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Abstract: *A rapid increase in travel energy consumption is becoming serious issues in Kathmandu, Nepal. This study examined the effect of urban form; 5Ds (density, diversity, design, destination accessibility and distance to transit) on the travel energy consumption. First, empirical analysis is performed based on 5Ds to understand the urban form of entire Kathmandu via 35wards. Afterward, homogenous groups are identified based on 5Ds and travel energy consumption by using k-means cluster analysis. The result highlights: (1) Compact planning in Kathmandu indicates the highest walking mode share, however among the energy-intensive mode, motorcycle is found highly used, (2) Residential area has direct effect on travel energy consumption, (3) Higher travel energy consumption is found due to maximum motorcycle use in highly road connected areas (D3) which are far from Central Business District (CBD) and longer travel distance as the effect of less density (D1), low land use mix (D2) and poor transit accessibility (D5).*

Keywords: Urban form; Travel energy consumption; 5Ds; Cluster analysis; Kathmandu

1. INTRODUCTION

Urban transportation is considered one of the major sources of energy consumption and environmental emissions. Like in many developing countries, the rapid urbanization and growing population in Nepal are causing the demand for energy to rise sharply. Nepal is one of the top ten fastest urbanizing countries in the world [1]. Also, Nepal's largest urban conurbation-Kathmandu Valley is growing at 4 percent per year, one of the fastest growing metropolitan in South Asia [2]. It is the first region in Nepal to face the unprecedented challenges of rapid urbanization and modernization at a metropolitan scale [3]. However, urbanization itself increases energy consumption, but it is less clear what sorts of policies could constrain this growth in energy consumption [4].

The rapid urbanization in the Kathmandu valley has caused the tremendous increase in the use of private modes. The vehicle registered in the valley comprises 66% of the total vehicles registered in Nepal [5,6]. Nepal has no known oil, gas or coal deposits. All commercial fossil fuels are imported from international markets. Fuel imports absorb over one-fourth of Nepal's foreign exchange earnings [7]. Almost all the imported petroleum fuel is consumed in the transportation sector [8]. As a result, Nepal is now facing the financing burden due to increasing trend of fuel import.

In addition to the threat of gasoline insecurity and financial burden, extensive transportation energy consumption also causes problems in the areas of public health and social equity. The study [9] showed that SO_2, NO_x and Pb concentration higher than WHO standard in the central part of Kathmandu. One of the major reasons for air pollution in the valley is the growing numbers of vehicles [10]. Therefore, it is necessary to study various options to reduce the dependency on private vehicles and consumption of petroleum fuel for the energy security of the country.

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 [11,12]. However, such studies are unacquainted in Nepal.

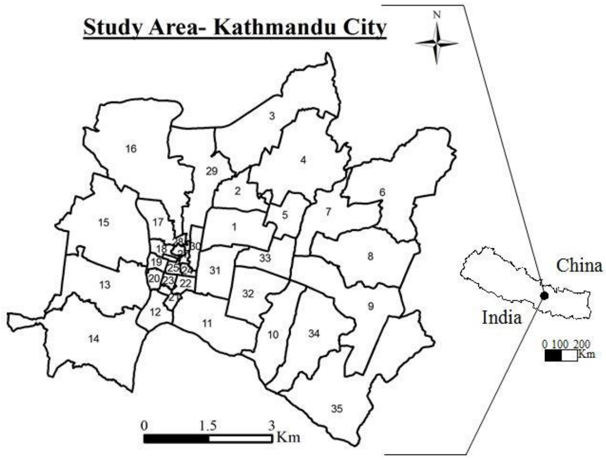

Fig. 1. Study area

The impact of urban form on travel behavior has been widely studied [13,14,15]; mostly based on western countries. In contrast, only a few studies [13,16,17] have explored the influence of urban form on energy consumption and concluded that urban density is the most important influencing factor for transportation energy consumption. However, the role of density in reducing automobile use still remains unclear [18]. The urban land use-transportation system is such a complex entity that all the components in the system work collaboratively rather than separately [19]. Considering only single or limited measures of urban form in an isolated way do not represent the reality. Therefore, this study considers multiple of urban form measures based on "5Ds" framework (density, diversity, design, destination accessibility and distance to transit). The "5Ds" has become widely accepted as an organizing framework to characterize land-use characteristics at the micro-scale level in travel behavior research (20,21).

