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AN EXPLORATORY STUDY OF THE RELATIONSHIP BETWEEN URBAN FORM AND TRAVEL BEHAVIOUR IN KADUNA, NIGERIA

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A major component of sustainability and sustainable development as it relates to cities is the interaction between urban form and transportation patterns. This study employed regression analysis in order to determine the relationship between urban form and travel behaviour. Urban form was quantified as land use mix and population density while travel behaviour was measured by vehicle miles travelled (VMT). The relationship between the urban form and travel behaviour was determined using regression analysis. The results show that population density with a p-value of 0.000 has a statistically significant relationship with the dependent variable, VMT while land use mix with a p-value of 0.48 has no statistically significant relationship with the dependent variable at 5% level of significance. The results obtained for Kaduna are comparable with results obtained by similar studies in cities in Europe, USA, Latin America, Australia and Asia. This suggests that the urban form and travel behavior relationship in Kaduna can be used in developing sustainable urban land use and transportation systems as has been demonstrated in other parts of the world. The paper concludes by suggesting further research that would improve on this exploratory one to cover other known urban form and travel behaviour variables such as mode choice, accessibility, trip frequency, neighbourhood design and travel demand management.

Keywords: land use patterns, regression analysis, sustainability, travel behavior, urban form

INTRODUCTION

Cities are at the forefront of the current debate and efforts towards achieving global sustainability (Newman and Kenworthy, 1999; Shore, 2006; Cohen, 2006; La Greca, 2009; Gossop and Alves, 2009; Owen, 2009). Sustainable development as it relates to urban planning and cities is concerned with the integration of land use and transportation systems in such a way that enables a modal shift from private automobile use to public transit and non-motorized modes of travel (Liu et al., 2016; Melville & Minnery 2015; Creutzig et al., 2015; Albayati et al., 2015 Currie & Gruyter 2018; Wolday, 2018; Zhang et al., 2018). In Western Europe, United States and Australia, urban development policies and built form initiatives are being drawn from empirical research that has shown excessive zoning of land uses and

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the tendency of the city to sprawl as environmentally untenable because they create the need to commute for longer distances using self-owned motorized means of travel (Curtis, 2011). These initiatives are guided by urban development principles and concepts that have been inspired by the desire to achieve sustainable development such as New Urbanism, Smart Growth, Transit-Oriented Development and Low Carbon Development (Levy, 2009; Owen 2009).

Generally speaking, strong and negative relationships are desired between vehicle miles travelled; which is the total distance travelled by individuals for work and non-work purposes (VMT) and urban form variables such as population density, land use mix and accessibility. This is because the objective of sustainable urban forms is a reduction in trip lengths. For public mode choice and non-motorized modes of travel like walking and cycling, it is desired that there exists a strong and positive relationship with urban form variables. Results from previous studies reveal varied patterns in these relationships. Bhatia (2004) and Albayati et al. (2015) reported a p-value of -0.34 for the relationship between population density and VMT while Kuzmyak (2009) and Liu et al. (2016) reported a p-value of -0.04 suggesting a statistically weak relationship in the case of the former and a statistically strong relationship in the case of the latter. This is rather odd, as the expectation is that there would be some significant relationship in all cases but the variation should be in terms of the direction of the relationships either positive or negative.

Similarly, VMT and job density relationships have also shown these kinds of variations in previous studies. Low but positive elasticity or p-values were established with respect to job density and VMT by Boarnet et al. (2004), Zhou and Kockelmen (2008) and Greenwald (2009). Negative values were obtained for the same relationship by Chatman (2008), Ewing et al. (2009) and Currie & Gruyter (2018). For trip lengths or VMT and land use mix, the values established by previous studies range between +0.03 in Greenwald (2009) to -0.27 in Kuzmyak (2009 although there is a lot of instances where an average of -0.10 was obtained (Kuzmyak et al., 2006; Sun et al., 1998 and Pushkar et al., 2000; Albayati et al. 2015). The key thing to note with these elasticity values is that they suggest statistically weak relationships between the dependent and independent variables. However, these relationships still have a lot of useful application in sustainable urban land use and transportation planning with overall objectives being a reduction in transportation energy use and a shift to non-motorized modes of transportation such as walking and cycling (Naess, 2012; Creutziga et al., 2015).

The argument on the need to use built form and its relation with transport to reduce energy consumption is well recognized in developed countries but perhaps less so in developing countries like Nigeria. This is in spite of Nigeria being a signatory to all the global environmental and sustainable development conventions and treaties including the Bali Action Plan agreed to in December, 2007. This plan stresses the need for nations to transition towards comprehensive Low-Carbon Development Strategies (LCDS). The Nigeria National Transport Policy recognizes the need to promote energy conservation and environmental protection in transportation systems (FMWHUD, 2006) but says nothing about the relationship between the built environment and urban transportation and how

better urban land planning and management can lead to a shift to greater use of public transit and non-motorized forms of travel.

