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An Empirical Analysis of the Relationship Between Diabetes and Demographic, Socioeconomic and Built Environment Factors Across Turkish Cities

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Abstract
Demographic, socioeconomic, and built environment factors of cities are considered among risk factors for many Noncommunicable Diseases (NCDs). Decreasing NCDs and supporting healthy, high-quality urban environments is one of the United Nations' Sustainable Development Goals (SDGs). In particular, diabetes is related to quality of life and physical activity, making the disease more responsive to built environment factors. This study examines the geographical distribution of diabetes disease rate and its risk factors across Turkish cities. Principal component analysis and spatial regression models are used for this purpose. It is observed that open green spaces with high accessibility can increase physical activity and thus have a reducing effect on diabetes prevalence. In addition, in cities with sufficient healthcare services per capita, diabetes prevalence is lower. On the other hand, private vehicle ownership can have an increasing effect on diabetes prevalence, and a high share of the elderly population can be another reason for high diagnosis. According to the study findings, planning settlements with high open green spaces prioritizing open green space development, public transportation and non-motorized vehicles, and accessible healthcare facilities can reduce diabetes risk factors by promoting physical activity and increased mobility along with a positive planning and design approach for public health. Elderly-friendly planning specifications need prioritization for some cities. This study presents evidence for the necessity of urban policies and public health strategies prioritizing health and physical activity in urban built environments.

1. Introduction

Noncommunicable diseases (NCDs) account for 74% of all deaths worldwide and are rapidly increasing [1]. 77% of NCD-related deaths occur in low and middle-income countries [1]. The United Nations' 2030 Sustainable Development Agenda aims to reduce premature deaths caused by NCDs by one-third by 2030 [2], [3]. In Turkey, NCD-related death rates are similar to countries in the WHO European Region, but the proportion of NCD-related deaths has increased from 68% in 2000 to 87% today [4]. This rate is higher than the global average.

NCDs result from long-term, genetic, physiological, environmental, and behavioral factors. The main types of NCDs include cardiovascular diseases (heart and vascular diseases, hypertension etc.), accounting for 44% of NCDs deaths; cancer at 23%; chronic respiratory diseases at 10%; and diabetes (including kidney disease caused by diabetes) at 5% [2]. While the risk of premature death from the four major NCDs has decreased globally from 2000 to 2016, the risk of premature death from diabetes has increased by 5% [5].

Type 2 diabetes is rapidly becoming a major public health issue worldwide [6], [7], [8], [9] and is the fourth most common NCDs globally; deaths from Type 1 and Type 2 diabetes account for 2% of all deaths, but in Turkey, it is approximately 3-3.5% [10], [2], [4]. It is estimated that by 2040, there will be 642

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million people (approximately 6% of the world's population) with diabetes worldwide [6], [8]. The majority of diabetes diagnoses (approximately 90%) are Type 2 diabetes [11], [12], [13]. Diabetes can cause serious damage to the kidneys and heart [6]. In Turkey, the prevalence of diabetes is increasing; in the National Burden of Disease Study (2004), the prevalence of diabetes in Turkey was approximately 5%. In the 2009 Turkish Adults' Heart Diseases and Risk Factors (TEKHARF) study, the prevalence of diabetes in the population over 35 was estimated to be 11.3%, with approximately 3.3 million people reported to have been diagnosed with diabetes [47]. While Type 2 diabetes is influenced by genetic factors, demographic, socioeconomic, and built environment risk factors are more influential for this disease than other NCDs [14], [15], [50]. Obesity and a physically inactive lifestyle are the most significant risk factors for the increasing rates of diabetes, as well as heart disease and cancer [8], [48]. Approximately 60% of Type 2 diabetes patients are described as obese [8], [49], [14]. Obesity is defined as excessive and abnormal fat accumulation leading to adverse health outcomes, with a body mass index (BMI) of $\geq$30 kg/m² [48]. It is estimated that by 2030, more than half of the world's population will be obese [48]. Obesity, like diabetes, as a significant modifiable risk factor, is related to physical activity and nutrition, both associated with urban planning, design, and built environment characteristics [16].

The built environment is a comprehensive structure that encompasses urban design, land use, transportation systems, and the physical surroundings. Urban design focuses on the arrangement of physical elements within a city, addressing the organization of public spaces and their functionality and attractiveness. Land use categorizes activities such as residential, commercial, office, and green spaces, expressing the distribution of activities in terms of location and intensity across the area. The transportation system includes the physical infrastructure and service levels of roads, as well as pedestrian and cycling paths [52]. Carmona categorizes built environment components into nine headings: spatial, morphological, contextual, visual, social, environmental, functional, perceptual, and sustainability, considering design and planning aspects [53]. This study interprets the relationship between built environment components and health through physical activity, land use functions, and urban air pollution.

Physical inactivity is the fourth most significant risk factor for noncommunicable diseases (NCDs) worldwide, contributing to approximately 3.2 million deaths [16]. Physical inactivity can influence the rates of diabetes and obesity [12], [17], [18], air pollution [13], [19], [6], leading them to increase. In a city, having a high level of walkability, cycling and green spaces can have a positive impact on reducing these rates [6]. To increase physical activity, individuals are recommended to engage in physical activities for at least 30 minutes on several days a week. [20]. While the rates of diabetes and obesity vary by geographical region, over 80% of diabetes patients live in low and middle-income countries [8], [13], [14], and the number of obese individuals is increasing in these countries [21]. Uncontrolled, car-centric urbanization in developing countries, along with a sedentary lifestyle and air pollution, is associated with the risk factor of physical inactivity, leading to an increase in obesity and Type 2 diabetes rates[9], [13], [19], [20].

The planning and design principles of cities are significant determinants of urban health, and factors such as residential density, the amount and accessibility of green spaces, the layout of walkable and cycle road networks, and air pollution features stand out. In England, a reverse relationship was found between obesity and residential density due to an increase in mixed land use and the likelihood of retail and workplace spaces in dense residential areas, suggesting that an increase in residential density results in a decrease in waist circumference measurements [22]. Density can be defined as "the amount of activity in an area" represented by population density, housing unit density, or employment density. High density represents compact land development, reducing dependence on motor vehicles by shortening the distance between starting and ending points [23]. It has a negative relationship with obesity because it increases the likelihood of physical activity.

The amount of green space has been associated with lower obesity and diabetes rates [6], [24]. Additionally, the accessibility of green spaces encourages an active lifestyle [25]. In a study, the amount of green space and the proximity of green spaces suitable for recreational use were found to promote physical activity within short distances [25], [26].

Walkability supports physical activity and has a reduction effect on both obesity and Type 2 diabetes prevalence. In cities with a specific residential density and high land use diversity, the level of walkability increases [27], [28], [29]. Besides residential density, intersection density, public transport density, and the number of parks within walking distance also increase physical activity [30].