This research aims to identify the influencing factors of urban form which affect travel energy consumption. Since urban form does not have a direct effect on travel energy consumption, we analyzed the relationship between urban form and travel energy consumption through intermediate variables: Travel mode choice (Fig.2).

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

5Ds	Variable	Operational Definition
D1 (Density)	Population density	Population/Residential area(km^2)
	Household density	No. of Household/ Residential area(km^2)
D2 (Diversity) [22,23]	Land use mix index (Entropy)	Entropy= $-\left\{\left(\sum_k \left(P_i \times (\ln p_i)\right)\right)/\ln(k)\right\}$ 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) [14]	Street connectivity	Number of 3-way road intersections Number of 4-way road intersections
D4 (Destination Accessibility) [14]	Distance to 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) [21]	Transit accessibility	Transit stops/ Total land area (km^2)

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

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}

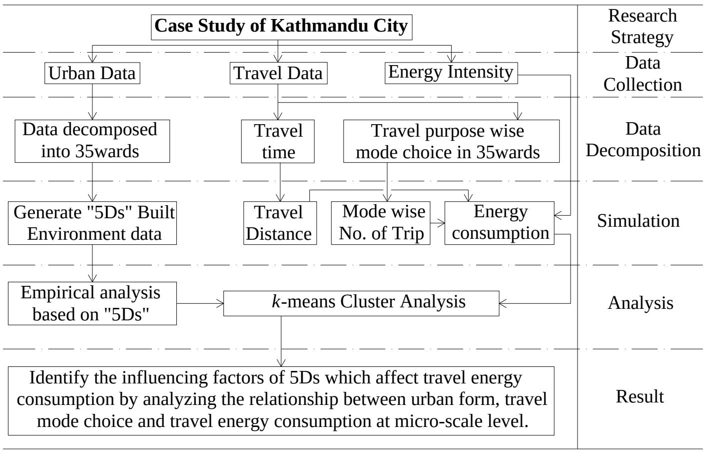

Fig. 2. Research methodology

2. MATERIALS and METHODS

2.1 Study area

Kathmandu City; the capital city of Nepal (Fig. 1) with a population of 1million is the most urbanized and high dense city in Nepal where walking once was the key mode. It 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. Kathmandu is divided into five sectors: Central, East, North, West and the City Core. Administratively, the city is divided into 35 Wards. As the central hub for education, employment, business and state administration, it attracts a continuous flow of people from other parts of the country. The ever-increasing demand for petroleum in Kathmandu has led growing concern on how to reduce travel energy consumption. So, this type of research is becoming the more and more important in Kathmandu.

2.2 Research data

2.2.1 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 variables (Table 1) for interpretation and analysis purpose.

2.2.2 Travel data

A structured questionnaire survey was conducted in all 35 wards of Kathmandu city to obtain one-day travel data. We applied personal interview method for the survey as it provides high response rates. The questionnaire survey included the questions regarding the personal information, the purpose of travel, the mode of travel and the travel time to go to the destination. Afterward, travel time was converted to travel distance for the calculation of energy consumption (Eq. 1). This research excludes taxi as only four persons are found using taxi. This result seemed obvious because in Kathmandu people use taxi rarely for daily purpose. This research covers 861 respondents (59.70% male and 40.30% female) and 1,789 total trips. We applied stratified random sampling where each ward has a proportionate stratified random sample of population, which provides a better representation of travel behavior in Kathmandu. According to [24], a sample of 200 people from a population of 10 million is just as precise as a sample of 200 people from a population of ten thousand. In this regard, this study has performed with the sufficient sample size to represent travel behavior of the population of Kathmandu.