Within the context of sustainable development and the urban form and travel behavior relationship, there exist knowledge gaps occasioned by a lack of empirical research on Nigerian cities. This is because transportation research in Nigeria has largely focused on issues surrounding the problems of infrastructure deficiency and poor transportation service delivery (Akinbami and Fadare, 1997; Ogunbodede, 2008; Ogwude, 2011). Very little is known about urban form in Nigerian cities (Agunbiade et al., 2012) and by extension its interaction with urban transportation. Hence the need to intervene in a way that ensures that the empirical evidence establishing the urban form and travel behavior relationships is scientifically established and documented in Nigerian cities. This evidence can then be used to facilitate long term plans that will lead to the emergence of urban forms that make people travel less and also encourage the use of non-motorized and public modes of transportation. The current study is an actualization of such intervention and an exploratory one that was conducted in Kaduna in North West Nigeria which sought to establish the relationship between vehicle miles travelled (selected travel behaviour indicator) and population density and land use mix (selected urban form indicators). The key research questions here are; is there a relationship between urban form and travel behaviour in Kaduna; what is the nature of the relationship between urban form and travel behavior in Kaduna? The study employed regression analysis to test the relationship between vehicle miles travelled (VMT) for work purposes (dependent variable) on the one hand and land use mix and population density (independent variables) on the other. The exploratory nature of the study which was informed by the paucity of data on urban form and travel behavior in Kaduna explains the selection of only two urban form variables and one travel behavior variable. The key concern of the study was exploring the extent to which the urban form of Kaduna as defined by population density and land use mix influence the distances travelled by residents in their daily commute trips or journeys to and from work.

LITERATURE REVIEW: ESTABLISHING AND MODELLING THE URBAN FORM AND TRAVEL BEHAVIOUR RELATIONSHIP

New urbanism and smart growth principles promote urban development patterns that encourage the use of non-motorized modes of travel, increase public transit ridership and reduce trip lengths. Ewing and Cervero (2010) compiled the results of studies that investigated the relationship between urban form and travel behaviour in Western European countries and established that in the case of urban form and VMT, it is desired that the elasticity values are negative because the aim is a reduction in trip lengths. It is also clear from Ewing and Cervero (2010) that accessibility, taken as distance to the city centre and access to jobs by automobiles reduce VMT considerably. Other variables that affect VMT marginally are land use diversity/mix, residential population density, access to jobs by transit and distance to public transit stops. For public transport mode choice and non-motorized modes of travel, positive elasticity values are desired. The inference from the European cases show that walking and the use of public transit are influenced

positively by neighbourhood design and land use mix to a large extent and by residential population density to a lesser extent.

Different results have been reported by individual investigations into the relationship between urban form and travel behaviour. The observed relationships range between strong in some cases and weak in others. Furthermore, some parameters found significant in some respect can be found insignificant in some others. For instance, the relationship between population density/household/job and vehicle miles travelled is usually generally unidirectional, but in Bhatia (2004) and Kuzmyak (2009) variations in elasticity values ranged from -0.34 to -0.04 for the former and latter respectively. Same can be said of the VMT and job density relationship where very low but positive elasticity values were established by Boarnet et al. (2004), Zhou and Kockelman (2008), Greenwald (2009) and Stojanovski (2018). Negative elasticity values for the relationship were established by Chatman (2008) and Ewing et al. (2009). In the case of trip lengths and diversity relationship, elasticity values established by past studies range from +0.03 in Greenwald (2009) to -0.27 in Kuzmyak (2009) even though it is frequently determined at an average of -0.10 (Kuzmyak et al., 2006; Sun et al., 1998 and Pushkar et al., 2000). Access to destination in relation to VMT has been observed to produce more consistent elasticity values averaging around -0.20 as reported in Pushkar et al. (2000), Boarnet et al. (20004) and Zegras (2007). Liu et al. (2016) established that urban form variables (density, land use mix and accessibility) have a strong and negative effect on VMT and by implication a reduction in CO2 emissions using Structural Equation Modelling in a study conducted in Beijing.

The importance of these relationships, practical or statistical, underscore their usefulness in sustainable urban planning. These relationships signified by the average weighted elasticity values can be applied in the evaluation of urban development plans and policies with respect to how they impact vehicle miles travelled, public transit ridership and use of non-motorized modes of travel. This is important because the aforementioned travel behaviour variables have impacts on energy used in transportation, and determine to some extent the level of urban greenhouse gas emissions and pollution. The results of the urban form and travel behaviour relationship from other parts of the world discussed in this section will be used as a good reference point for the evaluation of the results obtained for Kaduna. Comparisons will also be made between Kaduna and other cities and inferences will be drawn.

