都市内移動とエネルギー消費に対する都市環境の影響要因 : ネパールカトマンズ市を対象として

サリタ, マハラジャン
九州大学大学院人間環境学府都市共生デザイン専攻 : 博士後期課程

鶴崎, 直樹
九州大学大学院人間環境学研究院都市・建築学部門 : 准教授

プラサンナ, ディビガルピティヤ
九州大学大学院人間環境学研究院都市・建築学部門 : 准教授

https://doi.org/10.15017/2231645

出版情報：都市・建築学研究. 35, pp.1-13, 2019-01-15. 九州大学大学院人間環境学研究院都市・建築学部門

都市・建築学研究　九州大学大学院人間環境学研究院紀要　第35号，2019年１月
J. of Architecture and Urban Design, Kyushu University, No.35, pp.1～13, Jan. 2019

都市内移動とエネルギー消費に対する都市環境の影響要因
―ネパールカトマンズ市を対象として―

Influence Factor of Urban Form on Urban Transport and Energy Consumption
—Case study on Kathmandu city, Nepal—

サリタ　マハラジャン*，鶴崎直樹**，プラサンナ　ディビガルピティヤ**
Sarita MAHARJAN, Naoki TSURUSAKI and Prasanna DIVIGALPITIYA

The goal of this paper is to identify energy efficient planning approaches for Kathmandu by understanding the influencing factors of urban form (5Ds) to reduce travel energy consumption. The rapid urbanizing, growing population, increasing motorization and increasing rate of fuel import have led growing concern on how to reduce travel energy consumption via urban planning discipline in Kathmandu. This paper applies two analysis methods: Multiple Linear Regression Model (MLRM) and Cluster analysis. The analysis result shows that motorcycle is the most influencing factor among travel variables which affect the increase of travel energy consumption in Kathmandu. Also, the result shows that motorcycle reduction is highly associated with density (D1, 34%) followed by destination accessibility (D4, 22%) and design (D3, 23%). Likewise, the result highlights that motorcycle is highly used for study (64%) followed by work (35%) and private purpose (1%). This study proposes energy efficient planning approaches based on the findings of MLRM and Clusterization of Kathmandu.

Keywords: *Urban form, Travel Energy Consumption, Multiple Linear Regression Model, Cluster Analysis, Kathmandu*
都市環境，移動エネルギー消費，重回帰分析，クラスター分析，カトマンズ

1. Introduction

The transport sector, particularly in developing countries, plays a critical role in global energy consumption and greenhouse gas emissions reduction strategies[1]. In Kathmandu, energy consumption and pollutant emissions have increased annually with rapid urbanization and motorization, which has had a great impact on energy security, environment and people's living conditions. According to UN-Habitat report[2], Kathmandu is accounted for the highest share of energy consumption for transport sector. The rapid increase in motorization has negative impact on the national economy as the transport sector is increasingly reliant on imported petroleum fuel. Fuel imports absorb over one-fourth of Nepal's foreign exchange earnings[3]. The vehicle registered in the Kathmandu valley comprises 66% of the total vehicles registered in Nepal[4),5)]. Further, the total energy consumption in the Kathmandu Valley would grow at an average growth rate of 3.2% during 2005–2050 and a nearly five fold increase in CO_2 emissions[6]. Based on the recent trend, motorcycle and car ownership will increase continuously in the long run. In the do-nothing scenario until 2020, 80% of roads inside the ring road of Kathmandu will be terribly congested restricting every activity, particularly in central area[7].

Globally, in recent years, increasing concerns over climate change and transportation energy consumption have sparked research into the influences of urban form and land use patterns on travel behavior and energy consumption[8]. Land use planning is widely considered as a fundamental and long-term strategy to reduce the dependence on private modes because it determines the basic spatial settings for various activities[9),10)].

Many studies found that the urban form variables to be associated with the choice of non-motorized modes and transit[11)-16)]. The study by Cao et al.[17] showed urban form

＊　都市共生デザイン専攻　博士後期課程
＊＊ 都市・建築学部門

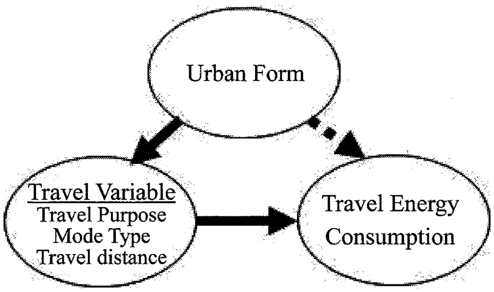

Fig. 1 Direct and Indirect relationship between urban form, travel variable and travel energy consumption

plays a modest role in vehicle choice. So far, there has been relatively little research on the linkage between urban form and travel energy consumption[18]. Most of the investigation has focused on the technical characteristics of vehicles such as higher-efficiency automobiles, fuel efficiency and reducing vehicle miles traveled. There is relatively little research, however, on the broader question of how urban form affects energy demand and environmental emissions[19].

In the case of Nepal, a considerable number of studies has concentrated on the growth trend of different vehicle types, their energy demand and associated environmental emissions[6),20)-22)]. However, these studies have failed to shed light on the direction of the causality between what kind of land use planning or urban form effect on travel energy consumption. Therefore, the concern on how to reduce travel energy consumption in Kathmandu via urban planning discipline has become motivation to conduct this research.

2. Objective

The goal of this research is to identify energy efficient planning approaches for Kathmandu by understanding the influencing factors of urban form to reduce travel energy consumption. Since urban form does not have a direct effect on travel energy consumption, it requires other intermediate factors to be considered that has a direct effect on both urban form and travel energy consumption. Therefore, we analyzed the relationship between urban form and travel energy consumption via other intermediate variables: Travel purpose, mode type and travel distance (Fig. 1).

To achieve the goal, following objectives were set out:

- To identify the most influencing factor among travel variables which affect the increase of travel energy consumption in Kathmandu by using MLRM.
- To identify the most influencing factors among urban form variables and travel purposes to reduce the highly affecting factor for travel energy consumption by using MLRM.
- To identify energy efficient planning solutions for Kathmandu based on MLRM and Cluster analysis.