Exposure to air pollution has been associated with glucose metabolism and biological outcomes, leading to its relationship with diabetes prevalence [31]. Studies have found that greater exposure to air pollution and traffic density is associated with higher diabetes prevalence [6]. Air pollutants such as particulate matter PM10 [31], [34], PM2.5 [31], [33], nitrogen dioxide [31], [34], [35], and sulfur dioxide [34] have been found to increase diabetes prevalence.

Despite extensive research in this field, more studies are needed to understand the relationship between built environment factors and the prevalence of chronic diseases. Therefore, there is a need for additional research to uncover these relationships. There is no other national study that has developed a model to explain the relationship between NCDs and the built environment. This study is the first and only original work in the field within the context of Turkey. This article investigates the relationship between the prevalence of Type 2 diabetes and built environment characteristics, utilizing provincial-level data and considering other influencing factors. The study aims to reveal the geographical distribution in Turkey and examine prominent built environment features that impact such a chronic disease. Urban policies guiding the effects of these built environment features will undoubtedly play a significant role in creating healthy urban environments. Following the article's introduction section, the second section covers the data used and the methodology. The third section presents the findings and discussions, while the final section lists the results.

2. Data and Methodology

a. Database

The prevalences of obesity and Type 2 diabetes defined according to International Classification of Diseases (ICD) codes for 81 cities are obtained from the Turkish Ministry of Health; socioeconomic data were sourced from the Turkish Statistical Institute (TÜİK) and the Social Security Institution (SGK). Built environment indicators were obtained from Başarsoft Information Technologies Inc., and air quality data for the year 2019 were acquired from the Ministry of Environment, Urbanism, and Climate Change. The data obtained in the study are listed in Table 1. The study covers a population of individuals aged 15 and over, totaling approximately 64 million.

Table 1. Data Description

Health Variables	Demographic and Socioeconomic Variables	Built Environment, Land Use, and Air Quality Variables
Prevalence of Type 2 Diabetes in Individuals Aged 15 and Over (**DIA**)	Population Density (person/ha) (**Popdensity**)	Area of Parks per 1,000 People (m^2) (**Parks**)
	The proportion of the Population aged 65 and over to the Total Population (**Pop65+**) (%)	Open green space per 1,000 People (m^2) (**Open green space**)
Prevalence of Obesity in Individuals Aged 15 and Over (**OBS**)	Proportion of the Population with a Bachelor's Degree to the Total Population (**BachDeg**) (%)	Residential Area per 1,000 People (m^2) (**Residential Area**)
	Per Capita Gross Domestic Product (GDP) ($) (**GDP**)	Trade Area per 1,000 People (m^2) (**Trade Area**)
	Number of Private Cars per 1,000 People (**Number of Cars**)	Area of Health Services per 1,000 People (m^2) (**Health Area**)
	The ratio of Agricultural Sector Workers to the Total Employment in the City (**Agriculture**) (%)	Particulate Matter in the Air ($\mu g/m^3$) (**PM10**)
	The ratio of Industrial Sector Workers to the Total Employment in the City (**Industry**) (%)	

In the Turkey Nutrition and Health Survey (TBSA) 2017 study, the prevalence of diabetes was 12.5%, and the obesity prevalence was 27.8% [35]. In the Turkey Household Health Survey Noncommunicable Diseases Risk Factors Prevalence (STEPS) 2017 survey, the prevalence of diabetes was 11.1%, and the obesity prevalence was 28.8% [36]. Diabetes is 29.5% in rural areas and 70.5% in urban areas [37]. In this study's Database, the average prevalence of Type 2 diabetes is 5.95, and the obesity rate is 0.45[2] (Table 2).

The population density across Turkish cities shows that the least densely populated city is Tunceli, with 0.11 person/hectare, and the most densely populated city is Istanbul, with 28.40 person/hectare. According to the data, the percentage of the population aged 65 and over to the total population is an average of 13.36%. The city with the highest percentage is Sinop at 22.58%, and the city with the lowest percentage is Hakkari at 4.87%. The average percentage of the proportion of the population with a bachelor's degree to the total population is 14.1%. The city with the highest percentage is Ankara at 22.9%, and the city with the lowest percentage is Ağrı at 8.98%.

According to the 2019 data, the average annual Gross Domestic Product (GDP) per capita is $7,062.50. Based on this average, Turkey ranks 94th among all countries [38]. The highest GDP is observed in Istanbul, an industrial-focused city, with $16,791.00, while the lowest is in Diyarbakır at $431.00. There are 45 cities with GDP below the average.

The average percentage of people working in the agricultural sector to total employment is 1.57, and the industrial sector to total employment is 24.59. The city with the highest percentage of people working in the agricultural sector is Bolu at 5.43, and the city with the lowest percentage is Istanbul at 0.10.

Table 2. Descriptive Statistical Analysis

	N	**Missing**	**Mean**	**Std. Deviation**	**Minimum**	**Maximum**
DIA	81	0	5.95	2.55	0.76	11.13
OBS	81	0	0.45	0.43	0.02	2.66
Popdensity	81	0	1.30	3.19	0.11	28.40
Pop65+ %	81	0	13.36	3.85	4.87	22.58
BachDeg %	81	0	14.10	2.45	8.98	22.90
GDP ($)	81	0	7,062.50	2,841.40	431	16,791.00
Number of Cars	81	0	122.30	58.40	8	262
Agriculture %	81	0	1.57	0.93	0.10	5.43
Industry %	81	0	24.59	12.48	3.89	54.89
Park Area	81	0	1,967.60	1,132.80	104	5,022.40
Open Green Space	81	0	467,573.40	1,117,880.40	816.6	7,476,859.60
Residential Area	81	0	8,150.90	5,715.60	557.60	3,242.50
Trade Area	78	3	461.20	572.90	0	4,229.60
Health Area	81	0	930.60	300	400.40	1,721.10
PM10	80	1	101	88.62	0	452.20

[2] The reason for the difference between the Database obtained from the Ministry of Health and the TBSA 2017 study findings for Turkey is that TBSA involves personal measurements, and the Ministry of Health data presents individuals' self-reported diagnoses.

