the surveys both cities. The findings from the AHP model will subsequently aid TDM decisions within transport investment portfolios.

5.3 Service quality evaluation

From the needs of transport demands delivered, the level of satisfaction can be assessed. Transport experts surveyed in the two cities (for their views on the transport demand decision) expressed positive, optimistic views accompanied by the highest expectation of quality services. Their judgments are, perhaps, influenced strongly by the attention received by transport infrastructure in the development plans of the three tiers of government in Nigeria (Ighodaro, 2009). Thus, their expectations were rated 5 on the Likert scale and the gap between mean expectation and perceptions were weighted for estimating satisfaction.
The study results in Tables 6a & 6b show that Tangibility has the highest weighted satisfaction gap when compared to other SERVQUAL dimensions while emotion ranks lowest in the satisfaction gap ranking.

Table 6a: *SERQUAL* dimension and *CSI* analysis for survey of Kano transport system

SERVQUAL Dimension	Expectation	Perception	Gap score	Weight criteria	Weighted Expectation	Weighted Perception	Weighted Gap	CSI
Tangibility	5	2.32	-2.68	0.3294	1.647	0.7642	-0.8828	
Reliability	5	2.46	-2.54	0.2288	1.144	0.5629	-0.5812	
Responsibility	5	2.40	-2.60	0.1853	0.9265	0.4447	-0.4818	48%
Safety assurance	5	2.50	-2.50	0.1452	0.726	0.3630	-0.3630	
Empathy	5	2.46	-2.54	0.1112	0.556	0.2736	-0.2825	
Total	25	12.14	-12.86	1.0000	4.9995	2.4083	-2.5912	

Table 6b: *SERQUAL* dimension and *CSI* analysis for survey of Lagos transport system

SERVQUAL Dimension	Expectation	Perception	Gap score	Weight criteria	Weighted Expectation	Weighted Perception	Weighted Gap	CSI
Tangibility	5	2.49	-2.51	0.327	1.635	0.8142	-0.8208	
Reliability	5	2.54	-2.46	0.1833	0.9165	0.4656	-0.4509	
Responsibility	5	2.23	-2.77	0.2382	1.191	0.5312	-0.6598	49%
Safety assurance	5	2.44	-2.56	0.1429	0.7145	0.3487	-0.3658	
Empathy	5	2.46	-2.54	0.1087	0.5435	0.2674	-0.2761	
Total	25	12.16	-12.84	1.0000	5.0005	2.4271	-2.5734	

The huge satisfaction gap in the model quality highlights low indicators of transport infrastructure, facilities, equipment, and personnel affecting urban mobility services in the Nigerian cities. While overall total weighted satisfaction gap scores and CSI values (% in brackets) of —2.5912 (48%) and —2.5734 (49%) respectively, were recorded for Kano and Lagos surveys can be dubbed as ‘unsatisfactory’ performances for these factors. In addition, the satisfaction ranking shown in Table 3 indicates low performance of *TDM* measures and is indicative of the gap between *expectation* and *perception* of transport services in the two of the most populous cities in Nigeria.

6.0 Conclusion

In the recent decades of urban migration and cities Geo-spatial expansion, transport mobility demand management has provided a unique opportunity for some measures of harmony between inordinate amounts of demand placed upon available transport resources. Hybrid AHP-SERVQUAL model used in this study are relevant for strategic decision analysis, prioritization and investment portfolio as the development framework provides a means for checking competitive advantage based on performance ranking and the hierarchy of intervention for service elements needing improvement.

The methodology presented here can be adapted to urban planning and development initiatives at any Geo-spatial scale. Therein, it pilots a framework for comparative assessment of recognizable standards in transport services and best management ethics in decision-making and portfolio allocation. Additionally, it can be used to prioritize in strategic multi-criteria decision(s) basing outcomes on users (or experts’) satisfaction and approach of gap analysis to optimize intervention and resource deployment.

Transportation is a critical urban service significant to connectivity, interaction and delivering of goods and services and the central principle of participatory city planning is to incorporate the viewpoint of the people regarding their needs and the thought of experts. Urban growth dynamics are correlated not only with the population and spatial dimensions, but with the intensifying socioeconomic implications. Priority based decision making presumes managing the exploding and rather complex scales of human interactions in growing urban spaces. The CSI which recorded respective values of 48% and 49% in Kano and Lagos in the analysis of performance and satisfaction are indicative of wide gaps in TDM measures and necessitates re-orientation of priorities towards transport infrastructure.

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APPENDIX A1: Frequency count for CSI Survey in Kano State

SERVQUAL Dimensions	TDM Strategic objectives	1	2	3	4	5	N
Tangibility	Transport infrastructures to enhance throughput & service quality	5	33	10	5	5	58
	Good infrastructure for biking, pedestrian and park facilities	25	19	6	5	3	58
	Improved land use planning and transport facilities	12	24	7	8	7	58
	Improved aesthetic along travel corridor	15	22	7	9	5	58
	Metro facilities, subway, light rails to reduce congestion	17	28	6	3	4	58
Reliability	Efficient and resilient public transport services	10	19	20	6	3	58
	Reducing delay or travel time	15	17	15	9	2	58
	Flexibility, linkages and available of door-to-door services	9	16	23	5	5	58
	Reliable and fast alternative transport modes	11	25	17	4	1	58
	Transport infrastructure access control and right-of-way	10	27	12	5	4	58
Responsibility	Congestion reduction and charging on vulnerable routes	14	21	14	8	1	58
	Road pricing, parking management and tolling	13	14	18	11	2	58
	Improved public transport services and ridership share	10	13	15	14	6	58
	Reduce motorization and private car ownership	17	20	18	3	0	58
	Promoting good environment: sustainable & renewable energy use	16	20	17	4	1	58
Safety assurance	Pedestrian crossing at busy intersection	8	12	25	11	2	58
	Speed and traffic calming measures	9	10	24	10	5	58
	Traffic signs and signal	11	21	10	12	4	58
	Reducing crime and law violation	13	18	17	8	2	58
	Traffic noise, pollution and waste reduction	15	20	16	5	2	58
	Transport accident and improved rescue responses	16	17	20	5	0	58
Empathy	Cheaper transport fare	10	15	20	10	3	58
	Social benefit (services for babies, students and old people)	16	20	14	7	1	58
	Duty of care for public health and sanitation services	7	17	20	11	3	58
	Education, awareness & public involvement in policy decision	12	23	18	5	0	58
	Disable public transport facilities and services	14	17	17	8	2	58
	Alternative to physical travel: Teleshopping & teleconferencing	15	19	13	9	2	58

APPENDIX A2: Frequency count for CSI Survey in Lagos State

SERVQUAL Dimensions	TDM Strategic objectives	1	2	3	4	5	N
Tangibility	Transport infrastructures to enhance throughput & service quality	20	19	25	12	7	83
	Good infrastructure for biking, pedestrian and park facilities	26	31	18	5	3	83
	Improved land use planning and transport facilities	18	17	29	10	9	83
	Improved aesthetic along travel corridor	15	20	25	13	10	83
	Metro facilities, subway, light rails to reduce congestion	27	27	18	6	5	83
Reliability	Efficient and resilient public transport services	18	23	28	10	4	83
	Reducing delay or travel time	21	25	25	7	5	83
	Flexibility, linkages and available of door-to-door services	17	23	26	9	8	83
	Reliable and fast alternative transport modes	19	25	24	11	4	83
	Transport infrastructure access control and right-of-way	16	23	26	8	10	83
Responsibility	Congestion reduction and charging on vulnerable routes	26	21	20	16	0	83
	Road pricing, parking management and tolling	20	22	21	12	8	83
	Improved public transport services and ridership share	14	24	28	11	6	83
	Reduce motorization and private car ownership	24	28	15	9	7	83
	Promoting good environment: sustainable & renewable energy use	25	28	17	10	3	83
Safety assurance	Pedestrian crossing at busy intersection	15	25	24	9	10	83
	Speed and traffic calming measures	18	23	27	8	7	83
	Traffic signs and signal	21	20	26	8	8	83
	Reducing crime and law violation	23	26	23	9	2	83
	Traffic noise, pollution and waste reduction	26	27	20	6	4	83
	Transport accident and improved rescue responses	23	25	25	8	2	83
Empathy	Cheaper transport fare	19	24	23	12	5	83
	Social benefit (services for babies, students and old people)	27	29	19	5	3	83
	Duty of care for public health and sanitation services	17	19	29	14	4	83
	Education, awareness & public involvement in policy decision	20	27	22	9	5	83
	Disable public transport facilities and services	22	24	21	9	7	83
	Alternative to physical travel: Teleshopping & teleconferencing	18	20	26	15	4	83

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER EIGHT
CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

8.1.1 Introduction

This concluding section presents the research findings as summaries of the specific research objectives. It provides a synthesis of the results and findings obtained from the research work and their discussions. It also includes the research major outcomes in terms of the realisation of the objectives, conclusions, scientific significance, benefits to policymakers and literary contributions. Finally, the future directions of research and further recommendations are equally highlighted.

8.2 Synthesis of the research objectives

8.2.1 Objective 1

The first objective was developed to calibrate a spatial-temporal model to analyse, quantify and predict the relationship between urban growth and transport development in the two Nigerian major cities (i.e., Kano and Lagos cities) in presented in Chapter 3a and 3b respectively. The spatial-temporal analysis adopted a disaggregate urban development model to decouple transportation infrastructure as a separate land use class to adequately track its development. The analysis of urban land use change was carried out using the remote sensing-GIS application for land use classification and CA-Markov algorithm implemented in IDRISI SELVA for temporal prediction of transition dynamics. The model provides a means for tracking and managing the complex causal spatial interactions between the urban chain process and transportation infrastructure development.

The study recorded fast spatial evolution of transport and other built-up areas on one hand, and the recession of vegetation and water catchments on the other. Based on the findings, Kano transport spatial area had grown from 137km^2 in 1984 to 290km^2 in 2019 while Lagos had grown from 337km^2 to 535km^2 in the same period. The dynamics model predicts spatial land demands of Kano city to reach 345km^2 in 2030 and 410km^2 in 2050 while the spatial requirements of Lagos are about 628km^2 and 692km^2 respectively in 2030 and 2050. The dynamic models are sufficient predictors of land use and transport spatial-temporal changes — Kano and Lagos's Kappa reliability coefficients were estimated to be 87.02% and 85.85%

respectively. The analysis shows strong relationship between urban chains and evolution of transportation environments.

The research has found discernible evidence of the spatial burden of transport infrastructure imposed by uncontrolled growths in the two Nigerian cities (Lagos and Kano). This is because the conventional urban land use planning model that lumps transport infrastructure development into many multi-sectoral and uneven investment portfolios cannot adequately tackle the socioeconomic and physical demands of the fast urbanization paces in these cities. The research treats the spatial demands and physical element of transport infrastructure development as a separate entity from the traditional aggregate demand model of urban planning practice to effectively track the dynamic growth and evolution of the cities using the hybrid Arc-GIS remote sensing and Markov-CA models.

Quantifying spatial proximity and temporal scales of the urban growth in relation to transportation infrastructure help in the development of indicators for evaluating suitability of urban transformation. This is necessary to bring equity to bear in modern urban development process where mixed land use, sustainable and resilient transportation, and integrated transportation planning are very crucial. It is noteworthy to highlight the imbalance between burgeoning urban landscapes and transportation infrastructure spaces revealed by the analysis of suitability maps.

The transition suitability predicts highly unsuitable future urban chain scenarios which reflects the plethora of transportation issues including rising gaps in infrastructure and service facilities and the consequent escalation of accessibility, travel demand, trip, motorization, congestion, and other sustainability problems. Population growth and urban expansion have contributed to the unsuitable spatial disparities in the temporal predictions of 2030 and 2050 milestones and are evidence suggesting that the trajectories of urban development policies need to align bespoke to the needs and management of physical infrastructure. The Geo-spatial interactions between transportation and land use dynamics have been calibrated, simulated, and the model is replicable as a useful tool for tracking transportation development and urban dynamics.

8.2.1.1 Reflection on Objective 1

This section is intended as a reflection of outcomes of the research and provides remarks on the validity or otherwise of the methodological approach, results, and findings of the spatial-temporal analysis. It also highlights the key contributions to knowledge and recommendations for further research.

First, the study has extended the knowledge domain and in-depth understanding of the complex spatial relationships between urban chain process and the development of transportation infrastructure. The combined GIS and CA-Markov methodological approach and calibration model has provided explicit spatial-temporal contexts to integrated land use-transport development process. While urban growth and mobility are closely linked, reciprocal and causal relationships of inherent complexity are prominent. Urban chains have not only put enormous pressure on the urban form, geography, ecology, and biodiversity, but they have also had a negative impact on accessibility, mobility, resilience, and sustainability.

Secondly, extreme weather and climate change have exerted their negative impacts on the two major cities. Kano is in the Sahara Desert region of Northern Nigeria grappling with increasing desert influences. Lagos, on the other hand, is a coastal city constantly under threats of rising sea level, the worst being the "*reclaimed lands*[38]" from the sea and lagoons and "*floating settlements*[39]" which are constantly inundated by flooding, wind gusts and other extreme weather conditions. Further research needs to analyse future spatial-temporal scenarios and what the effects weather and anthropogenic climate change will bear on the urban landscape and explore the resilient pathways to cope with the foreseen and unforeseen ecological footprints.

Thirdly, there is the question of social segregation, lack of equity and inclusion in the spatial allocation of transport infrastructure projects and maintenance portfolios. In Nigeria, like many developing countries' cities, much of the developmental efforts are usually concentrated in the areas that most benefits the privileged and 'well to do' citizens. This, therefore, relegates people in the lower social rungs to the slums and urban fringes where access to quality transport infrastructures, services, law and order and general safety declines. It may be worthwhile to expose how social segregation promotes emergences of urban sprawl and lack of planning harmony negatively influence urban chains and transport development in Africa.

Fourthly, the frenzy of urban migration and high natural population growth rates continues to challenge sustainability and liveability of many SSA cities. Apart from concentrating economic opportunities in the cities that have increased attraction to the cities, lack of infrastructures and amenities in the rural settings especially road facilities have contributed to migration push factors. Both Section 4.3 of Chapter 3A and Section 4.3 of Chapter 3B revealed very unsuitable

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38 Victoria Garden City (VGC) is the most popular city settlement built entirely on reclaimed land in Lagos.

39 Makoko is the popular Lagos floating informal slum settlement built on stilts along the creeks and lagoons.

and unsustainable spatial predictions for built environment and transport infrastructure. Fast urbanization and population boom in Nigeria, as with other SSA, have increased the complex diversity of economic structure, political and sociocultural institutions and has isolated the population mobility of the rural poor. There is no wondering that the SSA remains the fastest urbanization region in the world because of high birth rates, population growth and internal migration. But comparing data on urban and rural development pattern is difficult and cautioned since the models may differ from country to country.

For instance, the post genocide era "*Umuganda model*" of Rwanda has not only doused ethnic conflagration existing between *Hutus*[40] who are largely pastoral farmers and *Tutsis* who are mainly herders but has enhanced peace, stability, and rural classification in the country. The mutually beneficial *Umuganda* policy has increased the cooperation and minimized the open grazing nomadic lifestyle of Tutsi-herders who now depend on Hutus to forage their cattle while the herders depend on revenue from payment of herders and subsidy from government.