2.2.3 Energy intensity data

We collected the energy intensity data based on Kathmandu [25] to make the research result more consistent. Energy intensity is used for estimating the travel energy consumption of one day by an individual in each 35wards; using Eq. 1 as defined in the research by Jiang et al. [26]. The total travel energy consumed in each ward were ranked into 7 classes from low to high by using SPSS and processed in GIS for the analysis purpose (Fig. 8).

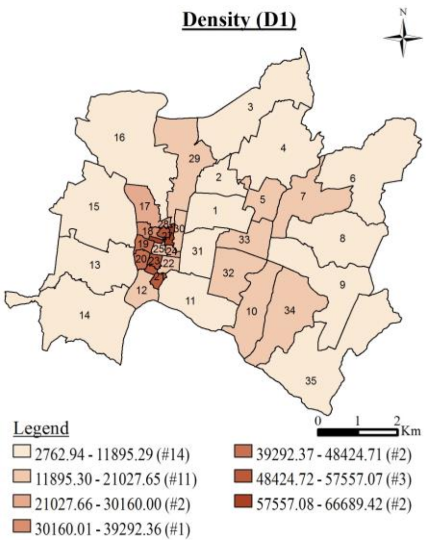

Fig. 3. D1- Density

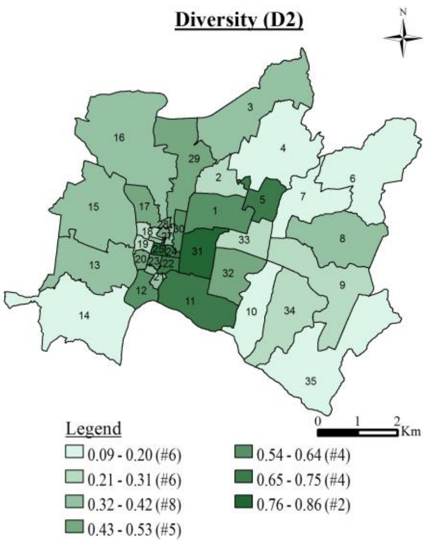

Fig. 4. D2 – Diversity

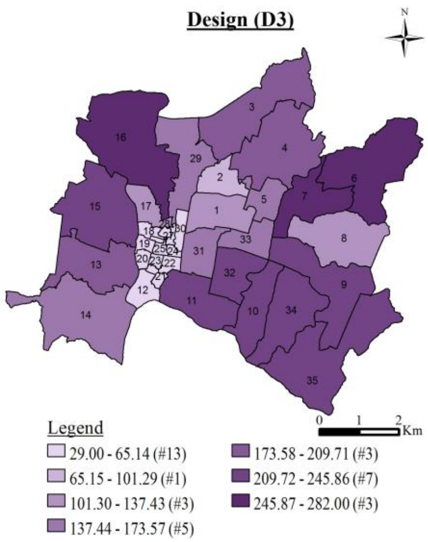

Fig. 5. D3 - Design

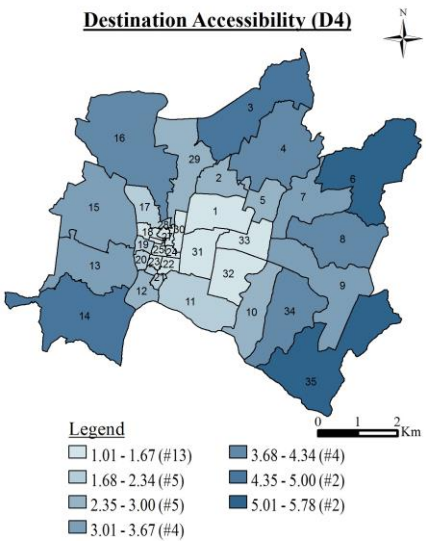

Fig. 6. D4 - Destination accessibility

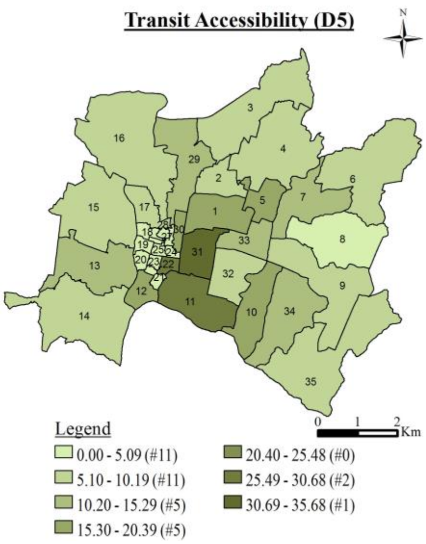

Fig. 7. D5 - Transit accessibility

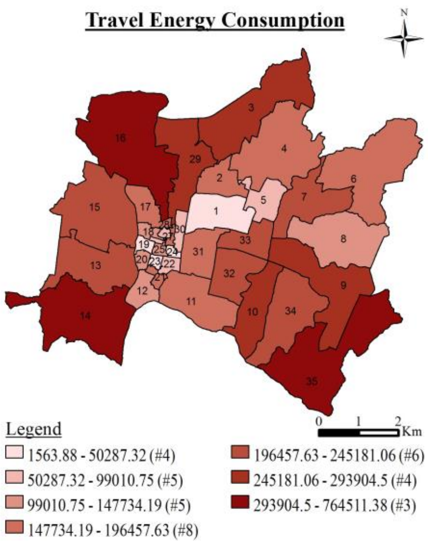

Fig. 8. Travel energy consumption

2.3 Analysis methods

First, empirical analysis of urban form characteristics of Kathmandu is performed based on "5Ds" framework at the micro level; i.e at ward level. The decomposed urban data into 35 wards were ranked into 7 classes from low to high by using SPSS and processed in GIS for the empirical analysis. 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.

3. RESULT AND DISCUSSION

3.1 "5Ds" Empirical analysis result

3.1.1 D1 (Density)

