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Research Paper

Investigating the Impact of Accessibility on Land Use and Its Role in Environmental Pollution in Tehran

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Abstract

Transportation and land use are the two major sectors that contribute the most to the spread of environmental pollution. Transportation through accessbility affects land use while land use through the production and attraction of trip affects transportation. The purpose of this study is to investigate the accessibility of 22 districts of Tehran metropolis, how the city develops and their impact on increasing air pollution. This is an applied research where the data and information used in this research were obtained from Tehran Municipality and Statistics Center of Iran and for their classification and analysis, depending on the need, SPSS, Arc GIS and Google Earth software have been used. The results of Pearson correlation show that about 24% of land uses in Tehran have a significant relationship, which indicates a high separation between types of land uses and ultimately the scattered growth of Tehran. By analyzing and calculating the accessbilities, it was found that 38% of the internal communications between the districts are at the level of good and very good accessbility, 32% have the average level of accessbility and 30% are at the level of poor and very poor. The average route factor of Tehran is estimated to be 1.52, which indicates that Tehran is classfied in the average level of accessbility. Another finding of this study is the effect of land uses and accessbility levels on increasing air pollution in Tehran which is important to urban planners and policy makers.

Keyword: Land use, Transportation, Air pollution, Tehran metropolis

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1. Introduction

The trend of global transportation activities in the last forty years indicates an increase in the level of dependence on cars and changes in social lifestyles, which in turn has led to an increase in sensitivity to environmental effects and its reflections in the field of health (Hine, 2000). Air pollution in Tehran is one of the major challenges of Tehran's urban management. International experience shows that there is a broad consensus among planners and policy makers that achieving CO2 emissions reduction is possible through integrated transportation and land use planning wherein accessibility is closely related with health and quality of human life (Broaddus, 2020).

According to the Tehran Air Quality Control Company, in the first nine months of 2020, the metropolis of Tehran had only 15 days of clean air, and the rest of the days were 185 days of acceptable or healthy air and 70 days of unhealthy air for sensitive groups and 2 unhealthy days have been recorded for all groups. The approval of the Clean Air Law by the Islamic Consultative Assembly in August 2017 and the approvals of the National Working Group for Reducing Air Pollution in Metropolises, as well as the more serious plan to control air pollution by requiring vehicles to undergo technical inspections and a stricter approach on technical inspection centers and approving vehicle health certificates and also, the publication of the annual report of Tehran Air Quality Control Company, all together indicate the importance and special place of reducing air pollution in the metropolis of Tehran (AirQualityControlCompany, 2020).

Urban land use is one of the important factors of the city system that is in direct and inverse relationship with the transportation system through communication networks and traffic flows. Therefore, transportation and land use are the two main sectors that have the largest share in CO2 emissions in the environment. Reducing CO2 emissions from the transportation sector has been identified as a major challenge (Chapman, 2007) (Hickman, Ashiru, & Banister, 2010).

In the scientific and professional community, the need to integrate transportation and land use policies in order to achieve sustainable urban development is widely recognized. Accessibility can provide a conceptual focus for this integration because it relates to both the features of the transport system as well as the land use system (Straatemeier & Bertolini, 2020).

Today, transportation is recognized as one of the biggest infrastructural challenges facing metropolitan districts. In other words, if metropolises are the engine of the global economy, it is the transportation network that keeps these engines efficient. In contrast, the inefficiency of the urban transportation system will lead to serious environmental effects such as air pollution and negative social and economic consequences and cause the inefficiency of the city's performance (Hutchison, 2010).

Transportation is one of the most important human achievements. People can walk the path that used to take weeks, within hours, and change our opportunities and our view of the world around us. The development of personal transportation - which allows anyone to travel freely whenever and wherever they want - has changed our experience. However, unfortunately, transportation advances have led to environmental problems (Thakur, Dutt, Thakur, & Pomeroy, 2020). Transportation is one of the main parts of shaping urban geography and promoting economic development. Further mobility paves the way for more spatial flexibility and a more active economy by increasing accessibility and networking opportunities (Sarı, Özdemir, & Uzun, 2019).

Prior to widespread industrial development and modernization, people's workplaces and living quarters were close together, and people were less likely to travel by car to meet their basic needs, and most cities were concentrated. However, with the specialization of occupations, diversity in land use and spatial distribution of activities, in addition to increasing the volume of daily trips, caused people today to have to travel long distances to meet their basic needs, especially personal cars to reach travel destinations (Ghadami, Divsalar, Ranjbar, & Asad, 2013). Accessibility varies between assessment methods, including measured displacements and proximity to the origin and destination of travel, on the one hand, and on household economics and land use, on the other hand (Levine, 2020).

Sprawl creates land use patterns with less accessibility, which increases the amount of space required for a given accessibility level and reduces transportation options. Low-density suburban households spend approximately more hours using vehicles than similar households in urban areas, which increases traffic congestion, accidents, higher fuel consumption, and exacerbates air pollution (Litman, 2016).

Today, urban planners face a difficult dilemma that needs to be addressed: how to cope with the fundamental role of transportation in increasing the well-being and health of cities and, on the other hand, in creating its adverse environmental effects on nature and society? In this study, the city of Tehran, as one of the main attractions of the population, has experienced rapid growth in recent years. This article emphasizes on the structure of urban growth, the pattern of urban development, the role of land uses, the study of accessibility and the factors affecting pollution in the metropolis of Tehran. The main problem of Tehran is air pollution caused by motor vehicles, among which the impact of private cars is significant. On the other hand, most of the area of Tehran is located in the suburbs. People living on the outskirts of the city have to drive more than people living close to the city center because they have to travel longer distances to meet the needs of the city center. Therefore, first the density of urban areas was investigated, then the mixing of land uses was done by calculating the correlation between them. Low correlation between land uses indicates the dispersion of the city. This has led to more people using private cars than other modes (public transportation, cycling and walking) to access different travel destinations. Existence of mazes, mountainous areas and dead-end roads in the areas of Tehran lead to low access. This means that by using the car, more distance and time than the ideal state (straight line between origin and destination) should be traveled, which leads to more fuel consumption, and this process has intensified environmental pollution in the metropolis of Tehran.

2. Research Goals and Questions

The motivation of this article is to try to analyze the growth structure of Tehran, to study the development model of Tehran, the role of land uses and the importance of accessibility to the 22 districts of Tehran. This research intends to deal with air pollution in Tehran, which is caused by various factors, such as land use and transportation, and which have received less attention in studies. This research seeks to answer these questions:

- What is the effect of population and density of metropolitan areas of Tehran and how they affect transportation and pollutants?
- Determining the accessibility of the 22 districts of Tehran and analyzing the suburb and central districts based on their level of accessibility?

3. Research Background and Theoretical Foundations

The first generation of land transportation and land use interconnection (LUTI) models was developed in North America in the 1950s. Lee was one of the first to discuss LUTI from an operational planning perspective (Lee, 1994). Transportation can affect the distribution, characteristics and growth of different land uses, as it improves the access conditions of different places in the urban space. Land use also affects transportation through production and travel attraction. Therefore, changes in the transportation system can affect the land use system and vice versa, as long as a balance is struck between the two (Wegener & Fürst, 1999) (Levinson & Krizek, 2007) (Bertolini, 2017).