Details of the structural workings and cooperation in *Umuganda* policy were explained in Section 1.1 of Chapter 1. Also, the networks of the railway system and BRTs network across South Africa have also helped to prop urban-rural balance. It is necessary to adopt inclusive developmental policies that increase the rural share of transport infrastructure and other amenities to improve economic wellbeing and quality of life. Inclusivity, diversity, and equity in development policies will not bridge the urban-rural dichotomy but enhance reclassification of rural areas. The effectiveness of transportation infrastructure in catalysing rural classification in Nigeria could be of further academic interest to researchers as well as beneficial to policymakers.

8.2.2 Objective 2

The necessity to compensate urban transport effects in the physical planning and development of emerging cities has become self-evident. Congestion determines economic viability, spatial-demographic patterns, air quality, shifting business and industrial hubs and employment opportunities. Congestion has direct effects on accessibility, traffic vulnerability, risk, resilience, efficiency, and capacity of the transport system. In Nigeria, like many of her SSA counterparts, the linkage between traffic congestion and transport infrastructure, spatial-demographics and motorization rate have not explored.

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[40] *Hutu* tribe (otherwise called *Wahutu* or *Bahutu*) is the Bantu-speaking and majority tribe in Rwanda and Burundi while the *Tutsi* tribe (also referred to as *Watutsi* or *Batusi*) were historically of aristocratic Nilotic origin who are minority of the two countries (https://www.britannica.com/place/Rwanda; accessed on 25/07/2021).

In Chapter 4, the research is focused on mapping out congestion indices of the various cluster development units of Kano and Lagos cities to expose the roles of transport infrastructure, spatial-demographic, and motorization effects. The methodology entails using a surrogate multi-layer feed-forward and back-propagation model with *input-output and curve fitting (NFTOOL)* implemented in artificial neural to model transport infrastructure, spatial-demographic, and motorization data, as well as evaluate congestion and accessibility indices of cluster development areas. The study recorded peak traffic regimes in the two cities with congestion indices ranging from 7.5 to 10 on a scale of 10. Out of the three algorithms used — Levenberg-Marquardt (LM), Bayesian regularization (BR) and Scaled conjugate gradient (SCG); LM has a better fit and ease of convergence. The model provides an innovative means of predicting discrete congestion scenarios to increase urban access and mobility. The main limitations experienced during the development of this objective were the dearth of data and historical information details relevant for long time traffic and congestion forecast. But nonetheless, this study pioneers the foundation for the temporal acquisition of these data and the groundwork for improvement.

Traffic congestion has unavoidably encumbered physical infrastructure and accessibility and has become an albatross to the economy of large emerging SSA cities including the two Nigerian major cities. Urban sustainability and resilience in the sub-region have continuously declined because of increasing infrastructure gap, rapid motorisation, fragmented urban development, lack of coordination of physical planning, non-aligned institutions, and policies as well as management problems. Cities are the *de facto* economies of countries within the sub-region - agglomeration of economy, trade, commerce, business, and industrial productivity in the urban centres increase motorization proliferation to support these activities as logistics and freight characterizes economic growth. The congestion problem is exacerbated by social segregation, spatial inequality, the current urban paradigms, and social structure that tend to support auto-mobility. The study suggests the necessity to apply the dual solutions involving infrastructure improvement and access control to lower extreme traffic and congestion regimes in the two major cities.

8.2.2.1 Reflection on Objective 2

This section reflects the findings of the research, including the appropriateness of the methodology, results, findings, and limitations. It also emphasizes the roles of physical infrastructure and policies in congestion management, as well as scholarly contributions and research recommendations. The research recognized a number of issues:

First, the traditional urban planning approach in the developing countries focused more on transport infrastructure provision as a one-stop solution to urban mobility demands, with less emphasis on access control measures. Notwithstanding that the study has been able to provide empirical basis for the understanding the reciprocal and causal relationship between urban chains and transportation development and highlighted the deficiency of transport infrastructure and modal shift. The success of transport development policy also depends on access control because of the compulsive actions and inactions of users, commuters and motorist who are obsessively attracted to good facilities.

Moderating this balance between infrastructure and access control requires "*push and pull factors"* in the sustainable transport development policy. The term "pull factors" refers to a variety of management strategies that result in more efficient utilization of infrastructure and services while also acting as deterrents to making unsustainable choices. The push factors include congestion charging, road tax, parking regulation, route vending, toll charging, fuel tax and other de-incentive to motorization and private car ownership.

For *"pull"* factors, the overall legitimacy and common good in the acceptance of public transportation must be enhanced through increased transit fare affordability, fast alternative modes, service quality and should be guided by equity for all, social inclusion and sharing especially for the disables, students, children, and old people. The pull factors are incentives to motivate sustainable travel choices, e.g., cheaper fares, recreation parks, biking, and pedestrian infrastructure. Many of these measures of push and pull factors are weak in SSA in the urban transport development policy and sustainability paradigm and require policy reorientation. The study recommends a balance between "hard" and "soft" measures including sustainable urban development policies, infrastructure improvement and institutional synergy that deliver more on liveability across major cities in Nigeria. The input-output and curve fitting (NFTOOL) model used has the reliability, reliability, and prediction qualities, but limited in time series capability because of lack of recurrent data for long time prediction. As more data are populated using the model, *nonlinear autoregressive exogenous model (NARX)* model is recommended to fill that temporal gaps in future research.

Secondly, there is no doubt that congestion is a global urban phenomenon, but more complicated in the SSA because of the multi-dimensional problems earlier mentioned. This research revealed extremely high traffic and congestion indices in two cities as shown by the results in Section 3.1 of Chapter 4. Researchers cannot exhaustively quantify the economic, environmental, and social costs of congestion, which transcends beyond individual (per capita) losses to corporate businesses and government. The findings in this study corroborates well with literature which revealed that Nigerian motorists are currently enduring severe traffic congestion and jam situations in cities, with vehicles barely able to travel at speeds ranging from 3 to 5 km/hr[41].

Conservative estimate in the literature which puts delay per capita economic loss in Nigeria at $8000 per person/annum[42] deprecates the socio-psychological impacts of congestion at the individual level and economic and environmental costs for corporate businesses and government. Based on this numerical estimate of $8000 loss per person/annum, 53.8% working age population as per World Bank (15-64 years)[43] and the main metropolitan population agglomeration estimates of 4.6 million for Kano and 15.5 million residents for Lagos[44]; congestion amounts to whooping annual losses of about of $19.8 billion for Kano Metropolis and $66.7 billion for Lagos city. The two cities alone record economic losses to congestion delays estimated at $86.5 billion per annum, which is about 15.8% of Nigeria's highest GDP in 2014 fiscal year. Further studies will provide detailed holistic assessments for different types of congestion losses and various per capita, corporate and government levels in Nigeria i.e., economic, socio-psychological, and environmental losses due to pollution in detail.

8.2.3 Objective 3

The term "sustainability" relates to the societal realization that natural resources are finite. Sustainability has come to define the progress of human society and the management of resources through innovation, policy, technical and institutional capacities to tackle ethical issues in socio-economic development and environmental stewardship. It bridges the gap in the human-environment system dynamics and facilitate modelling, integration, and appraisal of workable interventions to provide seamless linkage for policy, research, innovative technology, and management.

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[41] Onyeneke, C., Eguzouwa, C., & Mutabazi, C. (2018). Modelling the effects of traffic congestion on economic activities-accidents, fatalities, and casualties. Biomedical Statistics and Informatics, 3(2), 7-14. https://doi.org/10.11648/j.bsi.20180302.11

[42] Somuyiwa, A., & Dosunmu, A. (2008). Logistics infrastructure and port development at Apapa Port, Nigeria. Pakistan Journal of Social Sciences, 5(9), 953-959. (https://medwelljournals.com/abstract/?doi=pjssci.2008.953.959; accessed on 25/07/2021).

[43] World Bank (2021). Population structure: working ages 15-64, total – Nigeria. World Bank Group, Washington DC, USA. (https://data.worldbank.org/indicator/SP.POP.1564.TO?locations=NG; accessed on 25/07/2021).

[44] Demographia (2021). World Urban Areas: Built Up Urban Areas or World Agglomerations; 17th Annual Edition, June 2021. Stern Marron Institute Urban Expansion Project, New York University (NYU), USA. (http://www.demographia.com/db-worldua.pdf; accessed on 25/07/2021)

Sustainable transportation is defined as any development in transport that does not have detrimental effects on the environment or human society while promoting economic growth and productivity, boosting trade and business, and enhancing better accessibility to basic infrastructure and quality services. Sustained urbanization and population have left behind huge question of sustainable transport, as with other sustainability aspects in many SSA. There is also the problem of transportation infrastructure gaps, defective policies and physical development planning and management strategies underpinning the dilemma in major cities of Nigeria and SSA region.

Chapter 5 connects the transport sustainability paradigm to the ongoing debate and discourse on the role of users and government in salvaging the unsustainable situation, providing complementary conceptual and empirical background to the problem. To check for sustainability thinking among the urban populace and institutional capacity driving the policies, a mixed method of on-line and on-site questionnaire surveys was used for data collection in the Nigerian cities of Kano and Lagos. In compliance with the Helsinki Declaration, an Ethical Approval Certificate was obtained from the University of Birmingham, UK which vouchsafe consent, confidentiality, data protection and right of withdrawal.

First, sample sizes of 2000 questionnaire copies were distributed in each of Kano and Lagos cities and analysed using SPSS analytical software. The study revealed low sustainability literacy scores of 37.5% for Kano Metropolis and 45.2% for Lagos city. The results of the surveys of the two cities also showed determined that the measures and indicators of transport sustainability are below the average of 50percent recommended in the literature.

The study exposed low performances in virtually all indicators of sustainable transport development assessed. Environmental pollution, public health issues, and other social issues, as well as economic losses, have resulted from the failure to appropriately incorporate sustainable development policies into Nigerian transportation policy, infrastructure development and mobility management regulations. The sustainability indicators are low as well as awareness of sustainable choices among the population surveyed due to dysfunctional developmental policy framework in Nigeria, which culminate in the huge gap between contemporary transport development and the UN's Sustainable Development Goals (SDGs)[45].

[45] Relevant Sustainable Development Goals: SDG 9 recommends that planners, urban authorities, and governments should “build resilient infrastructure, promote sustainable industrialization, and foster innovation”; SDG 11 specifies that modern cities should be "inclusive, safe, resilient, and sustainable" and SDG 13 advised to "take urgent action to combat climate change and its impacts" (https://sustainabledevelopment.un.org/sdgs; accessed on 25/07/2021).

The study exposes the weaknesses in the development of transport infrastructure, modal shift policy, behavioral choices, technology innovation, transport demand management strategies, fuel and energy policy, climate change and carbon reduction indicators in the two cities. The research findings will not only broaden literary and academic discourse, but will also be beneficial to transport planners, technical experts, policymakers, political authorities, and the government, as well as transportation users who are also critical policy stakeholders. It has the potential for mainstreaming sustainable transportation policies, such as climate and low-carbon policies, mass transit facilities, modal shift, facilities for non-motorized commuting and integrated transportation systems, into the core of urban development policy. Future research will examine the socioeconomic benefits of low carbon travel in Nigeria cities and its potential to mitigate environmental risks and climate change.

8.2.3.1. Reflection on Objective 3

This section reflects on the research findings, including the methodological approach, outcomes, contributions, limitations, and recommendations. Apart from the novel example of Kigali-Rwanda as African "greenest city"[46] and South Africa to a lesser degree, many African governments are yet to implement sustainable transport policy. These policies include ecosystem-based system, integrated transport infrastructure, technology and innovation adaptations, risk management, age regulation for vehicle import, public transit system, biking and pedestrian, low carbon fuel and electric vehicles. Even though Africa appears to contribute the least to global warming and carbon emissions in terms of both per capita and absolute scale, it is the climate change most vulnerable.[47] Infrastructure is prominent among the plethora of problems increasing risk and vulnerability in Africa. The survey analysis results in Section 3.4 (Table 7) of Chapter 5 displays this evidence.

The most difficult element of promoting sustainable transportation is the change of behaviour and lifestyle, which has subjective variations in terms of choices, behaviour, beliefs, habits, and

[46]According to *Brilhante & Klaas (2018), *Green City* is a recent urban concept that creates "a greener, compact and liveable city that promotes energy efficiency and mixed land use in its planning systems anchored in the principles of green growth and equity"

*Brilhante, O., & Klaas, J. (2018). Green City Concept and a Method to Measure Green City Performance over Time Applied to Fifty Cities Globally: Influence of GDP, Population Size and Energy Efficiency. *Sustainability, 10*(6), 2031. https://doi.org/10.3390/su10062031.

[47]Sy, A. (2016). Africa: Financing adaptation and mitigation in the world's most vulnerable region. Africa Growth Initiative, Brookings Institution, Washington, D.C., U.S. Available from: https://www.brookings.edu/wp-content/uploads/2016/08/global_20160818_cop21_africa.pdf; [Accessed on 25/07/2021].

belief systems of people. Increasing lifestyle standards have significantly increased travel demand and mobility needs, necessitating the adoption and reorientation of urban development policy views that deliver resilient and sustainable transportation. Improving public acceptance of sustainable travel is a critical component of future transportation development planning.

To achieve this, first, creating public awareness about the collective responsibility of sustainable lifestyle, safe environment and public health concerns should be the logical priority and the purview of political authorities, policymakers, and government on a national scale. Transport planners, environmentalists, and other technical experts as well as non-government organisations and private research think-tanks, also have their contributions. Secondly, while a public awareness campaign is at best verbal proselytising about the consequences of inaction, increased scientific research provides provide empirical evidence. Evidence which abounds in this research identified both transport infrastructures, planning policy and travel choices as the culprits and advised change of strategies. Educators in Nigeria should implement sustainability education as a compulsory general knowledge course in pedagogy development and curriculum planning from primary to tertiary education levels to 'catch' future generation young; not as topics currently being done in many institutions.

Investment in Infrastructure, policy shifts, and management could deliver future goal of sustainable Africa. Measures such as mixed land-use planning, development of the public transport system, facilities for non-motorized commuting, auto-mobile and other regulatory policies, transit demand management can help SSA countries to mitigate pollution, carbon contribution, rapid motorization and grinding traffic congestion in major cities across Nigeria.

8.2.4 Objective 4

The study in Chapter 5 found urban regimes of the two cities (Kano and Lagos) to be defective in terms of transport development policies and level of awareness and mobility choices among the population to be unsustainable. The traditional "top-down" urban planning, development theory in Nigeria has shown its failings, but "bottom-top" approach was considered appropriate to galvanise multi-stakeholders' involvement in the decision-making process in the spirit of participatory public policy agenda.

Objective 3 was designed to allow for such inputs from the community of urban stakeholders and the outcome of the weak indicator justifies interviewing policymakers who represent government at the top decision-making hierarchy in Objective 4. The interview interaction with transport professionals who oversee the policies of the states' ministries of transportation was used to validate or check for congruence between multi-stakeholders and policy makers' assessments of transportation problem in the cities.

In Chapter 6, semi-structured interviews were conducted with the Heads of Ministry of Transport of the two cities to assess transport sustainability themes emerging from the policies, interventions, and priorities of urban transport development process. Thematic analysis is a qualitative analysis technique for collecting, identifying, categorising, analysing and interpreting patterns of themes based on the taxonomy of the subject matter considered. It explains how to code and categorise themes and analyse the data in a methodical way and connect it to a larger theoretical concept.