The methods employed in studies on the urban form and travel behaviour relationship are presented in Table 1 (pg. 6) (Joo, 2008; Kono, 2010; Tracy et al., 2011; Munshi, 2013; Zhang et al., 2018). It is clear from the information in Table 1 that multi-variate and logistic regression analysis are the most commonly used methods in these types of studies. Travel characteristics are cast as the outcome variable and urban form measures are cast as the predictor or independent variables. Multi-variate linear regression is mostly applied in investigating the VMT and urban form relationship while logistic regression is used in investigating the mode choice – urban form relationship.

Travel behaviour is represented by total distances travelled by individuals for work (VMT) and the modes used for such travels. Therefore, travel behaviour is a

representation of the decisions made by individuals when they have certain alternatives to choose from. These alternatives are trip lengths for work purpose and the preferred mode of transportation. The best way to study these type of preferential behaviour is at the disaggregated level of the individual. Thus, the model to be used should be built on real individual travel preferences and the factors which influence them.

As shown in Table 1, linear regression models are commonly used to model the relationship between travel distances and urban form indicators. The category of models that attempts to model the probability of making the transport mode choice is called 'probabilistic models'. These models measure the value of urban form indicators as input or a tool to analyse the individual's choice of travel behaviour, for example mode choice. In analysing mode choice, binary (0, 1) data inputs are used to analyse the probabilistic discriminant model of choice behaviour. The logit model estimates express the log of the odds of choosing a particular mode over other modes as a function of the log of urban form indicators that are found to significantly explain the choice of the mode under consideration. The logit model framework within a stochastic mode choice framework is based on the work of McFadden (1974) and Luce and Suppes (1965). A commonly used logit model in urban form and mode choice relationship problems is the logistic regression model as can be inferred again from Table 1.

Table 1: Empirical methods in urban form travel behaviour relation research

Data	Method of Analysis*#	#
Aggregate	Linear regression	5
	Nonlinear regression	1
	Simultaneous linear equation	1
Disaggregate	Linear regression	28
	Logistic regression	16
	Negative binomial regression	6
	Probit regression	3
	Tobit regression	3
	Propensity score matching	2

 # = No of times method has been used in urban form and travel behaviour analysis
Source: Adapted from Ewing and Cervero (2010)

However, evidence in the recent travel behaviour literature suggests that there have been further improvements in the empirical methodologies for studying the relationship between travel choices and explanatory variables such as socio-demographic and built environment factors. One of the most commonly applied methods is the multi-nomial logit (MNL) model, a discrete choice model developed on the basis of the random utility theory (Ben-Akiva and Lerman, 1985). The MNL model has an unordered-responsive choice mechanism that can be applied in determining the relationship between the predictor variables and the dependent variable at a disaggregate level of data analysis. Also available today are more advanced discrete choice modelling techniques that combine mixed revealed preference and stated preference data. In that light, Wen (2010) proposed an alternative tree modelling structure approach in the case of problems that involve multinomial and nested-choice heirachy (Zhang et al., 2018). Other modelling approaches that have been used in travel behaviour studies lately are the ordered

probit-demand model (Zito et al., 2011), artificial neural networks (Dia and Panwai, 2010), structural equation modelling (Lee, 2009; Liu et al., 2016) and the extended multiple discrete-continous choice model (Wang and Li, 2011). However, the studies that have employed these approaches are most often concerned with the influence of multi-faceted categories of predictor variables like social, economic, demographic as well as physical factors on travel behaviour. Therefore the research concern is usually centred on investigating the complex interactions simultaneously between endogenous variables as well as between endogenous and exogenous variables. This study being an exploratory one employed the most basic of analysis methods, which is the multiple regression analysis in order to test the relationship between urban form and travel behavior in Kaduna. This is because of the simplified research question and the non-inclusion of complex and diverse variables that would have required more sophisticated methods of analysis.