When it comes to the built environment data in terms of land use, on average, there is 1,967.60 m² of park area per 1,000 people and 467,573 m² of open green space per 1,000 people in each city. Similarly, there is an average of 8,150.90 m² of residential area, 461.20 m² of trade area, and 930.60 m² of health area per 1,000 people. Particulate matter (PM10) in the air, an important indicator of air quality, has an average level of 101 µg/m³. This level is well above the limit of 20 µg/m³ set by the World Health Organization for human health [51]. Regarding air quality, Hakkari has the lowest PM10 levels, while Istanbul has the highest at 452.20 µg/m³. There are 29 cities above the average, including Ankara, Kocaeli, and Izmir.

b. Method

In the study, first, the geographical distribution of the 2019 cross-sectional data for 81 cities was examined using thematic maps generated by GIS software. The level of spatial autocorrelations was specified with Moran's test. Moran's I statistic measures the degree of spatial dependency, examining how values diverge from the overall mean value across neighboring geographic units. The closer the Moran's I statistic is to +1, the more similar values are spatially dependent on each other, indicating positive spatial autocorrelation. If it is close to -1, it indicates negative spatial autocorrelation, where dissimilar values are clustered together. A value close to 0 indicates no spatial autocorrelation or randomness [39], [40] (Equation 1). Moran's I statistic for Diabetes prevalence is 0.39, indicating some spatial dependence for the variable DIA across cities (Figure 1).

$$I = \left(\frac{N}{\sum_i \sum_j w_{ij}}\right) x \left[\frac{\sum_i \sum_j w_{ij(y_i - \bar{y})(y_i - \bar{y})}}{\sum_i (y_i - \bar{y})^2}\right] \quad (1)$$

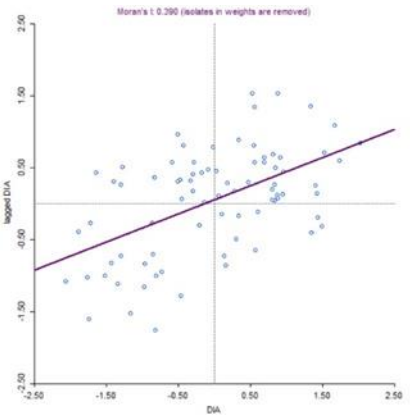

Figure 1. Moran's I statistic for Diabetes Prevalence

The spatial dependencies of various variables reflect the clustering tendencies. Cluster analysis was performed using the GeoDa program, and the LISA (Local Indicators of Spatial Association) analysis reveals the local clustering of the variables. Spatial dependencies are obtained for all cities and are calculated by dividing the differences between each region's value and the overall mean by the standard deviation. Spatial neighbor relationships are expressed using the spatial weights matrix "W" [41]. Equation (2) demonstrates the calculation of local indicators, where Xi is the observed value for each geographical unit from i to j, x is the mean value, s is the standard deviation, and Wij is the spatial weights matrix.

$$Local\ I = \frac{(x_i - \bar{x})}{S^2} \sum_j W_{ij}(x_j - \bar{x}) \quad (2)$$

In the second stage, Principal Component Analysis (PCA) [42] was used to understand the relationships between variables and reduce the number of selected variables. PCA is a statistical data reduction method that transforms study variables into fundamental features called principal components [42], [43]. This method helps reveal the similarities and differences between variables by using a few principal components [43].

In the third stage, regression models were set up to analyze the relationship between demographic, socioeconomic, and built environment variables with disease rates. Due to the high spatial dependence rates among variables at the provincial level, a spatial error model (SEM) was chosen as the most suitable model for regression analysis, and the findings of this model were presented. The spatial error model (SEM) is a spatial regression model that solves spatial dependence issues in Ordinary Least Squares (OLS) models [44].

The OLS model can be expressed as shown in Equation (3):

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \varepsilon, \varepsilon \backsim \mathrm{N}\,(0, \ \delta^2\,) \qquad (3)$$

The y in the model represents the dependent variable, which denotes disease rates. The x_i represents independent variables, including selected demographic, socioeconomic, and built environment factors. β_0 is the intercept, and β_i represents the parameter estimates for x_i. ε denotes the error term. The existence of spatial dependence in the error terms shows that the Spatial Error Model (SEM) was appropriately selected for this study.

$$y = X\beta + \lambda W u + \varepsilon, \varepsilon \backsim \mathrm{N}\,(0, \ \delta^2\,) \qquad (4)$$

The SEM is represented by Equation (4). W is the spatial weights matrix of size NxN, and N is the number of geographic units in the study area, which is 81.

3. Findings

3.1 Distribution of Health Variables by Cities

The distribution of Type 2 diabetes prevalence (Figure 2(a)) shows that it is particularly high in the southeast of the Aegean, Western Black Sea, and Mediterranean regions. The average diabetes prevalence in Turkey is 5.94, while in Manisa (11.13), Zonguldak (10.40), and Aydın (10.23), it is approximately twice as high. The lowest rates are in Şırnak (0.75), Şanlıurfa (1.19), and Kars (1.49), mainly located in the Southeastern and Eastern Anatolian regions.

The geographical distribution of obesity prevalence (Figure 2(b)) shows that it is high in the Aegean and Western Black Sea regions. The average obesity prevalence in Turkey is 0.45, while in Bolu (2.65), Bartın (1.59), and Aydın (1.32), it is higher than average. The lowest obesity prevalences are observed in Ardahan (0.020), Bingöl (0.026), and Bayburt (0.033).