D1 (Density) is measured as the central tendency of population density and household density. Highest D1 was found in the city core sector; specifically, in wards 26 and 27 (Fig. 3). Similarly, the wards 19,20,21,23 and 28 in the city core sector showed higher density. This result is intuitive since most of the wards in the city core sector include ancient neighborhoods that were developed as compact and walking neighborhoods in the years back. The city core was dominated by residential and mixed land uses. The lowest density was found in the wards (1, 11 and 31) situated in the central sector.

3.1.2 D2 (Diversity)

D2 (Diversity) is measured based on land use mix index (entropy) as shown in Table 1. The highest land use mix was found in wards 25 and 31(Fig. 4). However, these wards showed less density (D1). Similarly, the wards with higher density in city core also showed higher land use mix. Whereas, low land use mix was found in the wards having low density. So, this result suggests that increase in land use mix is not absolutely related to the increase in density or vice versa.

3.1.3 D3 (Design)

D3 (Design) includes the road connectivity and it is calculated as the central tendency of 3-way and 4-way road intersection. The highest road connectivity is found in the wards which are associated with less density and far from the central business district (CBD) (Fig. 5). The result showed that the ward even has higher road connectivity; there were less public mode facilities. In, turns, more road connectivity and more routing options likely attract people to use private mode for their convenience. However, a range of studies in the western country shows that better street connectivity resulted in increase of walking and cycling.