After interview and transcription, sustainability thematic analysis was carried out using NVivo software to compare both negative and positive sentiments expressed during interviews to assess the achievements. A preponderance of negative sentiments ($N_{Kano} = 217$ & $N_{Lagos} = 341$) over positive sentiments ($N_{Kano} = 75$ & $N_{Lagos} = 160$) showed the blight sides of transport developmental policies and is indicative of the poor performance of sustainability measures. In the word cloud analysis in Section 4.0 of Chapter 6, the apparent dominance of sustainability and transportation infrastructure issues highlighted the debt and seriousness of policy deficiencies.

The current situation exacerbates the previously described urban planning theory-practice gap, leaving "bottom-up" approaches and rational planning as the primary drivers of the contemporary transport policy debates. This study suggests new paradigm shifts towards sustainable transport and resilient infrastructure systems through smart and innovative policies, technology-centred and compact neighbourhood planning, strengthened by mixed land uses to meet rising demand for social integration, enhance economic growth, improve liveability and eco-system protection.

8.2.4.1. Reflection on Objective 4

Amongst the most crucial elements of an effective policy and performance management is planning. The most familiar planning approaches that present two contrasting strategies are "top-down" and "bottom-up" planning processes. Traditionally, the most common policy approach to urban planning and transport development in Nigeria is a "top-down" model, in which planners are seen as "experts" who provide policy decision and determine the course of action on behalf of the political authorities.

Public authorities as government employees are the sole policy purveyors, mediators, and influencers of transport sustainability in many developing countries. They are vested with the authority to manage, make key decisions, and steer the overall direction of government policies. For instance, the decision as to who gets what in terms of infrastructure is solely the whims of those government experts and not necessarily reflect the needs assessment of the infrastructures and facilities. The policy approach negates the principle of equity as it permits less inputs from users, operators and other segments of the society who should have been stakeholders in the process. This leads to arguments among stakeholders about public participation, social inclusion, economic development, environmental protection, and management of urban space.

The existence of meddlesome bureaucratic pressures of urban governance in management decisions also compounds the problem. Defective policy and ineffective planning have resulted in the rapid expansion of Nigerian cities, which are beset by infrastructure problems, ineffective public transit systems, traffic congestion, pollution and other environmental issues and social disharmonies. The study also noted the weakness in private car ownership policies being the "status symbol" of social class hierarchy and its negative contribution to the gathering tides of motorisation in the cities. Future research will analyse how much status symbolism determines the pecking order of choices of transport modes among the urban population and the overall influence on motorisation in the emerging cities.

To address the difficulties of congestion and pollution, infrastructure investment must be accompanied by effective regulation, active laws, and sustainable policy agenda setting the goals and targets. Provision of public transits, vehicle taxes and other regulatory policies will potentially reduce the rapid pace of motorization. Relevant stakeholders in the transportation sector, including policymakers, users, operators, and technical experts, must work in synergy to evolve and develop innovative ways to improve the country's transportation system.

A dedicated entity for sustainable transportation with delegated authority to allow timely decision-making may be required to bring about a paradigm shift in the Nigerian transport development. Such an institution would need to be free of political and professional barriers, with a common goal of developing liveable sustainable cities as its focus. It presents the current debate within the context of public interest, emphasizing the importance of embracing the concepts of needs, fairness, equity, and inclusion in transportation policy discussions.

8.2.5 Objective 5

Urbanization is accelerating exponentially, especially in emerging cities of developing countries with potential negative ramifications for economy, infrastructure, accessibility, and liveability. Standalone measures cannot bring about meaningful success to global emission reductions. Transportation is among major carbon contributors, sustainable mobility and infrastructure is achieved through a gamut of “push and pull” policy measures in the transportation sector. Cities around the world have their various goals and development approaches due to differences in developmental stages, model, strategy, political control, productivity, and economic resources, technological and innovation available. The differences in the developmental paces and resources warrant policy decision to strategically plan, set out the hierarchy and priorities of urban transport development.

In Objective 5, comprehensive transport mobility and infrastructure policy strategies have been developed based on TDM objectives which outlines the various policy alternatives and weight or hierarchy of priorities for enhancing sustainable and people-centred urban transportation development in Nigeria. The research involved the use of transport demand management objectives to survey satisfaction of transport services and to create an ordered hierarchy of interventions based on various dimensions of quality of transport services using SERVQUAL-AHP model. The result of satisfaction quality produced low performance scores of 48% and 49% respectively for Kano and Lagos cities respectively.

Also, AHP analysis result showed that tangibility has the least mean score, which puts transport infrastructure atop the hierarchy of policy interventions and suggests prioritization of transport facility development in the two cities. Aggressive “push—and—pull” policies that improves and increases the stock of transport infrastructure, public transit services, modal split, reduced motorization, and access control are recommended to cope with rising urbanization in Nigeria.

8.2.5.1. Reflection on Objective 5

Sustainable urban transport development promotes municipal aggregation and diffusion, which boosts local, regional, and national economies and significantly improve wellbeing of people and environmental footprints. Unfortunately, dysfunctional planning policies and transportation infrastructure in Nigeria as well as many SSA countries have shown their dire consequences. It includes congestion and increased journey time, environmental pollution, carbon emission, economic losses, higher traffic accidents, higher operating cost of the vehicle, unaffordable fare, and reduced transportation efficiency. The research addresses various flaws, knowledge gaps, and issues that shaped the study's specific focus of decision making. The research is a rigorous pioneering work on Nigerian transportation policy decision-making, contributing to the existing literature deficit. The study has offered detailed information on the quality and extent of the Nigerian city's transportation infrastructure, facilities, and services, as well as the factors for its under-performance.

Transport infrastructure continues to be issue in Africa, as many facilities are heritages of the colonial era and are currently inadequate in terms of efficiency, reliability, safety, speed, comfort, and environmental footprint. In Nigeria for instance, the only railway line connecting Northern and Southern Nigeria from Kano Metropolis to Lagos City is the narrow gauge which hardly functions properly. The country's average road spatial density is extremely low by any global standards. The low GDP and the fiscal burden of the under-performing facilities have hindered maintenance of infrastructures. Also, the country is lagging in policies that ought to harmonise urban development, especially land use, transportation planning and integration strategies which are necessary for long term sustainable outcomes. Integrated urban and transport planning will have to include sustainable development, goal definition, alignment of vision and prioritising objectives towards a shared development policy that supports the mutually beneficial land use and transportation policies.

8.3 Research Summary

The study pioneers rigorous trans-disciplinary research approach on the complex dimensions of addressing the relationship between urban chain process and transport development in emerging developing countries' cities. It, thus, contributes to closing the literature gap in the field of urban transport development in Nigeria and other SSA countries with similar problems. The traditional transport models cannot resolve the burden imposed by growing population development and the uncontrolled expansion on metropolitan transport infrastructures. The current approach to contain the pressures exerted by rising city growth and uncontrolled sprawl on the transport landscape is rather reactionary and ineffective.

The study accords shared engagement and priority for transport infrastructure development in the competing urban land use evolutionary process and brings focus on dynamic transition mapping, resilience, sustainability, and the demand management decisions. Table 8.1 provides the succinct summaries of the findings and contributions based on the various research objectives.

Table 8.1: Summary of research findings and contribution to knowledge

Research objectives	Summary of research findings and contribution to knowledge
1. Spatial and temporal analysis of interaction of urban chains with transport infrastructure space	a) The research has found unassailable evidence of the spatial burden of transport infrastructure imposed by uncontrolled urban growths in the two Nigerian cities (Lagos and Kano) using the disaggregate spatial analysis models. b) The empirical evidence in support of phenomenally rising urban chains in the two cities is revealed by spatial growths in the built-up-areas from $29km^2$ in 1984 to $111km^2$ in 2019 for Kano city while Lagos experienced a spatial change from $211km^2$ to $387km^2$during the same period. c) The spatial analysis revealed that the transport spatial area of Kano had grown from $137km^2$ in 1984 to $290km^2$ in 2019 while Lagos grew from $337km^2$ to $535km^2$ in the same time series. d) The predicted future spatial transition expects Kano city's transport landscape to have expanded to $345km^2$ in 2030 and $410km^2$ in 2050 while Lagos transport development would have exerted spatial requirements of about $628km^2$ & $692km^2$ respectively in 2030 & 2050. e) Furthermore, the potential transition suitability displayed standardized Boolean maps which revealed unsuitable and unsustainable transition area indicators for 2030 and 2050 temporal time-series and a necessity of policy re-orientation.
2. Modelling of traffic congestion vulnerability and accessibility analysis	a) The study found gross inaccessibility in both cities revealed by extreme traffic regimes and congestion indices ranging from 7.5 to 10 on a scale of 10 showing that motorisation has outgrown transport system capacity. b) The multi-layer feed-forward and back-propagation model involving input–output & curve fitting offers simple but scientifically valid approach as alternative to other data driven models and could be used for simulation of traffic and real- time discrete congestion prediction especially in the unorganized urban terrains of Africa.
3. Transport sustainability paradigm by multi-stakeholders' assessments	a) The sustainability literacy test revealed a low awareness level of 37.5% for Kano Metropolis and 45.2% for Lagos city. b) All the policy measures of transport sustainability and indicators of sustaining travel behaviors are below average recommended in the literature indicating gross under-performance of developments in the transport sector.
4. Transport sustainability by thematic assessment of the views of policy makers	a) Sustainability thematic analysis showed the preponderance of negative sentiments over expression of positive optimism highlighting the blight sides of transport sustainability policies in the two Nigerian cities.
5. Transport intervention	a) Out of the five generic dimensions of quality examined, tangibility, which refers to people's perceptions of the physical appearance

policies and strategy for priority decision based on TDM objectives		of infrastructure, facilities, equipment, and services, received the highest AHP priority weights (32.94 percent and 32.70 percent for Kano and Lagos cities respectively), indicating the huge infrastructure problems.
	b)	The analysis of AHP model the huge infrastructure prioritizes quality and quantity improvements to transport infrastructure to deliver more sustainable and resilient transport in the two cities.
	c)	The assessment of facilities and service satisfaction qualities using SERVQUAL quality domains produced low scores of 48% and 49% respectively for Kano and Lagos cities and are suggestive of re-orienting policies and priorities towards infrastructure and facility management.

With transport decoupled as a separate entity from the traditional aggregate urban development, the analysis provides in-depth knowledge of the causal relationships of urban growth phenomenon and the nexus of transport problems in the emerging Nigeria cities. It contains valid scientific models that incorporate behavioural choices in tracking mobility pattern and the supporting infrastructure for an adequate forecast of the complicated urban dynamics.
The outcome has provided empirical evaluation and prediction techniques for urban dynamic system tracking, effective management strategies to prioritize transport demands, and collaborative engagement of relevant stakeholders (via questionnaires and interviews) to adopt sustainable and resilient transportation scenario planning and application for current and future mega-cities. It is envisaged that the sophisticated evaluation of planning development and management techniques used in the research will serve as a technical blueprint to stakeholders (government, planners, and academics) and contribute to discussions and debates in urban transport development.

8.4 Interdisciplinarity in transport development

Interdisciplinarity defines the set of broad general perspectives and epistemological methods grounded in the creation of conceptual frameworks for analysing specific problems, incorporating prepositions from various disciplines, and synthesising similarities and differences between concepts and models. As a result of collaboration, individuals' disciplinary procedures and theoretical notions may be altered, encouraging new concept, themes, frameworks, and methodological unity. According to Klein (2017)[48], superficial nature of core discipline fixating on

[48] Klein, J. T. (2017). Typologies of interdisciplinarity. *The Oxford handbook of interdisciplinarity. Oxford University Press, United Kingdom*, 21-34. https://doi.org/10.1093/oxfordhb/9780198733522.001.0001

its subject based perspective renders critique of disciplinary understanding is frequently inferred due to a lack of depth and knowledge of the subject.

Frodeman et al (2017) linked the success of combating Ebola disease epidemic in West Africa to inter-disciplinary and multi-stakeholders' participation. According to the researcher, Interdisciplinarity helped galvanize the little resources of the sub-continent, together with the frontline multi-task force involving researchers from diverse fields of medical and life science, bio-medical engineering, health workers, government, law enforce agents and police. Transport has attained the interdisciplinary status because of the shared goal of sustainable and equitable growth that unite core concepts and a community of disciplinary stakeholders, including transport scientist, engineers, environmentalist, financial experts, psychologist, geographers, economists, social scientists, and business administrators etc.

The progress in interdisciplinary research in Africa has diminished dark alleys of flawlessness, orthodoxy, in-fighting, and lack of synergy in the traditional discipline-based scholarships. The current research adopted diverse background of interdisciplinary subject domains to address transport effects in the urban chain process. Intervention drags, lack of continuity and institutional synergy have by far encumbered the developmental pace of transport sector because of "*top-down*" hierarchy of policy making process of Nigeria. The multi-stakeholders' frameworks in interdisciplinarity needs to be embraced in policy formulation to minimize bureaucratic bottlenecks impeding the flow of the decision-making process. The research findings will extend the knowledge of the complex nature of transport development in Nigeria and SSA through the trans-disciplinary research approach and the outcomes will be beneficial to researchers and policy makers.

8.5 Recommendations

The research has evidently linked the lagging urban development in Nigeria and indeed, many SSA to lack of reliable, affordable, and efficient transportation facilities and services which helps to enhance liveability, prosperity and alleviate poverty. Regardless of the peculiarities of many SSA countries, there is a convergence of empirical evidence such as in the research that improvements in infrastructure, services, and embracing technology innovation and sustainable policy will lead to increased accessibility, safety, affordability, efficiency, and reliability of the entire system.

This study provided inter-disciplinary feedback on the complex interaction between urban chain processes and transportation development, drawing on knowledge from diverse fields such as urban science, transportation infrastructure planning, land use and Geo-spatial science, social science, behavioural psychology, modelling and computing. In this study, adopting the framework of interdisciplinary concepts has provided greater depth to identify blind spots and has contributed to institutional synergy that may aid in the development of collaborative identity, and foster communication in complex interdisciplinary settings like urban and transport science.

The pragmatic perspective to interdisciplinary concept has sparked a wide range of interest, with multiple domains of knowledge, information, and disciplines as inputs.

According to Klaassen (2020), interdisciplinary provides "*a different perspective on what we consider valid knowledge creation, driven by the desire to use measurements of inclusion rather than exclusions, and is collaboratively organized in a variety of trans-disciplinary backgrounds around the grand challenges of the twenty-first century*".[49] Frodeman et al. (2017) concluded that interdisciplinarity as a general portmanteau term for all approaches to knowledge that are more than disciplinary, with the overarching meaning of societal relevance.[50]

The underlying need for an interdisciplinary approach in urban transport science stems from rising challenges of the urban chain process and the need to integrate aspects of various disciplines while addressing the themes questions of transport effect and complex policy decision making. There is nowhere interdisciplinarity applies than in SSA - the world poorest, yet the most evolving natural population and urbanising region in the world. This current research has offered problem-solving approach to urban transport science with convergent feedback that transcends disciplinary boundaries to create a holistic and composite framework at the nexus of various fields.

Scientific relevance of urban growth on transport system models, requires adequate prediction of the behaviour and interaction of the complex and dynamic changes in the system which the study has made useful contributions. More research is however needed to explore the proactive efficacy of the proposed urban chains-transport effects and framework to address transportation issues in Nigeria and other fast-growing cities in developing countries. The research work has advanced the state-of-the-art methodologies in the field of complex transport systems and delimited the interdisciplinary concept of transport dynamics and urban chain process. Table 8.1 provides a list of recommended future interdisciplinary research areas to widen the depth of knowledge and broaden the scope of the understanding of urban transport development.