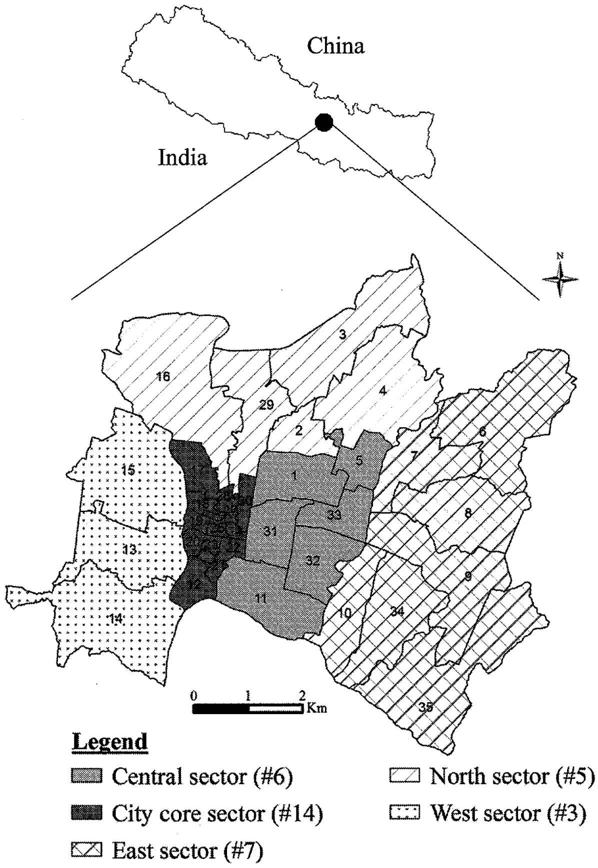

Fig. 2 Study Area- Kathmandu City

3. Methodology

3.1 Study Area

Kathmandu City is the capital city of Nepal (Fig. 2) which is the most urbanized and high dense city in Nepal. Kathmandu lies in the Central development region of the country. The city covers the area about 51.94 km^2 with a size of 9.5 km in the east-west direction and 8.3 km in the north-south direction. It is the eldest metropolitan city of Nepal with a population around 1 million (985,000) as of 2018 census. According to the World Bank[23)], Kathmandu has the highest population growth rate (4% per year). Kathmandu is the core of the largest urban agglomeration in the Kathmandu Valley, which includes other four major cities: Lalitpur, Bhaktapur, Kirtipur and Madhyapur Thimi. As Kathmandu is the central hub for education, employment, business and state administration, it attracts a continuous flow of people from other parts of the country. It is also the main gateway to the country's tourism industry. Kathmandu is divided into five sectors: Central, East, North, West and the City Core. Administratively, the city is divided into 35 wards. For micro level analysis in this research, we analyzed entire Kathmandu via 35 wards (Fig. 2).

Table. 1 "5Ds" Variables and its operational definition

5Ds	Variable	Operational Definition
D1 (Density)	Population density	Population/Total area(km^2)
	Household density	No. of Household/ Residential area(km^2)
D2 (Diversity)[24), 25)]	Land use mix index (Entropy)	Entropy $= -\{(\sum_k (P_i \times (\ln p_i)))/\ln(k)\}$
		P_i= proportions of each of the land use types (in this research; Residential, commercial, mixed, industrial, utility facility and public open space)
		k= number of land use types(in this research; 6)
D3 (Design)[26)]	Street connectivity	Number of 3-way road intersections
		Number of 4-way road intersections
D4 (Destination Accessibility)[26)]	Distance to Central Business District (CBD)	CBD = the existing location of Old Bus Park.
		Shortest travel distance from each zone to CBD is calculated by using OD Cost Matrix Analysis in GIS
D5 (Distance to transit)[27)]	Transit accessibility	Transit stops/ Total land area (km^2)

3.2 Research Data Type and Source

3.2.1 Urban Form Data

The urban form related data (population, household numbers, land use allocation, road networks, locations of transit stops and their networks) are collected from various sources and then developed "5Ds" framework (D1 density, D2 diversity, D3 design, D4 destination accessibility and D5 distance to transit) as shown in Table 1 for interpretation and analysis purpose. The 5Ds has become widely accepted as an organizing framework to characterize land-use characteristics at the micro-scale level in travel behavior research [27),28)].

3.2.2 Travel data

As this study aims to reduce energy consumption by urban planning, we need to understand the travel behavior of the people in Kathmandu. Most of the countries have a city-wise Person Trip Survey (PTS) data or it is also called National travel survey (NTS) data that provides the information on personal travel behavior like, the information of trip purpose, trip distance, travel time and travel mode. But such data do not exist in Nepal and therefore, we conducted a structured questionnaire survey in all 35 wards of Kathmandu city to obtain one-day travel data with the help of the students of Tribhuvan University, Nepal. The survey was carried out in April 2018 for 20 days. The survey was based on a personal interview as it provides a high response rate. The questionnaire survey included the questions regarding

$$EC = \sum_{j=1}^{j=n} \sum_{i=1}^{i=m} T_{ij} \times D_i \times EI_j \qquad \text{......Eq. (1)}$$

Where,

EC = Total Travel Energy consumption (MJ/person/day)

n = Total number of travel mode

j = Travel mode type {Public Mode, Car, Motorcycle}

m = Total number of travel purpose

i = Travel purpose {Work, School, Business, Private}

T_{ij} = Travel for purpose 'i' by mode 'j'

D_i = Travel Distance for travel purpose 'i' (km)

EI_j = Energy Intensity factor for travel mode 'j' (MJ/person-km)

{Public mode- 0.21, Car-1.2 and Motorcycle-0.5}[29)]

the personal information, the purpose of travel, the mode of travel and the travel time to go to the destination. This research covers 861 respondents (59.70% male and 40.30% female) and 1,789 total trips.

3.2.3 Energy intensity data

We collected the energy intensity data based on Kathmandu[29)] to make the research result more consistent. Energy intensity is used for estimating the travel energy consumption of one day by an individual in every 35 wards; using Eq. (1)[30)]. The travel distance is calculated by converting the travel time obtained from the questionnaire survey.

3.3 Database construction and application

For the clarification of the mechanism underlying the relationship between urban form and travel energy consumption, first, the database was constructed including multiple variables of urban form (5Ds), travel behavior and travel energy consumption of each 35 wards of Kathmandu, and then, applied Multiple Linear Regression Model (MLRM) as an analysis method (Fig. 3). MLRM provides a powerful analysis framework that helps to analyze the complex relationships of urban form, travel behavior and energy consumption. MLRM allows the degree of correlation between the variables to be determined.

5Ds data of each ward were processed in GIS and created geo-database for observation and management of the data. The 5Ds database was then inserted into the Postgresql database to combine with trip data (travel purpose wise and travel mode wise) and additional variables of travel energy consumption (travel distance and energy intensity) of each 35 wards. The constructed database of each ward was exported to MS-Excel for making it importable in SPSS and