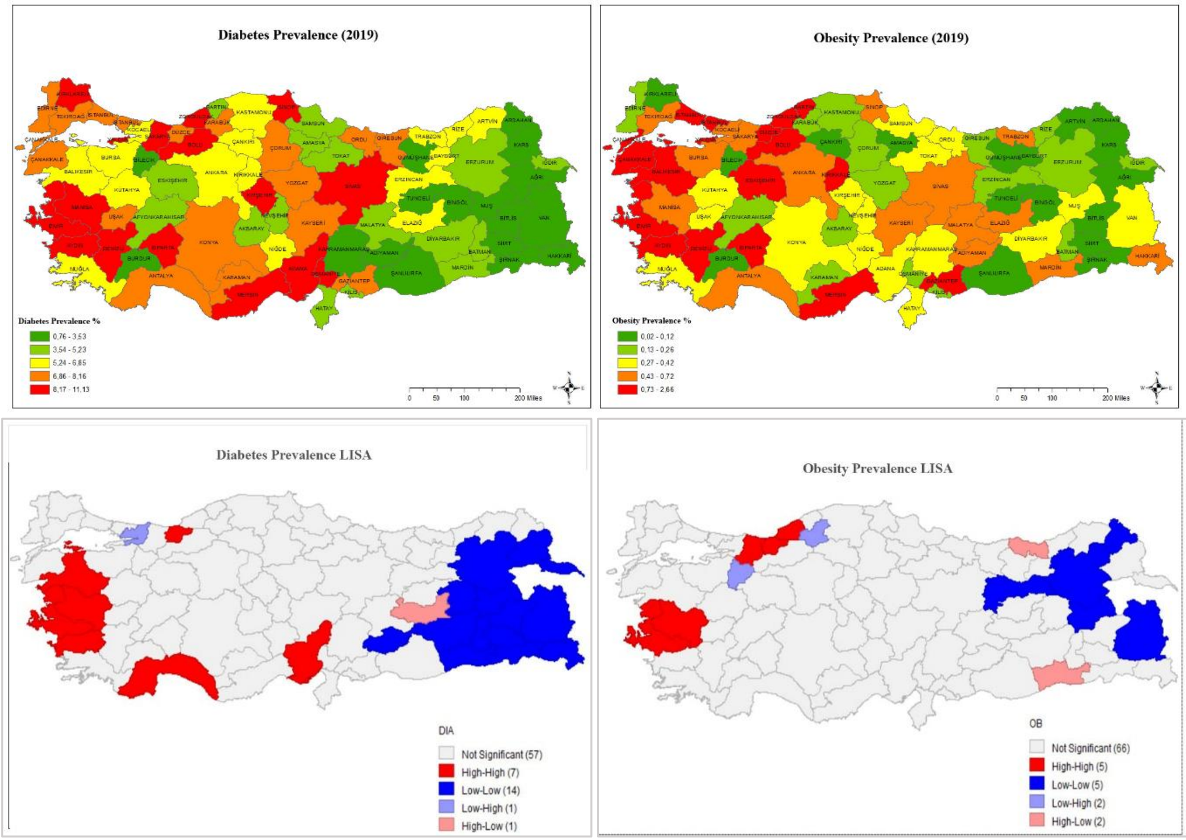

Figure 2. (a) Distribution of Type 2 diabetes prevalences by cities (Source: Ministry of Health, 2019), (b) Distribution of obesity prevalence by cities (Source: Ministry of Health, 2019), (c) Local spatial autocorrelation (LISA) analysis of Type 2 diabetes prevalence by cities, (d) Local spatial autocorrelation (LISA) analysis of obesity prevalence by cities.

LISA analysis reveals the spatial relationships of variables, as seen in Figure 2(c) and (d). In Figure 2(c), it is observed that the prevalence of type 2 diabetes is high and clustered in Aydın, Manisa, Izmir, Balıkesir in the Aegean region, in Antalya and Adana in the Mediterranean region, and Düzce in the Marmara region. In the Eastern Anatolian region, it is generally low and clustered. Kocaeli stands out as an outlier with significantly lower values than neighboring cities, and Elazığ stands out with significantly higher values than neighboring cities.

In Figure 2(d), it is evident that the prevalence of obesity is higher and clustered in Izmir and Manisa in the west, as well as in Düzce, Zonguldak, and Bartın in the north. In the east, it is recorded at low levels and clustered in Erzincan, Erzurum, Ardahan, Muş, and Van. Trabzon and Mardin have significantly higher prevalences than neighboring cities, while Karabük and Bilecik have lower prevalence than neighboring cities.

When comparing the geographical distribution of type 2 diabetes and obesity prevalence, similarities are observed in the Aegean and Eastern Anatolian regions. At the same time, differences are noted in the Mediterranean and Black Sea regions. Although obesity is a significant risk factor for diabetes, in Antalya, Adana, Düzce, and Elazığ, even if obesity prevalence is not high, a high prevalence of type 2 diabetes is observed. Obesity prevalence is varied and recorded at a high level in Sakarya, Zonguldak, Trabzon, and Mardin.

3.2 Distribution of Demographic Variables by Cities

When examining the distribution of population density by city (Figure 3(a)), it is observed that population density is higher in major cities, such as Istanbul, Ankara, and Izmir, as well as in coastal cities. In smaller cities, the proportion of the population aged 65 and over is higher (Figure 3(b)). In particular, in the North Aegean region (Çanakkale, Balıkesir), the Black Sea region (Sinop, Kastamonu), and in some cities in the Eastern Black Sea region (Giresun, Artvin), and the Central Anatolian region (Çankırı, Çorum, Tokat), this proportion is relatively high (between 16.38% and 22.58%). However, in the Southeastern Anatolian (Gaziantep, Şanlıurfa) and Eastern Anatolian (Van, Bitlis) cities, it is relatively lower (below 10.26%). The younger population (ages 15-34) predominantly resides in these regions.

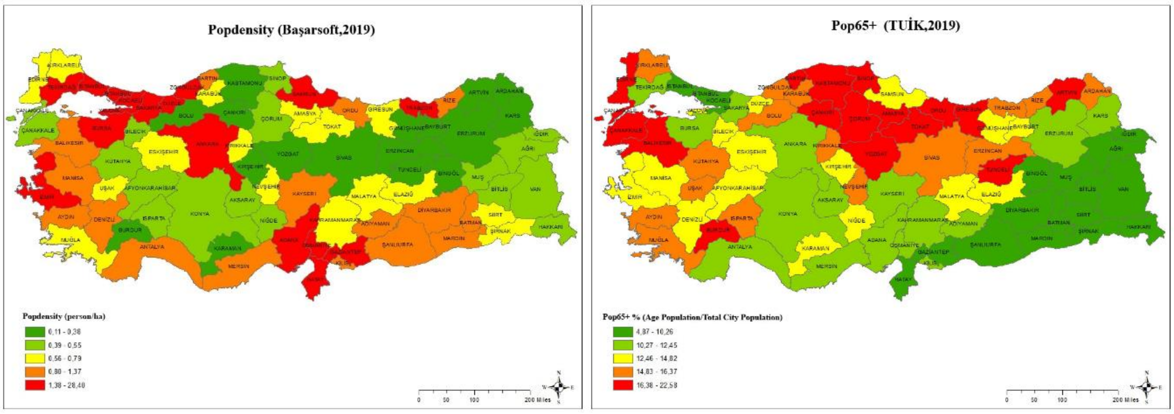

Figure 3. (a) Population density by city (Source: TÜİK, 2019), (b) The proportion of the population aged 65 and over to the total population by city (Source: Başarsoft, 2019).

3.3 Distribution of Socioeconomic Variables by Cities

To depict the socioeconomic status of the cities in the dataset, we chose variables associated with educational attainment. These variables encompass the percentage of the population holding a bachelor's degree, the per capita gross domestic product (GDP), the number of private cars per 1,000 individuals, and the proportion of the workforce engaged in the agricultural and industrial sectors relative to the total employed population.

When examining the geographical distribution of the proportion of the population with a bachelor's degree to the total population (Figure 4(a)), it is observed that in some cities in the Marmara Region (Istanbul, Kocaeli, Bursa, Çanakkale), Aegean Region (Izmir, Muğla), Mediterranean Region (Isparta, Antalya), Central Anatolia Region (Ankara, Eskişehir), Eastern Anatolia Region

(Malatya, Erzincan, Tunceli), and the Black Sea Region (Trabzon, Karabük), this proportion is relatively high (ranging from 15.85% to 22.92%).