To evaluate urban operations, the processes of urban change must be identified. According to Wegener's research in 2004, the city is divided into eight main subsystems, based on their speed of change, from slow to fast processes according to Table 1 (Wegener, 2004).

According to the table, land use changes are very slow, population changes are fast, and transportation changes are immediate.

Traveling between two regions in a transportation network depends on three basic elements: 1.The potential of the region of origin to generate the journey: This variable depends more on the number of inhabitants of the region, the movement of people and their standard of living and other factors. 2. The capacity of the region of destination to attract a trip: This attraction depends on the population, number of commercial places, number of jobs and other facilities offered in the destination area.

3.The difficulty in travelling between the regions of origin and destination: In order for this to affect travel, the impact of this cost must be less than the power of attraction of destination (El-Geneidy & Levinson, 2006).

Whereas transportation through accessibility affects land use. Therefore, calculating accessibility as a link between land use and transportation is essential. Accessibility can be defined as a measure of the capacity to communicate between human activities or settlements using a designated transportation system. The most common units of measurement are distance or time access (Batty, 2009a). The interrelationship between transportation and land use can be used to support strategic planning by examining land use patterns through a combination of mobility features, socio-demographic characteristics, geomorphology and broader environmental factors and the accessibility of urban networks (Pozoukidou, 2010).

Table 1. Urban change processes

Urban Change Processes							
Immediate		Fast		Slow		Very slow	
Travel	Goods transport	Population	Employment	Housing	Work places	Land use	Networks

One of the purposes of studying the relationship between land use and transportation is to study the theory of urban systems as well as urban planning and policy design. The second area is rarely the main purpose of articles, and we still have a research gap on this (Batty, 2009b) (Timmermans & Arentze, 2011) . Dilman et al. (2002) showed that there is a strong correlation between car dependence and gasoline consumption, and concluded that the compact urban form reduces vehicle dependence in the Netherlands (Dieleman, Dijst, & Burghouwt, 2002). Urban dispersion and land use change affect air quality, pollutant emissions and CO_2 emissions (Marshall, 2008) (Stone Jr, 2008)

(Liao, Chang, Su, & Chiueh, 2013). In 2014, Kashem et al. used transportation dynamics and environmental impacts for 60 US regions using data from 7 years (2000-2007). They assessed urban sprawl using indicators of density, land use mix, centrality, and street connectivity. They showed that people living in cities with stronger centers use less private cars and, over time, use more public transportation. Also, denser cities have a significant reduction in pollutant concentrations (Kashem, Irawan, & Wilson, 2014).

Silva et al. In 2015, after reviewing about 60 years of various researches in the field of LUTI (Land Use Transportation Interaction), found that in some fields we have a research gap in the interaction between land use and transportation. These include measuring accessibility and surveying the environment in the relationship between land use and transportation (Acheampong & Silva, 2015).

In 2016, Lu et al. examined the impact of urban shape on air quality in China. A geo-weight regression model has been used to determine the relationship between urban shape indices and pollution. The results show that urban shape has a significant impact on air quality in China (Lu & Liu, 2016). In 2016, Sajjadi et al. studied the sustainability of Isfahan. Using SPSS software, the analysis of city sustainability indicators was performed. The results show the downward trend of sustainable transportation in Isfahan (Sajjadi & Taqvaee, 2016). Shurcheh et al. in 2016 referred to the study of growth management policies in the comprehensive plan of Tehran, increasing the dispersion of the city of Tehran and dependence on cars, as well as increasing problems such as traffic and parking congestion (Shoorcheh, Varesi, Mohammadi, & Litman, 2016).

Urban development, both in land use and in transportation, instead of spontaneous development without prior planning, must be planned and managed, and the integration of land use and transportation in urban planning and management is essential (Tian, Ge, & Li, 2017). Accessibility, instead of focusing on movement, may bring the product closer to the consumer. Accessibility investments include zoning of land uses, delivery services, and high-speed internet services that reduce the need for transportation (Tumlin, 2012).

Azmoudeh et al in 2017, assessed land uses with regard to accessibility to transportation in District 6 of Tehran. After illustrating the parameters related to access, using GIS and using multi-criteria decision making methods to weight the parameters, the value of the blocks in the area was evaluated based on the access parameter and finally determined that among the studied parameters affecting access, the parameter of distance from public transportation "has the greatest impact on assessing the level of accessibility to districts" (Azmoudeh, Mohammad, Haghighi, & Reza, 2017). Gholami et al. in 2019 assessed the effects of city land use in creating traffic volume in the city of Kashan. The main data collection tool was interviews with experts and classified land use information from the municipality (Gholami, Younes, & Hosseyini, 2019).

In 2018, Nikpour et al. analyzed the relationship between city form and Babolsar city access index. Three indicators of density, connection and mixing were used to measure the shape of the city. The Hansen equation was used to calculate the access index. The results obtained from Pearson correlation test show a direct and significant relationship between the intensive form of Babolsar city and access (Nikpour, Amer, Lotfi, & Rezazadeh, 2018).

In 2020, Abbasi et al. examined integrated modeling of transportation and land use in Shiraz. In this research, travel approaches are illustrated in two forms: travel-based approach and activity-based approach. Finally, using urbanism software, it was found that accessibility and area have a direct impact on the price of housing units, choice of residence and employment (Shahabian & Abbasi, 2020).

In 2020, Moshfeghi et al. discussed land use and the efficiency of transportation laws due to air pollution in the metropolitan area of Tehran. In this study, the rules and regulations related to air pollution in the field of land use and transportation have been considered. Organizational perspectives, lack of regulatory mechanisms and issues related to the implementation of laws and regulations related to air quality control policies are among the most important problems in the implementation of poor policies and regulations (Moshfeghi, Haghighat Naeini, & Habibi, 2020).

In 2021, Novakovska et al. discussed the principles of optimal land use in Ukraine's car transport. To reduce the impact of transportation on the environment, through the use of alternative fuels, they considered the renewal and expansion of electric transportation facilities and the use of energy-saving technologies (Novakovska, Zholkevskyi, Stetsiuk, & Ishchenko, 2021).

In 2017, Vulevic et al. examined accessibility to central and peripheral areas of Serbia. They found that accessibility is strongly related to the dynamic demographic pattern in the regions. They compared the regions based on demographic information (population) and the length of the road network, using the network density accessibility index. Finally, accessibility was identified as a key factor for regional success (Vulević & Knežević, 2017).

In 2021, Plasencia-Lozano analyzed the transport network of the Stramadora region of Spain using the accessibility index. In this study, the route factor as well as the transport network density index were used to assess accessibility and it was found that the development of economic activities is increasingly related to the existence of a suitable communication network (Plasencia-Lozano, 2021).

Providing safe and efficient transportation today is one of the most important issues facing most developed and developing countries. As mentioned, in addition to transportation, land use in cities is also important. To examine the relationship between land use and transportation, having a look at successful cities in this field, we can mention the cities of Stockholm in Sweden, Portland in the United States, Copenhagen in Denmark, Toronto in Canada and Hong Kong in China (Boshielo, 2018). In 1960, the urban population was 34% of the total world population, while in 2018 this population increase reached 55%. This is expected to increase to 68% by 2050, with nearly 90% of this increase occurring in Asia and Africa (UnitedNations, 2018). The economic cost of air pollution in 2018 is estimated at $ 900 billion for China alone and $ 600 billion for the United States (WorldEconomicForum, 2020).