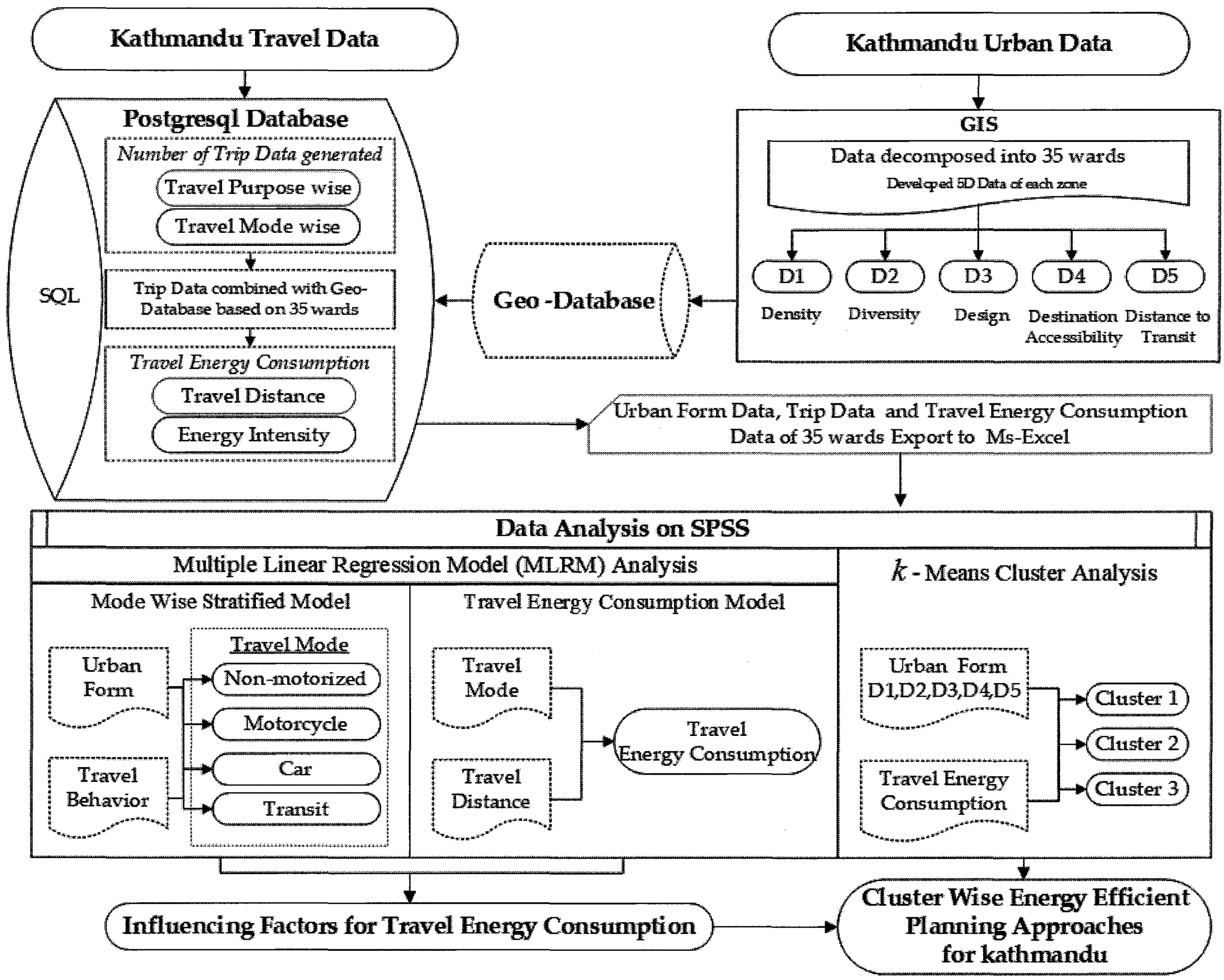

Fig. 3 Database construction and analysis method

then, the analysis was conducted by applying MLRM.

In this research, two separate MLRMs were performed. In the first phase of MLRM, urban form variables (D1 density, D2 diversity, D3 design, D4 destination accessibility and D5 distance to transit) and trip behavior variables (trip for work, school, business, private) were chosen as independent variables where travel mode choice is used as a dependent variable. In the second phase of MLRM for energy consumption, the independent variables consist of mode choice for travel (non-motorized, motorcycle, car and transit) and travel distance. The dependent variable is total travel energy consumption. Further, the test for multicollinearity between the independent variables was performed for both models: mode-wise stratified and travel energy consumption, by using VIFs (variance inflation factor).VIFs < 10[31] and Tolerance > 0.2[32] is the condition of satisfactory for the model. So, the two models of this research were found satisfies this condition; except the tolerance value for work trip (0.152 in the first model) and for travel distance (0.100 in the second model) as shown in Table 2. However, both the work trip and the travel distance satisfy the condition for VIF. Further, for work trip, tolerance was found to be 0.152, which is nearly 0.2 if we consider a round figure. Therefore, we decided to remain these two variables in the model.The result from MLRM analysis helps to identify influencing factors for travel energy consumption.

Then, a *k*-means Cluster analysis is performed in order to regroup wards into *k*- homogeneous clusters according to the characteristics based on 5Ds and travel energy consumption. The goal of using *k*-means statistical cluster analysis technique is to maximize inter-cluster variation while minimizing intra-cluster variation. Several attempts were made with different numbers of clusters by using a ward method and finally, three clusters were found a satisfactory number. The findings from both MLRM and Cluster analysis are used for identifying energy efficient planning approaches for Kathmandu.

Table. 2 Multicollinearity test

Stratified mode choice models			Travel energy consumption model		
Independent variables	Collinearity Statistics		Independent variables	Collinearity Statistics	
	Tolerance	VIF		Tolerance	VIF
Density (D1)	0.309	3.239	Non-motorized mode	0.240	4.163
Diversity (D2)	0.397	2.517	Motorcycle	0.281	3.562
Design (D3)	0.211	4.750	Car	0.585	1.711
Destination Accessibility (D4)	0.253	3.950	Transit	0.283	3.534
Distance to Transit (D5)	0.471	2.125	Travel Distance	0.100	10.005
Work Trip (WT)	0.152	6.564			
School Trip (ST)	0.314	3.186			
Business Trip (BT)	0.877	1.140			
Private Trip (PT)	0.293	3.409			

Table. 3 Mode wise stratified regression model

	Non Motorized			Motorcycle			Car			Transit (Public)		
Independent Variables	B	T	*p*	B	T	*p*	B	T	*p*	B	T	*p*
(Constant)	-1.128	-1.178	0.250	2.100	2.077	0.048*	0.662	0.347	0.732	4.050	2.556	0.017*
Urban form variables												
Density (D1)	0.047	0.412	0.684	-0.264	-2.218	0.036*	0.001	0.003	0.997	-0.294	-1.574	0.128
Diversity (D2)	0.006	0.058	0.954	-0.089	-0.798	0.432	0.068	0.321	0.751	-0.245	-1.401	0.174
Design (D3)	-0.010	-0.086	0.932	-0.192	-1.553	0.133	0.336	1.436	0.163	0.030	0.157	0.876
Destination Accessibility (D4)	0.246	1.971	0.060	-0.190	-1.441	0.162	-0.385	-1.544	0.135	-0.171	-0.827	0.416
Distance to Transit (D5)	0.084	0.746	0.462	-0.067	-0.570	0.574	-0.228	-1.024	0.316	-0.210	-1.132	0.268
Travel variables												
Work Trip (WT)	0.272	1.768	0.089	0.418	2.570	0.017*	0.713	2.324	0.029*	0.610	2.396	0.024*
Study Trip (ST)	0.250	1.718	0.098	0.722	4.696	0.000**	0.175	0.602	0.552	0.285	1.181	0.249
Business Trip (BT)	0.226	1.954	0.062	-0.267	-2.188	0.038*	-0.146	-0.634	0.532	-0.116	-0.606	0.550
Private Trip (PT)	0.456	4.287	0.000**	0.006	0.058	0.954	-0.283	-1.334	0.194	-0.324	-1.838	0.078
Summary statistics												
p-value			0.000**			0.000**			0.008*			0.000**
R			0.961			0.920			0.738			0.824
R-square(R^2)			0.924			0.846			0.545			0.680

Note: B means Unstandardized regression coefficient, T means test coefficient, *p* means Significance, ** means $p < 0.001$ and * means $p < 0.05$.