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[49]Klaassen, R. (2020). Disentangling the different layers of interdisciplinarity. *Journal of Science Communication, 19*(4), C03. https://doi.org/10.22323/2.19040303

[50]Frodeman, R., Klein, J. T., & Pacheco, R. C. D. S. (2017). The Oxford handbook of interdisciplinarity. Oxford University Press, United Kingdom. https://doi.org/10.1093/oxfordhb/9780198733522.001.0001

Table 8.2: Recommendations and suggested areas of future studies

Future areas of research	Further research to be carried out
Spatial temporal analysis	Further studies will be carried out to understand, quantify and predict how much anthropogenic climate change forcing elements will impact spatial and temporal aspects of urban transport infrastructure especially in Lagos and low-lying coastal cities of Sub-Sahara Africa
Spatial and aspatial analysis	The deep knowledge of the roles played by socioeconomic drivers (i.e., demography, income, and economic development) in the reciprocal relationships of urban growth and transport development is also worthy of attention.
Traffic congestion	The congestion prediction in the current research is instantaneous, an extended analysis and long-term prediction of the mono - centric structure of the urban traffic regime is possible with the availability of robust traffic data pool, origin and destination survey and a more detailed inventory of transport infrastructure.
Risk and urban transport resilience	Risk assessment of urban transport infrastructure in the emerging SSA cities and the thresholds of resilience within the transport networks will be further investigated
Sustainability: carbon footprint	Future research will quantify the scale and the drivers of the carbon footprint and carbon emission reduction of urban transport in Nigerian and other SSA cities.
Sustainability: congestion delays	Further research will develop a framework for holistic assessments of various types of congestion losses at various per capita, business, and government levels in Nigeria, including economic, socio-psychological, and environmental losses
Sustainability: intervention policy	Future research will investigate the influences of social hierarchy, culture and status symbolism on motorisation and modal choices in Nigeria
Transport demand management	Further research will investigate paradigm shift in policies that involves "push and pull" measures to bring about sustainable transport in the cities

APPENDICES TO CHAPTER FIVE

APPENDICES TO CHAPTER FIVE

APPENDIX A1: SAMPLING FOR SMALL POPULATION: ±5% AND ±10% MARGIN OF ERROR, C.L = 95% and p = 0.5 (Glenn, 1992)

Size of Population	Sample Size (n) for Precision (e) of:	
	±5%	±10%
100	81	51
125	96	56
150	110	61
200	134	67
250	154	72
300	172	76
350	187	78
400	201	81
450	212	82

APPENDIX A2: SAMPLING FOR LARGE POPULATION

Size of Population	Sample Size (n) for precision (e)	
	±5%	±10%
500	222	83
1,000	286	91
2,000	333	95
3,000	353	97
4,000	364	98
5,000	370	98
7,000	378	99
9,000	383	99
10,000	385	99
15,000	390	99
20,000	392	100
25,000	394	100
50,000	397	100
100,000	398	100
>100,000	400	100

APPENDIX B1: TRANSPORT SUSTAINABILITY QUESTIONNAIRE

University of Birmingham, U.K. Research Questionnaire on Transport Sustainability in Major Nigerian Cities	Ref. No. .... Identity No......................

A) INTRODUCTION

My name is **Suleiman Hassan Otuoze**. I am a Doctoral Researcher in the Department of Civil Engineering, University of Birmingham, U.K. I am working on a research topic entitled **"Critical Infrastructures for future transport in megacities"**. The survey is titled **"Awareness level of transport sustainability imperatives among stakeholders in Nigerian major cities"**, and is one of the research sub-themes or objectives to model sustainability awareness vis-à-vis the thinking among stakeholders (government, academia, public users and operators/managers) in the Nigerian transport sector.

We sincerely welcome your contributions to deliver the goal of the research. Minors, people with cognitive disabilities and others that lack capacity to consent will not be part of this survey.

Also, we hereby invoked your right of confidentiality and vouch that the data/information supplied in the survey will not be used for any purpose other than the declared research. Finally, we are categorically clear that there is no reward of any kind for your participation. We, therefore, wish to convey our deepest appreciations for your participation.

Consent right: Your participation is voluntary while your agreement to participate is taken as informed consent. Please, kindly tick "yes" or "no" respectively indicating your willingness to voluntarily participate or otherwise.
Yes, I wish to participate ☐ **No, I do not wish to participate** ☐

For further information, please contact the lead supervisor, Dr. Dexter Hunt through: Department of Civil Engineering, University of Birmingham, B15 2TT, United Kingdom; Email: D.Hunt@bham.ac.uk; Phone No.: [redacted]

Please, kindly return the completed questionnaire copy to the researcher through any of the following contact means:

- *By post to: Suleiman Hassan Otuoze, Dept of Civil Eng., University of Birmingham, B15 2TT, U.K.*
- *Via e-mail to:* HSO647@student.bham.ac.uk.
- *By phone contacts for the researcher to pick the hard copy:* [redacted]
- *Alternatively, complete the online version on the link:* https://goo.gl/forms/RBFOdrij557GMxCe2

B) DEMOGRAPHICS OF RESPONDENT

1. What is your sex?.
   a) Male ☐ b) Female ☐
2. Respondent's age?
   a) 16 – 25years ☐ b) 25 – 40 years ☐ c) 40 – 65years ☐ d) above 65 years ☐
3. Respondent's stake or involvement in transport policy:
   a) Student ☐ b) Lecturer ☐ c) Government Official ☐ d) Private manager/Operator ☐ e) User ☐
4. Highest degree or qualification:
   a) PhD ☐ b) Master ☐ c) Bachelor /HND ☐ d) Diploma/NCE ☐ e) O' Level ☐
   f) Primary school ☐ g) Other/non: Please state any form of education or none ....
5. Employment level/Designation (state please) ....

C) GENERAL SUSTAINABILITY LITERACY

6. Tick all the statement(s) which defines the concept of sustainability?

☐ The developments meeting the needs of the present generation without compromising the ability of future generations to meet their own needs.
☐ Responsibilities of continuously supporting the pursuit of economic prosperity, environmental quality and social equity together.

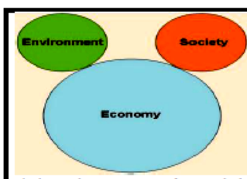
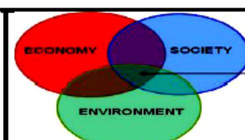
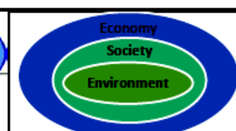
☐ A measures of adaptation that aims to protect humanity and the planetary systems supporting and cautiously enhancing the global potential to provide all people throughout time with equitable access to resources and good life.
☐ A process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations.
☐ Scientific endeavor to explore and exploit 'new found lands', sea and space; land reclamation, creation of 'floating cities' to shore up the stock of depleting natural and material resources.

7. Pick out all the relevant conventions, statutes and accords which lead to the formulation of sustainable development Agenda 2030 (2015)
☐ Kyoto Protocol for carbon reduction and carbon trading (1997)
☐ UN Nuclear Non-Proliferation Treaty (1968)
☐ UN Earth Summit called Rio de Janeiro Agenda 21 (1992)
☐ London accord for phasing out ozone-depleting chemicals (1990)
☐ Brundtland Report for the World Commission on Environment and Development (1987)

8. Indicate all that are appropriate themes forming the focus of UN Sustainable Development Agenda 2030 which are meant to stimulate global action plans of critical importance that bears positive impacts on "goals and targets" leading to transformation of "people, planet and prosperity"?
Prioritizing huge profit margin hoping that it will later impact on social and environmental outlooks
☐ Preservation of archaeological sites, relics; genetically improving exotic plants and animals and zoo keeping of endangered animal species.
☐ Focus and synergy on good environment, blossoming people with slow, but steady economic growth
☐ Economic development, social equity and environmental protection are mutually exclusive
☐ Promoting socialism (a system of government in which ownership of private property is disallowed) tackle environmental, social and economic disharmonies of profit driven capitalist system.

9. Select all the relevant initiatives which agree with the vision/themes of sustainable development goals (SDG)
☐ Viewing natural resources as limited in nature and seeking renewable alternatives
☐ Setting up agenda for recycling waste to wealth
☐ Advancing the frontiers and targets for 'green economies'
☐ Creating haven for cheaper outsources and hazardous productions
☐ Government, institutional and corporate responsibilities on sustainable behaviour

10. Reckoning with the priorities of governments, geo-political factors, economic gaps, social-cultural diversity, inequalities in the endowment of natural and human resources, which of these models would you perceive to be best suited for sustainability pillars in Nigeria?

 a) 'Mickey mouse' model where environment and society are subsidiary to the pivotal role of economy	 b) 'Bullseye' embedded model of hierarchy – the relationship pecking order starts from economy to society down to environment	 c) Triple bottom line model where equal interactions and relationships occur among environment, economic and societal pillars	 d) 'Bullseye' embedded model of hierarchy – the relationship pecking order starts from environment to society down to economy	 e) 'Bullseye' embedded model of hierarchy – the relationship pecking order starts from economy to society down to environment

11. In Nigeria, the regulation and control of ecological/environmental problems, impacts and its footprints is supervised by which agency of government?
    a) Nigerian Electricity Regulatory Commission
    b) Energy Commission of Nigeria
    c) Federal Environmental Protection Agency (FEPA)
    d) Federal Ministry of Agriculture
    e) Ministry of culture and tourism

12. Identify by selecting all environmental events and catastrophes linked to activities and/or impact of mankind unwholesome practices.
    - ☐ Extreme weather events – rising temperature, droughts, flooding
    - ☐ Falling of meteorites and other planetary debris
    - ☐ Earthquake and sinkholes especially in mining areas
    - ☐ Desertification and soil depletion
    - ☐ Wild fire and industrial bye-products

13. Please, rate how important are the following aspects are to sustainability paradigm of your country? (5 = very important, 4 = important, 3 = moderate, 2 = fairly unimportant, 1=not important)

Aspects	5	4	3	2	1
Mobility/transport	☐	☐	☐	☐	☐
Carbon reduction	☐	☐	☐	☐	☐
Resource use	☐	☐	☐	☐	☐
Water	☐	☐	☐	☐	☐
Energy	☐	☐	☐	☐	☐
Biodiversity	☐	☐	☐	☐	☐
Waste & pollution control	☐	☐	☐	☐	☐

14. Please, rate how much do the following sustainability pillars have been addressed by your city infrastructural development? (5 = very strongly addressed, 4 = strongly addressed, 3 = moderately addressed, 2 = poorly addressed, 1 = Not addressed)

Environmental factors	5	4	3	2	1
Resilient built environment including transport infrastructures	☐	☐	☐	☐	☐
Resource use: conservation, depletion and recycling (material, energy and materials)	☐	☐	☐	☐	☐
Climate change: global warming, temperature inversion, carbon-based and other air pollutants, industrial smog, ozone layer depletion	☐	☐	☐	☐	☐
Land use change: urbanization, sprawl, erosion, desertification, deforestation, soil depletion, and agriculture	☐	☐	☐	☐	☐
Pollution and noise: effluents, toxic waste, noise and acoustics	☐	☐	☐	☐	☐
Environmental impact assessment and management	☐	☐	☐	☐	☐
Product and services including clean production, eco-system integrity	☐	☐	☐	☐	☐
Ecology and habitat: Wild life and biodiversity	☐	☐	☐	☐	☐
Water and aquatic life	☐	☐	☐	☐	☐
Energy consumption: Renewable and alternative energy	☐	☐	☐	☐	☐
Waste and pollution: Poisonous chemicals, radioactive materials	☐	☐	☐	☐	☐
Environmental protection: policies, law and enforcement	☐	☐	☐	☐	☐

Social concept	5	4	3	2	1

Rising population and demographic factors					
Equity and sharing					
Labour and employment creation					
Religious beliefs, customs and tradition					
Cultural diversity, historical and tradition					
Empowerment and social services					
Community participation, diversity and social inclusion					
Education, skill acquisition, training and well-being					
Safety and security					
Public health, disease, infirmities and protection					
Outdoor activities, leisure, entertainments, sports & other social events					

Economic concept	5	4	3	2	1
Productivity, growth and income (GDP and GNP)					
Economic stability, growth and developmental economics					
Finances and accountability					
Productivity, manufacturing, consumption, good and services					
Commerce, business and asset management					
Employment, Income, and labour law					
Credit facility and tax burden					
Trade, commerce and business creation					

Multi-dimensional concepts	5	4	3	2	1
Politics, leadership, democracy and governance					
Ethics and Philosophy, and holistic thinking					
Addressing transparency, bribery and corruption					
Networking, cooperation, collaboration and synergetic relationships					
Responsibility and transparency					
Awareness, feedback, reporting information and communication					
System thinking, long-term and holistic thinking					
Sustainable development targets and benchmarks					
Tourism					
People, society, accomplishment and poverty reduction					
Migration, travel and integration					

D. TRANSPORT SUSTAINABILITY

15. Base on the list of available mobility/travel choices; choose your most frequent transport method(s) to commute the following journeys?

Journey \ Travel choice	Walk	Bicycle	Train	Bus	Taxi/car-hire	Motorbike	Personal car
Workplace/school							
Shopping							
Recreation/Leisure							
Religious centres							
Other.....................							

16. Please, rate your city's transport sustainability by how much the following performance indicators and policy initiatives have been addressed? (5 = very strongly addressed, 4 = strongly addressed, 3 = moderately addressed, 2 = poorly addressed, 1 = Not addressed)

Needs	Sustainability indicators	5	4	3	2	1
Promoting public transport choice	Availability of public transport service	☐	☐	☐	☐	☐
	Frequency of public transport service	☐	☐	☐	☐	☐
	Affordable travel cost	☐	☐	☐	☐	☐
	Proximity to the stations (both train and buses)	☐	☐	☐	☐	☐
	Reducing delay or travel time	☐	☐	☐	☐	☐
	Shortening the length of journey (shortest route)	☐	☐	☐	☐	☐
	Road infrastructure control, vending of routes and right-of-way	☐	☐	☐	☐	☐
	Reliability and efficiency of service	☐	☐	☐	☐	☐
	Travel route coverage	☐	☐	☐	☐	☐
	Comfort, convenience and entertainment on-board	☐	☐	☐	☐	☐
	Flexibility, linkages and available of door-to-door services	☐	☐	☐	☐	☐
	Information and communication	☐	☐	☐	☐	☐
	Availability of disable public transport service	☐	☐	☐	☐	☐
	Building infrastructures to enhance throughput and service quality	☐	☐	☐	☐	☐
	Cheaper fares	☐	☐	☐	☐	☐
	Parking restriction, regulation and tolling	☐	☐	☐	☐	☐
	Bike route and bike parks	☐	☐	☐	☐	☐
	Increased all weather and all time bus and train services	☐	☐	☐	☐	☐
	Scheme for car-sharing and hire services	☐	☐	☐	☐	☐
	Metro services, subway and underground tube to reduce congestion	☐	☐	☐	☐	☐
Measures of synergy between transport systems and economy	Infrastructures to enhance throughput and service quality	☐	☐	☐	☐	☐
	Congestion charging through congestion zones	☐	☐	☐	☐	☐
	Increasing road tax	☐	☐	☐	☐	☐
	Average income and wages	☐	☐	☐	☐	☐
	Mean transport cost	☐	☐	☐	☐	☐
	Employment and job creation	☐	☐	☐	☐	☐
	Vehicle hire	☐	☐	☐	☐	☐
	Road and parking toll	☐	☐	☐	☐	☐
Means of evaluating Environmental stewardship and energy use	Side walk and bike routes	☐	☐	☐	☐	☐
	Vehicle and tire recycling	☐	☐	☐	☐	☐
	Reduction of transport waste disposal	☐	☐	☐	☐	☐
	All weather transport alternatives (subways, underground tubes)	☐	☐	☐	☐	☐
	Vehicle driven by clean and renewable energy	☐	☐	☐	☐	☐
	Reduction of transport Greenhouse gas emissions (CO_2)	☐	☐	☐	☐	☐
	Air quality and reducing pollutants (PM10, NMVOCs, NOX, CO)	☐	☐	☐	☐	☐
	Reduced exposure to transport noise pollution	☐	☐	☐	☐	☐
	Reduced urban land consumption and land change	☐	☐	☐	☐	☐
Promoting alternatives to physical mobility	Telecommuting services including telephone and computer	☐	☐	☐	☐	☐
	Distant learning, open university and teleconferencing	☐	☐	☐	☐	☐
	Teleshopping and courier services	☐	☐	☐	☐	☐
Promoting non-motorized transport modes	Mixed land use and diversity of commercial services	☐	☐	☐	☐	☐
	Close proximity to school, shopping areas retail stores and green parks	☐	☐	☐	☐	☐
	Biking and pedestrian travel services, bike parks	☐	☐	☐	☐	☐
	Aesthetic and beautification of travel corridors	☐	☐	☐	☐	☐
Security and safety measures	Pedestrian crossing at busy intersection	☐	☐	☐	☐	☐
	Speed and traffic calming measures	☐	☐	☐	☐	☐
	Reducing crime rate and violations of law and order	☐	☐	☐	☐	☐
	Traffic signs and signal	☐	☐	☐	☐	☐