The per capita gross domestic product (GDP) (Figure 4(b)) is high in industrialized regions and the western parts of the country. In particular, it is high in some cities in the Marmara Region (Istanbul, Kocaeli, Sakarya, Bursa, Bilecik, Çanakkale), Aegean and Mediterranean Regions (Manisa, Izmir, Muğla, Antalya), Central Anatolia Region (Ankara, Eskişehir), and in some cities in the Western Black Sea Region (Bolu) (ranging from $9,136 to $16,791). In contrast, it is low in all cities in the Southeastern Anatolia Region (except Gaziantep) and in some cities in the Eastern Anatolia Region (Bingöl, Muş, Ağrı, Kars, Van, Bitlis, Hakkâri) (ranging from $431 to $5,294).

The number of private cars per 1,000 people (Figure 4(e)) may indicate increased mobility and high income. In western parts of the country, car ownership is high, similar to the GDP distribution. It is high in larger cities in the Marmara Region (Istanbul, Çanakkale), Aegean Region (Izmir, Muğla, Kütahya, Uşak, Denizli), Antalya Region (Isparta, Burdur, Antalya), Central Anatolia, Western and Central Black Sea Regions (Ankara, Eskişehir, Nevşehir, Bolu, Amasya) (ranging from 172 to 262 cars per 1,000 people). In contrast, it is low in all cities in the Southeastern Anatolia Region (except Gaziantep), some cities in the Eastern Anatolia Region (Bingöl, Muş, Ağrı, Kars, Van, Bitlis, Hakkâri, Iğdır, Tunceli), and some cities in the Eastern Black Sea Region (Gümüşhane, Ardahan) (ranging from 8 to 65 cars per 1,000 people).

The variable of the percentage of people working in agriculture (Figure 4(c)) is high in some cities in the Mediterranean Region (Antalya, Mersin, Adana), the Aegean and Marmara Regions (Aydın, Muğla, Afyonkarahisar, and Balıkesir), the Central Anatolian and Black Sea Regions (Kırşehir, Yozgat, Amasya, Kastamonu, Sinop, Bolu, Artvin), and in some cities in the Southeastern and Eastern Anatolian Regions (Muş, Şanlıurfa) where agricultural production is high. On the other hand, the percentage of people working in the industrial sector (Figure 4(d)) is predominantly high in industrial areas, in particular, in the Marmara Region (Kocaeli, Sakarya, Düzce, Kırklareli, Tekirdağ, Bursa, Bilecik), the Aegean and Central Anatolian Regions (Manisa, Uşak, Denizli, Eskişehir, Karaman), and in some cities in the Mediterranean and Southeastern Anatolian Regions (Kahramanmaraş, Gaziantep) with rates ranging from 36.77% to 54.89%.

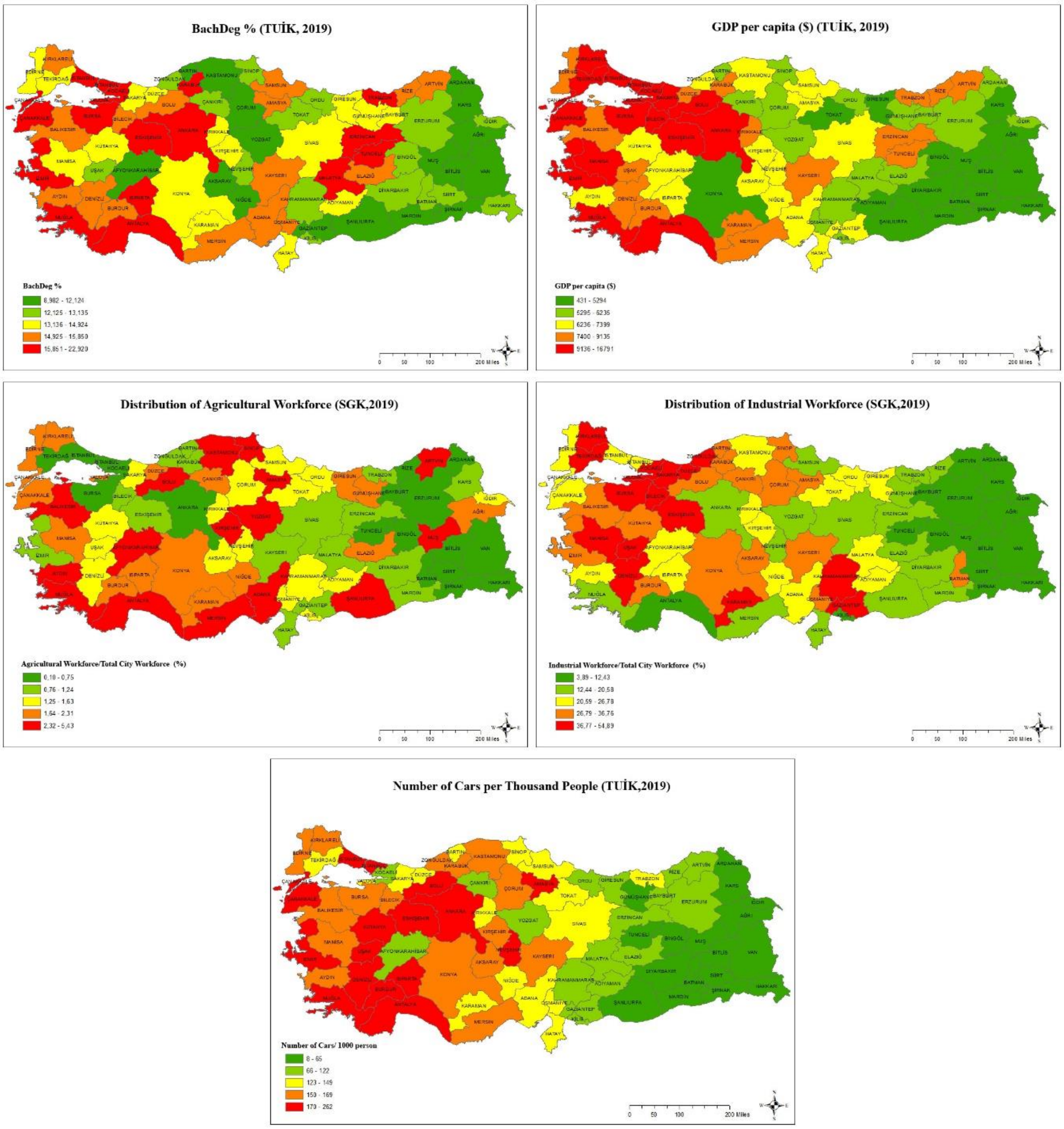

Figure 4. (a) Percentage of the population with bachelor's degree (Source: TURKSTAT, 2019), (b) Gross Domestic Product per capita ($) (Source: TURKSTAT, 2019), (c) Proportion of people employed in the agricultural sector to the total employment in the city (Source: SGK, 2019), (d) Proportion of people employed in the industrial sector to the total employment in the city (Source: SGK, 2019), (e) Number of private cars per 1,000 people (Source: TURKSTAT, 2019).