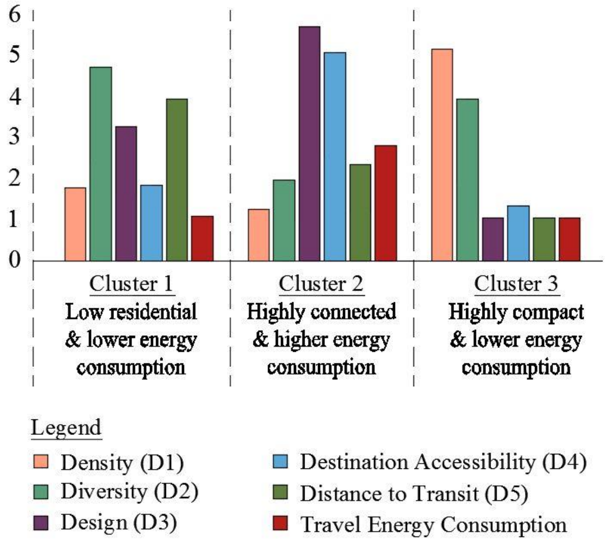

Fig. 9. Cluster centroid values

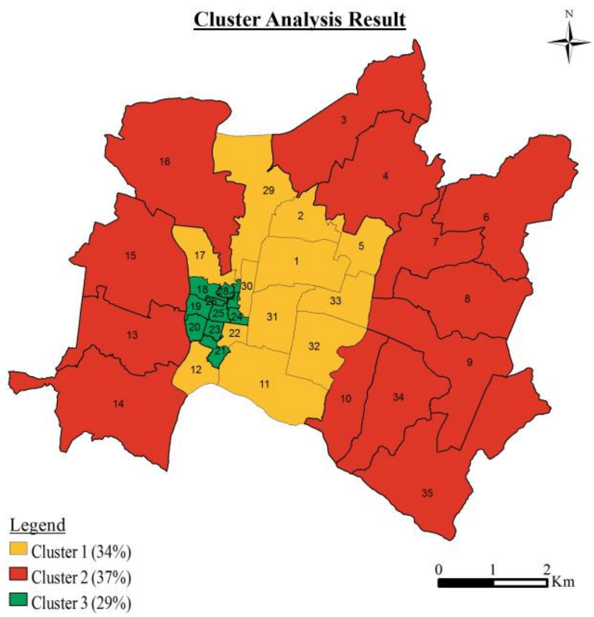

Fig. 10. Cluster analysis result

In the case of the new settlements (ward 6, 7 and 16) that are extended from city core sector showed higher road connectivity and so better facility of public transportation. On the other hand, D3 was found low in the city core sector. This result is intuitive since the planning of traditional settlement in city core such that highly built with attached-row-residential and road intersections were mainly at start or end of the neighborhood. The residential neighborhood planned with linear alleys and courtyard system so the wards in city core sector have fewer road intersections and so less road connectivity.

3.1.4 D4 (Destination accessibility)

D4 (Destination accessibility) measures ease of access to trip attractions. In this study, D4 is measured based on CBD and it is considered as the existing place of Old Bus Park which lies in ward 31 of the central sector (Fig. 6). Most of the wards situated in the city core and central sector were found accessible by walk to CBD. It is found that the ward nearer to CBD has higher land use mix (D2). This result is satisfied because CBD is the location with maximum employment and shopping opportunities. And in the case of Kathmandu, the CBD is near to the ancient neighborhood so there is higher density (D1) in and surround the CBD as well. The study showed that the wards further away from CBD were associated with less density (D1), less land use mix (D2) and higher road connectivity (D3).

3.1.5 D5 (Distance to transit)

D5 (Distance to transit) measures access to nearest transit or transit stop. The highest transit accessibility was found in ward 31 which has the highest land use mix (D2) but less density (D1) (Fig. 7). Ward 31 contains Old Bus Park from where transport is available to various places within and outside the valley. Commerce, education, entertainment and employment are the strong points of this centrally located ward. In Kathmandu, 10 of 35 wards (ward 18-21, 23-28) have no transit accessibility which is situated in city core sector. This is due to the fact that city core was developed as a walkable settlement in the ancient period; at that time walk was major means of transport mode for travel. Most of the residences were mix used (shop/work at first floor and living at upper floors) that had encouraged all urban facility in walking distance.

3.2 Cluster analysis result

After analyzing urban form characteristics of Kathmandu based on 5Ds, we performed cluster analysis by using 5Ds and travel energy consumption to identify homogenous clusters. Several attempts were made with different numbers of clusters and finally, it was found that three clusters were a satisfactory number (three different types of wards), where each one had an acceptable number of wards and sufficient variation between clusters. Fig. 9 shows the cluster centroid values and Fig. 10 shows the location of each cluster. Every three clusters' characteristics are described below.