	Reducing transport accident, death, injuries and economic losses	☐	☐	☐	☐	☐
Measures for reducing motorization and private car use	Reducing private car trips	☐	☐	☐	☐	☐
	Congestion charges on busy transport zones	☐	☐	☐	☐	☐
	Availability of fast routes for public buses and sub ways	☐	☐	☐	☐	☐
	Reliable surface rails, metros and underground rail services	☐	☐	☐	☐	☐
Promoting social benefits and equity	Cheaper transport fare	☐	☐	☐	☐	☐
	Social benefit (services for babies, students, disable and old people)	☐	☐	☐	☐	☐
	Duty of care for public health and sanitation services	☐	☐	☐	☐	☐
	Sustainability education, awareness & public involvement in policy decision	☐	☐	☐	☐	☐
	Good planning of policy direction by government/authorities	☐	☐	☐	☐	☐

17. Rate by summing up your perception on how effective the implementation of needs indicators and policy initiatives in Question 16 above could motivate sustainable transport delivery in your city?

a) very effective ☐ b) effective ☐ c) moderate ☐ d) ineffective ☐ e) very ineffective ☐

18. Rate how effective could the following communication/information channels increase awareness of transport sustainability? (5 = very effective; 4 = effective; 3 = moderate, 2 = ineffective, 1 = very ineffective)

Communication method	5	4	3	2	1
Billboard and posters	☐	☐	☐	☐	☐
Fliers and leaflets	☐	☐	☐	☐	☐
Print media like newspapers, magazines	☐	☐	☐	☐	☐
Electronic media like television, radio adverts	☐	☐	☐	☐	☐
Internet and Social media	☐	☐	☐	☐	☐
Incorporating sustainability into the teaching core and curriculum of education	☐	☐	☐	☐	☐

19. General assessment: Please rate your sustainability literacy and make additional comments

a) 5=Very good ☐ b) 4=Good ☐ c) 3=Average ☐ d) 2=Poor ☐ 1=Very poor ☐

20. You may be interested in knowing the research outcomes or findings, please, kindly drop your means of communication of the feedback (contact address/email/phone): ……………………………………………………………

Thank you for your time and contribution.

Suleiman Hassan Otuoze
Doctoral Researcher, Department of Civil Engineering, University of Birmingham, B15 2TT, U. K.
E-mail: HSO647@student.bham.ac.uk; Mobile No.:

APPENDIX B2: CONSENT FORM FOR QUESTIONNAIRE AND INTERVIEW PROTOCOL

My name is **Suleiman Hassan Otuoze**. I am a Doctoral Researcher in the Department of Civil Engineering, University of Birmingham, U.K. I am working on a research topic entitled **"Critical Infrastructures for future transport in megacities"**. The survey is titled **"Awareness level of transport sustainability imperatives among stakeholders in Nigerian major cities"** and is one of the research sub-themes or objectives to model sustainability awareness vis-à-vis the thinking among stakeholders (government, academia, public users and operators/managers) in the Nigerian transport sector. The study is focused on the Nigerian transport infrastructures and the future scenarios affecting the country's most populous cities (Lagos and Kano).
You are invited to take part in this research interview and sincerely welcome your contributions to deliver the goal of the research. Your participation is voluntary. Whilst your agreement to participate is taken as informed consent, this form called "informed consent" allows you to understand this study and guide you into making decision to participate or otherwise.

Statement of Research:
Critical Infrastructure for future transportation in Megacities:
As population grows in urban areas, not least in developing Mega-cities, the need for more sophisticated assessment of and planning for transport delivery is required. This research aims to investigate how this can be done both now and in the future in order to result in a more sustainable (and resilient) transport infrastructure development of mega-cities. Through collaboration with stakeholder engagement (using questionnaires, interviews and future scenario application and development) an assessment framework will be developed and applied to a number of Nigerian cities. The study will assist policy makers, government, managers and academics related stakeholders to wake up to the realities of transport infrastructure problems and the exigencies of sustainability awareness and knowledge about key linkages and developments that could increase livability and prosperity of city dwellers, reduce poverty, create economic and social benefits for both the people and government.

Procedures:
If you agree to be part of this study, you may be asked to participate in questionnaire session of the research. Accordingly, the survey will require you to complete a single hard copy of the questionnaire or follow the online link to complete a copy of the questionnaire - (https://www.soscisurvey.de/UoBprojectHSO647/). The questionnaire survey is expected to last for 15minutes.

The Right of Voluntary Nature: Your participation in this study is voluntary and your right to withdraw from the study can be invoked by you one month after submitting the questionnaire.

Risks of Participation: Being in this type of study involves some risk of the minor discomforts that can be encountered in daily life, such as stress or becoming upset. Being in this study would not pose risk to your safety or wellbeing. Any risk of injury or harm during the study interview is virtually nonexistent.

Compensation: Your participation in the study is voluntary and there will be no form of payment for participating.

Confidentiality: Any information you provide will be kept confidential. The researcher will not use your personal information for any purposes outside of this research project. Also, the researcher will not include your personal data in the study reports. The privacy of all participants will be protected with all sensitive data coded in place of source identification.

Contact address: For further information, please contact the lead supervisor, Dr. Dexter Hunt through: Department of Civil Engineering, University of Birmingham, B15 2TT, United Kingdom; Email: D.Hunt@bham.ac.uk; Phone No.: [redacted] The researcher can also be reached through: *Suleiman Hassan Otuoze, Dept of Civil Eng., University of Birmingham, B15 2TT, U.K. E-mail: HSO647@student.bham.ac.uk. Phone No:* [redacted]

Consent right: I have read the above information and I feel I understand the study well enough to make a decision about my involvement. By signing below, I am agreeing to the terms described above.
Printed Name of Participant (Or Alias) ………………………………………………………………………………..............…
Contact Address/Email/Phone Number of Participant: ……………………..………………..…………………………….
Date of consent ………………………………………………………………………………….……….……..…………..…….
Participant's Signature ……………………………………………………...………..………………………..………………
Researcher's Signature …..…………………………………………………………………………..………...…………………

Note: The essence of participant information requested is to communicate research outcome. Participants may consider it as optional. Whilst personal data is collected, it will be stored in a password protected file and will be destroyed after the end of the research. Your information will be kept on a secure laptop and any hard copy data sheets will have ID codes and no names.

APPENDIX B3: ETHICAL APPROVAL CERTIFICATION

Application for Ethical Review... - Suleiman Otuoze (PhD Dept of Civil Eng FT) 16/08/2021, 15:18

Application for Ethical Review ERN_18-1248

Susan Cottam (Research Support Group)
Mon 05/08/2019 09:55
Inbox

To: Suleiman Otuoze (PhD Dept of Civil Eng FT) <HSO647@student.bham.ac.uk>; Dexter Hunt (Department of Civil Engineering) <D.Hunt@bham.ac.uk>;

Cc: Ian Jefferson (College of Engineering and Physical Sciences) <I.Jefferson@bham.ac.uk>;

Dear Mr Otuoze and Dr Hunt

Re: "Critical infrastructure for future transportation in megacities"
Application for Ethical Review ERN_18-1248

Thank you for your application for ethical review for the above project, which was reviewed by the Science, Technology, Engineering and Mathematics Ethical Review Committee.

On behalf of the Committee, I confirm that this study now has full ethical approval.

I would like to remind you that any substantive changes to the nature of the study as described in the Application for Ethical Review, and/or any adverse events occurring during the study should be promptly brought to the Committee's attention by the Principal Investigator and may necessitate further ethical review.

Please also ensure that the relevant requirements within the University's Code of Practice for Research and the information and guidance provided on the University's ethics webpages (available at https://intranet.birmingham.ac.uk/finance/accounting/Research-Support-Group/Research-Ethics/Linksand-Resources.aspx) are adhered to and referred to in any future applications for ethical review. It is now a requirement on the revised application form (https://intranet.birmingham.ac.uk/finance/accounting/Research-Support-Group/Research-Ethics/EthicalReview-Forms.aspx) to confirm that this guidance has been consulted and is understood, and that it has been taken into account when completing your application for ethical review.

Please be aware that whilst Health and Safety (H&S) issues may be considered during the ethical review process, you are still required to follow the University's guidance on H&S and to ensure that H&S risk assessments have been carried out as appropriate. For further information about this, please contact your School H&S representative or the University's H&S Unit at healthandsafety@contacts.bham.ac.uk.

Kind regards

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Please remember to submit a new Self-Assessment Form for each new project.

Click Research Governance for further details regarding the University's Research Governance and Clinical Trials Insurance processes, or email researchgovernance@contacts.bham.ac.uk with any queries relating to research governance.

https://mail.bham.ac.uk/owa/#viewmodel=ReadMessageItem&ItemID=AAMkAGQwNjdjZmI2LW…AW3o8AABK8aWIFPlwR58y%2F%2Fke3e1uAABEaCCWAAA%3D&IsPrintView=1&wid=27&ispopout=1

APPENDIX C1: POPULATION ESTIMATES & SAMPLING FOR KANO POPULATION

Cluster Identity	Name of CDCA	No. of ward sub-units	[a]NPC, (2006)	[b]NBS, (2016)	[c]Population estimate (Author, 2018)	Sample share of CDCA
KN1	Ajingi	10	174,137	240,100	252814	-
KN2	Albasu	10	190,153	261,000	274821	-
KN3	Bagwai	10	162,847	224,700	236599	-
KN4	Bebeji	14	188,859	266,900	281034	-
KN5	Bichi	11	277,099	387,100	407599	-
KN6	Bunkure	10	170,891	242,700	255552	-
KN7	Dala**	12	418,777	582,500	613346	296
KN8	Dambatta	10	207,968	292,800	308305	-
KN9	Dawakin Kudu	15	225,389	313,700	330312	-
KN10	Dawakin Tofa	11	247,875	342,500	360637	-
KN11	Doguwa	10	151,181	209,500	220594	-
KN12	Fagge**	10	198,828	278,300	293037	142
KN13	Gabasawa	11	211,055	293,800	309358	-
KN14	Garko	10	162,500	225,300	237231	-
KN15	Garum Mallam	10	116,494	165,000	173737	-
KN16	Gaya	10	201,016	288,500	303777	-
KN17	Gezawa	11	282,069	392,700	413495	-
KN18	Gwale**	10	362,059	497,700	524055	253
KN19	Gwarzo	10	183,987	255,400	268925	-
KN20	Kabo	10	153,828	213,000	224279	-
KN21	Kano municipal**	13	365,525	516,400	543746	263
KN22	Karaye	10	141,407	200,400	211012	-
KN23	Kibiya	10	136,736	192,800	203010	-
KN24	Kiru	15	264,781	371,600	391278	-
KN25	Kumbotso**	11	295,979	409,500	431185	208
KN26	Kunchi	10	111,018	153,200	161313	-
KN27	Kura	10	144,601	199,000	209538	-
KN28	Madobi	12	136,623	191,500	201641	-
KN29	Makoda	11	222,399	306,100	322309	-
KN30	Minjibir	11	213,794	305,500	321678	-
KN31	Nasarawa**	11	596,669	829,600	873531	422
KN32	Rano	10	145,439	206,200	217119	-
KN33	Rimin Gado	12	104,790	143,800	151415	-
KN34	Rogo	10	227,742	316,600	333365	-
KN35	Shanono	10	140,607	193,500	203747	-
KN36	Sumaila	11	253,661	348,300	366744	-
KN37	Takai	10	202,743	281,900	296828	-
KN38	Tarauni**	10	221,367	308,600	324942	157
KN39	Tofa	15	97,734	137,200	144465	-
KN40	Tsanyawa	10	157,680	219,400	231018	-
KN41	Tudun wada	11	231,742	318,100	334945	-
KN42	Ungogo**	11	369,657	508,700	535638	259
KN43	Warawa	15	128,787	183,400	193112	-
KN44	Wudil	10	185,189	262,400	276295	-
Total		484	9,383,682	13,076,900	13769380	2,000

*Metropolitan Statistical Area (MSA) constituting Kano Metropolis = 8 LGA's
[a]Total population of Kano Metropolis based on MSA (NPC, 2006) = 2,828,861
[b]Total population of Kano Metropolis based on MSA (NBS, 2016) = 3,931,300
[c]Total population of Kano Metropolis based on MSA (Author, 2018) = 4,139,480

APPENDIX C2: POPULATION ESTIMATES & SAMPLING FOR LAGOS POPULATION

Cluster Identity	Name of CDCA	No. of ward sub-units	[a]NPC, (2006)	[b]NBS, (2016)	[c]Population estimate (Author, 2018)	Sample share of CDCA
LA1	Agege*	9	459,939	635,900	669574	115
LA2	Ajeromi-Ifelodun*	10	684,105	946,500	996621	171
L A3	Alimosho*	11	1,277,714	1,817,200	1913429	328
LA 4	Amuwo-Odofin*	11	318,166	453,000	476988	82
LA 5	Apapa*	9	217,362	307,100	323362	55
LA 6	Badagry	11	241,093	327,400	344737	-
L A7	Epe	19	181,409	250,300	263555	-
LA 8	Eti-osa*	10	287,785	390,800	411495	71
LA 9	Ibeju/Lekki	11	117481	162,200	170789	-
LA 10	Ifako-Ijaye*	11	427,878	589,000	620190	106
LA 11	Ikeja*	10	313,196	437,400	460562	79
LA 12	Ikorodu	19	535,619	727,000	765498	-
LA 13	Kosofe*	10	665,393	940,300	990093	170
LA14	Lagos Island*	19	209,437	292,900	308410	53
LA15	Lagos Mainland*	11	317,720	449,900	473724	81
LA16	Mushin*	14	633,009	870,100	916176	157
LA17	Ojo*	11	598,071	838,900	883324	151
LA18	Oshodi-Isolo*	11	621,509	866,300	912174	156
LA19	Shomolu*	13	402,673	555,800	585232	100
LA20	Surulere*	12	503,975	692,500	729171	125
	Total	**242**	**9,013,534**	**12,550,500**	**13,215,104**	**2,000**