3.4 Distribution of Built Environment and Air Quality Variables by Cities

In the dataset, variables representing the built environment in cities include parks, open green spaces, residential areas, commercial areas, and health areas per 1,000 people, as well as air pollutants, such as Particulate Matter (PM10), responsible for air pollution. When examining the geographical distribution of area of parks per 1,000 people (Figure 5(a)), it is observed to be high (ranging from 2,847 to 5,022 square meters) in all cities in the Central Anatolia Region except for Yozgat, Sivas, and Çankırı. It is also high in some cities in the Central Black Sea Region (Çorum) and a few cities in the Aegean Region (Uşak, Denizli). The least area of parks per 1,000 people is observed in the eastern part of Turkey.

Open green spaces per 1,000 people (Figure 5(b)) are high (ranging from 581,442 to 7,476,860 square meters) in the Marmara Region (Edirne, Çanakkale), the Central Black Sea Region (Bartın, Kastamonu, Bolu, Gümüşhane, Artvin, Ardahan), the Mediterranean Region (Burdur, Antalya), and in some cities in the Central Anatolia Region (Niğde). Open green spaces per 1,000 people represent large forest areas, parks, recreational areas and areas to be afforested.

In parallel with population density, the residential area per 1,000 people variable (Figure 5(d)) is high (ranging from 12,008 to 32,425 square meters) in cities in the Marmara Region (Tekirdağ, Edirne, Çanakkale, Balıkesir, Kocaeli, Sakarya, Düzce), the Aegean Region (Aydın, Muğla), Central Anatolia and Mediterranean Regions (Ankara, Antalya), and in some cities in the Southeastern and Eastern Anatolia Regions (Elazığ, Diyarbakır).

Trade area per 1,000 people (Figure 5(c)) is high in some cities in the Central Anatolia Region (Ankara, Konya, Aksaray, Nevşehir, Niğde), the Mediterranean Region (Isparta, Burdur, Mersin, Adana), the Marmara and Aegean Regions (Kırklareli, Edirne, Tekirdağ, Çanakkale, Kütahya), and in some cities in the Eastern and Southeastern Anatolia Regions (Erzurum, Batman). Data for the cities of Tunceli, Bayburt, and Ardahan is unavailable in the database.

.

The area of health services per 1,000 people (Figure 5(e)) is high (ranging from 1,228 to 1,721 square meters) in some cities in the Marmara and Aegean Regions (Bilecik, Kütahya), the Central Anatolia Region (Yozgat, Aksaray, Konya), the Central Black Sea Region (Bolu, Ardahan, Bayburt), the Mediterranean Region (Isparta, Kahramanmaraş), and in some cities in the Eastern Anatolia Region (Kars, Iğdır, Ağrı, Erzurum, Muş, Erzincan).

PM10 (Figure 5(f)), with a diameter of less than 10 µg/m3, represents coarse inhalable particles in air pollution data. PM10 values are derived from emissions released from traffic, residential heating, and industrial pollution. The areas with high pollution levels (ranging from 168.96 to 452.15 µg/m3) include cities with large industrial areas in the Marmara Region (Istanbul, Kocaeli, Bursa), in the Aegean Region (Izmir), and large cities, such as Ankara, Konya, and Kayseri in the Central Anatolian Region. Additionally, due to residential heating, high values are observed in some cities in the Black Sea Region (Çorum, Samsun, Amasya, Tokat, Ordu, Trabzon) and in some cities in the Eastern Anatolian Region (Erzurum, Ağrı, Iğdır).

