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Socio-demographic and built environment determinants of car use among older adults in Iran

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ABSTRACT

Internationally, an age-friendly built environment, including safe, affordable, and convenient transportation, has been identified as crucial in enhancing the quality of life for increasingly large numbers of elderly people. This study presents data on the urban travel and mobility patterns of older adults in Shiraz, Iran – a country where the population is ageing faster than the average of western societies. The relationship between car use and socio-demographic and built environment variables is investigated through Ordinary Least Squares and Geographically Weighted Regression models. These models show that the main determinants of car use among older adults are: employment status; household size; car ownership rate; trip purpose; property prices; and mixed land-uses. Also, the study reveals that car dependency is significant and more pronounced among wealthier individuals, who tend to be clustered in the northern section of the city. The population density and road network design characteristics do not affect car use among older adults, while a mix of land-uses tends to attenuate car dependency. Gender gaps in car use are much wider than in the West, and some level of spatial mismatch between travel needs and car access is observed in the southern section of the city. Clearly, Iranian cities must move away from the current car-centric development model.

1. Introduction

The world population is ageing (WHO, 2011). In Iran, a country of > 80 million inhabitants, the population is ageing faster than the average of western societies (UN, 2015). In addition to increasing life expectancy, declining birth rates and youth out-migration are contributing to the ageing of Iran's population (Statistical Center of Iran, 2017). In the 2016 census, 11% of the population was aged over 60, and 18% of this segment of population was employed (Statistical Centre of Iran 2016). Moreover, the growth rate in the number of older adults is higher than the total population growth rate in the country. By 2050, about a quarter of Iran's population is expected to be aged 60 and above (UN, 2015).

In the West, older people constitute a significant share of the car driving market (Banister and Bowling, 2004). Many are very reluctant to cease driving (Mifsud et al., 2017). Therefore, car dependency among the elderly has become a major concern in Western societies with ageing populations (Boschmann and Brady, 2013; Newbold et al., 2005). Car-dependency is partly driven by a lack of alternative travel options, and limited access to necessary daily services. Therefore, to enhance the quality of life for increasingly large numbers of elderly people, an age-friendly built environment, including safe, affordable, and convenient transportation, is crucial (WHO, 2011).

In Iran, the rate of car ownership is low compared to developed countries and even many developing countries. For example, based on the Shiraz Household Travel Survey (SHTS), this rate was about 293 cars per 1000 inhabitants in 2015. Nonetheless, the rate of private car use is very high, including among the elderly.

The World Health Organization has launched the Age-Friendly Environments Programme. However, this program is hardly operational in many Global South countries due to a lack of sufficient physical, financial, and social infrastructure. In Iran, poorly-designed walking and cycling environments and weak public transportation systems have been identified as two main factors which hinder the independent mobility of the elderly. In addition, a harsh climate with scorching summers and snowy winters in some regions, and cultural imperatives for women preclude the use of non-motorized transportation among older adults. (For example, until recently women were prohibited from cycling due to religious/ideological protocols.) The problem of independent mobility among the elderly in Iranian cities is slowly

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assuming crisis dimensions. But in urban transportation, as in other arenas, elderly affairs are marginalized. The available evidence reveals little success in empowering older people and incorporating their needs into national or local planning policies (Goharinezhad et al., 2016).

At present, very little is known about the relationship between transportation and ageing in the Middle Eastern region. Most existing studies, which are briefly reviewed in the next section, are based in high-income Western countries. This article presents data on the urban travel and mobility patterns of older adults in Shiraz. This is the first study of its kind based in Iran. A principal aim is to quantify the effect of socio-demographic and built environment characteristics on car ownership and use among older adults. The international literature suggest that these characteristics are associated with older adults' trip patterns (Feng et al., 2013; Roorda et al., 2010). The research is based on a comprehensive, large-scale survey of 20,000 households in the Shiraz metropolitan area, conducted by Shiraz University. The study outcomes can be of use not only to policy makers in Iran but also to researchers who seek to conduct international comparative studies on transportation and ageing.

2. Literature review

2.1. Elderly travel patterns in the Global North

The Global North has been the focus of most research to date. Here older people have been found to exhibit a rather complex travel behavior (Hildebrand, 2003). Overall, older people are making more daily trips and driving longer distances than ever before (Mifsud et al., 2017). However, it is clear that, compared to youth, older people encounter more hurdles in their daily transportation and mobility, partly due to the ageing process itself, and partly owing to the social and physical arrangement of their community (Banister and Bowling, 2004; Li et al., 2012; Schwanen and Páez, 2010). In other words, the activity spaces and travel modes of older people are determined by (1) health factors; (2) socio-demographic factors; (3) built environment factors.

2.1.1. Health factors

These include musculoskeletal weakness, chronic illness, visual or hearing loss, and a general decline in physical and mental health with advancing age. The relationship between health and car use by older adults is beyond the scope of this study. The effects of the other two sets of factors are unpacked below.

2.1.2. Socio-demographic factors

These include life transitions such as retirement, community support network, gender, age, ethnicity, affordability, and even perceptions about travel options. Single individuals living alone may find it difficult to access grocery stores, medical services, and social activities. This may lead to isolation, loss of freedom, and even hopelessness (Chaudhury et al., 2011; Musselwhite and Haddad, 2010; Schwanen and Páez, 2010; WHO, 2011). In terms of gender, men are more dependent on cars whereas women employ a broader variety of transportation modes. As their needs increase and capabilities decrease, older adults often make progressive adjustments to their travel behavior. Sometimes, these adjustments are prompted by family members who are aware of the increased risk of traffic accidents associated with ageing (Blanchard et al., 2010; Li et al., 2012; Takahashi et al., 2017).