*Metropolitan Statistical Area (MSA) constituting Lagos Megacity = 16 LGA's
[a]Total population of Lagos Megacity based on MSA (NPC, 2006) = 7,937,932
[b]Total population of Lagos Megacity based on MSA (NBS, 2016) = 11,083,700
[c]Total population of Lagos Megacity based on MSA (Author, 2018) = 11,670,525

APPENDIX D1: SUSTAINABILITY LITERACY TEST (SLT) FOR KANO RESPONDENTS

Questions and options (including remarks on whether option right wrong)	**Stakeholders pass counts & pass rate (%)**
Q6: Tick all the statement(s) which defines the concept of sustainability? a) The developments meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. (right) b) Responsibilities of continuously supporting the pursuit of economic prosperity, environmental quality, and social equity together. (right) c) A measure of adaptation that aims to protect humanity and the planetary systems supporting and cautiously enhancing the global potential to provide all people throughout time with equitable access to resources and good life. (right) d) A process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations. (right) e) Scientific endeavor to explore and exploit 'newfound lands', sea and space; land reclamation, creation of 'floating cities' to shore up the stock of depleting natural and material resources. (wrong)	Students: 26 (29.9%) Lecturers: 13 (24.5%) Government officials: 12 (20.7%) Private operator & Managers: 22 (25.6%) Users: 59 (26.7%) Total passed: 132 (26.1%)
Q7: Pick out all the relevant conventions, statutes and accords which lead to the formulation of sustainable development Agenda 2030 (2015) a) Kyoto Protocol for carbon reduction and carbon trading (1997) (right) b) UN Nuclear Non-Proliferation Treaty (1968) (wrong) c) UN Earth Summit called Rio de Janeiro Agenda 21 (1992) (right) d) London accord for phasing out ozone-depleting chemicals (1990) (right) e) Brundtland Report for the World Commission on Environment and Development (1987) (right)	Students: 23 (26.4%) Lecturers: 21 (39.6%) Government officials: 22 (37.9%) Private operator & Managers: 11 (12.8%) Users: 39 (17.7%) Total pass: 116 (23.0%)
Q8: Indicate all that are appropriate themes forming the focus of UN Sustainable Development Agenda 2030 which are meant to stimulate global action plans of critical importance that bears positive impacts on "goals and targets" leading to transformation of "people, planet and prosperity"? a) Prioritizing huge profit margin hoping that it will later impact on social and environmental outlooks (wrong) b) Preservation of archaeological sites, relics; genetically improving exotic plants and animals and zoo keeping of endangered animal species. (wrong) c) Focus and synergy on good environment, blossoming people with slow, but steady economic growth (right) d) Economic development, social equity and environmental protection are mutually exclusive. (wrong) e) Promoting socialism (a system of government in which ownership of private property is disallowed) and tackling environmental, social and economic disharmonies of profit driven capitalist system. (wrong)	Students: 15 (17.2%) Lecturers: 25 (47.1%) Government officials: 17 (29.3%) Private operator & Managers: 14 (16.3%) Users: 20 (9.1%) **Total passed: 91 (18.0**%**)**
Q9: Select all the relevant initiatives which agree with the vision/themes of sustainable development goals (SDG) a) Viewing natural resources as limited in nature and seeking renewable alternatives b) Setting up agenda for recycling waste to wealth c) Advancing the frontiers and targets for 'green economies' d) Creating haven for cheaper outsources and hazardous productions	Students: 17 (19.5%) Lecturers: 30 (56.6%) Government officials: 23 (39.7%) Private operator & Managers: 18 (20.9%) Users: 56 (25.3%) **Total passed: 144 (28.5**%**)**

e) Government, institutional and corporate responsibilities on sustainable behaviour	
Q11: In Nigeria, the regulation and control of ecological/environmental problems, impacts and its footprints is supervised by which agency of government? a) Nigerian Electricity Regulatory Commission (wrong) b) Energy Commission of Nigeria (wrong) c) Federal Environmental Protection Agency (FEPA) (right) d) Federal Ministry of Agriculture (wrong) e) Ministry of culture and tourism (wrong)	Students: 82 (94.3%) Lecturers: 50 (94.3%) Government officials: 54 (93.1%) Private operator & Managers: 77 (89.5%) Users: 204 (92.3%) **Total passed: 467 (92.5%)**
Q12: Identify by selecting all environmental events and catastrophes linked to activities and/or impact of mankind unwholesome practices. a) Extreme weather events – rising temperature, droughts, flooding (right) b) Falling of meteorites and other planetary debris (wrong) c) Earthquake and sinkholes especially in mining areas (right) d) Desertification and soil depletion (right) e) Wildfire and industrial bye-products (right)	Students: 30 (34.5%) Lecturers: 35 (66.0%) Government officials: 28 (48.3%) Private operator & Managers: 31 (36.1%) Users: 62 (28.1%) **Total passed: 186 (36.8%)**
SLT score average per stakeholder type (%) • **Students: 40.0%** • **Lecturers: 54.7%** • **Govt. officials: 44.8%** • **Private operators & managers: 33.5%** • **Users: 33.2%** • **SLT state average: 37.5%**	

APPENDIX D2: SUSTAINABILITY LITERACY LEST (SLT) FOR LAGOS RESPONDENTS

Questions and options (including remarks on whether option right wrong)	Stakeholders pass counts & pass rate (%)
Q6: Tick all the statement(s) which defines the concept of sustainability? a) The developments meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. (right) b) Responsibilities of continuously supporting the pursuit of economic prosperity, environmental quality, and social equity together. (right) c) A measure of adaptation that aims to protect humanity and the planetary systems supporting and cautiously enhancing the global potential to provide all people throughout time with equitable access to resources and good life. (right) d) A process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations. (right) e) Scientific endeavor to explore and exploit 'newfound lands', sea and space; land reclamation, creation of 'floating cities' to shore up the stock of depleting natural and material resources. (wrong)	Students: 29 (29.6%) Lecturers: 26 (44.8%) Government officials: 30 (36.2%) Private operator & Managers: 85 (80.2%) Users: 76 (46.3%) **Total passed: 246** (48.3%)
Q7: Pick out all the relevant conventions, statutes and accords which lead to the formulation of sustainable development Agenda 2030 (2015) a) Kyoto Protocol for carbon reduction and carbon trading (1997) (right) b) UN Nuclear Non-Proliferation Treaty (1968) (wrong) c) UN Earth Summit called Rio de Janeiro Agenda 21 (1992) (right) d) London accord for phasing out ozone-depleting chemicals (1990) (right) e) Brundtland Report for the World Commission on Environment and Development (1987) (right)	Students: 24 (24.5%) Lecturers: 32 (55.2%) Government officials: 24 (28.9%) Private operator & Managers: 19 (17.9%) Users: 41 (25.0%) **Total passed: 130** (25.5%)
Q8: Indicate all that are appropriate themes forming the focus of UN Sustainable Development Agenda 2030 which are meant to stimulate global action plans of critical importance that bears positive impacts on "goals and targets" leading to transformation of "people, planet and prosperity"? a) Prioritizing huge profit margin hoping that it will later impact on social and environmental outlooks (wrong) b) Preservation of archaeological sites, relics; genetically improving exotic plants and animals and zoo keeping of endangered animal species. (wrong) c) Focus and synergy on good environment, blossoming people with slow, but steady economic growth (right) d) Economic development, social equity and environmental protection are mutually exclusive. (wrong) e) Promoting socialism (a system of government in which ownership of private property is disallowed) and tackling environmental, social and economic disharmonies of profit driven capitalist system. (wrong)	Students: 10 (10.2%) Lecturers: 23 (39.7%) Government officials: 18 (21.7%) Private operators & Managers: 16 (15.1%) Users: 20 (12.2%) **Total passed: 87** (17.1%)
Q9: Select all the relevant initiatives which agree with the vision/themes of sustainable development goals (SDG) a) Viewing natural resources as limited in nature and seeking renewable alternatives b) Setting up agenda for recycling waste to wealth c) Advancing the frontiers and targets for 'green economies'	Students: 27 (27.6%) Lecturers: 41 (70.7%) Government officials: 39 (47.0%) Private operators & Managers: 55 (51.9%) Users: 63 (38.4%) **Total passed: 225** (44.2%)

d) Creating haven for cheaper outsources and hazardous productions e) Government, institutional and corporate responsibilities on sustainable behaviour	
Q11: In Nigeria, the regulation and control of ecological/environmental problems, impacts and its footprints is supervised by which agency of government? a) Nigerian Electricity Regulatory Commission (wrong) b) Energy Commission of Nigeria (wrong) c) Federal Environmental Protection Agency (FEPA) (right) d) Federal Ministry of Agriculture (wrong) e) Ministry of culture and tourism (wrong)	Students: 87 (88.8%) Lecturers: 55 (94.8%) Government officials: 75 (90.4%) Private operators & Managers: 100 (94.3%) Users: 147 (89.6%) **Total passed: 464 (**91.2%)
Q12: Identify by selecting all environmental events and catastrophes linked to activities and/or impact of mankind unwholesome practices. a) Extreme weather events – rising temperature, droughts, flooding (right) b) Falling of meteorites and other planetary debris (wrong) c) Earthquake and sinkholes especially in mining areas (right) d) Desertification and soil depletion (right) e) Wildfire and industrial bye-products (right)	Students: 38 (38.8%) Lecturers: 44 (75.9%) Government officials: 46 (55.4%) Private operators & Managers: 41 (38.7%) Users: 58 (35.4%) **Total passed: 227** (44.6%)
SLT score average per stakeholder type (%) • **Students: 35.6%** • **Lecturers: 63.5%** • **Govt. officials: 46.6%** • **Private operators & managers: 49.7%** • **Users: 41.2%** • **SLT state average: 45.2%**	

APPENDIX E1: RESPONSE COUNTS OF KANO RESPONDENTS TO Q10 (SUITABLE MODEL)

Model option	Students	Lecturers	Govt officials & managers	Private operators	Users	Option count (%)
Option A	10	5	2	3	11	31 (6.1%)
Option B	18	8	6	11	26	69 (13.7%)
Option C	47	29	43	60	152	331 (65.6%)
Option D	4	5	4	5	17	35 (6.9%)
Option E	8	6	3	7	15	39 (7.7%)
Total	**87**	**53**	**58**	**86**	**221**	**505 (100%)**

APPENDIX E2: RESPONSE COUNTS OF LAGOS RESPONDENTS TO Q10 (SUITABLE MODEL)

Model option	Students	Lecturers	Govt officials & managers	Private operators	Users	Option count (%)
Option A	2	0	3	5	4	14 (2.8%)
Option B	6	8	10	23	26	73 (14.3%)
Option C	87	39	60	56	113	355 (69.8)
Option D	1	9	7	18	15	50 (9.8%)
Option E	2	2	3	4	6	17 (3.3%)
Total	98	58	83	106	164	509 (100)

APPENDIX F1: CHI-SQUARE DISTRIBUTION TABLE (NIELSEN & SLATKIN, 2013)

Critical values of the Chi-square distribution with *d* degrees of freedom

	Probability of exceeding the critical value						
d	0.05	0.01	0.001	*d*	0.05	0.01	0.001
1	3.841	6.635	10.828	11	19.675	24.725	31.264
2	5.991	9.210	13.816	12	21.026	26.217	32.910
3	7.815	11.345	16.266	13	22.362	27.688	34.528
4	9.488	13.277	18.467	14	23.685	29.141	36.123
5	11.070	15.086	20.515	15	24.996	30.578	37.697
6	12.592	16.812	22.458	16	26.296	32.000	39.252
7	14.067	18.475	24.322	17	27.587	33.409	40.790
8	15.507	20.090	26.125	18	28.869	34.805	42.312
9	16.919	21.666	27.877	19	30.144	36.191	43.820
10	18.307	23.209	29.588	20	31.410	37.566	45.315

***INTRODUCTION TO POPULATION GENETICS*, Table D.1**

APPENDIX F2: ASPECTS OF SUSTAINABILITY BASED ON 'YES OR NO' DECISION RULE FOR KANO RESPONDENTS

Aspects of sustainability	Decision rule (Likert 5 to 1)	Response Counts						
		Students	Lecturers	Govt. officials	Private operator	Users	Row sum	Sample total
Mobility or transport	Yes (5,4)	82	52	55	80	195	464	505
	No (2,1)	4	1	2	5	15	27	
	Undecided (3)	1	0	1	1	11	14	
Carbon reduction	Yes (5,4)	70	49	51	63	179	412	505
	No (2,1)	15	3	5	18	22	63	
	Undecided (3)	2	1	2	5	10	30	
Resource use	Yes (5,4)	77	50	53	71	180	431	505
	No (2,1)	5	1	3	9	22	40	
	Undecided (3)	5	2	2	6	19	34	
Water	Yes (5,4)	78	52	53	64	182	429	505
	No (2,1)	6	1	2	14	27	50	
	Undecided (3)	3	0	3	8	12	26	
Energy	Yes (5,4)	74	49	53	70	186	432	505
	No (2,1)	6	2	2	8	17	35	
	Undecided (3)	7	2	3	8	18	38	
Biodiversity	Yes (5,4)	73	48	48	63	193	425	505
	No (2,1)	6	2	4	18	24	54	
	Undecided (3)	8	3	6	5	4	26	
Waste & pollution control	Yes (5,4)	70	49	50	65	187	421	505
	No (2,1)	11	1	5	12	18	47	
	Undecided (3)	6	3	3	9	16	37	

APPENDIX F3: ASPECTS OF SUSTAINABILITY BASED ON 'YES OR NO' DECISION RULE FOR LAGOS RESPONDENTS

Aspects of sustainability	Decision rule (Likert 5 to 1)	Response Counts						
		Students	Lecturers	Govt. officials	Private operators	Users	Row sum	Sample total
Mobility or transport	Yes (5,4)	93	56	81	100	154	484	509
	No (2,1)	3	1	1	4	6	15	
	Undecided (3)	2	1	1	2	4	10	
Carbon reduction	Yes (5,4)	86	57	81	91	146	461	509
	No (2,1)	4	0	0	5	6	15	
	Undecided (3)	8	1	2	10	12	33	
Resource use	Yes (5,4)	78	57	74	79	134	422	509
	No (2,1)	10	1	4	11	12	38	
	Undecided (3)	10	0	5	16	18	49	
Water	Yes (5,4)	75	53	75	79	141	423	509
	No (2,1)	10	1	4	13	11	39	
	Undecided (3)	13	4	4	14	12	47	
Energy	Yes (5,4)	84	56	77	84	138	439	509
	No (2,1)	6	0	3	10	12	31	
	Undecided (3)	8	2	3	12	14	39	
Biodiversity	Yes (5,4)	71	54	77	81	135	418	509
	No (2,1)	22	3	4	20	23	72	
	Undecided (3)	5	1	2	5	6	19	
Waste & pollution control	Yes (5,4)	81	58	79	86	133	437	509
	No (2,1)	5	0	0	5	9	19	
	Undecided (3)	12	0	4	15	22	53	

APPENDIX F4: CHI-SQUARED CONTINGENCY TABLE FOR KANO STATE ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Mobility/ transport	82	86	464	491	81.27088	0.006541
	52	53	464	491	50.08554	0.073178
	55	57	464	491	53.86558	0.023891
	80	85	464	491	80.32587	0.001322
	195	210	464	491	198.4521	0.060051
	4	86	27	491	4.729124	0.112415
	1	53	27	491	2.91446	1.257577
	2	57	27	491	3.13442	0.410573
	5	85	27	491	4.674134	0.022718
	15	210	27	491	11.54786	1.031988
						$\sum \chi_i^2 = 3.000255$