Today, the issue of environment in most major cities of Iran, especially in the metropolis of Tehran, which in recent years has faced population growth, urbanization, industrial development and increasing fuel consumption, is a major challenge. Therefore, dealing with transportation planning and land use is one of the basic issues for urban management.

4. Research Method

4.1. Materials and Methods

In this study, we used Google Earth Pro software to route between urban districts and estimate the actual and ideal distance. To draw tables, charts and sort data from Excel, SPSS 24 has been used for statistical

Analysis of various land uses of districts, to study how the development of Tehran metropolis and its impact on air pollution.

Also, Arc GIS 10.8 has been used to prepare the map of the study area, analysis of Tehran city layers and graphic output.

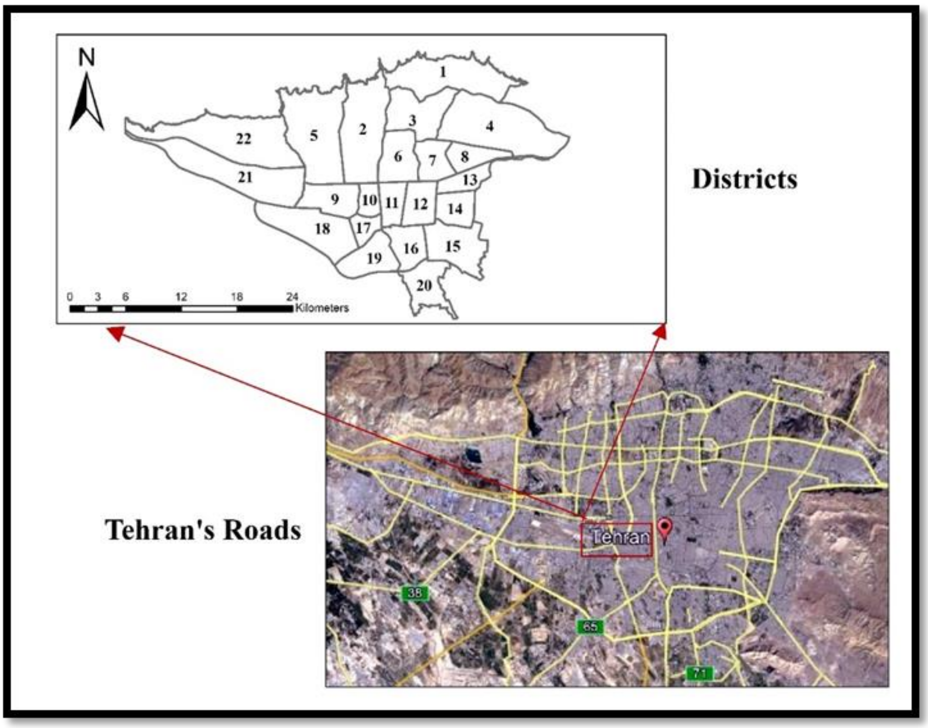

Figure 1. Location of the study area

4.2. Study Area

This study encompasses the districts of the metropolis of Tehran, as shown in Figure 1. Tehran, as the capital of Iran, has a population of about 8.7 million people according to the 2016 population and housing census of the Statistics Center of Iran. In addition to being the most populous city in the country, this city is also the most densely populated center in the country. Due to the special geographical situation, it has infrastructural and environmental problems such as being in the vicinity of the largest centers of earthquakes, traffic and air pollution. For the welfare and increase of the quality of life of the citizens, it requires the cooperation of all sectors and departments of government.

4.3. Accessibility Indicators

Different formulas and relationships can be used to calculate accessibility depending on the available information. In this study, the following relationships to estimate accessibility are presented (Cordera, Ibeas, dell'Olio, & Alonso, 2017) (Vulević & Knežević, 2017) (Plasencia-Lozano, 2021):

- Transport network density index

$$D = \frac{Network\ Kilometers}{Surface\ of\ the\ study\ area(km^2)} \quad (1)$$

This accessibility index reflects the density of communication infrastructure within an area and determines the relationship between the dimensions of the network and the dimensions of the land being serviced. Using it, the cohesion of the district can be evaluated in comparison with other districts. Developed districts usually have the densest network of roads. This index can be calculated and expressed in terms (km / km2) as well as (km/1000 inhabitants).

- Route factor

This index reports the efficiency of the transportation network. If there are two or more possible routes, the shortest route is selected. If it is a path, the same path is selected. The route factor determines the relationship between both actual and ideal distances:

$$r_{ij} = \frac{d_{ij}}{dg_{ij}} \quad (2)$$

rij: Rout factor between points i and j

dij: Minimum distance(actual operating distance) using the transport network between i and j

dgij : The physical distance in a straight line (ideal distance) from i to j.

- Integral route factor

The connection of node i with all other nodes in the district determines where n is the total number of nodes (districts):

$$R_i = \frac{1}{n-1}\sum^{n} \frac{d_{ij}}{dg_{ij}} \quad (3)$$

5. Analysis

5.1. Demographic Information

According to the data of the Statistics Center of Iran, the population of Tehran from 1996 to 2016 is shown in Figure 2. The city of Tehran in a period of 20 years, shows about 33% population growth.

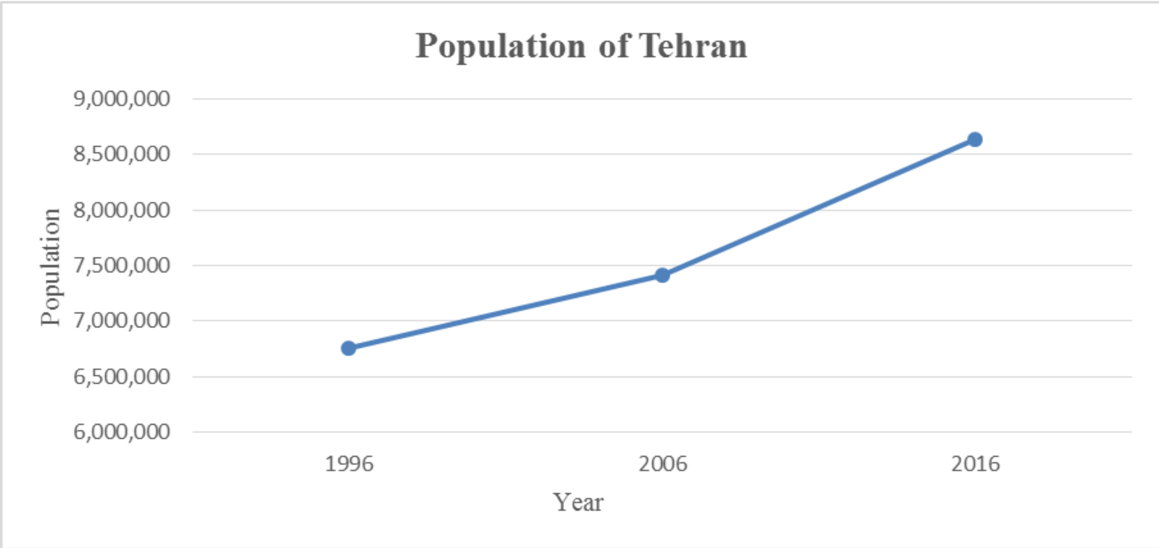

Figure 2. Population growth in Tehran in 1996-2016 (Source: Statistics Center of Iran)

According to the 2016 census, the most populous districts of Tehran (Population according to Table 3) are districts 4, 5 and 2, respectively, and the lowest population is related to districts 9, 22 and 21 (Figure 3).