4. Multiple Linear Regression Model (MLRM) Result

Among the mode wise stratified models, the model for non-motorized mode showed a better model fit with 92.4% variance ($R^2 = 0.924$, *p*-value < 0.000) as shown in Table 3. Even the regression model shows the best fit, the influence of urban form variables (5Ds) for non-motorized modes at the individual level is found less significant. However, when controlling other predicators, it showed the expected and meaningful result. Among urban form variables, destination accessibility (D4) is found positively predictive of non-motorized mode ($p = 0.06$). Among travel variables, private trip (PT) is positively significant on non-motorized mode choice (p = 0.000).

The regression result for motorcycle was 84.6% ($R^2 = 0.846$, *p*-value < 0.000). Among urban form variables, density (D1) showed significant inverse association with motorcycle use ($p < 0.05$). For motorcycle use, study trip (ST) and work trip (WT) showed positively significant (p = 0.000 for ST and $p < 0.05$ for WT). Whereas, business trip (BT) showed significant inverse association ($p < 0.05$) with motorcycle.

The regression result for car showed 54.5% ($R^2 = 0.545$, *p*-value < 0.05). Similar to the non-motorized model, the influence of urban form variables on car use was not found significant at individual level. However, design (D3) and destination accessibility (D4) showed relatively more influence while controlling other predicators. Among travel variables, work trip (WT) is positively significant ($p < 0.05$) on car use.

The regression results for public mode use showed 68% ($R^2 = 0.68$, *p*-value < 0.000). Similar to the models of non-motorized mode and car use, the model of public mode use also showed less significance of 5Ds. Among travel variables, work trip (WT) is found positively significant on

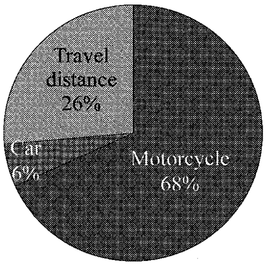

Fig. 4 The percentage share of effect factors for the increase in travel energy consumption

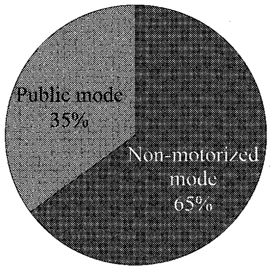

Fig. 5 The percentage share of effect factors for the reduction in travel energy consumption

Table. 4 Travel energy consumption regression model

Independent Variables	B	T	*p*
(Constant)	-0.157	-1.176	0.249
Non-Motorized mode	-0.305	-4.780	0.000**
Motorcycle	1.022	12.790	0.000**
Car	0.051	1.015	0.318
Public (Transit)	-0.189	-2.585	0.015*
Travel distance	0.485	4.952	0.000**
Summary statistics			
p-value			0.000**
R			0.982
R-square(R^2)			0.965

Note: B means Unstandardized regression coefficient, T means test coefficient, p means Significance, ** means $p < 0.001$ and * means $p < 0.05$.

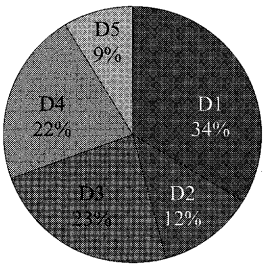

Fig. 6 The percentage share of 5Ds effect factors for the reduction in motorcycle use

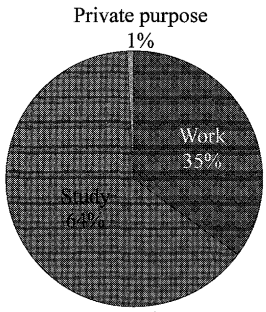

Fig. 7 The percentage share of travel purpose effect factors for the increase in motorcycle use

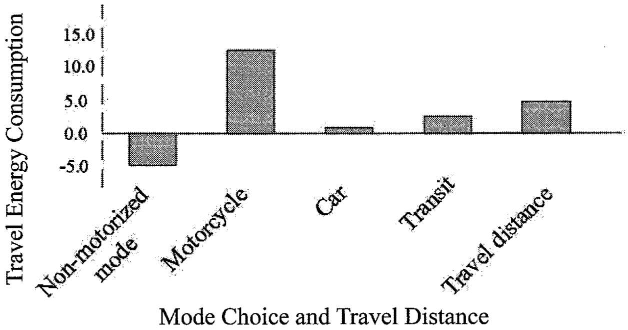

Fig. 8 Effect of mode choice and travel distance on travel energy consumption

public mode choice ($p < 0.05$).

The regression model result for travel energy consumption was 96.5% ($R^2 = 0.965$, p-value < 0.000) as shown in Table 4. This indicates a good model fit where non-motorized mode and public mode are found inversely significant ($p = 0.000$ for non-motorized mode and $p < 0.05$ for public mode use). Likewise, motorcycle and travel distance are positively significant ($p = 0.000$) with travel energy consumption. Car use showed positive association with travel energy consumption but with less significant ($p = 0.318$).

5. Discussion on the MLRM Result

The regression results for travel energy consumption (Table 4, Fig. 8) indicate that motorcycle and travel distance are major factors for increasing energy consumption. The result showed that among the increasing factors for travel energy consumption, motorcycle has the highest effect. The share percentage of each effect factors for the increase of travel energy consumption is shown in Fig. 4. Similarly, the result showed that increase in non-motorized mode and public mode can reduce energy consumption in Kathmandu. The share percentage of non-motorized mode and public mode for the reduction of travel energy consumption is shown in Fig. 5.

The regression result for travel energy consumption can be more clearly expressed in the form of Multiple Regression Equation as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n + \varepsilon \quad \text{......Eq. (2)}$$

Travel Energy Consumption = -0.157 + {-0.305(Non-Motorized)} + {1.022(Motorcycle)} + {0.051(Car) + {-0.189(Public)} + {0.485(Travel distance)} + 0

where,

y = Dependent variable

x_i = Independent variable (i = 1, 2, ... n)

β_0 = Constant (y-intersect)

βi = Regression coefficient of the variable xi (i = 1, 2, ... n)

ε = Error (In Multiple Linear equation, error term assumed to be zero)

In multiple regression, each coefficient is interpreted as the estimated change in y corresponding to a one unit change in an independent variable, when all other variables are held constant. So, the Eq. (2) explains that an increase in one motorcycle user will increase travel energy consumption by 1.022MJ/person/day when other variables are held constant. Similarly, the increase in one car will increase travel energy consumption by 0.051MJ/person/day and increase in one