3.2.1 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; whereas, this cluster represents higher land use mix (D2) and better transit accessibility (Fig. 9). That meant cluster 1 primarily comprises wards situated in the central sector of Kathmandu. From the empirical analysis, it is found that the wards in the central sector have low density, higher land use mix and better transit accessibility. This cluster also includes some wards from North sector (ward 2, 29) and core sector (ward 12,17,22,30). The wards in this cluster were highly dominated by open space, institutions, bus parks and entertainment facility. This cluster represents 34 percent of Kathmandu city (Fig. 10).

Though the wards in this cluster showed less energy consumption, among energy-intensive mode use, motorcycle was found highly used (26.74%) followed by public mode (14.42%) and car (1.86%) (Table 2, Fig. 11). It is worth noting that increase in the use of motorcycle meant more fuel consumption because motorcycle has energy intensity 0.5MJ/person-km which is more than double of public mode (0.2 MJ/person-km). This meant energy consumed by one passenger to travel 1 km by motorcycle is higher than using public mode. As a result, the total energy consumption in this cluster was found highest shared by motorcycle (540585.47 MJ/person/day), followed by car

Table 2. Cluster wise travel mode share

Travel Mode	Cluster 1		Cluster 2		Cluster 3	
	Used no.	Used %	Used no.	Used %	Used no.	Used %
Walk	233	54.19	692	58.74	95	52.49
Cycle	12	2.79	21	1.78	0	0.00
Motor cycle	115	26.74	270	22.92	49	27.07
Car	8	1.86	28	2.38	0	0.00
Public	62	14.42	167	14.18	37	20.44

Table 3. Cluster wise travel energy consumption

Travel Mode	Travel Energy Consumption (MJ/person/day)		
	Cluster 1	Cluster 2	Cluster 3
Motorcycle	540585.47	3302326	116416.79
Car	1320	9299.4	0
Public	3021.8	15506.21	901.53

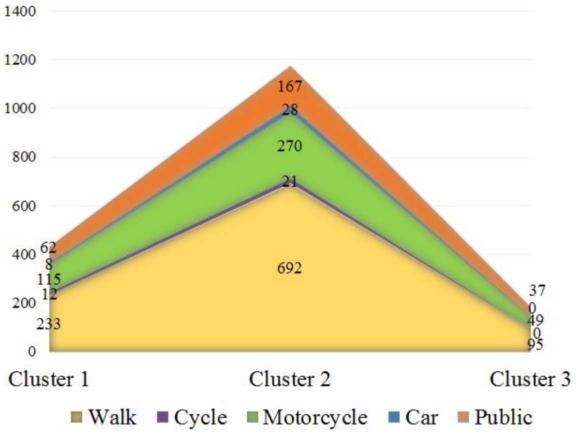

Fig. 11. Cluster wise travel mode share

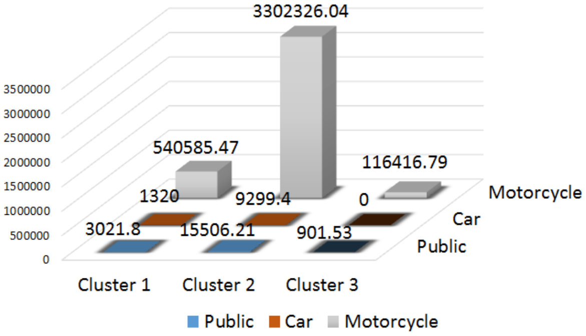

Fig. 12. Cluster wise travel energy consumption

(1320) and public mode (3021.8) (Table 3, Fig. 12). Also, this result highlights that even availability of nearest transit stops, a public mode is less used. It might be the poor service of public transportation in Kathmandu which discourages people to use it for travel.