APPENDIX F5: CHI-SQUARED CONTINGENCY TABLE FOR KANO STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Carbon reduction	70	85	412	475	73.72632	0.188337
	49	52	412	475	45.10316	0.336681
	51	56	412	475	48.57263	0.121305
	63	81	412	475	70.25684	0.749561
	179	201	412	475	174.3411	0.124502
	15	85	63	475	11.27368	1.231667
	3	52	63	475	6.896842	2.201787
	5	56	63	475	7.427368	0.793298
	18	81	63	475	10.74316	4.901888
	22	201	63	475	26.65895	0.814203
						$\sum \chi_i^2 = 11.46323$

APPENDIX F6: CHI-SQUARED CONTINGENCY TABLE FOR KANO STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Resource use	77	82	431	471	75.03609	0.051401
	50	51	431	471	46.66879	0.237781
	53	56	431	471	51.24416	0.060162
	71	80	431	471	73.20594	0.066473
	180	202	431	471	184.845	0.126994
	5	82	40	471	6.963907	0.553846
	1	51	40	471	4.33121	2.562093
	3	56	40	471	4.755839	0.648249
	9	80	40	471	6.794055	0.716243
	22	202	40	471	17.15499	1.368356
						$\sum \chi_i^2 = 6.391597$

APPENDIX F7: CHI-SQUARED CONTINGENCY TABLE FOR KANO STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Water	78	84	429	479	75.23173	0.101863
	52	53	429	479	47.46764	0.432764
	53	55	429	479	49.25887	0.284132
	64	78	429	479	69.85804	0.491233
	182	209	429	479	187.1837	0.143554
	6	84	50	479	8.768267	0.873982
	1	53	50	479	5.532359	3.713114
	2	55	50	479	5.741127	2.437855
	14	78	50	479	8.141962	4.214783
	27	209	50	479	21.81628	1.231691
						$\sum \chi_i^2 = 13.92497$

APPENDIX F8: CHI-SQUARED CONTINGENCY TABLE FOR KANO STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Energy	74	80	432	467	74.00428	2.48E-07
	49	51	432	467	47.17773	0.070386
	53	55	432	467	50.87794	0.088508
	70	78	432	467	72.15418	0.064313
	186	203	432	467	187.7859	0.016984
	6	80	35	467	5.995717	3.06E-06
	2	51	35	467	3.82227	0.868768
	2	55	35	467	4.122056	1.092445
	8	78	35	467	5.845824	0.79381
	17	203	35	467	15.21413	0.209629
						$\sum \chi_i^2 = 3.204847$

APPENDIX F9: CHI-SQUARED CONTINGENCY TABLE FOR KANO STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Biodiversity	73	79	425	479	70.09395	0.120483
	48	50	425	479	44.36326	0.298127
	48	52	425	479	46.13779	0.075163
	63	81	425	479	71.86848	1.094358
	193	217	425	479	192.5365	0.001116
	6	79	54	479	8.906054	0.948248
	2	50	54	479	5.636743	2.346373
	4	52	54	479	5.862213	0.591558
	18	81	54	479	9.131524	8.613005
	24	217	54	479	24.46347	0.00878
						$\sum \chi_i^2 = 14.09721$

APPENDIX F10: CHI-SQUARED CONTINGENCY TABLE FOR KANO STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Waste & pollution control	70	81	421	468	72.86538	0.112679
	49	50	421	468	44.97863	0.359535
	50	55	421	468	49.4765	0.005539
	65	77	421	468	69.26709	0.262868
	187	205	421	468	184.4124	0.036308
	11	81	47	468	8.134615	1.00932
	1	50	47	468	5.021368	3.220516
	5	55	47	468	5.523504	0.049616
	12	77	47	468	7.732906	2.354625
	18	205	47	468	20.58761	0.32523
						$\sum \chi_i^2 = 7.736237$

APPENDIX F11: CHI-SQUARED CONTINGENCY TABLE FOR LAGOS STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Mobility/ transport	93	96	484	499	93.11423	0.00014
	56	57	484	499	55.28657	0.009206
	81	82	484	499	79.53507	0.026982
	100	104	484	499	100.8737	0.007568
	154	160	484	499	155.1904	0.009131
	3	96	15	499	2.885772	0.004522
	1	57	15	499	1.713427	0.297053
	1	82	15	499	2.46493	0.870621
	4	104	15	499	3.126253	0.244201
	6	160	15	499	4.809619	0.294619
						$\sum \chi_i^2 = 1.764043$

APPENDIX F12: CHI-SQUARED CONTINGENCY TABLE FOR LAGOS STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Carbon reduction	86	90	461	476	87.16387	0.015541
	57	57	461	476	55.20378	0.058445
	81	81	461	476	78.44748	0.083054
	91	96	461	476	92.97479	0.041945
	146	152	461	476	147.2101	0.009947
	4	90	15	476	2.836134	0.477616
	0	57	15	476	1.796218	1.796218
	0	81	15	476	2.552521	2.552521
	5	96	15	476	3.02521	1.289099
	6	152	15	476	4.789916	0.305705
						$\sum \chi_i^2 = 6.630091$

APPENDIX F13: CHI-SQUARED CONTINGENCY TABLE FOR LAGOS STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Resource use	78	88	422	460	80.73043	0.092348
	57	58	422	460	53.2087	0.270144
	74	78	422	460	71.55652	0.083439
	79	90	422	460	82.56522	0.153948
	134	146	422	460	133.9391	2.77E-05
	10	88	38	460	7.269565	1.025546
	1	58	38	460	4.791304	3.000016
	4	78	38	460	6.443478	0.926609
	11	90	38	460	7.434783	1.709636
	12	146	38	460	12.06087	0.000307
						$\sum \chi_i^2 = 7.262021$

APPENDIX F14: CHI-SQUARED CONTINGENCY TABLE FOR LAGOS STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Water	75	85	423	462	77.82468	0.102523
	53	54	423	462	49.44156	0.256111
	75	79	423	462	72.33117	0.098473
	79	92	423	462	84.23377	0.325194
	141	152	423	462	139.1688	0.024094
	10	85	39	462	7.175325	1.111976
	1	54	39	462	4.558442	2.777815
	4	79	39	462	6.668831	1.068052
	13	92	39	462	7.766234	3.527103
	11	152	39	462	12.83117	0.261331
						$\sum \chi_i^2 = 9.552672$

APPENDIX F15: CHI-SQUARED CONTINGENCY TABLE FOR LAGOS STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Energy	84	90	439	470	84.06383	4.85E-05
	56	56	439	470	52.30638	0.260825
	77	80	439	470	74.7234	0.069361
	84	94	439	470	87.8	0.164465
	138	150	439	470	140.1064	0.031668
	5	90	31	470	5.93617	0.14764
	0	56	31	470	3.693617	3.693617
	3	80	31	470	5.276596	0.982241
	10	94	31	470	6.2	2.329032
	12	150	31	470	9.893617	0.448456
						$\sum \chi_i^2 =$ 8.127352

APPENDIX F16: CHI-SQUARED CONTINGENCY TABLE FOR LAGOS STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Biodiversity	71	93	418	490	79.33469	0.875621
	54	57	418	490	48.62449	0.594271
	77	81	418	490	69.09796	0.903677
	81	101	418	490	86.15918	0.30893
	135	158	418	490	134.7837	0.000347
	22	93	72	490	13.66531	5.083466
	3	57	72	490	8.37551	3.450072
	4	81	72	490	11.90204	5.246348
	20	101	72	490	14.84082	1.793512
	23	158	72	490	23.21633	0.002016
						$\sum \chi_i^2 =$18.25826

APPENDIX F17: CHI-SQUARED CONTINGENCY TABLE FOR LAGOS STATE SURVEY OF ASPECTS OF SUSTAINABILITY

Aspect of sustainability	Observed value (O_i)	Column total (a)	Row total (b)	Grand total (c)	Expected value $E_i = (a * b)/c$	$\chi_i^2 = (O_i - E_i)^2/E_i$
Waste & pollution control	81	86	437	456	82.41667	0.024351
	58	58	437	456	55.58333	0.105072
	79	79	437	456	75.70833	0.143116
	86	91	437	456	87.20833	0.016742
	133	142	437	456	136.0833	0.069861
	5	86	19	456	3.583333	0.560078
	0	58	19	456	2.416667	2.416667
	0	79	19	456	3.291667	3.291667
	5	91	19	456	3.791667	0.385073
	9	142	19	456	5.916667	1.606808
						$\sum \chi_i^2 = 8.619435$

APPENDIX G1: COUNTS OF KANO RESPONDENTS' RATING OF ENVIRONMENTAL CONCEPTS IN Q14

Environmental factors	**1**	**2**	**3**	**4**	**5**	**Total**
Resilient built environment including transport infrastructures	218	132	139	3	13	505
Resource use: conservation, depletion, and recycling (material, energy and materials)	227	121	111	44	2	505
Climate change: global warming, temperature inversion, carbon-based and other air pollutants, industrial smog, ozone layer depletion	218	79	165	43	0	505
Land use change: urbanization, sprawl, erosion, desertification, deforestation, soil depletion, and agriculture	75	219	151	56	4	505
Pollution and noise: effluents, toxic waste, noise, and acoustics	174	96	156	28	51	505
Environmental impact assessment and management	87	94	264	27	33	505
Product and services including clean production, eco-system integrity	133	143	158	14	57	505
Ecology and habitat: Wildlife and biodiversity	129	141	131	50	54	505
Water and aquatic life	98	148	148	22	89	505
Energy consumption: Renewable and alternative energy	101	119	93	119	73	505
Waste and pollution: Poisonous chemicals, radioactive materials	93	134	191	3	84	505
Environmental protection: policies, law & enforcement	60	154	168	27	96	505
Total	1613	1580	1875	436	556	6060
Percentage	26.6	26.1	30.9	7.2	9.2	100.0
Average						2.462

APPENDIX G2: COUNTS OF LAGOS RESPONDENTS' RATING OF ENVIRONMENTAL CONCEPTS IN Q14

Environmental factors	1	2	3	4	5	Total
Resilient built environment including transport infrastructures	45	213	220	23	8	509
Resource use: conservation, depletion, and recycling (material, energy, and materials)	43	223	197	44	2	509
Climate change: global warming, temperature inversion, carbon-based and other air pollutants, industrial smog, ozone layer depletion	45	191	235	38	0	509
Land use change: urbanization, sprawl, erosion, desertification, deforestation, soil depletion, and agriculture	20	235	216	37	1	509
Pollution and noise: effluents, toxic waste, noise, and acoustics	38	211	211	33	16	509
Environmental impact assessment and management	23	173	262	44	7	509
Product and services including clean production, eco-system integrity	37	195	238	24	15	509
Ecology and habitat: Wildlife and biodiversity	36	216	220	28	9	509
Water and aquatic life	31	225	226	18	9	509
Energy consumption: Renewable and alternative energy	33	204	172	77	23	509
Waste and pollution: Poisonous chemicals, radioactive materials	24	181	258	30	16	509
Environmental protection: policies, law & enforcement	23	205	231	27	23	509
Total	398	2472	2686	423	129	6108
Percentage	6.5	40.5	44.0	6.9	2.1	100.0
Average						2.576

APPENDIX G3: COUNTS OF KANO RESPONDENTS' RATING OF ECONOMIC CONCEPTS IN Q14

Economic concept	1	2	3	4	5	Total
Productivity, growth, and income (GDP & GNP)	99	74	291	40	1	505
Economic stability, growth, and developmental economics	105	128	220	51	1	505
Finances and accountability	100	181	172	47	5	505
Productivity, manufacturing, consumption, good & services	66	118	185	98	38	505
Commerce, business, and asset management	68	84	262	89	2	505
Employment, Income, and labour law	69	233	150	51	2	505
Credit facility and tax burden	58	238	165	37	7	505
Trade, commerce and business creation	70	199	141	93	2	505
Total	635	1255	1586	506	58	4040
Percentage	15.7	31.1	39.3	12.5	1.4	100.0
Average						2.529

APPENDIX G4: COUNTS OF LAGOS RESPONDENTS' RATING OF ECONOMIC CONCEPTS IN Q14

Economic concept	1	2	3	4	5	TOTAL
Productivity, growth, and income (GDP & GNP)	43	122	290	51	3	509
Economic stability, growth and developmental economics	31	154	271	53	0	509
Finances and accountability	29	218	222	37	3	509
Productivity, manufacturing, consumption, good & services	18	205	202	70	14	509
Commerce, business and asset management	23	141	276	65	4	509
Employment, Income, and labour law	30	231	211	37	0	509
Credit facility and tax burden	21	280	181	26	1	509
Trade, commerce and business creation	26	228	192	62	1	509
Total	221	1579	1845	401	26	4072
Percentage	5.4	38.8	45.3	9.8	0.6	100.0
Average						2.615

APPENDIX G5: COUNTS OF KANO RESPONDENTS' RATING OF SOCIAL CONCEPTS IN Q14

Social concept	1	2	3	4	5	Total
Rising population and demographic factors	155	116	158	26	50	505
Equity and sharing	166	146	135	58	0	505
Labour and employment creation	123	250	88	38	6	505
Religious beliefs, customs, and tradition	95	62	166	136	46	505
Cultural diversity, historical and tradition	83	53	200	168	1	505
Empowerment and social services	83	212	135	68	7	505
Community participation, diversity, and social inclusion	84	171	171	50	29	505
Education, skill acquisition, training, and well-being	64	144	136	153	8	505
Safety and security	125	83	248	46	3	505
Public health, disease, infirmities, and protection	68	184	230	23	0	505
Outdoor activities, leisure, entertainments, sports & other social events	52	183	214	35	21	505
Total	1098	1604	1881	801	171	5555
Percentage	19.8	28.9	33.9	14.4	3.1	100.0
Average						2.522

APPENDIX G6: COUNTS OF LAGOS RESPONDENTS' RATING OF SOCIAL CONCEPTS IN Q14

Social concept	1	2	3	4	5	Total
Rising population and demographic factors	66	185	222	22	14	509
Equity and sharing	63	188	213	45	0	509
Labour and employment creation	38	258	170	38	5	509
Religious beliefs, customs, and tradition	36	155	190	100	28	509
Cultural diversity, historical and tradition	36	123	216	129	5	509
Empowerment and social services	30	220	183	71	5	509
Community participation, diversity, and social inclusion	28	213	202	42	24	509
Education, skill acquisition, training, and well-being	25	196	185	97	6	509
Safety and security	31	148	287	41	2	509
Public health, disease, infirmities, and protection	32	185	265	27	0	509
Outdoor activities, leisure, entertainments, sports & other social events	30	195	232	37	15	509
Total	415	2066	2365	649	104	5599
Percentage	7.4	36.9	42.2	11.6	1.9	100.0
Average						2.636

APPENDIX G7: COUNTS OF KANO RESPONDENTS' RATING OF MULTI-DIMENSIONAL CONCEPTS IN Q14

Multi-dimensional concepts	1	2	3	4	5	Total
Politics, leadership, democracy, and governance	118	173	172	29	13	505
Ethics and Philosophy, and holistic thinking	106	243	135	17	4	505
Addressing transparency, bribery, and corruption	115	199	151	30	10	505
Networking, cooperation, collaboration & inter-government synergetic relationships	62	176	221	44	2	505
Responsibility and transparency	138	224	92	50	1	505
Awareness, feedback, reporting information and communication	90	186	204	24	1	505
System thinking, long-term and holistic thinking	101	195	187	16	6	505
Sustainable development targets and benchmarks	94	240	158	11	2	505
Tourism	110	179	204	6	6	505
People, society, accomplishment, and poverty reduction	52	187	243	21	2	505
Migration, travel and integration	82	231	156	35	1	505
Total	1068	2233	1923	283	48	5555
Percentage	19.2	40.2	34.6	5.1	0.9	100.0
Average						2.282