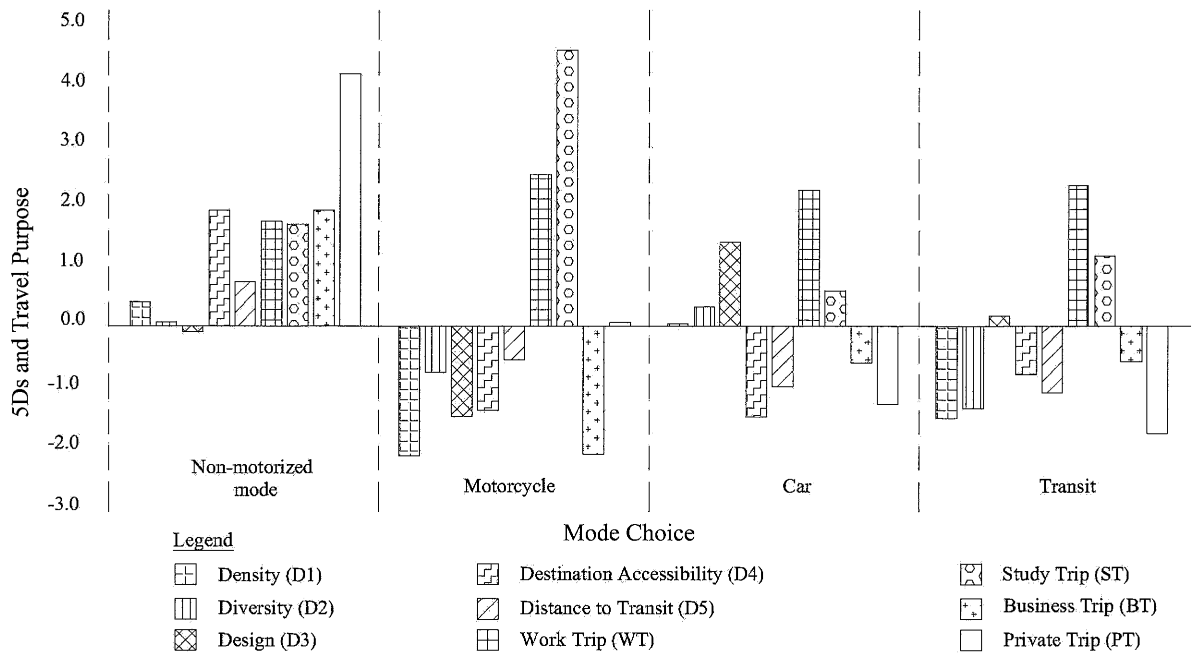

Fig. 9 Effect of 5Ds and travel purpose on mode choice

kilometer travel distance will increase energy consumption by 0.485MJ/person/day when other variables are held constant. So, in the case of Kathmandu, the planning strategy and policy need to focused on the reduction of motorcycle to have effective result in the reduction of energy consumption. Similarly, an increase in one non-motorize mode user and increase in one public mode user will reduce travel energy consumption by 0.305MJ/person/day and 0.189MJ/person/day accordingly when other variables are held constant. This meant promoting walking and cycling is significant to reduce travel energy consumption in Kathmandu. Also, an increase in public mode relatively supports the energy reduction.

After understanding that a motorcycle is the highly influencing factor for increasing travel energy consumption in Kathmandu, the regression result for motorcycle use was analyzed from the mode wise stratified regression result (Table 3, Fig. 9) in detail to understand the share percentage of the effect factors among 5Ds; urban form variables and travel purpose for the motorcycle use. The result showed that all the variables of urban form have the influencing role in the reduction in motorcycle use. However, the most effect factor is found density (D1, 34%) followed by design (D3, 23%) and destination accessibility (D4, 22%) as shown in Fig. 6. This meant as higher the density, energy consumption decreases. Regarding design (D3), as higher the road connectivity, motorcycle use reduces. The result showed that an increase in D3 increases public mode use with a very low significance which indicates that even road connectivity is higher it is less facilitated with public mode in Kathmandu. This research result showed that better the destination accessibility (D4), higher the use of private modes (motorcycle and car). This meant private mode is increased in and near the CBD areas and hence traffic congestion in the city center. Whereas non-motorized mode use is found higher in the areas further away from CBD even density and land use mix is comparatively low but transit accessibility (D5) is better.

The distance to transit (D5) also shows a meaningful relation with motorcycle use indicating that increase in public mode accessibilities can support in reducing motorcycle use, but surprisingly, the result showed that even rise in transit accessibilities it has an adverse effect on public mode use. It meant even public facilities are available at the easy access, people are less encouraged to use it. It is likely due to the poor quality in service.

The share percentage of travel purpose for the increase in motorcycle is shown in Fig. 7. The result showed that motorcycle is highly used for study (64%) purpose followed by work (35%) and private purpose (1%). In Nepal, people send their children (including kindergarten students) where they like to admit, regardless of the travel distance. Most of the families use motorcycle for dropping and picking their children from the school, likely on their way to work. As motorcycle is affordable for all economic group and convenient mode especially in the narrow streets like of Kathmandu, it is popular among college students, office worker and housewife. Whereas, increase in non-motorized mode is found strongly related with increase in private trip (PT). It indicates that people in Kathmandu travel short distance for PT.

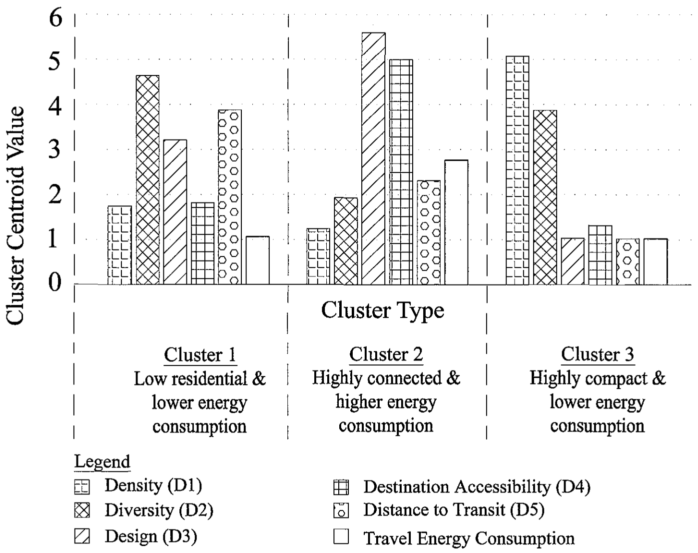

Fig. 10 Cluster centroid values

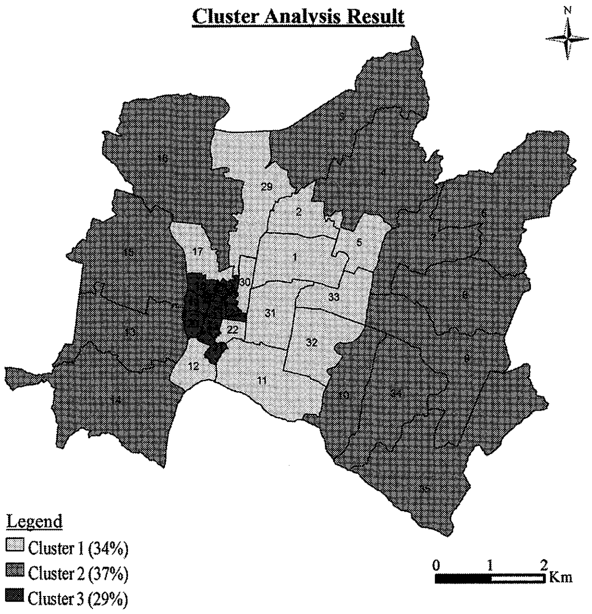

Fig. 11 Cluster analysis result

6. Clusterization of Kathmandu based on 5Ds and travel energy consumption

The findings from the MLRM analysis provides a clear idea on 'which' urban form factor need to be prioritized to reduce the most affecting factor i.e. motorcycle use for the reduction of travel energy consumption effectively. But implementing the findings in overall Kathmandu is not logical, for instance, density increase is not required or even not possible in all the wards of Kathmandu. So, to implement the findings and propose the solutions, Kathmandu is classified into three cluster groups. Each of clusters are described below.