3.2.2 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. 9). Also, this cluster indicates wards having less density (D1), low land use mix (D2) and poor transit accessibility (D5). This result also indicates that growth of road network in Kathmandu has taken place without adequate transportation infrastructure. According to report [27], there are many unplanned roads and further, those road conditions are poor caused by its inefficient design, construction, and maintenance. Buses, micros and tempos are the dominant modes of public transport in which the private sector is playing a major role in Kathmandu. So, public transport cannot operate on most of the roads. Further, the wards in this cluster are situated in the East, North and West sector which represent sparse residential area. This type of scatter growth is another reason for the difficulties in operating public transport. This cluster represents 37 percent of Kathmandu city (Fig. 10).

The mode share in this cluster shows highly dominated by walk (58.74%), followed by motorcycle (22.92%), public mode (14.18%) and car (2.38%) (Table 2, Fig. 11). Even, the highest trip by walk, the energy consumption is mainly due to motorcycle use (3302326.04MJ/person/day), followed by car (9299.4) and public mode (15506.21) (Table 3, Fig. 12).

3.2.3 Cluster 3- Highly compact and lower energy consumption:

Cluster 3 is characterized by higher density (D1), relatively better land use mix (D2) and lower energy consumption (Fig. 9). Also, this cluster represents wards having lowest road connectivity (D3), closer to CBD (D4) and unavailability of transit accessibilities (D5). This cluster comprises wards situated in the city core (Fig. 10) and found highly dominated by walk (52.49%.) as shown in Fig. 11 and Table 2. This result is satisfied since city core was developed as compact and walking city in the ancient time. In present also, access to urban facilities and CBD are at walking distance from city core has encouraged people to walk. Though the transit accessibility is null in the city core, the public mode users are found 20.44% (Fig. 7, Fig. 11, Table 2). This suggests that if the facilities of public transportation at a walkable distance, people get encouraged using it. However, like in cluster 1 and cluster 2, public mode is not found highly used as compared to private mode which indicates the fact that the Kathmandu has inadequate and unmanaged public transportation. In this cluster also, use of motorcycle occupied the highest share (27.07%) and the energy consumption by motorcycle is also found higher (116416.79MJ/person/day) compared to public mode (901.53) (Table 3, Fig. 12). The wards in this cluster show no use of cycle and car. In fact, the flat terrain in Kathmandu, especially in the core area is very feasible for cycling.

4. CONCLUSION

This study applied 5 dimensions of urban form (5Ds: density, diversity, design, destination accessibility and distance to transit) to explore the influence of urban form on travel energy consumption at a micro-scale level; studying entire Kathmandu city via 35wards.

This study highlights that compact planning in Kathmandu is still dominated by walking as all the three clusters showed highest mode share by walk. So, Compare to other international cities, Kathmandu is walkable and less energy consumer city but the rapidly urbanizing, increasing private mode specifically motorcycle and increasing rate of fuel import have led growing concern on how to reduce travel energy consumption in Kathmandu.

Cluster wise major findings of this research: First, cluster 1 revealed that residential zone has the direct effect on travel energy consumption. Second, cluster 2 showed that highly connected areas (D3) with less density D1 and diversity D2, poor transit accessibility (D5) and further away from CBD (D4) results in an increase in motorcycle and rise in energy consumption due to high energy intensity of private vehicle and longer travel distance. This study suggests that provision of transit facilities is essential with the increase in road connectivity to promote public mode, to reduce motorcycle use and consequently reduce travel energy consumption. Simultaneously, this study highlights that providing transit stops is not sufficient, it also needs to improve the service otherwise even there is a better transit accessibility, people use private mode as in the case of cluster 1. Third, cluster 3 highlights that only compact planning is not effective to reduce private mode use and travel energy consumption but simultaneously need to improve transit accessibilities (D5) and services.

Overall, this study has several important implications for land use planning and policy-making to reduce travel energy consumption in Kathmandu. The solutions for reducing travel energy consumption can be achieved based on clusters that have been identified in this study. Strategies that promote densification, increase land use mix and improve transit accessibility would positively influence transit use and reduce travel energy consumption.

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