THE STUDY AREA

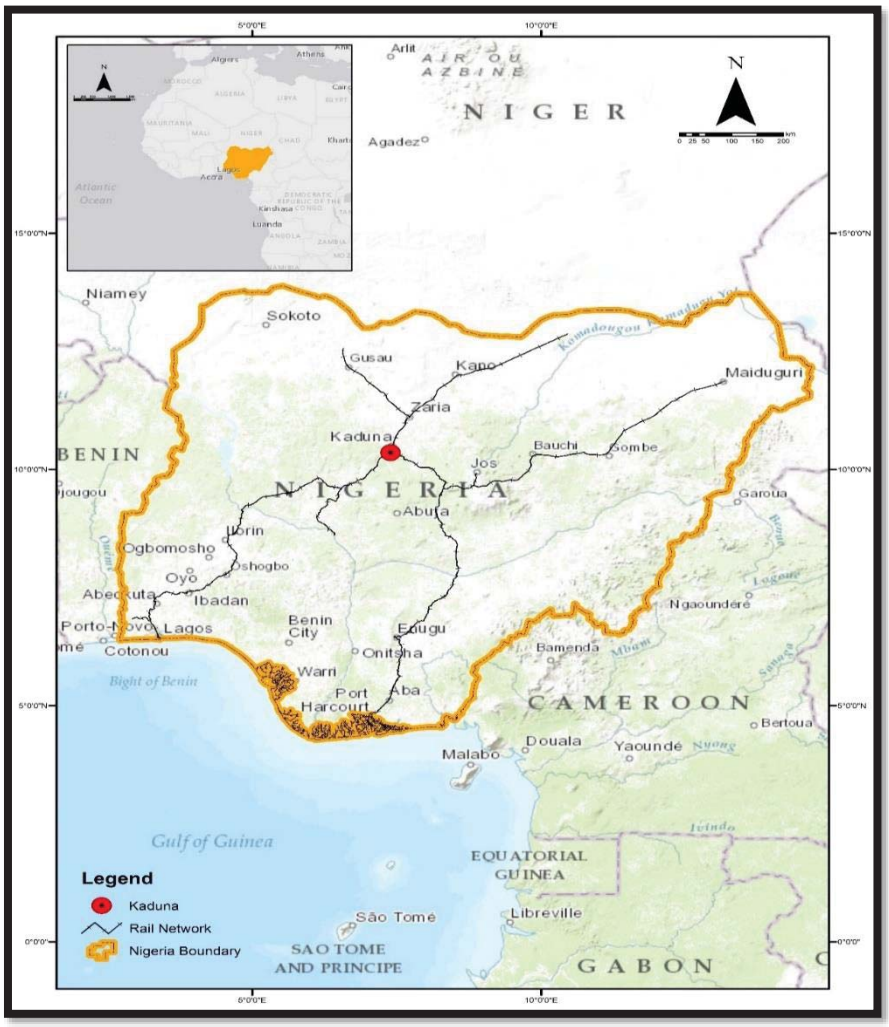

Figure 1: Kaduna in the Nigerian national context

The study area is Kaduna in northwest Nigeria (figure 1). In the hierarchy of Nigerian cities, Kaduna is considered a relatively young city. It was established by the British colonial administration headed by Lord Frederick Lugard in 1912 (Haruna, 2012). By 1919, 7 years after its establishment as the capital of the

Northern Nigerian Region, the estimated population was only 3,000. By 1930, it had risen to 10,000 people – an increase of 330%. Between 1952 and 1963, Kaduna recorded an annual average growth rate of 12.5%. 10.1% higher than the 2.4% average growth rate estimated for developing countries. From 1963 to 1985, Kaduna is estimated to have grown at an average of 7% per annum. Two types of urban growth are discernible in Kaduna – growth by fusion and outward expansion of the city's built mass. The former was basically the annexation of adjoining villages while the latter was the outward expansion of the city in directions where there were no previous settlements (Agboola, 1986). Between 1917 and 1930, the total extent of the city was 12.5km2. In 1982, it had grown to approximately 100km2 and by 1985 it was estimated at 140km2 (Agunbiade et al., 2012). By 2010, Kaduna's physical extent had grown to 420km2.

DATA AND METHODS

Methods

The empirical model applied in this research is a multiple linear regression model that was used in determining the relationship between urban form and vehicle miles travelled (VMT) which was measured as daily trip lengths of households for work purposes as the dependent variable. The independent variables in this model are population density and land use mix referred to as the urban form indicators. The dependent and independent variables used in the model are detailed in Table 2. The statistical significance level for decision making using the empirical models is set at =< 5%. The urban form indicators are disaggregated at and estimated for each grid cell where a household survey was conducted while the travel behaviour and socioeconomic variables are aggregated at the household level. The aggregation and disaggregation of data is crucial to the type of analysis employed in this study because it provided the basis for linking the travel behaviour data obtained at the household level with the parcel level urban form signatures obtained at the one hectare grid level that was the basic spatial unit of analysis. The explanation of the procedure and methods used in achieving the disaggregation and aggregation of the urban form and travel behaviour data is provided in Section 4.2. Urban form and travel behavior data was collected in all twenty four districts of Kaduna. The number of samples drawn from each district for the household survey was determined by its proportionate share of the metropolitan population.

Data

The data required to establish the urban form and travel behaviour relationship is categorized into two, travel behaviour data (VMT) as dependent variable and urban form data (population density & land use mix) as independent variables as shown in table 2.