However, for many, the private car remains vital in preserving independence (Banister and Bowling, 2004; Nakanishi and Black, 2015; Newbold et al., 2005; Schwanen and Páez, 2010). In fact, the 75–84 age cohort tends to rely most heavily on cars (Boschmann and Brady, 2013; Collia et al., 2003; Cui et al., 2017; Mercado and Newbold, 2009; Schmöcker et al., 2008; Schwanen et al., 2001). Only very advanced age (85 and over) finally forces people to give up driving. When this occurs, men are more likely to replace driving with walking and transit use, whereas women tend to rely on rides from others (Boschmann and Brady, 2013). An exception is impoverished retirees for whom private cars may become unaffordable (if they ever were affordable). In this case, it is a diminished income rather than advanced age that leads to giving up driving (Adler and Rottunda, 2006). Being more car-dependent, men might find it harder to adjust to this transition - especially in the absence of efficient and easy-to-use public transit (Banister and Bowling, 2004; Feng, 2017).

2.1.3. Built environment factors

These include transportation mode availability and preference, residential location, local land-use, and density. Generally, low-quality and unreliable transit systems are unlikely to satisfy the complex needs of different clusters of senior adults (Davey, 2007; Engels and Liu, 2011; Hildebrand, 2003; Kostyniuk and Shope, 2003; Risser et al., 2010). In recent years, demand-responsive transportation and car-sharing services have provided a middle ground between owning a car and being entirely carless. However, these services may be unaffordable to some, and unacceptable to others accustomed to owning and driving a car. Non-motorized transportation, including walking and cycling is also important in extending independent mobility for the elderly (Feng, 2017; Roorda et al., 2010). If sidewalks, road crossings, pedestrian signal timings, and cycle paths are not designed with the elderly in mind, travel by car might end up being the only option.

Urban design features, especially around the place of residence, significantly impact older adults' choice of travel modes (Alsnih and Hensher, 2003). Those who live in urban cores tend to be more mobile than those who live in remote suburban or rural areas. Generally, the elderly tend to avoid long distances or complex trips; therefore, an appropriate residential location, within reach of necessary services, may be more critical in old age than at any other time in life (Giuliano et al., 2003; Truong and Somenahalli, 2015). Urban environments with higher densities, diverse land-uses, and pedestrian-friendly streets are better poised to meet the needs of older people - especially as the importance of recreational-, social-, and shopping-related travel increases whereas the role of work-related trips declines (Chudyk et al., 2015; Cui et al., 2017; Fobker and Grotz, 2006; van den Berg et al., 2011; Van Holle et al., 2014; Winters et al., 2015).

2.2. Elderly travel patterns in the Global South

One cannot assume that the foregoing findings pertaining to Global North countries will apply to the Global South (Schwanen and Páez, 2010). The differences of meanings, understandings, and perceptions of older people in different geographical and cultural contexts justify more detailed empirical studies. Research set in the South is increasing slowly and on a case study by case study basis (see Ipingbemi (2010) on Ibadan, Nigeria; Gómez et al. (2010) on Bogota, Colombia; Pettersson and Schmöcker (2010) on Manila, Philippines; Corseuil et al. (2011) on Florianopolis, Brazil). One consistent finding is that public transit use seems to be increasing (Ipingbemi, 2010; Kim, 2011). However, the available studies ask different research questions and apply differing methodologies. Therefore no full picture has emerged of the travel and transport needs and patterns of the elderly in Global South.

3. Methodology

To reiterate, the objectives of this study include: (1) Examining the travel and mobility characteristics of older adults in Shiraz, and (2) Quantifying the effect of socio-demographic and built environment factors on car use among older adults in Shiraz.

3.1. Case study

The study is set in Shiraz, a city in southern Iran. A word on Iran's socio-economic and demographic situation is in order prior to discussing the case study.

Iran is a rapidly urbanizing country. The urban population (currently 70% of the total) is growing at an average annual rate of about 3% (Arefian and Moeini, 2016). Such high urbanization rates are due to internal rural-urban migration and the transformation of rural settlements into urban centres. Most North Atlantic countries undertook their urbanization process one century ago, within a context of rapid industrialization and job growth which is not associated with Iranian urbanization. Here urbanization has been driven primarily by poverty and lack of services in rural areas (Fanni, 2006).

Iran's vast oil reserves remain its primary economic asset. However, oil abundance is a doubled-edged sword: while is provides substantial revenues through exports, it has led to unsustainable transport practices. > 15 million cars are in use throughout the country. There is one car for every four people, and 85% of these vehicles are owned by urban residents. At a 15% annual growth rate, motorization is progressing more rapidly than urbanization (Soltani, 2017a), despite per capita incomes of only about $10,000 (UNDP 2013). Massive domestic car production coupled with car imports fuel car dependency (Mirsadeghi, 2016). While the general level of car ownership is still lower than in Western countries, the negative consequences of car use - pollution, congestion, accidents - are much higher (Arefian and Moeini, 2016).

In terms of driving eligibility, all adults over 60 are required by law to renew their driver's license on a five-year basis. This timeframe is shortened to two years for those aged over 75. To renew one's driver's license, one must take a test and present a recent medical examination report. Apart from these requirements, there are no age or gender limits on driving (Unlike in Saudi Arabia, Iranian women are allowed to drive and can move around cities with relative freedom).