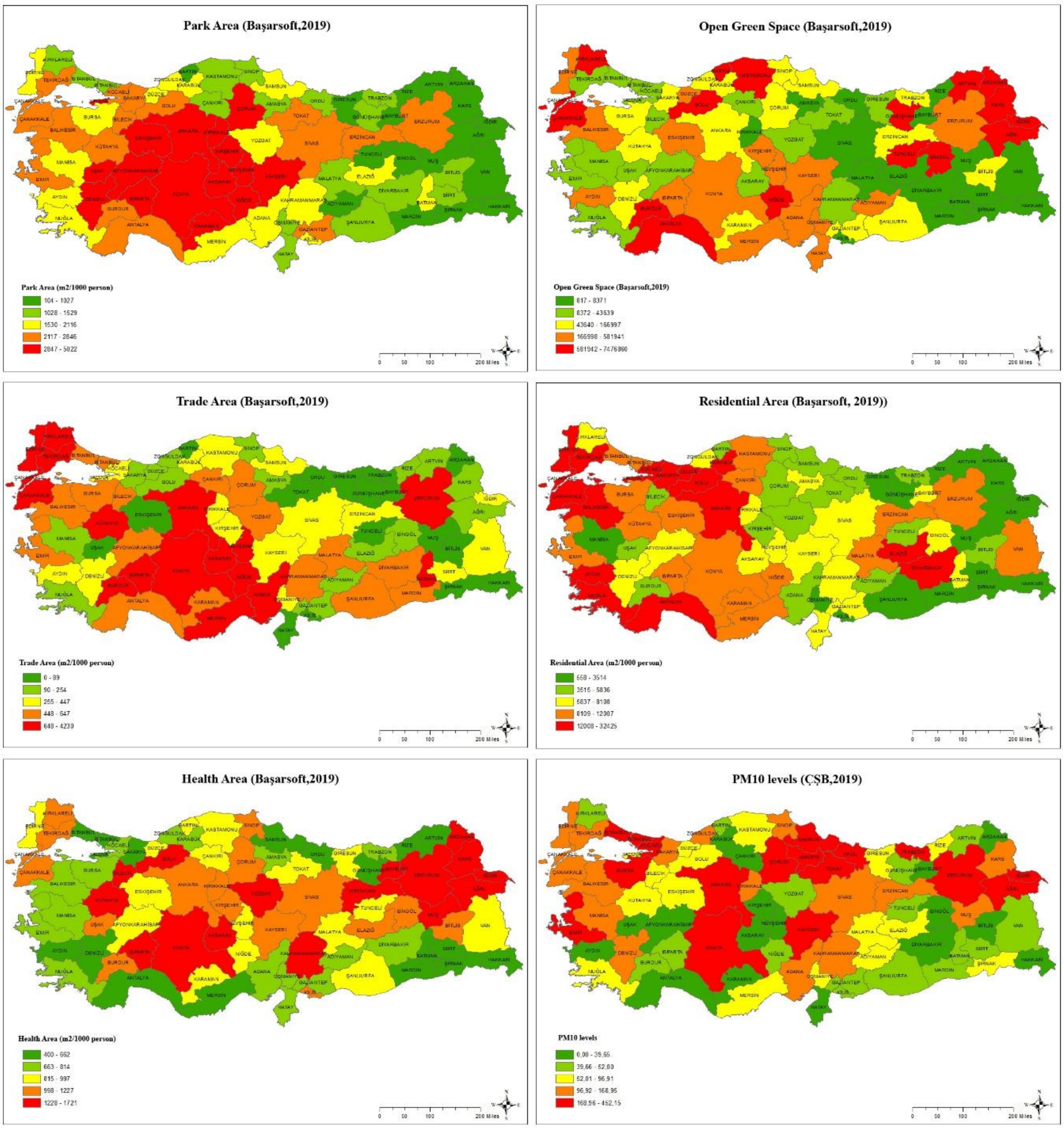

Figure 5. (a) Area of parks per 1,000 people (Source: Başarsoft, 2019), (b) Open green space per 1,000 people (Source: Başarsoft, 2019), (c) Commercial area per 1,000 people (Source: Başarsoft, 2019), (d) Residential area per 1,000 people (Source: Başarsoft, 2019), (e) Health area per 1,000 people (Source: Başarsoft, 2019), (f) Particulate Matter (PM10) in the air (Source: Başarsoft, 2019).

3.5 Principal Component Analysis (PCA)

Principal component analysis [42], [43] is used to examine the relationships across study variables and identify data suitable for regression models; the data is grouped into four components (Table 3). The first component is composed of health variables (DIA, OB), demographics, socioeconomic status of the population (Number of cars, Industry, and Agriculture %), and environmental variables (Residential area, parks). The second component includes demographic, socioeconomic status variables (Popdensity, GDP ($)), and the environmental variable PM10 value. The third component includes only the open green space variable, while the fourth component includes the environmental variables of the area of health services and trade areas. Kaiser-Meyer-Olkin (KMO) and Bartlett tests are examined for PCA validation. The Kaiser-Meyer-Olkin (KMO) test measures the sample adequacy, and a value greater than 0.60 is expected [45], [46].

In this study, the KMO value is 0.706, and the PCA explains a total variance of 70.6%. The significance value of the Bartlett test is also $p < 0.001$

(Table 3) [45]. Therefore, the data set is suitable for PCA, and the four components are used while selecting data for the following regression models.

Table 3. Principal Component Analysis

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.706
Bartlett's Test of Sphericity	Approx. Chi-Square	506,881
	df	105
	Sig.	.000

Rotated Component Matrix

	Component			
	1	2	3	4
Number of Cars	.857			
DIA	.813			
OBS	.625			
Industry %	.604			
Pop65+	.598			
Residential Area	.577			
Park Area	.550			
Agriculture %	.543			
Popdensity		.761		
PM10		.745		
GDP ($)		.680		
BachDeg %		.625		
Open green space			.843	
Health Area				.747
Trade Area				.527

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

3.6 Spatial Regression Models

In the study, diabetes prevalence is the dependent variable, while other variables are treated as independent variables. Spatial regression analysis was conducted to analyze the relationships between the selected data based on PCA components. Given the spatial dependency of the geographical distribution of diabetes prevalence (Moran's I=0.39), five SEM regression models are constructed (Table 4). In SEM, the spatial weights matrix across 81 cities is included, accounting for the influence of spatial dependence between geographical units. The Adjusted R^2 values range from 0.37 to 0.58, and the significance levels of the models being $p < 0.001$ indicate that significant relationships exist in the models within the scope of the study.

In the selection of models that exhibit spatial dependence, the Akaike Information Criterion (AIC) value is also taken into account. A low AIC value is important in model selection. Model 5 has the lowest AIC value (332.69) and the highest R^2 value (0.58). Therefore, Model 5 is considered the model with the highest explanatory power within the scope of the study.

Table 4. Spatial Regression Models

	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	4.79 (10.63)	1.35 (1.45) [a]	0.92 (1.07)[b]	1.76 (1.98)	1.72 (1.80)
OBS	2.33 (4.23)	2.34 (4.41)	1.57 (2.96)	1.77 (3.58)	1.82 (3.66)
Popdensity		0.08 (1.18) [b]	0.06 (0.80) [b]		0.002 (0.02) [b]
Pop65+ %		0.25 (3.88)	0.11 (1.73) [a]	0.20 (3.08)	0.19 (3.11)
GDP ($)			-0.00003 (0.25) [b]		
Number of Cars			0.02 (2.85)	0.009 (1.49) [b]	0.011 (2.15)
Agriculture %			0.18 (0.73) [b]	0.17 (0.72) [b]	
Industry %			0.03 (1.43) [b]		0.007 (0.41)[b]
Park Area				0.0001 (0.81) [b]	
Open green space				-0.0000003 (-1.95)	-0.0000003 (-1.97)
Residential Area				0.00003 (0.09) [b]	0.000006 (0.15)[b]
Trade Area				0.0006 (1.77) [a]	0.0005 (1.62)[b]
Health Area				-0.0014(-2.18)	-0.0012 (-1.80)[a]
PM10				0.001 (0.84) [b]	0.001 (0.49) [b]
Model Statistics	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Adjusted R squared	0.371	0.424	0.525	0.569	0.578
P-value	0.001	0.001	0.001	0.001	0.001
Akaike information criterion	350.90	344.44	336.09	333.31	332.69
N	81	81	81	81	81

a Significant at 0.1 level (two-tailed).

b Not significant.

Table 5. Breusch-Pagan Test Statistics

Breusch-Pagan test statistics	Model 1	Model 2	Model 3	Model 4	Model 5
Degrees of freedom	1	3	7	10	10
Statistics	0.102	2.007	13.199	17.679	19.779
P-value	0.750	0.571	0.067	0.100	0.031

The strong relationship between diabetes and obesity prevalence is evident at the provincial level in Turkey [8], [11], [14]. Measuring the impact of demographic, socioeconomic, and built environment variables on diabetes, including the prevalence of obesity in the model, allows for a better understanding of the effect of other factors (demographic, socioeconomic, built environment) on diabetes. In models where diabetes prevalence at the provincial level is considered as the dependent variable (Model 1, Model 2, Model 3, Model 4, Model 5), it is observed that this variable shows a positive and significant relationship with the obesity rate.

In Model 2, there is a significant and positive relationship between the demographic variable of the 65+ population as a percentage of the total population and diabetes prevalence. According to Model 2, it can be inferred that a 1% increase in this variable could lead to a 0.25% increase in diabetes prevalence.