APPENDIX G8: COUNTS OF LAGOS RESPONDENTS' RATING OF MULTI-DIMENSIONAL CONCEPTS IN Q14

Multi-dimensional concepts	1	2	3	4	5	Total
Politics, leadership, democracy, and governance	53	222	193	39	2	509
Ethics and Philosophy, and holistic thinking	40	227	199	37	6	509
Addressing transparency, bribery, and corruption	25	204	239	39	2	509
Networking, cooperation, collaboration & inter-government synergetic relationships	26	205	236	41	1	509
Responsibility and transparency	28	227	205	48	1	509
Awareness, feedback, reporting information and communication	37	199	234	38	1	509
System thinking, long-term and holistic thinking	35	231	225	18	0	509
Sustainable development targets and benchmarks	29	248	208	23	1	509
Tourism	38	212	247	12	0	509
People, society, accomplishment, and poverty reduction	33	211	236	29	0	509
Migration, travel and integration	37	250	191	30	1	509
Total	381	2436	2413	354	15	5599
Percentage	6.8	43.5	43.1	6.3	0.3	100.0
Average						2.497

APPENDIX H1: NEEDS OF TRANSPORT SUSTAINABILITY PROMOTED BY PUBLIC TRANSPORT CHOICES FOR KANO CITY

Sustainability indicators	1	2	3	4	5	Total
Availability of public transport service	59	187	92	146	21	505
Frequency of public transport service	60	205	124	92	24	505
Affordable travel cost	97	207	137	62	2	505
Proximity to the stations (both train and buses)	102	188	98	111	6	505
Reducing delay or travel time	82	221	87	96	19	505
Shortening the length of journey (shortest route)	124	225	87	63	6	505
Road infrastructure control, vending of routes and right-of-way	76	306	78	44	1	505
Reliability and efficiency of service	99	255	104	41	6	505
Travel route coverage	70	265	109	58	3	505
Comfort, convenience, and entertainment on-board	159	197	122	23	4	505
Flexibility, linkages & available of door-to-door services	131	161	123	69	21	505
Information and communication	145	209	126	25	0	505
Availability of disable public transport service	212	172	71	24	26	505
Building infrastructures to enhance throughput & service quality	76	256	120	42	11	505
Cheaper fares	182	181	107	19	16	505
Parking restriction, regulation, and tolling	119	226	58	98	4	505
Bike route and bike parks	204	139	67	74	21	505
Increased all weather and all-time bus and train services	197	168	86	51	3	505
Scheme for car-sharing and hire services	203	164	71	43	24	505
Metro services, subway & underground tube to reduce congestion	206	161	86	50	2	505
Total	2603	4093	1953	1231	220	10100
Percentage	25.6	40.2	19.2	12.1	2.2	100.0
Mean (standard deviation)					2.245 (1.037)	

APPENDIX H2: NEEDS OF TRANSPORT SUSTAINABILITY PROMOTED BY PUBLIC TRANSPORT CHOICES FOR LAGOS CITY

Sustainability indicators	1	2	3	4	5	Total
Availability of public transport service	47	209	91	142	20	509
Frequency of public transport service	46	218	107	115	23	509
Affordable travel cost	64	228	127	83	7	509
Proximity to the stations (both train and buses)	98	212	117	79	3	509
Reducing delay or travel time	79	264	80	77	9	509
Shortening the length of journey (shortest route)	54	234	87	123	11	509
Road infrastructure control, vending of routes and right-of-way	155	232	68	51	3	509
Reliability and efficiency of service	83	183	81	136	26	509
Travel route coverage	75	200	120	90	24	509
Comfort, convenience, and entertainment on-board	55	231	100	104	19	509
Flexibility, linkages & available of door-to-door services	102	236	98	68	5	509
Information and communication	70	311	84	43	1	509
Availability of disable public transport service	200	184	77	22	26	509
Building infrastructures to enhance throughput & service quality	75	265	123	38	8	509
Cheaper fares	58	204	102	123	22	509
Parking restriction, regulation, and tolling	63	217	131	82	16	509
Bike route and bike parks	91	221	128	64	5	509
Increased all weather and all-time bus and train services	87	204	106	106	6	509
Scheme for car-sharing and hire services	73	230	91	95	20	509
Metro services, subway & underground tube to reduce congestion	112	235	92	66	4	509
Total	1687	4518	2010	1707	258	10180
Percentage	16.6	44.4	19.7	16.8	2.5	100.0
Mean (standard deviation)						2.443 (1.032)

APPENDIX H3: NEEDS OF TRANSPORT SUSTAINABILITY PROMOTED BY MEASURES OF SYNERGY BETWEEN TRANSPORT SYSTEMS & ECONOMY FOR KANO CITY

Sustainability indicators	1	2	3	4	5	Total
Infrastructures to enhance throughput and service quality	116	215	144	30	0	505
Congestion charging through congestion zones	167	200	77	58	3	505
Increasing road tax	163	194	87	40	21	505
Average income and wages	116	225	100	61	3	505
Mean transport cost	153	157	134	48	13	505
Employment and job creation	192	131	126	54	2	505
Vehicle hire	147	199	102	55	2	505
Road and parking toll	145	228	80	50	2	505
Total	1199	1549	850	396	46	4040
Percent	29.7	38.3	21.0	9.8	1.1	100.0
Mean (standard deviation)						2.144 (0.990)

APPENDIX H4: NEEDS OF TRANSPORT SUSTAINABILITY PROMOTED BY MEASURES OF SYNERGY BETWEEN TRANSPORT SYSTEMS & ECONOMY FOR LAGOS CITY

Sustainability indicators	1	2	3	4	5	Total
Infrastructures to enhance throughput & service quality	98	225	144	42	0	509
Congestion charging through congestion zones	63	200	94	129	23	509
Increasing road tax	48	204	136	102	19	509
Average income and wages	81	216	130	77	5	509
Mean transport cost	73	203	108	114	11	509
Employment and job creation	52	216	102	117	22	509
Vehicle hire	97	214	96	89	13	509
Road and parking toll	144	230	82	51	2	509
Total	656	1708	892	721	95	4072
Percent	8.1	21.1	11.0	8.9	1.2	100.0
Mean (standard deviation)						2.482 (1.033)

APPENDIX H5: NEEDS OF TRANSPORT SUSTAINABILITY BY MEANS OF ENVIRONMENTAL STEWARDSHIP & ENERGY USE FOR KANO CITY

Sustainability indicators	1	2	3	4	5	Total
Side walk and bike routes	215	143	102	41	4	505
Vehicle and tire recycling	219	139	106	37	4	505
Reduction of transport waste disposal	291	135	67	11	1	505
All weather transport alternatives (subways, underground tubes)	284	105	79	24	13	505
Vehicle driven by clean and renewable energy	233	164	81	24	3	505
Reduction of transport Greenhouse gas emissions (CO2)	245	165	73	8	14	505
Air quality and reducing pollutants (PM10, NMVOCs, NOX, CO)	231	149	60	59	6	505
Reduced exposure to transport noise pollution	234	165	48	44	14	505
Reduced urban land consumption & land change	245	154	76	30	0	505
Total	2201	1315	696	274	59	4545
Percent	48.4	28.9	15.3	6.0	1.3	100.0
Mean (standard deviation)						1.828 (0.983)

APPENDIX H6: NEEDS OF TRANSPORT SUSTAINABILITY BY MEANS OF ENVIRONMENTAL STEWARDSHIP & ENERGY USE FOR LAGOS CITY

Sustainability indicators	1	2	3	4	5	Total
Side walk and bike routes	74	220	118	86	11	509
Vehicle and tire recycling	96	198	140	72	3	509
Reduction of transport waste disposal	99	232	93	75	10	509
All weather transport alternatives (subways, underground tubes)	64	237	96	99	13	509
Vehicle driven by clean and renewable energy	109	231	103	61	5	509
Reduction of transport Greenhouse gas emissions (CO2)	66	168	108	138	29	509
Air quality and reducing pollutants (PM10, NMVOCs, NOX, CO)	63	183	124	108	31	509
Reduced exposure to transport noise pollution	90	226	94	77	22	509
Reduced urban land consumption & land change	92	201	118	95	3	509
Total	753	1896	994	811	127	4581
Percent	16.4	41.4	21.7	17.7	2.8	100.0
Mean (standard deviation)						2.490 (1.048)

APPENDIX H7: NEEDS OF TRANSPORT SUSTAINABILITY BY PROMOTING ALTERNATIVES TO PHYSICAL MOBILITY FOR KANO CITY

Sustainability indicators	1	2	3	4	5	Total
Telecommuting services including telephone and computer	203	99	132	71	0	505
Distant learning, open university and teleconferencing	161	128	161	55	0	505
Teleshopping and courier services	236	131	136	2	0	505
Total	600	358	429	128	0	1515
Percent	39.3	23.4	28.1	8.4	0.0	99.2
Mean (standard deviation)						2.056 (1.007)

APPENDIX H8: NEEDS OF TRANSPORT SUSTAINABILITY BY PROMOTING ALTERNATIVES TO PHYSICAL MOBILITY FOR LAGOS CITY

Sustainability indicators	1	2	3	4	5	Total
Telecommuting services including telephone and computer	44	169	133	132	31	509
Distant learning, open university, and teleconferencing	54	175	158	99	23	509
Teleshopping and courier services	97	211	101	79	21	509
Total	195	555	392	310	75	1527
Percent	12.8	36.3	25.7	20.3	4.9	100.0
Mean (standard deviation)						2.682 (1.083)

APPENDIX H9: NEEDS OF TRANSPORT SUSTAINABILITY PROMOTING NON-MOTORIZED TRANSPORT MODES FOR KANO CITY

Sustainability indicators	1	2	3	4	5	Total
Mixed land use and diversity of commercial services	259	117	109	20	0	505
Close proximity to school, shopping areas retail stores & green parks	244	126	98	37	0	505
Biking and pedestrian travel services, bike parks	265	151	71	18	0	505
Aesthetic and beautification of travel corridors	233	187	68	17	0	505
Total	1001	581	346	92	0	2020
Percent	49.6	28.8	17.1	4.6	0.0	100.0
Mean (standard deviation)					1.767 (0.891)	

APPENDIX H10: NEEDS OF TRANSPORT SUSTAINABILITY PROMOTING NON-MOTORIZED TRANSPORT MODES FOR LAGOS CITY

Sustainability indicators	1	2	3	4	5	Total
Mixed land use and diversity of commercial services	50	178	162	98	21	509
Close proximity to school, shopping areas retail stores & green parks	85	217	105	81	21	509
Biking and pedestrian travel services, bike parks	74	236	99	80	20	509
Aesthetic and beautification of travel corridors	72	208	130	97	2	509
Total	281	839	496	356	64	2036
Percent	13.8	41.2	24.4	17.5	3.1	100.0
Mean (standard deviation)					2.550 (1.031)	

APPENDIX H11: NEEDS OF TRANSPORT SUSTAINABILITY BY MEANS OF SECURITY AND SAFETY MEASURES FOR KANO CITY

Sustainability indicators	1	2	3	4	5	Total
Pedestrian crossing at busy intersection	175	191	122	17	0	505
Speed and traffic calming measures	170	118	168	49	0	505
Reducing crime rate and violations of law & order	137	174	181	13	0	505
Traffic signs and signal	114	165	184	42	0	505
Reducing transport accident, death, injuries & economic losses	134	223	127	21	0	505
Total	730	871	782	142	0	2525
Percent	28.9	34.5	31.0	5.6	0.0	100.0
Mean (standard deviation)					2.133 (0.898)	

APPENDIX H12: NEEDS OF TRANSPORT SUSTAINABILITY BY MEANS OF SECURITY AND SAFETY MEASURES FOR LAGOS CITY

Sustainability indicators	1	2	3	4	5	Total
Pedestrian crossing at busy intersection	107	237	146	19	0	509
Speed and traffic calming measures	37	184	127	132	29	509
Reducing crime rate and violations of law & order	41	206	128	103	31	509
Traffic signs and signal	57	244	109	77	22	509
Reducing transport accident, death, injuries & economic losses	53	215	148	90	3	509
Total	295	1086	658	421	85	2545
Percent	11.6	42.7	25.9	16.5	3.3	100.0
Mean (standard deviation)					2.574 (1.004)	

APPENDIX H13: NEEDS OF TRANSPORT SUSTAINABILITY BY MEASURES FOR REDUCING MOTORIZATION AND PRIVATE CAR USE FOR KANO CITY

Sustainability indicators	1	2	3	4	5	Total
Reducing private car trips	229	120	143	13	0	505
Congestion charges on busy transport zones	260	104	121	20	0	505
Availability of fast routes for public buses and sub ways	182	167	126	30	0	505
Reliable metros and underground rail services	279	136	75	15	0	505
Reliable surface rails, metros, and underground rail services	287	111	92	15	0	505
Total	1008	518	414	80	0	2020
Percent	49.9	25.6	20.5	4.0	0.0	100.0
Mean (standard deviation)					1.785 (0.904)	

APPENDIX H14: NEEDS OF TRANSPORT SUSTAINABILITY BY MEASURES FOR REDUCING MOTORIZATION AND PRIVATE CAR USE FOR LAGOS CITY

Sustainability indicators	1	2	3	4	5	Total
Reducing private car trips	126	166	192	25	0	509
Congestion charges on busy transport zones	43	185	121	132	28	509
Availability of fast routes for public buses and sub ways	40	191	140	110	28	509
Reliable metros and underground rail services	94	220	146	45	4	509
Reliable surface rails, metros, and underground rail services	92	206	160	51	0	509
Total	269	802	567	338	60	2036
Percent	13.2	39.4	27.8	16.6	2.9	100.0
Mean (standard deviation)					2.567 (1.009)	

APPENDIX H15: NEEDS OF TRANSPORT SUSTAINABILITY PROMOTED BY SOCIAL BENEFITS AND EQUITY FOR KANO CITY

Sustainability indicators	1	2	3	4	5	Total
Cheaper transport fare	287	111	92	15	0	505
Social benefit (services for babies, students, disable and old people)	230	138	111	26	0	505
Duty of care for public health and sanitation services	216	158	110	21	0	505
Sustainability education, awareness & public involvement in policy decision	212	185	99	9	0	505
Good planning of policy direction by government/authorities	203	200	94	8	0	505
Total	1148	792	506	79	0	2525
Percent	45.5	31.4	20.0	3.1	0.0	100.0
Mean (standard deviation)				1.808 (0.862)		

APPENDIX H16: NEEDS OF TRANSPORT SUSTAINABILITY PROMOTED BY SOCIAL BENEFITS AND EQUITY FOR LAGOS CITY

Sustainability indicators	1	2	3	4	5	Total
Cheaper transport fare	114	203	165	27	0	509
Social benefit (services for babies, students, disable and old people)	78	198	201	32	0	509
Duty of care for public health and sanitation services	32	190	121	139	27	509
Sustainability education, awareness & public involvement in policy decision	28	200	147	108	26	509
Good planning of policy direction by government/authorities	75	232	154	44	4	509
Total	327	1023	788	350	57	2545
Percent	12.8	40.2	31.0	13.8	2.2	100.0
Mean (standard deviation)				2.523 (0.957)		