Returning to the case study of Shiraz: the city encompasses 1.7 million inhabitants (1.9 million in the metropolitan area), and about 10% of its population is over 60 (Statistical Center of Iran, 2017). The urbanized area is 19,000 ha and the population density is 82 people/ha. The physical growth pattern is semi-linear. Administratively, the metropolitan area is split into 11 zones, each of which has its own municipal authority.

In recent decades, Shiraz (as other Iranian cities) has pursued policies in favor of car use. It spends > 70% of its construction budget to build new roads, highways, and overpasses. Car-oriented planning policies have shaped a city in which people need to drive 10 of kilometers on average to reach their destinations. The government has tried to meet this demand through the "predict-and-provide" model. The Shiraz Household Travel Survey (SHTS, 2016) reveals the following modal split: private cars 50%, taxis 28%, metro and buses 12%, and all other modes 10%. (The survey has not measured walking rates.)

Single occupancy driving is standard. Some observations show that the average vehicle occupancy rate is only 1.5–1.7. Consequently, the demand for road and parking space is high. Given the development of the car industry in Iran, the availability of cheap fuel, the low quality of public transit, and a growing economy, car use trends are expected to increase for a while. However, such high (and increasing) levels of car use are unsustainable in a longer term.

Meanwhile, urbanites who cannot afford a car rely on grossly inadequate public and non-motorized transport systems. The needs of vulnerable road users are neglected in favor of accommodating motorized transportation (Soltani and Askari, 2014; Soltani, 2017b). Urban sprawl and fragmentation add another layer of urban problems. There is little order in the way different land-uses are arrayed across the urban landscape. The city includes vast tracts of informal settlements for the poor (often without formal public transportation services), as well as middle-class suburban estates, in which people lead increasingly isolated, individualistic lifestyles, cocooned in their cars. Consequently, Shiraz is already facing severe transport-related problems, in particular congestion and traffic accidents.

This preliminary review, as well as the authors field observations, suggest that four factors have combined to making older adults more reliant on cars: (a) urban sprawl and land-use segregation; (b) changing family structures in Iranian society from larger extended families to nuclear families – a trend which forces older adults into self-reliance and isolation; (c) older people continuing (or returning) to work beyond retirement age due to increasing inflation rates, decreasing purchasing power, and an inadequate social welfare and pension system, and (d) low-quality public transport and poor non-motorized transport infrastructure.

3.2. Data

The data employed in this study include the following:

- The Shiraz Household Travel Survey (SHTS) database, which was compiled by Shiraz University in 2016. The SHTS collected data from 20,000 randomly-selected households living throughout the Shiraz metropolitan area. This constitutes about 4% of total households - a sample size which is common in traffic studies (Ortúzar and Willumsen, 2011; Vaughan, 1972). A representative from each participating household reported the travel diary of all household members on the day prior to completing the survey, including trip origins and destinations (O-D). The survey collected information on residential location, household size, number of workers, number of adults (18 years and above), number of older adults (60 years and above), number of children (under 18), vehicle ownership, and the demographic characteristics of the household members. The information was aggregated for 325 traffic area zones (TAZs). For the purpose of the analysis, trips were divided into two categories: compulsory trips (work, education, and medical visits) and arbitrary trips (social, recreation, shopping, and personal business). The first category is assumed to be less flexible in terms of travel time, route choice, and destination. A fundamental limitation of the SHTS is that it ignored walking as mode of transport.
- Spatial data, extracted from existing GIS layers and census maps and the Statistical Center of Iran (SCI). These include shapefiles with information on land-use, land pricing, road network, population, and public transportation attributes. The land-use map consists of current function and activity data. It is a parcel-based map derived from valuation information and land parcel boundaries. The population and employment numbers are aggregated to city survey block level. The land-use data is presented in higher and lower level divisions linking to residents and employment numbers. The road network layer consists of segments which indicate the road typology (e.g., highways, streets, alleys), and intersection elements. The public transit layer includes information on the location of bus stops, bus routes, and underground metro stations.

These data were analyzed through descriptive statistics and two models: an Ordinary Least Squares regression model and a Geographically Weighted Regression model (see below).

4. Findings

4.1. Descriptive statistics

The data were initially analyzed in Excel using simple descriptive statistics. It was found that overall, older adults (60+) in Shiraz are highly dependent on cars – nearly as much as younger adults (16–60). Fig. 1 shows the modal splits for both groups. Cars are preferred for both work and non-work trip purposes. These findings are consistent with modal splits in Western cities (Hildebrand, 2003; Schwanen and Páez, 2010).

Within the elderly cohort, with increasing age, mobility and car use become lower while public transit use becomes higher (Fig. 2). The literature also suggests that, overall mobility levels decline as people reach 75 years of age (Giuliano et al., 2003; Rosenbloom, 2001), while public transportation use increases around the same time (Ipingbemi,

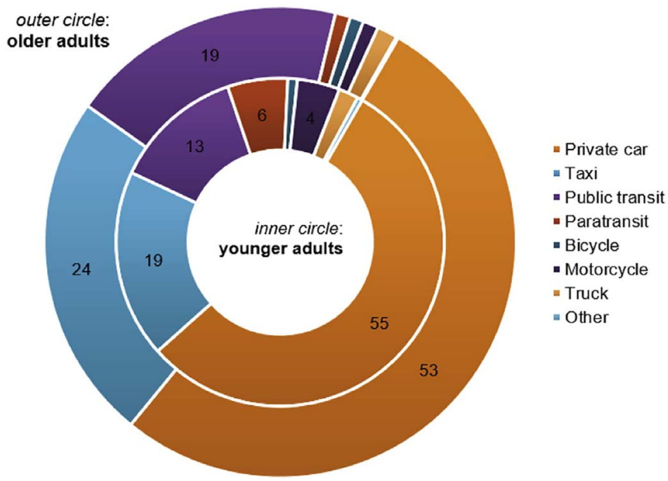

Fig. 1. Modal share of younger and older adults (percentage).