One of the factors that affects travel demand is density. This factor affects the travel pattern and the length of the trip, so that with increasing density, the length of trips becomes shorter and the use of private vehicles decreases and the use of public vehicles increases. In terms of population density comparison, the highest density is related to districts 10, 14 and 17 and the lowest population density is related to districts 21, 22 and 9 (Figure 4).

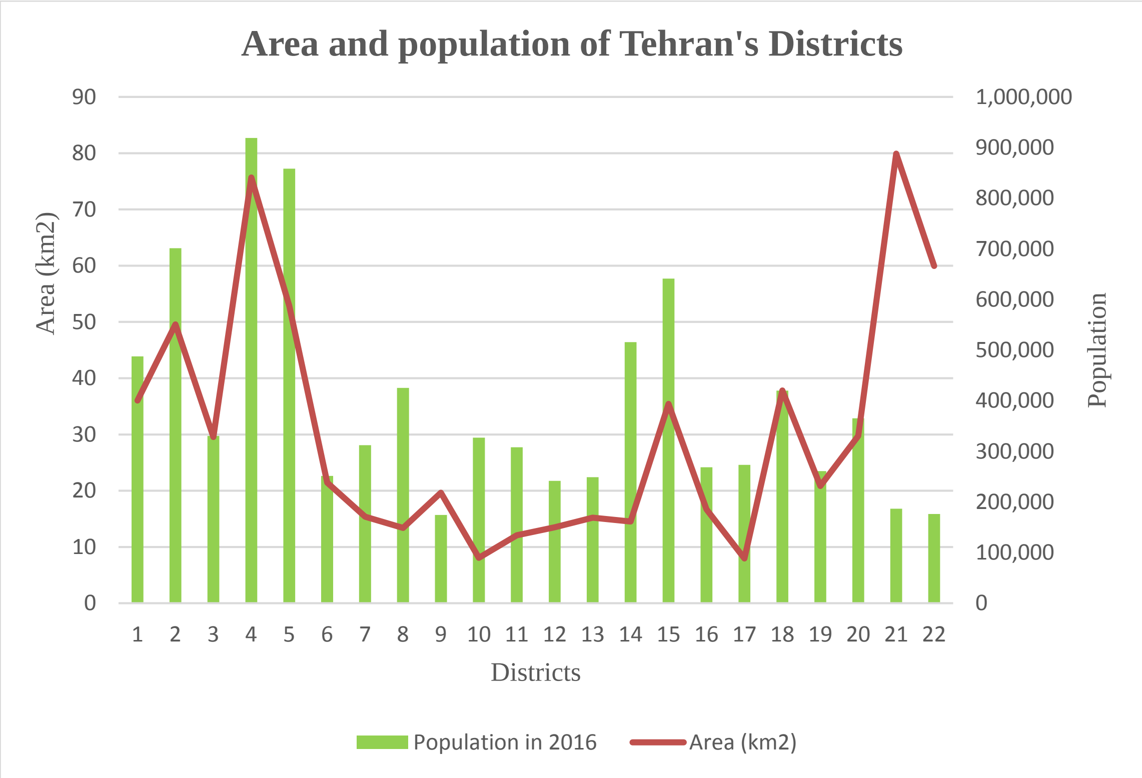

Figure 3. Population and area of Tehran's Districts in 2016

(Population and area according to Table 3)

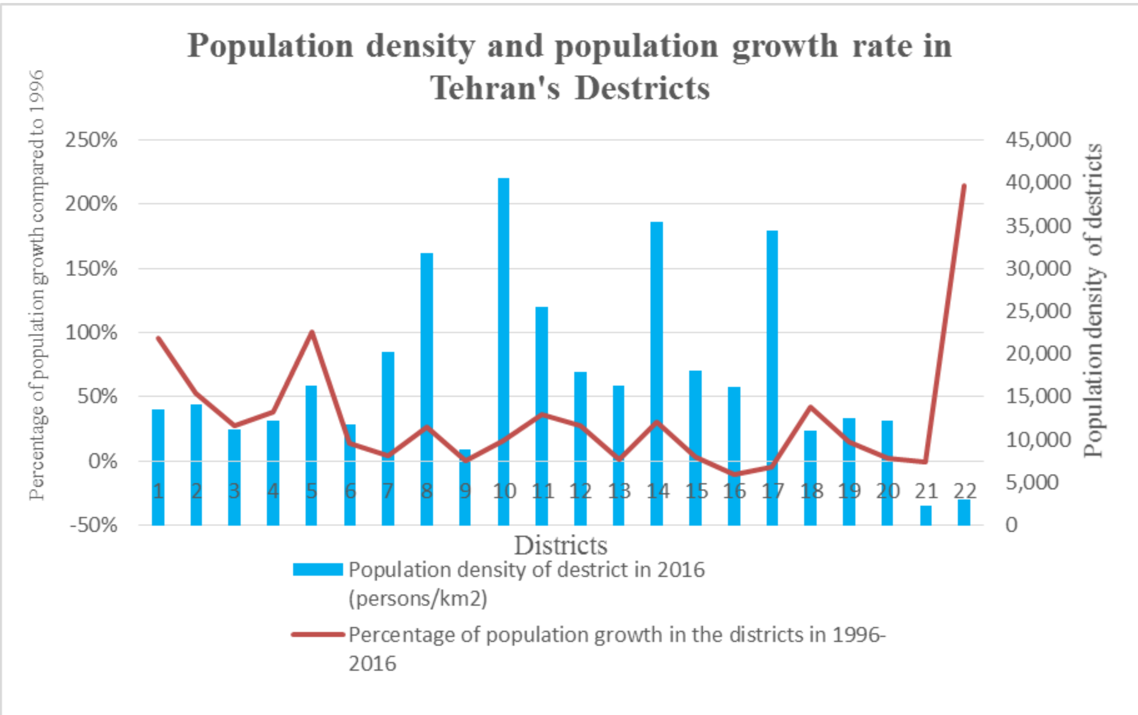

Figure 4. Population density of Tehran’s districts in 2016 and population growth percentage

(Population and area according to Table 3)

5.2. Land Use

In this study, the major uses of residential, commercial, office, educational, higher education, medical, military, industrial, green space, recreational, unbuilt and barren and road network were analyzed by SPSS 24 software. Pearson correlation coefficient was used as an indicator to study user mixing. The results are given in Table 2. Findings indicate that among the selected uses, only about 24% of the uses in Tehran have a significant relationship, among which 14% have a strong relationship (red) and the rest have a weak relationship (yellow). This indicates a low mix of uses or in other words a high separation between different types of uses. This situation indicates the scattered growth of Tehran.