6.1 Cluster 1- Low Residential and Lower Energy Consumption

Cluster 1 is characterized by low density (D1; low population density and household density) and lower energy consumption (Fig. 10). Whereas, this cluster represents higher land use mix (D2) and better public transit accessibility (D5). Cluster 1 primarily comprises wards situated in the central sector of Kathmandu. The wards in this cluster are highly dominated by employment and entertainment facility, institutions, open space and bus parks. This cluster represents 34 percent of Kathmandu city (Fig. 11).

Though the wards in this cluster showed less energy consumption, among energy-intensive mode use, motorcycle was found highly used (27%) followed by public mode (14%) and car (2%) (Table 5). As a result, the total energy consumption in this cluster was found highest shared by motorcycle (540585MJ/person/day), followed by car (1320) and public mode (3022) (Table 6). Also, this result highlights that even availability of nearest public transit stops, a public mode is less used. It might be the poor service of public transportation which discourages people to take public mode for travel. The public transport service in Kathmandu is fully operated by private sectors and self-financed i.e. without any government subsidies. As the revenue is based on the number of passengers carried by a vehicle, it results in unhealthy competition among operators such as pick up and drops off passengers from undesignated areas to maximize profit. Operators prefer profitable routes and timings which cause longer waiting time and unreliability. Public transportation service is almost not available after 8:00 pm in most of the areas that made inconvenient for the people who do not have private mode.

6.2 Cluster 2- Highly Connected and Higher Energy Consumption

Cluster 2 represents the wards with higher road connectivity (D3), further away from CBD (D4) and higher energy consumption (Fig. 10). Also, this cluster indicates low density (D1), low land use mix (D2) and poor transit accessibility (D5). The result highlights that public transport facilities are not available in most of the wards even there are good road networks. As the wards in this cluster are situated in the East, North and West sector, it represents sprawl residential area and due to sprawl development there are challenges for operating public transport in cluster 2. This cluster represents 37 percent of Kathmandu city (Fig. 11).

The mode share among the motorized mode in this cluster

Table. 5 Cluster wise travel mode share

Travel Mode	Cluster 1		Cluster 2		Cluster 3	
	Used no.	Used %	Used no.	Used %	Used no.	Used %
Walk	233	54	692	59	95	52
Cycle	12	3	21	2	0	0
Motorcycle	115	27	270	23	49	27
Car	8	2	28	2	0	0
Public	62	14	167	14	37	20

Table. 6 Cluster wise travel energy consumption

Travel Mode	Travel Energy Consumption (MJ/person/day)		
	Cluster 1	Cluster 2	Cluster 3
Motorcycle	540585	3302326	116417
Car	1320	9299	0
Public	3022	15506	902

shows highly dominated by motorcycle (23%), followed by public mode (14%) and car (2%) (Table 5). As a result, the highest energy consumption is mainly due to motorcycle use (3302326MJ/person/day), followed by car (9299) and public mode (15506) (Table 6).

6.3 Cluster 3- Highly Compact and Lower Energy Consumption

Cluster 3 is characterized by higher density (D1), a relatively higher land use mix (D2) and lower energy consumption (Fig. 10). Also, this cluster represents wards having lowest road connectivity (D3), closer to CBD (D4) and unavailability of public transit accessibilities (D5). This cluster comprises wards situated in the city core and found highly dominated by walk (53%)(Fig. 11). This result is satisfied since the city core was developed as a compact and walking city in the ancient time. Though the transit accessibility is null in the city core, the public mode users are found 20% (Table 5). This is because the wards in this cluster are closer to CBD and so, facilities of public transportation is available at a walkable distance and people get encouraged to use public mode.

In this cluster also, motorcycle use has the highest share (27%) among motorized mode use and so the energy consumption is also found mainly due to motorcycle use (116417MJ/person/day) compared to public mode (902) (Table 6). The sample result showed that cycle and car user for a daily purpose is null in this cluster. In Nepal, private mode is taken as a status symbol which perpetuates urban transport energy problems. Cycle is mainly used for the recreation purpose rather than as the daily commuting transport mode.

7. Energy efficient planning approaches for Kathmandu based on MLRM and Cluster analysis results

Aiming the reduction of travel energy consumption, the wards in cluster 2 are found the most important to be considered based on the characteristics of this cluster. Though the cluster 1 and cluster 3 showed lower energy consumption, the highest share is found by motorcycle among the motorized modes use. So, the reduction of motorcycle users in all the three clusters is necessary to promote transport energy efficiency in the entire Kathmandu city. The recommendations are proposed based on the cluster wise characteristics as described below:

7.1 Cluster 1

As this cluster already has higher mix land use and higher transit accessibility, we recommend to increase density by attracting people to live in this cluster by developing mix used high rise apartment based on TOD concept. In such high heterogeneity land use zone, most of the trips can be traveled by walk or bicycle which results in a cut off the trip by motorcycle use. In addition, according to Building bye-laws of Kathmandu city, the Floor area ratio (FAR) for mix used building is 3.0 in most of the wards belongs to cluster 1. This meant high rise building is feasible and implementable in this cluster. Among the wards situated in this cluster, the ward 1, 11 and 31 need to be focused first for implementing the proposal of mix used high rise apartments as these wards showed the lowest density.

As cluster 1 belongs to the CBD area, it attracts many people travel from different areas of the city. So, we recommend promotion of BRT in such a way that it integrates with other public transport modes; which serves as feeder services in the areas of cluster 2. There might be a possibility that even balance of land use mix and higher density, the workplace or study area might be different other than cluster 1. Even in such a case, if transit service facilitated with BRT, people can only choose transit; instead of using motorcycle. In addition, most of the main streets in Kathmandu have been recently expanded in cluster 1; so there is room for large buses.