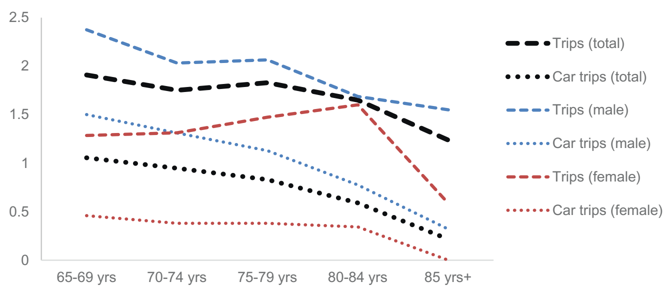

Fig. 2. Mobility and car-based trips for older adults by gender (percentage).

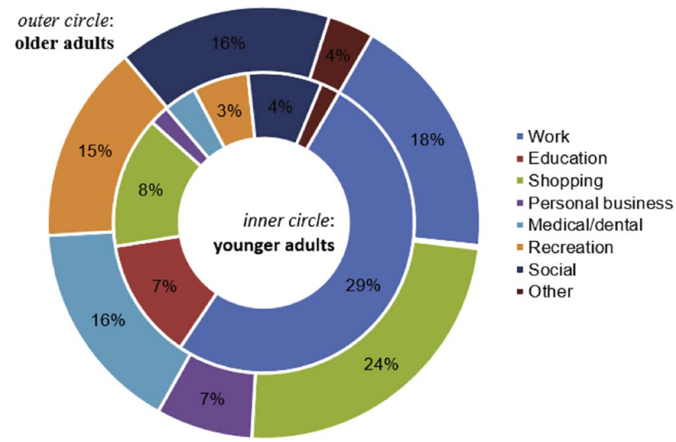

Fig. 3. Travel purposes of younger and older adults (percentage).

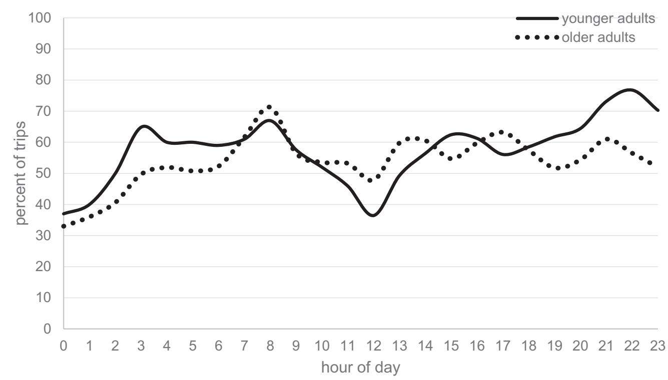

Fig. 4. Travel times of older adults compared to others (percentage).

2010; Kim, 2011; Rosenbloom and Staahl, 2002; Rosenbloom and Winsten-Bartlett, 2002). But in Shiraz, averages hide significant differences between men and women. Older women are less mobile (take fewer trips) than older men, and their rate of car-based trips is about one-third the rate of male counterparts. Car travel rates decline more sharply with advancing age for men – although they start at a much higher baseline than for women. Interestingly, elderly women's mobility increases between 65 and 85, after which it declines more sharply than men's. This trend may occur because female spouses must shoulder the burden of household tasks formerly performed by their husbands. Western-based literature suggests that, despite their longer lifespan, women have a higher disability rate compared to men. Therefore they are less mobile and more likely to require more assistance during travel activities (Alsnih and Hensher, 2003).

Clearly, older women in Shiraz are more dependent on alternative transportation modes (e.g., metro, buses, and taxis) than men. These gender gaps bear some relationship to Iranian social, cultural, and cognitive barriers to driving by women. However, they are also present elsewhere. A study set in Beijing shows that elderly women travel much less frequently than men, while there is no significant gender variance among middle-aged or young people (Liu et al., 2017). In the West too older women give up their driver's license earlier than men do, resulting in lower levels of car use (Davey, 2007) – although gender differences are not as striking as in Iran.

As expected, trip purposes vary substantially between older and younger adults (Fig. 3). Older adults' trips more often involve shopping, recreation, social events, and medical visits whereas for younger adults, educational and work-related trips are more frequent. This finding has implications for local policy makers who must carefully consider the location and accessibility of destinations that are not work-related or education-related. However, older adults take a significant share of work-related trips too (18%). This points to the fact that many people may be forced to keep working beyond the official retirement age, due to an underfunded pension system. In terms of travel spans, these are generally similar between older adults and younger adults (Fig. 4). However, the elderly travel less in the evening (perhaps due to reduced vision or lack of safety after dark, or less interest in nightlife) and more in the middle of the day when younger people are at work. These findings are consistent with national census statistics (Statistical Center of Iran, 2017).

4.2. Modelling results

Beyond descriptive statistics, two different models were applied to further analyze car use patterns and determinants among older adults: an Ordinary Least Squares (OLS) regression model and a Geographically Weighted Regression (GWR) model.