This pattern of development has led to suburban growth and Greenfield urban development, with more emphasis on private areas such as low-rise buildings with large courtyards, long distances between origin and destination, and greater use of private cars by individuals. Because those who live in the suburbs are away from the shopping, education and work centers that existed in the city center. Therefore, in order to move between origin and destination, people are forced to use their personal vehicle to access different uses. Finally, by increasing the volume of private cars, it will cause traffic congestion, increase fuel consumption and intensify the spread of air pollution in the metropolis of Tehran.

Table 2. Correlation between types of land uses in Tehran's districts

Land uses in 22 districts of Tehran		Residential	Commercial	Ministerial	Educational	Higher_education	Therapeutic	Military	Industrial	Greenland	Recreational	Unbuilt_barren	Network_of_roads
Residential	Pearson Correlation	1	-0.064	.493*	.697**	0.191	0.334	0.246	-0.132	.447*	.504*	0.226	.819**
	Sig. (2-tailed)		0.779	0.020	0.000	0.434	0.129	0.270	0.559	0.037	0.017	0.324	0.000
	N	22	22	22	22	22	22	22	22	22	22	22	22
Commercial	Pearson Correlation	-0.064	1	0.383	0.060	-0.265	-0.139	-0.259	-0.103	-0.134	-0.168	-0.191	-0.014
	Sig. (2-tailed)	0.779		0.079	0.792	0.274	0.537	0.245	0.650	0.553	0.455	0.406	0.950
	N	22	22	22	22	22	22	22	22	22	22	22	22
Ministerial	Pearson Correlation	.493*	0.383	1	0.274	0.206	.542**	-0.020	-0.240	0.130	0.168	-0.083	0.230
	Sig. (2-tailed)	0.020	0.079		0.218	0.397	0.009	0.931	0.282	0.566	0.454	0.721	0.303
	N	22	22	22	22	22	22	22	22	22	22	22	22
Educational	Pearson Correlation	.697**	0.060	0.274	1	-0.097	0.207	0.031	0.047	0.273	.466*	0.080	.729**
	Sig. (2-tailed)	0.000	0.792	0.218		0.694	0.355	0.891	0.834	0.219	0.029	0.731	0.000
	N	22	22	22	22	22	22	22	22	22	22	22	22
Higher_education	Pearson Correlation	0.191	-0.265	0.206	-0.097	1	0.279	.479*	-0.055	.707**	0.144	.708**	0.112
	Sig. (2-tailed)	0.434	0.274	0.397	0.694		0.248	0.038	0.823	0.001	0.556	0.001	0.647
	N	22	22	22	22	22	22	22	22	22	22	22	22
Therapeutic	Pearson Correlation	0.334	-0.139	.542**	0.207	0.279	1	0.099	0.139	-0.081	0.217	-0.097	0.271
	Sig. (2-tailed)	0.129	0.537	0.009	0.355	0.248		0.661	0.538	0.721	0.332	0.675	0.222
	N	22	22	22	22	22	22	22	22	22	22	22	22
Military	Pearson Correlation	0.246	-0.259	-0.020	0.031	.479*	0.099	1	.664**	.720**	-0.065	.450*	0.412
	Sig. (2-tailed)	0.270	0.245	0.931	0.891	0.038	0.661		0.001	0.000	0.774	0.040	0.056
	N	22	22	22	22	22	22	22	22	22	22	22	22
Industrial	Pearson Correlation	-0.132	-0.103	-0.240	0.047	-0.055	0.139	.664**	1	0.150	-0.139	0.061	0.286
	Sig. (2-tailed)	0.559	0.650	0.282	0.834	0.823	0.538	0.001		0.504	0.537	0.794	0.197
	N	22	22	22	22	22	22	22	22	22	22	22	22
Greenland	Pearson Correlation	.447*	-0.134	0.130	0.273	.707**	-0.081	.720**	0.150	1	0.021	.755**	.454*
	Sig. (2-tailed)	0.037	0.553	0.566	0.219	0.001	0.721	0.000	0.504		0.927	0.000	0.034
	N	22	22	22	22	22	22	22	22	22	22	22	22
Recreational	Pearson Correlation	.504*	-0.168	0.168	.466*	0.144	0.217	-0.065	-0.139	0.021	1	0.217	0.335
	Sig. (2-tailed)	0.017	0.455	0.454	0.029	0.556	0.332	0.774	0.537	0.927		0.344	0.128
	N	22	22	22	22	22	22	22	22	22	22	22	22
Unbuilt_barren	Pearson Correlation	0.226	-0.191	-0.083	0.080	.708**	-0.097	.450*	0.061	.755**	0.217	1	0.314
	Sig. (2-tailed)	0.324	0.406	0.721	0.731	0.001	0.675	0.040	0.794	0.000	0.344		0.166
	N	22	22	22	22	22	22	22	22	22	22	22	22
Network_of_roads	Pearson Correlation	.819**	-0.014	0.230	.729**	0.112	0.271	0.412	0.286	.454*	0.335	0.314	1
	Sig. (2-tailed)	0.000	0.950	0.303	0.000	0.647	0.222	0.056	0.197	0.034	0.128	0.166	
	N	22	22	22	22	22	22	22	22	22	22	22	22

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

5.3. Transportation

In urban districts, most goods produced are transported to markets using the road as a means of transportation to markets, so the development of economic activity is increasingly linked to a proper communication network. By calculating accessibility, it is possible to identify inequalities between the development levels of different districts and the lack of development of less popular districts, and to plan to improve them. A street network is an interconnected system of lines and points that represents a system of streets or roads for a given area. A street network is an interconnected system of lines and points that represents a system of streets or roads for a given district. A street network provides the basis for network analysis (for example, finding the best route).

According to Equation 1, road accessibility can be calculated in two ways: individuals' accessibility to road transport and measuring the density of the road network. After calculating the results for each district, it is given in Table 3.

Table 3. Network density index

Districts	Street network (km)*	Area of districts (km^2)	Population of districts **	Network density index (km/km^2)	Network density index (km/1000 inhabitants)
1	220	36.04	487,508	6.10	0.45
2	279	49.56	701,303	5.63	0.40
3	190	29.53	330,649	6.43	0.57
4	346	75.68	919,001	4.57	0.38
5	233	52.87	858,346	4.41	0.27
6	167	21.44	251,384	7.79	0.66
7	110	15.37	312,194	7.16	0.35
8	94	13.39	425,197	7.02	0.22
9	75	19.66	174,239	3.81	0.43
10	70	8.07	327,115	8.67	0.21
11	101	12.06	307,940	8.37	0.33
12	106	13.50	241,831	7.85	0.44
13	90	15.22	248,952	5.91	0.36
14	115	14.53	515,795	7.91	0.22
15	184	35.44	641,279	5.19	0.29
16	104	16.68	268,406	6.24	0.39
17	77	7.94	273,231	9.70	0.28
18	166	37.83	419,882	4.39	0.40
19	114	20.84	261,027	5.47	0.44
20	129	29.74	365,259	4.34	0.35
21	241	79.92	186,821	3.02	1.29
22	245	59.97	176,347	4.09	1.39

Source: * Tehran Municipality Spatial Information (year 2019) ** Statistics Center Yearbook (year 2016)