Table 2: Dependent and independent variables for regression models

Dependent Variables (Travel Behaviour Indicators)	Independent Variables (Urban Form Indicators)
Vehicle Miles Travelled (VMT)	Population Density
	Land Use Mix

Travel behaviour data

In this study, data on travel mode choice and on trip lengths for work and non-work trips in Kaduna is not available from any known secondary sources. Thus a household travel characteristics survey was conducted. Travel behaviour is described by measures such as vehicle miles travelled (VMT) per day by each individual for work and non-work purposes and the preferred mode of travel for such trips. Therefore, the variables listed below are used to measure the different aspects of travel behaviour:

1. Home-based VMT per person per day for work purpose;
2. Public transport use for work purposes;
3. Private vehicle use for work trips; and
4. Private vehicle use for non-work trips.

Although four indicators of travel behaviour were determined by the household survey, only one, which is the VMT is included in the regression analysis. The sample size for the survey was determined at 600 households which represents 0.3% of the estimated 195,125 households in Kaduna metropolis. To determine the sample size for the household travel characteristics survey, a 95% confidence level and a (+/-) 4 confidence interval were chosen. An extra 15 samples were added to the sample size in order to accommodate unforeseen circumstances like losses, damage and incomplete responses in the field. The location of each interviewed household was geocoded in order to facilitate linking it with observed urban form indicators (figure 2).

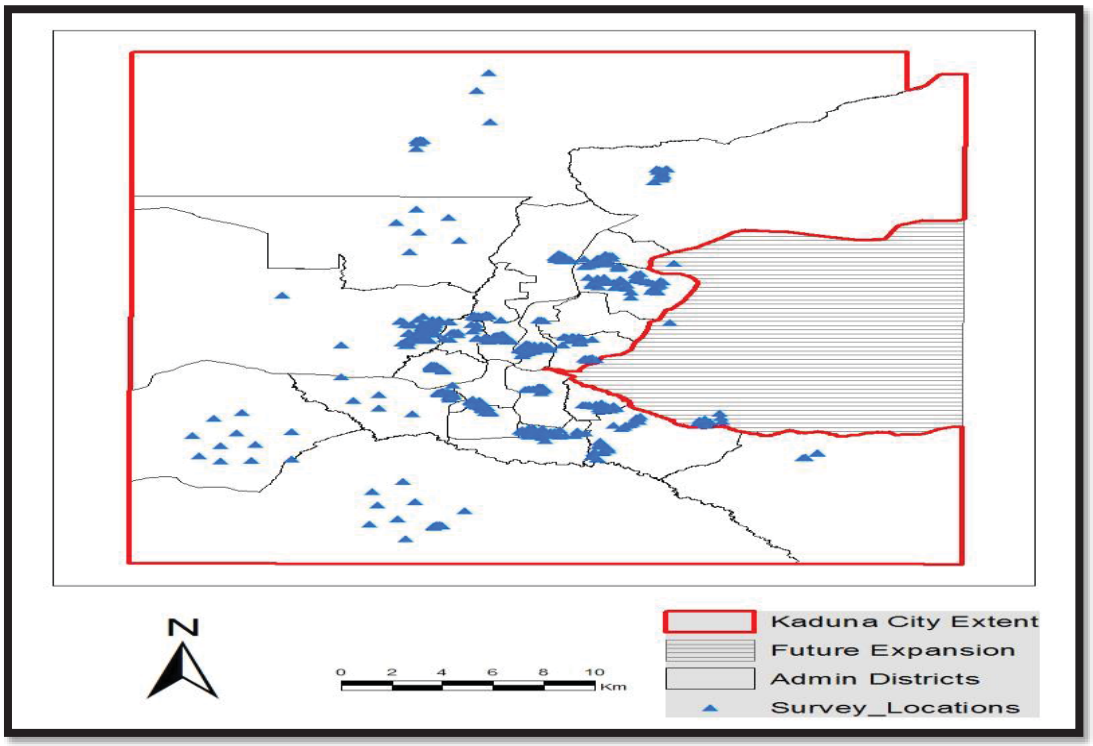

Figure 2: Household travel behaviour survey locations in the 24 districts of Kaduna

The questionnaire was designed to collect socio-demographic data and travel behavior data. Questions that were key to achieving this objective included those inquiring about location of work place, mode choice for journey to work, number

of persons in household, ownership of self-owned motorized vehicles among many others.

Urban form data

Urban form data for Kaduna was computed using a combination of GIS techniques, remotely sensed data and existing maps of the study area because just like the travel behaviour data, it is not readily available from any known secondary sources. The urban form measures considered in this study and the base data used to derive them are presented in Table 3. The data required to compute net residential density is a combination of data on residential population and the area under residential use. In order to compute land use diversity, floor area per land use is requiredAlso shown in Table 3 are the GIS data derived through universal GIS operators which have been used to populate the grid layer (or feature class Fishnet) in order to derive the required urban form indicators. The section that follows discusses the quantification of these indicators starting with population density and then followed by land use diversity.