4.2.1. Ordinary least squares (OLS) regression

OLS is a linear regression method that allows researchers to model and explore relationships between a dependent variable and multiple independent variables based on the shortest distance (“Least Squares”) to the mean. It is labeled “Ordinary” because it is the default regression technique in statistical packages such as SPSS or R. The residuals are assumed to be (a) independently and identically distributed around the mean; and (b) homoscedastic, meaning that any samples taken at random from the residuals will have the same mean and variance.

A widely-used diagnostic tool for collinearity in OLS regression was used, the Variance Inflation Factor (VIF). The VIF measures how much the variance of an estimated regression coefficient increases because of collinearity. As a rule of thumb, VIF values must be < 5 (Kutner et al., 2005; Rogerson, 2014). On this basis, several models were fitted until the best combination of significant variables was achieved. The analysis was conducted in SPSS version 24. The confidence level was set at 95%

Table 1
Descriptive statistics of the variables employed in the models.

Variable name	Description	Mean	Median	Std. dev.	Min.	Max.
M_PV (dependent variable)	Number of trips taken by private car as driver or passenger within the zone	284.6	172.9	318.8	0.0	1877.5
Drls (driver's license)	Percentage of older adults possessing driving license	0.33	0.34	0.11	0.00	0.50
Hhs (household size)	Average household size (households with older adults)	3.42	3.46	0.82	1.0	7.0
Vho (vehicle ownership)	Share of car-owning households that include older adults	70.3	74.6	25.6	0.0	100.0
Emp (employment status)	Number of employed older adults	74.7	56.8	72.4	0.0	400.9
Lp (land price)	Average property price (Iranian Tomans)	1391	1324	347	733	2322
Cmltrp (compulsory trips)	Number of essential trips (for work, medical visits, and shopping) taken by older adults	0.73	0.74	0.23	0.00	1.00
Lmx (land-use mix entropy)	Land-use mix entropy	0.31	0.30	0.18	0.00	0.80

and the significance level (p) was set at 0.05.

The dependent variable was the number of older adults' trips taken by car as either driver or passenger in each traffic area zone (TAZ). The independent variables included: (i) older adults possessing a driver's license; (ii) average household size for households with older adults; (iii) car ownership for households with older adults; (iv) number of compulsory trips (for work, medical visits, and education) taken by older adults; (v) employed older adults; (vi) average property prices; and (vii) land-use mix entropy. This set of independent variables was selected from a long list of potential variables based on two criteria: (1) Aligning with theory (i.e., prior research findings). (2) Avoiding collinearity (i.e., high correlation among independent variables). Table 1 lists the selected independent variables. The statistically significant variables and the metrics for the goodness of fit of the model are shown in Table 2.

The OLS model results indicated that the number of car-based trips is positively correlated with owning a car and possessing a driver's license, being employed, and living in a wealthier part of the city (as determined by higher land prices). These findings are as expected. They reinforce the idea that it is difficult to limit car use if car ownership and licensing are not curtailed.

The number of car-based trips among the elderly is negatively correlated with household size, the number of compulsory trips, and land-use mix. There are a number of potential explanations for these findings. Elderly people living in larger households (e.g., with extended family members) might have less disposable income to spend on private motorized transport. Compulsory trips which end at major destinations (e.g., a hospital) and do not involve trip chaining might be easier to accommodate on the trunk routes served by public transport. A mix of land-uses, with services well distributed across the city, shortens trip distances and reduces the need to travel by car.

However, an OLS model returns only citywide averages. It does not provide details on travel patterns in different parts of the city. Hence the need for a Geographically Weighted Regression (GWR) model.

4.2.2. Geographically weighted regression (GWR)

GWR introduces a spatial component to the analysis of variables. A basic geography maxim is that nearby entities tend to share more similarities than entities which are far apart. Characteristics at proximal locations tend to correlate, either positively or negatively. This covariance is called spatial dependency. Regression analyses, such as OLS, which do not compensate for spatial dependency (Clark, 2007), can have unstable parameter estimates and yield unreliable significance tests (Brunsdon et al., 1996). Moreover, unless a space is uniform and boundless, every location has some degree of uniqueness relative to other locations. Due to this spatial heterogeneity, overall parameters estimated through OLS modelling for the entire system may not adequately describe the nuances within a particular location. Spatial regression models such as GWR, are needed to measure the relationships between the independent and dependent variables by locality.

GWR builds an independent OLS equation for each location in the dataset (Fotheringham et al., 2002). In this study, the modelling was conducted in Esri ArcGIS version 10.5. The dependent variable in the GWR model, as in the OLS model, was the number of older adults' trips taken by car as either driver or passenger in each TAZ. Using the GWR model enhanced the explanation of the dependent variable and improved the fit of the data to the model. In the GWR model, the relationships among the explanatory variables are allowed to vary across the study area. The model produced a series of coefficient maps (Fig. 5A–H). These indicate where in the metropolitan area each variable is strongest. Spatial variation suggests that the parameters are affected by local characteristics – a finding that is of interest to urban

Table 2
Summary of OLS regression results.