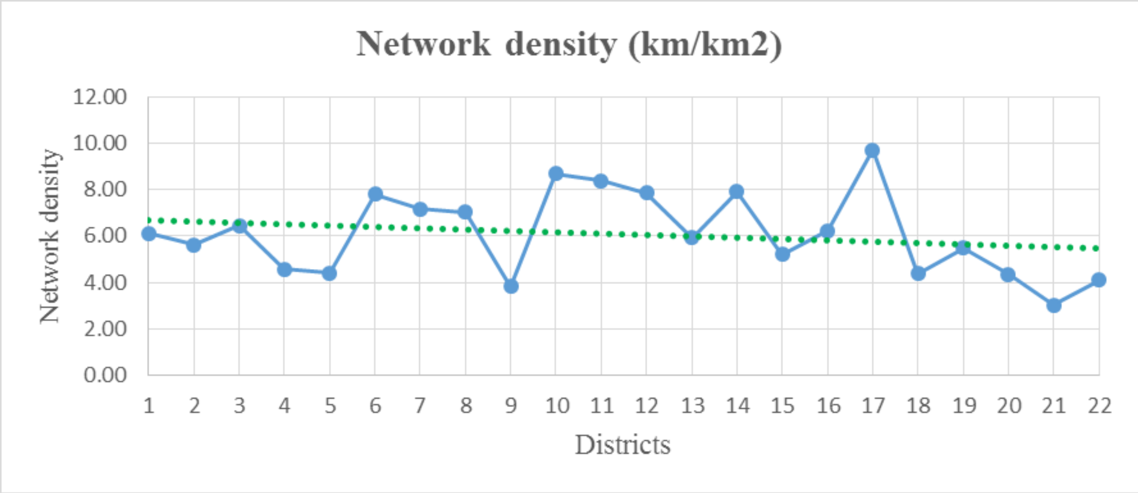

Figure 5. Network density index by population

According to Table 3, the network density index per kilometer per square kilometer of the network, which is a way to know the importance of network length in relation to a space with a specific range, its maximum value is for district 17 and then districts 10 and 11. Also, the lowest density index is related to district 21 and then districts 9 and 22. By drawing a trend line (green) as shown in Figure 5, it is possible to understand the approximate configuration of the road network in the district, in order to determine the imbalances and shortcomings in terms of communication in some districts.

If we examine the relationship between network densities per kilometer per thousand Inhabitants, the highest value of the density index is related to district 22 and then 21 and 6. The lowest value of the density index is district 10 with the value of 0.21 and then 8 and 14 with equal values of 0.22. The results of the network density index per population are shown in Figure 6.

Using Equation 2, the access between the districts is examined using the route factor, which indicates the quality of the infrastructure between the districts. The ideal operating distance data between districts is routed through Google Earth Pro software and the results after the calculations are given in Table 4.

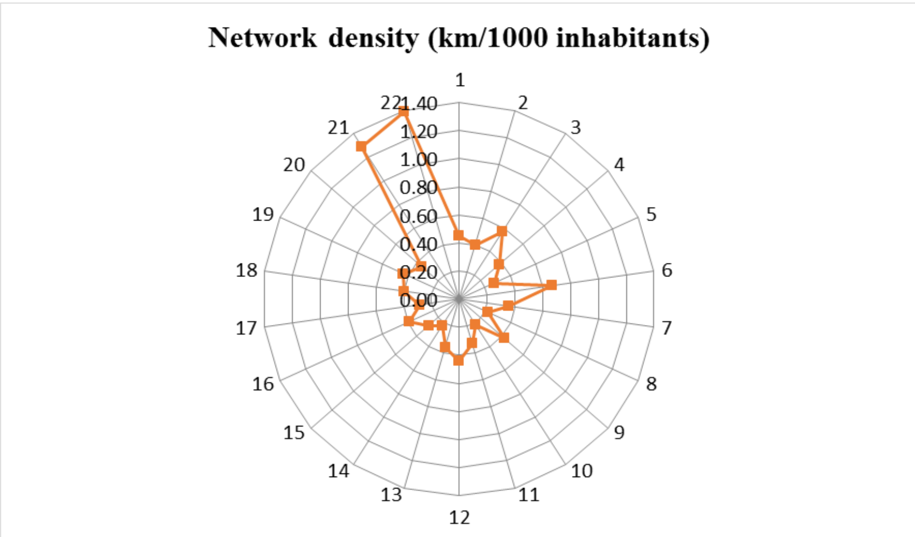

Figure 6. Network density index by population

Table 4. Route factor

Districts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	_	1.37	1.3	1.67	1.32	1.34	1.44	1.54	1.43	1.32	1.37	1.29	1.35	1.62	1.33	1.3	1.39	1.4	1.32	1.4	1.49	1.22
2		_	1.67	1.29	1.18	2.15	1.74	1.5	1.81	1.47	1.69	1.95	1.46	1.85	1.7	1.53	1.43	1.39	1.53	1.6	1.88	1.24
3			_	1.41	1.35	1.62	1.39	1.61	1.53	1.41	1.42	1.3	1.52	1.71	1.35	1.22	1.35	1.38	1.36	1.48	1.56	1.20
4				_	1.16	1.44	1.37	1.48	1.44	1.31	1.32	1.24	1.31	1.22	1.32	1.43	1.56	1.59	1.39	1.47	1.42	1.17
5					_	1.54	1.39	1.33	2.27	1.62	1.63	1.76	1.38	1.64	1.58	1.53	1.64	1.77	1.65	1.56	2.4	1.36
6						_	1.36	1.27	1.81	1.68	1.37	1.79	1.28	1.64	1.44	1.33	1.36	1.62	1.39	1.33	1.69	1.33
7							_	1.49	1.87	1.35	1.52	1.58	1.46	1.83	1.5	1.37	1.31	2.15	2.01	1.26	1.39	1.28
8								_	1.31	1.23	1.38	1.48	1.48	1.29	1.42	1.71	1.83	1.69	1.61	1.52	1.52	1.17
9									_	2.36	2.01	1.82	1.47	1.59	1.66	1.69	1.94	1.71	1.93	1.55	1.3	1.77
10										_	1.36	1.77	1.2	1.31	1.34	1.51	1.52	1.26	1.73	1.5	1.68	1.48
11											_	2.19	1.31	1.41	1.74	1.53	1.24	1.19	1.53	1.42	1.48	1.43
12												_	1.66	1.57	1.35	1.62	1.44	1.3	1.59	1.24	1.52	1.50
13													_	1.35	1.67	1.71	1.28	1.71	1.55	1.56	1.26	1.25
14														_	1.65	1.59	1.28	1.67	1.56	1.56	1.55	1.40
15															_	1.58	1.28	1.51	1.51	2.06	1.34	1.40
16																_	1.8	1.67	1.4	1.56	1.83	1.45
17																	_	1.4	1.74	1.63	1.64	1.47
18																		_	1.96	1.45	1.85	1.72
19																			_	1.5	1.84	1.53
20																				_	1.53	1.43
21																					_	2.00
22																						_

The results in Table 5 show five levels of accessibility between districts of Tehran. The lowest value of the route factor (4,5) is 1.16, which means that the distance traveled through the road transport network is 16% longer than the ideal route (straight line). Because the value obtained for the two districts is the lowest value in the table, it indicates the marginality of the two districts and high efficiency. In general, districts with low route factor values are due to the suburban of those districts, which indicate the best communication with other municipal districts and the most efficient road network.