Table 3: Urban form measures used in the study and their source data

Indicator	Variables	Base data used
Population Density	Net Population Density	Geocoded point data of location of households (MLCN, 2010), geocoded point data of location of sampled households, Fishnet/regular square grid covering the study area
Land Use Diversity	Floor Space Dissimilarity Index (land use mix)	Land use map of Kaduna metropolis (MLCN, 2010), geocoded point data of location of sampled households, Fishnet/regular square grid covering the study area

Population density

Density is defined as the mass of some entity (Batty, 2009). With respect to urban areas, density could be population, job or the aggregation of any other entity in the urban space like a building described by its size and normalized by some measure of the area it occupies. Commonly, density is expressed as population, household, residence or job density. Density measures maybe net implying the density of the total developed area or gross implying the density of total area under consideration. In this study, net residential density is considered more appropriate and is expressed as:

Dr = Pr/AR

Where: Dr = Net Residential Density; Pr = Residential Population; Ar = Area under residential land use in the grid cell, Source: Batty (2009)

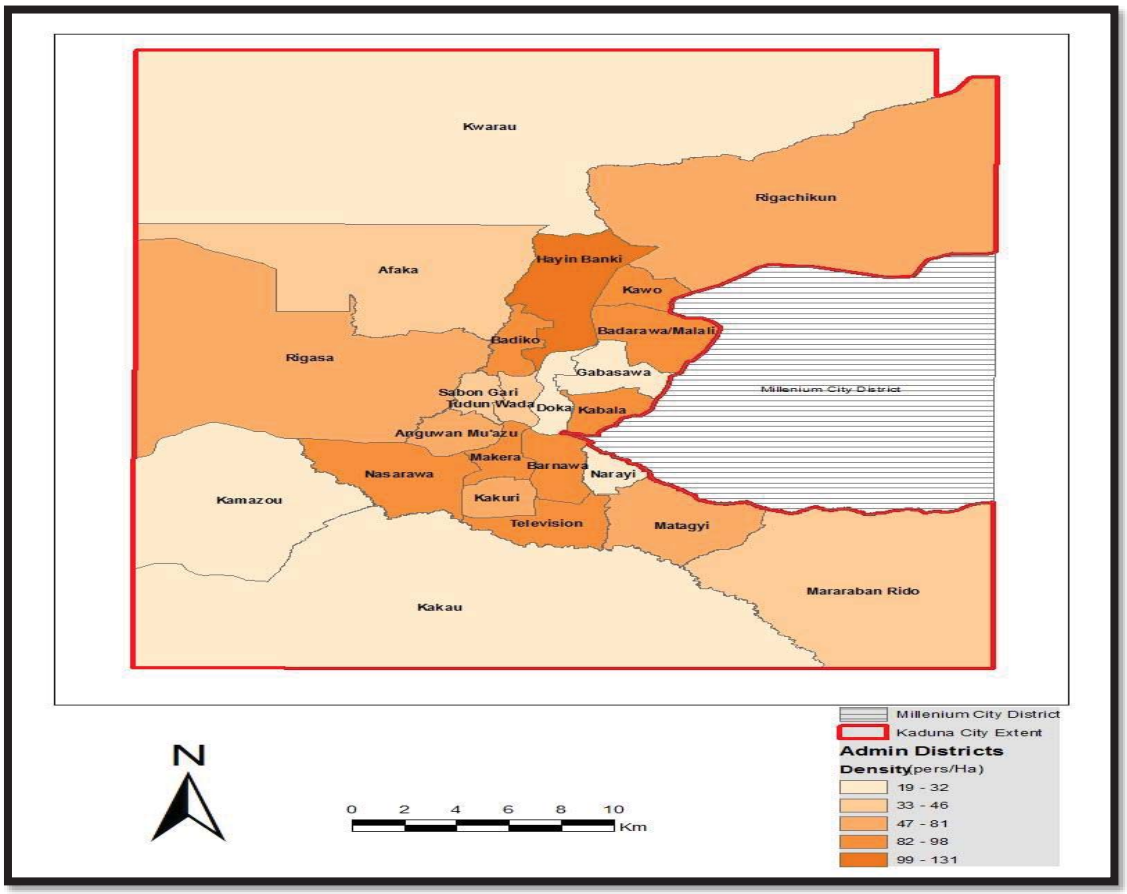

Figure 3: Mean residential density at district level in Kaduna

However, because population data is not readily available at disaggregated levels in Kaduna, there was the need to use proxy data to arrive at reasonable and acceptable estimates. A household survey conducted in 2010 by Max Lock Consultancy Nigeria created geocoded vector point data of the location of households which can be used as an excellent proxy for determining population distribution and residential population density. Population density is then computed by superimposing a Fishnet grid of 100m x 100m (1Ha) on the point dataset of all households in Kaduna and the point dataset of the surveyed households. For any grid cell where there is a surveyed household, the population density is calculated by counting the number of households in that grid cell and multiplying that sum by the average household size in the city. The average household size for Kaduna is estimated at 6 persons per household (The Consortium, 2008). In doing that, population density values were then derived for all grid cells (figure 3) where at least one household had been interviewed in the travel behavior survey and there were 614 of them in total. The use of a 1 sq. hectare grid cell for computing population density and land use diversity was informed by the fact that a city's net population density is conventionally expressed as a function of 1Ha of urban built space.

Land Use Diversity

Land use diversity is calculated based on the dissimilarity index following the work of Cervero and Kockelman (1997). It is expressed as a function of the difference between the land use type of a focal cell and that of its eight neighbours in a Moore neighbourhood arrangement. Where a focal cell's land use is residential and that

of three out of the eight neighboring cells is not residential, the dissimilarity index of that cell will be 3/8. Where none of the eight surrounding cells is residential, the dissimilarity index is 1 that is 8/8. If the land uses of all the eight neighbours is residential, the dissimilarity index is 0 that is 0/8. Therefore the dissimilarity index lies between 0 and 1. In Cervero and Kockelman (1997), mean dissimilarity index per hectare in a census tract was employed. In this study, the dissimilarity indices for the grid cells will be used as the grid cells superimposed on the study area represent the basic unit of analysis.

To compute the dissimilarity indices for sampled locations, the point data describing the location of sampled households and the land use map of Kaduna are overlaid in vector formats and the fishnet is superimposed on them. The target grids or cells are those containing a sampled point or surveyed households. The dissimilarity index is then computed for the target cells by taking into consideration the land uses of the 8 neighbouring grid cells using the procedure and formula described above.