Coefficients	Unstandardized coefficients		Standardized coefficients	t	Sig.	VIF
	B	Std. Error	Beta			
Constant	46.114	21.039	–	2.192	0.003	–
Drls (driver's license)	317.535	132.977	0.108	2.388	0.018[a]	1.582
Hhs (household size)	−64.593	15.591	−0.167	−4.143	0.000[b]	1.260
Vho (vehicle ownership)	1.960	0.575	0.157	3.406	0.001[b]	1.659
Emp (employment status)	2.812	0.166	0.638	16.891	0.000[b]	1.111
Lp (land price)	0.122	0.036	0.133	3.421	0.001[b]	1.170
Cmltrp (compulsory trips)	−146.434	50.430	−0.105	−2.904	0.004[b]	1.018
Lmx (land-use mix entropy)	−181.998	64.973	−0.105	−2.801	0.005[b]	1.095

F = 72.014; $p < 0.000$; adjusted R^2 = 0.639; general R^2 = 0.64.8.
The interpretation is as follows:
(a) Absolute t values over 1.96 indicate that the coefficient is significant.
(b) Small *Sig.* values (probabilities) are more significant than large ones.
(c) All VIF values are < 2, indicating that there is no redundancy in the selected variables.
The OLS regression analysis returns an adjusted R^2 value of almost 0.64. This means that the independent variables in the model explain the 64% of the variations in car use by older adults in each TAZ. The adjusted R^2 (64%) is derived from general R^2 (64.8%) after controlling for sample size and number of variables.
[a] Statistically significant variables at $p < 0.05$.
[b] Statistically significant variables at $p < 0.01$.

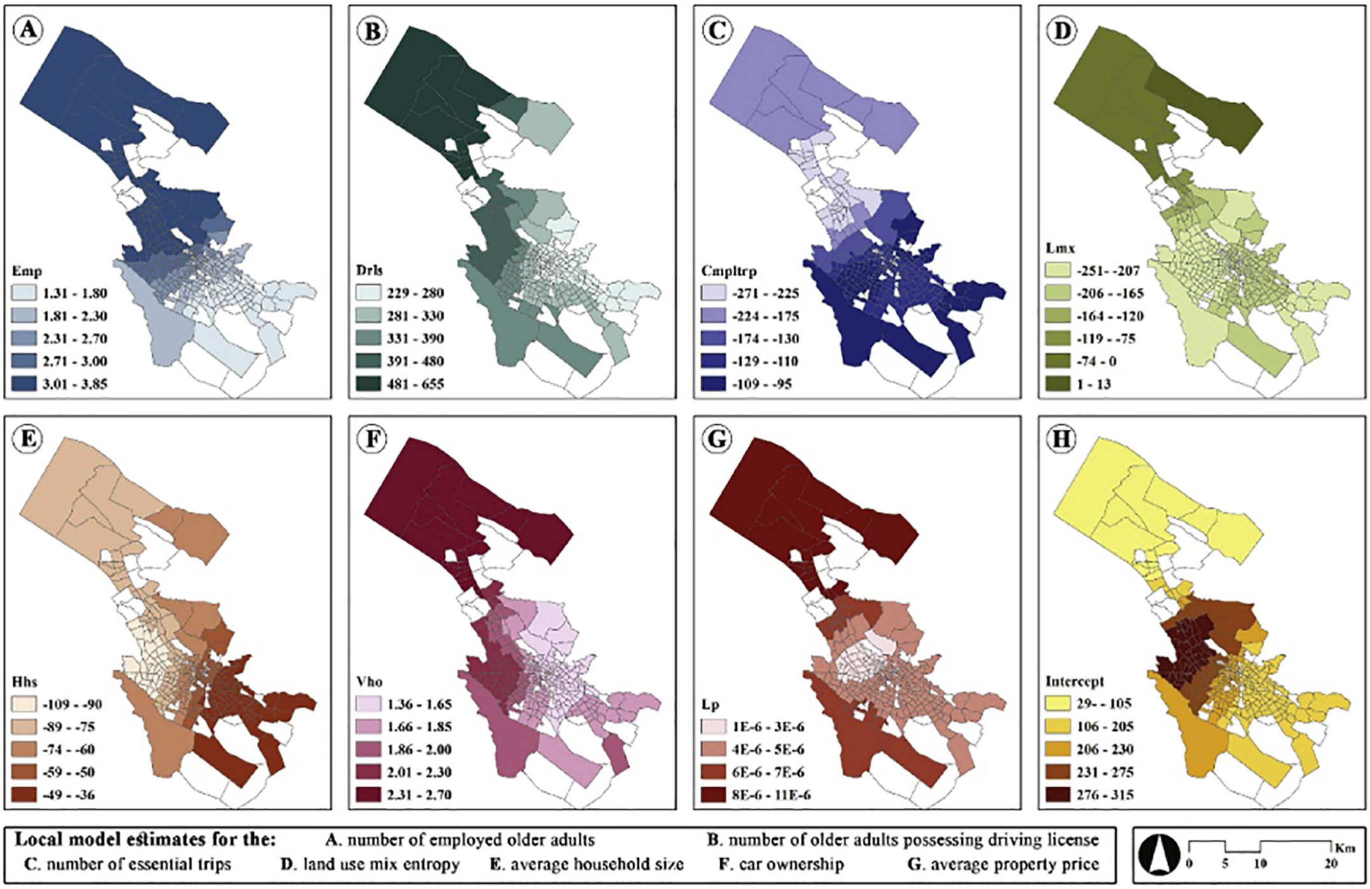

Fig. 5. GWR coefficient maps.

planners.

Significant positive correlations between employment density and car use among older adults are prevalent in the north-west. This suggests dissatisfaction with public transport services in this area, but also higher incomes (Fig. 5, A). Fig. 5(F) and (B) show the impact on car use of possessing a car and a driver's license across all zones. The estimated parameters for both variables are higher in the centre-western and north-western portions of Shiraz, especially in new urban extensions. Similarly, significant positive correlations between property prices and car use by older adults are primarily located in the north-western, central, and south-western areas of city (Fig. 5G). Again, this reflects a higher socio-economic level of older adults in these locations. Because they have more transport choice (including car access), elderly residents in these areas are likely to have higher expectations in terms public transport quality.