In Model 3, a significant and positive relationship was found between the number of cars per 1,000 people variable and diabetes prevalence, indicating car dependency for mobility and higher income levels. In cities with extensive road infrastructure, private vehicles are commonly used transportation modes (e.g., Ankara ranks first with 262 cars per 1,000 people); therefore, higher car ownership rates are observed. According to this model, a 1% increase in number of cars per 1,000 people could potentially lead to a 0.02% increase in diabetes prevalence.

Model 4 demonstrates a negative and significant relationship between the area of health services as a built environment variable and diabetes prevalence. This suggests that in cities with more health facilities, residents may be able to take necessary precautions against diabetes before being diagnosed. An increase of 1% in health areas in a city may result in a 0.0014% lower diabetes prevalence.

The size of open green spaces plays a role in reducing diabetes prevalence, although at the provincial level, the marginal impact is low (i.e., 0.0000003%). As the open green space in square meters increases, diabetes prevalence decreases. On the other hand, having a higher proportion of trade area has an increasing effect on diabetes prevalence within a 10% confidence interval. The positive relationship between diabetes prevalence and trade areas could be associated with the size of the cities. Physical activity is generally high in cities with larger trade areas; however, nutrition status is also a notable risk factor for diabetes. The density of fast-food restaurants and the prevalence of supermarkets selling unhealthy and processed food products in trade areas might contribute to this outcome. However, it should be noted that heteroskedasticity is detected in this model based on the Breusch-Pagan test results (p=0.10) (Table 5). The presence of heteroskedasticity in the model affects the accuracy and reliability of the model and analysis. Therefore, for a model to be accepted, the significance level of the Pagan test is expected to be less than 0.05.

Model 5 is constructed with variables that have shown significant relationships in other models. According to Model 5, the obesity prevalence, the percentage of the 65+ population in the total population, the number of cars per 1,000 people, open green spaces, and areas of health services variables have shown significant relationships with diabetes prevalence within a 10% confidence interval. The presence of health services and open green spaces has a reducing effect on diabetes prevalence. In contrast, the percentage of the 65+ population in the total population and the number of cars per 1,000 people have an increasing effect on diabetes prevalence.

The three cities with the highest obesity rates are Bolu (2.65), Bartın (1.59), and Aydın (1.32). The three cities with the highest diabetes rates are Manisa (11.13), Zonguldak (10.40), and Aydın (10.23). Aydın is the third city where both diabetes and obesity rates are the highest. Zonguldak (1.25) is among the top five cities regarding obesity rates, and Manisa (0.71) is among the top twenty cities.

The models indicate that diabetes rates are associated with the percentage of the 65+ aged population. When examining this relationship, it is observed that Aydın (16.24) and Zonguldak (15.31) have a higher percentage of the elderly population. The national average for the percentage of the 65+ population in the total population is 13.00%. The number of cars per 1,000 people is also high in these cities. Access to healthcare services is important for diabetes patients for diagnosis and treatment. The models show that when the area of health services per 1,000 people increases, diabetes rates tend to decrease.

4. Conclusion

The relationship between the prevalence of diabetes and obesity and the built environment has been extensively studied in the literature. However, it is possible to reach different results based on local characteristics among countries. Particularly in developing countries, there is still a debate on which demographic, socio-economic, and built environment characteristics differentiate and influence the burden of health outcomes. On the other hand, evidence-based policies are developed for urban and public health interventions planned under Sustainable Urban Development Goals, particularly SDG3 – good health and well-being and SDG11 – Sustainable Cities and Communities. With the development of these policies, healthier and higher-quality living environments can be achieved within the context of sustainable urbanization.

The relationship between diabetes prevalence and physical activity is well-known [6], [12], [17], [18]. Studies in the literature have demonstrated an inverse relationship between green spaces and diabetes prevalence [6], [24], [25], [26]. This situation is associated with the opportunities that green spaces provide for physical activity. In this context, similar findings have emerged in this study regarding the relationship between diabetes prevalence and green spaces in Turkey. Therefore, there is a need to consciously emphasize that, according to the "3194 Law on Land Development Planning and Control," a minimum of 15 square meters of active green space per person is recommended throughout the city. According to the regulation, "active green space" includes larger green uses such as recreational areas, forest areas, areas to be afforested, fairgrounds, and festival areas, as well as urban parks, children's park areas, and recreational areas within the entire city. The open green space used in the study corresponds to the definition of active green space in the regulation. [54]. In the study, the amount of open green space in 19 cities is below 15 m^2/person.

Similarly, the positive relationship between the size of healthcare facilities and diabetes prevalence in cities suggests that the presence of adequate healthcare facilities for diagnosis and treatment can be effective in reducing the disease. According to the Law on Land Development Planning and Control, the health square meter per person is a minimum of 1.50 in cities with a population of less than 500,000, while in cities with a population exceeding 500,000, it is at least 1.60 square meters [54]. In Erzurum (approximately 768,000 people), this value is 1.63, whereas in Kars (approximately 289,000 people), it is higher than the values specified in the regulation at 1.72 square meters. For the reduction of diabetes prevalence, the promotion of physical activity, and the creation of healthy cities, it is necessary to reevaluate and increase the per capita unit values in the regulation.

Balanced planning of mixed-use areas to reduce diabetes prevalence in Turkey, increasing access to affordable healthy food, making appropriate choices for the location of healthcare institutions, increasing the amount of open green spaces, ensuring accessibility, and enhancing opportunities for physical activity are necessary.

Additionally, the diabetes rate can be higher in cities with a high elderly population. In this case, increasing age-friendly built environment characteristics can effectively prevent the disease. The presence of healthcare facilities for diabetes patients and access to these institutions are of great importance. The SEM results show that as the number of vehicles per thousand people increases, diabetes prevalence also increases. As vehicle ownership increases, people can choose motorized mobility instead of active, non-motorized mobility, which leads to lower physical activity. Urban development in car-oriented cities should be redesigned to support physical activity through non-motorized vehicle access and infrastructure, public transportation systems, and the promotion of walkability and cycling.

There are certain limitations in the study. Health data in Turkey is obtained at the provincial level. To conduct detailed spatial studies, data should be obtained or generated at the neighborhood or community level. Similarly, air pollution data is available at the provincial level. Pollutants are not distributed equally across provincial boundaries. To better understand their effect on non-communicable diseases such as diabetes, more detailed analyses should be conducted in areas where pollutant concentrations occur. This way, the impact of air pollution values on NCDs, such as diabetes, can be measured for Turkey as well.

This study presents findings that can help determine the priorities for urban and public health plans, policies, and programs for health and physical activity-focused urban development in Turkey.

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Contributions of the Authors

The authors' contributions to the paper are equal.

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There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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