The maximum value of the route factor between districts (4.21) is 2.40, which indicates an exaggerated difference between the road transport network and the ideal route. Despite the proximity of the two districts, the exaggerated index is approximately 2.5 times ideal. This means that the operational route between the two districts has a greater deviation than the ideal. In general, neighboring districts have a high amount of route factor. Because the ideal distance between them is very small compared to the real distance. Districts with average route factor values include the districts between the suburb and the center. The average route factor of Tehran city is 1.52, which indicates the average level of accessibility.

Table 5. Route factor accessibility level analysis

Districts	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	_	1.37	1.30	1.67	1.32	1.34	1.44	1.54	1.43	1.32	1.37	1.29	1.35	1.64	1.33	1.30	1.39	1.40	1.32	1.40	1.49	1.22
2		_	1.67	1.29	1.18	2.15	1.74	1.50	1.81	1.47	1.69	1.95	1.46	1.85	1.70	1.53	1.43	1.39	1.53	1.60	1.88	1.24
3			_	1.41	1.35	1.62	1.39	1.61	1.53	1.41	1.42	1.30	1.52	1.71	1.35	1.22	1.35	1.38	1.36	1.48	1.56	1.20
4				_	1.16	1.44	1.37	1.48	1.44	1.31	1.32	1.24	1.31	1.22	1.32	1.43	1.56	1.59	1.39	1.47	1.42	1.17
5					_	1.54	1.39	1.33	2.27	1.62	1.63	1.76	1.38	1.64	1.58	1.53	1.64	1.77	1.65	1.56	2.40	1.36
6						_	1.36	1.27	1.81	1.68	1.37	1.79	1.28	1.64	1.44	1.33	1.36	1.62	1.39	1.33	1.69	1.33
7							_	1.49	1.87	1.35	1.52	1.58	1.46	1.83	1.50	1.37	1.31	2.15	2.01	1.26	1.39	1.28
8								_	1.31	1.23	1.38	1.48	1.48	1.29	1.42	1.71	1.83	1.69	1.61	1.52	1.52	1.17
9									_	2.36	2.01	1.82	1.47	1.59	1.66	1.69	1.94	1.71	1.93	1.55	1.30	1.77
10										_	1.36	1.77	1.20	1.31	1.34	1.51	1.52	1.26	1.73	1.50	1.68	1.48
11											_	2.19	1.31	1.41	1.74	1.53	1.24	1.19	1.53	1.42	1.48	1.43
12												_	1.66	1.57	1.35	1.62	1.44	1.30	1.59	1.24	1.52	1.50
13													_	1.35	1.67	1.71	1.28	1.71	1.55	1.56	1.26	1.25
14														_	1.65	1.59	1.28	1.67	1.56	1.56	1.55	1.40
15															_	1.58	1.28	1.51	1.51	2.06	1.34	1.40
16																_	1.80	1.67	1.40	1.56	1.83	1.45
17																	_	1.40	1.74	1.63	1.64	1.47
18																		_	1.96	1.45	1.85	1.72
19																			_	1.50	1.84	1.53
20																				_	1.53	1.43
21																					_	2.00
22																						_

(dark green)	Very good accessibility	$1 < r_{ij} \leq 1.20$
(light green)	Good accessibility	$1.20 < r_{ij} \leq 1.40$
(yellow)	Average accessibility	$1.40 < r_{ij} \leq 1.60$
(orange)	Poor accessibility	$1.60 < r_{ij} \leq 1.80$
(red)	Very poor accessibility	$r_{ij} > 1.80$

Table 6. Percentage of accessibility levels of route factor

Accessibility quality	Number	Percent of total
Very good accessibility	7	3%
Good accessibility	80	35%
Average accessibility	74	32%
Poor accessibility	45	19%
Very poor accessibility	25	11%
Total route factors	231	100%

Table 7. Integral route factor

Ri	Districts
1.39	1
1.59	2
1.43	3
1.38	4
1.57	5
1.51	6
1.53	7
1.47	8
1.73	9
1.5	10
1.5	11
1.57	12
1.44	13
1.54	14
1.51	15
1.54	16
1.5	17
1.59	18
1.6	19
1.51	20
1.63	21
1.42	22

According to Table 6, a total of 30% of districts have poor and very poor accessibility levels and only 3% of districts have very good accessibility levels. This means that most city trips do not have an efficient network.

According to Equation 3, the integral route factor is calculated. This index makes it possible to check the status of road communications in each municipal district compared to other districts. The results are shown in Table 7.

After transferring the results to the delimitation layer of Tehran city districts and analysis in Arc GIS 10.8 environment, it was observed that the values of the integral route factor are between 1.38 and 1.73, which after dividing into three intervals, the graphic output of the districts is according to Figure 7.

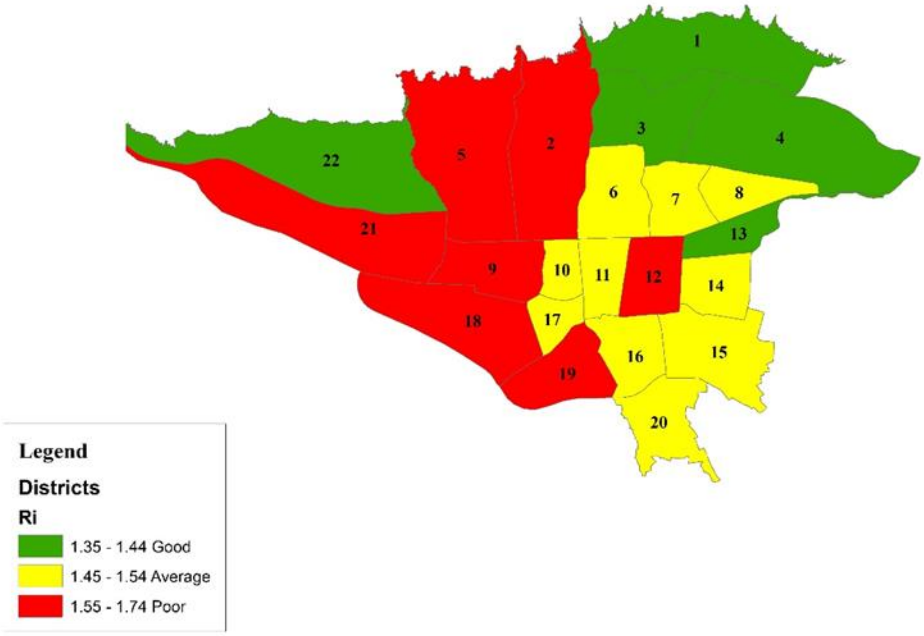

Figure 7. Integral route factor of Tehran districts based on types of accessibility levels

According to Figure 7, the minimum value of the integral route factor is 1.38, which is related to district 4 located in the northeastern margin of Tehran. In other words, this district has the most efficient road transportation network compared to 22 other districts. Only five districts, equivalent to about 23% of all districts, are in good accessibility, located on the northeastern and northwestern outskirts of Tehran.