Significant negative correlations between the frequency of compulsory trips (work, educational, medical) and car use among older adults are primarily distributed in the central, southern, and eastern parts of the city (Fig. 5C). Significant negative correlations between average household size and car use by older adults are observed in the same areas (Fig. 5E). This may be attributed to the lower socio-economic level of local residents (which in itself may owe to larger households). Locals here opt to reduce private car use in order to save money. Therefore, improving public transport services and providing fare subsides to the elderly in these parts of the city is paramount.

Significant negative correlations between car use by older adults and local land-use mix are primarily observed in the north-western and eastern areas of Shiraz (Fig. 5D), which are among the most diverse and economically vibrant.

4.3. Accuracy tests

Three tests were performed to quantify and compare the accuracy of the OLS and GWR models:

- Root Mean Squared Error (RMSE) was computed, which indicates how closely the observed data points match the model's predicted values. Lower RMSE values indicate a better model fit. In this case, the RMSE values for the OLS and GWR models were 189 and 171 respectively, indicating that the GWR model was an improvement over the OLS model.
- Moran's I was computed, which measures the spatial dependency of the models, i.e., the correlation between residuals (errors). Moran's I values vary between -1 and 1. Perfect dispersion of residuals (low similarity between neighbors) would yield a -1 value while perfect clustering (high similarity between neighbors) would yield a 1 value. In the OLS model, spatial dependency (clustering) was evident. Residuals correlated when the confidence level was set at a 90% (Moran's $I = 0.011$, $p < 0.070$, z = 1.81). By contrast, in the GWR model the residuals were randomly distributed (Moran's $I = 0.003$, $p < 0.391$, z = 0.86, Fig. 6). This also indicated that the GWR model was an improvement over the OLS model.
- For the GWR model only, a map of local R^2 values (Fig 6) was produced. This map is another indicator of how well the model fits observations. Typically, values over 0.50 are considered as acceptable. In this case, the model performed well for the majority of metropolitan area, although the performance was weak in the southeastern suburbs. Here, the model has less power in estimating seniors' car travel determinants. This is partly due to the diversity of socio-economic characteristics among Shiraz's residents. (Income-based segregation is less accentuated than in Western settings.)

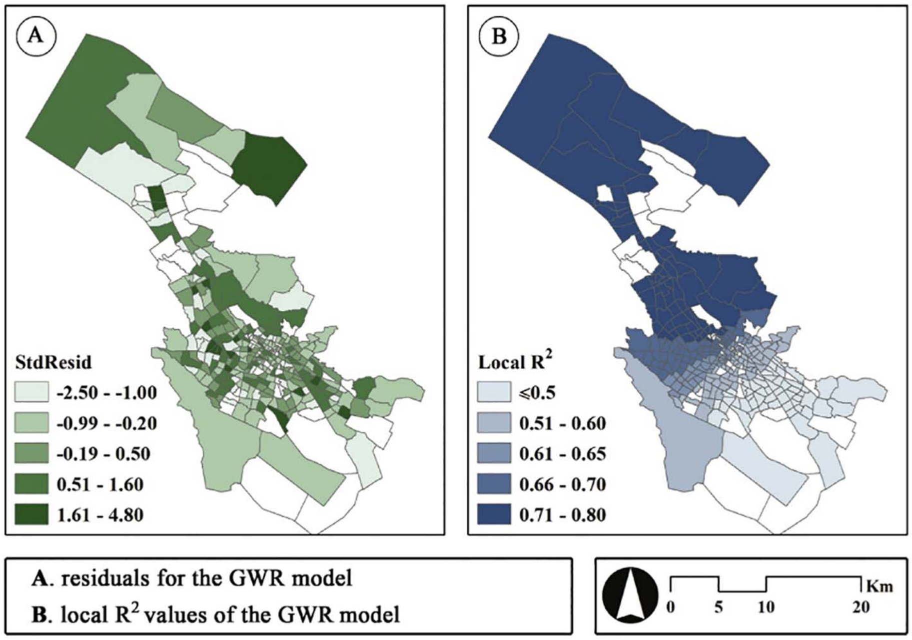

Fig. 6. GWR test: A. random distribution of residuals and B. distribution of local R^2.

5. Discussion

Overall, as expected, possessing a car and a driver's license has a positive and statistically significant relationship with car use among older adults. Previous studies based in Europe, the US, and Japan, suggest that car ownership and use are positively correlated to the quality of life for the elderly (Chikaraishi, 2017; Hjorthol et al., 2010; Murtagh et al., 2015; Schmöcker et al., 2008; Schwanen et al., 2001). In part, this might mean that the elderly appreciate the freedom and independence afforded by cars and feel isolated and insignificant when they can no longer drive (Siren and Haustein, 2013). However, a positive correlation does not necessarily mean that cars and driving "cause" well-being among the elderly. It may simply mean that wealthier people, who are more likely to own and drive cars, also display higher levels of wellbeing – which might be due to other factors such as access to healthy food, exercise facilities, and medical services. In fact, driving at a very advanced age might place at risk both the driver and others - passengers, passersby, other drivers on the road. (As noted, in Iran, as in many other countries, older adults are required to take new driving tests starting at age 60).