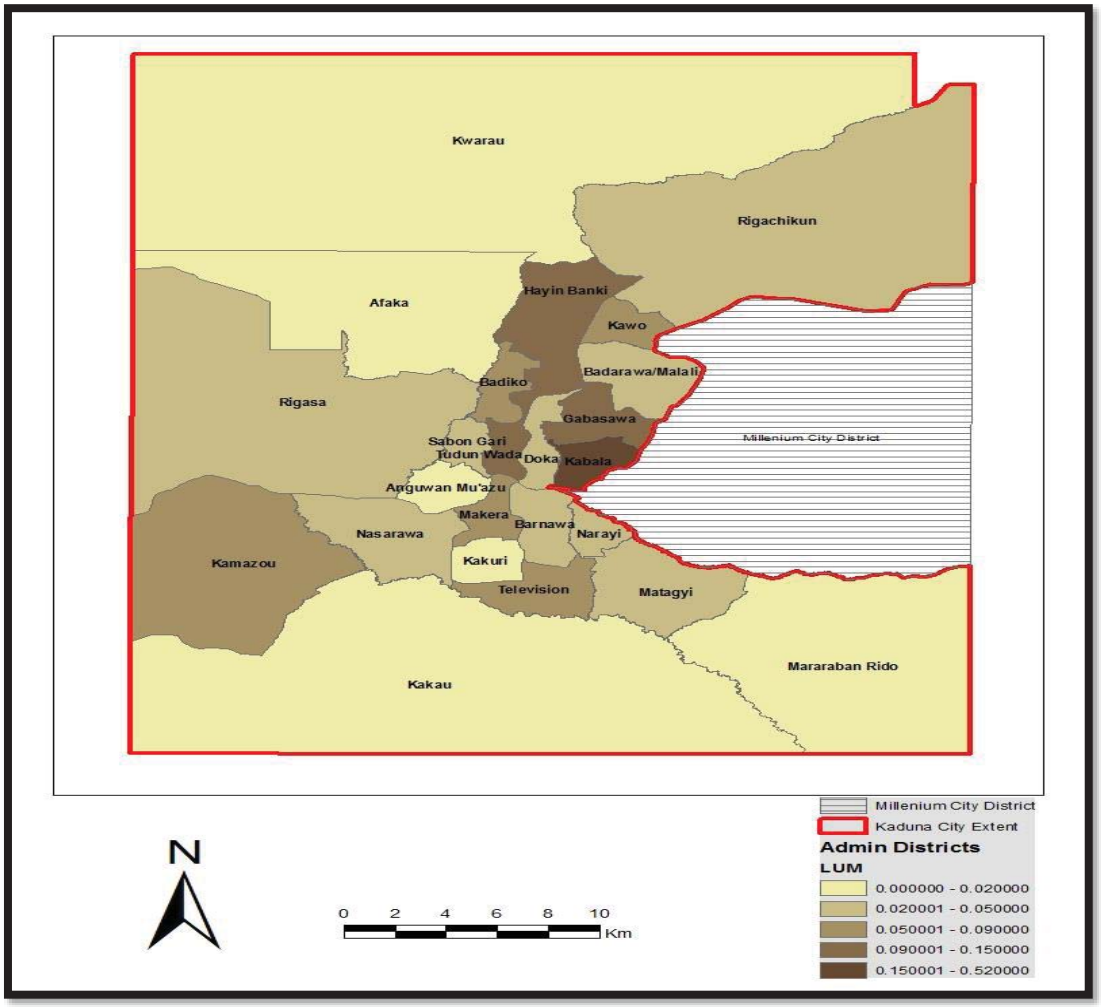

Figure 4: Mean land use mix at district level in Kaduna

RESULTS

As mentioned previously, vehicle miles travelled was used in the VMT model as the dependent variable in the multivariate regression model. Tables 4 and 5 summarize

the results of the interim and final multivariate regression analysis for the relationship between the dependent variable (VMT for work trips) and the independent variables (urban form). Only density had a p-value suggesting a statistically significant relationship with the dependent variable, VMT. The non-significant predictor was excluded from the final regression analysis and the result shows that the p-value obtained for density in the second step of analysis implies a statistically significant relationship with the dependent variable. The Beta coefficient for density has a negative sign suggesting that it has a significant negative relationship with VMT. This implies that a unit increase in density for the area under study will result in a corresponding decrease in VMT. This goes in line with general expectations because the more compact and densely built a city is the higher the density of activities within it and also the closer together the different activity locations within it would be (Ewing and Cervero, 2010).

Table 4: The interim VMT model

Dependent Variable	Independent Variables	Beta Coefficients (unstandardized)	Beta Coefficients (standardized)	Sig.
	Density	-397.80	-.172	.000
VMT	Land use mix	-3.218	-.027	.480

Table 5: The final VMT model

Dependent Variable	Independent Variables	Beta Coefficients (unstandardized)	Beta Coefficients (standardized)	Sig.
VMT	Density	-450.253	-.166	.000

DISCUSSION AND CONCLUSION

The regression models developed for the urban form and travel behaviour relationship provide the elasticity values that show how urban form affects travel behavior. The results obtained for Kaduna which show that population density has a strong and negative relationship with VMT bridge an essential knowledge gap in the Nigerian context and is in line with expectations as established in the literature by previous studies in other parts of the world (Chatman, 2008; Ewing et al., 2009; Kuzmyak, 2009). Some other studies have established a positive and statistically weak relationship between VMT and population density (Boarnet et al., 2004; Zhou and Kockelmen, 2008 & Greenwald, 2009). This shows that there can be variations in the strength and direction of the relationship between population density and VMT depending on where the test is conducted.