The maximum integral route factor is 1.73, which is related to district 9 in the center of Tehran. In other words, this district has the most inefficient road transportation network compared to other districts. Seven of districts, equivalent to about 32% of all districts in Tehran, are in poor accessibility status and 10 districts, equivalent to about 45%, are in average accessibility status. Therefore, most of the central districts of Tehran are in a state of average and poor accessibility (such as District 12 - Tehran Grand Bazaar) that the municipality and responsible agencies are expected to plan to improve the current situation.

5.4. Major Effective Factors in Causing Air Pollution

Based on the results in this study, according to Figure 4, the central districts of the city have a high population density and the suburban districts have a low population density. This causes people in the suburbs to use more personal vehicles than people living in the central districts. On the other hand, according to Table 2, the residents of the central districts use less personal vehicles compared to the people living in the suburbs due to the high land use mix. The spatial distribution of activities in the city of Tehran, in addition to increasing the volume of daily travel, caused people in the current days to have to travel long distances to meet their basic needs, especially private cars. On the other hand, the inefficiency of the urban transportation system, as mentioned in the transportation sector, has intensified air pollution in the metropolis of Tehran.

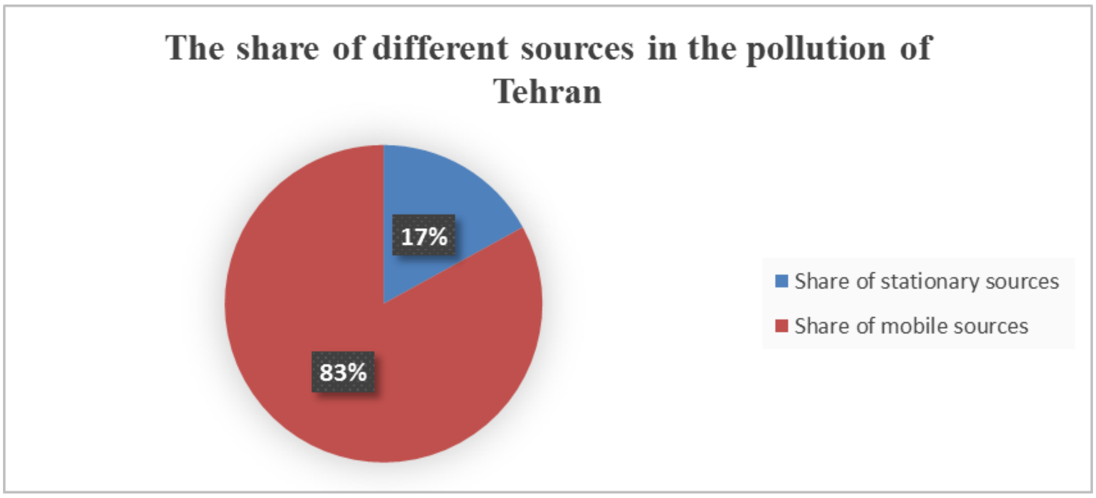

Figure 8. The share of different sources in pollution in Tehran (Source: Author based on air quality control company estimates)

Meanwhile, according to the report of Tehran Air Quality Control Company in 2019 (Figure 8), the share of mobile sources (motor vehicles) from the collection of publications was about 83% (equivalent to 579 thousand tons) and the share of stationary sources (refinery and power plant, polluting industries, fuel distribution station and domestic consumption) was about 17% (equivalent to 122 thousand tons). Therefore, mobile sources are the most important source of pollution in Tehran.

6. Discussion and Conclusion

One of the important factors of urban development is the population of that city. The population statistics of Tehran from 1996 to 2016 show that the population of Tehran has a population growth of approximately 33%, which has led to the development of Tehran. The development of the city will not be the same in terms of population density in the districts. Usually, the central districts have a higher density than the peripheral districts. Density is one of the factors affecting travel demand. With increasing density, the length of trips becomes shorter and the use of personal vehicles decreases. According to the last census in 2016, the lowest population density is related to the western suburb of Tehran, southern and southwestern districts (18 to 22) and the northern suburb to the northeast (districts 1 to 4). Also, the population density of District 9, which is west of the center of Tehran, is low due to the occupation of most of its district by Mehrabad Airport and the lands on the south side of Azadi Square, which are uninhabitable. These low-density districts lead to a tendency for people to use a private car.

On the other hand, the highest population growth in all districts of Tehran, with an exaggerated difference compared to other districts, is related to district 22 in the western suburbs of Tehran, which indicates the immediate growth in the structure of that district and its development. After that, low density districts, as described in districts 1 to 4 and district 18, which have a greater role in creating air pollution and are important to us in this study. Due to the high percentage of population growth compared to the base year of this study (1996), should be considered when planning urban. Because these districts, in addition to being low density populated, will have the potential and latent demand for personal vehicle travel due to their high population growth. In addition to the impact of population on the structure of the city, it is also important to study the distribution of land uses. In this study, after statistical analysis of major land uses in Tehran by SPSS software, it was concluded that only about 24% of land uses in Tehran have a significant relationship. This indicates low mixing of users or in other words, high separation between different types of uses.

Sprawl causes people to be separated from shopping, work, leisure and education. Therefore, to move between districts, they have to move using private cars. Sprawl patterns, due to low housing, employment and other facilities, strengthen the dependence on private cars.

Land use patterns with greater accessibility can increase productivity and economic development.

Sprawl and car-oriented development patterns can be detrimental to low-income people because they reduce their accessibility and transportation options and increase their transportation costs.

By examining the network density index per kilometer of network per thousand inhabitants, it can be seen that districts 21 and 22 have provided the highest level of accessibility to the transportation network. Also, with an overview of the values, districts 1 to 4 and districts 18 to 22, along with central districts 6, 9 and 11, have provided high accessibility of the road network to the population.

By determining the scattered growth pattern of Tehran and people's preference to use private cars to move between the origin and destination of travel, using the route factor, which indicates the efficiency of the inter-regional road network, the relative access of the districts was investigated. Then 5 relative accessibility levels were defined as very poor, poor, average, good and very good. 38% of internal communications between districts are at a good and very good level of accessibility. This means that people will have access to the desired uses over a shorter distance. About 32% have average accessibility and 30% have internal communication between districts at poor and very poor levels, which has led to inefficiency of the transportation network between them. This low network efficiency leads to longer distances, time wastage, higher fuel consumption and ultimately air pollution.

The integral route factor indicates the efficiency of each district's transportation network in relation to other districts. The results show that the northeastern and northwestern districts of Tehran have good accessibility levels. Also, most of the central districts of Tehran are in a state of average and poor accessibility (such as District 12 - Tehran Grand Bazaar) which, if not properly planned by the municipalities, will lead to the isolation of those areas after a while.

Districts in the minimum accessibility category should be considered to improve accessibility. Transport planners can try to implement better planning methods to improve accessibility to places with minimal accessibility. Areas with minimal to average accessibility should be considered for improvement to make opportunities more accessible to the public. According to the calculations, the accessibility index of Tehran is 1.52, which is at the average accessibility level.

Therefore, low population density in the districts, sprawl growth of Tehran, inefficiency of the transportation network in some parts, make people more dependent on private cars, more gasoline consumption and ultimately intensify pollution in the metropolis of Tehran.

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