Household size is negatively correlated to car use: couples and single individuals use cars more. This finding is consistent with the results reported in the literature (see Rubin et al., 2014). The reason might be that larger households have less disposable income to spend on transport, and therefore their members opt for public transport more often.

Overall, changes in household structures in Iranian society have affected the travel patterns of older adults in recent decades. Most often living alone, the elderly are left to fend for themselves. While before family members would take care of their needs, now older adults need to travel in order to buy food or visit the doctor. Moreover, due to worsening economic conditions among middle- and low-income strata, older adults are remaining in paid employment for much longer than before, which has also resulted in higher mobility. Employment, which implies higher incomes, increases the likelihood of using a car, whereas retirement leads to more frequent public transit use. This is evident in developed counties too, including the Netherlands (van den Berg et al., 2011) and Japan (Hjorthol et al., 2010).

Similarly, higher property prices in a zone – also a proxy for higher incomes – increase the likelihood of using a car among the elderly. Studies based in Australia and the US have discovered a similar relationship (Alsnih and Hensher, 2003; Kim and Ulfarsson, 2004).

These findings have policy implications. For example, concessionary tickets and fare subsidies for the elderly could be varied by residential zone, not only by age or income. A strong spatial justice argument can be advanced here. From a sustainability standpoint, public transportation and non-motorized modes should be promoted irrespective of income. However, the poor and elderly portions of the population - which is Shiraz are concentrated in the southern and eastern parts of the city - deserve special care and extra subsidies. On the other hand, means testing is generally based on income, and policy makers need to take into consideration the cost of administering complex structures for public transport operators.

The study shows that the higher the share of compulsory trips, the lower the likelihood of using a car. For compulsory trips with a fixed destination and schedule, people tend to select public transit, which typically operates along trunk routes and links major destinations such as workplaces, university campuses, and hospitals. By contrast, cars are preferred for arbitrary trips which are poorly related to transit operations (e.g., involve trip chaining, have flexible or late schedules, link isolated destinations). As people age, and especially after retirement, compulsory trips are replaced by arbitrary trips (Yang et al., 2013). Meanwhile, as noted, the ability to drive declines with age as well. This finding has important policy implications.

Clearly, older adults living in the northern section of the metropolitan area are more likely to own a car and possess a driver's license. Here land prices and employment levels are higher while household sizes are smaller, suggesting a stronger purchasing power among elderly residents in these zones. At the same time, the number of compulsory trips (likely for medical visits rather than work) is higher for older adults living towards the south, indicating a mismatch between travel needs and private transport access.

As for built environment features, the most important predictor of car use by older adults (either as driver or passenger) is the land-use mix within each TAZ. More mixed land-use leads to less driving, more walking, and higher public transit use. A mix of land-uses at neighborhood level is crucial to allow the elderly to reach as least some non-work-related activities on foot. The literature confirms that walking and public transportation ridership among older adults is positively correlated to mixed land-use, and supportive land-uses are more important than income in shifting people away from cars (Hu et al., 2016; Kim and Ulfarsson, 2004; Winters et al., 2015). Surprisingly, built environment features such as population density and road network design characteristics are not statistically significant in Shiraz. Their importance pales in comparison to the socio-economic factors discussed above. By contrast, in the literature (see, for example, Walford et al., 2017) population density and road network design are highlighted as important predictors of car use by older adults.

6. Conclusion

By Global South city standards, car use is high in Shiraz - among the adult population in general and seniors in particular. However, car dependency is high in other major Iranian cities too, such as Tehran (Soltani, 2017a). To reveal the key determinants of car use among the elderly, this study employed global (OLS) and local (GWR) regression models. Seven variables were examined: (i) older adults possessing a driver's license; (ii) average household size for households with older adults; (iii) car ownership for households with older adults; (iv) number of compulsory trips (for work, medical visits, and education) taken by older adults; (v) employed older adults; (vi) average property prices; and (vii) land-use mix entropy. All these variables were statistically significant both at the global and the local levels (with parameters varying across city zones). Clearly, and as postulated in the theory, both socio-demographic and built environment factors have an effect on car use among older adults in Shiraz.

Car dependency is significant and more pronounced among wealthier individuals – who tend to be clustered in the northern section of Shiraz. Some level of spatial mismatch between travel needs (e.g., for medical visits) and car access is observed in the southern section of the city. A mix of land-uses tends to attenuate car dependency. The findings are mostly aligned with the literature, with the exception of gender gaps which are much wider than in the West, and built environment factors such as population density and road network design characteristics which do not affect car use among older adults in Shiraz.

The policy recommendations are rather obvious and echo the recommendations of many prior studies: diversify land-use, strengthen public transportation access, and improve walking conditions - especially in impoverished areas and for disadvantaged groups such as elderly women. A move away from the current car-centric urban development model, with sprawling and segregated land-uses, will be necessary to assist older adults in remaining active and independent as late in life as possible – beyond their driving years. Designing age-friendly communities will likely be beneficial to the general population as well.

In terms of further research, OLS and GWR models, such as those employed in this study, are simple but powerful methods to identify and measure the predictors of car use among older adults. In the future, these methods can be used to generate forecasts, as well as to simulate scenarios. Future studies can modify the models by increasing the number of explanatory variables and filtering them. Including health characteristics of older adults and transport system characteristics (e.g., routes, frequencies, stops, and the like) may improve the overall goodness of fit of the models. Qualitative interviews and observations would be desirable too, which capture in more detail the needs and wants or older people with regard to urban mobility.

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