Similarly, in the case of land use diversity and VMT, the results of the regression analysis show a statistically weak and positive relationship (0.48) suggesting that land use diversity does not have any significant effect on trip lengths or VMT in Kaduna. This result is in line with those of similar studies carried out in some other cities that resulted in elasrticity values within a range between 0.03 in Greenwald (2009) to -0.27 in Kuzmyak (2009) although there is a lot of instances where an average of -0.10 was obtained (Kuzmyak et al., 2006; Sun et al., 1998 and Pushkar et al., 2000). Notwithstanding these variations and the lack of strong connections in the urban form and travel behavior relationship in some instances, Newman,

Beatley & Boyer (2009), Naess (2012), Creutziga et al., (2015) and Newman & Kenworthy (2015) have argued that the urban form and travel behavior relationship has immense usefulness in urban transportation and land use planning policy and decision making. There are basically two approaches that can be adopted depending on the nature of urban planning policy in the city under consideration. These approaches have been adopted in studies such as Joo (2008) and Munshi (2013). The first is the evaluatory approach wherein the elasticity values are used as indicators in the evaluation of the implication of planning proposals on travel behaviour. In doing that, the elasticity values can either be fed as input into transport models leading to the planning and provision of transport infrastructure or as feedback in the urban development process or policy implementation. The second is the prescriptive approach. Here, the elasticity values describing the derived relationship between urban form and travel behaviour are used in the formulation of urban development policies which are then used in an urban growth simulation model that explores different future scenarios by asking the question 'what if'? The alternative scenarios are then assessed to determine travel behaviour impacts that serve as information to guide future policy. For that reason, more research is required in this field in cities in Nigeria in order to take into consideration other indicators of urban form such as mode choice, trip frequency and ownership of motorized vehicles and indicators of urban form such as accessibility, neighbourhood design and travel demand management measures that have not been included in this exploratory study.

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