The research findings showed that providing access to the public mode is not sufficient to promote public mode but also require improvement on public transit accessibility (more transit stops at a walkable distance in dense residential areas) and services (favorable service routes, information

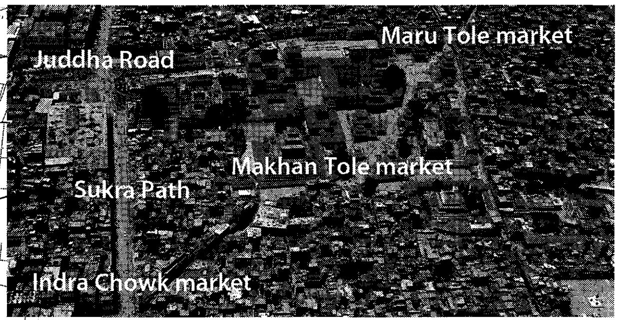

Fig.13 Combined street network including traditional streets and market squares in the city core area[33)]

Fig.12 Proposed Transit Oriented Development (TOD) and Bicycle Sharing System in cluster 3; the City core sector

on the time schedule, punctuality, reasonable charge and safety). In the Kathmandu, the off-peak (early morning and late evening) transit facilities could be one of the attractive strategies to encourage people to use public mode. Also, the policy on public transportation needs to provide better quality services i.e. to create public transport services those are service-oriented rather than profit-oriented.

7.2 Cluster 2

For the energy reduction in cluster 2, increase in density is proposed in such a manner that other urban form variables also maintained according to the result of percentage share of other urban form variables as shown in Fig. 6. Due to the limitation of Floor area ratio, FAR (only 1.75) as mentioned in Building bye-laws of Kathmandu, high rise apartment in cluster 2 is not much possible. In such a case, increase in density is possible with the increase in closer integration of residential development with urban facilities (work areas, schools, commercial, civic and recreational uses). Cluster 2 has still a plenty of undeveloped plots. So, we proposed increase in land use mix to support density increase based on TOD concept. It will promote trip reduction by motorcycle for study, work and private purpose. The MLRM showed that along with density (D1), destination accessibility (D4) and road connectivity (D3) has a higher influencing role.

Even land use mix is better and achieve higher density in this cluster 2, people living here will neither necessarily be employed at the workplaces in the same cluster nor primarily use the local shopping. In addition, cluster 2 is found further away from CBD compared to other clusters, indicating that people tend to use motorcycle for longer travel distance as there is poor transit accessibility. Whereas, this cluster has higher road connectivity compared to other clusters which highlight that with the increase in road connectivity, it needs to provide easy access to transit and quality in service to encourage people to use public mode for daily travel. Unless we provide the choice of alternative transport mode, reduction of motorcycle use is not possible. Likewise, unless a density threshold is met, providing public mode is not effective. So, this study recommends the regular service of low passenger public mode in cluster 2 as a solution to reduce motorcycle use and simultaneously energy consumption.

As D4; accessibility to the CBD has no control by urban planning in the existing city, so this study proposes solutions related to policy interventions. Most of the travel originated from cluster 2 end in cluster 1 as cluster 1 has higher land use mix compare to cluster 2. This has led not only higher energy consumption but also one of the main reasons for traffic congestion in the city center of Kathmandu. So, to solve this problem high fixed charges, such as parking charges, vehicle taxes and insurance, can actually affect vehicle use as once the charges have been paid, the private vehicle user generally feels that he/she should get use out of it. The main challenge associated with shifting transport mode is that they are generally unpopular with the public and so require political courage to implement.

To reduce motorcycle use for study, like in Fukuoka, people need to be encouraged to send their children to elementary school within the ward they living. This help to encourage walking. Furthermore, an attractive street design (landscaping, furniture, aligning shade trees along sidewalks, breaking up the horizontal length) with short and direct connections between urban facilities (work areas, schools, market, and parks) need to promote walking.

Among the wards situated in cluster 2, the wards 3, 8 and 9 are required to be focused first as these wards showed lowest density. D2 is mainly required to increase in the wards 4, 6 and 7 whereas D3 needs to increase in the wards 4, 8 and 14. Regarding D5, the wards 3, 6 and 35 showed the farthest from the CBD, so density and land use mix need to increase in these wards. Regarding D5, the lowest transit accessibility is found in the wards 6, 8 and 9. Increasing density, land use mix and road connectivity in these wards will support transit accessibility.

7.3 Cluster 3

Unlike cluster 1 and 2, this cluster already has higher density and higher land use mix; representing the city core of Kathmandu. Though this cluster has no transit accessibility, it has proximity to transit stop located in cluster 1 and cluster 2. Therefore, this study recommends to revitalize the city core as Transit-oriented development (TOD) by developing transit accessibilities with quality in service surrounding the cluster 3; to create a vibrant community centered on walking, cycling, transit access and reduced motorcycle dependence. According to LEED for Neighborhood Development, proximity within ½ mile walking distance promotes TOD.

With this reference, TOD has been proposed to the city core sector at the radius of 1/2mile from the center of the city core as shown in Fig. 12. The proposed BRT in cluster 1 will enhance TOD. Also, in order to improve the quality of TOD, this study recommends restriction of motorcycle accessibility in the city core area to limit the intrusion of private mode and provide better and safer conditions for pedestrians and cyclist. This will also enhance the preservation of historic streets and places (Fig. 13) in the city core.

As this cluster is closer to CBD, most of the trips can be done by using non-motorized mode (walk and bicycle). However, cycle user is found null in this cluster. In fact, the flat terrain in Kathmandu, especially the city core area is very feasible for cycling. The roads of the city core are oriented for non-motorized mode as developed in the years back, so the operation of a bicycle sharing system is feasible in this cluster. So, this study recommends bicycle sharing system in the city core areas and near major transit stations outside the TOD as shown in Fig. 12. Bicycle sharing can be a substitute for transit, particularly for short distance trips. On the other hand, for the long distance trips, bicycle sharing may complement public mode by connecting origins to transit stops and thus increase transit accessibility and reduce motorcycle use.

The ring of the proposed bicycle sharing system in cluster 3 satisfies the threshold distance for bicycling which is about 2.5 miles[34),35)]. The banks of river networks can serve dual purposes in transportation and recreation. So, Bishnumati Link road is proposed to develop as safe bicycle routes.

8. Conclusion

This study is very important in the present context of Nepal as the country is facing financial burden due to ever increasing fuel import. This study has several important implications for land use planning and policy-making to reduce travel energy consumption in Kathmandu. This study has presented the relationships between urban form, travel variables and travel energy consumption by applying Multiple Linear Regression Model (MLRM) based on all the 35 wards of Kathmandu city. This study dealt with the methodological challenges for modeling and analyzing complex relationships between urban form, travel purpose, mode choice, travel distance and energy consumption. The research results adequately responded to the objectives that were set out in Section 2.

This study has identified the significant influencing factor for travel energy consumption based on multiple linear regression model (MLRM) analysis. The research results highlighted that the motorcycle use is the most influencing factor for the increase in travel energy consumption. Likewise, this study highlighted that density has a key role in the motorcycle use reduction. This study has identified that Kathmandu city can be divided into 3 cluster groups based on the heterogeneity characteristics. Also, this study has identified the target area (specific ward) and measures for Kathmandu city for reducing travel energy consumption that has different condition and limitation compared with a city in developed country.

Acknowledgement

This research is supported by the Japanese Government MEXT Scholarship under SGU framework (176595). We like to thank Dr. Padma Bahadur Shahi (Technical Adviser, Nepal India Regional Trade and Transport Project) for providing the GIS shape files of Kathmandu City. We also like to thank Mr. Sugam, Nirajan and their team from Tribhuvan University, Nepal for their indispensable help in the questionnaire survey to collect Kathmandu city's travel data. Also, special thanks to Rabindra Maharjan (Software engineer) for assisting in Postgresql database.

References

1) Krambeck, H. Transport Energy Consumption Trends - Three Trajectories. Available online: http://blogs.worldbank.org/transport/global-implications-of-transport-sector-energy-consumption-in-the-developing-world-0 (accessed on 15 June, 2010)

2) UN-Habitat. State of the World's Cities 2008-2009: Harmonious Cities. https://sustainabledevelopment.un.org/content/documents/11192562_alt-1.pdf (accessed on 20 November, 2016)

3) Asia Trade Hub website: https://nepal.asiatradehub.com/Infrastructure/1445/Introduction (accessed 18.05.23)

4) Ministry of Physical Infrastructure and Transport, Department of Transport Management, Government of Nepal, Registration of Transport in Bagmati, Fiscal Year 2046/47-070/71 office wise.https://www.dotm.gov.np/uploads/files/transport_registration_fiscal_year_2046_47_070_71_typewise.pdf (accessed 18.02.12)

5) The Federal Democratic Republic of Nepal Ministry of Physical Planning, Works and Transport Management Department of Roads, Data Collection Survey on Traffic Improvement in Kathmandu Valley, JICA, Nippon Koei Co., Ltd, Eight-Japan Engineering Consultants Inc., 2012.

6) Shrestha, R. M.,; Rajbhandari S. Energy and Environmental Implications of Carbon Emission Reduction Targets- Case of Kathmandu Valley, Nepal, Energy Policy 2010, 38(9), pp. 4818-4827

7) MoPIT/JICA: Final Report- Data Collection Survey on Traffic Improvement, 2012.

8) Ding, C., Wang, Y., Xie, B., & Liu, C. Understanding the Role of Built Environment in Reducing Vehicle Miles Traveled Accounting for Spatial Heterogeneity. Sustainability, 2014, 6(2), 589-601. doi:10.3390/su6020589.

9) Hong, J., Shen, Q., Zhang, L., How do built-environment factors affect travel behavior? A spatial analysis at different geographic scales, Transportation. 2013, doi: 10.1007/s11116-013-9462-9.

10) Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., Chen, D., Growing Cooler: The Evidence on Urban Development and Climate Change, Urban Land Institute: Washington, DC, USA, 2008.

11) Cervero, R. Transit-based housing in California: Evidence on ridership impacts. Transp. Policy 1994, 1, 174–183.

12) Handy, S. Methodologies for Exploring the Link between Urban Form and Travel Behavior. Transp. Res. Part D Transp. Environ. 1996, 1, 151–165.

13) Ewing, R.; Cervero, R. Travel and the built environment: A synthesis. Transp. Res. Rec. Transp. Res. Board 2001, 1780, 87–114.

14) Frank, L.; Pivo, G. Impacts ofMixed Use and Density on Utilization of ThreeModes of Travel: Single-occupant Vehicle, Transit, and Walking. Transp. Res. Rec. 1994, 1466, 44–52.

15) Badoe, D.A.; Miller, E.J. Transportation-Land-use Interaction: Empirical Findings in North America, and their Implications for Modeling. Transp. Res. Part D Transp. Environ. 2000, 5, 235–263.

16) Zhang, M. The Role of Land Use in Travel Mode Choice: Evidence from Boston and Hong Kong. J. Am. Plan. Assoc. 2004, 70, 344–360.

17) Cao, X., Mokhtarian, P. L., and Handy, S. L. Neighborhood design and vehicle type choice: Evidence from Northern California. Transp. Res. D 2006,13 (2), 133-145.

18) Anderson, W., Kanaroglou, P., and Miller, E. Urban Form, Energy and the Environment: A Review of Issues, Evidence, and Policy. Urban Studies 1996, 33, 7-35.

19) Pisarski, A.E. Overview , in: Transportation, urban form, and the environment. Transportation Research Board Special Report 231, National Research Council, Washington, DC, 1991.

20) Pokharel, Shaligram: An Econometric Analysis of Energy Consumption in Nepal, Energy Policy 35, , 2007, No. 1, pp. 350-361

21) Bajracharya, Iswor, and Nawaraj Bhattarai: RoadTransportation Energy Demand and Environmental Emission: A Case of Kathmandu Valley, Hydro Nepal-Journal of Water, Energy and Environment, 2016, 18, pp. 30-40

22) Bastola, Umesh, and Pratikshya Sapkota: Relationships among Energy Consumption, Pollution Emission, and Economic Growth in Nepal, Energy 80, pp. 254-262.

23) The World Bank Group. April 1, 2013. Managing Nepal's Urban Transition. Retrieved October 16, 2016. http://www.worldbank.org/en/news/feature/2013/04/01/managing-nepals-urban-transition

24) Cervero, R., Kockelman, K., Travel demand and the 3Ds: Density, Diversity and Design, Transp. Res. D. 2,1997, 199–219.

25) Zhang, M., The Role of Land Use in Travel Mode Choice: Evidence from Boston and Hong Kong, J. Am. Plan. Assoc. 2004, 70, 344–360.

26) Ewing, R., Cervero, R., Travel and the built environment: A meta-analysis, Journal of the American Planning Association. 2010, 76, 265–294.
27) Lee, G., Jeong, Y., Kim, S., Impact of individual traits, urban form, and urban character on selecting cars as transportation mode using the hierarchical generalized linear model, Journal of Asian Architecture and Building Engineering. 2016, 15, 223-230.
28) Boarnet, M.G., Joh, K., Siembab, W., Fulton, W., Nguyen, M. T., Retrofitting the Suburbs to Increase Walking: Evidence from a Land-use-travel Study, Urban Studies. 2011, 48, 129-159.
29) Dhakal S., Implications of transportation policies on energy and environment in Kathmandu Valley, Nepal, Energy Policy. 2003, 31, 1493-1507.
30) Jiang, Y.; Zegras, P.C.; He, D.; Mao, Q. Does energy follow form? The case of household travel in Jinan, China. Mitig. Adapt. Strateg. Glob. Chang. 2015, 20, 701–718, doi:10.1007/s11027-014-9618-8.
31) Myers, R.H. Classical and Modern Regression with Applications, 2nd ed.; Duxbury/Thomson Learning:Pacific Grove, CA, USA, 1990; ISBN 978-0534380168.
32) Menard, S. Applied Logistic Regression Analysis, 2nd ed.; Quantitative Applications in the Social Sciences;Sage University: Thousand Oaks, CA, USA, 2002; p. 106.
33) Shrestha, B. Street typology in Kathmandu and street transformation. Urbani Izziv, 2011, 22(2), 107-121. doi: 10.5379/urbani-izziv-en-2011-22-02-004
34) Daddio, D. W. Maximizing Bicycle Sharing: An Empirical Analysis of Capital Bikeshare Usage. University of North Carolina at Chapel Hill, 2012.
35) Witte, A., and P. Dorby. Characteristics of Successful Public Bike Systems. Presented at the Canadian Institute of Transportation Engineers Annual Meeting, Montreal, Quebec, Canada, 2009.

（受理：平成30年10月29日）